Blue Lake Diagnostic Study

Whitley County, Indiana

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BLUE LAKE DIAGNOSTIC STUDY
WHITLEY COUNTY, INDIANA

EXECUTIVE SUMMARY

Blue Lake is a 239-acre (96.7-ha) natural lake that lies in the headwaters of the Eel River Basin northwest of Churubusco, Indiana. Blue Lake's watershed encompasses approximately 2,300 acres (930 ha or 3.6 square miles). Most of the watershed (75%) is utilized for agricultural purposes (row crops, hay, and pasture). Remnants of the native landscape, including forested areas and wetlands, cover approximately 11% of the watershed, while residential and commercial land uses account for less than three percent of the watershed's total acreage. Blue Lake itself covers 11% of the total watershed.

The distinct geological setting of the interlobate region where the Packerton, Mississinewa, and Salamonie Moraines meet influences the characteristics of the watershed soils. The watershed's steep slopes combined with the till origin of soils increases the potential for soil erosion. Approximately 48% of the watershed is mapped in a highly erodible or potentially highly erodible soil unit. These easily eroded soils form much of the watershed where agricultural activities currently occur.

Blue Lake has one primary tributary, Maloney Ditch. Maloney Ditch exhibited moderate water quality during base flow, or "normal", conditions. The stream's biotic community integrity score reflected its moderate water quality; Maloney Ditch's biotic community fell in the "moderately impaired" category using the Indiana Department of Environmental Management's scoring criteria. Of greatest concern were the stream's low dissolved oxygen and elevated *E. coli* and total phosphorus concentrations, which were all outside the recommended criteria or applicable state standard during the base flow monitoring event.

Blue Lake itself is productive. Historical data for the lake suggest that Blue Lake's water quality has declined over the past 25 years. The lake possesses poorer water clarity and higher nutrient levels than most Indiana lakes. Evaluating the lake using various trophic state indices suggest the lake is eutrophic in nature. However, Blue Lake's phosphorus concentration has the potential to increase the lake's productivity. Blue Lake supports a diverse submerged plant community that includes a number of high quality species. The lake offers good fishing opportunities.

Improving water quality in Blue Lake will require both in-lake and watershed management. The lake possesses a moderate hydraulic residence time of 1.8 years. Thus, attention to shoreline and immediate watershed processes is necessary. The results of the inlet sampling and the phosphorus modeling indicate the watershed is capable of contributing significant amounts of nutrient and sediment to the lake, making good watershed management a necessity as well. Blue Lake's relatively small watershed area to lake area ratio of 9.5:1 suggests near shore residents have substantial control over influencing the health of their lake.

Recommended watershed management techniques include: stream channel maintenance, sewer system maintenance, homeowner best management practices, wetland restoration, use of the Conservation Reserve Program and conservation tillage, and streambank stabilization. Within the lake itself, Blue Lake stakeholders are encouraged to develop a comprehensive lake management plan for the lake. This plan should include a rooted plant management section to protect the plant community's health as well as a plan for managed recreation.

ACKNOWLEDGEMENTS

The Blue Lake Diagnostic Study was made possible with funding from the Indiana Department of Natural Resources (IDNR) Division of Soil Conservation and the Blue Lake Association. The Blue Lake Diagnostic Study was completed by JFNew and their subcontractor, Indiana University School of Public and Environmental Affairs. Contributors to this study included Cecil Rich and Ed Braun with the IDNR Division of Fish and Wildlife and Ron Hellmich with the IDNR Division of Nature Preserves. Special thanks to the dedicated board directors and members of the Blue Lake Association for their initiative and assistance in getting this study completed. Blue Lake residents who participated in the study included: Marc Shoda, who served as the primary liaison between JFNew and the Blue Lake Association; Vince Simmers, who navigated JFNew biologists around the lake during the rooted plant survey and toured watershed sites with JFNew to identify potential water quality improvement projects; and Jerry McClure, who kept an eagle eye on the precipitation, or lack there of, and helped collect and deliver samples to the laboratory. Authors of this report included William Jones, Chris Bobay, Sheela Doshi, Melissa Clark, Aaron Johnson, David Fuente, and Rachel Price at Indiana University and Sara Peel, John Richardson, Joe Exl, Mark Pranckus, and Scott Namestnik at JFNew.

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1.0 INTRODUCTION

Blue Lake is a 239-acre (96.7-ha) natural lake that lies in northeast corner of Whitley County, Indiana (Figure 1). Specifically, the lake is located in Sections 9, 10, 15, and 16 of Township 32 North, Range 10 East in Whitley County. The Blue Lake watershed stretches out to the east and south of the lake encompassing nearly 2,300 acres (930 ha or 3.6 square miles) (Figure 2). Water discharges through the lake's outlet in the northwest corner to the Blue River. Water in the Blue River flows southwest and empties into the Eel River south of Columbia City. The Eel River transports water to the Wabash River which eventually discharges into the Ohio River, exiting the state of Indiana.

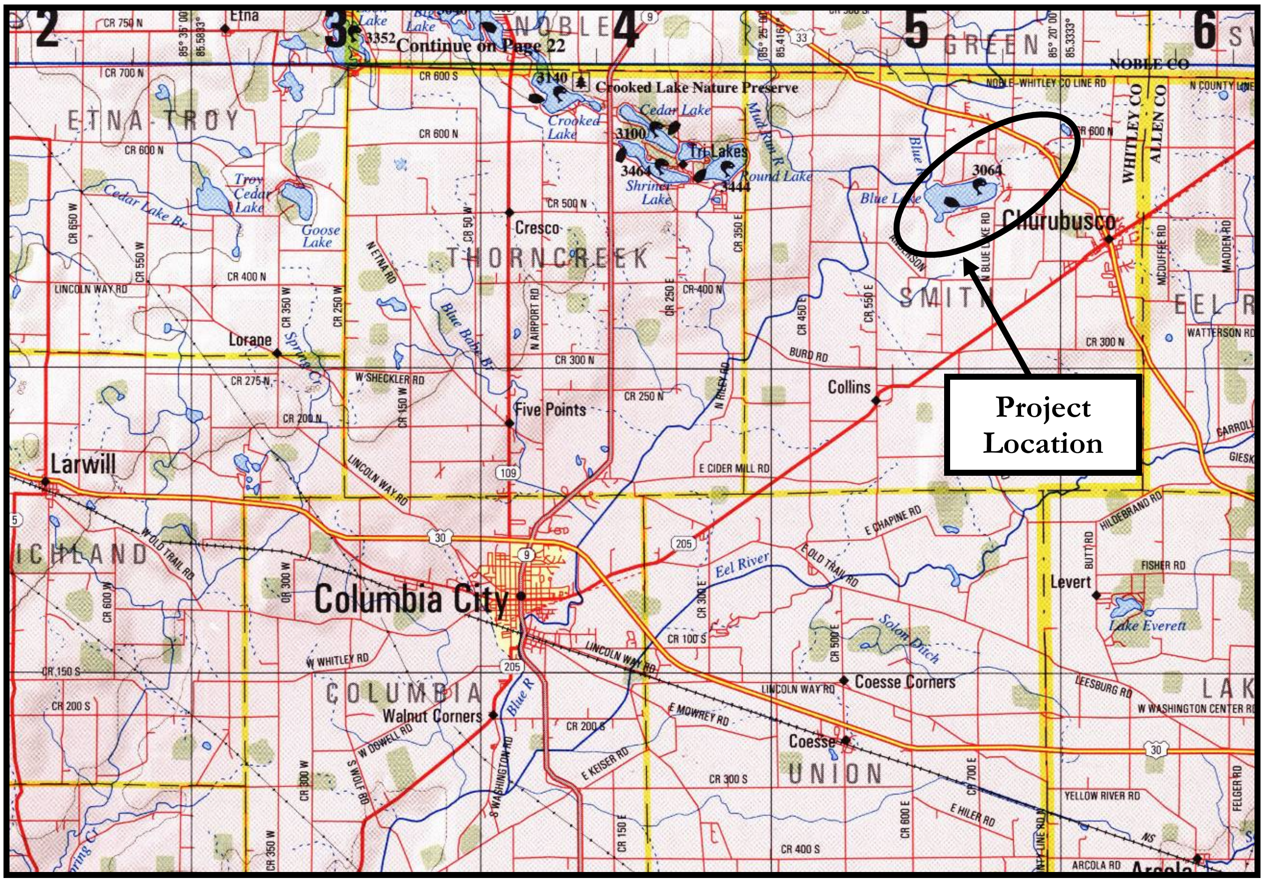

Figure 1. General location of the Blue Lake watershed. Source: DeLorme, 1998.

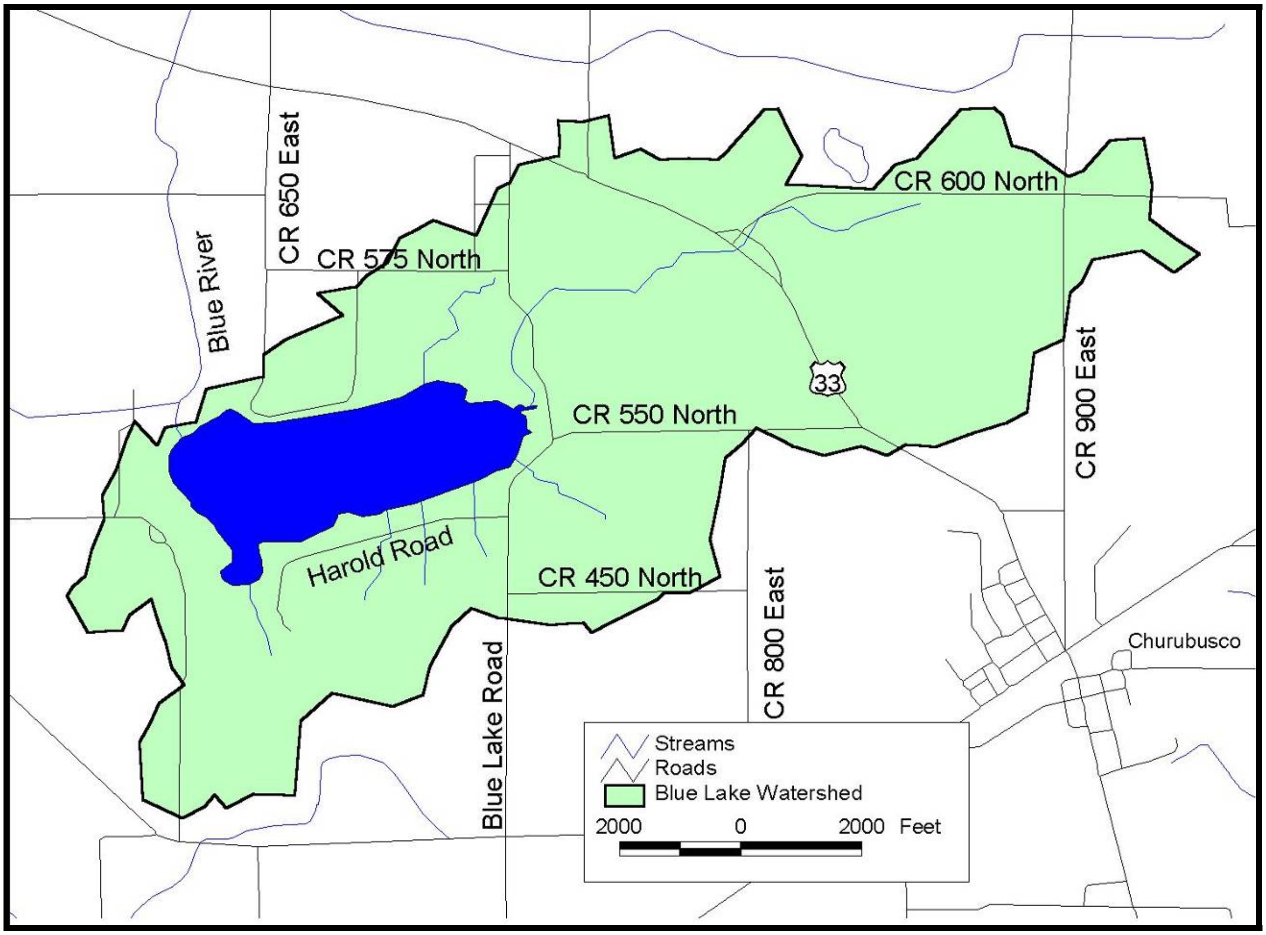

Figure 2. Blue Lake watershed. Source: See Appendix A.

Blue Lake has historically exhibited moderately poor water quality characteristic of mesotrophic to eutrophic lakes. The lake's water clarity declined over the past 25 years reaching levels that are relatively poor compared to other lakes in the region. Historical records (ISPCB, 1986; Shipman, 1976; Braun and Pearson, 1980; Braun, 1999; CLP, 1990, 1995, 1998, and 2004) from the past 25 years show that the lake's Secchi disk transparency (a measure of water clarity) declined from an average of 6 feet (1.8 m) to the current transparency of 2.3 feet (0.7 m). These data indicate that current water quality in Blue Lake is poorer than the regional median of less than 6 feet (1.8 m) (Giolitto, 2002). Blue Lake's nutrient levels also indicate a general decline in water quality. Total phosphorus concentrations increased from 0.15 mg/L to a high of 0.306 mg/L during the current assessment. Total phosphorus concentrations are elevated compared to the statewide and regional median values (Clean Lakes Program data files, unpublished; Giolitto, 2002; JFNew, 2005b). Primary productivity of the lake (algae and plant growth) has been relatively high as well. Chlorophyll *a* concentrations (an indicator of algae production) were above 20 μg/L in 2004 and 2005. Concentrations this high are typical of hypereutrophic lakes.

Blue Lake has been and continues to be a good lake for fishing. Fisheries surveys conducted by the Indiana Department of Natural Resources (IDNR) show little change in the lake's fishing potential over the past 30 years (Shipman, 1976; Braun, 1979; Braun, 1999). Gamefish dominate the total biomass of the lake's fishery accounting for 76% of the fishery by weight in 1998 compared to only 53% by weight in 1976. This means more of the lake's food source is going to support gamefish rather than non-sportfish. However, the presence of gizzard shad during the last assessment (1998) is of concern. Gizzard shad are a prolific species that is known to have negative impacts on bluegill and largemouth bass populations; they compete directly with young sunfishes for valuable food resources. Gizzard shad are a prolific reproducers and omnivorous feeder than can quickly become one of the most numerous fish species in the lake and affect several other components of the lake ecosystem. However, this has not impacted fishing pressures within Blue Lake. Braun (1999) indicated that nearly 48.8 hours of fishing occurred on Blue Lake per acre of open water during the 1998 creel survey. Most of the individuals fishing Blue Lake were from Allen County (49.8%), while another 38.3% of individuals were from Whitley County. Only 6.3% of interviewed anglers reside on Blue Lake (Braun, 1999). Fishing and boating pressures from off-lake residents suggest that more individuals used the lake in 1998 than the number observed during the 1981 creel survey (Braun, 1982).

The composition and structure of Blue Lake's rooted plant community indicate that water quality within the lake may be better than the water chemistry data indicate. Several of Blue Lake's dominant submerged plant species, including large-leaf pondweed and northern watermilfoil, thrive in clear water (Davis and Brinson, 1980; Borman et al., 1997; Curtis, 1998). Other species that are less abundant than the ones listed above, such as grassy pondweed and flatstem pondweed, are also characteristic of clear northeastern lakes (Davis and Brinson, 1980). While Blue Lake supports some species that are very tolerant of lower light conditions such as coontail, southern naiad, and Sago pondweed, these species are ubiquitous in northeastern lakes. The presence of these high quality species coupled with a lack of exotic invasive species, like Eurasian watermilfoil, indicates that the plant community within Blue Lake is of high quality. Additionally, American lotus is present in Blue Lake. This species is believed to be present in only a limited number of lakes in northern Indiana (Deam, 1921).

Blue Lake residents have been proactive in protecting their lake's health. Residents have worked on their own and with natural resource agencies to try to treat problems in the lake and its watershed. Residents of Blue Lake formed a conservancy district to address water quality problems created by septic system use. Residents now have a sewer system and are part of the Blue Lake Conservancy District. The Blue Lake Association also installed buoys to reduce the negative impact of boating and wave action on the lake's shoreline erosion. Members of the Blue Lake Association have discussed some concerns with the Whitley County Soil and Water Conservation District (SWCD). The Whitley County SWCD assisted in improving the water quality of the lake by implementing a number of grassed waterways and water and sediment control basins (WASCOBs) on farmland in the watershed. Members of the Blue Lake Association have also talked with property owners adjacent to the eroding drainages along the southern shoreline of the lake and along Maloney Ditch. There is initial indication that these individuals are open to working with the association to implement measures to protect the lake. While these practices have slowed the import of sediment to Blue Lake from its watershed and the conversations have sparked the interest of watershed residents, members of the Blue Lake Association have identified additional areas of concerns. Lake residents have also expressed a desire to learn about practices that can be implemented on residential properties that might improve the lake's water quality. To achieve these goals, the Blue Lake Association applied for and received funding from the IDNR Lake and River Enhancement Program (LARE) to complete a diagnostic study of the lake.

The purpose of the diagnostic study was to describe the conditions and trends in Blue Lake and its watershed, identify potential problems, and make prioritized recommendations addressing these problems. The study consisted of a review of historical studies, interviews with lake residents and state/local regulatory agencies, the collection of current water quality data, pollutant modeling, and field investigations. In order to obtain a broad understanding of the water quality in Blue Lake and the water entering the lake, the diagnostic study included an examination of the lake and inlet stream water chemistry and their biotic communities (macroinvertebrates, plankton, macrophytes) which tend to reflect the long-term trends in water quality. The lake and inlet streams' habitat was also assessed to help distinguish between water quality and habitat effects on the existing biotic communities. This report documents the results of the study.

2.0 WATERSHED CHARACTERISTICS

2.1 Topography and Physical Setting

Blue Lake is a headwaters lake in the Mississippi River Basin. The lake and its 2,272-acre (919.4-ha) watershed lie south of the north-south continental divide. Similar to its more famous cousin, the east-west Continental Divide which divides the United States into two watersheds, one that drains to the Atlantic Ocean and one that drains to the Pacific Ocean, the north-south continental divide separates the Mississippi River Basin (land that drains south to the Mississippi River) from the Great Lakes Basin (land that drains north to the Great Lakes). As part of the Mississippi River Basin, water exits Blue Lake near the lake's northwest corner and flows south through Whitley County as the Blue River. The Blue River combines with the Eel River south of Columbia City, which eventually discharges into the Wabash River near Logansport, Indiana. The Wabash River converges with the White River in southern Indiana before flowing into the Ohio River, then the Mississippi River.

The topography of the Blue Lake watershed reflects the geological history of the watershed. The highest areas of the watershed lie along the watershed's southern and eastern edges, where the Erie Lobe of the last glacial age left end moraines. Along the watershed's northeastern boundary, the elevation nears 910 feet (277.4 m) above mean sea level. The ridges along the watershed's southeastern boundary are equally as high, but are much less steep than the ridge along the northeastern watershed boundary. Maloney Ditch, its floodplain, and Blue Lake occupy a lower elevation valley in the watershed. Blue Lake, elevation 850 feet (259.1 m) above mean sea level, is the lowest point in the watershed. Figure 3 presents a topographical relief map of the Blue Lake watershed.

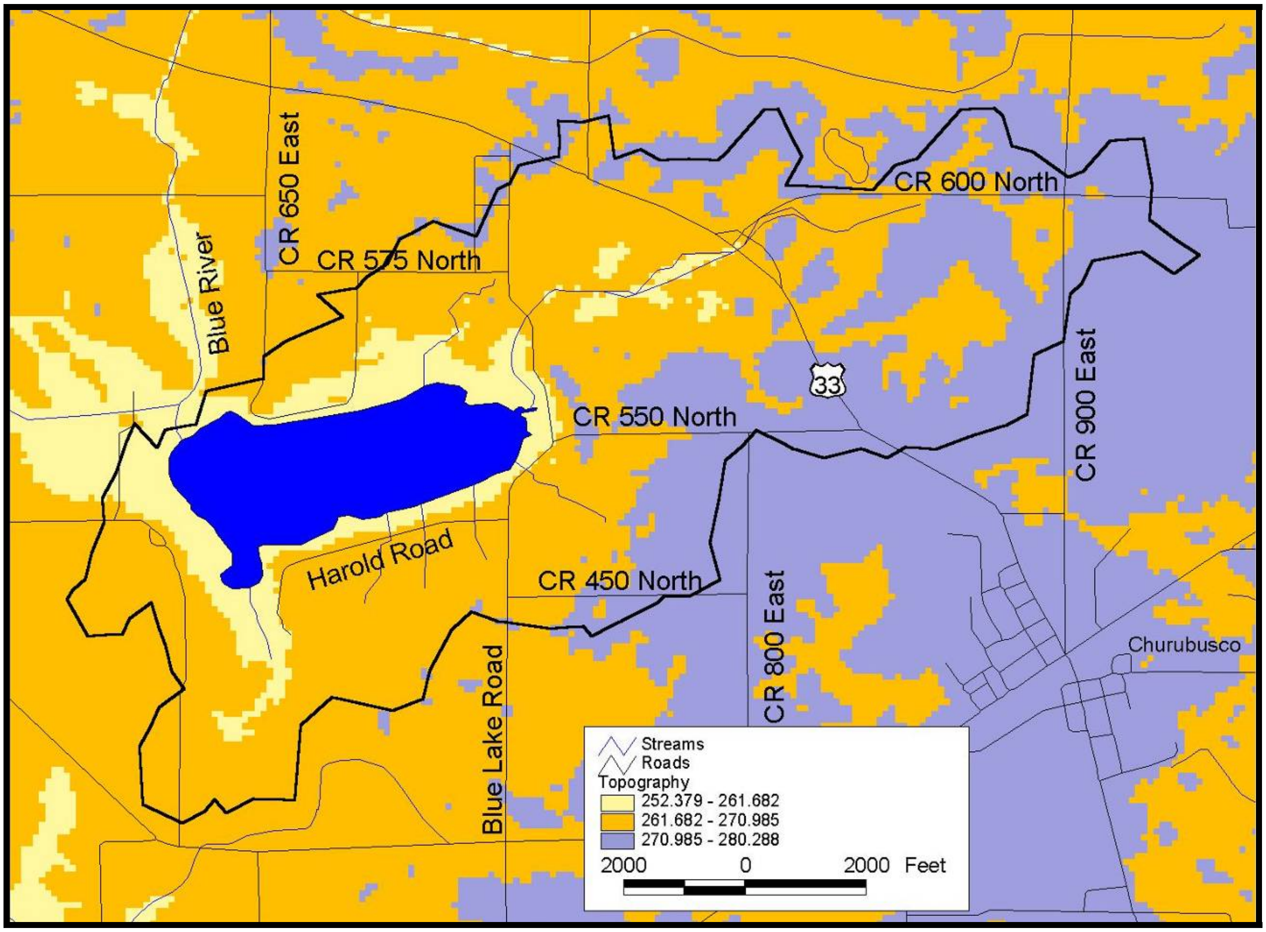

Figure 3. Topographical map of the Blue Lake watershed.
Source: See Appendix A.

2.1.1 Blue Lake

Surface water drains to Blue Lake via two primary routes: through Maloney Ditch and via direct drainage. Multiple minor tributaries also drain steep ravines along the southern shoreline of Blue Lake. Maloney Ditch drains approximately 1,010 acres (408.7 ha or 44.5%) of the watershed east and north of Blue Lake (Table 1). This stream empties into Blue Lake in the lake's northeast corner. A series of unnamed tributaries or ravines transport water to Blue Lake along its southern boundary. The largest of these tributaries drains into Horseshoe Bay carrying water from 185.6 acres (75.1 ha), while the second largest carries water from the watershed to the southeast corner of the lake draining 184.5 acres (74.7 ha). The other four small drainages carry water from 1.3 to 6.7% of the Blue Lake watershed. The remaining 28% of the land in the Blue Lake watershed (576.8 acres or 233.4 ha) drains directly to Blue Lake. Figure 4 illustrates the boundaries of each of these subwatersheds of Blue Lake.

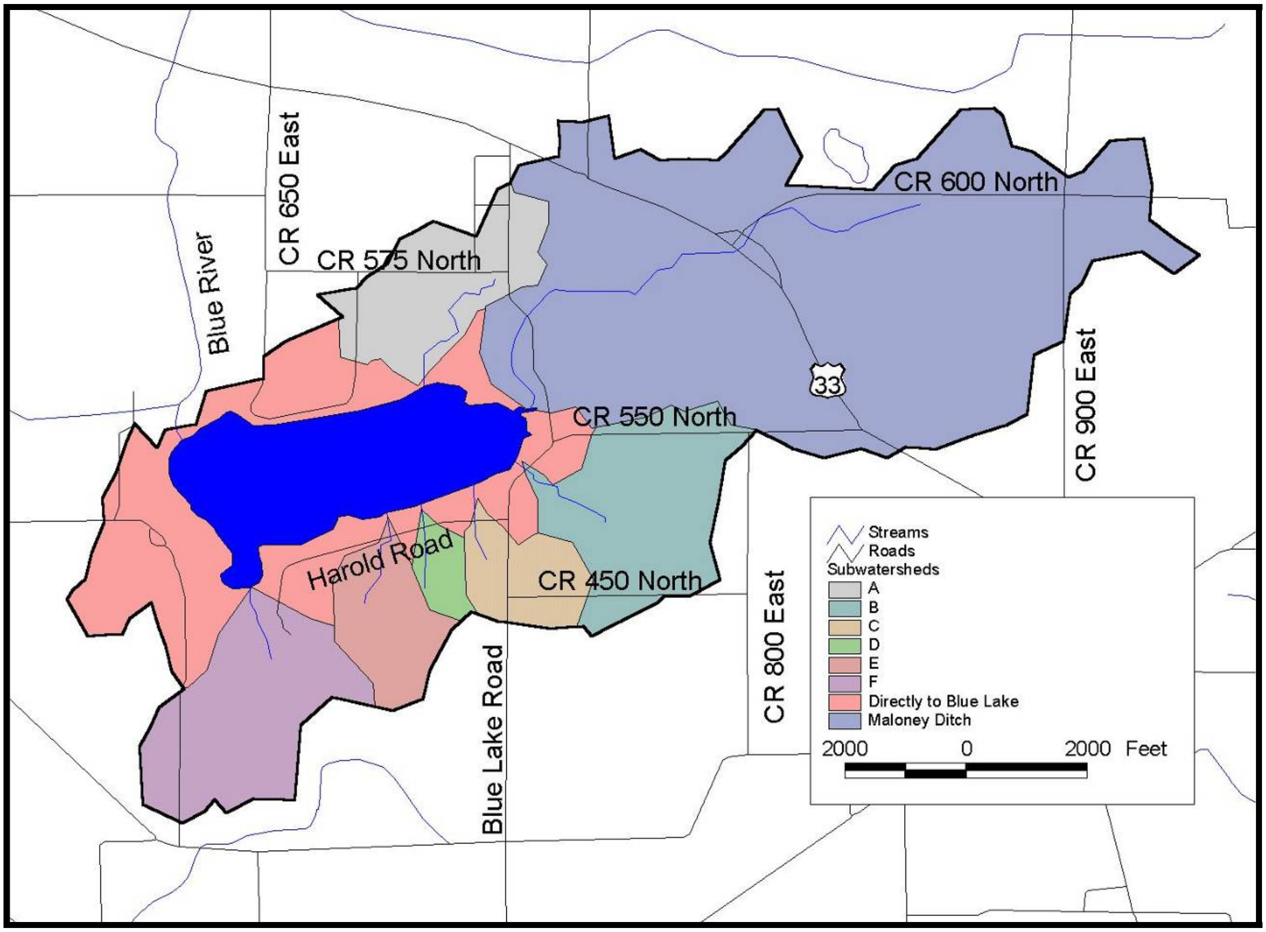

Figure 4. Blue Lake subwatersheds.
Source: See Appendix A.

Table 1. Watershed and subwatershed sizes for the Blue Lake watershed.

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
Maloney Ditch	1010.2	408.8	49.7%
Unnamed Tributary A (northeast corner)	137.2	55.5	6.7%
Unnamed Tributary B (southeast corner)	184.5	74.7	9.1%
Unnamed Tributary C (south central)	67.3	27.2	3.3%
Unnamed Tributary D (south central)	26.8	10.9	1.3%
Unnamed Tributary E (southwest)	83.6	33.8	4.1%
Unnamed Tributary F (Horseshoe Tributary)	185.6	75.1	9.1%
Area Draining Directly to Blue Lake	576.8	233.4	28.4%
Watershed Draining to Lake	**2,033**	**829.8**	**89.5%**
Blue Lake	239	96.7	10.5%
Total Watershed	**2,272**	**927.3**	**100%**
Watershed to Lake Area Ratio	9.5:1		

Table 1 also provides the watershed area to lake area ratio for Blue Lake. Watershed size and watershed to lake area ratios can affect the chemical and biological characteristics of a lake. For example, lakes with large watersheds have the potential to receive greater quantities of pollutants (sediments, nutrients, pesticides, etc.) from runoff than lakes with smaller watersheds. For lakes with large watershed to lake ratios, watershed activities can potentially exert a greater influence on the health of the lake than lakes possessing small watershed to lake ratios. Conversely, for lakes with small watershed to lake ratios, shoreline activities and internal lake processes may have a greater influence on the lake's health than lakes with large watershed to lake ratios.

Blue Lake possesses a watershed area to lake area ratio of approximately 9.5:1. This is a fairly typical watershed area to lake area ratio for glacial lakes (Vant, 1987). This ratio is also relatively normal when compared to other lakes in northern Indiana. For example, Lake of the Woods in Marshall County, which is similarly sized, possesses a watershed area to lake area ratio of approximately 15:1. Likewise, Lawrence Lake, which is less than one-third the size of Blue Lake, has a watershed area to lake area ratio of approximately 5:1. Conversely, Lake Tippecanoe, Ridinger Lake, and Smalley Lake, glacial lakes in the Upper Tippecanoe River watershed in Kosciusko, Noble, and Whitley Counties, possess watershed area to lake area ratios of 93:1, 165:1, and 248:1, respectively. All of these lakes have extensive watersheds compared to Blue Lake. Blue Lake's watershed area to lake area ratio is typical for glacial lakes. Many glacial lakes have watershed area to lake area ratios of less than 50:1 and watershed area to lake area ratios on the order of 10:1 are fairly common (Vant, 1987).

In terms of lake management, Blue Lake's watershed area to lake area ratio means that near lake (i.e. shoreline) and in-lake activities and processes can potentially exert a significant influence on the health of Blue Lake. Consequently, implementing best management practices along the lake's shoreline, such as maintaining native, emergent vegetated buffers between the lakeside residences and the lake, should rank high when prioritizing management options. Similarly, in-lake management practices, should receive special attention. This does not mean that watershed or ravine management should be ignored. However, the relatively small watershed area to lake area ratio should be considered when prioritizing the use of limited funds for lake management.

2.2 Climate

Indiana Climate

Indiana's climate can be described as temperate with cold winters and warm summers. The National Climatic Data Center summarizes Indiana weather well in its 1976 Climatology of the United States document no. 60: "Imposed on the well known daily and seasonal temperature fluctuations are changes occurring every few days as surges of polar air move southward or tropical air moves northward. These changes are more frequent and pronounced in the winter than in the summer. A winter may be unusually cold or a summer cool if the influence of polar air is persistent. Similarly, a summer may be unusually warm or a winter mild if air of tropical origin predominates. The action between these two air masses of contrasting temperature, humidity, and density fosters the development of low-pressure centers that move generally eastward and frequently pass over or close to the state, resulting in abundant rainfall. These systems are least active in midsummer and during this season frequently pass north of Indiana" (National Climatic Data Center, 1976). Prevailing winds in Indiana are generally from the southwest but are more persistent and blow from a northerly direction during the winter months.

Blue Lake Watershed Climate

The climate of the Blue Lake watershed is characterized as having four well-defined seasons of the year. Winter temperatures average 26º F (-3.3º C), while summers are warm, with temperatures averaging 70º F (21.1º C). The growing season typically begins in early April and ends in September. Yearly annual rainfall averages 38.52 inches (97.8 cm). Winter snowfall averages about 30 inches (76.2 cm). During summers, relative humidity varies from about 60 percent in mid-afternoon to near 80 percent at dawn. Prevailing winds typically blow from the southwest except during the winter when westerly and northwesterly winds predominate. In 2005, almost 35 inches (88.9 cm) of precipitation (Table 2) was recorded at Columbia City in Whitley County during 2005. This is more than 3 inches (7.6 cm) less than the normal amount of rainfall for Columbia City.

Table 2. Monthly rainfall data (in inches) for year 2005 as compared to average monthly rainfall. All data were recorded at Columbia City in Whitley County. Averages are 30-year normals based on available weather observations taken during the years of 1971-2000 at Columbia City (Purdue Applied Meteorology Group, 2005).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2005	6.43	2.80	2.07	1.35	2.02	5.07	4.10	1.97	3.75	0.44	2.49	2.44	**34.93**
Average	2.12	1.80	2.90	3.67	3.70	4.44	3.82	3.58	3.52	2.80	3.31	2.86	**38.52**

Although, precipitation amounts for 2005 approximate normal amounts for Whitley County over the 30-year period from 1971 to 2000, total precipitation was more than 3.5 inches (8.9 cm) below normal for the Blue Lake watershed (Table 2). The National Weather Service indicated that the summer of 2005 was warmer and drier than is typical for much of northern Indiana (Hitchcock, 2005). Dry weather in the spring led to lower than normal soil moisture content. This, coupled with persistent warm, humid air masses that migrated into northern Indiana, created a situation where heat from the sun warmed the ground and air rather than evaporating moisture from the soil's surface. Additionally, the majority of precipitation events throughout the summer occurred as thunderstorms, which creates extremely variable rainfall total across northern Indiana. The National Weather Service (2005) documented a drought that covered northern Indiana for much of the summer (Figure 5). For Fort Wayne, temperatures averaged 2.4 degrees higher than normal, but did not rank in the ten warmest summers on record since 1911. June averaged 3.8 degrees above normal and ranks as the 8th warmest June on record, while July averaged 1.6 degrees above normal or the 20th warmest July on record. August averaged 1.8 degrees above normal and ranked as the 19th warmest August on record. Precipitation followed similar patterns with 1.95 inches (4.95 cm) less rain than normal in June, 1.61 inches (4.1 cm) less rain than normal in July, and 1.65 inches (4.19 cm) less rain than normal in August (Hitchcock, 2005). Dry stream channels were observed around Blue Lake in early July. Photographs taken during the July 28, 2005 plant survey document water levels well below the normal lake level (Figure 6). The sediment exposed in front of the concrete seawall indicates that as of July 28th, water levels were at least 8 to 10 inches (20 to 25 cm) below normal levels. By the end of the summer, the lake was approximated to be almost 2 feet (0.7 m) below normal water levels.

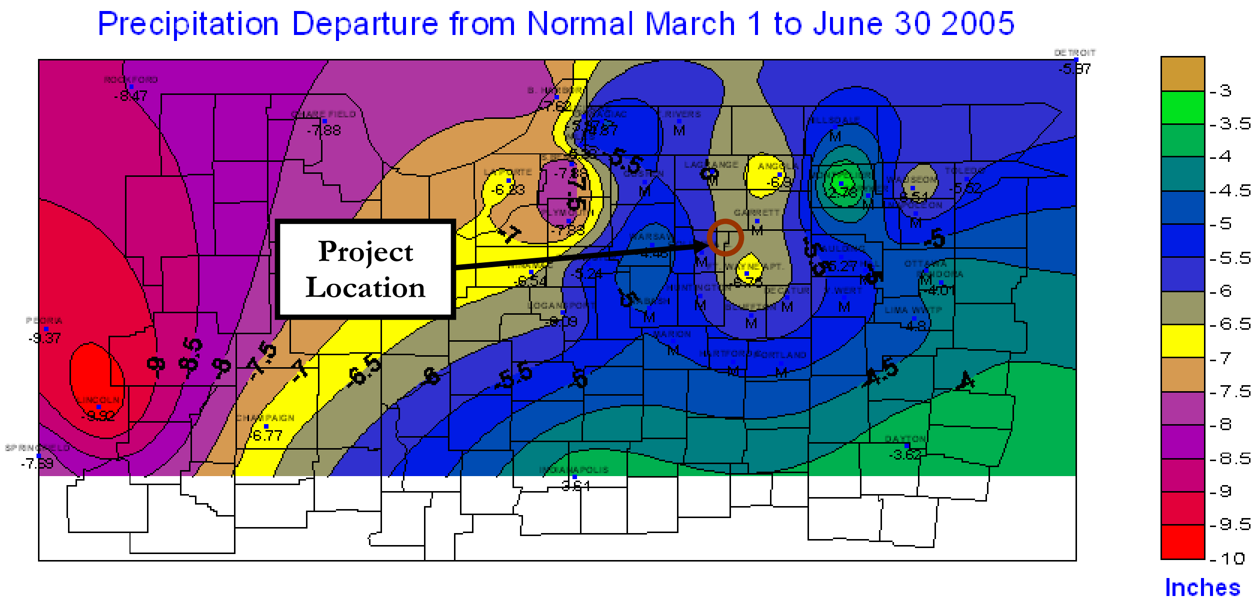

Figure 5. Drought conditions present in northern Indiana in 2005.
Source: National Weather Service, 2005.

Figure 6. Exposed sediment in front of a concrete seawall observed during July 2005. Low water levels within the lake are testimony to the dry conditions present during 2005.

2.3 Geology

The advance and retreat of the glaciers in the last ice age (the Wisconsin Age) shaped much of the landscape found in Indiana today. As the glaciers moved, they laid thick till material over the northern two thirds of the state. Ground moraine left by the glaciers covers much of the central portion of the state. In the northern portion of the state, ground moraines, end moraines, lake plains, and outwash plains create a more geologically diverse landscape compared to the central portion of the state. End moraines, formed by the layering of till material when the rate of glacial retreat equals the rate of glacial advance, add topographical relief to the landscape. Distinct glacial lobes, such as the Michigan Lobe, Saginaw Lobe, and the Erie Lobe, left several large, distinct end moraines, including the Valparaiso Moraine, the Maxinkuckee Moraine, and the Packerton Moraine, scattered throughout the northern portion of the state. Glacial drift and ground moraines cover flatter, lower elevation terrain in northern Indiana. Major rivers in northern Indiana cut through sand and gravel outwash plains. These outwash plains formed as the glacial meltwaters flowed from retreating glaciers, depositing sand and gravel along the meltwater edges. Lake plains, characterized by silt and clay deposition, are present where lakes existed during the glacial age.

The movement and stagnation of the Saginaw and Erie Lobes of the Wisconsin glacial age shaped much of the Blue Lake watershed. The Saginaw glacial lobe moved out of Canada to the south carrying a mixture of Canadian bedrock with it. The Packerton Moraine, an end moraine which marks the edge of the Saginaw Lobe's advance into Indiana, formed north and west of the northwestern boundary of the Blue Lake watershed. The Packerton Moraine extends northeasterly blending into the Mississinewa Moraine, which marks the stagnation point of the Erie Lobe that originated from the east. The Mississinewa Moraine is just one of the many concentric end moraines marking the stall points of the Erie Lobe. In between these concentric end moraines, ground moraines formed from the material which is continuously reworked as glacial lobes move back and forth. Fragments of the Packerton Moraine are scattered along Blue Lake watershed's northeastern edge (shown in purple in Figure 3). These fragments form a ridge separating the Blue River basin from the mainstem Eel River basin. The areas of greater relief associated with the Packerton Moraine are located north of the watershed's northern boundary, while the relief associated with the interlobate region, where the Packerton Moraine meets the Mississinewa and Salamonie Moraines, covers most of the watershed (shown in orange in Figure 3). The relief associated with the fragments of the Mississinewa Moraine form the ridge located along the watershed's southeastern edge.

The geology and resulting physiography of the Blue Lake watershed typify the physiographic region in which the watershed lies. The Blue Lake watershed lies within Malott's Steuben Morainal Lake Area. Schneider (1966) notes that the landforms common in this diverse physiographic region include till knobs and ice-contact sand and gravel kames, kettle holes and lakes, meltwater channels lined with outwash deposits or organic sediment, valley trains, outwash plains, and small lacustrine plains. Many of these landforms are visible on the Blue Lake watershed landscape. Blue Lake is a good example of a deep (relative to many lakes in the region) kettle lake lying in an end moraine. It's part of the "knob and kettle" topography that is characteristic of end moraines. The flat area northwest of Blue Lake likely demarcates the extent of the original waterbody that covered Blue Lake and the area to the northwest of the lake many years ago. This waterbody has been reduced to only Blue Lake. As will be discussed in the next section, Houghton muck, a common soil type of aged lakes, is the dominant soil type in this area, lending evidence to the idea that this area was once part of a larger lake. Till knobs and kames occur along the watershed's southeastern edge. Many other reminders of the watershed's geologic history exist for those who look closely.

Surficial geology indicates that Blue Lake lies within a muck deposit. As mentioned above, this area was likely covered by a glacial lake. The remainder of the watershed's surficial geology originates from silty clay loam and clay loam till materials. The bedrock underlying the watershed's surficial geology includes rock from one period. Antrim shale underlies the entire Blue Lake watershed. This bedrock shale is from the Devonian-Mississippian Period (Gutschick, 1966).

2.4 Soils

Before detailing the major soil associations covering the Blue Lake watershed, it may be useful to examine the concept of soil associations. Major soil associations are determined at the county level. Soil scientists review the soils, relief, and drainage patterns on the county landscape to identify distinct proportional groupings of soil units. The review process typically results in the identification of eight to fifteen distinct patterns of soil units. These patterns are the major soil associations in the county. Each soil association typically consists of two or three soil units that dominate the area covered by the soil association and several soil units that occupy only a small portion of the soil association's landscape. Soil associations are named for their dominant components. For example, the Houghton-Sloan soil association consists primarily of Houghton muck and Sloan loam.

Two major soil associations, the Blount-Pewamo-Glynwood soil association and the Houghton-Sloan soil association, cover the Blue Lake watershed (Figure 7). The Blount-Pewamo-Glynwood soil association is the most common soil association in Whitley County and covers over half the county. This soil association covers most of the Blue Lake watershed. In contrast, the Houghton-Sloan soil association covers only about 3% of the county. This soil association covers the area immediately adjacent to Blue Lake. The following discussion on soil associations in the Blue Lake watershed relies heavily on the *Soil Survey of Whitley County* (Ruesch, 1990). Readers should refer to this source for a more detailed discussion of soil associations covering Whitley County.

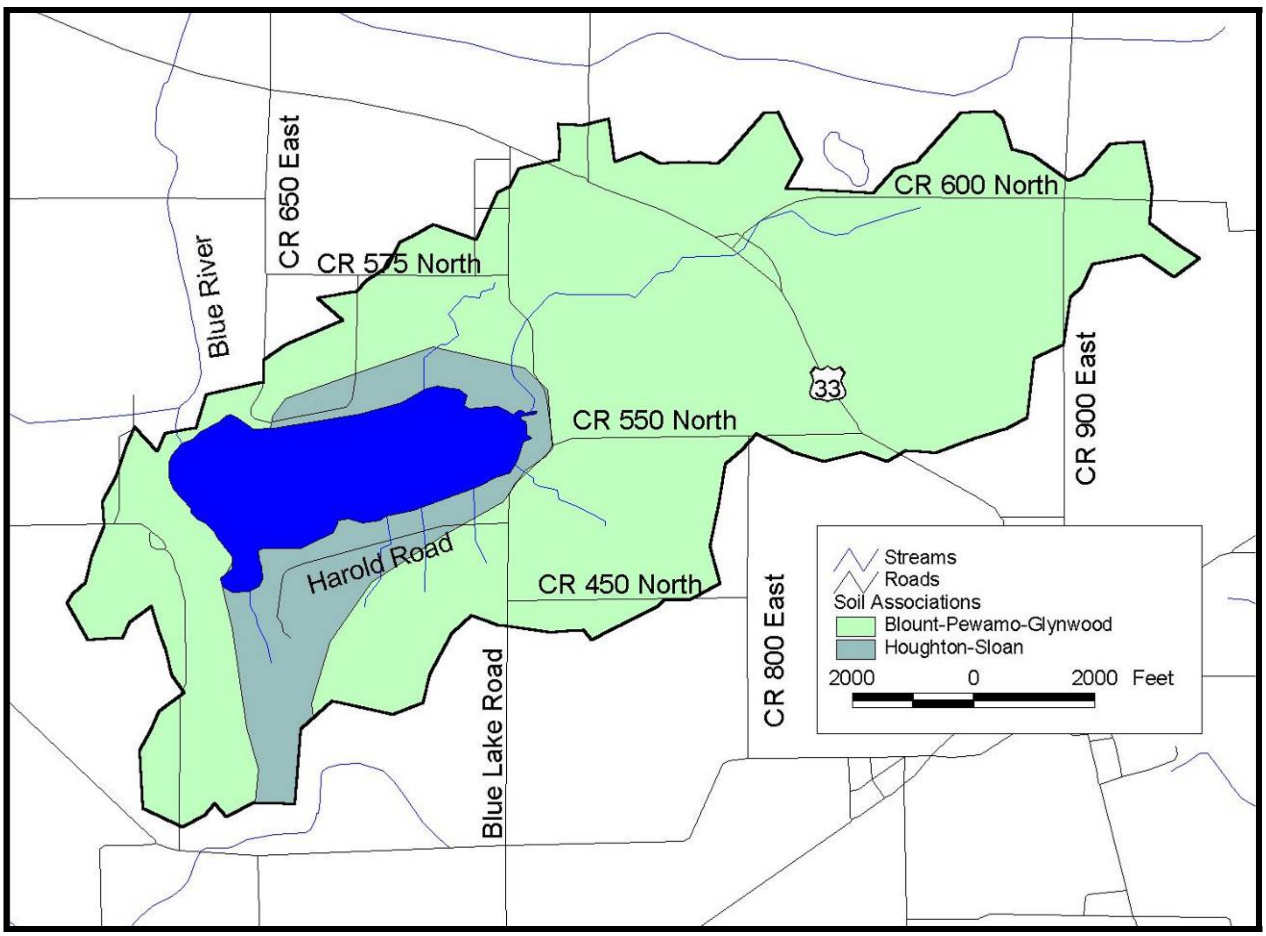

Figure 7. Soil associations in the Blue Lake watershed. Source: See Appendix A.

The Blount-Pewamo-Glynwood soil association covers nearly all of the Blue Lake watershed except for the area immediately adjacent to Blue Lake and a portion of the southwest corner of the watershed. Soils in this soil association developed from glacial till and occur on till plains and moraines. Thirty seven percent of the soil association consists of Blount soils, while 20% and 14% of the soil association consists of Pewamo and Glynwood soils, respectively. Blount soils are somewhat poorly drained soils found on level or gently sloping areas. The surface layer of Blount soils is silty clay in texture, while the subsurface layer has a clay or clay loam texture. Pewamo soils are hydric soils that are typically found at lower elevations than Blount soils. These very poorly drained soils possess a silty clay loam surface layer covering clay, silty clay loam, and/or clay loam subsoils. Glynwood soils cover gently to moderately sloping landscapes. Depending upon the severity of erosion, the surface layer of Glynwood soils has a loam or clay loam texture. The surface layer of Glynwood soils lies over clay subsoil. Minor components in the Blount-Pewamo-Glynwood soil association include Haskins, Mermill, Milford, Morley, Rawson, and Shoals soils.

Ruesch (1990) describes the Blount-Pewamo-Glynwood soil association as being "well suited" for corn and soybean production. Given the significant clay component in this soil association, erosion can be a concern with agricultural production on sloped areas of this soil association. Many of the soils in the Blount-Pewamo-Glynwood soil association have severe limitations when used as a septic tank absorption field. As a consequence, this soil association is not well suited for residential development if septic tank absorption fields are the main source of wastewater treatment at the residences.

The Houghton-Sloan soil association borders Blue Lake and extends south of the lake into the southwest corner of the watershed. Soils in this association formed from organic materials. The soil association can be found on moraines and in bottomlands. Houghton and similar soils are the dominant component of the Houghton-Sloan soil association accounting for 35% of the soil association. Sloan and similar soils account for 25% of the soil association, while minor components include Boyer, Mermill, Morley, Sebewa, and Shoals soils. Houghton soils are muck soils located on the bottom of depressions. Sloan soils possess a loamy surface layer over a stratified sandy loam, silt loam, and loam subsoil. Sloan soils exist on bottom lands along small streams that enter and exit old glacial lakes.

Soils in the Houghton-Sloan soil association are very poorly drained limiting their use. Ruesch (1990) indicates that most of the land covered in this soil association is utilized for agricultural purposes. He notes that due to the poor drainage areas mapped in this soil association is "unsuitable" for residential development and "poorly suited" for intensive recreational uses.

2.4.1 Highly Erodible Soils

Soils that erode from the landscape are transported to waterways where they degrade water quality, interfere with recreational uses, and impair aquatic habitat and health. In addition, such soils can carry attached nutrients, which further impair water quality by increasing production of plant and algae growth. Soil-associated chemicals, like some herbicides and pesticides, can kill aquatic life and damage water quality.

Highly erodible and potentially highly erodible are classifications used by the Natural Resources Conservation Service (NRCS) to describe the potential of certain soil units to erode from the landscape. The NRCS examines common soil characteristics such as slope and soil texture when classifying soils. The NRCS maintains a list of highly erodible soil units for each county. Table 3 lists the soil units in the Blue Lake watershed that the NRCS considers to be highly erodible and potentially highly erodible.

Highly erodible and potentially highly erodible soil units in the form of Blount silt loam, Boyer loam, Glynwood loam, Hennepin loam, Morley loam and clay loam, Rawson sandy loam, and Spinks sand soils cover much of the Blue Lake watershed. Areas of the watershed that are mapped in these soil units and have gentle slopes are considered only slightly limited for agricultural production. An exception to this statement is the Blount soil unit, which is somewhat poorly drained and limited due to its wetness. As slope increases, the severity of the limitation increases. Some steeply sloped Hennepin and Morley soils are considered unsuitable for agricultural production due to erosion hazard. The erosion hazard would also exist during residential development on these soils.

Table 3. Highly erodible and potentially highly erodible soil units in the Blue Lake watershed.

Soil Unit	Status	Soil Name	Soil Description
BmB2	PHES	Blount silt loam	1 to 4 percent slopes, eroded
ByC3	PHES	Boyer loam	6 to 15 percent slopes, severely eroded
GsB2	PHES	Glynwood loam	3 to 6 percent slopes, eroded
GtB3	PHES	Glynwood loam	6 to 8 percent slopes, severely eroded
HeG	HES	Hennepin loam	25 to 50 percent slopes
MvB2	PHES	Morley loam	3 to 6 percent slopes, eroded
MvC2	HES	Morley loam	6 to 12 percent slopes, eroded
MvD2	HES	Morley loam	12 to 20 percent slopes, eroded
MvE2	HES	Morley loam	20 to 30 percent slopes, eroded
MxC3	PHES	Morley clay loam	5 to 12 percent slopes, severely eroded
MxD3	HES	Morley clay loam	12 to 20 percent slopes, severely eroded
RcB	PHES	Rawson sandy loam	2 to 6 percent slopes
RcC	PHES	Rawson sandy loam	6 to 12 percent slopes
SpC	PHES	Spinks sand	6 to 15 percent slopes

Note: PHES stands for potentially highly erodible soil and HES stands for highly erodible soil.

As Figure 8 indicates, potentially highly erodible soils cover a substantial portion (813.3 acres (329.1 ha) or nearly 36%) of the Blue Lake watershed. This acreage is spread throughout the watershed. Highly erodible soil exists on approximately 266.3 acres (107.8 ha or nearly 12%) of the watershed. The highly erodible and the potentially highly erodible soils mainly cover areas of the watershed that are currently being used for row crops and pasture or hay fields. No highly erodible or potentially highly erodible soils surround the shoreline of Blue Lake.

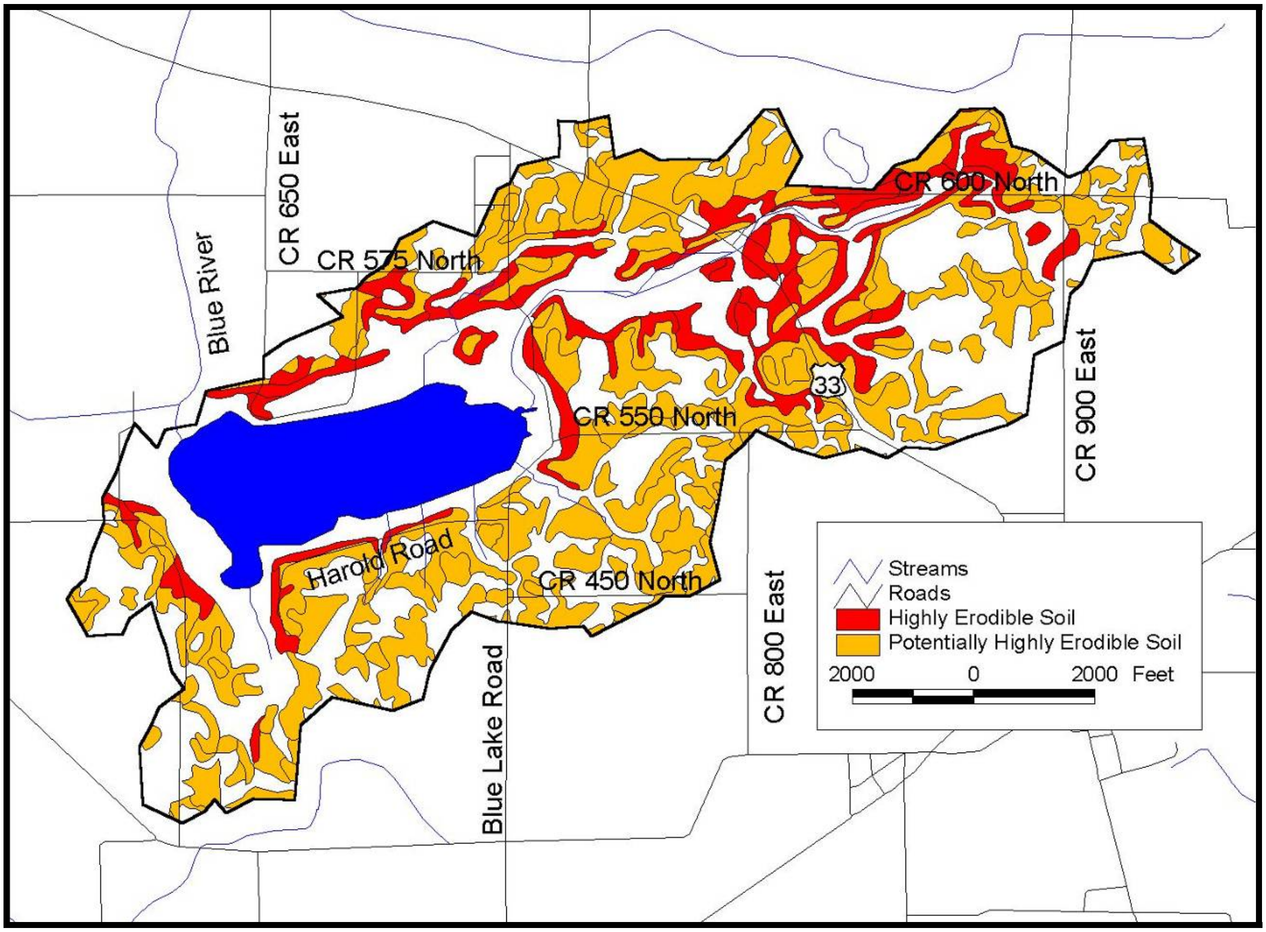

Figure 8. Highly erodible and potentially highly erodible soils within the Blue Lake watershed.
Source: See Appendix A.

