THE BARBEE LAKES DIAGNOSTIC STUDY
Kosciusko County, Indiana

December 14, 2000

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EXECUTIVE SUMMARY

The Barbee Lakes chain is a group of seven inter-connected natural lakes on the Grassy Creek tributary of the Tippecanoe River, in Kosciusko County, Indiana. The lakes encompass 851 acres of surface area with a drainage area of 52 square miles. The land use in the watershed is 75 percent agriculture with woodland and wetlands making up most of the remaining land use. Approximately 1% of the land use is residential and none is urban, however, the vast majority of residential use is within several hundred yards of the lakes in the watershed. The Barbee Chain has as many as 2300 residences in the vicinity of the lakes, all of which are on standard septic systems. Development of the Barbee Lakes was limited to the high ground around the lakes until the 1950's when much of the surrounding wetland was channelized and filled for development. The lakes' shoreline areas were fully developed by the early 1970's. The Barbee Lakes have good fish populations dominated by bluegill, gizzard shad, largemouth bass, yellow perch and other sunfish in descending order of abundance. Muskies have migrated to the chain from Lake Webster. The lakes in general are dominated by Eurasian water milfoil and curly leaf pondweed, which are invasive, as well as native coontail and large leaf pondweed. Kuhn Lake exhibits the most diverse native plant community with several state endangered and threatened species present. Volunteer secchi disk readings graph a slightly increasing trend in water clarity in the last 10 years for all seven lakes. However, the trend does not correlate well with other water quality data indicators such as phosphorus levels which have been increasing in all seven lakes since 1990.

In-lake sampling suggests that lakes directly on the pathway of Grassy Creek have the worst water quality. Kuhn and Banning Lakes have the best water quality followed by Sechrist and Irish, while Sawmill, Big Barbee, and Little Barbee are the most nutrient rich. All of the lakes fall within the eutrophic or hyper-eutrophic range on Carlson's Eutrophication Index. Phosphorus is the nutrient of concern in all of these lakes. Storm water sample results on tributaries confirmed that the most concentrated source of total phosphorus to the system is Putney Ditch. Although the greatest source of nitrogen enrichment and suspended solids export is still Grassy Creek due to its greater watershed. Phosphorus release from in lake sediments are a problem Big Barbee, Little Barbee and Sawmill Lakes. The flushing or turnover rate in the same three lakes is only from 8.2 days in Little Barbee to 52 days in Big Barbee Lake. Due to the short turn over rate, in-lake treatments for phosphorus are not recommended. Efforts to reduce phosphorus loading should be concentrated in the watershed.

Focusing on phosphorus reduction in the watershed should begin on Putney Ditch by first installing filter strips and grassed waterways at the upper end of the ditch near tiled areas leading to the ditch. Second, three potential wetland restoration sites were identified along Putney Ditch. Restoration of wetlands reduces flooding while trapping and storing sediments and associated nutrients. The third area of focus should be to work with the major landowners between Ridinger Lake and County Road 850 East to install filter strips and fencing around pastures and cropped areas adjacent to Grassy Creek. The Barbee Lakes Property Owners should also support the efforts of the Tippecanoe Environmental Lake and Watershed Foundation to construct filtration wetlands, stabilize eroding stream banks and install Best Management Practices in the Upper Grassy Creek watershed. Closer to the lake, a feasibility study should be conducted to look into the potential of restoring a wetland at the northeast corner of 350 North and 850 East. Also the Association should have a comprehensive plant management plan completed to address the invasive plants and the subsequent biological oxygen demand created by the decaying plant material after weed control efforts. Lake shore home owner recommendations include eliminating the use of fertilizers that contain phosphorus, refraining from the disposal of lawn or animal waste in the lake, considering ways to filter drains from roads, rooftops and driveways, cleaning septic tanks regularly, and using idle speeds in shallow water areas. Channel bottoms that have several feet of organic debris and are easily disturbed by motor boat props should be considered for dredging. Finally, although septic system issues were not directly within the scope of this study, it is our opinion that bringing sewers to all residences within the vicinity of the lake would be beneficial in reducing total phosphorus, nitrogen and pathogen levels in the lake.

ACKNOWLEDGMENTS

This Diagnostic Study was performed with funding from the Indiana Department of Natural Resources - Division of Soil Conservation and the Barbee Lakes Property Owners Association. The team of J. F. New and Associates, Inc. and Indiana University - School of Public and Environmental Affairs documented the historical information available, completed lake and tributary stream sampling for nutrient and sediment loading and modeled nutrient export to the lakes. Significant contributors to this study included Samuel St. Clair and Julie Harrold of the Kosciusko County Soil and Water Conservation District. Special thanks are due the Barbee property owners Richard Long, Ed Raymann, Al Young and Barry Hecker for their initiative and assistance in getting this study completed. Marshall Minnick, Gwen White, Jed Pearson, Bob Johnson and numerous others assisted with their comments and contributions on historic lake activities. Authors of this report include William Jones and Melissa Laney at Indiana University, and Marianne Giolitto, John Richardson, Jason Thron, and Cornelia Sawatzky at J. F. New and Associates, Inc.

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KOSCIUSKO COUNTY, INDIANA

INTRODUCTION

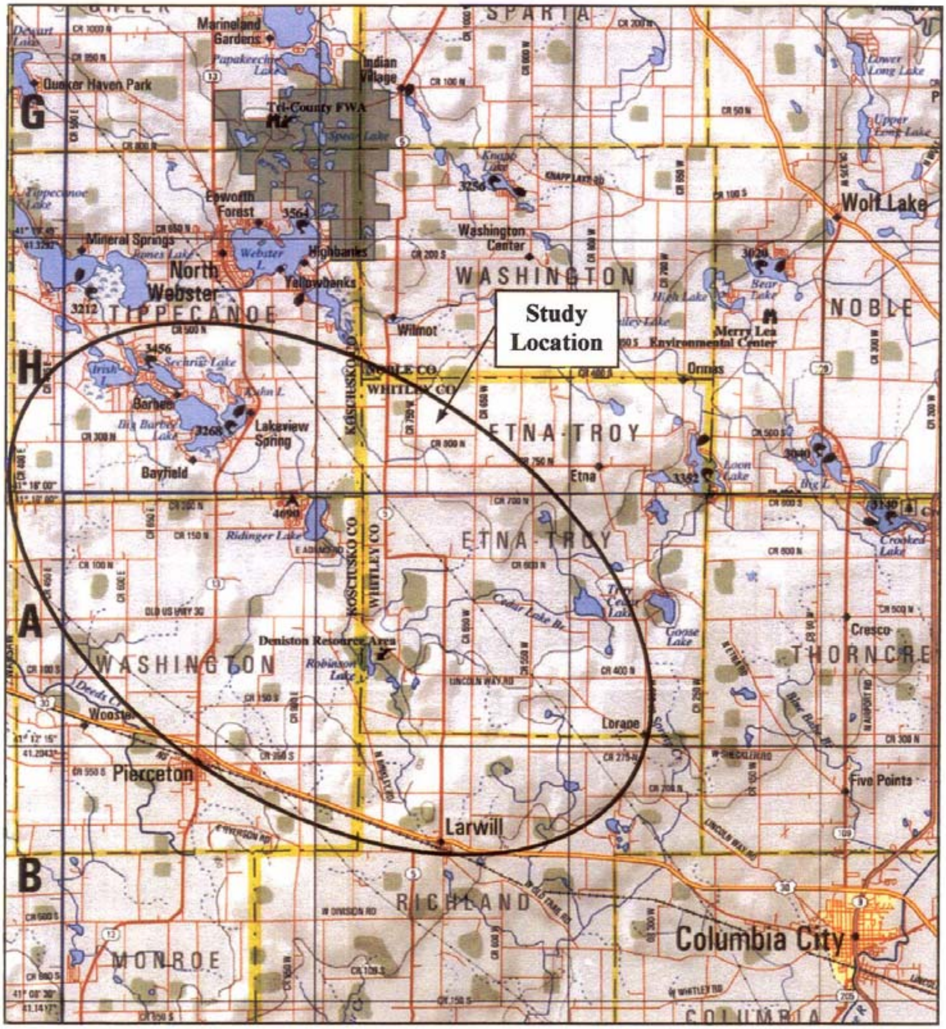
The Barbee Lakes chain is composed of seven interconnected, natural lakes situated west of North Webster, Indiana (Figure 1). Specifically, the lakes are located in Sections 20, 21, 26, 27, 28, 29, 33, and 34, Township 33 North, Range 7 East, in Kosciusko County. The lakes' watershed stretches southeast into Whitley County, encompassing approximately 33,150 acres (13,420 ha) or 52 square miles (133 km^2). Water from the lakes discharge to Lake Tippecanoe. From Lake Tippecanoe, water drains through the Tippecanoe River to the Wabash River, eventually reaching the Ohio River in southwestern Indiana.

The Barbee Lakes and their watershed formed during the most recent glacial retreat of the Pleistocene era. The advance and retreat of the Saginaw Lobe of a later Wisconsian age glacier as well as the deposits left by the lobe shaped much of the landscape found in northeast Indiana (Homoya et al., 1985). In Whitley and Kosciusko counties, the receding glacier left a nearly level topography dotted with a network of lakes, wetlands and drainages.

The Barbee Lakes are located in the central portion of the Northern Lakes Natural Area (Homoya et al., 1985). The Northern Lakes Natural Area covers most of northeastern Indiana where the majority of the state's natural lakes are located. Natural communities found in the Northern Lakes Natural Area prior to European settlement included bogs, fens, marshes, prairies, sedge meadows, swamps, seep springs, lakes, and deciduous forests. Historically, much of the Barbee Lakes watershed was likely swamp habitat. Upland areas were likely forested with oak and hickory species. Wetlands likely bordered the lakes with red and silver maple, American elm, and green and black ash being the dominant species in forested areas and cattails, swamp loosestrife, bulrush, marsh fern, and sedges being the dominant species in more open areas. A 1900 report by Blatchley supports this view of the lakes reporting expansive wetland habitat adjacent to the Barbee Lakes (Figure 2).

Changes in land use have altered the watershed's natural landscape. Settlers to the area drained wetlands to farm the area's rich soil. Today, approximately 75% of the Barbee Lakes watershed is utilized for agricultural purposes. The lakes' shorelines have been heavily developed for residential use. Channels were constructed through the wetlands adjacent to the lakes provide additional lakefront property. Lots have been subdivided further increasing the density of housing along the lakefront. These changes in land use have likely accelerated the natural eutrophication process in the Barbee Lakes.

Several studies have documented changes in Barbee Lakes. Work done by the Clean Lakes Program reports increasing phosphorus concentrations in the lake over the past decade. A comparison of oxygen profiles derived from the Clean Lakes Program assessments of the Barbee



Scale: 1" = 2.5 miles

JFNA# 98-03-27

Figure 1: **Location Map**
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

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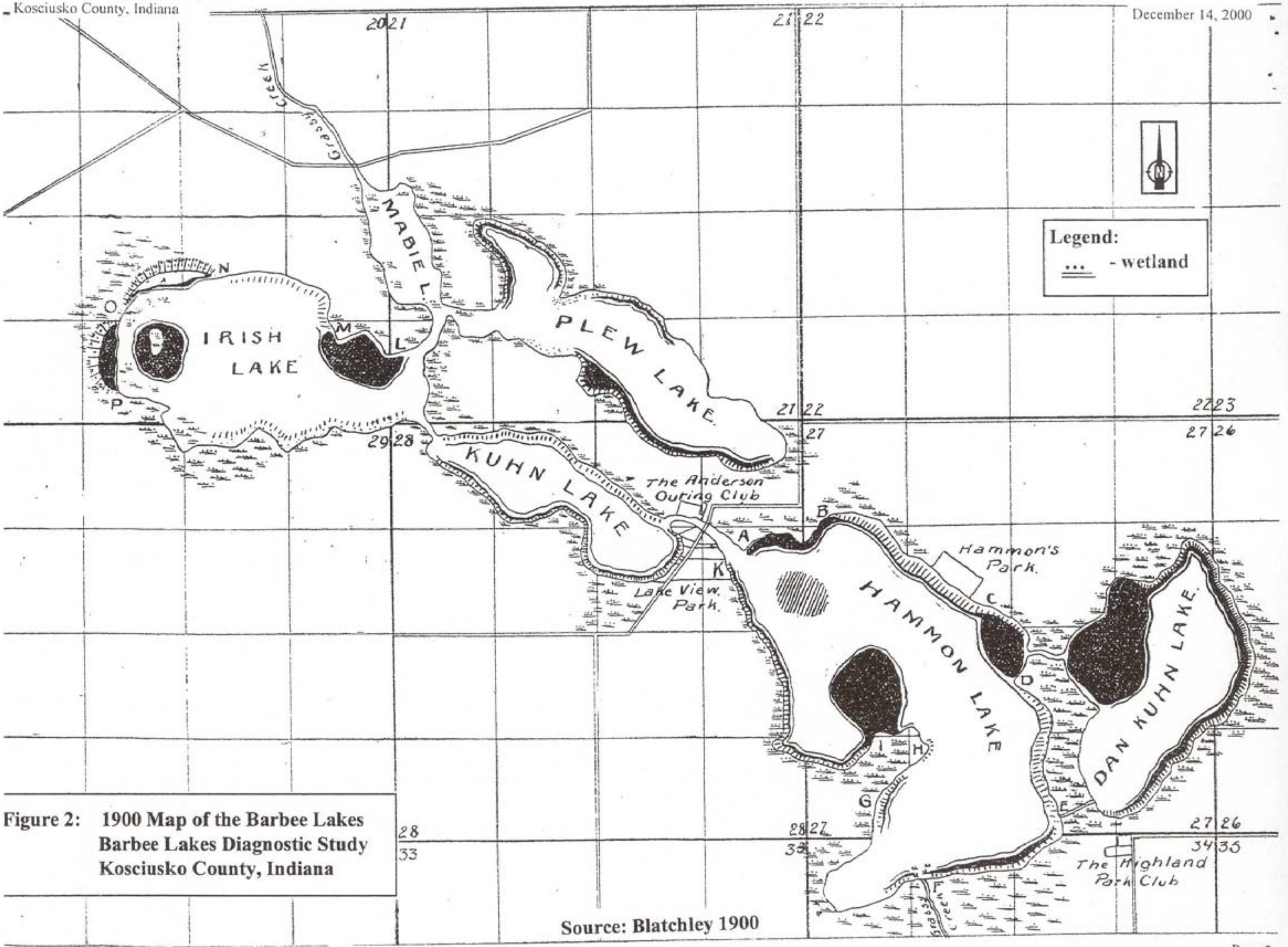

Figure 2: 1900 Map of the Barbee Lakes
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

Source: Blatchley 1900

Lakes to oxygen profiles prepared from historic Indiana Department of Natural Resources fisheries surveys indicates an increasing volume of anoxic water in several of the lakes. This evidence suggests that human induced pressures are artificially accelerating the natural eutrophication process in the Barbee Lakes.

To gain a better understanding of the factors affecting the lake's health, the Barbee Property Owners Association applied for and received funding through the Indiana Department of Natural Resources Lake and River Enhancement Program for a lake and watershed diagnostic study. The purpose of the study is to describe the conditions and trends in Barbee chain lakes as well as their watershed, identify potential problems, and make prioritized recommendations addressing these problems. The study included a review of historical studies, interviews with lake residents and state/local regulatory agencies, the collection of lake and stream water quality samples, an inventory of aquatic macrophytes and plankton, and field investigations identifying land use patterns. This report documents the results of the study.

REVIEW OF EXISTING INFORMATION

Lake and Watershed Physical Characteristics

The Barbee Lake chain is composed of seven interconnected, natural lakes totaling 851 acres (Figure 3). The chain includes Kuhn, Big and Little Barbee, Irish, Banning, Sechrist, and Sawmill Lakes. Two smaller lakes, Shoe and Heron Lakes, are also hydrologically connected to the Barbee chain. Water from Heron Lake flows into Kuhn Lake, which in turn flows into Big Barbee Lake. Shoe Lake discharges to Banning Lake which discharges to Irish Lake. Sechrist Lake discharges to Sawmill Lake. The remaining four lakes of the chain, Big and Little Barbee, Irish, and Sawmill Lakes, lie along Grassy Creek, a major tributary to the Tippecanoe River.

While Shoe and Heron Lakes are hydrologically connected to the Barbee chain, they were omitted from the study largely due to the lack of access to these lakes. No public access sites are located at these lakes. Nor can they be accessed by boat from Banning or Kuhn Lakes. In addition, the lakes influence on the Barbee chain's water quality is likely small in comparison to the influence exerted by the rest of the watershed included in the study. Both lakes have very small watersheds, limited primarily to their immediate shorelines. Wetland vegetation surrounds Heron Lake protecting its water quality. Wetland vegetation between Heron Lake and Kuhn Lake filters water discharging to Kuhn Lake. While single family residences border Shoe Lake's shoreline, wetland vegetation filters water at the lake's outlet before it reaches Banning Lake. This vegetation likely removes much of the suspended solids (and any nutrients attached to the solids), but may not affect dissolved nutrient transport to Banning.

Grassy Creek is the largest source of discharge to the Barbee chain draining approximately 25,000 acres or 75% of the total watershed. Several other lakes exist upstream of the Barbee chain on Grassy Creek and its tributaries. Ridinger Lake lies immediately upstream of the chain. Pierceton Lake, Robinson Lake, Troy Cedar Lake and other smaller lakes are located further

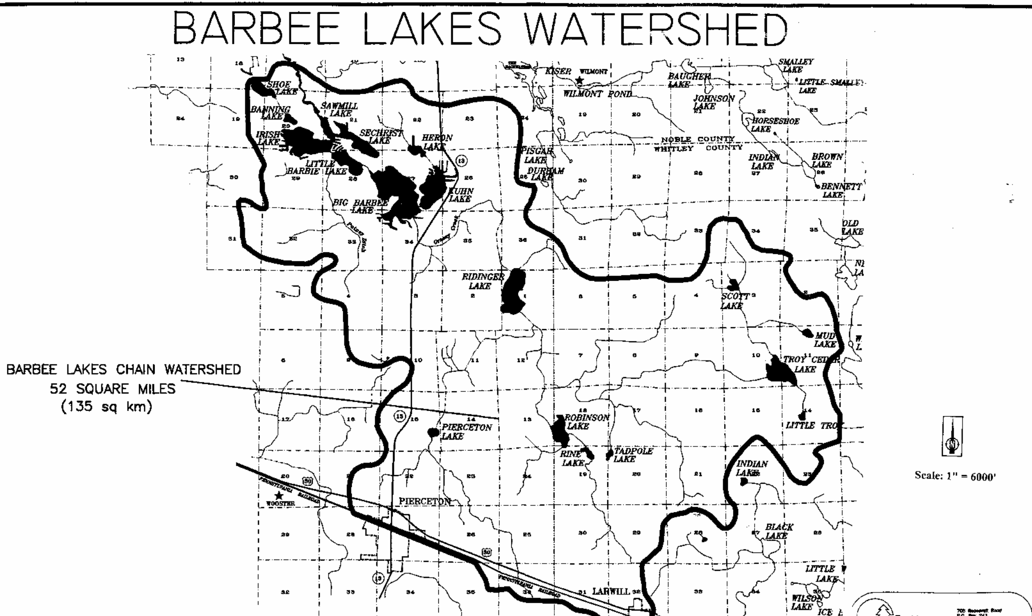

Figure 3: **Barbee Lakes Watershed**
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

upstream. Putney Ditch, draining approximately 2,750 acres, is the second largest inlet to the Barbee chain.

Table 1 summarizes the surface area, volume and other geographic information for Barbee Lakes and their watershed. The Barbee Lakes chain watershed encompasses approximately 33,150 acres (13,420 ha) or 52 square miles (133 km^2). This results in a watershed area to lake area ratio of approximately 39:1. Watershed size can affect the chemical and biological characteristics of a lake. For example, lakes with large watersheds have the potential to receive more pollutants (sediments, nutrients, pesticides, etc.) from runoff than lakes with smaller watersheds. Consequently, 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 may have a greater influence on the lake's health than is the case for lake's with large watershed to lake ratios.

The average depth of the Barbee Lakes is 16 feet (4.9 m). The deepest point, 59 feet (18 m), is located in Sechrist Lake. Big Barbee Lake possesses the greatest volume (4749 acre-ft or 5.9 x 10^6 m^3), largely due to its large surface area. Shoreline Development (D_L) is a measure of how circular a lake is. It compares the shoreline length to the circumference of a circle of the same area. For example, a perfect circle has a D_L of 1.0 since its length and circumference are equal. As lake shape deviates from a perfect circle, D_L increases in value and there is proportionately more shoreline per lake area. Embayments along the shoreline add to shoreline length. All this has important implications for shoreline impacts such as the amount of shoreline available for home sites, the amount of shallow water, and the amount of shoreline that could erode. Of the Barbee Lakes, Kuhn has the highest D_L and Banning has the smallest D_L.

TABLE 1. Barbee Lakes Morphometry.

Lake	Surface Area (acres)	Maximum Depth (ft)	Mean Depth (ft)	Volume (ac-ft)	Watershed size (ac)	Shoreline Development (DL)
Big Barbee	304	45	15.6	4749	28737	2.72
Kuhn	137	28	7.9	1076	2374	3.84
Little Barbee	74	26	11.0	816	31607	2.34
Irish	182	36	10.7	1952	32483	2.98
Sechrist	105	63	18.9	1989	270	1.92
Banning	17	17	7.8	93	312	1.50
Sawmill	36	27	8.6	308	33099	1.94

Climate

The climate in Kosciusko and Whitley counties is characterized as cool and humid with winters that typically provide enough precipitation, in the form of snow, to supply the soil with sufficient moisture to minimize drought conditions when the hot summers begin. The average daily winter temperature is usually around 26 degrees Fahrenheit (-3 ^{o}C); the summer average is close to 70 degrees (21 ^{o}C). The highest temperature ever recorded was 103 degrees (39 ^{o}C) on July 17, 1976. Total annual precipitation averages 35 to 38 inches (89 to 97 cm). In 1999 just over 35 inches (89 cm) of precipitation was recorded at Columbia City, Indiana in Whitley County. Although the difference between the annual total precipitation in 1999 compared to the average does not seem to be drastic, the year was characterized by extensive dry periods in March, July, and October through December. Some months saw greater than average precipitation, while those stated above saw levels far below the normal average.

Soils

The soil types found in Kosciusko and Whitley Counties are a product of the original parent materials deposited by the glaciers that covered this area 12,000 to 15,000 years ago. The main parent materials found in these two counties are glacial outwash and till, lacustrine material, alluvium, and organic materials that were left as the glaciers receded. The interaction of these parent materials with the physical, chemical, and biological variables found in the area (climate, plant and animal life, time, and the physical and mineralogical composition of the parent material) formed the soils located in Kosciusko and Whitley Counties today. The dominant soil type in the Barbee Lakes chain watershed is sandy loam.

Soils in the watershed, and in particular their ability to erode or sustain certain land use practices, can impact the water quality of a lake. For example, highly erodible soils are, as their name suggests, easily erodible. Soils that erode from the landscape are transported to waterways or waterbodies where they impair water quality and often interfere with recreational uses by forming sediment deltas in the waterbodies. In addition, such soils carry attached nutrients, which further impair water quality by fertilizing macrophytes (rooted plants) and algae. Soils that are used as septic tank absorption fields deserve special consideration as well. The presence of highly erodible soils and the use of septic fields in the Barbee Lakes chain watershed are described in further detail below.

Highly erodible soils

The scope of the diagnostic study did not allow for exact calculation of acreage of highly erodible soils in the Barbee Lakes chain watershed. In a detailed study of lakes in Kosciusko County, Hippensteel (1989) found that approximately 35.3% of the Grassy Creek watershed is mapped as highly erodible land. Because the Grassy Creek watershed accounts for approximately 75% of the total acreage in the entire Barbee Lakes chain watershed, this figure provides a good estimate for the entire watershed. Hippensteel (1989) also noted approximately 27% of the Stonebrunner-Putney watershed (draining to Little Barbee) is mapped as highly erodible land.

General estimates of highly erodible soils were also obtained for the two counties in which the watershed lies. In Kosciusko County, approximately 30% of the county is mapped as highly erodible soils (Sam St. Clair, personal communication). In Whitley County approximately 60%

of the county is mapped as highly erodible. Most of the highly erodible soils occur in the northern portion of the Whitley County (Amy Lybarger, personal communication). Work done by the Purdue University Cooperative Extension Service on the Upper Tippecanoe River Hydrologic Unit Area confirms that much of the highly erodible land in the Upper Tippecanoe River watershed is concentrated in the upper Grassy Creek watershed as well as the Lake Webster watershed.

Septic Use

Septic systems

As is common in rural areas, septic tank and septic tank absorption fields are utilized for wastewater treatment in the Barbee Lakes chain watershed. With the exception of the Lake Estates Mobile Home Park on Irish Lake, which has a cluster system, all the residences on the lakes use individual on-site septic tank systems. This type of wastewater treatment system relies on the septic tank for primary treatment to remove solids and the soil for secondary treatment to reduce the remaining pollutants in the septic tank effluent to levels that protect the groundwater from contamination. Groundwater is one of the water sources to the lakes. Consequently, the type of soil located adjacent the Barbee Lakes chain and the soil's ability to function as a septic tank absorption field will affect the lakes' water quality.

A variety of factors can affect a soil's ability to function as a septic absorption field. Whether or not a soil is typically ponded during a portion of the year has obvious impacts on its ability to serve as a septic field. Frequently ponded soils offer little or no treatment to waste effluent. Untreated effluent is often simply flushed to the lake. Soils located on sloped land may have difficulty in treating wastewater as well. Septic fields sited on these soils may require enlarged fields to treat the waste effluent. Soils that have been disturbed through excavation and fill or compaction are also unsuitable for wastewater discharge using soil absorption fields.

In addition, soils with very slow percolation rates are limited in their ability to serve as septic fields. These soils can become clogged due to the high levels of organic material in the septic effluent. Like soils on sloped land, these soil types require very large absorption fields due to the low permeability of the soil. Soils with slow percolation rates are prone to septic failure resulting in overland flow of untreated septic effluent to the adjacent lake. Conversely, in soils with very rapid percolation rates, effluent travels quickly through the soil to the groundwater without being treated. Contaminated groundwater often reaches the lakes as well.

The NRCS ranks each soil series in terms of its limitations for use as a septic tank absorption field. Each soils series is placed in one of three categories: slightly limited, moderately limited, or severely limited. Use of septic absorption fields on soils in the moderately or severely limited soils generally requires special designs, planning, or maintenance to overcome the limitations. Table 2 summarizes the soil series located adjacent to the Barbee Lakes chain in terms of their suitability for use as a septic tank absorption field. Figure 4 shows the location of soil types adjacent to the Barbee Lakes.

TABLE 2. Soil Types Adjacent to the Barbee Lakes Chain

Symbol	Name	High Water Table	Suitability for Septic Tank Absorption Field
Ao	Aquents-Urban land complex, rarely flooded	-	unsuitable, flooding
He	Histosols and Aquolls	-	unsuitable, ponding
Ed	Edwards muck, drained	+1-0.5	Severe, ponding, percs slowly
Ht	Houghton muck, undrained	+1-1.0	severe, subsides, ponding, percs slowly
BoC	Boyer loamy sand	>6.0	severe, poor filter
ClC	Coloma loamy sand	>6.0	severe, poor filter
KoA, KoC	Kosciusko sandy loam	>6.0	severe, poor filter
KxC3	Kosciusko sandy clay loam	>6.0	severe, poor filter
OrA	Ormas loamy sand	>6.0	severe, poor filter

Source: Soil Survey of Kosciusko County

Aquents-Urban land complex, rarely flooded (Ao) typically occurs on the edges of lakes, where marshes have been filled with soil material. This unit is rarely flooded, except for brief periods by stream or lake overflow. In many areas, it is ponded by runoff from the higher adjacent soils. The physical characteristics of the Aquents are highly variable, and suitability for use depends on the thickness and texture of the fill, depth to the seasonal high water table, and the nature of the underlying material. Because of the flooding, the soils are generally unsuitable as sites for buildings and septic tank absorption fields. Under current Indiana regulations, it is illegal to place septic systems in these soils.

The Histosols and Aquolls (He) are very poorly drained soils frequently ponded by runoff from the higher adjacent soils or by lake or stream overflow. The water table is typically near or above the surface most of the year, which makes these soils generally unsuitable for septic tank absorption fields.

The Edwards muck, drained (Ed) and Houghton muck, undrained (Ht) are poorly drained soils with a water table near or above the surface most of the year. Due to the seasonal high water table, these soils are severely limited for septic tank absorption fields.

BARBEE LAKES WATERSHED

Scale: 1" = 1320'

Source of map: Natural Resource Conservation Service Soil Survey of Kosciusko County

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Figure 4: **Soil Map**
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

Rapid permeability impairs ability of the remaining four soil types adjacent to the Barbee Lakes to serve as septic absorption fields. Boyer loamy sand (BoC) is a well-drained soil with moderately rapid permeability in the subsoil and very rapid permeability in the material underlying the subsoil. Coloma loamy sand (ClC) is a somewhat excessively drained soil which is rapidly permeable. Kosciusko sandy loam (KoB, KoC) and Kosciusko sandy clay loam (KxC3) are well-drained soils. Permeability is moderate in the subsoil and very rapid in the underlying material. Ormas loamy sand (OrA) is a well-drained soil. Permeability rates are rapid to moderately rapid in the subsoil and very rapid in the underlying material. Due to the rapid permeability of these four soil types, they do not provide adequate filtering capability for septic tank absorption fields and may cause pollution of the ground water.

Septic survey

A 1999 study (Grant, 1999) conducted on the Barbee Lakes chain supports the premise that all of the soils surrounding the lakes are not suitable for siting septic systems. The study surveyed all seven of the lakes with a septic leachate detector. This instrument is attached to a boat which surveys the near shore area to detect the presence of septic effluent. The study noted the presence of septic effluent in nearly all areas of the Barbee Lakes chain. Not only was the presence of septic effluent observed, the study described the septic effluent infiltration as “severe” in all areas of the lakes except for the north shore of Irish Lake (excluding the northeast bay) and the north shore of Sechrist Lake (excluding the northwest bay).

The study highlights several reasons for the observed results. First, the density of septic systems around the Barbee Lakes is too high. Septic systems were designed for use in rural areas where systems are spaced at half or quarter mile intervals. The EPA defines a high-density septic area as an area in which there is more than one septic system per 16 acres (EPA, 1977). The density of septic systems around the Barbee Lakes chain greatly exceeds this threshold.

In addition to the high-density of septic systems, the study points to the poor soils in which the septic systems are sited. As noted above, all of the soils around the Barbee Lakes rate as severe or unsuitable for use as septic absorption fields. The soil characteristics responsible for these ratings are the presence of a high water table, frequency of flooding or ponding, poor filtering capabilities, and rapid permeability of the subsoil and underlying material. The study also suggests the conversion of cottages to fulltime residences with the accompanying addition of more water-using appliances, such as washing machines and dishwashers, has further taxed the existing septic systems.

The study warns that the results may have been more severe had the study area not been experiencing a drought. Under wetter conditions, the water table would be higher and likely limit the ability of the septic absorption field. The study suggests that given the location of many of these septic systems, none would function properly under wetter conditions. Consequently, untreated septic effluent would reach the lakes.

Effects of septic effluent

Pollution from septic tank effluent can affect a lake and its users in a variety of ways. It can contribute to eutrophication, or nutrient enrichment, of the lake which impairs the lake water quality. The nutrients present in septic tank effluent can fertilize algae and macrophytes in the lake promoting algae blooms and macrophyte growth. In addition, septic tank effluent potentially poses a health concern for lake users. Swimmers, anglers, or boaters that have body contact with contaminated water may be exposed to waterborne pathogens. Fecal contaminants can be harmful to humans and cause serious diseases, such as infectious hepatitis, typhoid, gastroenteritis, and other gastrointestinal illness.

Soil Summary

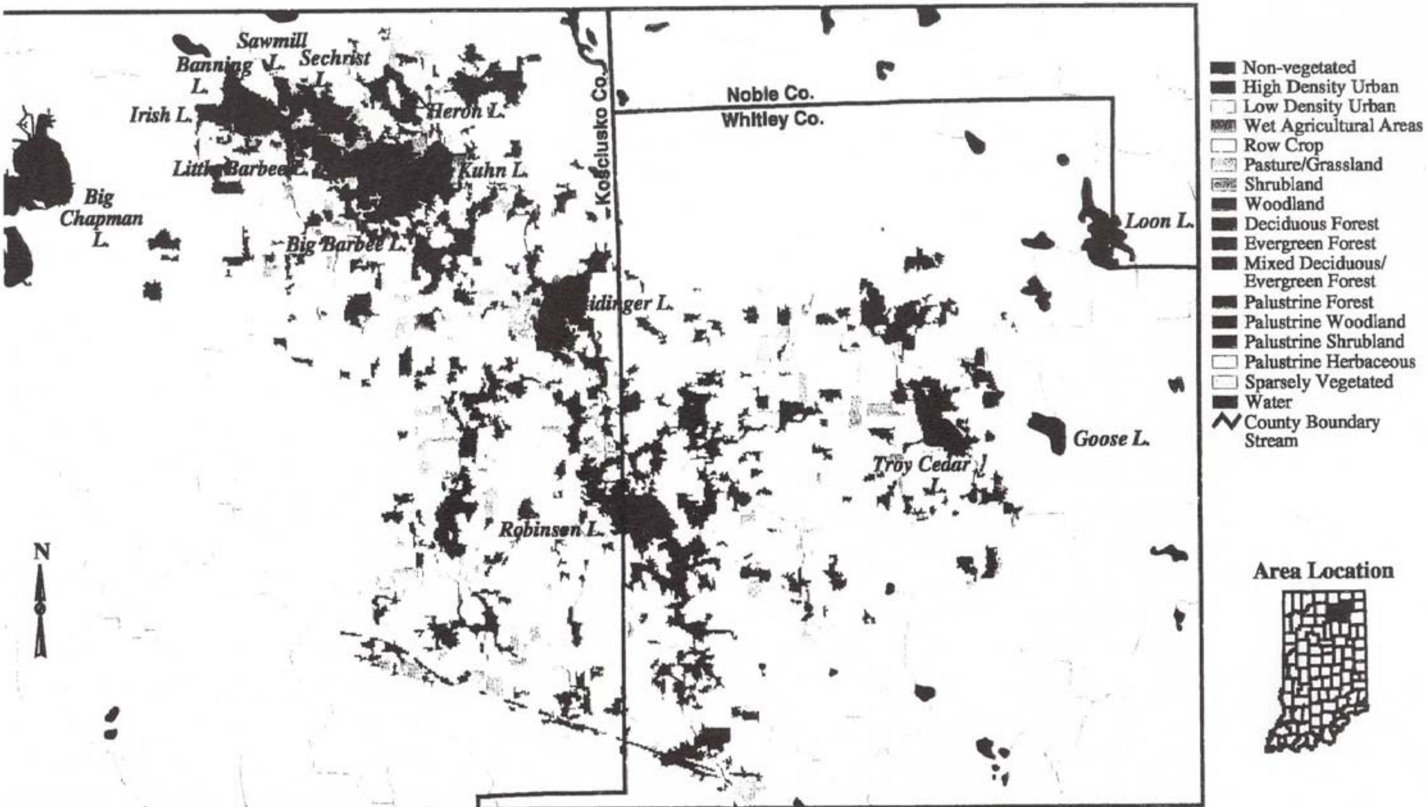
The type of soils in a watershed and the land uses practiced on those soils can affect a lake's health. The Barbee Lakes watershed contains a higher concentration of highly erodible soils compared to watersheds located lower in the Upper Tippecanoe watershed. Soil erosion contributes sediment to the lakes reducing the lake's water quality and interfering with recreational uses of the lakes. Nutrients attached to eroded soils will help fertilize algae and rooted plants. Consequently, conservation methods and best management practices (BMPs) should be utilized when soils are disturbed in these areas. This includes development of shoreline property as well as farming in highly erodible soils.

