Yellow Creek Lakes Watershed Diagnostic Study
Kosciusko County, Indiana

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Yellow Creek Lake

Beaver Dam Lake

Diamond Lake

Hill Lake

McClures Lake

Loon Lake

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YELLOW CREEK LAKES DIAGNOSTIC STUDY
KOSCIUSKO COUNTY, INDIANA

EXECUTIVE SUMMARY

The six Yellow Creek Lakes combined have 515 acres (208.4 ha) of open water in a drainage area (watershed) of 6,535 acres (2,645 ha). The lakes and drainage patterns in the watershed were formed by ice and glacial melt waters in outwash plains during the end of the last ice age. There is 53 feet (16.2 m) of relief from the highest elevation in the watershed to the outlet at Yellow Creek Lake. The water leaving these lakes heads north to the Tippecanoe River on its way to the Gulf of Mexico.

The soils surrounding the lakes are muck in the lowlands, sands and sandy loams on the ridges and slopes, and loams and clay loams on the plateaus or drainages. Approximately 30% of the soils are mapped as potentially highly erodible and 0.2% are mapped as highly erodible. More importantly, 58% of the watershed soils are mapped as severely limited for septic systems and another 29% as moderately limited for septic systems. Over 85% of the wetlands, which serve to trap and filter nutrients and sediment, have been lost from the Yellow Creek Lakes watershed to development of the lakeshores and agricultural drainage. As of 2002, 70% of the watershed was in row crop agriculture.

Beaver Dam Lake is 146 acres (59 ha) with a watershed of 1266 acres (512.4 ha) and a hydraulic residence time of 1.4 years. The lake has a maximum depth of 61 feet (18.6 m) and a mean depth of 15.6 feet (4.7 m). Approximately 1/3 of the lake area can sustain rooted aquatic plants (macrophytes) with its average Secchi disk reading (clarity) of four feet (1.2 m) in summer. The macrophyte community was made up of 26 species dominated by Sago pondweed, musk grass, and coontail, with Eurasian watermilfoil (EWM) present. Spatterdock and duckweed are the floating leaved dominants. Purple loosestrife and reed canary grass dominated the shorelines. These two species and EWM, are introduced (non-native) and aggressive plants that limit the growth and reproduction of native species that can be more beneficial to fish and wildlife. The Indiana Department of Natural Resources (IDNR) has conducted 12 fish surveys since 1965 and documented 29 species. One fish eradication event and subsequent stocking of game fish have yielded mixed results. Bluegill and largemouth bass fishing remain relatively good; however, the growth rates have not improved as expected. Beaver Dam Lake has shown no distinct trend in water quality since 1966, but may have improved slightly. The Indiana State Trophic Index (ITSI) score has decreased from 55 (hyper-eutrophic) to 33 (eutrophic) since 1966; however, hypolimnetic ammonia nitrogen (NH_4) and soluble reactive phosphorus (SRP) remain above the median for Indiana lakes. The abundant nutrient supply is fueling a dominant blue-green algae population that drives oxygen saturation in the epilimnion and oxygen depletion in the hypolimnion, with the loss of an estimated 8% of the lakes volume for fish habitat during limited periods. Beaver Dam Lake would benefit from non-native species control and Best Management Practices (BMP's) in the watershed to reduce sediment and nutrient input to the lake. The lake may also benefit from internal control of phosphorous using alum or dredging. Specifically, the drainage into the south end of the lake needs banks stabilization and filter strips, and Amanda Point, on the west side of the lake, needs bank protection. Additionally, homeowners should implement BMP's along the shoreline.

Diamond Lake is a 79 acre (32 ha) lake with a watershed of 1,555 acres (629.3 ha) and a hydraulic residence time of 6 months. The lake has a maximum depth of 29 feet (8.8 m) and a mean depth of 16.4 feet (5 m). Currently, 25 species of macrophytes grow within 25% of the lake area with the average summer clarity of 3 feet (0.9 m). The macrophyte community was

dominated by southern naiad, EWM, Sago pondweed, and musk grass. Whorled loosestrife, reed canary grass and cattails dominated the shorelines, while spatterdock, white water lily and duckweed were the floating leaved dominants. The IDNR has conducted 12 fish surveys since 1964 and documented 33 species. One fish eradication event and subsequent stocking of game fish have yielded good results. Bluegill, yellow perch, and largemouth bass fishing are relatively good with normal growth rates. Diamond Lake has had historically poor water quality since monitoring began in 1964. On a positive note, the ITSI score has decreased from 77 (hyper-eutrophic) to 44 (eutrophic); however, there has been a general increase in nutrient concentrations during this same period. NH_4 and SRP concentrations were measured at 2 and 3 times the median for Indiana lakes. The abundant nutrient supply is fueling a dominant blue-green algae population that drives oxygen saturation in the epilimnion and oxygen depletion in the hypolimnion, with the loss of an estimated 25% of the lakes volume for fish habitat during limited periods. Diamond Lake's water quality will improve with non-native species control, especially EWM, and BMP's in the watershed to reduce sediment and nutrient inputs to the lake. Specifically, the smaller drainages from the east and south need filter strips, and the drainage from the southwest needs a nutrient filter or has to have a source reduction.

Hill Lake is a 67 acre (27 ha) lake with a watershed of 479 acres (193.9 ha) and a hydraulic residence time of 2 years. The lake has a maximum depth of 35 feet (10.7 m) and a mean depth of 18.9 feet (5.8 m). Twenty-three species of macrophytes grow to a depth of 14 feet (about 30% of the lake area) with average summer clarity of approximately 7 feet (2.1 m). The macrophyte community was dominated by coontail, EWM, and musk grass. Reed canary grass, whorled loosestrife, and cattails dominated the shorelines, while spatterdock, white water lily and duckweed were the floating leaved dominants. The IDNR has conducted nine fish surveys since 1965 and documented 27 species. One fish eradication event and subsequent stocking of game fish have yielded good results. Bluegill, yellow perch, and largemouth bass fishing are relatively good with normal growth rates. Northern Pike are present, but maintain a small population. Hill Lake has better water quality then most Indiana lakes. The ITSI score has consistently remained between 26 and 34 (mesotrophic-eutrophic) since 1972. Nutrient concentrations during this same period have remained at or below the median for Indiana lakes with the exception of NH_4 which is 20 times greater in the hypolimnion then the epilimnion and 10 times greater then the median for Indiana lakes. The abundant nutrient supply is fueling a dominant blue-green algae population that drives oxygen saturation in the epilimnion and oxygen depletion in the hypolimnion, with the loss of an estimated 20% of the lakes volume for fish habitat due to anoxia during limited periods. Hill Lake's water quality will improve with EWM control and potentially other in-lake or lakeshore nutrient reduction methods.

Loon Lake is a 43 acre (17.4 ha) lake with a watershed of 461 acres (186.6 ha) and a hydraulic residence time of 4 months. The lake has a maximum depth of 40 feet (12.2 m) and a mean depth of 16.7 feet (5.1 m). Twenty-two species of macrophytes grow to a depth of 7 feet (2.1 m; or about 20% of the lake area) with average summer clarity of approximately 4 feet. The macrophyte community was dominated by coontail, with EWM present in small populations, and filamentous algae at 87% of the sample sites. Whorled loosestrife, reed canary grass and cattails dominated the shorelines, while spatterdock, white water lily and duckweed were the floating leaved dominants. The IDNR has conducted three fish surveys since 1965 and documented 26 species. A large population of gar is present which, as the IDNR has suggested, is keeping the panfish from overpopulating. Bluegill and largemouth bass fishing are relatively good with normal growth rates. Loon Lake has had historically worse water quality then other Indiana lakes since monitoring began in 1966 with no trend. The ITSI score has oscillated between 52 (hyper-eutrophic) and 27 (mesotrophic) due to algae blooms which account for up to 10 points. Both NH_4 and SRP concentrations are higher then the median for Indiana lakes in

the hypolimnion. The abundant nutrient supply is fueling a dominant blue-green algae population that drives oxygen saturation in the epilimnion and oxygen depletion in the hypolimnion, with the loss of an estimated 48% of the lakes volume for fish habitat due to anoxia during limited periods. Loon Lake's water quality will improve with non-native species control, especially EWM, BMP's in the watershed to reduce sediment and nutrient input to the lake, and improvements to Beaver Dam Lake's water quality. No specific BMP's or in-lake water quality improvement measures were identified.

McClures Lake is a 32 acre (12.9 ha) lake with a watershed of 614 acres (248.5 ha) and a hydraulic residence time of 11 months. The lake has a maximum depth of 30 feet (9.1 m) and a mean depth of 22.2 feet (6.7 m). Eighteen species of macrophytes grow to a depth of 3 feet (0.9 m; about 30% of the lake area) with average summer clarity of approximately 2 feet (0.6 m). The macrophyte community was dominated by coontail. Whorled loosestrife, reed canary grass and cattails dominated the shorelines, while spatterdock, white water lily and duckweed were the floating leaved dominants. Filamentous algae were documented at 79% of the sample sites. The IDNR has conducted two fish surveys and documented 21 species. Game fish represented over 90% of the sample in 1965 and 79% in 1985. Bluegill and largemouth bass dominated the population and growth rates were good. McClures Lake has had declining water quality as documented in 10 water quality sampling events since 1966. This poor water quality is not being driven by phosphorus which is at or below the median of other Indiana lakes. A spike in total nitrogen (including ammonia and nitrate) concentration was apparent in 1991 sampling but has declined in subsequent samples. The ITSI score has oscillated between 51 (hyper-eutrophic) to 23 (mesotrophic) with the current score of 40 (eutrophic). The abundant nutrient supply is fueling a dominance of blue-green algae (87%). Anoxia is present in most samples at 15 feet causing the loss of an estimated 20% of the lakes volume for fish habitat during limited periods. Purchasing and restoring a native plant community to the south end of the lake and or investigating the camp for potential pollution sources are the recommended actions. Aeration to reduce nitrogen may be a potential restoration measure for McClures Lake.

Yellow Creek Lake is a 151 acre (61.1 ha) lake with a watershed of 2,160 acres (874 ha) and a hydraulic residence time of 7 months. The lake has a maximum depth of 67 feet (20.4 m) and a mean depth of 31.6 feet (9.63 m). Thirty-one species of macrophytes were found growing to a maximum depth of 8 feet (2.4 m), representing 15% of the lake area with the average summer clarity of 3.5 feet (1.1 m). The macrophyte community was dominated by sago pondweed, northern watermilfoil, and EWM. Purple loosestrife and reed canary grass dominated the shorelines, while spatterdock and duckweed were the floating leaved dominants. Curly-leaved pondweed has also been documented from this lake. The IDNR has conducted five fish surveys since 1965 and documented 34 species. The lake was privately stocked before the IDNR surveys. Bluegill, yellow perch, and largemouth bass are the dominant game fish and have normal growth rates. Yellow Creek Lake has been historically below the median for Indiana lakes since monitoring began in 1966, but is showing signs of slight improvement. The ITSI score has decreased from 67 (hyper-eutrophic) to 41 (eutrophic); however, there has not been a general decrease in nutrient concentrations during this same period. Total nitrogen and total phosphorus is at least two times the Indiana median in the hypolimnion; however, when averaged with the concentrations in the epilimnion, total phosphorus concentrations have remained relatively constant just below the mean value of Indiana lakes from 1991 to present. Blue-green algae made up 68% of the moderate plankton population. The high hypolimnetic concentration of nutrients and summer anoxia at an average depth of 16 feet is evidence of phosphorus release from the substrate. The estimated loss of fish habitat is estimated at 43% of the lakes volume for limited periods during the summer. Yellow Creek Lake's water quality will improve with improvement to water quality in upstream lakes, non-native species control,

especially EWM, and BMP's in the immediate watershed to reduce sediment and nutrient input to the lake. Specifically, the Yellow Creek Lake Conservation Club should address the shoreline erosion on the south lakeshore, the discharge of a private sewage treatment plant directly into the lake, and homeowner BMP's adjacent to the shoreline.

The water flowing into and between lakes was sampled at seven locations in the watershed for habitat, macroinvertebrates, water chemistry, and physical parameters. These streams are all branches of the legal drain known as the Swick-Meredith Drain. The sample locations included the south end of Beaver Dam Lake, between Loon Lake and Yellow Creek Lake but before the junction with the McClures Lake tributary, between Loon Lake and Yellow Creek Lake but after the junction of the McClures Lake tributary, between Diamond Lake and Yellow Creek Lake, at the south end of Diamond lake, at the southeast side of Diamond Lake, and between Hill and Diamond Lake. All seven streams had a Qualitative Habitat Evaluation Index (QHEI) score of less then 51 and are considered non-supporting of aquatic life. With one exception, all streams were scored by the macroinvertebrate Index of Biotic Integrity as being severely impaired. The exception was the drainage into the southeast corner of Diamond Lake, it was moderately impaired.

Dissolved oxygen (DO) concentrations ranged from 0.9 mg/l to 12.1 mg/l and DO saturation ranged from 8.7% to 142% indicating that 6 of 7 streams had high biological oxygen demands (BOD) at base and storm flows. The stream sampled between Diamond and Yellow Creek Lake had the abnormally high DO concentration and saturation values at storm flows. This may be due to supersaturated water being flushed from Diamond Lake during the storm. Higher total solids and turbidity during storm flows compared to base flow was recorded at 6 of 7 streams sampled. The exception was the stream flowing into Beaver Dam Lake, and the higher total solids at base flow were likely due to the high organic matter content. Nearly all of the streams exceeded Ohio EPA standards for nitrate in warmwater streams at either base flow, storm flow or both. High base flow ammonia concentrations in the Beaver Dam Lake tributary site, the site between Loon Lake and Yellow Creek Lake (but upstream of McClures drainage), and the site between Diamond and Yellow Creek Lake indicate an adjacent source of nitrogen. Total phosphorus increased with storm flows in all but two sample sites, indicating the source of phosphorus was surface runoff. *E coli* bacteria exceeded state water quality standards at all but one site, and typically increased with storm flow with the highest reading of 5170 col/100 ml. in the stream between Hill and Diamond Lake.

Improving stream water quality flowing to the Yellow Creek lakes addresses the pollution issues discussed for both the streams and the lakes. BMP's like grass filter strips, forested buffer strips, and grassed waterways in agricultural fields, septic system maintenance, and wetland restoration, all help improve water quality. Maintaining road side grass buffers adjacent to drains, or where the roads cross drainages, are also good places to reduce pollutant loading to the streams. In-stream filters, sediment traps, and wet or dry detention basins constructed to intercept and treat pollutants, can be effective in smaller drainages but are have higher installation and maintenance costs. Lakeside residents should focus on lakeshore issues first including increased septic field maintenance, limiting hard armoring of shorelines, examining alternative paths for drainage from driveways and homes like rain barrels and rain gardens, and eliminating the use of fertilizers containing phosphorus on lawns and gardens adjacent to the lakes. These homeowner BMP's are the least expensive to implement and demonstrate to landowners off the lake a real commitment to improve water quality.

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1.0 INTRODUCTION

Beaver Dam, Diamond, Hill, Loon, McClure, and Yellow Creek Lake make up a chain of lakes covering approximately 515 acres (208.4 ha) of open water within the Tippecanoe River Watershed, south of Warsaw, Indiana (Figure 1). The drainage area for all six of the lakes is approximately 6,535 acres (2,645 ha). The Yellow Creek Lakes watershed is roughly equivalent to the 14 digit Hydrologic Unit Code (HUC) 05120106040050.

Water flows from the eastern side of the watershed through Hill Lake into Diamond Lake and then into Yellow Creek Lake; and from the western portion of the watershed where it flows into Beaver Dam and then into Loon Lake whose outlet stream joins with the outlet from McClures Lake to drain into Yellow Creek Lake. Water from Yellow Creek Lake discharges into Yellow Creek, on the north shoreline, which carries water northwesterly to its junction with the Tippecanoe River at a point approximately 4 miles west of Mentone. Ultimately the water from the Yellow Creek Lakes reaches the Mississippi River in southwestern Illinois on its way to the Gulf of Mexico.

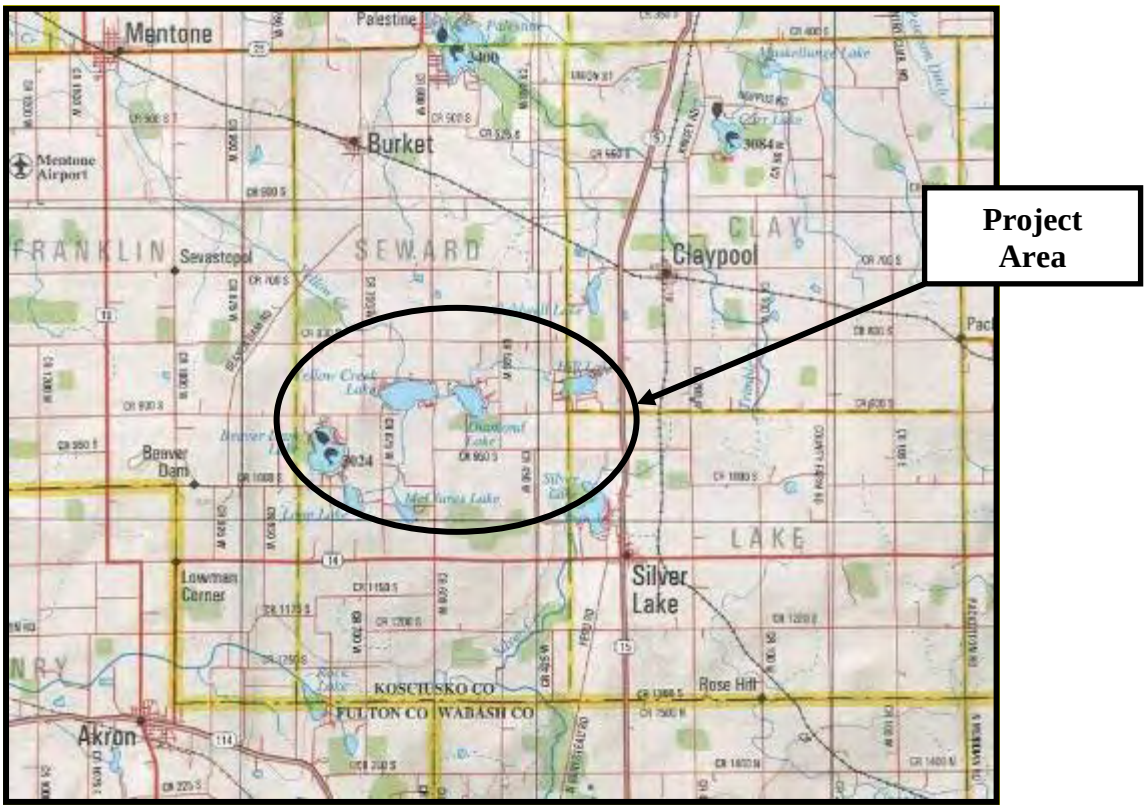


Figure 1. General location of the Yellow Creek Lakes watershed, Kosciusko County, Indiana. Source: DeLorme, 1998. Scale: inch=approximately 2.5 miles

Members of the Diamond Lake Conservation Club, Beaver Dam-Loon Lake Conservation Club, and Yellow Creek Lakes Conservation Club began working together in 2006 to improve the aesthetics and water quality of their lakes. The Diamond Lake Conservation Club was already working to control Eurasian watermilfoil and realized that this would entail the involvement of Hill Lake upstream. Beaver Dam and Loon Lake were also interested in controlling the spread of invasive aquatic vegetation, while Yellow Creek residents were generally concerned about several water quality issues. To achieve their goals, the clubs joined together and applied for

and received funding from the Indiana Department of Natural Resources (IDNR) Lake and River Enhancement Program (LARE) to complete a diagnostic study.

The purpose of the diagnostic study was to describe the conditions and trends in Beaver Dam, Diamond, Hill, Loon, McClures, and Yellow Creek Lakes, the streams between the lakes, and their watershed; identify potential problems; and make prioritized recommendations addressing these problems. The study consisted of a review of previous studies, interviews with lake residents and state/local regulatory agencies, the collection of current water quality data, pollutant modeling, and field investigations. In order to obtain a broad understanding of the water quality in the Yellow Creek Lakes and the streams flowing into and between lakes, the diagnostic study included an examination of the water chemistry and physical measurements of the lake and streams. The study also included review of historical studies and a collection of new biotic community data, which reflects the long-term water quality trends. This report documents the results of the study.

Additional information that may be useful for understanding the individual topics addressed within this report are located in the following Appendices:

1) Appendix A is a glossary of key water quality terms
2) Appendix B is the IDNR communication regarding ETR species in the watershed
3) Appendix C is a detailed summary and discussion of each lakes IDNR fish reports
4) Appendix D contains the raw data and metrics for macroinvertebrates collected
5) Appendix E is the public information handout or brochure
6) Appendix F documents the two public meetings and the watershed tour
7) Appendix G lists agency contacts and grant resources for more assistance
8) Appendix H is an annotated list of historical studies reviewed for this report
9) Appendix I is an annotated list of recommended projects with timelines, potential costs and expected benefits.

2.0 WATERSHED CHARACTERISTICS

The Yellow Creek Lakes drainage area (watershed) based on topography is approximately 7,145 acres (2,982 ha.); however, as Figure 2 below shows, artificial drainage on the west side of Beaver Dam Lake has reduced the effective watershed to 6,535 acres (2,645 ha).

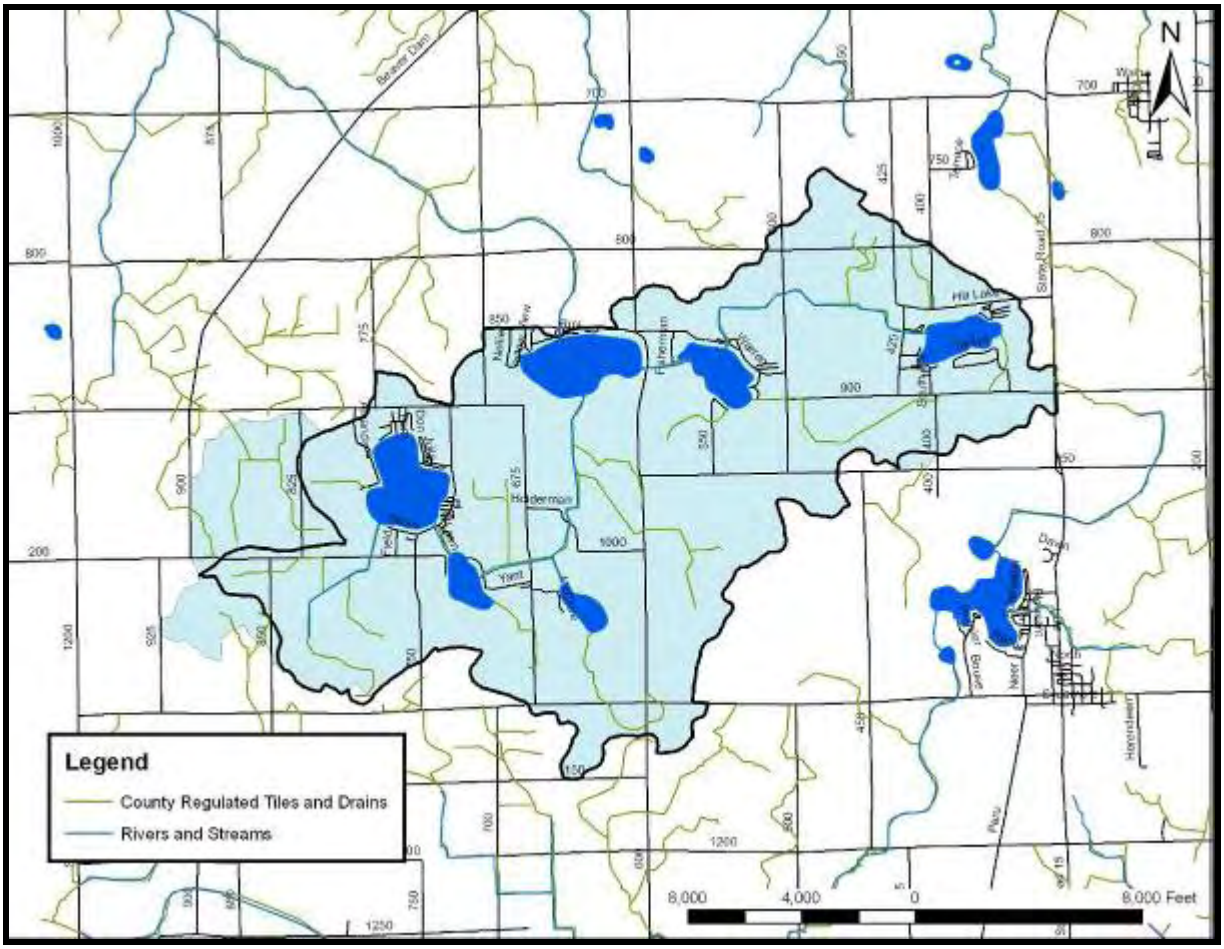


Figure 2: Regulated drains, natural drainage basin (highlighted), and modified watershed boundary (black border) of the Yellow Creek Lakes, Kosciusko County, Indiana.

2.1 Topography and Physical Setting

The topography of the Yellow Creek Lakes watershed reflects the geological history of the watershed. The highest areas of the watershed lie along the watershed's eastern and southern edges, where the Erie Lobe of the last glacial age left end moraines. Along the watershed's eastern boundary, the elevation nears 910 feet (277.4 m) above mean sea level. The ridges along the watershed's southern boundary are equally as high, but are much less steep than the ridge along the eastern watershed boundary. The highest point in the watershed is located north of Diamond Lake at an elevation of 914 feet (278.6 m). The Swick-Meredith Drain carries water from these higher elevations to Yellow Creek Lake at an elevation 861 feet (262.4 m) above mean sea level (Figure 3).

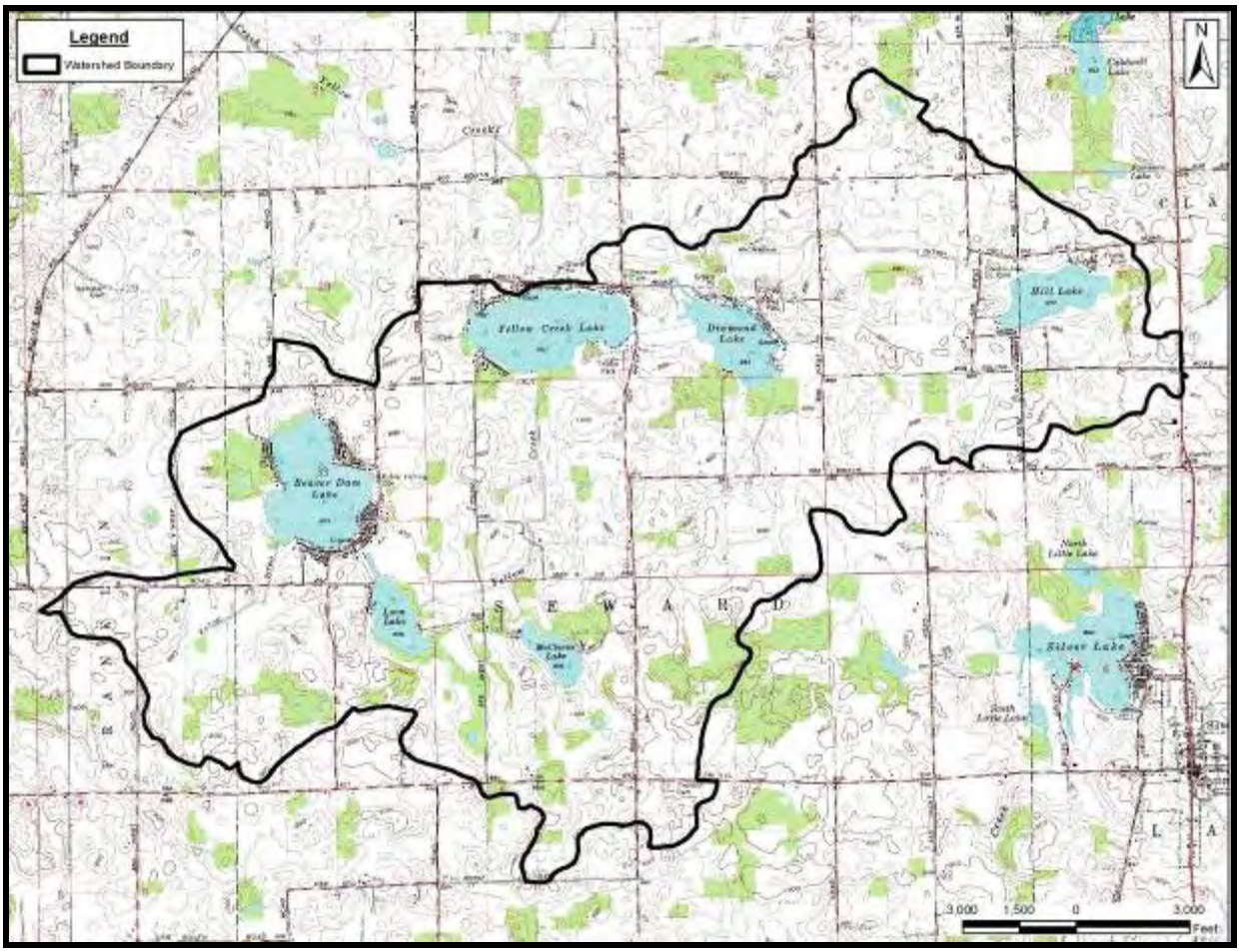


Figure 3. Topographical map and boundaries of the Yellow Creek Lakes watershed, Kosciusko County, Indiana

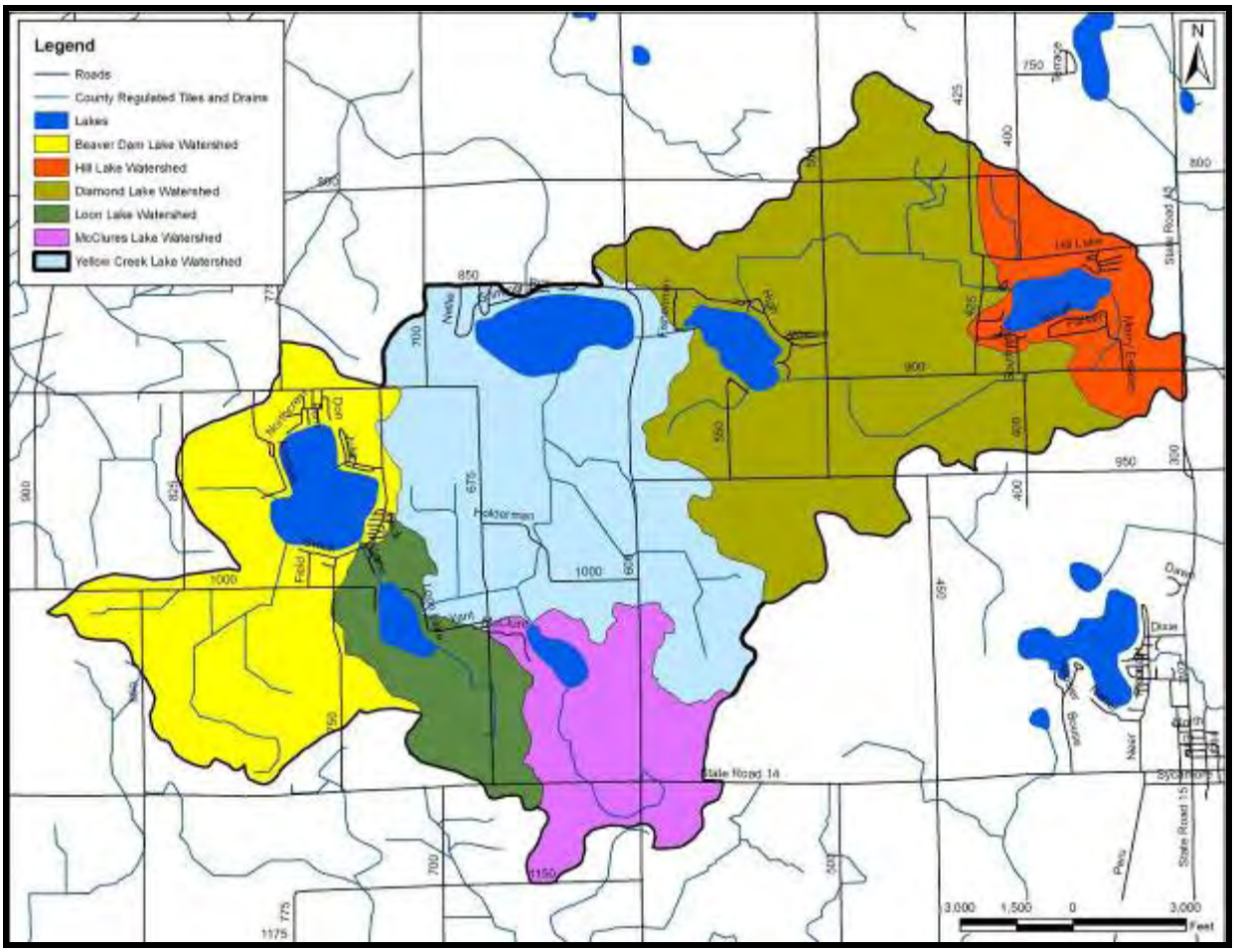


Figure 4. Subwatersheds of the Yellow Creek Lakes watershed, Kosciusko County, Indiana

2.1.1 Beaver Dam Lake

Surface water drains to Beaver Dam Lake via three primary routes (Figure 4). The Effie Eaton Arm of Swick-Meredith Drain captures water from approximately 706 acres (285.7 ha) southwest of Beaver Dam Lake (Table 1). This stream empties into Beaver Dam Lake in the lake's southwest corner. Arm 7 of Swick-Meredith Drain transports water from the western portion of the watershed to Beaver Dam Lake after traveling through a wetland east of County Road 825 West. This stream drains approximately 154 acres (62.3 ha) into Beaver Dam Lake. The remainder of the land in the Beaver Dam Lake watershed (258.7 acres or 104.7 ha) drains directly to Beaver Dam Lake.

Table 1. Watershed and subwatershed sizes for the Beaver Dam Lake watershed.

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
Effie Eaton Arm Swick-Meredith Drain	706.5	285.7	55.8%
Arm 7 Swick-Meredith Drain	154.7	62.3	12.2%
Area Draining Directly to Beaver Dam Lake	258.7	104.7	36.1%
Watershed Draining to Lake	**1,119.9**	**453.2**	**88%**
Beaver Dam Lake	146	59.1	12%
Total Watershed	**1,265.9**	**512.3**	**100%**
Watershed to Lake Area Ratio	7.7:1		

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

Beaver Dam Lake possesses a watershed area to lake area ratio of approximately 7.7:1. This is a fairly typical watershed area to lake area ratio for glacial lakes (Vant, 1987). This ratio is also relatively normal when compared to other lakes in northern Indiana. For example, Chapman Lake, which is nearly double the size of Beaver Dam Lake, possesses a watershed area to lake area ratio of approximately 6:1. Conversely, Lake Tippecanoe, Ridinger Lake, and Smalley Lake, glacial lakes in the Upper Tippecanoe River watershed in Kosciusko, Noble, and Whitley Counties, possess watershed area to lake area ratios of 93:1, 165:1, and 248:1, respectively. All of these lakes have extensive watersheds compared to Beaver Dam Lake.

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

2.1.2 Diamond Lake

Surface water drains to Diamond Lake via four primary routes (Table 2). The Michaels Arm of Swick-Meredith Drain drains approximately 1293.4 acres (523.3 ha) north and west of Diamond Lake. This stream receives drainage from Hill Lake and empties into Diamond Lake along the lake's northern shoreline. The Johnson Arm of Swick-Meredith Drain enters the lake on the eastern shoreline. This drain originates southeast of the intersection of County Roads 900 South and 500 West transporting water from the eastern portion of the watershed to Diamond Lake. This stream drains approximately 525.8 acres (212.5 ha) of the Diamond Lake watershed. A second branch of Swick-Meredith Drain (Hanes William) transports water from the southern portion of the watershed to Diamond Lake entering the lake on the southern shoreline. This

stream drains approximately 403.3 acres (163.1 ha) of the Diamond Lake watershed. The remainder of the land in the Diamond Lake watershed (270.8 acres or 109.6 ha) drains directly to Diamond Lake.

Table 2. Watershed and subwatershed sizes for the Diamond Lake watershed.

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
Michaels Arm Swick-Meredith Drain	1293.4	523.3	51.5%
Johnson Arm Swick-Meredith Drain	525.8	212.5	20.9%
Hanes William Arm Swick-Meredith Drain	403.3	163.1	16.1%
Area Draining Directly to Diamond Lake	270.8	109.6	10.8%
Watershed Draining to Lake	**2,434.4**	**985.2**	**99.3%**
Diamond Lake	79	32	0.7%
Total Watershed	**2,513.4**	**1,017.1**	**100%**
Watershed to Lake Area Ratio	30.8:1		

Diamond Lake possesses a watershed area to lake area ratio of approximately 30.8:1. This ratio is also relatively normal when compared to other lakes in northern Indiana. In terms of lake management, Diamond Lake's watershed area to lake area ratio means that near lake (i.e. shoreline) and watershed-based activities and processes both exert significant influence on the health of Diamond Lake. Consequently, implementing best management practices along the lake's shoreline, such as maintaining native, emergent vegetated buffers between the lakeside residences and the lake as well as watershed-wide practices should rank equally when prioritizing management options with the use of limited funds.

2.1.3 Hill Lake

Hill Lake does not contain any tributary drains. Therefore, water enters Hill Lake as overland flow or as groundwater. In total, 479 acres (194 ha) drain to Hill Lake from its watershed. Hill Lake possesses a relatively small watershed area to lake area ratio of approximately 6:1. This is on the low end of typical watershed area to lake area ratio for glacial lakes (Vant, 1987).

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

2.1.4 Loon Lake

Surface water drains to Loon Lake via three primary routes (Table 3). A branch of Swick-Meredith Drain enters Loon Lake from the southeast. This stream originates along County Road 675 West and transports water from the southeastern portion of the watershed to Loon Lake. This stream drains approximately 246.5 acres (99.3 ha) of the Loon Lake watershed. The second tributary (Arm 3) carries water from Beaver Dam Lake to Loon Lake. This drain carries water from 1332.8 acres (539.4 ha) within the Loon Lake watershed. The remainder of the land in the Loon Lake watershed (106.9 acres or 43.3 ha) drains directly to Loon Lake.

Table 3. Watershed and subwatershed sizes for the Loon Lake watershed.

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
Swick-Meredith Drain	246.5	99.3	14.3%
Beaver Dam Lake Outlet (Arm 3)	1332.8	539.4	77.2%
Directly to Loon Lake	106.9	43.3	6.2%
Watershed Draining to Lake	**1,686.2**	**682.4**	**97.7%**
Loon Lake	40	16.2	2.3%
Total Watershed	**1,726.2**	**698.6**	**100%**
Watershed to Lake Area Ratio	42.1:1		

Loon Lake possesses a watershed area to lake area ratio of approximately 42.1:1. This is a fairly high watershed area to lake area ratio for glacial lakes (Vant, 1987). However, this ratio is also relatively normal when compared to other lakes in northern Indiana. In terms of lake management, Loon Lake's watershed area to lake area ratio means that both shoreline and watershed-based activities and processes influence on the health of Loon Lake. Because much of the drainage to Loon Lake comes through Beaver Dam Lake (75%), actions to reduce pollution in Beaver Dam Lake will have a significant influence on the water quality of Loon Lake. Therefore, in-lake and shoreline treatments should be prioritized in Loon Lake.

2.1.5 McClures Lake

Surface water drains to McClures Lake via two primary routes (Table 4). A branch of Swick-Meredith Drain (Smith Mark Arm) carries water from the southern portion of the watershed to McClures Lake. This stream drains approximately 76.4 acres (30.9 ha) and empties into McClures Lake along the lake's southern shoreline. The remainder of the land in the McClures Lake watershed (506.2 acres or 204.9 ha) drains directly to McClures Lake.

Table 4. Watershed and subwatershed sizes for the McClures Lake watershed.

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
Smith Mark Arm Swick-Meredith Drain	76.4	30.9	12.4%
Directly to McClures Lake	506.2	204.6	82.3%
Watershed Draining to Lake	**582.6**	**235.8**	**94.7%**
McClures Lake	32	12.9	5.2%
Total Watershed	**614.6**	**248.7**	**100%**
Watershed to Lake Area Ratio	18:1		

McClures Lake possesses a relatively typical watershed area to lake area ratio of approximately 18:1. In terms of lake management, McClures Lake's watershed area to lake area ratio indicates

that near lake (i.e. shoreline) and in-lake activities and processes exert a significant influence on the health of the Lake. Since McClures Lake is largely undeveloped with no obvious watershed pollution, in-lake processes will likely be the focus of water quality improvement efforts.

2.1.6 Yellow Creek Lake

Surface water drains to Yellow Creek Lake via three primary routes (Table 5). The Johnson Arm 2 of Swick-Meredith Drain drains approximately 2,666.55 acres (1,079.1 ha) south of Yellow Creek Lake. Yellow Creek receives water from Beaver Dam, Loon, and McClures lakes before entering Yellow Creek Lake. A branch of Swick-Meredith (Michaels) Drain carries water from Hill and Diamond Lake to Yellow Creek Lake. This stream drains approximately 3,401.6 acres (1,376.6 ha) of the Yellow Creek Lake watershed and empties into Yellow Creek Lake along the lake's eastern shoreline. The remainder of the land in the Yellow Creek Lake watershed (361.2 acres or 127.9 ha) drains directly to Yellow Creek Lake.

Table 5. Watershed and subwatershed sizes for the Yellow Creek Lake watershed.

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
Johnson Arm 2 of Swick-Meredith Drain	2666.5	1079.1	40.8%
Michaels Arm Swick-Meredith Drain	3401.6	1376.6	52.0%
Directly to Yellow Creek Lake	316.2	127.9	4.8%
Watershed Draining to Lake	**6,384.3**	**2,583.6**	**97.7%**
Yellow Creek Lake	151	61.1	2.3%
Total Watershed	**6,535.3**	**2,644.7**	**100%**
Watershed to Lake Area Ratio	42:1		

Yellow Creek Lake possesses a watershed area to lake area ratio of approximately 42:1. This is a fairly high watershed area to lake area ratio for glacial lakes (Vant, 1987). However, this ratio is also relatively normal when compared to other lakes in northern Indiana. In addition, the majority of the drainage from the watershed passes through the other lakes before reaching Yellow Creek Lake (76%). In terms of lake management, Yellow Creek Lake's water quality can be improved most efficiently by improving water quality in the upstream lakes and the immediate landscape draining to the lake. However, implementing best management practices along the lake's shoreline, such as reducing erosion of the shoreline, managing the native plant community, and keeping septic systems cleaned should not be ignored.

2.2 Climate

2.2.1 Indiana Climate

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

2.2.2 Yellow Creek Watershed Climate

The climate of the Yellow Creek Lakes watershed is characterized as having four well-defined seasons of the year. Winter temperatures average 26º F (-3.3º C), with warm summer temperatures averaging 70º F (21.1º C). The growing season typically begins in early April and ends in September. Annual rainfall averages 38.54 inches (98 cm). Winter snowfall averages about 26 inches (66 cm). During summers, relative humidity varies from about 60 percent in mid-afternoon to near 80 percent at dawn. Prevailing winds typically blow from the southwest except during the winter when westerly and northwesterly winds predominate. (All of the proceeding statistics with the exception of the annual rainfall average were from Staley (1989). Average monthly precipitation for the Yellow Creek Lakes area exceeded that of the 30 year average by 8.26 inches (21cm) in 2008 (Figure 5 and Table 6, NOAA, 2008).

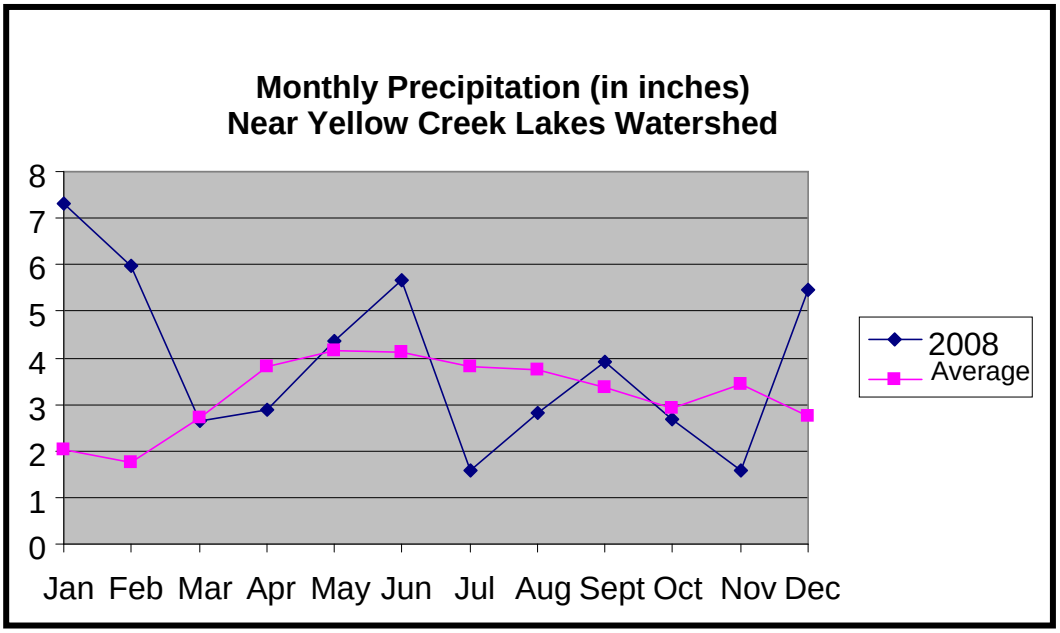


Figure 5. Monthly rainfall data for 2008. All data were recorded at Rochester, approximately 10 miles (16 Km) west of the Yellow Creek Lakes. Averages are 30-year normals based on available weather observations taken during the years of 1971-2000 (NOAA, 2008).

Table 6. Monthly rainfall data (in inches) for year 2008 as compared to average monthly rainfall recorded in Rochester, Indiana (NOAA, 2008)**.**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2008	7.33	5.96	2.63	2.88	4.37	5.65	1.57	2.8	3.9	2.67	1.57	5.47	**46.80**
Average	2.03	1.74	2.7	3.81	4.16	4.12	3.81	3.73	3.36	2.91	3.42	2.74	**38.54**

2.3 Geology

The advance and retreat of the glaciers in the last ice age (the Wisconsin Age) removed, shaped and reshaped much of the landscape found in Indiana today. In the northern portion of the state, ground moraines, end moraines, lake plains, outwash plains, and other geologically complex features dominate the landscape. Further, the interaction of three glacial lobes, (Michigan Lobe, Saginaw Lobe, and the Erie Lobe, respectively) left behind a vast array of deposits and landforms that changed the region's hydrogeology. In comparison to the central portion of the state, surface water, groundwater and soils are more varied and complex. Large

raised landforms including the Valparaiso Moraine, the Maxinkuckee Moraine, and the Packerton Moraine, indicate the glacial margins of these ice sheets in the northern portion of the state. Major rivers in northern Indiana cut through course grained outwash and transect these dominant topographical features, suggesting a drainage pattern that was established in an ice proximal and/or subglacial environment. Later, outwash plains formed as the glacial melt waters flowed from retreating glaciers. This further altered the drainage of the landscape as dams between ice, morainal deposits and melt water pooled into lakes. As a result, lake plains and kettle lakes formed as stagnant water settled out and deposited silt and clay (Brown and Jones, 1999).

These processes and subsequent erosion shaped much of the Yellow Creek Lakes watershed. Sediments in these landforms contain remnants of bedrock from Michigan, Canada and local sources. The geology and resulting physiography of the Yellow Creek Lakes watershed typify the region in which the watershed lies. The Yellow Creek Lakes watershed lies within Malott's Steuben Morainal Lake Area (Schneider, 1966). Landforms common in this diverse ice-marginal region surrounding Yellow Creek Lakes watershed include kettle lakes, outwash plains, and melt water channels, (Wright, 1932). Many of these landforms are visible as raised features and carved channels in the Yellow Creek Lakes watershed surficial landscape. Till knobs and kames occur along the watershed's southwestern edge.

Subsurface geology indicates that the Yellow Creek Lakes lies within a sequence of post glacial sediment reaching depths of 300 to 400 feet (91.2 to 122 m; Wayne, 1966). The watershed's soils originated from glacially derived silty clay loam, clay loam, and muck of lacustrine origin. This indicates that this portion of the watershed was likely once home of a larger lake basin during wetter times. This sequence of sediment lies on a broad lowland of bedrock. Known as the Dekalb Lowland, this bedrock unit is comprised of Upper Devonian and Lower Mississippian shales (Wayne, 1966; Gutschick, 1966).

2.4 Soils

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

Three major soil associations cover the Yellow Creek Lakes watershed. These soil associations are the Houghton-Palms association, the Ormas-Kosciusko association, and the Wawasee-Crosier-Miami association. The Houghton-Palms soil association is limited to the western portion of the watershed and encompasses a majority of the watersheds for Beaver Dam, Loon, and McClures lakes. The Houghton-Palms association covers approximately 9% of the county. The Ormas-Kosciusko soil association is restricted to the eastern portion of the Yellow Creek watershed and borders the outlet of Hill Lake. The Ormas-Kosciusko soil association also covers a large portion of the Diamond Lake and Yellow Creek Lake watersheds and accounts for approximately 19% of the county soil associations. The Wawasee-Crosier-Miami soil association accounts for the remainder of the Yellow Creek Lakes watershed and includes the shoreline and nearly the entire watershed for Hill Lake. This is the most common soil

association in Kosciusko County, covering approximately 28% of the county landscape. The following discussion on soil associations in the Yellow Creek Lakes watershed relies heavily on the *Soil Survey of Kosciusko County* (Staley, 1989). Readers should refer to this source for a more detailed discussion of soil associations covering Kosciusko County.

The Houghton-Palms soil association covers a portion of the Yellow Creek Lakes watershed surrounding Beaver Dam, Loon, and McClures lakes. The Houghton-Palms soil association consists largely of Houghton (46%) and Palms (16%) soils. The Houghton soils typically consist of black muck to a depth of more than 51 inches and are located in depressions on moraines, outwash plains, and till plains. The Palms soils are also found in depressions with a surface consisting of black muck. The subsoil consists of sandy clay loam and loam while the underlying material is coarse sand. Minor components of this association include Gilford, Sebewa, Edwards, and Coloma soils. Management concerns for this soil include wetness, ponding, and soil blowing. The Houghton-Palms soil association is severely limited for septic system usage.

The Ormas-Kosciusko association covers a majority of the eastern portion of the Yellow Creek Lakes watershed. This association is found along the shorelines of Diamond, Hill, and Yellow Creek Lakes. Well-drained soils with poorly defined surface drainage patterns characterize this soil association. Soils in this association are typically found on broad plains and terraces interspersed with the swells and swales of low moraines. Ormas soils comprise 33% of the association, while Kosciusko soils comprise 30%. Ormas soils are found on outwash plains, old river terraces, and low moraines. Ormas soils consist of brown loamy sand over yellowish brown loamy sand and sand substratum. Kosciusko soils are found on outwash plains and moraines. Kosciusko soils consist of a sandy loam surface layer over gravelly sandy clay loam and gravelly loamy sand. Minor components in the Ormas-Kosciusko association include Boyer, Brady, Gilford, Homer, Riddles, and Sebewa soils. Producers should consider the erosion potential of this soil association when cultivating crops on sloped land in this soil association. The Ormas and Kosciusko soils are severely limited for septic system development due to poor filtering capacity.

The Wawasee-Crosier-Miami soil association covers the remainder of the Yellow Creek Lakes watershed including the shoreline and nearly the entire watershed for Hill Lake. Wawasee soils comprise 30% of the soil association, while Crosier and Miami soils account for 26% and 24% of the association, respectively. Wawasee soils occur in well-drained, gently to strongly sloped areas along ridge tops and side slopes. Fine sandy loam soils overlie loam and sandy loam subsoils. Crosier soils are poorly drained soils found at lower elevations than Wawasee soils on the landscape. Well-drained Miami soils occur on knobs and low ridges and in swales. Both soils possess loam and clay loam textured surface and subsurface layers, which overlay loam layers. Aubbeenaubbee sandy loam and fine sandy loam, Barry loam, Metea loamy sand and loamy fine sand, Rensselaer loam, Riddles fine sandy loam, and Washtenaw silt loam soils are minor components of the Wawasee-Crosier-Miami soil association. Like many of the other soils in the Yellow Creek watershed, erosion is a concern on sloped areas. Wetness and slow percolation severely limit the use of Crosier soils as septic system leach fields. Slope and slow percolation moderately to severely limit Wawasee and Miami soils for use as septic system leach fields.