2.4.2 Soils Used for Septic Tank Absorption Fields

Nearly half of Indiana's population lives in residences having private waste disposal systems. As is common in many areas of Indiana, septic tanks and septic tank absorption fields are utilized for wastewater treatment throughout the Blue Lake watershed. The shoreline of Blue Lake is one exception to this. Wastewater from nearly 400 residences around Blue Lake is treated by a sewer system owned and operated by the Blue Lake Conservancy District. The sewer system treats wastewater from nearly the entire shoreline of Blue Lake. Wastewater from the Blue Lake Conservancy District sewer is transported to the Churubusco wastewater treatment plant. Wastewater from the remaining 100 homes on the east end of the lake is treated by Churubusco Utilities. (The areas treated by a wastewater sewer system are mapped in Figure 9.) Treated effluent from the Churubusco Utilities discharges to the Blue River south and west of Churubusco. Until 5 years ago, residences along the shoreline of Blue Lake utilized individual septic tanks to treat wastewater. Much of the wastewater from the remainder of the Blue Lake watershed is still primarily treated by private waste disposal systems. Private waste disposal systems rely on the septic tank for primary treatment to remove solids and the soil for secondary treatment to reduce the remaining pollutants in the effluent to levels that protect surface and groundwater from contamination. The soil's ability to sequester and degrade pollutants in septic tank effluent will ultimately determine how well surface and groundwater is protected.

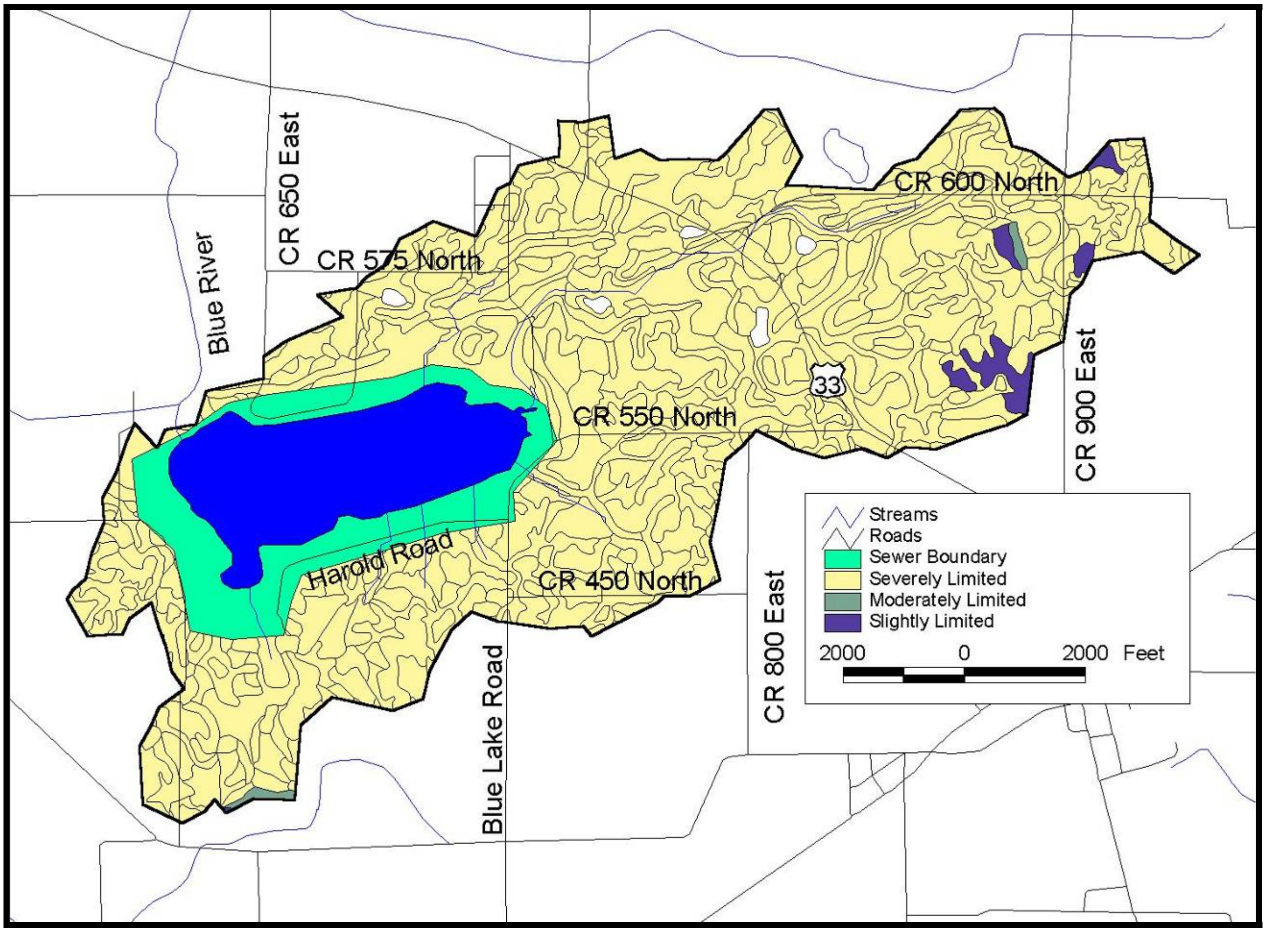

Figure 9. Soil septic tank suitability within the Blue Lake watershed. Areas shaded in green indicate those residences where wastewater is treated by a sewer system maintained by either the Blue Lake Conservancy District or Churubusco Utilities.
Source: See Appendix A.

A variety of factors can affect a soil's ability to function as a septic absorption field. Seven soil characteristics are currently used to determine soil suitability for on-site sewage disposal systems: position in the landscape, slope, soil texture, soil structure, soil consistency, depth to limiting layers, and depth to seasonal high water table (Thomas, 1996). The ability of soil to treat effluent (waste discharge) depends on four factors: the amount of accessible soil particle surface area; the chemical properties of the soil particle's surface; soil conditions like temperature, moisture, and oxygen content; and the types of pollutants present in the effluent (Cogger, 1989).

The amount of accessible soil particle surface area depends both on particle size and porosity. Because they are smaller, clay particles have a greater surface area per unit volume than silt or sand; and therefore, a greater potential for chemical activity. However, soil surfaces only play a role if wastewater can contact them. Soils of high clay content or soils that have been compacted often have few pores that can be penetrated by water and are not suitable for septic systems because they are too impermeable. Additionally, some clays swell and expand on contact with water closing the larger pores in the profile. On the other hand, very coarse soils may not offer satisfactory effluent treatment either because the water can travel rapidly through the soil profile. Soils located on sloped land also may have difficulty in treating wastewater due to reduced contact time.

Chemical properties of the soil surfaces are also important for wastewater treatment. For example, clay materials have imperfections in their crystal structure which gives them a negative charge along their surfaces. Due to their negative charge, they can bond cations of positive charge to their surfaces. However, many pollutants in wastewater are also negatively charged and are not attracted to the clays. Clays can help remove and inactivate bacteria, viruses, and some organic compounds.

Environmental soil conditions influence the microorganism community which ultimately carries out the treatment of wastewater. Factors like temperature, moisture, and oxygen availability influence microbial action. Excess water or ponding saturates soil pores and slows oxygen transfer. The soil may become anaerobic if oxygen is depleted. Decomposition process (and therefore, effluent treatment) becomes less efficient, slower, and less complete if oxygen is not available.

Many of the nutrients and pollutants of concern are removed safely if a septic system is sited correctly. Most soils have a large capacity to hold phosphate. On the other hand, nitrate (the end product of nitrogen metabolism in a properly functioning septic system) is very soluble in soil solution and is often leached to the groundwater. Care must be taken in siting the system to avoid well contamination. Nearly all organic matter in wastewater is biodegradable as long as oxygen is present. Pathogens can be both retained and inactivated within the soil as long as conditions are right. Bacteria and viruses are much smaller than other pathogenic organisms associated with wastewater; and therefore, have a much greater potential for movement through the soil. Clay minerals and other soil components may adsorb bacteria and viruses, but retention is not necessarily permanent. During storm flows, bacteria and viruses may become resuspended in the soil solution and transported throughout the soil profile. Inactivation and destruction of pathogens occurs more rapidly in soils containing oxygen because sewage organisms compete poorly with the natural soil microorganisms, which are obligate aerobes requiring oxygen for life. Sewage organisms live longer under anaerobic conditions without oxygen and at lower soil temperatures because natural soil microbial activity is reduced.

Taking into account the various factors described above, the NRCS ranks each soil series in the Blue Lake watershed in terms of its limitations for use as a septic tank absorption field. Each soil series is placed in one of three categories: slightly limited, moderately limited, or severely limited. Use of septic absorption fields in moderately or severely limited soils generally requires special design, planning, and/or maintenance to overcome the limitations and ensure proper function. Figure 9 displays the septic tank suitability of soils throughout the Blue Lake watershed, while Table 4 lists the soils located within the watershed and their associated properties. Soils severely limited for use as septic tank absorption fields cover nearly 88% of the watershed (1,986 acres or 803.7 ha), while moderately limited soils cover an additional 0.3% of the watershed (6.2 acres or 2.5 ha). Less than 2% of the Blue Lake watershed is covered by soils that are only slightly limited for use as septic tank absorption fields. (The remaining 10% of the watershed is covered by Blue Lake itself.)

Table 4. Soil types in the Blue Lake watershed and the features restrictive to their suitability to serve as a septic tank absorption field.

Soil Unit	Soil Name	Depth to High Water Table (ft.)	Restrictive Features
Ae	Adrian muck	+1-1.0	Severe: ponding, poor filter
BmA	Blount silt loam	1.0-3.0	Severe: wetness, percs slowly
BmB2	Blount silt loam	1.0-3.0	Severe: wetness, percs slowly
ByC3	Boyer loam	>6.0	Severe: poor filter
Co	Coesse silty clay loam	+1-1.0	Severe: ponding, percs slowly
GsB2	Glynwood loam	2.0-3.5	Severe: wetness, percs slowly
GtB3	Glynwood loam	2.0-3.5	Severe: wetness, percs slowly
HbA	Haskins loam	1.0-2.5	Severe: wetness, percs slowly
HeG	Hennepin loam	>6.0	Severe: percs slowly, slope
Hs	Houghton muck	+1-1.0	Severe: ponding, percs slowly
Ht	Houghton muck	+1-1.0	Severe: ponding, percs slowly
Md	Martisco muck	+1-0.5	Severe: flooding, ponding, percs slowly
Mg	Mermill loam	+1-1.0	Severe: ponding, percs slowly
Ms	Milford silty clay loam	+.5-2.0	Severe: ponding, percs slowly
MvB2	Morley loam	>6.0	Severe: percs slowly
MvC2	Morley loam	>6.0	Severe: percs slowly
MvD2	Morley loam	>6.0	Severe: percs slowly
MvE2	Morley loam	>6.0	Severe: percs slowly
MxC3	Morley clay loam	>6.0	Severe: percs slowly, slope
MxD3	Morley clay loam	>6.0	Severe: percs slowly, slope
Mz	Muskego muck, clay loam substratum	+1-1.0	Severe: ponding, percs slowly
Pb	Palms muck, sandy substratum	+1-1.0	Severe: ponding
Pw	Pewamo silty clay loam	+1-1.0	Severe: percs slowly, ponding
RcB	Rawson sandy loam	2.5-4.0	Severe: wetness, percs slowly
RcC	Rawson sandy loam	2.5-4.0	Severe: wetness, percs slowly
Re	Rensselaer loam	+.5-1.0	Severe: ponding
Sa	Saranac silty clay loam, sandy substratum	+.5-1.0	Severe: flooding, ponding, percs slowly
SfB	Seward loamy fine sand	3.0-6.0	Severe: wetness, percs slowly
So	Sloan loam, sandy substratum	0-1.0	Severe: flooding, wetness, percs slowly
SpB	Spinks sand	>6.0	Slight
SpC	Spinks sand	>6.0	Moderate: slope

Soil Unit	Soil Name	Depth to High Water Table (ft.)	Restrictive Features
Wa	Wallkill silty clay loam	+.5-1.0	Severe: ponding
Wc	Wallkill silty clay loam	+1-1.0	Severe: ponding, percs slowly

2.5 Natural History

Geographic location, climate, topography, geology, soils, and other factors play a role in shaping the native floral and faunal communities in a particular area. Various ecologists (Deam, 1921; Petty and Jackson, 1966; Homoya et. al, 1985; Omernik and Gallant, 1988) have divided Indiana into several natural regions or ecoregions, each with similar geographic history, climate, topography, and soils. Because the groupings are based on factors that ultimately influence the type of vegetation present in an area, these natural areas or ecoregions tend to support characteristic native floral and faunal communities. Under many of these classification systems, the Blue Lake watershed lies at or near the transition between two or more regions. For example, the watershed lies in the southern part of Homoya's Northern Lakes Natural Region, near its transition with the Buffton Till Plain Section of the Central Till Plain Natural Region. Similarly, the Blue Lake watershed lies in the northern portion of Omernik and Gallant's Eastern Corn Belt Plains Ecoregion, near its transition with the Southern Michigan/Northern Indiana Till Plains Ecoregion. The Blue Lake watershed also lies in the transition zone between Petty and Jackson's Oak-Hickory and Beech-Maple Climax Forest Associations. As a result, the native floral community of the Blue Lake watershed likely consisted of components of neighboring natural areas and ecoregions in addition to components characteristic of the natural area and ecoregion in which it is mapped.

Homoya et. al (1985) noted that prior to European settlement, the region was a mixture of numerous natural community types, including bog, fen, marsh, prairie, sedge meadow, swamp, seep spring, lake, and deciduous forest. The dry to dry-mesic uplands were likely forested with red oak, white oak, black oak, shagbark hickory, and pignut hickory. More mesic areas probably harbored beech, sugar maple, black maple, and tulip poplar. Omernick and Gallant (1988) describe the region as consisting mostly of cropland agriculture, with remnants of natural forest cover. Mesic forests are dominated by American beech and sugar maple, with a significant component of white oak, black oak, northern red oak, yellow poplar, hickory, white ash, and black walnut. Petty and Jackson (1966) list pussy toes, common cinquefoil, wild licorice, tick clover, blue phlox, waterleaf, bloodroot, Joe-pye-weed, woodland asters, goldenrods, wild geranium, and bellwort as common components of the forest understory in the watershed's region. Historically, Smith Township was covered by swamps, streams, and forests (Historical Landmarks Foundation, 2002). Historical records support the observation that prior to European settlement of Smith Township dense oak-hickory forests covered the Blue Lake watershed (Petty and Jackson, 1966). Chamberlain (1849) described the area as possessing undulating topography covered by fields of open forest. The state legislature (1938) noted that the northern portion of the county was dotted with beautiful lakes, the largest of which was Blue River Lake (later known as Blue Lake). White oak was the dominant component of the heavily timbered areas with shagbark hickory, maple, beech, elm, walnut, butternut, and red and black oak as subdominants (Petty and Jackson, 1966; Omernik and Gallant, 1988; Historic Landmarks Foundation, 2002).

Wet habitat (ponds, swamps, marshes, and bogs) intermingled with the upland habitat throughout the Blue Lake watershed. The hydric soils map and an 1876 map of Whitley County indicate that wetland habitat existed throughout the Blue Lake watershed including all of the area adjacent to the lake. These wet habitats supported very different vegetative communities than the drier portions of the landscape (Homoya et. al, 1985). Sycamore, American elm, red elm, green ash, silver maple, red maple, cottonwood, hackberry, and honey locust likely dominated the floodplain forests. Swamp communities bordering lakes typically consisted of red maple, silver maple, green ash, American elm, black ash, and yellow birch. Marshes associated with lake communities typically contained swamp loosestrife, cattails, bulrush, marsh fern, marsh cinquefoil, and sedges. Aquatic species within the lake communities included spatterdock, watershield, fragrant water-lily, pickerel weed, hornwort, wild celery, pondweeds, Virginia arrow-arum, and sedges. Kaler and Maring (1907) noted the presence of a great variety of aquatic and wetland plants which formed uniform rings in zones around Blue Lake. Furthermore, Deam (1921) indicated that Blue Lake was the only lake in northern Indiana which contained American lotus. Deam (1921) indicated that the plants were numerous unless picked by lake residents and visitors. Bogs were more numerous in this region than any other in the state. Bog communities included Sphagnum moss, leatherleaf, cranberry, bog rosemary, pitcher plant, sundews, mountain holly, tamarack, Virginia chain fern, grass-pink orchid, rose pogonia orchid, sedges, and poison sumac. A history of Smith Township (Mossman, 1882) mentions an outing to gather cranberries in the year 1836, indicating that bogs were present in the area of the watershed.

2.6 Land Use

Just as soils, climate, and geology shape the native communities within the watershed, how the land in a watershed is used can impact the water quality of a waterbody. Different land uses have the potential to contribute different amounts of nutrients, sediment, and toxins to receiving water bodies. For example, Reckhow and Simpson (1980) compiled phosphorus export coefficients (amount of phosphorus lost per unit of land area) for various land uses by examining the rate at which phosphorus loss occurred on various types of land. (The Phosphorus Modeling Section of the report contains more detailed information on this work and its impact on Blue Lake and its watershed.) Several researchers have also examined the impact of specific urban and suburban land uses on water quality (Bannerman et. al, 1992; Steuer et al., 1997; Waschbusch et al., 2000). Bannerman et al. (1992) and Steuer et al. (1997) found high mean phosphorus concentrations in runoff from residential lawns (2.33 to 2.67 mg/L) and residential streets (0.14 to 1.31 mg/L). These concentrations are well above the threshold at which lakes might begin to experience algae blooms. (Lakes with total phosphorus concentrations greater than 0.03 mg/L will likely experience algae blooms.) Finally, the Center for Watershed Protection has estimated the association of increased levels of impervious surface in a watershed with increased delivery of phosphorus to receiving waterbodies (Caraco and Brown, 2001). Land use directly affects the amount of impervious surface in a watershed. Because of the effect watershed land use has on water quality of the receiving lakes, mapping and understanding a watershed's land use is critical in directing water quality improvement efforts.

2.6.1 Blue Lake Watershed

Figure 10 and Table 5 present current land use information for the Blue Lake watershed. (Land use data from the U.S. Geological Survey (USGS) form the basis of Figure 10.) Like many Indiana watersheds, agricultural land use dominates the Blue Lake watershed, accounting for approximately 75% of the watershed. Row crop agriculture makes up the greatest percentage of agricultural land use at 54.8%, while pastures or hay vegetate another 19.8%. Most of the agricultural land in the Blue Lake watershed and throughout Whitley County (USDA, 2002) is used for growing soybeans and corn. County-wide tillage transect data for Whitley County provide an estimate for the portion of cropland in conservation tillage for the Blue Lake watershed. In Whitley County, soybean producers utilize no-till methods on 76% of soybean fields and some form of reduced tillage on 19% of soybean fields (IDNR, 2004b). Whitley County corn producers used no-till methods on 22% of corn fields and some form of reduced tillage on 72% of corn fields in production (IDNR, 2004a). The percentages of fields on which no-till methods were used in Whitley County were above the statewide median percentages for both soybean and corn production.

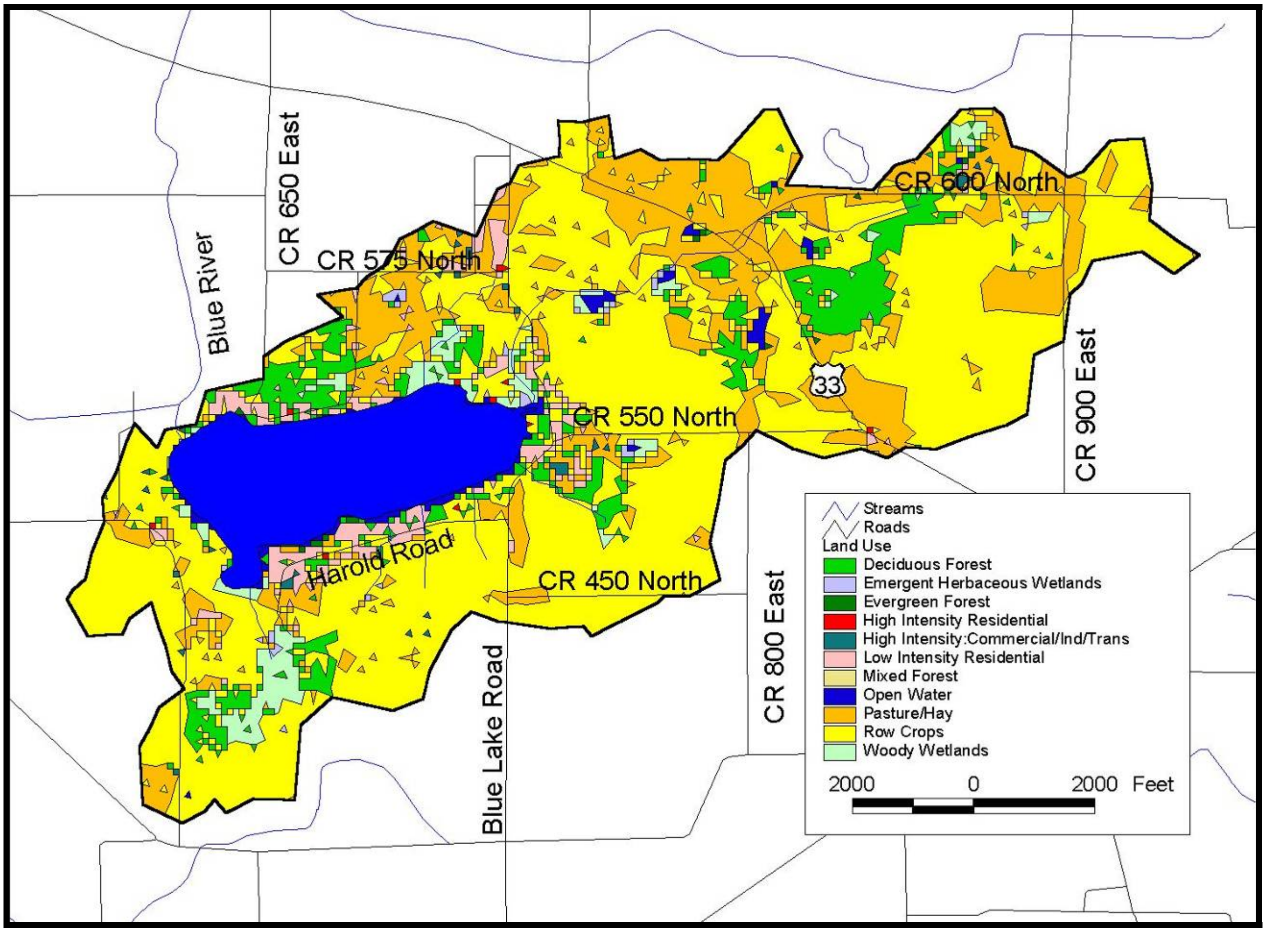

Figure 10. Land use in the Blue Lake watershed.
Source: See Appendix A.

Land uses other than agriculture account for the remaining 25% of the watershed. This is a fairly uniform percentage for watersheds in northern Indiana. Natural landscapes, including forests and wetland, cover approximately 11% of the watershed. Most of the natural areas in the watershed are small tracts, which are scattered across the watershed. Two larger tracts are located in the northeast and in the southwest portions of the watershed. Only a small portion of the area surrounding Blue Lake is in a natural state. These natural areas consist of small tracts of wooded wetlands or deciduous forest, and are scattered along the shoreline. Two tracts along the northern shore, one deciduous forest and one wooded wetland, are larger remnants that extend away from the lake to the north. Open water, including Blue Lake and several small ponds, accounts for another 11% of the watershed.

Most of the remaining 3% of the watershed is occupied by low intensity residential land, with less than 1% of high intensity residential or commercial land. Much of the residential land lies directly adjacent to Blue Lake.

Table 5. Detailed land use in the Blue Lake watershed.

Land Use	Area (acres)	Area (hectares)	% of Watershed
Row Crops	1245.4	504.2	54.8%
Pasture/Hay	450.4	182.4	19.8%
Open Water	249.7	101.1	11.0%
Deciduous Forest	171.9	69.6	7.6%
Woody Wetlands	67.8	27.5	3.0%
Low Intensity Residential	64.9	26.3	2.9%
Emergent Herbaceous Wetlands	7.8	3.1	0.3%
High Intensity Commercial	7.2	2.9	0.3%
Evergreen Forest	4.4	1.8	0.2%
High Intensity Residential	2.1	0.9	0.1%
Mixed Forest	0.2	0.1	<0.1%
Entire Watershed	**2271.9**	**919.8**	**100.0%**

Impervious surfaces, or those surfaces, covered by hardscape such as pavement, asphalt, and buildings, limit the ability for water to infiltrate the groundwater. Increasing percentages of impervious surfaces often results in greater volumes of stormwater runoff thereby increasing the volume of water reaching adjacent water bodies. Sediment and nutrient loads associated with this runoff also increase when more hard (impervious) surfaces are present.

Impervious surface coverage was calculated by using adapted impervious values for selected land used in Lee and Toonkel (2003), but does not include road surfaces. Impervious surfaces cover approximately 2.1% of the watershed. This estimate of impervious surface coverage is below the threshold at which the Center for Watershed Protection has found an associated decline in water quality. The land uses contributing to the impervious surface coverage in the Blue Lake watershed are agricultural (1.5%), residential (0.4%), and commercial (0.2%).

2.7 Wetlands

Because wetlands perform a variety of functions in a healthy ecosystem, they deserve special attention when examining watersheds. Functioning wetlands filter sediments and nutrients in runoff, store water for future release, provide an opportunity for groundwater recharge or discharge, and serve as nesting habitat for waterfowl and spawning sites for fish. By performing these roles, healthy, functioning wetlands often improve the water quality and biological health of streams and lakes located downstream of the wetlands.

The United States Fish and Wildlife Service's (USFWS) National Wetland Inventory (NWI) Map (Figure 11) shows that wetlands cover approximately 16% of the Blue Lake watershed. (Table 6 presents the acreage of wetlands by type according to the National Wetland Inventory.) Blue Lake itself accounts for most of this wetland acreage. The acreage listed for Blue Lake in Table 6 differs from the generally accepted surface are of the lake. This difference is due to the classification of a portion of the open water area as emergent or forested wetland. Forested and herbaceous wetlands cover approximately 5% of the watershed. The largest contiguous tracts of wetland habitat lie in the southwest corner of the watershed, along the lake's northeastern edge, and along Maloney Ditch. The remaining wetland habitat is scattered throughout the watershed.

Table 6. Acreage and classification of wetland habitat in the Blue Lake watershed.

Wetland Type	Area (acres)	Area (hectares)	Percent of Watershed
Lake	231.3	93.7	10.2%
Forested	79.2	32.1	3.5%
Herbaceous	33.2	13.4	1.5%
Pond	11.6	4.7	0.5%
Shrubland	9.7	3.9	0.4%
Submerged	1.8	0.7	0.0%
Total	**366.7**	**148.5**	**16.1%**

Source: National Wetlands Inventory.

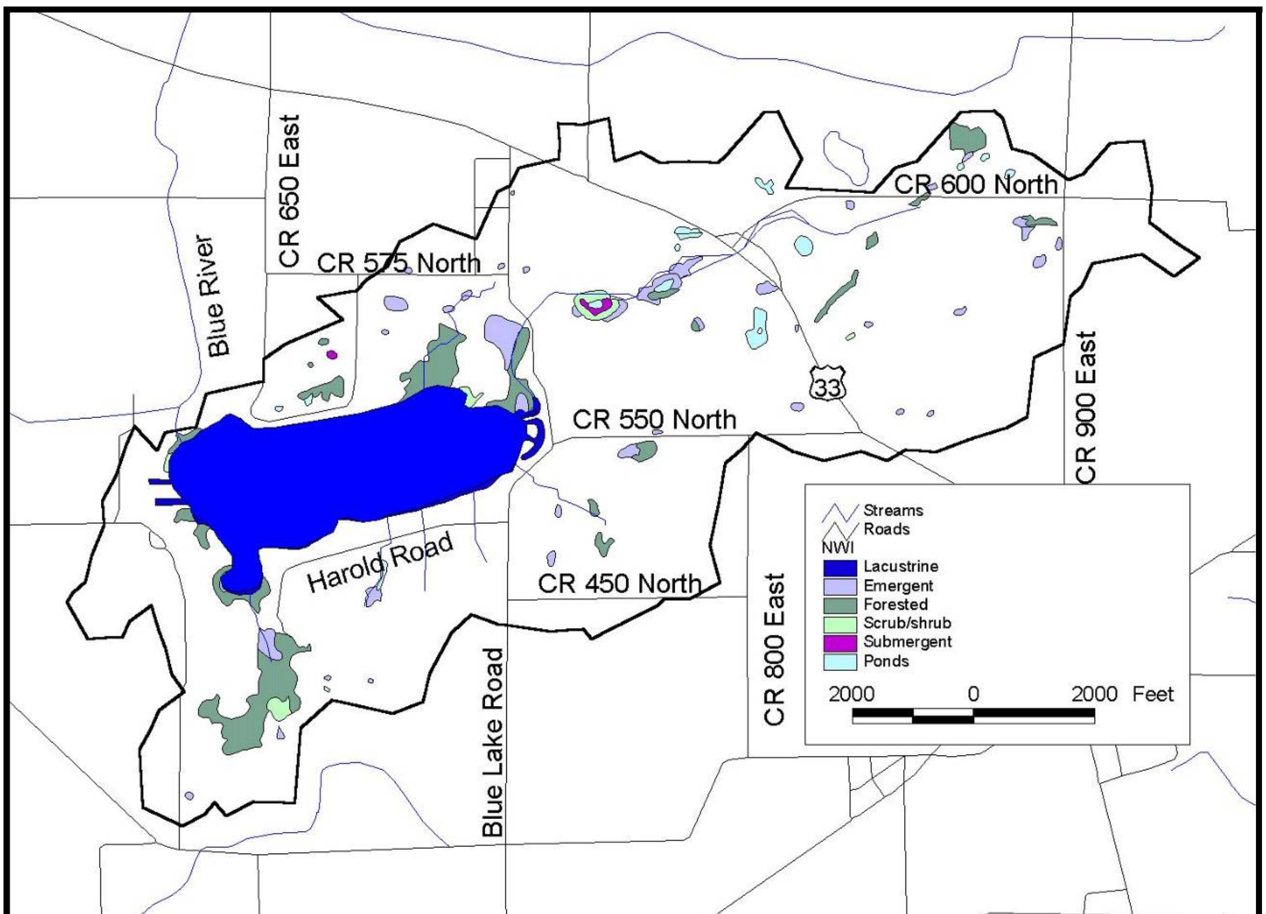

Figure 11. National wetland inventory wetlands in the Blue Lake watershed. Source: See Appendix A.

The USFWS NWI data differ in their estimate of wetland habitat acreage in the watershed from the USGS data presented in Table 5 and Figure 11. The USGS Land Cover Data Set suggests that wetlands cover approximately 3.3% of the Blue Lake watershed and open water covers an additional 11% of the watershed (Table 7). The primary difference between the two data sets is the acreage of emergent wetland. The USFWS reports over 33 acres of emergent wetland habitat exists in the Blue Lake watershed compared to slightly less than 8 acres of emergent wetland habitat reported by the USGS. The differences in reported wetland acreage in the Blue Lake watershed reflect the differences in project goals and methodology used by the different agencies to collect land use data.

The U.S. Fish and Wildlife Service estimates an average of 2.6% of the nation's wetlands were lost annually from 1986 to 1997 (Zinn and Copeland, 2005). The IDNR estimates that approximately 85% of the state's wetlands have been filled (IDNR, 1996). The greatest loss has occurred in the northern counties of the state such as Whitley County. The last glacial retreat in these northern counties left level landscapes dotted with wetland and lake complexes. Development of the land in these counties for agricultural purposes altered much of the natural hydrology, eliminating many of the wetlands. The 1978 Census of Agriculture found that drainage is artificially enhanced on 45% of the land in Whitley County (cited in Hudak, 1995).

Shoreline development around Blue Lake and the use of agricultural drainage tiles has undoubtedly reduced wetland acreage in the watershed as well. Hydric soils, which formed under wetland conditions, rings Blue Lake suggesting wetland habitat likely fringed the entire lake prior to residential development around the lake (Figure 12). Along the southern shoreline, residential development has been restricted to the drier hydric soils such as Mermill loam. Areas mapped in the wettest of hydric soils, such as Martisco muck and Houghton muck, have largely remained undeveloped. Small, relatively linear patches of hydric soils are present throughout the watershed. Hydric soils in these patterns suggest that mall drainage may have covered a large percentage of the Blue Lake watershed. Many of these drainages have likely been replaced by agricultural drainage tiles. (Private drain tiles were not mapped as part of this project; therefore, not exact assessment of the impact of these tiles on water quality can be made.) Overall, hydric soils cover 651 acres (263.5 ha or 29%) of the Blue Lake watershed. When compared to the acreage of wetland mapped by the USFWS NWI map, only approximately 20% of wetlands remain in the Blue Lake watershed.

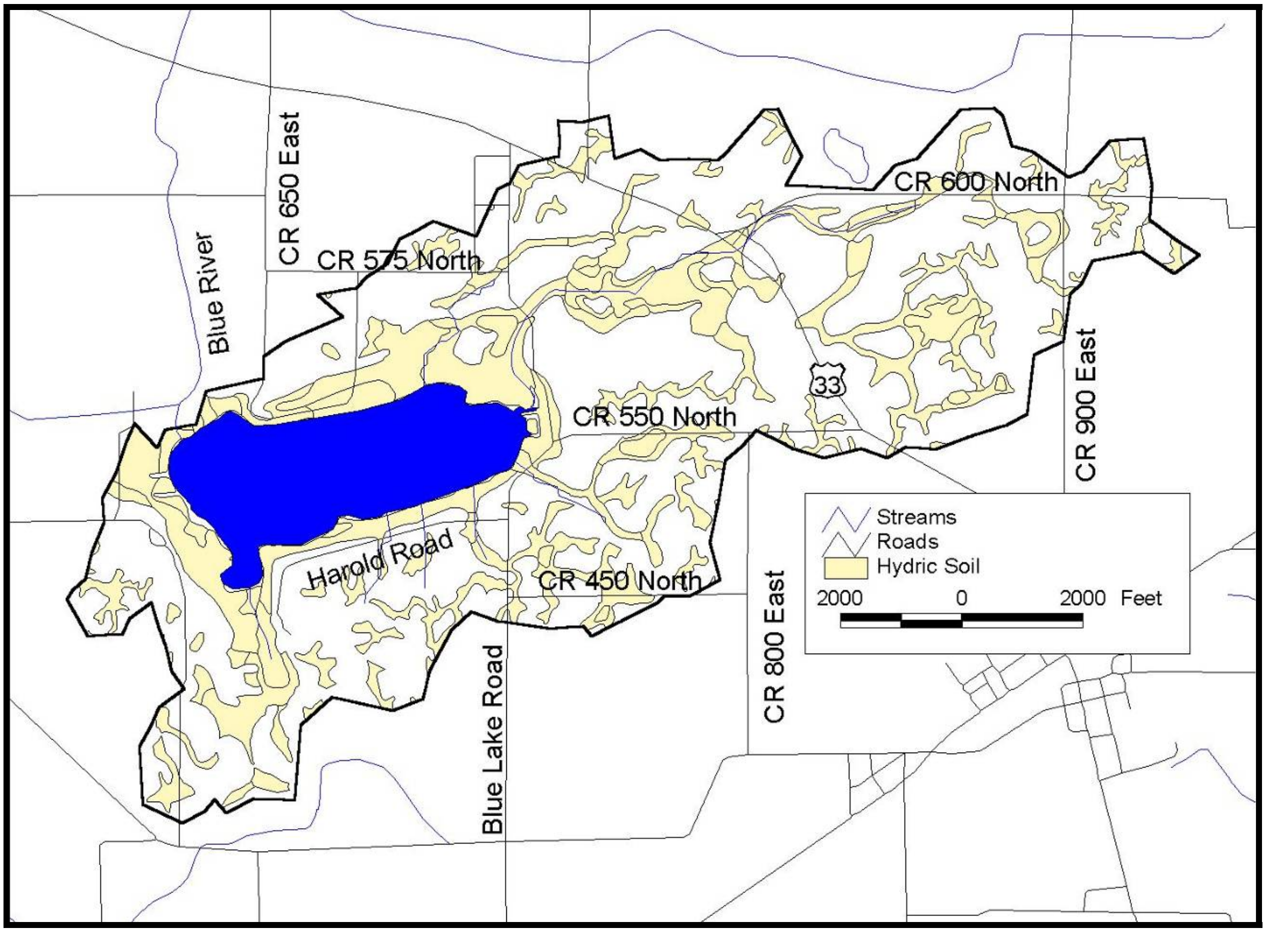

Figure 12. Hydric soils in the Blue Lake watershed. Source: See Appendix A.

2.8 Natural Communities and Endangered, Threatened, and Rare Species

The Indiana Natural Heritage Data Center database provides information on the presence of endangered, threatened, or rare species; high quality natural communities; and natural areas in Indiana. The Indiana Department of Natural Resources developed the database to assist in documenting the presence of special species and significant natural areas and to serve as a tool for setting management priorities in areas where special species or habitats exist. The database relies on observations from individuals rather than systematic field surveys by the IDNR. Because of this, it does not document every occurrence of special species or habitat. At the same time, the listing of a species or natural area does not guarantee that the listed species is present or that the listed area is in pristine condition. To assist users, the database includes the date that the species or special habitat was last observed in a specific location.

Appendix B presents the results from the database search for the Blue Lake watershed. (For additional reference, Appendix C provides a listing of endangered, threatened, and rare species (ETR) documented in Whitley County.) No federally listed endangered, threatened, and rare species are known to exist in the watershed. Two state listed species inhabit Blue Lake and its watershed. The state of Indiana uses the following definitions when listing species:

- *Endangered*: Any species whose prospects for survival or recruitment with the state are in immediate jeopardy and are in danger of disappearing from the state. This includes all species classified as endangered by the federal government which occur in Indiana. Plants known to occur currently on five or fewer sites in the state are considered endangered.

- *Threatented*: Any species likely to become endangered within the foreseeable future. This includes all species classified as threatened by the federal government which occur in Indiana. Plants known to occur currently on six to ten sites in the state are considered endangered.
- *Rare*: Plants and insects known to occur currently on from eleven to twenty sites.

The Indiana Natural Heritage Data Center database contains only two records for the area encompassed by the Blue Lake watershed. In 2000, weathered shells of purple lilliput (*Toxolasma lividus*), a mussel, were observed in Blue Lake. The purple lilliput is a state species of special concern. No live purple lilliput mussels were observed during the 2000 survey of the lake. The database also includes a record for Blanding's turtle (*Emydoidea blandingii*). This state endangered species was documented to be in the Blue Lake area in 1903.

Whitley County supports a variety of endangered, threatened, and rare animals and plants as detailed by the Indiana Natural Heritage database listing for Whitley County, which was last updated in 1999. (Additional sighting have likely occurred since this time; however, the list has not been updated since then.) The listed animals include one freshwater mussel (pointed campeloma), one amphibian (northern leopard frog), and two reptiles, including the state endangered Blanding's turtle eastern massasauga. One insect (big broad-winged skipper) and three birds, including the great blue heron, western meadowlark, and the state endangered loggerhead shrike are also listed. Two state endangered mammals, bobcat and American badger, have also been identified in the county. More than twenty plant species, many of which are hydrophytic (wetland or aquatic species), are also included in the database for Whitley County. The county also supports five high quality communities: dry-mesic upland, mesic upland, lake, fen, and marsh.

3.0 STREAM ASSESSMENT

3.1 Stream Assessment Introduction

To better understand the transport of nutrients and other pollutants to Blue Lake from its watershed, this study included an evaluation of the water quality of Maloney Ditch, Blue Lake's main inlet stream (Figure 13). (Attempts were made to sample additional minor tributaries; however, none of the minor tributaries (Figure 4) contained sufficient water during the base flow assessment. An attempt will be made to sample these tributaries early in the 2006 growing season. Sample results will be included in an addendum to the final report.) The water quality evaluation consisted of the collection of water samples from the stream. These samples were analyzed for an array of physical and chemical parameters and results of the analysis were compared to historical data, state standards (if available), and other known measures of stream water quality. Additionally, a review of historical water quality data collected by the IDEM is included to provide a baseline for comparison of the current data with data collected under more normal precipitation conditions.

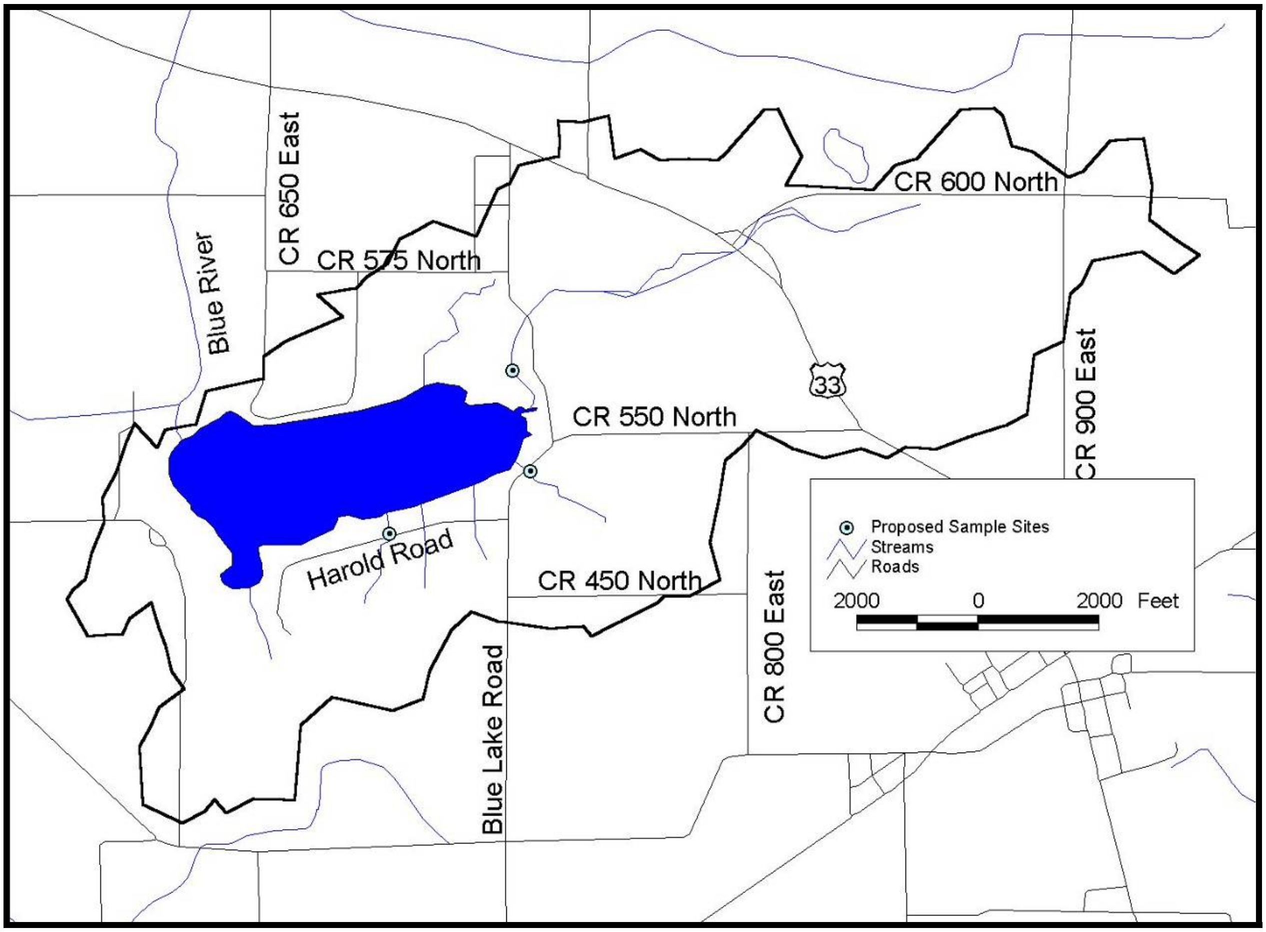

Figure 13. Stream sampling locations. Note: Only Maloney Ditch was sampled during base flow sampling. Storm flow samples could not be collected from watershed streams during 2005. Source: See Appendix A.

Maloney Ditch's biological community was also assessed to supplement the findings from the physical and chemical parameter analysis. A stream's biological communities (fish, macroinvertebrates, and periphyton communities) tend to reflect the stream's long-term water quality. For example, streams that carry significant sediment loads on a regular basis tend to support few or no stoneflies, since stoneflies are sediment-intolerant organisms. Evaluating the biological community characteristics, such as species diversity and composition, helps understand the stream's water quality over a longer term than can be assessed with the collection of only grab samples.

While a stream's biota serve as a useful means for assessing the stream's water quality, it is important to remember that water quality is not the only factor that shapes a stream's biological community. Habitat quality, energy source, flow regime, and biological pressures (predation, parasitism, competition, etc.) also affect a stream's biological community composition (Karr et al., 1986). For example, a stream fish community dominated by very tolerant fish does not necessarily mean the water quality is very poor. Lack of appropriate spawning habitat or changes in the stream's hydrological regime could play a larger role in shaping the stream's fish community than water quality in some instances.

To provide a complete assessment of Maloney Ditch's water quality, the study included the collection of water chemistry and biological (macroinvertebrate) samples. Attempts were made to collect water quality samples twice, once during base flow or normal conditions and once following a storm event, at the location indicated in Figure 13. However, limited precipitation during the summer of 2005 prevented the collection of storm samples from any of the lake's tributaries including Maloney Ditch. (JFNew will attempt to collect storm event samples during the 2006 growing season and will present these results as an addendum to the final report.) Maloney Ditch's biological community was sampled during base flow conditions as required by standard protocol. Sampling occurred in mid-summer to avoid the May and October macroinvertebrate diversity peaks. The in-stream and riparian habitat along Maloney Ditch was also evaluated to help in isolating which factors are responsible for shaping the creek's biotic communities. Before detailing the sampling methodology and results, it may be useful to detail historic water quality results. Following these results, the stream sampling methods and results are outlined in greater detail.

3.2 Historical Stream Water Quality

The Indiana Department of Environmental Management (IDEM) collected water chemistry samples from Maloney Ditch at its intersection with Blue Lake Road on August 17, 2004. The samples were collected as part of their assessment of the impaired biotic communities listing for the Upper Eel River and Blue River watershed. The assessment included the collection of grab samples for nutrient, sediment, and metals analysis and *in situ* measurements of water temperature, dissolved oxygen concentration, pH, and conductivity.

In general, the results indicate that water quality within Maloney Ditch was poor at the time of the assessment (Table 7). The dissolved oxygen concentration (1.58 mg/L) was below the Indiana state standard (4 mg/L). In total, the stream was only 12.8% saturated, which suggests that there were insufficient levels of dissolved oxygen in the stream at the time of the assessment. The turbidity concentration was elevated at the time of the assessment measuring more than 10 times the USEPA recommended criteria (9.9 NTU). The total suspended sediment concentration reflects the elevated turbidity concentration present in Maloney Ditch. However, the TSS concentration does not exceed the concentration determined by Waters (80 mg/L; 1998) to be deleterious to aquatic biota. The total phosphorus concentration was also high measuring nearly 6 times the concentration determined by the Ohio EPA for the protection of aquatic biota (0.1 mg/L). All other nutrient, sediment, and metals concentrations are within normal levels typically observed in Indiana streams. Based on the IDEM's methodologies for determining impaired waterbodies, data suggests that Maloney Ditch should be included on this list for total phosphorus (exceeds 0.3 mg/L target) and dissolved oxygen (below Indiana state standard of 4 mg/L). The IDEM included Maloney Ditch on the draft 2006 list of impaired waterbodies (303(d) list) for two impairments: impaired biotic communities and dissolved oxygen (Indiana Register, 2005). Much of this impairment can likely be attributed to the fact that Maloney Ditch is an intermittent stream and does not contain flowing water throughout the growing season.

Table 7. Field, nutrient, sediment, and metal sample results for IDEM sampling of Maloney Ditch on August 17, 2004.

Parameter	Concentration	Parameter	Concentration
Water Temperature	20.32 (degrees C)	Total Antimony	< 1 µg/L
Dissolved Oxygen	1.58 mg/L	Total Arsenic	< 5 µg/L
Saturation Percent	12.8%	Total Barium	65 µg/L
pH	7.55	Total Beryllium	< 1 µg/L
Conductivity	576 µS/cm	Total Cadmium	< 1 µg/L
Turbidity	127 NTU	Total Calcium	70200 µg/L
Alkalinity	210 mg/L	Total Chromium	< 2 µg/L
Chloride	41.2 mg/L	Total Copper	3.5 µg/L
Chemical Oxygen Demand	50.7 mg/L	Total Iron	4490 µg/L
Total Cyanide	< 0.005 mg/L	Total Lead	2.5 µg/L
Fluoride	0.273 mg/L	Total Magnesium	21600 µg/L
Hardness	264 mg/L	Total Manganese	534 µg/L
Ammonia-Nitrogen	0.577 mg/L	Total Mercury	< 0.2 µg/L
Nitrate+Nitrite-Nitrogen	< 0.01 mg/L	Total Nickel	7 µg/L
Total Phosphorus	0.613 mg/L	Total Selenium	< 5 µg/L
Sulfate	11.6 mg/L	Soluble Reactive Silica	8.8 mg/L
Total Organic Carbon	28.8 mg/L	Total Silver	< 1 µg/L
Total Solids	395 mg/L	Total Sodium	21200 µg/L
Total Suspended Solids	51 mg/L	Total Thallium	< 1 µg/L
Total Aluminum	1650 µg/L	Total Zinc	16.4 µg/L

3.3 Stream Assessment Methods

3.3.1 Water Chemistry

During the current assessment, stream water chemistry samples were analyzed for pH, conductivity, total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, organic nitrogen, total suspended solids, turbidity, and *E. coli* bacteria. Conductivity, temperature, and dissolved oxygen were measured *in situ* with an YSI Model 85 meter. Stream water velocity was measured using a Marsh-McBirney Flo-Mate current meter. The cross-sectional area of the stream channel was measured and discharge calculated by multiplying water velocity by the cross-sectional area.

All water samples were placed in the appropriate bottle (with preservative if needed) and stored in an ice chest until analysis at Indiana University School of Public and Environmental Affair's (SPEA) laboratory in Bloomington. Soluble reactive phosphorus samples were filtered in the field through a Whatman GF-C filter. The *E. coli* bacteria samples were taken to Great Lakes Analytical Laboratory in Fort Wayne, Indiana for analysis. All sampling techniques and laboratory analytical methods were performed in accordance with procedures in *Standard Methods for the Examination of Water and Wastewater*, 20th Edition (APHA, 1998).

The following is a brief description of the parameters analyzed during the stream sampling efforts. Samples collected from the Blue Lake watershed streams will be compared with these standards in the following sections:

Temperature. Temperature can determine the form, solubility, and toxicity of a broad range of aqueous compounds. For example, water temperature affects the amount of oxygen dissolved in the water column. Water temperature also governs species composition and activity of aquatic biological communities. Since essentially all aquatic organisms are 'cold-blooded' the temperature of the water regulates their metabolism and ability to survive and reproduce effectively (USEPA, 1976). The Indiana Administrative Code (327 IAC 2-1-6) sets maximum temperature limits to protect aquatic life for Indiana streams according to the time of year. For example, temperatures during the summer months should not exceed 90 °F (32.2 °C).

Dissolved Oxygen (DO). DO is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3 to 5 mg/L of DO. Coldwater fish such as trout generally require higher concentrations of DO than warmwater fish such as bass or bluegill. The Indiana Administrative Code (IAC) sets minimum DO concentrations at 4 mg/L, but all waters must have a daily average of 5 mg/L. DO 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 DO. 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 high discharge 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.

Rather than setting a conductivity standard, the IAC sets a standard for dissolved solids (750 mg/L). Multiplying a dissolved solids concentration by a conversion factor of 0.55 to 0.75 μmhos per mg/L of dissolved solids roughly converts a dissolved solids concentration to specific conductance (Allan, 1995). Thus, converting the IAC dissolved solids concentration standard to specific conductance by multiplying 750 mg/L by 0.55 to 0.75 μmhos per mg/L yields a specific conductance range of approximately 1000 to 1360 μmhos. This report presents conductivity measurements at each site in μmhos.

pH. The pH of water describes the concentration of acidic ions (specifically H+) present in water. Water's pH determines the form, solubility, and toxicity of a wide range of other aqueous compounds. The IAC establishes a range of 6 to 9 pH units for the protection of aquatic life. pH concentrations in excess of 9 are considered acceptable when the concentration occurs as daily fluctuations associated with photosynthetic activity.

Nutrients. Scientists measure nutrients to predict the amount of algae growth and/or rooted plant (macrophyte) growth that is possible in a lake or stream. Algae and rooted plants are a natural and necessary part of aquatic ecosystems. Both will always occur in a healthy lake or stream. Complete elimination of algae and/or rooted plants is neither desirable nor even possible and should, therefore, never be the goal in managing a lake or stream. Algae and rooted plant growth can, however, reach nuisance levels and interfere with the aesthetic and recreational uses of a lake or stream. Scientists commonly measure nutrient concentrations in aquatic ecosystem evaluations to determine the potential for such nuisance growth.

Nutrients themselves, as well as the primary producers (algae and plants) they feed, can also affect the composition of secondary producer communities such as macroinvertebrates and fish. Changes in secondary producer communities can, in turn, impact the way chemical constituents in the water are processed. This is an additional reason for examining nutrient levels in an aquatic ecosystem.