Soil type should also be considered in siting septic systems. Some soils do not provide adequate treatment for septic tank effluent. All of the Barbee Lakes chain shoreline is mapped in soils that rate as severely limited or generally unsuitable for use as a septic tank absorption field. This is typical of much of Indiana. Research by Dr. Donald Jones suggests that 80% of the soils in Indiana are unsuitable for use as a septic tank absorption field (Grant, 1999). The increased density of housing and the conversion of summer cottages to fulltime living quarters has exacerbated the situation. Careful consideration should be given to sewering the homes around the lakes. While it may be expensive, a sewer system would eliminate a portion of the nutrient load reaching the lakes, improving their water quality and limiting their productivity.

Land Use

Figure 5 and Table 3 present land use information for the entire Barbee Lakes chain watershed. Land use data was obtained from the Indiana Gap Analysis project. (Land use categories shown in Table 3 are general in nature; Appendix 1 breaks the data into more detailed categories as well as providing land use by subwatershed.) 75% of the land in the watershed is used for agricultural purposes, including cropland, pasture and agricultural woodlots. The Barbee Lakes chain watershed is typical of Kosciusko County as a whole where 72% of the land in the county is used for agricultural purposes. Agricultural land accounts for 77% of the total land in Whitley County (U.S. Census of Agriculture, 1999). Forested land and wetlands account for much of the remaining land in the Barbee Lakes chain watershed (13% and 7 % respectively). Less than one percent of the land in the watershed is utilized for residential or commercial purposes.

Barbee Lake Chain Watershed Area and Land Cover



Data Sources:

County boundaries from U.S. Census Bureau TIGER files at 1:100,000 scale.

Land cover classifications from the Indiana Gap Analysis with a resolution of 30 meters and a minimum mapping unit of 1 hectare.

Stream and lake boundaries from USGS Digital Line Graph files at 1:24,000 scale.

Watershed delineations by Kevin Beale using USGS Digital Elevation Models at 1:24,000 scale and SureMaps topographic Digital Raster Graphics at 1:24,000 scale.

Universal Transverse Mercator Projection; Zone 16; North American Datum 1983.

This plot was created May 1999 at the School of Public & Environmental Affairs, Geographic Information Systems Laboratory, Bloomington, IN.

0 2 4 6 Kilometers

0 2 4 Miles

Figure 5: Land Use in the Barbee Lakes Watershed
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

Clean Lakes Program

TABLE 3. Land Use in the Barbee Lakes Chain Watershed

Land use	Area (acres)	Area (hectares)	Percent of watershed
Agricultural	323	131	75.0%
Forested	24829	10052	13.0%
Wetland	4306	1743	6.8%
Residential/commercial	2258	914	1.0%
Other	172	70	0.6%
Open water	1197	485	3.6%
Total	33085	13395	100%

Source: Indiana Gap Analysis Project

In 1998, approximately 49% of the cropland in Kosciusko County was planted in corn and 39% in soybeans (U.S. Census of Agriculture, 1999). Conservation tillage practices are utilized throughout the county. In 1998, no-till was practiced on approximately 17% of the farmland planted in corn. Mulch tillage (a tillage method that leaves at least 30% of residue cover on the surface after planting) was practiced on approximately 13% of the farmland planted in corn. For fields planted in soybeans, the percentage of farmland utilizing conservation tillage methods was higher: 57% in no-till, 25% in mulch-till (Julie Harrold, Kosciusko County NRCS, personal communication).

Whitley County reports similar percentages in cropland use and slightly higher conservation tillage use. In 1998, 39% of the cropland in Whitley County was planted in corn while 44% was planted in soybeans. Landowners practiced no-till farming on approximately 34% of the land planted in corn and approximately 68% of the land planted in soybeans (Amy Lybarger, District Conservationist, personal communication). Lybarger also noted that use of no-till practices on cropland planted in corn has declined in recent years. However, she also observed a decrease in the use of wide-row bean planting.

Wetlands

Wetlands provide a variety of functions for an ecosystem. These functions include filtering sediment and nutrients in runoff, detaining water and allowing for groundwater recharge and discharge, and providing 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 land use table above (Table 3) indicates that wetlands account for approximately 6.8% of the Barbee Lakes chain watershed. Table 4 presents the acreage of wetlands by type. The IDNR (Indiana Wetland Conservation Plan, 1996) estimates that approximately 85% of the state's wetlands have been filled. The greatest loss has occurred in the northern counties of the state such as Kosciusko and Whitley Counties. The last glacial retreat in these 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 38% and 45% of the land in Kosciusko and Whitley Counties, respectively (cited in Hudak, 1995).

TABLE 4. Acreage and Classification of Wetland Habitat in the Barbee Lakes Watershed

Wetland Type	Area (acres)	Area (hectares)	Percent of watershed
Forested	1169.1	473.3	3.5%
Shrubland	656.9	265.9	2.0%
Herbaceous	432.4	175.1	1.3%
Total	**2,258.4**	**914.3**	**6.8%**

Source: Indiana Gap Analysis Project

As part of the United States Army Corps of Engineers study on the upper Tippecanoe River Basin (1995), the Kosciusko County Natural Resources Conservation Service identified 28 potential wetland restoration sites. Fifteen of these sites are located within the Barbee Lakes chain watershed (Figure 6). The Corps study focused on water retention upstream of the Barbee Lakes as a way to ameliorate flooding along the Barbee Lakes shorelines. As a consequence, many of these restoration sites involve damming ditches rather than complete restoration of pre-settlement hydrology. Despite this, these proposed wetlands will serve many of the functions that fully restored wetlands would provide.

The proposed restoration sites total approximately 1,250 acres (506 ha). Some of this acreage is currently wetland habitat. However, many of these wetlands are disturbed and/or partially drained. The proposed restoration would increase site hydrology improving the existing wetland habitat. While 1,250 acres (506 ha) is a small amount of land relative to the size of the Barbee lakes watershed, the restored habitat would increase water storage and filter nutrients and sediments from runoff, which in turn would decrease downstream flooding and improve downstream water quality. Based on the figures for artificially enhanced drainage land given above, it is likely that additional wetland restoration sites exist in the Barbee Lakes chain watershed. Restoration of these areas could further add to the benefits for the watershed.

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 database was developed 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 Indiana Department of Natural Resources (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 the presence of the listed species

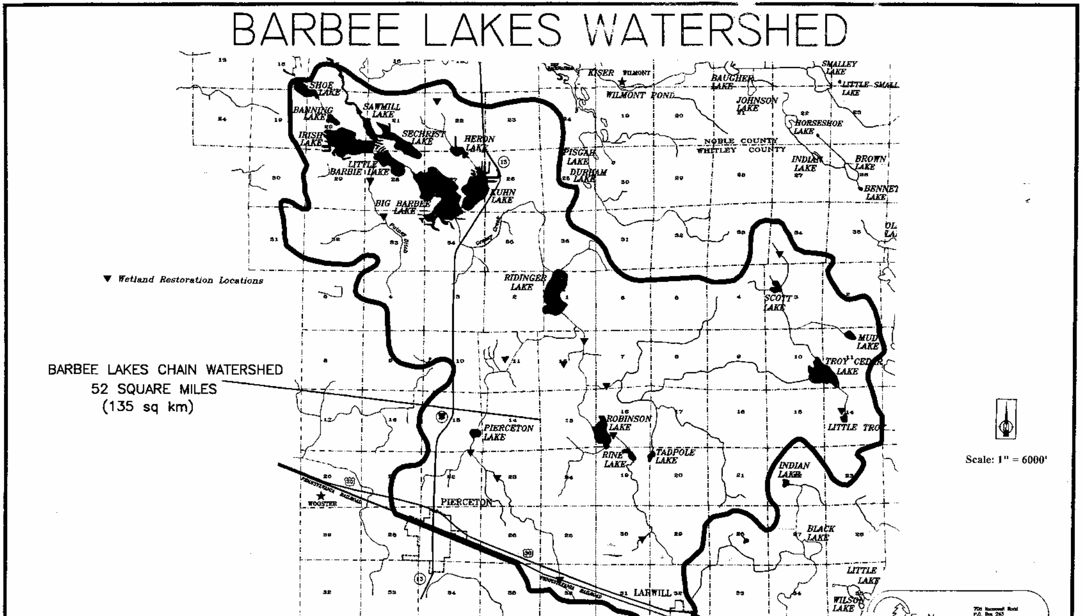


Figure 6: **Potential Wetland Restoration Sites**
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

or that the listed natural area is in pristine condition. To assist users, the database does include the date that the species or special habitat was last observed in a specific location.

Results from the database search for the Barbee lakes watershed are presented in Appendix 2. (For additional reference, a listing of endangered, threatened and rare species documented in Kosciusko and Whitley Counties is included in Appendix 3.) Cisco (*Coregonus artedi*), a state species of concern, are recorded as occurring in Sechrist and Big Barbee Lakes in 1955 and 1913. The presence of cisco in these lakes at this time is unlikely as the 1997 IDNR study did not find any. Nor were any observed during a supplemental study conducted by the IDNR in 1999 (Bob Robertson, personal communication). This supplemental study, which focused only on cisco, was conducted on all northern Indiana lakes known to have cisco at some point in recent history.

The marsh around Heron Lake is listed in the database as supporting a high quality community of marsh flora and fauna. This high quality community includes marsh wren (*Cistothorus palustris*) which is a state endangered species. The database also lists the Camp Crossland Natural Area as supporting two state endangered species, bobcats (*Lynx rufus*) and foxtail sedge (*Carex alopecoidea*). The presence of a state endangered pondweed, nutall pondweed (*Potamogeton epihydrus*), in Ridinger Lake was recorded in the database in 1962.

Fisheries

Several studies have been conducted to document the condition of the Barbee lakes fisheries. The earliest study on record is Tucker's 1922 hydrographic study. In 1942, Ricker examined the growth rates of bluegill in the lakes. Indiana Department of Natural Resources (IDNR) began tracking the condition of the Barbee Lakes fisheries in 1972. The 1972 IDNR survey was followed by surveys in 1980, 1988, and 1997. Additional studies focusing on the Barbee Lakes' Property Owners Association stocking efforts were conducted in 1983, 1987, and 1990. A list of species observed in the Barbee Lakes is presented in Appendix 4.

1972 study

The 1972 IDNR study included Irish, Sechrist, Sawmill, Banning and Little Barbee Lakes. Kuhn and Big Barbee Lakes were not examined. The study rated the sport fishery on these lakes as fair to poor. It found bluegill numbers to be low with slow growth rates compared to other northeastern Indiana lakes. Slow growth was also noted in the largemouth bass population. The yellow perch collected were small; few fish collected were of catchable size (8.0 inches or more). The IDNR expressed some concern over the large size of the lake chubsuckers collected. These fish may be too large to serve as forage fish for game species. The study concluded that eradication followed by restocking would be the best method to manage the lakes' fisheries, however, it does not recommend this option. Weed control, particularly around pier areas, was recommended in three of the five lakes.

1980 study

In 1980, IDNR (Pearson, 1980) surveyed all seven of the lakes in the Barbee Chain. Survey sampling methods consisted of 676 hours of gill netting, electrofishing, and trap netting. The effort resulted in the capture of 1,212 fish from 31 species. Bluegill dominated the catch accounting for 30.5% of the total number of individuals. Other species caught in large numbers included suckers (16.7%), perch (13.0%), black crappie (8.5%) and redear (7.9%). Suckers accounted for 43% of the total weight of the catch.

To allow for comparison to the 1972 study, the study split the lakes into two groups: the Upper Barbee Lakes - Kuhn and Barbee Lakes and the Lower Barbee Lakes - Irish, Sechrist, Sawmill, Banning and Little Barbee Lakes. As in 1972, the 1980 study showed bluegill numbers to be low compared to other northeastern Indiana lakes. However, the relative abundance of bluegills increased and the growth rate was slightly higher than that recorded in the 1972 study. Yellow perch were small with only 12% of the perch collected being of harvestable size. The number of perch collected increased from the 1972 effort and was comparable to other northeastern Indiana lakes. Like perch, the black crappie caught were small with only 7% of the fish being of harvestable size (8.0 inches or more). The number of black crappies caught was low compared to other northeastern Indiana lakes, however, the number had increased from 1972. Largemouth bass experienced a decline in numbers from 1972 levels. This decline was most evident in the smaller class sizes. More redear were collected in 1980 than in 1972. Those collected exhibited average weight and growth rates. Sixty-five percent of those collected were of harvestable size (6.0 inches or more).

The 1980 survey results generated three recommendations from the IDNR. First, residents should control plant growth around their piers. Second, dye testing should be initiated to determine nutrient inputs to the lakes. Third, successful stocking programs could supplement the present fishery.

1988 IDNR study

As in 1980, the 1988 IDNR (Pearson, 1988) fishery survey encompassed all seven lakes in the Barbee chain. Sampling included deployment of 16 overnight gill nets and 16 traps sets as well as 1.5 hours of electrofishing. Results of the 1988 survey compared similarly to the 1972 and 1980 surveys. A total of 1,683 individuals representing 30 species were captured. Bluegill ranked first in relative abundance by number of individuals (56%), followed by largemouth bass (9.5%), redear (6.0%), channel catfish (4.4%), and yellow perch (4.4%). Bluegill also ranked first in relative abundance by weight (20%). The number and size of bluegills increased from the 1972 and 1980 survey levels. Approximately 50% of the bluegill catch was of harvestable size (6.0 inches or more). The number of largemouth bass caught per unit effort fell in the normal range according to IDNR standards. Those largemouth bass collected exhibited average growth rates and weight. Continuing the trend, yellow perch in the catch were small in size.

The 1988 study makes several recommendations to improve the Barbee Lakes fishery. First, restrictions on bass harvest should be implemented to prevent the over-harvest of larger bass.

Second, aquatic weed control efforts and septic system dye testing recommended in previous studies should continue. Third, the study suggested the lakes' stocking programs should be evaluated. Fourth, the study recommended limiting future shoreline development. Lastly, the study advocated examining other sources of nutrient and sediment input from the watershed.

1997 study

The most recent Barbee Lakes fishery survey was conducted in 1997 (Pearson, 1997). The sampling methods included gill netting, net trapping, and electrofishing. 1,486 individuals representing 28 species were collected during the 1997 survey. Bluegills again ranked first in relative abundance by number at 36% followed by gizzard shad (16%) and largemouth bass (12%). Gizzard shad ranked first in relative abundance by weight (23%). The survey also noted the presence of muskie in the Barbee Lakes fishery. The muskie appear to have migrated from lakes along the Tippecanoe River that have muskie stocking programs. Bluegill numbers were low compared to area lakes, but growth was average. More larger-sized bluegills were collected in the 1997 survey than in the 1972 and 1980 surveys. The number of largemouth bass captured increased over the number caught in earlier studies. In addition, those caught were larger than those collected in previous surveys. The 12-inch size limit on largemouth bass, which went into effect in 1990, may have played a role in the observed increase in large largemouth bass. The study concluded that the Barbee Lakes sport fishery is "adequate" and recommends only continued monitoring.

Stocking efforts

In an effort to supplement the natural sport fishery, the IDNR and the Barbee Lakes Property Owners Association have initiated several stocking programs in the lakes. Over the past several decades, brown trout, rainbow trout, walleyes, and channel catfish have been stocked in the Barbee Lakes chain. Sechrist Lake was stocked with trout in the 1960's. This initial stocking effort ended before 1970. In 1982, 1,000 brown trout were released in Sechrist Lake followed by the release of 1,000 rainbow trout in 1983. Rainbow trout were stocked annually in Sechrist Lake until muskie management in the Upper Tippecanoe River began in the 1990's. Walleye fingerlings (3-4 inch) were released in the Barbee chain in 1982, 1984-1987. The channel catfish stocking program included biennial releases in 1981, 1983, 1985, and 1987. Catfish were initially stocked at a rate of 100 per acre in 1981. This rate decreased to 10 per acre in 1987.

The IDNR conducted several studies tracking these stocking efforts. In 1983, IDNR (Pearson, 1983) examined the trout stocking program through a creel and gill netting survey. Trout fishing was found to be most popular among weekday shore anglers, suggesting that local anglers were interested in trout fishing. To evaluate the number of harvestable trout in the lake, IDNR biologists set up gill nets throughout the lake. The gill netting effort resulted in 14% harvestable rate. While the harvest rate was high enough to continue stocking efforts, the study suggested a reevaluation of the trout stocking program in three years.

The IDNR conducted studies examining the walleye stocking program in 1983 and 1987 (Pearson, 1987). In 1983, gill nets were deployed for a total of 665 hours in April, July, and

October. The deployment resulted in the capture of 6 walleyes. Two additional walleyes were collected during night electrofishing in July. Citing other studies, the IDNR study suggested that gill netting may not be the best method for collecting walleyes smaller than 10 inches. It recommends varying the density of walleye fingerlings released to determine the release density needed to obtain optimum survival.

Sampling in 1987 consisted of 2 hours of night electrofishing. Five walleyes, one from each stocking year, were collected. Based on this capture rate, the walleye stocking was considered "unsuccessful" by the IDNR. The study recommended a reevaluation of the walleye stocking program, which by 1987 had cost approximately $12,000. The study suggested that anglers may not be catching enough walleyes or have enough interest in walleye fishing to justify this cost.

A 1990 IDNR survey (Pearson, 1990) focused on the channel catfish stocking program. Unlike the walleye surveys, results from the catfish survey were very positive. Despite a tenfold decrease in stocking rates, the catch per unit effort has only decreased by 50% from 1981 to 1990. The study suggests that the catfish may be reproducing in sufficient numbers to end the stocking program. While the study recommended that stocking should be renewed if gill net catches fall below 1.0 catfish per net, current regional IDNR policy supports stocking only one fish species in a lake. Thus, even if catfish collection rates fall, it is unlikely that additional catfish stocking will occur as the IDNR is focusing on muskie management in the Upper Tippecanoe River Basin.

Summary

Table 5 summarizes the relative abundance of dominant fish species found in the Barbee Lakes from 1972 to 1997. The Barbee lakes chain fishery is typical of many lakes in northeastern Indiana. Bluegill dominate the fishery with yellow perch, largemouth bass, redear, and lake chubsuckers accounting for much of the remaining fishery. The stocking program on the lakes has added channel catfish and trout to the fish community. Despite being the dominant species, fewer bluegill have been observed in the Barbee lakes compared to other lakes in the area. The catch per unit effort has increased though from 1972 to 1997. The yellow perch population is more comparable to other area lakes, however, the yellow perch are generally small in size. Although largemouth bass often experience fluctuations in their populations, the largemouth bass population in the Barbee lakes appears to be benefiting from the 12-inch catch size limit. In 1998, the size limit was increase to 14 inches (35 cm), which may provide additional benefits to the largemouth bass population. Lastly, the increase in gizzard shad observed in 1997 is of some concern. Non-game fish, in general, tie up much of the lakes' production. Increases in the number of planktivores are often related to an increase in nutrient inputs to the lakes. Future studies should continue to track gizzard shad population sizes to reveal the presence of any trend toward population increases.

TABLE 5: Relative Abundance of Selected Fish Species in Barbee Lakes, 1972-1997.

Fish species	1970	1980	1988	1997
Bluegill	29.0%	30.5%	55.7%	35.7%
Largemouth bass	12.5%	3.6%	9.5%	12.4%
Gizzard shad	6.9%	0.9%	4.1%	16.2%
Yellow perch	9.9%	12.8%	4.5%	8.6%
Warmouth	11.4%*	8.5%**	2.5%	7.5%
Redear	-	7.9%	6.0%	6.7%

* includes all sunfish other than bluegill
** includes pumpkinseed, longear, and other sunfish hybrids

Unionids

The Upper Tippecanoe watershed which encompasses the Barbee Lakes chain is historically known for its diverse community of unionids including several federally endangered species. The Indiana Department of Natural Resources is currently working on a natural lakes mussel survey documenting the presence of mussels in each natural lake. In 1998, six of the seven lakes in the Barbee chain were surveyed for the presence of mussels. Seven unionid species including the three ridge clam (*Amblema plicata*), the Wabash pigtoe (*Fusconaia flava*), the fatmucket clam (*Lampsilis siliquoidea*), pondmussel (*Ligumia subrostrata*), the giant floater clam (*Pyganodon grandis*), the purple lilliput (*Toxolasma lividus*), and paper pondshell (*Utterbackia imbecillis*) were found in at least one of the lakes. Two exotics, the Asiatic clam (*Corbicula fluminea*) and zebra mussels (*Dreissena polymorpha*), were also found in most of the Barbee lakes. Zebra mussels were first observed in the Barbee Lakes chain in 1995 (Pearson, 1997). Zebra mussels were observed throughout the Barbee Lakes during the macrophyte survey conducted as part of this diagnostic study.

STUDY METHODS, RESULTS, AND DISCUSSION

Watershed Investigation

Methods

The Barbee Lakes chain watershed was investigated to identify areas of concern. The investigations included field inspection, interviews with lake residents, county NRCS biologists, and local officials, and aerial inspection via a small engine aircraft.

Results and Discussion

Agricultural Land Use

Approximately 75% of the watershed is utilized for agricultural purposes. This land use, particularly on highly erodible soils, can have an impact on water quality downstream. Runoff from farm fields can contain a variety of pollutants including nutrients (nitrogen and phosphorus), pesticides, sediment, and bacteria (*E. coli*). In addition, the original creation of agricultural land involved draining low wet areas with drainage tiles. This has decreased the storage capacity of the land and increased peak flows of water in stream in the watershed. An increase in peak flows typically leads to increases in channel erosion and ultimately increases in sediment loads to the lakes. Several programs and best management practices (BMPs) have been developed to address non-point source pollution associated with agriculture. These programs and BMPs and their impact on water quality are discussed below.

Conservation Reserve Program

The Conservation Reserve Program (CRP), run by the U.S. Department of Agriculture, 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. Ideal areas for this program include highly erodible lands, riparian zones, and farmed wetlands. In exchange for the plantings, farmers receive cost share assistance for the plantings and annual payments for their land. (See the Appendix 5: Additional Funding for more details on the Conservation Reserve Program.)

Removing land from production and planting it with vegetation has a positive impact on the water quality of lakes in the watershed. In a review of Indiana lakes sampled from 1989 to 1993 for the Indiana Clean Lakes Program, Jones (1996) showed that ecoregions reporting higher percentages of cropland in CRP had lower mean trophic state index (TSI) scores for their lakes. (A TSI is an indicator of lake productivity or health. Lower TSI scores indicate lower productivity or generally better water quality. See In-Lake Sampling Section for more details)

Conservation Tillage

Removal of land from agricultural production may not be economically feasible in some cases. Conservation tillage offers the potential for reducing erosion without removing the land from production. Conservation tillage requires leaving some portion of the crop on the land after its harvest rather than completely tilling the soil under as is done in conventional tillage. No till is a type of conservation tillage. Depending upon the type of conservation tillage used, reported decreases in sediment loading to waterways have ranged from 60 to 98 percent; reduction in phosphorus input range from 40 to 95 percent. Reductions of pesticide loadings have also been reported (Olem and Flock, 1990). In the review of Indiana lakes referred to above (Jones, 1996), lower TSI scores were observed in ecoregions with higher percentages of conservation tillage.

Buffer Strips

Buffer or filter strips, and grassed waterways along drainages and riparian zones are effective BMPs. Filter strips slow runoff flows from adjacent agricultural areas and reduce flow volume by increasing infiltration of the runoff. Slower runoff velocities and reduced flow volumes will lead to decreased erosion downstream. Buffers also help stabilize stream banks. Vegetative strips filter sediments, nutrients, and pesticides from the runoff preventing them from reaching the lakes and streams. Buffer strips can reduce up to 80% of the sediment, 50% of the phosphorus, and 60% of the pathogens in runoff (Conservation Technology Information Center, 2000).

Buffer strips are effective in reducing sediments and nutrient runoff from feedlot or pasture areas as well. Olem and Flock (1990) report that buffer strips remove nearly 80% of the sediment, 84% of the nitrogen and approximately 67% of the phosphorus from runoff from feedlots. In addition, they found a 67% reduction in runoff volume.

Recent and current watershed projects

Watershed organizations, local officials, and private individuals have proposed and in some cases implemented projects utilizing the programs and BMPs described above in an effort to improve watershed habitat and downstream water quality. State and local conservation agencies teamed with Purdue University to complete work recently in the Upper Tippecanoe River Hydrologic Unit, which includes the entire Barbee Lakes watershed. This project encouraged more landowners to implement conservation tillage and other BMPs on their land. The Purdue Cooperative Extension Service reported an increase in conservation tillage to the 1996 levels of 40% for corn and 80% for soybeans (Purdue Agronomy Extension, 2000). The project also boasts an increase in buffer strips and grassed waterways. Local NRCS offices note that these numbers have decreased since the project ended in 1996, but are still fairly high.

In 1991, a feasibility study completed on Little Barbee Lake suggested that Putney Ditch, which drains approximately 2,750 acres (1,115 ha) from an agricultural area directly south of Little Barbee Lake, was the primary source of sediments and associated pollutants to the lake. Subsequent feasibility and design work throughout the 1990's resulted in the construction of approximately 300 feet (92 m) of bank stabilization in the spring of 2000. A combination of log cribwalls and coconut fiber rolls planted with trees, shrubs and herbaceous plants were used to create permanent vegetative protection for this section of severely eroding creek just downstream of McKenna Road and 1/4 mile (0.4 km) upstream from the lake.

Because the Barbee Lakes chain watershed accounts for nearly one half of the Lake Tippecanoe watershed, Tippecanoe Environmental Lake and Watershed Foundation (TELWF) has initiated feasibility work on several projects in the Barbee Lakes chain watershed. In 1999, TELWF applied for a Build Indiana Fund Grant to conduct a feasibility study on several projects recommended by the US Army Corps of Engineers in a 1995 reconnaissance report. The Corps projects were conceptually examined as an option to reduce flooding on several major lakes along Grassy Creek including Lake Tippecanoe, Ridinger Lake, and the Barbee Lakes Chain.

Three projects were proposed in the initial phase of the study. They included the creation of 450 acre (182 ha) wetland on Elder Ditch, a branch of the Grassy Creek, by placing a dam at the Kosciusko-Whitley County line; creation of a smaller wetland, approximately 200 acres (81 ha) in size, by placing a dam across Elder Ditch one mile (1.6 km) north of Old State Road 30; and creation of a 300 acre (121 ha) wetland on Shanton Ditch, the other major branch of Grassy Creek.

None of these projects were feasible due to the opposition encountered by some landowners, county drainage boards, and regulatory restrictions. However, TELWF continues to pursue the feasibility of developing small projects in the same areas. Specifically, TELWF is focusing on Elder Ditch and its tributaries in Whitley County and Shanton Ditch tributaries northeast of Pierceton. The small projects being developed include several wetlands from 1-5 acres (0.4-2 ha) each, bank stabilization and cattle exclusion along 1/4 mile (0.4 km) of open ditch, grassed waterway development, purchase and restoration of wetland areas adjacent to ditches, sediment traps and riparian buffer strips. While not providing the same benefit in terms of flood storage capacity and habitat creation, the smaller projects will provide some benefits to the watershed. TELWF's goal is to have 10 projects conceptually designed and approved by the end of 2000. TELWF has already requested additional Build Indiana Funds for the final design and construction of these projects in 2001-2002.

Proposed projects

Putney Ditch watershed

The bank erosion of the area recently protected by the Putney Ditch project was caused by changes in the velocity and volume of water entering the ditch during and following storm events over many decades. To reverse the upward trend of peak flow volumes and subsequent bank erosion, several other projects should be considered. Funding for these projects may be available from the Lake and River Enhancement Program under its feasibility study program or from the Soil and Water Conservation District under their land and water treatment programs. More immediate implementation may be possible under a SWCD program.

Putney Ditch begins as surface water run-off to tile drains in agricultural fields south of County Road 150 North and on both sides of County Road 650 East. The tiles join, discharging to a large culvert. This culvert opens up at the intersection of County Road 200 North and County Road 650 East. The open ditch flows through two active agricultural fields east of County Road 650 East for approximately 0.7 miles (1.1 km). This section is in need of grassed or forested buffer between the tilled farmland and the edges of the stream bank. Upstream of this point, the installation of grassed buffers around tile openings would prevent surface erosion into the tile.

Downstream of the point where Putney Ditch crosses County Road 650 East and before it crosses County Road 300 North, there is an opportunity to create an approximately 30-40 acre (12-16 ha) wetland with a dam along County Road 300 North. This wetland could be used to trap sediment and nutrients if they cannot be controlled further up stream. Another wetland/open water creation opportunity to trap sediment occurs on the north side of McKenna Road. A dam placed parallel to McKenna road would back up from 5-10 acres (2-4 ha) in an existing wooded valley. The Natural Resource Conservation Service in a 1994 report to the US Army Corps of Engineers identified both of these sites.

The projects along Putney Ditch should be considered in the order listed. The suggestions are in order from the least cost and landowner impact to the most impact and expense. Alternatives might also include retiring farmland that currently has drain tiles leading to Putney Ditch.

Grassy Creek Watershed

Goals in the Grassy Creek watershed should be similar to those in the Putney Ditch watershed. Wetland restoration, the installation of filter strips and grassed waterways, and stream bank stabilization will help to reduce peak flows in the Barbee Lakes inlets and limit the amount nutrients and sediment reaching the inlet streams. As described above, the Natural Resource Conservation Service and TELWF have identified and begun work on several projects in the Grassy Creek watershed to achieve these goals. Continued support of these projects is recommended.

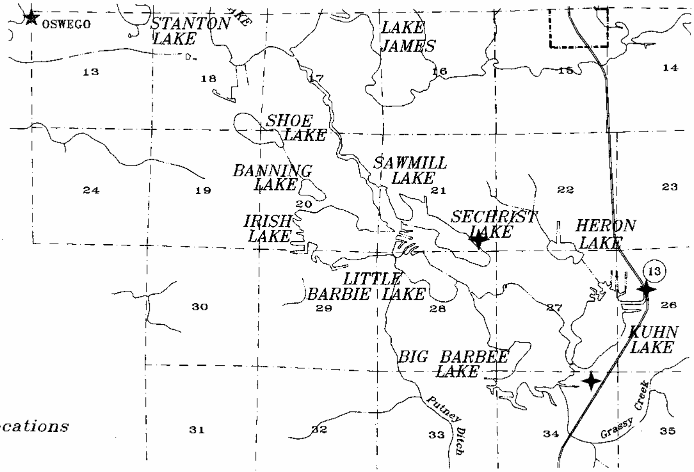
One additional area of concern identified in this study is the area of Grassy Creek upstream of Rhine Lake. During storm events, NRCS representatives have observed Rhine Lake and Robinson exhibiting a chocolate brown color due to the turbidity of inlet water (Sam St. Clair, personal communication). Significant stream cutting upstream of Rhine Lake is likely responsible for this. Reduction in peak flows through the creation of wetland habitat, installation of filter strips and grassed waterways, or retirement of agricultural land would help alleviate the erosion problems noted in Grassy Creek in this section.

Storm Water Drains

As noted in the sections above, agricultural land accounts for the largest portion of the watershed, and consequently, land treatment to improve water quality should focus on this area. However, a tour of land immediately adjacent to the lakes revealed several areas where minor projects could be implemented to provide immediate solutions to water quality problems. A drainage swale originating in agricultural land east of State Road 13 flows west to one of the Big Barbee southern channels (Figure 7). Runoff from a motor cross track, State Road 13, and an excavation company drain into this swale before the swale enters a stormwater drain and is conveyed via tile to Big Barbee Lake. Sediment accumulation and oil sheens were noted in the channel where the tile discharges to the lake. This stormwater drain should be fitted with equipment designed to remove sediment as well as oil, gas, and other roadside pollutants. Regular maintenance would be required to ensure effectiveness.

Sediment accumulation and gas sheens were noted in Sechrist Lake and one of the channels along Kuhn Lake (Figure 7). Where possible, these drains should be fitted with similar equipment to remove sediment and other pollutants before releasing to the lakes. At the very least, stormwater drains, particularly those along well-traveled roads, should be equipped with catch basins. Again, such basins require regular maintenance to be effective.

BARBEE LAKES WATERSHED



✦ *Storm Drain Locations*

Scale: 1" = 3000'

Source of base map: U.S.G.S. 7.5 Minute Topographical Map

J.F. New & Associates, Inc.

Permitting • Delineations • Mitigation Design • Biological Inventories
Wetland and Prairie Nursery • Lake and Stream Enhancement
Natural Systems for Wastewater Treatment

Figure 7: **Storm Drain Location Map**
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

Shoreline Development

Early historical accounts of the area suggest settlers of European descent utilized the Barbee Lakes chain area as early as 1840. These records show the construction of a dam on Grassy Creek downstream of Sawmill Lake in an effort to harness power for a gristmill (Blatchley, 1900). Blatchley (1900) also notes that the Barbee Lakes were well known for their fishing and consequently club houses/resort areas were built along the lakes' shorelines for anglers in the 1800's. Despite this, a 1900 map of the area shows much of the shoreline as undeveloped, native wetland habitat (Figure 2).