Soils in the watershed, and in particular their ability to erode or sustain certain land use practices, can impact a lake's water quality. The dominance of Wawasee, Riddles, Miami, Ormas and Kosciusko soils on steeply sloped areas across the Yellow Creek Lakes watershed suggests that large portions of the watershed are prone to erosion. Common erosion control methods should be implemented when the land is used for agriculture or during residential

development to protect the Yellow Creek watershed and its streams. Similarly, many of these same soils lie under the residentially developed portions of the Yellow Creek Lakes watershed, along lake shorelines, and are used to treat residential septic tank effluent. Unfortunately, these soils are moderately to severely limited in their ability to treat septic tank effluent. The coupling of moderate to high density residential land use with soils that are poorly suited for treating septic tank effluent is of concern for water quality in the Yellow Creek Lakes watershed. A more detailed discussion how highly erodible soils and soils used to treat septic tank effluent impact the Yellow Creek Lakes watershed lakes follows below.

2.4.1 Highly Erodible Soils

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

Highly erodible and potentially highly erodible are classifications used by the Natural Resources Conservation Service (NRCS) to describe the potential of certain soil units to erode from the landscape. The NRCS examines common soil characteristics such as slope and soil texture when classifying soils. The NRCS maintains a list of highly erodible soil units for each county. Table 7 lists the soil units in the Yellow Creek Lakes watershed that the NRCS considers to be highly erodible and potentially highly erodible.

Table 7. Highly erodible and potentially highly erodible soil units in the Yellow Creek Lakes watershed, Kosciusko County, Indiana.

Soil Unit	Status	Soil Name	Soil Description
KoB	PHES	Kosciusko sandy loam	2-6% slopes
KoC	PHES	Kosciusko sandy loam	6-12% slopes
MaB	PHES	Martinsville sandy loam	2-6% slopes
MaC	PHES	Martinsville sandy loam	6-12% slopes
MbC	PHES	Metea loamy sand	6-12% slopes
MIB	PHES	Miami Loam	2-6% slopes
MrC3	HES	Miami clay loam	6-12% slopes, severely eroded
MzB	PHES	Morley-Glynwood complex	1-4% slopes
OtC	PHES	Ormas loamy sand, sandy substratum	6-12% slopes
RlB	PHES	Riddles fine sandy loam	2-6% slopes
RlC	PHES	Riddles fine sandy loam	6-12% slopes
RxB	PHES	Riddles-Ormas-Kosciusko complex	2-6% slopes
RxC	PHES	Riddles-Ormas-Kosciusko complex	6-12% slopes
WlB	PHES	Wawasee fine sandy loam	2-6% slopes
WlC2	PHES	Wawasee fine sandy loam	6-12% slopes, eroded
WlD2	HES	Wawasee fine sandy loam	12-18% slopes, eroded

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

Highly erodible (HES) and potentially highly erodible soil (PHES) units in the form of Wawasee fine sandy loam, Ormas loamy sand, Riddles fine sandy loam, Kosciusko sandy loam, Martinsville sandy loam, Metea loamy sand, and Miami loam and clay loam soils cover much of the Yellow Creek watershed (Figure 6). Areas of the watershed that are mapped in these soil units and have gentle slopes are considered only slightly limited for agricultural production. As slope increases, the severity of the limitation increases. Some steeply sloped Wawasee soils

are considered unsuitable for agricultural production due to erosional hazards. The erosion hazard would also exist during residential development on these soils.

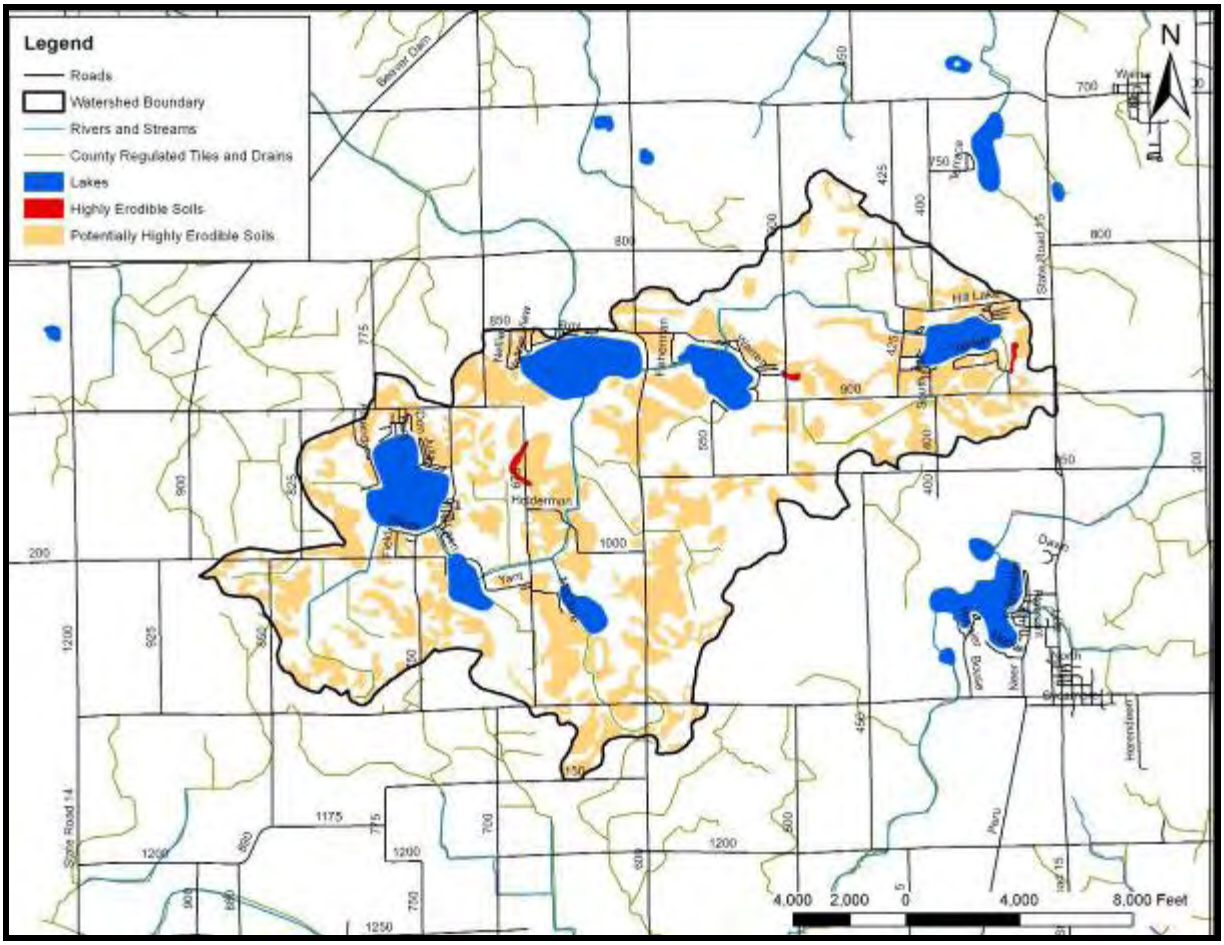


Figure 6. Highly erodible and potentially highly erodible soils within the Yellow Creek Lakes watershed.

As Figure 6 indicates, potentially highly erodible soils cover approximately 30% (3,991.2 acres or 1,615.0 ha) of the Yellow Creek watershed. This acreage is spread throughout the watershed with a majority by drainage area lying in the headwaters areas of McClures Lake (43%) and the Hill Lake watershed (38.7%). Highly erodible soils are mapped on only 28.4 acres (11.5 ha or approximately 0.2%) of the watershed and are limited to three areas. It is especially important that best management practices (BMPs) are utilized during residential development projects along portions of the shoreline mapped as potentially highly erodible. Table 8 documents the potentially highly erodible and highly erodible soils by subwatershed.

Table 8. Highly erodible and potentially highly erodible acreages by lake subwatersheds.

Lake Watershed	HES	PHES	Total Watershed
Beaver Dam Lake	--	414.6 acres (32.8%)	1265.9 acres
Diamond Lake	7.6 acres (0.3%)	598.6 acres (23.8%)	2,513.4 acres
Hill Lake	4.1 acres (0.9%)	185.5 acres (38.7%)	479.2 acres
Loon Lake	--	538.9 acres (31.2%)	1,726.2 acres
McClures Lake	--	264.4 acres (43.0%)	614.6 acres
Yellow Creek Lake	16.6 acres (0.3%)	1,989.2 acres (30.4%)	6,535.3 acres

2.4.2 Soils Used for Septic Tank Absorption Fields

Nearly half of Indiana's population lives in residences having private waste disposal systems. As is common in many areas of Indiana, septic tanks and septic tank absorption fields are utilized for wastewater treatment throughout the Yellow Creek Lakes watershed. Private waste disposal systems rely on the septic tank for primary treatment to remove solids and the soil for secondary treatment to reduce the remaining pollutants in the effluent to levels that protect surface and groundwater from contamination. The soil's ability to sequester and degrade pollutants in septic tank effluent will ultimately determine how well surface and groundwater is protected.

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

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

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

Environmental soil conditions influence the associated microorganism community which ultimately carries out the treatment of wastewater. Factors like temperature, moisture, and oxygen availability influence microbial action. Excess water or ponding saturates soil pores and

slows oxygen transfer. The soil may become anaerobic if oxygen is depleted. Decomposition processes (and therefore, effluent treatment) becomes less efficient, slower, and less complete if oxygen is not available.

Many nutrients and pollutants of concern are removed safely if a septic system is sited correctly. Most soils have a large capacity to hold phosphate. On the other hand, nitrate (the end product of nitrogen metabolism in a properly functioning septic system) is very soluble in soil solution and is often leached to the groundwater. Care must be taken in siting the system to avoid well contamination. Nearly all organic matter in wastewater is biodegradable as long as oxygen is present. Pathogens can be both retained and inactivated within the soil as long as conditions are right. Bacteria and viruses are much smaller than other pathogenic organisms associated with wastewater; and therefore, have a much greater potential for movement through the soil. Clay minerals and other soil components may adsorb bacteria and viruses, but retention is not necessarily permanent. During storm flows, bacteria and viruses may become re-suspended in the soil solution and transported throughout the soil profile. Inactivation and destruction of pathogens occurs more rapidly in soils containing oxygen because sewage organisms compete poorly with the natural soil microorganisms, which are obligate aerobes requiring oxygen for life. Also, some sewage organisms only thrive under anaerobic conditions. Sewage organisms live longer under anaerobic conditions and at lower soil temperatures because natural soil microbial activity, and thus competition, is reduced.

Taking into account the various factors described above, the NRCS ranks each soil series in the Yellow Creek Lakes watershed in terms of its limitations for use as a septic tank absorption field. Each soil series is placed in one of three categories: slightly limited, moderately limited, or severely limited. Use of septic absorption fields in moderately or severely limited soils generally requires special design, planning, and/or maintenance to overcome the limitations and ensure proper function. Figure 7 displays the septic tank suitability of soils throughout the Yellow Creek watershed, while Table 9 lists the soils located within the watershed and their associated properties.

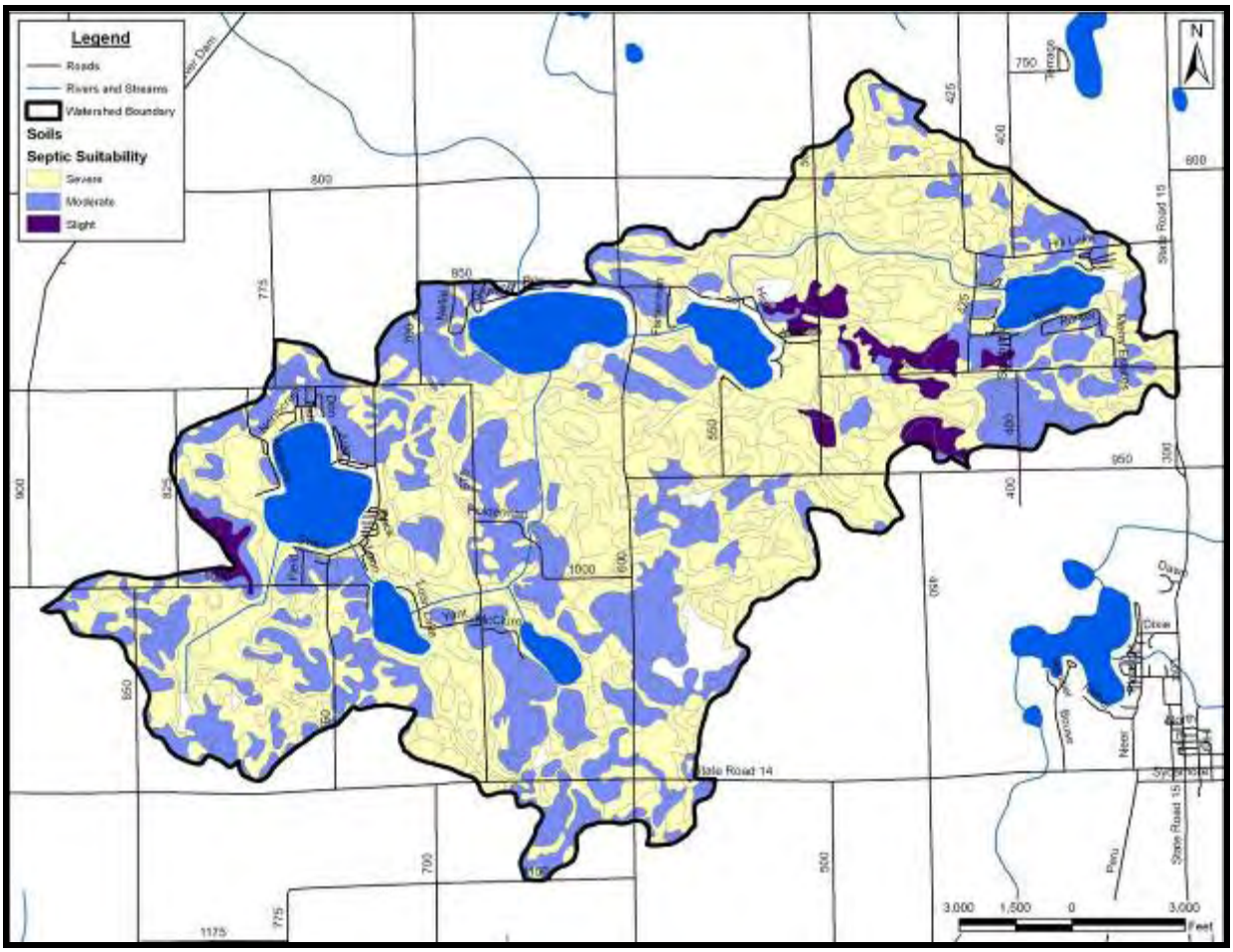


Figure 7. Soil septic tank suitability within the Yellow Creek Lakes watershed.

Soils that are severely limited for use as septic systems cover 7,573 acres (3,064.7 ha or 58%) of the watershed. Severely limited soils cover the Michaels Ditch and Eaton Ditch floodplain, border the eastern shorelines of Loon Lake and the southern shorelines of Diamond Lake, and cover much of the central portion of the Yellow Creek Lakes watershed. Soils that are moderately limited cover an additional 29% or 3,750 acres (1,517.4 ha) of the Yellow Creek Lakes watershed. These soils border nearly the entire shoreline of Hill Lake, border the eastern shorelines of Yellow Creek Lake, McClures Lake, and Loon Lakes, and cover the northern and southern shorelines of Beaver Dam Lake. A large portion of these soils are also found to the west of McClures Lake and adjacent to Yellow Creek. Soils that are rated as slightly limited for septic system usage cover 384 acres (155.6 ha or 3%) of the watershed. Soils that are not rated for septic treatment cover an additional 10%; these areas include a small buffer surrounding each of the six lakes, or areas classified by the soil survey as 'water', other waterbodies or ponds throughout the watershed, and gravels pits.

Table 9. Soil types (series) in the Yellow Creek Lakes watershed and the features restrictive to their suitability to serve as a septic tank absorption field.

Soil Unit	Soil Name	Depth to High Water Table	Restrictive Features
Ao	Aquents-Urban land complex	--	--
AtA	Aubbeenaubbee fine sandy loam	1 to 3 feet	Severe: wetness
Bc	Barry loam	+1 to 1 feet	Severe: ponding
Bp	Brady sandy loam	1 to 3 feet	Severe: wetness
BrA	Bronson sandy loam	2 to 3.5 feet	Severe: wetness
ClB-ClC	Coloma loamy sand	>6 feet	Severe: poor filter
CrA-CrB	Crosier loam	1 to 3 feet	Severe: percs slowly, wetness
De	Del Rey silt loam	1 to 3 feet	Severe: wetness, percs slowly
Ed	Edwards muck	+1 to 0.5 feet	Severe: ponding, percs slowly
Gf	Gilford sandy loam	+0.5 to 1 feet	Severe: ponding, poor filter
Gm	Gilford mucky sandy loam	+0.5 to 1 feet	Severe: ponding, poor filter
He	Histosols and Aquolls	--	--
Ho	Homer sandy loam	1 to 3 feet	Severe: wetness, poor filter
Ht; Hx	Houghton muck	+1 to 1 feet	Severe: subsides, ponding, percs slowly
KoB-KoC	Kosciusko sandy loam	>6 feet	Severe: poor filter
MaA-MaB	Martinsville sandy loam	>6 feet	Slight
MaC	Martinsville sandy loam	>6 feet	Moderate: slope
MbA-MbC	Metea loamy sand	>6 feet	Severe: poor filter
MeA	Metea loamy fine sand	>6 feet	Severe: percs slowly, poor filter
MlB	Miami loam	>6 feet	Severe: percs slowly
MrC3	Miami clay loam	>6 feet	Severe: percs slowly
MzB	Morely-Glynwood complex	>6 feet	Severe: percs slowly
OtA-OtC	Ormas loamy sand	>6 feet	Severe: poor filter
Pa; Pb	Palms muck, drained	+1 to 1 feet	Severe: subsides, ponding
Re	Rensselaer loam	+0.5 to 1 feet	Severe: ponding
RlA-RlB	Riddles fine sandy loam	>6 feet	Moderate: percs slowly
RlC	Riddles fine sandy loam	>6 feet	Moderate: percs slowly, slope
RxB	Riddles-Ormas-Kosciusko complex	>6 feet	Moderate: percs slowly; Severe:
RxC	Riddles-Ormas-Kosciusko complex	>6 feet	Moderate: percs slowly, slope;
Se	Sebewa loam	+1 to 1 feet	Severe: poor filter, ponding
To	Toledo silty clay	+1 to 1 feet	Severe: ponding, percs slowly
Uf	Udorthents-Urban land complex	--	--
Wa	Wallkill silt loam	+0.5 to 1 feet	Severe: ponding, poor filter
Wc	Washtenaw silt loam	+0.5 to 1 feet	Severe: ponding, percs slowly
We	Washtenaw loam	+1 to 1 feet	Severe: ponding, percs slowly
WlB	Wawasee fine sandy loam	>6 feet	Moderate: percs slowly
WlC2	Wawasee fine sandy loam	>6 feet	Moderate: slope, percs slowly
WlD2	Wawasee fine sandy loam	>6 feet	Severe: slope
Wt	Whitaker loam	1 to 3 feet	Severe: wetness

Source: Staley, 1989.

While all septic system use in the Yellow Creek Lakes watershed has the potential to impact the water quality of the area Lakes, the ability of the soil immediately adjacent to each of the lakes to treat septic effluent has a more direct effect on the individual lakes' water quality than the ability of the soil in other areas of the watershed. For example, the soils directly adjacent to Diamond Lake have a more direct effect on Diamond Lake than the soils in other areas of the watershed. Likewise, the soils directly adjacent to Hill Lake have a more direct effect on the water quality within Hill Lake. Therefore, the following discussion focuses on the soils adjacent to Beaver Dam, Diamond, Hill, Loon, McClures, and Yellow Creek Lakes respectively.

Beaver Dam Lake

Table 10 summarizes the soils' suitability for use as septic tank absorption fields, while Figure 8 shows the soil units surrounding Beaver Dam Lake. A short description of the soils listed in the table follows.

Table 10. Soils adjacent to Beaver Dam Lake and their suitability for septic tank absorption fields.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
Ao	Aquents-Urban land complex	--	--
Bc	Barry loam	+1 to 1 feet	Severe: ponding
Bp	Brady sandy loam	1 to 3 feet	Severe: wetness
Ed	Edwards muck	+1 to 0.5 feet	Severe: ponding, percs slowly
Ht	Houghton muck, undrained	+1 to 1 feet	Severe: subsides, ponding, percs slowly

Source: Staley, 1989.

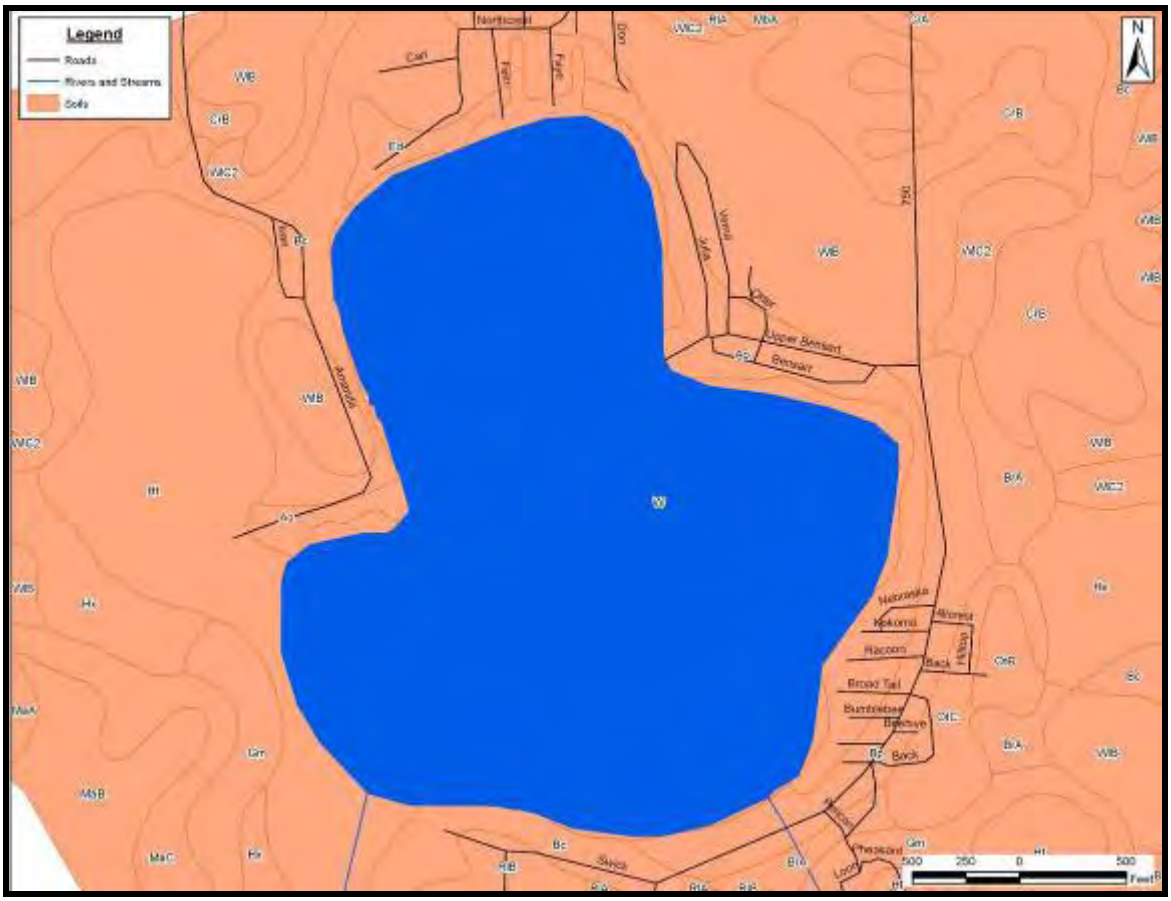


Figure 8. Soil series bordering Beaver Dam Lake.

Aquents-Urban land complex (Ao) soils occurs as nearly level areas on outwash plains, till plains, and moraines. The suitability of these soils for most uses depends on the thickness and texture of the fill, the depth to seasonal high water table, and the nature of underlying material. Because of the flooding, the soils are generally unsuitable as sites for buildings and septic tank absorption fields.

Barry Loam (Bc) soils are nearly level, poorly drained soils found on broad flats, in shallow, narrow, meandering depressions, and in drainageways on till plains and moraines. This soil is moderately permeable and the available water capacity is high with runoff being slow or ponded. Because of ponding and the water table located near or above the surface during winter and spring, this soil is generally unsuited to septic tank absorption fields.

Brady sandy loam (Bp) soils are nearly level, somewhat poorly drained soils in outwash plains. Permeability is moderately rapid in the subsoil of the Brady soil and very rapid in the underlying material with runoff being very slow. The Brady soils are severely limited for septic tank absorption fields due to the wetness. If utilized for septic tank absorption field, interceptor drains around the outer edge of the absorption field will help remove excess water.

Edwards muck (Ed) soils are nearly level, very poorly drained soils found in depressions and along the edges of lakes and streams. In most places it is frequently ponded by runoff from the higher adjacent soils. Shallow water generally covers them for some portion of the year. These soils are unsuitable for sanitary facilities due to ponding and permeability issues.

Houghton muck, undrained (Ht) soils are nearly level, very poorly drained soils located in broad depressions on outwash plains and around lakes. This soils type is also found in small depressions on uplands. The Houghton soil is moderately rapidly permeable to moderately slowly permeable and the available water capacity is very high. Runoff is very slow or ponded and the water table is near or above the surface most of the year. Due to ponding, this soil is generally unsuitable for septic tank absorption fields.

All of the soils that border Beaver Dam Lake are severely limited for use as a septic tank absorption field. Given these the limitations of the soil, residents in existing homes should take steps to properly care for their septic systems, such as cleaning their septic tanks regularly, avoiding the disposal of household chemicals that may kill soil bacteria, and implementing water conservation measures to alleviate strain on the system. Lake residents should work with the county health department, county planning, and builders to ensure the appropriate adjustments, such as installing large septic leach fields, are made to overcome any limitations posed by the soil when new homes or developments are constructed around the lake.

Diamond Lake

Table 11 summarizes the soils' suitability for use as septic tank absorption fields around Diamond Lake while, Figure 9 shows the soil units surrounding Diamond Lake. Following Figure 9 is a short description of the Ormas loamy sand and Sebewa loam soils listed in the table. For a description of the remaining soils see the discussion above, under the Beaver Dam Lake section.

Table 11. Soils adjacent to Diamond Lake and their suitability for septic tank absorption fields.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
Ao	Aquents-Urban land complex	--	--
Ed	Edwards muck	+1 to 0.5 feet	Severe: ponding, percs slowly
Ht	Houghton muck	+1 to 1 feet	Severe: subsides, ponding, percs slowly
OtB	Ormas loamy sand, sandy substratum	>6 feet	Severe: poor filter
Se	Sebewa loam	+1 to 1 feet	Severe: poor filter, ponding

Source: Staley, 1989.

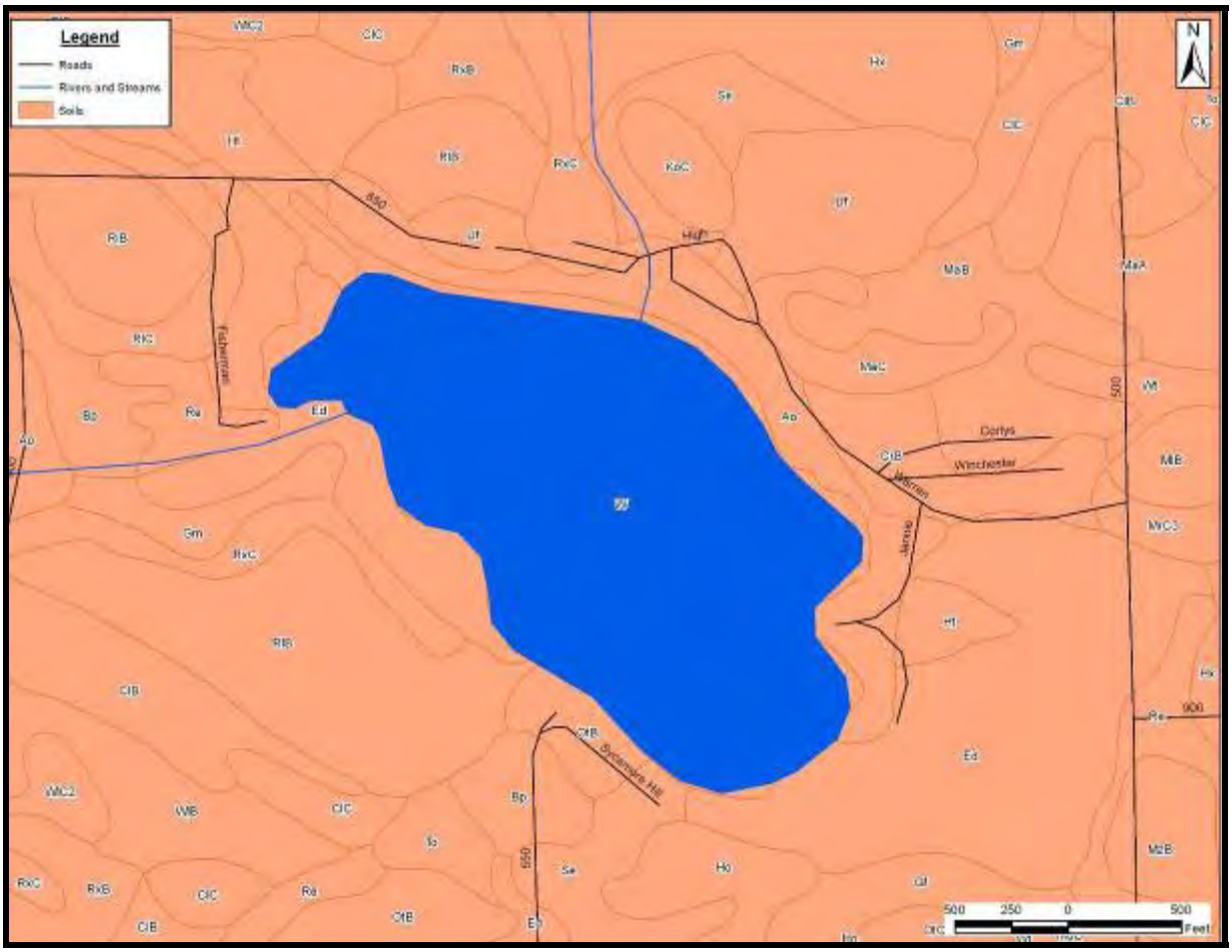


Figure 9. Soil series bordering Diamond Lake.

Ormas loamy sand, sandy substratum (OtB) soil is a gentle sloping, well drained soil found on high terraces, in areas of valley fill, and on moraines. The Ormas soil is rapidly permeable and moderately rapidly permeable in the subsoil and rapidly permeable in the underlying material. Due to the rapid permeability of these soil types, they do not provide adequate filtering capability for septic tank absorption fields and may pollute the groundwater.

Sebewa loam (Se) is a nearly level, poorly drained soil on outwash plains and terraces. In some concave areas it is frequently ponded by runoff from the higher adjacent soils. Permeability is moderate in the subsoil and rapid in the underlying material with runoff being very slow or ponded. Due to ponding, this soil is generally unsuitable as a site for septic tank absorption fields.

Diamond Lake is surrounded by soils that are severely limited for septic tank absorption fields. The same advice discussed above for Beaver Dam Lake applies to Diamond Lake.

Hill Lake

Figure 10 shows the soil units surrounding Hill Lake, while Table 12 summarizes the soils' suitability for use as septic tank absorption fields. Following Table 12 is a short description of the Gilford mucky sandy loam, Histosols and Aquolls, and drained Houghton muck soils listed in the table. For a description of the remaining soils see the discussion above, under the Beaver Dam and Diamond Lake sections.

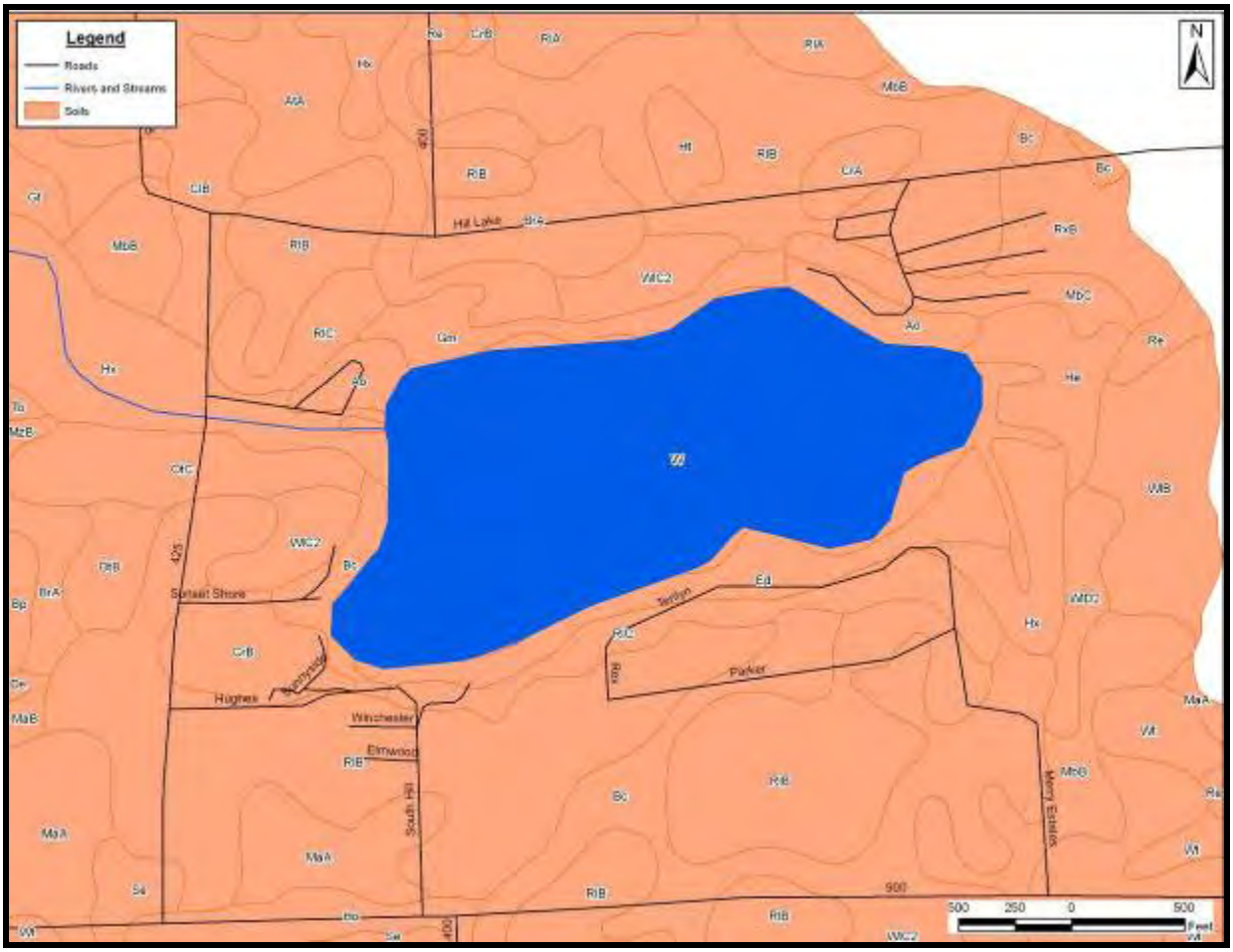


Figure 10. Soil series bordering Hill Lake.

Table 12. Soils adjacent to Hill Lake and their suitability for septic tank absorption fields.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
Ao	Aquents-Urban land complex	--	--
Bc	Barry loam	+1 to 1 feet	Severe: ponding
Ed	Edwards muck	+1 to 0.5 feet	Severe: ponding, percs slowly
Gm	Gilford mucky sandy loam	+0.5 to 1 feet	Severe: ponding, poor filter
He	Histosols and Aquolls	--	--
Hx	Houghton muck, drained	+1 to 1 feet	Severe: subsides, ponding, percs slowly

Source: Staley, 1989.

Giilford muck sandy loam (Gm) soils are nearly level, very poorly drained soils in depressions on broad outwash plains. In most cases it is frequently ponded by runoff from the higher adjacent soils. The Gilford soil has a moderately rapid permeability in the subsoil and very rapid in the underlying material. Runoff is very slow and the water table is near or above the surface during winter and early spring. Due to ponding, this soil is generally unsuitable as a site for septic tank absorption fields.

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.

Houghton muck, drained (Hx) soils are nearly level, very poorly drained soils located in broad depressions on outwash plains and around lakes. This soil type is also found in small depressions on uplands. The Houghton soil is moderately rapidly permeable to moderately slowly permeable and the available water capacity is very high. Runoff is very slow or ponded and the water table is near or above the surface most of the year. Due to ponding, this soil is generally unsuitable for septic tank absorption fields.

The entire shoreline of Hill Lake has soils that are severely limited for septic tank absorption fields. Several hundred feet back from the lakeshore the soils are only moderately limited for absorption fields on the south west and north shorelines. Development should be limited to these soils, unless a sewage treatment system is utilized off of the lake. The advice given above for Beaver Dam Lake applies to Hill Lake as well.

Loon Lake

Table 13 summarizes the soils' suitability for use as septic tank absorption fields, while Figure 11 shows the soil units surrounding Loon Lake. Following Figure 11 is a short description of the soils listed in the table with the exception of the Barry loam and Houghton muck soils which can be found in the preceding sections.

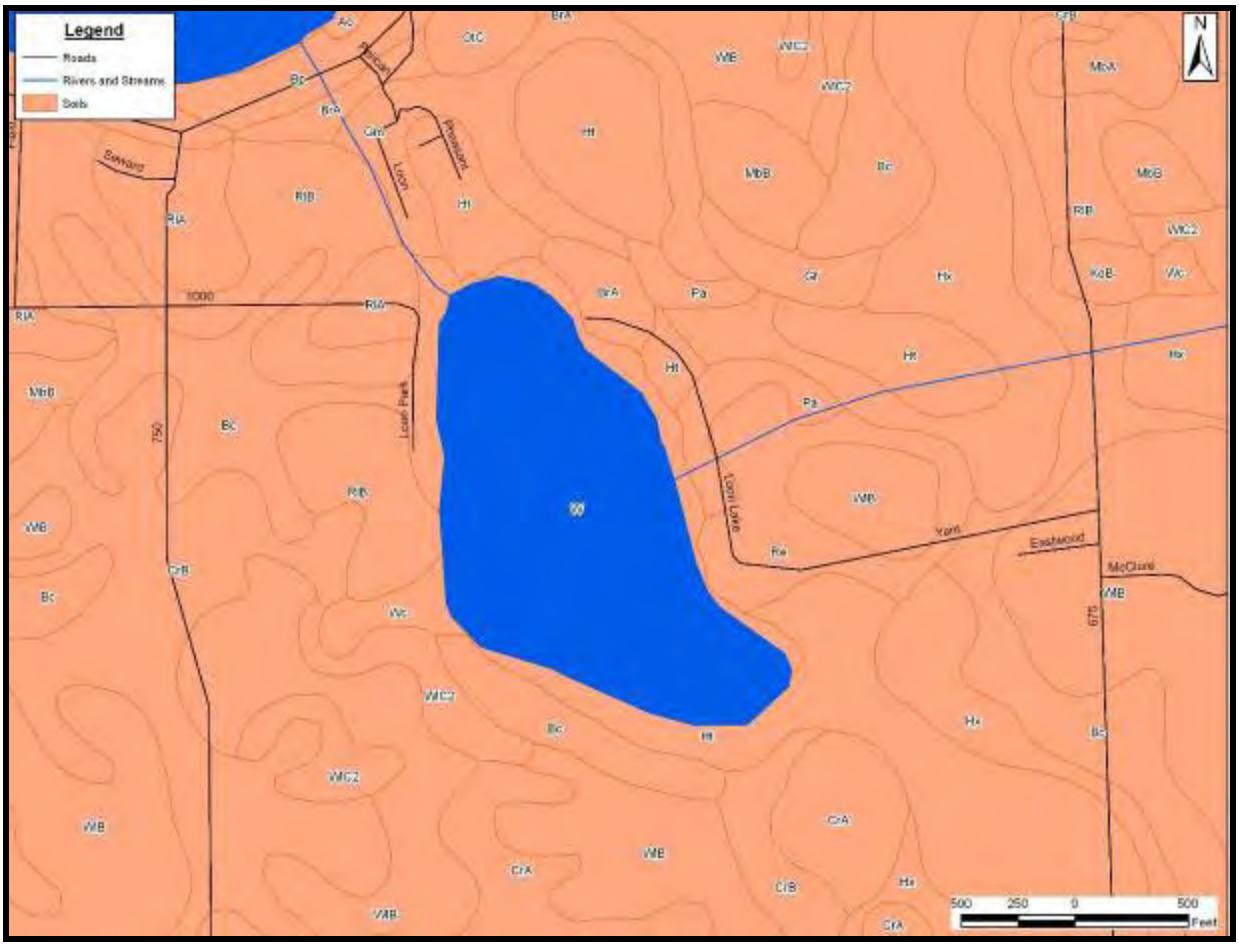


Figure 11. Soil series bordering Loon Lake.

Table 13. Soils adjacent to Loon Lake and their suitability for septic tank absorption fields.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
Bc	Barry loam	+1 to 1 feet	Severe: ponding
BrA	Bronson sandy loam	2 to 3.5 feet	Severe: wetness
Ht	Houghton muck	+1 to 1 feet	Severe: subsides, ponding, percs slowly
Pa	Palms muck, drained	+1 to 1 feet	Severe: subsides, ponding
Re	Rensselaer loam	+0.5 to 1 feet	Severe: ponding
RIB	Riddles fine sandy loam	>6 feet	Moderate: percs slowly
Wc	Washtenaw silt loam	+0.5 to 1 feet	Severe: ponding, percs slowly

Source: Staley, 1989.

Bronson sandy loam (BrA) soils are nearly level, moderately well drained soils on broad outwash plains and on low moraines. The Bronson soil is moderately rapid in permeability within the subsoil and rapid in the underlying material. Runoff is slow and the water table is at a depth typically between 2 – 3.5 feet during winter and early spring. The Bronson soils are severely limited as site for septic tank absorption due to wetness.

Palms muck, drained (Pa) soils are poorly drained, organic soils found in depressional areas and on outwash plains. Typically, these soils are located adjacent to lakes and streams. Shallow water generally covers them for some portion of the year. The NRCS (2003) characterizes these soils as optimal for wildlife habitat but poor for all other uses. These soils are absolutely unsuitable for sanitary facilities due to ponding and permeability issues. Because these soils generally occupy some of the lowest points on the landscape, pumping systems are necessary for adequate drainage.

Rensselaer loam (Re) soils are very poorly drained soils which are frequently ponded. The ponding severely limits these soils for siting septic tank absorption fields. The water table is typically near the soil surface in winter and spring months. Proper septic system function in these soils is severely limited because the soil tends to remain wet and does not readily absorb liquid waste.

Riddles fine sandy loam, 2 to 6 percent slope (RIB) soils are gentle sloping, well drained soils located on dissected till plains and on benches and tops of ridges on moraines. Permeability is moderate and runoff is medium in cultivated areas. Because of the moderate permeability these soils are moderately limited as sites for septic tank absorption fields. Creating a larger absorption area will improve the capacity of the field to absorb the effluent.

Washtenaw silt loam (Wc) soils are nearly level, poorly drained soils in depressions and drainageways on till plains and moraines which are often ponded by runoff from higher adjacent soils. Permeability is moderate in the upper part of the soil and slow in the subsoil and underlying material. Runoff is very slow or ponded and the water table is at or above the surface during winter and early spring. Due to ponding, these soils are generally unsuitable for septic tank absorption fields.

Loon Lake is also surrounded by soils that are severely limited for septic tank absorption fields. There is not a location within 250 feet (76 m) of the lake that does not have some limitation for septic systems. Therefore, any proposed development of the shoreline should consider off site wastewater treatment. Given these the limitations of the soil, residents in existing homes should take steps to properly care for their septic systems, such as cleaning their septic tanks regularly, avoiding the disposal of household chemicals that may kill soil bacteria, and implementing water conservation measures to alleviate strain on the system. Lake residents should work with the county health department, county planning, and builders to overcome the limitations if expanding their current residents or building new homes.

McClures Lake

Figure 12 shows the soil units surrounding McClures Lake, while Table 14 summarizes the soils' suitability for use as septic tank absorption fields. Following Table 14 is a short description of the Gilford sandy loam soils listed in the table. The remainder of the soils adjacent to McClures Lake are discussed in the preceding sections.

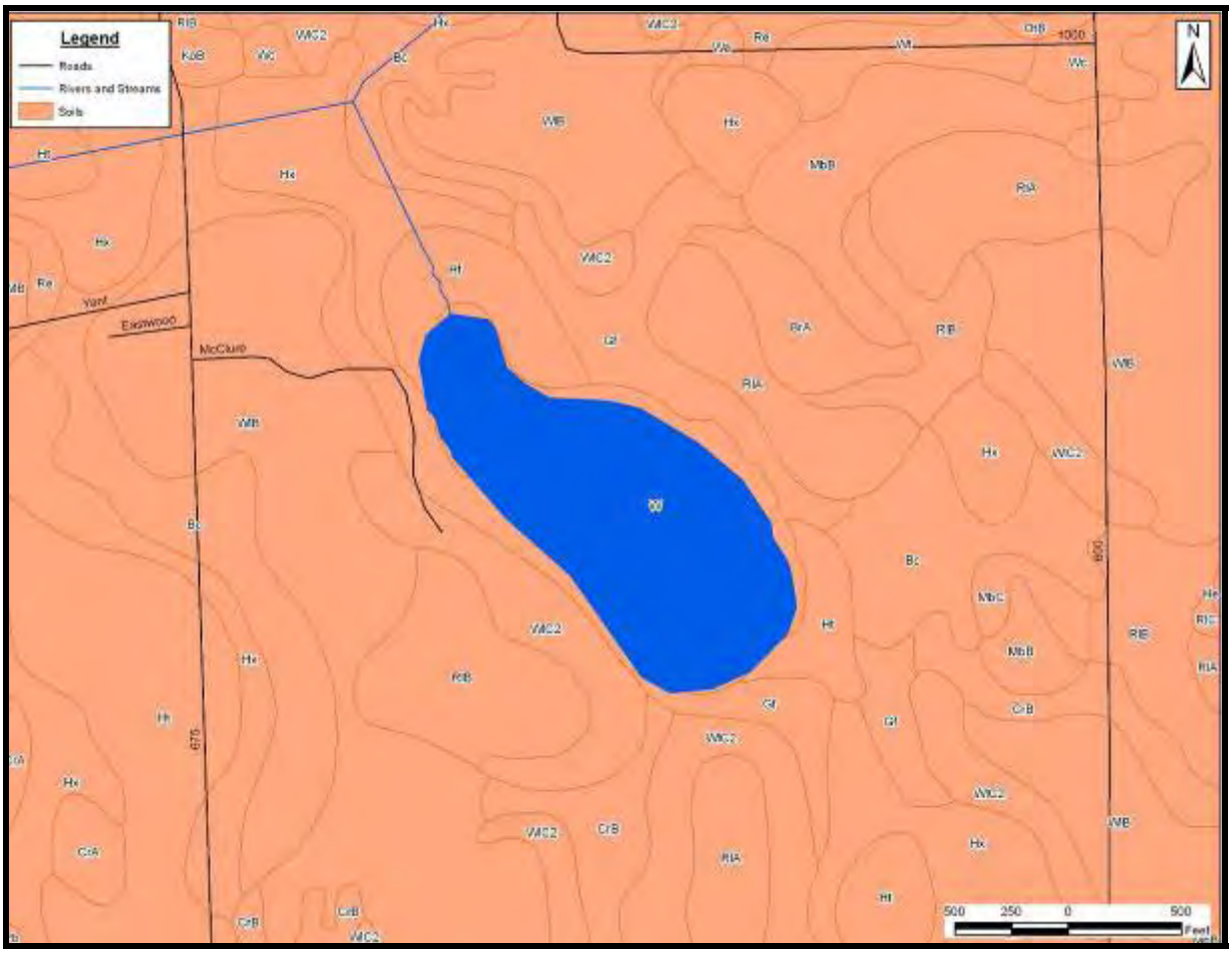


Figure 12. Soil series bordering McClures Lake.

Table 14. Soils adjacent to McClures Lake and their suitability for septic tank absorption fields.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
Bc	Barry loam	+1 to 1 feet	Severe: ponding
Gf	Gilford sandy loam	+0.5 to 1 feet	Severe: ponding, poor filter
Ht	Houghton muck	+1 to 1 feet	Severe: subsides, ponding, percs slowly

Source: Staley, 1989.

Gilford sandy loam (Gf) soils are nearly level, very poorly drained soils located on benches along old drainageways and on broad outwash plains. Some depressional areas are frequently ponded by runoff from higher adjacent soils. Permeability is moderately rapid in the subsoil of the Gilford soil and very rapid in the underlying material with very slow runoff and ponding. These soils are generally unsuited to septic tank absorption fields due to ponding.

Like Loon Lake, McClures Lake is surrounded by soils that are severely limited for septic tank absorption fields. While there is currently very limited development on McClures Lake, any proposed development of the shoreline should consider off site wastewater treatment. Existing

residents and the camp should follow the recommendations given above for Loon Lake and pay special attention to system maintenance.

Yellow Creek Lake

Figure 13 shows the soil units surrounding Yellow Creek Lake, while Table 15 summarizes the soils' suitability for use as septic tank absorption fields. A description of the soils listed in the table can be found in the preceding sections.

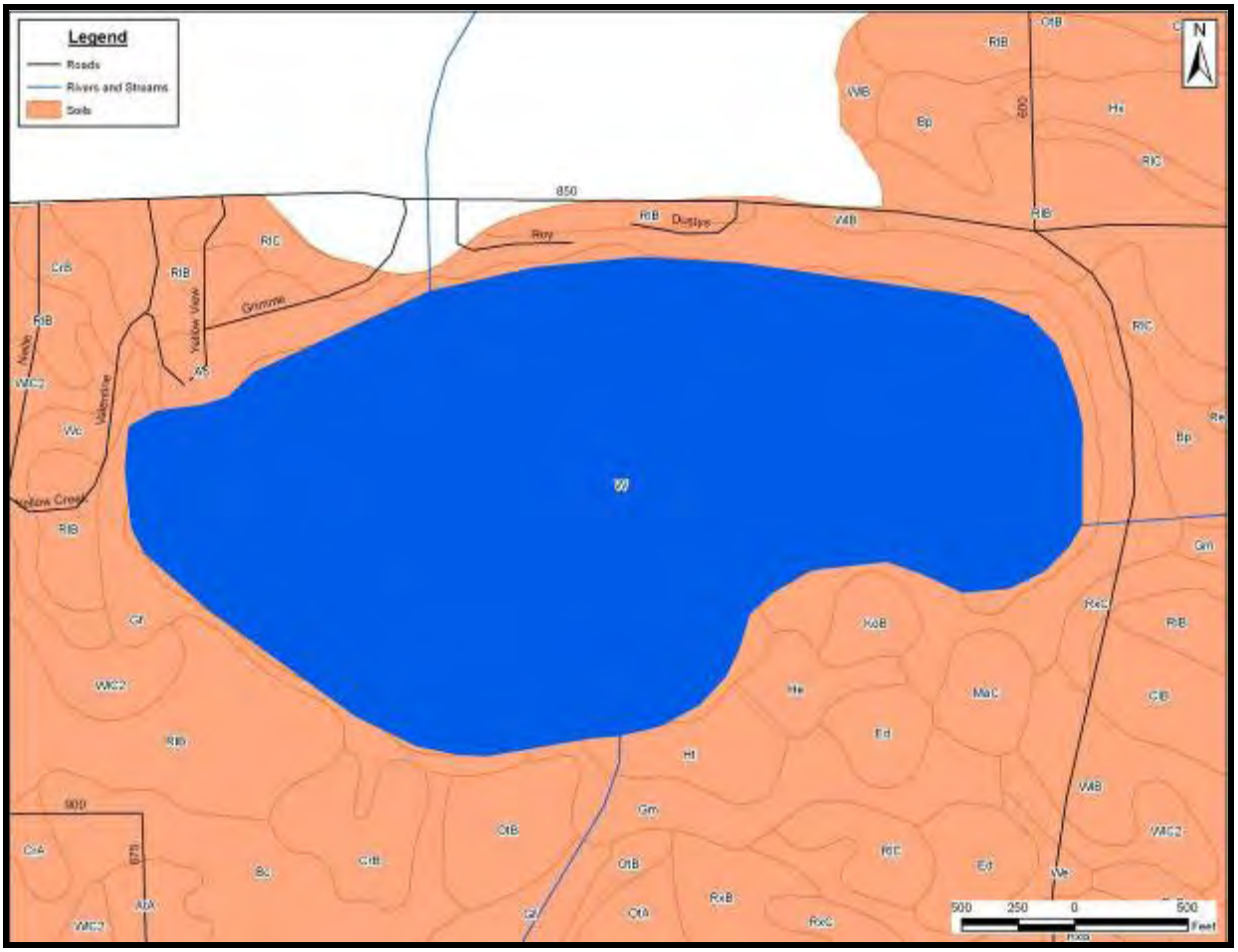


Figure 13. Soil series bordering Yellow Creek Lake.