Phosphorus and nitrogen have several forms in water. The two common phosphorus forms are **soluble reactive phosphorus (SRP)** and **total phosphorus (TP)**. SRP is the dissolved form of phosphorus. It is the form that is "usable" by algae. Algae cannot directly digest and use particulate phosphorus. Total phosphorus is a measure of both dissolved and particulate forms of phosphorus. The most commonly measured nitrogen forms are **nitrate-nitrogen (NO_3)**, **ammonium-nitrogen (NH_4^+)**, and **total Kjeldahl nitrogen (TKN)**. Nitrate is a dissolved form of nitrogen that is commonly found in the upper layers of a lake or anywhere that oxygen is readily available. Because oxygen should be readily available in stream systems, nitrate-nitrogen is often the dominant dissolved form of nitrogen in stream systems. In contrast, ammonium-nitrogen is generally found where oxygen is lacking. Ammonium is a byproduct of decomposition generated by bacteria as they decompose organic material. Like SRP, ammonium is a dissolved form of nitrogen and the one utilized by algae for growth. The TKN measurement parallels the TP measurement to some extent. TKN is a measure of the **total organic nitrogen** (particulate) and ammonium-nitrogen in the water sample.

While the United States Environmental Protection Agency (USEPA) has established some nutrient standards for drinking water safety, it has not established similar nutrient standards for protecting the biological integrity of a stream. (The USEPA, in conjunction with the States, is currently working on developing these standards.) The USEPA has issued recommendations for numeric nutrient criteria for streams (USEPA, 2000b). While these are not part of the Indiana Administrative Code, they serve as potential target conditions for which watershed managers might aim. The Ohio EPA has also made recommendations for numeric nutrient criteria in streams based on research on Ohio streams (Ohio EPA, 1999). These, too, serve as potential target conditions for those who manage Indiana streams. Other researchers have suggested thresholds for several nutrients in aquatic ecosystems as well (Dodd et al., 1998). Lastly, the Indiana Administrative Code (IAC) requires that all waters of the state have a nitrate concentration of less than 10 mg/L, which is the drinking water standard for the state.

Researchers have recommended various thresholds and criteria for nutrients in streams. The USEPA's recommended targets for nutrient levels in streams are fairly low. The agency recommends a target total phosphorus concentration of 0.033 mg/L in streams (USEPA, 2000b). Dodd et al. (1998) suggest the dividing line between moderately (mesotrophic) and highly (eutrophic) productive streams is a total phosphorus concentration of 0.07 mg/L. The Ohio EPA recommended a total phosphorus concentration of 0.08 mg/L in headwater streams to protect the streams' aquatic biotic integrity (Ohio EPA, 1999). (This criterion is for streams classified as Warmwater Habitat, or WWH, meaning the stream is capable of supporting a healthy, diverse warmwater fauna. Streams that cannot support a healthy, diverse community of warmwater fauna due to "irretrievable, extensive, man-induced modification" are classified as Modified Warmwater Habitat (MWH) streams and have a different criterion.) While the entire length of Maloney Ditch may not fit the WWH definition, 0.08 to 0.1 mg/L total phospherous is a good goal for the creek.

The USEPA sets aggressive nitrogen criteria recommendations for streams compared to the Ohio EPA. The USEPA's recommended criteria for nitrate-nitrogen and total Kjeldahl nitrogen concentrations for streams in Aggregate Nutrient Ecoregion VII are 0.30 mg/L and 0.24 mg/L, respectively (USEPA, 2000b). In contrast, the Ohio EPA suggests using nitrate-nitrogen criteria of 1.0 mg/L in WWH wadeable and headwater streams and MWH headwater streams to protect aquatic life. Dodd et al. (1998) suggests the dividing line between moderately and highly productive streams using nitrate-nitrogen concentrations is approximately 1.5 mg/L.

It is important to remember that none of the threshold or recommended concentrations listed above are state standards for water quality. They are presented here to provide a frame of reference for the concentrations found in Maloney Ditch and other minor tributaries. The IAC sets only nitrate-nitrogen and ammonia-nitrogen standards for waterbodies in Indiana. The Indiana Administrative Code requires that all waters of the state have a nitrate-nitrogen concentration of less than 10 mg/L, which is the drinking water standard for the state. The IAC standard for ammonia-nitrogen depends upon the water's pH and temperature, since both can affect ammonia-nitrogen's toxicity. The draft 2006 303(d) list of impaired waterbodies listing criteria indicates that the IDEM will include waterbodies with total phosphorus concentrations greater than 0.3 mg/L on subsequent lists of impaired waterbodies (Indiana Register, 2005).

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 to 17.5 NTU (Crighton and Hosier, 2004). Turbidity measurements >20 NTU have been found to cause undesirable changes in aquatic life (Walker, 1978). As part of their effort to make numeric nutrient criteria recommendations, the USEPA set 9.9 NTUs as a target for turbidity in stream ecosystems (USEPA, 2000b).

Total Suspended Solids (TSS). A TSS measurement quantifies all particles suspended and dissolved in water. Closely related to turbidity, this parameter quantifies sediment particles and other solid compounds typically found in water. In general, the concentration of suspended solids is greater in streams during high flow events due to increased overland flow. The increased overland flow erodes and carries more soil and other particulates to the stream. The sediment in water originates from many sources, but a large portion of sediment entering streams comes from active construction sites or other disturbed areas such as unvegetated stream banks and poorly managed farm fields.

Suspended solids impact streams and lakes in a variety of ways. When suspended in the water column, solids can clog the gills of fish and invertebrates. As the sediment settles to the creek or lake bottom, it covers spawning and resting habitat for aquatic fauna, reducing the animals' reproductive success. Suspended sediments also impair the aesthetic and recreational value of a waterbody. Few people are enthusiastic about having a picnic near a muddy creek or lake. Pollutants attached to sediment also degrade water quality. In general, TSS concentrations greater than 80 mg/L have been found to be deleterious to aquatic life (Waters, 1995).

***E. coli* Bacteria.** *E. coli* is one member of a group of bacteria that comprise the fecal coliform bacteria and is used as an indicator organism to identify the potential for the presence of pathogenic organisms in a water sample. Pathogenic organisms can present a threat to human health by causing a variety of serious diseases, including infectious hepatitis, typhoid, gastroenteritis, and other gastrointestinal illnesses. *E. coli* can come from the feces of any warm-blooded animal. Wildlife, livestock, and/or domestic animal defecation, manure fertilizers, previously contaminated sediments, and failing or improperly sited septic systems are common sources of the bacteria. The IAC sets the maximum concentration of *E. coli* 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.

3.3.2 Macroinvertebrates

Aquatic macroinvertebrates are important indicators of environmental change. Numerous studies have shown that different macroinvertebrate orders and families react differently to pollution sources. Additionally, aquatic biota integrate cumulative effects of sediment and nutrient pollution (Ohio EPA, 1995). Thus, a stream's insect community composition provides a long term reflection of the stream's water quality.

To help evaluate the water quality flowing into Blue Lake, macroinvertebrates were collected during base flow conditions on August 10, 2005 from Maloney Ditch using the multihabitat approach detailed in the USEPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers, 2nd ed. (Barbour et al., 1999). Organisms were identified to the family level. The family-level approach was used: 1) to collect data comparable to that collected by IDEM in the state; 2) because it allows for increased organism identification accuracy; and 3) because several studies support the adequacy of family-level analysis (Furse et al., 1984; Ferraro and Cole, 1995; Marchant, 1995; Bowman and Bailey, 1997; Waite et al., 2000).

The benthic community in Maloney Ditch was evaluated using IDEM's macroinvertebrate Index of Biotic Integrity (mIBI). The mIBI is a multi-metric index that combines several aspects of the benthic community composition. As such, it is designed to provide a complete assessment of a creek's biological integrity. Karr and Dudley (1981) define biological integrity as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to the best natural habitats within a region". It is likely that this definition of biological integrity is what IDEM means by biological integrity as well. The mIBI consists of ten metrics (Table 8) which measure the species richness, evenness, composition, and density of the benthic community at a given site. The metrics include family-level HBI (Hilsenhoff's FBI or family level biotic index; Hilsenhoff, 1988), number of taxa, number of individuals, percent dominant taxa, EPT Index, EPT count, EPT count to total number of individuals, EPT count to Chironomid count, Chironomid count, and total number of individuals to number of squares sorted. (EPT stands for the *Ephemeroptera, Plecoptera*, and *Trichoptera* orders.) A classification score of 0, 2, 4, 6, or 8 is assigned to specific ranges for metric values. For example, if the benthic community being assessed supports nine different families, that community would receive a classification score of 2 for the "Number of Taxa" metric. The mIBI is calculated by averaging the classification scores for the ten metrics. mIBI scores of 0-2 indicate the sampling site is severely impaired; scores of 2-4 indicate the site is moderately impaired; scores of 4-6 indicate the site is slightly impaired; and scores of 6-8 indicate that the site is non-impaired.

Table 8. Benthic macroinvertebrate scoring criteria used by IDEM in the evaluation of pool-riffle streams in Indiana.

	SCORING CRITERIA FOR THE FAMILY LEVEL MACROINVERTEBRATE INDEX OF BIOTIC INTEGRITY (mIBI) USING PENTASECTION AND CENTRAL TENDENCY ON THE LOGARITHMIC TRANSFORMED DATA DISTRIBUTIONS OF THE 1990-1995 RIFFLE KICK SAMPLES				
	CLASSIFICATION SCORE				
	0	2	4	6	8
Family Level HBI	≥5.63	5.62- 5.06	5.05-4.55	4.54-4.09	≤4.08
Number of taxa	≤7	8-10	11-14	15-17	≥18
Number of individuals	≤79	129-80	212-130	349-213	≥350
Percent dominant taxa	≥61.6	61.5-43.9	43.8-31.2	31.1-22.2	<22.1
EPT index	≤2	3	4-5	6-7	≥8
EPT count	≤19	20-42	43-91	92-194	≥195
EPT count to total number of individuals	≤0.13	0.14-0.29	0.30-0.46	0.47-0.68	≥0.69
EPT count to chironomid count	≤0.88	0.89-2.55	2.56-5.70	5.71-11.65	≥11.66
Chironomid count	≥147	146-55	54-20	19-7	≤6
Total number of individuals to number of squares sorted	≤29	30-71	72-171	172-409	≥410

Where: 0-2 = Severely Impaired, 2-4 = Moderately Impaired, 4-6 = Slightly Impaired, 6-8 = Non-impaired

IDEM developed the classification criteria based on five years of wadeable riffle-pool data collected in Indiana. Because the values for some of the metrics can vary depending upon the collection and subsampling methodologies used to survey a stream, it is important to adhere to the collection and subsampling protocol IDEM used when it developed the mIBI. Since the multihabitat approach detailed in the USEPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers, 2nd ed. (Barbour et al., 1999) was utilized in this survey to ensure adequate representation of all macroinvertebrate taxa, the mIBI at each site was calculated without the protocol dependent metrics of the mIBI (number of individuals and number of individuals to number of squares sorted). (Protocol dependent methods were defined by Steve Newhouse, IDEM, in personal correspondence.) Eliminating the protocol dependent metrics allows the mIBI scores at sites surveyed using different survey protocols to be compared to mIBI scores at sites sampled using the IDEM recommended protocol.

Although the Indiana Administrative Code does not include mIBI scores as numeric criteria for establishing whether streams meet their aquatic life use designation, the IDEM hints that it may be using mIBI scores to make this determination. (Under state law, all waters of the state, except for those noted as Limited Use in the Indiana Administrative Code, must be capable of supporting recreational and aquatic life uses.) In the 2006 draft 303(d) listing methodology, the IDEM suggests that those waterbodies with mIBI scores less than 1.4 when using the multi-habitat approach are considered non-supporting for aquatic life use. Similarly, waterbodies with mIBI scores greater than 1.4 when assessed using the multi-habitat approach are considered fully supporting for aquatic life use (Indiana Register, 2005). Under federal law, waters that do not meet their designated uses must be placed on the 303(d) list and remediation/restoration plans (Total Maximum Daily Load plans) must be developed for these waters.

3.3.3 Habitat

The physical habitat at the macroinvertebrate sampling site on Maloney Ditch was evaluated using the Qualitative Habitat Evaluation Index (QHEI) The Ohio EPA developed the QHEI for streams and rivers in Ohio (Rankin 1989, 1995). The QHEI is a physical habitat index designed to provide an empirical, quantified evaluation of the general lotic macrohabitat (Ohio EPA, 1989). While the Ohio EPA originally developed the QHEI to evaluate ***fish*** habitat in streams, IDEM and other agencies routinely utilize the QHEI as a measure of general "habitat" health. The QHEI is composed of six metrics including substrate composition, in-stream cover, channel morphology, riparian zone and bank erosion, pool/glide and riffle-run quality, and map gradient. Each metric is scored individually then summed to provide the total QHEI score. The QHEI score generally ranges from 20 to 100.

Substrate type(s) and quality are important factors of habitat quality and the QHEI score is partially based on these characteristics. Sites that have greater substrate diversity receive higher scores as they can provide greater habitat diversity for benthic organisms. The quality of substrate refers to the embeddedness of the benthic zone. Because the rocks (gravel, cobble, boulder) that comprise a stream's substrate do not fit together perfectly like pieces in a jigsaw puzzle, small pores and crevices exist between the rock in the stream's substrate. Many stream organisms can colonize these pores and crevices, or microhabitats. In streams that carry high silt loads, the pores and crevices between rock substrate become clogged over time. This clogging, or "embedding", of the stream's substrate eliminates habitat for the stream's biota. Thus, sites with heavy embeddedness and siltation receive lower QHEI scores for the substrate metric.

In-stream cover, another metric of the QHEI, refers to the type(s) and quantity of habitat provided within the stream itself. Examples of in-stream cover include woody logs and debris, aquatic and overhanging vegetation, and root wads extending from the stream banks. The channel morphology metric evaluates the stream's physical development with respect to habitat diversity. Pool and riffle development within the stream reach, the channel sinuosity, and other factors that represent the stability and direct modification of the site comprise this metric score.

A stream's buffer, which includes the riparian zone and floodplain zone, is a vital functional component of riverine ecosystems. It is instrumental in the detention, removal, and assimilation of nutrients. Riparian zones govern the quality of goods and services provided by riverine ecosystems (Ohio EPA, 1999). Riparian zone (the area immediately adjacent to the stream), floodplain zone (the area beyond the riparian zone that may influence the stream though runoff), and bank erosion were examined at each site to evaluate the quality of the buffer zone of the stream, the land use within the floodplain that affects inputs to the waterway, and the extent of erosion in the stream, which can reflect insufficient vegetative stabilization of the stream banks. For the purposes of the QHEI, a riparian zone consists only of forest, shrub, swamp, or woody old field vegetation. Typically, weedy, herbaceous vegetation has higher runoff potential than woody components and does not represent an acceptable riparian zone type for the QHEI (Ohio EPA, 1989). Streams with grass or other herbaceous vegetation growing in the riparian zone receive low QHEI scores for this metric.

Metric 5 of the QHEI evaluates the quality of pool/glide and riffle/run habitats in the stream. These zones in a stream, when present, provide diverse habitat and, in turn, can increase habitat quality. The depth of pools within a reach and the stability of riffle substrate are some factors that affect the QHEI score in this metric.

The final QHEI metric evaluates the topographic gradient in a stream reach. This is calculated using topographic data. The score for this metric is based on the premise that both very low and very high gradient streams will have negative effects on habitat quality. Moderate gradient streams receive the highest score, 10, for this metric. The gradient ranges for scoring take into account the varying influence of gradient with stream size.

The QHEI evaluates the characteristics of a stream segment, as opposed to the characteristics of a single sampling site. As such, individual sites may have poorer physical habitat due to a localized disturbance yet still support aquatic communities closely resembling those sampled at adjacent sites with better habitat, provided water quality conditions are similar. QHEI scores from hundreds of stream segments in Ohio have indicated that values greater than 60 are *generally* conducive to the existence of warmwater faunas. Scores greater than 75 typify habitat conditions that have the ability to support exceptional warmwater faunas (Ohio EPA, 1999). IDEM indicates that QHEI scores above 64 suggest the habitat is capable of supporting a balanced warmwater community; scores between 51 and 64 are only partially supportive of a stream's aquatic life use designation (IDEM, 2000).

3.4 Stream Assessment Results and Discussion

3.4.1 Water Chemistry

Physical concentrations and characteristics

Physical parameter results measured during base flow sampling of Maloney Ditch are presented in Table 9. Maloney Ditch's negligible base flow discharge suggests very low flow is normal for this stream. Lake residents (personal communication) report that Maloney Ditch is often dry by late summer or early fall. Lower than normal precipitation levels through much of the summer likely contributed to the low flow in Maloney Ditch and the lack of water in other tributaries to Blue Lake.

Table 9. Physical characteristics of Maloney Ditch on August 10, 2005 (base flow).

Site	Flow (cfs)	Temp (°C)	DO (mg/L)	DO Sat (%)	TSS (mg/L)	Conductivity (μhos/cm)	pH	Alkalinity (mg/L)
Maloney Ditch	0.001	22.2	2.2	24	1.25	557	7.8	223
	Storm flow data have not yet been collected from Blue Lake tributaries.							

Temperature, conductivity, and total suspended solids levels within Maloney Ditch during base flow were normal for Indiana streams and were sufficient to support aquatic life. Alkalinity and pH levels measured within typical levels for Indiana streams. The alkalinity concentration provides evidence of the presence of carbonates and other alkalinity-producing materials in the watershed's bedrock. The dissolved oxygen concentration in Maloney Ditch was below the 4 mg/L minimum required by most aquatic fauna for respiration. This is consistent with results obtained by the IDEM during sampling conducted in Maloney Ditch during 2004 (Table 7).

Chemical and Bacterial Characteristics
Table 10 shows the chemical and bacterial characteristics of Maloney Ditch. In a recent study of 85 relatively undeveloped basins across the United States, the USGS reported the following median concentrations: ammonia (0.020 mg/L), nitrate (0.087 mg/L), soluble reactive phosphorus (0.010 mg/L), and total phosphorus (0.022 mg/L) (Clark et al., 2000). Except for one instance, namely the nitrate-nitrogen concentration, nutrient concentrations within Maloney Ditch all exceeded these median concentrations. Some parameters exceeded the median concentrations by one to two orders of magnitude.

Table 10. Chemical and bacterial characteristics of Maloney Ditch August 10, 2005.

	Date	Event	NH_4	NO_3	TKN	TP	SRP	*E. coli*
Concentration (mg/L)*	8/10/05	base	0.044	0.084	1.549	0.192	0.135	17,800
	Storm flow data have not yet been collected from Blue Lake tributaries.							

*All concentration parameters were measured in mg/L except E. coli, which was measured in colonies/100 mL. All loading parameters are in kg/d.

Nitrogen concentrations measured in Maloney Ditch are relatively normal for Indiana streams; however, Maloney Ditch exhibited high phosphorus and *E. coli* concentrations during the base flow sampling event. Nitrate-nitrogen and ammonia-nitrogen concentrations are relatively low and did not exceed the Indiana state standards for either parameter. Nitrate-nitrogen concentrations are also lower than the level determined by the Ohio EPA for the protection of aquatic biota (1.0 mg/L). However, nitrate-nitrogen and total Kjeldahl nitrogen concentrations were greater than the USEPA recommended criteria. (This is not surprising, as USEPA recommended criteria are extremely low. Many streams within Indiana cannot meet these criteria at this time.) Despite the low nitrogen concentrations, Maloney Ditch's total phosphorus concentration is well above target concentrations recommended by various agencies to protect aquatic life. The concentration exceeds the USEPA recommended criteria (0.033 mg/L), the dividing line between moderately productive and highly productive streams (0.07 mg/L) as determined by Dodd et al. (1998), and the level determined by the Ohio EPA (1999) at which nutrient levels can negatively influence aquatic biota (0.08 mg/L). This is consistent with the total phosphorus measured by the IDEM during their 2004 assessment of Maloney Ditch. The soluble reactive phosphorus concentration indicates that a majority of the phosphorus present in Maloney Ditch is in a soluble, readily usable form. Finally, the stream's *E. coli* concentration is extremely high and exceeds to the IAC standard (235 col/100 mL). The *E. coli* concentration observed in Maloney Ditch during base flow sampling is over 75 times the state standard.

3.4.2 Macroinvertebrates and Habitat

Macroinvertebrate samples were collected from Maloney Ditch during a summer with limited rainfall. This results in stagnant or very slow flow conditions within the stream. Some of the poor biotic character present within the stream is likely due to the increased stress associated with the low flow and low dissolved oxygen present in the stream. It should be noted that Maloney Ditch will likely never possess a high quality biotic community due to its intermittent nature. Table 11 presents the results of the macroinvertebrate sampling of Maloney Ditch. (Appendix D includes a complete list of macroinvertebrate found during the Maloney Ditch sampling.)

Overall, Maloney Ditch possessed a mIBI score of 2.4, suggesting the stream's biotic community is moderately impaired. The stream supports a below average species richness, individual density, and an average level of dominant taxa that accounted for 36% of the community composition. Many of the taxa in Maloney Ditch exhibited moderate to high tolerance to pollution. This is reflected in the fairly high HBI score of 6.9. Finally, no members of the more sensitive *Ephemeroptera*, *Plecoptera*, and *Trichoptera* or EPT orders were observed in Maloney Ditch. Additionally, none of the members of the more tolerant *Chironomidae* family were present in Maloney Ditch. A dominance of members of the EPT orders is typically associated with higher quality streams, while dominance by the *Chiromidae* family is typically associated with degraded water quality. Maloney Ditch was dominated by members of the order *Gastropoda*. All of the families represented possess high tolerance values ranging from 6 to 9 (maximum of 10 points possible). Gastropods can tolerate low dissolved oxygen levels and elevated total phosphorus concentrations like those found in Maloney Ditch and can move out of the water if and when conditions become too poor to sustain most other aquatic biota.

Table 11. Classification scores and mIBI score for Maloney Ditch, August 10, 2005.

Metric	Value	Metric Score
HBI	6.93	0
Number of Taxa (family)	9	2
Number of Individuals	50	0
Percent Dominant Taxa	36.0	4
EPT Index	0	0
EPT Count	0	0
EPT Count/Total Count	0.00	0
EPT Abundance/Chironomid Abundance	N/A	8
Chironomid Count	0	8
mIBI Score		**2.4**

Where: 0-2 = Severely Impaired, 2-4 = Moderately Impaired, 4-6 = Slightly Impaired, 6-8 = Non-impaired

Table 12 presents the Qualitative Habitat Evaluation Index (QHEI) score for Maloney Ditch and includes the maximum possible score for each metric evaluated. (Appendix D contains the QHEI data sheet.) Maloney Ditch's QHEI score was fairly low (39). The Indiana Department of Environmental Management characterizes QHEI scores less than 51 as non-supporting of aquatic life uses in Indiana (IDEM, 2002). The low QHEI score is due in large part to the stream's history. Judging by the stream's straight profile (Figures 13 and 14) and the prevalence of hydric soils along the stream's corridor, Maloney Ditch was likely dug through historic wetlands to facilitate drainage for agricultural purposes. The stream's straight profile and the sand substrate limit the development of pool/riffle sequences. Additionally, poor instream cover and a narrow riparian zone result in poor habitat availability in Maloney Ditch. Combined, these characteristics help to lower the stream's QHEI score.

Table 12. QHEI Scores for the Maloney Ditch, August 10, 2005.

Site	Substrate Score	Cover Score	Channel Score	Riparian Score	Pool Score	Riffle Score	Gradient Score	Total Score
Maximum Possible Score	20	20	20	10	12	8	10	**100**
Maloney Ditch	14	3	9	5	0	0	8	**39**

Figure 14. Maloney Ditch sampling site, April 12, 2005.

At the sampling point, Maloney Ditch possesses a very narrow (less than 15 feet or 4.6 m) riparian zone on both its northern and southern banks. Further upstream of the sampling site, Maloney Ditch's riparian corridor is wider and completely composed of wetland vegetation. A narrow fringe of trees, some shrubs, and myrtle dominate the riparian vegetation. Beyond the riparian zone, a mobile home/trailer park with mowed grass dominates the floodplain use on the south, while old field vegetation dominates the northern floodplain.

The stream banks were in moderately good shape; little or no bank erosion was observed on the right bank, while the left bank suffered moderate erosion. In-stream cover at the site was sparse and consisted mainly of aquatic macrophytes and woody debris. Sand was the primary substrate type throughout the sampling reach.

Due to Maloney Ditch's relatively poor habitat score, it is difficult to determine with any certainty whether the moderate impairment of the stream's biotic community is due to water quality or some other reason. The stream's QHEI score suggests that the habitat may be contributing to the observed impairment of the biotic community. At the same time, total phosphorus concentrations observed during base flow were above the threshold at which the Ohio EPA found to impair a stream's biotic community. Thus, it is likely that both poor habitat and water quality are impairing the stream's biotic community.

4.0 LAKE ASSESSMENT

4.1 Morphology

Figure 15 presents Blue Lake's moderately complex morphology. The lake consists of five deep holes surrounded by shallower water. The lake's deepest point lies in the north-central portion of the 239-acre (96.7-ha) lake. Here, the lake extends to it maximum depth of 49 feet (14.9 m; Table 13). Two shallower holes lie in the eastern portion of the lake; the most eastern hole reaches a depth of 30 feet (9.1 m), while the east-central hole possesses a maximum depth of 35 feet (10.7 m). A fourth deep hole lies in the western end of the lake and reaches a depth of 35 feet (10.7 m). The fifth and final deep hole lies in the southern portion on the lake along the western shoreline. This hole reaches a depth of 30 feet (9.1 m). Water as shallow as 25 feet (7.6 m) separates these holes from the other parts of the lake.

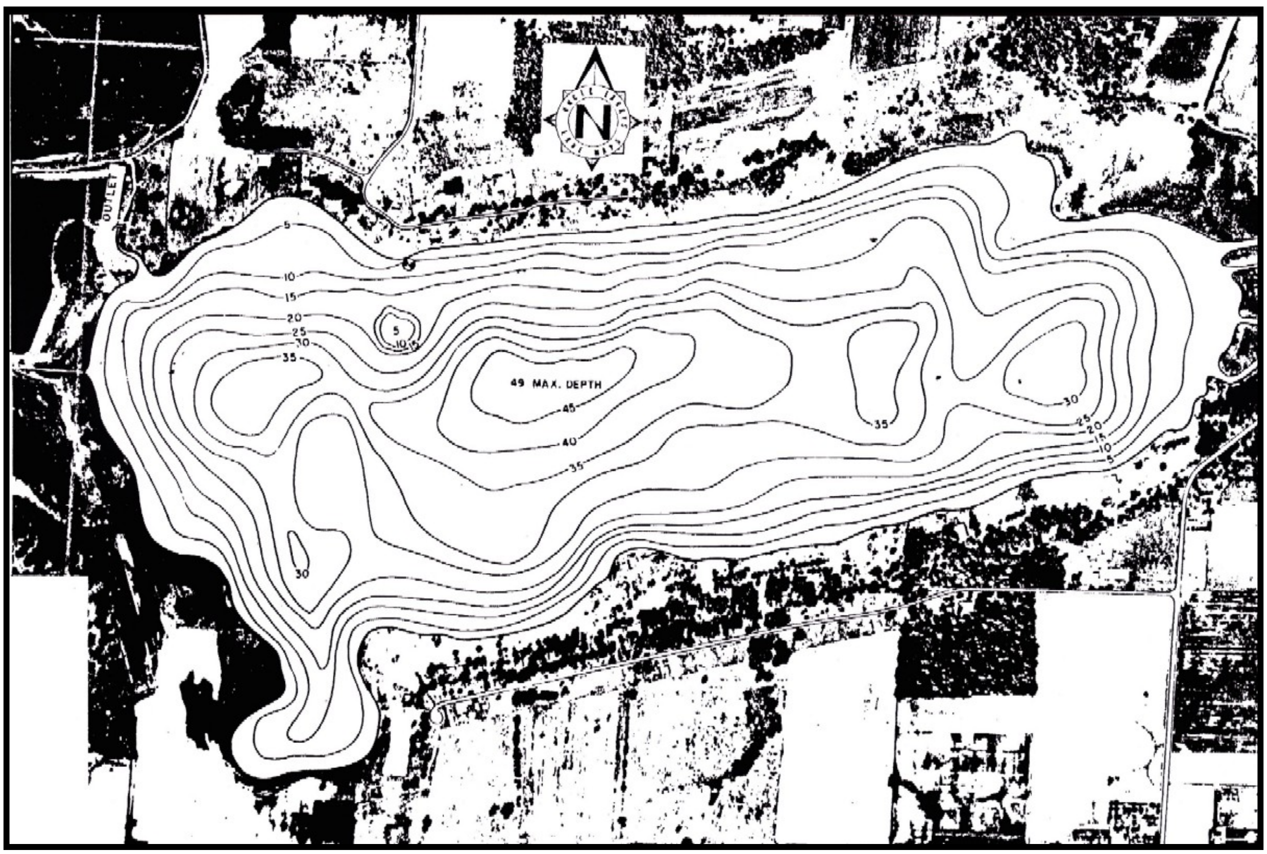

Figure 15. Blue Lake bathymetric map. Source: IDNR, 1956.

Table 13. Morphological characteristics of Blue Lake.

Characteristic	Value
Surface Area	230 acres (93.1 ha)
Volume	4,994 acre-feet (6,160,008 m^3)
Maximum Depth	49 feet (14.9 m)
Mean Depth	20.9 feet (6.3 m)
Shallowness Ratio	0.12
Shoalness Ratio	0.45
Shoreline Length	17,803 feet (5,426 m)
Shoreline Development Ratio	1.58

Blue Lake possesses limited expanses of shallow water. According to its depth-area curve (Figure 16), only 32 acres (12.9 ha) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 105 acres (44.1 ha) is covered by water less than 20 feet (6.1 m) deep. This translates into a very low shallowness ratio of 0.29 (ratio of area less than 5 feet (1.5 m) deep to total lake area) and a moderately high shoalness ratio of 0.46 (ratio of area less than 20 feet (6.1 m) deep to total lake area) (Table 13), as defined by Wagner (1990). Very little of the lake's acreage (approximately 10 acres or 4.0 ha) covers the water deeper than 40 feet (12.1 m).

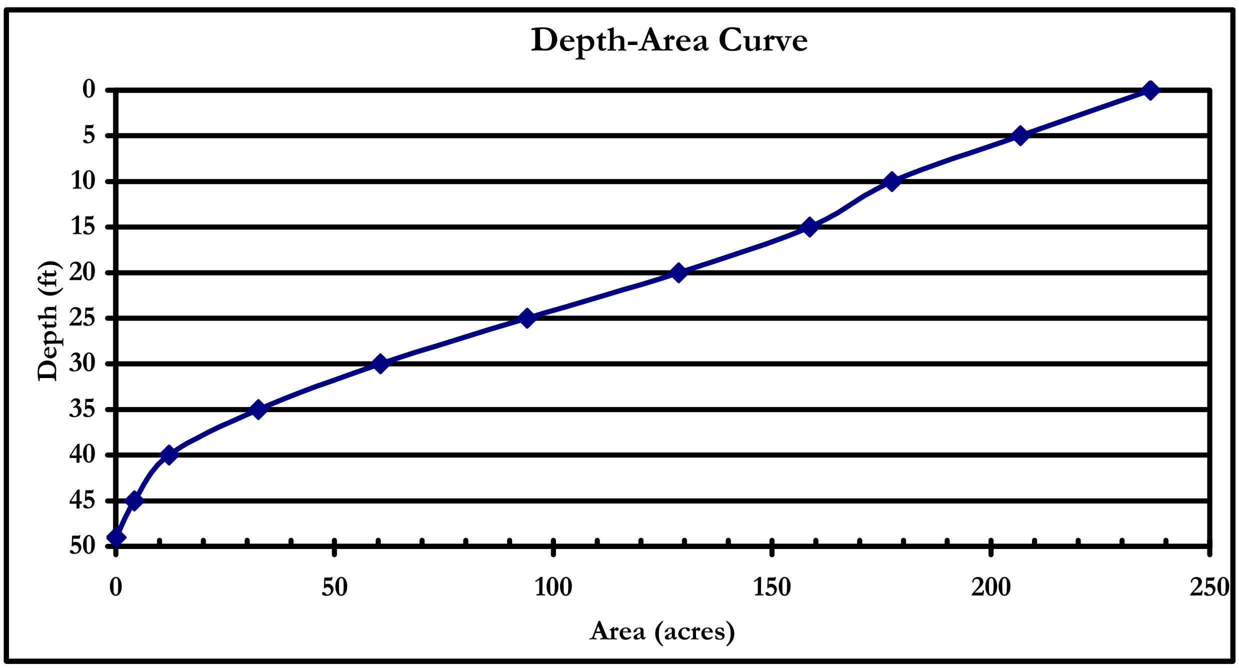

Figure 16. Depth-area curve for Blue Lake.

Blue Lake holds approximately 4,994 acre-feet (6,160,008 m^3) of water. As illustrated in the depth-volume curve (Figure 17), most of the lake's volume is contained in the shallower areas of the lake. Nearly 95% of the lake's volume is contained in water that is less than 35 feet (10.7 m) deep. The lake's volume gradually increases with depth to a water depth of about 25 feet (7.6 m). Below 25 feet (7.6 m), the steep curve indicates a greater change in depth per unit volume.

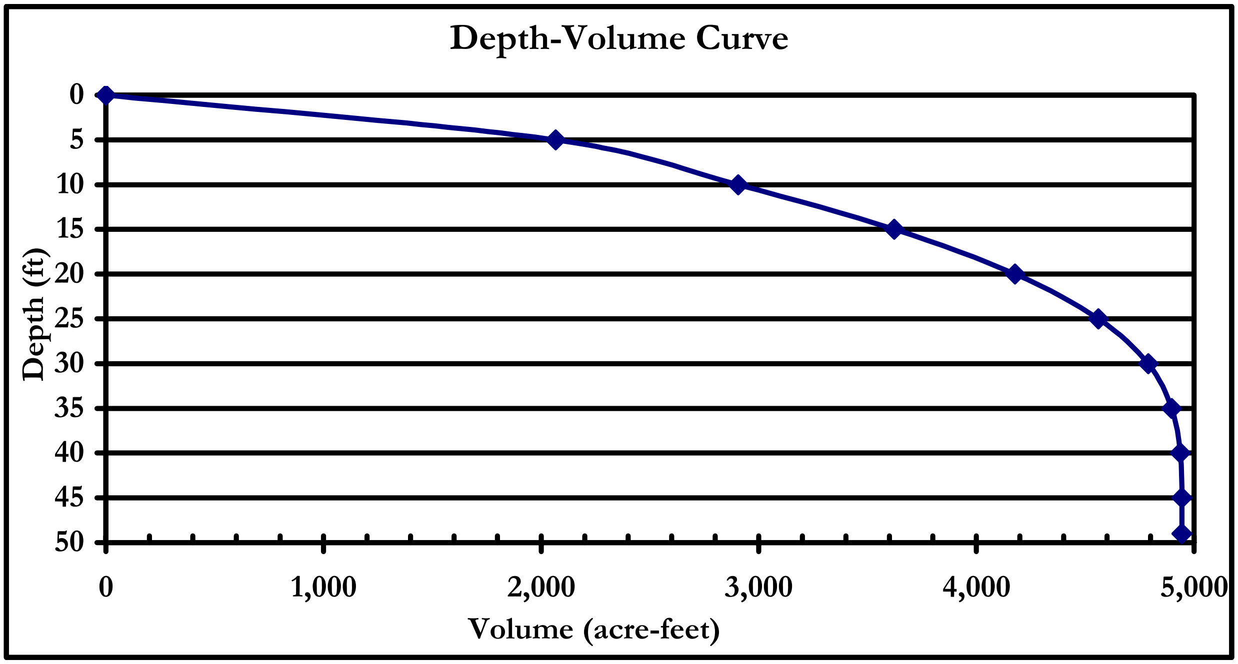

Figure 17. Depth-volume curve for Blue Lake.

A lake's morphology can play a role in shaping the lake's biotic communities. For example, Blue Lake's moderately sized shallow area coupled with its moderate clarity suggests the lake is capable of supporting a quality rooted plant community. Based on the lake's clarity (as measured by the lake's 1% light level), Blue Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the point where water depths are approximately 9 feet (2.7 m). Referring to Blue Lake's depth-area curve (Figure 16), this means that the lake's littoral zone is approximately 54 acres (21.8 ha) in size or approximately 23% of the lake. This size littoral zone can impact other biotic communities in the lake such as fish that use the plant community for forage, spawning, cover, and resting habitat.

A lake's morphology can indirectly influence water quality by shaping the human communities around the lake. The shoreline development ratio is a measure of the development potential of a lake. It is calculated by dividing a lake's shoreline length by the circumference of a circle that has the same area as the lake. A perfectly circular lake with the same area as Blue Lake (239 acres or 96.7 ha) would have a circumference of 11,437 feet (3,485 m). Dividing Blue Lake's shoreline length (17,803 feet or 5,426 m) by 11,437 feet yields a ratio of 1.55:1. This ratio is relatively low. Blue Lake lacks extensive shoreline channeling observed on other popular Indiana lakes such as lakes in the Barbee Chain and Lake Tippecanoe. Given the immense popularity of lakes in northern Indiana, lakes with high shoreline development ratios are often highly developed. Increased development around lakes often leads to decreased water quality.

4.2 Shoreline Development

Residential development of the shoreline of Blue Lake likely began in the 1830s. The Whitley County Historical Society documents cabins scattered throughout the area north of Anderson Road and west of Blue Lake Road by 1838 (Palmer, 1983). Running electrical lines to the lake generated a rivalry between two lake residents in the 1920s. Mr. Rapp and Mr. Harrold each requested that lines be ran to the lake for a variety of reasons. By 1924, Rapp possessed electricity to power his dance hall located on Rapp's Landing near the southeastern corner of the lake. Concurrently, Harrold's electrical line powered homes scattered along the southern lakeshore and adjacent farms (Flowers, 1999).

During this period of slow development, Blue Lake possessed a size and shape or morphometry similar to what is present today. The lake also contained a diverse plant community. Kaler and Maring (1907) note that Blue River Lake, or as it is known today Blue Lake, measured 1.5 miles (2,414 m) long and 0.5 miles (804.7 m) across. The lake possessed low shorelines and a uniform depth to approximately 40 to 55 feet (12.1 to 16.7 m). Kaler and Maring (1907) also noted the variety and variation of aquatic plants surrounding the entire lake. These plants occurred in distinctive zones. A band of water willow, cattails, and willow were located on the outside followed by a ring of pickerel weed, then spatterdock, chara, and duckweed, and finally a mixture of bladderwort, pondweeds, and northern milfoil (Kaler and Maring, 1907).

Early aerial photography of Blue Lake (1938) shows the presence of a limited number of houses around Blue Lake, indicating that although electricity was available along the lakeshore, minimal development occurred around Blue Lake during that timeframe. Houses present in the 1938 aerial are scattered along both the northern and southern shorelines. Much of the remaining shoreline is covered by wetland, forest, and agricultural land. By 1957, development had progressed around Blue Lake. The houses and piers identified in the 1957 aerial are mostly located along the southern, eastern, and northern shoreline of the lake.

By the 1970s, development covered similar areas as those present in the 1957 aerials; however, houses were present in much greater density. During the 1975 fisheries survey, Shipman (1976) estimated that approximately 60% of Blue Lake's shoreline including the channels around the islands was developed for residential use. Shipman noted that access to the lake could be garnered through use of a dirt ramp located on the east end of the lake off of Blue Lake Road. Additional access was also available through two private ramps contained within trailer courts on the lake (Shipman, 1976). Aerial photographs from 1972 confirm the presence of houses scattered along nearly the entirety of Blue Lake's southern shoreline with these houses more densely packed together than those present in 1957. Additional development of the campground/trailer park covered much of the east end of the lake, while more houses were located along the northern shoreline.

Development continued along Blue Lake's shoreline over the next 35 years. During assessments completed in 1995 and 2000, Indiana Clean Lakes Program field biologists noted that nearly 60% and 65%, respectively of Blue Lake's shoreline was developed for residential land use. Aerial photographs from 1998 support these conclusions; however, more development off of the lake on the west end and near Horseshoe Bay allowed for additional users to access the lake without building directly on the shoreline (this practice is known as funneling). The 2003 aerial photograph indicates little change in development along the shoreline of Blue Lake with the exception of additional mobile homes or campers in the camp ground on the east end of the lake. In 2004, CLP biologists estimated that residential development covered nearly 85% of Blue Lake's shoreline.

Despite the plethora of houses along Blue Lake's shoreline, nearly 57% of Blue Lake's shoreline vegetation remains in its natural state. Areas mapped as natural in Figure 18 are those portions of the shoreline where the natural plan community remains in its natural state and has not been impacted by the removal of emergent or shoreline vegetation. In these locations, bands of plants like those described by Kaler and Maring (1907) are present with trees, emergent vegetation, floating vegetation, and submerged vegetation located in distinct zones along the lakeshore (Figure 19). Natural wetland buffers cover much of the western and northeastern shorelines of Blue Lake and, in some shallow locations like Horseshoe Bay, are spreading into the lake.

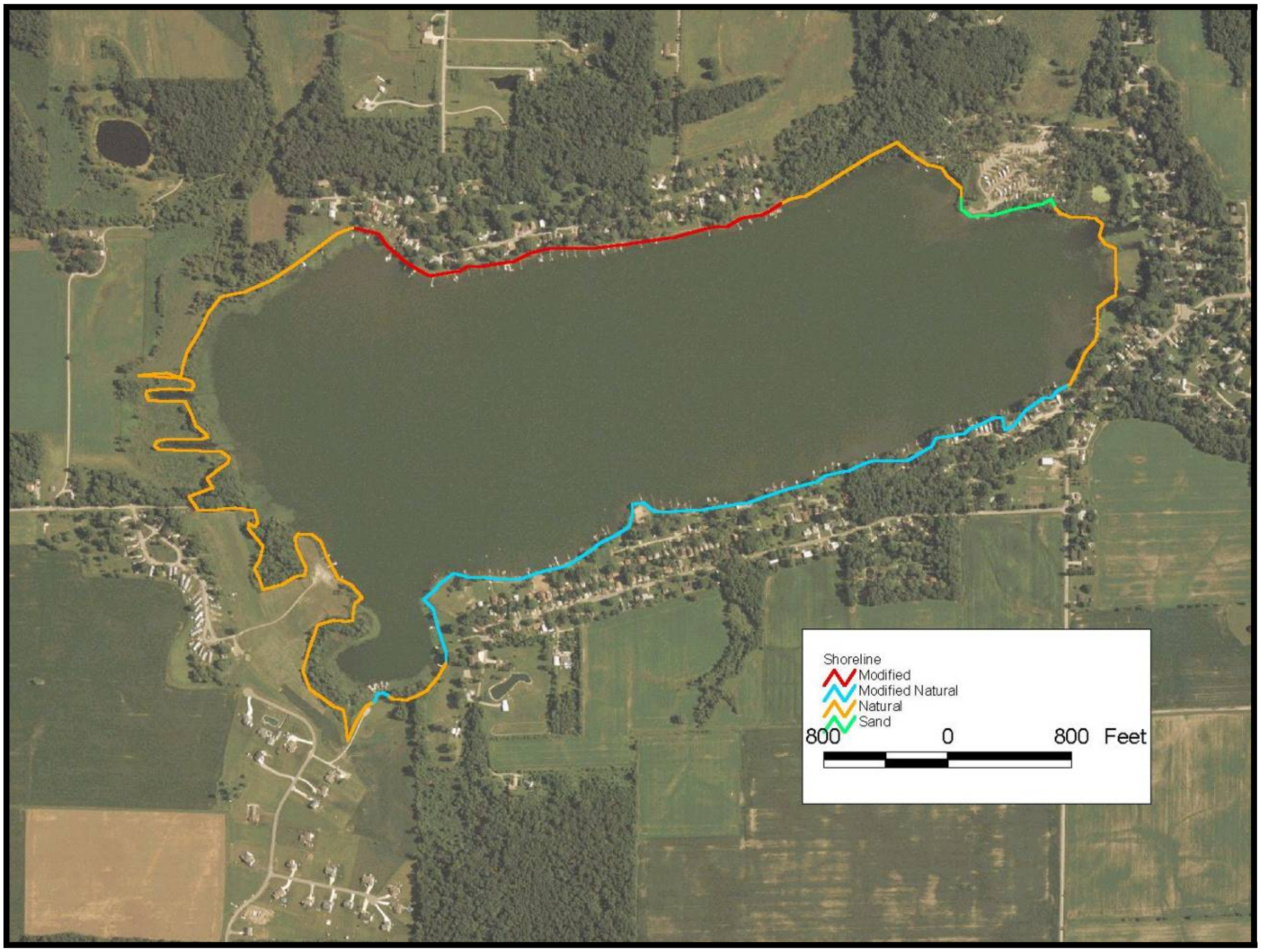

Figure 18. Shoreline surface type observed at Blue Lake, July 28, 2005. Natural shorelines are those that possess no apparent modification from their natural state. Around these shorelines, bands of trees, emergent, floating, and submerged plant communities are maintained. Modified natural shorelines are those shorelines that have had some portion of their natural characteristics removed; however, in most cases a narrow, limited band of emergent vegetation. Modified shorelines are those where all of the emergent vegetation has been removed. Many of these shorelines are covered by wooden, metal, or concrete seawalls. Sand refers to the portion of shoreline covered by sandy beach.

Source: See Appendix A.

Figure 19. Natural shoreline present within Blue Lake.

An additional 26% is minimally or only moderately disturbed meaning that a portion of the emergent and shoreline vegetation remains intact. (These areas are mapped as modified natural in Figure 18.) However, these shoreline areas are not as pristine or natural as the shoreline areas that maintain distinct bands of vegetation. Trees and emergent vegetation have been thinned along these areas of Blue Lake's shoreline; however, these areas possess at least a narrow band of emergent plants. Other portions of the shoreline that are also mapped as modified natural include those areas where only the portion of the shoreline vegetation required to access the lake have been removed. An example of this type of modified natural shoreline is depicted in Figure 20.

Figure 20. Modified natural shoreline present within Blue Lake. Note that vegetation was removed in areas required to access the lake. The remaining vegetation along the shoreline acts as a natural buffer.

Approximately 14% of Blue Lake's shoreline has been largely altered from its natural state (Figure 21). Along these portions of Blue Lake's shoreline emergent and floating rooted vegetation has been completely removed to expose soils or mowed, residential lawns. In some areas wooden railroad timbers, concrete seawalls, glacial stone, or riprap cover the shoreline. Along a limited number of properties (mapped as modified) emergent plants are growing in front of the seawall. One example is the metal seawall depicted in Figure 22 where bulrushes in front of the seawall dampen wave energy and provide habitat for fish and wildlife.

Figure 21. Modified shoreline present within Blue Lake. Note that much of this concrete seawall was refaced with riprap stone; however, the increased wave energy caused by seawalls will still occur here.

Figure 22. Modified shoreline present within Blue Lake. Note the growth of bulrushes in front of the seawall acting as a wave break in this shallow water area.

The shoreline surface becomes especially important in and adjacent to shallow portions of Blue Lake. In areas where concrete seawalls are present, wave energy from wind and boats strike the flat surface and reflect back into the lake. This creates an almost continuous turbulence in the shallow areas of the lake. At points where the waves reflect back into the lake and meet incoming waves, the wave height increases resulting in additional in-lake turbulence. This turbulence resuspends bottom sediments thereby increasing the transfer of nutrients from the sediment-water interface to the water column. Continuous disturbance in shallow areas can also encourage the growth of disturbance-oriented plants.

In contrast, shorelines vegetated with emergent or rooted floating vegetation or those areas covered by sand will absorb more of the wave energy created by wind or boats. In these locations, wave energy will dissipate along the shoreline each time a wave meets the shoreline surface. Similarly, stone seawalls or those covered by wood can decrease shallow water turbulence and lakeward wave energy reflection while still providing shoreline stabilization.

4.3 Boating History

The conversion of access to Blue Lake from a dirt ramp to a concrete ramp changed the type and volume of lake usage at Blue Lake. The installation of a state-owned concrete boat ramp on the lake's southern shoreline occurred 1997. Prior to that time, access to Blue Lake could be gained from a dirt ramp on the east end of the lake or via two private ramps located in campgrounds or trailer parks along the lakeshore. A creel survey completed by the IDNR in 1982 indicated that fishing pressure was lower in Blue Lake than in other lakes in northern Indiana (Braun, 1983). Braun also noted that weekend boaters were more numerous in 1982 than weekday boaters. With the construction of the public boat ramp, more boat owners not living on Blue Lake were able to access the lake. Because of this change, a subsequent creel survey was completed by the IDNR in 1998 (Braun, 1999). This survey found that fishing pressures had increased since 1982. An additional question asked of visitors regarding their primary residence location indicated that only 6.8% of individuals boating on Blue Lake during the 1998 assessment lived on Blue Lake itself. 38.3% of the survey respondents lived off the lake somewhere in Whitley County, while the largest constituency resided in Allen County (49.8%).

These numbers reflect concerns voiced by Blue Lake residents regarding non-resident boaters of their lake. In order to track boat density and lake usage, Blue Lake residents conducted a boat count three times during the summer of 2005. Boat survey information indicates that during summer weekends and holidays, there are 5 to 6 acres of open water available for each boat present on the lake during peak usage periods (Table 14). During lower usage periods (as evidenced by the August 20 count), each boat is allowed nearly 30 acres of open water for personal use. During high density time periods, the size and speed of boats and the number of lake users increases (Figure 23). Use of Blue Lake by non-resident boaters should be taken into account when determining management options for the lake. (More information regarding the impact of boating on Blue Lake are included in the In- Lake Management Section.)

Table 14. Results of boat counts completed during the summer of 2005 on Blue Lake.

Boat Type	**Mid-Summer Saturday June 25, 2005**	**Summer Holiday July 4, 2005**	**Mid-Summer Saturday August 20, 2005**
Speedboat/Ski Boat	14	18	2
Personal Watercraft	8	10	1
Fishing/Bass Boat	7	9	4
Pontoon	7	14	1
Paddle Boat	2	5	0
Kayak	3	0	0
Total	**41**	**46**	**8**

Figure 23. Lake users enjoy an afternoon on Blue Lake.

4.4 Historical Water Quality

The Indiana Department of Natural Resources, Division of Fish and Wildlife, the Indiana State Pollution Control Board, and the Indiana Clean Lakes Program (CLP) have conducted various water quality tests on Blue Lake. Table 15 presents some selected water quality parameters for these assessments of Blue Lake.

Table 15. Summary of historic data for Blue Lake.

Date	Secchi (ft)	Percent Oxic	epi pH	Mean TP (mg/L)	Plankton Density (#/L)	TSI Score (based on means)	Data Source
1974	5.6	41%	--	0.150*	--	35^{δ}	ISPCB, 1974
8/8/75	6.0	41%	9.0	--	--	--	Shipman, 1976
6/4/79	3.8	61%	9.7	--	--	--	Braun and Pearson, 1980
7/7/90	5.9	38%	7.1	0.176	35,870	36	CLP, 1990
8/14/95	4.6	33%	8.8	0.298	10,509	42	CLP, 1995
6/1/98	9.0	--	8.5	--	--	--	Braun, 1999
7/14/98	6.1	46%	8.5	0.244	5,144	32	CLP, 1998
6/30/04	3.6	33%	8.7	0.241	58,304	41	CLP, 2004
8/10/05	2.6	31%	8.8	0.306	28,574	43	Present Study

*Water column average; all other values are means of epilimnion and hypolimnion values.

$^{\delta}$Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.

Water clarity measurements recorded over the last 30 years indicate that water quality declined slightly since 1974. Secchi disk transparency depths fluctuated from 5.6 feet (1.7 m) in 1974 to 6.1 feet (1.9 m) in 1998 but generally changed little over the 24-year period before declining to levels observed in 2004 and 2005 (3.6 feet (1.1 m) and 2.6 feet (0.8 m), respectively). The 1979 assessment, which occurred during an algal bloom (as evidenced by the extremely high epilimnetic pH and the supersaturated oxygen conditions), and the June 1998 assessment, which occurred early in the season before the plankton community reached its peak, are two exceptions to the gradual change in water quality. All recorded transparencies, with the exception of the June 1998 reading, were poorer than the median transparency depth for Indiana lakes. The poorest Secchi disk transparency depth of 2.6 feet (0.8 m) was recorded during the current assessment, which occurred during a dry year. The cause of the poor transparency will be discussed in further detail in the Lake Water Quality Assessment Results Section.

Total phosphorus concentrations follow a similar pattern. Total phosphorus concentrations increased from 0.15 mg/L in 1974 to 0.298 mg/L in 1995. Since that time, total phosphorus concentrations have fluctuated but generally remain in the 0.24 mg/L to 0.30 mg/L range. The relatively high total phosphorus concentrations present in Blue Lake exceed the median concentrations observed in Indiana lakes (0.17 mg/L) during all assessments except the 1974 sampling event. Historic total phosphorus concentrations indicate that Blue Lake likely supported algal blooms in the summer. The lake's algal (plankton) density reflects the relatively high nutrient levels. Nutrients (phosphorus and nitrogen) promote the growth of algae and rooted plants; thus, lakes with high nutrient levels are expected to support dense algae and/or rooted plant populations. This pattern can be observed in Blue Lake as well.

Blue Lake's plankton density mimics the pattern of the lake's Secchi disk transparency more than it follows changes in the total phosphorus concentration. This is to be expected since lake transparency is typically determined by algal and non-algal (sediment, organic material) turbidity. In Blue Lake, data suggest that algal turbidity typically affects water clarity more than non-algal turbidity. The highest observed plankton density occurred in 2004, which corresponds with one of the poorest Secchi disk transparency measurements. Likewise, lower density plankton communities were present during the 1995 and 1998 assessments, which correspond with better Secchi disk transparency measurements in Blue Lake. (The current assessment does not follow this pattern. More explanation of these data are detailed in the Water Quality assessment Section.)

The Indiana Trophic State Index (ITSI) scores displayed in Table 15 place Blue Lake in the eutrophic productivity class. These scores indicate that the lake's water quality has changed little over the past 30 years. This classification indicates that the lake is productive and will typically support dense plant or plankton populations and have poor transparency. The lake's overall ITSI varied from a low of 32 in 1998 to a high of 43 during the current assessment. These scores suggest that natural factors such as climate variation affect Blue Lake's ITSI more than actual changes in water quality. Looking at individual ITSI points, variations in the ITSI scores arise from Secchi disk transparency variations and the resultant plankton densities. Points attributed to nutrients, both nitrogen and phosphorus, varied but remained generally similar over all of the assessments.