Modern development around the Barbee Lakes chain began in the 1920's with most homes built above the high water mark. In the 1950's as lakefront property became scarce, development expanded into wetland areas. Most of the wetland areas surrounding these lakes were eliminated by the early 1970's. Channels were constructed by dredging lanes through the wetlands adjacent to the lakes and placing the dredged spoil on the remainder of the wetland to create higher land for residential development. By the time the IDNR started comprehensive fisheries studies on the lakes (1972), nearly all of the lakes' shorelines were at least partially developed. Only Banning Lake had not been developed by the date of the survey, but dredging in preparation for development had begun along the shoreline. Taylor (1972) reported that the extensive channeling and development have destroyed much of the natural shoreline. Hippensteel (1989) documented 894 homes bordering six of the Barbee Lakes in 1980. (This count excludes Banning Lake.) By 1997, virtually all of shoreline along Sechrist, Sawmill, Little Barbee and Big Barbee Lakes was developed (Pearson, 1997).

Not much has changed since the 1997 fisheries study. Today, all of the shoreline along Sechrist, Sawmill, and Little Barbee is developed for residential use. Large portions of Big Barbee, Kuhn, Banning and Irish Lakes shorelines are also developed. Heavily developed channels exist along the Kuhn, Big and Little Barbee, and Irish Lake shorelines. Channels are also present between many of the lakes. Large, remnant wetlands exist between Kuhn and Big Barbee Lakes, at the mouth of Grassy Creek on the southern shoreline of Big Barbee Lake and along the southern shoreline of Irish Lake. Smaller wetland pockets exist along Kuhn, Irish, Big Barbee and Banning Lakes.

Estimates for the number of homes along the Barbee Lakes shoreline range from 1500 to 2300. Barry Hecker, Lake Barbee Conservancy District, (personal communication) estimated the number of homes around the Barbee Lakes at 1550. Of these homes, one third are permanent residences; one third are utilized seasonally and on weekends; and one third are occupied during all but the winter months of the year (December through March). The Kosciusko County Assessor's Office (personal communication) placed the number of homes around the Barbee Lakes chain closer to 2300.

As is typical of other northern Indiana lakes, the number of permanent residences around the Barbee Lakes chain is increasing as lake residents retire to live at their lake homes fulltime. Many lake residents are remodeling or improving their existing lake cottages to convert them to permanent residences. Destroying an existing cottage and replacing it on the same property with a more modern residence is common as well. Additional cottages are also being placed on lots that were previously occupied by only one cottage, further increasing the density of development along the lakes' shorelines.

With residential development of the lakes, landscaped lawns and seawalls replace natural wetland areas and shoreline vegetation. Currently, seawalls line much of the developed shoreline along the Barbee Lakes. Seawalls border almost all of Little Barbee, Sechrist, and Sawmill Lakes and along the developed areas of Big Barbee, Irish and Kuhn Lakes. Concrete seawalls line all of the channel areas on the lakes. Many of the seawalls are made of concrete, however, riprap and rail tie seawalls were also noted along the lakes' shorelines. Groomed lawns are maintained behind the seawalls. Private beaches were noted along several of the lakes as well.

While seawalls provide some temporary erosion control along shorelines, they cannot provide all the functions of a healthy shoreline plant community. Native shoreline communities filter runoff water to the lake, protect the shore from wave action limiting erosion, release oxygen to the water column for use by aquatic biota, and provide food, cover and spawning/nesting habitat for a variety of fish, waterfowl, insects, mammals and amphibians. Removal of the native plant community eliminates many of these functions.

Shoreline BMPs

Lakeshore landowners should reduce or eliminate the use of lawn fertilizers. 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 will run into the lake, providing a nutrient base for plants and algae in the lake. At the very minimum, landowners should follow dosing recommendations on product labels. Landowners should also avoid depositing lawn waste such as leaves and grass clippings in the lake as this adds to the nutrient base in the lakes. This includes disposal of animal waste in the lake. It is not uncommon for lake residents to dispose of goose droppings by tossing them into the lake. Unfortunately, this action contributes further nutrients to the water, fertilizing the submerged plants immediately adjacent to the shore.

In addition to reducing the amount of fertilizer used, landowners 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 cannot be absorbed by the grass or plants and runs off into the lake. 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 local Soil and Water Conservation District or the NRCS can usually provide information on soil testing.

Lake residents should also consider replacing maintained lawns with native vegetation. In those areas that do not have seawalls, rushes (*Juncus* spp.), sedges (*Carex* spp.), pickerel weed (*Pontederia cordata*), arrowhead (*Sagittaria latifolia*) and lizard's tail (*Saururus cernua*) offer an aesthetically attractive, low profile community in wet areas. Behind existing seawalls, a variety of upland forbs and grasses that do not have the same fertilizer/pesticide maintenance requirements as turf grass may be planted in its place. Plantings can even occur in front of existing seawalls. Bulrushes (*Scirpus spp.*) and taller emergents are recommended for this. While not providing all the functions of a native shoreline, plantings in front of seawalls provide fish and invertebrate habitat. In addition, the restoration of native shoreline or the planting of emergents in front of seawalls also discourages Canadian geese. The 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. Partial or full restoration of the native shoreline community with these measures would provide shoreline erosion control and filter runoff to the lakes, thus improving the lake's overall health, without interfering with recreational uses of the lake.

Finally, each lake owner should investigate local drains, roads, parking area, driveways, and rooftops. These drains also contribute to sediment and nutrient loading and thermal pollution. 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.

Aquatic Plant Survey

A general macrophyte (rooted plant) survey of Barbee Lakes chain was conducted on May 26, 1999. The survey located areas with a high density of submerged and emergent aquatic vegetation in the lake. Due to the limited scope of this LARE study, the survey consisted of a general reconnaissance in shallow areas of the lakes. In areas possessing the greatest density of rooted plant growth, random grabs were performed to determine the species present. No quantitative measures of species abundance or percent cover were recorded. While this methodology has some shortcomings, it provides good information on the dominant species present and extent of coverage in the lakes from which general management recommendations can be made.

Beds mapped on Figure 8 reflect areas with high density and high diversity (relative to the Barbee Lakes). Like many of the lakes in northeastern Indiana, the Eurasian water milfoil and curly leaf pondweed have established large beds in the lakes. Despite this, four state endangered, threatened and rare species were observed in at least one of the Barbee Lakes. A complete list of plants found in the Barbee Lakes chain during this survey as well as historical surveys is presented in Appendix 6. Before detailing the results of the macrophyte survey, it may be useful to understand the conditions under which lakes may support macrophyte growth and the roles macrophytes plan in a healthy, functioning lake ecosystem.

BARBEE LAKES WATERSHED

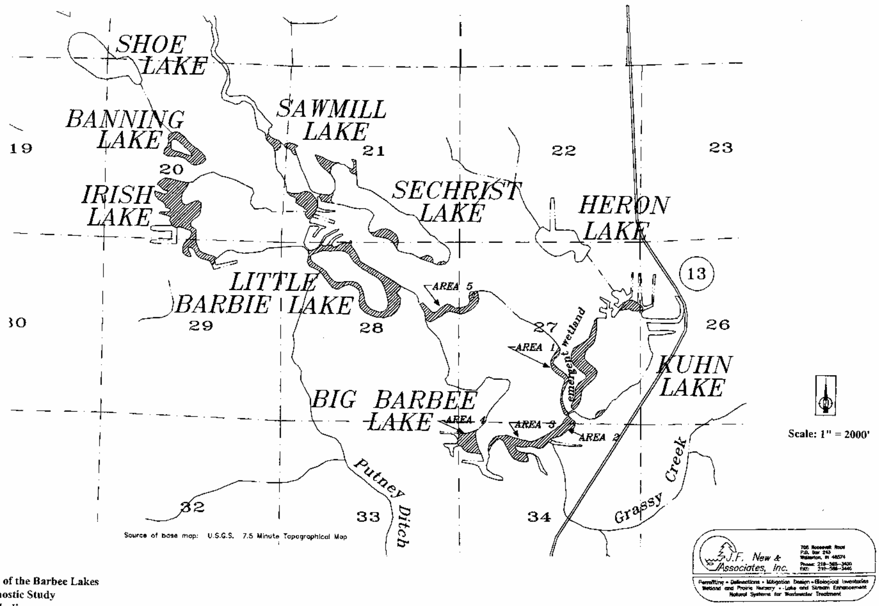


Figure 8: **Macrophyte Survey of the Barbee Lakes**
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

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 water depths of 5 or 6 feet (1.5 to 1.8 m), but lakes with greater water clarity have a greater potential for plant growth. Some species such as Eurasian water milfoil can grow in up to 12 feet (3 m) of water.

Aquatic plants also require a steady source of nutrients for survival. 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 most nutrients are obtained from the sediments, it does not necessarily follow that lakes with a high input of nutrients from the waterbody's watershed to the water column will automatically have aquatic macrophyte problems. Other factors, such as those listed above, play a role in limiting or promoting the growth of aquatic macrophytes.

The type of substrate present and the forces acting on the substrate 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. Many of the channels on the Barbee Lakes were constructed in muck wetlands. As a consequence these channels provide ideal substrate for rooted plant growth. In addition, 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 affect the availability of nutrients for the macrophytes. Wave action may also create significant shearing forces prohibiting plant growth altogether. Boating activity may also affect macrophyte growth by disturbing bottom sediments.

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 uptaking 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. Aquatic vegetation serves as substrate for aquatic insects, the primary diet of insectivorous fish. Waterfowl and shorebirds depend on aquatic vegetation for nesting and brooding areas. Aquatic plants such as pondweed, coontail, duckweed, water milfoil, and arrowhead, also provide a food source to waterfowl. Turtles and snakes utilize emergent vegetation as basking sites. Amphibians rely on the emergent vegetation zones as primary habitat.

Because aquatic vegetation plays these roles in a healthy lake ecosystem, complete removal of aquatic vegetation is not desirable. In areas where the vegetation does not interfere with other uses of the lake, diverse beds of vegetation should be maintained. For example, as will be discussed below, a diverse mix of native pondweeds vegetates the western portion of Kuhn Lake. The vegetation provides good fish habitat as evidenced by the popularity of this site among anglars on the lake. Aquatic vegetation in this area does not interfere with other uses of the lakes and should be preserved.

Survey Results

Kuhn

The largest beds of aquatic vegetation lie along the undeveloped portions of the western and southern shorelines. The western shoreline is formed by a peninsula of emergent vegetation jutting south almost completely enclosing Kuhn Lake. The channel connecting Kuhn and Big Barbee Lakes was cut some time prior to 1900. Blatchley (1900) reports the existence of natural channel on the north end of the marshy peninsula. Emergent vegetation had colonized this channel, however, and row boaters dug the existing channel to the south. From approximately 1840 to 1857, a dam at the north end of Sawmill Lake raised the lakes' water level by five feet. During this period the peninsula was under water. Currently the peninsula lies approximately 1 to 3 feet (0.3 to 0.9 m) above water level.

Dominant vegetation on the peninsula includes willow shrubs, button bush, black willow, dogwood, and silver maple. Emergents such as water willow, arrow arum, pickerel weed, and bulrush line the peninsula's shoreline in shallow areas. Spatterdock and white water lilies occupy slightly deeper water. Curly leaf pondweed beds surround the spatterdock. Grassy pondweed, whorled milfoil, and chara were also noted in the submerged vegetation around the peninsula.

Emergents including soft stem bulrush, arrow head and willow shrubs vegetate the undeveloped portion of the southern shoreline. Slender pondweed, curly leaf pondweed, and chara mats were observed at greater depths from the shoreline. Patches of spatterdock, typically surrounded by beds of whorled milfoil, curly leaf pondweed, slender pondweed and Eurasian water milfoil, dot the shoreline, particularly near channel outlets to the lake. White stem pondweed was also noted in Kuhn.

In general, macrophytes do not pose a problem on Kuhn. The densest beds are located along the undeveloped western portion of the lake. These areas provide good fish habitat, but because of their location, they do not inhibit recreational uses of the lake. Vegetation is sparse along the eastern shoreline. Wave action along the eastern shoreline likely inhibits the growth of macrophytes.

Four state listed species were found in Kuhn. White stem pondweed and grassy pondweed are state endangered plants. Whorled water milfoil is state threatened, while slender pondweed is a state rare plant. By definition, state endangered plants are those plants known to occur on five or fewer sites within the state. State threatened plants are known to occur in six to ten sites, while state rare plants are known to occur on 11 to 20 sites in the state. The presence of these species in Kuhn suggests the lake supports a healthier, more diverse community than other northeastern Indiana lakes where aggressive exotics have excluded sensitive native species.

Big Barbee

Big Barbee is more densely vegetated than Kuhn Lake. Five of the densest areas in Big Barbee are mapped on Figure 8. These areas are described in greater detail below.

Area 1

Area 1 refers to the undeveloped, emergent peninsula separating Kuhn and Big Barbee. Fewer emergent and submerged macrophytes border the edge of the peninsula compared to the peninsula's eastern shoreline in Kuhn Lake. Wave action has likely limited plant growth on the peninsula western shoreline. Water willow and pickerel weed were the most common emergents noted along the peninsula's western shoreline in Big Barbee.

Area 2

Area 2 is located in the lake's southeast corner. Large beds of curly leaf pondweed and Eurasian water milfoil dominate the vegetation in the area. Beds of coontail were also noted. Waterweed and whorled milfoil were observed as subdominate species. Much of the vegetation in Area 2 was covered with filamentous algae at the time of inspection.

Area 3

Area 3 is an undeveloped, wetland area along Big Barbee's southern shoreline. Black willow, purple loosestrife and rosemallow dominate the wetland edge. Patches of spatterdock extend out from the wetland into the shallow water. Beds of curly leaf pondweed and Eurasian water milfoil surround the spatterdock. Waterweed, flat stem pondweed, coontail, and other pondweeds were observed in Area 3 as well.

Area 4

Area 4 is a seawall-lined cove in the southwest corner of Big Barbee. Water in Area 4 is protected from wind and wave energy by its location. The lake is shallow in this area and supports a dense bed of Eurasian water milfoil. At the time of inspection, free-floating algae observed in the cove and the thick layers of filamentous algae coated the milfoil.

Area 5

Area 5 is located in the lake's northwest corner. Dense beds of flat stem pondweed, Eurasian water milfoil, and curly leaf pondweed vegetate this portion of the Big Barbee's shoreline. Chara mats and coontail were also observed in this area. As in Area 4, filamentous algae coated much of the aquatic vegetation. Shallow depths in Area 5 allow for plant growth to extend up to 300 feet from the shoreline. Vegetation becomes sparser to the east of Area 5 and largely limited to Eurasian water milfoil.

In addition to these larger beds of vegetation, smaller areas of vegetation exist on Big Barbee, particularly along undeveloped shoreline. These areas typically contain patches of spatterdock surrounded by white water lilies, Eurasian water milfoil and curly leaf pondweed. Common emergents noted along the shoreline include pickerel weed, willow shrubs, dogwood shrubs, cattails, bulrush, and rosemallow. Duckweed and water meal were observed in some of the spatterdock patches where the vegetation was protected from wind and wave energy.

As evidenced by the dominance of Eurasian water milfoil and curly leaf pondweed in large portions of the lake, Big Barbee lacks some of the diversity observed in Kuhn Lake. Both species are capable of establishing dense beds of vegetation to the exclusion of other aquatic plant species. These dense beds often provide too much cover for forage fish resulting in stunted growth of these fish. In addition, the dense beds of milfoil around piers interfere with other recreational uses of the lake. Control of the Eurasian water milfoil is necessary to establish a healthier, better functioning ecosystem.

Little Barbee

Little Barbee possesses the least diverse aquatic macrophyte community of the seven lakes. Large, dense beds of Eurasian water milfoil and curly leaf pondweed line the entire shoreline. These two species have excluded many of the native pondweeds found in the other lakes. Some coontail, spatterdock, and large leaf pondweed beds were noted in Little Barbee, but in lesser quantities than the Eurasian water milfoil and curly leaf pondweed. Algae, both planktonic (free floating) and filamentous, were observed in Little Barbee. In a few areas, the algae coverage was dense.

Little Barbee's physical attributes create ideal conditions for macrophyte growth. Cooke et al. (1993) identifies lake morphometry as one of the most significant factors in determining the presence or absence of macrophyte problems. Shallow littoral zone slopes and a long fetch characterize little Barbee's morphometry. Shallow littoral zone slopes enable greater plant establishment than more steeply sloped littoral zones. The long, narrow fetch concentrates wave energy toward the south east corner of the lake protecting much of the northern and southern shores. The maintenance of lawns around Little Barbee likely contributes to aquatic plant growth as well by providing a source of nutrients for the plants.

While Little Barbee's morphometry may create the ideal conditions for macrophyte growth, steps may still be taken to improve the lake's situation. Controlling and/or thinning the Eurasian water milfoil and curly leaf pondweed populations may allow for the establishment of native pondweeds and other aquatic plant species. This would create a more diverse habitat which would likely enhance the fishery in the lake. Limiting the use of lawn fertilizers, using phosphorus free fertilizers, and/or planting buffer strips along the shoreline would help prevent excess nutrients from reaching the littoral hydrosoil.

Irish

The northern and southern shorelines on the eastern half of Irish Lake are similar to the northern shoreline of Big Barbee Lake. These shorelines are vegetated with Eurasian water milfoil with some curly leaf pondweed, large leaf pondweed and coontail. Vegetation is dense in a few areas, but, in general, could not be classified as "problem" vegetation.

The shorelines along the western half of Irish Lake are more heavily vegetated. In addition to growth along the shoreline, open water portions of the western half of Irish Lake are vegetated as well. In most of the western portion of Irish Lake, water depth is less than 10 feet (3 m). As a consequence, plant growth was observed up to 500 feet (152 m) from the shoreline in this area.

Vegetation in typical macrophyte beds along the developed portions of the western shoreline included Eurasian water milfoil, curly leaf pondweed and large leaf pondweed. Chara mats are common in areas not dominated by submerged vegetation. Some of the milfoil beds and chara mats extend to the peninsula in the southwest corner of the lake. Patches of white water lilies were observed in a few areas as well.

The aquatic plant communities in undeveloped portions of the western half of Irish Lake exhibit somewhat higher diversity compared to the aquatic plant communities in developed portions of Irish Lake. However, large beds of Eurasian water milfoil were observed in the undeveloped area. Dominant species along the undeveloped shoreline and on the peninsula include willow shrubs, dogwood shrubs, and buttonbush. Cattails, rosemallow, and pickerel weed were the most common emergents observed in the shallow water. Patches of spatterdock and white water lilies occupy the water immediately off shore. Three genera of duckweed (*Lemna* sp., *Spirodela polyrhiza*, and *Wolffia* sp.) were observed in the spatterdock patches. Other species noted in these areas include bladderwort, threadleaf pondweed, waterweed, eel grass, and curly leaf pondweed. Filamentous algae coated the vegetation in spots.

Sechrist

The areas of heaviest plant growth are located at the lake's outlet to Sawmill Lake, along the western shoreline, and in a small bay in the central portion of the southern shoreline. Large beds of curly leaf pondweed and large leaf pondweed line the northern and southern sides of the lake's outlet channel. The shallow depth in this area allows light penetration throughout the outlet channel, promoting plant establishment and growth. Large leaf pondweed and chara mats dominate the lake's western shoreline. Beds of the same species vegetate portions of the northern shoreline. Large leaf pondweed beds are scattered along the southern shoreline as well. Patches of spatterdock and white water lilies occupy shallow protected coves along these shorelines.

An emergent peninsula vegetated with button bush and silver maple is located along the southern shoreline, immediately east of a protected cove. A bed of white water lilies occupies the cove.

A diverse mix of whorled water milfoil, bladderwort, curly leaf pondweed, large leaf pondweed, and chara is established in the cove as well.

In terms of diversity, the plant community ranks closer to Kuhn and Big Barbee Lakes exhibiting greater diversity than that found in Little Barbee, Banning, and Sawmill Lakes. Most notable is the relative lack of Eurasian water milfoil in comparison to the other lakes in the chain. Patches of large leaf pondweed dominate the lake's shoreline. Dense beds of this pondweed were noted along much of the western shoreline. The dominance of this species suggests the presence of a good fishery (Curtis, 1998). IDNR fishery reports confirm this.

Sawmill

The plant community in Sawmill Lake is similar to that found in Little Barbee. Heaviest vegetation occurs at the mouths of Sechrist and Irish Lakes and the outlet to Grassy Creek. Eurasian water milfoil dominates the vegetation along the lake's shoreline, although beds of curly leaf pondweed were also observed. Coontail was noted in lesser quantities on the lake. Two large patches of spatterdock occupy the southeast corner and northwest corner of the lake. Some white water lilies are scattered near the spatterdock patches.

Banning

Banning Lake is largely undeveloped with the exception of the lake's southeast and northwest corners. Willow shrubs, cattails, and dogwood shrubs dominant the undeveloped shoreline. Large patches of spatterdock and white water lilies float along the shoreline and in open water portions of the lake. Dominant submerged plants in Banning include Eurasian water milfoil, curly leaf pondweed, large leaf pondweed and whorled milfoil. Threadleaf pondweed was also observed along the western shoreline. Chara mats dominate in areas that lack dense submerged beds of vegetation.

Discussion and Summary

A general macrophyte survey of the Barbee Lakes chain was conducted on May 26, 1999. In general, the lakes possess macrophyte communities similar to those found in other northeastern Indiana lakes. Dominant vegetation observed during the survey included Eurasian water milfoil, curly leaf pondweed, coontail, and large leaf pondweed. Big and Little Barbee, Sawmill, Banning, and portions of Irish Lake exhibited low diversity, while Kuhn and Sechrist Lakes possessed the highest diversity in the chain.

Vegetative patterns in the Barbee lakes largely follow the lakes' morphometries. The areas of heaviest growth correspond well to shallow, wind-protected areas such as the cove areas and Little Barbee's shorelines (Figure 11 and 22). In addition, sediment sampling done as a part of this study showed several feet of muck substrate in several well-vegetated areas of the lake such as the channels between the lakes (Figure 9). The muck provides a nutrient-rich substrate that is ideal for the establishment of certain aquatic plants. On the other hand, in areas of Kuhn Lake where lake depth is shallow enough to support aquatic plant growth, sandy material placed in the lake to create private beaches inhibits the establishment of aquatic plants. The drift of this sandy material prevents the aquatic plant establishment in other areas as well.

The dominance of Eurasian water milfoil and curly leaf pondweed is of concern. These non-native species typically grow in dense mats excluding other plants and offering little, if any, habitat potential for aquatic fauna. The survey results confirm this. Big and Little Barbee and Sawmill Lakes possess the greatest populations of Eurasian water milfoil and curly leaf pondweed and exhibit the lowest diversity. Conversely, in Sechrist and Kuhn Lakes, lakes that possess the greatest diversity with a variety of native pondweed in their plant communities, Eurasian water milfoil was not a typical dominant.

It is important to note, however, that the presence of curly leaf pondweed and Eurasian water milfoil is typical for northern Indiana lakes. These species were observed in every lake in Kosciusko County in 1997 (White, 1998a). Moreover, their absence was only documented in seven lakes in 15 of the 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 permits to treat aquatic plants in 1998, Eurasian water milfoil was listed as the primary target in those permits (White, 1998b).

Many natives were observed in the Barbee Lakes chain. Spatterdock, eel grass, pickerel weed, coontail, and pondweeds are typical natives in the Northern Lakes Natural Region (Homoya et al., 1985) Healthy individuals of these species were noted in the Barbee Lakes chain. In addition, patches of large-leaved pondweed, which provide excellent fish habitat (Curtis, 1998), exist in sections of the several lakes including Sechrist where it is a dominant species. Several state endangered, rare and threatened species including white stem pondweed, grassy pondweed, slender pondweed, and whorled milfoil were observed in the Barbee Lakes chain.

Aquatic Plant Management

Based on the results of this survey, development of an aquatic plant management plan that balances the varied needs of the lakes' users is recommended for the Barbee Lakes chain. The management plan should target nuisance populations of Eurasian water milfoil and curly leaf pondweed particularly in Little Barbee, the northern shoreline of Big Barbee, and the western shoreline of Irish. Reductions in the populations of these species will allow for the growth of native, less aggressive macrophytes that provide many of the functions of healthy lake ecosystem. In areas where BOD (biological oxygen demand) and internal phosphorus release are of concern (See Lake Sampling Results Section), such as Big and Little Barbee, Irish and Sawmill Lakes, special consideration should be given to management techniques that remove plant material. In these areas, control techniques that leave plant material in place will exacerbate water quality problems. Vegetated areas dominated by native pondweeds should be preserved to provide fish and other aquatic organism habitat.

Good aquatic plant management plans often employ a combination of techniques, utilizing different ones in different locations on the lake, to achieve their goals. Lake users' needs, plant species, cost, and other factors affect the selection of specific techniques for specific locations. Not all techniques are suitable or even feasible for a given lake. The following is a brief summary of the available plant management techniques. It is intended to inform lake residents of the options available for management and serve as a starting point for the devlopment of a comprehensive aquatic plant management plan for the lakes. It is not an aquatic plant management plan itself.

Chemical control

Herbicides are the most traditional means of controlling aquatic vegetation. 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 algalcides; 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 plant 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 $275 to $300 per acre ($680 to $750 per hectare, Jim Donahoe, Aquatic Weed Control, 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 algalcide 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 (algalcide) 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).

Past use on the Barbee Lakes

Chemical control has been used in the past decade as the principal means of aquatic plant control on the Barbee Lakes chain. For the past six years, Aquatic Control has been treating select areas of the Barbee Lakes. The control effort targets Eurasian water milfoil, curly leaf pondweed, and various native macrophytes. Aquatic Control uses contact herbicides including Reward, copper sulfate, Komeen, and Navigate. Aquathol-k has been used in the past, but is considered disadvantageous due to a 3-day restriction on fishing that must follow its application. The chemicals are generally applied to a narrow littoral band of 50-75 feet (15-23 m), and cumulatively, about 90 acres (36 ha) are treated each year. Aquatic Control applies the maximal amount of herbicide permitted by the Indiana Department of Natural Resources.

Over the course of their work on the lakes, Aquatic Control has observed the same species in the Barbee Lakes. (Scott Shuler, Aquatic Control, personal communication). Mr. Schuler notes that these lakes contain a much higher density and diversity of macrophytes than other natural lakes of the region. However, the aquatic plant community composition has shifted toward a dominance of Eurasian water milfoil within the past six years. In addition, dense weed beds exist in undeveloped areas of shoreline and on open water despite the treatment effort. The current treatment regime successfully controls nuisance vegetation throughout the months of June and July; however, by August significant re-growth has occurred. Mr. Schuler accredits the re-growth to naiads and other vegetation that are still in seed when the contact herbicides are applied. Without vegetation control, Mr. Schuler believes boating in some areas would be impossible. Aquatic Control anticipates meeting with the Lake Association(s) and the Indiana Department of Natural Resources later this year to formulate a better aquatic vegetation control program and more carefully delineate the areas most suited to treatment.

Effectiveness
Table 6 is a guide for common herbicides and their effectiveness in treating the dominant macrophytes found in Indiana lakes. This table is general in nature. While the table rates the chemical as effective vs. non-effective, some chemicals are obviously more effective than others. The effectiveness of any chemical often depends upon the water chemistry of the lake to which it is applied. Any chemical herbicide treatment program should always be developed with the help of a certified applicator who is familiar with the water chemistry of a targeted lake. In addition, application of a chemical herbicide may require a permit from the Indiana Department of Natural Resources, depending on the size and location of the treatment area. Information on permit requirements is available from the DNR Division of Fish and Wildlife or Conservation officers.

TABLE 6: Common Herbicides and Their Effectiveness

Species	Diquat	Endothal	2,4 D	Fluridone
Eurasian water milfoil	M	M	E	E
Curly leaf pondweed	E	E	N	E
Other pondweeds	E	E	-	E*
Coontail	E	E	E	E
Elodea	E	M	N	E
Naiads	E	E*	E*	M

* Depends on species
E = effective
N = non effective
M = mixed results
Table based on information from Olem and Flock, 1990, Westerdahl and Getsinger, 1988, Pullman, 1992 and SePro, 1999.

Mechanical Harvesting
Harvesting involves the physical removal of vegetation from lakes. Harvesting should 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 situation where removal of plant biomass will improve a lake's water chemistry. (Chemical control leaves dead plant biomass in the lake to decay and use up 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, are managed well 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 water milfoil 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.

The cost of the harvester is typically the largest single outlay of money. Depending upon the capacity of the harvester, costs can range from $3,500 to over $100,000 (Cooke et al., 1993). Other costs associated with harvesting include labor, disposal site availability and proximity, amortization rate, size of lake, density of plants, reliability of the harvester, and other factors. Depending upon the specific situation, harvesting costs can range up to $650 per acre ($1,600 per hectare, Prodan, 1983; Adams, 1983). Estimated costs of the mechanical harvesting program at Lake Lemon in Bloomington, Indiana averaged $267 per acre ($659 per hectare, Zogorski et al., 1986). In general, however, excluding the cost of the machine, the cost of harvesting is comparable to that for chemical control (Cooke et al., 1993, Olem and Flock, 1990). Hand harvesting equipment is also available for smaller areas around piers at a cost of from $50-$1,500 (McComas, 1993).

Drawdown

Lake level drawdown can be used as a macrophyte control technique or as an aid to other lake improvement techniques. This technique requires the ability to discharge water from a lake through an outlet structure or dam. Drawdown can be used to provide access to dams, docks, and shoreline stabilizing structures for repairs; to allow dredging with conventional earthmoving equipment; and to facilitate placement of sediment covers.

As a macrophyte control technique, drawdown is recommended in situations where prolonged (one month or more) dewatering of sediments is possible under conditions of severe heat or cold and where susceptible species are the major nuisances. Eurasian watermilfoil control for example, apparently requires three weeks or longer of dewatering prior to a one-month freezing period (Cooke, 1980). Cooke (1980) classifies 63 macrophyte species as decreased, increased, or unchanged after drawdown. One must note the presence of resistant species as well as susceptible species, since resistant species can experience a growth surge after a successful drawdown operation.

Macrophyte control during drawdown is achieved by destroying seeds and vegetative reproductive structures (e.g., tubers, rhizomes) via exposure to drying or freezing conditions. To do so, complete dewatering and consolidation of sediments is necessary. Dewatering may not be possible in seepage lakes.

There are a number of other benefits to lakes and reservoirs from drawdown. Game fishing often improves after a drawdown because it forces smaller fish (bluegill) out of the shallow areas and concentrates them with the predators (bass). This decreases the probability of stunted fish and increases the winter growth of the larger game fish. Drawdown has also been used to consolidate loose, flocculent sediments that can be a source of turbidity in lakes. Dewatering compacts the sediments, and they remain compacted after re-flooding (Born et al. 1973 and Fox et al. 1977).

A final consideration in implementation of lake level drawdown is season; winter or summer are usually chosen because they are most severe. According to Cooke (1980), “it is not clear whether drawdown and exposure of lake sediments to dry, hot conditions is more effective than exposure to dry, freezing conditions.” One factor to consider is which season is most rigorous. Advantages of winter drawdown include less interference with recreation, ease of spring versus autumn refill, and no invasion of terrestrial plants. Sediment dewatering is easier in summer.

In Murphy Flowage, a 180-acre (73 ha) reservoir in Wisconsin, a five foot drawdown from mid-October to March greatly reduced the presence of aquatic macrophytes the following growing season. Milfoil was reduced from 20 to <2.5 acres (8 ha to <1 ha), spatterdock was reduced from 42 to 12.5 acres (17 ha to 5 ha), and pondweeds were reduced from 114 to 7.5 acres (46 ha to 3 ha) (Beard 1973).

Drawdowns are not possible on all lakes. In lakes and reservoirs that do not have legal lake levels, manipulation of water level is possible without obtaining permission from regulatory agencies. Any effort to raise or lower the lake level requires that the legal level be changed. This process can be quite time consuming taking up to a year for a decision to be made. In addition, drawdowns are not physically practical on lakes that lack water control structures. On lakes where drawdowns are feasible, however, they offer a low cost management technique that does not require the introduction of chemicals or machinery.

<u>Biological Control</u>

Grass carp

Grass carp are the most well known species used for biological control of aquatic plants. Grass carp are an exotic fish species brought to this country from Malaysia. These carp feast on a wide range of aquatic weeds; *Elodea* spp. and pondweeds are among their favorites. Unfortunately, grass carp do not like milfoil and will only eat milfoil when its favorite foods are depleted. Over the course of time, grass carp typically will devour all the plants in a lake, leaving none for fish habitat or bank/substrate stabilization. In addition, grass carp may negatively alter resident fish communities, increase nutrient release from sediments promoting algal blooms and increase the turbidity of lakes. For these reasons, the use of grass carp in public waters is banned in 18 states including Indiana. Carp stocked in private ponds must be certified as genetically triploid and must have no possible access to other waterways.

Insects
The use of specific insect species in controlling aquatic plant growth has been investigated as well. Much of this research has concentrated on aquatic plants that are common in southern lakes such as alligator weed, hydrilla and water hycinth. Cooke et al. (1993) also points to four different species that may reduce Eurasian water milfoil infestations: *Triaenodes tarda*, a caddisfly, *Cricotopus myriophylii*, a midge, *Acentria nivea*, a moth and *Litodactylus leucogaster*, a weevil.

Eurasian water milfoil
Recent research suggests another alternative: *Euhrychiopsis lecontei*, a weevil. *E. lecontei* has been implicated in a reduction of Eurasian water milfoil in several Northeastern and Midwestern lakes (EPA, 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. 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 water milfoil.

Cost effectiveness and environmental safety are among the advantages to using the weevil rather than traditional herbicides in controlling Eurasian water milfoil (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 water milfoil 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. Because the weevils require natural shoreline on which to over-winter, the extensive shoreline development along the Barbee Lakes may limit the success of any weevil program attempted on these lakes.

Purple loosestrife
Biological control may also be possible for controlling the growth and spread of the emergent purple loosestrife. Like Eurasian water milfoil, 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 habitat, 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*).

Like biological control of Eurasian water milfoil, 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. Releases in Indiana to date have had mixed results. At Fish Lake, LaPorte County, after six years the loosestrife is showing signs of deterioration.

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. Sand or gravel anchors can act as substrate for new macrophyte growth, however. Materials 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.

Dredging

Dredging is occasionally used as a means to control aquatic plant growth. Dredging may control aquatic vegetation by two means. First, it removes aquatic vegetation. Second, it may prevent the re-establishment of vegetation by removing the substrate in which vegetation flourished and deepening the lake to a depth at which the sunlight penetration may be too limited or water pressure may be too great to allow for plant growth. Any dredging activities in a fresh water public lake will require permits from the Corps of Engineers, the Indiana Department of Environmental Management (IDEM), and IDNR. Dredging operations are fairly costly with prices ranging from $15,000 to $20,000 per acre ($37,000 to $49,400 per hectare, Jeff Krevda, Dredging Technologies, personal communication). This estimate excludes the cost of transportation to a disposal site and purchasing the disposal site if one is not available for free.