Table 15. Soils adjacent to Yellow Creek Lake and their suitability for septic tank absorption fields.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
Ao	Aquents-Urban land complex	--	--
Gf	Gilford sandy loam	+0.5 to 1 feet	Severe: ponding, poor filter
Gm	Gilford mucky sandy loam	+0.5 to 1 feet	Severe: ponding, poor filter
He	Histosols and Aquolls	--	--
Ht	Houghton muck	+1 to 1 feet	Severe: subsides, ponding, percs slowly

Source: Staley, 1989.

Yellow Creek Lake, like many of the lakes in this watershed, is bordered by soils that are at best, moderately suitable for septic tank absorption fields. There is a high probability that existing systems are contributing above average nutrient loading to the lake. Existing residents should schedule regular maintenance of their septic systems and take special pre-cautions to protect these systems from damage. Before consideration of new construction or the expansion of existing homes residents should work with the county health department and builders to ensure the appropriate adjustments are made to overcome any limitations posed by the soil.

2.5 Natural History

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

Homoya et al. (1985) noted that prior to European settlement, the region was a mixture of numerous natural community types, including bog, fen, marsh, prairie, sedge meadow, swamp, seep spring, lake, and deciduous forest. The dry to dry-mesic uplands were likely forested with red oak, white oak, black oak, shagbark hickory, and pignut hickory. More mesic areas probably harbored beech, sugar maple, black maple, and tulip poplar. Omernik and Gallant (1988) describe the region as consisting mostly of cropland agriculture, with remnants of natural forest cover. Mesic forests are dominated by American beech and sugar maple, with a significant component of white oak, black oak, northern red oak, yellow poplar, hickory, white ash, and black walnut. Petty and Jackson (1966) list pussy toes, common cinquefoil, wild licorice, tick clover, blue phlox, waterleaf, bloodroot, Joe-pye-weed, woodland asters, goldenrods, wild geranium, and bellwort as common components of the forest understory in the watershed's region. Historical records support the observation that prior to European settlement of the Yellow Creek Lakes watershed dense oak-hickory forests covered the watershed (Petty and Jackson, 1966). White oak was the dominant component of the heavily timbered areas with shagbark hickory, maple, beech, elm, walnut, butternut, and red and black oak as subdominants (Petty and Jackson, 1966; Omernik and Gallant, 1988).

Historically, wet habitat (ponds, swamps, marshes, and bogs) intermingled with the upland habitat throughout the Yellow Creek Lakes watershed. The hydric soils map and an 1876 map of Kosciusko County indicate that wetland habitat existed throughout the Yellow Creek Lakes watershed. These wet habitats supported very different vegetative communities than the drier portions of the landscape (Homoya et. al, 1985). Sycamore, American elm, red elm, green ash, silver maple, red maple, cottonwood, hackberry, and honey locust likely dominated the floodplain forests. Swamp communities bordering lakes typically consisted of red maple, silver

maple, green ash, American elm, black ash, and yellow birch. Marshes associated with lake communities typically contained swamp loosestrife, cattails, bulrush, marsh fern, marsh cinquefoil, and sedges. Aquatic species within the lake community included spatterdock, water shield, fragrant water lily, pickerel weed, coonttail, eelgrass, pondweeds, Virginia arrow arum, and sedges.

2.6 Land Use

Just as soils, climate, and geology shape the native communities within the watershed, how the land in a watershed is used can impact the water quality of a waterbody. Land use can have a significant impact on water quality since different land use types receive different pollutants and have different capacities for retaining and/or assimilating pollutants. For example, residential areas are often subject to high rates of fertilizer application, whereas forests often receive little human-applied fertilizer. Residential areas do not have the same capacity as forests to assimilate pollutants that reach the landscape. Forested and other vegetated landscapes assimilate nutrients that reach these areas via plant growth. Land uses with high amounts of impervious surfaces have reduced, or in extreme cases, no ability to retain or assimilate pollutants.

Pollutants that cannot be assimilated by the landscape leave the landscape during rain events. Researchers have examined the pollutant loss from different landscapes and developed pollutant export coefficients for different landscapes. Pollutant export coefficients are a measure of the rate a pollutant is lost from a landscape per unit area of the landscape. To illustrate how different land types assimilate pollutants, Table 16 presents some mid-range phosphorus export coefficients for different land use types. (Phosphorus was selected for this illustration since it is one of the pollutants of critical concern in lakes. Phosphorus is the nutrient that typically controls algae and rooted plant growth in aquatic ecosystems.) As shown in Table 16, high and low density residential land, commercial land, agricultural land, and golf courses have relatively high phosphorus export rates compared to more natural landscapes such as wetlands, forests, and old fields. The export coefficients provided in Table 16 are simply estimates. The use of best management practices, such as filter strips on agricultural land or stormwater infiltration trenches on commercial land, can reduce the export of pollutants to adjacent waterways.

Table 16. Mid-range phosphorus export coefficients.

Land Use	Phosphorus Export Coefficient (kg/ha-yr)
Agricultural	1.0
EM/SS Wetland	0.1
Emergent Wetland	0.1
Forested	0.2
High Density Residential	2.5
Low Density Residential	0.8
Open Space	0.2
Open Water	0.0
High Density Commercial	2.5
Low Density Commercial	1.5
Old Field	0.2
Golf Course	1.5

Source: Reckhow et al. 1980 and Reckhow and Simpson, 1980.

Several researchers have also examined the impact of specific urban and suburban land uses on water quality (Bannerman et. al, 1993; Steuer et al., 1997; Waschbusch et al., 2000).

Bannerman et al. (1993) and Steuer et al. (1997) found high mean phosphorus concentrations in runoff from residential lawns (2.33 to 2.67 mg/L) and residential streets (0.14 to 1.31 mg/L). These concentrations are well above the threshold at which lakes might begin to experience algae blooms. (Lakes with total phosphorus concentrations greater than 0.03 mg/L will likely experience algae blooms.) Finally, the Center for Watershed Protection has estimated the association of increased levels of impervious surface in a watershed with increased delivery of phosphorus to receiving waterbodies (Caraco and Brown, 2001). Land use directly affects the amount of impervious surface in a watershed. Because of the effect watershed land use has on water quality of the receiving lakes, mapping and understanding a watershed's land use is critical in directing water quality improvement efforts.

Figure 14 and Table 17 present current land use information for the Yellow Creek Lakes watershed. (Land use data from the U.S. Geological Survey (USGS) forms the basis of Figure 14. Corrections to the Indiana Land Cover Data Set were made based on 2003 aerial photographs.) Like many Indiana watersheds, agricultural land use dominates the Yellow Creek Lakes watershed accounting for approximately 80% of the watershed. Row crop agriculture makes up the greatest percentage of agricultural land use at 70% while pastures or hay another 10%. Most of the agricultural land in the Yellow Creek Lakes watershed and throughout Kosciusko County (USDA, 2002) is used for growing soybeans and corn. Kosciusko County ranks the highest of all 92 state counties for chicken production (USDA, 2002). Additionally, Kosciusko County ranks among the top five Indiana counties for total value of farmland and production, total number of and sales of cattle and calves and the sale of poultry and eggs. County-wide tillage transect data for Kosciusko County provide an estimate for the portion of cropland in conservation tillage for the Yellow Creek watershed. In Kosciusko County, soybean producers utilize no-till methods on 68% of soybean fields and some form of reduced tillage on 28% of soybean fields (USDA, 2002). Kosciusko County corn producers used no-till methods on 68% of corn fields and some form of reduced tillage on 24% of corn fields in production (USDA, 2002). Overall, Kosciusko County ranked in the top half of Indiana counties for usage of no-till on corn and soybean fields. Additionally, the percentages of fields on which no-till methods were used in Kosciusko County were near the statewide median percentage for soybean and corn production.

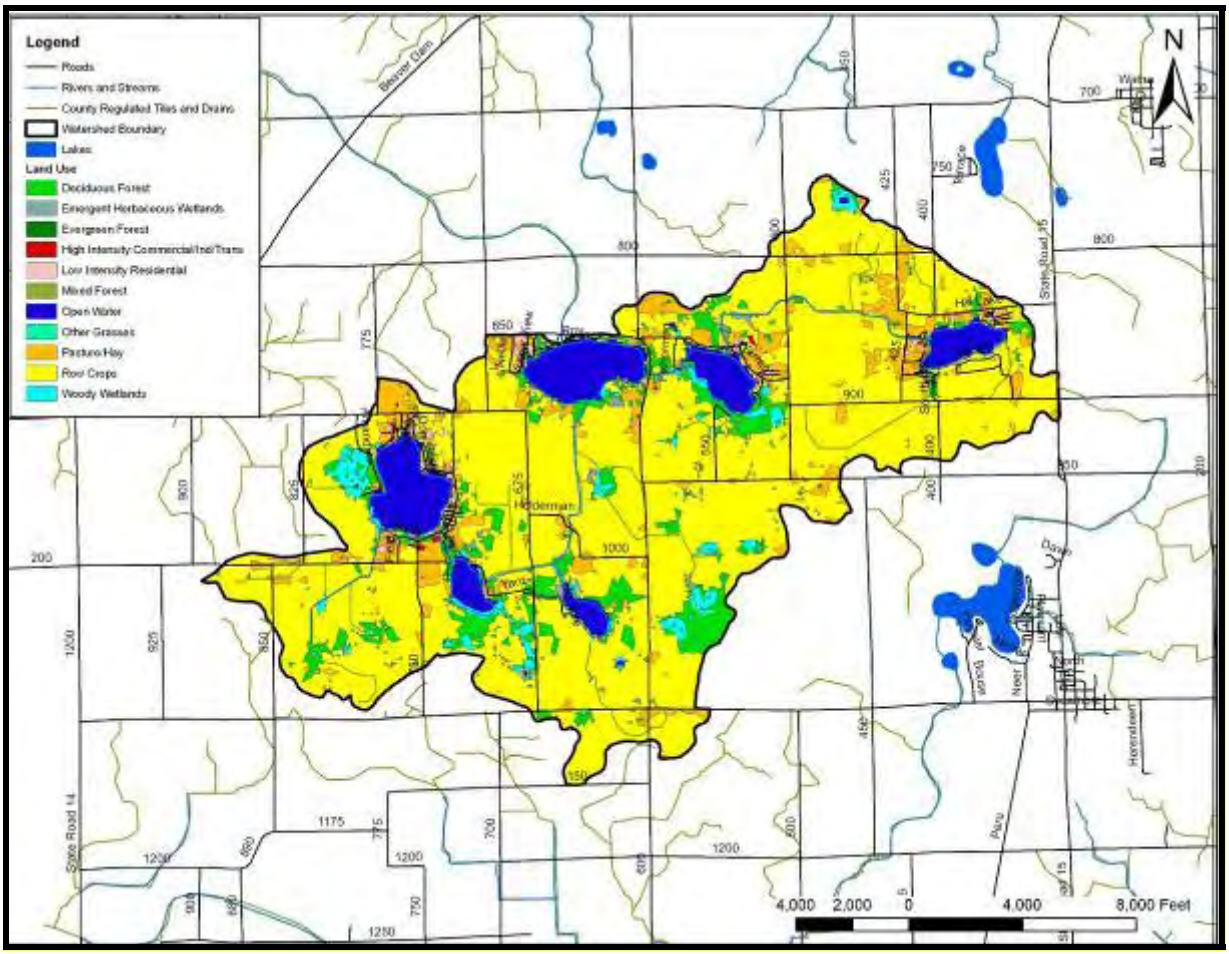


Figure 14. Land use in the Yellow Creek Lakes watershed.

Table 17. Detailed land use in the Yellow Creek Lakes watershed.

	Area (ha)	Area (ac)	Percent of Watershed
Row Crops	3,721.7	9,196.4	69.5%
Pasture/Hay	523.2	1,292.8	10.1%
Open Water	460.3	1,137.5	9.5%
Deciduous Forest	369.7	913.6	6.5%
Woody Wetlands	136.1	336.4	2.2%
Low Intensity Residential	63.4	156.7	1.3%
Emergent Herbaceous Wetlands	26.1	64.4	0.5%
High Intensity Commercial	11.1	27.4	0.3%
High Intensity Residential	4.4	10.8	0.1%
Evergreen Forest	0.5	1.3	<0.1%
Mixed Forest	0.1	0.3	<0.1%
Entire Watershed	**5,316.7**	**13,137.7**	**100%**

Native landscapes, including forested areas and wetlands, cover approximately 9% of the watershed. Open water from the six lakes within Yellow Creek Lakes watershed accounts for an additional 10% of the watershed. Approximately 2% of the watershed is used for residential or commercial purposes. Low intensity residential areas account for a majority of the residential

and commercial development within the watershed. (In the Indiana Land Cover Data Set, the USGS defines low intensity residential areas as those areas which consist largely of single-family homes where impervious surfaces (rooftops, roads, sidewalks, etcetera) cover 30 to 80% of the landscape.) Using this definition, and assuming that impervious surfaces cover approximately 50% of the residential land use (an estimate on the low side of the range), impervious surfaces cover approximately 1% of the watershed.

2.6.1 Beaver Dam Lake Watershed

Agricultural land use dominates the Beaver Dam Lake watershed (Table 18). Row crop agriculture covers approximately 65% of the watershed, while pasture or hay covers an additional 10% of the watershed. Natural landscapes, such as forests and wetlands, account for 6% and 4% of the Beaver Dam Lake watershed, respectively. Open water within Beaver Dam Lake accounts for approximately 12% of the watershed. Commercial and residential land uses cover the remaining 3% of the watershed.

Table 18. Detailed land use in the Beaver Dam Lake watershed.

	Area (ha)	Area (ac)	Percent of Watershed
Row Crops	331.8	820.0	64.8%
Open Water	62.9	155.4	12.3%
Pasture/Hay	52.3	129.2	10.2%
Deciduous Forest	32.7	80.8	6.4%
Woody Wetlands	18.5	45.8	3.6%
Low Intensity Residential	10.5	26.0	2.1%
High Intensity Commercial	1.7	4.3	0.3%
High Intensity Residential	1.1	2.7	0.2%
Emergent Herbaceous Wetlands	0.7	1.6	0.1%
Evergreen Forest	0.1	0.1	<0.1%
Entire Watershed	**512.3**	**1,265.9**	**100%**

2.6.2 Diamond Lake Watershed

Agricultural land use dominates the Diamond Lake watershed (Table 19). Row crop agriculture covers approximately 71% of the watershed, while pasture or hay covers an additional 9% of the watershed. Natural landscapes, such as forests and wetlands, account for 8% and 3% of the Diamond Lake watershed, respectively. Open water within Diamond Lake accounts for approximately 8% of the watershed. Commercial and residential land uses cover the remaining 1% of the watershed.

Table 19. Detailed land use in the Diamond Lake watershed.

	Area (ha)	Area (ac)	Percent of Watershed
Row Crops	1,868.9	4,618.1	70.7%
Pasture/Hay	241.9	597.8	9.1%
Open Water	216.9	536.0	8.2%
Deciduous Forest	199.4	492.7	7.5%
Woody Wetlands	68.4	169.1	2.6%
Low Intensity Residential	27.8	68.6	1.0%
Emergent Herbaceous Wetlands	15.1	37.2	0.6%
High Intensity Commercial	4.3	10.7	0.2%
High Intensity Residential	1.6	4.0	0.1%
Evergreen Forest	0.4	1.0	<0.1%
Mixed Forest	0.1	0.1	<0.1%
Entire Watershed	**2,644.7**	**6,535.3**	**100%**

2.6.3 Hill Lake Watershed

Agricultural land use dominates the Hill Lake watershed (Table 20). Row crop agriculture covers approximately 62% of the watershed, while pasture or hay covers an additional 16% of the watershed. Natural landscapes, such as forests and wetlands, account for 4.5% and 0.2% of the Hill Lake watershed, respectively. Open water within Hill Lake accounts for approximately 14% of the watershed. Commercial and residential land uses cover the remaining 3% of the watershed.

Table 20. Detailed land use in the Hill Lake watershed.

	Area (ha)	Area (ac)	Percent of Watershed
Row Crops	121.1	299.2	62.4%
Pasture/Hay	30.6	75.6	15.8%
Open Water	27.3	67.4	14.1%
Deciduous Forest	8.7	21.5	4.5%
Low Intensity Residential	4.7	11.5	2.4%
High Intensity Commercial	1.0	2.5	0.5%
Emergent Herbaceous Wetlands	0.3	0.8	0.2%
High Intensity Residential	0.3	0.7	0.1%
Woody Wetlands	0.1	0.1	0.0%
Entire Watershed	**193.9**	**479.2**	**100%**

2.6.4 Loon Lake Watershed

Agricultural land use dominates the Loon Lake watershed (Table 21). Row crop agriculture covers approximately 62% of the watershed, while pasture or hay covers an additional 10% of the watershed. Natural landscapes, such as forests and wetlands, account for 9% and 5% of the Loon Lake watershed, respectively. Open water within Loon Lake accounts for approximately 11% of the watershed. Commercial and residential land uses cover the remaining 3% of the watershed.

Table 21. Detailed land use in the Loon Lake watershed.

	Area (ha)	Area (ac)	Percent of Watershed
Row Crops	434.0	1072.5	62.1%
Open Water	79.7	197.0	11.4%
Pasture/Hay	73.4	181.5	10.5%
Deciduous Forest	62.2	153.8	8.9%
Woody Wetlands	31.7	78.3	4.5%
Low Intensity Residential	11.2	27.6	1.6%
Emergent Herbaceous Wetlands	3.1	7.6	0.4%
High Intensity Commercial	2.1	5.2	0.3%
High Intensity Residential	1.1	2.7	0.2%
Evergreen Forest	0.1	0.1	0.0%
Entire Watershed	**698.6**	**1726.2**	**100%**

2.6.5 McClures Lake Watershed

Agricultural land use dominates the McClures Lake watershed (Table 22). Row crop agriculture covers approximately 82% of the watershed, while pasture or hay covers an additional 4% of the watershed. Natural landscapes, such as forests and wetlands, account for 7% and 2% of the McClures Lake watershed, respectively. Open water within McClures Lake accounts for approximately 5% of the watershed. Only trace amounts of commercial and residential land uses occur within the watershed.

Table 22. Detailed land use in the McClures Lake watershed.

	Area (ha)	Area (ac)	Percent of Watershed
Row Crops	204.7	505.7	82.3%
Deciduous Forest	16.4	40.4	6.6%
Open Water	13.0	32.2	5.2%
Pasture/Hay	9.3	22.9	3.7%
Emergent Herbaceous Wetlands	3.1	7.6	1.2%
Woody Wetlands	2.4	5.8	1.0%
Entire Watershed	**248.7**	**614.6**	**100%**

2.6.6 Yellow Creek Lake Watershed

Agricultural land use dominates the Yellow Creek Lakes watershed (Table 23). Row crop agriculture covers approximately 70% of the watershed, while pasture or hay covers an additional 9% of the watershed. Natural landscapes, such as forests and wetlands, account for 8% and 3% of the Yellow Creek Lakes watershed, respectively. Open water within Yellow Creek Lake accounts for approximately 8% of the watershed. Commercial and residential land uses cover the remaining 2% of the watershed.

Table 23. Detailed land use in the Yellow Creek Lake watershed.

	Area (ha)	Area (ac)	Percent of Watershed
Row Crops	1,868.9	4,618.1	70.7%
Pasture/Hay	241.9	597.8	9.2%
Open Water	216.9	536.0	8.2%
Deciduous Forest	199.4	492.7	7.5%
Woody Wetlands	68.4	169.1	2.6%
Low Intensity Residential	27.8	68.6	1.1%
Emergent Herbaceous Wetlands	15.1	37.2	0.6%
High Intensity Commercial	4.3	10.7	0.2%
High Intensity Residential	1.6	4.0	0.1%
Evergreen Forest	0.4	1.0	<0.1%
Mixed Forest	0.1	0.1	<0.1%
Entire Watershed	**2,644.7**	**6,535.3**	**100%**

2.7 Wetlands and Floodplain Management Areas

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

The United States Fish and Wildlife Service's (USFWS) National Wetland Inventory (NWI) Map (Figure 15) shows that wetlands cover approximately 16% of the Yellow Creek Lakes watershed. (Table 24 presents the acreage of wetlands by type according to the National Wetland Inventory.) Forested (3%), scrub-shrub (0.3%), and emergent (4%) wetlands cover approximately 7.3% of the watershed. The largest contiguous tracts of wetland habitat lie to the west of Beaver Dam Lake, south of Loon Lake, north of McClures Lake and adjacent to the watershed's streams. Beaver Dam Lake, Diamond Lake, Hill Lake, McClures Lake, Loon Lake, Yellow Creek Lake and several ponds account for the remaining wetland acreage (8.7%).

The Federal Emergency Management Agency (FEMA) has developed floodway maps for most permanent waterbodies in the United States. The Yellow Creek Lakes watershed has been mapped (Figure 15). The IDNR regulates all construction activities within mapped floodways. Structures, excavations, and fills all require permits from the IDNR Division of Water for work in a floodway. The condition of the riparian zones are within these floodway are addressed in the stream section of this report.

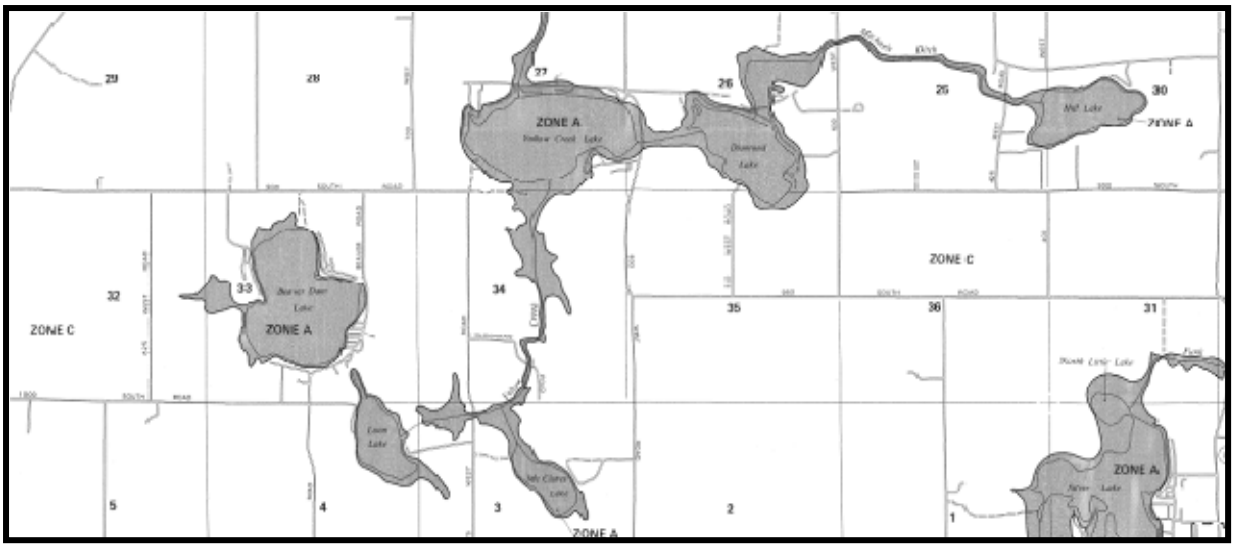


Figure 15: FEMA floodway map in the vicinity of the Yellow Creek Lake's watershed.

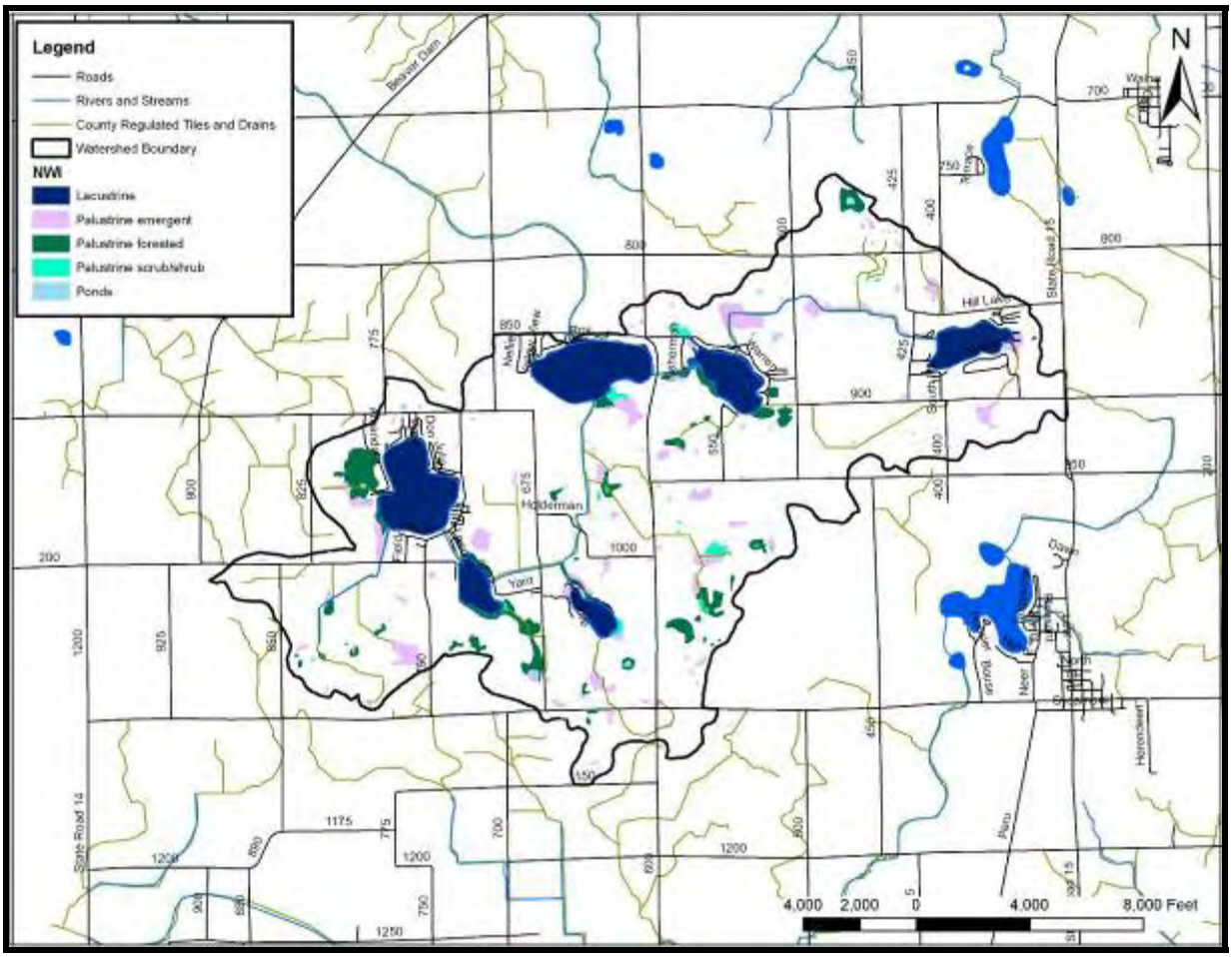


Figure 16. National wetland inventory for the Yellow Creek Lakes watershed.

Table 24. Acreage and classification of wetland habitat, Yellow Creek Lakes watershed.

Wetland Type	Area (acres)	Area (hectares)	Percent of Watershed
Lacustrine	1,129.8	457.2	8.5%
Palustrine emergent	511.8	207.1	4.0%
Palustrine forested	407.0	164.7	3.0%
Palustrine scrub/shrub	36.6	14.8	0.3%
Ponds	21.3	8.6	0.2%
Wetland Total	**2,106.5**	**852.4**	**16%**

The USFWS NWI data and the USGS land use data differ in their acreage estimate of wetlands in the Yellow Creek Lakes watershed. The USGS Land Cover Data Set suggests that wetlands cover approximately 3.2% of the Yellow Creek Lakes watershed and open water covers an additional 8.2% of the watershed. The primary difference between the two data sets is the acreage of emergent wetland. The USFWS reports nearly 512 acres (207 ha) of emergent wetland habitat exists in the Yellow Creek Lakes watershed compared to slightly more than 64 acres (25.9 ha) of emergent wetland habitat reported by the USGS. Additionally, the USFWS reports nearly 444 acres (180 ha) of shrub-scrub and forested wetlands, while the USGS reports only 336 acres (136 ha) of woody wetland. The differences in reported wetland acreage reflects the differences in project goals and methodology used by the different agencies to collect land use data. The NWI maps are likely more accurate in total wetland acreage.

The U.S. Fish and Wildlife Service estimates an average of 2.6% of the nation's wetlands were lost annually from 1986 to 1997 (Zinn and Copeland, 2005). The IDNR estimates that approximately 85% of the state's wetlands have been drained or filled (IDNR, 1996). The greatest loss has occurred in the northern counties of the state such as Kosciusko County. 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 28% of the land in Kosciusko County. Shoreline development around lakes has also significantly reduced wetland acreage.

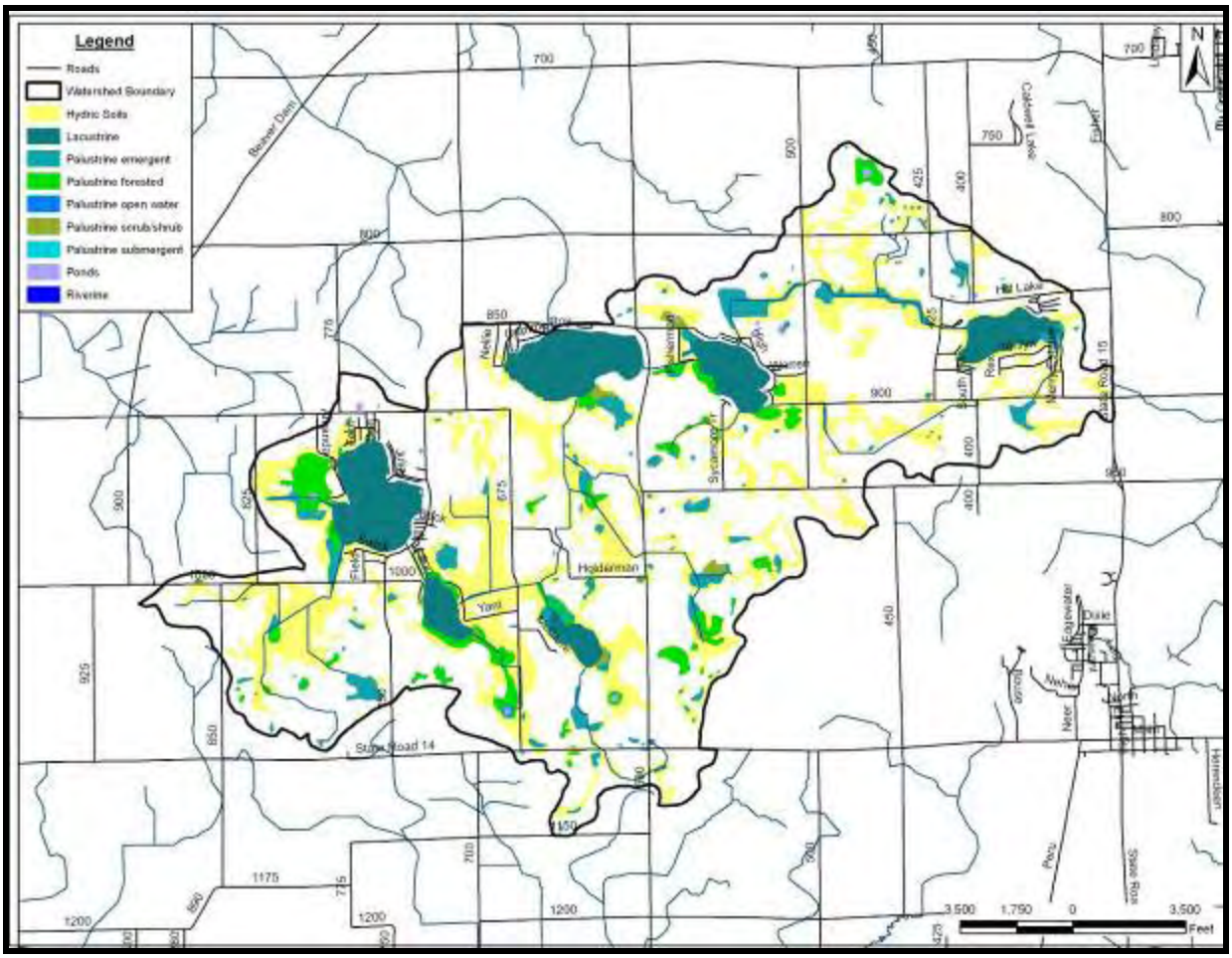


Figure 17. Hydric soils and NWI mapped wetlands in the Yellow Creek Lakes watershed.

Development within the Yellow Creek Lakes watershed has undoubtedly reduced wetland acreage in the watershed as well. Hydric soils, which form under anaerobic and saturated conditions, cover a majority of the watersheds for Beaver Dam Lake and Loon Lake, border the eastern shorelines of McClures Lake and a large portion of the shorelines of Diamond and Hill Lake, and are dotted throughout the watershed (Figure 17). Areas mapped in the wettest of hydric soils, such as Houghton muck, Edwards muck, and Palms muck, have largely remained undeveloped. Overall, hydric soils cover approximately 3,597 acres (1,456 ha or 55%) of the Yellow Creek watershed. When compared to the acreage of wetland mapped by the USFWS NWI map (2,107 acres or 852 ha), nearly 59% of wetlands remain in the Yellow Creek Lakes watershed. However, it should be noted that a majority of the NWI wetlands mapped within the Yellow Creek Lakes watershed are lacustrine (lakes). Soils underlying lakes are not mapped as hydric soils by the soil survey. Excluding the area of the lakes from the calculations of watershed wetland loss, results in 976 acres (394.9 ha) of remaining wetland on the mapped hydric soils. Using this information we calculated that approximately 85% of the historic wetlands in the Yellow Creek Lakes watershed have been drained or filled.

2.8 Natural Communities and Endangered, Threatened, and Rare Species

The Indiana Natural Heritage Data Center database provides information on the presence of endangered, threatened, or rare species; high quality natural communities; and natural areas in Indiana. The Indiana Department of Natural Resources developed the database to assist in

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

No high quality natural communities or natural areas were reported to exist in the Yellow Creeks watershed by IDNR. I naddition, no federally listed endangered, threatened, and rare species are known to exist in the watershed. Three state threatened plants and two state rare plants do inhabit the Yellow Creek Lakes watershed. Appendix B provides a listing of endangered, threatened, and rare species (ETR) documented in the Yellow Creek Lakes watershed. The state of Indiana uses the following definitions when listing species:

- *Endangered*: Any species whose prospects for survival or recruitment with the state are in immediate jeopardy and are in danger of disappearing from the state. This includes all species classified as endangered by the federal government which occur in Indiana. Plants known to occur currently on five or fewer sites in the state are considered endangered.
- *Threatened*: Any species likely to become endangered within the foreseeable future. This includes all species classified as threatened by the federal government which occur in Indiana. Plants known to occur currently on six to ten sites in the state are considered endangered.
- *Rare*: Plants and insects known to occur currently on from eleven to twenty sites.

The Indiana Natural Heritage Data Center database contains eight records for the area included within the Yellow Creek Lakes watershed. The ETR species identified within the watershed include five herbaceous plants. These include: Bebb's sedge, which was last observed in 1939 southwest of Loon Lake (Township 30 North, Range 5 East, Section 4), straight-leaf pondweed, state threatened, was last observed near Beaver Dam Lake in 2000 (Township 31 North, Range 5 East, Section 33). The yellow sedge (state threatened), the golden-fruited sedge (state rare), and shining ladies'-tresses (state rare) were last observed in 1982 near Beaver Dam Lake (Township 31 North, Range 5 East, Section 33).

No other records exist for the Yellow Creek Lakes watershed; however, Kosciusko County supports a variety of endangered, threatened, and rare animals and plants as detailed by the Indiana Natural Heritage database listing for Kosciusko County, which was last updated in 2005. The listed animals include thirteen freshwater mussels, including the state endangered white cat's paw pearlymussel, the northern riffleshell, the clubshell, and the rabbitsfoot; four amphibians, including the state endangered four-toed salamander; five reptiles, like the spotted turtle, Blanding's turtle, copperbelly water snake, Kirtland's snake, and eastern massasauga, all of which are state endangered; and six fish, two of which are state endangered-the lake sturgeon and gilt darter. Nearly twenty insects, more than fifteen birds, and five mammals that are considered to possess at least state species of special concern status have been documented in Kosciusko County. More than fifty plant species, many of which are hydrophytic (wetland or aquatic species), are also included in the database for Kosciusko County. The county also supports twelve high quality communities.

2.9 State Owned Land and Easements

The State does not own any land within the Yellow Creek lakes watershed except for the public access site at Beaver Dam Lake.

3.0 METHODS

3.1 Morphology

JF New and Indiana University (IU) reviewed lake bathymetry images from the IDNR to determine lake morphology. Lake depth-area and depth-volume curve were generated from information provided on the bathymetry maps. Ratios and calculations of areas were then generated from the depth-area and depth-volume curves.

3.2 Shoreline Development

A survey of historical documents (primarily fisheries reports), maps, and interviews was conducted to describe shoreline development of each lake within the Yellow Creek watershed. JF New staff also conducted a survey of each lake by boat to assess erosion, and development along the shoreline.

3.3 Macrophytes

JFNew surveyed each lake's plant communities in the Yellow Creek watershed according to the IDNR 2007 sampling protocols. JFNew surveyed Diamond, Hill, and Yellow Creek lakes plant communities on August 27, 2007 and Beaver Dam, Loon, and McClures lakes plant communities on August 28, 2007.

The survey included two components: 1) a general survey to identify aquatic plants present in the lakes and to map exotic species locations within the lakes and 2) a Tier II survey, which requires sampling at specific points throughout the lakes' littoral zones.

In order to create exotic species maps, JFNew examined the entire littoral zone of the lakes. A survey crew, consisting of one aquatic ecologist, one technician, and a citizen volunteer boat driver, surveyed the lakes in a clockwise manner. The survey crew drove their boat in a zig-zag pattern across the littoral zone of the lake while visually identifying plant species. The crew maintained a tight pattern to ensure the entire zone was observed. Additionally, in areas of dense plant coverage, rake grabs were performed to ensure all species were identified. All identified species were recorded; all exotic species locations were mapped on an aerial photograph.

The Tier II survey protocol is designed to develop a quantitative estimate of the dominance and diversity of all submerged aquatic species within each lake. The survey protocol requires that a specific number of sampling locations occur within each lake. Additionally, the sampling points are stratified over the entire depth of the lake's littoral zone as defined by the Tier II protocol (IDNR, 2007). Total points sampled per stratum were determined as follows:

1. The IDNR survey protocol was consulted to determine the number of points to be sampled and the maximum sampling depth. This determination was based on the lake size (surface area) and trophic status.
2. The IDNR survey protocol was referenced as an indicator of the number of sample points per stratum. Table 25 lists the sampling strategy for each individual lake.

Stratum refers to the depth at which plants were observed. Dominance presented in subsequent tables was calculated by the IDNR protocol. The frequency per species presented in subsequent tables provides a measure of the frequency of a species sampled in each stratum.

Table 25. Tier II sampling strategy for the Yellow Creek lakes using the 2007 IDNR Tier II protocol.

Lake	Size	Trophic Status	Number of Points	Stratification of Points
Diamond	67 acres	Eutrophic	40	17 pts 0-5 foot stratum 13 pts 5-10 foot stratum 10 pts 10-15 foot stratum
Hill	79 acres	Mesotrophic	40	10 pts 0-5 foot stratum 10 pts 5-10 foot stratum 10 pts 10-15 foot stratum 10 pts 15-20 foot stratum
Beaver Dam	146 acres	Hypereutrophic	50	40 pts 0-5 foot stratum 10 pts 5-10 foot stratum
Loon	40 acres	Eutrophic	30	10 pts 0-5 foot stratum 10 pts 5-10 foot stratum 10 pts 10-15 foot stratum
McClure	32 acres	Mesotrophic	30	10 pts 0-5 foot stratum 10 pts 5-10 foot stratum 7 pts 10-15 foot stratum 3 pts 15-20 foot stratum
Yellow Creek	151 acres	Eutrophic	50	23 pts 0-5 foot stratum 17 pts 5-10 foot stratum 10 pts 10-15 foot stratum

The data from the surveys are used to calculate different lake characteristics and community and species metrics. The different characteristics and metrics calculated from the Tier II method are defined below:

- Littoral depth: Maximum depth that aquatic vegetation is present.
- Total sites: Total number of sites sampled.
- Littoral sites: Number of sites within the littoral depth.
- Secchi depth: Measurement of the transparency of water.
- Species richness: count of all submersed plant species collected.
- Native species richness: count of all native submersed plant species collected.
- Maximum number of species per site: highest number of species collected at any site.
- Mean number of species per site: The average number of all species collected per site.
- Mean number of native species per site: The average number of native species per site.
- Species diversity index: Modified Simpson's diversity index—a measure that provides a means of comparing plant community structure and stability over time.
- Frequency of occurrence: Measurement of the percentage of sampled sites where each species is present.
- Relative frequency of occurrence: Measures the distribution of plants occurrence throughout the lake in relation to each other.
- Dominance index: Combines the frequency of occurrence and relative density into a dominance value. This value characterizes how dominant a species is within the aquatic plant community (IDNR, 2007).

3.4 Fisheries

Fish sampling was not conducted under this study. JFNew reviewed previous IDNR fish reports conducted in each lake between 1964 and 2006. Table 26 lists the reports reviewed for each

Lake. Graphs and tables presented in the Results Section of this report were developed using Excel spreadsheets and the data provided in the IDNR reports. Lake specific recommendations in the Results Section are usually those of the IDNR report authors. General recommendations regarding fisheries made in the Discussion and Recommendation Sections of this report are those of JFNew. These general recommendations may or may not be supported by IDNR fisheries biologists.

Table 26. Indiana Department of Natural Resources Fisheries reports completed for the Yellow Creek Lakes from 1964 to 2006. Dates in parentheses are date of report. Other dates are year of actual survey.

Beaver Dam	Diamond	Hill	Loon	McClures	Yellow Creek
McGinty (1965) 1964	McGinty (1966b) 1964	McGinty (1966c) 1965	McGinty (1966d) 1965	McGinty (1966e) 1965	McGinty (1967) 1965
Hudson (1969) 1968	Hudson (1969b) 1968	Taylor (1973) 1972	Braun (1981c)1980	Braun (1986c) 1985	Hudson (1968) 1967
Gulish (1972) 1971	Johnson (1971) 1970	Taylor (1974) 1974	Grier (2006) 2006		Hudson (1970) 1969
Braun (1978a) 1977	Taylor (1975) 1974	Shipman (1975a) 1975			Pearson (1977c) 1977
Braun (1978b) 1978	Shipman (1976b) 1975	Pearson (1977b) 1977			Braun (1986d) 1986
Braun (1982) 1982	Pearson (1977a) 1977	Braun (1981b) 1980			
Braun (1983a) 1983	Braun (1981a) 1980	Braun (1983c) 1983			
Braun (1993) 1992	Braun (1983b) 1983	Braun (1986b) 1985			
Braun (1995a) 1994	Braun (1986a) 1985	Braun (1995b) 1994			
Benson (2006) 2005	Braun (1996) 1995				
	Meyer (2006) 2005				
	Edgell (2006) 2006				

3.5 Historic Water Quality

The Department of Natural Resources-Division of Fish and Wildlife, the Indiana State Pollution Control Board, Tri-State University, Grace College, the Indiana Clean Lakes Program (CLP), and Volunteer Monitors have conducted various water quality tests or completed studies on the Lakes in Yellow Creek watershed. JF New reviewed, tabulated, and summarized historical water quality parameters from these studies that had been documented between 1964 and 2007. Graphs and tables presented in the Results Section of this report were developed using Excel spreadsheets with data from the historical reports. Summaries and interpretation of the historical data in these reports was completed by JFNew or IU staff.

3.6 Water Budget

As there are no discharge gages within the area of study, JFNew and IU estimated the water budget for the Yellow Creek watershed by reviewing annual mean precipitation, GIS and

topographic data, soil and vegetation data, nearby gaging station data, and nearby evaporation pan station data.

The water budget model is used to estimate how much water drains to lake and how much leaves a lake (it is important for lake managers to know how long water stays in the lake as this plays a large role in management decisions). Inputs of water to the Yellow Creek watershed lakes are limited to direct precipitation to the lake, discharge from the inlet streams, sheet runoff from land immediately adjacent to the lake, and groundwater. Water leaves the lake system from discharge from the individual lakes' outlet channel, evaporation, and groundwater. Knowing this, the model assumptions or input data was determined by the following means:

1. Direct precipitation to the lakes was calculated from mean annual precipitation falling directly on the lakes' surface.
2. Runoff from the Yellow Creek watershed lakes was estimated by applying runoff coefficients. A runoff coefficient refers to the percentage of precipitation that occurs as surface runoff, as opposed to that which soaks into the ground. Runoff coefficients may be estimated by comparing discharge from a nearby gaged watershed of similar land and topographic features, to the total amount of precipitation falling on that watershed. The nearest gaged watershed is a U.S.G.S. gaging station on the Eel River at North Manchester, Indiana (USGS 2008). The 77-year (1931–2007) mean annual daily discharge for this watershed is 386.3 cubic feet per second (cfs). However, discharge from the Eel River has been higher in recent decades so we used the mean annual daily discharge (444.7 cfs) over the past 20 years of record in our water budget. With mean annual precipitation of 37 inches (Clark, 1980), this means that on average, about 39% of the rainfall falling on this watershed runs off on the land surface.
3. Because Loon, Diamond, and Yellow Creek lakes are downstream waterbodies, receiving discharge from upstream lakes, their total watersheds include those lakes upstream. In the water budget for the downstream lakes, we estimated direct runoff only for the direct watershed area (downstream lakes' total watershed minus the upstream lake's watershed). The water budget tables show the estimated discharge from any upstream lakes.
4. There exist no groundwater records for the lake so we must assume that groundwater inputs equal outputs. In most drainage lakes, groundwater inputs and outputs are small relative to surface inflow and outflow. Given the limited funds available for LARE studies, it is my opinion that any groundwater model we could use would not be worth much. To do a really good groundwater model, using local input data, would be too expensive and time-consuming to warrant doing it.
5. We estimated evaporation losses by applying evaporation rate data to the lakes. Evaporation rates are determined at six sites around Indiana by the National Oceanic and Atmospheric Administration (NOAA). The nearest site to the study lakes is located in Wanatah (Porter County), Indiana. Annual evaporation from a 'standard pan' at the Wanatah site averaged 41.8 inches per year between 2003-2005 (NOAA, 2005). Because evaporation from the standard pan overestimates evaporation from a lake by about 30% because standard pans are located on land. The relative humidity at 3 feet off the land is much lower than the relative humidity at 3 feet above a lake surface in the same area. Air surrounding a pan situated in the middle of a lake would therefore have very high humidity. Since evaporation is driven, in part, by the gradient in humidity between high (the water) to low (the air), this gradient is much lower over water and higher over land. Thus, the pan on land evaporates at a higher rate and overestimates lake evaporation. In simpler terms, the humid air at the lake surface retards evaporation since there isn't much of a gradient present. We correct the evaporation rate by this

percentage, which yields an estimated evaporation rate from the lake surface of 29.3 inches per year. Multiplying this rate times the surface area of each lake yields an estimated volume of evaporative water loss from the study lakes.

3.7 Phosphorus Budget

The limited scope of this LARE study did not allow us to determine phosphorus inputs and outputs outright. Therefore, we have used a standard phosphorus model to estimate the phosphorus budget. (Reckhow et al., 1980) compiled phosphorus loss rates from various land use activities as determined by a number of different studies, and from this, they calculated phosphorus export coefficients for various land uses. We used mid-range estimates of these phosphorus export coefficient values for all watershed land uses (Table 27). Phosphorus export coefficients are expressed as kilograms of phosphorus lost per hectare of land per year. The export coefficient for a particular land use was multiplied by the area of land in that land use category to derive an estimate of annual phosphorus export (as kg/year) for each land use.

Table 27. Phosphorus export coefficients (units are kg/hectare except the septic category, which are kg/capita-yr).

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

Source: (Reckhow and Simpson,1980)

We estimated direct phosphorus input via precipitation to the lakes by multiplying mean annual precipitation in Marshall County (36.8 in./yr) times the surface area of the lake times a typical phosphorus concentration in Indiana precipitation (0.03 mg/L).

3.8 Water Quality Sampling

The water sampling and analytical methods used for the Yellow Creek watershed lakes and streams were consistent with those used in IDEM's Indiana Clean Lakes Program and IDNR's Lake and River Enhancement Program. We collected water samples from the Yellow Creek lakes on July 10, July 16, and July 17, from the surface waters (***epilimnion***) and from the bottom waters (***hypolimnion***) at a location over the deepest water of each lake. Chlorophyll was determined only for the epilimnetic sample. Other parameters such as Secchi disk transparency, light transmission, and oxygen saturation are single measurements made in the epilimnion. In addition, dissolved oxygen and temperature were measured at one-meter intervals from the surface to the bottom. A tow (Plankton tow net) to collect plankton was made from the 1% light level to the water surface.

We also sampled stream sites in Yellow Creek's watershed under storm flows on June 5, 2008 and under base flow conditions on July 16, 2008 (Table 28). The LARE sampling protocol requires assessing water quality of each designated stream site once during base flow and once during storm flow. This is because water quality characteristics change markedly between these two flow regimes. A storm flow sample will be influenced by runoff from the land, which usually contains soil and associated nutrients. A base flow sample represents the 'usual' water characteristics of the stream.

Table 28. Location of stream sampling sites.

Site No.	Stream Name	Sampling Location	Latitude	Longitude
1	Eaton Arm	CR 1000 South	N41^0 05.174'	W85^0 58.835'
2	Loon Lake Outlet	CR 650 West	N41^0 05.139'	W85^0 57.597'
3	Swick-Meredith Drain	Private road	N41^0 05.900'	W85^0 57.284'
4	Swick-Meredith Drain	CR 600 West	N41^0 06.254'	W85^0 56.686'
5	Swick-Meredith Drain	CR 550 West	N41^0 05.617'	W85^0 55.990'
6	Swick-Meredith Drain	CR 500 West	N41^0 06.060'	W85^0 55.623'
7	Swick-Meredith Drain	High Street	N41^0 06.398'	W85^0 56.077'

Conductivity, temperature, and dissolved oxygen were measured *in situ* at the lake sampling site and at the stream sites with an YSI Model 85 meter. Stream water velocity was measured using a Marsh-McBirney Flo-Mate current meter. The cross-sectional area of the stream channel at each site was measured and discharge calculated by multiplying water velocity by the cross-sectional area.

In addition, water samples were collected for the following parameters:

- pH
- alkalinity – lake only
- total phosphorus (TP)
- soluble reactive phosphorus (SRP)
- nitrate-nitrogen (NO_3^-)
- ammonia-nitrogen (NH_4^+)
- total Kjeldahl nitrogen (TKN)
- total suspended solids (TSS) – stream only
- turbidity
- *E. coli* bacteria – stream only
- plankton – lake only
- chlorophyll *a* – lake only

These samples were placed in the appropriate bottle (with preservative if needed) and stored in an ice chest until analysis at SPEA's laboratory in Bloomington. SRP samples were filtered in the field through a Whatman GF-C filter. The *E. coli* bacteria samples were taken to Sherry Laboratories in Warsaw, Indiana for analysis.

All sampling techniques and laboratory analytical methods were performed in accordance with procedures in *Standard Methods for the Examination of Water and* Wastewater, 21th Edition (APHA, 2005). Plankton counts were made using a standard Sedgewick-Rafter counting cell. Fifteen fields per cell were counted. Plankton identifications were made according to: Wehr and Sheath (2003), Prescott (1982), Ward and Whipple (1959) and Whitford and Schumacher (1984).

3.9 Macroinvertebrates

Because they are considered to be more sensitive to local conditions and respond relatively rapidly to environmental change, benthic (bottom-dwelling) organisms were used to document the biological condition of each stream. The U.S. Environmental Protection Agency (EPA) has

recently developed a "rapid bioassessment" protocol which has been shown to produce highly reproducible results that accurately reflect changes in water quality.