Consistent with increasingly poor Secchi disk transparency depths described above, other parameters indicate that Blue Lake's clarity is declining. The amount of light that penetrated the lake's water column to a depth of 3 feet (0.9 m) was a maximum of 55% during the 1990 assessment, but measured only 30 to 33% during the 1995, 1998, and 2004 assessments (Tables 16 through 19). The decline continued through the current assessment, which indicates that at a depth of 3 feet (0.9 m) only 15% of light is able to penetrate. In clearer lakes, light transmission at 3 feet (0.9 m) can be expected to exceed 50%. This limits the habitat availability for rooted plants.

The data also suggest that Blue Lake supports an over-abundant algal population on occasion. Blue Lake contained an elevated epilimnetic pH during the 1974 and 1979 assessments (Table 15). Although pH levels were not as high in the epilimnion during some assessments completed in the last 20 years, pH levels during these assessments (1995, 2004, and 2005) suggests a water quality issue. A high epilimnetic pH may indicate the presence of photosynthesizing algae. During the process of photosynthesis, algae remove carbon dioxide, a weak acid, from the water column, thereby increasing the water's pH. Additionally, the concentration of chlorophyll *a* was high during the 2004 and 2005 assessments measuring 21.15 and 20.5 μg/L, respectively. Chlorophyll *a* concentrations of this magnitude are typically characteristic of hypereutrophic lakes. Additionally, blue-green algae, a nuisance algae generally associated with productive lakes, dominated the Blue Lake algal community during all of the Clean Lakes Program assessments.

Figure 24 displays the temperature profiles recorded during IDNR fisheries surveys and Indiana CLP assessments. All of the temperature profiles show that Blue Lake was stratified, albeit in some cases stratification was weak. For example, the temperature profile recorded by the IDNR during 1979 occurred early in the growing season resulting in weaker stratification than is present during other surveys. The developed hypolimnion present during the 1990, 1995, and 1999 surveys is more typical of Indiana lakes.

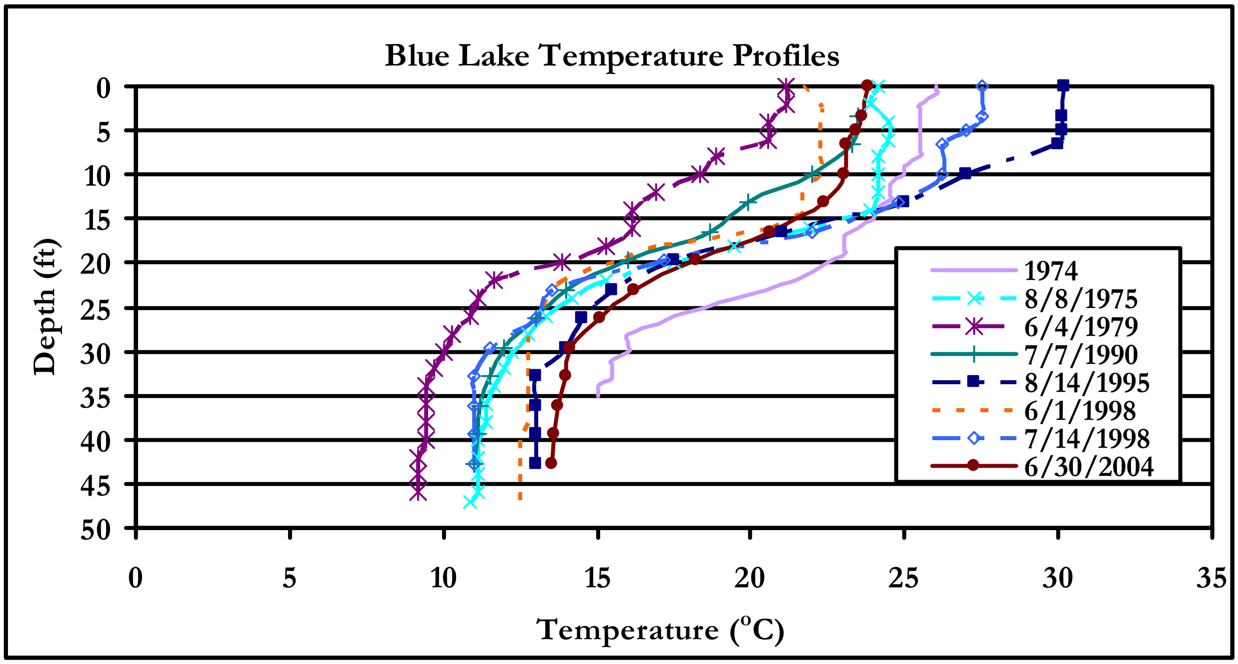

Figure 24. Historical temperature profiles for Blue Lake.
Source: ISPCB, 1986; Shipman, 1976; Braun and Pearson, 1980; Braun, 1999; CLP, 1990, 1995, 1998, and 2004.

Much of the data presented above suggest that Blue Lake is relatively productive. The historical dissolved oxygen results lend further evidence to this suggestion (Figure 25). Dissolved oxygen profiles indicate that the lake was typically anoxic below 15 feet (4.5 m). This decline in dissolved oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments. Generally, data recorded over the past 30 years indicate that less than 45% of the water column contained sufficient oxygen to support healthy biotic communities (Table 15). The 1979 sampling profile illustrates different conditions than those observed during the other assessments. In the 1979 dissolved oxygen profile, there is a sharp increase in dissolved oxygen in the lake's metalimnion. This results in a positive-heterograde profile. Positive-heterograde profiles are characterized by a peak in oxygen concentration at a depth below the water surface, such as the peak in the 1979 profile beginning at 5 feet (1.5 m) below the water's surface. The peak is likely associated with a higher concentration in phytoplankton at that particular depth layer. Called a ***metalimnetic oxygen maximum***, the peak results when the rate of settling plankton slows in the denser waters of the metalimnion. At this depth, the plankton can take advantage of nutrients diffusing from the nutrient-enriched hypolimnion. As the plankton at this depth photosynthesize, they release oxygen into the water column, creating a peak in oxygen at that level. The 1975 and both 1998 assessments profiles are also examples of metalimnetic oxygen maxima, although in all of these cases, the peaks are much smaller than that present during the 1979 assessment.

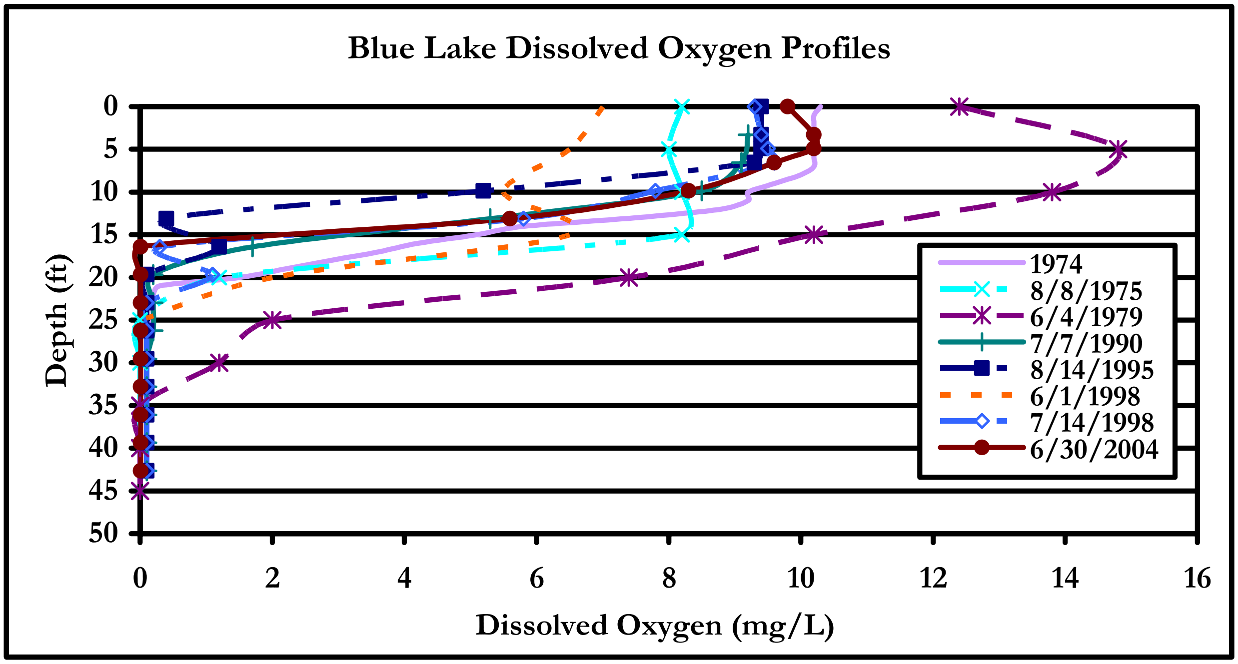

Figure 25. Historical dissolved oxygen profiles for Blue Lake.
Source: ISPCB, 1986; Shipman, 1976; Braun and Pearson, 1980; Braun, 1999; CLP, 1990, 1995, 1998, and 2004.

The lack of oxygen in Blue Lake's hypolimnion also affects the lake's chemistry. While mean total phosphorus concentrations are variable for the years displayed in Tables 16 through 19, a more detailed evaluation shows that hypolimnetic total phosphorus concentrations are much higher than epilimnetic total phosphorus concentrations. Under anoxic conditions, the iron in iron phosphate, a common precipitate in lake sediments, is reduced, and the phosphate ion is released into the water column. This phosphate ion is readily available to algae, and can therefore spur algal growth. Further review of historical phosphorus data indicate that much of the total phosphorus was in the dissolved form of phosphorus (SRP). This indicates that Blue Lake was releasing phosphorus from its bottom sediments. Additionally, Blue Lake exhibited higher hypolimnetic ammonia concentrations than those observed in the lake's epilimnion during all of the assessments, suggesting decomposition of organic matter was occurring in the lake's bottom waters. Overall, these data suggest that Blue Lake was a eutrophic lake during the 1990, 1995, 1999, and 2004 assessments.

Table 16. Historical water quality characteristics of Blue Lake, July 7, 1990.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
Secchi Depth Transparency	1.8 m	-	0
Light Transmission @ 3 ft.	55%	-	2
Total Phosphorous	0.034 mg/L	0.317 mg/L	3
Soluble Reactive Phosphorous	0.007 mg/L	0.435 mg/L	4
Nitrate-Nitrogen	0.193 mg/L	0.182 mg/L	3
Ammonia-Nitrogen	0.018 mg/L	0.804 mg/L	2
Organic Nitrogen	1.092 mg/L	0.942 mg/L	4
Oxygen Saturation @ 5ft.	107%	-	0
% Water Column Oxic	38.40%	-	3
Plankton Density	35,870/L	-	5
Blue-Green Dominance	90.5%	-	10
		TSI Score	**36**

Table 17. Historical water quality characteristics of Blue Lake, August 14, 1995.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.74	7.5	-
Alkalinity	190 mg/L	179 mg/L	-
Conductivity	430 μmhos	430 μmhos	-
Secchi Depth Transparency	1.4 m	-	6
Light Transmission @ 3 ft.	30%	-	4
1% Light Level	15 ft	-	-
Total Phosphorous	0.056 mg/L	0.54 mg/L	4
Soluble Reactive Phosphorous	0.009 mg/L	0.524 mg/L	4
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	1.453 mg/L	3
Organic Nitrogen	0.613 mg/L	2.195 mg/L	3
Oxygen Saturation @ 5ft.	124.3%	-	2
% Water Column Oxic	38%	-	3
Plankton Density	10,509/L	-	3
Blue-Green Dominance	70.9%	-	10
Chlorophyll *a*	0.92 mg/m^3	-	-
		TSI Score	**42**

Table 18. Historical water quality characteristics of Blue Lake, July 14, 1998.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.49	7.42	-
Alkalinity	120.3 mg/L	181.8 mg/L	-
Conductivity	425 µmhos	405 µmhos	-
Secchi Depth Transparency	1.85 m	-	0
Light Transmission @ 3 ft.	43%	-	3
1% Light Level	18.5 ft	-	-
Total Phosphorous	0.014 mg/L	0.473 mg/L	4
Soluble Reactive Phosphorous	0.070 mg/L	0.444 mg/L	4
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	0.936 mg/L	2
Organic Nitrogen	0.588 mg/L	1.421 mg/L	3
Oxygen Saturation @ 5ft.	121.0%	-	2
% Water Column Oxic	46%	-	3
Plankton Density	5,144/L	-	1
Blue-Green Dominance	57.9%	-	10
Chlorophyll *a*	3.5 mg/m^3	-	-
		TSI Score	**32**

Table 19. Historical water quality characteristics of Blue Lake, June 30, 2004.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.7	7.6	-
Alkalinity	129 mg/L	178 mg/L	-
Conductivity	379 µmhos	387 µmhos	-
Secchi Depth Transparency	1.1 m	-	6
Light Transmission @ 3 ft.	33%	-	3
1% Light Level	12 ft	-	-
Total Phosphorous	0.059 mg/L	0.423 mg/L	4
Soluble Reactive Phosphorous	0.024 mg/L	0.428 mg/L	4
Nitrate-Nitrogen	0.013 mg/L	0.013 mg/L	0
Ammonia-Nitrogen	0.075 mg/L	0.89 mg/L	2
Organic Nitrogen	1.298 mg/L	2.283 mg/L	3
Oxygen Saturation @ 5ft.	119.0%	-	1
% Water Column Oxic	31%	-	3
Plankton Density	58,304/L	-	5
Blue-Green Dominance	94.7%	-	10
Chlorophyll *a*	21.15 mg/m^3	-	-
		TSI Score	**41**

4.5 Lake Water Quality Assessment

4.5.1 Lake Water Quality Assessment Methods

The water sampling and analytical methods used for Blue Lake were consistent with those used in IDEM's Indiana Clean Lakes Program and IDNR's Lake and River Enhancement Program. Water samples were collected and analyzed for various parameters from Blue Lake on August 10, 2005 from the surface waters (***epilimnion***) and from the bottom waters (***hypolimnion***) of the lake at a location over the deepest water. These parameters include conductivity, total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, and organic nitrogen. In addition to these parameters, several other measurements of lake health were recorded. Secchi disk, light transmission, and oxygen saturation are single measurements made in the epilimnion. Chlorophyll was determined only for an epilimnetic sample. 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 depth up to the water surface. Conductivity, temperature, and dissolved oxygen were measured *in situ* with an YSI Model 85 meter.

All lake samples were placed in the appropriate bottle (with preservative if needed) and stored in an ice chest until analysis at SPEA's laboratory in Bloomington. SRP samples were filtered in the field through a Whatman GF-C filter.

All sampling techniques and laboratory analytical methods were performed in accordance with procedures in *Standard Methods for the Examination of Water and Wastewater*, 20th Edition (APHA, 1998). Plankton counts were made using a standard Sedgewick-Rafter counting cell. Fifteen fields per cell were counted. Plankton identifications were made according to: Ward and Whipple (1959), Prescott (1982), Whitford and Schumacher (1984), and Wehr and Sheath (2003).

The following is a brief description of the parameters analyzed during the lake sampling efforts:

Temperature. Temperature can determine the form, solubility, and toxicity of a broad range of aqueous compounds. For example, water temperature affects the amount of oxygen dissolved in the water column. 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 (USEPA, 1976). The Indiana Administrative Code (327 IAC 2-1-6) sets maximum temperature limits to protect aquatic life for Indiana waters. For example, temperatures during the summer months should not exceed 90 °F (32.2 °C).

Dissolved Oxygen (DO). DO is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3 to 5 mg/L of DO. Coldwater fish such as trout generally require higher concentrations of DO than warmwater fish such as bass or bluegill. The IAC sets minimum DO concentrations at 4 mg/L for warmwater fish, but all waters must have a daily average of 5 mg/L. DO 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 DO. 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). Rather than setting a conductivity standard, the Indiana Administrative Code sets a standard for dissolved solids (750 mg/L). Multiplying a dissolved solids concentration by a conversion factor of 0.55 to 0.75 μmhos per mg/L of dissolved solids roughly converts a dissolved solids concentration to specific conductance (Allan, 1995). Thus, converting the IAC dissolved solids concentration standard to specific conductance by multiplying 750 mg/L by 0.55 to 0.75 μmhos per mg/L yields a specific conductance range of approximately 1000 to 1360 μmhos. This report presents conductivity measurements at each site in μmhos.

Nutrients. Limnologists measure nutrients to predict the amount of algae growth and/or rooted plant (macrophyte) growth that is possible in a lake. Algae and rooted plants are a natural and necessary part of aquatic ecosystems. Both will always occur in a healthy lake. Complete elimination of algae and/or rooted plants is neither desirable nor even possible and should, therefore, never be the goal in managing a lake. Algae and rooted plant growth can, however, reach nuisance levels and interfere with the aesthetic and recreational uses of a lake. Limnologists commonly measure nutrient concentrations in aquatic ecosystem evaluations to determine the potential for such nuisance growth.

Like terrestrial plants, algae and rooted aquatic plants rely primarily on phosphorus and nitrogen for growth. Aquatic plants receive these nutrients from fertilizers, human and animal waste, atmospheric deposition in rainwater, and yard waste or other organic material that reaches the lake or stream. Nitrogen can also diffuse from the air into the water. This nitrogen is then "fixed" by certain algae species into a usable, "edible" form of nitrogen. Because of this readily available source of nitrogen (the air), phosphorus is usually the "limiting nutrient" in aquatic ecosystems. This means that it is actually the amount of phosphorus that controls plant growth in a lake or stream.

Phosphorus and nitrogen have several forms in water. The two common phosphorus forms are **soluble reactive phosphorus (SRP)** and **total phosphorus (TP)**. SRP is the dissolved form of phosphorus. It is the form that is "usable" by algae. Algae cannot directly digest and use particulate phosphorus. Total phosphorus is a measure of both dissolved and particulate forms of phosphorus. The most commonly measured nitrogen forms are **nitrate-nitrogen (NO_3)**, **ammonium-nitrogen (NH_4^+)**, and **total Kjeldahl nitrogen (TKN)**. Nitrate is a dissolved form of nitrogen that is commonly found in the upper layers of a lake or anywhere that oxygen is readily available. In contrast, ammonium-nitrogen is generally found where oxygen is lacking. ***Anoxia***, or a lack of oxygen, is common in the lower layers of a lake. Ammonium is a byproduct of decomposition generated by bacteria as they decompose organic material. Like SRP, ammonium is a dissolved form of nitrogen and the one utilized by algae for growth. The TKN measurement parallels the TP measurement to some extent. TKN is a measure of the **total organic nitrogen** (particulate) and ammonium-nitrogen in the water sample.

While the United States Environmental Protection Agency (USEPA) has established some nutrient standards for drinking water safety, it has not established similar nutrient standards for protecting the biological integrity of a lake. (The USEPA, in conjunction with the States, is currently working on developing these standards.) The USEPA has issued recommendations for numeric nutrient criteria for lakes (USEPA, 2000a). While these are not part of the Indiana Administrative Code, they serve as potential target conditions for which watershed managers might aim. Other researchers have suggested thresholds for several nutrients in lake ecosystems as well (Carlson, 1977; Vollenweider, 1975). Lastly, the Indiana Administrative Code (IAC) requires that all waters of the state have a nitrate concentration of less than 10 mg/L, which is the drinking water standard for the state.

With respect to lakes, limnologists have determined the existence of certain thresholds for nutrients above which changes in the lake's biological integrity can be expected. For example, Correll (1998) found that soluble reactive phosphorus concentrations of 0.005 mg/L are enough to maintain eutrophic or highly productive conditions in lake systems. For total phosphorus concentrations, 0.03 mg/L (0.03 ppm – parts per million or 30 ppb – parts per billion) is the generally accepted threshold. Total phosphorus concentrations above this level can promote nuisance algae blooms in lakes. The USEPA's recommended nutrient criterion for total phosphorus is fairly low, 14.75 μg/L (USEPA, 2000a). This is an unrealistic target for many Indiana lakes. It is unlikely that IDEM will recommend a total phosphorus criterion this low for incorporation in the IAC. Similarly, the USEPA's recommended nutrient criterion for nitrate-nitrogen in lakes is low at 8 μg/L. This is below the detection limit of most laboratories. In general, levels of inorganic nitrogen (which includes nitrate-nitrogen) that exceed 0.3 mg/L may also promote algae blooms in lakes. High levels of nitrate-nitrogen can be lethal to fish. The nitrate LC_{50} is 5 mg/L for logperch, 40 mg/L for carp, and 100 mg/L for white sucker. (Determined by performing a bioassay in the laboratory, the LC_{50} is the concentration of the pollutant being tested, in this case nitrogen, at which 50% of the test population died in the bioassay.) The USEPA's recommended criterion for total Kjeldahl nitrogen in lakes is 0.56 mg/L.

It is important to remember that none of the threshold or recommended concentrations listed above are state standards for water quality. They are presented here to provide a frame of reference for the concentrations found in Blue Lake. The IAC sets only nitrate-nitrogen and ammonia-nitrogen standards for waterbodies in Indiana. The Indiana Administrative Code requires that all waters of the state have a nitrate-nitrogen concentration of less than 10 mg/L, which is the drinking water standard for the state. The IAC standard for ammonia-nitrogen depends upon the water's pH and temperature, since both can affect ammonia-nitrogen's toxicity. The Blue Lake samples did not exceed the state standard for either nitrate-nitrogen or ammonia-nitrogen.

Secchi Disk Transparency. This refers to the depth to which the black and 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 land, and riverbanks. Bottom sediments may be resuspended by bottom feeding fish such as carp, or in shallow lakes, by motorboats or strong winds. In general, lakes possessing Secchi disk transparency depths greater than 15 feet (4.5 m) have outstanding clarity. Lakes with Secchi disk transparency depths less than 5 feet (1.5 m) possess poor water clarity (ISPCB, 1976; Carlson, 1977). The USEPA recommended a numeric criterion of 10.9 feet (3.3 m) for Secchi disk depth in lakes (USEPA, 2000a).

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. The volume of water above the 1% light level is referred to as the ***photic zone***.

Plankton. Plankton are important members of the aquatic food web. Plankton include the algae (microscopic plants) and the zooplankton (tiny shrimp-like animals that eat algae). Plankton are collected by towing a net with a very fine mesh (63-micron openings = 63/1000 millimeter) up through the lake's water column from the one percent light level to the surface. Of the many different planktonic species present in the water, the blue-green algae are of particular interest. 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 in 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. In general, chlorophyll *a* concentrations below 2 μg/L are considered low, while those exceeding 10 μg/L are considered high and indicative of poor water quality. The USEPA recommended a numeric criterion of 2.6 μg/L as a target concentration for lakes in Aggregate Nutrient Ecoregion VII (USEPA, 2000a).

4.5.2 Lake Water Quality Assessment Results

Results from the Blue Lake water characteristics assessment are included in Table 20 and Figure 26.

Table 20. Water Quality Characteristics of Blue Lake, August 10, 2005.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.8	7.7	-
Alkalinity	104 mg/L	168 mg/L	-
Conductivity	376 μmhos	331 μmhos	-
Secchi Depth Transparency	0.8 meters	-	6
Light Transmission @ 3 ft.	15%	-	4
1% Light Level	9.5 feet	-	-
Total Phosphorous	0.047 mg/L	0.565 mg/L	4
Soluble Reactive Phosphorous	0.018 mg/L	0.558 mg/L	4
Nitrate-Nitrogen	0.016 mg/L	0.013* mg/L	0
Ammonia-Nitrogen	0.154 mg/L	1.302 mg/L	3
Organic Nitrogen	0.937mg/L	0.628 mg/L	2
Oxygen Saturation @ 5ft.	145%	-	3
% Water Column Oxic	29%	-	3
Plankton Density	28,574/L	-	4
Blue-Green Dominance	90.1%	-	10
Chlorophyll *a*	20.7 μg/L	-	-
		TSI Score:	**43**

*Method detection limit

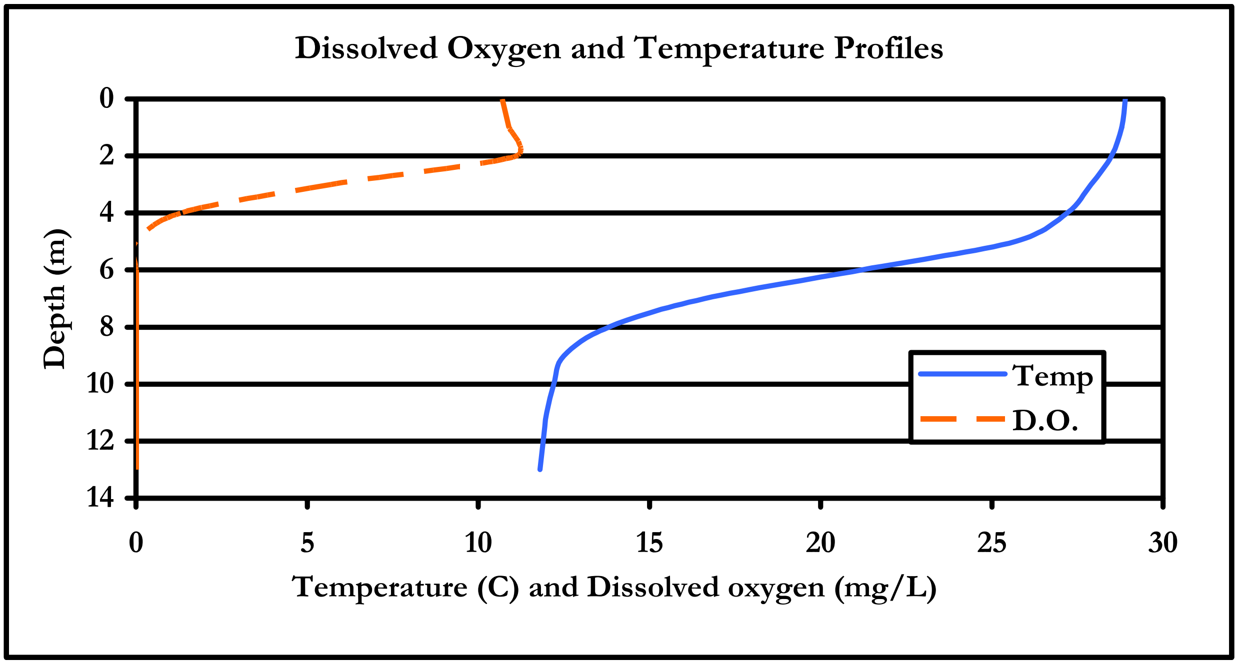

Figure 26. Temperature and dissolved oxygen profiles for Blue Lake on August 10, 2005.

The temperature profile for Blue Lake shows that the lake was stratified at the time of sampling (Figure 26). During thermal stratification, the bottom waters (*hypolimnion*) of the lake are isolated from the well-mixed *epilimnion* (surface waters) by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth, is called the *metalimnion*. At the time of sampling, the epilimnion was confined to the upper 13.1 feet (4 m) of water. The decline in temperature between 13.1 and 29.5 feet (4 and 9 m) defines the metalimnion or transition zone. The hypolimnion occupied water deeper than 9 meters.

The dissolved oxygen profile mirrors the temperature profile and is consistent with historical dissolved oxygen profiles for the lake (Figure 25). The lake was supersaturated in the *epilimnion* (surface waters) maintaining a saturation of 145% at 5 feet (1.5 m). Although the peak is not as large as that present during the 1979 assessment, this supersaturation represents a *metalimnetic oxygen maximum* and is likely associated with a higher concentrations of phytoplankton at that particular depth layer. A peak like this typically results when the rate of settling plankton slows in the denser waters of the metalimnion. As the plankton at this depth photosynthesize, they release oxygen into the water column, creating a peak in oxygen at that level. The oxygen concentration decreases rapidly within the epilimnion to a depth of 13.1 feet (4 m), at which there is no dissolved oxygen remaining in the lake. This is likely due to biological oxygen demand (BOD) from excess organic detritus in the lake's deeper waters. Respiration by aquatic fauna and decomposition of organic matter likely depleted the oxygen supply in the lake's deeper waters. Water below 13.1 feet (4 m) did not contain sufficient dissolved oxygen to support fish and other aquatic organisms. The lack of oxygen at the lake-sediment interface created conditions conducive to the release of phosphorus from the lake's sediments. Only 29% of the lake's water column was oxic, limiting the amount of habitat available for aquatic fauna.

Water clarity was relatively poor in Blue Lake. The Secchi disk transparency depth was 2.6 feet (0.8 m) which is less than the USEPA (2000b) target Secchi disk transparency depth of 10.8 feet (3.3 m).

Likewise, Blue Lake's transparency was poorer than the median Secchi disk depth observed in Indiana lakes (6.9 feet or 2.1 m). Given its relatively poor water clarity, it is not surprising that Blue Lake exhibited poor light penetration through the water column. During a dry year like 2005, most lakes exhibit improved water clarity. This did not occur in Blue Lake during the current assessment. No obvious explanation is available as to why Blue Lake's transparency declined in 2005; however, data suggest that non-algal and algal turbidity increased during 2005 resulting in poorer water transparency.

Blue Lake's rather limited littoral and photic zones are further highlighted by the lake's poor water clarity. In previous sections of this report, Blue Lake's littoral zone was estimated to be the area of the lake in which water depth was less than three times the lake's Secchi disk transparency depth. While this is a good estimate, by definition, the lake's littoral zone is an area of the lake in which water is shallow enough to support plant growth. Limnologists often use the lake's 1% light level to determine the lower limit of sufficient light to support plant photosynthesis, or growth. Thus, by definition, a lake's littoral zone is that area of the lake with water that is shallower than the lake's 1% light level.

Because of the lake's poor water clarity, Blue Lake's 1% light level is relatively shallow, extending to a depth of 9.5 feet (2.9 m). Using the definition of littoral zone provided above, Blue Lake's littoral zone is that portion of the lake with water depths less than 9.5 feet (2.9 m). Based on the depth-area curve in Figure 16, this would mean that Blue Lake's littoral zone is approximately 60 acres (24.3 ha) in size and covers 25% of the lake's surface area. A previous section of this document suggests Blue Lake's littoral zone is approximately 54 acres (21.8 ha) in size and covers approximately 23% of the lake. (This estimate was based on the lake's Secchi disk transparency as detailed in Schuler and Hoffmann, 2002.) The estimate of the lake's littoral zone using the 1% light level is more consistent with actual field conditions. Rooted plants cover an estimated 87 acres (35.1 ha) of the lake as observed during the rooted plant survey. Regardless of which estimate is used, Blue Lake's littoral zone is limited.

The lake's 1% light level also defines the lake's *photic zone.* A lake's ***photic zone*** is the volume of water with sufficient light to support algae growth. Based on Blue Lake's depth-volume curve (Figure 17), more than 2,900 acre-feet of Blue Lake (58% of total lake volume) lies above the 9.5-foot (2.9-m) 1% light level. This volume represents the amount of water with sufficient light to support algae growth. This volume constitutes the lake's photic zone.

Phosphorus and nitrogen are the primary plant nutrients in lakes and therefore are measured in lake water quality analyses. In the summer, Indiana lakes typically possess lower nutrient concentrations in their epilimnia compared to nutrient concentrations present in their hypolimnia. Algae in the lake's epilimnion often utilize a large portion of the readily available nutrients for growth. When the algae die and settle to the bottom sediments, nutrients are relocated to the hypolimnion. Higher concentrations of phosphorus in the hypolimnion may also result from chemical processes occurring at the sediment-water interface.

Overall, total and soluble reactive phosphorus concentrations were generally high in Blue Lake. The total phosphorus concentration in Blue Lake's epilimnion was relatively low for Indiana lakes. Because of this, the total phosphorus concentration of 0.047 mg/L was above the 0.03 mg/L concentration threshold that is considered high enough to support eutrophic conditions (Wetzel, 2001). Furthermore, the total phosphorus concentration was considerably higher in the hypolimnion, 0.565 mg/L. Therefore, the mean total phosphorus concentration (0.306 mg/L) exceeded the USEPA target total phosphorus concentration of 0.015 mg/L (USEPA, 2000a) by nearly a factor of 20. The soluble reactive phosphorus concentration in the epilimnion was also relatively low measuring 0.018 mg/L. This is typical in lakes since SRP is readily consumed by algae in the lake's epilimnion. The SRP concentration in Blue Lake's hypolimnion was high measuring 0.558 mg/L. The data indicate that most of the total phosphorus concentration in the hypolimnion consists of soluble reactive phosphorus. This dominance of the dissolved form of phosphorus coupled with the lack of oxygen in the deep waters over the bottom sediments suggests that dissolved phosphorus is being released from the lake's bottom sediments. This is called ***internal phosphorus loading*** and can be a significant additional source of phosphorus in some lakes. (The extent of internal phosphorus loading will be examined using a model later in this report.) Comparing the 2005 results to historic assessments, phosphorus concentrations appear to have changed little since the 1995 assessment. (Concentrations declined in the 1998 and 2004 assessments. Mean total phosphorus concentrations for these two assessments are lower than levels pesent during the 1995 and current assessments.) Additionally, concentrations are more than double the concentration measured during the initial assessment of the lake in 1974.

Nitrate-nitrogen concentrations were low throughout the water column. Nitrate-nitrogen concentrations measured 0.016 mg/L in the epilimnion and were below the detection level (0.013 mg/L) in the hypolimnion. Nitrate-nitrogen concentrations were higher than the USEPA target concentration of 0.008 mg/L (USEPA, 2000a); however, this concentration is less than the laboratory detection level and may be difficult to actually meet this recommendation. Nitrate-nitrogen is reduced to ammonia when oxygen is low. Blue Lake's hypolimnion lacks oxygen; therefore, any nitrate-nitrogen reaching the lake's lower waters is quickly converted to ammonia. Ammonia is also a by-product of bacterial decomposition. The decomposition of organic matter likely occurring in Blue Lake's hypolimnion contributes to the relatively high ammonia concentration observed in Blue Lake's hypolimnion (1.302 mg/L) compared to the epilimnetic concentration (0.154 mg/L). Like the total phosphorus concentration, ammonia concentrations, particularly the hypolimnetic concentration, has changed little since 1995 suggesting that water quality is relatively similar to that observed ten years ago.

Values for pH were within the normal range for Indiana lakes and typical of most fresh waters (Kalff, 2002). The epilimnetic pH was relatively high. A high epilimnetic pH may indicate the presence of photosynthesizing algae. During the process of photosynthesis, algae remove carbon dioxide, a weak acid, from the water column, thereby increasing the water's pH. The lack of photosynthesis in the hypolimnion and the liberation of carbon dioxide by respiring bacteria keep pH levels lower in the hypolimnion. The alkalinity values, a measure of buffering capacity, indicate that Blue Lake is well buffered against large changes in pH. Conductivity values, a measure of dissolved ions, were within the normal range for Indiana lakes.

Plankton enumerated from the sample collected from Blue Lake are shown in Table 21. Overall plankton density was relatively normal for Indiana lakes measuring 28,574 organisms/L. The lake's chlorophyll *a* concentration was 20.7 μg/L, which is nearly double the median chlorophyll *a* concentration measured in most Indiana lakes (12.9 μg/L). Blue Lake's plankton community is also dominated by blue-green algae. Blue-green algae account for a much larger percentage of Blue Lake's plankton community (89%) compared with the median percentage for Indiana lakes (54%). The dominance of blue-green algae may account for the higher than average chlorophyll *a* concentrations that are present within Blue Lake when the plankton density is relatively normal for most Indiana lakes. Blue Lake's chlorophyll *a* concentration is also much higher (nearly seven times higher) than the target USEPA chlorophyll *a* concentration of 3.7 μg/L (USEPA, 2000a). Blue Lake's chlorophyll *a* concentration also exceeds Vollenweider's median chlorophyll *a* concentration measured in eutrophic lakes (14.3 μg/L; Vollenweider, 1975). *Anabaena*, a blue-green algae, was the most dominant algae found in Blue Lake accounting for more than three-quarters of the plankton density. This particular blue-green algae as well as other blue-green species accounted for 90% of the plankton community. Blue-greens are usually associated with degraded water quality. 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 21. The plankton sample representing the species assemblage on August 10, 2005.

Species	Abundance (#/L)	Percentage of Plankton Population
Blue-Green Algae (Cyanophyta)		
Anabaena	21645	75.8%
Aphanizomenon	2348	8.2%
Microcystis	694	2.4%
Coelosphaerium	267	0.9%
Lyngbya	213	0.7%
Gomphosphaeria	160	0.6%
Anabaenopsis	160	0.6%
Aphanocapsa	53	0.2%
Green Algae (Chlorophyta)		
Staurastrum	587	2.1%
Pediastrum	320	1.1%
Ulothrix	213	0.7%
Asterococcus	213	0.7%
Micractinium	107	0.4%
Diatoms (Bacillariophyta)		
Fragilaria	267	0.9%
Synedra	53	0.2%
Rotifers		
Keratella	427	1.5%
Other Algae		
Mallomonas	427	1.5%
Ceratium	374	1.3%
Zooplankton		
Daphnia	22	0.1%
Nauplius	12	<0.1%
Calanoid Copepod	7	<0.1%
Cyclopoid Copepod	5	<0.1%
Chaoborus	0.01	<0.1%
Total Number of Plankton	28,574	100%

4.5.3 Lake Water Quality Assessment Discussion

The interpretation of a comprehensive set of water quality data can be quite complicated. Often, attention is directed at the important plant nutrients (phosphorus and nitrogen) and to water transparency (Secchi disk) since dense algal blooms and poor transparency greatly affect the health and use of lakes.

To more fully understand the water quality data, it is useful to compare data from the lake in question to standards, if they exist, to other lakes, or to criteria that most limnologists agree upon. Because there are no nutrient standards for Indiana Lakes, results from Blue Lake are compared below with data from other lakes and with generally accepted criteria.

Comparison with Vollenweider's Data

Results of studies conducted by Richard Vollenweider in the 1970's are often used as guidelines for evaluating concentrations of water quality parameters. His results are given in Table 22. Vollenweider relates the concentrations of selected water quality parameters to a lake's *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***. Lake conditions characteristic of these trophic states are:

Oligotrophic - lack of plant nutrients keep productivity low (i.e. few rooted plants, no algae blooms); lake contains oxygen at all depths; clear water; deeper lakes can support trout.

Mesotrophic - moderate plant productivity; hypolimnion may lack oxygen in summer; moderately clear water; warm water fisheries only - bass and perch may dominate.

Eutrophic - contains excess nutrients; blue-green algae dominate during summer; algae scums are probable at times; hypolimnion lacks oxygen in summer; poor transparency; rooted macrophyte problems may be evident.

Hypereutrophic - algal scums dominate in summer; few macrophytes; no oxygen in hypolimnion; fish kills possible in summer and under winter ice.

These are only guidelines; similar concentrations in a particular lake may not cause problems if something else is limiting the growth of algae or rooted plants.

Table 22. Mean values of some water quality parameters and their relationship to lake production (after Vollenweider, 1975).

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Total Phosphorus (mg/L)	0.008	0.027	0.084	>0.750
Total Nitrogen (mg/L)	0.661	0.753	1.875	-
Chlorophyll *a* (μg/L)	1.7	4.7	14.3	-

Blue Lake's total phosphorus concentration (mean of 0.306 mg/L) was greater than lakes in Vollenweider's eutrophic category; however, the mean total phosphorus level was lower than lakes in the hypereutrophic category. The lake's total nitrogen concentration 0.782 mg/L (mean) places Blue Lake in the mesotrophic category, while the chlorophyll *a* concentrations (20.7 μg/L) suggests that Blue Lake is more hypereutrophic in nature, using Vollenweider's criteria.

Comparison with Other Indiana Lakes

The Blue Lake results can also be compared with other Indiana lakes. Table 23 presents data from 456 Indiana lakes collected during July and August from 1994 to 2004 under the Indiana Clean Lakes Program. The set of data summarized in the table are mean values obtained by averaging the epilimnetic and hypolimnetic pollutant concentrations in samples from each of the 456 lakes. It should be noted that a wide variety of conditions, including geography, morphometry, time of year, and watershed characteristics, can influence the water quality of lakes. Thus, it is difficult to predict and even explain the reasons for the water quality of a given lake.

Table 23. Water quality characteristics of 456 Indiana lakes sampled from 1994 through 2004 by the Indiana Clean Lakes Program. Means of epilimnion and hypolimnion samples were used.

	Secchi Disk (ft)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	Chl *a* (µg/L)	Plankton (#/L)	Blue-Green Dominance
Minimum	0.3	0.01	0.004	0.230	0.01	0.01	0.013	39	0.08%
Maximum	32.8	9.4	22.5	27.05	2.84	2.81	380.4	753,170	100%
Median	6.9	0.275	0.818	1.66	0.12	0.17	12.9	35,570	53.8%
Blue	**2.6**	**0.014**	**0.728**	**0.78**	**0.29**	**0.31**	**20.7**	**28,574**	**89%**

Overall, Blue Lake possessed poorer water quality than most lakes in Indiana (Table 23) during the August 10, 2005 assessment. Blue Lake's Secchi disk transparency depth measured less than half that found in most lakes in Indiana. The total phosphorus concentration was nearly double those found in most Indiana lakes, while the soluble phosphorus concentration was more than double the level observed in Indiana lakes (Figure 27). Blue Lake was also more productive, as measured by chlorophyll *a* concentration, than most Indiana lakes.

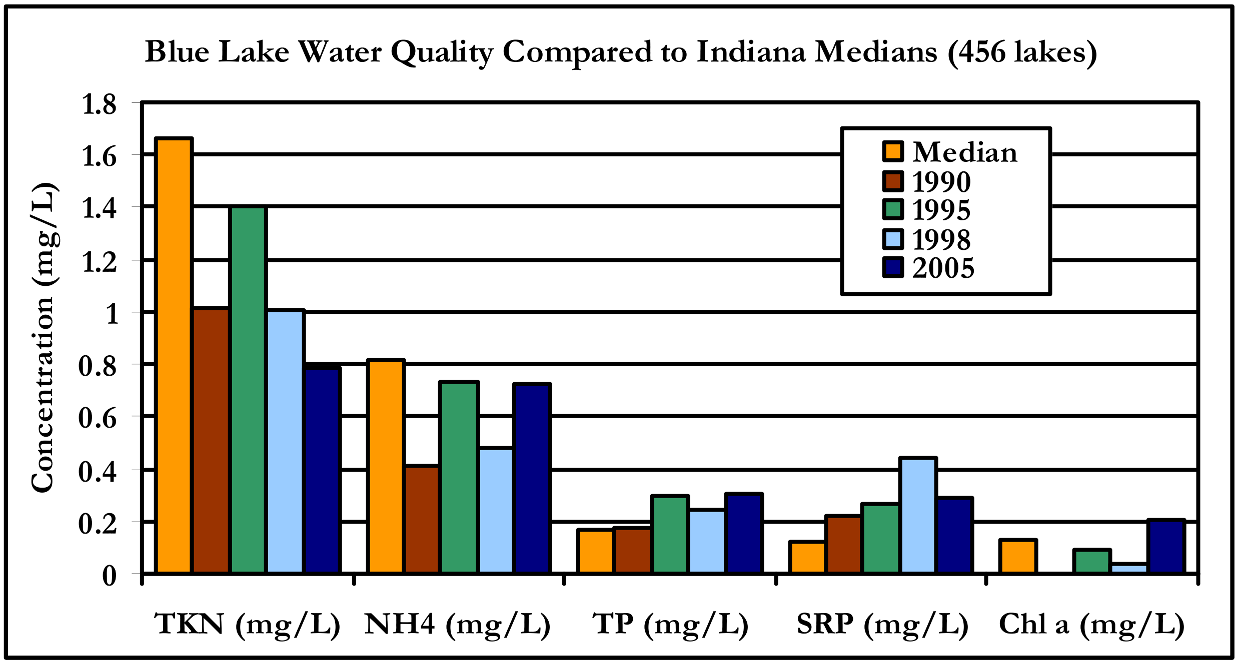

Figure 27. Selected nutrient concentrations within Blue Lake compared to concentrations present in most lakes in Indiana during the 1994 through 2004 sampling period. Median concentrations (orange) represent the median concentration for the means of the epilimnetic and hypolimnetic samples collected for each lake sampled during the 1994 to 2004 time period. All other colors represent the mean for the epilimnetic and hypolimnetic samples collected within Blue Lake during the specified year.

Using a Trophic State Index

In addition to simple comparisons with other lakes, lake water quality data can be evaluated through the use of a trophic state index or TSI. 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, numeric 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 Indiana TSI

The Indiana TSI (ITSI) was developed by the Indiana Stream Pollution Control Board and published in 1986 (IDEM, 1986). The original ITSI differed slightly from the one in use today. Today's ITSI uses ten different water quality parameters to calculate a score. Table 24 shows the point values assigned to each parameter.

Table 24. 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% to 119%	1
	C.	120% to 129%	2
	D.	130% to 149%	3
	E.	150% or more	4
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% to 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 - 5000,000 organisms/L	20
J.	greater than 500,000 organisms/L	25
K.	Blue-Green Dominance: additional points	10

Values for each water quality parameter are totaled to obtain an ITSI score. Based on this score, lakes are then placed into one of five categories:

TSI Total	Water Quality Classification
0-15	Oligotrophic
16-31	Mesotrophic
32-46	Eutrophic
47-75	Hypereutrophic

These categories correspond to the qualitative lake productivity categories described earlier (IDEM, 2000). A rising TSI score for a particular lake from one year to the next indicates that water quality is worsening, while a lower TSI score indicates improved conditions. However, natural factors such as climate variation can cause changes in TSI scores that do not necessarily indicate a long-term change in lake condition. (Jones (1996) suggests that changes in TSI scores of 10 or more points are indicative of changes in trophic status, while smaller changes in TSI scores may be more attributable to natural fluctuations in water quality parameters.)

At the time of the August 10, 2005 sampling, Blue Lake possessed an Indiana Trophic State Index value of 43. This value places Blue Lake in the eutrophic range. This conclusion is generally consistent with results obtained from the comparison of the lake data to Vollenweider's data (Table 22), where nutrient parameters suggested the lake was mesotrophic to eutrophic in nature. As will be described later in this section, the Indiana TSI score for Blue Lake is also generally consistent with the analysis of the lake data using Carlson's TSI.

Because the ITSI captures one snapshot of a lake in time, using the ITSI to track trends in lake productivity may be the best use of the ITSI. Figure 28 illustrates the change in Blue Lake's ITSI score over time. Figure 28 shows an increase in Blue Lake's ITSI score (6 points) from 1974 to 1995. (An increase in ITSI score indicates an increase in productivity of a lake and generally a decline in water quality.) ITSI scores measured during the 2004 and 2005 assessments measured 41 and 43, respectively, which approximates the ITSI score calculated during the 1995 assessment. ITSI scores dropped 10 points from the 1995 to the 1998 assessments. (A decline in ITSI score typically indicates a decline in the productivity of a lake and a general improvement in water quality.) This changes in ITSI score can be attributed to variations in water transparency and the resultant plankton density that was observed in 1998. ITSI scores have remained fairly stable since 1998, with variations of 3 or fewer eutrophy points among the years. This suggests water quality in Blue Lake has remained fairly stable over the past 30 years.

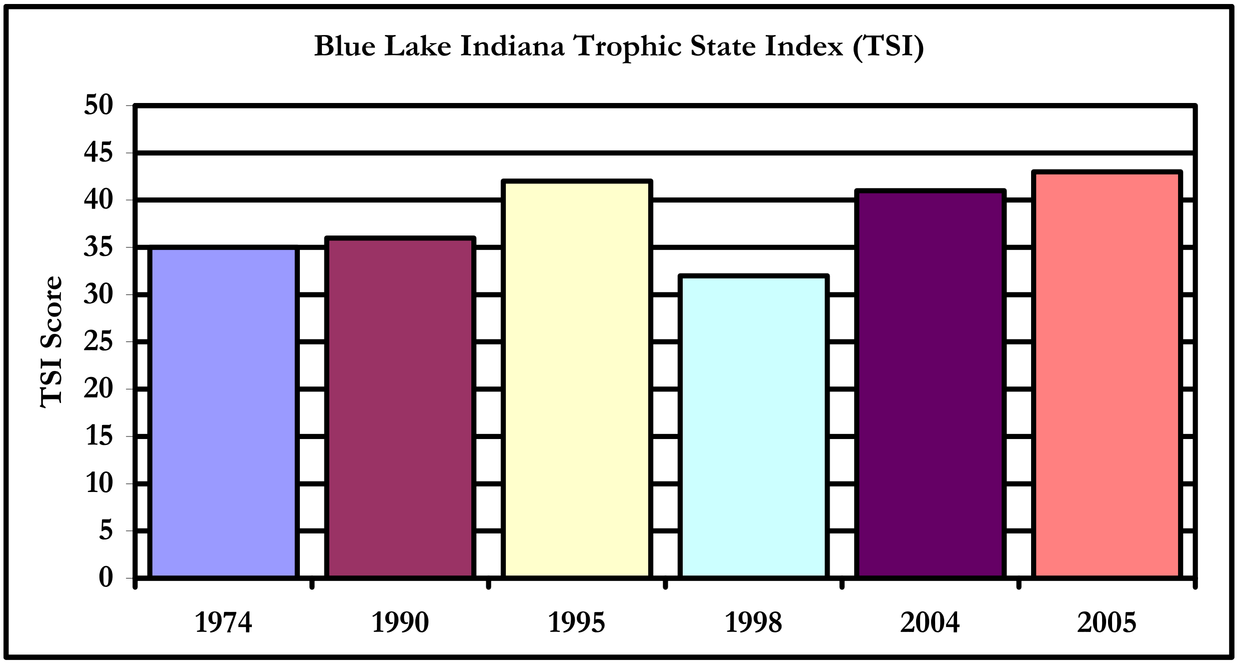

Figure 28. Indiana Trophic Index State scores for Blue Lake from 1974 to 2005.

Using the ITSI to compare Blue Lake to other lakes in the region, Blue Lake's water quality is on par with other lakes in the region. Based on data collected by the Indiana Clean Lakes Program 1998 assessment, approximately 12% of the lakes in the Upper Wabash Basin (which includes the Blue Lake watershed) were classified as oligotrophic (IDEM, 2000). Another 35% rated as mesotrophic. Forty five percent fell in the eutrophic category, while 8% fell in the hypereutrophic category. Blue Lake's placement in the eutrophic category based on the ITSI suggests its water quality is among the middle 44% of lakes in the region when ranked by water quality. Blue Lake's water quality rates better than 10% of the lakes in the Upper Wabash Basin. This evaluation is consistent with the comparison of raw data scores for the lake to those for all lakes in Indiana (Table 23).

The Carlson TSI

Developed by Bob Carlson (1977), the Carlson TSI is the most widely used and accepted TSI. Carlson analyzed summertime 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 relationships form the basis for the Carlson TSI. Using this index, a TSI value can be generated by one of three measurements: Secchi disk transparency, chlorophyll *a*, or total phosphorus. Data for one parameter can also be used to predict a value for another. The TSI values range from 0 to 100. Each major TSI division (10, 20, 30, etc.) represents a doubling in algal biomass (Figure 29).

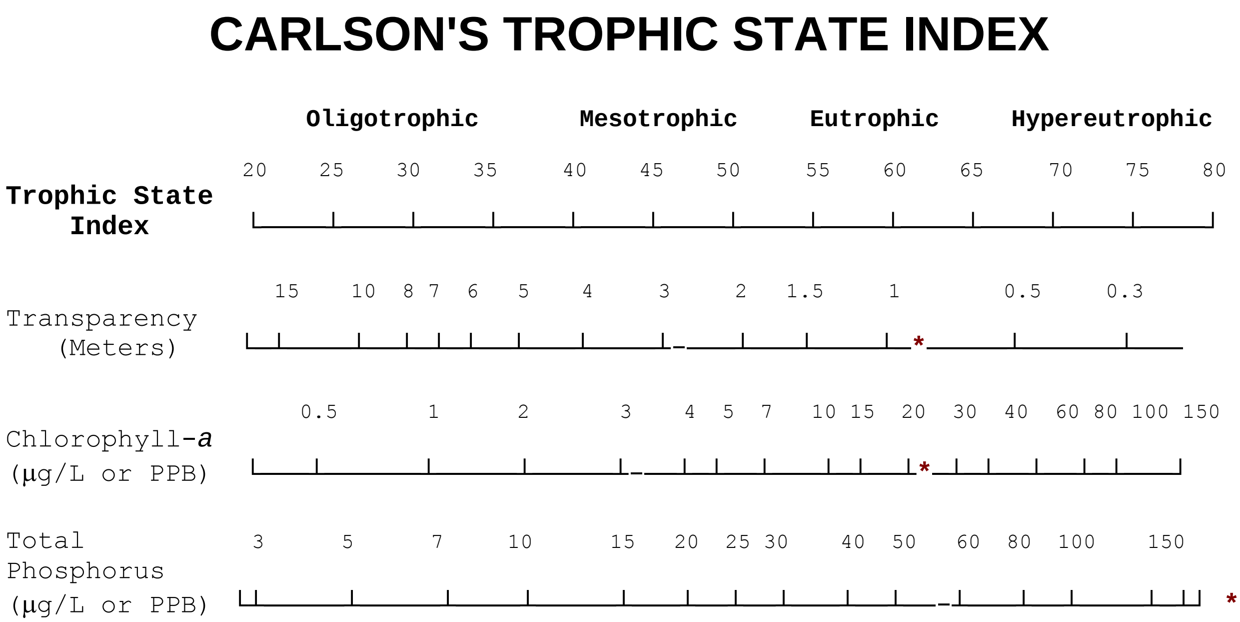

Figure 29. Carlson's Trophic State Index with Blue Lake results indicated by asterisks.

As a further aid in interpreting TSI results, Carlson's scale is divided into four lake productivity categories: oligotrophic (least productive), mesotrophic (moderately productive), eutrophic (very productive), and hypereutrophic (extremely productive).

Using Carlson's index, a lake with a summertime Secchi disk depth of 1 meter (3.3 feet) would have a TSI of 60 points (located in line with the 1 meter or 3.3 feet). This lake would be in the eutrophic category. Because the index was constructed using relationships among transparency, chlorophyll *a*, and total phosphorus, a lake having a Secchi disk depth of 1 meter (3.3 feet) would also be expected to have 20 µg/L chlorophyll *a* and 48 µg/L total phosphorus.

Not all lakes have the same relationship between transparency, chlorophyll *a*, and total phosphorus as Carlson's lakes do. Other factors such as high suspended sediments or heavy predation of algae by zooplankton may keep chlorophyll *a* concentrations lower than might be otherwise expected from the total phosphorus concentrations or transparency measurements. High suspended sediments would also make transparency worse than otherwise predicted by Carlson's index.