Dredging has several negative ecological impacts associated with it. For example, habitat for many aquatic insects (the macrophytes and top portion of the lake sediment) is removed along with the insects. These insects serve as an important food source to fish, and their removal may harm a lake's fishery. In addition, mechanical dredging resuspends nutrient rich sediments which could lead to algae blooms. Because of these reasons and given the amount of material that would have to be removed in order to achieve the desired effect in any of the Barbee Lakes, dredging is not recommended as a cost effective means of aquatic plant control. However, limited dredging in select areas to facilitate recreational uses of the lakes could be considered.

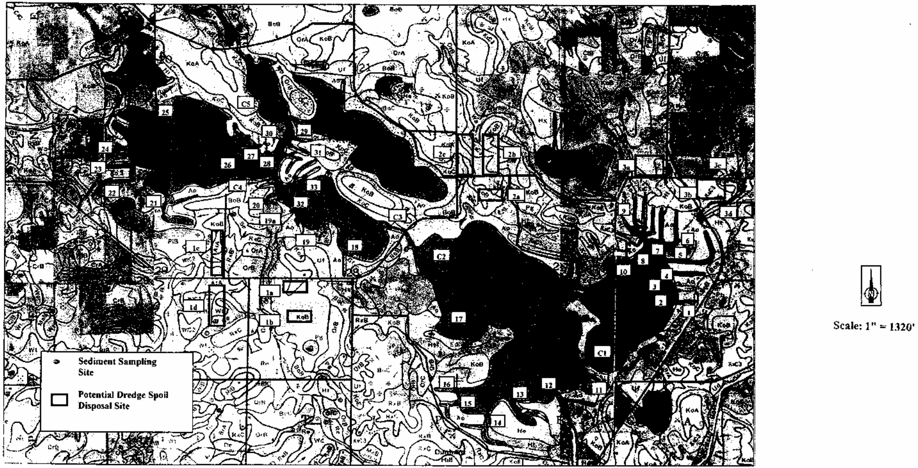
Sediment Sampling

In early November 1999, sediment depths in all channels attached to the Barbee lakes and all passages between the lakes were measured. The measurements were taken by pushing a two-inch diameter plastic pipe into the substrate. The pipe was graduated to measure the difference between the surface of the substrate and what was assumed to be the natural bottom of the lake or original depth of excavated channels. The original bottom generally had a different resistance to the pipe or a significant change in substrate material. In areas of dominant sand, no conclusions can be drawn on sediment deposition using this technique. Figure 9 and Table 7 detail the location of samples taken and depth of sediment observed. Five samples were taken in passages between lakes, and 33 samples were taken in artificial channels or inlets to the lakes.

In Kuhn Lake, 10 channels were sampled including four channels that had three feet (1 m) or more of unconsolidated sediments. All channels sampled possessed muck or marl bases with unconsolidated organic matter on the bottom. Because these channels were artificially constructed in wetland areas, this type of substrate will always be present. These channels included one between roads labeled B-14 and B-15; a channel between B-8 and B-9; the channel between B-8 and B-7; and the channel between B-3A and B-3B. The channel between B-14 and B-15 was of most concern as only 2 feet 10 inches (0.9 m) of water covered the unconsolidated sediment. Although, the channels located between B-10, B-11, and B-12 had only ten inches or less of unconsolidated sediment there was two feet (0.6 m) or less of water over the sediment accumulation causing boat access problems for residents on these channels. One property owner on the lake suggested that much of the sediment in these channels came from beach sanding activities to the south and west (personal communication). He postulated that prevailing winds and subsequent wave action wash the sand eastward. Thus, stricter regulation of beach sanding activities may be needed to reduce sediment accumulation in the Kuhn Lake channels.

In Big Barbee Lake, seven channels on the south edge of the lake were sampled including the Grassy Creek inlet. None of these channels had more than two feet (0.6 m) of unconsolidated sediments except for a small channel just south of B-29 lane and the large channel between B-22

BARBEE LAKES WATERSHED



Source of map: Natural Resource Conservation Service Soil Survey of Kosciusko County

Figure 9: Sediment Sampling and Potential Dredge Spoil Disposal Location Map
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

J.F. New & Associates, Inc.

and South Barbee Drive. As observed in Kuhn Lake, all the channels except for the Grassy Creek outlet, were artificially constructed in muck soils and will collect and settle out organic matter as it blows or washes into these protected areas.

Three samples were taken in channels along the south side of Little Barbee Lake including the mouth of Putney Ditch. As expected, the Putney Ditch outlet had the largest sediment accumulation of these three with just over two feet (0.6 m) of unconsolidated sediment measured at the mouth. To compound the problem, this sediment accumulation occurs in less than three feet (0.9 m) of water, allowing boat props to recycle the nutrient laden sediment back into the water column. Two additional samples were taken in the channels at the north end of Little Barbee Lake. These channels had approximately three feet of unconsolidated sediments each with approximately 3.5 feet (1.1 m) of water over the sediment. These channels are likely settling areas for material being carried into Little Barbee Lake from Putney Ditch.

Eight channels were sampled on Irish Lake including the channel to Banning Lake. With one exception, all of these channels had over four feet of water over the unconsolidated sediments. The sediment depth ranged from 2" to three feet (5 cm to 0.9 m) with the greatest organic matter accumulation occurring in a channel north of B-40G, near Irish Lake's outlet to Sawmill Lake. The sediment accumulation in this location is likely to continue until the total sediment load in Grassy Creek is reduced.

The channels between the lakes all had comparatively little sediment accumulation. One possible exception is the small passage between Kuhn Lake and Big Barbee Lake. This passage had less than six inches (15 cm) of water over the substrate surface. Approximately 1' (0.3 m) of sand was documented over top of muck and marl at this location. It is unknown if this shallow depth of water between the two lakes was normal or if sediment has decreased this depth over time. The channel between Big Barbee and Little Barbee Lake splits at it enters Little Barbee. The eastern channel is relatively free of unconsolidated sediments while the western channel has approximately 2.5 feet (0.75 m) of organic matter on the bottom.

There are three general areas in the Barbee Chain of Lakes that are in need of dredging. These areas are several channels on the east end of Kuhn Lake, the east side (north end) of the channel between Little Barbee and Big Barbee and the outlet of Putney Ditch. Those channels with less than three feet of water and more than two feet of unconsolidated sediments should be considered for dredging if the residents of those channels desire better access. The channel on Kuhn Lake between B-14 and B-15 and the channel adjacent to the Putney Ditch outlet qualify by these criteria at their outlets to the lake. Many additional channels have filled with leaf litter and milfoil to the surface within 50-100 feet of their terminus. It would not be detrimental to dredge small sections of these channels. Dredge spoil disposal areas and permits must be obtained before dredging. Potential disposal areas are identified on Table 7.

The potential dredged disposal areas are grouped according to the area they will serve. Area 1 could serve the dredge spoil disposal needs for Putney Ditch. There are 4 potential properties identified within one mile of the project site. Area 2 could serve both the Putney Ditch project and channels at the east end of Kuhn Lake, and three potential disposal areas are identified within Area 2. Area 3 could serve as disposal sites for any channels off Kuhn Lake. The landowners of identified properties would need to be contacted before plans are finalized. It is recommended that one or more of these landowners be approached for potential cooperation in the dredging project.

Permits required for dredging activities include U. S. Army Corps of Engineers Section 404, IDNR Lake Preservation Act, and IDEM Water Quality Certification. These permits may require one or more years to obtain.

While dredging may provide immediate relief to recreational problems that result from sediment accumulation, it should not be viewed as a long-term lake restoration solution. Reducing motorboat activity in shallow water areas, completing projects in the watershed that decrease sediment loads to tributary streams and prohibiting the disposal of yard waste in the lakes are practical methods to reduce sediment accumulation in the channels. Reducing speeds in shallow areas will limit the amount of organic matter and sediment stirred up by boat propellers. Implementing Best Management Practices such as filter strips and grassed waterways in the watershed will decrease loading from tributary streams. Keeping leaves, animal waste, and grass clippings out of the lake or out of areas that can wash this material to the lake will also reduce the amount of organic material available to settle out in channels.

TABLE 7. Sediment Sample Summary

Sample ID	Adjacent Road	Depth of Water	Depth of Sediment
1	B-15	2' 10”	3' 2"
2	B-11	1' 6"	10"
3	B-10	2'	4"
4	B-8	4' 6"	3'
5	B-7	4'	3' 6"
6	B-6	2' 6"	1' 8"
7	B-6C	5' 8"	2' 7"
8	B-5	5' 4"	2' 8"
9	B-4	5'	2' 4"
10	B-3	3' 8"	3.0'
11	B-20	5'	1' 6"
12	B-20 Grassy Creek	3' 5"	2'
13	B-22	5' 2	2' 4"
14	B-23	3' 6"	1' 8"
15	B-26	4' 2"	1' 2"
16	B-27	4'	2'
17	B-29	4' 10"	2' 8"
18	B-31/32	3'	1' 6"
19	B-33	2' 10"	2' 2"
19a	B33A Putney Ditch outlet	6” to 1.5’	2’ to 4’
20	B-35	6'	1' 4"
21	B-37	5' 8"	2' 4"
22	B-38	7'	3'
23	B-38A	4' 4"	2' 8"
24	B-38B	4'	1' 6"
25	Irish to Banning Lake Channel	7'	1' 6"
26	B-40E	3'	2"
27	B-40F	4' 6"	2'
28	B-40G	4'	3'
29	B-61K	4'	2' 6"
30	B-61J	4' 5"	1' 8"
31	B-61I	4'	4'
32	B-61H	3' 6"	2' 8"
33	B-61G	3' 6"	3'
C1	Kuhn to Big Barbee	1'	2" soft sand
C2	Big to Little Barbee - south end		2' 2"
C3	north end Big Barbee to Little Barbee		2' 4" east channel, 6" west channel
C4	Little Barbee to Irish		1" soft sediment
C5	Irish to Sechrist channel		2' 10" soft sediment

Lake and Stream Sampling

Methods

The water sampling and analytical methods used for Barbee Chain of Lakes were consistent with those used in IDEM's Indiana Clean Lakes Program and IDNR's Lake and River Enhancement Program. Water samples were collected for various parameters on August 11, 1999 from the surface waters (***epilimnion***) and from the bottom waters (***hypolimnion***) of each lake. These parameters include pH, alkalinity, conductivity, total suspended solids, 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. Dissolved oxygen and temperature were measured at one-meter intervals from the surface to the bottom. Chlorophyll was determined only for an epilimnetic sample. A tow to collect plankton was made from the 1% light level depth up to the water surface.

The major streams flowing into and out of the Barbee Lakes chain area were sampled once during this project at less than base flow conditions on 8/11/99 and once after a storm runoff event on 4/21/00. The area was experiencing a drought during late summer 1999. As a result, discharge could not be measured during base flow sampling. Site 5 was not sampled at base flow conditions as there was no water present at the time of sampling. Storm sampling followed a major storm on 4/20/00. Two to five inches (5 to 13 cm) of rain were reported for Kosciusko County that day. The sampling locations included (Figure 10):

Site 1	Tippecanoe River outlet at SR 13
Site 2	Gaff Ditch at County Road 450 North
Site 3	Tippecanoe River at SR 5
Site 4	Ditch at County Road 675 North and County Road 925 East
Site 5	Ditch at County Road 700 North

The comprehensive evaluation of lakes requires collecting data on a number of different, and sometimes hard-to-understand, water quality parameters. Some of the more important parameters analyzed include:

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

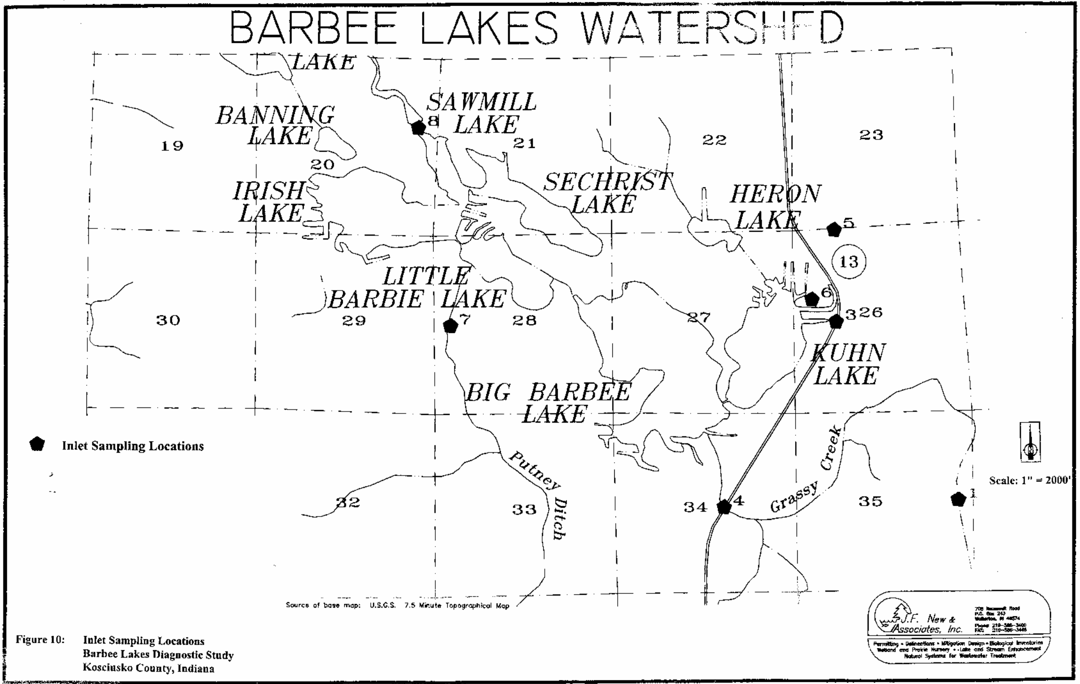


Figure 10: Inlet Sampling Locations
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

managed and (b) reducing phosphorus can reduce algae production. Two common forms of phosphorus are:

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

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

<u>Nitrogen</u> Nitrogen is an essential plant nutrient found in fertilizers, human and animal wastes, yard waste, and the air. About 80% of the air we breathe is nitrogen gas. This nitrogen can diffuse into water where it can be "fixed", or converted, by blue-green algae for their use. Nitrogen can also enter lakes and streams as inorganic nitrogen and ammonia. Because of this, there is an abundant supply of available nitrogen to lakes. The three common forms of nitrogen are:

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

Ammonium (NH_4) **–** Ammonium is dissolved nitrogen that is the preferred form for algae use. Bacteria produce ammonium as they decompose dead plant and animal matter. Ammonium is found where dissolved oxygen is lacking, often in the hypolimnia of eutrophic lakes.

Organic Nitrogen (Org N) **–** Organic nitrogen includes nitrogen found in plant and animal materials. It may be in dissolved or particulate form. In the analytical procedures, total Kjeldahl nitrogen (TKN) was analyzed. Organic nitrogen is TKN minus ammonia.

<u>Dissolved Oxygen (D.O.)</u> D.O. is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3-5 parts per million (ppm) of D.O. Cold-water fish such as trout and cisco generally require higher concentrations of D.O. than warm water fish such as bass or bluegill. D.O. affects a variety of chemical reactions in water. For example, the lack of D.O. near the bottom sediments may allow dissolved phosphorus (SRP) to be released from the sediments into the water. If less than 50% of a lake's water column has oxygen, greater hypolimnetic concentrations of SRP and ammonia are common as well. D.O. enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algae growth can over-saturate (greater than 100% saturation) the water with D.O. Dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

<u>Secchi Disk Transparency</u>. Secchi disk transparency is the depth to which the black & white Secchi disk can be seen in the water. Water clarity, as determined by a Secchi disk, is affected by two primary factors: algae and suspended particulate matter. Particulates (for example, soil or dead leaves) may be introduced into the water by either runoff from the land or from sediments already on the bottom of the lake. Many processes may introduce sediments from runoff; examples include erosion from construction sites, agricultural lands and riverbanks. Bottom sediments may be resuspended by bottom feeding fish such as carp, or in shallow lakes, by motorboats or strong winds.

Light Transmission. Similar to the Secchi disk transparency, this measurement uses a light meter (photocell) to determine the rate at which light transmission is diminished in the upper portion of the water column. Another important light transmission measurement is the 1% light level. The 1% light level is the water depth to which one percent of the surface light penetrates. This is considered the lower limit of algal growth.

Plankton. Plankton are important members of the aquatic food web. They include algae (microscopic plants) and zooplankton (tiny shrimp-like animals that eat algae). Plankton density is determined by filtering water through a net having a very fine mesh (63 micron openings = 63/1000 millimeter). The plankton net is towed up through the water column from the one percent light level to the surface. Of the many different algal species present in the water, the blue-green algae are of particular interest. Blue-green algae are those that most often form nuisance blooms; their dominance in lakes may indicate poor water conditions.

Chlorophyll *a*. The plant pigments of algae consist of the chlorophylls (green color) and carotenoids (yellow color). Chlorophyll *a* is by far the most dominant chlorophyll pigment and occurs in great abundance. Thus, chlorophyll *a* is often used as a direct estimate of algal biomass.

In-Lake Sampling Results

Big Barbee

Morphometry

Big Barbee Lake is the largest lake within the chain at 304 acres (123 ha). It is the second deepest lake with a maximum depth of 45 feet (14 m). The total lake volume is 4,749 acre-feet (5.9×10^6 m^3). (Refer to Table 1 for comparisons.)

Using a bathymetric map (Figure 11) prepared by the IDNR Division of Water in 1965 (IDNR 1965a), depth-area and depth-volume curves were prepared for Big Barbee Lake (Figures 12 and 13). (IDNR bathymetric maps are based on extensive survey work by the United States Geological Survey. While these maps are 35 years old and some sedimentation has occurred, the Division of Water (Bob Wilkinson, IDNR – Div. of Water, personal communication) does not believe current conditions are significantly different from those on which the maps are based.) These curves are useful for determining the extent of shallow habitat where rooted plants could grow and the volume of water below the mixing zone. Figure 12 shows that Big Barbee Lake has a gradually deepening lake with only 31% of the lake area as shallow as 10 feet (3 m) deep. Figure 13 shows that volume increases uniformly with depth until about the 30-foot (9 m) depth

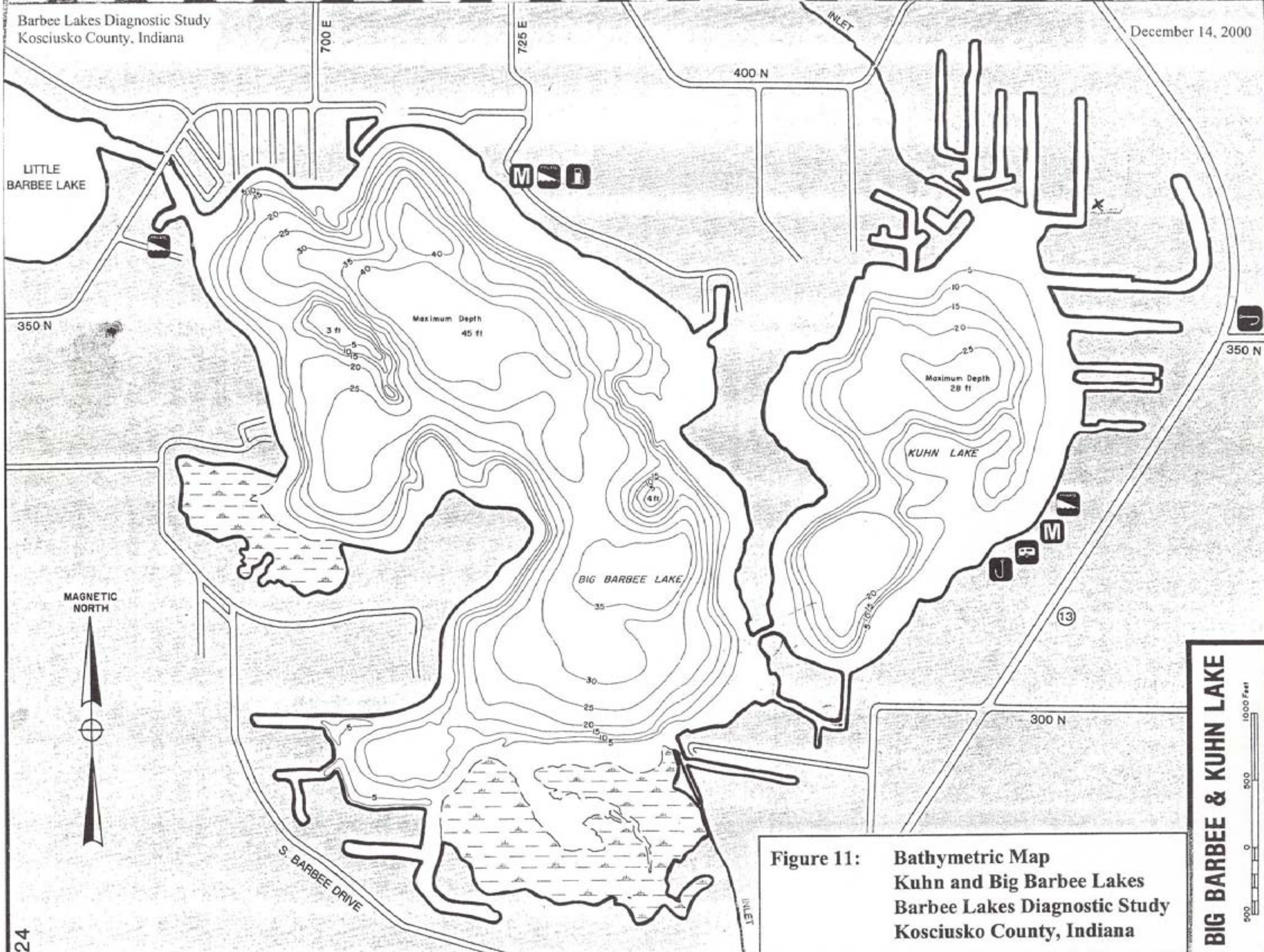


Figure 11: **Bathymetric Map**
Kuhn and Big Barbee Lakes
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

Source: Indiana Department of Natural Resources

where the steeper curve indicates a greater change in depth per unit of volume. In other words, the deepest waters of Big Barbee Lake contain a relatively small volume.

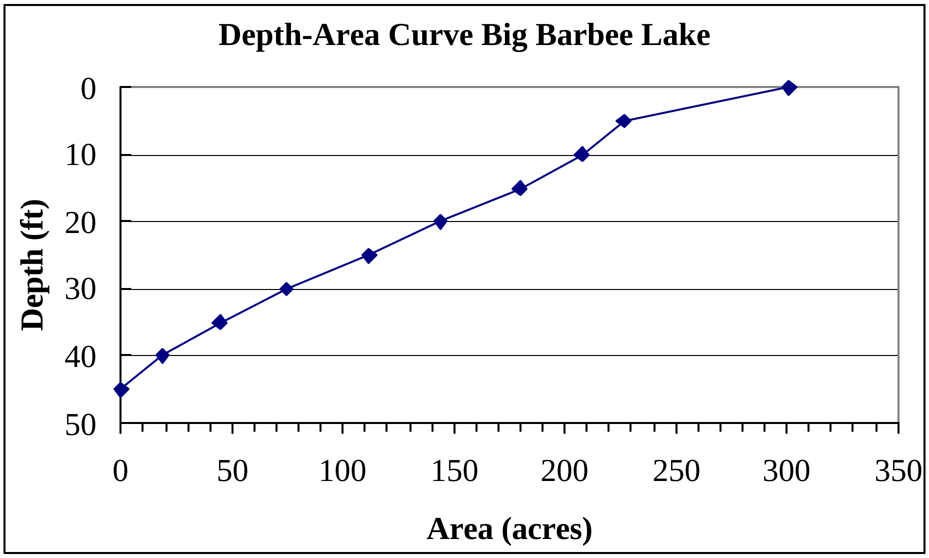


Figure 12 . Depth-area curve for Big Barbee Lake.

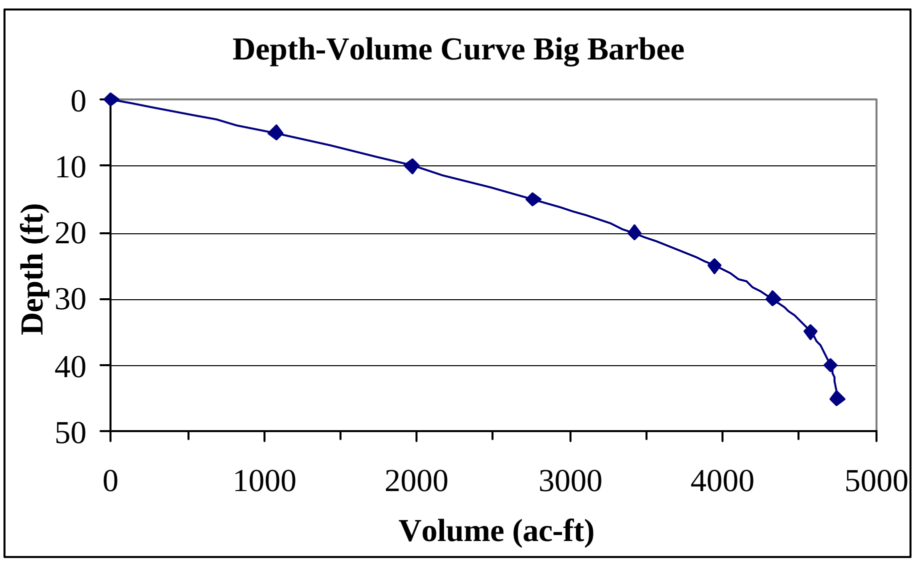


Figure 13. Depth-volume curve for Big Barbee Lake.

Historical Information

A summary of selected historic water quality parameters (including this study) for Big Barbee Lake is given in Table 8. Secchi disk transparency was variable as expected but there was a general trend toward increasing transparency over time (Figure 14). Concentrations of total phosphorus (TP) have varied somewhat over time (Table 8). TP concentrations in the surface waters (epilimnion or 'epi') were relatively low but the TP concentrations in the bottom waters (hypolimnion or 'hypo') were quite high. A consistent pattern exists of lower concentrations in the surface waters and higher concentrations in the bottom waters. That suggests that phosphorus was being released from the sediments during stratified conditions.

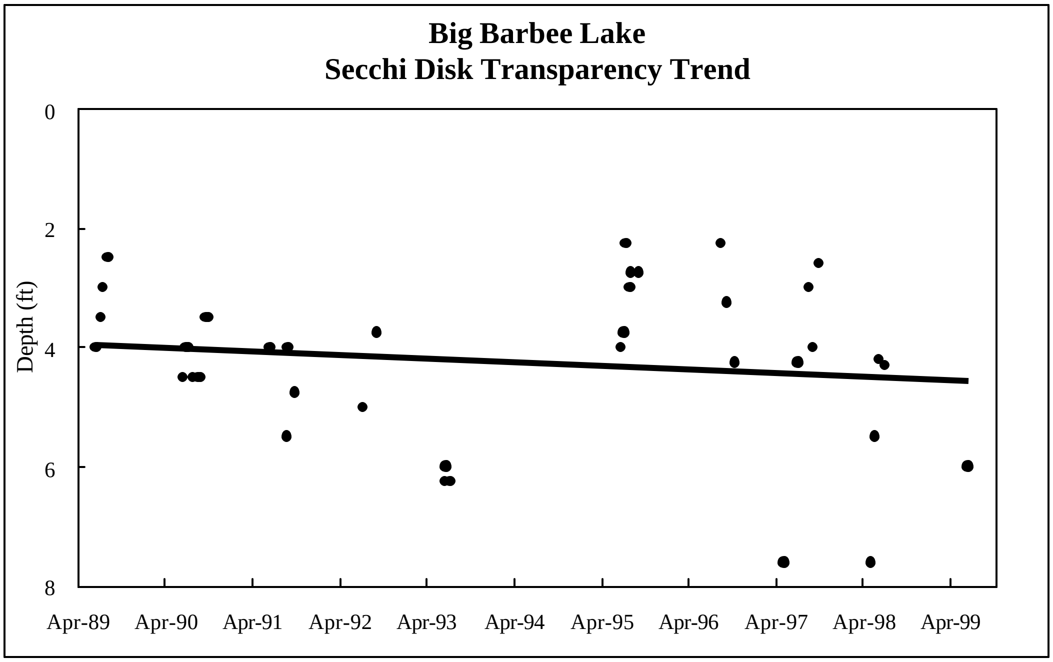


Figure 14. Secchi Disk Transparency Trend for Big Barbee Lake. Source: Indiana Volunteer Lake Monitoring Program.

TABLE 8. Summary of Historic Data for Big Barbee Lake.

Date	pH	TP (epi) (mg/L)	TP (hypo) (mg/L)	Plankton Density (#/L)	TSI Scores (based on means)	Data Source
8/22/90	7.6	0.059	0.059	15745	36	CLP, 1990
8/9/94	7.9	0.061	0.482	28119	39	CLP, 1994
7/6/98	7.9	0.06	0.404	14480	32	CLP, 1998
8/11/99	7.5	0.045	0.797	3857	20	Present Study

Several dissolved oxygen profiles (D.O.) exist for Big Barbee Lake (Figure 15). Although the 1997 D.O. profile shows that more oxygen was present at lower depths, the general trend shows that there was virtually no D.O. in the water below 6 to 7 meters (19.7 to 23 feet). Dissolved oxygen concentrations ranged from 6 to 9 mg/L within the epilimnion. Biochemical oxygen demand (BOD) greatly reduces the oxygen availability within the hypolimnion. BOD is caused by excess organic matter (dead plants and animals) on the sediments that provide food for bacteria. The bacteria use up oxygen as they feed.

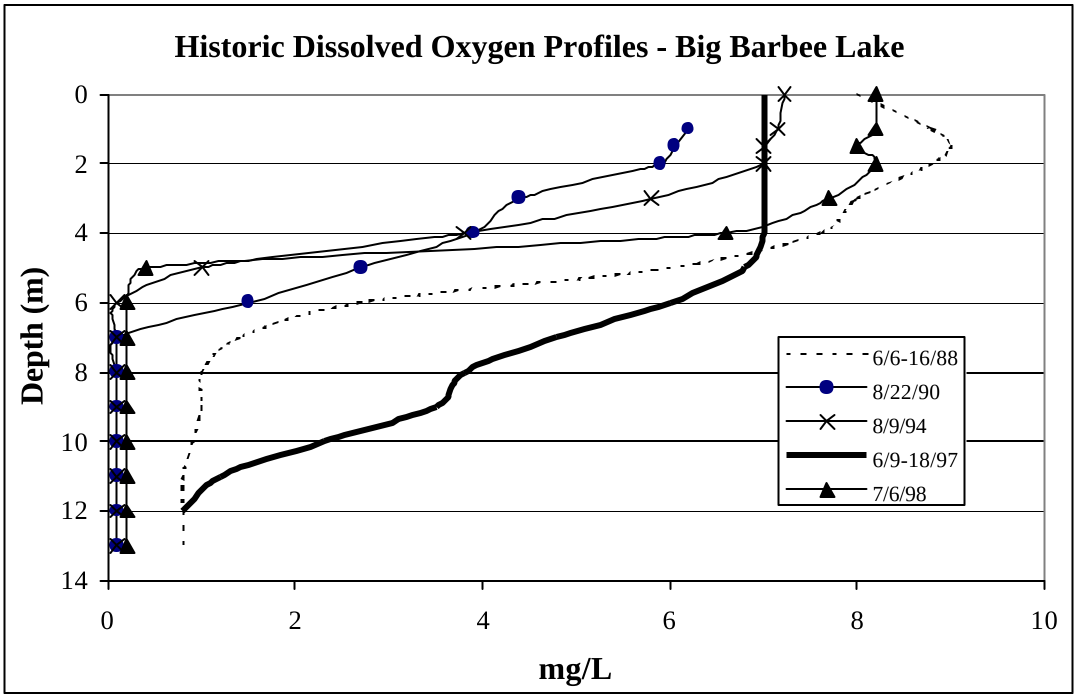


Figure 15. Historic dissolved oxygen (DO) profiles for Big Barbee Lake. Sources: Clean Lakes Program (1990, 1994, 1998) and IDNR fisheries surveys (1988, 1997).

Results

Results from the Big Barbee Lake water characteristics assessment are included in Table 9 and Figure 16.

TABLE 9. Water Quality Characteristics of Big Barbee Lake, 8/11/99.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	7.4	7.6	-
Alkalinity	155 mg/L	211 mg/L	-
Conductivity	421 μmhos	366 μmhos	-
Secchi Disk Transp.	5.2 feet	-	0
Total Suspended Solids	5.63 mg/L	11.24 mg/L	-
Light Transmission @ 3 ft	35%	-	3
1% Light Level	13 feet	-	-
Total Phosphorus	0.045 mg/L	0.797 mg/L	4
Soluble Reactive Phos.	0.034 mg/L	0.514 mg/L	4
Nitrate-Nitrogen	<0.022 mg/L	<0.022 mg/L	0
Ammonia-Nitrogen	<0.018 mg/L	1.971 mg/L	3
Organic Nitrogen	0.941 mg/L	0.843 mg/L	2
Oxygen Saturation @ 5 ft.	105%	-	0
% Water Column Oxic	38%	-	3
Plankton Density	3857 per L	-	1
Blue-Green Dominance	No	-	0
		TSI score	20

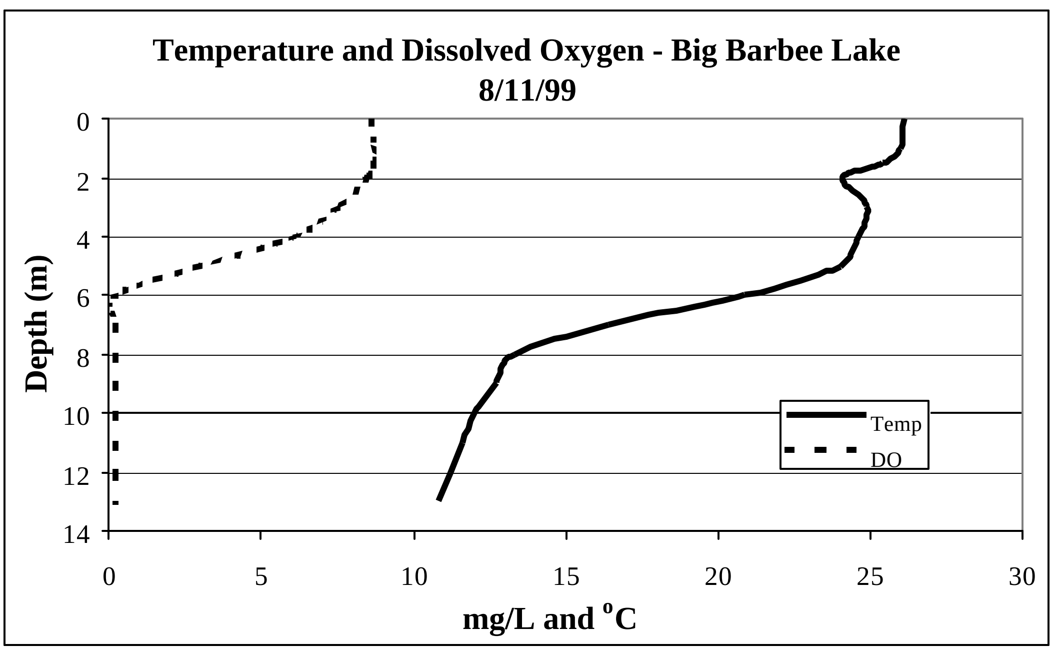


Figure 16. Temperature and dissolved oxygen profiles for Big Barbee Lake on 8/11/99.