Benthic samples in this study were collected by the "kick net" method from riffles on November 29, 2007. The samples were preserved in the field with 70% isopropanol and returned to the lab for analysis. In the laboratory, a 100 organism subsample was prepared from each site by evenly distributing the whole sample in a white, gridded pan. Grids were randomly selected and all organisms within grids were removed until 100 organisms had been selected from the entire sample.

Each animal was identified to the lowest practical taxon (usually genus or species). As each new taxon was identified, a representative specimen was preserved as a "voucher." All voucher specimens have been deposited in the Purdue University Department of Entomology collection. The data were analyzed using two different indices: the IDEM family level mIBI and the Ohio EPA species level IBI. The Ohio EPA technique is considered more accurate because the sensitivity of individual species is taken into account.

Macroinvertebrate data were used to calculate the family-level Hilsenhoff Biotic Index (HBI). Calculation of the HBI involves applying assigned macroinvertebrate family tolerance values to all taxa present that have and assigned HBI tolerance value, multiplying the number of organisms present by their family tolerance value, summing the products, and dividing by the total number of organisms present (Hilsenhoff, 1988). A higher value on the HBI scale indicates greater impairment. In addition to the HBI, macroinvertebrate results were analyzed by applying an adaptation of the IDEM mIBI (IDEM, 1996). These mIBI scores allow comparison with data compiled by IDEM for wadeable riffle-pool streams. Table 29 lists the eight scoring metrics used in this study with classification scores of 0-8. The mean of the eight metrics is the mIBI score. mIBI scores of 0-2 indicate the sampling site is severely impaired, scores of 2-4 indicate the site is moderately impaired, scores of 4-6 indicate the site is slightly impaired, and scores of 6-8 indicate that the site is non-impaired.

Table 29. Benthic Macroinvertebrate Scoring Criteria Used by IDEM.

	SCORING CRITERIA FOR THE FAMILY LEVEL MACROINVERTEBRATE INDEX OF BIOTIC INTEGRITY(mIBI) USING PENTASECTION AND CENTRAL TENDENCY ON THE LOGARITHMIC TRANSFORMED DATA DISTRIBUTIONS OF THE 1990-1995 RIFFLE KICK SAMPLES				
		CLASSIFICATION SCORE			
	0	2	4	6	8
Family Level HBI	>5.63	5.62- 5.06	5.05-4.55	4.54-4.09	<4.08
Number of Taxa	<7	8-10	11-14	15-17	>18
Percent Dominant Taxa	>61.6	61.5-43.9	43.8-31.2	31.1-22.2	<22.1
EPT Index	<2	3	4-5	6-7	>8
EPT Count	<19	20-42	43-91	92-194	>195
EPT Count To Total Number of Individuals	<0.13	0.14-0.29	0.30-0.46	0.47-0.68	>0.69
EPT Count To Chironomid Count	<0.88	0.89-2.55	2.56-5.70	5.71-11.65	>11.66
Chironomid Count	>147	146-55	54-20	19-7	<6

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

3.10 Stream Habitat

Habitat analysis for the Yellow Creek watershed streams was conducted on November 7, 2007. Physical habitat at each stream site was evaluated using the Qualitative Habitat Evaluation Index (QHEI) developed by the Ohio EPA for streams and rivers in Ohio (Rankin 1989, 1995). Various attributes of the habitat are scored based on the overall importance of each to the maintenance of viable, diverse, and functional aquatic faunas. The type(s) and quality of substrates, amount and quality of in-stream cover, channel morphology, extent and quality of riparian vegetation, pool, run, and riffle development and quality, and gradient are some of the metrics used to determine the QHEI score All assigned values are added together to obtain a "Qualitative Habitat Evaluation Index " or QHEI. The habitat assessment values obtained generally range from a low of 20 to a high of 100. An example of the QHEI data sheet is given in Appendix D.

4.0 LAKE ASSESSMENT RESULTS

A complete assessment of each lake is addressed in this section of the report. The assessment includes examining the lakes morphology, development, aquatic macrophytes, fishery, and historic water sampling results. Water budgets are then calculated for each lake and a phosphorus model is used to predict the nutrient load. This information is then compared to water samples taken over the deepest point of each lake (Figure 18). These samples included a full temperature and oxygen profile of the water column and 16 physical, chemical, and biological parameters measured in the field or laboratory.

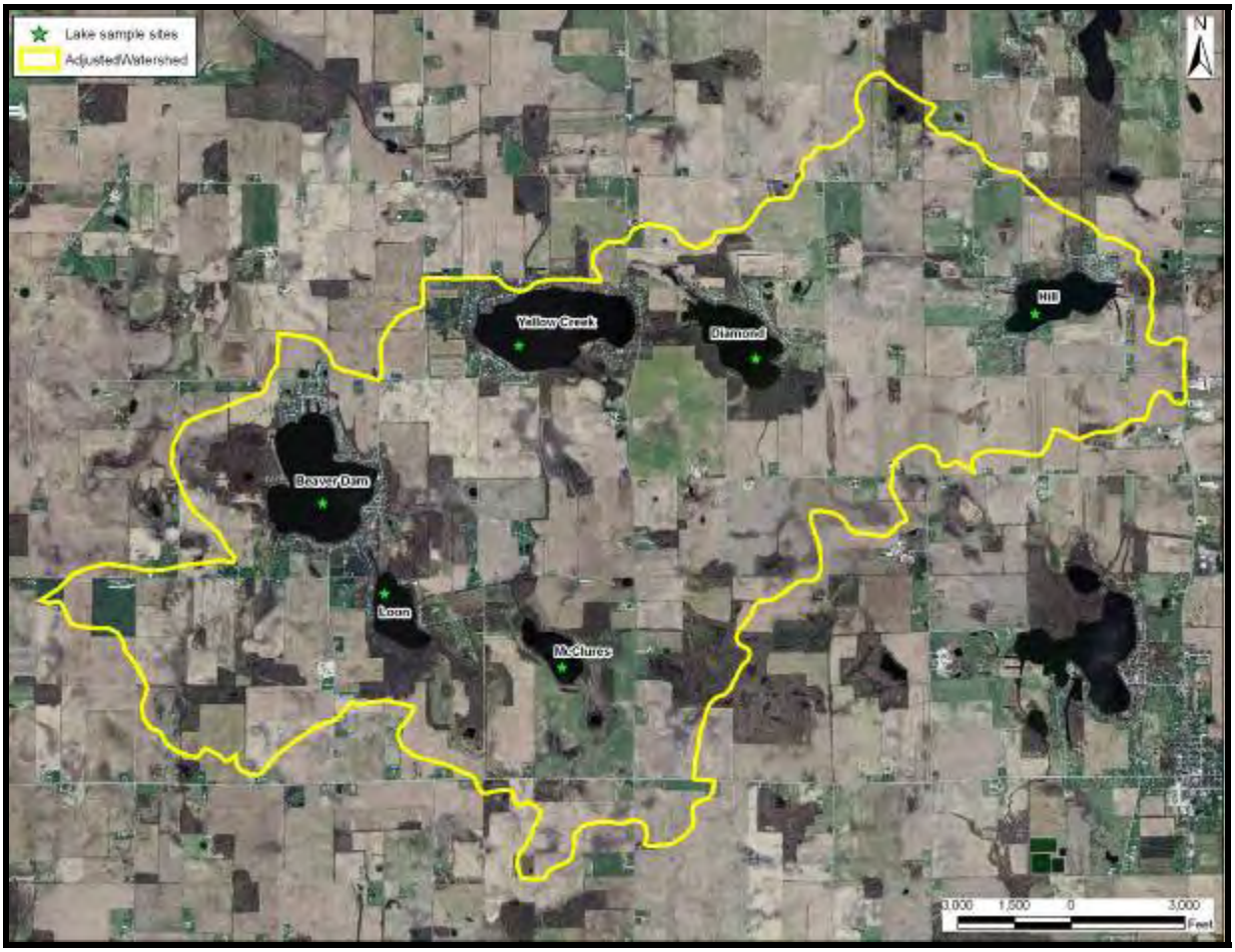


Figure 18: Location of the In-Lake samples within the Yellow Creek Lakes taken July 10 through 17, 2008.

4.1 Beaver Dam Lake

4.1.1 Beaver Dam Lake Morphology

Figure 19 presents Beaver Dam Lake's moderately complex morphology. The lake consists of six deep holes surrounded by shallower water. The lake's deepest point lies slightly south of the center of the 146-acre (59-ha) lake. Here, the lake extends to its maximum depth of 61 feet (18.6 m; Table 30). One shallower hole lies in the southeastern portion of the lake reaching a maximum depth of 41 feet (12.5 m), while four deep holes lie in the northern portion of the lake. These holes range in depth from 38 to 50 feet (11.6 to 15.3 m). Water as shallow as 35 feet (10.7 m) separates these holes from the other parts of the lake. All six holes are relatively small and account for a relatively small portion of the lake's total volume. The lake also contains one

shallow island near the western shoreline and large expanses of shallow area along the lakes northern and eastern shorelines.

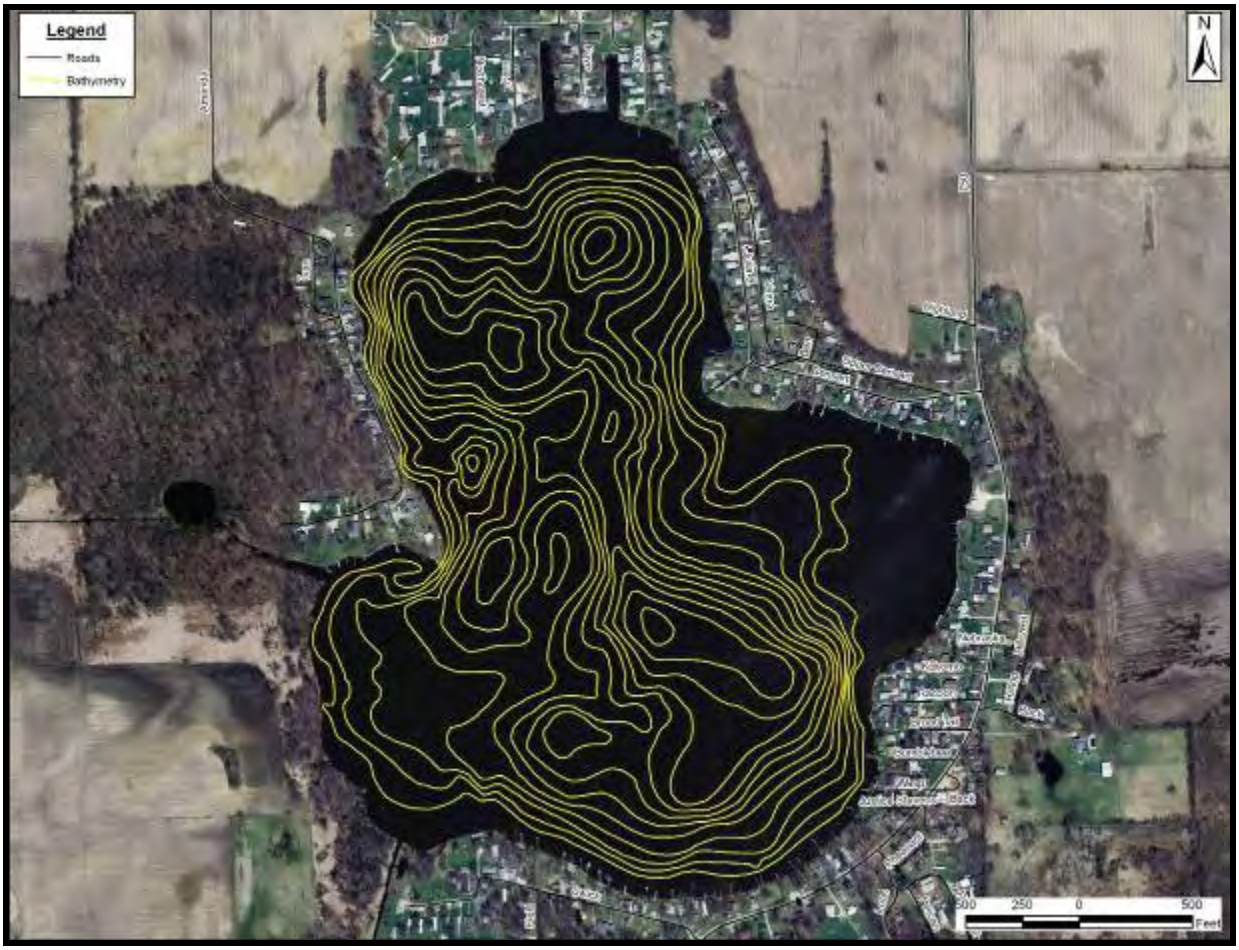


Figure 19. Bathymetric map of Beaver Dam Lake, Kosciusko County, Indiana. Source: Kosciusko County GIS Department, digitized from 1956 IDNR contour maps.

Table 30. Morphological characteristics of Beaver Dam Lake.

Characteristic	Value
Surface Area	146 acres (59 ha)
Volume	2,276 acre-feet (2,807,568 m^3)
Maximum Depth	61 feet (18.6 m)
Mean Depth	15.6 feet (4.7 m)
Shallowness Ratio	0.31
Shoalness Ratio	0.48
Shoreline Length	13,314 feet (4,058 m)
Shoreline Development Ratio	1.49

Beaver Dam Lake possesses large expanses of shallow water. According to its depth-area curve (Figure 20), nearly 31 acres (12.5 ha) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 70 acres (28.3 ha) is covered by water less than 20 feet (6.1 m) deep. This translates into a relatively low shallowness ratio of 0.31 (ratio of area less than 5 feet (1.5 m) deep to total lake area) and a moderately high shoalness ratio of 0.48 (ratio of area less than

20 feet (6.1 m) deep to total lake area), as defined by Wagner (1990). A small portion of the lake's acreage (approximately 14.2 acres or 5.7 ha) covers the water deeper than 40 feet (12.1 m). The lake's area gradually increases with depth to a water depth of about 5 feet (1.5 m) before the rate of change increases. This rate (slope of lake bottom) continues to approximately 50 feet (15.4 m) where the rate of change increases before reaching the lake's maximum depth (82 feet or 25 m).

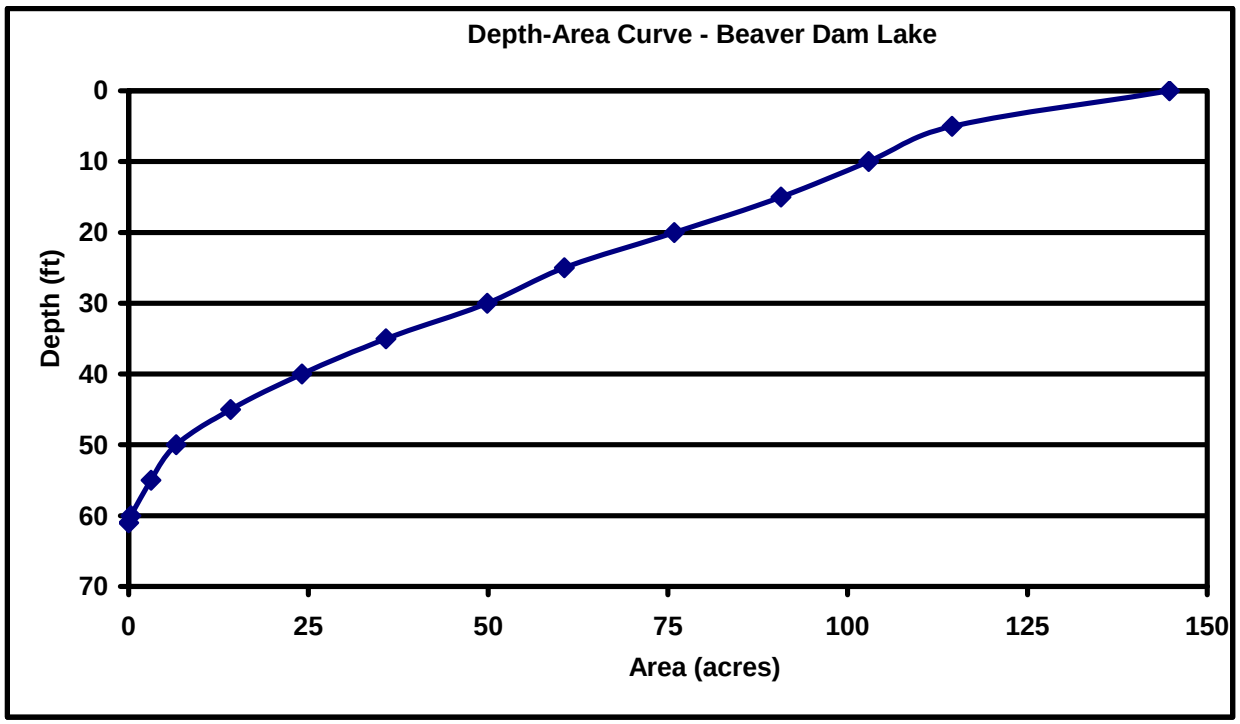


Figure 20. Depth-area curve for Beaver Dam Lake, Kosciusko County, Indiana.

Beaver Dam Lake holds approximately 2,276 acre-feet (2,807,568 m^3) of water. As illustrated in the depth-volume curve (Figure 21), most of the lake's volume is contained in the shallower areas of the lake. More than 50% of the lake's volume is contained in water that is less than 5 feet (1.5 m) deep, while nearly 75% of the lake's volume is contained within water less than 10 feet (3.1 m) deep. The lake's volume gradually increases with depth to a water depth of about 15 feet (4.6 m) before the rate of change increases. Below 15 feet (4.6 m), the steep curve indicates a greater change in depth per unit volume. This rate continues to the lakes maximum depth (61 feet or 18.6 m). The importance of this rate of increase will be discussed with regard to light penetration and the planktonic community in the Results Section.

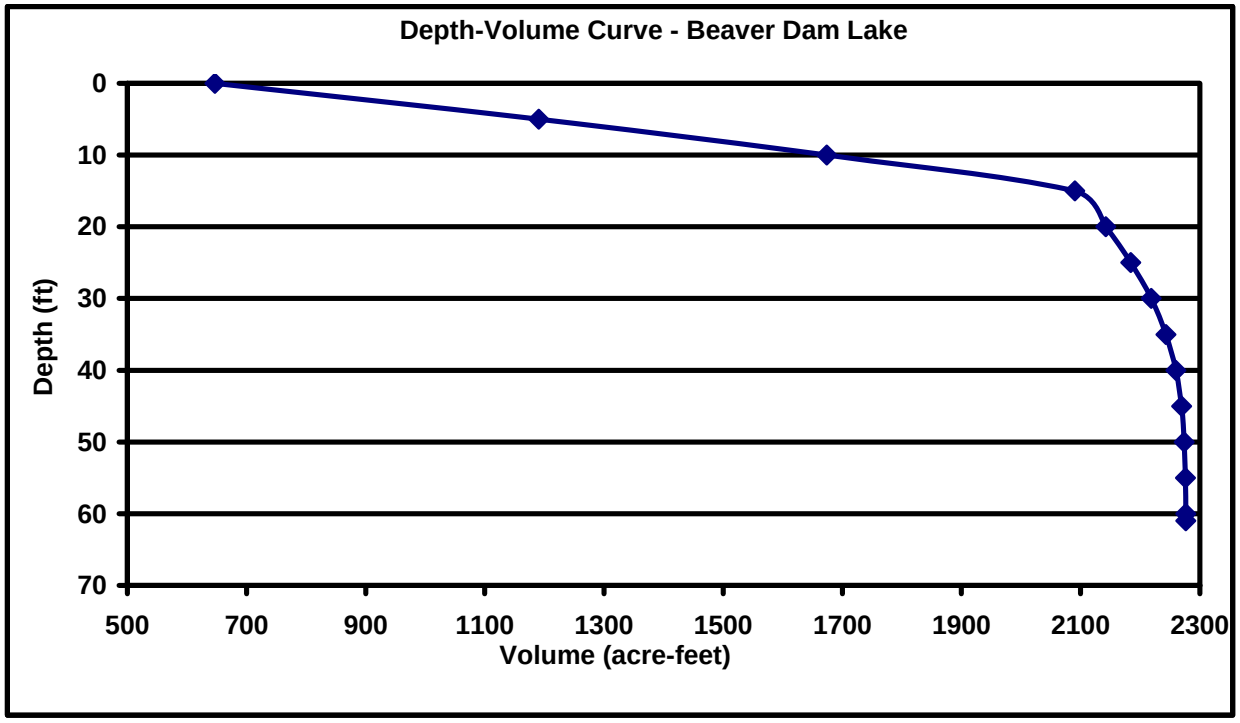


Figure 21. Depth-volume curve for Beaver Dam Lake, Kosciusko County, Indiana.

A lake's morphology can play a role in shaping the lake's biotic communities. For example, Beaver Dam Lake's large-sized shallow area and wide, shallow shelf around much of the perimeter of the lake coupled with its moderate to poor clarity suggests the lake is capable of supporting a quality rooted plant community. Based on the lake's measured Secchi disk readings (clarity), Beaver Dam Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the point where water depths are approximately 15 feet (4.6 m). Referring to Beaver Dam Lake's depth-area curve, this means that the lake's littoral zone is approximately 54 acres (36.4 ha) in size or approximately 38% of the lake. This size littoral zone can impact other biotic communities in the lake such as fish that use the plant community for forage, spawning, cover, and resting habitat.

A lake's morphology can indirectly influence water quality by shaping the human communities around the lake. The shoreline development ratio is a measure of the development potential of a lake. It is calculated by dividing a lake's shoreline length by the circumference of a circle that has the same area as the lake. A perfectly circular lake with the same area as Beaver Dam Lake (146 acres or 59 ha) would have a circumference of 8,939 feet (2,725 m). Dividing Beaver Dam Lake's shoreline length (13,314 feet or 4,058 m) by 8,939 feet yields a ratio of 1.49:1. This ratio is relatively low. Although Beaver Dam Lake is not relatively round, it lacks extensive shoreline channeling observed on other popular Indiana lakes such as lakes in the Barbee Chain and Lake Tippecanoe in Kosciusko County.

4.1.2 Beaver Dam Lake Shoreline Development

Development around Beaver Dam Lake began relatively late when compared with other Kosciusko County lakes. Development may have been limited by the soils present along the lake's shoreline. The southern shoreline of Beaver Dam Lake is comprised of sand and loamy sand, while the northern and eastern shorelines were predominantly muck and peat. McGinty (1966a) suggested that dredging and filling allowed for development of these shorelines. He

further indicated that much of Beaver Dam Lake's development occurred over a 15 year period beginning in 1950. By 1964, nearly 145 cottages, 12 trailers, and 1 resort were present along Beaver Dam Lake's shoreline. During this count, McGinty estimated that nearly 80% of the shoreline was covered by housing units. Braun (1978a, 1987b, 1982, 1995) concurred with this estimate and noted during the 1994 assessment that all of Beaver Dam Lake's shoreline except for a small portion along the western edge was developed for residential use. The only natural shoreline is present along the southern portion of the lake's western shoreline (Figure 22).

Figure 22. Beaver Dam Lake aerial photograph circa 2005.

A count of the homes shown on a 2005 aerial photograph within 400 feet of the lake yielded 324 residential structures. Given the plethora of houses along Beaver Dam Lake's shoreline, it is not surprising that nearly 90% of Beaver Dam Lake's shoreline has been altered in some manner. Approximately 55% of Beaver Dam Lake's shoreline has been significantly modified from its natural state using concrete, rocks, or timbers (Figure 23). Approximately 150 feet of shoreline was eroding at a moderate rate around a southward facing point (Amanda Point; Figure 22). The erosion is about 16-18 inches in height and is undercutting trees and lawn.

Figure 23. Modified shoreline present along Beaver Dam Lake's western shoreline.

Figure 24. Shoreline surface type observed at Beaver Dam Lake, August 27, 2007.

Along the less modified shoreline (32%; 4,304 feet or 1,312 m), emergent and floating rooted vegetation has been largely removed, exposing residential lawns to wave action (Figure 24). However, many of these areas possess at least a narrow band of emergent plants. These areas are mapped as modified natural shoreline because they still possess at least a small portion of all these strata (submerged, emergent, and floating). Other portions of the shoreline that are also mapped as modified natural include those areas where individuals removed only the portion of the shoreline vegetation required to view or access the lake (Figure 25).

Figure 25. Modified natural shoreline present within Beaver Dam Lake. Note that vegetation was removed in areas required to place the dock for access to the lake. The remaining vegetation along the shoreline acts as a natural buffer.

Natural shoreline remains along approximately 13% of Beaver Dam Lake's shoreline where bands of plants like those described by McGinty (1966a) are present with trees, emergent vegetation, floating vegetation, and submerged vegetation located in distinct zones along the lakeshore (Figure 26). In these areas, the submerged, floating, emergent, and shoreline canopy layers all remain intact.

Figure 26. Natural shoreline present along Beaver Dam Lake's southwestern shoreline.

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

In contrast, shorelines vegetated with emergent or rooted floating vegetation or those areas covered by sand will absorb more of the wave energy created by wind or boats. In these

locations, wave energy will dissipate along the shoreline each time a wave meets the shoreline surface. Similarly, stone seawalls or those covered by wood can decrease shallow water turbulence and lakeward wave energy reflection while still providing shoreline stabilization.

4.1.3 Beaver Dam Lake Aquatic Macrophyte Assessment

JFNew surveyed Beaver Dam Lake plant communities on August 28, 2007 according to the IDNR sampling protocols (IDNR 2007). Transparency was found to be 4.5 feet in Beaver Dam Lake during the Tier II survey. Beaver Dam Lake supports a modest rooted aquatic plant community. The community extends from the lake's shoreline to water that is just over 8 feet (2.4 m) deep. In total, 26 aquatic plant species inhabit the water and shoreline of Beaver Dam Lake (Table 31). The LARE protocol used to conduct the aquatic plant survey requires surveyors to note all plant species observed from a boat. Thus, plants in the wetland complexes adjacent to the lake were only counted if they were visible from the boat. If these wetland complexes had been explored in greater detail, it is likely that the total number of plant species would increase significantly.

Table 31. Plant species observed in Beaver Dam Lake on August 28, 2007.

Scientific Name	Common Name	Stratum
Ceratophyllum demersum	Coontail	Submergent
Chara species	Musk grass species	Submergent
Decodon verticillatus	Whorled loosestrife	Emergent
Filamentous algae	Filamentous algae	Algae
Heteranthera dubia	Water star grass	Submergent
Lythrum salicaria	Purple loosestrife	Emergent
Myriophyllum spicatum	Eurasian watermilfoil	Submergent
Najas flexilis	Slender naiad	Submergent
Najas guadalupensis	Southern naiad	Submergent
Nuphar advena	Spatterdock	Floating
Nuphar variegatum	Yellow pond lily	Floating
Nymphaea tuberosa	White water lily	Floating
Phalarus arundinacaea	Reed canary grass	Emergent
Polygonum hydropiperoides	Swamp smartweed	Emergent
Polygonum lapathifolium	Willow-weed	Emergent
Potamogeton berchtoldii	Broad-leaf small pondweed	Submergent
Potamogeton foliosis	Leafy pondweed	Submergent
Potamogeton gramineus	Grassy pondweed	Submergent
Potamogeton illinoensis	Illinois pondweed	Submergent
Potamogeton nodosus	Long-leaf pondweed	Submergent
Scirpus pungens	Chairmaker's rush	Emergent
Stuckenia pectinatus	Sago pondweed	Submergent
Typha angustifolia	Narrow-leaf cattail	Emergent
Typha x *glauca*	Blue cattail	Emergent
Typha latifolia	Broad-leaf cattail	Emergent
Vallisneria americana	Eel grass	Submergent

Of the 26 species observed in Beaver Dam Lake, one is classified as algae, three as floating leaved, thirteen as submergent, and nine as emergent plant species. (It is important to note that there are significantly fewer floating aquatic species that are native to Indiana lakes compared to the number of emergent and submergent species. Consequently, many lakes possess low numbers of floating species.) Of the thirteen submergent species, nearly all of those are adapted to high nutrient environments. Six of the submergent species were pondweeds (i.e. belonging to the *Potamogeton* genus), which are typically adapted to better water quality conditions. However, most of these species were identified in relatively low density. Sago pondweed, musk grass, and coontail dominated the submerged plant community and were observed throughout the lake. The most common emergent species include purple loosestrife and reed canary grass. The most common floating species are spatterdock and duckweed. Three exotic species, including Eurasian watermilfoil, purple loosestrife, and reed canary grass, were identified within or adjacent to Beaver Dam Lake.

During the Tier II survey, sago pondweed dominated the plant community over all depths (0-10 feet; Table 32). This species was found at the highest percentage of sites throughout the water column (32%) and also had the highest relative density (0.8). Throughout the entire sampled water column, other species were somewhat frequent with musk grass present at 18% of the sites and coontail present at 14% of the sites. With regards to density, sago pondweed dominated the submerged plant community throughout the entire sampled water column with a dominance of 16. (A dominance of 250 represents a perfect score or the highest dominance possible within Beaver Dam Lake. This results from multiplying the highest density score (5) by the number of sites where plants were sampled (50). Dominance scores are reported as percentages of this maximum.) All other species were relatively sparse throughout the entire sampled water column, with coontail possessing a dominance of 6, long-leaf pondweed a dominance of 4.4, musk grass a dominance of 3.6, and southern naiad a dominance of 2.0. All other species had dominances less than 2. Filamentous algae were also present at 40% of the sites; however, densities are not assigned to this species.

Sago pondweed also dominated the submerged plant community in the 0-5 foot stratum. Sago pondweed was the most frequent species as it was found at nearly 40% of the sites in the 0-5 foot stratum. Sago pondweed generated the highest dominance rating (20) in the 0-5 foot stratum. In this same stratum, musk grass was identified at 20% of the sites, but was relatively sparse scoring a dominance of 4.0. Coontail was found at 17.5% of the sites in the 0-5 foot stratum and possessed a dominance of 7.5. Long-leaf pondweed was found at only 12.5% of the sites in the 0-5 foot stratum, but possessed a dominance of 5.5. All other species were relatively infrequent occurring at less than 12.5% of the sites and possessing dominances of 2.0 or less. Southern naiad and musk grass were the only plant species identified in the 5-10 foot stratum. Each species were found at 10% of the sites and measured a dominance of 2.0 in the 5-10 foot stratum. Filamentous algae were found at 50% of the sites in the 5-10 foot stratum. As previously mentioned, Eurasian watermilfoil was identified at 2% of the sites throughout Beaver Dam Lake (Figure 27).

Table 32. Frequency and dominance of submerged aquatic plant species identified during the Tier II survey of Beaver Dam Lake conducted August 28, 2007.

Occurrence and abundance of submersed aquatic plants in Beaver Dam Lake.					
Total Sites:	50	Mean species / site:	1.08	Native diversity:	0.84
Littoral Sites:	47	Maximum species / site:	5	Species diversity:	0.84
Littoral Depth (ft):	8	Number of species:	13	SE Mean natives / site:	0.17
Date:	8/28/07	Littoral sites with plants:	29	Mean natives / site:	1.06
Lake:	Beaver Dam	Secchi(ft):	4.5	SE Mean species / site:	0.18

All depths (0-10')		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Stuckenia pectinatus	Sago pondweed	32.00	68.00	14.00	12.00	6.00	16.00
Chara species	Chara species	18.00	82.00	18.00	0.00	0.00	3.60
Ceratophyllum demersum	Coontail	14.00	86.00	6.00	8.00	0.00	6.00
Najas guadalupensis	Southern naiad	10.00	90.00	10.00	0.00	0.00	2.00
Potamogeton nodosus	Long-leaf pondweed	10.00	90.00	6.00	2.00	2.00	4.40
Potamogeton berchtoldii	Broad-leaf small pondweed	6.00	94.00	6.00	0.00	0.00	1.20
Potamogeton gramineus	Grassy pondweed	4.00	96.00	4.00	0.00	0.00	0.80
Potamogeton foliosis	Leafy pondweed	4.00	96.00	4.00	0.00	0.00	0.80
Myriophyllum spicatum	Eurasian watermilfoil	2.00	98.00	2.00	0.00	0.00	0.40
Potamogeton illinoensis	Illinois pondweed	2.00	98.00	2.00	0.00	0.00	0.40
Najas flexilis	Slender naiad	2.00	98.00	2.00	0.00	0.00	0.40
Heteranthera dubia	Water star grass	2.00	98.00	2.00	0.00	0.00	0.40
Vallisneria americana	Eel grass	2.00	98.00	0.00	2.00	0.00	1.20
Filamentous algae	Filamentous algae	40.00					
0-5' Stratum		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Stuckenia pectinatus	Sago pondweed	40.00	60.00	17.50	15.00	7.50	20.00
Chara species	Chara species	20.00	80.00	20.00	0.00	0.00	4.00
Ceratophyllum demersum	Coontail	17.50	82.50	7.50	10.00	0.00	7.50
Potamogeton nodosus	Long-leaf pondweed	12.50	87.50	7.50	2.50	2.50	5.50
Najas guadalupensis	Southern naiad	10.00	90.00	10.00	0.00	0.00	2.00
Potamogeton berchtoldii	Broad-leaf small pondweed	7.50	92.50	7.50	0.00	0.00	1.50
Potamogeton gramineus	Grassy pondweed	5.00	95.00	5.00	0.00	0.00	1.00
Potamogeton foliosis	Leafy pondweed	5.00	95.00	5.00	0.00	0.00	1.00
Myriophyllum spicatum	Eurasian watermilfoil	2.50	97.50	2.50	0.00	0.00	0.50
Potamogeton illinoensis	Illinois pondweed	2.50	97.50	2.50	0.00	0.00	0.50
Najas flexilis	Slender naiad	2.50	97.50	2.50	0.00	0.00	0.50
Heteranthera dubia	Water star grass	2.50	97.50	2.50	0.00	0.00	0.50
Vallisneria americana	Eel grass	2.50	97.50	0.00	2.50	0.00	1.50
Filamentous algae	Filamentous algae	37.50					
5-10' Stratum		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Najas guadalupensis	Southern naiad	10.00	90.00	10.00	0.00	0.00	2.00
Chara species	Chara species	10.00	90.00	10.00	0.00	0.00	2.00
Filamentous algae	Filamentous algae	50.00					

Unfortunately, limited data detailing Beaver Dam Lake's historical rooted plant community exist for comparison to the current data. In the past, IDNR fisheries biologists conducted cursory vegetation surveys as a part of their general fisheries surveys. For additional information on historical Tier II surveys see the 2007 Excerpt of Beaver Dam and Loon Lakes (JFNew, 2007a). In 1965, McGinty (1966a) noted the presence of 14 emergent species and 10 submerged species. McGinty noted the abundance and variety of pondweed species, including large-leaf, fine-leaf, Illinois, sago, and leafy pondweeds, and the presence of the state rare whorl-leaf or whorled watermilfoil during this survey. Further notation of the abundance of submerged vegetation from the shoreline to a depth of approximately 15 feet (4.5 m) was noted during this survey. By 1977, the aquatic plant community within Beaver Dam Lake changed significantly.

Only eight submerged and emergent species were identified during the survey (Braun, 1977). Both water turbidity and extensive algal blooms were noted during this survey. Similar species were identified by DNR biologists in 1978 and 2002. During the 2005 assessment, Benson (2006) noted the predominance of Eurasian watermilfoil within Beaver Dam Lake but also indicated that a relatively sparse aquatic plant community was present within the lake. These historic plant survey data suggests that Beaver Dam Lake shifted from a high quality aquatic plant community in 1966 to a relatively turbid system dominated by algae in 1977. The partial fish eradication program enacted in 1966 may have created some of this shift. The winter kill of shad in 1962-1963 and again in 1970-1971 indicates that a shift in community structure occurred within this time frame.

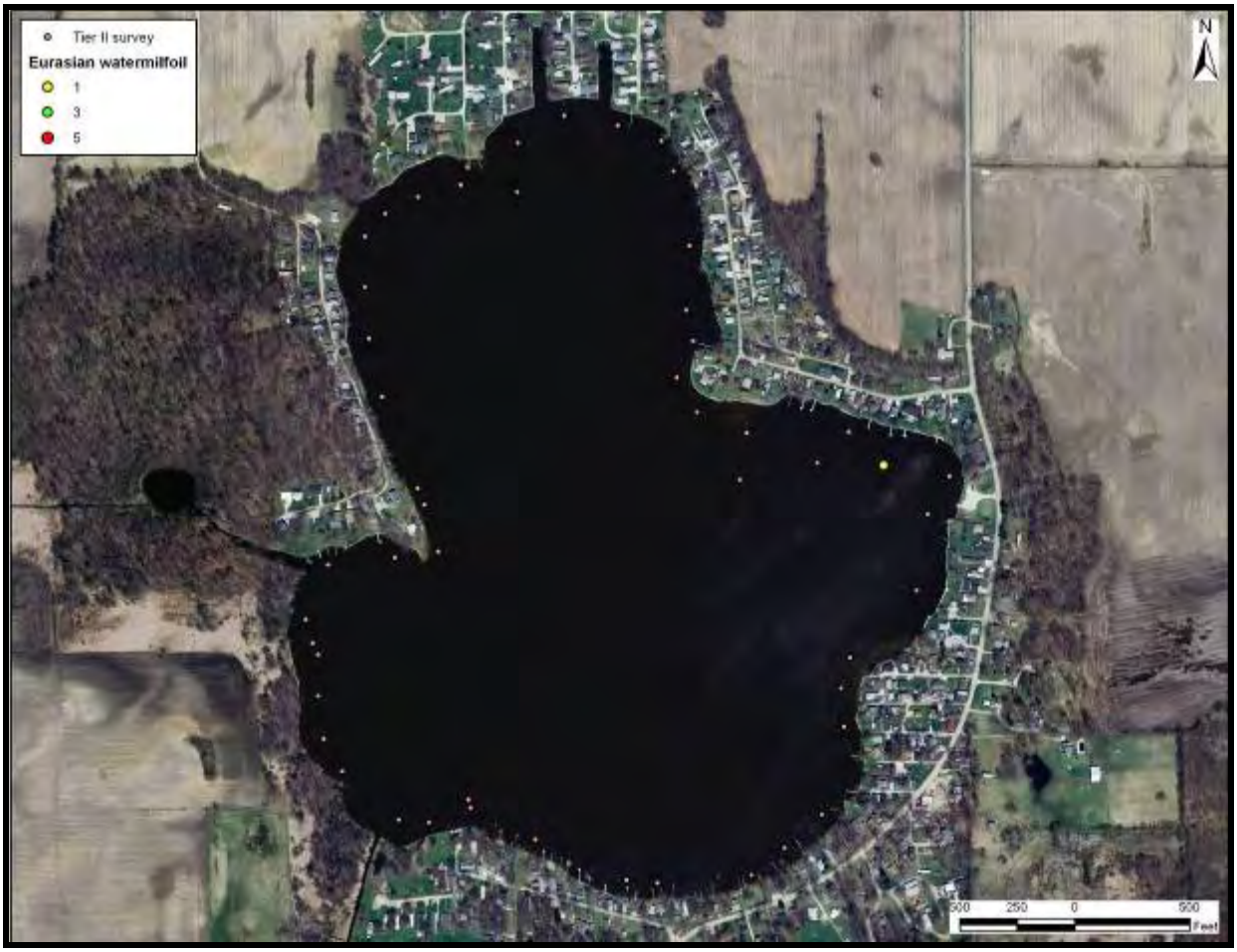


Figure 27. Points sampled during the Tier II aquatic plant assessment and the location/density of Eurasian watermilfoil identified in Beaver Dam Lake during the August 28, 2007 Tier II survey.

4.1.4 Beaver Dam Lake Fisheries Summary

Introduction

The IDNR initially surveyed Beaver Dam Lake's fish community in 1965 with subsequent surveys in 1968, 1970, 1971, 1977, 1978, 1982, 1983, 1992, 1994, 2002, and 2005 (Table 33). Over this survey period, Beaver Dam Lake's fish community has been used for experimental and management purposes. In 1966, IDNR conducted a partial fish kill in Beaver Dam Lake targeting a large population of small bluegill and an undesirable population of longear sunfish. In 1970-71, Beaver Dam Lake was used to collect preliminary data that could later be used to

study the effects of destratification as a lake management method. At the conclusion of the preliminary study, Beaver Dam Lake was not recommended for the full study due to an unstable fish community observed within the lake at that time. Tiger muskie fingerlings were stocked in 1981 with the hope of introducing another top predator to help control the population of gizzard shad within the lake; however, a survey of the lake in 1982 yielded no tiger muskie and a fishable population never developed. In 1984, Beaver Dam Lake became one of eight lakes in Indiana used to evaluate a 14 inch (35.6 cm) minimum size limit on largemouth bass; subsequent surveys were focused on evaluating the minimum size limit and its effects on the fish community over time. The 14 inch (35.6 cm) minimum size limit on largemouth bass went into affect in 1986. Figure 28 and 29 present the changes in species community composition over time and then a comparison of PSD values from selected game fish during each sample event.Appendix C contains a summary and discussion of fish growth rates from each IDNR report.

Fish community summary

In general, Beaver Dam Lake can be described as a largemouth bass and bluegill fishery. Additional angling opportunities for yellow perch and black crappie are present, but due to the cyclic population fluctuations of these species, fishing success can vary greatly between years. Beaver Dam Lake is connected to Loon Lake through its outlet at the southeast corner of the lake. The short distance between these two lakes would suggest that some immigration and emigration of fishes occurs. Therefore, one lake's fish community or management of that community may impact the other lake's fish community.

Beaver Dam Lake has not been sampled in three years; therefore, the current fish community composition is not known. If the fish community in Beaver Dam Lake is similar to that sampled in 2005, then Beaver Dam Lake could benefit from smart fishing practices such as catch and release of largemouth bass and selective harvest of panfish (bluegill and black crappie).

As a result of numerous surveys over the years, Beaver Dam Lake has developed a good working set of data. The advantage of a good working set of data is that trends or changes within a population can be observed more readily. Over the years, Beaver Dam Lake has exhibited a few changes to its fish community. Noticeably, the largemouth bass population has improved since the implementation of the 14 inch (35.6 cm) minimum size limit. For example, the number of stock size bass (≥8 in; 20.3 cm) improved from 13.3 per acre in 1992 to 20 per acre in 2005. Over time, bluegill have been the dominant species by number in Beaver Dam Lake and, as of the 2005 survey, bluegill exhibited average to above average growth rates and their PSD remains low.

The abundance of spotted gar has increased in Beaver Dam Lake since the lake was first surveyed in 1965. In 1965, two spotted gar were collected in the general survey and accounted for 0.2% of the sample by number. In 2005, thirty-seven spotted gar were collected accounting 2.5% of the sample by number. While spotted gar are not desirable to most anglers for consumption, they can provide an alternative angling opportunity to some. The presence of a sizable population of spotted gar in Beaver Dam Lake is considered desirable based on their influence as a top predator and availability as an additional angling opportunity.

Table 33: Summary of IDNR Fish sampling results in Beaver Dam Lake, Kosciusko County, Indiana

Common Name	Scientific Name	1965	1968	1970	1971	1977	1978	1982	1983	1992	1994	2002	2005
Sunfish Family													
Bluegill	*Lepomis macrochirus*	X	X	X	X	X	X	X	X	X	X	X	X
Black Crappie	*Pomoxis nigromaculatus*	X	X	X	X	X	X	X	X	X		X	X
Green Sunfish	*Lepomis cyanellus*	X		X			X					X	
Hybrid Sunfish							X	X					X
Largemouth Bass	*Micropterus salmoides*	X	X	X	X	X	X	X	X	X	X	X	X
Longear Sunfish	*Lepomis megalotus*	X		X	X	X	X	X	X	X		X	X
Pumpkinseed	*Lepomis gibbosus*		X	X	X	X		X	X	X	X	X	X
Redear Sunfish	*Lepomis microlophus*		X	X	X	X	X					X	
Warmouth	*Lepomis gulosus*	X			X	X		X	X	X	X	X	X
Catfish Family													
Black Bullhead	*Ameiurus melas*						X	X		X			
Brown Bullhead	*Ameiurus nebulosus*	X	X	X	X	X	X	X	X	X	X	X	X
Channel Catfish	*Ictalurus punctatus*					X						X	X
Yellow Bullhead	*Ameiurus natalis*	X		X	X	X		X	X	X	X	X	X
Minnow Family													
Common Carp	*Cyprinus carpio*	X	X	X	X	X	X	X	X	X	X	X	X
Common Shiner	*Luxilus cornutus*						X						
Golden Shiner	*Notemigonus crysoleucas*	X	X	X	X	X	X	X	X	X	X	X	X
Sucker Family													
Lake Chubsucker	*Erimyzon sucetta*	X	X	X	X	X	X			X			
Northern Hog Sucker	*Hypentelium nigricans*											X	

Common Name	Scientific Name	1965	1968	1970	1971	1977	1978	1982	1983	1992	1994	2002	2005
Silver Redhorse	*Moxostoma anisurum*	X											
Spotted sucker	*Minytrema melanops*					X							
White Sucker	*Catostomus commersoni*	X	X	X	X	X	X	X	X	X		X	X
Bowfin Family													
Bowfin	*Amia calva*	X	X	X	X	X	X	X	X	X	X	X	X
Herring Family													
Gizzard Shad	*Dorosoma cepedianum*	X	X	X	X	X	X	X	X	X	X	X	X
Silversides Family													
Brook Silverside	*Labidesthes sicculus*			X	X	X	X			X	X	X	X
Gar Family													
Spotted Gar	*Lepisosteus oculatus*	X				X	X		X	X	X	X	X
Temperate Basses													
White Bass	*Morone chrysops*				X								
Pike Family													
Grass Pickeral	*Esox americanus vermiculatus*	X	X		X								
Perch Family													
Johnny Darter	*Etheostoma nigrum*									X		X	
Yellow Perch	*Perca flavescens*	X	X	X	X	X	X	X	X	X	X	X	X
Number Species		18	14	17	19	20	18/1 hybrid	15/1 hybrid	15	19	13	21	17/1 hybrid

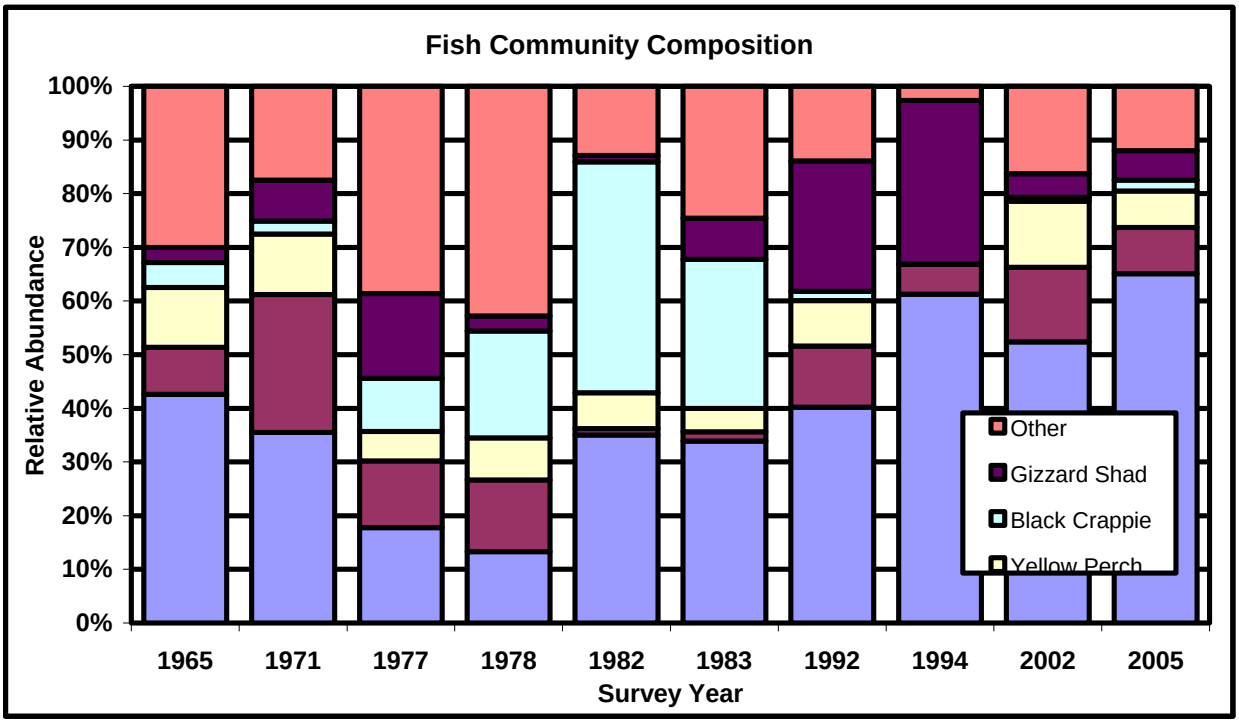


Figure 28. Beaver Dam Lake fish community composition, 1965-2005.

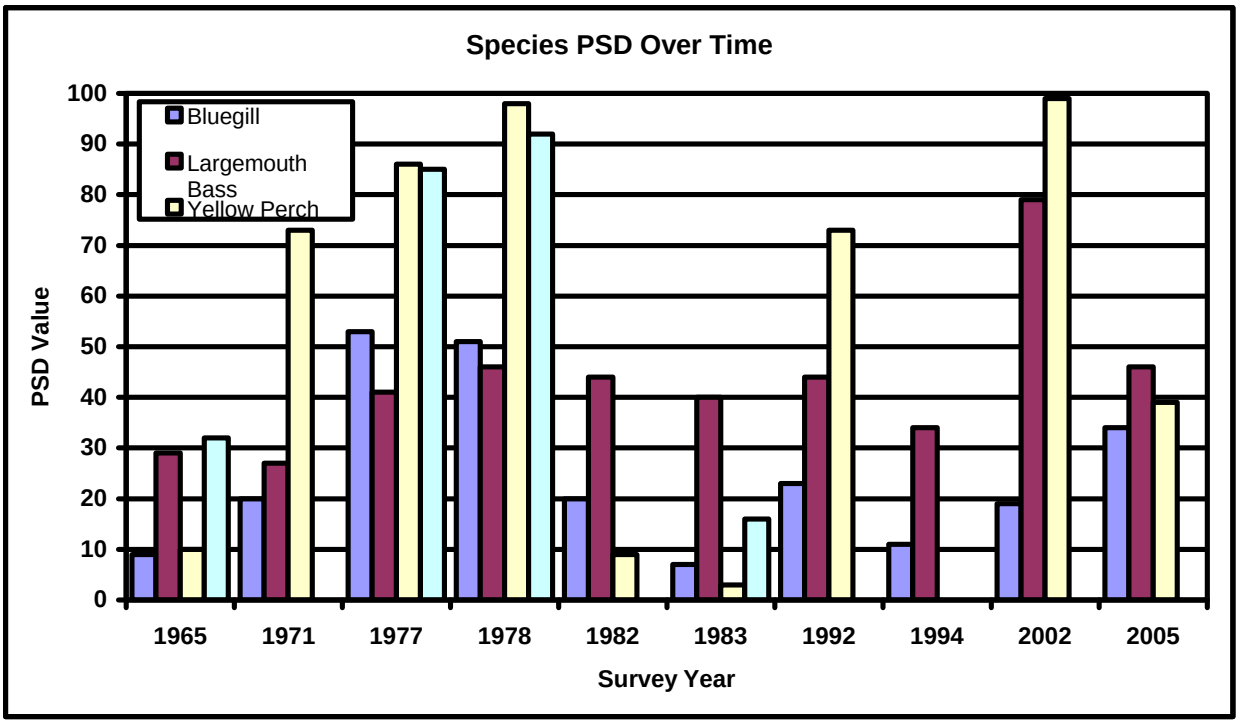


Figure 29. Beaver Dam Lake Proportional Stock Density, 1965-2005.

Fish Community Recommendations

Anglers are encouraged to lower their harvest of large adult panfish (bluegill and black crappie) and increase their harvest of younger, smaller panfish. This would be beneficial to the panfish population for a couple of reasons: 1) the release of most large adults would help develop a large, healthy stock of breeding individuals capable of producing many offspring, which would young fish into the population each year; and 2) the increased harvest of smaller individuals would decrease the amount of intra-specific competition for space and food resources between young panfish resulting in a healthy recruitment of individuals into the larger sized breeding population. The overall goal would be to develop a distribution of sizes within the population that would allow for the harvest of quality size fish while ensuring the replacement of those individuals the following year. It was suggested by IDNR in the 2005 fish management report that once bluegill reached harvestable size, they were harvested from the fishery. Additionally, it was suggested that a minimum size limit, or bag limit, on bluegill should be considered for Beaver Dam Lake.