It is also useful to compare the actual trophic state points for a particular lake from one year to the next to detect any trends in changing water quality. While climate and other natural events will cause some variation in water quality over time (possibly 5-10 trophic points), larger point changes may indicate important changes in lake quality.

Analysis of Blue Lake's total phosphorus, transparency, and chlorophyll *a* data using to Carlson's TSI suggests that the lake is eutrophic to hypereutrophic (Figure 29). Blue Lake's transparency and chlorophyll *a* concentration place the lake in the eutrophic category, while its total phosphorus concentration places it off of the scale above the hypereutrophic categories. This analysis is basically consistent with the results obtained when comparing the Blue Lake data to Vollenweider's data.

Both analyses suggest that Blue Lake possesses sufficient phosphorus to support a greater level of productivity than the level suggested by the lake's already elevated chlorophyll *a* concentration.

As described above, the expected relationship between transparency, chlorophyll *a* concentration, and total phosphorus concentration is that Carlson's TSI score for each is the same. For Blue Lake, Carlson's TSI scores using transparency and chlorophyll *a* concentration are roughly equal (TSI (SD) = 63 and TSI (chl *a*) = 60). However, Carlson's TSI score for total phosphorus concentration is much higher (TSI (TP) = 87). When TSI (SD) = TSI (chl *a*) < TSI (TP), something other than phosphorus is limiting algae growth. Potential limiting factors include zooplankton grazing and/or nitrogen limitation. In the case of Blue Lake, zooplankton grazing may affect the lake's algal community. (Further studies would be needed to confirm this.) Additionally, the lake's extensive rooted plant community likely plays a role in limiting algae growth. Rooted plants have been shown to secrete alleopathic chemicals preventing algae growth. Again, more research (i.e. year round evaluation of the lake's temperature profile) is needed to determine if this is a factor in limiting algae production.

Summary
Blue Lake contains more phosphorus than is ideal. The potential exists for excessive algal production to occur in Blue Lake. Blue Lake is considered hypereutrophic when evaluated with Carlson's total phosphorus TSI; however, when compared with Vollenweider's phosphorus data, the lake rates as eutrophic. While conditions visible on the surface of Blue Lake may not appear overly bad, conditions in the lake's hypolimnion are of concern. Years of excessive plant and algae production and transport of organic material into Blue Lake from its watershed have led to the build-up of decaying organic matter in the sediments of Blue Lake (Table 25). As bacteria decompose this material, they consume oxygen and leave the bottom waters *anoxic* (dissolved oxygen concentrations < 1.0 mg/L). Currently, the lake becomes anoxic below 13.1 feet (4 m).

Table 25. Summary of mean total phosphorus, total nitrogen, Secchi disk transparency, and chlorophyll a results for Blue Lake.

Parameter	Blue Lake
Mean total phosphorus (mg/L)	0.306
Mean soluble reactive phosphorus (mg/L)	0.288
Hypolimnetic ammonia-nitrogen (mg/L)	1.302
Total nitrogen:Total phosphorus[2]	19.9
Total nitrogen (mg/L)	1.519
Secchi disk transparency (ft)	2.6
Chlorophyll *a* (µg/L)	20.7
Sediment phosphorus release factor[2]	31

[1]Total nitrogen:Total phosphorus ratio is calculated based on epilimnetic concentrations.
[2]Hypo SRP concentration/Epi SRP concentration. For example, Blue's hypolimnetic SRP concentration is 31 times that in the epilimnion. This difference is evidence of substantial internal loading of phosphorus.

Additionally, there is evidence of internal phosphorus release from Blue Lake's sediment (Table 25). There is considerably more soluble phosphorus in the hypolimnia (bottom waters) of Blue Lake when compared to the lake's epilimnetic concentration. This is strong evidence that phosphorus is being liberated from the sediments when oxygen is depleted or the lake is *anoxic*. The column headed "Sediment Phosphorus Release" details the amount of soluble phosphorus (the form of phosphorus that can be released from the sediments) in the deepwater (hypolimnetic) sample to the surface (epilimnetic) sample. In Blue Lake, the ratio is 31, which indicates that sediment phosphorus release is occurring. Phosphorus release from the sediments is an additional and important source of phosphorus to Blue Lake that must be addressed along with watershed practices when designing a management plan to reduce nutrient loading to the lake. This *internal loading* of phosphorus is another source of phosphorus to these lakes that can promote excessive algae production.

Blue Lake also contains a relatively high ammonia nitrogen concentration in its hypolimnion (Table 25). Ammonia is a by-product of bacterial decomposition. When ammonia occurs in high concentrations, it is evidence of high biological oxygen demand. This biological oxygen demand comes from organic waste, such as dead algae and rooted plants, within the sediments, which provides further evidence of excess algae and rooted plant growth in these lakes.

4.6 Macrophyte Inventory

4.6.1 Macrophyte Inventory Introduction

There are many reasons to conduct an aquatic rooted plant survey as part of a complete assessment of a lake and its watershed. Like other biota in a lake ecosystem (e.g. fish, microscopic plants and animals, etc.), the composition and structure of the lake's rooted plant community often provide insight into the long term water quality of a lake. While sampling the lake water's chemistry (dissolved oxygen, nutrient concentrations, etc.) is important, water chemistry sampling offers a single snapshot of the lake's condition. Because rooted plants live for many years in a lake, the composition and structure of this community reflects the water quality of the lake over a longer term. For example, if one samples the water chemistry of a typically clear lake immediately following a major storm event, the results may suggest that the lake suffers from poor clarity. However, if one examines the same lake and finds that rooted plant species such as northern watermilfoil, white stem pondweed, and large leaf pondweed, all of which prefer clear water, dominate the plant community, one is more likely to conclude that the lake is typically clear and its current state of turbidity is due to the storm rather than being its inherent nature.

The composition and structure of a lake's rooted plant community also help determine the lake's fish community composition and structure. Submerged aquatic vegetation provides cover from predators and is a source of forage for many different species of fish (Valley et al, 2004). However, extensive and dense stands of exotic aquatic vegetation can have a negative impact on the fish community. For example, a lake's bluegill population can become stunted because dense vegetation reduces their foraging ability, resulting in slower growth. Additionally, dense stands reduce predation by largemouth bass and other piscivorous fish on bluegill which results in increased intraspecific competition among both prey and predator species (Olsen et al, 1998). Vegetation removal can have variable results on improving fish growth rates (Cross et al, 1992, Olsen et al, 1998). Conversely, lakes with depauperate plant communities may have difficulty supporting some top predators that require emergent vegetation for spawning. In these and other ways, the lake's rooted plant community illuminates possible reasons for a lake's fish community composition and structure.

A lake's rooted plant community impacts the recreational uses of the lake. Swimmers and power boaters desire lakes that are relatively plant-free, at least in certain portions of the lake. In contrast, anglers prefer lakes with adequate rooted plant coverage, since those lakes offer the best fishing opportunity. Before lake users can develop a realistic management plan for a lake, they must understand the existing rooted plant community and how to manage that community. This understanding is necessary to achieve the recreational goals lake users may have for a given lake.

For the reasons outlined above, as well as several others, JFNew conducted a general macrophyte (rooted plant) survey on Blue Lake as part of the overall lake and watershed diagnostic study. Before detailing the results of the macrophyte survey, it may be useful to outline the conditions under which lakes may support macrophyte growth. Additionally, an understanding of the roles that macrophytes play in a healthy, functioning lake ecosystem is necessary for lake users to manage the lake's macrophyte community. The following paragraphs provide some of this information.

Conditions for Growth

Like terrestrial vegetation, aquatic vegetation has several habitat requirements that need to be satisfied in order for the plants to grow or thrive. Aquatic plants depend on sunlight as an energy source. The amount of sunlight available to plants decreases with depth of water as algae, sediment, and other suspended particles block light penetration. Consequently, most aquatic plants are limited to maximum water depths of approximately 10 to 15 feet (3 to 4.5 m), but some species, such as Eurasian watermilfoil, have a greater tolerance for lower light levels and can grow in water deeper than 32 feet (10 m) (Aiken et al., 1979). Hydrostatic pressure rather than light often limits plant growth at deeper water depth (15 to 20 feet or 4.5 to 6 m).

Water clarity affects the ability of sunlight to reach plants, even those rooted in shallow water. Lakes with clearer water have an increased potential for plant growth. Blue Lake possesses poorer water clarity than the average Indiana lake. The Secchi disk depth measured during the plant survey was 2.7 feet (0.8 m). (This measurement was slightly better than the Secchi disk depth measured for the lake during the in-lake sampling portion of the study (2.6 feet or 0.8 m).) As a general rule of thumb, rooted plant growth is restricted to the portion of the lake where water depth is less than or equal to 2 to 3 times the lake's Secchi disk depth. This is true in Blue Lake, where rooted plants were observed in water to a depth of approximately 10 feet (3 m), which is nearly 3 times the lake's average Secchi disk depth.

Aquatic plants also require a steady source of nutrients for survival. Many aquatic macrophytes differ from microscopic algae (which are also plants) in their uptake of nutrients. Aquatic macrophytes receive most of their nutrients from the sediments via their root systems rather than directly utilizing nutrients in the surrounding water column. Some competition with algae for nutrients in the water column does occur. The amount of nutrients taken from the water column varies for each macrophyte species. Because macrophytes obtain most of their nutrients from the sediments, lakes which receive high watershed inputs of nutrients to the water column will not necessarily have aquatic macrophyte problems.

A lake's substrate and the forces acting on the substrate also affect a lake's ability to support aquatic vegetation. Lakes that have mucky, organic, nutrient-rich substrates have an increased potential for plant growth compared to lakes with gravelly, rocky substrates. Sandy substrates that contain sufficient organic material typically support healthy aquatic plant communities. Lakes that have significant wave action that disturb the bottom sediments have decreased ability to support plants. Disturbance of bottom sediment may decrease water clarity, limiting light penetration, or may affect the availability of nutrients for the macrophytes. Wave action may also create significant shearing forces prohibiting plant growth altogether.

Boating activity may affect macrophyte growth in conflicting ways. Rooted plant growth may be limited if boating activity regularly disturbs bottom sediments. Alternatively, boating activity in rooted plant stands of species that can reproduce vegetatively, such as Eurasian watermilfoil or coontail, may increase macrophyte density rather than decrease it. Herbicide treatment can also affect the presence and distribution of aquatic macrophytes within a lake. As species or areas are selectively treated, the density and diversity of plant present within those locations can, and typically do change. For example, continuing to treat a specific plant bed which contains Eurasian watermilfoil can result in the disappearance of Eurasian watermilfoil and the resurgence of a variety of native species. It should be noted, however, that non-native plants can regrow in these locations just as easily as native plants.

Ecosystem Roles
Aquatic plants are a beneficial and necessary part of healthy lakes. Plants stabilize shorelines holding bank soil with their roots. The vegetation also serves to dissipate wave energy further protecting shorelines from erosion. Plants play a role in a lake's nutrient cycle by up-taking nutrients from the sediments. Like their terrestrial counterparts, aquatic macrophytes produce oxygen which is utilized by the lake's fauna. Plants also produce flowers and unique leaf patterns that are aesthetically attractive.

Emergent and submerged plants provide important habitat for fish, insects, reptiles, amphibians, waterfowl, shorebirds, and small mammals. Fish utilize aquatic vegetation for cover from predators and for spawning and rearing grounds. Different species depend upon different percent coverages of these plants for successful spawning, rearing, and protection for predators. For example, bluegill require an area to be approximately 15 to 30% covered with aquatic plants for successful survival, while northern pike achieve success in areas where rooted plants cover 80% or more of the area (Borman et al., 1997).

Aquatic vegetation also serves as substrate for aquatic insects, the primary diet of insectivorous fish. Waterfowl and shorebirds depend on aquatic vegetation for nesting and brooding areas. Numerous waterfowl were observed utilizing Blue Lake as habitat during the macrophyte survey. Aquatic plants such as pondweed, coontail, duckweed, watermilfoil, and arrowhead, also provide a food source to waterfowl. Duckweed in particular has been noted for its high protein content and consequently has served as feed for livestock. Turtles and snakes utilize emergent vegetation as basking sites. Amphibians rely on the emergent vegetation zones as primary habitat.

4.6.2 Macrophyte Inventory Methods

JFNew surveyed Blue Lake on July 28, 2005 according to the Indiana State Tier One sampling protocol (Schuler and Hoffmann, 2002). JFNew examined the entire littoral zone of the lake. As defined in the protocol, the lake's littoral zone was estimated to be approximately three times the lake's Secchi disk depth. This estimate approximates the 1% light level, or the level at which light penetration into the water column is sufficient to support plant growth. (See the **Lake Assessment** section for a full discussion of the 1% light level and the reading recorded during the in-lake sampling effort.) At the time of sampling, Blue Lake's Secchi disk depth was 2.7 feet (0.8 m); thus, its 1% light level was estimated to be approximately 8.1 feet (2.5 m). Consequently, JFNew sampled that area of Blue Lake that is less than 10 feet (3.1 m) deep.

A survey crew, consisting of one aquatic ecologist, one botanist, and a citizen volunteer boat driver, surveyed Blue Lake in a clockwise manner, starting at the lake's northwest corner. The survey crew drove their boat in a zig-zag pattern across the littoral zone of the lake while visually identifying plant species. The crew maintained a tight pattern to ensure the entire zone was observed. While the estimated littoral zones of the lake were quite shallow allowing for good visual identification of plant species, in areas of dense plant coverage, rake grabs were performed to ensure all species were identified.

Rooted plants ring Blue Lake's entire perimeter. For the purposes of the survey, the plant community in the lake was divided into different beds. The survey crew used plant community structure, species diversity, and species dominance (all visually estimated) to differentiate one bed from another. For example, an area dominated by only coontail would be separated from an area supporting a more diverse mix of submerged species. While there is subjectivity inherent in this method, it allows for a rapid evaluation of the lake's rooted plant community that still meets the goals of the survey.

Once the crew had visually surveyed an entire plant bed, the crew broadly estimated species abundance, canopy coverage by strata (emergent, rooted floating, non-rooted floating, and submergent), and bed size. The crew also noted the bed's bottom substrate type and created a field sketch of the bed. The crew recorded all data on data sheets (Appendix E). After completing one bed, the crew continued surveying the littoral zone until all plant beds were identified and the appropriate data were recorded. GIS technology was utilized to estimate the perimeters of plant beds based on the field sketches, field notes regarding the depth of rooted plant growth, the lake's bathymetric map, and aerial photography.

4.6.3 Macrophyte Inventory Results

Blue Lake supports an extensive rooted plant community. The community extends from the lake's shoreline to water that is just over 15 feet (4.6 m) deep. This is better than the extent of the littoral zone based on the lake's 1% light level of 9.5 feet (2.9 m), measured at the time of the in lake water quality survey. Blue Lake's aquatic plant community can be roughly divided into seven beds that differ in community composition and structure. Figure 30 shows the approximate location and extent of each bed.

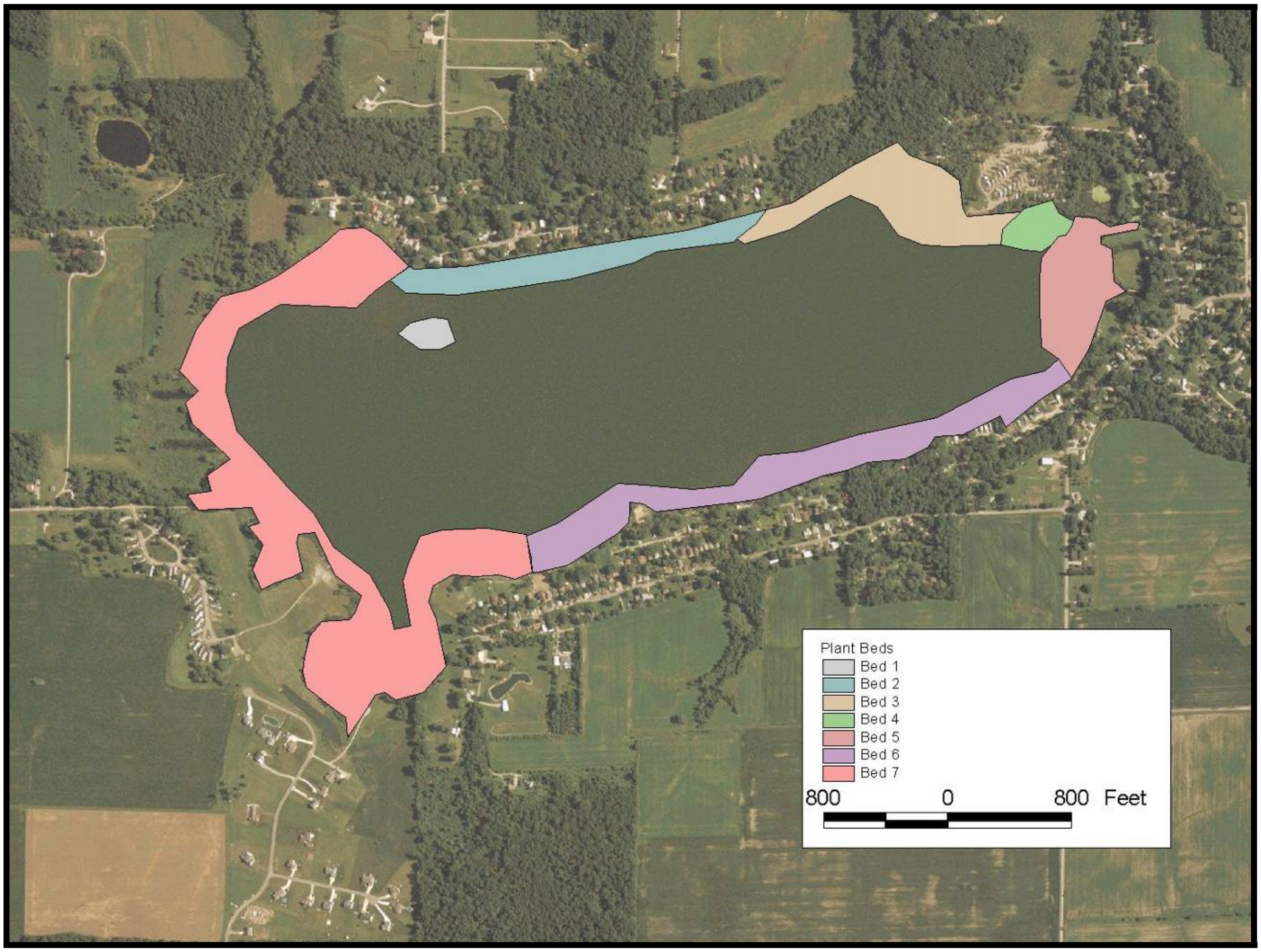

Figure 30. Blue Lake plant beds as surveyed July 28, 2005. Source: See Appendix A.

In total, approximately 48 aquatic plant species inhabit the water and shoreline of Blue Lake (Table 26). The LARE protocol used to conduct the aquatic plant survey requires surveyors to note all plant species observed from a boat. Thus, plants in the wetland complexes adjacent to the lake were only counted if they were visible from the boat. If these wetland complexes had been explored in greater detail, it is likely that the total number of plant species would increase significantly.

Table 26. Plant species observed in Blue Lake by plant bed as surveyed on July 28, 2005.

Common Name	Scientific Name	Bed 1	Bed 2	Bed 3	Bed 4	Bed 5	Bed 6	Bed 7
American lotus	*Nelumbo lutea*	--	--	--	<2%	2-20%	--	--
Barnyard grass	*Echinochloa crusgalli*	--	<2%	--	--	--	--	--
Broad leafed cattail	*Typha latifolia*	--	--	<2%	--	2-20%	<2%	<2%
Buttonbush	*Cephalanthus occidentalis*	--	--	<2%	--	--	<2%	--
Chairmakers rush	*Scirpus pungens*	--	<2%	2-20%	<2%	<2%	2-20%	<2%
Chara species	*Chara species*	--	--	2-20%	--	--	--	--
Climbing nightshade	*Solanum dulcomera*	--	--	--	--	--	<2%	<2%
Common arrowhead	*Sagittaria latifolia*	--	--	--	--	--	--	<2%
Common burreed	*Sparganium eurycarpum*	--	--	--	--	--	--	<2%

Common Name	Scientific Name	Bed 1	Bed 2	Bed 3	Bed 4	Bed 5	Bed 6	Bed 7
Common duckweed	*Lemna minor*	--	--	--	<2%	<2%	<2%	<2%
Common water weed	*Elodea canadensis*	--	<2%	--	--	<2%	<2%	<2%
Coontail	*Ceratophyllum demersum*	>60%	2-20%	2-20%	<2%	<2%	2-20%	21-60%
Curly leaf pondweed	*Potamogeton crispus*	--	2-20%	<2%	<2%	<2%	2-20%	<2%
Eel grass	*Vallisneria americana*	--	21-60%	2-20%	2-20%	--	21-60%	2-20%
Filamentous algae	*Filamentous algae*	--	2-20%	2-20%	--	2-20%	--	21-60%
Flat-stem pondweed	*Potamogeton zosteriformis*	--	<2%	<2%	--	--	<2%	--
Grassy pondweed	*Potamogeton gramineus*	--	--	<2%	<2%	--	2-20%	--
Hardstem bulrush	*Scirpus acutus*	--	--	--	<2%	<2%	--	<2%
Illinois pondweed	*Potamogeton illinoiensis*	--	<2%	21-60%	--	2-20%	<2%	<2%
Lady's thumbprint	*Polygonum persicaria*	--	<2%	--	--	--	--	--
Large duckweed	*Spirodela polyrhiza*	--		--	--	--	--	<2%
Large-leaf pondweed	*Potamogeton amplifolius*	--	2-20%	2-20%	2-20%	2-20%	2-20%	2-20%
Leafy pondweed	*Potamogeton foliosis*	--	<2%	--	--	--	<2%	--
Long-leaf pondweed	*Potamogeton nodosus*	--	2-20%	<2%	<2%	--	<2%	2-20%
Narrow leafed cattail	*Typha angustifolia*	--	--	--	--	--	--	2-20%
Nodding bur marigold	*Bidens cernua*	--	<2%	--	--	--	<2%	--
Nodding smartweed	*Polygonum lapathifolia*	--	--	--	<2%	--	--	--
Northern watermilfoil	*Myriophyllum exalbescens*	--	<2%	<2%	--	<2%	2-20%	2-20%
Pickerel weed	*Pontedaria cordata*	--	--	2-20%	2-20%	<2%	<2%	<2%
Purple loosestrife	*Lythrum salicaria*	--	<2%	<2%	<2%	<2%	<2%	<2%
Reed canary grass	*Phalarus arundinacaea*	--	--	--	--	<2%	<2%	<2%
River bulrush	*Scirpus fluviatilis*	--	--	--	--	<2%	--	--
Sago pondweed	*Potamogeton pectinatus*	--	2-20%	<2%	--	2-20%	2-20%	<2%
Sandbar willow	*Salix interior*	--	--	<2%	--	--	<2%	--
Silky dogwood	*Cornus obliqua*	--	--	--	--	--	--	<2%
Slender naiad	*Najas flexilis*	--	<2%	2-20%	--	<2%	<2%	<2%
Slender water weed	*Elodea nuttallii*	--	<2%	--	--	2-20%	--	--
Small pondweed	*Potamogeton berchtoldii*	--	<2%	<2%	--	--	2-20%	<2%
Small pondweed	*Potamogeton pusillus*	--			--	--	<2%	--
Softstem bulrush	*Scirpus validus*	--		<2%	--	<2%	--	--
Southern naiad	*Najas guadalupensis*	--	2-20%	<2%	--		<2%	--
Spatterdock	*Nuphar advena*	--	<2%	<2%	--	<2%	<2%	21-60%
Star duckweed	*Lemna trisulca*	--	<2%	<2%	--	--	--	--
Water heartsease	*Polygonum coccineum*	--	--	--	<2%	--	--	<2%
Water meal	*Wolffia columbiana*	--	--	--	<2%	<2%	--	<2%
Water star grass	*Heteranthera dubia*	--	2-20%	2-20%	--	2-20%	21-60%	2-20%
Whirled loosestrife	*Decodon verticillatus*	--	--	--	--	--	--	2-20%

Common Name	Scientific Name	Bed 1	Bed 2	Bed 3	Bed 4	Bed 5	Bed 6	Bed 7
White water lily	*Nyphaea tuberosa*	--	<2%	2-20%	<2%	<2%	<2%	<2%

Of the 48 species observed in Blue Lake, nearly half (19) were submerged plant species. Additionally, of the 19 submerged species, more than half of those (10) were pondweeds (i.e. belonging to the *Potamogeton* genus). Compared to other lakes in the region this represents excellent species richness of the submerged strata. Eel grass, water star grass, and coontail were by far the most dominant submerged species. These species were found in six of the lake's seven plant beds. Large-leaf pondweed and northern watermilfoil are also common in Blue Lake. Large-leaf pondweed was also observed in six of the seven plant beds but with generally less density representing 2 to 20% of the bed's canopy. Northern watermilfoil inhabited five of the seven plant beds and it usually covered 2 to 20% of the bed' canopy. Common waterweed, curly-leaf pondweed, Sago pondweed, and Illinois pondweed are also important components of the Blue Lake submerged community. Three exotic species, including purple loosestrife, reed canary grass, and curly-leaf pondweed, were identified within Blue Lake.

The species richness of the emergent strata was slightly higher than the submerged strata, while the floating strata's richness was much lower than the emergent and submerged strata. Twenty-one emergent species were noted bordering Blue Lake's edges, while only seven floating species were observed in the lake. (It is important to note that there are significantly fewer floating aquatic species that are native to Indiana lakes compared to the number of emergent and submerged species. Consequently, many lakes possess low numbers of floating species.) The most common emergent species include pickerel weed, chairmaker's rush, purple loosestrife, and cattails. Chairmaker's rush and purple loosestrife were observed in six of the seven plant beds, although they tended to be very sparse in some of the beds. Pickerel weed was observed in five of the seven plant beds, while cattails were present in four of the seven plant beds. The most common floating species are spatterdock, which was found in six of the seven beds, and white water lily, which was found in five of the seven beds. Of special note, American lotus (Figure 31) was found in two plant beds. This species is believed to be present in only a limited number of lakes in northern Indiana. Historically, it was estimated that American lotus covered much of the eastern end of Blue Lake (Deam, 1921).

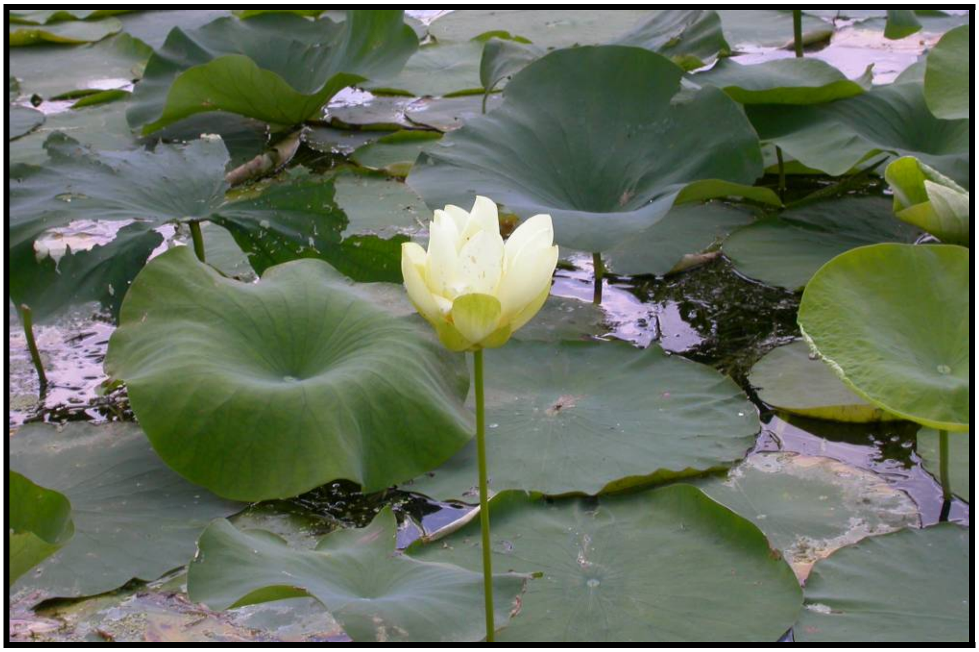

Figure 31. American lotus photographed near the mouth of Maloney Ditch on Blue Lake, July 28, 2005.

Blue Lake's plant community covers approximately 36% (87 acres or 35.1 ha) of the lake's surface area. Canopy coverage is generally fairly dense around all but the east end of the lake, with submerged species accounting for most of the coverage in each plant bed. Canopy coverage of the submerged portion of the community ranges from a low of about 2% in Bed 04 to more than 60% canopy cover in Bed 01. In contrast, canopy coverage of emergent strata is sparse. Emergent species accounted for less than 2% of the canopy coverage in all seven plant beds. Canopy coverage of the floating strata varies across the lake. In most (five) beds, the floating species cover less than 20% of the bed. In Beds 05 and 07, however, canopy coverage of the floating species approached 60%.

The following paragraphs detail each of the seven plant beds in Blue Lake. Appendix E contains a list of species found in each bed during the plant survey. Both common and scientific name are provided in the list. Appendix E also included the data sheets prepared for each bed. Data sheets provide information on the size and location of each bed and the type of substrate supporting each bed.

Bed 01

Bed 01 is the least diverse plant bed on the lake. Located in the northwest corner of Blue Lake, Bed 01 is isolated from the shoreline of Blue Lake and supports only one species. This is the submerged species coontail which covers more than 60% of the bed's surface area. Local residents indicate that floating-leaf pondweed and soft stem bulrush are typically present in this bed. In total, this bed covers 1.2 acres (0.5 ha) or approximately 2% of Blue Lake's surface area.

Bed 02

Bed 02 occupies the shallow water in front of Blue Lake's developed, northern shoreline. Bed 02's limited floating and emergent strata separates Bed 02 from Beds 03 and 07. Bed 02 supports 25 species. A majority of these species (16 of 25) are in the submerged strata, which possesses a canopy cover of 21 to 60%. Emergent, non-rooted floating, and rooted floating species account for only 9 of the 25 species present in Bed 02 and cover less than 2% of the canopy cover of Bed 02. Eel grass dominates the canopy cover in Bed 02 accounting for more than 60% of the bed's 8.5 acres (3.4 ha). Coontail, filamentous algae, southern naiad, large-leaf pondweed, curly-leaf pondweed, long-leaf pondweed, and Sago pondweed are also common in Bed 02. Two exotic species, curly-leaf pondweed and purple loosestrife were present within Bed 02. In total, these species account for less than 2% and less than 20% of the plant bed's canopy cover, respectively. Additionally, purple loosestrife is used as landscaping material in yards adjacent to Bed 02 (Figure 32).

Figure 32. Purple loosestrife used for landscaping adjacent to Blue Lake. Note the lack of emergent vegetation along the shoreline.

Bed 02's current condition may be the result of human impact over the years. Early photography of the lake suggests that the northern shoreline possessed a narrow band of submerged plants adjacent to natural and agricultural shoreline. By 1971, the northern shoreline adjacent to Bed 02 was developed for residential use. Today, a sparse emergent and floating community grows in spots along Bed 02; however, much of the emergent vegetation that likely once filtered runoff is gone. As northern shoreline residents navigate their boats through Bed 02 to take advantage of the lake's deeper waters, the shallowness of the immediate shoreline area increases the likelihood of propeller damage to the submerged plant community. This combined with intentional plant removal and declines in water quality likely decreased Bed 02's richness and diversity.

Bed 03

Bed 03 covers the northeastern shoreline of Blue Lake including most of the area that possesses a natural shoreline that remains undeveloped (Figure 33). The presence and predominance of emergent and rooted-floating species marks the transition between Beds 02 and 03 (Figure 34). Combined, emergent and rooted-floating species account for 11 of the 26 species identified within Bed 03 and cover nearly 40% of the bed's 11.1 acres (4.5 ha) canopy. Spatterdock, pickerel weed, and chairmakers rush dominate the emergent and rooted-floating plant communities. Submerged species account for 15 of the 26 species identified in Bed 03 and cover over 60% of Bed 03's surface area. Illinois pondweed dominates the submerged community; coontail, chara, water star grass, slender naiad, large-leaf pondweed, and eel grass are also common submerged species in Bed 03. Bed 03 also supports two exotic species: purple loosestrife and curly-leaf pondweed. Both species account for less than 2% of the Bed 03's canopy cover.

Figure 33. Natural shoreline adjacent to Bed 03 along Blue Lake's northeastern shoreline. Note the presence of forested and emergent species zones.

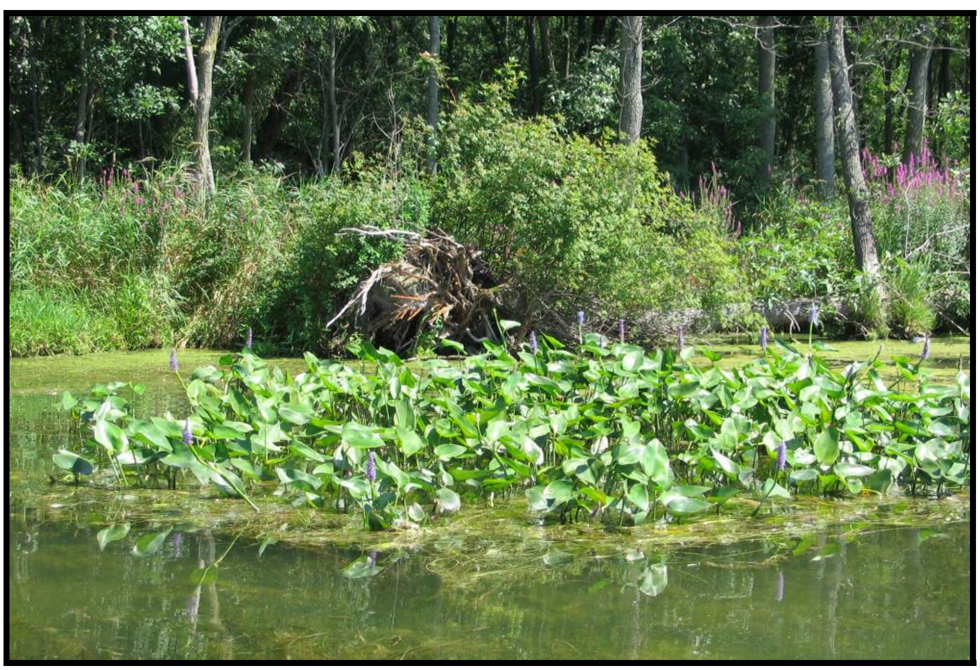

Figure 34. Submerged, emergent, and forested zones along Bed 03's shoreline. Note the presence of isolated purple loosestrife patches that are located throughout the bed.

Bed 04

Bed 04 is the smallest of Blue Lake's plant beds accounting for 2.3 acres (0.9 ha) along Blue Lake's northeastern corner. This bed occupies the area in front of the campground and beach, where much of the natural shoreline vegetation has been removed by lakeside residents. A reduction in plant diversity and density marks the transition from Bed 03 to 04. Emergent, submerged, and rooted-floating species possess approximately equal cover; each stratum accounts for less than 20% of Bed 04's canopy cover. However, the submerged and emergent plant strata are more diverse than the floating strata; seven submerged, six emergent, and three floating plant species were identified in Bed 04. Bed 04 possesses the least diverse shoreline plant community; in total, sixteen species were identified within Bed 04. Pickerel weed possessed the greatest cover of the emergent species accounting for 2 to 20% of the plant bed's cover. Purple loosestrife, nodding smartweed, hardstem bulrush, river bulrush, and water heartsease were also present within Bed 04's emergent plant community. Large stands of large-leaf pondweed and eel grass occupy a majority of the submerged strata. Coontail, curly-leaf pondweed, grassy pondweed, and long-leaf pondweed were also present within Bed 04. American lotus and spatterdock account for the largest portion of the rooted-floating strata (Figure 35). Two invasive species, purple loosestrife and curly-leaf pondweed, were observed scattered throughout Bed 04.

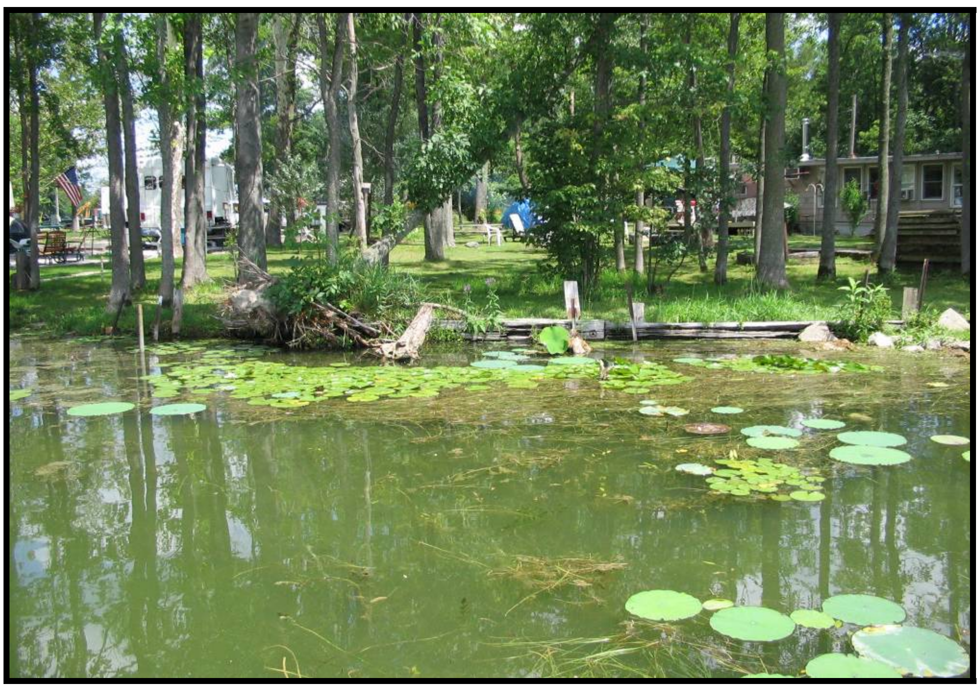

Figure 35. American lotus, spatterdock, and eel grass with Bed 04 adjacent to the campground in Blue Lake's northeastern corner.

Bed 05

Bed 05 includes the emergent plant community adjacent to Maloney Ditch's outlet to the lake and the channels from behind the islands in the southeastern corner of Blue Lake. Unlike many other plant beds on the lake, Bed 05 has a relatively even coverage distribution among the three strata (emergent, floating, and submerged). Floating species, including American lotus, spatterdock, white water lilies, small duckweed, and water meal are an important component of Bed 05. These species account for over 20% of the bed's canopy cover but account for only 4 of the 24 species observed in this bed (Figure 36). Submerged species cover approximately 20% of Bed 05's canopy cover. The most common submerged species in Bed 05 are slender waterweed, water star grass, large-leaf pondweed, Illinois pondweed, and sago pondweed. Cattails dominate the emergent portion of this bed's canopy coverage. Two exotic emergent species, purple loosestrife and reed canary grass, are present in isolated patches along the shoreline adjacent to Bed 05; curly-leaf pondweed is also present within this plant bed. In total, Bed 05 covers 8.2 acres (3.3 ha) of Blue Lake's surface area.

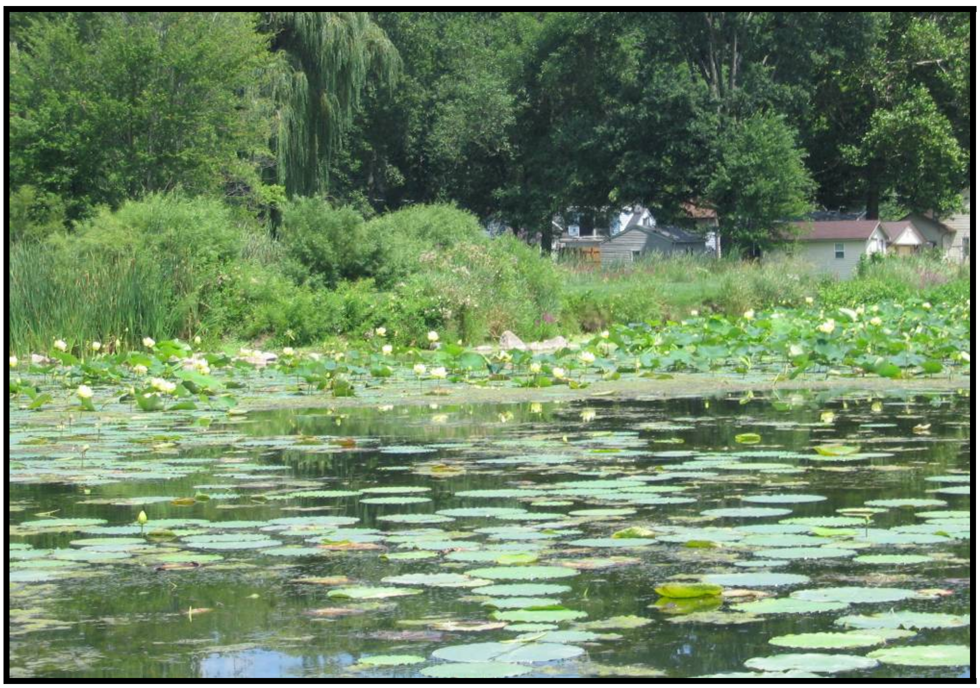

Figure 36. Spatterdock and American lotus with adjacent emergent species within Blue Lake's Bed 05.

Bed 06

Bed 06 covers approximately 16.5 acres (6.7 ha) along nearly the entire southern shoreline of Blue Lake. The limited growth of emergent and floating vegetation sets Bed 06 apart from Beds 05 and 07 (Figure 37). Residents along this shoreline removed some of the natural emergent vegetation adjacent to the shoreline; however, isolated patches of cattails, reed canary grass, pickerel weed, and chairmakers rush are located adjacent to the lake within this bed. Some residents even use the invasive species, reed canary grass, for landscaping adjacent to the lakeshore (Figure 38). Submerged species dominate the plant community within Bed 06 accounting for 17 of the 29 species identified. Additionally, submerged species dominate canopy cover occupying 21 to 60% of the bed's canopy. Eel grass and water star grass are the most prolific species; each covers 21 to 60% of the plant bed's canopy cover. Coontail, northern watermilfoil, large-leaf pondweed, curly-leaf pondweed, small pondweed, grassy pondweed, and sago pondweed are also primary components of the submerged plant community. Representatives of the floating stratum, including common duckweed, spatterdock, and white water lily, are present in Bed 06 in limited quantities and coverage. Bed 06 supports the largest number of exotic species, including purple loosestrife, reed canary grass, and curly-leaf pondweed, observed within Blue Lake.

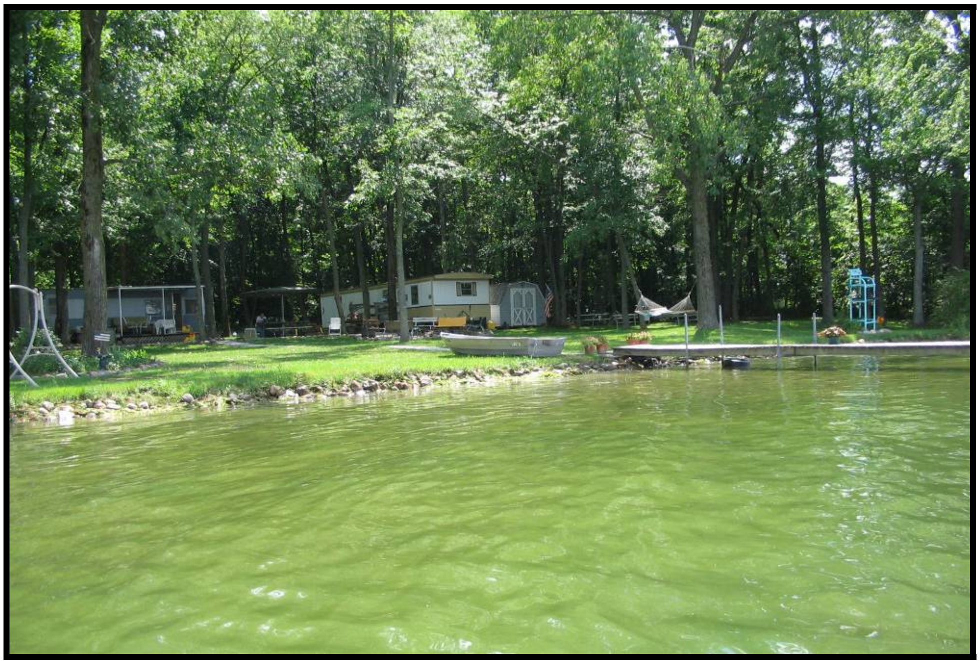

Figure 37. Typical shoreline within Bed 06. The natural shelf along the southern shoreline of the lake within this plant bed provides perfect substrate for the growth of submerged species.

Figure 38. Reed canary grass adjacent to Blue Lake's shoreline within Bed 06.

Bed 07

Bed 07 is the largest plant bed on Blue Lake covering 39 acres (15.8 ha) along the southwestern, western, and northwestern shorelines of the lake including Horseshoe Bay. Bed 07 is the most diverse plant bed; in total, 31 aquatic plant species were identified in Bed 07. The predominance of emergent and floating plant strata mark the transition from Bed 06 to Bed 07. Spatterdock and coontail cover the largest portions of the bed's canopy each accounting for 21 to 60% of the canopy cover (Figure 39). Common duckweed, white water lily, large duckweed, and water meal also compose the bed's floating plant strata. Emergent species account for the largest number of species identified. Emergent species cover approximately 20% of the canopy associated with Bed 07. Whirled loosestrife and cattails are the most predominant species, each of which covers 2 to 20% of Bed 07's canopy cover. Reed canary grass, pickerel weed, arrowhead, hardstem bulrush, chairmakers rush, purple loosestrife, and nightshade are all components of Bed 07's emergent plant community (Figure 40). Coontail, water star grass, eel grass, northern watermilfoil, long-leaf pondweed, and large-leaf pondweed are the primary components of the bed's submerged strata. Together, these and other submerged species account for 21 to 60% of the bed's canopy cover. In total, six pondweed species, including large-leaf, small, curly-leaf, Illinois, long-leaf, and sago, are present within Bed 07. Three exotic species, curly-leaf pondweed, purple loosestrife, and reed canary grass, are present in Bed 07. Individually, these species account for less than 2% of the canopy cover in Bed 07.

Figure 39. Predominance of spatterdock within Bed 07.

Figure 40. Emergent plants covering the shoreline adjacent to Blue Lake within Bed 07.

4.6.4 Macrophyte Inventory Discussion

As noted earlier in this section, the composition and structure of the lake's rooted plant community often reflect the long-term water quality of a lake. Limnologists can use rooted plant data to support or better understand results of a chemical analysis of a lake. Because of their relative longevity (compared to the chemical constituents of a lake), rooted plant data may help in confirming trends observed in historical data. Blue Lake's rooted plant data are no exception. The survey and analysis of Blue Lake's rooted plant community presented above confirms many of the conclusions drawn from analysis of the lake's water chemistry

Secchi disk transparency depths measured as part of this study indicated that Blue Lake possessed moderate water clarity. The Secchi disk transparency depth recorded during the rooted plant survey extended to 2.7 feet (0.8 m) which is shallower than the statewide median Secchi disk transparency depth. Historical Secchi disk data suggest that Blue Lake's transparency has declined over the last 30 years.

Blue Lake's rooted plant community indicates that water quality is better than suggested by this moderately poor water clarity. Several of Blue Lake's dominant submerged plant species, including large-leaf pondweed and northern watermilfoil, thrive in clear water (Davis and Brinson, 1980; Borman et al., 1997; Curtis, 1998). Other species that are less abundant than the ones listed above, such as grassy pondweed and flatstem pondweed, are also characteristic of clear northeastern lakes (Davis and Brinson, 1980). IDNR aquatic plant control permit applications indicate that the state listed species Richardson's pondweed (*Potamogeton richardsonii*) was present in the lake in 2003. While no evidence of this plant could be found during the current assessment, its presence is indicative of a high quality plant community. While Blue Lake supports some species that are very tolerant of lower light conditions such as coontail, southern naiad, and Sago pondweed, these species are ubiquitous in northeastern lakes. Thus, their presence is not necessarily an indication of turbid water.

Blue Lake exhibits elevated nutrient concentrations similar to nutrient concentrations observed in many other lakes in the region. Blue Lake's diverse rooted plant community indicates that water quality may have been better historically than is currently present. Based on the elevated nutrient levels, it is anticipated that the plant community present within the lake would be of poorer quality. For example, regional lakes with relatively similar total phosphorus levels, such as Silver Lake (Kosciusko County), Ridinger Lake (Kosciusko County), Robinson Lake (Whitley County), Smalley Lake (Kosciusko County), and the Four Lakes (Cook, Holem, Kreighbaum, and Mill Pond lakes, Marshall County), possess far fewer submerged species compared to Blue Lake (JFNew, 2000b; JFNew, 2004a; JFNew, 2004b; JFNew, 2005c). Additionally, in lakes with high total phosphorus concentrations, species tolerant of eutrophic water such as Eurasian watermilfoil, Sago pondweed, and coontail tend to dominate the rooted plant communities to the exclusion of species that are more sensitive to eutrophic conditions. In contrast, Blue Lake supports a rooted plant community more similar to lakes with more moderate nutrient levels, like Big Chapman Lake in Kosciusko County (JFNew, 2000). Both Blue Lake and Big Chapman Lake exhibit good species richness and dominant species include species such as large-leaf pondweed which is less tolerant of eutrophic conditions (JFNew, 2000; Chapman Lake Conservation Association et al., unpublished data; JFNew, 2005 unpublished data).

Blue Lake's rooted plant community highlights some of the differences among various areas of the lake. For example, rooted plant beds inhabiting water in front of developed portions of the lake generally possessed lower submerged species diversity than rooted plant beds in front of undeveloped portions of the lake. This lack of diversity may be due to efforts to remove (either mechanically or chemically) submerged plants to improve access to and recreational use of the lake. Alternatively, submerged plants in the developed areas may be subjected to more damage from boat propellers or wash from speeding boats. These pressures may prevent more sensitive species from becoming established in front of developed shoreline. Similarly, developed portions of the lake tended to lack emergent plant cover compared to undeveloped portions. It is likely that lake residents removed emergent plants along their property to improve access to and views of the lake.

Manipulation of Blue Lake's plant either via mechanical (harvesting, boating damage) or chemical (herbicide/algicide applications) can impact the surviving plant community. For example, emergent vegetation filters runoff from adjacent areas and removal of emergent vegetation eliminates this function. The loss of this function may lead to an increase in nutrient and sediment concentration in the area of lake in front of developed shoreline. An increase in nutrient and sediment concentration can, in turn, shift the submerged plant community from a balanced community to one dominated by species tolerant of eutrophic water conditions.

Despite some areas of nuisance species growth, Blue Lake generally supports a healthy, relatively high quality rooted aquatic plant community. Blue Lake supports a rich submerged community that includes 10 species of pondweed. Additionally, several high quality, sensitive species live in Blue Lake. The presence of high quality sensitive species coupled with the diversity of pondweed species are all characteristics of lakes with high quality plant communities (Nichols et al., 2000).

Into the Future

Changes in a lake's rooted plant communities over time can illustrate unseen chemical changes in the lake. Unfortunately, limited data detailing Blue Lake's historical rooted plant community exists for comparison to the current data. In the past, IDNR fisheries biologists conducted cursory vegetation surveys as a part of their general fisheries surveys. Historical studies recorded many of the same species that currently dominate Blue Lake. The 1975 IDNR Division of Fish and Wildlife fisheries surveys of the lake noted that spatterdock, coontail, curly-leaf pondweed, chara, and filamentous algae each covered 5% of Blue Lake. American lotus, arrow arum, leafy pondweed, and duckweed were also noted for their presence (Shipman, 1976). Data from the 1979 survey indicate that coontail, chara, and filamentous algae were abundant within Blue Lake, and that spatterdock, water lily, cattail, bulrush, whirled loosestrife, pickerel weed, black willow, arrow arum, arrowhead, curly-leaf pondweed, leafy pondweed, duckweed, and big duckweed were common in Blue Lake in 1979 (Braun, 1979). These same species dominated Blue Lake's plant community during the current assessment. The maximum depth at which plants were found was also similar among historical studies and the current study. During the current study, plants were not observed in water depths greater than 12 feet (3.6 m). The IDNR studies place the extent of the littoral zone closer to 6 feet (1.8 m) or 12 feet (3.6 m) as observed during the 1974 and 1979 surveys, respectively.

The biggest differences between the current study of Blue Lake's plant community and the historical study is the variation in the diversity of submerged species and in the overall species richness. During the 1974 survey, the IDNR observed 13 plant species, 3 of which were submerged species. The 1979 IDNR plant survey indicates that 20 plant species, including 5 submerged species, were present within Blue Lake. The current survey reports the presence of 48 species (19 submerged) within Blue Lake. A difference in survey methodology is likely the reason for the observed difference in species richness rather than an actual increase in the number of plant species in Blue Lake. Future IDNR fisheries surveys will likely be more detailed in scope than the historic surveys. These future IDNR fisheries surveys should be compared to the results of the rooted plant survey detailed in this report for the current assessment to document any of the changes described above.

Other species that should be monitored in Blue Lake to determine if the plant community is signaling a larger change in water quality include large-leaf pondweed, grassy pondweed, long-leaf pondweed, leafy pondweed, and flat stem pondweed. Davis and Brinson (1980) suggest these pondweeds are fairly sensitive to increasing eutrophication. All of these species rate low on Davis and Brinson's survival index. (A low rating is associated with an inability to survive as the lake environment changes.) A decline or loss of these species from Blue Lake might indicate an increase in eutrophication of Blue Lake.

Nuisance and Exotic Plants

Although they have not yet reached the levels observed on many other regional lakes, several nuisance and/or exotic aquatic plant species grow in Blue Lake. As nuisance species, these species will continue to proliferate if unmanaged, so data collected during the plant survey will be outdated quickly and should not be used to precisely locate nuisance species individuals or stands. (Additionally, it is likely that the watershed supports many terrestrial nuisance species plant species, but this discussion will focus on the aquatic nuisance species.) The plant survey revealed the presence of one submerged, aggressive exotic: curly leaf pondweed. It also supports two emergent exotic plant species: purple loosestrife and reed canary grass. As nuisance species, these species have the potential to proliferate if left unmanaged, so lake residents and visitors must treat these species as a threat to the lake's health. It is possible that these or other exotic species could exist within the thick emergent portions of the rooted plant community near the east and west ends of the lake but were not observed during this survey.