Temperature and oxygen profiles for Big Barbee Lake show that the lake was stratified at the time of sampling (Figure 16). The lake reached anoxic conditions at the depth of 6 meters (20 feet) due to biochemical oxygen demand.

The 1% light level, which limnologists use to determine the lower limit of sufficient light for photosynthesis (algal growth) to occur, extended to a depth of 13 feet (3.96 m) in Big Barbee Lake. Based on the depth-volume curve in Figure 13, approximately 53% of the water volume in the lake has sufficient light to support algae

Water quality data for Big Barbee Lake are presented in Table 9. Phosphorus and nitrogen are the primary plant nutrients in lakes. Concentrations of these nutrients are relatively low in the surface waters of the lake, in fact the nitrate and ammonium concentrations are below the detection limits. All the chemical parameters increase within the hypolimnion except the total organic nitrogen which is actually higher in the surface waters. Values of the pH are within the normal range for Indiana lakes. The high alkalinity concentrations indicate that Big Barbee Lake is a well-buffered system.

Plankton genera enumerated in the sample collected from Big Barbee Lake are shown in Table 10. *Synedra*, a diatom, was the most abundant genera present. Blue-green algae, the group that most often causes nuisance blooms, were relatively abundant but accounted for less than 50% of all plankton (by number) found.

TABLE 10. Plankton Species Composition in Big Barbee Lake, 8/11/99

SPECIES	ABUNDANCE (#/L)
Blue-Green Algae (Cyanophyta)	
Anabaena	777
Lyngbya	66
Aphanizomenon	132
Oscillatoria	290
Microcystis	40
Coelospharium	26
Green Algae (Chlorophyta)	
Pediastrum	145
Staurastrum	26
Ulothrix	356
Ophiocytium	13
Diatoms (Bacillariophyceae)	
Fragilaria	184
Synedra	1370
Astrionella	13
Other Algae	
Ceratium	329
Dinobryon	66
Zooplankton	
Miscellaneous Protists	13
Calanoid Copepod	2.4
Cyclopoid Copepod	0.3
Daphnia	0.3
Nauplii	5.7
Leptodora	0.9
Other Rotifers	40
Keratella	53

Kuhn Lake

Morphometry

Kuhn Lake is an average sized lake within the chain with a volume of 1076 acre-feet (1.3 x 10^6 m^3) and a maximum depth of 28 feet (8.5 m). Even though Kuhn Lake covers only 137 acres (55.5 ha), it has the highest shoreline development (D.L. = 3.84).

Using a bathymetric map (Figure 11) prepared by the IDNR Division of Water in 1965 (IDNR 1965a), depth-area and depth-volume curves were prepared for Kuhn Lake (Figures 17 and 18). Figure 17 shows Kuhn Lake is a gradually deepening lake with approximately 50% of the lake area as shallow as 5 feet (1.5 m) deep. Figure 18 shows that volume increases uniformly with depth until about the 25-foot (7.5 m) depth where the steeper curve indicates a greater change in depth per unit of volume. The extensive shallow areas of Kuhn Lake provide significant habitat for rooted aquatic plants.

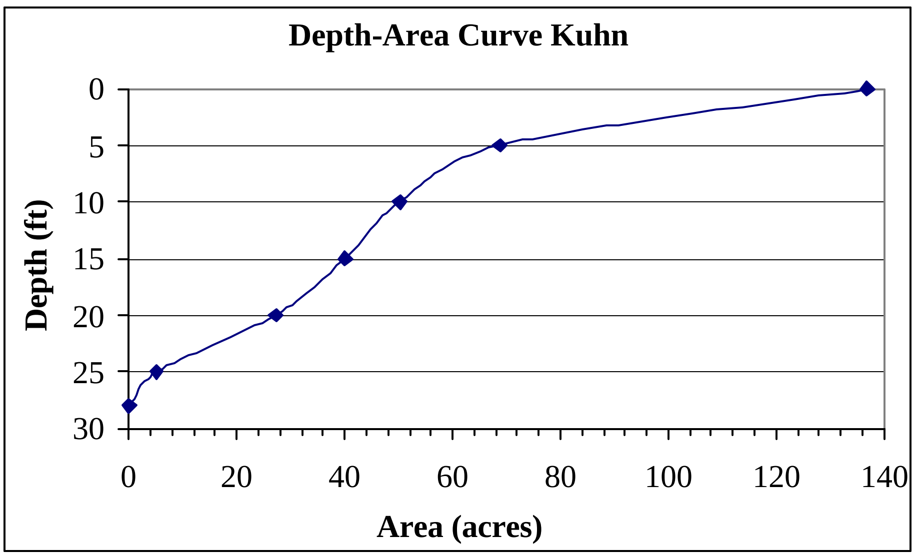


Figure 17. Depth-area curve for Kuhn Lake.

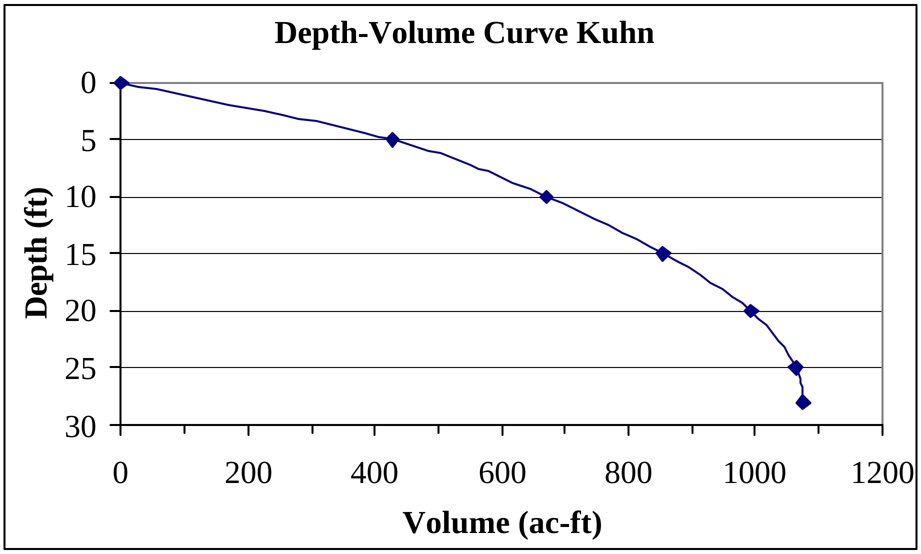


Figure 18. Depth-volume curve for Kuhn Lake.

Historical Information

A summary of selected historic water quality parameters (including this study) for Kuhn Lake is given in Table 11. Secchi disk transparency was variable as expected but there was a general trend toward increasing transparency over time (Figure 19). Concentrations of total phosphorus (TP) have varied somewhat over time (Table 11). TP concentrations in the epilimnion were relatively low as well as the TP concentrations in the hypolimnion. This suggests that there is not much phosphorus being released from the sediments even though stratified conditions existed.

TABLE 11. Summary of Historic Data for Kuhn Lake.

Date	pH	TP (epi) (mg/L)	TP (hypo) (mg/L)	Plankton Density (#/L)	TSI Score (based on means)	Data Source
8/22/90	7.4	0.012	0.034	4559	24	CLP, 1990
8/9/94	8.0	0.028	0.032	4887	29	CLP, 1994
7/6/98	7.9	0.0285	0.051	1012	15	CLP, 1998
8/11/99	7.6	0.031	0.034	342	6	Present Study

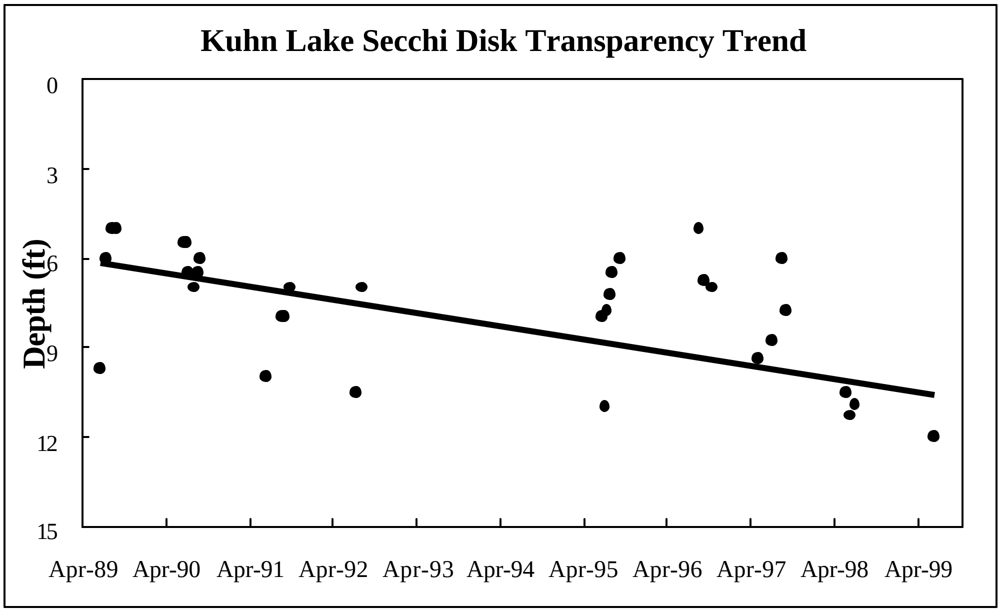


Figure 19. Secchi disk transparency trend of Kuhn Lake. Source: Indiana Volunteer Lake Monitoring Program files.

Several dissolved oxygen profiles exist for Kuhn Lake (Figure 20). The general trend shows that oxygen reduction starts at the depth of 3 meters (10 feet) and produces anoxic conditions around 6 meters (20 feet) and deeper due to biochemical oxygen demand (BOD) within the hypolimnion.

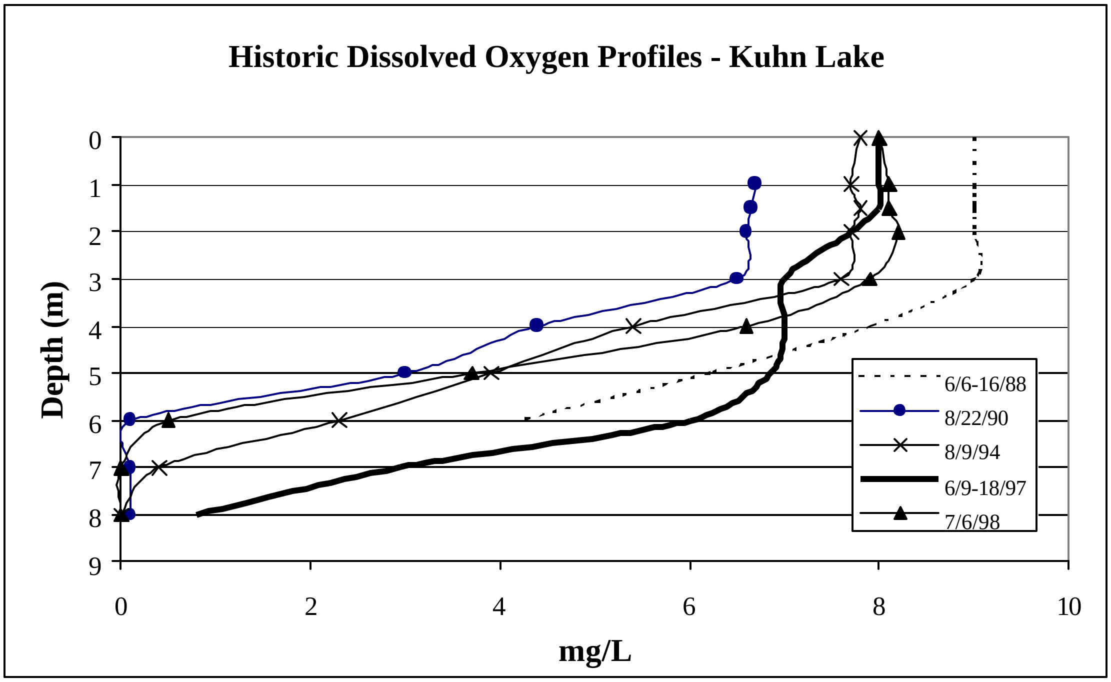


Figure 20. Historic dissolved oxygen profiles for Kuhn Lake. Sources: Clean Lakes Program (1990, 1994, 1998) and IDNR fisheries surveys (1988, 1997).

Results

Results from the Kuhn Lake water characteristics assessment are included in Table 12 and Figure 21.

TABLE 12. Water Quality Characteristics of Kuhn Lake, 8/11/99.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	8.2	7.1	-
Alkalinity	166 mg/L	203 mg/L	-
Conductivity	429 μmhos	431 μmhos	-
Secchi Disk Transp.	7.9 feet	-	0
Total Suspended Solids	2.65 mg/L	0.4 mg/L	-
Light Transmission @ 3 ft	50%	-	3
1% Light Level	20 feet	-	-
Total Phosphorus	0.031 mg/L	0.034 mg/L	1
Soluble Reactive Phos.	0.023 mg/L	0.026 mg/L	0
Nitrate-Nitrogen	<0.022 mg/L	<0.022 mg/L	0
Ammonia-Nitrogen	<0.018 mg/L	0.111 mg/L	0
Organic Nitrogen	0.667 mg/L	0.633 mg/L	2
Oxygen Saturation @ 5 ft.	104%	-	0
% Water Column Oxic	86%	-	0
Plankton Density	342 per L	-	0
Blue-Green Dominance	No	-	0
		TSI score	6

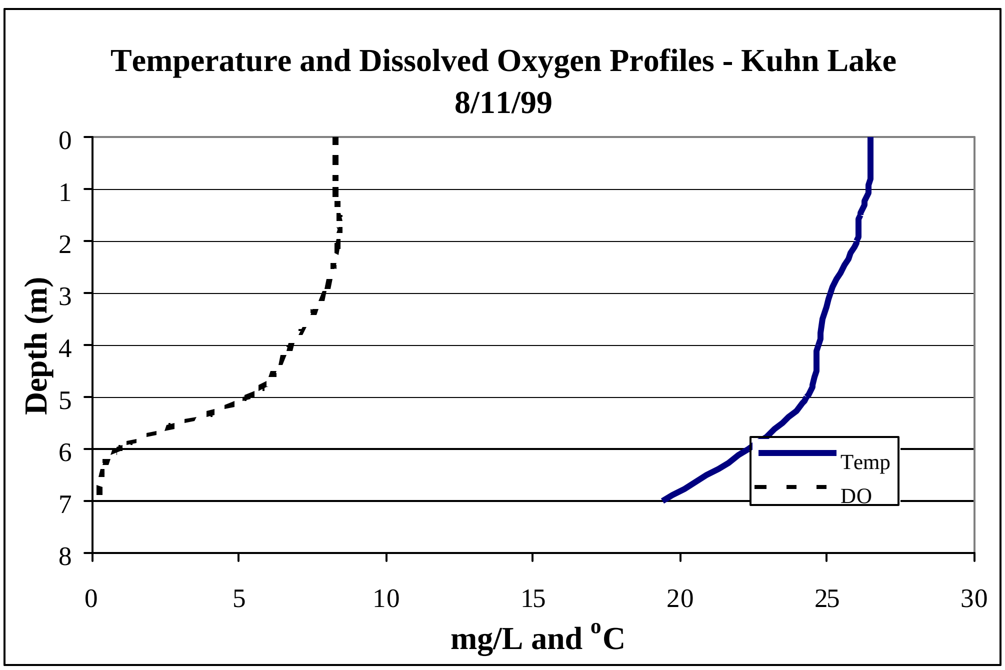


Figure 21. Temperature and dissolve oxygen profiles for Kuhn Lake on 8/11/99.

Temperature and oxygen profiles for Kuhn Lake show that the lake was slightly stratified at the time of sampling (Figure 21). The lake barely reached anoxic conditions at the depth of 7 meters (23 feet) due to biochemical oxygen demand. This created a 1.5-meter (5 foot) anoxic layer at the depths of the hypolimnion.

The 1% light level extended deep into the lake to a depth of 20 feet (6.1 meters). Based on the depth-volume curve in Figure 18, approximately 93% of the water volume in the lake has sufficient light to support algae.

Water quality data for Kuhn Lake are presented in Table 12. Concentrations of phosphorus and nitrogen are relatively low in the epilimnion and the hypolimnion, with nitrate and ammonium being below the laboratory detection limits in the epilimnion. Values of pH are within the normal range for Indiana lakes. The high alkalinity concentrations indicate that Kuhn Lake is a well-buffered system.

TABLE 13. Plankton Species Composition in Kuhn Lake on 8/11/99

SPECIES	ABUNDANCE (#/L)
Blue-Green Algae (Cyanophyta)	
Anabaena	86
Lyngbya	14
Oscillatoria	7
Microcystis	29
Coelospharium	14
Green Algae (Chlorophyta)	
Pediastrum	7
Ulothrix	14
Diatoms (Bacillariophyceae)	
Synedra	79
Other Algae	
Ceratium	36
Dinobryon	50
Zooplankton	
Cyclopoid Copepod	0.7
Daphnia	0.8
Nauplii	2.1
Keratella	14

Kuhn Lake had the lowest plankton density (Table 13) at the time of the sampling of any of the Barbee Chain lakes – only 355 organisms per liter. The low plankton densities contribute to the high transparency in the lake but, on the other hand, the high transparency creates a deep photic zone (93% of the lake's volume has enough light to support algae growth) that should enhance algal production. The low nutrient concentrations in the lake are the primary limiting factor to algal growth.

Little Barbee

Morphometry

Little Barbee is a 74-acre (30 ha) natural lake with a volume of 816 acres-feet (1.0 x 10^6 m^3). Even though Little Barbee is one of the smaller lakes within the Barbee chain, it has the third largest watershed with a shoreline development of 2.34.

Using a bathymetric map (Figure 22) prepared by the IDNR Division of Water in 1965 (IDNR 1965b), depth-area and depth-volume curves were prepared for Little Barbee Lake (Figures 23 and 24). Figure 23 shows that Little Barbee Lake gradually deepens with approximately 38% of the lake area as shallow as 10 feet deep. Figure 24 shows that volume increases uniformly with depth until about the 20-foot depth where the steeper curve indicates a greater change in depth per unit of volume.

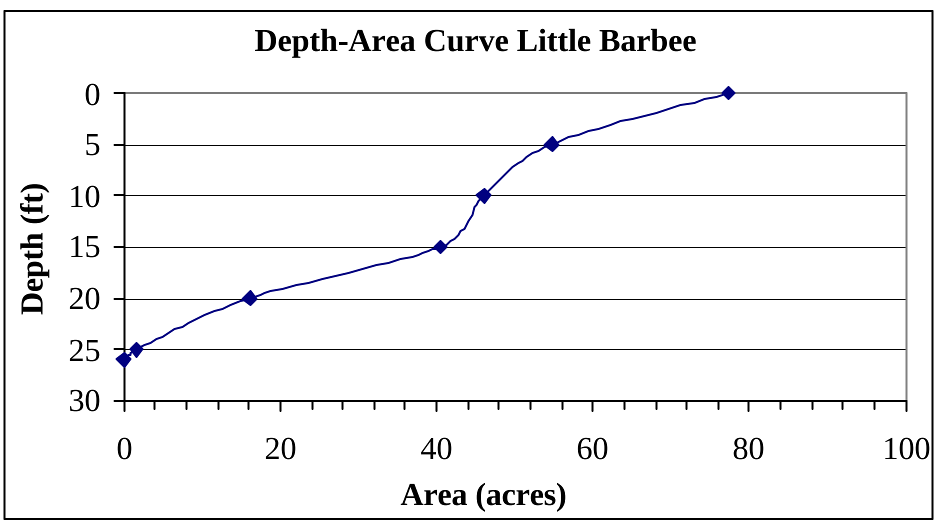


Figure 23. Depth-area curve for Little Barbee Lake.

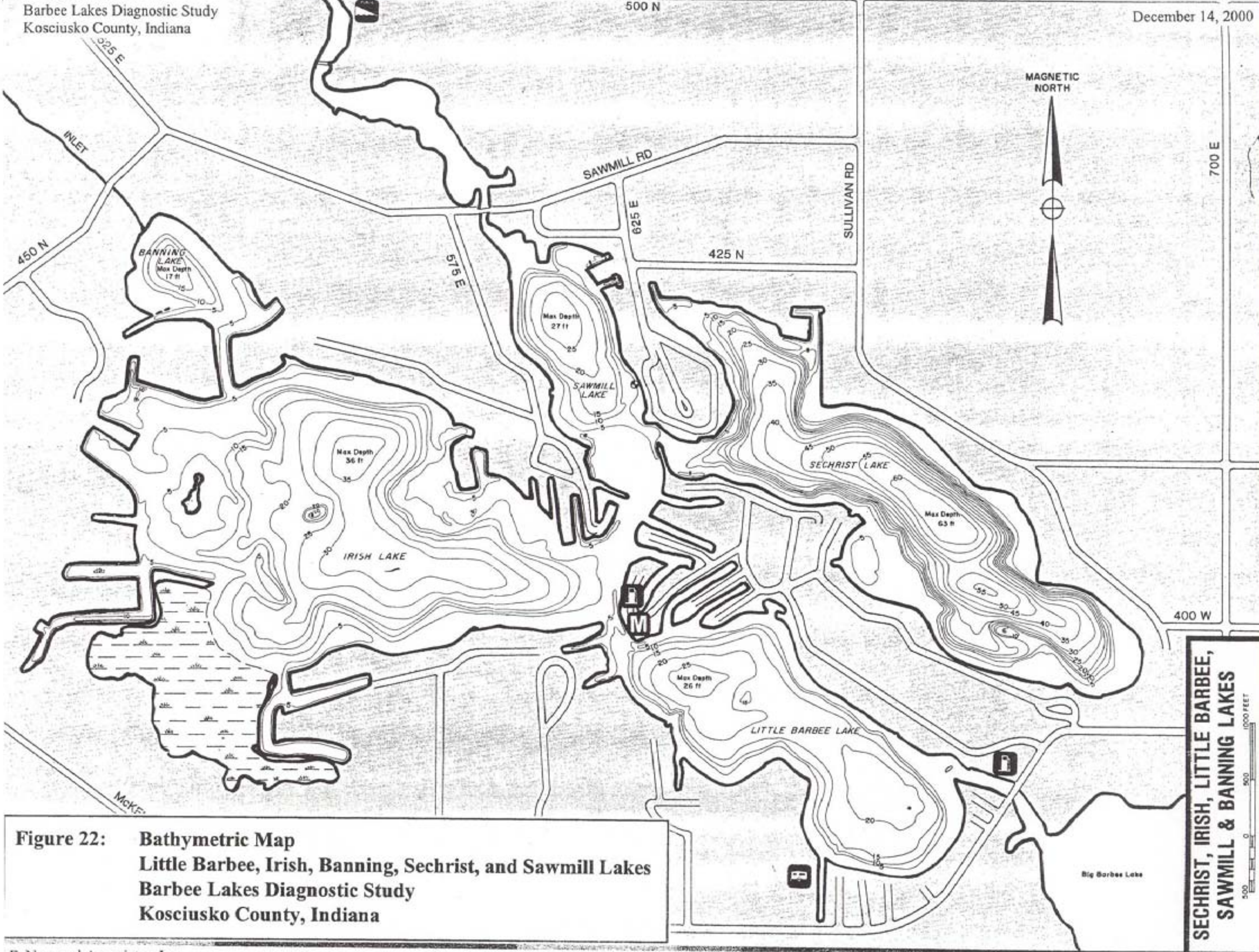


Figure 22: Bathymetric Map
Little Barbee, Irish, Banning, Sechrist, and Sawmill Lakes
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

Source: Indiana Department of Natural Resources

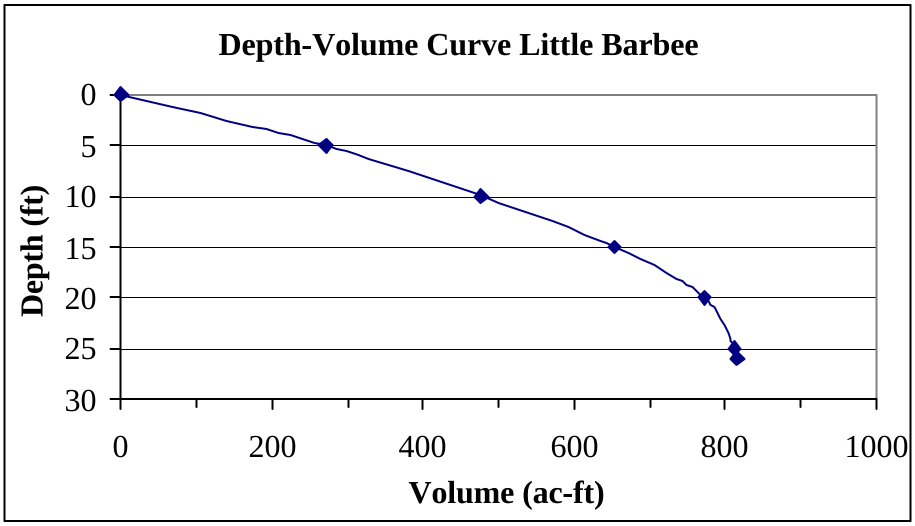


Figure 24. Depth-volume curve for Little Barbee Lake.

Historical Information

A summary of selected historic water quality parameters (including this study) for Little Barbee Lake is given in Table 14. Secchi disk transparency was variable as expected but there was a general trend for increasing transparency over time (Figure 25). Concentrations of total phosphorus (TP) have varied somewhat over time (Table 14). TP concentrations in the epilimnion were relatively low while the TP concentrations in the hypolimnion where much higher. A consistent pattern exists of lower concentrations in the surface waters and higher concentrations in the bottom waters. This suggests that there is phosphorus being released from the sediments.

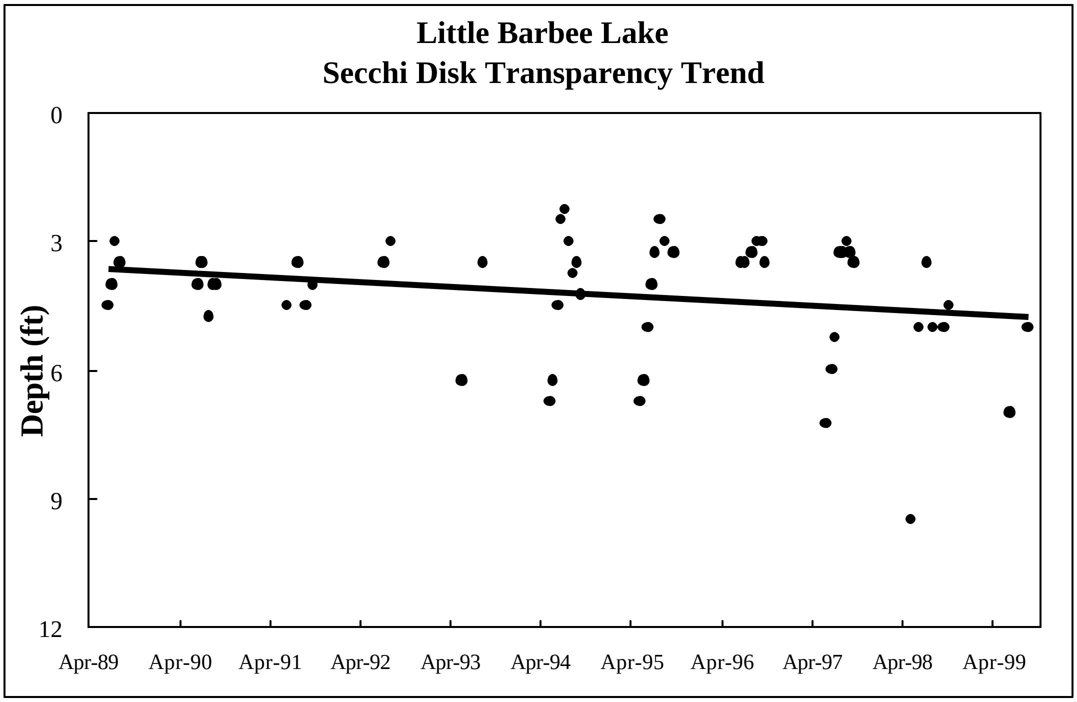


Figure 25. Secchi disk transparency trend of Little Barbee Lake. Source: Indiana Volunteer Lake Monitoring Program files.

TABLE 14. Summary of Historic Data for Little Barbee Lake.

Date	pH	TP (epi) (mg/L)	TP (hypo) (mg/L)	Plankton Density (#/L)	TSI score (based on means)	Data Source
8-24/89	8.3	0.041	0.578	-	59	IST, 1989
8/22/90	7.5	0.078	0.478	26880	40	CLP, 1990
8/9/94	7.7	0.074	0.671	30840	38	CLP, 1994
7/9/98	8.0	0.072	0.224	13760	37	CLP, 1998
8/11/99	7.6	0.058	0.609	6083	38	Present Study

Several dissolved oxygen profiles exist for Little Barbee Lake (Figure 26). The general trend shows a steep decrease in oxygen concentrations ranging from 3 to 6 meters (10 to 20 feet) in depth. The 1997 extrapolated values indicate that oxygen availability persisted through a majority of the water column.

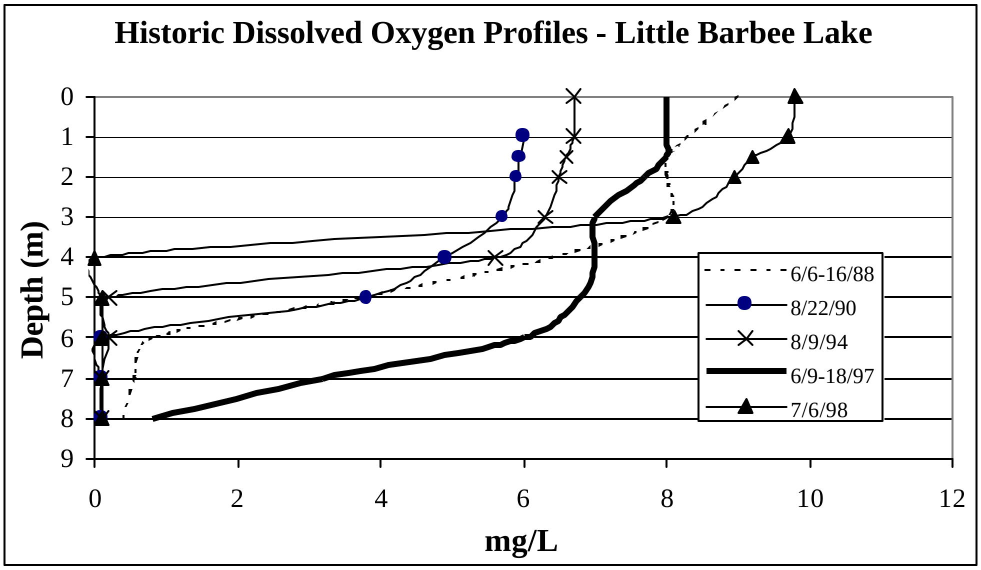


Figure 26. Historic dissolved oxygen profiles for Little Barbee Lake. Sources: Clean Lakes Program (1990, 1994, 1998) and IDNR fisheries surveys (1988, 1997).

Results

Results from the Little Barbee Lake water characteristics assessment are included in Table 15 and Figure 27.

TABLE 15. Water Quality Characteristics of Little Barbee Lake, 8/11/99.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	7.9	7.3	-
Alkalinity	149 mg/L	233 mg/L	-
Conductivity	401 µmhos	435 µmhos	-
Secchi Disk Transp.	4.3 feet	-	6
Total Suspended Solids	5.84 mg/L	11.45 mg/L	-
Light Transmission @ 3 ft	25%	-	4
1% Light Level	11 feet	-	-
Total Phosphorus	0.058 mg/L	0.609 mg/L	4
Soluble Reactive Phos.	<0.022 mg/L	0.444 mg/L	4
Nitrate-Nitrogen	0.037 mg/L	0.031 mg/L	0
Ammonia-Nitrogen	<0.018 mg/L	2.000 mg/L	4
Organic Nitrogen	0.841 mg/L	1.109 mg/L	3
Oxygen Saturation @ 5 ft.	93%	-	0
% Water Column Oxic	71%	-	1
Chlorophyll a	11.87 µg/L	-	-
Plankton Density	6083 per L	-	2
Blue-Green Dominance	Yes	-	10
		TSI score	38

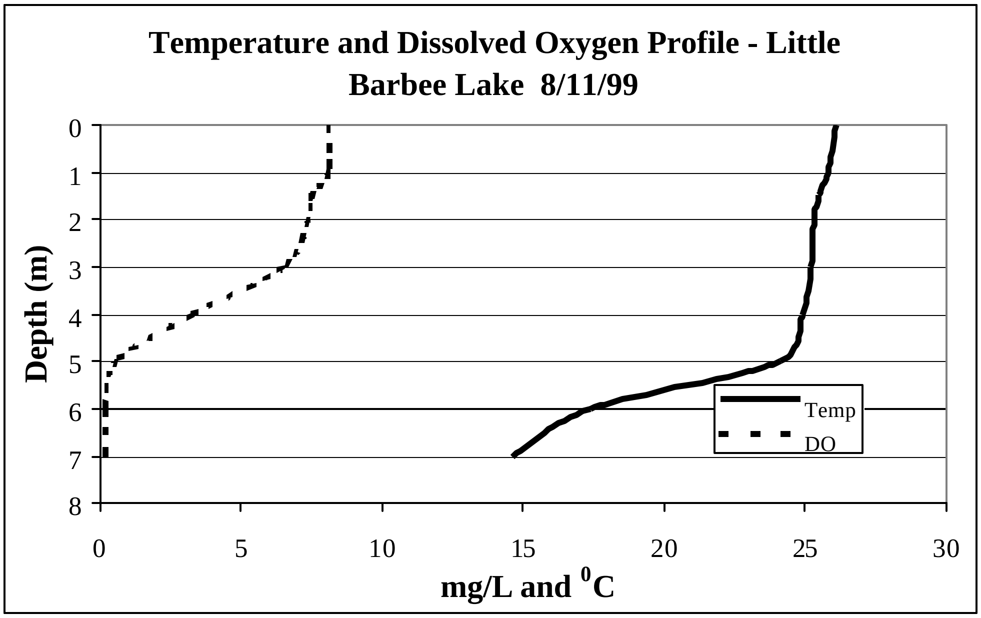


Figure 27. Temperature and dissolve oxygen profiles of Little Barbee Lake on 8/11/99.