Catch and release of largemouth bass is also encouraged. Furthermore, it is suggested that predation by largemouth bass can play an important role in controlling the population of desirable game-fish species, such as bluegill, and undesirable fish species, such as gizzard shad. This occurs in two ways: 1) by helping to reduce intra-specific competition between young bluegill through limitation of their numbers; and 2) by reducing inter-specific competition of resources between young gizzard shad and young bluegill through the control of gizzard shad numbers. Having a sizable population of largemouth bass can not only benefit prey species, but can also provide anglers with quality fishing opportunities. Anglers are encouraged to release largemouth bass beyond that required by law. According to the 2005 fish management report, anglers on Beaver Dam Lake are currently doing this, as the creel survey indicated few largemouth bass were harvested compared to the numbers which were released.

Finally, efforts made by the Beaver Dam Lake Conservation Club to treat Eurasian watermilfoil are advantageous to the fishery and should be continued. Eurasian watermilfoil often creates dense stands thereby reducing the amount of space and visibility within the water. By reducing the density of Eurasian watermilfoil, predators such as largemouth bass and spotted gar are allowed to forage more effectively on prey such as bluegill. As mentioned above, the predation of largemouth bass on young bluegill can be important to the bluegill population.

4.1.5 Beaver Dam Lake Historical Water Quality

The IDNR, Division of Fish and Wildlife, the Indiana State Pollution Control Board, the Indiana Clean Lakes Program (CLP), Tri State University, and Grace College have conducted various water quality tests on Beaver Dam Lake. Table 34 presents some selected water quality parameters for these assessments of Beaver Dam Lake.

Table 34. Summary of historic data for Beaver Dam Lake.

Date	Secchi (ft)	% Oxic	Epi pH	TP (mg/L)	Plankton (#/L)	Chl *a* (μg/L)	ITSI Score	Source
4/18/66	4.0	32.8%	7.80	0.050	--	--	--	McGinty, 1966a
8/16/72	4.0	--	--	0.452*	--	--	55$^{\delta}$	ISPCB, 1986
1975	--	--	--	0.850*	--	--	--	Hippensteel, 1989
6/6/77	3.0	32.3%	9.50	--	--	--	--	Braun, 1978a
8/1/77	5.0	--	--	--	--	--	--	Braun, 1978a
6/5/78	5.2	32.3%	9.70	--	--	--	--	Braun, 1978b
6/14/82	2.4	32.3%	10.00	--	--	--	--	Braun, 1982
8/8/83	5.4	16.1%	9.50	--	--	--	--	Braun, 1983a
1988	--	--	--	0.160	--	--	--	Hippensteel, 1989
7/1/92	7.0	35.5%	--	--	--	--	--	Burlingame, 2002
7/1/94	2.5	40.3%	--	--	--	--	--	Burlingame, 2002
8/22/94	3.3	21.1%	8.70	0.297	9,188	11.6	39	CLP, 1994
8/10/98	2.3	21.1%	9.07	0.287	64,028	37.3	52	CLP, 1998
7/13/04	2.6	15.8%	9.10	0.190	3,032	18.1	40	CLP, 2004
5/3/05	3.0	--	--	--	--	--	--	Benson, 2006
6/13/05	4.0	22.6%	--	--	--	--	--	Benson, 2006
7/25/05	2.8	--	--	--	--	--	--	Benson, 2006
6/26/07	5.2	--	8.60	0.017^{+}	--	--	--	Lesko, 2007
7/18/07	3.3	--	9.07	0.093^{+}	--	--	--	Lesko, 2007
8/6/07	4.4	--	8.83	0.097^{+}	--	--	--	Lesko, 2007

*Water column average; all other values are means of epilimnion and hypolimnion values.
$^{+}$Surface water (epilimnetic) sample only; all other values are means of epilimnion and hypolimnion values.
$^{\delta}$Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.

Based on the data presented in Table 34, water quality in Beaver Dam Lake has remained stable over the past 40 years. Water clarity in Beaver Dam Lake rates as relatively poor for the region, but is on par with clarity measurements completed for other lakes in the watershed. Since 1966, Secchi disk transparency (a measure of water clarity) has ranged from 2.3 feet (0.7 m) in August 1998 to 7.0 feet (2.1 m) in July 1992. Data collected by a variety of organizations confirms that clarity has remained relatively stable at Beaver Dam Lake over the past 40 years; however, the trend line indicated in Figure 30 suggests that water clarity declined over time. (Note that poor water clarity is at the top of the graph.) In actuality, the number of samples collected on an annual basis likely accounts for the water clarity differences observed early in the sample period compared to later in the period. From 1966 to 1974, only two samples were collected; however, six samples were collected during the 2005 to 2007 sampling period. Additionally, samples collected later in the sampling period occur throughout the sampling season including periods when water clarity is typically better (spring and fall) and periods when it is typically poorer (summer). All of these factors combine to suggest a decline in water clarity based on the trend line; however, it is more likely that water clarity within Beaver Dam Lake has changed little over the past 40 years.

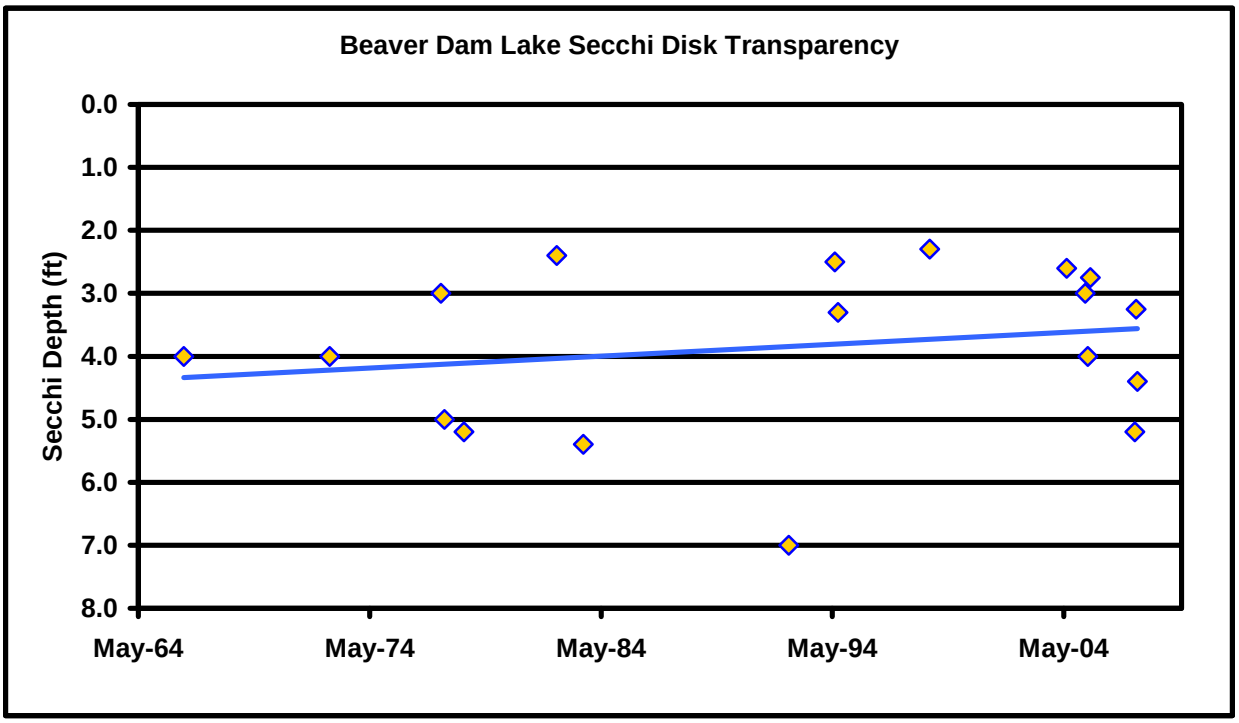


Figure 30. Historic Secchi disk transparency data for Beaver Dam Lake.
Source: Benson, 2006; Braun, 1978a, 1978b, 1982, 1983; Burlingame, 2002; CLP, 1994, 1998, 2004; ISPCB, 1986; Lesko, 2007; and McGinty, 1966a.

Total phosphorus concentrations measured relatively high within Beaver Dam Lake with all but one sample exceeding the median concentration (0.17 mg/L) observed in Indiana lakes. Total phosphorus concentrations ranged from 0.016 mg/L in 1988 to 0.850 mg/L in 1975 (Figure 31). It should be noted that the 1975 sample is a water column composite sample rather than surface water (epilimnetic) and bottom water (hypolimnetic) samples as were collected for all but the 2007 samples (Lesko, 2007). The 2007 samples are surface water samples and therefore represent the conditions present in the epilimnion (surface water) of the lake rather than the entire water column. It is likely that these concentrations would be higher if bottom water (hypolimnetic) samples were collected as well. Declining total phosphorus concentrations from 0.297 mg/L recorded in 1994 to less than 0.1 mg/L in 2007 suggest an improvement in water quality throughout the sample period (Figure 31). The disparity in sample collection methodologies may account for some of the change in concentration over time. It is more likely that there has been little change in total phosphorus concentrations from 1994 to 2007. A similar decline in dissolved phosphorus concentrations is apparent based on Figure 32. Regardless of whether the decline in phosphorus concentrations is real or not, both dissolved and total phosphorus concentrations remain higher than the median concentration found in Indiana lakes.

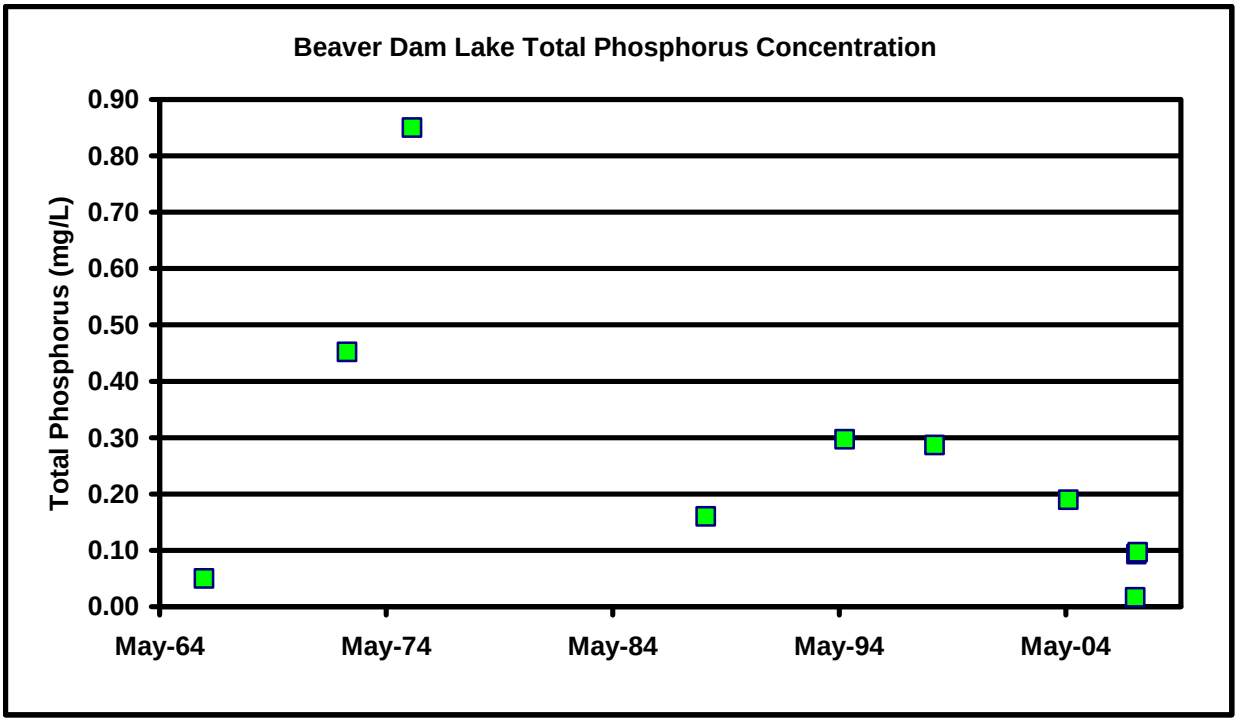


Figure 31. Historic total phosphorus concentrations measured in Beaver Dam Lake.
Source: Benson, 2006; Braun, 1978a, 1978b, 1982, 1983; Burlingame, 2002; CLP, 1994, 1998, 2004; Hippensteel, 1989; ISPCB, 1986; Lesko, 2007; and McGinty, 1966a.

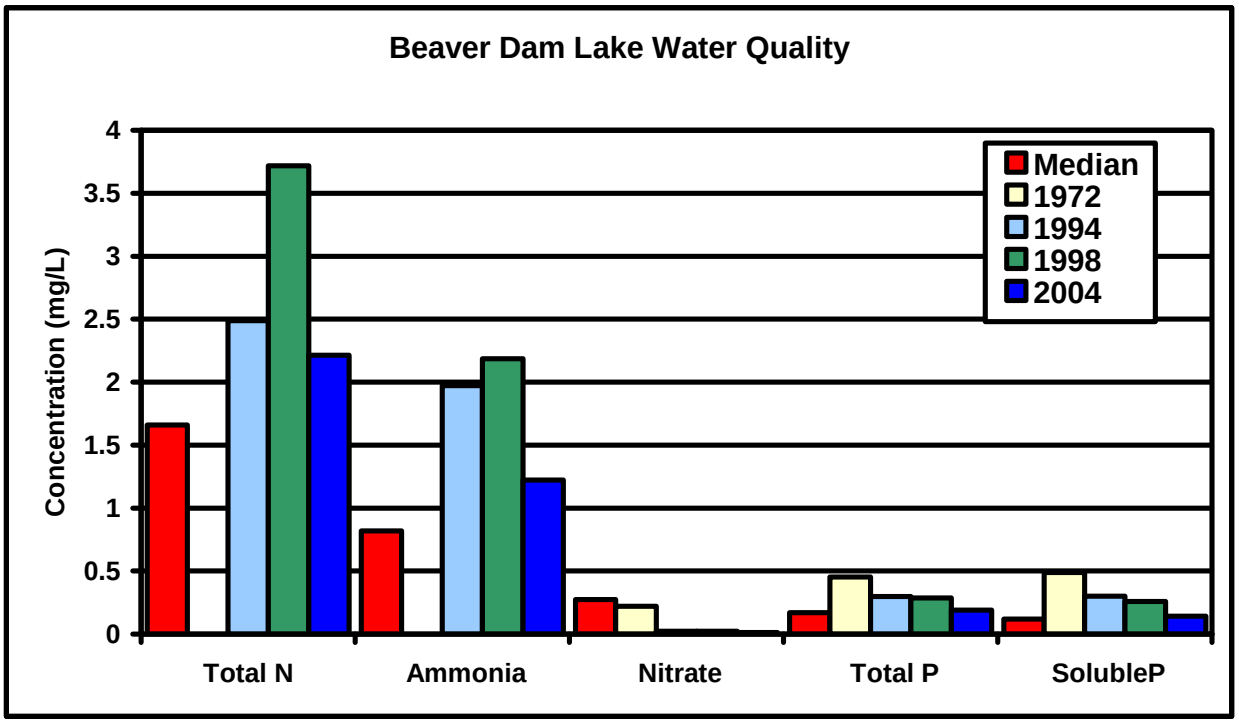


Figure 32. Variation in nutrient concentrations in Beaver Dam Lake, 1972 to 2004.
Source: CLP, 1994, 1998, 2004; ISPCB, 1986.

The lake's algae (plankton) density is relatively low compared with what would be expected given the lakes relatively high nutrient concentrations. Nutrients (nitrogen and phosphorus) promote the growth of algae and/or rooted plant populations. Thus, lakes with high nutrient levels are expected to support dense algae and/or rooted plants. Plankton densities are relatively low within Beaver Dam Lake; however, given the relatively high nutrient concentrations present within the lake, it is expected that plankton densities would typically be higher than concentrations measured in the lake. The high surface water (epilimnetic) pH values also suggest that algal densities would be high. A high epilimnetic pH may indicate the presence of photosynthesizing algae. During the process of photosynthesis, algae remove carbon dioxide, a weak acid, from the water column, thereby increasing the water's pH. Overall, plankton density and total phosphorus concentrations were unrelated in that the highest plankton density does not coincide with the highest total phosphorus concentration measured in the lake. Conversely, the lowest plankton density does coincide with the lowest total phosphorus concentration. These data suggest that something other than nutrients limit plankton production within Beaver Dam Lake. Chlorophyll *a* concentrations reflect the variation in plankton densities found in the lake. However, these chlorophyll *a* concentrations typically exceeded the median concentration observed in Indiana lakes (12.9 μg/L). The lake's Indiana Trophic Score Index (ITSI) ranged from 55 in 1972 to 39 in 1994. The two most recent samples follow a similar pattern with the 1998 ITSI rating 52 and the 2004 assessment rating 40. All of these scores suggest that the lake is mesotrophic to slightly eutrophic.

Figure 33 displays the temperature profiles recorded during IDNR fisheries surveys and Indiana CLP assessments. All of the temperature profiles show that Beaver Dam Lake was stratified at the time of the assessments. The developed hypolimnion (bottom water) present during the surveys is very typical of Indiana lakes. The metalimnion, or area of rapidly changing water temperature, typically extends from 5 feet (1.5 m) to approximately 20 feet (6.1 m). The epilimnion (surface water) is located above the metalimnion, while the hypolimnion (bottom water) is located below the metalimnion. Water within the epilimnion and hypolimnion are typically separated during the summer in stratified lakes and do not mix.

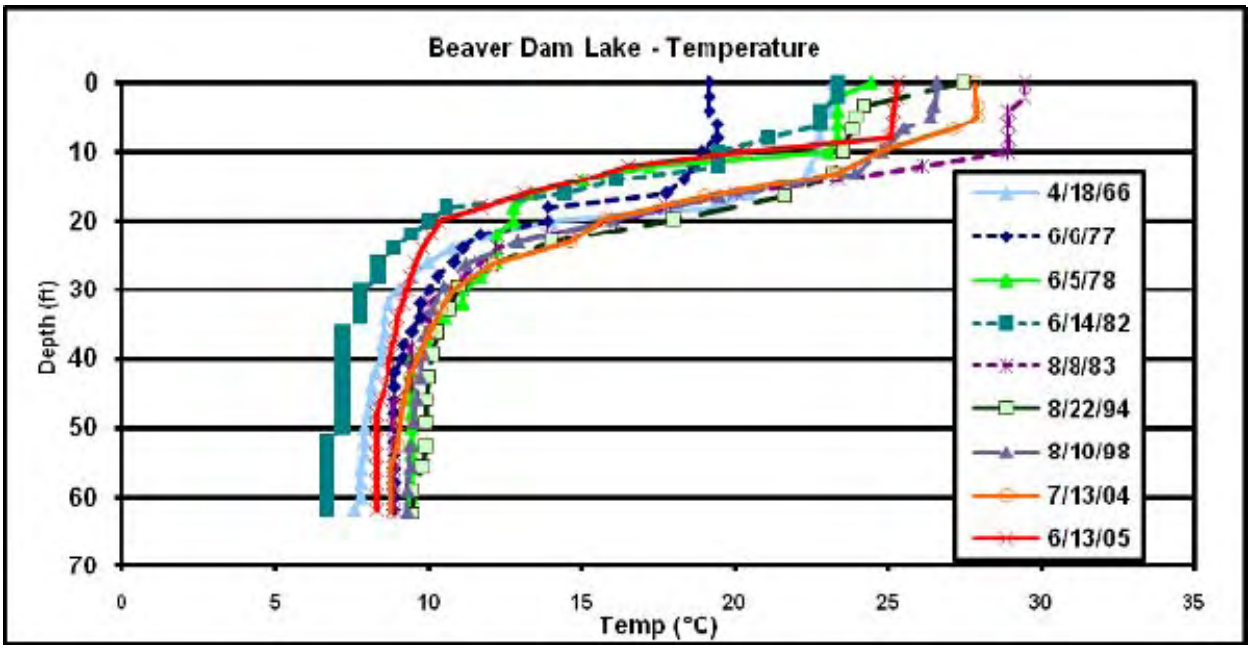


Figure 33. Historical temperature profiles for Beaver Dam Lake.

Much of the data presented above suggest that Beaver Dam Lake is moderately to highly productive. Along those same lines, the historical percent oxic results (Table 34) and dissolved oxygen profiles (Figure 34) are typical of a eutrophic (productive) lake. Dissolved oxygen data indicate that the lake typically possessed dissolved oxygen greater than 1 mg/L in less than 35% of the water column. This decline in dissolved oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments. The 1977, 1983, and 1994 sampling profiles illustrate different conditions than those observed during the other assessments. The 1977 profile displays similar dissolved oxygen concentrations from the lake's surface to a depth of 12 feet (3.6 m). The lack of change in dissolved oxygen concentration coupled with a similar lack of change in temperature suggests that Beaver Dam Lake underwent mixing in the top 12 feet (3.6 m) of water during this sampling event. The 1983 and 1994 dissolved oxygen profiles show sharp increases in dissolved oxygen immediately above the lake's metalimnion. These conditions result in a positive-heterograde profile. Positive-heterograde profiles are characterized by a peak in oxygen concentration at a depth below the water surface, such as the peak in the 1994 profile beginning at 5 feet (1.5 m) below the water's surface. The peak is likely associated with a higher concentration in phytoplankton at that particular depth layer. Called a ***metalimnetic oxygen maximum***, the peak results when the rate of settling plankton slows in the denser waters of the metalimnion. At this depth, the plankton can take advantage of nutrients diffusing from the nutrient-enriched hypolimnion. As the plankton at this depth photosynthesize, they release oxygen into the water column, creating a peak in oxygen at that level. The 1983 assessment profile is also an example

of a metalimnetic oxygen maximum. Both the 1983 and 1994 peaks are relatively small suggesting a limit in the density of phytoplankton floating at these locations within Beaver Dam Lake.

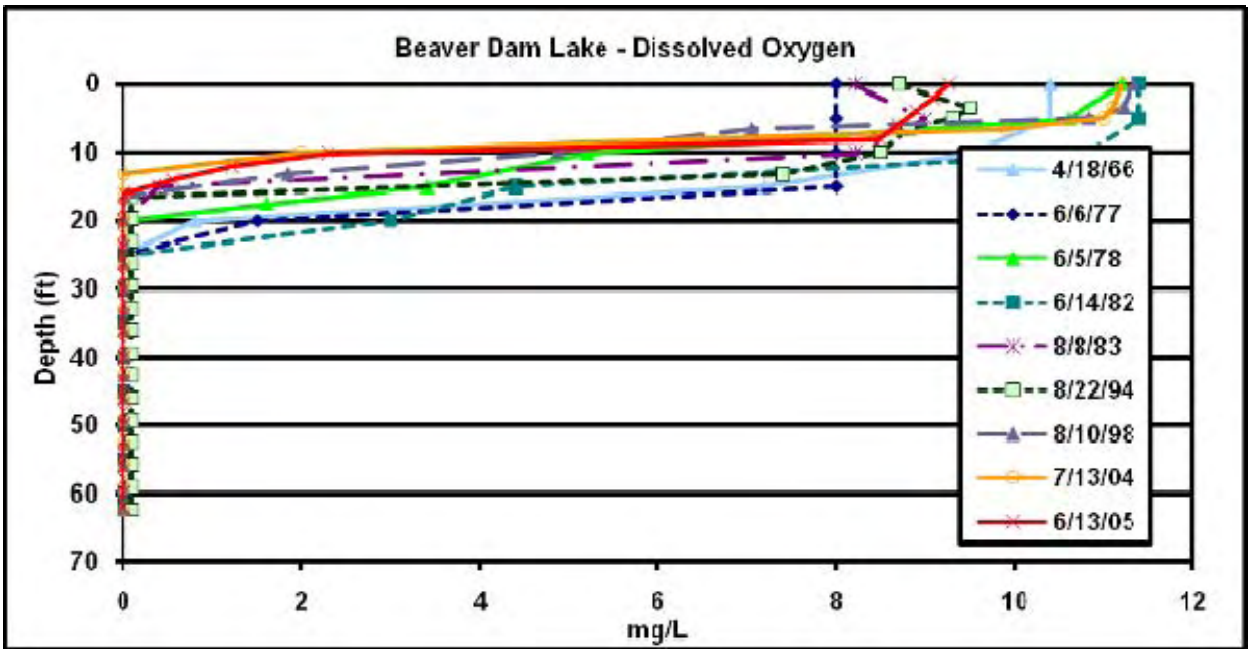


Figure 34. Historical dissolved oxygen profiles for Beaver Dam Lake.

The lack of oxygen in the lake's water column likely reflects intense decomposition of plant material within Beaver Dam Lake during the summer months. Decomposition of plant material undoubtedly occurs in the lake's deeper waters, removing oxygen from the water column. (Higher hypolimnetic ammonia concentrations suggest decomposition is occurring in the lake's bottom waters). Additionally, this lack of oxygen poses a problem for the lake's inhabitants. Fish and other aquatic organisms require oxygen to live. The lack of oxygen in the lake's hypolimnion reduces the amount of habitat available to fish. Fortunately, most of the lake's volume has oxygen levels sufficient to support fish. Based on the depth-volume curve (Figure 21), approximately 92% of the lake's volume is oxygenated. (The percent oxic parameter measures the vertical percent, not volumetric percent, of the water column with oxygen.)

The lack of oxygen in Beaver Dam Lake's hypolimnion also affects the lake's chemistry. While mean total phosphorus concentrations are variable for the years 1966 to 2007 (Table 34), a more detailed evaluation shows that hypolimnetic total phosphorus concentrations are typically higher than epilimnetic total phosphorus concentrations. Under anoxic conditions, the iron in iron phosphate, a common precipitate in lake sediments, is reduced, and the phosphate ion is released into the water column. This phosphate ion is readily available to algae, and can therefore spur algal growth. Further review of historical phosphorus data indicate that much of the total phosphorus was in the dissolved form of phosphorus (SRP). This indicates that Beaver Dam Lake was releasing phosphorus from its bottom sediments. Additionally, Beaver Dam Lake exhibited higher hypolimnetic ammonia concentrations than those observed in the lake's epilimnion during all of the assessments, suggesting decomposition of organic matter was occurring in the lake's bottom waters. Overall, these data suggest that Beaver Dam Lake was a productive (eutrophic) to highly productive (hypereutrophic) lake during the 1994, 1998, and 2004 assessments.

4.1.6 Beaver Dam Lake Water Budget

The watershed or drainage area of Beaver Dam Lake is approximately 1266 acres (512.4 ha). The mean annual watershed runoff volume calculated to drain into Beaver Dam Lake is 1527 acre-feet per year. Comparing the runoff to a lake volume of 2276 acre-feet and factoring in evaporation and rainfall from and to the lake, results in a hydraulic residence time of 1.4 years (Table 35). This residence time is about normal for Indiana Lakes.

Table 35. Water Budget Calculations for Beaver Dam Lake. (See Appendix A for a graphic model of model inputs and outputs**)**

Watershed	Beaver Dam - Kosciusko Co.
Watershed size (ac)	1266
Mean watershed runoff (ac-ft/yr)	1527
Lake volume (ac-ft)	2276
Closest gaged stream	Eel River @ N. Manchester
Stream watershed (mi^2)	417
Stream watershed (acres)	266880
Mean annual daily Q (cfs)	444.7
Mean annual total Q (ac-ft/yr)	321948
Mean ppt (in/yr)	37
Mean watershed ppt (ac-ft/yr)	822880
Watershed C	0.39125
Pan evaporation (in/yr)	41.80
Pan evaporation coefficient	0.70
Lake surface area (acres)	146
Estimated lake evaporation (ac-ft)	356
Direct precipitation to lake (ac-ft)	450
	= input data
	= output data
Water Budget Summary	
Direct precipitation to lake (ac-ft)	450
Runoff from watershed (ac-ft)	1527
Evaporation (ac-ft)	356
TOTAL LAKE OUTPUT (ac-ft)	1621
Hydraulic residence time (yr)	1.40

4.1.7 Beaver Dam Lake Current Water Quality Assessment

Temperature and oxygen profiles for Beaver Dam Lake show that the lake was stratified during the July 10, 2008 sampling (Figure 35). Beaver Dam Lake was supersaturated in the *epilimnion* (surface waters), with 120.8% dissolved oxygen at 5 feet (1.5 m). Supersaturated dissolved oxygen is usually symptomatic of intense phytoplankton photosynthesis. The lake reached anoxic ([D.O.] < 1.0 mg/L) conditions around the depth of 13 feet (4 m).This is likely due to biochemical oxygen demand in the deeper waters. Water below this depth had no oxygen content to support fish and other aquatic organisms. During thermal stratification, the bottom waters (*hypolimnion*) of the lake are isolated from the well-mixed epilimnion by temperature-

induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth is called the *metalimnion*. At the time of our sampling, the epilimnion was confined to the upper 7-10 feet (2-3 m) of water. The sharp decline in temperature between approximately 10 and 26 feet (3 and 8 m) defines the metalimnion or transition zone. The hypolimnion occupied water deeper than 26 feet (8 m).

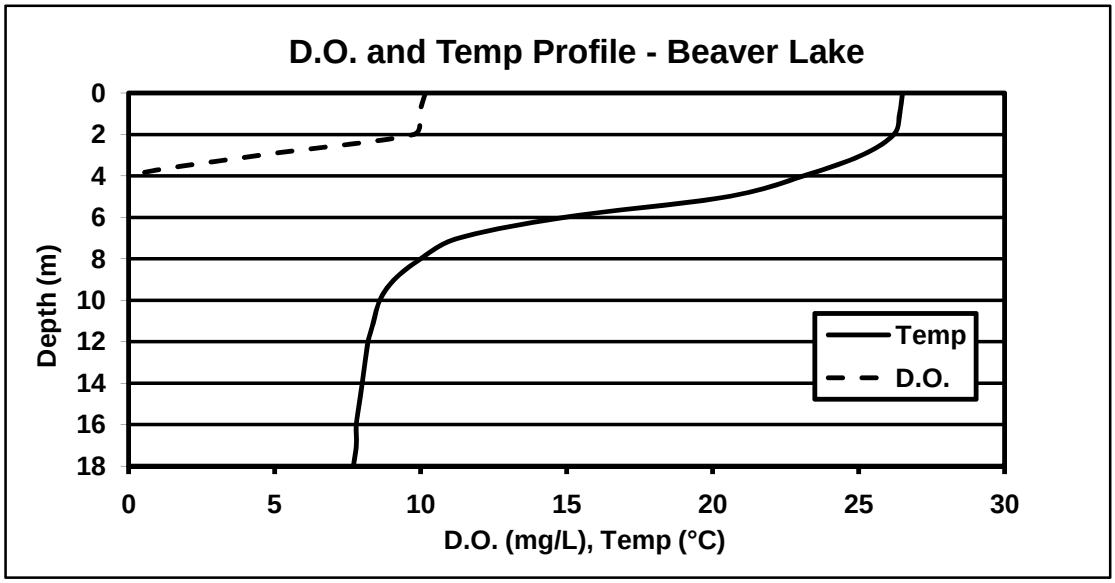


Figure 35. Temperature and dissolved oxygen profiles for Beaver Dam Lake on July 10, 2008.

The 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to 8.2 ft (~2.5 m). Based on the depth-area curve in Figure 20 approximately 23.6% of lake bottom (approximately 34 acres or 13.8 ha) lies above 8.2 ft. This represents the area of the lake bottom with sufficient light to support rooted plants. This area is called the *littoral zone*. Furthermore, based on the depth-volume curve (Figure 21), we see that a volume of approximately 950 acre-feet of Beaver Dam Lake (41% of total lake volume) lies above the 8.2 foot 1% light level. This area, referred to as the *photic zone*, represents the amount of water with sufficient light to support algae growth.

Phosphorus and nitrogen are the primary plant nutrients in lakes. Phosphorus concentrations were relatively high in both the epilimnion and hypolimnion of Beaver Dam Lake (0.104 mg/L and 0.367 mg/L respectively; Table 36). Higher phosphorus concentrations within the hypolimnion are usually associated with nutrient release from the sediments under anoxic conditions. Sedimentation of particulates and plankton also provide a source of phosphorus to the hypolimnion. Both the epilimnion and hypolimnion concentrations exceeded the 0.03 mg/L concentration that is considered high enough to support eutrophic conditions.

Table 36. Water Quality Characteristics of Beaver Dam Lake, July 10, 2008.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.3	7.9	-
Alkalinity	184 mg/L	187 mg/L	-
Conductivity	322.8 µS/m	258.2 µS/m	-
Secchi depth	0.85 m	-	6
Light Transmission @ 3 ft	11.8%	-	4
1% Light level	8.2 ft	-	-
Total Phosphorus	0.104 mg/L	0.367 mg/L	4
Soluble Reactive Phosphorus	0.010* mg/L	0.192 mg/L	3
NO_3	0.076 mg/L	0.013* mg/L	0
NH_4	0.043 mg/L	2.503 mg/L	4
TKN	1.356 mg/L	3.404 mg/L	3
Oxygen Saturation @ 5 ft.	120.8%	-	2
% Water column oxic	16.6%	-	4
Plankton Density	12146 N.U./L	-	3
Blue-Green Dominance	55%	-	0
Chl-a	20.83 µg/L	-	-
		TSI Score	**33**

* Method detection limit

Nitrate nitrogen (NO_3) was relatively high in the epilimnion measuring 0.076 mg/L. Ammonia (NH_4) oxidizes rapidly to nitrate in the presence of adequate oxygen and nitrifying bacteria, which partially explains the increased concentrations in the epilimnion in comparison to the hypolimnion. Nitrate, on the other hand, is reduced to ammonia when oxygen is low. The low epilimnetic ammonia concentration (0.043 mg/l) compared to the high hypolimnetic ammonia concentration measured (2.503 mg/L) indicates the presence of a high amount of biochemical oxygen demand (BOD) to produce the ammonia and a low amount of dissolved oxygen present to maintain these relatively high concentrations.

Values for pH were within the normal range for Indiana lakes, pH 8.3 for the epilimnion and pH 7.9 for the hypolimnion. pH values for most fresh waters fall between pH 6-9 (Kalff, 2002). The high alkalinity values of 184 mg/L and 187 mg/L, for the epilimnion and hypolimnion, indicate that Beaver Dam Lake is not a well buffered system.

Plankton enumerated from the sample collected from Beaver Dam Lake are shown in Table 37. *Aphanizomenon*, a blue-green alga, was the most dominant genera found, and accounted for over half the plankton density. In addition to this particular blue-green alga, other blue-green species contributed to the overall plankton dominance by blue-greens of 55%. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers.

Table 37. Beaver Dam Lake plankton sample representing the species assemblage on July 10, 2008.

SPECIES	ABUNDANCE (N.U./L)
Blue-Green Algae (Cyanophyta)	
Aphanizomenon	2710
Anabaena	2484
Aphanocapsa	1016
Chroococcus	677
Oscillatoria	564
Lyngbya	452
Microcystis	339
Green Algae (Chlorophyta)	
Coelastrum	113
Gloeocystis	564
Staurastrum	226
Ankistrodesmus	113
Mougeotia	113
Desmodesmus	113
Diatoms (Bacillariophyta)	
Synedra	2032
Navicula	226
Fragillaria	113
Other Algae	
Ceratium	2710
Peridinium	339
Zooplankton	
Nauplius	1.6

4.2 Diamond Lake

4.2.1 Diamond Lake Morphology

Diamond Lake has a relatively non-complex morphology (Figure 36). The lake consists of one deep hole surrounded by shallower water. The lake's deepest point lies slightly east of the center of the 79-acre (32-ha) lake. Here, the lake extends to it maximum depth of 39 feet (11.9 m; Table 38). Diamond Lake possesses limited expanses of shallow water. According to its depth-area curve (Figure 37), nearly 11 acres (4.5 ha) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 56 acres (22.6 ha) is covered by water less than 20 feet (6.1 m) deep. This translates into a very low shallowness ratio of 0.11 (ratio of area less than 5 feet (1.5 m) deep to total lake area) and a high shoalness ratio of 0.71 (ratio of area less than 20 feet (6.1 m) deep to total lake area), as defined by Wagner (1990). A large portion of the lake's acreage (approximately 12.9 acres or 5.2 ha) covers the water deeper than 25 feet (7.6 m). The lake's area gradually increases with depth to a water depth of about 15 feet (4.6 m) before the rate of change decreases. The rate (slope of lake bottom) increases again at 25 feet (7.6 m) and continues at this rate to the lakes maximum depth (39 feet or 11.9 m).

Figure 36. Diamond Lake bathymetric map. Source: Kosciusko County GIS Department, digitized from 1956 IDNR contour maps.

Table 38. Morphological characteristics of Diamond Lake.

Characteristic	Value
Surface Area	79 acres (32 ha)
Volume	1,257 acre-feet (54,746,031 m^3)
Maximum Depth	39 feet (11.9 m)
Mean Depth	16.4 feet (5 m)
Shallowness Ratio	0.11
Shoalness Ratio	0.71
Shoreline Length	9,969 feet (3,038 m)
Shoreline Development Ratio	1.52

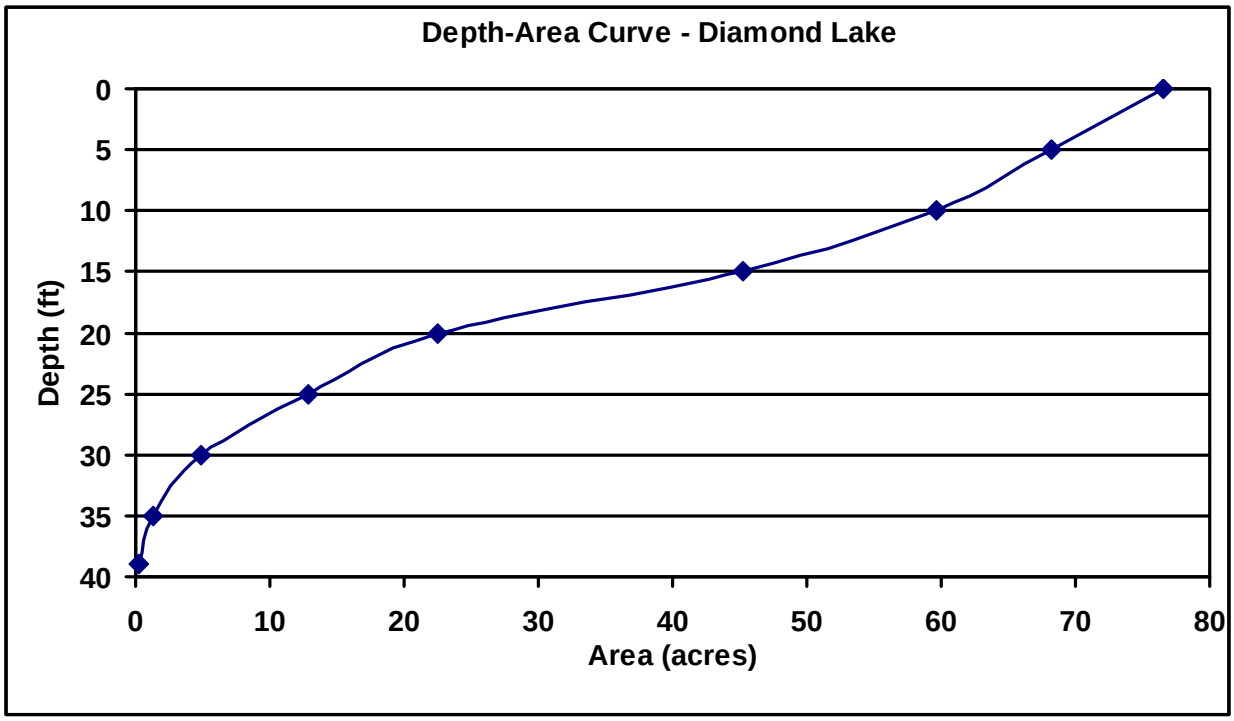


Figure 37. Depth-area curve for Diamond Lake.

Diamond Lake holds approximately 1,257 acre-feet (54,746,031 m^3) of water. As illustrated in the depth-volume curve (Figure 38), much of the lake's volume is contained equally throughout the water column. Nonetheless, more than 50% of the lake's volume is contained in water that is less than 10 feet (3.1 m) deep. The lake's volume gradually increases with depth to about 25 feet (7.6 m) before the rate of change increases. Below 25 feet (7.6 m), the steep curve indicates a greater change in depth per unit volume. This rate continues to the lakes maximum depth (39 feet or 11.9 m).

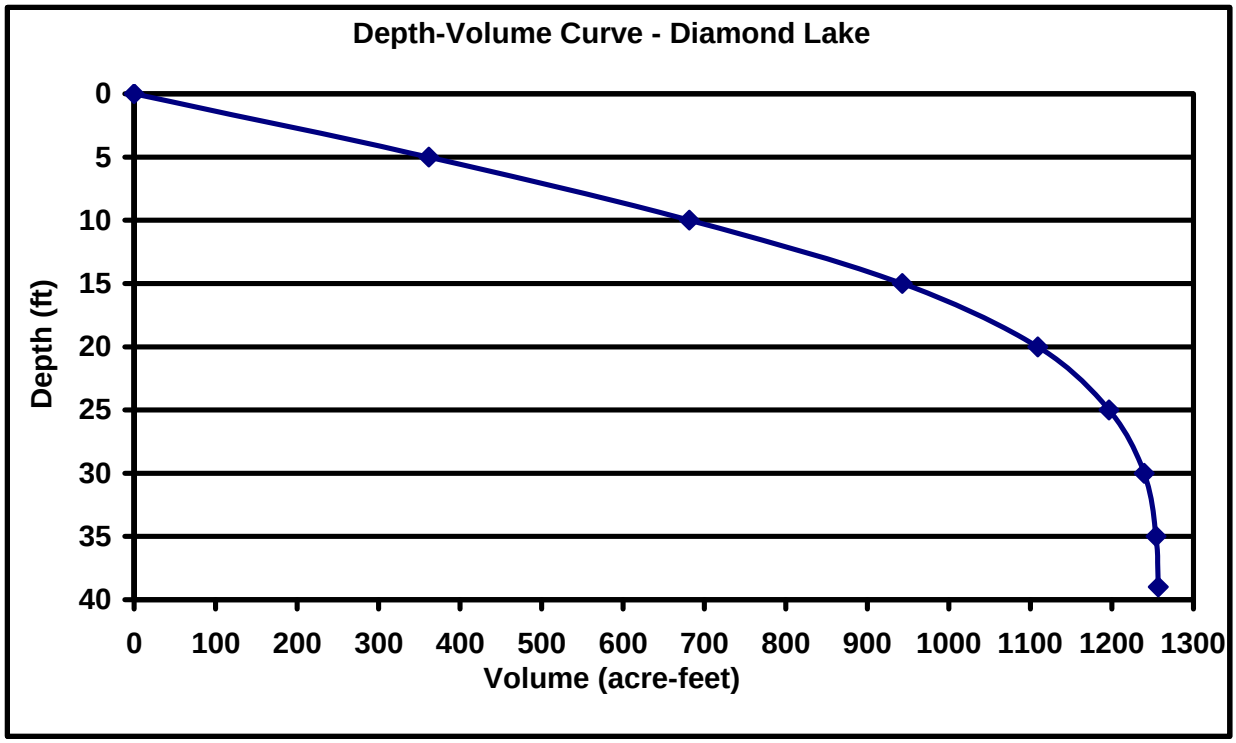


Figure 38. Depth-volume curve for Diamond Lake.

A lake's morphology can play a role in shaping the lake's biotic communities. For example, Diamond Lake's moderately sized shallow area and moderately poor clarity suggests the lake is capable of supporting a dense, but low quality rooted plant community. Based on the lake's clarity, Diamond Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the point where water depths are approximately 10.5 feet (3.2 m). Referring to Diamond Lake's depth-area curve, this means that the lake's littoral zone is approximately 21 acres (8.5 ha) in size or approximately 25% of the lake. This size littoral zone can impact other biotic communities in the lake such as fish that use the plant community for forage, spawning, cover, and resting habitat.

A lake's morphology can indirectly influence water quality by shaping the human communities around the lake. The shoreline development ratio is a measure of the development potential of a lake. It is calculated by dividing a lake's shoreline length by the circumference of a circle that has the same area as the lake. A perfectly circular lake with the same area as Diamond Lake (79 acres or 32 ha) would have a circumference of 6,576 feet (2,004 m). Dividing Diamond Lake's shoreline length (9,969 feet or 3,038 m) by 6,576 feet yields a ratio of 1.52:1. This ratio is relatively low. Diamond Lake is triangular in shape, but possesses relatively round shorelines and lacks extensive shoreline channeling observed on other popular Indiana lakes such as lakes in the Barbee Chain in Kosciusko County. Given the immense popularity of lakes in northern Indiana, lakes with high shoreline development ratios are often highly developed. Increased development around lakes often leads to decreased water quality.

4.2.2 Diamond Lake Shoreline Development

Development around Diamond Lake began early and by 1964, approximately 70 cottages were located along Diamond Lake's shoreline (McGinty, 1966b). Most of the houses were scattered around the lake's northern and eastern shorelines. McGinty counted a total of 48 cottages and

24 trailers to which 88 boats and 3 rafts belonged. Over the next 25 years, development around the shores of Diamond Lake increased. By 1975, nearly half of the shoreline was developed. Development increased slowly resulting in 60% of the shoreline being developed by 1980. Development essentially slowed to nothing in the past 30 years with houses along the lake's northern and eastern shorelines being refurbished and minimal development along the lakes southwestern shoreline and adjacent to the lake's outlet structure.

Given the nearly equal split between developed and undeveloped shoreline around Diamond Lake, it is not surprising that shoreline alteration follows a similar pattern (Figure 39). Natural shoreline is the most prevalent shoreline cover; natural shoreline remains along approximately 45% of Diamond Lake's shoreline. In these locations, bands of plants like those described by McGinty (1966b) are present with trees, emergent vegetation, floating vegetation, and submerged vegetation located in distinct zones along the lakeshore (Figure 40). In these areas, the submerged, floating, emergent, and shoreline canopy layers all remain intact.

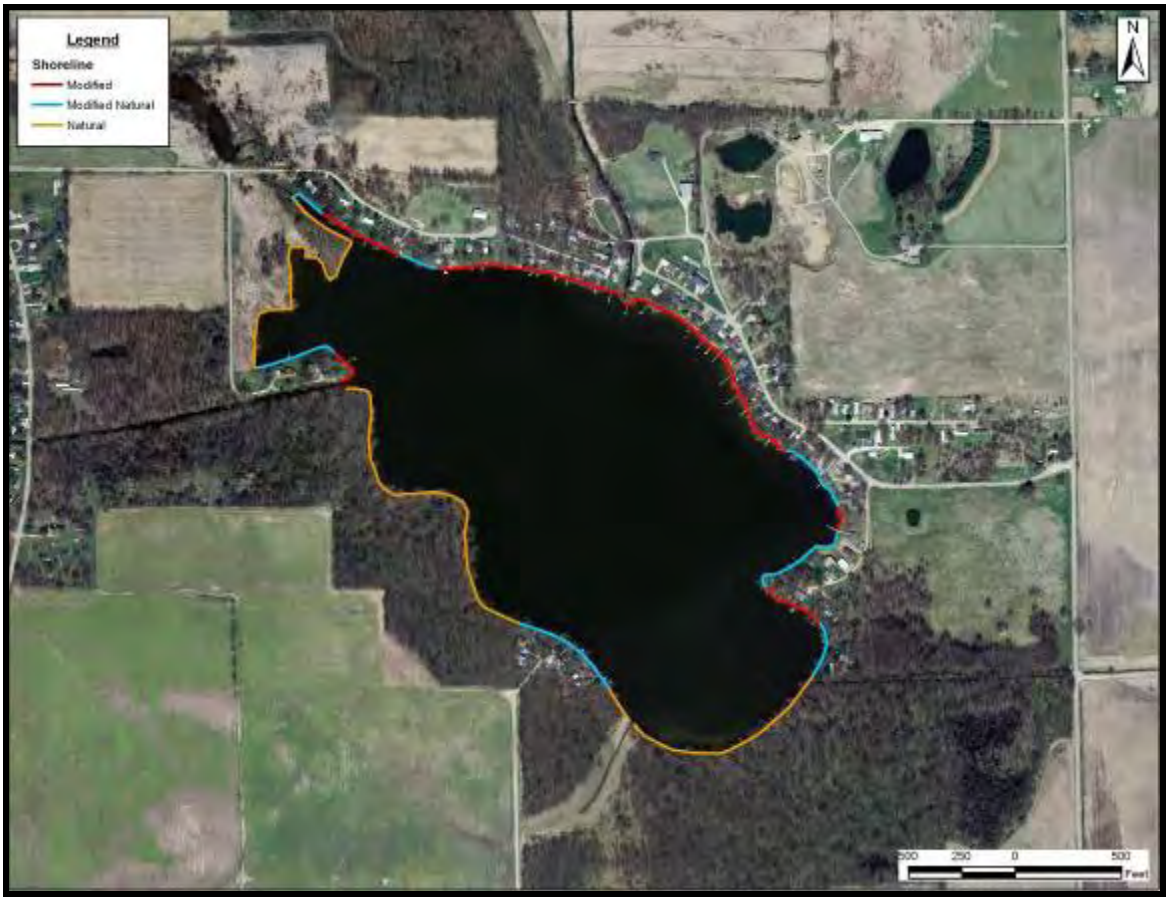


Figure 39. Shoreline surface type observed at Diamond Lake, August 27, 2007.

Figure 40. Natural shoreline present along Diamond Lake's western shoreline.

Despite the relatively natural state of much of Diamond Lake's shoreline, nearly 55% of the shoreline has been altered in some form. Along much of the modified portion of the shoreline (31%; 3,076 feet or 937 m), Diamond Lake's shoreline has been largely altered from its natural state (Figure 41). Along these portions of Diamond Lake's shoreline emergent and floating rooted vegetation has been completely removed adjacent to the shoreline. This leaves exposed soils or mowed, residential lawns exposed to wave action. In some areas wooden railroad timbers, concrete seawalls, glacial stone, or riprap cover the shoreline. This type of shoreline is especially prevalent in the lake's northern and eastern shorelines where wind and wave energy is higher than other areas of the lake.

Figure 41. Modified shoreline present along Diamond Lake's northern and eastern shorelines.

Along a nearly equal portion of Diamond Lake's shoreline (2,460 feet or 750 m), trees and emergent vegetation have been thinned; however, these areas possess at least a narrow band of emergent plants. These areas are mapped as modified natural shoreline because they still possess at least a small portion of all these strata (submerged, emergent, and floating). Other portions of the shoreline that are also mapped as modified natural include those areas where individuals removed only the portion of the shoreline vegetation required to view or access the lake such as the property (Figure 42).

Figure 42. Modified natural shoreline present within Diamond Lake. Note that vegetation was removed in areas required to place the dock for access to the lake. The remaining vegetation along the shoreline and within the lake itself acts as a natural buffer**.**

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

In contrast, shorelines with emergent or rooted floating vegetation will absorb more of the wave energy created by wind or boats. In these locations, wave energy will dissipate along the shoreline each time a wave meets the shoreline surface. Similarly, stone seawalls laid on a naturally occurring slope angle can decrease wave energy reflection while still providing shoreline stabilization.

4.2.3 Diamond Lake Macrophyte Assessment

JFNew surveyed Diamond and Hill lakes' plant communities on August 27, 2007 according to the IDNR sampling protocols (IDNR 2007). The survey included two components: 1) a general survey to identify aquatic plants present in the lakes and to map exotic species locations within the lakes and 2) a Tier II survey, which requires sampling at specific points throughout the lakes' littoral zones (Figure 43). For additional information on historical Tier II surveys see the 2007 Excerpt of Diamond and Hill Lakes (JFNew, 2007b).

Figure 43. Points sampled during the Tier II aquatic plant assessment of Diamond Lake.

Transparency was found to be 3.5 feet in Diamond Lake during the Tier II survey. Diamond Lake supports a varied aquatic plant community. The community extends from the lake's shoreline to water that is just over 9 feet (2.7 m) deep. In total, 25 aquatic plant species inhabit the water and shoreline of Diamond Lake (Table 39). The LARE protocol used to conduct the aquatic plant survey requires surveyors to note all plant species observed from a boat. Thus, plants in the wetland complexes adjacent to the lake were only counted if they were visible from the boat. If these wetland complexes had been explored in greater detail, it is likely that the total number of plant species would increase significantly.

Of the 25 species observed in Diamond Lake, one was a filamentous alga, eleven were submerged plant species. Of the eleven submerged species, nearly all of those are adapted to high nutrient environments. Only three of the submerged species were pondweeds (i.e. belonging to the *Potamogeton* genus), which are typically adapted to better water quality conditions. However, most of these species were identified in relatively low density. Compared to other lakes in the region, this diversity of submerged species represents relatively normal species richness for the submerged strata. Southern naiad, Eurasian watermilfoil, musk grass, and Sago pondweed dominated the submerged plant community and were observed throughout the lake. Two exotic species, Eurasian watermilfoil and reed canary grass, were identified within or adjacent to Diamond Lake.