The lack of Eurasian watermilfoil documented in the survey results of Blue Lake should be noted. The presence of this species in lakes in the region is of concern, but it is not uncommon for lakes in northern Indiana. Eurasian watermilfoil has been noted in Blue Lake in the past. Herbicide applicators submitted herbicide permits including treatment of Eurasian watermilfoil for each of the last four years. However, no evidence of Eurasian watermilfoil could be found in Blue Lake. Eurasian watermilfoil is an aggressive, non-native species common in northern Indiana lakes. It often grows in dense mats excluding the establishment of other plants. For example, once the plant reaches the water's surface, it will continue growing horizontally across the water's surface. This growth pattern has the potential to shade other submerged species preventing their growth and establishment. In addition, Eurasian watermilfoil does not provide the same habitat potential for aquatic fauna as many native pondweeds. Its leaflets serve as poor substrate for aquatic insect larva, the primary food source of many panfish.

Depending upon water chemistry, curly leaf pondweed can be more or less aggressive than Eurasian watermilfoil. Its presence in the lake is a concern. Like many exotics, curly leaf pondweed gains a competitive advantage over native submerged species by sprouting early in the year. The species can do this because it is more tolerant of cooler water temperature than many of the native submerged species. Curly leaf pondweed experiences a die back during early to mid summer. This die back can degrade water quality by releasing nutrients into the water column and increasing the biological oxygen demand.

Purple loosestrife is an aggressive, exotic species introduced into this country from Eurasia for use as an ornamental garden plant. Like Eurasian watermilfoil, purple loosestrife has the potential to dominate habitats, in this case wetland and shoreline communities, excluding native plants. The stiff, woody composition of purple loosestrife makes it a poor food source substitute for many of the native emergents it replaces. In addition, the loss of diversity that occurs as purple loosestrife takes over plant communities lowers the wetland and shoreline habitat quality for waterfowl, fishes, and aquatic insects.

Like purple loosestrife, reed canary grass is native to Eurasia. Farmers used (and many likely still use) the species for erosion control along ditch banks or as marsh hay. The species escaped via ditches and has spread to many of the wetlands in the area. Swink and Wilhelm (1994) indicate that reed canary grass commonly occurs at the toe of the upland slope around a wetland. Reed canary grass was often observed above the ordinary high water mark around Smalley Lake. Like other nuisance species, reed canary grass forms a monoculture mat excluding native wetland/shoreline plants. This limits a wetland's or shoreline's diversity ultimately impacting the habitat's functions.

The presence of Eurasian watermilfoil, curly leaf pondweed, and other exotics is typical in northern Indiana lakes. Of the lakes surveyed by aquatic control consultants and IDNR Fisheries Biologists, nearly every lake supported at least one exotic species (White, 1998a). In fact, White (1998a) notes the absence of exotics in only seven lakes in the 15 northern counties in Indiana. These 15 counties include all of the counties in northeastern Indiana where most of Indiana's natural lakes are located. Of the northern lakes receiving permission to treat aquatic plants in 1998, Eurasian watermilfoil was listed as the primary target in those permits (White, 1998b). Despite the ubiquitous presence of nuisance species, lakeshore property owners and watershed stakeholders should continue management efforts to limit nuisance species populations. Management options are discussed in the **Management** section of this report.

4.7 Fisheries

Blue Lake was first surveyed by the Indiana Department of Natural Resources in 1975. Prior to this, the only other study of Blue Lake was conducted by the United States Geological Survey (USGS) for hydrologic mapping. During the 1975 survey the DNR collected a total of 19 fish species. (Appendix F contains a listing of fish species observed during each of the IDNR assessments.) The most dominant fish species collected by number was brook silverside. Brook silverside are an excellent forage species as the adults rarely attain sizes greater than four inches. Bluegill was the second most abundant species by number (26.6%) followed by largemouth bass (13%), black crappie (7.4%), and yellow perch (6.0%). White sucker was the most abundant fish by weight.

The DNR considered the Blue Lake fishery satisfactory, supporting four desirable fish species which included bluegill, largemouth bass, black crappie, and yellow perch (Figure 41). Bluegill collected ranged from 1 to 9 inches (2.5 to 22.8 cm) in size while largemouth bass ranged from 2 to 18 inches (5.0 to 45.7 cm). Both bluegill and largemouth bass growth rates were considered average for northeast Indiana. During the 1975 survey, nearly 70% of the largemouth bass collected were young-of-the-year (YOY) indicating a strong year class. This year class was anticipated to be a major contributor the largemouth bass fishery beginning in 1978 when they would be recruited to the fishery (catchable size). Historically, Blue Lake was also considered a good northern pike fishery (Shipman, 1976). However, during the 1975 survey only one northern pike was collected. Shipman believed that the decline of the Blue Lake northern pike fishery was partially due to spawning habitat loss. Soon after ice out, northern pike move into marshes or other shallow weedy flats to spawn. The loss of this habitat is likely due to shoreline development. Shipman recommended restoring or establishing marsh habitat spawning areas to reestablish northern pike populations.

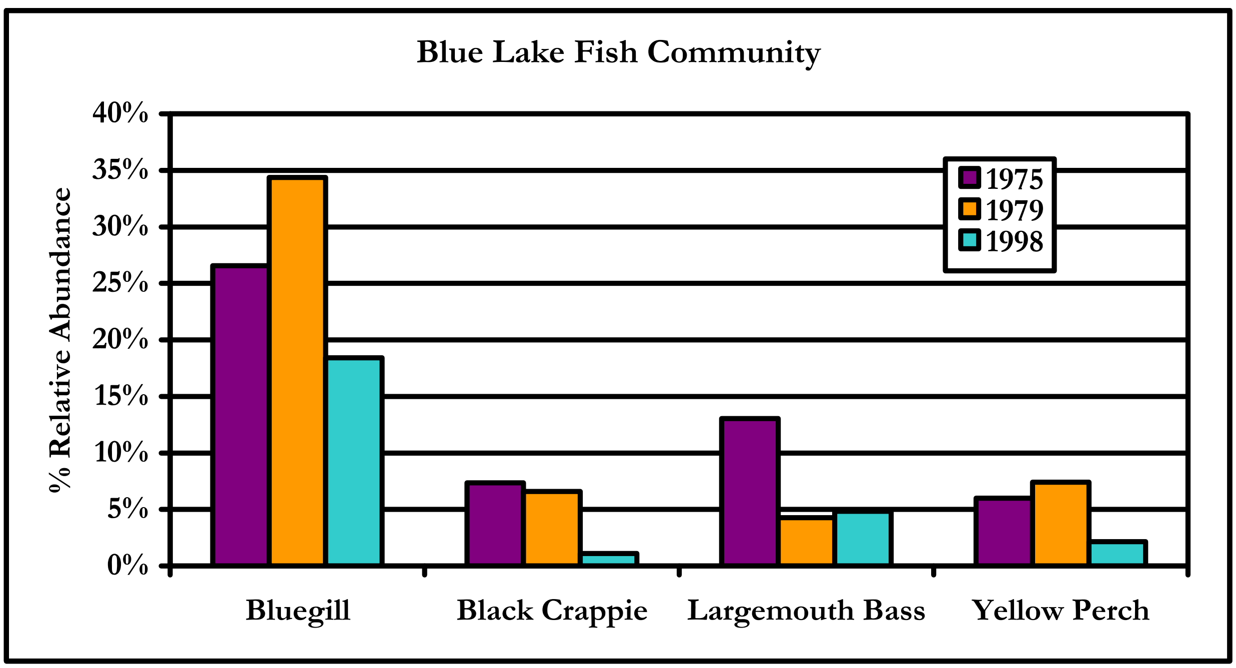

Figure 41. Percent relative abundance of selected fish species collected from Blue Lake during DNR surveys in 1975, 1979, and 1998. Source: Shipman, 1976; Braun, 1979; Braun, 1999.

The DNR next surveyed Blue Lake in 1979 (Braun, 1979). This assessment was initiated to evaluate tiger muskellunge stockings from the previous year as well as to gather other sport fishery data for future management recommendations. A total of 22 species were collected during the survey (Appendix F). Bluegill was the most abundant species by number (34.4%) followed by warmouth (18.0%) and pumpkinseed (12.1%) (Appendix F). Brook silverside were listed as present although they were likely rather abundant. (This species is rather difficult to collect with electrofishing gear or nets.) Spotted gar was the most abundant fish species by weight.

Bluegill and largemouth bass continued to provide excellent sport fishing opportunities in 1979 according the DNR. Bluegill collected ranged from 1 to 9 inches (2.5 to 22.8 cm) in size while largemouth bass ranged from 2 to 21 inches (5.0 to 53.3 cm). Both bluegill and largemouth bass growth rates were considered average for northeast Indiana. As in the 1975 survey, only one northern pike was collected during the 1979 survey. No mention of spawning habitat restoration was documented in the report. It appears that the DNR had moved its primary focus towards stocking hybrid musky rather than restoring northern pike populations. This is further evident in the management recommendation by the DNR to continue tiger musky stockings along with annual spring trap netting assessment coupled with creel surveys.

A number of other surveys that focused on species specific data collection occurred between 1980 and 1983 (Braun and Pearson, 1980; Braun, 1982; Braun, 1983; Braun, 1984). These were largely focused on musky and largemouth bass populations in Blue Lake. As such, these data are not being presented here as the purpose of this summary is to provide fish community data. The most recent Blue Lake general fisheries survey was conducted in 1998 in concert with a creel survey. During the 1998 survey a total of 18 fish species were collected (Appendix F). Bluegill was once again the most abundant fish species collected by numbers (48.0%). Largemouth (12.6%), warmouth (10.2%), and yellow perch (5.6%) were the next most abundant species respectively. In general, bluegill and largemouth bass populations displayed average growth rates for northeast Indiana while continuing to provide an excellent sport fishery according to the DNR.

Of special note and possible concern during the 1998 survey was the collection of gizzard shad. Gizzard shad are a prolific species that is known to have negative impacts on bluegill and largemouth bass populations. Gizzard shad compete directly with young sunfishes for valuable food resources. Gizzard shad are a prolific reproducers and omnivorous feeder than can quickly become one of the most numerous fish species in the lake and affect several other components of the lake ecosystem. They can have negative impacts on a lake by reducing the abundance of zooplankton which then can increase the abundance of algae leading to more frequent and more dramatic blooms (DeVries and Stein, 1990). After the zooplankton population is reduced, gizzard shad can switch to feeding on other sources of food such as detritus and plant material which can lead to increased turbidity in the lake (Schaus and Vanni, 2000). They also compete directly and indirectly with young panfish such as bluegills resulting in lower panfish abundance (Aday et al., 2003). Young largemouth bass can forage on young gizzard shad and are an important food source in some lakes. However, young gizzard shad quickly grow to a size where they are less vulnerable to predation by bass (Garvey and Stein, 1998).

4.8 Zebra Mussels

Zebra mussels are an exotic species of concern for many lakes and rivers throughout the state and for Blue Lake as well. Zebra mussels are small, fingernail-size, freshwater mollusks which are native to the Caspian, Black, and Aral Seas of Eastern Europe. Mature females can produce between 30,000 and 100,000 eggs per year which hatch into larvae, called veligers, the size of the period at the end of this sentence. Within two to three weeks of hatching the veliger shells begin to harden and become able to attach and detach from hard surfaces like rock, wood, glass, rubber, metal, gravel, other zebra mussels, and shellfish. Zebra mussel shells were also found attached to vegetation during the aquatic plant survey conducted as part of this study.

Zebra mussels are one of at least 139 non-indigenous aquatic species that have become established in the Great Lakes area since the early 1800s. They were probably introduced from transoceanic ship ballast water around 1986. They rapidly spread throughout the Great Lakes and into several river systems of the eastern U.S. including the Ohio, Illinois, Mississippi, Mohawk, Hudson, Susquehanna, Tennessee, and Arkansas. Zebra mussels were probably first introduced into Blue Lake in the early to mid-1990s. Brant Fisher (personal communication) reports the presence of zebra mussels in Blue Lake during his 2000 survey of the lake. Larry Clemens (personal communication) of The Nature Conservancy claims that because larger Indiana lakes received zebra mussels first, the primary mechanism of spread has been via boat transport from Lake Michigan. Experts accredit their rapid spread mainly to veliger drift in currents and transport from one water body to another via bilges, bait buckets, and ballast water. Zebra mussels will likely continue spreading throughout most of the U.S. unless effective preventative measures are employed.

Property damage and ecosystem impairment can be attributed to the nuisance exotic species. Zebra mussels pose a multi-billion dollar threat to water supplies for municipalities, industry, and agriculture and cause costly damage to shoreline facilities and residences. Mussel colonies, reaching densities of $115{,}000/m^2$, can clog water intake pipes, valves, and screens at municipal water facilities, industrial facilities, and power plants. The mollusks cause costly shipping and boating damages by attaching to motors, propellers, buoys, hulls, and cooling systems of engines. Zebra mussels also have detrimental effects on the biological and ecological functions of aquatic ecosystems in North America. They colonize the shell surfaces of native unionid mussels disrupting feeding, locomotion, respiration, and reproduction. Death usually occurs within two years. Due to the zebra mussel invasion and other environmental problems, fifty-five percent of native North American unionid mussels are extinct or imperiled.

Zebra mussels are efficient filter-feeders and consume large amounts of phytoplankton (microscopic algae) which are food for zooplankton (small animals) that nourish small fish. Without the plants at the base of the food chain, zooplankton populations decline causing fish recruitment to decline as well. Additionally, mussels essentially filter out contaminants like PCB and other hazardous hydrocarbons from the water column and concentrate them in their tissues. The toxins may then be biomagnified in mussel predators higher in the food web. Filter-feeding also results in a rerouting of dissolved and particulate-bound contaminants from the water column to the sediments in the form of feces and pseudofeces where benthic or bottom-feeding invertebrates may ingest them. Fish consuming the invertebrates further biomagnify the toxins, and since zebra mussel introduction, PCB concentrations in top-predators have increased.

Because zebra mussels did not evolve in North America, infected waters lack an efficient predator to biologically control their populations. Although diving ducks, freshwater drum, carp, sturgeon, sunfishes, and suckers do eat mollusks, no predator is capable of controlling mussel populations. Introducing other Eurasian molluscivores is risky because biomanipulation efforts often fail since introduced predators will not feed on the introduced pest or will not inhabit the areas occupied by the pests. Historically, the introduced predator has become an invader itself or has negatively affected other native species.

Zebra mussels also affect water quality by altering the sediments and the water column of infested water bodies. Colonies of mussels increase the amount of benthic organic matter through the production of waste products. A shift in the community composition of the invertebrates that inhabit the benthic sediments occurs, and invertebrates usually indicative of poorer water quality become dominant (like tubificid oligochaetes and chironomids). Zebra mussels are also associated with an increase in water clarity and light penetration which in turn may result in increased macrophytic vegetation growth. However, they selectively filter out small forms of phytoplankton (diatoms and cryptophytes), with no impact on colonial and filamentous cyanobacteria. Nutrient resources no longer used by the small members of the algal community become available to cyanobacteria causing noxious blooms. Zebra mussels also release large amounts of bioavailable nitrogen (ammonium, NH_4^+) which may be utilized by large, undesirable algae. Additionally, the invading mussels are associated with increasing fractions of dissolved, bioavailable toxins in the water column.

Because recreational boating is the primary mechanism for dissemination of adult and larval zebra mussels, following some simple precautions can help prevent the spread of this aquatic nuisance organism:

1. Remove visible vegetation from equipment and objects that were in the water.
2. Flush engine cooling system, live wells, and bilge with hot water or tap water. Water of 110°C and 140°C will kill veligers and adults respectively.
3. Rinse any other areas that get wet like trailers, boat decks, etc.
4. Air dry boat and equipment for two to five days before using in uninfested waters.
5. Examine boat exterior if it has been docked in mussel-infested waters. If mussels or large amounts of algae are found, clean the surfaces or dry the boat for at least five days.
6. Do not reuse bait or bait bucket water if they have been exposed to mussel-invaded waters.

Many times recreational users are the first to document exotic species in an area. To help local natural resource officials, learn how to identify exotic species found in northeastern Indiana. If an unidentifiable fish or other aquatic organism is encountered, note the date and location where the specimen was found and collect it if possible. Store it in rubbing alcohol and contact the local USFWS or state natural resources office.

Identify zebra mussels by:

1. Shell Appearance: zebra mussels look like small D-shaped clams of a yellow or brown color. The shell is characterized by light and dark striping resembling tiger stripes (Figure 42).
2. Size and Location: most zebra mussels are only the size of a fingernail but may be up to two inches long. They tend to grow in colonies of multiple individuals in shallow, productive waters.
3. Attachment: no other freshwater mussels can firmly attach themselves to solid substrates.

Figure 42. Adult zebra mussel.

5.0 MODELING

5.1 Water Budget

Inputs of water to Blue Lake are limited to:

1. direct precipitation to the lake
2. discharge from the intermittent inlet streams
3. sheet runoff from land immediately adjacent to the lake
4. groundwater

Water leaves the lake system from:

1. discharge from the outlet channel to the Blue River
2. evaporation
3. groundwater

There are no discharge gauges in the watershed to measure water inputs and the limited scope of this study did not allow us to quantitatively determine annual water inputs or outputs. Therefore, the water budget for Blue Lake was estimated from other records.

- Direct precipitation to the lake was calculated from mean annual precipitation falling directly on the lake's surface.
- Runoff from the lake's watershed was estimated by applying runoff coefficients. A runoff coefficient refers to the percentage of precipitation that occurs as surface runoff, as opposed to that which soaks into the ground. Runoff coefficients may be estimated by comparing discharge from a nearby gauged watershed of similar land and topographic features, to the total amount of precipitation falling on that watershed. The nearest gauged watershed is a U.S.G.S. gauging station on the Tippecanoe River near North Webster, Indiana (Morlock et al., 2004). The 18-year (1987–2004) mean annual runoff for this watershed is 13.21 inches (33.5 cm). With mean annual precipitation of 35.52 inches (90.2 cm) (Staley, 1989), this means that on average, 37.2% of the rainfall falling on this watershed runs off on the land surface.
- No groundwater records exist for the lake, so it was assumed that groundwater inputs equal outputs or groundwater effects are insignificant when compared to surface water impacts. It

is unlikely that the latter is true for Blue Lake. However, since no groundwater records for the lake exist we must assume that groundwater inputs equal outputs.

- Evaporation losses were estimated by applying evaporation rate data to the lake. Evaporation rates are determined at six sites around Indiana by the National Oceanic and Atmospheric Administration (NOAA). The nearest site to Blue Lake is located in Fort Wayne, Indiana. Annual evaporation from a 'standard pan' at the Valparaiso site averages 28.05 inches (71.2 cm) per year. Because evaporation from the standard pan overestimates evaporation from a lake by about 30%, the evaporation rate was corrected by this percentage, yielding an estimated evaporation rate from the lake surface of 19.95 inches (50.7 cm) per year. Multiplying this rate times the surface area of each lake yields an estimated volume of evaporative water loss from Blue Lake.

The water budget for Blue Lake, based on the assumptions discussed above, is shown in Table 27.

Table 27. Water budget calculation for Blue Lake.

Parameter	**Data**
Watershed size (ac)	2,272
Mean Watershed Runoff (ac-ft/yr)	2,497
Lake Volume (ac-ft)	4,944
Runoff Estimates	
Closest gauged stream	Tippecanoe River at North Webster
Stream watershed (mi^2)	49.3
Stream watershed (acres)	31,552
Mean annual daily Q (cfs)	47.9
Mean annual total Q (ac-ft/yr)	34,678
Mean ppt (in/yr)	35.5
Mean watershed ppt (ac-ft/yr)	93,341
Watershed C	0.372
Evaporation Estimates	
Pan evaporation (in/yr)	28.05
Pan evaporation coefficient	0.70
Lake Surface Area (acres)	239
Estimated lake evaporation (ac-ft)	391
Direct precipitation to lake (ac-ft)	704
Runoff from watershed (ac-ft)	2,497
Evaporation (ac-ft)	391
TOTAL LAKE OUTPUT (ac-ft)	**2,813**
Hydraulic Residence Time (yr)	1.8
Watershed Area: Lake Area	9.5:1

Dividing the volume of water flowing out of Blue Lake by the lake's volume yields a *hydraulic residence time* of 1.8 years (22 months). This means that on average, water entering the lake stays in the lake for nearly one and three-quarters years before it leaves. This hydraulic flushing rate is typical for glacial lakes in this part of the county. In a study of 95 north temperate lakes in the U.S., the mean hydraulic residence time for the lakes was 2.12 years (Reckhow and Simpson, 1980). A lake's hydraulic residence time is strongly correlated with its watershed size to lake surface area ratio. Blue

Lake possesses a watershed size to lake surface area ratio of 9.8 to 1. Most glacial lakes have a watershed area to lake surface area ratio of around 10:1 (Vant, 1987). Thus, the water budget estimate appears reasonable.

5.2 Phosphorus Budget

Since phosphorus is the limiting nutrient in Blue Lake, a phosphorus model was used to estimate the dynamics of this important nutrient. With its role as the limiting nutrient, phosphorus should be the target of management activities to lower the biological productivity of Blue Lake.

The limited scope of this LARE study did not allow for the outright determination of phosphorus inputs and outputs. Therefore, a standard phosphorus model was used to estimate the phosphorus budget. Reckhow et al. (1980) compiled phosphorus loss rates from various land use activities as determined by a number of different studies. They used these phosphorus loss rates to calculate phosphorus export coefficients for various land uses. Phosphorus export coefficients are expressed as kilograms of phosphorus lost per hectare of land per year. Table 28 shows the phosphorus export coefficients developed by Reckhow and Simpson (1980).

Table 28. Phosphorus export coefficients (units are kg/hectare except the septic category, which are kg/capita-yr).

Estimate Range	Agriculture	Forest	Precipitation	Urban	Septic
High	3.0	0.45	0.6	5.0	1.8
Mid	0.40-1.70	0.15-0.30	0.20-0.50	0.80-3.0	0.4-0.9
Low	0.10	0.2	0.15	0.50	0.3

Source: Reckhow and Simpson, 1980.

To obtain an annual estimate of the phosphorus exported to Blue Lake from the lake's watershed, the export coefficient for a particular land use was multiplied by the area of land in the land use category. Mid-range estimates of phosphorus export coefficient values for all watershed land uses (Table 27) were used in this calculation.

Direct phosphorus input via precipitation to Blue Lake was estimated by multiplying mean annual precipitation in Kosciusko County (0.90 m/yr) times the surface area of the lake times a typical phosphorus concentration in Indiana precipitation (0.03 mg/L). Because homes surrounding Blue Lake are on sewer, there is no current phosphorus input from septic systems. It should be noted that nutrients can continue to leach from old septic systems into the lake for a number of years after use of these systems has been discontinued. Additionally, any septic inputs due to sewer shutoffs or overflows also impact phosphorus levels in Blue Lake. However, neither of these items can be addressed by Vollenweider's model.

Adding the phosphorus export loads from the watershed and precipitation yielded an estimated 929 kg of phosphorus loading to Blue Lake (Table 29). The greatest estimated source of phosphorus loading to the lake is from row crop agriculture which accounts for over 97% of total watershed loading.

Table 29. Phosphorus model results for Blue Lake.

Input Data		**Unit**		
Area, Lake	239	acres		
Volume, Lake	4944	ac-ft		
Mean Depth	20.7	ft		
Hydraulic Residence Time	1.80			
Flushing Rate	0.56	1/yr		
Mean Annual Precipitation	0.90	m		
[P] in precipitation	0.03	mg/l		
[P] in epilimnion	0.047	mg/l		
[P] in hypolimnion	0.565	mg/l		
Volume of epilimnion	4,177	ac-ft		
Volume of hypolimnion	767	ac-ft		
Land Use (in watershed)	**Area**	--------	**P-export Coefficient**	
Deciduous Forest	69.60	hectare	0.2	kg/ha-yr
Emergent Herbaceous Wetlands	3.10	hectare	0.1	kg/ha-yr
Evergreen Forest	1.80	hectare	0.15	kg/ha-yr
High Intensity Residential	0.90	hectare	1.5	kg/ha-yr
High Intensity Commercial	2.90	hectare	1.3	kg/ha-yr
Low Intensity Residential	26.3	hectare	0.6	kg/ha-yr
Mixed Forest	0.1	hectare	0.175	kg/ha-yr
Pasture/Hay	182.4	hectare	0.6	kg/ha-yr
Row Crops	504.2	hectare	1.5	kg/ha-yr
Woody Wetlands	27.5	hectare	0.1	kg/ha-yr
Septic Systems	--------	--------	0.50	kg/ha-yr
OUTPUT				
P load from watershed	903.9	kg/yr		
P load from precipitation	26.17	kg/yr		
P load from septic systems	---	kg/yr		
Total External P load	930.08	kg/yr		
Areal P loading	0.962	g/m^2-yr		
Predicted P from Vollenweider	0.071	mg/l		
Back Calculated L total	1.720	g/m^2-yr		
Estimation of L internal	0.758	g/m^2-yr		
% of External Loading	55.9	%		
% of Internal Loading	44.1	%		

The relationships among the primary parameters that affect a lake's phosphorus concentration were examined employing the widely used Vollenweider (1975) model. Vollenweider's empirical model says that the concentration of phosphorus ([P]) in a lake is proportional to the areal phosphorus loading (L, in g/m^2 lake area - year), and inversely proportional to the product of mean depth ($\bar{z}$) and hydraulic flushing rate (ρ) plus a constant (10):

$$[P] = \frac{L}{10 + \bar{z}\rho}$$

During the August 10, 2005 sampling of Blue Lake, the mean volume weighted phosphorus concentration in the lake was 0.127 mg/L. It is useful to determine how much phosphorus loading from all sources is required to yield a mean phosphorus concentration of 0.127 mg/L in Blue Lake. Plugging this mean concentration along with the lake's mean depth and flushing rate into Vollenweider's phosphorus loading model and solving for L yields an areal phosphorus loading rate (mass of phosphorus per unit area of lake) of 1.720 g/m^2-yr. This means that in order to get a mean phosphorus concentration of 0.127 mg/L in Blue Lake, a total of 1.720 grams of phosphorus must be delivered to each square meter of lake surface area per year.

Total phosphorus loading (L_T) is composed of external phosphorus loading (L_E) from outside the lake (watershed runoff and precipitation) and internal phosphorus loading (L_I). Since L_T = 1.720 g/m^2-yr and L_E = 0.962 g/m^2-yr (estimated from the watershed loading in Table 28), then internal phosphorus loading (L_I) equals 0.758 g/m^2-yr. Thus, internal loading accounts for about 44% of total phosphorus loading to the water column Blue Lake.

It is important to check this conclusion that internal phosphorus loading accounts for 44% of total phosphorus loading to Blue Lake with the data collected on August 10, 2005. There is evidence in Blue Lake that soluble phosphorus is being released from the sediments during periods of anoxia. For example, the concentration of soluble phosphorus in Blue Lake's hypolimnion on August 10, 2005 was 31 times higher than concentrations in the epilimnion (0.018 mg/L vs. 0.558 mg/L). The source of this hypolimnetic total phosphorus is primarily internal loading in most lakes. This internal loading can be a major source of phosphorus in many productive lakes.

The significance of areal phosphorus loading rates is better illustrated in Figure 43 in which areal phosphorus loading is plotted against the product of mean depth times flushing rate. Overlain on this graph is a curve, based on Vollenweider's model, which represent an acceptable loading rate that yields a phosphorus concentration in lake water of 30 μg/L (0.03 mg/L). The areal phosphorus loading rate for Blue Lake is well above the acceptable line.

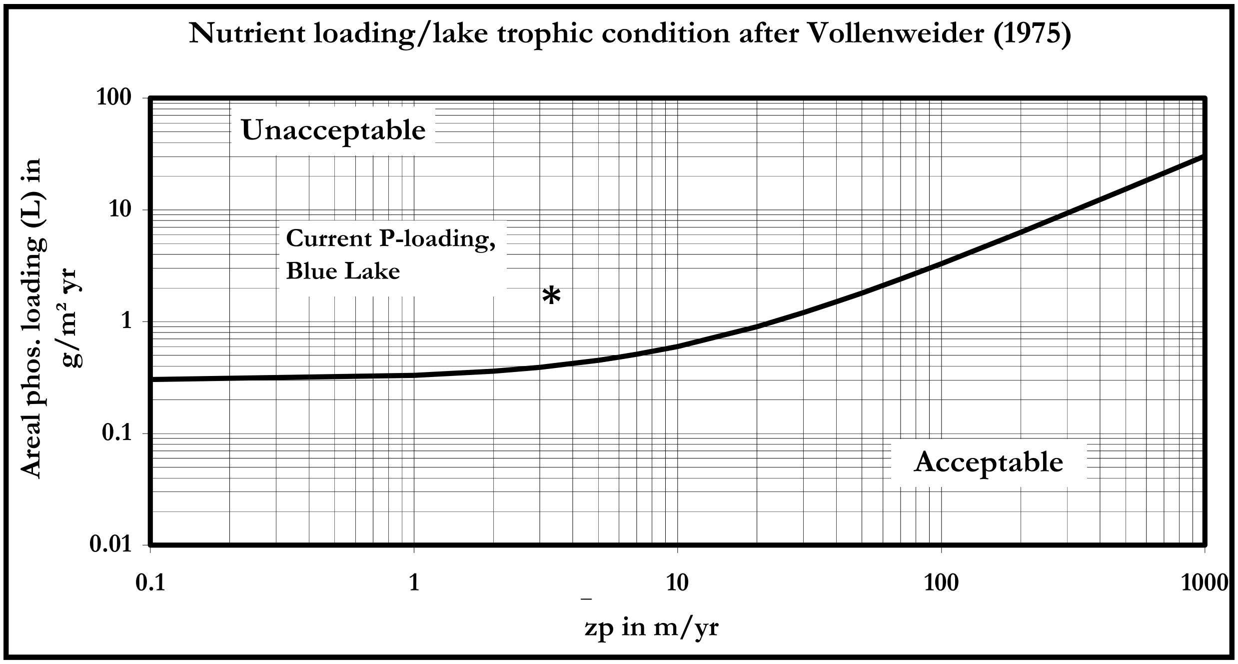

Figure 43. Phosphorus loadings to Blue Lake compared to acceptable loadings determined from Vollenweider's model. The dark line represents the upper limit for acceptable loading.

This figure can also be used to evaluate management needs. For example, areal phosphorus loading to Blue Lake would have to be reduced from 1.720 g/m^2-yr to 0.413 g/m^2-yr (the downward vertical intercept with the line) to yield a mean lake water concentration of 0.030 mg/L. This represents a reduction in areal phosphorus loading of 1.307 g/m^2-yr to the lake, which is equivalent to a total phosphorus mass loading reduction of 1,370 kg P/yr or 76% of current total loading to the lake. Eliminating internal phosphorus loading alone will not meet this reduction needed. Likewise, eliminating watershed phosphorus loading alone will not meet this reduction. Both internal and watershed loading reductions are required to reduce the trophic state of Blue Lake (Table 30).

Table 30. Phosphorus reduction required to achieve acceptable phosphorus loading rate and a mean lake concentration of 0.03 mg/L.

	Current Total Areal P Loading (g/m^2-yr)	Acceptable Areal P Loading (g/m^2-yr)	Reduction Needed (kg P/yr and %)
Blue Lake	1.720	0.413	1,370 (76%)

6.0 MANAGEMENT

The preceding sections of this report detailing Blue Lake's current condition indicate that the lake possesses poor water quality in comparison to other lakes in the region and throughout the state. The lake has moderately poor clarity with a Secchi disk depth of 2.7 feet (0.8 m). Nutrient concentrations are higher than the state medians. The lake's volume weighted total phosphorus concentration places the lake in the hypereutrophic category based on Carlson's TSI, but a much of this phosphorus is in the lake's hypolimnion where it is not accessible to algae. The higher than average nutrient levels present in Blue Lake result in an elevated productivity level. The lake's chlorophyll *a* concentration, Indiana TSI score, and Secchi disk depth suggest Blue Lake is eutrophic in nature.

The lake's relatively healthy biological community indicates that the long-term water quality may be better than what is indicated by its water chemistry sampling. Blue Lake supports a diverse submerged plant community including several pondweeds and northern watermilfoil. Recent historical evidence indicates that the state listed species, Richardson's pondweed, was also present in Blue Lake as recent as 2003. These species are all indicators of good water quality and are found in several places throughout the lake. IDNR fisheries biologists also describe Blue Lake's fisheries community as healthy. The popularity of the lake for fishing supports this assessment.

While Blue Lake historically has exhibited good water quality, recent samplings indicate that water quality may be declining in the lake. There is some evidence that this trend may continue into the future. The phosphorus modeling shows that more phosphorus is entering the lake from the watershed than can be absorbed by the lake and still maintain a moderate level of productivity. Similarly, the lack of oxygen in the lake's lower levels suggests the rate of photosynthesis (oxygen production) is less than the rate of oxygen consumption. The relatively high concentration of ammonia in Blue Lake's hypolimnion suggests decomposition rates may be the primary reason for the oxygen consumption. Likewise, high soluble reactive phosphorus concentrations in the epilimnion indicate that phosphorus release from the sediment is likely occurring within the lake. Based on this evidence, the rate of organic material input to the lake may be exceeding the level that the lake can effectively process without compromising water quality.

To date, Blue Lake's relatively large capacity (volume) has likely helped offset the effects of the phosphorus and organic matter loading from both the lake's watershed (external loading) and the lake's sediment (internal loading). Thus, despite relatively high phosphorus inputs, the lake's productivity (algae, plant, and fish populations) is more typical of moderately productive to productive lake. However, the lake cannot continue to absorb phosphorus and organic matter indefinitely without a concurrent change in its water quality. It is likely that Blue Lake will reach a "breaking point" at which the lake's biological community may begin to reflect more eutrophic conditions. The observable effects once this "breaking point" is reached could included more algae blooms, poorer water clarity, and shifts in the rooted plant and fish community to a dominance of less desirable species.

To prevent, or at least delay, degradation of Blue Lake's water quality and biological communities, Blue Lake residents and other watershed stakeholders are strongly encouraged to actively manage their lake and watershed. Management efforts should focus on reducing both external and internal phosphorus loading to the lake. Blue Lake's low watershed area to lake area ratio suggests actions taken along the shoreline and in the immediate watershed can have a significant impact of the lake's health. Thus management of near shore channels or ravines, individual residential properties, and campground areas should be prioritized. Maloney Ditch's high phosphorus and bacteria levels indicate that watershed management techniques that treat these pollutants are also important. Finally, the lake's relatively long hydraulic residence time means in-lake management, which can affect nutrient cycling, should also receive a high priority. The following paragraphs describe the management techniques recommended for Blue Lake and its watershed. For the sake of clarity, the techniques are separating into two categories: watershed management techniques and in-lake management techniques.

6.1 Watershed Management

The areas that would benefit most from watershed management techniques are detailed in Figure 44. Watershed management techniques are broken into a few major categories. Specifics about each of these areas are detailed below.

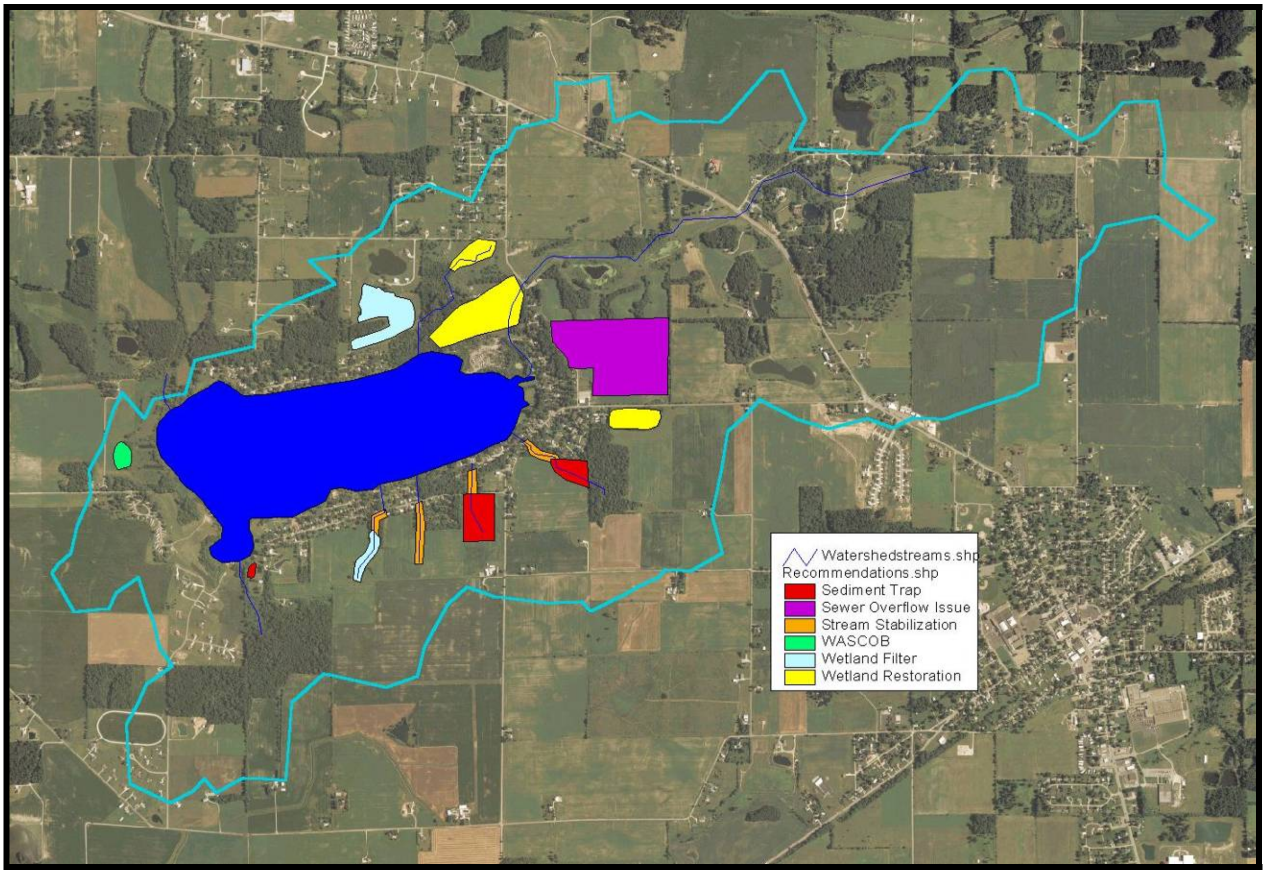

Figure 44. Areas that would benefit from watershed management technique installation.

6.1.1 Stream Channel Management

A series of small, steep stream channels or ravines drain the landscape south of Blue Lake (Figure 4). Four drainages were identified along the southern shoreline. Most of these drainages exhibit grades of 10% or higher. Many of the soil units in these areas are considered highly or potentially highly erodible (Figure 8). Given these site conditions, it is not surprising that several of the drainages are actively eroding (Figures 45 and 46). Erosion under and around tree roots and slumping side slopes were observed during site inspection conducted during the course of this study. Property owners indicate that during storm events sediment from many of these drainages turn Blue Lake chocolate brown. Erosion along streambanks at the lakeshore indicates that water moves through these drainages at high velocity and likely scours additional material from these banks carrying it into Blue Lake.

Figure 45. View of a stream channel along the south shore of Blue Lake where erosion is occurring.

Figure 46. Actively eroding stream south of Blue Lake. Note the undercut root wads along this section of the stream.

Sediment reaching Blue Lake has the potential to impair the lake via several mechanisms. Of greatest concern to the residents is the impact sediment can have on the lake's water clarity. Sediment from actively eroding stream channels contributes to this problem. The sediment also reduces lake depth which can affect swimming and other recreational uses of the lake. Lastly, nutrients attached to sediment that reaches the lake can promote algae and rooted plant growth, which in turn can impact recreational use of the lake.

Some of the erosion occurring within the stream channels is natural. The landscape's steep slopes coupled with the sandy soil naturally predispose the ravine area to erosion. However, erosion rates within the stream channels were likely slower in pre-settlement times. In pre-settlement times, forest likely covered the landscape south of Blue Lake. Due to the structure and physical composition of forested land, forested land typically has very low stormwater runoff volumes and flow rates. To understand this, it is helpful to consider the path of rain falling on a forested landscape. Some portion of the rain falling on forested land never reaches the ground. The multi-layered canopy of forested land captures this portion of rain. Of the rain that does reach the forest floor, herbaceous ground cover and decaying organic matter absorb another portion of the total rain volume. An additional portion of the total rain volume is infiltrated into the forest soil. This leaves a very small amount of rain that actually leaves the forest floor as overland runoff. This low stormwater runoff volume and consequently low flow rate translates into lower potential for soil erosion.

At some point during settlement of the Blue Lake watershed, settlers cleared much of the forested areas to allow for agricultural production. Historical aerial photography confirms that much of the land at the headwaters of these stream channels (southern edge of drainage) has been, and in some cases still is, in agricultural production. Agricultural land has significantly higher stormwater runoff volumes and rates compared to forested land. These higher stormwater runoff volumes and rates are increased even further when agricultural land is tiled to improve drainage. The result is an increase in the volume and rate of stormwater runoff reaching the ravines as the water drains toward the lake. The increased volume and rate of stormwater runoff increases the erosion within the ravines.

While the shift from forested land to agricultural land use likely accelerated erosion within the stream channels south of Blue Lake, the conversion of agricultural and/or forested land to residential land use that is occurring in some of these subwatersheds today presents an even greater concern for erosion in the ravines. While stormwater runoff volumes and rates are greater on agricultural land compared to forested land, they are even higher on residential land. Residential land can have a significant amount of impervious surface (roads, sidewalks, driveways, houses, etc.) associated with it. Impervious surface provides no infiltration of stormwater. Even if common stormwater management practices are utilized, the potential is high for increased erosion in ravines that released stormwater runoff from residential areas.

A multi-pronged approach is recommended to address the erosion problem within the ravines along the southern edge of Blue Lake's watershed. First, the landscape up-gradient from the stream channels should be examined to determine whether a reduction of stormwater runoff from these areas is possible. Retiring agricultural land and planting the land to forest or prairie habitat would reduce stormwater runoff from areas up-gradient of the ravines. Use of the Conservation Reserve Program (described below) may be a cost-effective means to achieve this goal.

Erosion control may be possible within the stream channels themselves. Depending upon the slope and soil composition, it may be possible to install a series of check dams in certain ravines. Check dams reduce erosion by pooling water behind them, slowing the velocity and erosive potential of runoff. As the water slows behind the check dam, some of the sediment in the runoff will drop out of suspension and remain trapped behind the check dam. Like many of the other practices described above, sediment traps slow and store water for release in the future. As water pools within a sediment trap, heavier particles drop out of suspension, reducing the sediment load that reaches the lake.

Specific areas available for restoration should be investigated to determine the feasibility for sediment trap and check dam installation. The former pond located at the headwaters of the most western drainage along Harrold Road (Subwatershed E) is of highest priority and should be included in the first investigation. Individuals indicate that the landowner may be interested in restoring the blown out dam (Figure 47) and reconstructing the pond as either wet or dry detention to filter sediment and reduce sediment and nutrient loading to Blue Lake (Figure 48). Downstream of the pond, check dams should be installed to reduce the erosive force of the water moving through the stream channel. Additional options for the installation of sediment traps or wetland filters at the headwaters of Subwatersheds B, C, and D should also be investigated (Figure 49). In each case, a sediment trap or wetland filter could be installed in the headwaters of the drainage (southern edge) with check dams or grade control structures installed downstream of the basin. Landowners along some of these drainages have expressed an interest in working with the lake association to improve filtration options and reduce sediment erosion and nutrient loading from these drainages.

Figure 47. Dam reconstruction necessary to restore the pond in the headwaters of Subwatershed E.

Figure 48. Current condition of the former pond in the headwaters of Subwatershed E.

Figure 49. Erosion created by storm water exiting a tile line within Subwatershed D.

Finally, with respect to reducing erosion from the stream channel, very careful planning will be necessary when developing the land around or up-gradient of these streams for residential or commercial use. Residential/commercial development of these areas should employ conservation designs to reduce impervious surfaces and maximize buffer zones and infiltration areas. Other best management practices that should be considered are the use of grassed pavers in place of roads, driveways, and sidewalks; reduction in street, driveway, and sidewalk widths; the use of vegetated roadside swales rather than curb and gutter systems; and the use of green rooftops, rain gardens, and/or rain barrels to keep stormwater on individual lots. Reducing the volume and velocity of stormwater reaching nearby ravines will be essential to limiting erosion within these ravines.

6.1.2 Sewer System Maintenance

The Blue Lake Conservancy District operates a sewer system which services nearly 400 homes around the shoreline of Blue Lake. Additionally, it serves residences along County Roads 575 North and 550 North on the west end of the lake and the Edison Subdivision on Horseshoe Bay. The sewer system was completed five years ago. Since that time, the agricultural field behind the Blue Lake Conservation property has been utilized as sewer overflow (Figure 44). Adjacent residents and users of the Conservation Club building report a strong sewer smell in this area when an overflow or emergency shut off occurs. As tile lines carry water from this tilled agricultural field directly to Blue Lake, it is likely that untreated sewage is carried from this field to the lake during these time periods. This impact is of greater consequence to the health of Blue Lake than the previous operation of old or poorly maintained septic systems located around the lakeshore. The Blue Lake Conservancy District should work with their sewer system engineer to correct this issue as quickly as possible.

6.1.3 Individual Property Management

Individual property owners can take several actions to improve Blue Lake. First, shoreline landowners should seriously consider re-landscaping lakeside properties to protect their lake. Many of the homes on Blue Lake have maintained turf grass lawns that extend to the lake's edge (Figure 50). Runoff from residential lawns can be very high in phosphorus. In a study on residential areas in Madison, Wisconsin, Bannerman et al. (1992) found extremely high total phosphorus concentrations in stormwater samples from residential lawns. The average phosphorus concentration of runoff water from residential lawns was nearly 100 times the concentration at which algae blooms are expected in lake water. While some dilution occurs as runoff water enters the lake, this source of phosphorus is not insignificant. Other researchers have found similarly high total phosphorus concentrations in lawn runoff water (Steuer et al., 1997).

The ideal way to re-landscape a shoreline is to replant as much of the shoreline as possible with native shoreline species. Rushes, sedges, pickerel weed, arrowhead, and blue-flag iris are all common species native to northeastern lake margins. These species provide an aesthetically attractive, low profile community that will not interfere with views of the lake. Plantings can even occur in front of existing seawalls. Bulrushes and taller emergents are recommended for this. On drier areas, a variety of upland forbs and grasses that do not have the same fertilizer/pesticide maintenance requirements as turf grass may be planted to provide additional filtering of any runoff. Plantings can be arranged so that access to a pier or a portion of the lakefront still exists, but runoff from the property to the lake is minimized. Thus, the lake's overall health improves without interfering with recreational uses of the lake. Henderson et al. (1998) illustrate a variety of landscaping options to achieve water quality and access goals. Appendix G contains a list of potential species that could be planted at the lake's shoreline and further inland to restore the shoreline.

Figure 50. View of the water's edge along Blue Lake. Native shoreline vegetation has been removed and replaced with turf grass and a concrete seawall. Plants removed from the lake adjacent to this frontage are piled on the concrete seawall.

Restoring Blue Lake's shoreline by planting the area with native vegetation will return the functions the shoreline once provided the lake. In addition to filtering runoff, well-vegetated shorelines are less likely to erode, reducing sediment loading to the lake. Well-vegetated shorelines also discourage Canada geese. Canada geese prefer maintained lawns because any predators are clearly visible in lawn areas. Native vegetation is higher in profile than maintained lawns and has the potential to hide predators, increasing the risk for the geese. Wire fences or string lines do little to discourage geese, since these devices do not obscure geese sight line and geese learn to jump wire fences. Unlike concrete or other hard seawalls, vegetated shorelines dampen wave energy, reducing or even eliminating the "rebound" effect seen with hard seawalls. Waves that rebound off hard seawalls continue to stir the lake's bottom sediments, reducing water clarity and impairing the lake's aesthetic appeal. (Residents might also consider replacing concrete seawalls with glacial stone to reduce the "rebound" effect.) Finally, well-vegetated shorelines provide excellent habitat for native waterfowl and other aquatic species.

Individual landowners along Blue Lake also use exotic species like purple loosestrife and reed canary grass to landscape their lakeshore and adjacent lawn (Figures 32 and 38). Both of these species are introduced from Eurasia and spread rapidly through prolific seed production and cultivation. Without individual control, both species can spread along the lakeshore inhibiting boat mooring and individual access to the lake (JFNew, 2005c). (See the Macrophyte Discussion for more information on these plants.) Landowners should replace these plants with native species that provide equal or better quality aesthetics and are more useful to birds, butterflies, and other wildlife as habitat and a food source. Reed canary grass should be replaced with switch grass, Indian grass, or even big blue stem depending on the landowner's desired landscaping (Figure 51). Swamp blazing star, swamp milkweed, cardinal flower, blue-flag iris, or blue lobelia all offer more habitat and aesthetic variety than that offered by purple loosestrife (Figure 52). A mixture of these species will also allow for colorful blooms throughout the growing season.

Figure 51. Switch grass (left), big bluestem (center), and Indian grass (right) are some of the grass species suggested for shoreline planting along Blue Lake.

Figure 52. Some of the forbs suggested for shoreline planting along Blue Lake are swamp blazing star (top left), swamp milkweed (top center and with bumblebee top right), cardinal flower (bottom left), blue-flag iris (bottom center), and blue lobelia (bottom right).

In addition to re-landscaping lakefront property, all lake and watershed property owners should reduce or eliminate the use of fertilizers and pesticides. These lawn and landscape-care products are a source of nutrients and toxins to the lake. Landowners typically apply more fertilizer to lawns and landscaped areas than necessary to achieve the desired results. Plants can only utilize a given amount of nutrients. Nutrients not absorbed by the plants or soil can run into the lake either directly from those residents' lawns along the lake's shoreline or indirectly via storm drains. This simply fertilizes the rooted plants and algae in the lake. At the very minimum, landowners should follow dosing recommendations on product labels and avoid fertilizer/pesticide use within 10 feet of hard surfaces such as roads, driveways, and sidewalks and within 10 to 15 feet of the water's edge. Where possible, natural landscapes should be maintained to eliminate the need for pesticides and fertilizers.

If a landowner considers fertilizer use necessary, the landowner should apply phosphorus-free fertilizers. Most fertilizers contain both nitrogen and phosphorus. However, the soil usually contains enough natural phosphorus to allow for plant growth. As a consequence, fertilizers with only nitrogen work as well as those with both nutrients. The excess phosphorus that cannot be absorbed by the grass or plants can enter the lake, either directly or via storm drains. Landowners can have their soil tested to ensure that their property does indeed have sufficient phosphorus and no additional phosphorus needs to be added. The Purdue University Extension or a local supplier can usually provide information on soil testing.

Shoreline landowners should also avoid depositing lawn waste such as leaves and grass clippings in Blue Lake or its tributaries (Figure 53) as this adds to the nutrient base of the lake. Pet and other animal waste that enters the lake also contributes nutrients and pathogens to it. All of these substances require oxygen to decompose. This increases the demand on the lake. Yard, pet, and animal waste should be placed in residents' solid waste containers to be taken to the landfill rather than leaving the waste on the lawn or piers to decompose.

Each lake property owner should investigate local drains, roads, parking areas, driveways, and roof tops. Resident surveys conducted on other northern Indiana lakes have indicated that many lakeside houses have local drains of some sort on their properties (JFNew, 2000c; JFNew, 2002). These drains contribute to sediment and nutrient loading and thermal pollution of the lake. Driveways transversing steep slopes adjacent to Blue Lake should be constructed in a manner that limits the transport of sediment and nutrients to the lake. For example, this driveway along Harrold Place (Figure 54) would benefit from paving and the installation of French drains (gravel filled trenches) along the sides of the driveway to reduce the transport of sediment down the hill. A wetland filter or catch basin adjacent to the driveway to filter the runoff from the driveway would also limit sediment and nutrient loading to the lake. Where possible, alternatives to piping the water directly to the lake should be considered. Alternatives include French drains (gravel filled trenches), wetland filters, catch basins, and native plant overland swales. Residents might also consider the use of rain gardens or rain barrels to treat stormwater on individual lots.

Figure 53. Leaf pile raked into one of Blue Lake's tributaries. The yard waste adds additional nutrients to the lake.

Figure 54. Maintenance would reduce sediment and nutrient loading to Blue Lake from driveways around the lake.

Individuals should take steps to prevent unnecessary pollutant release from their property. With regard to car maintenance, property owners should clean any automotive fluid (oil, antifreeze, etc.) spills immediately. Driveways and street fronts should be kept clean and free of sediment. Regular hardscape cleaning would help reduce sediment and sediment-attached nutrient loading to the waterbodies in the watershed. Street cleaning would also reduce the loading of heavy metals and other toxicants associated with automobile use. Residents should avoid sweeping driveway silt and debris into storm drains. Rather, any sediment or debris collected during cleaning should be deposited in a solid waste container.

6.1.4 Campground Management

The management techniques described above for individual residential properties are also applicable to the campgrounds around Blue Lake. Eliminating or reducing fertilizer use, installing shoreline buffers, and preventing organic waste (yard, pet, and wildlife waste) from reaching the lake are important management steps that should be taken in the campground areas.

6.1.5 Residential and Commercial Development Erosion Control

There are many active residential developments currently in progress in the Blue Lake watershed. Additionally, areas immediately adjacent to Blue Lake continue to experience development pressure. Active construction sites are a common source of sediment to nearby waterways. Sediment loss from active construction sites can be several orders of magnitude greater than sediment loss from a completed subdivision or agricultural field. Use of appropriate erosion control management techniques on active construction sites is necessary to reduce pollutant loading to nearby waterbodies. During the watershed inspection, several areas were observed where the use of erosion control methods would have prevented or at least minimized the loss of sediment from the site. Of particular concern was a lot on Blue Lake's shoreline where either new development or remodeling was occurring. As seen in Figure 55, silt fencing was not utilized to contain dirt piles placed adjacent to the lake. While current regulations may not have required the use of silt fencing on this site (under new regulations, anyone planning to disturb more than an acre of land must file an erosion control plan with the State), the use of erosion control practices would certainly reduce the amount of sediment reaching Blue Lake from this site. Because water clarity has been indicated as one of the concerns in the public meeting held as a part of this study, the use of common erosion control practices are strongly recommended regardless of whether they are required by the State.

Figure 55. Development (or re-development) site along Blue Lake that appears to lack silt fencing to protect the lake or adjacent wetlands from on-site erosion.