Temperature and oxygen profiles for Little Barbee Lake show that the lake was stratified at the time of sampling (Figure 27). The lake reached anoxic conditions at the depth of 5 meters (16.5 feet) likely due to biochemical oxygen demand in the deeper waters.

The 1% light level extended to 11 feet (3.5 m). Based on the depth-volume curve in Figure 24, approximately 59% of the water volume in the lake has sufficient light to support algae.

Water quality data for Little Barbee Lake are presented in Table 15. Concentrations of phosphorus and nitrogen are relatively low in the epilimnion but are considerably higher in the hypolimnion. Values of pH are within the normal range for Indiana lakes. The high alkalinity concentrations indicate that Little Barbee Lake is a well-buffered system.

Plankton enumerated from the sample collected from Little Barbee Lake are shown in Table 16. While *Synedra*, a diatom, was the most abundant genera found, blue-green algae were the dominant group of algae, accounting for 50% of all plankton. Blue-greens are usually associated with degraded water quality.

TABLE 16. Plankton Species Composition in Little Barbee Lake on 8/11/99

SPECIES	ABUNDANCE (#/L)
Blue-Green Algae (Cyanophyta)	
Anabaena	1062
Lyngbya	311
Oscillatoria	440
Microcystis	207
Coelospharium	104
Aphanizomenon	1036
Green Algae (Chlorophyta)	
Pediastrum	181
Ulothrix	492
Ophiocytium	155
Diatoms (Bacillariophyceae)	
Synedra	1295
Fragillaria	233
Asterionella	26
Other Algae	
Ceratium	518
Zooplankton	
Cyclopoid Copepod	0.6
Nauplii	15.9
Leptodora	2.4
Calanoid Copepod	4.1
Keratella	181
Other Rotifers	78

Sechrist Lake

Morphometry

Sechrist Lake is mid size (105 acres or 42.5 ha) relative to other lakes in the Barbee chain, however it possesses the greatest depth (maximum depth: 63 feet or 19 meters). Its volume is

1989 acre-feet (2.5 x 10^6 m^3). Sechrist Lake has the smallest watershed, 270 acres (109 ha), which is only 0.2% of the compiled watershed of the entire chain of lakes. Sechrist Lake has the second lowest shoreline development value (DL = 1.92).

Working with a bathymetric map (Figure 22) prepared by the IDNR Division of Water in 1965 (IDNR 1965b), depth-area and depth-volume curves were prepared for Sechrist Lake (Figures 28 and 29). Figure 28 shows that Sechrist Lake gradually deepens with approximately 41% of the lake area as shallow as 10 feet (3 m) deep. Figure 29 shows that volume increases uniformly with depth until about the 50-foot (15 m) depth where the steeper curve indicates a greater change in depth per unit of volume. Despite being the deepest lake in the chain, Sechrist Lake has extensive shallow areas.

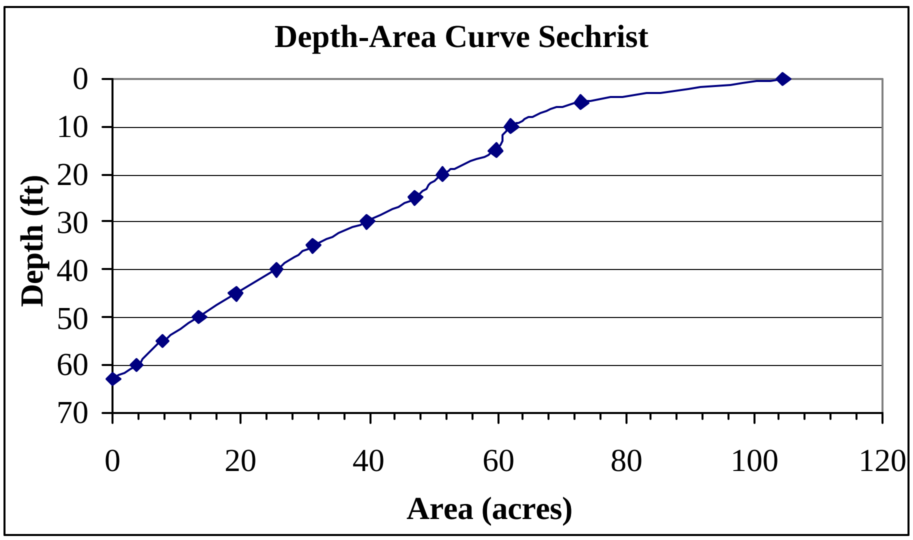


Figure 28. Depth-area curve for Sechrist Lake.

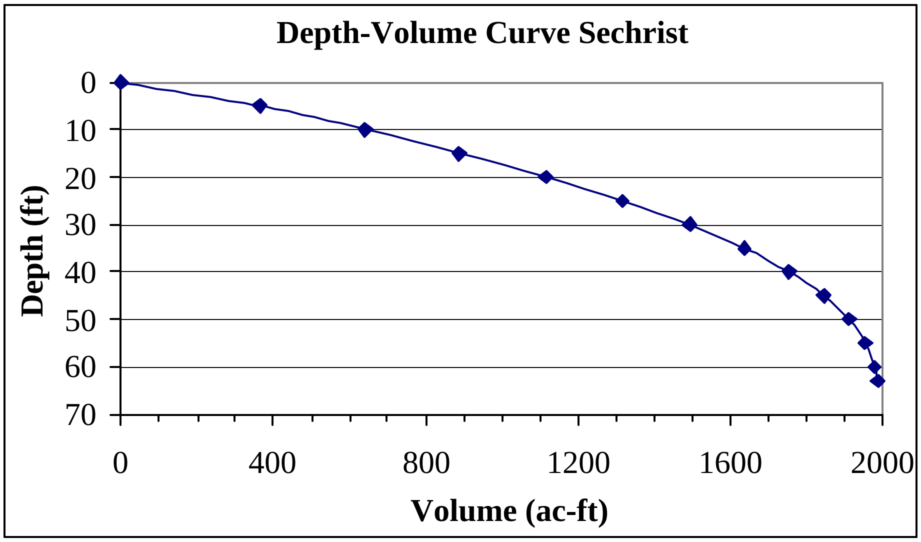


Figure 29. Depth-volume curve for Sechrist Lake.

Historical Information

A summary of selected historic water quality parameters (including this study) for Sechrist Lake is given in Table 17. Secchi disk transparency was variable as expected but there was a general trend toward increasing transparency over time (Figure 30). Concentrations of total phosphorus (TP) have varied somewhat over time (Table 17). TP concentrations in the epilimnion were relatively low while the TP concentrations in the hypolimnion where higher. A consistent pattern exists of lower concentrations in the surface waters and higher concentrations in the bottom waters. This suggests that there is phosphorus being released from the sediments.

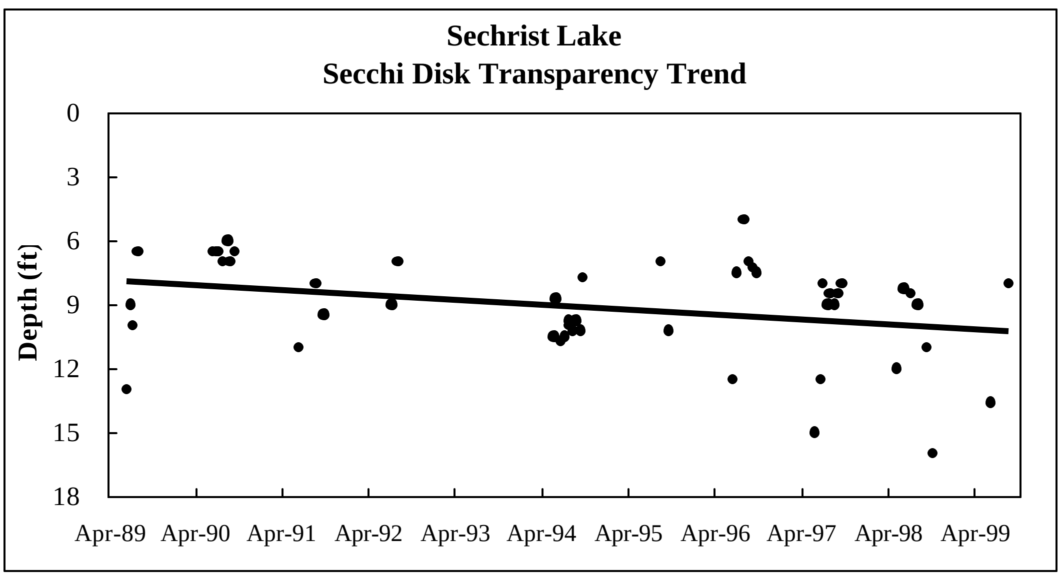


Figure 30. Secchi disk transparency trend for Sechrist Lake.

TABLE 17. Summary of Historic Data for Sechrist Lake.

Date	pH	TP (epi) (mg/L)	TP (hypo) (mg/L)	Plankton Density (#/L)	TSI score (based on means)	Data Source
8/22/90	7.7	0.019	0.112	2841	27	CLP, 1990
8/9/94	7.9	0.021	0.111	44772	29	CLP, 1994
7/9/98	7.9	0.03	0.057	18412	21	CLP, 1998
8/11/99	7.6	0.044	0.144	2909	17	Present Study

Several dissolved oxygen profiles exist for Sechrist Lake (Figure 31). Profiles from 1990, 1994, and 1998 follow a generalized trend of steep declines in dissolved oxygen concentrations between 4 and 7 meters (13 and 23 feet). These three profiles indicate anoxic lake conditions by the 8-meter depth (26 feet). The 1988 and 1997 extrapolated profiles have interesting oxygen profiles. The epilimnion is nearly saturated with oxygen but concentrations increase around 8 meters (26 feet). The 1988 D.O. profile almost appears exaggerated with the peak oxygen concentrations reaching 15 mg/L. This phenomenon is known as a metalimnetic oxygen maximum and is likely due to a high density of photosynthesizing algae positioned in the upper metalimnion where there is still adequate light and where the algae have access to more plentiful nutrients in the hypolimnion. Below this point, oxygen concentrations decline rapidly as bacteria decompose algae as they settle down through the water column. We usually see this type of oxygen profile in lakes that are clear enough to allow light to penetrate that deep. Following the hyper-saturated D.O. peak, decomposition again increases, and the remaining oxygen is eventually consumed. There is a slight metalimnetic oxygen maximum evident in the 1998 D.O. profile.

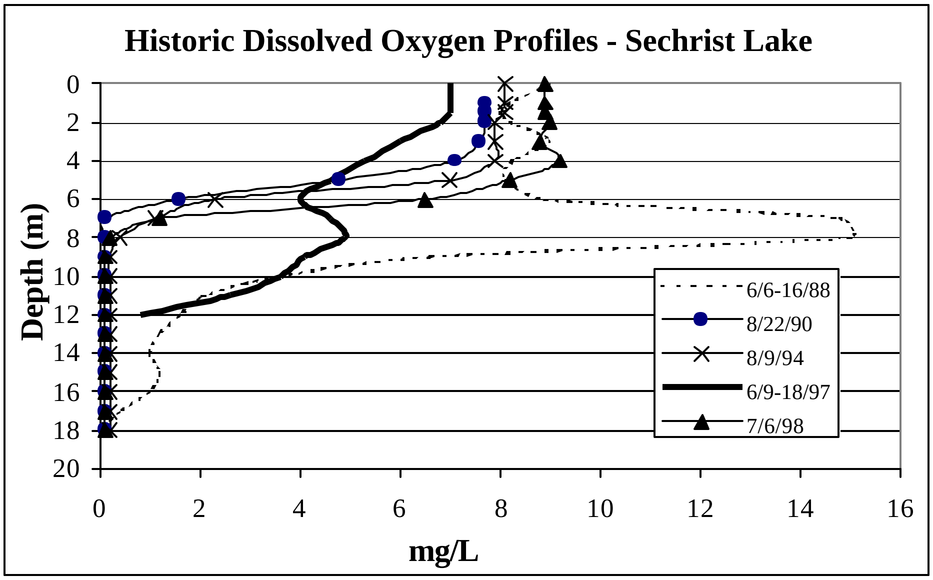


Figure 31. Historic dissolved oxygen profiles for Sechrist Lake. Sources: Clean Lakes Program (1990, 1994, 1998) and IDNR fisheries surveys (1988, 1997).

Results

Results from the Sechrist Lake assessment are included in Table 18 and Figure 32.

TABLE 18. Water Quality Characteristics of Sechrist Lake, 8/11/99.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	8.1	7.2	-
Alkalinity	135 mg/L	172 mg/L	-
Conductivity	389 µmhos	386 µmhos	-
Secchi Disk Transp.	8.2 feet	-	0
Total Suspended Solids	4.41 mg/L	0.36 mg/L	-
Light Transmission @ 3 ft	50%	-	3
1% Light Level	22 feet	-	-
Total Phosphorus	0.044 mg/L	0.144 mg/L	3
Soluble Reactive Phos.	0.033 mg/L	0.112 mg/L	3
Nitrate-Nitrogen	<0.022 mg/L	<0.022 mg/L	0
Ammonia-Nitrogen	<0.018 mg/L	0.964 mg/L	2
Organic Nitrogen	0.684 mg/L	0.691 mg/L	2
Oxygen Saturation @ 5 ft.	115%	-	1
% Water Column Oxic	39%	-	3
Chlorophyll a	3.73 µg/L	-	-
Plankton Density	2909 per L	-	0
Blue-Green Dominance	No	-	0
		TSI score	17

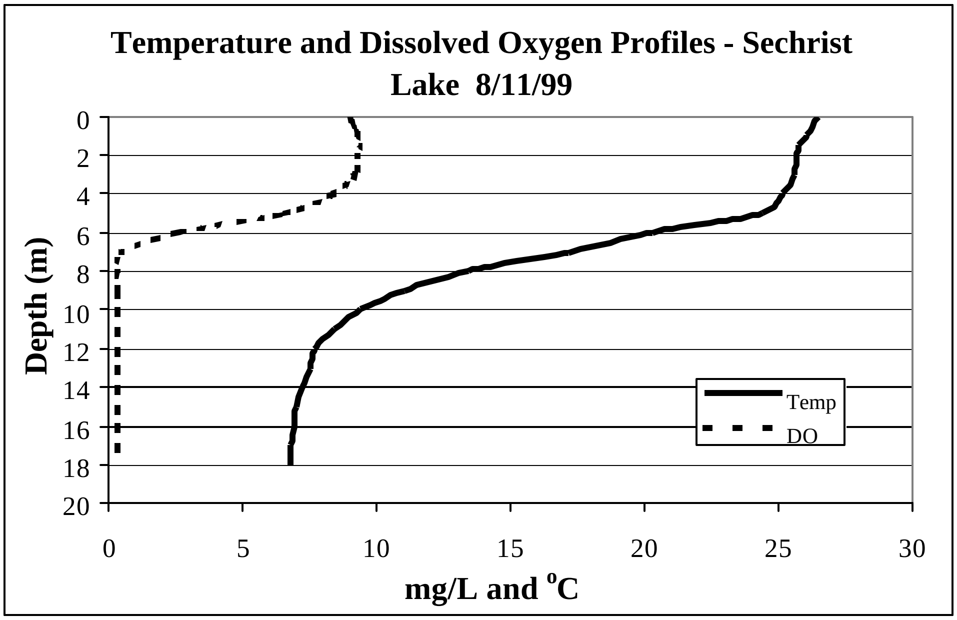


Figure 32. Temperature and dissolved oxygen profiles for Sechrist Lake on 8/11/99.

Temperature and oxygen profiles for Sechrist Lake show that the lake was stratified at the time of sampling (Figure 32). The epilimnion is nearly saturated with oxygen but concentrations increase to 115% saturation at 5 meters (16.5 feet). This again is explained by a metalimnetic oxygen maximum and is likely due to a high density of photosynthesizing algae positioned in the upper metalimnion where there is still adequate light and where they have access to more plentiful nutrients in the hypolimnion. The lake reached anoxic conditions at the depth of 7 meters (23 feet) due to biochemical oxygen demand.

The 1% light level extended to a depth of 22 feet (6.5 m). Based on the depth-volume curve in Figure 29, approximately 57% of the water volume in the lake has sufficient light to support algae.

Water quality data for Sechrist Lake are presented in Table 18. Concentrations of phosphorus and nitrogen are relatively low in the epilimnion but are considerably higher in the hypolimnion, except with nitrate-nitrogen, which was below detection limits in both the epilimnion and hypolimnion. Values of pH are within the normal range for Indiana lakes. The high alkalinity concentrations indicate that Sechrist Lake is a well-buffered system.

Plankton enumerated in the sample collected from Sechrist Lake are shown in Table 19. Overall plankton density was only 2,909 organisms per liter. Blue-green algae made up only 14% of the total number of plankton organisms counted.

TABLE 19. Plankton Species Composition in Sechrist Lake on 8/11/99

SPECIES	ABUNDANCE (#/L)
Blue-Green Algae (Cyanophyta)	
Anabaena	178
Lyngbya	47
Oscillatoria	128
Coelospharium	23
Green Algae (Chlorophyta)	
Pediastrum	140
Ulothrix	70
Diatoms (Bacillariophyceae)	
Synedra	35
Fragillaria	409
Other Algae	
Ceratium	1752
Zooplankton	
Cyclopoid Copepod	1.6
Nauplii	4.5
Leptodora	2.9
Calanoid Copepod	1.9
Daphnia	0.5
Chaoborus	0.3
Asplanchna	35
Keratella	12

Banning Lake

Morphometry

Banning Lake is the smallest lake of the Barbee chain occupying only 17 acres (7 ha). Banning reaches a maximum depth at 17 feet (5 m) and has a volume of only 93 acre-feet (1.2 x 10^5 m^3). Banning Lake also has the lowest shoreline development value (DL = 1.5). Banning Lake's watershed is the second smallest among the Barbee chain lakes.

Using a bathymetric map (Figure 22) prepared by the IDNR Division of Water in 1965 (IDNR 1965b), depth-area and depth-volume curves were prepared for Banning Lake (Figures 33 and 34). Figure 33 shows that Banning Lake gradually deepens with approximately 76% of the lake area as shallow as 10 feet (3 m) deep. Figure 34 shows that volume increases uniformly throughout the entire depth.

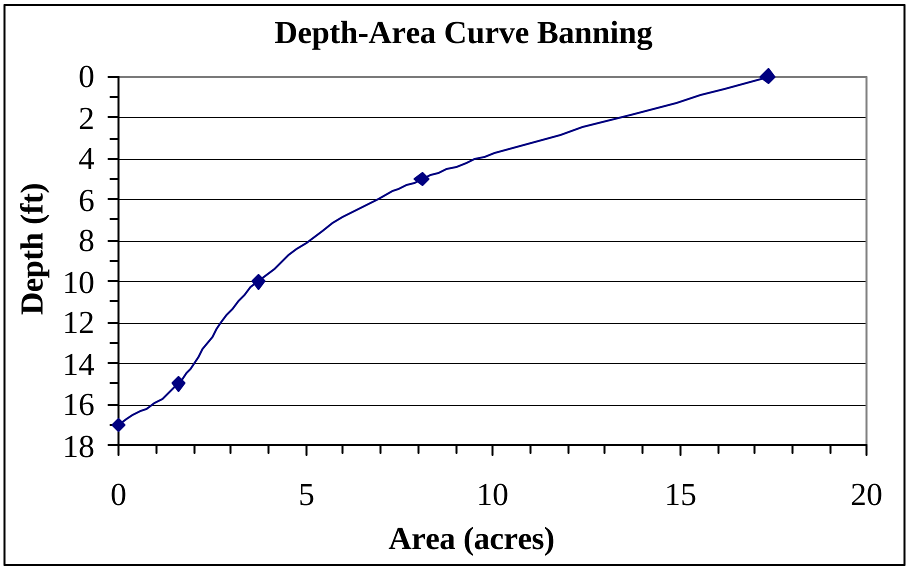


Figure 33. Depth-area curve for Banning Lake.

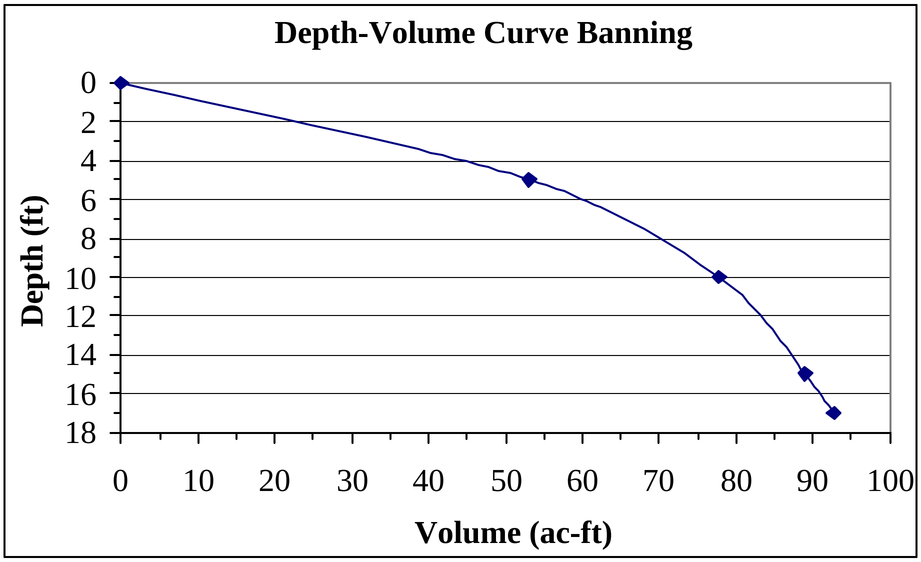


Figure 34. Depth-volume curve for Banning Lake.

Historical Information

A summary of selected historic water quality parameters (including this study) for Banning Lake is given in Table 20. There was a general trend for increasing transparency over time (Figure 35). Concentrations of total phosphorus (TP) have varied somewhat over time (Table 20). Concentrations of TP in both the epilimnion and hypolimnion are moderate, and there is no evidence of long-term phosphorus release from the sediments.

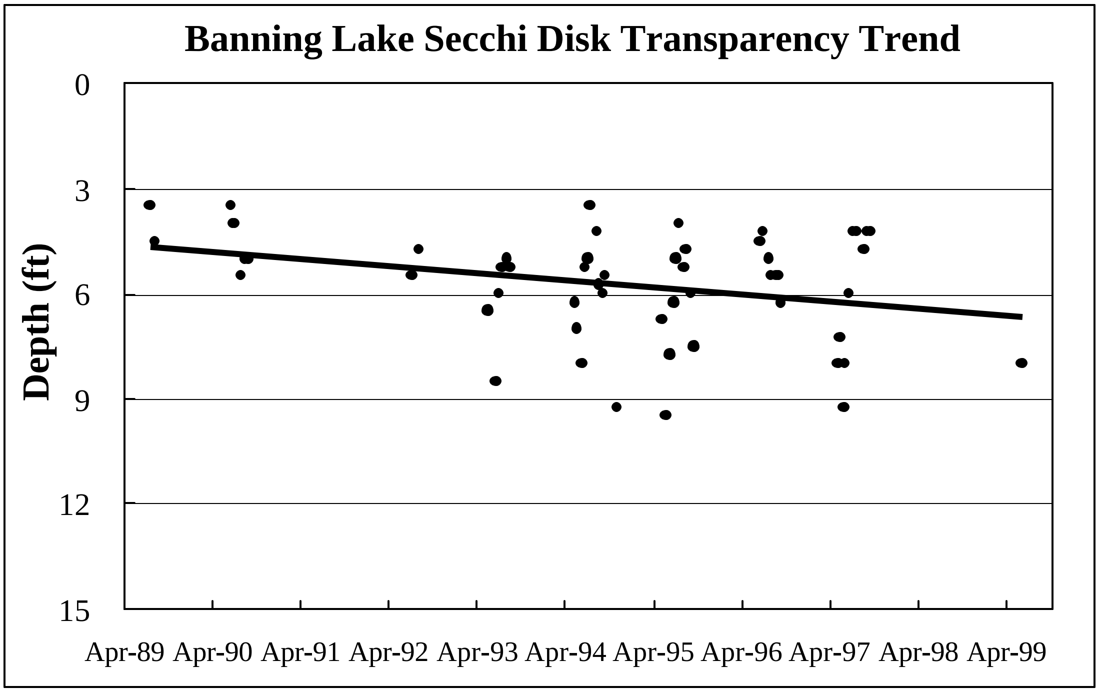


Figure 35. Secchi disk transparency trend for Banning Lake. Source: Indiana Volunteer Monitoring Program files.

TABLE 20. Summary of Historic Data for Banning Lake.

Date	pH	TP (epi) (mg/L)	TP (hypo) (mg/L)	Plankton Density (#/L)	TSI Score (based on means)	Data Source
8/21/90	7.3	0.044	0.034	1369	11	CLP, 1990
8/9/94	7.7	0.045	0.038	2011	22	CLP, 1994
7/6/98	7.9	0.063	0.063	11790	27	CLP, 1998
8/11/99	7.6	0.044	0.082	1677	12	Present Study

Three previous dissolved oxygen profiles for Banning Lake (Figure 36) show that the lake stratifies weakly to only 1-2 meters (3-6.5 feet). Anoxia is evident at the 4 and 5-meter (13 and 16 feet) depths.

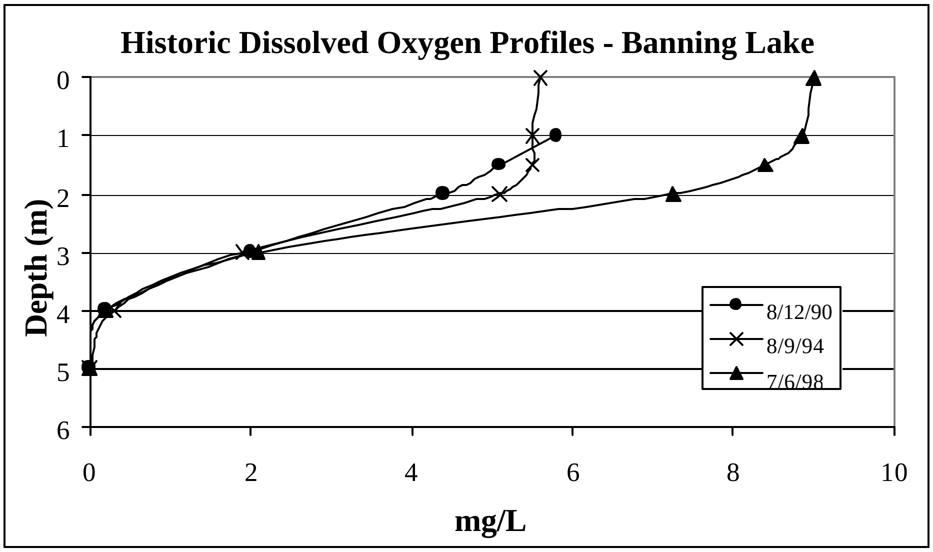


Figure 36. Historic dissolved oxygen profiles for Banning Lake. Sources: Clean Lakes Program (1990, 1994, 1998) and IDNR fisheries surveys (1988, 1997).

Results

Results from the Banning Lake water characteristics assessment are included in Table 21 and Figure 37.

TABLE 21. Water Quality Characteristics of Banning Lake, 8/11/99.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	7.8	7.5	-
Alkalinity	147 mg/L	150 mg/L	-
Conductivity	393 μmhos	390 μmhos	-
Secchi Disk Transp.	5.6 feet	-	0
Total Suspended Solids	0.8 mg/L	1.47 mg/L	-
Light Transmission @ 3 ft	28%	-	4
1% Light Level	12 feet	-	-
Total Phosphorus	0.044 mg/L	0.082 mg/L	3
Soluble Reactive Phos.	0.025 mg/L	0.025 mg/L	0
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	0.145 mg/L	0
Organic Nitrogen	1.245 mg/L	1.341 mg/L	3
Oxygen Saturation @ 5 ft.	70%	-	0
% Water Column Oxic	60%	-	2
Plankton Density	1677 per L	-	0
Blue-Green Dominance	No	-	0
		TSI score	12

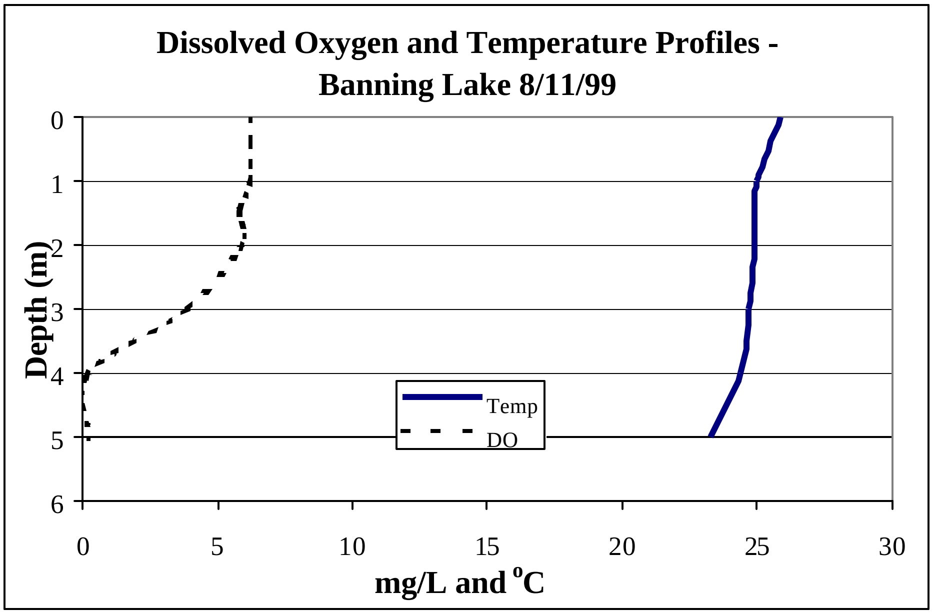


Figure 37. Temperature and dissolved oxygen profiles for Banning Lake on 8/11/99.

Temperature and oxygen profiles for Banning Lake show that the lake was largely unstratified at the time of sampling (Figure 37). Despite this, the lake reached anoxic conditions at the depth of 4 meters (13 feet) due to biochemical oxygen demand.

The 1% light level extended to a depth of 12 feet (4 meters). Based on the depth-volume curve in Figure 34, approximately 90% of the water volume in the lake has sufficient light to support algae.

Water quality data for Banning Lake are presented in Table 21. Phosphorus levels are relatively low for an Indiana lake. There is no increase in soluble phosphorus in the hypolimnion, however, since the lake was only weakly stratified at the time of sampling a build-up of soluble phosphorus would not be expected even if it was released from the sediments. Ammonium concentrations are significantly higher in the hypolimnion. Since ammonium is a by-product of bacterial decomposition this, and the anoxia, suggest that BOD levels may be a problem. Values of pH are within the normal range for Indiana lakes. The high alkalinity concentrations indicate that Banning Lake is a well-buffered system.

Plankton abundance in Banning Lake at the time of our sampling is shown in Table 22. Overall plankton densities were only 1,677 organisms per liter, the second lowest of all the lakes. Blue-green algae accounted for 41% of all plankton organisms counted.

TABLE 22. Plankton Species Composition in Banning Lake on 8/11/99

SPECIES	ABUNDANCE (#/L)
Blue-Green Algae (Cyanophyta)	
Anabaena	198
Lyngbya	40
Oscillatoria	264
Microcystis	79
Green Algae (Chlorophyta)	
Pediastrum	93
Ulothrix	145
Staurastrum	13
Diatoms (Bacillariophyceae)	
Synedra	291
Fragillaria	66
Melosira	13
Pinnularia	40
Other Algae	
Ceratium	172
Dinobryon	145
Zooplankton	
Cyclopoid Copepod	4.2
Nauplii	21.7
Leptodora	0.6
Calanoid Copepod	4.8
Daphnia	6.0
Miscellaneous Protists	79
Asplanchna	40
Keratella	40
Other Rotifers	66

Irish Lake
Morphometry

Irish Lake is the second largest lake in the Barbee chain at 182 surface acres (74 ha). The lake's maximum depth is 36 feet (11 meters) and it has a volume of 1,989 acre-feet (2.5 x 10^6 m^3). Irish Lake has a shoreline development value (DL) of 2.98. Because four other lakes drain into Irish, it has the second largest watershed within the chain.

Using a bathymetric map (Figure 22) prepared by the IDNR Division of Water in 1965 (IDNR, 1965b), depth-area and depth-volume curves were prepared for Irish Lake (Figures 38 and 39). Figure 38 shows that Irish Lake has extensive shallows; 56% of the lake is less than 10 feet (3 meters) deep. Figure 39 shows that volume increases uniformly throughout the entire depth.

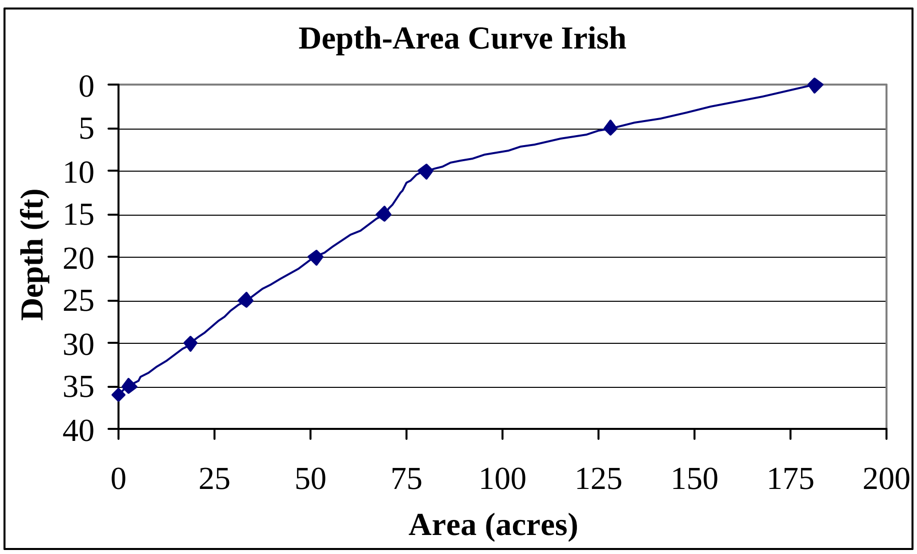


Figure 38. Depth-area curve for Irish Lake.