Table 39. Plant species observed in Diamond Lake as identified on August 27, 2007.

Scientific Name	Common Name	Stratum
Ceratophyllum demersum	Coontail	Submergent
Chara species	Musk grass species	Submergent
Decodon verticillatus	Whorled loosestrife	Emergent
Elodea canadensis	Common waterweed	Submergent
Equisetum arvense	Field horsetail	Emergent
Filamentous algae	Filamentous algae	Algae
Hibiscus species	Hibiscus species	Emergent
Lemna minor	Common duckweed	Floating
Myriophyllum exalbescens	Northern watermilfoil	Submergent
Myriophyllum spicatum	Eurasian watermilfoil	Submergent
Najas flexilis	Slender naiad	Submergent
Najas guadalupensis	Southern naiad	Submergent
Nuphar advena	Spatterdock	Floating
Phalaris arundinacaea	Reed canary grass	Emergent
Polygonum hydropiperoides	Swamp smartweed	Emergent
Pontederia cordata	Pickerel weed	Emergent
Potamogeton amplifolius	Large-leaf pondweed	Submergent
Potamogeton gramineus	Grassy pondweed	Submergent
Potamogeton illinoensis	Illinois pondweed	Submergent
Sagittaria latifolia	Common arrowhead	Emergent
Scirpus acutus	Hard-stem bulrush	Emergent
Scirpus pungens	Chairmaker's rush	Emergent
Stuckenia pectinatus	Sago pondweed	Submergent
Typha x *glauca*	Blue cattail	Emergent
Typha latifolia	Broad-leaf cattail	Emergent

Eleven emergent species were noted bordering Diamond Lake's edges, while only two floating species were observed in the lake. (It is important to note that there are significantly fewer floating aquatic species that are native to Indiana lakes compared to the number of emergent and submerget species. Consequently, many lakes possess low numbers of floating species.) The most common emergent species were reed canary grass, whorled loosestrife, and cattails. The most common floating species were spatterdock, white water lily, and duckweed.

Tier II Survey

During the Tier II survey, southern naiad dominated the plant community over all sampled depths (0-15 feet; Table 40). Southern naiad was found at the highest percentage of sites throughout the entire sampled water column (35%) and also had the highest relative density (0.45). Throughout the entire sampled water column, Eurasian watermilfoil, musk grass, and Sago pondweed were each present at 10% of the sites; slender naiad and coontail were each present at 7.5% of the sites; grassy pondweed, large-leaf pondweed, northern watermilfoil, and

common waterweed were each present at 5% of the sites; and Illinois pondweed was present at only 2.5% of the sites. With regards to dominance, southern naiad dominated the submerged plant community throughout the entire sampled water column with a dominance of 9.0. (A dominance of 200 represents a perfect score or the highest dominance possible within Diamond Lake. This results from multiplying the highest density score (5) by the number of sites where plants were sampled (40). Dominance scores are reported as percentages of this maximum.) Eurasian watermilfoil and musk grass recorded a dominance of 4.0. All other species were relatively sparse throughout the entire sampled water column, with coontail possessing a dominance of 2.5, and slender naiad a dominance of 1.5. All other species had dominances of 1. Filamentous algae were also present at 55% of sites; however, densities are not assigned to this species.

Southern naiad also dominated the submerged plant community in the 0-5 foot and 5-10 foot strata. Southern naiad was the most frequent as it was found at 61.5% of the sites in the 0-5 foot stratum and 31.6% of the sites in the 5-10 foot stratum. Southern naiad generated the highest dominance rating of 12.3 in the 0-5 foot stratum and 10.5 in the 5-10 foot stratum. Eurasian watermilfoil, musk grass, and sago pondweed were each found at 23% of the sites in the 0-5 foot stratum. These species had dominances of 10.8, 7.7, and 4.6, respectively. Eurasian watermilfoil was observed at only 5.3% of the sites in the 5-10 foot stratum with a dominance of 1.05. Eurasian watermilfoil was not identified in the 10-15 foot stratum of Diamond Lake. Overall, Eurasian watermilfoil was identified at 10% of the sampled sites throughout the lake.

Changes in a lake's rooted plant communities over time can illustrate unseen chemical changes in the lake. Unfortunately, limited data detailing Diamond Lake's historical rooted plant community exist for comparison to the current data. In the past, IDNR fisheries biologists conducted cursory vegetation surveys as a part of their general fisheries surveys. Historical studies recorded many of the same species that currently dominate Diamond Lake. In 1964, McGinty (1966b) noted the presence of 16 emergent and floating species and 11 submerged species. McGinty noted the abundance of coontail and sago pondweed with coontail covering 95% of shallow water to a depth of six feet (1.8 m) and sago pondweed dominating the community from six to ten feet (1.8 to 3.1 m). McGinty also made further notation of the abundance of filamentous algae clinging to vegetation throughout the lake. By 1969, the aquatic plant community within Diamond Lake changed significantly. Only four submerged and emergent species were identified during the survey (Hudson, 1969b). Both water turbidity and extensive algal blooms were noted during this survey as was the predominance and need to control coontail growth throughout the lake. Similar species were identified by DNR biologists in 1970, 1975, 1977, and 1980. During the 2004 assessment, Meyer (2006) noted the predominance of Eurasian watermilfoil within Diamond Lake and indicated that future control efforts targeting this species should improve fish production within Diamond Lake.

Table 40. Frequency and dominance of submerged aquatic plant species identified during the Tier II survey of Diamond Lake conducted August 27, 2007.

Occurrence and abundance of submersed aquatic plants in Diamond Lake.					
Total Sites:	40	Mean species / site:	1.03	Native diversity:	0.81
Littoral Sites:	30	Maximum species / site:	5	Species diversity:	0.83
Littoral Depth (ft):	9	Number of species:	11	SE Mean natives / site:	0.22
Date:	8/27/07	Littoral sites with plants:	17	Mean natives / site:	0.93
Lake:	Diamond	Secchi(ft):	3.5	SE Mean species / site:	0.24

All depths (0-15')		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Najas guadalupensis	Southern naiad	35.00	65.00	32.50	0.00	2.50	9.00
Myriophyllum spicatum	Eurasian watermilfoil	10.00	90.00	5.00	5.00	0.00	4.00
Chara species	Chara species	10.00	90.00	5.00	5.00	0.00	4.00
Stuckenia pectinatus	Sago pondweed	10.00	90.00	10.00	0.00	0.00	2.00
Najas flexilis	Slender naiad	7.50	92.50	7.50	0.00	0.00	1.50
Ceratophyllum demersum	Coontail	7.50	92.50	5.00	2.50	0.00	2.50
Potamogeton gramineus	Grassy pondweed	5.00	95.00	5.00	0.00	0.00	1.00
Potamogeton amplifolius	Large-leaf pondweed	5.00	95.00	5.00	0.00	0.00	1.00
Myriophyllum exalbescens	Northern water milfoil	5.00	95.00	5.00	0.00	0.00	1.00
Elodea canadensis	Common water weed	5.00	95.00	5.00	0.00	0.00	1.00
Potamogeton illinoensis	Illinois pondweed	2.50	97.50	0.00	2.50	0.00	1.50
Filamentous algae	Filamentous algae	55.00					
0-5' Stratum		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Najas guadalupensis	Southern naiad	61.54	38.46	61.54	0.00	0.00	12.31
Myriophyllum spicatum	Eurasian watermilfoil	23.08	76.92	7.69	15.38	0.00	10.77
Chara species	Chara species	23.08	76.92	15.38	7.69	0.00	7.69
Stuckenia pectinatus	Sago pondweed	23.08	76.92	23.08	0.00	0.00	4.62
Najas flexilis	Slender naiad	15.38	84.62	15.38	0.00	0.00	3.08
Myriophyllum exalbescens	Northern water milfoil	15.38	84.62	15.38	0.00	0.00	3.08
Elodea canadensis	Common water weed	15.38	84.62	15.38	0.00	0.00	3.08
Potamogeton illinoensis	Illinois pondweed	7.69	92.31	0.00	7.69	0.00	4.62
Potamogeton gramineus	Grassy pondweed	7.69	92.31	7.69	0.00	0.00	1.54
Potamogeton amplifolius	Large-leaf pondweed	7.69	92.31	7.69	0.00	0.00	1.54
Ceratophyllum demersum	Coontail	7.69	92.31	7.69	0.00	0.00	1.54
Filamentous algae	Filamentous algae	53.85					
5-10' Stratum		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Najas guadalupensis	Southern naiad	31.58	68.42	26.32	0.00	5.26	10.53
Ceratophyllum demersum	Coontail	10.53	89.47	5.26	5.26	0.00	4.21
Myriophyllum spicatum	Eurasian watermilfoil	5.26	94.74	5.26	0.00	0.00	1.05
Potamogeton gramineus	Grassy pondweed	5.26	94.74	5.26	0.00	0.00	1.05
Potamogeton amplifolius	Large-leaf pondweed	5.26	94.74	5.26	0.00	0.00	1.05
Najas flexilis	Slender naiad	5.26	94.74	5.26	0.00	0.00	1.05
Chara species	Chara species	5.26	94.74	0.00	5.26	0.00	3.16
Stuckenia pectinatus	Sago pondweed	5.26	94.74	5.26	0.00	0.00	1.05
Filamentous algae	Filamentous algae	68.42					
10-15' Stratum		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Filamentous algae	Filamentous algae	25.00					

4.2.4 Diamond Lake Fisheries Summary

Introduction

The IDNR initially surveyed Diamond Lake in 1964. Subsequent general fish surveys occurred in 1968, 1970, 1974, 1975, 1977, 1980, 1983, 1985, 1995, 2005, and 2006. The 1964 survey revealed an over abundance of small bluegill and large numbers of undesirable sunfish species including longear sunfish, pumpkinseed, warmouth, and gizzard shad in the Diamond Lake fishery (McGinty, 1966b). Based on these findings, IDNR biologists recommended a partial fish eradication program for Diamond Lake. In 1967, IDNR biologists implemented this plan. Rotenone was applied throughout the lake at depths measuring eight feet or less to target the undesirable fish species and small bluegill population. By 1973, the Diamond Lake fishery had not improved so IDNR biologists decided to implement a whole lake renovation and restocking effort on Diamond Lake (Johnson, 1971; October 26, 1973 Fish Population Control Plan report). In 1973, the entire lake was treated with rotenone to eradicate the fish population; stocking of bluegill, largemouth bass, black crappie, walleye, northern pike, and channel catfish followed. A complete list of species identified during the various assessments can be found in Table 41.

Diamond Lake can be defined as a bluegill-largemouth bass fishery. Channel catfish provided limited fishing opportunities in the past due to stockings of channel catfish in 1973, 1981, 1984, and 1992. A naturally reproducing population of channel catfish was never established in Diamond Lake. Currently, a channel catfish population is almost nonexistent. Diamond Lake is located upstream of Yellow Creek Lake and downstream of Hill Lake; therefore, the overall species composition in Diamond Lake is influenced by Yellow Creek and Hill lakes. Evidence of this is clear when species composition was documented following the 1973 renovation and restocking effort. Figure 34 and 35 present the changes in species community composition over time and then a comparison of PSD values from selected game fish during each sample event. Appendix C contains a summary and discussion of fish growth rates from each IDNR report.

Fish Community Summary

Diamond Lake has been fortunate to have been surveyed enough times over the years to accumulate a valuable amount of historical fisheries data. A good working set of historical data is important when evaluating the current state of a fishery or identifying changes in the fish community over time. If the current fish population structure is similar to that from the 2006 survey, then Diamond Lake could benefit most from smart fishing practices, such as catch and release of largemouth bass and selective harvest of bluegill.

Some general trends are apparent when the historical data of Diamond Lake is studied. For example, when the relative abundance of bluegill is high, the PSD value of bluegill is low. Survey years 1995, 2005, and 2006 are good examples of this relationship. Also, the adoption of a 12-inch size limit in 1990 and increase to a 14-inch size limit in 1998 appear to be having a positive affect on the Diamond Lake fishery. The three surveys following the adoption of a minimum size limit, (1995, 2005, 2006) showed an increase in largemouth bass relative abundance and PSD. Additionally, in the 2005 and 2006 survey years, which follow the adoption of the 14-inch minimum size limit, bluegill PSD increased to levels higher than that of all other survey years except 1977.

The addition of walleye and northern pike to the Diamond Lake fishery proved to be unsuccessful, and while channel catfish were shown to survive in Diamond Lake, a naturally reproducing population of channel catfish never developed. A fishable population of channel catfish only became available to anglers for periods of time after stocking events occurred. Continuing a stocking program for channel catfish in Diamond Lake could be advantageous to

the fishery in three ways: 1) additional fishing opportunity to anglers; 2) help control the gizzard shad population, and 3) help increase the PSD of bluegills by predation on young bluegill.

Table 41: Summary of IDNR Fish surveys in Diamond Lake from 1964-2006, Kosciusko County, Indiana.

Common Name	Scientific Name	1964	1968	1970	1974	1975	1977	1980	1983	1985	1995	2005	2006
Sunfish Family													
Bluegill	*Lepomis macrochirus*	X	X	X	X	X	X	X	X	X	X	X	X
Black Crappie	*Pomoxis nigromaculatus*	X		X	X	X	X	X	X	X	X	X	X
Green Sunfish	*Lepomis cyanellus*	X	X	X		X	X		X				
Hybrid Sunfish					X								
Largemouth Bass	*Micropterus salmoides*	X	X	X	X	X	X	X	X	X	X	X	X
Longear Sunfish	*Lepomis megalotus*	X	X	X	X	X		X	X	X	X	X	X
Pumpkinseed	*Lepomis gibbosus*	X	X	X	X	X	X	X	X	X	X	X	
Redear Sunfish	*Lepomis microlophus*	X	X	X	X		X				X	X	X
Rock Bass	*Ambloplites rupestris*	X											
Warmouth	*Lepomis gulosus*	X	X	X		X	X	X	X	X	X	X	X
White Crappie	*Pomoxis annularis*	X	X				X				X		
Catfish Family													
Black Bullhead	*Ameiurus melas*	X				X	X	X	X	X	X		
Brown Bullhead	*Ameiurus nebulosus*	X	X	X		X	X	X	X	X	X	X	
Channel Catfish	*Ictalurus punctatus*	X			X	X	X	X	X	X	X	X	
Yellow Bullhead	*Ameiurus natalis*	X	X	X		X	X	X	X	X	X	X	X
Minnow Family													
Bluntnose minnow	*Pimephales notatus*								X				
Common Carp	*Cyprinus carpio*	X	X	X				X	X	X	X	X	X
Golden Shiner	*Notemigonus crysoleucas*	X	X	X	X	X	X	X	X	X	X	X	
Sucker Family													
Lake Chubsucker	*Erimyzon sucetta*	X	X	X	X	X	X	X	X	X	X	X	
Northern Hog Sucker	*Hypentelium nigricans*											X	

Common Name	Scientific Name	1964	1968	1970	1974	1975	1977	1980	1983	1985	1995	2005	2006
Spotted sucker	*Minytrema melanops*		X	X				X		X			
White Sucker	*Catostomus commersoni*	X	X	X	X	X	X	X	X	X	X	X	X
Bowfin Family													
Bowfin	*Amia calva*										X		
Herring Family													
Gizzard Shad	*Dorosoma cepedianum*	X	X	X	X	X	X	X	X	X	X	X	X
Silversides Family													
Brook Silverside	*Labidesthes sicculus*			X		X			X		X	X	X
Gar Family													
Spotted Gar	*Lepisosteus oculatus*	X	X	X			X	X	X	X	X	X	X
Temperate Basses													
White Bass	*Morone chrysops*	X		X						X	X	X	
Pike Family													
Grass Pickeral	*Esox americanus vermiculatus*	X					X	X		X	X		
Northern Pike	*Esox lucius*					X	X		X				
Trout and Salmon Family													
Rainbow Trout	*Oncorhynchus mykiss*	X											
Perch Family													
Iowa Darter	*Etheostoma exile*										X		
Walleye	*Sander vitreum*					X	X						
Yellow Perch	*Perca flavescens*	X	X	X	X	X	X	X	X	X	X	X	X
Number Species		24	18	20	12/1 hybrid	19	21	19	21	20	24	20	13

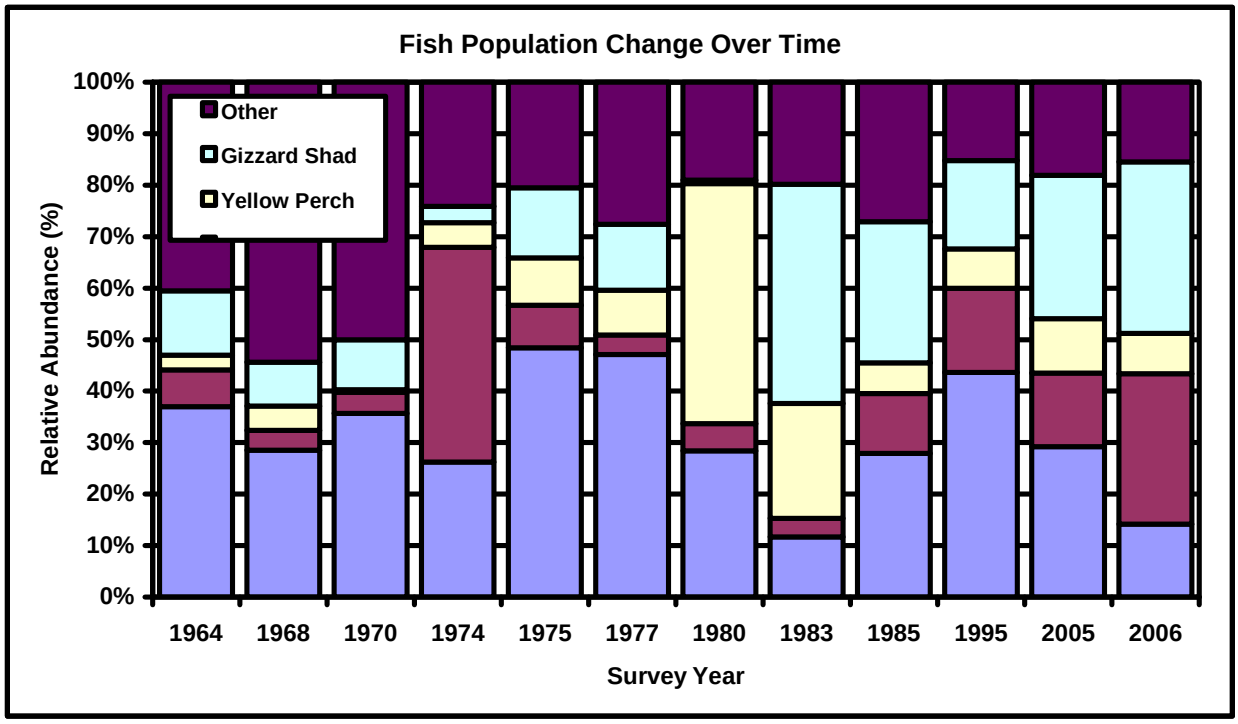


Figure 44. Historical fish community composition in Diamond Lake based on IDNR surveys from 1964-2006. Source: Braun, 1981, 1983, 1986, 1996; Edgell, 2006; Hudson, 1969; Johnson, 1971; McGinty, 1966b; Meyer, 2006; Pearson, 1977; Shipman, 1976; Taylor, 1975.

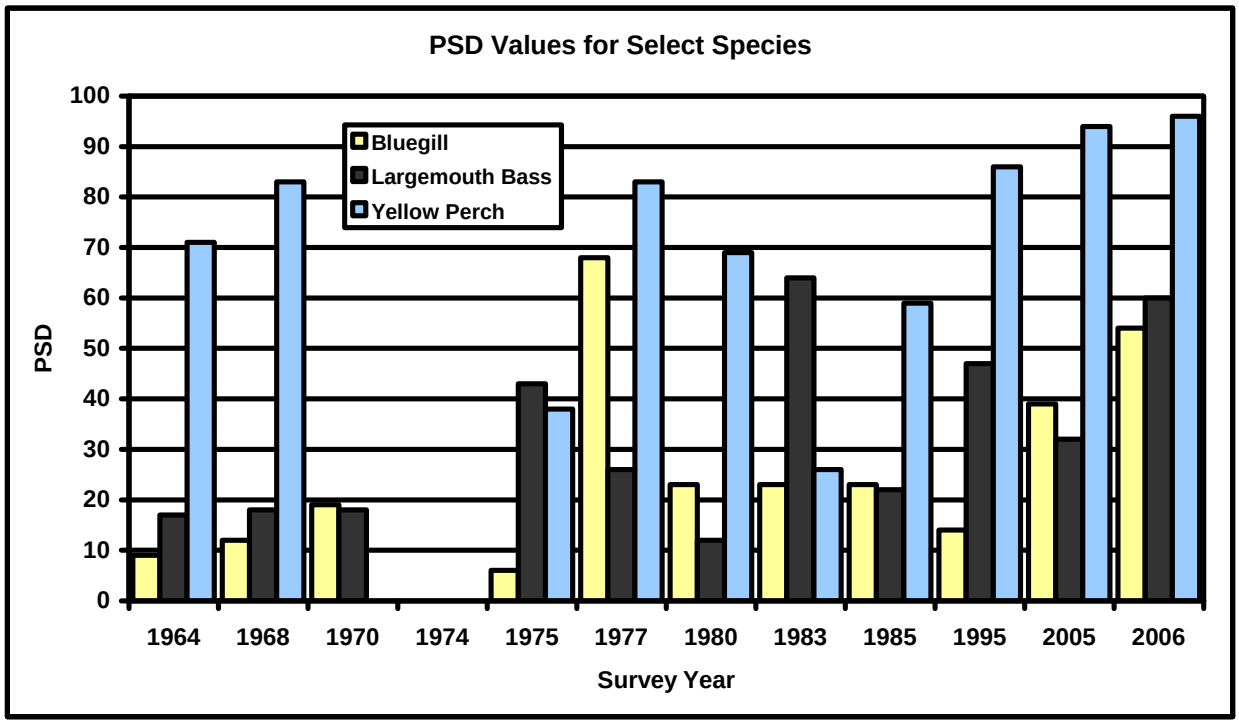


Figure 45. Calculated PSD values for bluegill, largemouth bass, and yellow perch from all survey years in Diamond Lake . Source: Braun, 1981, 1983, 1986, 1996; Edgell, 2006; Hudson, 1969; Johnson, 1971; McGinty, 1966b; Meyer, 2006; Pearson, 1977; Shipman, 1976; Taylor, 1975.

4.2.5 Diamond Lake Historical Water Quality

The IDNR, Division of Fish and Wildlife, the Indiana State Pollution Control Board, the Indiana Clean Lakes Program (CLP), the Tri-State University, Grace College, and Volunteer Monitors have conducted various water quality tests on Diamond Lake. Table 42 presents some selected water quality parameters for these assessments of Diamond Lake.

Table 42. Summary of historic data for Diamond Lake.

Date	Secchi (ft)	% Oxic	Epi pH	TP (mg/L)	Plankton (#/L)	Chl *a* (µg/L)	ITSI Score	Source
7/20/64	4.5	25.6%	8.40	--	--	--	--	McGinty, 1966b
7/15/68	3.5	25.6%	--	--	--	--	--	Hudson, 1969
8/10/70	4.0	25.6%	--	--	--	--	--	Johnson and Peterson, 1971
8/10/74	4.0	38.5%	8.70	--	--	--	--	Taylor, 1975
7/28/75	3.0	25.6%	9.00	--	--	--	--	Shipman, 1976b
12/2/75	--	--	8.80	0.030*	--	--	--	ISBH Laboratory results, 1975
6/13/77	3.0	38.5%	9.00	--	--	--	--	Pearson, 1977a
7/19/77	--	38.5%	--	0.218*	--	--	60[δ]	ISPCB, 1986
7/7/80	8.4	38.5%	9.00	--	--	--	--	Braun, 1981a
6/13/83	3.8	38.5%	9.30	--	--	--	--	Braun, 1983b
7/17/85	3.3	38.5%	9.00	--	--	--	--	Braun, 1985
1988	--	--	--	0.230*	--	--	--	Hippensteel, 1989
8/22/90	3.9	33.3%	7.7	0.252	127,454	--	56	CLP, 1990
8/1/93	3.3	--	--	--	--	--	--	Volunteer monitor
8/22/93	3.5	--	--	--	--	--	--	Volunteer monitor
7/24/95	4.0	25.6%	7.80	--	--	--	--	Braun, 1996
7/21/98	2.0	25.6%	9.24	0.392	10,081	82.5	44	CLP, 1998
7/2/04	2.1	--	--	--	--	--	--	Volunteer monitor
7/13/04	2.3	25.6%	9.40	0.220	55,488	41.9	42	CLP, 2004
8/8/04	2.6	--	--	--	--	--	--	Volunteer monitor
9/6/04	2.2	--	--	--	--	--	--	Volunteer monitor
5/22/05	4.3	--	--	--	--	--	--	Volunteer monitor
6/12/05	4.0	100.0%	--	--	--	--	--	Meyer, 2006
6/26/05	3.4	--	--	--	--	--	--	Volunteer monitor
7/31/05	3.5	--	--	--	--	--	--	Volunteer monitor
8/27/05	3.6	--	--	--	--	--	--	Volunteer monitor
9/30/05	3.4	--	--	--	--	--	--	Volunteer monitor
6/21/06	5.5	30.8%	--	--	--	--	--	Edgell, 2006
6/12/07	3.0	--	--	--	--	--	--	DNR, unpublished
6/27/07	3.5	--	8.50	0.017[+]	--	--	--	Lesko, 2007
7/18/07	2.6	--	8.80	0.020[+]	--	--	--	Lesko, 2007
8/2/07	3.5	--	--	--	--	--	--	DNR, unpublished
8/6/07	3.0	--	8.95	0.150[+]	--	--	--	Lesko, 2007

*Water column average; all other values are means of epilimnion and hypolimnion values.
[+]Surface water (epilimnetic) sample only; all other values are means of epilimnion and hypolimnion values.
[δ]Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.

Based on the data presented in Table 42, water quality in Diamond Lake has remained relatively stable over the past 45 years. Water clarity rates as relatively poor for lakes in the region, but is on par with other lakes in the Yellow Creek watershed. Since 1964, Secchi disk transparency (a measure of water clarity) has ranged from 2 feet (0.6 m) in July 1998 to 8.4 feet (2.6 m) in July 1980. The July 1980 measurement likely over-exaggerates the best conditions found in Diamond Lake as this measurement is more than 3 feet (0.9 m) better than the next best measurement (5.5 feet or 1.7 m in June 2006). Water clarity has been variable over the years with a suggested trend of declining water quality (Figure 46). However, it is likely that the limited number of sampling events conducted prior to 1974 pull the historic end of the trendline towards better water quality, while the high number of more recent measurements suggests poorer quality. With more data collected over time, a better understanding of the typical and long-term conditions found within the lake will become more apparent. Nonetheless, Secchi disk transparencies recorded in Diamond Lake are typically poorer than those measured in most lakes in Indiana.

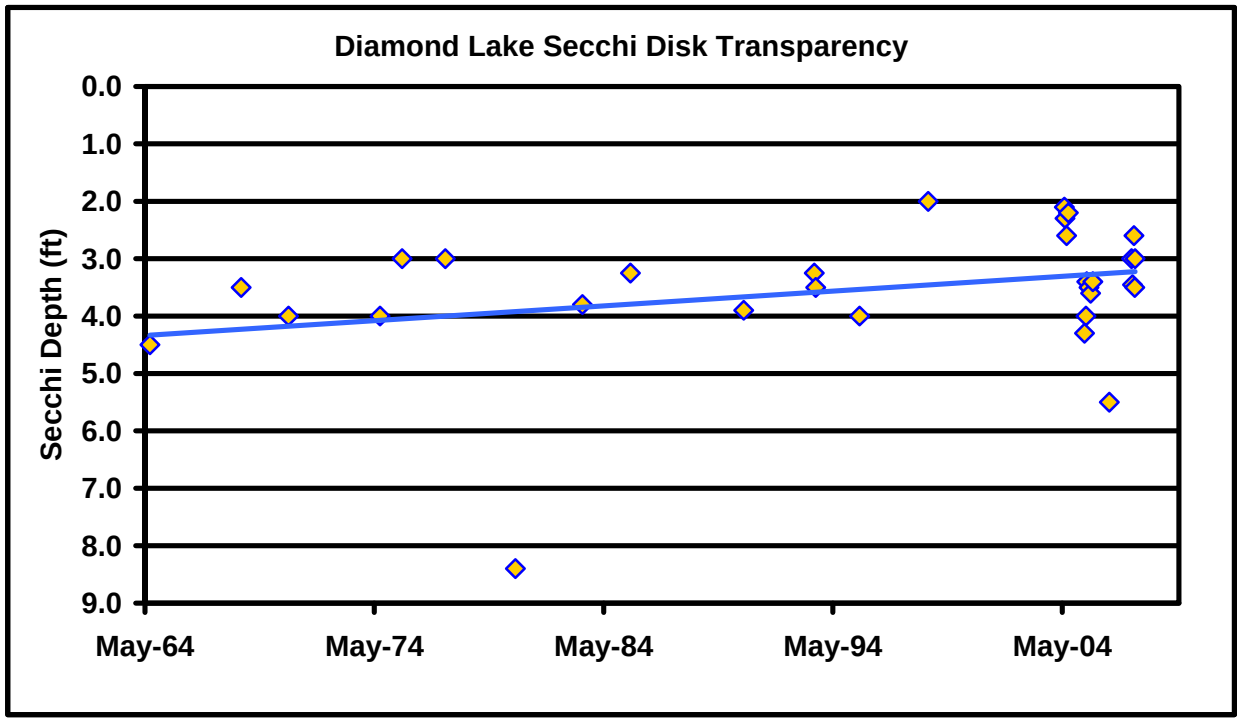


Figure 46. Historic Secchi disk transparency data for Diamond Lake.
Source: Braun, 1981a, 1983b, 1985; CLP, 1990, 1998, 2004; Edgell, 2006; Hippensteel, 1989; Hudson, 1969; ISPCB, 1986; Indiana Volunteer Monitoring Program; Johnson and Peterson, 1971; Lesko, 2007; McGinty, 1966b; Meyer, 2006; Pearson, 1977a, Shipman, 1976a; Taylor, 1975.

Other parameters suggest that water clarity within Diamond Lake remains poor, but that clarity may be improving. The amount of light that penetrated Diamond Lake's water column to a depth of 3 feet (0.9 m) measured a maximum of 18 to 20% during the 1990 and 1998 assessments. Data collected during 2004 indicate that light penetration doubled with 40% of available light reaching 3 feet (0.9 m). The observed light levels are still below levels anticipated in deeper lakes where light levels at 3 feet (0.9 m) typically exceed 50%. The maximum depth of light penetration also increased from those observed during the 1998 assessment to the 2004 assessment. During the 1998 assessment, at a depth of 8.3 feet (2.5 m), light was completely extinguished to a point where photosynthesis could not be supported. During the 2004 assessment, light penetrated deeper reaching a depth of 10.8 feet (3.3 m). Data suggest that

something other than algal growth is limiting light penetration within Diamond Lake. As the penetration of light limits the ability for rooted plant growth, lake residents could expect increased rooted plant growth if water clarity, and thus light penetration, continues to improve.

Historical data also suggests that Diamond Lake supported a healthy algal population. Diamond Lake contained an elevated epilimnetic pH during all assessments. A high epilimnetic pH may indicate the presence of photosynthesizing algae. During the process of photosynthesis, algae remove carbon dioxide, a weak acid, from the water column, thereby increasing the water's pH. Supersaturated dissolved oxygen levels present within the upper 5 feet (1.5 m) of the water column during the 1998 and 2004 assessments lend further evidence to the presence of photosynthesizing algae during this assessment.

The lake's algae (plankton) density reflects the relatively high nutrient levels typically present in Diamond Lake. As previously detailed, nutrients promote the growth of algae and/or rooted plant populations. Plankton densities are relatively high within Diamond Lake, reflecting the relatively high nutrient concentrations present within the lake. Elevated chlorophyll *a* concentrations also reflect the relatively high plankton densities and total phosphorus concentrations found in the lake. Both of the chlorophyll *a* concentrations exceed the median concentration measured in Indiana lakes (12.9µg/L). Additionally, blue-green algae, a nuisance alga typically characteristic of hypereutrophic lakes, dominated the Diamond Lake algal community during the 1990, 1998, and 2004 assessments. During these assessments, blue-green algae accounted for 81 to 94% of the algal community present within Diamond Lake. Finally, during the 1990 assessment, Diamond Lake's algal community measured nearly two-and-one-half times the density measured during the most recent (2004) assessment. As a consequence, more than 15 additional points were added to the lake's ITSI score. The lack of these points during the 2004 assessment was enough to move the lake from the hypereutrophic to the eutrophic category. The weightings of the ITSI based on algal data have been one of the problems with the ITSI. However, Diamond Lake's poor Secchi disk transparencies, high nitrogen and phosphorus concentrations, and high chlorophyll *a* concentrations would place the lake in the eutrophic to hypereutrophic category during all of the historic Clean Lakes Program assessments if it were evaluated using Carlson's (1977) ITSI. Thus, the ITSI scores of 38 to 56 suggesting that Diamond Lake was eutrophic to hypereutrophic is likely accurate.

Total phosphorus concentrations are generally elevated within Diamond Lake. Total phosphorus concentrations increased from 1975 to 1998 before declining in 2004. The relatively high total phosphorus concentrations exceed the median concentration observed in Indiana lakes. Historic total phosphorus concentrations indicate that Diamond Lake likely supported algal blooms in the summer. The lake's algal (plankton) density reflects the relatively high nutrient levels. Nutrients (phosphorus and nitrogen) promote the growth of algae and rooted plants; thus, lakes with high nutrient levels are expected to support dense algae and/or rooted plant populations. More recent data suggest that Diamond Lake's phosphorus concentrations continue to decline, with samples collected during 2007 measuring an order of magnitude less than those measured in 2004. However, 2007 samples included collection of surface water only and did not include the typically nutrient-rich bottom waters. This limits the comparability of these samples to those collected historically. Nonetheless, total phosphorus concentrations in Diamond Lake remain high with concentrations typically exceeding the median total phosphorus concentration for Indiana lakes.

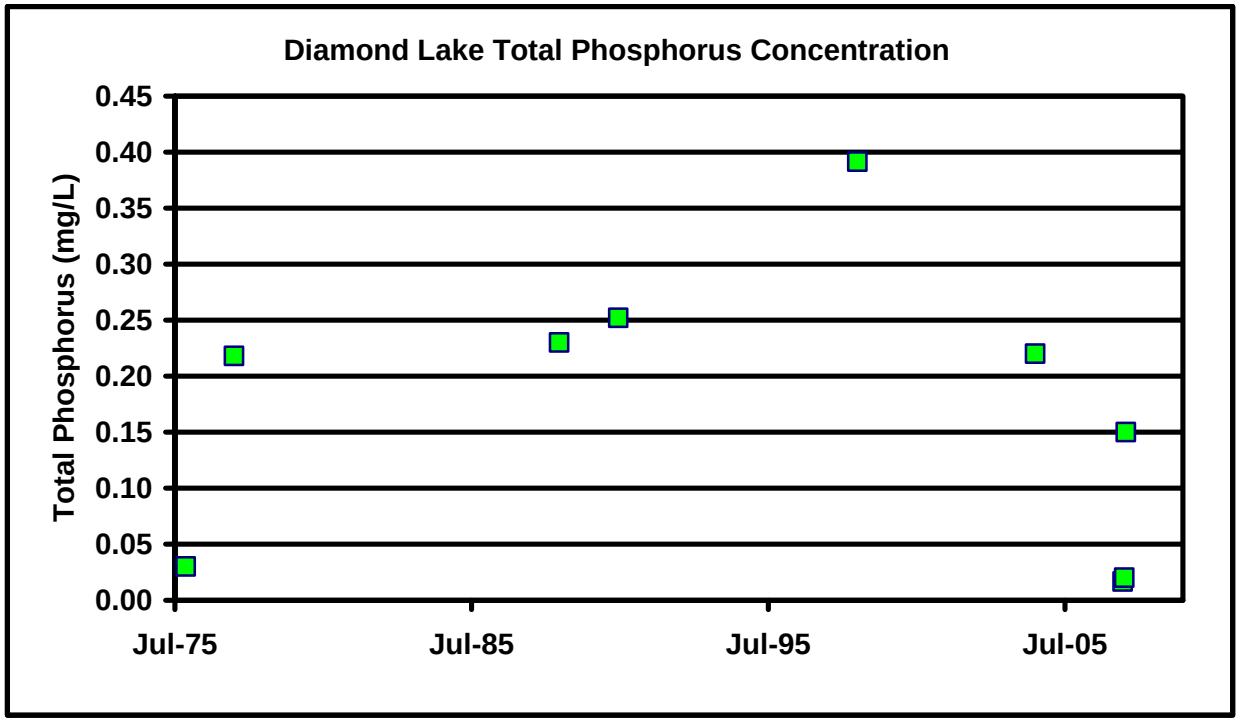


Figure 47. Historic total phosphorus concentrations measured in Diamond Lake.
Source: CLP, 1990, 1998, 2004; Hippensteel, 1989; ISPCB, 1986; Lesko, 2007.

There is no real trend in nutrient concentrations in Diamond Lake even though total phosphorus concentrations seem to increase and then decline within the sample period (Figure 47). The Total phosphorus concentration increases from 0.218 mg/L in 1977 to 0.392 mg/L in 1998 and then decline in 2007 to concentrations less than 0.1 mg/L (epilimnion measurement). Both dissolved and total phosphorus concentrations remain higher than the median concentration found in Indiana lakes. Nitrogen concentrations follow a similar pattern with total nitrogen concentrations increasing from 1977 through 2004. Ammonia-nitrogen and nitrate-nitrogen concentrations increased from 1977 to 1990 before declining in 1998 and 2004 (Figure 48).

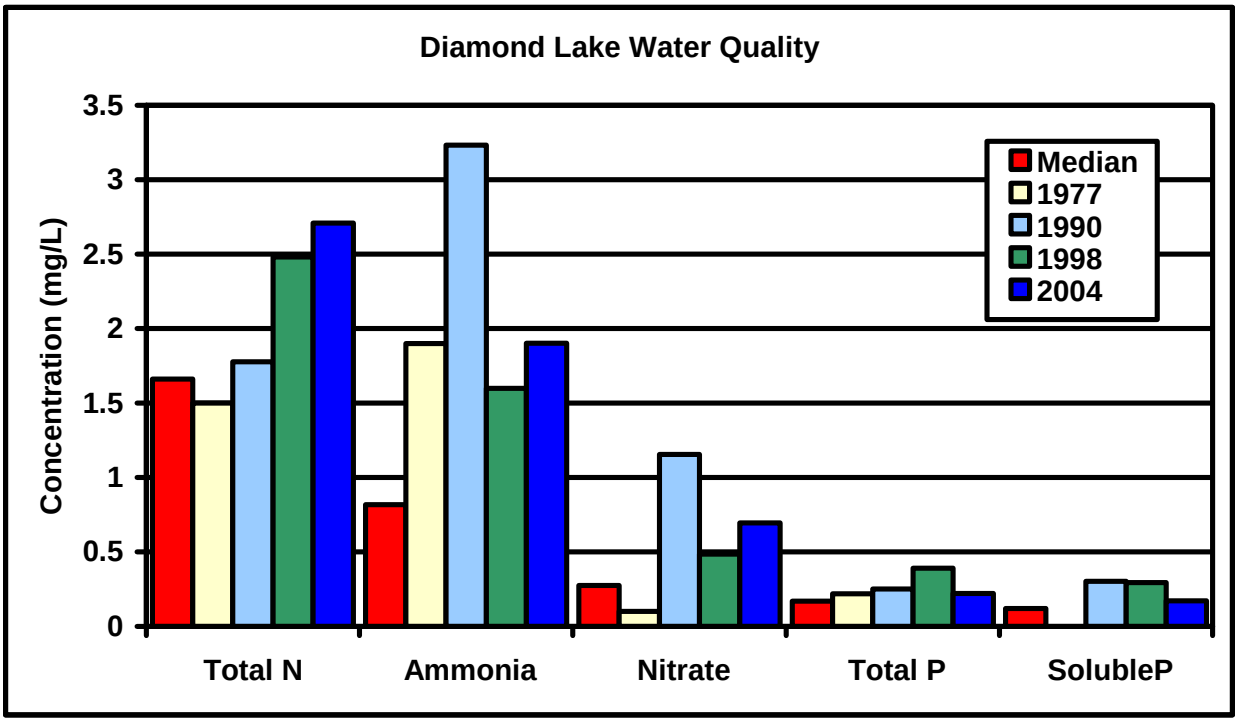


Figure 48. Variation in nutrient concentrations in Diamond Lake, 1977 to 2004.
Source: CLP, 1990, 1998, 2004; ISPCB, 1986.

Figure 49 displays the temperature profiles recorded during IDNR fisheries surveys and Indiana CLP assessments. All of the temperature profiles show that Diamond Lake continues to be stratified. The developed hypolimnion (bottom water) present during the surveys is very typical of Indiana lakes. The metalimnion, or area of rapidly changing water temperature, typically extends from 5 feet (1.5 m) to approximately 25 feet (7.6 m). The epilimnion (surface water) is located above the metalimnion, while the hypolimnion (bottom water) is located below the metalimnion. Water within the epilimnion and hypolimnion are typically separated during the summer in stratified lakes and do not mix.

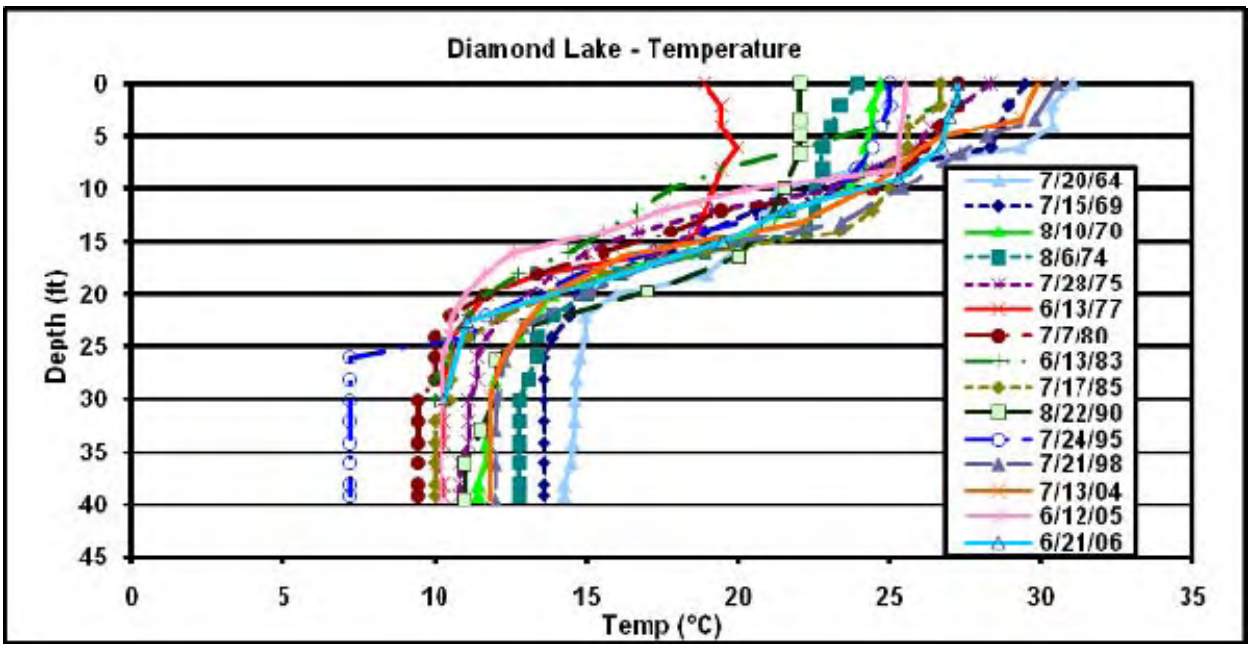


Figure 49. Historical temperature profiles for Diamond Lake.
Source: Braun, 1981a, 1983b, 1985; CLP, 1990, 1998, 2004; Edgell, 2006; Hudson, 1969; Johnson and Peterson, 1971; McGinty, 1966b; Meyer, 2006; Pearson, 1977a, Shipman, 1976a; Taylor, 1975.

Much of the data presented above suggest that Diamond Lake is highly productive; the historical percent oxic results (Table 42) and dissolved oxygen profiles (Figure 50) support these findings. The lake possessed dissolved oxygen greater than 1 mg/L in less than 40% of the water column. This decline in dissolved oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments. The 1983 sampling profile illustrates different conditions than those observed during the other assessments. In this dissolved oxygen profile, there is a sharp increase in dissolved oxygen in the lake's metalimnion. This results in a positive-heterograde profile. Positive-heterograde profiles are characterized by a peak in oxygen concentration at a depth below the water surface, such as the peak in the 1983 profile beginning at 10 feet (3.0 m) below the water's surface. The peak is likely associated with a higher concentration in phytoplankton at that particular depth layer. Called a ***metalimnetic oxygen maximum***, the peak results when the rate of settling plankton slows in the denser waters of the metalimnion. At this depth, the plankton can take advantage of nutrients diffusing from the nutrient-enriched hypolimnion. As the plankton at this depth photosynthesize, they release oxygen into the water column, creating a peak in oxygen at that level. The 1998 and 2004 profiles also display unique conditions in Diamond Lake. These two profiles suggest supersaturated conditions were present at the lake's surface with surface dissolved oxygen concentrations measuring greater than 17.5 mg/L. Diamond Lake's surface water was more than 200% saturated at the time of these sampling events.

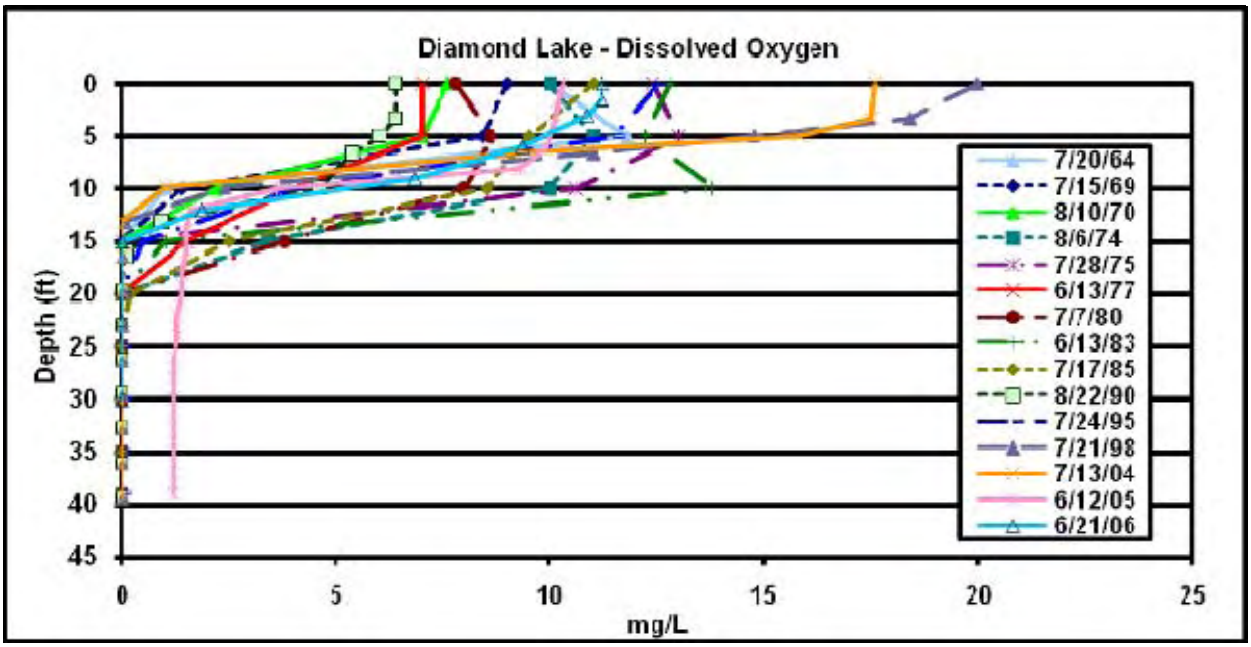


Figure 50. Historical dissolved oxygen profiles for Diamond Lake.
Source: Braun, 1981a, 1983b, 1985; CLP, 1990, 1998, 2004; Edgell, 2006; Hudson, 1969; Johnson and Peterson, 1971; McGinty, 1966b; Meyer, 2006; Pearson, 1977a, Shipman, 1976a; Taylor, 1975.

The lack of oxygen in the lake's water column is likely a sign of intense decomposition of plant material during the summer months. Decomposition of plant material undoubtedly occurs in the lake's deeper waters, removing oxygen from the water column. Higher hypolimnetic ammonia concentrations suggest decomposition is occurring in the lake's bottom waters. Overall, this lack of oxygen poses a problem for the lake's inhabitants. Fish and other aquatic organisms require oxygen to live. The lack of oxygen in the lake's hypolimnion reduces the amount of habitat available to fish. Fortunately, most of the lake's volume has oxygen levels sufficient to support fish. Based on the depth-volume curve (Figure 39), approximately 75% of the lake's volume is oxygenated. (The percent oxic parameter measures the vertical percent, not volumetric percent, of the water column with oxygen.)

The lack of oxygen in Diamond Lake's hypolimnion also affects the lake's chemistry. While mean total phosphorus concentrations are variable for the years 1975 to 2007, a more detailed evaluation shows that hypolimnetic total phosphorus concentrations are typically higher than epilimnetic total phosphorus concentrations. Under anoxic conditions, the iron in iron phosphate, a common precipitate in lake sediments, is reduced, and the phosphate ion is released into the water column. This phosphate ion is readily available to algae, and can therefore spur algal growth. Further review of historical phosphorus data indicate that much of the total phosphorus was in the dissolved form of phosphorus (SRP). This indicates that Diamond Lake was releasing phosphorus from its bottom sediments. Additionally, Diamond Lake exhibited higher hypolimnetic ammonia concentrations than those observed in the lake's epilimnion during all of the assessments, suggesting decomposition of organic matter was occurring in the lake's bottom waters. Overall, these data suggest that Diamond Lake was a moderately eutrophic to hypereutrophic lake or was productive to highly productive during the 1990, 1998, and 2004 assessments.

4.2.6 Diamond Lake Water Budget

The watershed or drainage area of Diamond Lake is approximately 1,555 acres (629.3 ha). The mean annual watershed runoff volume calculated to drain into Diamond Lake is 1,876 acre-feet per year. Comparing the runoff to a lake volume of 1,257 acre-feet and factoring in evaporation and rainfall from and to the lake, results in a hydraulic residence time of about six months (Table 43). This residence time is about normal for Indiana Lakes.

Table 43. Water Budget Calculations for Diamond Lake. (See Appendix A for a graphic model of model inputs and outputs**)**

Watershed	Diamond Lake - Kosciusko Co.
Direct Watershed size (ac)	1555
Mean watershed runoff (ac-ft/yr)	1876
Lake volume (ac-ft)	1257
Closest gaged stream	Eel River @ N. Manchester
Stream watershed (mi^2)	417
Stream watershed (acres)	266880
Mean annual daily Q (cfs)	444.7
Mean annual total Q (ac-ft/yr)	321948
Mean ppt (in/yr)	37
Mean watershed ppt (ac-ft/yr)	822880
Watershed C	0.39125
Pan evaporation (in/yr)	41.80
Pan evaporation coefficient	0.70
Lake surface area (acres)	77
Estimated lake evaporation (ac-ft)	356
Direct precipitation to lake (ac-ft)	450
	= input data
	= output data
Water Budget Summary	
Direct precipitation to lake (ac-ft)	236
Runoff from watershed (ac-ft)	1876
Evaporation (ac-ft)	187
Discharge from Hill Lake (ac-ft)	620
TOTAL LAKE OUTPUT (ac-ft)	2545
Hydraulic residence time (yr)	0.49

4.2.7 Diamond Lake Current Water Quality Assessment

Temperature and oxygen profiles for Diamond Lake show that the lake was stratified at the time of sampling but there wasn't much mixing of the surface waters, since the water temperature steadily declines with depth (Figure 51). The bottom waters (*hypolimnion*) below 23 feet (7 m) are uniform in temperature and were unmixed due to stratification at the time of sampling. Diamond Lake is supersaturated in the surface waters, with 178.40% dissolved oxygen at 5 feet (1.5 m). Supersaturated dissolved oxygen is usually symptomatic of intense phytoplankton

photosynthesis. Diamond Lake reached anoxic conditions below 6 m ([D.O.] < 1.0 mg/L), leaving little oxygen available to support fish. During thermal stratification, the hypolimnion of the lake is isolated from the *epilimnion* (surface waters having uniform temperature with depth) by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth (≥1^{0}C change per 1m depth) is called the *metalimnion*. At the time of our sampling, there was no epilimnion present, which is unusual. This suggests that Diamond Lake is protected from wind or that it was a particularly calm period at the time we sampled. Because of this unusual temperature profile, the depth from the surface down to about 7 meters was all metalimnion. The hypolimnion occupied water deeper than 23 feet (7 m).