6.1.6 Island Stabilization

Wave action from boating activity and wind is eroding the front side of the islands near the east end of Blue Lake. Based on aerial photographs from 1951, more than 0.5 acre of island has eroded off of the front side of the two islands over the past 55 years. The islands are vegetated with Kentucky blue grass and fescue (Figure 56) which provide very limited protection against wind and wave energy. A narrow bad of cattails covers the northern end of the north island closest to Maloney Ditch's outlet to Blue Lake. A plant bed dominated by rooted floating and submerged aquatic plants (American lotus, spatterdock, water lily, eel grass, coontail, and sago pondweed) borders these cattails and extends south along the northern island. The southern portion of the northern island and the entirety of the shoreline adjacent to the southern island are not protected by emergent or rooted floating vegetation. This has allowed waves from boating and wind activity to hit the shoreline eroding away the toe of the slope. Once the soil is exposed to the waves, erosion continues along the length of the island eventually collapsing entire sections of the islands. Because these islands will continue to be buffeted by wind and waves, steps should be taken to stabilize these shorelines and provide a wave break to protect the existing island frontage. A combination of hard structure, such as rock or porous pavers, and biological stabilization, like biologs or soil-encapsulated lifts, should be installed along the front of the two islands. Additionally, emergent and rooted floating vegetation should be cultivated in front of the islands to serve as a natural wave break. This vegetation will also serve as exemplary habitat for fish, amphibians, and reptiles.

Figure 56. Front and back side of island near the east end of Blue Lake. Shoreline erosion due to wind and wave action causes a portion of the island to erode into the lake annually.

6.1.7 Conservation Reserve Program

Some landowners in the Blue Lake watershed are currently enrolled in the Conservation Reserve Program (CRP), but increased participation in the program would benefit the lake's health. The CRP is a cost-share program designed to encourage landowners to remove a portion of their land from agriculture and establish vegetation on the land in an effort to reduce soil erosion, improve water quality, and enhance wildlife habitat. The CRP targets highly erodible land or land considered to be environmentally sensitive. The CRP provides funding for a wide array of conservation techniques including set-asides, filter strips (herbaceous), riparian buffer strips (woody), grassed waterways, and windbreaks. These techniques are particularly appropriate along surface drainages; however, they do not account for pollutants transported to the lake via subsurface drainage tiles.

Land that is removed from agricultural production and planted with herbaceous or woody vegetation benefits the health of aquatic ecosystems located down gradient of that property in a variety of ways. Woody and/or herbaceous vegetation on CRP land stabilizes the soil on the property, preventing its release off site. Vegetation on CRP land can also filter any runoff reaching it. More importantly, land set aside and planted to prairie or a multi-layer community (i.e. herbaceous, shrub, and tree layers) can help restore a watershed's natural hydrology. Rainwater infiltrates into the soil more readily on land covered with grasses and trees compared to land supporting row crops. This reduces the erosive potential of rain and decreases the volume of runoff. Multi-layer vegetative communities intercept rainwater at different levels, further reducing the erosive potential of rain and volume of runoff.

Given the ecological benefits that land enrolled in CRP provides, it is not surprising that removing land from production and planting it with vegetation has a positive impact on water quality. In a review of Indiana lakes sampled from 1989 to 1993 for the Indiana Clean Lakes Program, Jones

(1996) showed that lakes within ecoregions reporting higher percentages of cropland in CRP had lower mean trophic state index (TSI) scores. A lower TSI score is indicative of lower productivity and better water quality.

Specific areas where enrollment in CRP is recommended are shown in Figure 41. Each of these areas shares the some common characteristics: they are mapped in a highly erodible soil unit and are currently being utilized for agricultural production. Some of the areas shown in Figure 41 may already utilize grassed waterways under the CRP, but removal of a larger portion of these fields from agricultural production should be considered. Further, there may be other areas in the watershed that were not observable from the road during the windshield tour that may warrant consideration for enrollment in CRP.

6.1.8 Conservation Tillage

Removing land from agricultural production is not always feasible. Conservation tillage methods should be utilized on highly erodible agricultural land where removing land from production is not an option. Conservation tillage refers to several different tillage methods or systems that leave at least 30% of the soil covered with crop residue after planting (Holdren et al., 2001). Tillage methods encompassed by the phrase "conservation tillage" include no-till, mulch-till, and ridge-till. The crop residue that remains on the landscape helps reduce soil erosion and runoff water volume.

Several researchers have demonstrated the benefits of conservation tillage in reducing pollutant loading to streams and lakes. A comprehensive comparison of tillage systems showed that no-till results in 70% less herbicide runoff, 93% less erosion, and 69% less water runoff volume when compared to conventional tillage (Conservation Technology Information Center, 2000). Reductions in pesticide loading have also been reported (Olem and Flock, 1990). In his review of Indiana lakes, Jones (1996) documented lower mean lake trophic state index scores in ecoregions with higher percentages of conservation tillage. A lower TSI score is indicative of lower productivity and better water quality.

Although an evaluation of the exact percentage of watershed crop land on which producers were utilizing conservation tillage methods was beyond the scope of this study, use of conservation tillage on some of the agricultural land was noted during the windshield tour of the watershed. County-wide estimates from tillage transect data may serve as a reasonable estimate of the amount of crop land on which producers are utilizing conservation tillage methods in the Blue Lake watershed. County-wide tillage transect data for Whitley County provides an estimate for the portion of cropland in conservation tillage for the Blue Lake watershed. In Whitley County, soybean producers utilize no-till methods on 76% of soybean fields and some form of reduced tillage on 95% of soybean fields (IDNR, 2004b). Whitley County corn producers used no-till methods on 22% of corn fields and some form of reduced tillage on 72% of corn fields in production (IDNR, 2004a). The percentages of fields on which no-till methods were used in Whitley County were above the statewide median percentages for both soybean and corn production. Continued use of conservation tillage, particularly no-till conservation tillage, is recommended in the Blue Lake watershed. The areas targeted for CRP implementation noted above should be farmed using no-till methods if they are not already doing so and removal of the land from production is not a feasible option.

6.1.9 Streambank and Channel Stabilization and Restoration

Eroding banks add sediment directly to streams. Sediment can impair stream habitat by filling interstitial crevices in a stream's substrate and smothering spawning gravel. This will, in turn, negatively affect the stream's biota. Sediment from eroding stream banks is also transported downstream to the lakes in the watershed where it degrades the lake habitat and can impair recreational uses of the lake. Sediment deltas at lake mouths often support nuisance levels of rooted aquatic plants. Sediment deltas can also restrict boating in the area. Excess sediment in lakes reduces water clarity, particularly when it is stirred by boating activity. This is a major concern in Blue Lake.

Although much of Maloney Ditch is not visible from the roadside, one small area that may benefit from bank stabilization or restoration was identified during the windshield tour. Landowners living adjacent to Maloney Ditch and other drainages may be aware of additional stream bank areas in need of stabilization. In general, bioengineering techniques, which utilize vegetation to stabilize stream banks, are recommended to prevent stream bank erosion. Riprap or other hard armoring is not recommended since armoring only transfers the erosive energy downstream. Finding ways to infiltrate and store more water on the landscape before the water reaches the stream is more economical than trying to stabilize sections of the stream.

Figure 57 details the outlet of one of the drainages along the southern shoreline of Blue Lake. Streambank stabilization, wetland filter installation, or filter strip construction would likely reduce sediment and nutrient loading to Blue Lake from this drainage. The best option for treatment in this area is likely the installation of a wetland filter. The trees would need to be cleared from the banks, the streambanks regraded, and a variety of wetland plants installed within the channel. Current research suggests that the installation of wetlands can remove more than 80% of sediment and approximately 45% of nutrients (Metropolitan Washington Council of Governments, 1992; Claytor and Schueler, 1996; and Winer, 2000). However, if the individual landowner is reluctant to install a wetland filter, at a minimum, a rock lined culvert out fall and vegetated embankments should be installed at this site to reduce nutrient and sediment loading to the lake.

Figure 57. Area along one of the southern tributaries that would benefit from streambank stabilization and/or buffer installation.

6.1.10 Wetland Restoration

Visual observation and historical records indicate at least a portion of the Blue Lake watershed has been altered to increase its drainage capacity. The 1978 Census of Agriculture found that drainage is artificially enhanced on 45% of the land in Whitley County (cited in Hudak, 1995). Riser tiles in low spots on the landscape and tile outlets along the waterways in the Blue Lake watershed confirm the fact that the landscape has been hydrologically altered. Historical aerial photography shows that Blue Lake's shoreline has been hydrologically altered.

This hydrological alteration and subsequent loss of wetlands has implications for the watershed's water quality. Wetlands serve a vital role storing water and recharging the groundwater. When wetlands are drained with tiles, the stormwater reaching these wetlands is directed immediately to nearby ditches and streams. This increases the peak flow velocities and volumes in the ditch. The increase in flow velocities and volumes can in turn lead to increased stream bed and bank erosion, ultimately increasing sediment delivery to downstream water bodies. Wetlands also serve as nutrient sinks at times. The loss of wetlands can increase pollutant loads reaching nearby streams and downstream waterbodies.

Restoring wetlands in the Blue Lake watershed could return many of the functions that were lost when these wetlands were drained. Figure 44 shows the locations where wetland restoration is recommended. While other areas of the watershed could be restored to wetland conditions, the areas shown in Figure 44 were selected because they are areas where large scale restoration is possible.

6.1.11 Water Control Structure (Dam) Restoration

Concern has been raised over the status and condition of Blue Lake's water control structure (Figure 58). However, based on information provided in the last dam inspection report, the water control structure is in relatively good condition. The only items of concern noted during the inspection are the overgrowth of vegetation adjacent to the stream channel and the presence of an overabundance of beavers within the channel itself. The dam inspection report does note a spall, or large chunk of concrete, measuring 3 feet by 6 feet lying in front of the dam. Overall, the dam is noted as being in good conditions without any need for repair or replacement.

Figure 58. Blue Lake's water control structure (dam).

6.2 In-Lake Management
6.2.1 Boat Management
During multiple conversations, several watershed stakeholders expressed a concern over the potential ecological impact to Blue Lake from motor boats. The stakeholders also communicated a perceived increase in the number of boats using Blue Lake over the past few years since the installation of the concrete boat ramp in 1997. Although an assessment of the ecological impact of motor boating on Blue Lake's health was beyond the scope of this study, the scientific literature contains several studies documenting the effects of motor boating on lake health in general. A review of the potential ecological impacts of motor boating on lake health may be useful to understand how Blue Lake may be affected by this activity.

Water Clarity Concerns
One of the most common impacts associated with motor boating, and one of the primary concerns noted by Blue Lake stakeholders, is a decrease in water clarity. As motor boats travel through shallow water, the energy from movement of the boat propeller may be sufficient to resuspend sediment from the lake bottom, decreasing the lake's water clarity. Several researchers have documented either an increase in turbidity or a decrease in Secchi disk transparency during and following motor boat activity (Wagner, 1990; Asplund, 1996; Yousef et al., 1980). Crisman (1986) reports a decrease in Secchi disk transparency following holiday weekend use of Lake Maxinkuckee in Culver, Indiana. Asplund (1996) also observed poorer water clarity in his study lakes following weekend boating and that this decrease in water clarity is more pronounced in lakes with generally better water clarity. This finding is particularly significant for Blue Lake, since Blue Lake already possesses poorer water clarity than the typical Indiana lake.

The ability of a motor boat to resuspend sediment from the lake bottom depends on several factors. Some of these factors, such as boat length, motor size, and boat speed, are related to the boat itself and the boat's operator. Yousef et al. (1978) found that 10 horsepower (hp) motors were capable of mixing the water column to a depth of 6 feet (1.8 m), while 50 hp motors were capable of mixing the water column to a depth of 15 feet (4.6 m). While larger motor sizes have a greater potential to resuspend sediments than smaller motors, longer boats and higher speeds do not automatically translate to a greater ability to resuspend sediments. Boats that are 'planing' on the water actually have little impact on the lake's bottom. This is because the velocity of water at the lake bottom created by a motor boat depends on the boat's displacement, which is a function of boat length and speed. Beachler and Hill (2003) suggest that boat speeds in the range of 7 to 12 mph may have the greatest potential to resuspend sediment from the lake bottom. (This range is based on typical recreational boat length.)

Certain characteristics of lakes also influence the ability of motor boats to resuspend sediments. Shallow lakes are obviously more prone to water clarity degradation associated with motor boating than deeper lakes. Wagner (1990) suggests little impacts from motor boating are likely in water deeper than 10-15 feet (3.0-4.6 m). Lakes with soft fine sediments are more likely to suffer from sediment resuspension than lakes with coarser substrates. Lakes with extensive rooted plant coverage throughout the littoral zone are less prone to motor boat related resuspension problems than lakes with sparse vegetation since plants help hold the lake's bottom substrate in place.

Given this information, it is clear that some of Blue Lake's physical characteristics predispose it to water clarity problems associated with motor boating. Because Blue Lake residents petitioned IDNR for high speed boating, high speed boating is permissible on Blue Lake daily from 1 p.m. to 4 p.m. Consequently, the lake is likely to be a popular boating destination due to its close proximity to Fort Wayne, and boats are likely to, at least during some portion of the time, travel at the rate of speed (7 to 12 mph) suggested above to have the greatest potential to resuspend sediment from the lake bottom.

It is important to note that the decrease in water clarity is not usually permanent. Once motor boating activity ceases, resuspended materials will sink to the lake bottom again. However, this process can take several days. Wagner (1990) found that while turbidity levels steadily decreased following boating activity in his shallow study lakes, the turbidity had not returned to baseline levels even two days after the activity. Crisman (1986) found similar lags on Lake Maxinkuckee. Thus, Blue Lake residents may need to wait several days before their lake returns to its baseline clarity following heavy weekend motor boating use.

Other Potential Concerns

In addition to a decrease in water clarity, several other potential ecological impacts from motor boating exist. Various researchers have documented increased phosphorus concentrations, damage to rooted plants, changes in rooted plant distribution, and increased shoreline erosion associated with motor boating activity (Asplund, 1996; Asplund, 1997; Schloss, 1990; Yousef et al., 1980). Less commonly studied concerns include potential increases in heavy metal and hydrocarbon pollution, changes in algal populations, and impacts to lake fauna.

Just as the potential impact of motor boating on a lake's water clarity depends in large part to the specific characteristics of the lake, the potential for other ecological impacts associated with motor boating often depend on characteristics of the specific lake (Wagner, 1990). For example, Yousef et al. (1980) found increases in total phosphorus concentrations associated with motor boating activity in all his study lakes. However, only one of Wagner's study lakes showed an increase in phosphorus concentrations associated with motor boating activity. This lake possessed a nutrient rich, fine particle substrate. Similarly, Schloss (1990) reported greater increases in phosphorus concentrations due to motor boat activities in those New Hampshire lakes with high levels of internal phosphorus loading. New Hampshire lakes with lower levels of internal phosphorus loading were less likely to see large increases in phosphorus concentration associated with motor boat activity.

The lack of Eurasian watermilfoil within Blue Lake combined with an increase in off-lake motor boat users is a problem for Blue Lake. Since motor boats driven through stands of Eurasian watermilfoil have the potential to spread the invasive plant throughout a lake and catch pieces of the plant on propellers and in water in-take valves, this plant can be easily transferred from lake to lake. The species is already a nuisance to recreation in many northern Indiana lakes. The spread of the species will only further impair recreation. Increased growth of Eurasian watermilfoil might also result in the decline of some of the lake's more sensitive rooted plant species. Eurasian watermilfoil has the potential to shade out other native plants. This would reduce the diversity of rooted plants in the lake and could, in turn, adversely affect the lake's fish community.

Blue Lake's relatively long residence time means that any changes in the lake's water quality due to motor boating may have a greater impact on Blue Lake than they would in a lake with a shorter residence time. In lakes with very short hydraulic residence times (less than 2-3 months) water within the lake is constantly being replaced with new water from the watershed. Thus, any pollutants added to the water column from motor boating are quickly flushed from the lake. In lakes with longer residence times, like Blue Lake, these pollutants stay within the lake longer before being flushed.

Carrying Capacity

Boat density on a lake influences the magnitude of effect possible from motor boating activity. Typically, more power watercraft utilizing a lake results in a greater potential for ecological damage to the lake. While there is little or no documentation available on exactly how many motor boats a lake can support without impairing its ecological health, several researchers have tackled the question of how many motor boats a given lake can support at one time without compromising user safety or what is the lake's safety-related carrying capacity. This estimate of a lake's safety-related motor boat carrying capacity may be used as a surrogate for the lake's ecological-related motor boat carrying capacity. It is important to note that a lake's safety-related carrying capacity is not necessarily directly related to its ecological-related carrying capacity. There is a certain amount of subjectivity with respect to a lake's safety-related carrying capacity since some users will feel safer than others at different levels of congestion. However, a lake's safety-related carrying capacity may be the best approximation we have for a lake ecological-related carrying capacity.

Dudiack (2004) suggests a conservative estimate of a lake's motor boat carrying capacity is around 15-20 acres of usable lake per boat, while an estimate that allows a little more congestion is around 10-15 acres of usable lake per boat. (A lake's "usable" acreage usually refers to those areas that are obstruction free and have sufficient depth to support motor boating.) Applying this to Blue Lake, this suggests Blue Lake has a safety-related carrying capacity of 10 to 20 motor boats if 10 to 20 acres per boat is necessary for safety of the boat operators and other lake users. (This calculation assumes that the area of Blue Lake that is less than 5 feet (1.8 m) deep is not usable.) Interestingly, the boat survey conducted by the Blue Lake Association as part of this study (Table 14) indicated that on a normal summer day boats on Blue Lake have approximately 6 acres of public space. Additionally, the public launch area for Blue Lake has 12 to 20 parking spots depending on vehicle and trailer size. While certainly not every boat being launched from the public boat ramp is a motor boat, there is certainly the potential for concern. This does not even begin to account for the number of boats permanently moored at Blue Lake by residents. An exact count of residents boats was not completed as part of this study; however, it is estimated that more than 200 boats are present on permanent moorings around the lake (personal communication, Blue Lake Association).

Boat Management
It is clear from the preceding discussion, the management of boating, particularly motor boating, is necessary to ensure Blue Lake continues to be a healthy, functioning lake capable of providing recreation and aesthetic enjoyment for all users. However, "managing" boat use of any lake often entails limiting use of the lake in some way. This is highly contentious and different user groups will undoubtedly have differing opinions on the best course of management.

Despite this, development of a use management plan, which includes motor boat use and an investigation of the creation of eco-zones within the lake, are recommended for Blue Lake. The management plan or eco-zone needs to take into account Blue Lake's specific morphological and ecological characteristics noted above. For example, the plan might restrict boat speeds in areas less than 10 feet of depth to idle only. This would help reduce water clarity impacts. The plan should also consider safety issues. Likewise, the establishment of an eco-zone would restrict boat access to high quality plant beds or ecologically sensitive areas. Most importantly, the plan or eco-zone must be developed with input of all users (including non-residents). Finally, representatives from the IDNR Division of Fish and Wildlife and Division of Law Enforcement should be intimately involved in the development of any lake use management plan or the creation of an eco-zone. These divisions are responsible for the management of Blue Lake's resources and the enforcement of state laws with respect to use of Blue Lake.

6.2.2 Aquatic Plant Management
Development of an aquatic plant management plan is also a recommended in-lake management step for Blue Lake. Like a recreational use management plan, an aquatic plant management plan takes into account the lake's current and historical ecological condition as well as the recreational desires of the lake's user groups. The following is a list of recommendations that should form the foundation of any aquatic plant management plan for Blue Lake. Lake users should remember that rooted plants are a vital part of a healthy functioning lake ecosystem; complete eradication of rooted plants is neither desirable nor feasible. A good aquatic plant management plan will reflect these facts.

1. Blue Lake's high rooted plant diversity and high quality plant species should be protected. The lake supports excellent rooted plant diversity and this undoubtedly plays a role in supporting its healthy fishery. Management techniques that are not species specific, such as contact herbicides or large scale harvesting, should be avoided to ensure the protection of the high quality community.

2. Blue Lake residents should take steps to restore the lake's shoreline vegetation. Currently, some of the developed portion of the lake's shoreline lacks a healthy emergent plant population (Figure 59). In other areas, residents utilize exotic species like purple loosestrife and reed canary grass in landscaping adjacent to the lake. Removal of these species and restoration of the shoreline would return many of the functions provided by healthy riparian

areas. A more detailed discussion of shoreline functions and restoration techniques was provided above in the **Individual Property Management** Section.

Figure 59. Representative area along Blue Lake's shoreline that would benefit from shoreline restoration.

3. Blue Lake residents should investigate spot treatment options for areas where aquatic plants are especially dense or occur in nuisance stands. Specific areas include the dense eel grass and coontail along the northern shoreline of Blue Lake in Beds 02 and 03 (Figure 60) and dense coontail and filamentous algae in Horseshoe Bay (Bed 07). Spot treatment within these areas will likely improve travel through these areas and increase individual resident's ability to utilize their shoreline. Additional treatment history indicates that curly-leaf pondweed and Eurasian watermilfoil reach nuisance levels in various locations within the lake. However, at the time of the current survey, curly-leaf pondweed was found in low density throughout the lake, while Eurasian watermilfoil was not identified at any location within the lake. Curly-leaf pondweed typically reaches its greatest density early in the growing season; therefore, its lack of dominance at the time of the assessment is not surprising. If individual residents in these areas feel that the amount of plant growth in front of their property is limiting the recreational potential of the lake, these residents might consider management techniques such as hand harvesting of plant material, spot treatment of aquatic vegetation, or the use of bottom covers. Please be aware that permits may be required for these activities. Residents should consult with the IDNR Division of Fish and Wildlife before implementing any of these management methods. If hand harvesting is utilized as a treatment method, residents need to remove the plant material from the lake rather than allowing it to remain in the lake, float to other areas, and re-root. Additionally, plants should not be left along the shoreline or piled on adjacent sea walls (Figure 61). The nutrients from the plants return to the water through decomposition and decay. This is an additional source

of nutrient loading to the lake. An educational program highlighting the benefits a healthy plant community, including emergent species, might help residents make informed decisions on balancing their desire for relatively plant-free water in front of their property with the desire for a healthy, productive fish community in the lakes.

Figure 60. Example of the density of eel grass along the north shoreline of Blue Lake.

Figure 61. Plants drying on a concrete seawall adjacent to Blue Lake. This provides a great example of spot treating the plant community at this particular residence.

4. Residents should take action to protect their lake from Eurasian watermilfoil. Given Blue Lake's proximity to Fort Wayne and its popularity as an afternoon recreation location, the fact that it is not currently infested with Eurasian watermilfoil is of special note. Eurasian watermilfoil offers poor habitat to the lake's biota and often interferes with recreational uses of the lake. Creating an inspection or boat washing facility would likely be the best option to prevent the infestation of the lake with Eurasian watermilfoil. Furthermore, lake users should also educate themselves on Eurasian watermilfoil. Taking precautionary measures such as ensuring that all plant material is removed from their boat propellers following their use prevents the spread of the species. Lake users should also refrain from boating through stands of Eurasian watermilfoil in other lakes. Pieces of the plant as small as one inch in length that are cut by a boat propeller as it moves through a stand of Eurasian watermilfoil can sprout and establish a new plant. Signage at the public boat ramp informing visitors of these best management practices would also be useful. It is important to note that IDNR approval is required to post any signs at the public boat ramp.

A good aquatic plant management plan includes a variety of management techniques applicable to different parts of a lake depending on the lake's water quality, the characteristics of the plant community in different parts of the lake, and lake users' goals for different parts of the lake. Many aquatic plant management techniques, including chemical control, harvesting, and biological control, require a permit form the IDNR. Depending on the size and location of the treatment area, even individual residents may need a permit to conduct a treatment. Residents should contact the IDNR Division of Fish and Wildlife before conducting any treatment. The following paragraphs describe some aquatic plant management techniques that may be applicable to Blue Lake, given its specific ecological condition.

Chemical Control

Herbicides are the most traditional means of controlling aquatic vegetation. Herbicides have been used in the past on Blue Lake. In 2005, the Indiana Department of Natural Resources, Division of Fish and Wildlife issued permits to two chemical applicators for treatment of three locations along Blue Lake's shoreline (Ed Braun, personal communication, and DNR permit files). One commercial applicator treated two areas totaling 2.37 acres (0.95 ha) along the northeastern and southwestern shorelines to control Eurasian watermilfoil and curly-leaf pondweed. Because of its value to fish, the Division of Fish and Wildlife restricted treatment in dense areas of large-leaf pondweed. The other commercial applicator received a permit to treat one area totaling 0.45 acre (0.2 ha). The treatment area was located along the lake's northwestern shoreline. The applicator targeted Eurasian watermilfoil, curly-leaf pondweed, coontail, and filamentous algae. Neither applicator intended to treat plants in water deeper than 5 feet (1.5 m), according to their permit applications. Both applicators applied for permits to treat the similar locations in 2002 and 2003. However, treatment in 2003 covered approximately 18.3 acres (7.4 ha) and included treatment in beds containing the state-listed species Richardson's pondweed (*Potamogeton richardsonii*) as well as large-leaf pondweed, curly-leaf pondweed, and Eurasian watermilfoil. This treatment covered much of the northern, eastern, and southern shorelines of the lake. According to the permit application, the plants were treated to a depth of 7 feet (2.8 ha). (IDNR records beyond that date were not requested, but it is likely that the same areas receive routine treatment.)

It is likely that some residents may have conducted their own spot treatments around piers and swimming areas. It is important for residents to remember that any chemical herbicide treatment program should always be developed with the help of a certified applicator who is familiar with the water chemistry of the target lake. In addition, application of a chemical herbicide may require a permit from the IDNR, depending on the size and location of the treatment area. Information on permit requirements is available from the IDNR Division of Fish and Wildlife or conservation officers.

Herbicides vary in their specificity to given plants, method of application, residence time in the water, and the use restrictions for the water during and after treatments. Herbicides (and algaecides; chara is an algae) that are non-specific and require whole lake applications to work are generally not recommended. Such herbicides can kill non-target plants and sometimes even fish species in a lake. Costs of an herbicide treatment vary from lake to lake depending upon the type of plant species present in the lake, the size of the lake, access availability to the lake, the water chemistry of the lake, and other factors. Typically in northern Indiana, costs for treatment range from $300 to $400 per acre or $750 to $1000 per hectare (Cecil Rich, IDNR, personal communication).

While providing a short-term fix to the nuisances caused by aquatic vegetation, chemical control is not a lake restoration technique. Herbicide and algaecide treatments do not address the reasons why there is an aquatic plant problem, and treatments need to be repeated each year to obtain the desired control. In addition, some studies have shown that long-term use of copper sulfate (algaecide) has negatively impacted some lake ecosystems. Such impacts include an increase in sediment toxicity, increased tolerance of some algae species, including some blue-green (nuisance) species, to copper sulfate, increased internal cycling of nutrients, and some negative impacts on fish and other members of the food chain (Hanson and Stefan, 1984 cited in Olem and Flock, 1990).

Chemical treatment should be used with caution on Blue Lake since treated plants are often left to decay in the water. This will contribute nutrients to the lake's water column. Additionally, plants left to decay in the water column will consume oxygen. The in-lake sampling conducted during this study showed that Blue Lake possessed relatively high nutrient concentrations compared to many Indiana lakes. As evidenced during the plant survey, the lake's total phosphorus concentration is high enough to support filamentous algae and based on the water chemistry samples collected during the in-lake assessment may also experience algal blooms. The plankton community present in Blue Lake further iterates this issue in that the community is dominated by blue-green algae. Furthermore, the blue-green algae that comprised the largest portion of the plankton community have been known to cause taste, odor, and toxicity problems in other lakes. Spot chemical treatments are recommended only for patches of curly-leaf pondweed or Eurasian watermilfoil, if Eurasian watermilfoil appears in the lake in the future.

Mechanical Harvesting

Harvesting involves the physical removal of vegetation from lakes. Harvesting should also be viewed as a short-term management strategy. Like chemical control, harvesting needs to be repeated yearly and sometimes several times within the same year. (Some carry-over from the previous year has occurred in certain lakes.) Despite this, harvesting is often an attractive management technique because it can provide lake users with immediate access to areas and activities that have been affected by excessive plant growth. Mechanical harvesting is also beneficial in situations where removal of plant biomass will improve a lake's water chemistry. (Chemical control leaves dead plant biomass in the lake to decay and consume valuable oxygen.)

Macrophyte response to harvesting often depends upon the species of plant and particular way in which the management technique is performed. Pondweeds, which rely on sexual reproduction for propagation, can be managed successfully through harvesting. However, many harvested plants, especially milfoil, can re-root or reproduce vegetatively from the cut pieces left in the water. Plants harvested several times during the growing season, especially late in the season, often grow more slowly the following season (Cooke et al., 1993). Harvesting plants at their roots is usually more effective than harvesting higher up on their stems (Olem and Flock, 1990). This is especially true with Eurasian watermilfoil and curly leaf pondweed. Benefits are also derived if the cut plants and the nutrients they contain are removed from the lake. Harvested vegetation that is cut and left in the lake ultimately decomposes, contributing nutrients and consuming oxygen.

Hand harvesting may be the most economical means of harvesting on Blue Lake. Hand harvesting is recommended in small areas where human uses are hampered by extensive growths (docks, piers, beaches, boat ramps). In these small areas, plants can be efficiently cut and removed from the lake with hand cutters such as the Aqua Weed Cutter (Figure 62). In less than one hour every 2-3 weeks, a homeowner can harvest 'weeds' from along docks and piers. Depending on the model, hand-harvesting equipment for smaller areas cost from $50 to $1500 (McComas, 1993). To reduce the cost, several homeowners can invest together in such a cutter. Alternatively, a lake association may purchase one for its members. This sharing has worked on other Indiana lakes with aquatic plant problems. Use of a hand harvester is more efficient and quick-acting, and less toxic for small areas than spot herbicide treatments. Depending on the size to be treated, a permit may be required for hand-harvesting. (The IDNR Division of Fish & Wildlife can assist lake residents in determining whether a permit is needed and how to obtain one.)

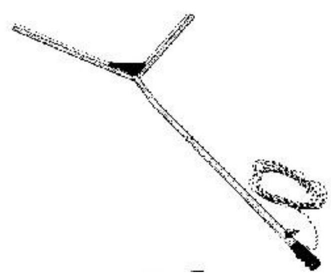

Figure 62. An aquatic weed cutter designed to cut emergent weeds along the edge of ponds. It has a 48" cutting width, uses heavy-duty stainless steel blades, can be sharpened, and comes with an attached 20' rope and blade covers.

Biological Control
Biological control involves the use of one species to control another species. Often when a plant species that is native to another part of the world is introduced to a new country with suitable habitat, it grows rapidly because its native predators have not been introduced to the new country along with the plant species. This is the case with some of the common pest plants in northeast Indiana such as Eurasian watermilfoil and purple loosestrife. Neither of these species is native to Indiana, yet both exist in and around Whitley County.

Researchers have studied the ability of various insect species to control both Eurasian watermilfoil and purple loosestrife. Cooke et al. (1993) points to four different species that may reduce Eurasian watermilfoil infestations: *Triaenodes tarda*, a caddisfly, *Cricotopus myriophylii*, a midge, *Acentria nivea*, a moth and *Litodactylus leucogaster*, a weevil. Recent research efforts have focused on the potential for *Euhrychiopsis lecontei*, a native weevil, to control Eurasian watermilfoil. Purple loosestrife biocontrol researchers have examined the potential for three insects, *Gallerucella calmariensis, G. pusilla*, and *Hylobius transversovittatus,* to control the plant.

While the population of purple loosestrife on Blue Lake is relatively small and therefore may not be suitable for biological control efforts, it may be worthwhile for Blue Lake residents to understand the common biocontrol mechanisms for this species should the situation on the lake change. Likewise, although Eurasian watermilfoil does not currently exist in Blue Lake the lake's proximity to Fort Wayne and the number of off-lake boaters indicate that residents should be cognizant of infestation issues and biocontrol mechanisms for Eurasian watermilfoil. Therefore, treatment options for the plant are discussed below merely as reference material for use in case of future infestation. Residents should also be aware that under new regulations an IDNR permit is required for the implementation of a biological control program on a lake.

Eurasian Watermilfoil

Euhrychiopsis lecontei has been implicated in a reduction of Eurasian watermilfoil in several Northeastern and Midwestern lakes (USEPA, 1997). *E. lecontei* weevils reduce milfoil biomass by two means: one, both adult and larval stages of the weevil eat different portions of the plant and two, tunneling by weevil larvae cause the plant to lose buoyancy and collapse, limiting its ability to reach sunlight. The weevils' actions also cut off the flow of carbohydrates to the plant's root crowns impairing the plant's ability to store carbohydrates for over wintering (Madsen, 2000). Techniques for rearing and releasing the weevil in lakes have been developed and under appropriate conditions, use of the weevil has produced good results in reducing Eurasian watermilfoil. A nine-year study of nine southeastern Wisconsin lakes suggested that weevil activity might have contributed to Eurasian watermilfoil declines in the lakes (Helsel et al, 1999).

Cost effectiveness and environmental safety are among the advantages to using the weevil rather than traditional herbicides in controlling Eurasian watermilfoil (Christina Brant, EnviroScience, personal communication). Cost advantages include the weevil's low maintenance and long-term effectiveness versus the annual application of an herbicide. In addition, use of the weevil does not have use restrictions that are required with some chemical herbicides. Use of the weevil has a few drawbacks. The most important one to note is that reductions in Eurasian watermilfoil are seen over the course of several years in contrast to the immediate response seen with traditional herbicides. Therefore, lake residents need to be patient. Additionally, the weevils require natural shorelines for over-wintering.

The Indiana Department of Natural Resources released *E. lecontei* weevils in three Indiana lakes to evaluate the effectiveness of utilizing the weevils to control Eurasian watermilfoil in Indiana lakes. The results of this study were inconclusive (Scribailo and Alix, 2003), and the IDNR considers the use of the weevils on Indiana lakes an unproven technique and only experimental (Rich, 2005). If future infestation of Eurasian watermilfoil should occur, Blue Lake residents should take the lack of proven usefulness in Indiana lakes into consideration before attempting treatment of the lake's Eurasian watermilfoil with the *E. lecontei* weevils.

Purple Loosestrife

Biological control may also be possible for inhibiting the growth and spread of the emergent purple loosestrife. Like Eurasian watermilfoil, purple loosestrife is an aggressive non-native species. Once purple loosestrife becomes established in an area, the species will readily spread and take over the shallow water and moist soil environment, excluding many of the native species which are more valuable to wildlife. Conventional control methods including mowing, herbicide applications, and prescribed burning have been unsuccessful in controlling purple loosestrife.

Some control has been achieved through the use of several insects. A pilot project in Ontario, Canada reported a decrease of 95% of the purple loosestrife population from the pretreatment population (Cornell Cooperative Extension, 1996). Four different insects were utilized to achieve this control. These insects have been identified as natural predators of purple loosestrife in its native habitat. Two of the insects specialize on the leaves, defoliating a plant (*Gallerucella calmariensis* and *G. pusilla*), one specializes on the flower, while one eats the roots of the plant (*Hylobius transversovittatus*). Insect releases in Indiana to date have had mixed results. After six years, the loosestrife of Fish Lake in LaPorte County is showing signs of deterioration.

Like biological control of Eurasian watermilfoil, use of purple loosestrife predators offers a cost-effective means for achieving long-term control of the plant. Complete eradication of the plant cannot be achieved through use of a biological control. Insect (predator) populations will follow the plant (prey) populations. As the population of the plant decreases, so will the population of the insect since their food source is decreasing.

Bottom Covers

Bottom shading by covering bottom sediments with fiberglass or plastic sheeting materials provides a physical barrier to macrophyte growth. Buoyancy and permeability are key characteristics of the various sheeting materials. Buoyant materials (polyethylene and polypropylene) are generally more difficult to apply and must be weighted down. Unfortunately, sand or gravel anchors used to hold buoyant materials in place can act as substrate for new macrophyte growth. Any bottom cover materials placed on the lake bottom must be permeable to allow gases to escape from the sediments; gas escape holes must be cut in impermeable liners. Commercially available sheets made of fiberglass-coated screen, coated polypropylene, and synthetic rubber are non-buoyant and allow gases to escape, but cost more (up to $66,000 per acre or $163,000 per hectare for materials, Cooke and Kennedy, 1989). Indiana regulations specifically prohibit the use of bottom covering material as a base for beaches.

Due to the prohibitive cost of the sheeting materials, sediment covering is recommended for only small portions of lakes, such as around docks, beaches, or boat mooring areas. This technique may be ineffective in areas of high sedimentation, since sediment accumulated on the sheeting material provides a substrate for macrophyte growth. The IDNR requires a permit for any permanent structure on the lake bottom, including anchored sheeting.

Preventive Measures

Preventive measures are necessary to curb the spread of nuisance aquatic vegetation. Although milfoil is thought to ‘hitchhike’ on the feet and feathers of waterfowl as they move from infected to uninfected waters, the greatest threat of spreading this invasive plant is humans. Plant fragments snag on boat motors and trailers as boats are hauled out of lakes (Figure 63). Milfoil, for example, can survive for up to a week in this state; it can then infect a milfoil-free lake when the boat and trailer are launched next. It is important to educate boaters to clean their boats and trailers of all plant fragments each time they retrieve them from a lake.

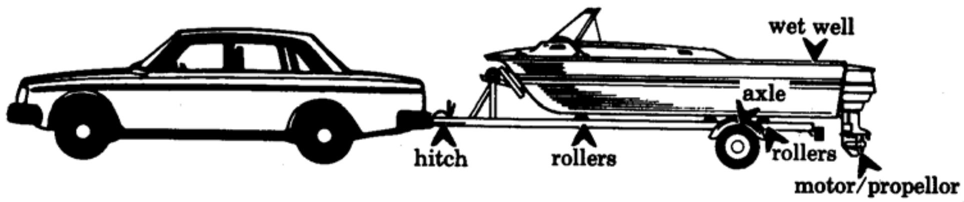

Figure 63. Locations where aquatic macrophytes are often found on boats and trailers.

Educational programs are effective ways to manage and prevent the spread of aquatic nuisance species (ANS) such as Eurasian watermilfoil, zebra mussels, and others. Of particular help are signs at boat launch ramps asking boaters to check their boats and trailers both before launching and after retrieval. All plants should be removed and disposed of in refuse containers where they cannot make their way back into the lake. The Illinois-Indiana Sea Grant Program has examples of boat ramp signs and other educational materials that can be used at Blue Lake. Eurasian watermilfoil does not currently exist in Blue Lake; therefore, educational programs and lake signage will help prevent the spread of this nuisance species into the lake. This is particularly important given the popularity of Blue Lake. Non-resident anglers and other visitors will use their boats in other lakes in addition to Blue Lake, potentially spreading Eurasian watermilfoil to uninfested lakes like Blue Lake. Signs addressing any best management practices to prevent the spread of nuisance aquatic species will ultimately help protect all lakes as new nuisance (often non-native) species are finding their way to Indiana lakes all the time.

6.2.3 Dredging

Sediment removal by dredging removes phosphorus enriched sediments from lake bottoms, thereby reducing the likelihood of phosphorus release from the sediments. Dredging also deepens lakes for recreational purposes and limits the growth area for rooted macrophytes. Because this technique is capital-intensive, it can only be justified in small lakes or in lakes where the sediment-bound phosphorus is limited to a small, identifiable area. Dredging is not effective in lakes where additional sediment loading cannot be controlled. Sediment removal might be justified in a seepage lake, where watershed controls are not applicable. Furthermore, the use of dredging as a plant control technique may not be completely effective considering that dredged areas may be recolonized by nuisance exotic species.

A potentially troublesome consequence of dredging is the resuspension of sediments during the dredging operation and the possible release of toxic substances bound loosely to sediments. Because of this, sediment cores must be analyzed prior to dredging to determine sediment composition. Such an analysis would also provide a profile of phosphorus concentrations with depth in the sediments. If phosphorus concentrations do not decline with depth, dredging for phosphorus control would not be effective since phosphorus could continue to be released from the sediments.

Cost must be carefully evaluated before dredging operations occur. In deep lakes, the cost of dredging can be prohibitive. In small lakes, it may be easier and more cost-effective to dewater the lake and remove sediments with front end loaders and trucks. Perhaps the most economically and logistically prohibitive part of a dredging operation is disposal of the removed sediments. Sediment disposal must be investigated *before* the decision to dredge can be made. Dredging costs range from $25,000 to $30,000 per acre (JFNew, 2005a; JFNew, 2005c). This estimate excludes any administrative costs associated with dredging. Any dredging activities in a freshwater public lake will require permits from the Corps of Engineers, the Indiana Department of Environmental Management, and Indiana Department of Natural Resources, further increasing the cost of dredging.

Dredging should not be the first priority to resolve nutrient problems in Blue Lake. After the association addresses sediment and nutrient loading issues within the watershed, a sediment removal plan should be completed. Under the Lake and River Enhancement sediment removal program, applicants have to complete a sediment removal plan in order to qualify for funding. Lake and River Enhancement program staff indicate that lake associations that have targeted watershed issues to reduce sediment and nutrient loading will receive higher priority for sediment removal funding. After addressing these issues, completing a sediment removal plan would be the ideal avenue for understanding dredging needs on the lakes. The Blue Lake Association has already identified areas where recreation is impaired and dredging may be a solution. These areas include the mouth of Maloney Ditch, the channels flowing behind the islands on the east end of the lake, and the mouths of several other drainage channels. Before any dredging or sediment removal planning begins, the Blue Lake Association should consult with local IDNR fisheries biologists to determine if dredging of desired areas is feasible.

6.2.4 Alum Treatment

Phosphorus precipitation and inactivation is designed to remove phosphorus from the water column *and* to prevent release of phosphorus from sediments. This nutrient control strategy is aimed at minimizing plank tonic algal growth. The treatment involves adding aluminum salts to the lake. These salts form a floc or an agglomeration of small particles. This floc (e.g. $Al(OH)_3$) acts in two ways: (a) it attracts (or adsorbs) phosphorus from the water column as it settles, and (b) it seals the bottom sediments if a thick enough layer has been deposited. Phosphorus can also precipitate out as an aluminum salt (e.g. $AlPO_4$).

Most phosphorus precipitation treatments employ liquid aluminum sulfate (alum) or sodium aluminate. The dosages are determined by a standard jar test, keeping in mind that aluminum solubility is lowest in the pH range of 6.0 to 8.0. Cooke et al. (2005) offer a detailed dose determination method. Aluminum toxicity does not appear to be a problem at treatment concentrations in well-buffered lakes as long as the pH of the water remains above 6.0. Chemicals added for phosphorus control are applied either to the lake surface or to the hypolimnion, depending upon whether water column or sediment phosphorus control is most necessary.

The application procedure of aluminum salts to lake water has changed little since the first treatment in Horseshoe Lake, Wisconsin (Peterson et al., 1973). At Horseshoe Lake, alum slurry was pumped from a barge through a manifold pipe that trailed behind the vessel just below, and perpendicular to, the water surface. Today, new LORAN-guided high-speed barges applying 75,000 gallons of liquid alum per day are the most advanced application vessels available (Eberhardt, 2005)

The season of application is critical for phosphorus removal, since different forms of phosphorus predominate in the water column on a seasonal basis. Phosphorus removal is most effective in early spring or late fall when most phosphorus is in a dissolved (inorganic) form that can be removed almost entirely by the floc.

Phosphorus precipitation and inactivation is most effective in lakes with long hydraulic residence times and low watershed phosphorus loading (Holdren et al., 2001). In lakes with short residence times, new water from the watershed is continually replacing the water in a lake basin. If this water contains a high phosphorus load, the new phosphorus immediately replaces the phosphorus that was precipitated out of the water column. This new phosphorus also promotes the growth of algae and rooted plants. When these organisms die and sink to the lake's bottom, they form a new sediment layer over the alum treatment's seal. The seal is not able to prevent the release of phosphorus from the dead organisms that have settled on top of it.

Regardless of the lake hydraulic residence time, decomposition of aquatic organisms and sedimentation will naturally occur within a lake. This may limit the alum treatment's effectiveness to approximately five to ten years (Holdren et al., 2001). In some lakes, the phosphorus inactivation has been effective for as long as eighteen years. The treatment's expected length of effectiveness should always be weighed against its cost. Costs vary depending upon the location and size of lake, type of applicator barge utilized for treatment, and other factors. Cooke et al. (2005) report a cost of approximately $2,070 per acre ($838/ha) using a newer (faster) barge applicator.

An alum treatment should always be performed by an experienced applicator. An experienced applicator will test chemical conditions in the lake to ensure parameters are within ranges necessary to attempt a treatment (i.e. sufficient buffering capacity and water hardness). In addition, an experienced applicator will monitor the lake during treatment to ensure that the pH of the lake does not fall below 5.5-6.0. Below this pH range, conditions are appropriate for the formation of Al^{3+}, which is toxic to many organisms.

Cooke et al. (2005) outline several of the potential drawbacks to alum treatments. These include the potential for increased rooted plant growth. As phosphorus that was once available for algae growth is removed from the water column, algae growth is reduced. This may increase water transparency. Increased water clarity allows for greater light penetration which could enhance rooted plant growth. Food chain impacts from the immediate reduction of algae could also affect a lake's fishery. Finally, the toxicity of aluminum even in neutral or basic conditions (pH >7) is of some concern to researchers.

Blue Lake is a prime candidate for an alum treatment in the future. The internal load of phosphorus that results from Blue Lake's anoxic hypolimnion represents another source of nutrient enrichment that must be addressed for the long-term health of the lake. For now, the released phosphorus only reaches the surface waters (where the algae are) during spring and fall turnover or, in other words, at times when algal growth is limited due to cool temperatures and low seasonal light. Over time, the epilimnetic phosphorus concentration in Blue Lake will gradually increase, eventually reaching the point where regular and persistent algae blooms are the norm.

6.2.5 Water Quality Monitoring

The Indiana Clean Lakes Volunteer Monitoring Program trains and equips citizen volunteers to measure Secchi disk transparency, water color, total phosphorus, and chlorophyll *a* in Indiana lakes. Citizen volunteers monitor over 115 lakes for transparency and 40 lakes for phosphorus and chlorophyll. Volunteers also have access to temperature and oxygen meters to track changes in these parameters throughout the year. Data collected by volunteers helps elucidate any trends in water quality and provides more timely information with which lake management decisions can be made. Blue Lake has not participated in this program in the past and should consider options for a citizen volunteer. Participation in the Indiana Clean Lakes Volunteer Monitoring Program is highly recommended.

6.2.6 Fisheries Management

Monitor the gizzard shad population directly through casual observations and indirectly through any perceived decrease in bluegill and largemouth bass abundance. Because Blue Lake is a eutrophic lake with extensive aquatic vegetation cover, gizzard shad may not come to dominate the fish community (Allen et al., 1999; Michaletz and Bonneau, 2005), however, it is an issue of concern that lake stakeholders should follow closely. If there is a decrease in the recreational fishery in the future, potentially due to gizzard shad, there are several management options. The simplest would be to institute a minimum size regulation for largemouth bass to encourage increased predation on gizzard shad. Stocking of other large predators such as walleye (*Sander vitreus*) or an esocid species such as muskellunge (*Esox masquinongy*) is another option, although it is more complicated and might require stringent harvest regulations.

7.0 RECOMMENDATIONS

As noted in the previous section, Blue Lake currently possesses poor water quality. However, negative effects from the elevated nutrient concentrations do not seem to be fully realized within Blue Lake. The biotic communities (algae, plants, fish) have not yet begun to exhibit the characteristics typically observed within lakes which possess nutrient concentrations as high as those present in Blue Lake. It is unlikely that the lake can continue to absorb the pollutant load reaching the lake. Results from the modeling and lake and stream assessments indicate that current pollutant concentrations and loads, particularly phosphorus, nitrate, organic matter, and bacteria, are of concern for the lake's long-term health. Lake residents have already noted declines in water clarity following heavy boating activity or after storm events, suggesting sediment is also of concern. Many residents have also observed negative shifts in the lake's rooted plant composition and density.

Given the Blue Lake's specific characteristics, both in-lake and watershed management is recommended to maintain the lake's good water quality. Blue Lake's low watershed area to lake area ratio suggests actions taken along the shoreline and immediate watershed can have a significant impact of the lake's health. Thus, management of near shore drainages and ravines, individual residential properties, and campground areas should be prioritized. The lake's relatively long hydraulic residence time means in-lake management, which can affect nutrient cycling, should also receive a high priority. Watershed management techniques to reduce the high phosphorus and bacteria levels observed in Maloney Ditch are also important but should receive a lower priority since flow in Maloney Ditch is often intermittent.

The following list summarizes the recommendations for maintaining and improving Blue Lake's chemical, biological, and physical condition. The recommendations are separated in two groups based on priority described above. Recommendations in the first group are of higher priority than recommendations in the second group since implementation of these recommendations would provide greatest benefit to Blue Lake. Implementation of recommendations in the second group is, however, important and should not be ignored. Each of the following recommendations should be implemented and will help improve Blue Lake's water quality.

The list is prioritized based on the current ecological conditions of Blue Lake and its watershed. These conditions may change as land and lake use change requiring a change in the order of prioritization. Watershed stakeholders may also wish to prioritize these management recommendations differently to accommodate specific needs or desired uses of the lake. It is important for watershed stakeholders to know that actions need not be taken in this order. Some of the smaller, less expensive recommendations, such as the individual property owner recommendations, may be implemented while funds are being raised to implement some of the larger projects. (Appendix H provides a list of possible funding sources to implement recommended projects.) Many of the larger projects will require feasibility studies to ensure landowner willingness to participate in the project and regulatory approval of the project.

Primary recommendations

1. Reduce the transport of sediment and sediment-attached pollutants from the small drainages along the southern shoreline of Blue Lake. Stabilize these channels or ravines by reducing the amount of water reaching the channels or ravines and slowing the velocity of water that does reach the ravine. Consider the installation of sediment traps and check dams in ravines where erosion is most severe.

2. Implement the minor projects mapped in Figure 44. These include driveway stabilization along Harrold Place and wetland filter installation at the outlet of Subwatershed E. The Blue Lake Association should apply for a LARE-funded Engineering Feasibility Study to determine the feasibility for addressing channel and ravine erosion as well as opportunities for driveway stabilization and wetland filter installation along the lake's southern shoreline.

3. Address the sewer overflow/emergency shutoff problem which results in raw sewage overflowing into the agricultural field behind the Conservation Club building. Work with the design engineer to correct this issue as it may be one of the highest sources of nutrient and pathogenic contamination to the lake.

4. Implement individual property owner management techniques. These apply to all watershed property owners rather than simply those who live immediately adjacent to Blue Lake.
   a. Reduce the frequency and amount of fertilizer and herbicide/pesticide used for lawn care.
   b. Use only phosphorus-free fertilizer. (This means that the middle number on the fertilizer package listing the nutrient ratio, nitrogen:phosphorus:potassium is 0.)
   c. Consider re-landscaping lawn edges, particularly those along the watershed's lakes and streams, to include plant species that are capable of filtering runoff water better than turf grass. This is especially important on properties adjacent to Blue Lake where exotic, invasive species are currently used as landscaping materials.
   d. Consider planting native emergent vegetation along shorelines or in front of existing seawalls to provide fish and invertebrate habitat and dampen wave energy. Additionally, consider replacing concrete seawalls with glacial stone seawalls.
   e. Keep organic debris like lawn clippings, leaves, and animal waste out of the water.
   f. Properly maintain septic systems. Systems should be pumped regularly and leach fields should be properly cared for.
   g. Examine all drains that lead from roads, driveways, or rooftops to the watershed's lake and/or streams; consider alternate routes for these drains that would filter pollutants before they reach the water. Stabilize bare drainage ditches with vegetation where possible or rock where flow rates are too high for vegetation.
   h. Obey no-wake zones.
   i. Clean boat propellers after lake use and refrain from dumping bait buckets into the lake to prevent the spread of non-native and invasive species.

5. Stabilize and revegetate the lakeward side of the islands along the lake's east end.

6. With the help of the Indiana Department of Natural Resources, manage the boating activity on Blue Lake. The best way to do this may be to develop a recreational use management plan for the lake that considers the needs of the users and the ecological limitations of the lake. This plan should include an aquatic plant management component since aquatic plant management is inextricably linked with recreational use management. The need for eco-zones on the lake should be investigated during the development of any management plan.

7. Minimize the impact of exotic species on the lake. Eurasian watermilfoil was not present during the current assessment of the lake. However, recent herbicide permit applications indicate that both Eurasian watermilfoil and curly-leaf pondweed can be a problem in Blue Lake. Special care should be taken to prevent the spread of these species and protect the diverse, native submerged rooted plant community.

8. Post informational signage at the boat launch on Blue Lake to inform lake users of best management practices to prevent the spread of aquatic nuisance species, particularly Eurasian watermilfoil, curly-leaf pondweed, and zebra mussels. Any signage posted at a public boat launch requires permission from the IDNR Division of Fish and Wildlife.

9. Monitor and improve erosion control techniques on residential and commercial development sites. Bring areas of concern to appropriate authorities.

10. Become an active volunteer in the Indiana Clean Lakes Program volunteer monitoring program. Blue Lake has never had a volunteer in the past. Volunteer monitoring is easy and does not take much time. The CLP staff provides the training and equipment needed to participate in the program. The data collected by the volunteer monitor will be extremely useful in tracking long-term trends in the lake water quality and measuring the success of any restoration measures implemented in the watershed.

Secondary Recommendations

11. Work with the Whitley County Health Department to determine the cause of the extremely high E. coli concentration observed in Maloney Ditch during the base flow event. Potential sources of the bacteria include a failing septic system, illicit discharges, wildlife, and livestock.

12. Increase usage of the Conservation Reserve Program in the Blue Lake watershed particularly on land mapped in highly erodible soils.

13. Restore wetland habitat within the Blue Lake watershed where feasible. Figure 44 shows areas that are good candidates for wetland restoration.

14. Stabilize Maloney Ditch's banks in the location shown in Figure 44 and any other areas identified by adjacent property owners.

15. Once watershed issues have been addressed, develop a sediment removal plan addressing accumulated sediment at the mouth of Maloney Ditch, the mouths of the minor tributaries along the southern shoreline, and behind and around the islands on the east end of the lake. Dredging of these areas will likely extend over a number of years and could involve the creation of sediment traps at the mouths of each of the outlets. These actions should only be considered after all options for implementing watershed techniques have been addressed.

16. Following implementation of watershed management techniques and opportunities for sediment removal, reassess the lake to determine if other in-lake management techniques, such as an alum treatment, should be considered.

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APPENDICES

BLUE LAKE DIAGNOSTIC STUDY
WHITLEY COUNTY, INDIANA

APPENDIX A:

GEOGRAPHIC INFORMATION SYSTEMS (GIS) MAP DATA SOURCES

BLUE LAKE DIAGNOSTIC STUDY WHITLEY COUNTY, INDIANA

Appendix A. Geographic Information Systems (GIS) map data sources.