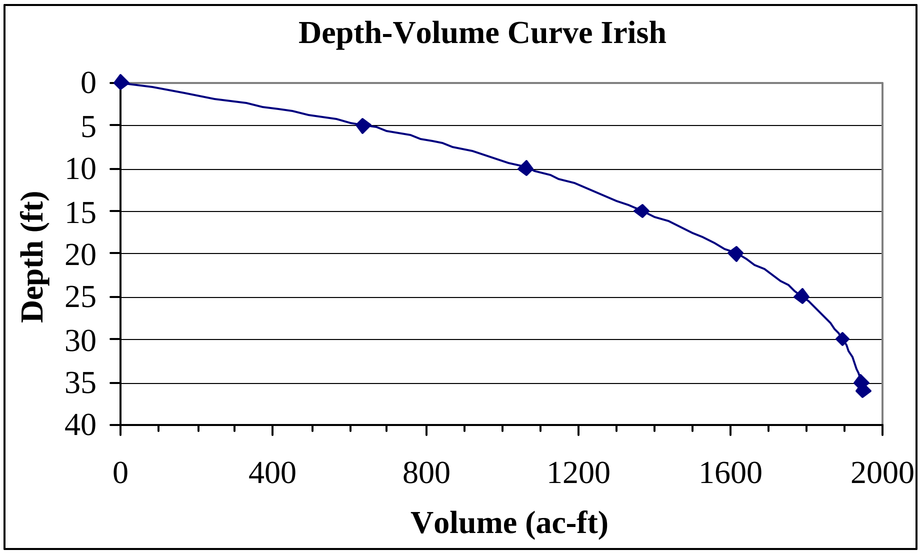


Figure 39. Depth-volume curve for Irish Lake.

Historical Information

A summary of selected historic water quality parameters (including this study) for Irish Lake is given in Table 23. There was a general trend for increasing transparency over time (Figure 40). Concentrations of total phosphorus (TP) have varied somewhat over time (Table 23). Concentrations of TP in both the epilimnion and hypolimnion are moderate, and there is no evidence of long-term phosphorus release from the sediments.

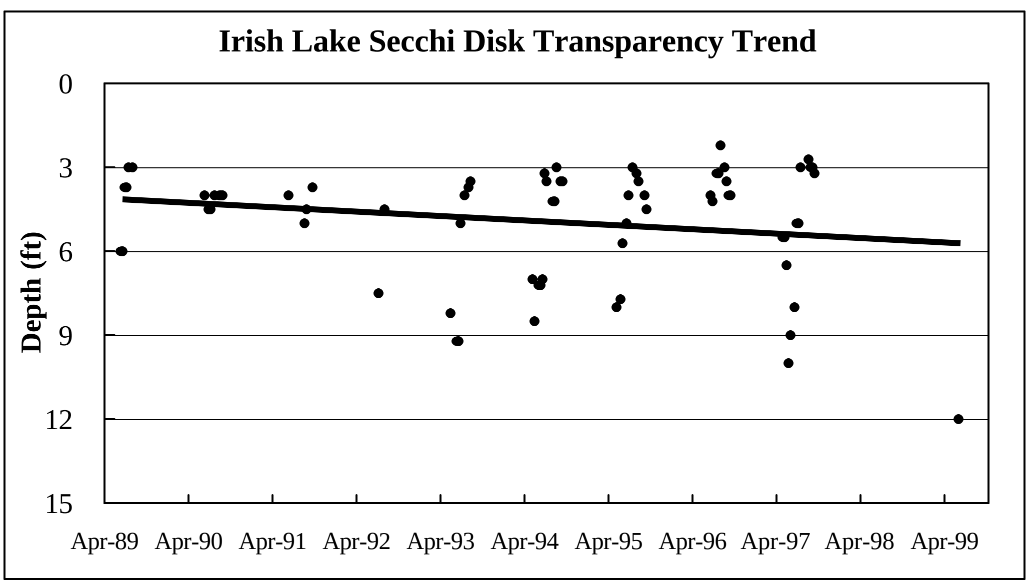


Figure 40. Secchi disk transparency trend for Irish Lake.

TABLE 23. Summary of Historic Data for Irish Lake.

DATE	pH	TP (epi) (mg/L)	TP (hypo) (mg/L)	Plankton Density (#/L)	TSI score (based on means)	Data Source
8/21/90	7.7	0.028	0.025	23350	34	CLP, 1990
8/9/94	7.9	0.051	0.145	50971	36	CLP, 1994
7/9/98	8.0	0.022	0.031	10920	28	CLP, 1998
8/11/99	7.2	0.055	0.109	2513	33	Present Study

Historic dissolved oxygen profiles (Figure 41) show the lake well mixed down to about 3 meters (10 feet) during summer stratification. Anoxia in the hypolimnion develops by July during each summer of record but this is not evident in June samples. This suggests that BOD is an increasing problem in the lake.

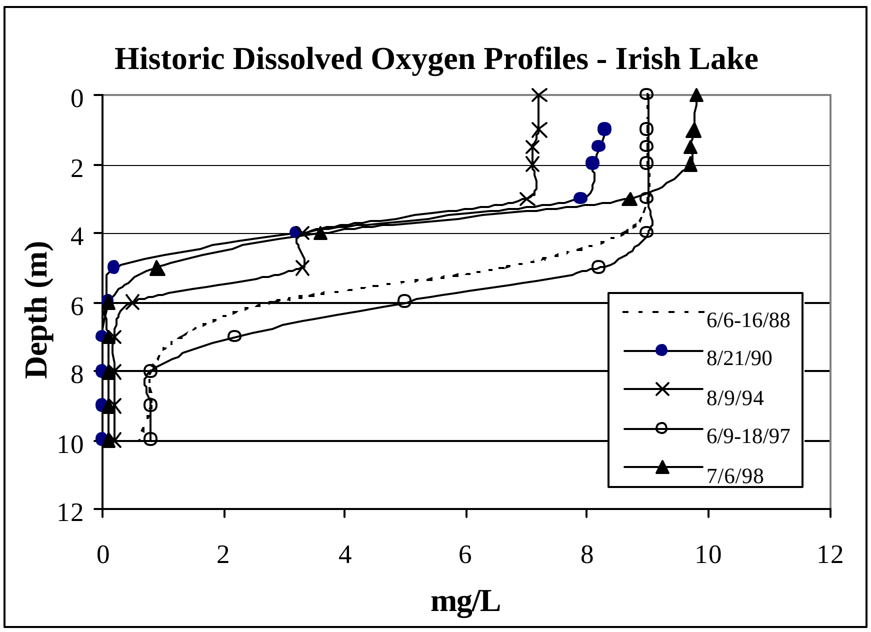


Figure 41. Historic dissolved oxygen profiles for Irish Lake. Sources: Clean Lakes Program (1990, 1994, 1998) and IDNR fisheries surveys (1988, 1997).

Results

Results from the Irish Lake water characteristics assessment are included in Table 24 and Figure 42.

TABLE 24. Water Quality Characteristics of Irish Lake, 8/11/99.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	7.3	7.15	-
Alkalinity	145 mg/L	199 mg/L	-
Conductivity	385 µmhos	363 µmhos	-
Secchi Disk Transp.	3.9 feet	-	6
Total Suspended Solids	5.2 mg/L	1.58 mg/L	-
Light Transmission @ 3 ft	30%	-	4
1% Light Level	13 feet	-	-
Total Phosphorus	0.055 mg/L	0.109 mg/L	3
Soluble Reactive Phos.	0.02 mg/L	0.087 mg/L	2
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	1.671 mg/L	3
Organic Nitrogen	0.667 mg/L	0.548 mg/L	2
Oxygen Saturation @ 5 ft.	109%	-	0
% Water Column Oxic	45%	-	3
Plankton Density	2513 per L	-	0
Blue-Green Dominance	Yes	-	10
		TSI score	33

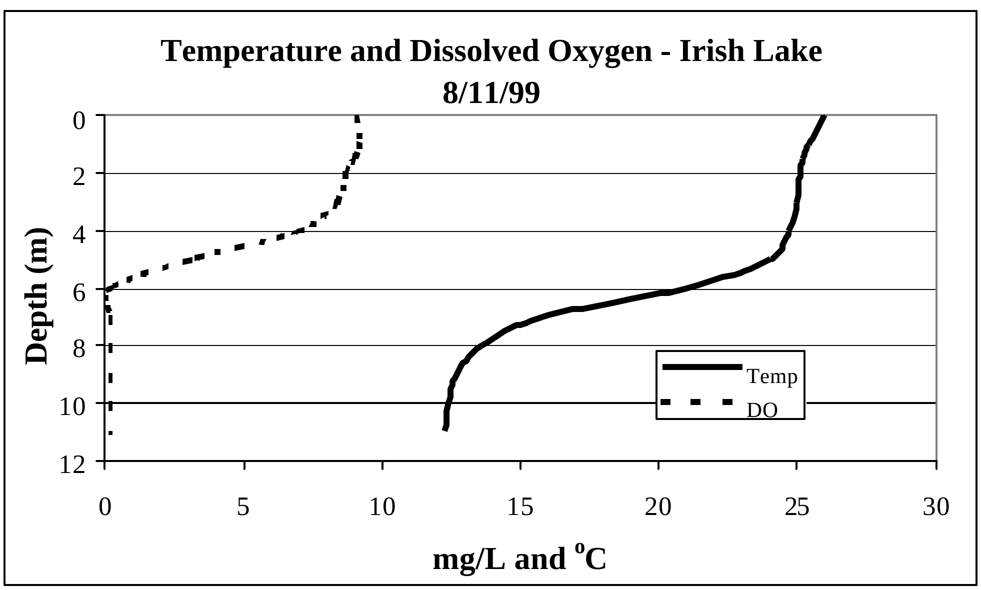


Figure 42. Temperature and dissolved oxygen profile for Irish Lake on 8/11/99.

Temperature and oxygen profiles for Irish Lake show that the lake was largely stratified at the time of sampling (Figure 42). The lake reached anoxic conditions at the depth of 6 meters (20 feet). This depth is still within the metalimnion. This indicates that decomposition processes in the hypolimnion and metalimnion are serious enough to deplete oxygen in the water.

Water quality data for Irish Lake are presented in Table 24. The 1% light level extended to a depth of 13 feet (4 meters). Based on the depth-volume curve in Figure 39, approximately 65% of the water volume in the lake has sufficient light to support algae.

Phosphorus levels are relatively high for an Indiana lake. There is moderate release of soluble phosphorus in the hypolimnion as concentrations are four times those of the epilimnion. Ammonium concentrations are significantly higher in the hypolimnion. Since ammonium is a by-product of bacterial decomposition this, and the anoxia, suggest that BOD levels may be a problem. Values of pH are within the normal range for Indiana lakes. The high alkalinity concentrations indicate that Irish Lake is a well-buffered system.

Plankton genera found in Irish Lake during the sampling are shown in Table 25. Overall plankton densities were very low. However, blue-green algae, the group most often associated with nuisance blooms, was the dominant group. Blue-greens accounted for 50% of all plankton found.

TABLE 25. Plankton Species Composition in Irish Lake on 8/11/99

SPECIES	ABUNDANCE (#/L)
Blue-Green Algae (Cyanophyta)	
Anabaena	24
Spirulina	24
Lyngbya	98
Coelosphaerium	195
Merismopedia	73
Microcystis	537
Oscillatoria	366
Green Algae (Chlorophyta)	
Pediastrum	171
Staurastrum	49
Ulothrix	220
Diatoms (Bacillariophyceae)	
Fragilaria	24
Synedra	342
Other Algae	
Ceratium	147
Dinobryon	24
Zooplankton	
Miscellaneous Protists	171
Calanoid Copepod	3.9
Cyclopoid Copepod	1.1
Daphnia	7.8
Nauplii	8.9
Leptodora	0.6
Asplanchna	49
Keratella	98

Sawmill Lake

Morphometry

Sawmill Lake is the second smallest lake in the Barbee chain at 36 surface acres (15 ha). The lake's maximum depth is 27 feet (8 meters), and it has a volume of 308 acre-feet (3.8×10^5 m^3). Irish Lake has a shoreline development value (DL) of 1.94. Because this lake is the outlet for the chain, it has the largest watershed within the chain.

Using a bathymetric map (Figure 22) prepared by the IDNR Division of Water in 1965 (IDNR, 1965b), depth-area and depth-volume curves were prepared for Sawmill Lake (Figures 43 and 44). Figure 43 shows that Sawmill Lake has extensive shallows – 44% of the lake is less than 10 feet (3 meters) deep. Figure 44 shows that volume increases uniformly throughout the entire depth.

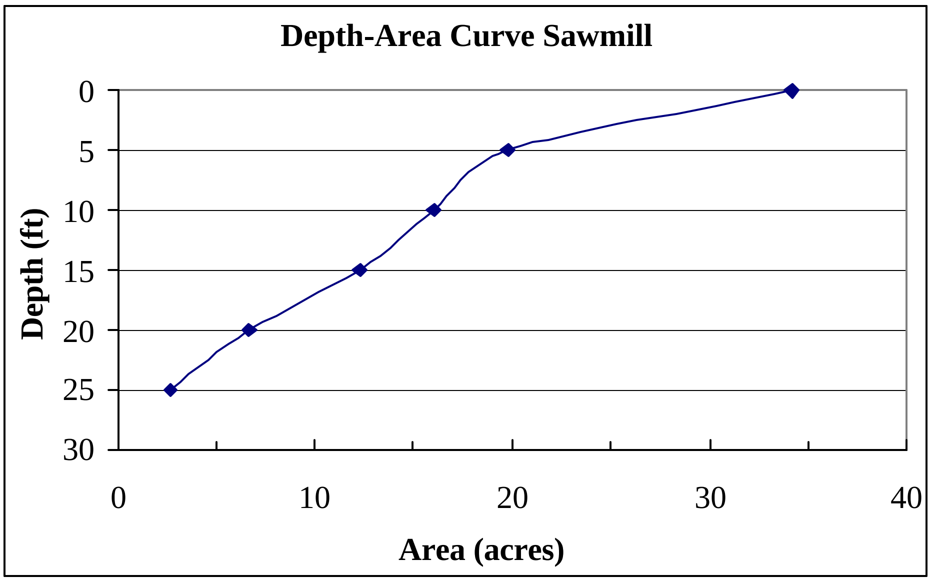


Figure 43. Depth-area curve for Sawmill Lake.

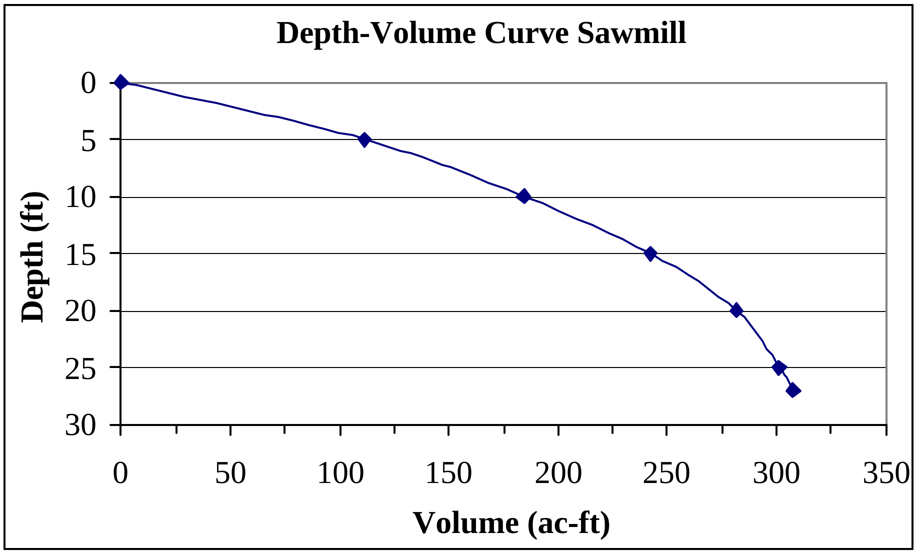


Figure 44. Depth-volume curve for Sawmill Lake.

Historical Information

A summary of selected historic water quality parameters (including this study) for Sawmill Lake is given in Table 26. There was a general trend toward increasing transparency over time (Figure 45). Concentrations of TP in the hypolimnion are relatively high and indicate significant phosphorus release from the sediments.

Historic dissolved oxygen profiles (Figure 46) show the lake well mixed down to only 2 meters (6.5 feet) during summer stratification. This is not unexpected because of the large amount of water flowing through the lake. There was a large metalimnetic oxygen maximum in 1988 but none were apparent during the other sampling dates. Anoxia in the hypolimnion develops below 5 meters (16.4 feet) by July during each summer of record but this is not evident in June samples. Again, BOD in the sediments is the likely cause of this.

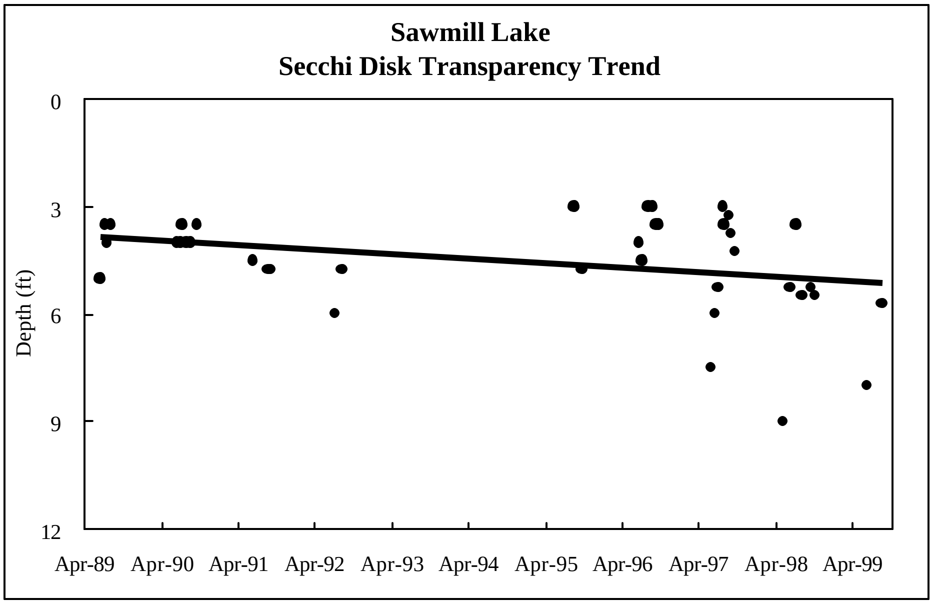


Figure 45. Secchi disk transparency trend of Sawmill Lake.

TABLE 26. Summary of Historic Date for Sawmill Lake.

DATE	pH	TP (epi) (mg/L)	TP (hypo) (mg/L)	Plankton Density (#/L)	TSI score (based on means)	Data Source
8/21/90	7.45	0.047	0.159	27809	40	CLP, 1990
8/9/94	7.8	0.047	0.336	18906	25	CLP, 1994
7/9/98	7.95	0.06	0.17	14316	28	CLP, 1998
8/11/99	7	0.058	0.369	2646	19	Present Study

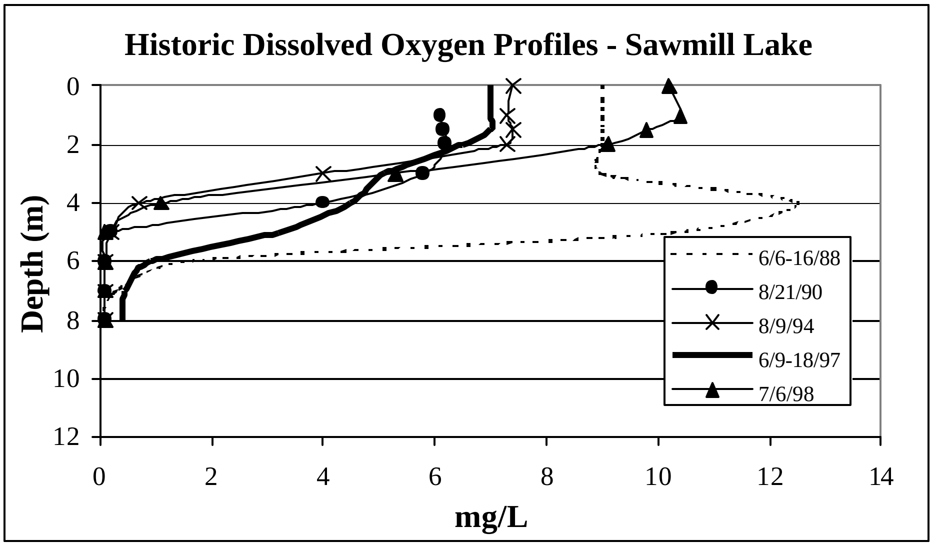


Figure 46. Historic dissolved oxygen profiles for Sawmill Lake. Sources: Clean Lakes Program (1990, 1994, 1998) and IDNR fisheries surveys (1988, 1997).

Results

Results from the Sawmill Lake water characteristics assessment are included in Table 27 and Figure 47.

TABLE 27. Water Quality Characteristics of Sawmill Lake, 8/11/99.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	7.2	6.8	-
Alkalinity	148 mg/L	206 mg/L	-
Conductivity	396 µmhos	394 µmhos	-
Secchi Disk Transp.	5.2 feet	-	0
Total Suspended Solids	4.24 mg/L	11.79 mg/L	-
Light Transmission @ 3 ft	30%	-	4
1% Light Level	13 feet	-	-
Total Phosphorus	0.058 mg/L	0.369 mg/L	4
Soluble Reactive Phos.	0.025 mg/L	0.294 mg/L	3
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	1.888 mg/L	3
Organic Nitrogen	0.849 mg/L	1.255 mg/L	3
Oxygen Saturation @ 5 ft.	110%	-	0
% Water Column Oxic	57%	-	2
Chlorophyll a	8.89 µg/L	-	-
Plankton Density	2646 per L	-	0
Blue-Green Dominance	No	-	0
		TSI score	19

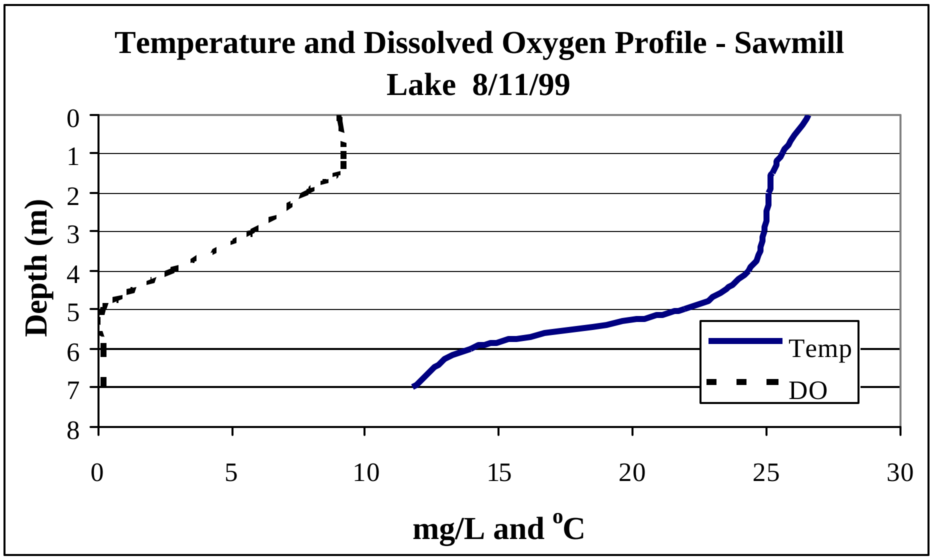


Figure 47. Temperature and dissolved oxygen profiles for Sawmill Lake on 8/11/99.

Temperature and oxygen profiles for Sawmill Lake show that the lake was stratified at the time of sampling (Figure 47). The lake reached anoxic conditions at the depth of 5 meters (16.4 feet). This depth is still within the metalimnion. This indicates that decomposition processes in the hypolimnion and metalimnion are serious enough to deplete oxygen in the water.

Water quality data for Sawmill Lake are presented in Table 27. The 1% light level extended to a depth of 13 feet (4 meters). Based on the depth-volume curve in Figure 44, approximately 73% of the water volume in the lake has sufficient light to support algae.

Phosphorus levels are relatively high for an Indiana lake, especially in the hypolimnion. There is significant release of soluble phosphorus in the hypolimnion as concentrations are ten times those of the epilimnion. Ammonium concentrations are 100 times higher in the hypolimnion than in the epilimnion. Since ammonium is a by-product of bacterial decomposition this, and the anoxia, suggest that BOD levels may be a problem. Values of pH are within the normal range for Indiana lakes although the hypolimnion pH is slightly acidic, further evidence of the intense respiration. The high alkalinity concentrations indicate that Sawmill Lake is a well-buffered system.

Blue-green algae were abundant in Sawmill Lake (Table 28) but they accounted for 47% of the total plankton. A blue-green, *Oscillatoria*, was the most abundant genera present.

TABLE 28. Plankton Species Composition in Sawmill Lake on 8/11/99.

SPECIES	ABUNDANCE (#/L)
Blue-Green Algae (Cyanophyta)	
Anabaena	321
Lyngbya	77
Oscillatoria	643
Microcystis	77
Coelospharium	51
Aphanizomenon	103
Spirulina	13
Green Algae (Chlorophyta)	
Pediastrum	77
Ulothrix	270
Staurastrum	39
Diatoms (Bacillariophyceae)	
Synedra	296
Fragillaria	64
Tabellaria	13
Other Algae	
Ceratium	373
Dinobryon	39
Zooplankton	
Cyclopoid Copepod	4.1
Nauplii	13.2
Leptodora	2.0
Calanoid Copepod	6.1
Daphnia	9.7
Keratella	26
Miscellaneous Protists	141
Other Rotifers	51

Inlet Streams – Results and Discussion

Base flow

Base flow stream sampling results are given in Table 29. (Please refer to Figure 10 for sampling site locations.) Base flow sampling included measurements of common chemical and physical characteristics as well as nutrient and suspended sediment levels (Table 30). This provides an understanding of typical conditions in the Barbee Lakes inlet streams. Storm water sampling focused on nutrient and sediment input to understand influences of the watershed during runoff events.

There are two useful ways to report water quality data in flowing water. *Concentrations* describe the mass of a particular material contained in a unit of water, for example milligrams of phosphorus per liter (mg/L). *Mass loading* on the other hand describes the mass of a particular material being carried in the stream per unit of time. For example, a high concentration of phosphorus in a stream with very little flow can deliver a smaller total amount of phosphorus to the lake than will a stream with a low concentration of phosphorus but a high flow of water. It is the total amount (mass) of phosphorus, solids and bacteria actually delivered to the lake that are most important when considering the effects of these materials on a lake. Because there was so little water flowing in the streams at the time of base flow sampling, discharge was not measured. Thus, only concentrations are reported for the base flow sampling.

TABLE 29. Nutrient and Sediment Concentration Data from Barbee Inlet Streams

Site	Date	Flow (cfs)	Timing	TN (mg/l)	NH_3 (mg/l)	NO_3^- (mg/l)	TP (mg/l)	OP (mg/l)	TSS (mg/l)
1	08/11/99	*	Base	1.031	0.034	0.660	0.130	0.115	5.75
1	04/21/00	126.6	Storm	1.10	<0.05	2.30	<0.05	<0.05	20
3	08/11/99	*	Base	0.344	0.018	2.923	0.027	0.043	4.22
3	04/21/00	0.25	Storm	3.00	0.05	4.60	0.17	0.09	3
4	08/11/99	*	Base	0.681	0.043	0.325	0.065	0.046	2
4	04/21/00	**	Storm	1.10	<0.05	2.30	0.12	0.06	30
5	04/21/00	0.55	Storm	3.10	0.12	6.00	0.07	0.06	2
6	08/11/99	*	Base	0.554	0.018	0.094	0.041	0.034	1.8
6	04/21/00	0.77	Storm	1.80	<0.05	1.80	0.08	0.08	15
7	08/11/99	*	Base	0.605	0.018	0.937	0.092	0.076	4
7	04/21/00	3.6	Storm	1.10	0.27	<0.10	0.27	0.12	68
8	08/11/99	*	Base	0.660	0.018	0.022	0.031	0.031	5
8	04/21/00	15.4	Storm	0.52	<0.05	<0.10	<0.05	<0.05	1

* Flows too low flow measure due to drought.

** Flow too high to measure.

TABLE 30. Physical and Chemical Characteristics of Barbee Inlet Streams at Base Flow

Site	Date	Timing	pH	Alkalinity (mg/L)	Conductivity (μmhos)	Temperature (°C)	Dissolved O_2 (mg/L)
1	08/11/99	Base	8.4	238	411	26.7	7.3
3	08/11/99	Base	8.1	283	575	16.8	8.9
4	08/11/99	Base	7.7	230	465	18.6	6.1
6	08/11/99	Base	8.2	231	400	26.2	7.0
7	08/11/99	Base	8.3	243	365	22.1	8.1
8	08/11/99	Base	8.4	146	403	21.8	10.0

During base flow conditions, temperatures in the streams vary from 16.8 °C to 26.7 °C. Those streams with cooler temperatures likely have a greater proportion of groundwater flowing in them. The high temperature for Grassy Creek likely reflects the lack of riparian shading along the creek. Stream temperatures are generally cooler than lake temperatures due to the groundwater influence and because there is less solar warming of shaded stream water.

Dissolved oxygen (D.O.) concentrations vary from 6.1 ppm to 10.0 ppm. Because D.O. varies with temperature (cold water can contain more oxygen than warm water), it is more relevant to consider D.O. saturation values. This refers to the amount of oxygen dissolved in water compared to the maximum possible when the water is saturated with oxygen. The saturation value of water at 20 °C is 9.1 ppm. Stream dissolved oxygen concentrations that are less than this value suggest that: a) decomposition processes within the streams consume oxygen more quickly than it can be replaced by diffusion from the atmosphere, and b) flow in the streams is not turbulent enough to entrain sufficient atmospheric oxygen. Results from this sampling indicate that oxygen was sufficient in the inlet streams despite the low flows.

Alkalinity is lowest in the streams during storm events because during periods of high runoff, the alkalinity is diluted by rainwater and the runoff water moves across carbonate-containing bedrock materials so quickly that little carbonate is dissolved to add additional alkalinity. During low discharges, alkalinity is usually high because it picks up carbonates from the bedrock. This accounts for the high alkalinity measurements recorded during low flow in Barbee Lakes inlet streams.

Total phosphorus concentrations were high at Sites 1 and 7. Nitrate-nitrogen was very high at Site 3. These streams could be important sources of these nutrients to the lakes. Total suspended solids (TSS) were expectedly low due to the low flow.

Storm flow

Storm flow stream sampling results are given in Table 31. For laboratory data sheets, see Appendix 7.

TABLE 31. Nutrient and Sediment Loading Data from Barbee Inlet Streams - Storm Event

Site	Date	Flow (cfs)	Timing	TN Load (mg/s)	NH_3 Load (mg/s)	NO_3^- Load (mg/s)	TP Load (mg/s)	OP Load (mg/s)	TSS Load (mg/s)
1	04/21/00	126.6	Storm	3941.06	-	8240.39	-	-	71655.60
3	04/21/00	0.25	Storm	21.22	0.35	32.55	1.20	0.64	21.23
4	04/21/00	*	Storm	-	-	-	-	-	-
5	04/21/00	0.55	Storm	48.25	1.87	93.39	1.09	0.93	31.13
6	04/21/00	0.77	Storm	39.22	-	39.22	1.66	1.63	326.87
7	04/21/00	3.6	Storm	112.07	27.51	-	27.51	12.22	6927.84
8	04/21/00	15.4	Storm	226.63	-	-	-	-	435.82

* Flow too high to measure.

The collection of discharge during the storm event allows for relative comparison between the inlet streams. Grassy Creek (Site 1) delivered the greatest amount of total nitrogen, nitrate-nitrogen and total suspended solids to the lakes. This result is not surprising given the fact that Grassy has the largest drainage area of the three inlets, providing the greatest potential for runoff. Grassy Creek also has the potential to deliver the greatest amount of the remaining nutrient parameters. Results for ammonia-nitrogen, total phosphorus and ortho-phosphorus were below detection levels. Despite this, even a very low concentration (one below the detect level) of these nutrients combined with the discharge of Grassy Creek would result in the delivery of more pollutant mass than in other inlets.

Putney Ditch (Site 7) delivered the high amounts of total phosphorus, ortho-phosphorus, and total suspended solids. Two unnamed tributaries of Kuhn Lake (Sites 3 and 5) recorded high loadings amounts for nitrate-nitrogen. In addition, for its size, Site 6 delivered a relatively large amount of total suspended solids to Kuhn Lake.

To assist in prioritizing management efforts, sediment and nutrient loads were divided by the acreage of each inlet's watershed (Table 32). Figure 48 illustrates the Barbee chain's subwatersheds. Site 8 was not included in the analysis as it represents the lakes' outlet. Site 4 was omitted since no discharge data and consequently no loading data was collected at that site. Site 3 was omitted because its watershed consists largely of the homes immediately adjacent. Residents of these homes should perform regular maintenance of their septic systems, however, no other larger scale projects could be proposed in this area.