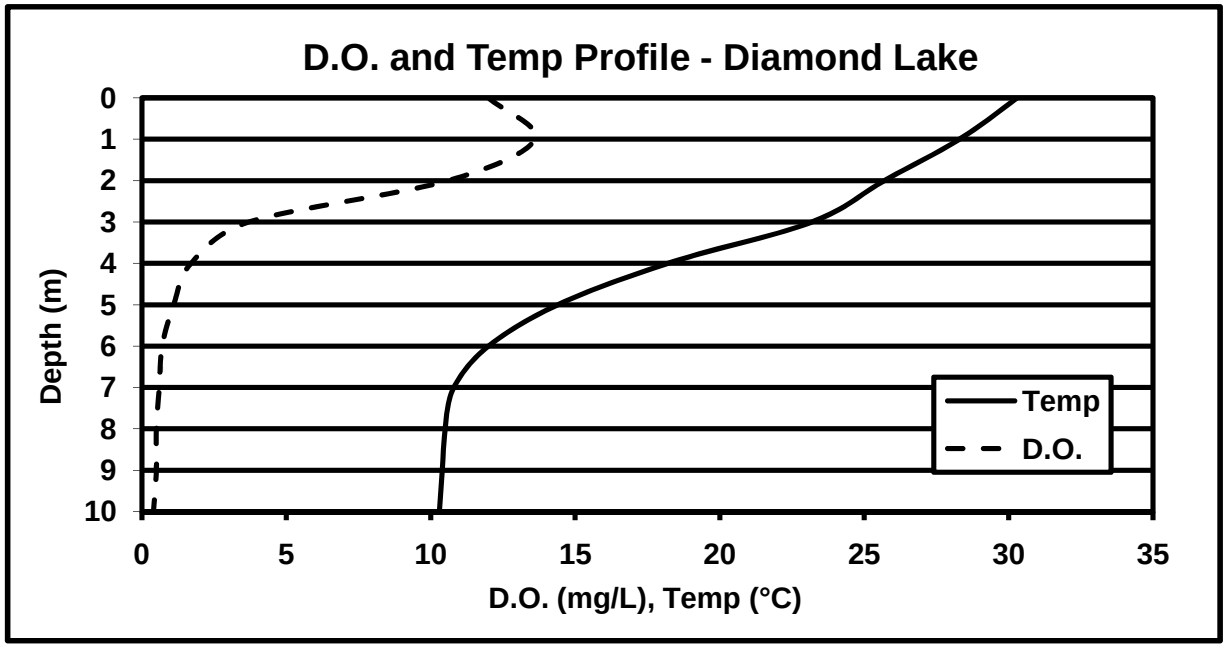


Figure 51. Temperature and dissolved oxygen profiles for Diamond Lake on July 16, 2008.

The 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to 6.4 ft (~2 m). Based on the depth-area curve in Figure 37 approximately 13 % of lake bottom (approximately 10 acres or 4 ha.) is shallower than 6.4 ft (2 m). This represents the area of the lake bottom with sufficient light to support rooted plants. This area is called the *littoral zone*. Furthermore, based on the depth-volume curve (Figure 38), we see that a volume of greater than 450 acre-feet of Diamond Lake (37.8% of total lake volume) lies above the 6.4-ft 1% light level. This area, referred to as the *photic zone*, represents the amount of water with sufficient light to support algae growth.

Phosphorus and nitrogen are the primary plant nutrients in lakes. Phosphorus concentrations were relatively low in the epilimnion of Diamond Lake but were considerably higher (0.425 mg/L) in the hypolimnion (Table 44). Higher phosphorus concentrations within the hypolimnion are usually associated with nutrient release from the sediment during anoxic conditions. Sedimentation of particulates and plankton also provide a source of phosphorus to the hypolimnion. The lower total phosphorus concentration (0.034 mg/L) in the epilimnion is right at the concentration considered high enough to support eutrophic conditions.

Table 44. Water Quality Characteristics of Diamond Lake, July 16, 2008.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	9.1	7.3	-
Alkalinity	108.5 mg/L	218.5 mg/L	-
Conductivity	306 µS/m	485 µS/m	-
Secchi depth	0.7m	-	6
Light Transmission @ 3 ft	5.8%	-	4
1% Light level	6.4 ft	-	-
Total Phosphorus	0.034 mg/L	0.425 mg/L	4
Soluble Reactive Phosphorus	0.010* mg/L	0.376 mg/L	3
NO_3	0.279 mg/L	0.013* mg/L	0
NH_4	0.090 mg/L	3.297 mg/L	4
TKN	0.983 mg/L	4.023 mg/L	2
Oxygen Saturation @ 5 ft.	178.4%	-	4
% Water column oxic	50%	-	2
Plankton Density	45,258 N.U./L	-	5
Blue-Green Dominance	70.9%	-	10
Chl-a	20.83 ug/L	-	-
		TSI Score	**44**

*Method Detection Limit

Nitrate nitrogen (NO_3) in the epilimnion was measured at 0.279 mg/L and was at the detection limit of our analytical methods in the hypolimnion (0.013mg/L). Ammonia (NH_4) oxidizes rapidly to nitrate in the presence of adequate oxygen and nitrifying bacteria, which partially explains the increased concentrations in the epilimnion in comparison to the hypolimnion. Nitrate, on the other hand, is reduced to ammonia when oxygen is low. The high hypolimnetic ammonia concentrations of 3.297 mg/L indicates the presence of a high amount of biochemical oxygen demand (BOD) to produce the ammonia and a low amount of dissolved oxygen present to maintain these relatively high concentrations.

Values for pH were within the normal range for Indiana lakes, pH 9.1 for the epilimnion and pH 7.3. for the hypolimnion. pH values for most fresh waters fall between pH 6-9 (Kalff, 2002). The high alkalinity values of 180.5 and 218.5 mg/L, for the epilimnion and hypolimnion, indicate that Diamond Lake is a well buffered system.

Plankton enumerated from the sample collected from Diamond Lake are shown in Table 45. *Lyngbya*, a blue-green alga, was the most dominant genera found, and accounted for almost half the plankton density. In addition to this particular blue-green alga, other blue-green species contributed to the overall plankton dominance by blue-greens of 70.9%. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers. This blue-green dominance is the primary reason for the higher TSI score in 2008.

Table 45. The plankton sample representing the species assemblage on July 16, 2008.

SPECIES	ABUNDANCE (N.U./L)
Blue-Green Algae (Cyanophyta)	
Aphanizomenon	914
Anabaena	2540
Microcystis	1219
Chroococcus	1219
Aphanocapsa	914
Lyngbya	25301
Green Algae (Chlorophyta)	
Pediastrum	305
Ulothrix	1829
Staurastrum	203
Scenedesmus	102
Diatoms (Bacillariophyta)	
Synedra	6706
Other Algae	
Miscellaneous Protozoa	1321
Ceratium	2235
Dinobryon	102
Zooplankton	
Bosmina	1.4
Daphnia	19
Calanoid Copepod	1.4
Leptodora	1.4
Nauplius	19

4.3 Hill Lake

4.3.1 Hill Lake Morphology

Figure 52 presents Hill Lake's moderately complex morphology. The lake consists of two deep holes surrounded by shallower water. The lake's deepest point is in the western half of the 67-acre (27-ha) lake. Here, the lake extends to it maximum depth of 35 feet (10.7 m; Table 46). One shallower hole lies in the eastern portion of the lake reaching a maximum depth of 30 feet (9.1 m). Water depths of 25 feet (7.6 m) separate these holes from the other parts of the lake.

Figure 52. Hill Lake bathymetric map. Source: Kosciusko County GIS Department, digitized from 1956 IDNR contour maps.

Table 46. Morphological characteristics of Hill Lake.

Characteristic	Value
Surface Area	67 acres (27 ha)
Volume	1,267 acre-feet (1,562,994 m^3)
Maximum Depth	35 feet (10.7 m)
Mean Depth	18.9 feet (5.7 m)
Shallowness Ratio	0.16
Shoalness Ratio	0.40
Shoreline Length	8,493 feet (2,588 m)
Shoreline Development Ratio	1.35

Hill Lake possesses limited expanses of shallow water. According to its depth-area curve (Figure 53), approximately 10 acres (4.0 ha) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 26 acres (10.5 ha) is covered by water less than 20 feet (6.1 m) deep. This translates into a very low shallowness ratio of 0.16 (ratio of area less than 5 feet (1.5 m) deep to total lake area) and a moderate shoalness ratio of 0.40 (ratio of area less than 20 feet (6.1 m) deep to total lake area) as defined by Wagner (1990). The lake's area gradually increases with depth to a water depth of about 20 feet (6.1 m) before the rate of change

decreases. This rate (slope of lake bottom) continues to a depth of 30 feet (9.1 m) where the rate of change increases. This rate continues to the lake's maximum depth (35 feet or 10.7 m).

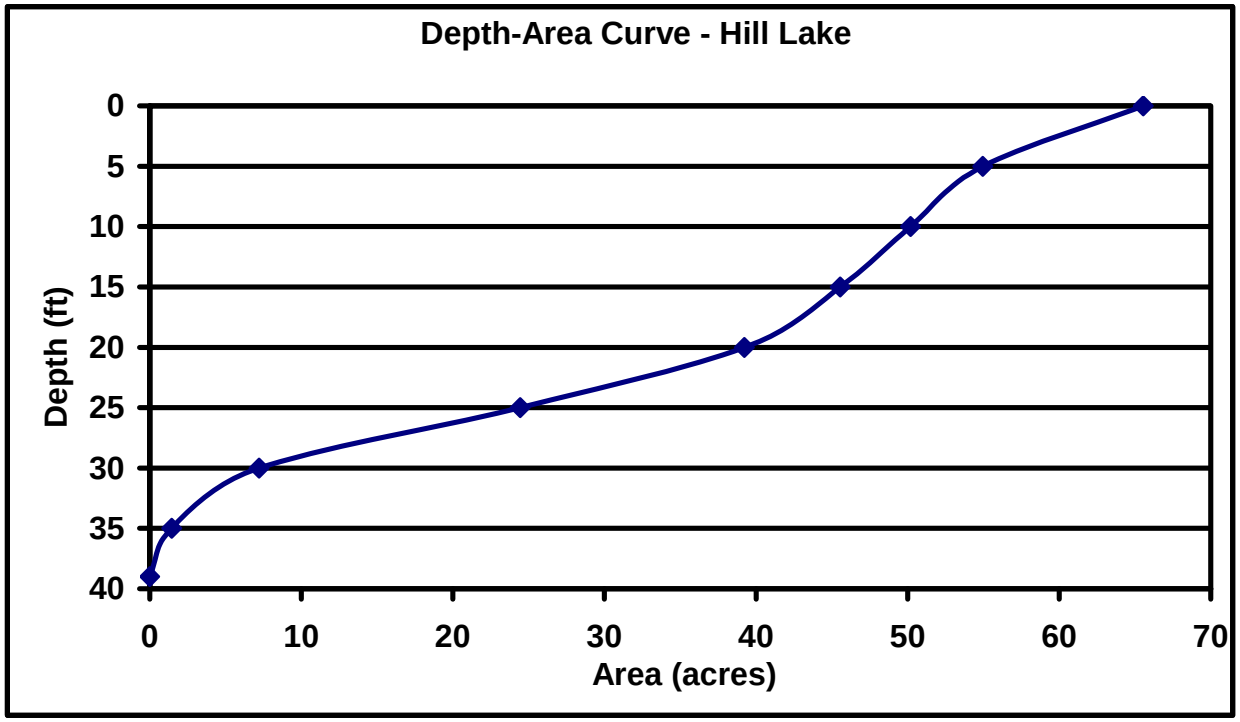


Figure 53. Depth-area curve for Hill Lake.

Hill Lake holds approximately 1,267 acre-feet (1,562,994 m^3) of water. As illustrated in the depth-volume curve (Figure 54), most of the lake's volume is contained in the shallower areas of the lake. More than 80% of the lake's volume is contained in water that is less than 15 feet (4.6 m) deep. The lake's volume gradually increases with depth to a water depth of about 25 feet (7.6 m) before the rate of change increases. Below 25 feet (7.6 m), the steep curve indicates a greater change in depth per unit volume. This rate continues to the lakes maximum depth (35 feet or 10.7 m). The importance of this rate of increase will be discussed with regard to light penetration and the planktonic community in the Results Section.

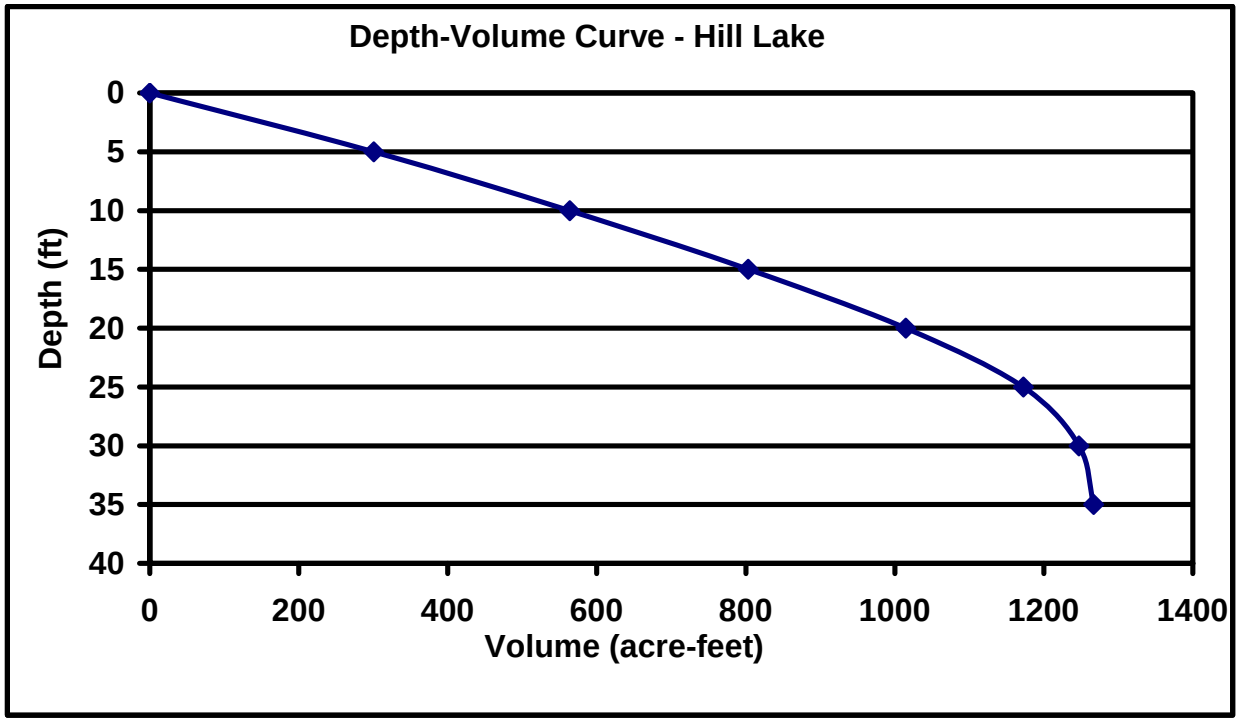


Figure 54. Depth-volume curve for Hill Lake.

A lake's morphology can play a role in shaping the lake's biotic communities. For example, Hill Lake's moderately sized shallow area and wide, shallow shelf around much of the perimeter of the lake coupled with its moderate clarity suggests the lake is capable of supporting a quality rooted plant community. Based on the lake's clarity, Hill Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the lake's maximum depth. Referring to Hill Lake's depth-area curve (Figure 53), this means that the lake's littoral zone is approximately 67 acres (27 ha) in size or approximately 100% of the lake.

A lake's morphology can indirectly influence water quality by shaping the human communities around the lake. The shoreline development ratio is a measure of the development potential of a lake. It is calculated by dividing a lake's shoreline length by the circumference of a circle that has the same area as the lake. A perfectly circular lake with the same area as Hill Lake (67 acres or 27 ha) would have a circumference of 6,056 feet (1,846 m). Dividing Hill Lake's shoreline length (8,493 feet or 2,588 m) by 6,056 feet yields a ratio of 1.35:1. This ratio is relatively low. Hill Lake is relatively round and lacks extensive shoreline channeling observed on other popular Indiana lakes such as lakes in the Barbee Chain and Lake Tippecanoe in Kosciusko County. Given the immense popularity of lakes in northern Indiana, lakes with high shoreline development ratios are often highly developed. Increased development around lakes often leads to decreased water quality.

4.3.2 Hill Lake Shoreline Development

Development around Hill Lake began early and by 1964, a number of residences bordered Hill Lake's shoreline. McGinty (1966c) estimated that 3 resorts and 29 cottages were located adjacent to Hill Lake in 1964. The resorts varied in size from 14 trailer parking spaces at Compass Court Resort, to 26 trailer units, 8 cottages, and a livery at Pleasant View Resort and 6 year-around trailers, 56 summer-residence trailers, 11 summer rental cottages, and a boat livery at Hill Lake Resort. If all residences were full, then approximately 115 cottages were

located along Hill Lake's shoreline. Most of the residences were limited to the four developed areas on the lake on the on the northeastern, northwestern, and southwestern shorelines of Hill Lake. Despite the relatively dense development and because many of the residences being located off the lakeshore but with lake access, only a limited area of Hill Lake is actually developed. Taylor (1973) estimated that only 20% of the shoreline of Hill Lake was developed. The boat and residence counts completed during this survey differ from those completed by McGinty; however, it is likely that Taylor counted only those residences adjacent to the lakeshore rather than those within each of the parks located on the lake. In total, Taylor estimated the presence of 16 homes at which 117 boats were located. In 1975, Shipman estimated 30% of Hill Lake's shoreline was developed with another 40 to 50% undergoing development at the time of the survey. Despite these development plans, more recent estimates indicate that still only 20 to 40% of the shoreline has been developed (Braun, 1995b). Recent aerial photographs confirm the limited shoreline development around Hill Lake (Figure 55).

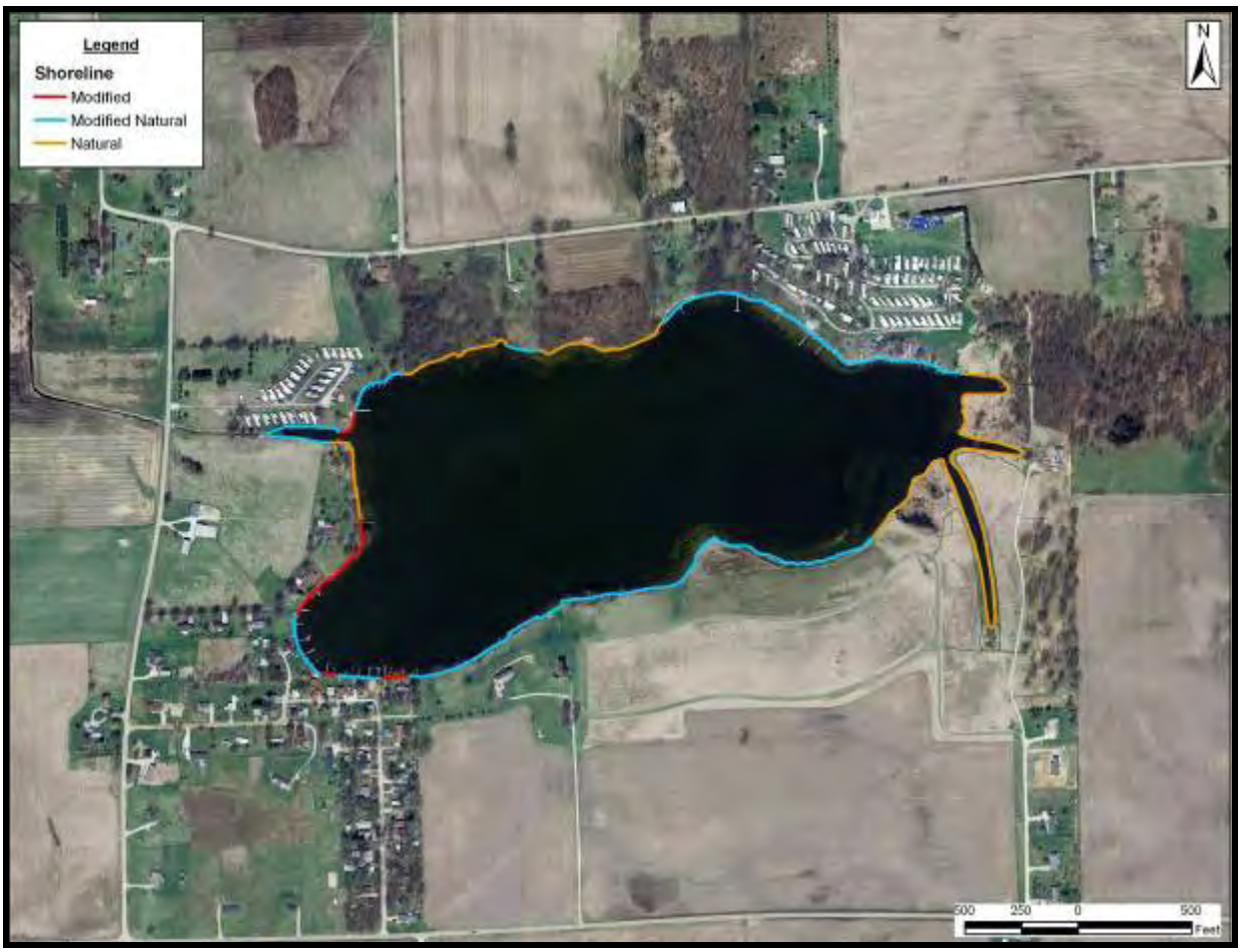


Figure 55. Hill Lake aerial photograph circa 2005. Indiana Spatial Data Portal (ISDP), 2005

Given the limited development along Hill Lake's shoreline, it is not surprising that only 8% of the shoreline rated as modified. Much of the modified shoreline occurs along Hill Lake's southwestern and western shorelines where more permanent residences are located. Along these portions of Hill Lake's shoreline emergent and floating rooted vegetation has been completely removed from the lake adjacent to the shoreline.

Figure 56. Modified natural shoreline present within Hill Lake.

Vegetation remains intact along much of the remainder of Hill Lake's shoreline. In areas mapped as modified natural shoreline some submergent, emergent, or floating vegetation remains, even in areas of relatively intense use (Figure 57). Other portions of the shoreline that are also mapped as modified natural include those areas where individuals removed only the portion of the shoreline vegetation required to view or access the lake such as the property. Modified natural shoreline is present along much of Hill Lake's southern shoreline where livestock grazing occurred historically (McGinty, 1966c). This area continues to be used for pasture and/or hay production and although a narrow band of vegetation is present, it is not in its natural state.

Figure 57. Modified natural shoreline present within Hill Lake. Note that vegetation was removed in areas required to place the docks and boats for access to the lake. The remaining vegetation along the shoreline acts as a natural buffer preventing erosion.

Figure 58. Natural shoreline present along Hill Lake's northern shoreline.

In some areas along the lake's northern and eastern shorelines, native vegetation remains in. Trees, emergent vegetation, floating vegetation, and submergent vegetation are located in distinct zones along the lakeshore (Figure 58). No erosion is occurring in these areas as the vegetation is doing a good job of absorbing wave energy.

4.3.3 Hill Lake Aquatic Macrophyte Assessment

JFNew surveyed Hill Lake's plant communities on August 27, 2007 according to the IDNR sampling protocols (IDNR 2007). Transparency was found to be 8.5 feet (2.6 m) in Hill Lake during the Tier II survey. Hill Lake's plant community extends from the lake's shoreline to water that is 14 feet (4.3 m) deep. In total, 23 aquatic plant species inhabit the water and shoreline of Hill Lake (Table 47). The LARE protocol used to conduct the aquatic plant survey requires surveyors to note all plant species observed from a boat. Thus, plants in the wetland complexes adjacent to the lake were only counted if they were visible from the boat. If these wetland complexes had been explored in greater detail, it is likely that the total number of plant species would increase significantly. For additional information on historical Tier II surveys see the 2007 Excerpt of Diamond and Hill Lakes (JFNew, 2007b).

Table 47. Plant species observed in Hill Lake as identified on August 27, 2007.

Scientific Name	Common Name	Stratum
Asclepias incarnata	Swamp milkweed	Emergent
Ceratophyllum demersum	Coontail	Submergent
Chara species	Musk grass species	Submergent
Decodon verticillatus	Whorled loosestrife	Emergent
Elodea canadensis	Common waterweed	Submergent
Filamentous algae	Filamentous algae	Algae
Myriophyllum exalbescens	Northern watermilfoil	Submergent
Myriophyllum heterophyllum	Variable-leaf watermilfoil	Submergent
Myriophyllum spicatum	Eurasian watermilfoil	Submergent
Najas guadalupensis	Southern naiad	Submergent
Nuphar advena	Spatterdock	Floating
Nuphar variagatum	Yellow pond lily	Floating
Nymphaea tuberosa	White water lily	Floating
Polygonum coccineum	Water heartsease	Emergent
Polygonum lapathifolium	Willow-weed	Emergent
Pontederia cordata	Pickerel weed	Emergent
Potamogeton amplifolius	Large-leaf pondweed	Submergent
Scirpus acutus	Hard-stem bulrush	Emergent
Scirpus pungens	Chairmaker's rush	Emergent
Stuckenia pectinatus	Sago pondweed	Submergent
Typha angustifolia	Narrow-leaf cattail	Emergent
Typha x *glauca*	Blue cattail	Emergent
Typha latifolia	Broad-leaf cattail	Emergent

Of the 23 species observed in Hill Lake, one was a filamentous alga and nine were submergent plant species. Of the nine submergent species, nearly all of those are adapted to high nutrient environments. Only two of the submergent species were pondweeds (i.e. belonging to the *Potamogeton* genus), which along with northern watermilfoil, are typically adapted to better water quality conditions. However, both species were identified in relatively low density. Compared to other lakes in the region, this diversity of submergent species represents relatively low species richness for the submergent strata. Coontail, Eurasian watermilfoil, and musk grass dominated the submergent plant community and were observed throughout the lake. Only one exotic species, Eurasian watermilfoil was identified within or adjacent to Hill Lake.

Ten emergent species were noted bordering Hill Lake's edges, while only three floating species were observed in the lake. It is important to note that there are significantly fewer floating aquatic species that are native to Indiana lakes compared to the number of emergent and submergent species. Consequently, many lakes possess low numbers of floating species. The most common emergent species were reed canary grass, whorled loosestrife, and cattails including narrow-leaf, broad-leaf, and blue cattail. The most common floating species were spatterdock, white water lily, and duckweed.

During the Tier II survey, coontail dominated the plant community over all depths (0-15 feet; Table 48). This species was found at the highest percentage of sites throughout the entire sampled water column (56%) and also had the highest relative density (1.44). Throughout the entire sampled water column, other species were relatively frequent with Eurasian watermilfoil present at 36% of the sites and musk grass present at 20% of the sites. Sago pondweed and northern watermilfoil were each found at 15.4% of the sites. With regards to dominance, coontail dominated the submergent plant community throughout the entire sampled water column with a dominance of 29. (A dominance of 200 represents a perfect score or the highest dominance possible within Hill Lake. This results from multiplying the highest density score (5) by the number of sites where plants were sampled (40). Dominance scores are reported as percentages of this maximum.) All other species were relatively sparse throughout the entire sampled water column, with Eurasian watermilfoil possessing a dominance of 18.5; musk grass a dominance of 14.4; and sago pondweed, northern watermilfoil, and southern naiad each having a dominance of 3. All other species had dominances of 1 or less. Filamentous algae were also present at 5.1% of the sites; however, densities are not assigned to this species.

Table 48. Frequency and dominance of submergent aquatic plant species identified during the Tier II survey of Hill Lake conducted August 27, 2007.

Occurrence and abundance of submersed aquatic plant species in Hill Lake.					
Total Sites:	39	Mean species / site:	1.64	Native diversity:	0.74
Littoral Sites:	35	Maximum species / site:	5	Species diversity:	0.80
Littoral Depth (ft):	14	Number of species:	9	SE Mean natives / site:	0.18
Date:	8/27/07	Littoral sites with plants:	29	Mean natives / site:	1.28
Lake:	Hill	Secchi(ft):	8.5	SE Mean species / site:	0.23

All depths (0-15')		**Frequency of Occurrence**	**Frequency per Species**				
Scientific Name	**Common Name**		**0**	**1**	**3**	**5**	**Dominance**
Ceratophyllum demersum	Coontail	56.41	43.59	23.08	23.08	10.26	28.72
Myriophyllum spicatum	Eurasian watermilfoil	35.90	64.10	17.95	7.69	10.26	18.46
Chara species	Chara species	20.51	79.49	5.13	5.13	10.26	14.36
Stuckenia pectinatus	Sago pondweed	15.38	84.62	15.38	0.00	0.00	3.08
Myriophyllum exalbescens	Northern watermilfoil	15.38	84.62	15.38	0.00	0.00	3.08
Najas guadalupensis	Southern naiad	10.26	89.74	7.69	2.56	0.00	3.08
Myriophyllum heterophyllum	Variable-leaf watermilfoil	5.13	94.87	5.13	0.00	0.00	1.03
Potamogeton amplifolius	Large-leaf pondweed	2.56	97.44	2.56	0.00	0.00	0.51
Elodea canadensis	Common water weed	2.56	97.44	2.56	0.00	0.00	0.51
Filamentous algae	Filamentous algae	5.13					
0-5' Stratum		**Frequency of Occurrence**	**Frequency per Species**				
Scientific Name	**Common Name**		**0**	**1**	**3**	**5**	**Dominance**
Chara species	Chara species	60.00	40.00	0.00	20.00	40.00	52.00
Ceratophyllum demersum	Coontail	50.00	50.00	30.00	10.00	10.00	22.00
Myriophyllum spicatum	Eurasian watermilfoil	40.00	60.00	30.00	0.00	10.00	16.00
Stuckenia pectinatus	Sago pondweed	30.00	70.00	30.00	0.00	0.00	6.00
Najas guadalupensis	Southern naiad	20.00	80.00	10.00	10.00	0.00	8.00
Myriophyllum exalbescens	Northern watermilfoil	20.00	80.00	20.00	0.00	0.00	4.00
Potamogeton amplifolius	Large-leaf pondweed	10.00	90.00	10.00	0.00	0.00	2.00
5-10' Stratum		**Frequency of Occurrence**	**Frequency per Species**				
Scientific Name	**Common Name**		**0**	**1**	**3**	**5**	**Dominance**
Ceratophyllum demersum	Coontail	78.57	21.43	35.71	28.57	14.29	38.57
Myriophyllum spicatum	Eurasian watermilfoil	57.14	42.86	21.43	21.43	14.29	31.43
Myriophyllum exalbescens	Northern watermilfoil	28.57	71.43	28.57	0.00	0.00	5.71
Stuckenia pectinatus	Sago pondweed	21.43	78.57	21.43	0.00	0.00	4.29
Najas guadalupensis	Southern naiad	14.29	85.71	14.29	0.00	0.00	2.86
Myriophyllum heterophyllum	Variable-leaf watermilfoil	14.29	85.71	14.29	0.00	0.00	2.86
Chara species	Chara species	14.29	85.71	14.29	0.00	0.00	2.86
Elodea canadensis	Common water weed	7.14	92.86	7.14	0.00	0.00	1.43
Filamentous algae	Filamentous algae	14.29					
10-15' Stratum		**Frequency of Occurrence**	**Frequency per Species**				
Scientific Name	**Common Name**		**0**	**1**	**3**	**5**	**Dominance**
Ceratophyllum demersum	Coontail	54.55	45.45	9.09	36.36	9.09	32.73
Myriophyllum spicatum	Eurasian watermilfoil	18.18	81.82	9.09	0.00	9.09	10.91

Coontail also dominated the submergent plant community in the 0-5 foot, 5-10 foot, and 10-15 foot strata. Coontail was the second most frequent as it was found at 50% of the sites in the 0-5 foot stratum and musk grass was found at 60% of the sites. Coontail was the most frequent and was found at 78.6% of the sites in the 5-10 foot stratum and at 54.6% of the sites in the 10-15 foot stratum. Musk grass generated the highest dominance rating of 52 in the 0-5 foot stratum, while coontail generated a dominance of 22. Coontail generated the highest dominance rating of 38.6 in the 5-10 foot stratum and 32.7 in the 10-15 foot stratum. Eurasian watermilfoil was

also very frequent and somewhat dominant. This species was identified at 40%, 57%, and 18% of the sites in the 0-5 foot, 5-10 foot, and 10-15 foot strata, respectively. No plants were found in the 15-20 foot stratum. Both frequency and density of Eurasian watermilfoil increased in the 5-10 foot stratum. Overall, Eurasian watermilfoil was identified at 35.9% of the sampled sites throughout the lake (Figure 59).

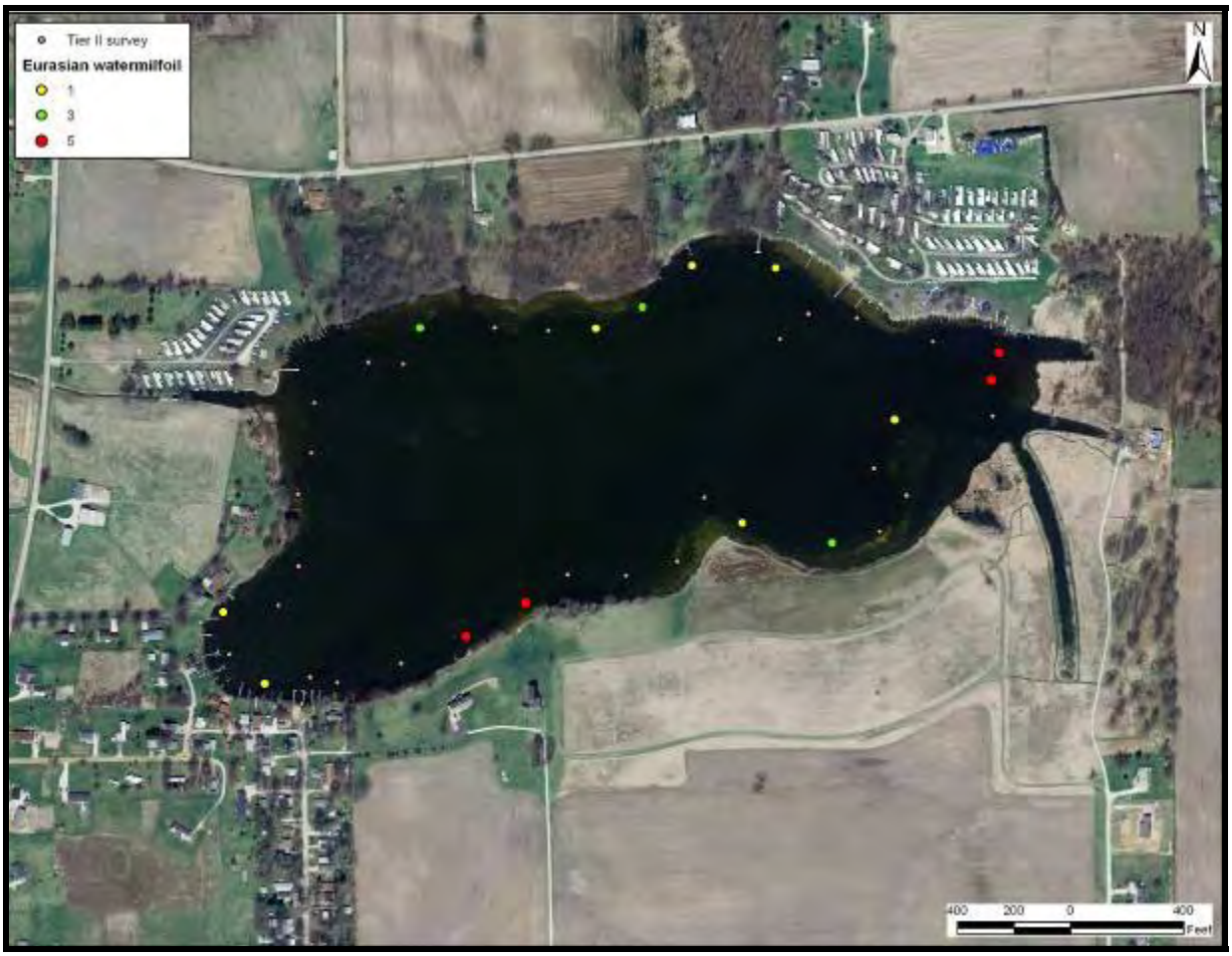


Figure 59. Points sampled and the location/density of Eurasian watermilfoil identified in Hill Lake during the August 27, 2007 Tier II aquatic vegetation survey.

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

Changes in a lake's rooted plant communities over time can illustrate unseen chemical changes in the lake. Unfortunately, limited data detailing Hill Lake's historical rooted plant community

exist for comparison to the current data. In the past, IDNR fisheries biologists conducted cursory vegetation surveys as a part of their general fisheries surveys. Historical studies recorded many of the same species that currently dominate Hill Lake. In 1964, McGinty noted the presence of 11 emergent species and 9 submergent species. The dominance of large-leaf pondweed and coontail were noted during this survey. McGinty (1966c) indicated that heavy blooms of filamentous, free-floating algae were also prevalent on emergent and submergent vegetation. Similar species were identified by DNR biologists in 1973, 1975, and 1977. Overall, the plant community present in Hill Lake suggests that water quality has changed little over time as many of the same species were present in the lakes. Additionally, the relatively moderate diversity of submergent species suggests that water clarity and nutrient levels have been relatively moderate within the lake.

4.3.4 Hill Lake Fisheries Summary

Introduction

The IDNR initially surveyed Hill Lake in 1965. Subsequent general fish surveys occurred in 1972, 1974, 1975, 1977, 1980, 1983, 1985, and 1994. Results from the 1972 survey indicated slow growth and unbalanced population structure within game-fish species and high numbers of undesirable fish species, such as gizzard shad and longear sunfish (Taylor, 1973). Based on these findings, IDNR biologists recommended renovation and restocking of Hill Lake. In 1973, the IDNR salvaged all desirable game-fish species from the lake and rotenone was applied to completely eradicate the remaining fish population. Salvaged fish were then returned to the lake; additional stocking of bluegill, largemouth bass, black crappie, walleye, northern pike, and channel catfish occurred concurrently. Table 49 is a complete list of species identified during the various assessments.

Hill Lake can be described as a panfish-largemouth bass fishery with additional angling opportunities for channel catfish and northern pike. Channel catfish do not reproduce naturally within the lake and were stocked in 1973, 1981, 1982, and 1985. Therefore, current channel catfish populations in Hill Lake are either the result of migration from Diamond Lake (downstream and connected to Hill Lake via the Michaels Arm of Swick-Meredith Drain), where channel catfish were stocked as of the 1994 survey, illegal stocking by individuals, or holdovers from previous stockings in Hill Lake. However, it is unlikely that the stockings are contributing many fish to the population at this point. Northern pike exhibit natural reproduction; however, reproduction occurs with varying levels of success. This is due to water level changes each year which influence the quality of and access to their spawning areas (wetlands) adjacent to the lake. Hill Lake's overall species composition is influenced by Diamond Lake as documented following the 1973 renovation and restocking effort (Taylor, 1974). Figure 60 and 61 present the changes in species community composition over time and then a comparison of PSD values from selected game fish during each sample event.

Table 49: Summary of IDNR Fish sampling results in Hill Lake, Kosicusko County, Indiana

Common Name	Scientific Name	1965	1972	1974	1975	1977	1980	1983	1985	1994
Sunfish Family										
Bluegill	*Lepomis macrochirus*	X	X	X	X	X	X	X	X	X
Black Crappie	*Pomoxis nigromaculatus*	X	X	X	X	X	X	X	X	X
Green Sunfish	*Lepomis cyanellus*	X			X	X	X	X		
Largemouth Bass	*Micropterus salmoides*	X	X	X	X	X	X	X	X	X
Longear Sunfish	*Lepomis megalotus*	X	X		X			X	X	
Pumpkinseed	*Lepomis gibbosus*	X	X		X	X	X	X	X	X
Redear Sunfish	*Lepomis microlophus*					X	X	X	X	X
Warmouth	*Lepomis gulosus*	X	X				X	X	X	X
Catfish Family										
Black Bullhead	*Ameiurus melas*					X		X	X	
Brown Bullhead	*Ameiurus nebulosus*	X	X			X	X	X	X	X
Channel Catfish	*Ictalurus punctatus*			X	X	X	X	X	X	X
Tadpole Madtom	*Noturus gyrinus*									X
Yellow Bullhead	*Ameiurus natalis*	X	X			X	X	X	X	X
Minnow Family										
Common Carp	*Cyprinus carpio*	X	X					X	X	X
Golden Shiner	*Notemigonus crysoleucas*		X	X	X	X	X	X	X	X
Sucker Family										
Golden Redhorse	*Moxostoma erythurum*	X								
Lake Chubsucker	*Erimyzon sucetta*		X		X	X	X	X	X	X
White Sucker	*Catostomus commersoni*		X	X	X	X	X	X	X	X
Herring Family										
Gizzard Shad	*Dorosoma cepedianum*	X	X			X	X	X	X	X
Silversides Family										
Brook Silverside	*Labidesthes sicculus*					X	X	X	X	X
Gar Family										
Shortnose Gar	*Lepisosteus platostomus*		X							
Spotted Gar	*Lepisosteus oculatus*	X	X							
Pike Family										
Grass Pickeral	*Esox americanus vermiculatus*		X				X	X	X	X
Northern Pike	*Esox lucius*			X	X	X	X	X	X	X

Common Name	Scientific Name	1965	1972	1974	1975	1977	1980	1983	1985	1994
Mudminnow Family										
Central Mudminnow	*Umbra limi*			X						
Perch Family										
Walleye	*Sander vitreum*		X		X	X	X	X		
Yellow Perch	*Perca flavescens*	X	X				X	X	X	X
Number Species		14	18	8	12	17	19	22	20	19

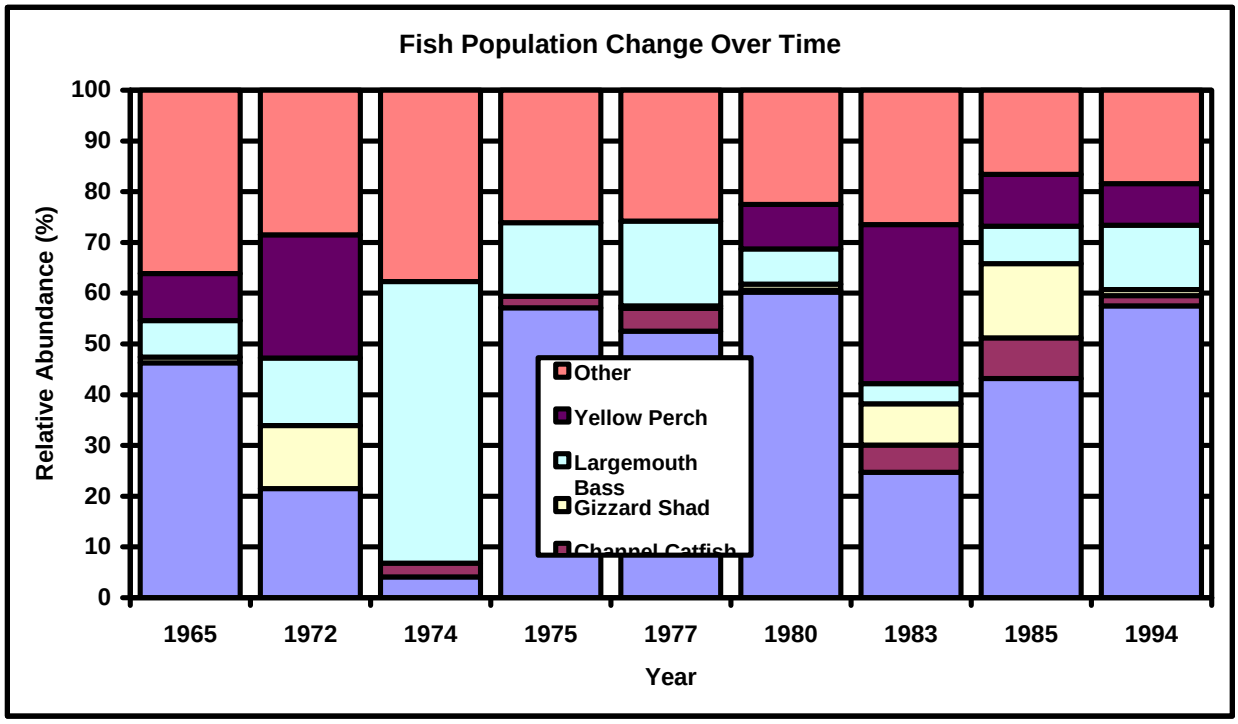


Figure 60. Historical fish community composition in Hill Lake (1965 to 1994). Source: Braun, 1981, 1984, 1986, 1995; McGinty, 1966c; Pearson, 1977; Shipman, 1976; Taylor, 1973; Taylor 1974.

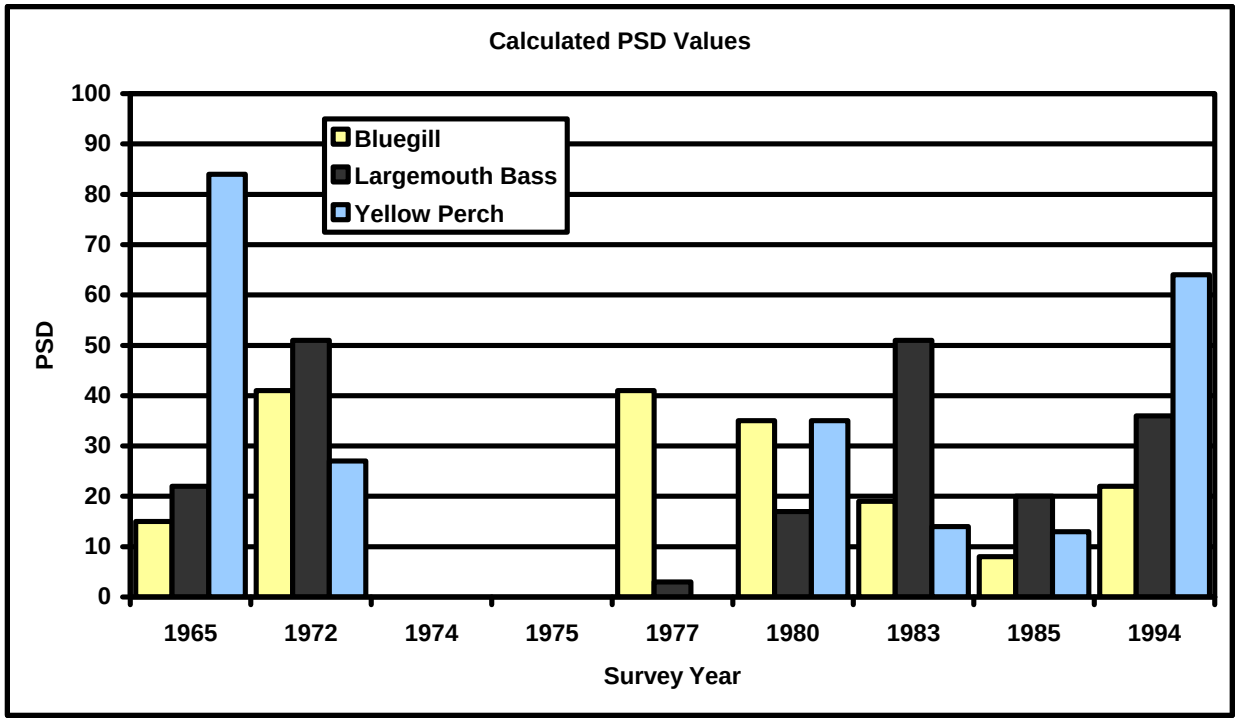


Figure 61. Calculated PSD values for select gamefish species in Hill Lake. Source: Braun, 1981, 1984, 1986, 1995; McGinty, 1966c; Pearson, 1977; Shipman, 1976; Taylor, 1973; Taylor 1974.

Fish Community Summary

With the exception of walleye, the six species stocked for the 1973 renovation and restocking effort still existed in Hill Lake as of the 1994 survey. Overall, the fish community has not changed much since the 1973 renovation and restocking effort. One benefit of the renovation and restocking effort has been the addition of channel catfish and northern pike to the Hill Lake fishery. The addition of northern pike and channel catfish has provided previously unavailable fishing opportunities to anglers of Hill Lake. Also, Braun (1995), suggested bluegill and largemouth bass populations have improved with more and larger individuals collected in the 1994 survey. However, growth rates are still low, which is a reoccurring problem for the Hill Lake fishery through the years. Additionally, while black crappie were still present during the 1994 assessment, they did not contribute significantly to the overall fishery.

General trends about condition and growth rates of bluegill and yellow perch have become apparent. In general, yellow perch show below average growth and condition when populations become large and increased growth and condition when populations are smaller (Braun, 1980). Bluegill populations follow a similar pattern. Bluegill exhibit decreased growth rates and condition when populations are most abundant (Braun, 1981b, 1986b); growth rates and condition tend to improve when bluegill are less abundant (Braun, 1983c). Species growth rates and condition have not been stable in Hill Lake during the assessment period overall. Appendix C contains a summary and discussion of fish growth rates from each IDNR report.

Hill Lake has not been surveyed in fourteen years; therefore, the current distribution of species is not well known. If species relative abundances are similar to that of the 1994 survey, then the lake could benefit from selective harvest of predator species (largemouth bass). Largemouth bass play an important role in controlling the population of desirable game-fish, such as bluegill, and undesirable fish species, such as gizzard shad. This occurs in two ways: 1) by helping to reduce intra-specific competition between young bluegill through limitation of their numbers; and 2) by reducing inter-specific competition of resources between young gizzard shad and young bluegill through the control of gizzard shad numbers.

4.3.5 Hill Lake Historical Water Quality

The IDNR, Division of Fish and Wildlife, the Indiana State Pollution Control Board, the Indiana Clean Lakes Program (CLP), the Tri-State University, Grace College, and Volunteer Monitors have conducted various water quality tests on Hill Lake. Table 50 presents some selected water quality parameters for these assessments of Hill Lake.

Table 50. Summary of historic data for Hill Lake.

Date	Secchi (ft)	% Oxic	Epi pH	TP (mg/L)	Plankton (#/L)	Chl *a* (g/L)	ITSI Score	Source
4/18/66	5.0	57.1%	8.10	--	--	--	--	McGinty,1966c
7/19/72	12.0	--	--	0.120	--	--	31	ISPCB, 1986
7/24/72	3.5	42.9%	8.70	--	--	--	--	Taylor, 1973
1/25/73	--	--	--	0.060	--	--	--	ISBH, 1973
8/5/74	15.0	57.1%	8.70	--	--	--	--	Taylor, 1974
1975	--	--	--	0.120	--	--	--	Hippensteel, 1989
7/28/75	4.5	42.9%	9.00	--	--	--	--	Shipman, 1976a
12/30/75	--	--	--	0.030	--	--	--	ISBH, 1975
6/13/77	7.5	57.1%	9.00	--	--	--	--	Pearson, 1977b
7/7/80	3.5	57.1%	9.30	--	--	--	--	Braun, 1981b
6/6/83	6.0	57.1%	9.70	--	--	--	--	Braun, 1983c
7/15/85	7.5	57.1%	9.00	--	--	--	--	Braun, 1986b
6/27/94	5.6	57.1%	7.80	--	--	--	--	Braun, 1995
8/23/94	9.5	57.1%	8.60	0.076	7,053	4.7	26	CLP, 1994
7/21/98	4.9	37.4%	8.72	0.095	7,596	3.3	34	CLP, 1998
7/13/04	3.3	37.4%	8.70	0.030	11,976	5.2	29	CLP, 2004
6/27/07	5.3	--	8.57	0.010	--	--	--	Lesko, 2007
7/18/07	4.6	--	8.48	0.130	--	--	--	Lesko, 2007
8/6/07	11.9	--	8.26	0.113	--	--	--	Lesko, 2007

*Water column average; all other values are means of epilimnion and hypolimnion values.
[+]Surface water (epilimnetic) sample only; all other values are means of epilimnion and hypolimnion values.
[δ]Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.