Figure 2. Blue Lake watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set.

Figure 3. Topographical map of the Blue Lake watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Relief coverage is the U.S. Geological Survey National Elevation Data set.

Figure 4. Blue Lake subwatersheds.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Watershed and subwatershed boundaries were delineated based using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI.

Figure 7. Soil associations in the Blue Lake watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soil associationss coverage is from Reusch, 1990.

Figure 8. Highly erodible and potentially highly erodible soils within the Blue Lake watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soils coverage is from the Natural Resources Conservation Service National Ssurgo Soils Database. Highly erodible and potentially soils criteria were set by the NRCS.

Figure 9. Soil septic tank suitability within the Blue Lake watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soils coverage is from the Natural Resources Conservation Service National Ssurgo Soils Database. Soil septic tank limitations were set by the NRCS and are reported in Smallwood (1980).

Figure 10. Land use in the Blue Lake watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Land use comes from the USGS Indiana Land Cover Data Set. The data set was corrected based on 2003 aerial photographs.

Figure 11. National wetland inventory wetlands in the Blue Lake watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Wetland location source is U.S. Fish and Wildlife Service National Wetland Inventory GIS coverage.

Figure 12. Hydric soils in the Blue Lake watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soils coverage is from the Natural Resources Conservation Service National Ssurgo Soils Database. Hydric soil classifications were previously set by the NRCS.

Figure 13. Stream sampling locations.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Sample locations were recorded using a Trimble Pro XRS GPS unit with sub-meter accuracy.

Figure 18. Shoreline surface type observed at Blue Lake.
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Shoreline surface coverages are based on field surveys conducted August 6, 2004 and were drawn by JFNew.

Figure 29. Blue Lake plant beds as surveyed July 28, 2005.
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Plant bed coverages are based on field surveys conducted July 28, 2005 and were drawn by JFNew.

Figure 44. Areas that would benefit from watershed management technique installation.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Improvement project locations are based upon field surveys conducted by JFNew. Coverages were drawn by JFNew. Latitude and longitude coordinates for potential water quality improvement projects are listed below.

APPENDIX B:

ENDANGERED, THREATENED, AND RARE SPECIES LIST, BLUE LAKE WATERSHED

BLUE LAKE DIAGNOSTIC STUDY WHITLEY COUNTY, INDIANA

January 18, 2005

Mr. Joe Exl
J.F. New & Associates, Inc.
708 Roosevelt Road
Walkerton, IN 46574

Dear Mr. Exl:

I am responding to your request for information on the endangered, threatened, or rare (ETR) species, high quality natural communities, and natural areas documented from the Blue Lake Watershed, Whitley County, Indiana. The Indiana Natural Heritage Data Center has been checked and following you will find information on the ETR species documented from the project area.

1. Weathered shells of the state species of special concern mussel *Toxolasma lividus*, purple lilliput, was documented from Blue Lake in 2000.
2. There is a historical occurrence of the state endangered turtle *Emydoidea blandingii*, Blanding's turtle, documented from Blue Lake in 1903.

For more information on the animal species mentioned, please contact Katie Smith, Nongame Supervisor, Division of Fish and Wildlife, 402 W. Washington Room W273, Indianapolis, Indiana 46204, (317)232-4080.

The information I am providing does not preclude the requirement for further consultation with the U.S. Fish and Wildlife Service as required under Section 7 of the Endangered Species Act of 1973. You should contact the Service at their Bloomington, Indiana office.

U.S. Fish and Wildlife Service
620 South Walker St.
Bloomington, Indiana 47403-2121
(812)334-4261

At some point, you may need to contact the Department of Natural Resources' Environmental Review Coordinator so that other divisions within the department have the opportunity to review your proposal.

For more information, please contact:

John Goss, Director
Department of Natural Resources
attn: Christie Kiefer
Environmental Coordinator
Division of Water
402 W. Washington Street, Room W264
Indianapolis, IN 46204
(317)232-4160

Please note that the Indiana Natural Heritage Data Center relies on the observations of many individuals for our data. In most cases, the information is not the result of comprehensive field surveys conducted at particular sites. Therefore, our statement that there are no documented significant natural features at a site should not be interpreted to mean that the site does not support special plants or animals.

Due to the dynamic nature and sensitivity of the data, this information should not be used for any project other than that for which it was originally intended. It may be necessary for you to request updated material from us in order to base your planning decisions on the most current information.

Thank you for contacting the Indiana Natural Heritage Data Center. You may reach me at (317)232-8059 if you have any questions or need additional information.

Sincerely,

Ronald P. Hellmich

Ronald P. Hellmich
Indiana Natural Heritage Data Center

enclosure: invoice

APPENDIX C:

ENDANGERED, THREATENED, AND RARE SPECIES LIST, WHITLEY COUNTY, INDIANA

BLUE LAKE DIAGNOSTIC STUDY WHITLEY COUNTY, INDIANA

November 16, 1999

ENDANGERED, THREATENED AND RARE SPECIES DOCUMENTED FROM WHITLEY COUNTY, INDIANA

SPECIES NAME	COMMON NAME	STATE	FED	SRANK	GRANK
VASCULAR PLANT					
ANDROMEDA GLAUCOPHYLLA	BOG ROSEMARY	SR	**	S2	G5
BIDENS BECKII	BECK WATER-MARIGOLD	SE	**	S1	G4G5T4
CAREX ALOPECOIDEA	FOXTAIL SEDGE	SE	**	S1	G5
CAREX ATLANTICA SSP ATLANTICA	ATLANTIC SEDGE	ST	**	S2	G5T4
CAREX CHORDORRHIZA	CREEPING SEDGE	SE	**	S1	G5
CAREX LIMOSA	MUD SEDGE	SE	**	S1	G5
COELOGLOSSUM VIRIDE VAR VIRESCENS	LONG-BRACT GREEN ORCHIS	ST	**	S2	G5T5
ELEOCHARIS EQUISETOIDES	HORSE-TAIL SPIKERUSH	SE	**	S1	G4
ERIOCAULON AQUATICUM	PIPEWORT	SE	**	S1	G5
ERIOPHORUM GRACILE	SLENDER COTTON-GRASS	ST	**	S2	G5
PHLOX OVATA	MOUNTAIN PHLOX	SE	**	S1	G4
PLANTAGO CORDATA	HEART-LEAVED PLANTAIN	SE	**	S1	G4
POTAMOGETON FRIESII	FRIES' PONDWEED	SE	**	S1	G4
POTAMOGETON PRAELONGUS	WHITE-STEM PONDWEED	SE	**	S1	G5
POTAMOGETON RICHARDSONII	REDHEADGRASS	ST	**	S2	G5
POTAMOGETON ROBBINSII	FLATLEAF PONDWEED	ST	**	S2	G5
POTAMOGETON STRICTIFOLIUS	STRAIGHT-LEAF PONDWEED	SE	**	S1	G5
SPIRANTHES LUCIDA	SHINING LADIES'-TRESSES	SR	**	S2	G5
UTRICULARIA MINOR	LESSER BLADDERWORT	SE	**	S1	G5
UTRICULARIA RESUPINATA	NORTHEASTERN BLADDERWORT	SX	**	SX	G4
MOLLUSCA: GASTROPODA					
CAMPELOMA DECISUM	POINTED CAMPELOMA	SSC	**	S2	G5
ARTHROPODA: INSECTA: LEPIDOPTERA (BUTTERFLIES; SKIPPERS)					
POANES VIATOR VIATOR	BIG BROAD-WINGED SKIPPER	SR	**	S2	G5T4
FISH					
COREGONUS ARTEDI	CISCO	SSC	**	S2	G5
AMPHIBIANS					
RANA PIPIENS	NORTHERN LEOPARD FROG	SSC	**	S2	G5
REPTILES					
EMYDOIDEA BLANDINGII	BLANDING'S TURTLE	SE	**	S2	G4
SISTRURUS CATENATUS CATENATUS	EASTERN MASSASAUGA	SE	**	S2	G3G4T3T4
BIRDS					
ARDEA HERODIAS	GREAT BLUE HERON	**	**	S4B,SZN	G5
LANIUS LUDOVICIANUS	LOGGERHEAD SHRIKE	SE	**	S3B,SZN	G5
STURNELLA NEGLECTA	WESTERN MEADOWLARK	SSC	**	S2B	G5

STATE: SX=extirpated, SE=endangered, ST=threatened, SR=rare, SSC=special concern, WL=watch list, SG=significant,** no status but rarity warrants concern

FEDERAL: LE=endangered, LT=threatened, LELT=different listings for specific ranges of species, PE=proposed endangered, PT=proposed threatened, E/SA=appearance similar to LE species, **=not listed

November 16, 1999

ENDANGERED, THREATENED AND RARE SPECIES DOCUMENTED FROM WHITLEY COUNTY, INDIANA

SPECIES NAME	COMMON NAME	STATE	FED	SRANK	GRANK
MAMMALS					
LYNX RUFUS	BOBCAT	SE	**	S1	G5
TAXIDEA TAXUS	AMERICAN BADGER	SE	**	S2	G5
HIGH QUALITY NATURAL COMMUNITY					
FOREST - UPLAND DRY-MESIC	DRY-MESIC UPLAND FOREST	SG	**	S4	G4
FOREST - UPLAND MESIC	MESIC UPLAND FOREST	SG	**	S3	G3?
LAKE - LAKE	LAKE	SG	**	S2	
WETLAND - FEN	FEN	SG	**	S3	G3
WETLAND - MARSH	MARSH	SG	**	S4	GU

STATE: SX=extirpated, SE=endangered, ST=threatened, SR=rare, SSC=special concern, WL=watch list, SG=significant,** no status but rarity warrants concern

FEDERAL: LE=endangered, LT=threatened, LELT=different listings for specific ranges of species, PE=proposed endangered, PT=proposed threatened, E/SA=appearance similar to LE species, **=not listed

APPENDIX D:

MACROINVERTEBRATE AND HABITAT DATA SHEETS

BLUE LAKE DIAGNOSTIC STUDY
WHITLEY COUNTY, INDIANA

Macroinvertebrate data as assessed in Maloney Ditch on August 10, 2005.

Table D1. Macroinvertebrate community and mIBI scoring calculation.

Order	Family	#	EPT	# w/t	Tolerance (t)	# x t	%
Bivalvia	Sphaeriidae	3		3	8	24	6.00
Colepotera	Curculionidae	1				0	2.00
Colepotera	Dytiscidae	3		3	5	15	6.00
Gastropoda	Lymnaeidae	3		3	6	18	6.00
Gastropoda	Physidae	13		13	8	104	26.00
Gastropoda	Planorbidae	2		2	7	14	4.00
Gastropoda	Viviparidae	18		18	6	108	36.00
Odonata	Coenagrionidae	4		4	9	36	8.00
Oligochaeta		3				0	6.00
Totals		**50**	**0**	**46**		**319.0**	**100.00**

Table D2. mIBI scoring calculation.

mIBI Metric		Metric Score
HBI	6.93	0
Number of Taxa (family)	9	2
Total Count (# of individuals)	50	0
% Dominant Taxa	36.0	4
EPT Index (# families)	0	0
EPT Count (# individuals)	0	0
EPT Count/Total Count	0.00	0
EPT Abundance/Chironomid Abundance	N/A	8
Chironomid Count	0	8
mIBI Score		**2.4**

STREAM: Maloney Ditch **RIVER MILE:** Blue Lake Road **DATE:** 8/10/2005 **QHEI SCORE** 39

1) SUBSTRATE: (Check ONLY Two Substrate Type Boxes: Check all types present) **SUBSTRATE SCORE** 14

TYPE			POOL	RIFFLE				POOL	RIFFLE
[ ]	[ ]	BLDER/SLAB(10)	___	___	[ ]	[ ]	GRAVEL(7)	___	___
[ ]	[ ]	BOULDER(9)	___	___	[X]	[X]	SAND(6)	___	___
[ ]	[ ]	COBBLE(8)	___	___	[ ]	[ ]	BEDROCK(5)	___	___
[ ]	[ ]	HARDPAN(4)	___	___	[ ]	[ ]	DETRITUS(3)	___	___
[ ]	[ ]	MUCK/SILT(2)	___	___	[ ]	[ ]	ARTIFIC(0)	___	___

SUBSTRATE ORIGIN (all)
- [ ] LIMESTONE(1)
- [X] TILLS(1)
- [ ] SANDSTONE(0)
- [ ] SHALE(-1)
- [ ] COAL FINES(-2)
- [ ] RIP/RAP(0)
- [ ] HARDPAN(0)

SILT COVER (one)
- [ ] SILT-HEAVY(-2)
- [X] SILT-NORM(0)
- [ ] SILT-MOD(-1)
- [ ] SILT-FREE(1)

Extent of Embeddedness (check one)
- [ ] EXTENSIVE(-2)
- [ ] LOW(0)
- [ ] MODERATE(-1)
- [X] NONE(1)

TOTAL NUMBER OF SUBSTRATE TYPES: [ ] >4(2) [ ] <4(0)

NOTE: (Ignore sludge that originates from point sources: score is based on natural substrates)

COMMENTS:

2) INSTREAM COVER: **COVER SCORE** 3

TYPE (Check all that apply)
- [ ] UNDERCUT BANKS(1)
- [ ] OVERHANGING VEGETATION(1)
- [ ] SHALLOWS (IN SLOW WATER)(1)
- [ ] DEEP POOLS(2)
- [ ] ROOTWADS(1)
- [ ] BOULDERS(1)
- [ ] OXBOWS(1)
- [X] AQUATIC MACROPHYTES(1)
- [X] LOGS OR WOODY DEBRIS(1)

AMOUNT (Check only one or Check 2 and AVERAGE)
- [ ] EXTENSIVE >75%(11)
- [ ] MODERATE 25-75%(7)
- [ ] SPARSE 5-25%(3)
- [X] NEARLY ABSENT <5%(1)

COMMENTS:

3) CHANNEL MORPHOLOGY: (Check ONLY ONE per Category or Check 2 and AVERAGE) **CHANNEL SCORE** 9

SINUOSITY
- [ ] HIGH(4)
- [ ] MODERATE(3)
- [X] LOW(2)
- [ ] NONE(1)

DEVELOPMENT
- [ ] EXCELLENT(7)
- [ ] GOOD(5)
- [ ] FAIR(3)
- [X] POOR(1)

CHANNELIZATION
- [ ] NONE(6)
- [ ] RECOVERED(4)
- [X] RECOVERING(3)
- [ ] RECENT OR NO RECOVERY(1)

STABILITY
- [X] HIGH(3)
- [ ] MODERATE(2)
- [ ] LOW(1)

MODIFICATION/OTHER
- [ ] SNAGGING
- [ ] RELOCATION
- [ ] CANOPY REMOVAL
- [ ] DREDGING
- [ ] ONE SIDE CHANNEL MODIFICATION
- [ ] IMPOUND
- [ ] ISLAND
- [ ] LEVEED
- [ ] BANK SHAPING

COMMENTS:

4) RIPARIAN ZONE AND BANK EROSION: (Check ONE box or Check 2 and AVERAGE per bank) **RIPARIAN SCORE** 5

River Right Looking Downstream

RIPARIAN WIDTH (per bank)

L	R	(per bank)
[ ]	[ ]	WIDE >150 ft.(4)
[ ]	[ ]	MODERATE 30-150 ft.(3)
[ ]	[ ]	NARROW 15-30 ft.(2)
[X]	[X]	VERY NARROW 3-15 ft.(1)
[ ]	[ ]	NONE(0)

EROSION/RUNOFF-FLOODPLAIN QUALITY

L	R	(most predominant per bank)	L	R	(per bank)
[ ]	[ ]	FOREST, SWAMP(3)	[ ]	[ ]	URBAN OR INDUSTRIAL(0)
[ ]	[ ]	OPEN PASTURE/ROW CROP(0)	[X]	[ ]	SHRUB OR OLD FIELD(2)
[ ]	[X]	RESID.,PARK,NEW FIELD(1)	[ ]	[ ]	CONSERV. TILLAGE(1)
[ ]	[ ]	FENCED PASTURE(1)	[ ]	[ ]	MINING/CONSTRUCTION(0)

BANK EROSION

L	R	(per bank)
[ ]	[X]	NONE OR LITTLE(3)
[X]	[ ]	MODERATE(2)
[ ]	[ ]	HEAVY OR SEVERE(1)

COMMENTS: Trailer park/campground on right

5) POOL/GLIDE AND RIFFLE/RUN QUALITY **NO POOL = 0** **POOL SCORE** 0

MAX.DEPTH (Check 1)
- [ ] >4 ft.(6)
- [ ] 2.4-4 ft.(4)
- [ ] 1.2-2.4 ft.(2)
- [ ] <1.2 ft.(1)
- [X] <0.6 ft.(Pool=0)(0)

MORPHOLOGY (Check 1)
- [ ] POOL WIDTH>RIFFLE WIDTH(2)
- [ ] POOL WIDTH=RIFFLE WIDTH(1)
- [ ] POOL WIDTH<RIFFLE WIDTH(0)

POOL/RUN/RIFFLE CURRENT VELOCITY (Check all that Apply)
- [ ] TORRENTIAL(-1)
- [ ] FAST(1)
- [ ] MODERATE(1)
- [ ] SLOW(1)
- [ ] EDDIES(1)
- [ ] INTERSTITIAL(-1)
- [ ] INTERMITTENT(-2)

COMMENTS:

RIFFLE SCORE 0

RIFFLE/RUN DEPTH
- [ ] GENERALLY >4 in. MAX.>20 in.(4)
- [ ] GENERALLY >4 in. MAX.<20 in.(3)
- [ ] GENERALLY 2-4 in.(1)
- [X] GENERALLY <2 in.(Riffle=0)(0)

RIFFLE/RUN SUBSTRATE
- [ ] STABLE (e.g., Cobble,Boulder)(2)
- [ ] MOD.STABLE (e.g., Pea Gravel)(1)
- [ ] UNSTABLE (Gravel, Sand)(0)
- [X] NO RIFFLE(0)

RIFFLE/RUN EMBEDDEDNESS
- [ ] EXTENSIVE(-1)
- [ ] MODERATE(0)
- [ ] LOW(1)
- [ ] NONE(2)
- [X] NO RIFFLE(0)

COMMENTS: No pools

6) GRADIENT (FEET/MILE): 13.3 **% POOL** 0 **% RIFFLE** 0 **% RUN** 0 **GRADIENT SCORE** 8

APPENDIX E:

PLANT COMMUNITY SURVEY

BLUE LAKE DIAGNOSTIC STUDY
WHITLEY COUNTY, INDIANA

Abbreviation	Scientific Name	Common Name	Stratum	1975	1979	2005
BIDCER	*Bidens cernua*	Nodding bur marigold	Emergent			X
BRASCH	*Brasenia schreberi*	Water shield	Floating		X	
CEPOCC	*Cephalanthus occidentalis*	Buttonbush	Emergent			X
CERDEM	*Ceratophyllum demersum*	Coontail	Submergent	X	X	X
CHARA	*Chara species*	Chara species	Submergent	X	X	X
COROBL	*Cornus obliqua*	Silky dogwood	Emergent			X
DECVER	*Decodon verticillatus*	Whirled loosestrife	Emergent	X	X	X
ECHCRU	*Echinochloa crusgalli*	Barnyard grass	Emergent			X
ELOCAN	*Elodea canadensis*	Common water weed	Submergent			X
ELONUT	*Elodea nuttallii*	Slender water weed	Submergent			X
FILALG	*Filamentous algae*	Filamentous algae	Algae		X	X
HETDUB	*Heteranthera dubia*	Water star grass	Submergent			X
JUNSP	*Juncus* species	Soft rush	Emergent	X		
LEMMIO	*Lemna minor*	Common duckweed	Floating	X	X	X
LEMTRI	*Lemna trisulca*	Star duckweed	Floating			X
LYTSAL	*Lythrum salicaria*	Purple loosestrife	Emergent			X
MYREXA	*Myriophyllum exalbescens*	Northern water milfoil	Submergent			X
NAJFLE	*Najas flexilis*	Slender naiad	Submergent			X
NAJGUA	*Najas guadalupensis*	Southern naiad	Submergent			X
NELLUT	*Nelumbo lutea*	American lotus	Floating	X		X
NUPADV	*Nuphar advena*	Spatterdock	Floating	X	X	X
NYMTUB	*Nymphaea tuberosa*	White water lily	Floating	X	X	X
PELVIR	*Peltandra virginica*	Arrow arum	Emergent			
PHAARU	*Phalarus arundinacaea*	Reed canary grass	Emergent	X	X	X
POLCOC	*Polygonum coccineum*	Water heartsease	Emergent		X	X
POLLAP	*Polygonum lapathifolia*	Nodding smartweed	Emergent			X
POLPER	*Polygonum persicaria*	Lady's thumbprint	Emergent			X
PONCOR	*Pontedaria cordata*	Pickerel weed	Emergent		X	X
POTAMP	*Potamogeton amplifolium*	Large-leaf pondweed	Submergent			X
POTCRI	*Potamogeton crispus*	Curly leaf pondweed	Submergent	X	X	X
POTFOL	*Potamogeton foliosis*	Leafy pondweed	Submergent	X	X	X
POTBER	*Potamogeton berchtoldii*	Small pondweed	Submergent			X
POTGRA	*Potamogeton gramineus*	Grassy pondweed	Submergent			X
POTILL	*Potamogeton illinoiensis*	Illinois pondweed	Submergent			X
POTNAT	*Potamogeton natans*	Floating-leaf pondweed	Submergent		X	
POTNOD	*Potamogeton nodosus*	Long-leaf pondweed	Submergent			X
POTPEC	*Potamogeton pectinatus*	Sago pondweed	Submergent		X	X
POTPUS	*Potamogeton pusillus*	Small pondweed	Submergent			X
POTZOS	*Potamogeton zosteriformis*	Flat-stem pondweed	Submergent			X
SAGLAT	*Sagittaria latifolia*	Common arrowhead	Emergent		X	X
SALINT	*Salix interior*	Sandbar willow	Emergent			X
SALNIG	*Salix nigra*	Black willow	Emergent		X	
SCIACU	*Scirpus acutus*	Hardstem bulrush	Emergent		X	X
SCIFLU	*Scirpus fluviatilis*	River bulrush	Emergent			X
SCIPUN	*Scirpus pungens*	Chairmakers rush	Emergent			X
SCIVAL	*Scirpus validus*	Softstem bulrush	Emergent			X

SOLDUL	*Solanum dulcomera*	Climbing nightshade	Emergent			**X**
SPAEUR	*Sparganium eurycarpum*	Common burreed	Emergent			**X**
SPIPOL	*Spirodela polyrhiza*	Large duckweed	Floating		**X**	**X**
TYPANG	*Typha angustifolia*	Narrow leafed cattail	Emergent			**X**
TYPLAT	*Typha latifolia*	Broad leafed cattail	Emergent	**X**	**X**	**X**
VALAME	*Vallisneria americana*	Eel grass	Submergent			**X**
WOLCOL	*Wolffia columbiana*	Water meal	Floating			**X**

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: July 28, 2005**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 1	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 1.25 acres					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S: 4	N: 1	F: 1	E: 1	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
CERDEM	4			

Individual Plant Bed Survey

Comments: Small, isolated plant bed near northwestern corner of the lake. Residents indicate that bulrushes and floating-leaf pondweed are typically found within this bed. Neither of those species were present during the 2005 survey.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew | **DATE: July 28, 2005**

SITE INFORMATION					SITE COORDINATES
Plant Bed ID: 2	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 5.5 acres					Latitude: NA
Substrate: 6	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 1	F: 1	E: 1	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
BIDCER	1			
CERDEM	2			
ECHCRU	1			
ELOCAN	1			
ELONUT	1		1	
FILALG	2			
HETDUB	2			
LEMTRI	1			
LYTSAL	1			
MYREXA	1		1	
NAJFLE	1		1	
NAJGUA	2		1	
NUPADV	1			
NYMTUB	1			
POLPER	1			
POTAMP	2		1	
POTBER	1		1	
POTCRI	2			
POTFOL	1			
POTILL	1			
POTNOD	2			
POTPEC	2			

Individual Plant Bed Survey

Comments: Plant bed 2 covers the developed portion of the northern shoreline of Blue Lake. The entire shoreline is modified with either mowed lawn, sand, or wooden seawalls covering the shoreline. Residents have raked plant material or treated individual shorelines with chemical to remove plant material from the lake. In areas where treatment or hand removal has not occurred, eel gras (VALAME) is especially thick. Much of the loose, floating material remains in the lake and clumps along the shoreline.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: July 28, 2005**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 2	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 5.5 acres					Latitude: NA
Substrate: 6	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S:3	N: 1	F: 1	E: 1	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
POTZOS	1			
SCIPUN	1			
VALAME	3			

Individual Plant Bed Survey

Comments:

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew | **DATE: July 28, 2005**

SITE INFORMATION					SITE COORDINATES
Plant Bed ID: 3	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 7.5 acres					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 1	F: 2	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
CEPOCC	1			
CERDEM	2			
CHARA	2			
FILALG	2			
HETDUB	2			
LEMTRI	1			
LYTSAL	1			
MYSEXA	1			
NAJFLE	2		1	
NAJGUA	1			
NUPADV	1			
NYMTUB	2			
PONCOR	2			
POTAMP	2		1	
POTBER	1		1	
POTRCI	1			
POTGRA	1			
POTILL	3			
POTNOD	1			
POTPEC	1			
POTZOS	1			
SALINT	1			

Individual Plant Bed Survey

Comments: Plant bed 3 covers the northern shoreline and northeastern corner of Blue Lake. This plant bed extends to just west of the beach in the northeast corner of the lake. The shoreline abutting this plant bed is natural with an intact submergent, emergent, and forested corridor. This plant bed is dominated by pondweeds.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew

DATE: July 28, 2005

SITE INFORMATION					SITE COORDINATES
Plant Bed ID: 3	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 7.5 acres					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**Canopy Abundance at Site**				Latitude: NA
	S: 3	N: 1	F: 2	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
SCIPUN	2			
SCIVAL	1			
TYPLAT	1			
VALAME	2			

Individual Plant Bed Survey

Comments:

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew

DATE: July 28, 2005

SITE INFORMATION					SITE COORDINATES
Plant Bed ID: 4	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 0.5 acre					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S:2	N: 1	F: 2	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
CERDEM	1			
LEMMIO	1			
LYTSAL	1			
NELLUT	1			
NYMTUB	1			
POLCOC	1			
POLLAP	1			
PONCOR	2			
POTAMP	2		1	
POTCRI	1			
POTGRA	1			
POTNOD	1			
SCIACU	1			
SCIPUN	1			
VALAME	2			
WOLCOL	1			

Individual Plant Bed Survey

Comments: Much of the shoreline adjacent to plant bed 4 is natural. The lake naturally transitions from submergent to emergent within this plant bed. This bed is bounded on the west by the beach and on the south by the outlet of Maloney Ditch.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					DATE: July 28, 2005
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 5	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 6.5 acres					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S: 2	N: 1	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
CERDEM	1			
ELOCAN	1			
ELONUT	2			
FILALG	2			
HETDUB	2		1	
LEMMIO	1			
LYTSAL	1			
MYREXA	1			
NAJFLE	1			
NELLUT	2		1	
NUPADV	1		1	
NYMTUB	1			
PHAARU	1			
PONCOR	1			
POTAMP	2			
POTCRI	1			
POTILL	2		1	
POTPEC	2			
SCIACU	1			
SCIFLU	1			
SCIPUN	1			
SCIVAC	1			

Individual Plant Bed Survey

Comments: Plant bed 5 contains an extensive area of American lotus (NELLUT), which is not particularly common in northern Indiana. Two historic sources document Blue Lake as possessing on the few American lotus populations in northern Indiana. This plant bed covers much of the east end of the lake. It extends from the mouth of Maloney Ditch around to where landowners have removed the emergent and much of the floating plant bed components.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: July 28, 2005**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 5	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 6.5 acres					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S: 2	N: 1	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
TYPLAT	2			
WOLCOL	1			

Individual Plant Bed Survey

Comments:

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew

DATE: July 28, 2005

SITE INFORMATION					SITE COORDINATES
Plant Bed ID: 6	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 9 acres					Latitude: NA
Substrate: 3	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 1	F: 1	E: 1	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
BIDCER	1			
CEPOCC	1			
CERDEM	2			
ELOCAN	1			
HETDUB	3			
LEMMIO	1			
LYTSAL	1			
MYREXA	2		1	
NAJFLE	1		1	
NAJGUA	1			
NUPADV	1			
NYMTUB	1			
PHAARU	1			
PONCOR	1			
POTAMP	2			
POTBER	2		1	
POTCRI	2			
POTFOL	1			
POTGRA	2			
POTILL	1			
POTNOD	1			
POTPEC	2			

Individual Plant Bed Survey

Comments: Plant bed 6 covers the southern shoreline of the lake. Much of the emergent portion of this plant community has been altered by landowners. The submergent component is sparse in some locations, especially where landowners continue to treat plants with chemicals or remove plant material by hand. Emergent stands are located in isolated patches along the southern shoreline.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: July 28, 2005**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 6	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 9 acres					Latitude: NA
Substrate: 3	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 1	F: 1	E: 1	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
POTPUS	1		1	
POTZOS	1			
SALINT	1			
SCIPUN	2			
SOLDUL	1			
TYPLAT	1			
VALAME	3			

Individual Plant Bed Survey

Comments:

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifiec

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew

DATE: July 28, 2005

SITE INFORMATION						SITE COORDINATES
Plant Bed ID: 7	Waterbody Name: Blue Lake					Center of the Bed
Bed Size: 193 acres						Latitude: NA
Substrate: 1	Waterbody ID:					Longitude: NA
Marl?	Total # of Species: 48					Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**					Latitude: NA
	S: 3	N: 1	F: 3	E: 2		Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
CERDEM	3			
COROBL	1			
DECVER	2			
ELOCAN	1			
FILALG	3			
HETDUB	2			
LEMMIO	1			
LYTSAL	1			
MYREXA	2		1	
NAJFLE	1		1	
NUPADV	3			
NYMTUB	1			
PHAARU	1			
POLCOC	1			
PONCOR	1			
POTAMP	2			
POTBER	1		1	
POTCRI	1			
POTILL	1			
POTNOD	2			
POTPEC	1			
SAGLAT	1			

Individual Plant Bed Survey

Comments: Plant bed 7 covers The Horseshoe and the western end of the lake. Most of this plant bed remains intact with an emergent, floating, then submergent component. Landowners have removed isolated areas of plants to allow for access and boat docking. Most of the shoreline adjacent to plant bed 7 is natural.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					DATE: July 28, 2005
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 7	Waterbody Name: Blue Lake				Center of the Bed
Bed Size: 193 acres					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 48				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 1	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
SCIACU	1			
SCIPUN	1			
SOLDUL	1			
SPAEUR	1			
SPIPOL	1			
TYPANG	2			
TYPLAT	1			
VALAME	2			
WOLCOL	1			

Individual Plant Bed Survey

Comments:

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

APPENDIX F:

FISH SPECIES IDENTIFIED IN BLUE LAKE BY THE INDIANA DEPARTMENT OF NATURAL RESOURCES DIVISION OF FISH AND WILDLIFE

BLUE LAKE DIAGNOSTIC STUDY
WHITLEY COUNTY, INDIANA

Fish present in Blue Lake as observed by Indiana Department of Natural Resources Fisheries Biologists.

Common Name	Scientific Name	1975	1979	1998
Sunfish Family				
Bluegill	*Lepomis macrochirus*	X	X	X
Black Crappie	*Pomoxis nigromaculatus*	X	X	X
Green Sunfish	*Lepomis cyanellus*	X	X	
Hybrid Sunfish	*Lepomis* spp.		X	X
Largemouth Bass	*Micropterus salmoides*	X	X	X
Pumpkinseed	*Lepomis gibbosus*	X	X	X
Redear Sunfish	*Lepomis microlophus*	X	X	X
Warmouth	*Lepomis gulosus*	X	X	X
Catfish Family				
Black Bullhead	*Ameiurus melas*		X	X
Brown Bullhead	*Ameiurus nebulosus*	X	X	X
Yellow Bullhead	*Ameiurus natalis*	X	X	X
Minnow Family				
Common Carp	*Cyprinus carpio*	X	X	
Golden Shiner	*Notemigonus crysoleucas*	X	X	
Sucker Family				
Lake Chubsucker	*Erimyzon sucetta*	X	X	X
Spotted Sucker	*Minytrema melanops*			X
White Sucker	*Catostomus commersoni*	X	X	X
Herring Family				
Gizzard Shad	*Dorosoma cepedianum*			X
Bowfin Family				
Bowfin	*Amia calva*	X	X	X
Gar Family				
Spotted Gar	*Lepisosteus oculatus*	X	X	X
Pike Family				
Grass Pickerel	*Esox americanus vermiculatus*	X	X	
Northern Pike	*Esox lucius*	X	X	
Tiger Muskellunge	*Esox* spp.		X	
Perch Family				
Yellow Perch	*Perca flavescens*	X	X	X
Silverside Family				
Brook Silverside	*Labidesthes sicculus*	X	X	X
Mudminnow Family				
Central Mudminnow	*Umbra limi*			X
Number Species		**19**	**21**	**18**

APPENDIX G:

POTENTIAL SHORELINE BUFFER SPECIES

BLUE LAKE DIAGNOSTIC STUDY
WHITLEY COUNTY, INDIANA

Appendix G. Potential shoreline buffer species.

Common Name	**Botanical Name**	**Approximate Location***
Arrow Arum	*Peltandra virginica*	Shallow water/water's edge
Big Blue Stem	*Andropogon gerardii*	Varies/broad range
Black-Eyed Susan	*Rudbeckia hirta*	Drier soils
Blue Flag Iris	*Iris virginica shrevei*	Shallow water/water's edge
Blue Joint Grass	*Calamagrostis canadensis*	Wet to mesic soils
Bottle Gentian	*Gentiana andrewsii*	Mesic to dry soils
Butterfly Milkweed	*Asclepias tuberosa*	Mesic to dry soils
Chairmakers rush	*Scirpus pungens*	Shallow water/water's edge
Common Bur Reed	*Sparganium eurycarpum*	Shallow water/water's edge
Compass Plant	*Silphium laciniatum*	Varies/broad range
Cream Wild Indigo	*Baptisia leucophaea*	Mesic to dry soils
Culver's Root	*Veronicastrum virginianum*	Varies/broad range
Cup Plant	*Silphium perfoliatum*	Wet to mesic soils
Early Goldenrod	*Solidago juncea*	Wet to mesic soils
False Dragonhead	*Physostegia virginiana*	Wet to mesic soils
Goats Rue	*Tephrosia virginiana*	Varies/broad range
Golden Alexanders	*Zizia aurea*	Wet to mesic soils
Great Blue Lobelia	*Lobelia siphilitica*	Wet soils
Halberd-leaved Rose Mallow	*Hibiscus laevis*	Shallow water/water's edge
Hard-stemmed Bulrush	*Scirpus acutus*	Shallow water/water's edge
Heart-Leaved Meadow Parsnip	*Zizia aptera*	Mesic to dry soils
Heath Aster	*Aster ericoides*	Wet to mesic soils
Illinois Sensitive Plant	*Desmanthus illinoensis*	Mesic to dry soils
Illinois Tick Trefoil	*Desmodium illinoiense*	Varies/broad range
Indian Grass	*Sorghastrum nutans*	Varies/broad range
Ironweed	*Vernonia altissima*	Wet to mesic soils
Little Blue Stem	*Andropogon scoparius*	Varies/broad range
Marsh Blazing Star	*Liatris spicata*	Wet to mesic soils
New England Aster	*Aster novae-angliae*	Wet to mesic soils
New Jersey Tea	*Ceanothus americanus*	Varies/broad range
Old-Field Goldenrod	*Solidago nemoralis*	Mesic to dry soils
Partridge Pea	*Cassia fasciculata*	Varies/broad range
Pickerel Weed	*Pontederia cordata*	Shallow water/water's edge
Prairie Bergamot	*Monarda fistulosa*	Varies/broad range
Prairie Cinquefoil	*Potentilla arguta*	Mesic to dry soils
Prairie Cord Grass	*Spartina pectinata*	Wet to mesic soils
Prairie Coreopsis	*Coreopsis palmata*	Mesic to dry soils
Prairie Dock	*Silphium terebinthinaceum*	Varies/broad range
Prairie Switch Grass	*Panicum virgatum*	Varies/broad range
Prairie Wild Rye	*Elymus canadensis*	Varies/broad range
Purple Coneflower	*Echinacea purpurea*	Mesic to dry soils
Rattlesnake Master	*Eryngium yuccifolium*	Varies/broad range

Common Name	**Botanical Name**	**Approximate Location***
Rosin Weed	*Silphium integrifolium*	Varies/broad range
Rough Blazing Star	*Liatris aspera*	Mesic to dry soils
Round-Head Bush Clover	*Lespedeza capitata*	Varies/broad range
Rushes	*Juncus* spp.	Depends upon the species
Saw-Tooth Sunflower	*Helianthus grosseserratus*	Wet to mesic soils
Sedges	*Carex* spp.	Depends upon the species
Showy Goldenrod	*Solidago speciosa*	Mesic to dry soils
Side Oats Grama	*Bouteloua curtipendula*	Mesic to dry soils
Sky-Blue Aster	*Aster azureus*	Mesic to dry soils
Smooth Aster	*Aster laevis*	Mesic to dry soils
Sneezeweed	*Helenium autumnale*	Wet to mesic soils
Softsem Bulrush	*Scirpus validus creber*	Shallow water/water's edge
Spider-Wort	*Tradescantia ohiensis*	Wet to mesic soils
Stiff Goldenrod	*Solidago rigida*	Varies/broad range
Swamp Loosestrife	*Decodon verticillatus*	Shallow water/water's edge
Swamp Rose Mallow	*Hibiscus palustris*	Shallow water/water's edge
Sweet Black-Eyed Susan	*Rudbeckia subtomentosa*	Wet to mesic soils
Sweet Flag	*Acorus calamus*	Shallow water/water's edge
Tall Coreopsis	*Coreopsis tripteris*	Wet to mesic soils
Thimbleweed	*Anemone cylindrica*	Mesic to dry soils
Virginia Mountain Mint	*Pycnanthemum virginianum*	Varies/broad range
White Wild Indigo	*Baptisia leucantha*	Varies/broad range
Wild Lupine	*Lupinus perennis*	Mesic to dry soils
Wild Quinine	*Parthenium integrifolium*	Varies/broad range
Wrinkled Goldenrod	*Solidago rugosa*	Wet to mesic soils
Yellow Coneflower	*Ratibida pinnata*	Varies/broad range

** These approximate locations are very general. Each species can have specific site conditions requirements (i.e. sun exposure, soil type, soil moisture). Consequently, site inspection should occur before determining an exact species list for a given site.*

APPENDIX H:

POTENTIAL FUNDING SOURCES

BLUE LAKE DIAGNOSTIC STUDY
WHITLEY COUNTY, INDIANA

Appendix H. Potential Funding Sources.

There are several cost-share grants available from both state and federal government agencies specific to watershed management. Community groups and/or Soil and Water Conservation Districts can apply for the majority of these grants. The main goal of these grants and other funding sources is to improve water quality though the use of specific BMPs. As public awareness shifts towards watershed management, these grants will become more and more competitive. Therefore, any association interested in improving water quality through the use of grants must become active soon. Once an association is recognized as a "watershed management activist" it will become easier to obtain these funds repeatedly. The following are some of the possible major funding sources available to lake and watershed associations for watershed management.

Lake and River Enhancement Program (LARE)
LARE is administered by the Indiana Department of Natural Resources, Division of Fish and Wildlife. The program's main goals are to control sediment and nutrient inputs to lakes and streams and prevent or reverse degradation from these inputs through the implementation of corrective measures. Under present policy, the LARE program may fund lake and watershed specific construction actions up to $100,000 for a single project or $300,000 for all projects on a lake or stream. The LARE program also provides a maximum of $100,000 for the removal of sediment from a particular site on a lake and a cumulative total of $300,000 for all sediment removal projects on a lake. An approved sediment removal plan must be on file with the LARE office for projects to receive sediment removal funding. Finally, the LARE program will provide $100,000 for a one-time whole lake treatment to control aggressive, invasive aquatic plants. A cumulative total of $20,000 over a three year period may be obtained for additional spot treatment following the whole lake treatment. As with the sediment removal funding, an approved aquatic plant management plan must be on file with the LARE office for the lake association to receive funding. All approved projects require a 0 to 25% cash or in-kind match, depending on the project. LARE also has a "watershed land treatment" component that can provide grants to SWCDs for multi-year projects. The funds are available on a cost-sharing basis with landowners who implement various BMPs. All of the LARE programs are recommended as a project funding source for the Blue Lake watershed. More information about the LARE program can be found at http://www.in.gov/dnr/fishwild/lare/.

Clean Water Act Section 319 Nonpoint Source Pollution Management Grant
The 319 Grant Program is administered by the Indiana Department of Environmental Management (IDEM), Office of Water Management, Watershed Management Section. 319 is a federal grant made available by the Environmental Protection Agency (EPA). 319 grants fund projects that target nonpoint source water pollution. Nonpoint source pollution (NPS) refers to pollution originating from general sources rather than specific discharge points (Olem and Flock, 1990). Sediment, animal and human waste, nutrients, pesticides, and other chemicals resulting from land use activities such as mining, farming, logging, construction, and septic fields are considered NPS pollution. According to the EPA, NPS pollution is the number one contributor to water pollution in the United States. To qualify for funding, the water body must meet specific criteria such as being listed in the state's 305(b) report as a high priority water body or be identified by a diagnostic study as being impacted by NPS pollution. Funds can be requested for up to $300,000 for individual projects. There is a 25% cash or in-kind match requirement. To qualify for implementation projects, there must be a watershed management plan for the receiving waterbody. This plan must meet all of the current 319 requirements. This diagnostic study serves as an excellent foundation for developing a

watershed management plan since it satisfies several, but not all, of the 319 requirements for a watershed management plan. More information about the Section 319 program can be obtained from http://www.in.gov/idem/water/planbr/wsm/319main.html.

Section 104(b)(3) NPDES Related State Program Grants
Section 104(b)(3) of the Clean Water Act gives authority to a grant program called the National Pollutant Discharge Elimination System (NPDES) Related State Program Grants. These grants provide money for developing, implementing, and demonstrating new concepts or requirements that will improve the effectiveness of the NPDES permit program that regulates point source discharges of water pollution. Projects that qualify for Section 104(b)(3) grants involve water pollution sources and activities regulated by the NPDES program. The awarded amount can vary by project and there is a required 5% match. For more information on Section 104(b)(3) grants, please see the IDEM website at: http://www.in.gov/idem/water/planbr/wsm/104main.html.

Section 205(j) Water Quality Management Planning Grants
Funds allocated by Section 205(j) of the Clean Water Act are granted for water quality management planning and design. Grants are given to municipal governments, county governments, regional planning commissions, and other public organizations for researching point and non-point source pollution problems and developing plans to deal with the problems. According to the IDEM Office of Water Quality website: "The Section 205(j) program provides for projects that gather and map information on non-point and point source water pollution, develop recommendations for increasing the involvement of environmental and civic organizations in watershed planning and implementation activities, and implement watershed management plans. No match is required. For more information on and 205(j) grants, please see the IDEM website at: http://www.in.gov/idem/water/planbr/wsm/205jmain.html.

Other Federal Grant Programs
The USDA and EPA award research and project initiation grants through the U.S. National Research Initiative Competitive Grants Program and the Agriculture in Concert with the Environment Program.

Watershed Protection and Flood Prevention Program
The Watershed Protection and Flood Prevention Program is funded by the U.S. Department of Agriculture and is administered by the Natural Resources Conservation Service. Funding targets a variety of watershed activities including watershed protection, flood prevention, erosion and sediment control, water supply, water quality, fish and wildlife habitat enhancement, wetlands creation and restoration, and public recreation in small watersheds (250,000 or fewer acres). The program covers 100% of flood prevention construction costs or 50% of construction costs for agricultural water management, recreational, or fish and wildlife projects.

Conservation Reserve Program

The Conservation Reserve Program (CRP) is funded by the USDA and administered by the Farm Service Agency (FSA). CRP is a voluntary, competitive program designed to encourage farmers to establish vegetation on their property in an effort to decrease erosion, improve water quality, or enhance wildlife habitat. The program targets farmed areas that have a high potential for degrading water quality under traditional agricultural practices or areas that might make good wildlife habitat if they were not farmed. Such areas include highly erodible land, riparian zones, and farmed wetlands. Currently, the program offers continuous sign-up for practices like grassed waterways and filter strips. Participants in the program receive cost share assistance for any plantings or construction as well as annual payments for any land set aside.

Wetlands Reserve Program

The Wetlands Reserve Program (WRP) is funded by the USDA and is administered by the NRCS. WRP is a subsection of the Conservation Reserve Program. This voluntary program provides funding for the restoration of wetlands on agricultural land. To qualify for the program, land must be restorable and suitable for wildlife benefits. This includes farmed wetlands, prior converted cropland, farmed wet pasture, farmland that has become a wetland as a result of flooding, riparian areas which link protected wetlands, and the land adjacent to protected wetlands that contribute to wetland functions and values. Landowners may place permanent or 30-year easements on land in the program. Landowners receive payment for these easement agreements. Restoration cost-share funds are also available. No match is required.

Grassland Reserve Program

The Grassland Reserve Program (GRP) is funded by the USDA and is administered by the NRCS. GRP is a voluntary program that provides funding the restoration or improvement of natural grasslands, rangelands, prairies or pastures. To qualify for the program the land must consist of at least a 40 acre contiguous tract of land, be restorable, and provide water quality or wildlife benefit. Landowners may enroll land in the Grassland Reserve Program for 10, 15, 20, or 30 years or enter their land into a 30-year permanent easement. Landowners receive payment of up to 75% of the annual grazing value. Restoration cost-share funds of up to 75% for restored or 90% for virgin grasslands are also available.

Community Forestry Grant Program

The U.S. Forest Service through the Indiana Department of Natural Resources Division of Forestry provides three forms of funding for communities under the Community Forestry Grant Program. Urban Forest Conservation Grants (UFCG) are designed to help communities develop long term programs to manage their urban forests. UFCG funds are provided to communities to improve and protect trees and other natural resources; projects that target program development, planning, and education are emphasized. Local municipalities, not-for-profit organizations, and state agencies can apply for $2,000-20,000 annually. The second type of Community Forestry Grant Program, the Arbor Day Grant Program, funds activities which promote Arbor Day efforts and the planting and care of urban trees. $500-1000 grants are generally awarded. The Tree Steward Program is an educational training program that involves six training sessions of three hours each. The program can be offered in any county in Indiana and covers a variety of tree care and planting topics. Generally, $500-1000 is available to assist communities in starting a county or regional Tree Steward Program. Each of these grants requires an equal match.

Forest Land Enhancement Program (FLEP)

FLEP replaces the former Forestry Incentive Program. It provides financial, technical, and educational assistance to the Indiana Department of Natural Resources Division of Forestry to assist private landowners in forestry management. Projects are designed to enhance timber production, fish and wildlife habitat, soil and water quality, wetland and recreational resources, and aesthetic value. FLEP projects include implementation of practices to protect and restore forest lands, control invasive species, and preserve aesthetic quality. Projects may also include reforestation, afforestation, or agroforestry practices. The IDNR Division of Forestry has not determined how they will implement this program; however, their website indicates that they are working to determine their implementation and funding procedures. More information can be found at http://www.in.gov/dnr/forestry.

Wildlife Habitat Incentive Program

The Wildlife Habitat Incentive Program (WHIP) is funded by the USDA and administered by the NRCS. This program provides support to landowners to develop and improve wildlife habitat on private lands. Support includes technical assistance as well cost sharing payments. Those lands already enrolled in WRP are not eligible for WHIP. The match is 25%.

Environmental Quality Incentives Program

The Environmental Quality Incentives Program (EQIP) is a voluntary program designed to provide assistance to producers to establish conservation practices in target areas where significant natural resource concerns exist. Eligible land includes cropland, rangeland, pasture, and forestland, and preference is given to applications which propose BMP installation that benefits wildlife. EQIP offers cost-share and technical assistance on tracts that are not eligible for continuous CRP enrollment. Certain BMPs receive up to 75% cost-share. In return, the producer agrees to withhold the land from production for five years. Practices that typically benefit wildlife include: grassed waterways, grass filter strips, conservation cover, tree planting, pasture and hay planting, and field borders. Best fertilizer and pesticide management practices, innovative approaches to enhance environmental investments like carbon sequestration or market-based credit trading, and groundwater and surface water conservation are also eligible for EQIP cost-share.

Small Watershed Rehabilitation Program

The Small Watershed Rehabilitation Program provides funding for rehabilitation of aging small watershed impoundments that have been constructed within the last 50 years. This program is newly funded through the 2002 Farm Bill and is currently under development. More information regarding this and other Farm Bill programs can be found at http://www.usda.gov/farmbill.

Farmland Protection Program

The Farmland Protection Program (FPP) provides funds to help purchase development rights in order to keep productive farmland in use. The goals of FPP are: to protect valuable, prime farmland from unruly urbanization and development; to preserve farmland for future generations; to support a way of life for rural communities; and to protect farmland for long-term food security.

Debt for Nature

Debt for Nature is a voluntary program that allows certain FSA borrowers to enter into 10-year, 30-year, or 50-year contracts to cancel a portion of their FSA debts in exchange for devoting eligible acreage to conservation, recreation, or wildlife practices. Eligible acreage includes: wetlands, highly erodible lands, streams and their riparian areas, endangered species or significant wildlife habitat, land in 100-year floodplains, areas of high water quality or scenic value, aquifer recharge zones, areas containing soil not suited for cultivation, and areas adjacent to or within administered conservation areas.

Partners for Fish and Wildlife Program

The Partners for Fish and Wildlife Program (PFWP) is funded and administered by the U.S. Department of the Interior through the U.S. Fish and Wildlife Service. The program provides technical and financial assistance to landowners interested in improving native habitat for fish and wildlife on their land. The program focuses on restoring wetlands, native grasslands, streams, riparian areas, and other habitats to natural conditions. The program requires a 10-year cooperative agreement and a 1:1 match.

North American Wetland Conservation Act Grant Program

The North American Wetland Conservation Act Grant Program (NAWCA) is funded and administered by the U.S. Department of Interior. This program provides support for projects that involve long-term conservation of wetland ecosystems and their inhabitants including waterfowl, migratory birds, fish, and other wildlife. The match for this program is on a 1:1 basis.

National Fish and Wildlife Foundation (NFWF)

The National Fish and Wildlife Foundation is administered by the U.S. Department of the Interior. The program promotes healthy fish and wildlife populations and supports efforts to invest in conservation and sustainable use of natural resources. The NFWF targets six priority areas which are wetland conservation, conservation education, fisheries, neotropical migratory bird conservation, conservation policy, and wildlife and habitat. The program requires a minimum of a 1:1 match. More information can be found at http://www.nfwf.org/about.htm.

Bring Back the Natives Grant Program

Bring Back the Natives Grant Program (BBNG) is a NFWF program that provides funds to restore damaged or degraded riverine habitats and the associated native aquatic species. Generally, BBNP supports on the ground habitat restoration projects that benefit native aquatic species within their historic range. Funding is jointly provided by a variety of federal organizations including the U.S. Fish and Wildlife Service, Bureau of Land Management, and U.S. Department of Agriculture and the National Fish and Wildlife Foundation. Typical projects include those that revise land management practices to remove the cause of habitat degradation, provide multiple specie benefit, include multiple project partners, and are innovative solutions that assist in the development of new technology. A 1:1 match is required; however, a 2:1 match is preferred. More information can be obtained from http://www.nfwf.org.

Native Plant Conservation Initiative

The Native Plant Conservation Initiative (NPCI) supplies funding for projects that protect, enhance, or restore native plant communities on public or private land. This NFWF program typically funds projects that protect and restore of natural resources, inform and educate the surrounding community, and assess current resources. The program provides nearly $450,000 in funding opportunities annually awarding grants ranging from $10,000-50,000 each. A 1:1 match is required for this grant. More information can be found at http://www.nfwf.org/programs/grant_apply.htm.

Freshwater Mussel Fund

The National Fish and Wildlife Foundation and the U.S. Fish and Wildlife Service fund the Freshwater Mussel Fund which provides funds to protect and enhance freshwater mussel resources.

The program provides $100,000 in funding to approximately 5-10 applicants annually. More information can be found at http://www.nfwf.org/programs/grant_apply.htm.

Non-Profit Conservation Advocacy Group Grants

Various non-profit conservation advocacy groups provide funding for projects and land purchases that involve resource conservation. Ducks Unlimited and Pheasants Forever are two such organizations that dedicate millions of dollars per year to projects that promote and/or create wildlife habitat.

U.S. Environmental Protection Agency Environmental Education Program

The USEPA Environmental Education Program provides funding for state agencies, non-profit groups, schools, and universities to support environmental education programs and projects. The program grants nearly $200,000 for projects throughout Illinois, Indiana, Michigan, Minnesota, Wisconsin, and Ohio. More information is available at http://www.epa.gov/region5/ened/grants.html.

Core 4 Conservation Alliance Grants

Core 4 provides funding for public/private partnerships working toward Better Soil, Cleaner Water, Greater Profits and a Brighter Future. Partnerships must consist of agricultural producers or citizens teaming with government representatives, academic institutions, local associations, or area businesses. CTIC provides grants of up to $2,500 to facilitate organizational or business plan development, assist with listserve or website development, share alliance successes through CTIC publications and other national media outlets, provide Core 4 Conservation promotional materials, and develop speakers list for local and regional use. More information on Core 4 Conservation Alliance grants can be found at http://www.ctic.purdue.edu/CTIC/GrantApplication.pdf.

Indianapolis Power and Light Company (IPALCO) Golden Eagle Environmental Grant

The IPALCO Golden Eagle Grant awards grants of up to $10,000 to projects that seek improve, preserve, and protect the environment and natural resources in the state of Indiana. The award is granted to approximately 10 environmental education or restoration projects each year. Deadline for funding is typically in January. More information is available at http://www.ipalco.com/ABOUTIPALCO/Environment/Golden_Eagle.html

Nina Mason Pulliam Charitable Trust (NMPCT)
The NMPCT awards various dollar amounts to projects that help people in need, protect the environment, and enrich community life. Prioritization is given to projects in the greater Phoenix, AZ and Indianapolis, IN areas, with secondary priority being assigned to projects throughout Arizona and Indiana. The trust awarded nearly $20,000,000 in funds in the year 2000. More information is available at www.nmpct.org