As shown in Table 32, Grassy Creek delivered most TN and TSS per acre of watershed. Putney Ditch delivered most TP and second greatest amount of Site 6 delivered second greatest amount of TN and TP. Low delivery rates per acre of watershed from Site 5 were not surprising in light

BARBEE LAKES WATERSHED

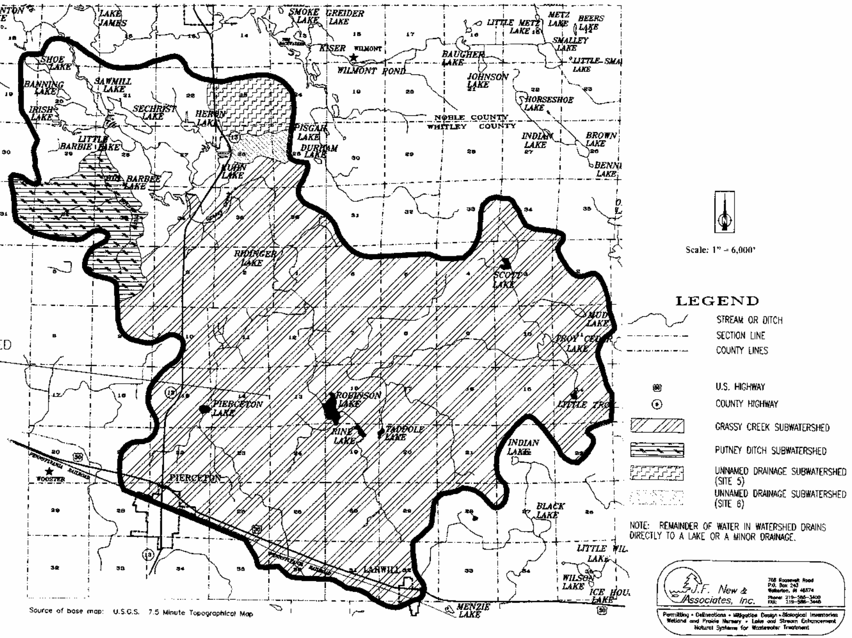


Figure 49: Barbee Lakes Subwatersheds
Barbee Lakes Diagnostic Study
Kosciusko County, Indiana

J.F. New and Associates, Inc.
JFNA #98-03-27

TABLE 32. Nutrient and Sediment Load in Inlet Streams Per Acre of Watershed

Site	TN Load (mg/s-ac)	TP Load (mg/s-ac)	TSS Load (mg/s-ac)
1	0.18	-	3.2
5	0.07	0.002	0.04
6	0.11	0.005	0.9
7	0.04	0.01	2.5

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, the Barbee Chain results 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 33 below. 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; 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.

The units in the table are either milligrams per liter (mg/L) or micrograms per liter (µg/L). One mg/L is equivalent to one part per million (PPM) while one microgram per liter is equivalent to one part per billion (PPB). 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 33. 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 or PPM)	0.008	0.027	0.084	>0.750
Total Nitrogen (mg/L or PPM)	0.661	0.753	1.875	-
Chlorophyll *a* (µg/L or PPB)	1.7	4.7	14.3	-

Table 34 shows historic mean total phosphorus concentrations for the Barbee Chain of Lakes. In general, total phosphorus concentrations in 1999 were higher than in previous years. This is the opposite trend needed for improving lake conditions. When the 1999 values are compared to Vollenweider's guidelines above, Kuhn, Banning and Irish lakes are below the mean value for eutrophic lakes. Of these, only Kuhn could be considered mesotrophic based on phosphorus alone. The remaining lakes all have mean total phosphorus concentrations greater than the mean for eutrophic lakes in Vollenweider's data.

TABLE 34. The Barbee Chain of Lakes: Total Mean Phosphorus Concentrations from 1990-1999 (mg/L)

	1990	1994	1998	1999
Banning Lake	0.040	0.019	0.063	0.063
Big Barbee Lake	0.060	0.272	0.232	0.421
Irish Lake	0.030	0.073	0.027	0.082
Kuhn Lake	0.020	0.016	0.040	0.033
Little Barbee	0.280	0.373	0.148	0.334
Sawmill Lake	0.100	0.168	0.115	0.214
Sechrist Lake	0.070	0.056	0.044	0.094

Source: Indiana Department of Environmental Management. "Clean Lakes Program." 1990-1998.

Comparison With Other Indiana Lakes

The Barbee Lakes results can also be compared to other Indiana lakes. Table 35 presents data from 355 Indiana lakes collected during July and August 1994-98 under the Indiana Clean Lakes Program. The set of data summarized in the table represent mean values of epilimnetic and hypolimnetic samples for each of the 355 lakes. Again, it should be noted that a wide variety of conditions, including geography, morphometry, time of year, and watershed characteristics, could influence the water quality of lakes. Thus, it is difficult to predict or even explain the reasons for the water quality of a given lake.

TABLE 35. Water Quality Characteristics of 355 Indiana Lakes Sampled From 1994 thru 1998 by the Indiana Clean Lakes Program. Means of epilimnion and hypolimnion samples were used.

	Secchi Disk (m)	NO_3 (mg/L)	NH_4 (mg/L)	Total Phos (mg/L)	SRP (mg/L)
Median	1.8	0.025	0.472	0.097	0.033
Maximum	9.2	9.303	11.248	4.894	0.782
Minimum	0.1	0.022	0.018	0.001	0.001

Table 36 compares the mean of selected water quality parameters for the Barbee Chain of lakes to the median value for all Indiana lakes. Kuhn is better in all parameters. Banning is better in all but the Secchi disk transparency. Sechrist is better in three parameters. The other lakes have generally higher values for the water quality parameters when compared to all Indiana lakes. Little Barbee is worse in all parameters.

TABLE 36. Comparison of Barbee Lakes Chain to Median For All Indiana Lakes For Selected Water Parameters.

Lake	Secchi Disk	NO_3	NH_4	Total P	SRP
Big Barbee	worse	better	better	worse	worse
Kuhn	better	better	better	better	better
Little Barbee	worse	worse	worse	worse	worse
Irish	worse	better	worse	better	worse
Sechrist	better	better	worse	better	worse
Banning	worse	better	better	better	better
Sawmill	worse	better	worse	worse	worse

Using a Trophic State Index

In addition to simple comparisons to 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, numerical index. Different index (or eutrophy) points are assigned for various water quality concentrations. The index total, or TSI, is the sum of individual eutrophy points for a lake.

The Indiana TSI

The Indiana TSI (IDEM, 1986) ranges from 0 to 75 total points. The TSI totals are grouped into the following three lake quality classifications:

TSI Total	Water Quality Classification
0-25	highest quality (oligotrophic)
26-50	intermediate quality (mesotrophic)
51-75	lowest quality (eutrophic)

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 score that do not necessarily indicate a long-term change in lake condition. Parameters and values used to calculate the Indiana TSI are given in Table 37.

TABLE 37. The Indiana Trophic State Index

Parameter and Range			Eutrophy Points
I.	Total Phosphorus (ppm)		
	A.	At least 0.03	1
	B.	0.04 to 0.05	2
	C.	0.06 to 0.19	3
	D.	0.2 to 0.99	4
	E.	1.0 or more	5
II.	Soluble Phosphorus (ppm)		
	A.	At least 0.03	1
	B.	0.04 to 0.05	2
	C.	0.06 to 0.19	3
	D.	0.2 to 0.99	4
	E.	1.0 or more	5
III.	Organic Nitrogen (ppm)		
	A.	At least 0.5	1
	B.	0.6 to 0.8	2
	C.	0.9 to 1.9	3
	D.	2.0 or more	4

IV. Nitrate (ppm)

A.	At least 0.3	1
B.	0.4 to 0.8	2
C.	0.9 to 1.9	3
D.	2.0 or more	4

V. Ammonia (ppm)

A.	At least 0.3	1
B.	0.4 to 0.5	2
C.	0.6 to 0.9	3
D.	1.0 or more	4

VI. Dissolved Oxygen:
Percent Saturation at 5 feet from surface

A.	114% or less	0
B.	115% 50 119%	1
C.	120% to 129%	2
D.	130% to 149%	3
E.	150% or more	4

VII. Dissolved Oxygen:
Percent of measured water column with at least 0.1 ppm dissolved oxygen

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

VIII. Light Penetration (Secchi Disk)

A.	Five feet or under	6

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

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

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

A.	less than 3,000 organisms/L	0
B.	3,000 - 6,000 organisms/L	1

C.	6,001 - 16,000 organisms/L	2
D.	16,001 - 26,000 organisms/L	3
E.	26,001 - 36,000 organisms/L	4
F.	36,001 - 60,000 organisms/L	5
G.	60,001 - 95,000 organisms/L	10
H.	95,001 - 150,000 organisms/L	15
I.	150,001 - 5000,000 organisms/L	20
J.	greater than 500,000 organisms/L	25
K.	Blue-Green Dominance: additional points	10

The Indiana Trophic State Index values calculated for the Barbee Chain lakes over the years are shown in Table 38. While there is much variability in the year-to-year TSI values, there is a general trend for decreasing TSIs (improved conditions). Caution must be used with the 1999 scores as we often see "improved" lake conditions during drought years. The lower scores for 1999 may be more related to the drought than to improving lake conditions. Nonetheless, the overall trend of lower TSI values is encouraging.

TABLE 38. The Barbee Chain of Lakes: Indiana Trophic Index 1990, 1994, 1998, and 1999.

	1990	1994	1998	1999
Banning Lake	11	22	27	12
Big Barbee Lake	36	39	35	20
Irish Lake	34	36	28	33
Kuhn Lake	24	29	15	6
Little Barbee	40	38	37	38
Sawmill Lake	40	25	28	19
Sechrist Lake	27	29	21	17

Source: Indiana Department of Environmental Management. "Clean Lakes Program." 1990-1998.

The Indiana TSI has not been statistically validated. It tends to rely heavily on algae and does not weigh poor transparency or nutrients high enough in the total score. The Indiana TSI's reliance on algae may be of particular concern this year. Algae densities for all lakes in Indiana were depressed this year (Bill Jones, Director of the Indiana Clean Lakes Program, personal communication). The drought may be responsible for decrease in regular inputs of inorganic nutrients from runoff. In addition, lower inlet flows may have reduced turbulent mixing, including settling of plankton. For these reasons, the algal densities may be low in 1999. This will in turn skew results of the Indiana TSI.

The Carlson TSI

The Carlson TSI may be more appropriate to use in evaluating Indiana lake data. 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 49).

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 summer time Secchi disk depth of 1 meter (3.3 feet) would have a TSI of 60 points (located in line with the 1 meter (3.3 feet)). This lake would be in the mesotrophic category. Because the index was constructed using relationships among transparency, chlorophyll, 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 and 43 µg/L total phosphorus.

Not all lakes have the same relationship between transparency, chlorophyll 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 concentrations lower than might be otherwise expected from the total phosphorus or chlorophyll concentrations. 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.

CARLSON'S TROPHIC STATE INDEX

	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Trophic State Index	20 25 30 35	40 45 50	55 60	65 70 75 80

Transparency (Meters)	15 10 8 7 6 5 4 3 2 1.5 1 0.5 0.3
Chlorophyll-*a* (μg/L or PPB)	0.5 1 2 3 4 5 7 10 15 20 30 40 60 80 100 150
Total Phosphorus (μg/L or PPB)	3 5 7 10 15 20 25 30 40 50 60 80 100 150

Figure 49. Carlson's Trophic State Index.

When compared to Carlson's TSI, the mean total phosphorus concentrations for the Barbee Chain of Lakes in 1999 (Figure 49 above) were all in the hypereutrophic range (highest level of productivity – TSI > 65) except for Kuhn which was eutrophic.

Summary

All the lakes of the Barbee Chain have more phosphorus than is ideal. The potential exists for excessive algae production, and this occurs periodically in the lakes. There is evidence of historic excessive biological production in the sediments of the lakes (Table 40). For example, there is considerably more soluble phosphorus in the hypolimnia (bottom waters) of Sawmill, Big Barbee and Little Barbee lakes – 11 to 20 times that of the epilimnia. This is strong evidence that phosphorus is being liberated from the sediments when oxygen is depleted. This *internal loading* of phosphorus is another source of phosphorus to these lakes that can promote excessive algae production. Sechrist and Irish lakes have some phosphorus release while there is no evidence of phosphorus release from the sediments of Kuhn or Banning lakes.

These same lakes (Sawmill, Big and Little Barbee) and Irish also have relatively high ammonia-nitrogen concentrations in their hypolimnetic waters (Table 40). Ammonium is a by-product of bacterial decomposition. When ammonium occurs in high concentrations, it is evidence of high biochemical oxygen demand (BOD). This BOD comes from organic wastes (dead algae, rooted plants) on the sediments – further evidence of excess algae and plant growth in these lakes.

A review of historical algae densities in the lakes further supports the hypothesis that historical organic wastes may be greater in some lakes (Big and Little Barbee, Sawmill) compared to other lakes in the chain (Banning, Kuhn). Table 39 presents a ranking by year of plankton densities in the lakes. A score of 1 indicates the lake that had the greatest density of plankton relative to other lakes in the chain. A score of 7 means the lake had the lowest density of plankton compared to other lakes in the chain for that year. Big and Little Barbee consistently had greater densities of plankton, while Kuhn and Banning consistently possessed the lowest densities of plankton. Plankton in the water column eventually die and sinks to the bottom to decompose. Greater algae densities likely will lead to greater organic waste accumulation on the bottom sediments and, therefore, increased BOD.

TABLE 39. Ranking of Plankton Densities by Year

Lake	1990	1994	1998	1999
Big Barbee	4	3	2	2
Little Barbee	2	4	4	1
Irish	3	1	6	5
Sawmill	1	5	3	4
Sechrist	6	2	1	3
Banning	7	7	5	6
Kuhn	5	6	7	7

On the positive side, all of the Barbee Chain of Lakes have improving Secchi disk transparencies over the past ten years or so. This means that less particles (algae and suspended sediments) are in the water now than in the past. This is certainly the right direction to be heading.

TABLE 40. Summary data for the Barbee Chain.

Lake	Secchi Disk Transparency Trend	Sediment Phos. Release Factor[1]	Hypolimnetic Ammonia Conc. (mg/L)	Carlson's Total Phosphorous TSI
Barbee	increasing	15.1	1.97	>80
Kuhn	increasing	1.1	0.11	56
Little Barbee	increasing	20.2	2.00	>80
Irish	increasing	4.4	1.67	70
Banning	increasing	1.0	0.15	66
Sechrist	increasing	3.4	0.96	72
Sawmill	increasing	11.8	1.89	>80

[1]Hypo SRP concentration/Epi SRP concentration. For example, Little Barbee's hypolimnetic SRP concentration is 20 times that in the epilimnion. This difference is strong evidence of substantial internal loading of phosphorus.

Water Budget

Water budgets are useful for lakes because they help identify significant water sources that may be important in the management plan. For example, one inlet stream may contribute more water and nutrients than another, and this could help direct management efforts. The total amount of water flowing into and out of a lake is used to determine the *hydraulic residence time* and the *hydraulic flushing rate*. The hydraulic residence time is the average time that a given unit of water resides in the lake. The hydraulic flushing rate is the reverse – the number of times the complete volume of water in the lake is exchanged per year. The rate at which water flows through a lake affects turbulence and settling rates of sediments and nutrients. It also helps determine whether the lake's water quality is influenced more by water flowing into the lake or by water already in the lake.

Water enters the Barbee Chain of lakes from the following sources:

- direct precipitation to the lake
- channelized flow from:
- Grassy Creek, which drains into Big Barbee,
- several unnamed streams draining into Kuhn Lake, and
- Putney Ditch, which drains into Little Barbee
- sheet runoff from land immediately adjacent to the lake
- groundwater

Water leaves the chain from:

- discharge from the Grassy Creek outlet at Sawmill Lake
- evaporation
- groundwater

There are no discharge gages in the watershed to measure water inputs or outputs so we must estimate this from other records. Direct precipitation to the lake can be calculated from mean annual precipitation and the lake's surface area. Runoff from the lake's watershed can be 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 gaged watershed to the total amount of precipitation falling on that watershed. The nearest gaged watershed is a U.S.G.S. gaging station on the Tippecanoe River southeast of North Webster, Indiana (Stewart et al., 1999). The 11-year (1987– 1998) mean annual runoff for this watershed is 13.54 inches. With annual precipitation of 35.52 inches (Staley, 1989), this means that 38.1% of the rainfall falling on this watershed runs off on the land surface. No groundwater records exist for the lake so it was assumed for the purposes of this model that groundwater inputs equal outputs.

Calculating individual water budgets for each of the six Barbee Chain lakes is made even more difficult due to the inputs from 'upstream' lakes. For example, Kuhn discharges into Big Barbee.

The combined flow from both Kuhn and Big Barbee discharge into Little Barbee, and so forth. Within each lake, evaporation and groundwater inputs and discharge through the bottom sediments affect the total amount of water leaving each lake. As previously stated, for the purposes of this analysis, it was assumed that groundwater inputs and outputs balance each other out over the year. Evaporation losses were estimated by applying evaporation rate data to each lake. Evaporation rates are determined at six sites around Indiana by the National Oceanic and Atmospheric Administration (NOAA). The nearest site to the Barbee Chain is located in Valparaiso, Indiana. Annual evaporation from a 'standard pan' at the site averages 28.05 inches per year. Because evaporation from the standard pan overestimates evaporation from a lake by about 40% (Chow, 1964), the evaporation rate was corrected by this percentage, which yields an estimated evaporation rate from the lake surface of 16.83" per year. Multiplying this rate times the surface area of each lake in the Barbee Chain yields the volume of evaporative water loss from each lake.

Annual water budget estimates for the Barbee Chain are summarized in Figure 50. Table 41 shows the hydraulic residence times for each lake. They range from only 2.9 days for Sawmill Lake, a small-volume lake that the entire Barbee Chain watershed drains through, to 4.3 years for Sechrist Lake, a lake with a relatively large volume but small watershed.

The implications for these disparate residence times are quite revealing. Sawmill Lake has so much water flowing through it that it is totally dependent on conditions in the upstream lakes and watershed areas. Management of Sawmill Lake with in-lake techniques will have little effect due to this tremendous watershed influence. Sechrist Lake's watershed, on the other hand, has little effect on that lake's condition. The relatively large volume of that lake can dilute most pollutants that run off the land into the lake, providing that there is not a catastrophic event of some kind. More management implications of the water budget are discussed in the Management Section following.

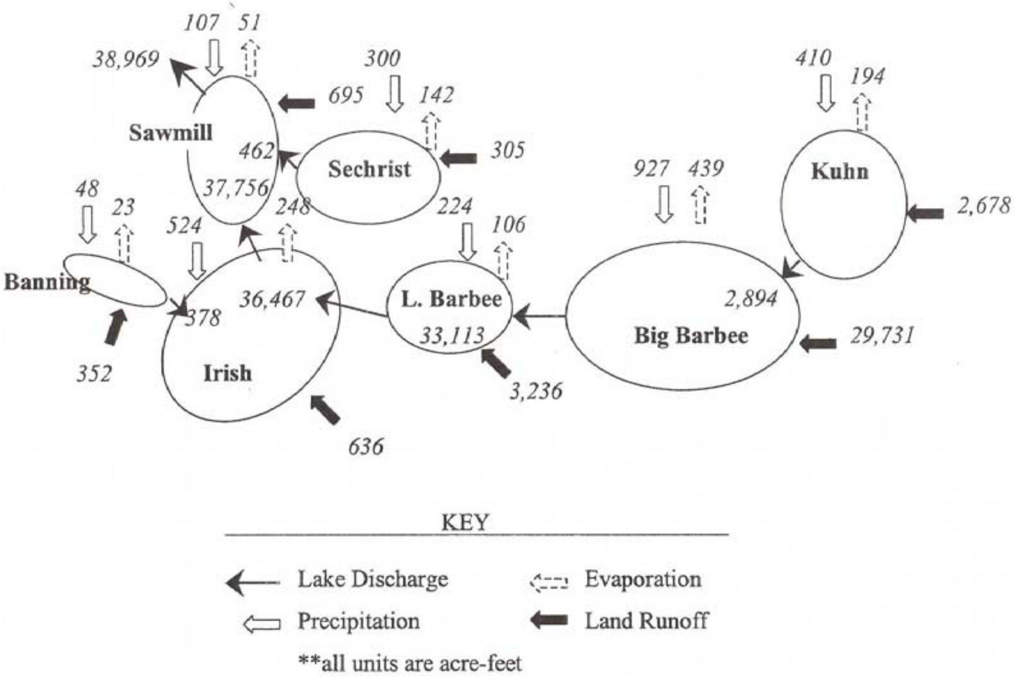


Figure 50. Water Budget Flow Chart for the Barbee Chain

TABLE 41. Hydraulic Residence Times of the Barbee Chain Lakes.

LAKE	VOLUME (V) (in acre-feet)	DISCHARGE (Q) (in acre-feet per year)	RESIDENCE TIME (V/Q) (in years/days)
Kuhn	1,076	2,894	0.37 yrs. (135days)
Big Barbee	4,749	33,113	0.14 (52)
Little Barbee	816	36,467	0.02 (8.2)
Irish	1,952	37,756	0.05 (18.9)
Banning	93	378	0.25 (89.8)
Sechrist	1,989	462	4.3 (1,571)
Sawmill	308	38,969	0.008 (2.9)

Phosphorus Budget

Since phosphorus is the primary nutrient regulating the growth of algae in lakes, it is helpful to develop a phosphorus budget for lakes. The limited scope of this LARE study did not allow for the determination phosphorus inputs and outputs outright. In addition, since one lake discharges into another, the fate of phosphorus cannot be well predicted as it moves through lakes. Therefore, only estimates of phosphorus export from various land uses draining directly into each lake are presented below.

Reckhow et al. (1980) compiled phosphorus loss rates from various land use activities as determined by a number of different studies and calculated phosphorus export coefficients for each land use in the watershed. Conservative estimates of these phosphorus export coefficient values, which are expressed as kilograms of phosphorus lost per hectare of land per year were utilized in this analysis. These estimates were multiplied by the amounts of land in each of the land use categories to derive an estimate of annual phosphorus export (as kg/year) for each land use per watershed (Table 42).

The results of this model are shown in the Table 43. Obviously, the largest amount of phosphorus exported from a watershed is from the largest watershed. For example, using this model approximately 5,258 kg (1.2×10^4 lb) of phosphorus per year is exported from Big Barbee's watershed and only 13 kg (28.7 lb) of phosphorus per year from the land draining directly into Sawmill Lake.

Of more use for comparison is evaluating the mean overall rate of phosphorus export from each watershed (Table 42). The highest mean rate of phosphorus export is from the Little Barbee Lake watershed. The model estimated that 0.543 kg (1.2 lb) of phosphorus is exported from each hectare of land in the watershed. Only 0.499 kg/ha-year (1.1 lb/ha-year) is estimated for the Irish Lake watershed. The higher **rate** of phosphorus loss from Little Barbee's watershed suggests that watershed improvements could be targeted in that watershed.

TABLE 42. Mean annual phosphorus export from land draining directly into each of the Barbee lakes.

Lake	P-export (kg/ha-yr)
Banning	0.498
Big Barbee	0.502
Irish	0.449
Kuhn	0.466
Little Barbee	0.543
Sawmill	0.495
Sechrist	0.451

TABLE 43. Phosphorus Modeling Results.

Banning Lake

Land Use (in watershed)	Area (ha)	--------	P-export Coefficient		Total	
Row Crop	80.0	hectare	0.6	kg/ha-yr	48.01	kg/yr
Pasture	1.4	hectare	0.4	kg/ha-yr	0.54	kg/yr
Forest	18.5	hectare	0.2	kg/ha-yr	3.71	kg/yr
Urban	0.0	hectare	0.5	kg/ha-yr	0.00	kg/yr
Shrubland	8.5	hectare	0.2	kg/ha-yr	1.69	kg/yr
Water	18.1					
Septic Systems	--------	--------	0.6	kg/ha-yr		
Total	108				53.95	kg/yr

Big Barbee Lake

Land Use (in watershed)	Area (ha)	--------	P-export Coefficient		Total	
Row Crop	7603.3	hectare	0.6	kg/ha-yr	4561.98	kg/yr
Pasture	450.4	hectare	0.4	kg/ha-yr	180.16	kg/yr
Forest	1923.2	hectare	0.2	kg/ha-yr	384.64	kg/yr
Urban	111.5	hectare	0.5	kg/ha-yr	55.75	kg/yr
Shrubland	381.7	hectare	0.2		76.34	kg/yr
Water	198.8					
Septic Systems	--------	--------	0.6	kg/ha-yr		
Total	10470				5258.87	kg/yr

Irish Lake

Land Use (in watershed)	**Area (ha)**	**--------**	**P-export Coefficient**		**Total**	
Row Crop	125.6	hectare	0.6	kg/ha-yr	75.36	kg/yr
Pasture	0.3	hectare	0.4	kg/ha-yr	0.12	kg/yr
Forest	43.7	hectare	0.2	kg/ha-yr	8.74	kg/yr
Urban	8.0	hectare	0.5	kg/ha-yr	4.00	kg/yr
Shrubland	33.8	hectare	0.2		6.76	kg/yr
Water	16.7					
Septic Systems	--------	--------	0.6	kg/ha-yr		
Total	211				94.98	kg/yr

Kuhn Lake

Land Use (in watershed)	**Area (ha)**	**--------**	**P-export Coefficient**		**Total**	
Row Crop	613.3	hectare	0.6	kg/ha-yr	368.0	kg/yr
Pasture	66.5	hectare	0.4	kg/ha-yr	26.6	kg/yr
Forest	200.4	hectare	0.2	kg/ha-yr	40.1	kg/yr
Urban	14.4	hectare	0.5	kg/ha-yr	7.2	kg/yr
Shrubland	92.7	hectare	0.2		18.5	kg/yr
Water	5.2					
Septic Systems	--------	--------	0.6	kg/ha-yr		
Total	987				460.4	kg/yr

Little Barbee Lake

Land Use (in watershed)	**Area (ha)**	**--------**	**P-export Coefficient**		**Total**	
Row Crop	861.7	hectare	0.6	kg/ha-yr	517.0	kg/yr
Pasture	30.8	hectare	0.4	kg/ha-yr	12.3	kg/yr
Forest	115.3	hectare	0.2	kg/ha-yr	23.1	kg/yr
Urban	11.1	hectare	0.5	kg/ha-yr	5.6	kg/yr
Shrubland	15.1	hectare	0.2		3.0	kg/yr
Water	127.3					
Septic Systems	--------	--------	0.6	kg/ha-yr		
Total	1034				561.0	kg/yr

Sawmill Lake

Land Use (in watershed)	**Area (ha)**	**--------**	**P-export Coefficient**		**Total**	
Row Crop	16.1	hectare	0.6	kg/ha-yr	9.7	kg/yr
Pasture	0.0	hectare	0.4	kg/ha-yr	0.0	kg/yr

Forest	4.3	hectare	0.2	kg/ha-yr	0.9	kg/yr
Urban	5.2	hectare	0.5	kg/ha-yr	2.6	kg/yr
Shrubland	1.5	hectare	0.2		0.3	kg/yr
Water	112.9					
Septic Systems	--------	--------	0.6	kg/ha-yr		
Total	27				13.4	kg/yr

Sechrist Lake

Land Use (in watershed)	**Area (ha)**	**--------**	**P-export Coefficient**		**Total**	
Row Crop	52.8	hectare	0.6	kg/ha-yr	31.7	kg/yr
Pasture	3.1	hectare	0.4	kg/ha-yr	1.2	kg/yr
Forest	22.1	hectare	0.2	kg/ha-yr	4.4	kg/yr
Urban	14.1	hectare	0.5	kg/ha-yr	7.1	kg/yr
Shrubland	11.5	hectare	0.2		2.3	kg/yr
Water	5.6					
Septic Systems	--------	--------	0.6	kg/ha-yr		
Total	103.60				46.7	kg/yr

MANAGEMENT

Like all efforts to manage lakes, limited financial and time resources will constrain the Barbee Lakes chain management effort. The large size of the Barbee Lakes chain watershed and number of interconnected lakes further complicates any management effort. While individual lakes may have a particular management need, the focus of this study has been on the entire lake chain and its watershed. As a consequence, what follows is a discussion of where financial and time resources should be spent to provide the greatest benefit to the lakes as a whole.

The lakes suffer from excess phosphorus concentrations. A review of past data on the lakes suggests the phosphorus concentrations are increasing with time. Phosphorus is entering the water column through two means: internal release from bottom sediments and external release from the watershed. Evidence is strong that internal loading is and will continue to be a problem for Big Barbee, Little Barbee, and Sawmill Lakes in particular. In terms of external loading of phosphorus, the Little Barbee watershed exports the greatest amount of phosphorus per acre of watershed according to the model used in this study. The Big Barbee watershed ranks second in phosphorus export per acre of watershed. Stream inlet sampling showed that Putney Ditch which outlets to Little Barbee delivers the greatest amount of phosphorus to the lakes per acre of watershed. Based on this evidence, management efforts should focus on the Putney Ditch and Grassy Creek watersheds.

In-lake management techniques, such as whole lake alum treatment and hypolimnetic aeration, have been developed to manage internal phosphorus release. Because the hydraulic residence times of Big Barbee, Little Barbee, Irish, and Sawmill Lakes are short (Table 41), these lakes are so dominated by watershed runoff that their water quality is almost entirely dependent upon watershed activities and the associated runoff. As a consequence, in-lake management techniques are not recommended. Management efforts should focus on improvements in the watershed.

In addition to high concentrations of phosphorus, Big Barbee, Little Barbee, Irish, and Sawmill suffer from high ammonium concentrations in their hypoliminia. High hypolimnetic concentrations of ammonium indicate significant BOD. Excessive runoff from the watershed is one source of organics contributing to the observed BOD problem. Stream inlet sampling showed that Grassy Creek delivers the greatest amount of total suspended solids to the lakes per acre of watershed. Putney Ditch ranked second in the delivery of total suspended solids to the lakes per acre of watershed. Based on this evidence, management efforts should focus on the Grassy Creek and Putney Ditch watersheds.

Dead plant material (algae and macrophytes) also contributes to the BOD problem in the lakes. Although the densities were low in general, the same lakes with high concentrations of ammonium also possessed the greatest algae densities. Historically, Big and Little Barbee have possessed high algae densities compared to other lakes in the chain. Settling and decomposition of this algae increase BOD in the lakes' sediments. In addition, the macrophyte survey showed Big Barbee, Little Barbee, Sawmill and parts of Irish had the greatest amount of plant growth. Die back of plants in these lakes only contributes to the BOD. Reduction of phosphorus from the watershed to limit algae growth and development of an aquatic plant management plan that includes the removal of plant material is recommended for these lakes to combat the BOD problem.

This evidence suggests that management should focus on restoration and implementation of BMP's in the watershed, particularly in the Putney Ditch and Grassy Creek watershed. While management efforts should be focused on Big Barbee, Little Barbee, and Sawmill Lakes and the watersheds that drain to these lakes, Kuhn, Sechrist, and Banning Lakes should not be ignored. Despite having better water quality compared to other lakes in the chain, phosphorus concentrations in these lakes create the potential for a worsening of conditions. Sechrist Lake, in particular, fell in the hypereutrophic range of Carlson's index based on phosphorus concentration. Again, the effects of the drought may be responsible for the low plankton densities despite the presence of sufficient phosphorus in the lakes' water columns. In addition, one of the unnamed inlets to Kuhn Lake delivered the second greatest amount of total phosphorus and total nitrogen per acre of watershed. The installation of filter strips along this ditch is recommended to prevent a worsening of conditions in Kuhn Lake.

The problems facing the Barbee Lakes chain did not occur overnight. Restoration of any lake is often a long-term process. It is important to note that the short hydraulic residence times will be a great benefit to Little and Big Barbee, Sawmill and Irish Lakes in the restoration effort. Short residences times mean these lakes are flushed regularly with runoff from the watershed. When this watershed runoff contains high concentrations of pollutants, the lakes receive regular inputs of these nutrients. However, if improvements are made in the watershed to reduce pollutant load, lakes with short residence time will have speedier recover than lakes with longer residence times as they are continually flushed with clean water.

It should also be noted that Sechrist and Banning Lakes have the small watershed to lake size ratios (2.6:1 and 18:1 respectively). As a consequence, property immediately adjacent to the lakes account for a proportionally larger percentage of total watershed compared to lakes such Big and Little Barbee. Land practices on the shoreline property can have a bigger impact on the water quality of Sechrist and Banning Lakes. Thus, lakeside property owners can exert greater influence over the health of their lakes. Residents of these lakes may see quicker improvements to their lakes' health by implementing some of the BMPs discussed in the Shoreline Development Section.

RECOMMENDATIONS

Below is a list of prioritized management recommendations. The recommendations are organized around the framework discussed above: the management of Big and Little Barbee, Irish, and Sawmill Lakes should focus on watershed solutions, while the management of Sechrist, Kuhn, and Banning Lakes should focus on near shore solutions. Some of the recommendations are larger and more complex in scope. Regardless of where they fall in the prioritized list, some of the smaller recommendations, such as the implementation of shoreline BMPs by shoreline residents, can and should be implemented immediately. The recommendations listed below were limited to those that would provide the greatest improvement to the lakes' water quality and appear to be *potentially* feasible. For example, restoring the Barbee Lakes chain watershed to its natural state, a nearly level landscape dotted with a network of wetlands and lakes, would not be feasible. Smaller restoration projects and implementation of BMPs may be possible. For larger projects, full feasibility studies would need to be conducted to ensure landowner agreement, cost-effectiveness, and regulatory approval. Specific benefits to the lakes from each proposed treatment are detailed in the preceding sections of the report and not repeated here. Please refer to the text for a discussion on the recommended treatments' benefits.

1. Work with the SWCD office in Warsaw to implement buffer or filter strip installation along two reaches of Putney Ditch east of County Road 650 East and north of County Road 200 North and grassed waterways or filters on the property at the southwest corner of County Road 200 North and County Road 650 East.

2. Initiate a feasibility study to examine three potential wetland restoration projects along Putney Ditch southward from County Road 300 North and a potential wetland restoration at the northeast corner of County Road 850 East and County Road 350 North. The primary functions of the restored wetlands in the Putney Ditch watershed will be to provide water storage and filtration of sediments.

3. Work with the SWCD to increase levels of conservation tillage practices, particularly no-till methods.

4. Work with the SWCD and landowner to install Best Management Practices such as fencing and filter strips on property along the east side of County Road 850 East and adjacent to the south side of the Grassy Creek and continuing 1.5 miles south to Ridinger Lake.

5. Support the efforts of the Tippecanoe Environmental Lake and Watershed Foundation to implement Best Management Practices, restore wetlands and stabilize ditches in the upper Grassy Creek watershed south of Ridinger Lake.

6. Develop a plant management plan that comprehensively addresses control of invasive species, the issue of high Biological Oxygen Demand created by decomposing plants, and the importance of preserving and promoting native plants for water quality, fish and aquatic invertebrate habitat.

7. Home Owner Recommendations:

   a) use only phosphorus free fertilizers.
   b) consider natural stone or aquatic vegetation to protect shoreline from erosion instead of concrete seawalls; consider planting native vegetation in front of existing seawalls.
   c) examine all drains that lead from roads, driveways or rooftops to the lake and consider alternate routes for these drains that would filter pollutants before they reach the lake.
   d) keep organic debris such as lawn clippings, leaves or animal waste out of the water.
   e) use idle speeds in shallow water to limit prop wash and mark those areas with buoys.
   f) clean septic systems regularly.

8. Equip storm water drains with technology to trap sediment and remove pollutants from runoff.

9. Complete a design-feasibility study for dredging select shallow water areas in artificial channels and at the mouth of Putney Ditch to decrease recycling of nutrients from unconsolidated sediment.

10. Install a comprehensive sanitary sewer system to serve the entire chain of lakes possibly in conjunction with other lakes in the area.

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