Based on the data presented in Table 50, water quality in Hill Lake has remained relatively stable over the past 40 years. Water clarity rates as relatively good for lakes in the region, and is better than other lakes in the Yellow Creek watershed. Since 1966, Secchi disk transparency (a measure of water clarity) has ranged from 3.3 feet (1.0 m) in July 2004 to 15 feet (4.6 m) in August 1974. Water clarity has been variable over the years with a suggested trend of declining water quality (Figure 62). However, it is likely that the limited number of sampling events conducted prior to 1974 pull the historic end of the trendline towards better water quality, while the high number of more recent measurements suggests poorer quality. With more data collected over time, a better understanding of the typical and long-term conditions found within the lake will become more apparent. Nonetheless, Secchi disk transparencies recorded in Hill Lake are typically better than those measured in most Indiana lakes.

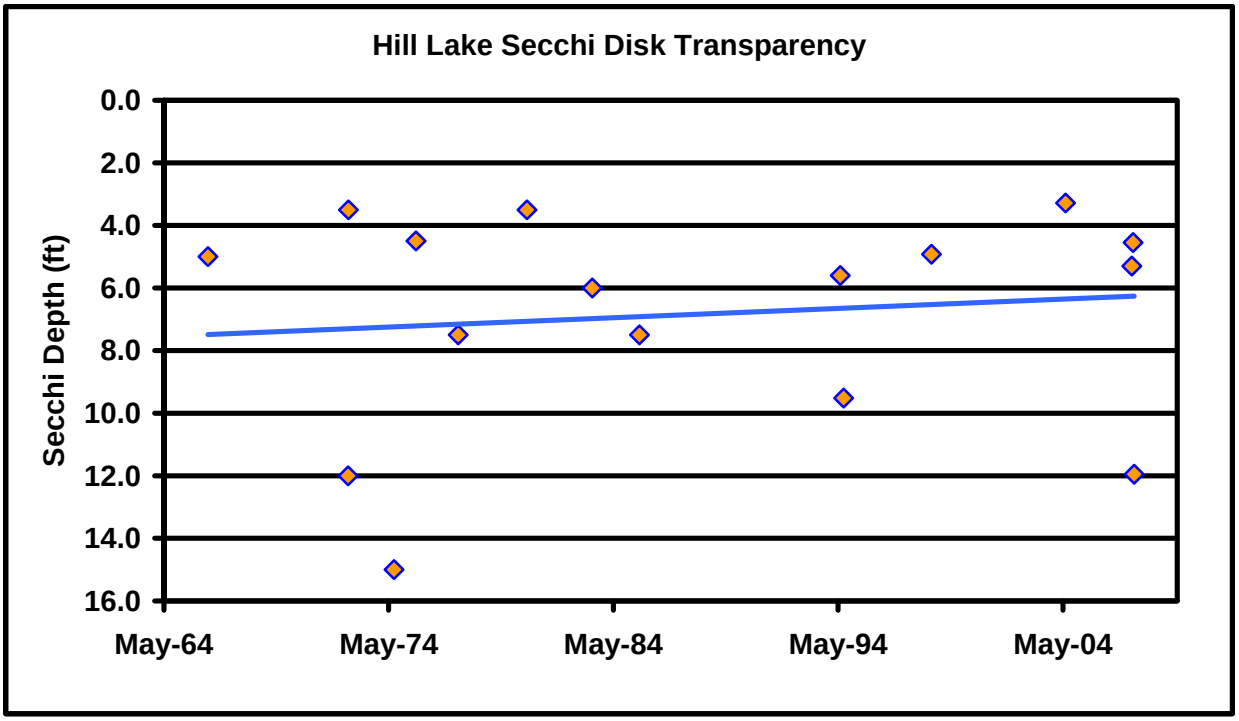


Figure 62. Historic Secchi disk transparency data for Hill Lake.
Source: Braun, 1981b, 1983c, 1986a, 1995; CLP, 1994, 1998, 2004; Hippensteel, 1989; ISBH, 1975; ISPCB, 1986; Lesko, 2007; McGinty, 1966c; Pearson, 1977b; Shipman, 1976b; Taylor, 1973.

Other parameters suggest that water clarity within Hill Lake varies over time and that clarity may be relatively stable or could be improving. The amount of light that penetrated Hill Lake's water column to a depth of 3 feet (0.9 m) measured 28% during the 1994 assessment and improved to 46% during the 1998 assessment. Data collected during 2004 indicate that light penetration was more than double that recorded in 1994 with 62% of available light reaching 3 feet (0.9 m). The historic observed light levels are below levels anticipated in deeper lakes; however, the most recent assessment indicates that Hill Lake is on par with deeper lakes with good water quality where light levels at 3 feet (0.9 m) typically exceed 50%. However, the maximum depth of light penetration has changed little over time. During the 1994 assessment, light was completely extinguished to a point where photosynthesis could not be supported at a depth of 19.5 feet (5.9 m). During the 2004 assessment, light penetrated slightly shallower reaching a depth of 16.2 feet (4.9 m). Data suggest that light penetration is not a problem within Hill Lake and that heavy rooted plant growth is likely within the lake.

Total phosphorus concentrations have generally remained low within Hill Lake (Figure 63). Total phosphorus concentrations declined from a high of 0.120 mg/L in 1972 and 1988 to 0.076 mg/L in 1994 and to 0.030 mg/L during the 2004 assessment. It should be noted that the 1972 and 1988 sample are water column average samples rather than surface and bottom water samples. Therefore, total phosphorus concentrations could be somewhat higher in these historic samples due to differences in sampling technique. Conversely, samples collected during January 1973 and December 1975 suggest that Hill Lake contains relatively low total phosphorus concentration. As these samples were collected during the winter when productivity is low and watershed runoff is limited, nutrient concentrations, specifically total phosphorus, can be expected to be relatively low. More recent samples were collected from the surface water only and do not include the typically nutrient-rich bottom waters. Therefore, regionalized conditions

within the lake could affect the total phosphorus concentrations for samples collected in 2007. These samples suggest that total phosphorus concentrations are near levels observed in Hill Lake 20 to 30 year ago. Nonetheless, none of these samples exceeded the median total phosphorus concentration measured in most Indiana lakes (0.17 mg/L). Additionally, total phosphorus concentrations measured in Hill Lake are relatively low compared to other lakes in the Yellow Creek watershed.

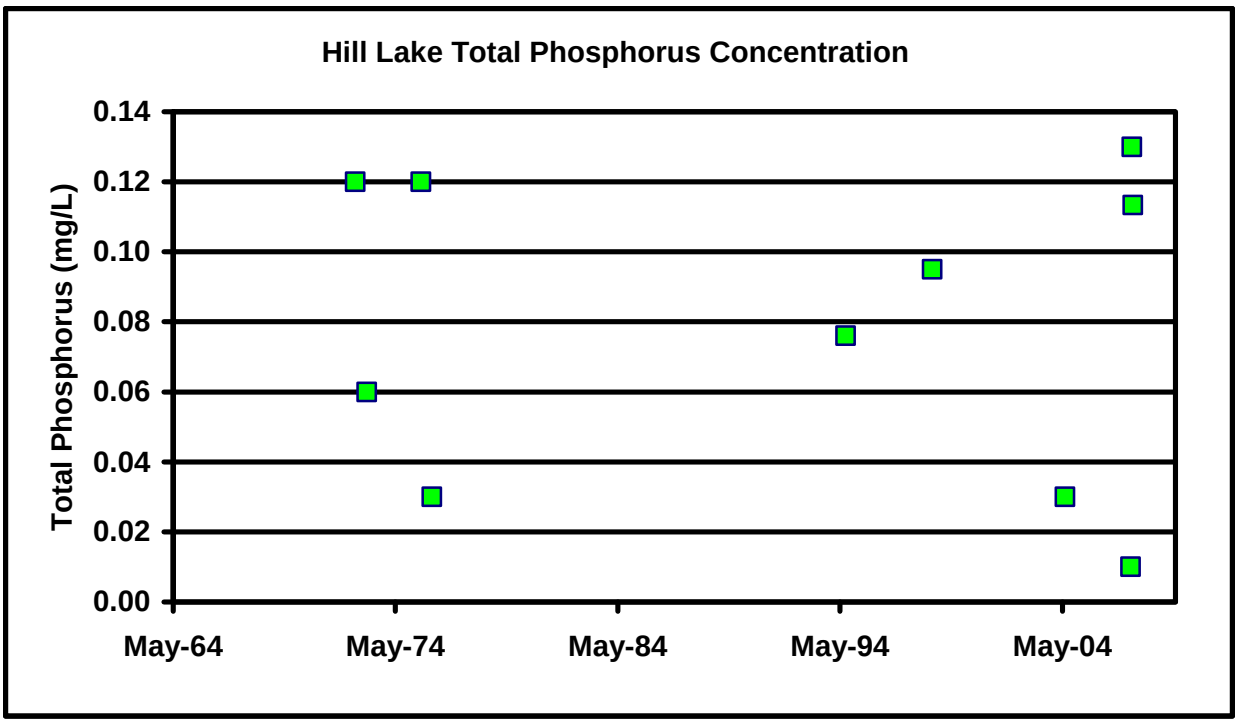


Figure 63. Historic total phosphorus concentrations measured in Hill Lake.
Source: CLP, 1994, 1998, 2004; Hippensteel, 1989; ISBH, 1975; ISPCB, 1986; Lesko, 2007.

Plankton (algae) densities are relatively moderate within Hill Lake, reflecting the relatively moderate nutrient concentrations present within the lake. Nutrients (nitrogen and phosphorus) promote the growth of algae and/or rooted plant populations. Plankton densities range from 7,053/L in 1994 to 11,976/L in 2004. These concentrations are relatively low compared to other lakes in the Yellow Creek watershed. Low chlorophyll *a* concentrations also reflect the relatively low plankton densities and total phosphorus concentrations found in the lake. None of the chlorophyll *a* concentrations exceed the median concentration measured in Indiana lakes (12.9 µg/L). The lake's overall ITSI ranged from 26 in 1994 to 34 in 1998. Overall, ITSI scores calculated for Hill Lake changed little over time. All of these scores suggest that the lake is mesotrophic to slightly eutrophic.

There is not a significant trend in nutrient concentrations in Hill Lake; however, concentrations suggest an improvement in water quality throughout the sample period (Figure 64). Concentrations indicate a slight increase in total phosphorus concentration from 0.076 mg/L in 1994 to 0.095 mg/L in 1998 before declining to concentrations measuring 0.030 mg/L in 2004. A similar pattern in dissolved phosphorus concentrations is also apparent. Both dissolved and total phosphorus concentrations remain below the median concentration found in Indiana lakes. Nitrogen concentrations follow a similar pattern with total nitrogen concentrations decreasing from 1.527 mg/L in 1994 to 0.571 mg/L in 2004. Ammonia-nitrogen and nitrate-nitrogen

concentrations also decreased from 1994 to 2004. With the exception of total nitrogen and ammonia-nitrogen, nutrient concentrations in Hill Lake are below the median concentrations measured in Indiana lakes.

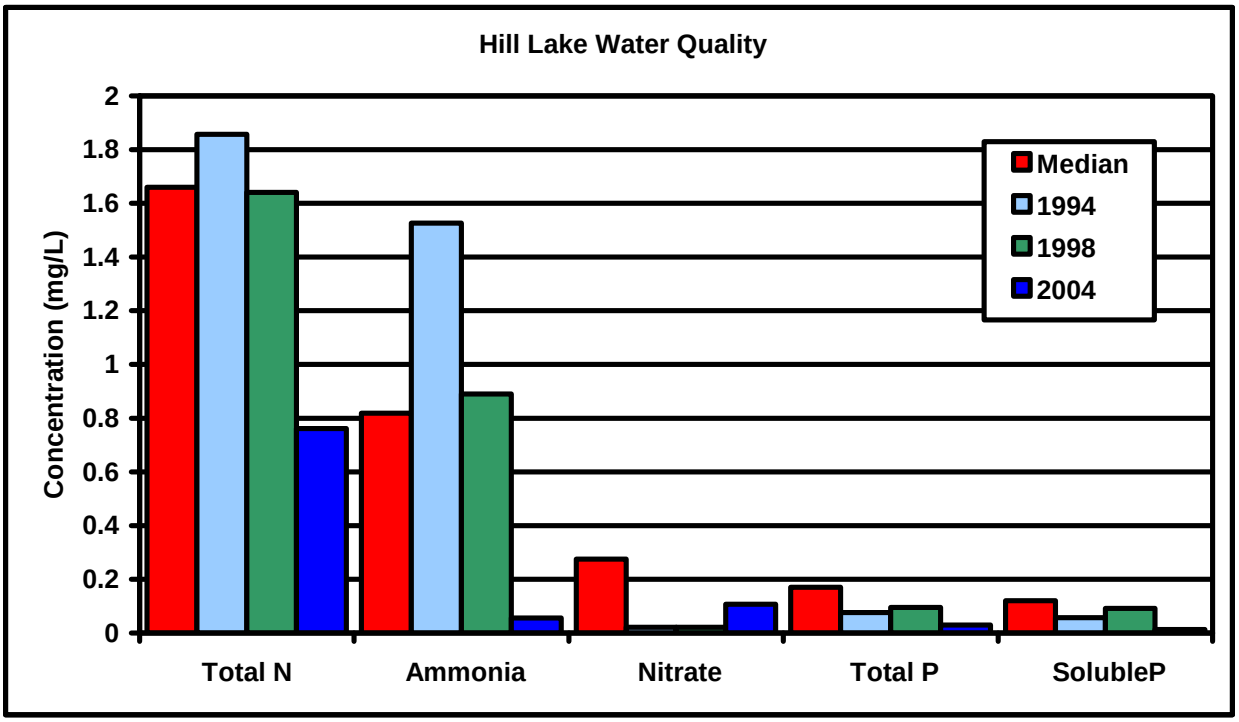


Figure 64. Variation in nutrient concentrations in Hill Lake, 1994 to 2004.
Source: CLP, 1990, 1998, 2004.

Figure 65 displays the temperature profiles recorded during IDNR fisheries surveys and Indiana CLP assessments. All of the temperature profiles show that Hill Lake was stratified at the time of sampling. The only exception to this occurred during the 1974 and 1983 assessments, where the lake was only weakly stratified. This temperature profile suggests that Hill Lake could have easily been destratified by wind or wave action during these periods. These profiles are not abnormal for lakes in this region early in the season. However, the developed hypolimnion (bottom water) present during the remainder of the surveys is very typical of Indiana lakes under summer, stratified conditions. The metalimnion, or area of rapidly changing water temperature, typically extends from 7 feet (2.1 m) to approximately 25 feet (7.6 m). The epilimnion (surface water) is located above the metalimnion, while the hypolimnion (bottom water) is located below the metalimnion. Water within the epilimnion and hypolimnion are typically separated during the summer in stratified lakes and do not mix.

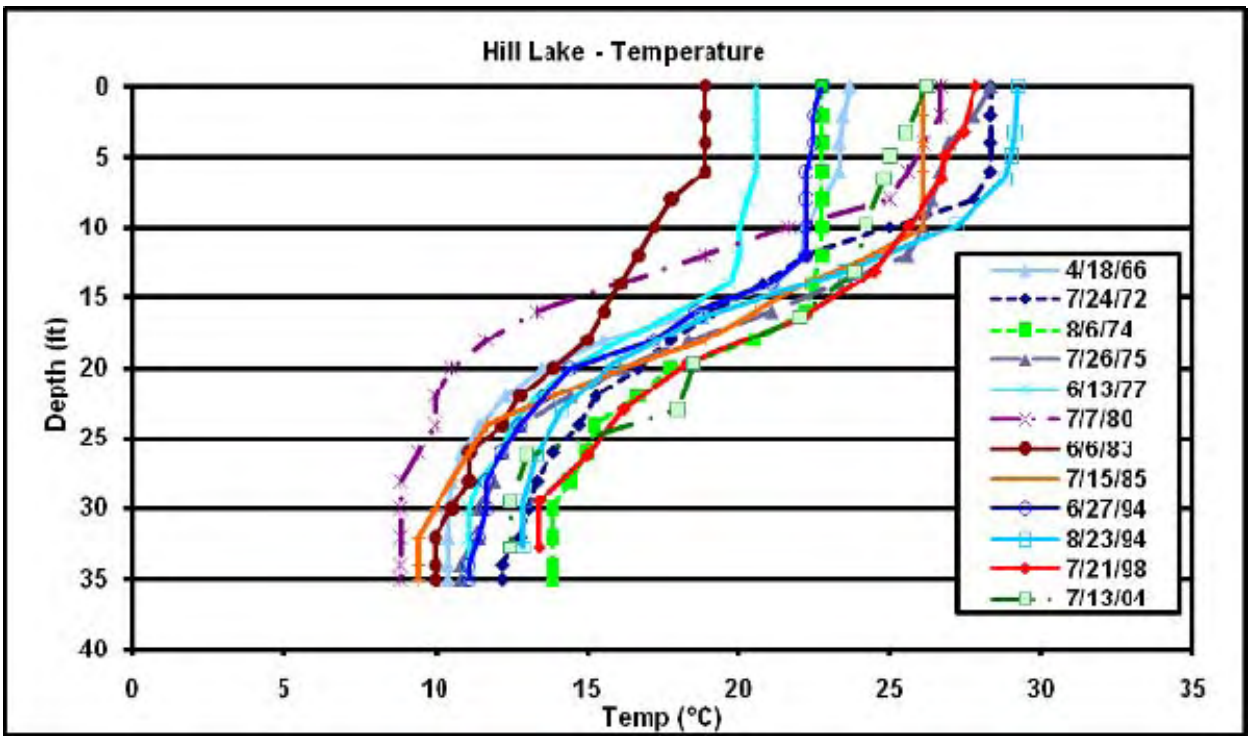


Figure 65. Historical temperature profiles for Hill Lake.

Much of the data presented above suggest that Hill Lake is moderately productive; the historical percent oxic results (Table 50) and dissolved oxygen profiles (Figure 66) support these findings. Dissolved oxygen data indicate that the lake possessed dissolved oxygen greater than 1 mg/L in 40 to 60% of the water column. This decline in dissolved oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments. The 1975 sampling profile illustrates different conditions than those observed during the other assessments. In this dissolved oxygen profile, there is a sharp increase in dissolved oxygen in the lake's metalimnion. This results in a positive-heterograde profile. Positive-heterograde profiles are characterized by a peak in oxygen concentration at a depth below the water surface, such as the peak in the 1975 profile beginning at 5 feet (1.5 m) below the water's surface. The peak is likely associated with a higher concentration in phytoplankton at that particular depth layer. Called a ***metalimnetic oxygen maximum***, the peak results when the rate of settling plankton slows in the denser waters of the metalimnion. At this depth, the plankton can take advantage of nutrients diffusing from the nutrient-enriched hypolimnion. As the plankton at this depth photosynthesize, they release oxygen into the water column, creating a peak in oxygen at that level. The 1974 and 1994 profiles also display unique conditions in Hill Lake. These two profiles suggest that the upper 10 to 15 feet (3.0 to 4.6 m) of the water column contained equal concentrations of dissolved oxygen. This suggests that during these periods, the upper portion of the lake's water column was undergoing continuous mixing.

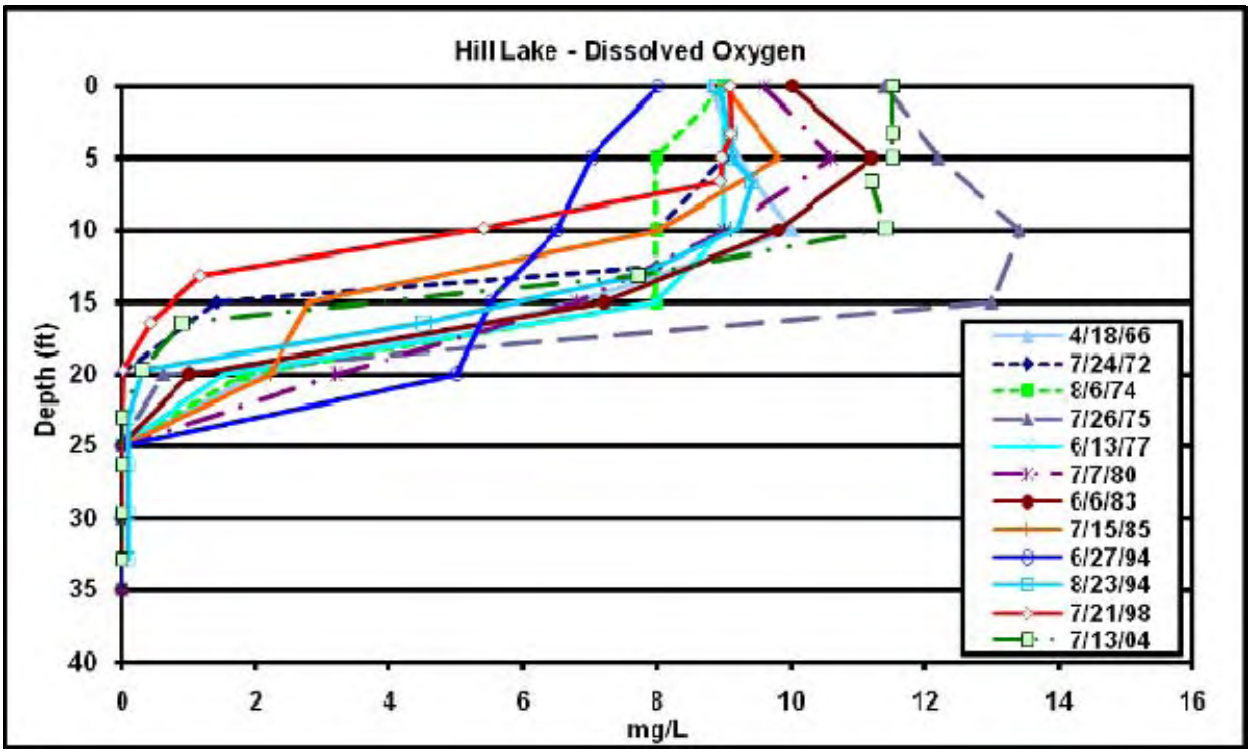


Figure 66. Historical dissolved oxygen profiles for Hill Lake.

The lack of oxygen in the lake's water column is likely a sign of intense decomposition of plant material during the summer months. Decomposition of plant material undoubtedly occurs in the lake's deeper waters, removing oxygen from the water column. (Higher hypolimnetic ammonia concentrations suggest decomposition is occurring in the lake's bottom waters). Overall, this lack of oxygen poses a problem for the lake's inhabitants. Fish and other aquatic organisms require oxygen to live. The lack of oxygen in the lake's hypolimnion reduces the amount of habitat available to fish. Fortunately, most of the lake's volume has oxygen levels sufficient to support fish. Based on the depth-volume curve (Figure 54), approximately 80% of the lake's volume is oxygenated. (The percent oxic parameter measures the vertical percent, not volumetric percent, of the water column with oxygen.)

The lack of oxygen in Hill Lake's hypolimnion also affects the lake's chemistry. While mean total phosphorus concentrations are variable for the years 1972-2007, a more detailed evaluation shows that hypolimnetic total phosphorus concentrations are typically higher than epilimnetic total phosphorus concentrations. Under anoxic conditions, the iron in iron phosphate, a common precipitate in lake sediments, is reduced, and the phosphate ion is released into the water column. This phosphate ion is readily available to algae, and can therefore spur algal growth. Further review of historical phosphorus data indicate that much of the total phosphorus was in the dissolved form of phosphorus (SRP). This indicates that Hill Lake was releasing phosphorus from its bottom sediments. Additionally, Hill Lake exhibited higher hypolimnetic ammonia concentrations than those observed in the lake's epilimnion during all of the assessments, suggesting decomposition of organic matter was occurring in the lake's bottom waters. Overall, these data suggest that Hill Lake was a moderately mesotrophic to eutrophic lake or was moderately productive to productive during the 1994, 1998, and 2004 assessments.

4.3.6 Hill Lake Water Budget

The watershed or drainage area of Hill Lake is approximately 479 acres. The mean annual watershed runoff volume calculated to drain into Beaver Dam Lake is 578 acre-feet per year. Comparing the runoff to a lake volume of 1270 acre-feet and factoring in evaporation and rainfall from and to the lake, results in a hydraulic residence time of about two years (Table 51). This residence time is normal for Indiana Lakes.

Table 51. Water Budget Calculations for Hill Lake. (See Appendix A for a graphic model of model inputs and outputs**)**

Watershed	Hill Lake - Kosciusko Co.
Watershed size (ac)	479
Mean watershed runoff (ac-ft/yr)	578
Lake volume (ac-ft)	1270
Closest gaged stream	Eel River @ N. Manchester
Stream watershed (mi^2)	417
Stream watershed (acres)	266880
Mean annual daily Q (cfs)	444.7
Mean annual total Q (ac-ft/yr)	321948
Mean ppt (in/yr)	37
Mean watershed ppt (ac-ft/yr)	822880
Watershed C	0.39125
Pan evaporation (in/yr)	41.80
Pan evaporation coefficient	0.70
Lake surface area (acres)	65
Estimated lake evaporation (ac-ft)	158
Direct precipitation to lake (ac-ft)	200
	= input data
	= output data
Water Budget Summary	
Direct precipitation to lake (ac-ft)	200
Runoff from watershed (ac-ft)	578
Evaporation (ac-ft)	158
TOTAL LAKE OUTPUT (ac-ft)	620
Hydraulic residence time (yr)	2.05

4.3.7 Hill Lake Current Water Quality Assessment

Temperature and oxygen profiles for Hill Lake show that the lake was thermally stratified at the time of sampling (Figure 67). (NOTE: we apparently didn't position our sampling boat directly over the deepest water (35 feet or 10.7 m), our profiles only extend down to a depth of 8 meters.) During thermal stratification, the well-mixed surface waters (*epilimnion*), characterized by uniform water temperature, are separated from the deep, bottom waters (*hypolimnion*) by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth is called the *metalimnion*. At the time of our

sampling, the epilimnion was confined to the upper 7-10 feet (2-3 m) of water. The sharp decline in temperature between 10 and 20 feet (3 and 6 m) defines the metalimnion or transition zone. The hypolimnion occupied water deeper than 30 feet (9 m). At the 7 foot (2 m) depth, there is a sharp increase in oxygen concentration. This is caused by intense photosynthesis by algae that prefer the lower light that exists at depth. The sharp decline of dissolved oxygen at the 13 foot (4 m) depth is caused by a layer of bacteria suspended in the metalimnion that are decomposing algae at it settles down through the water column. Bacterial decomposition consumes oxygen during this process. The hypolimnion of Hill Lake is anoxic ([D.O.] < 1.0 mg/L) conditions below 20 feet (6 m) leaving little oxygen available to support fish and other aquatic organisms.

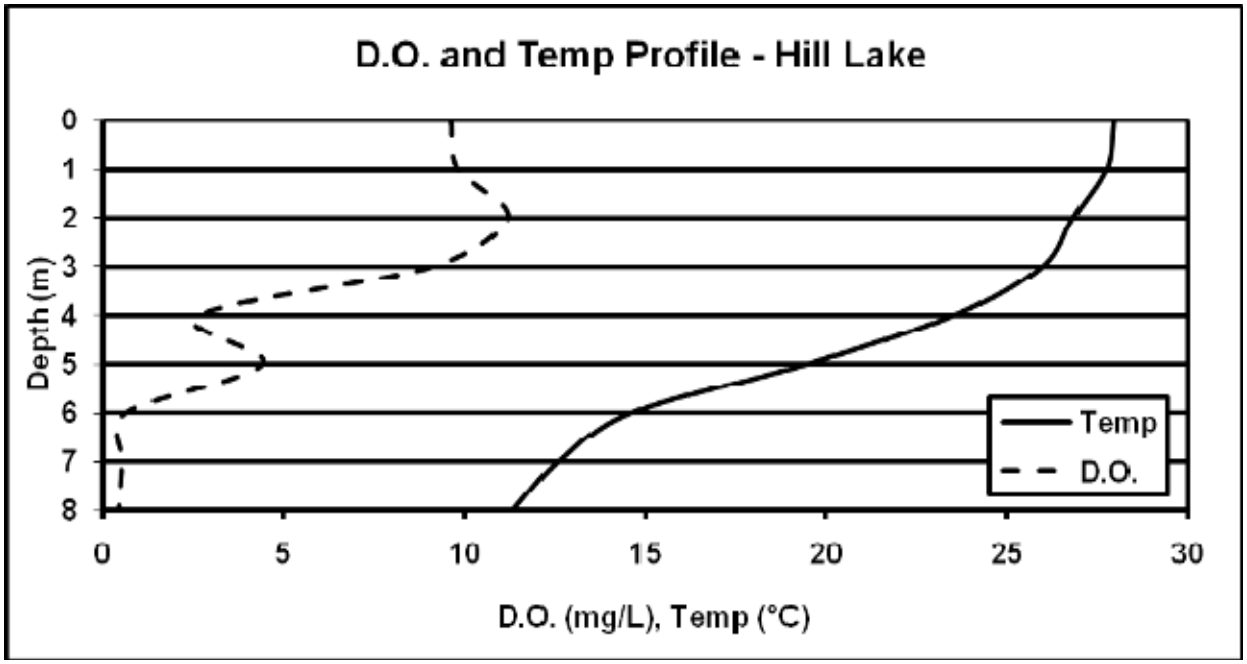


Figure 67. Temperature and dissolved oxygen profiles for Hill Lake on July 17, 2008.

The 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to 15.7 ft (~5 m). Based on the depth-area curve in Figure 53 approximately 31.3% of lake bottom (about 20 acres or 8 ha) is shallower than 15.7 ft. This represents the area of the lake bottom with sufficient light to support rooted plants. This area is called the *littoral zone*. Furthermore, based on the depth-volume curve (Figure 54), we see that a volume of greater than 810 acre-feet of Hill Lake (approximately 64% of total lake volume) lies above the 15.7-foot 1% light level. This area, referred to as the *photic zone*, represents the amount of water with sufficient light to support algae growth.

Phosphorus and nitrogen are the primary plant nutrients in lakes. At 0.010 mg/L, soluble phosphorus concentrations were at or below the detection limits of our analytical methods. Total phosphorus concentrations were relatively low in both the epilimnion and hypolimnion of Hill Lake (0.019 mg/L and 0.060 mg/L respectively; Table 52). However, even with the relatively lower epilimnion concentration, the hypolimnion still exceeded the 0.03 mg/L concentration that is considered high enough to support eutrophic conditions.

Table 52. Water Quality Characteristics of Hill Lake, July 17, 2008.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.7	7.1	-
Alkalinity	121 mg/L	188.5 mg/L	-
Conductivity	301 µS/m	433 µS/m	-
Secchi depth	1.8m	-	-
Light Transmission @ 3 ft	21.3%	-	4
1% Light level	15.7 ft	-	-
Total Phosphorus	0.019 mg/L	0.060 mg/L	2
Soluble Reactive Phosphorus	0.010* mg/L	0.010* mg/L	0
NO_3	0.013* mg/L	0.013* mg/L	0
NH_4	0.116 mg/L	2.667 mg/L	4
TKN	0.668 mg/L	2.922 mg/L	1
Oxygen Saturation @ 5 ft.	54.1%	-	2
% Water column oxic	21.4%	-	2
Plankton Density	7656 N.U. /L	-	2
Blue-Green Dominance	87.5%	-	10
Chl-a	2.78 µg/L	-	-
		TSI Score	**27**

*Method Detection Limit

Nitrate nitrogen (NO_3) was at the detection limits (0.013 mg/L) of our analytical methods in the epilimnion and hypolimnion. Nitrate is used by growing algae and is reduced to ammonia (NH_4) when oxygen is low. Ammonia oxidizes rapidly to nitrate in the presence of adequate oxygen and nitrifying bacteria. Ammonia in the epilimnion was 0.116 mg/L and 2.667 mg/L in the hypolimnion. The higher hypolimnetic ammonia concentrations indicate the presence of a high amount of biochemical oxygen demand (BOD) to produce the ammonia and a low amount of dissolved oxygen present to maintain these relatively high concentrations.

Values for pH were within the normal range for Indiana lakes, pH 8.7 for the epilimnion and pH 7.1 for the hypolimnion. pH values for most fresh waters fall between pH 6-9 (Kalff, 2002). The high alkalinity values of 121 mg/L and 188.5 mg/L, for the epilimnion and hypolimnion, indicate that Hill Lake is a well buffered system.

Plankton enumerated from the sample collected from Hill Lake are shown in Table 53. *Aphanizomenon*, a blue-green alga, was the most dominant genera found, and accounted for almost half the plankton density. In addition to this particular blue-green alga, other blue-green species contributed to the overall plankton dominance by blue-greens of 87.5%. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in

lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers.

Table 53. The plankton sample representing the species assemblage on July 17, 2008.

SPECIES	ABUNDANCE (N.U./L)
Blue-Green Algae (Cyanophyta)	
Aphanizomenon	5893
Anabaena	650
Microcystis	41
Chroococcus	14
Lyngbya	95
Oscillatoria	190
Green Algae (Chlorophyta)	
Closteriopsis	27
Mougeotia	230
Staurastrum	54
Diatoms (Bacillariophyta)	
Synedra	41
Fragillaria	27
Other Algae	
Synura	244
Dinobryon	41
Ceratium	108
Zooplankton	
Nauplius	33.2
Cyclopoid Copepod	2.7
Calanoid Copepod	7.3

4.4 Loon Lake

4.4.1 Morphology

Loon Lake's consists of a single deep water hole surrounded by gradually shallower water (Figure 68). The lake's deepest point lies north of the center of the 43-acre (17.4-ha) lake extending to a maximum depth of 40 feet (12.2 m; Table 54). Loon Lake possesses limited expanses of shallow water. According to its depth-area curve (Figure 69), nearly 7 acres (2.8 ha) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 27 acres (10.9 ha) is covered by water less than 20 feet (6.1 m) deep. This translates into a very low shallowness ratio of 0.16 (ratio of area less than 5 feet (1.5 m) deep to total lake area) and a moderately high shoalness ratio of 0.63 (ratio of area less than 20 feet (6.1 m) deep to total lake area), as defined by Wagner (1990). The lake's area gradually increases to a water depth of about 25 feet (7.6 m) before the rate of change increases. This rate (slope of lake bottom) continues to the lakes maximum depth (40 feet or 12.2 m).

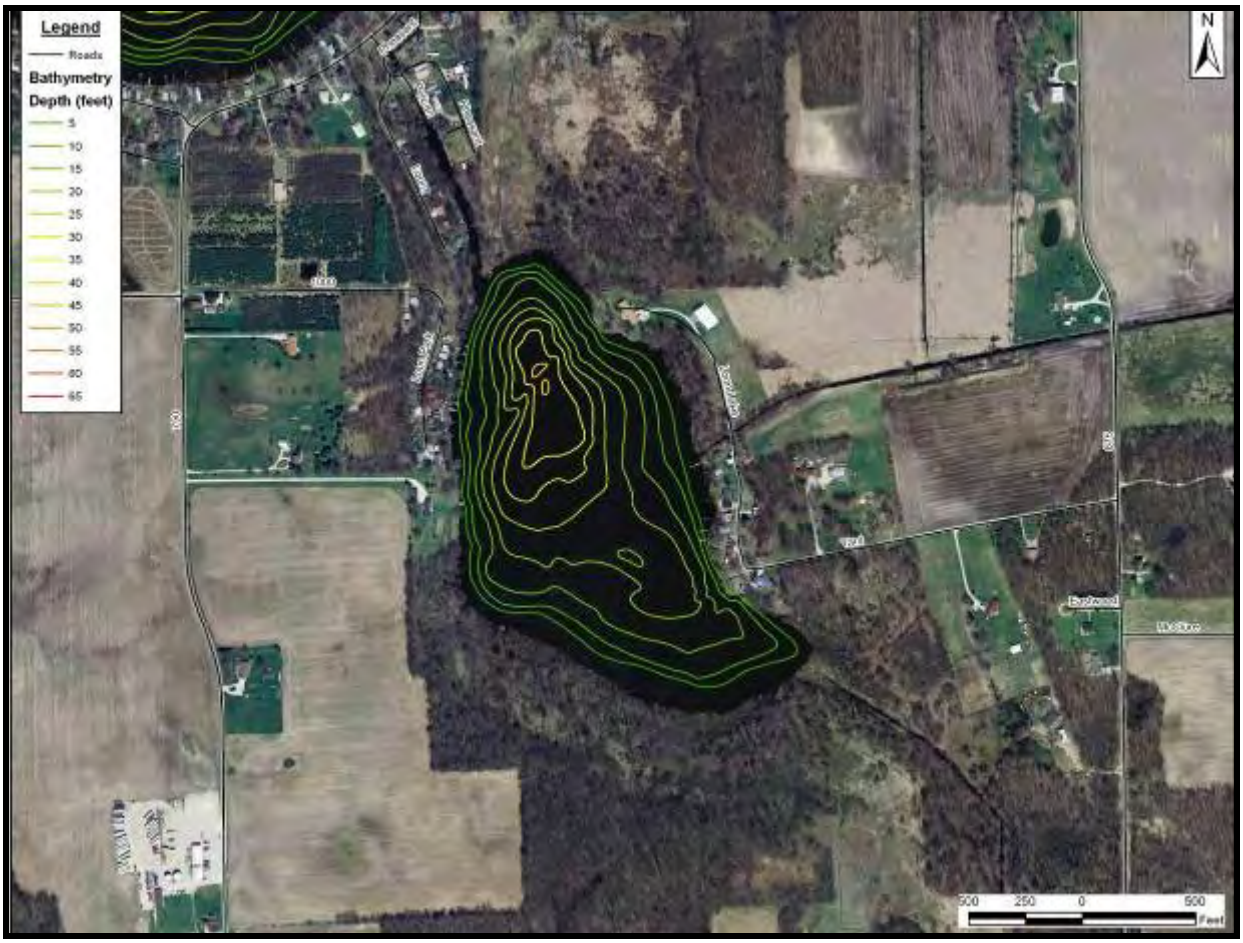


Figure 68. Loon Lake bathymetric map. Source: Kosciusko County GIS Department, digitized from 1956 IDNR contour maps.

Table 54. Morphological characteristics of Loon Lake.

Characteristic	Value
Surface Area	43 acres (17.4 ha)
Volume	719 acre-feet (887,278 m^3)
Maximum Depth	40 feet (12.2 m)
Mean Depth	16.7 feet (5.1 m)
Shallowness Ratio	0.16
Shoalness Ratio	0.63
Shoreline Length	5,954 feet (1,815 m)
Shoreline Development Ratio	1.23

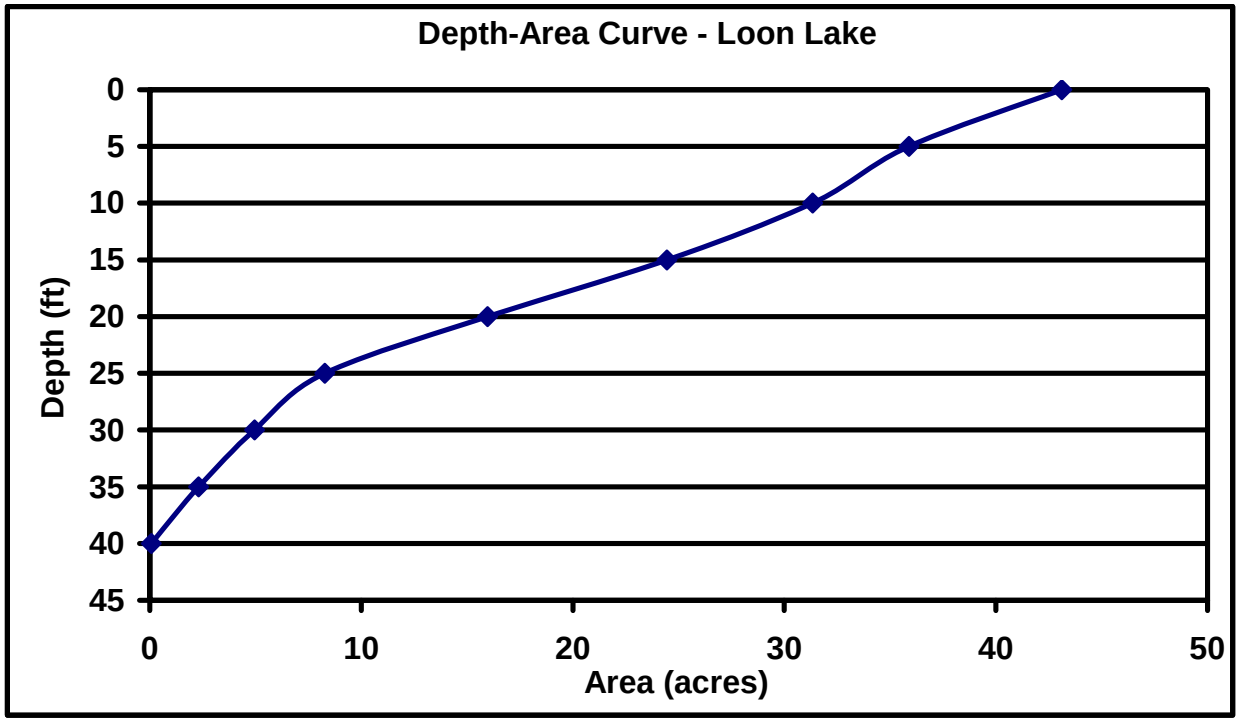


Figure 69. Depth-area curve for Loon Lake.

Loon Lake holds approximately 719 acre-feet (887,278 m^3) of water. As illustrated in the depth-volume curve (Figure 70), most of the lake's volume is contained in the shallower areas of the lake. More than 90% of the lake's volume is contained in water that is less than 20 feet (6.1 m) deep. The lake's volume gradually increases with depth to a water depth of about 25 feet (7.6 m) before the rate of change increases. Below 25 feet (7.6 m), the steep curve indicates a greater change in depth per unit volume. This rate continues to the lakes maximum depth (40 feet or 12.2 m).

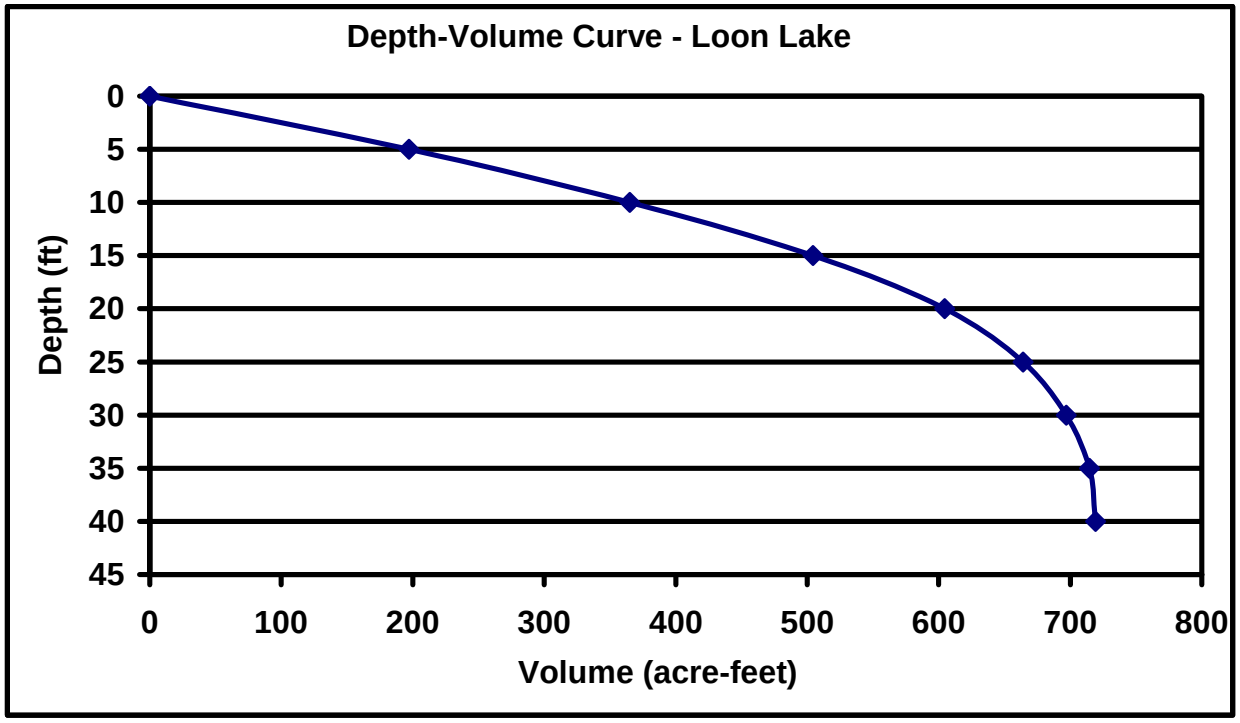


Figure 70. Depth-volume curve for Loon Lake.

A lake's morphology can play a role in shaping the lake's biotic communities. For example, Loon Lake's moderately sized shallow area coupled with its poor clarity suggests the lake although the lake provides area for plant growth, light may limit the quality of the rooted plant community. Based on the lake's clarity, Loon Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the point where water depths are approximately 13.5 feet (4.1 m). Referring to Loon Lake's depth-area curve, this means that the lake's littoral zone is approximately 30 acres (14.1 ha) in size or approximately 75% of the lake. This size littoral zone can impact other biotic communities in the lake such as fish that use the plant community for forage, spawning, cover, and resting habitat.

A lake's morphology can indirectly influence water quality by shaping the human communities around the lake. The shoreline development ratio is a measure of the development potential of a lake. It is calculated by dividing a lake's shoreline length by the circumference of a circle that has the same area as the lake. A perfectly circular lake with the same area as Loon Lake (43 acres or 17.4 ha) would have a circumference of 4,852 feet (1,479 m). Dividing Loon Lake's shoreline length (5,954 feet or 1,815 m) by 4,852 feet yields a ratio of 1.23:1. This ratio is relatively low. Loon Lake is relatively round and lacks extensive shoreline channeling. Given the immense popularity of lakes in northern Indiana, lakes with high shoreline development ratios are often highly developed. Increased development around lakes often leads to decreased water quality.

4.4.2 Loon Lake Shoreline Development

By 1964 approximately 20 cottages were located along Loon Lake's shoreline (McGinty, 1966d). Most of the houses were limited to Loon Lake's northeastern and eastern shorelines. McGinty noted the presence of 47 boats, three rafts, and one pontoon. Over the next 15 years, development around the shores of Loon Lake increased. By 1980, nearly half of the shoreline

was developed. Development from 1980 to 2006 changed little with Benson (2006) still noting the presence of residences along approximately half of Loon Lake's shoreline.

Given the limited number of houses along Loon Lake's shoreline, it is not surprising that nearly 56% of Loon Lake's shoreline remains in its natural form (Figure 71). Nearly the entire southern shoreline and large portions of the eastern and southwestern shorelines remain in their natural form. Natural wetland vegetation is present along much of the southern shoreline where bands of plants like those described by McGinty (1966d) are present with trees, emergent vegetation, floating vegetation, and submergent vegetation located in distinct zones along the lakeshore (Figure 72).

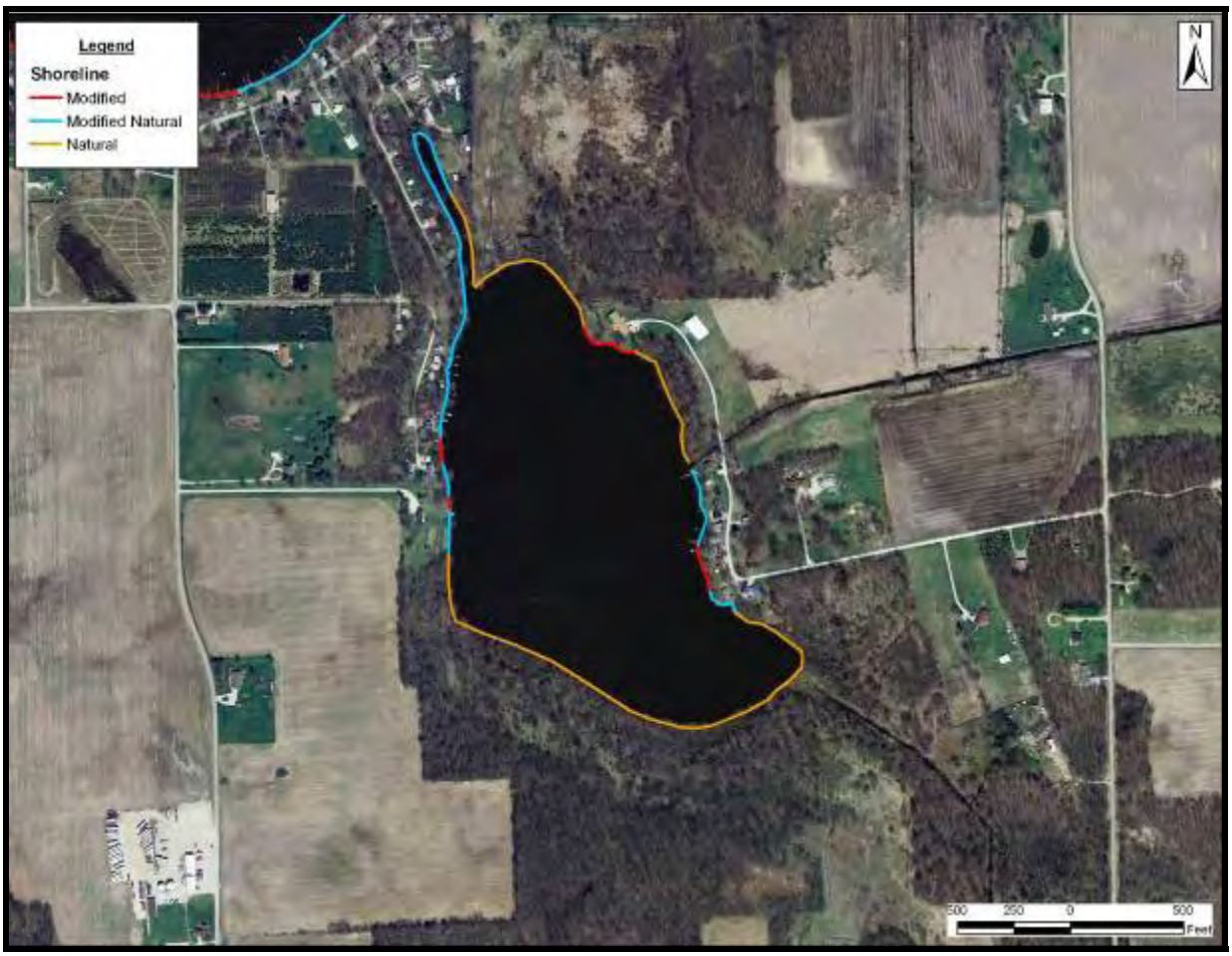


Figure 71. Shoreline surface type observed at Loon Lake, August 27, 2008.

Figure 72. Natural shoreline present along Loon Lake's southern shoreline.

A large portion of the remainder of Loon Lake's shoreline remains largely natural but has been altered in some form. Along nearly 35% of Loon Lake's shoreline, trees and emergent vegetation have been thinned; however, these areas possess at least a narrow band of emergent plants. These areas are mapped as modified natural shoreline because they still possess at least a small portion of all these strata (submergent, emergent, and floating). Other portions of the shoreline that are also mapped as modified natural include those areas where individuals removed only the portion of the shoreline vegetation required to view or access the lake such as the property depicted in Figure 73.

Figure 73. Modified natural shoreline present within Loon Lake. Note that vegetation was removed in areas required for access to the lake. The remaining vegetation along the shoreline acts as a natural buffer, while the stone installation provides lake access.

Approximately 9% of Loon Lake's shoreline has been largely altered from its natural state (Figure 74). Along these portions of Loon Lake's shoreline, emergent and floating rooted vegetation has been completely removed from adjacent to the shoreline. Modified shorelines are relatively small and located along the lake's eastern and western shorelines. No significant areas of erosion were noted along Loon Lakes shoreline.

Figure 74. Modified shoreline present along Loon Lake's shoreline.

4.4.2 Loon Lake Aquatic Macrophyte Assessment

JFNew surveyed Loon Lake's plant communities on August 28, 2007 according to the IDNR sampling protocols (IDNR, 2007). Transparency in Loon Lake was 4.5 feet (1.4 m) during the survey. As a general rule of thumb, rooted plant growth is restricted to the portion of the lake where water depth is less than or equal to 2 to 3 times the lake's Secchi disk depth. This was not the case in Loon Lake where plants were observed to a depth of only 7 feet (2.1 m). Please refer to the Discussion Section of this report for more information about the importance of the rooted plant community.

Loon Lake supports a modest aquatic plant community. The community extends from the lake's shoreline to water that is 7 feet (2.1 m) deep. In total, 22 aquatic plant species inhabit the water and shoreline of Loon Lake (Table 55). The LARE protocol used to conduct the aquatic plant survey requires surveyors to note all plant species observed from a boat. Thus, plants in the wetland complexes adjacent to the lake were only counted if they were visible from the boat. If these wetland complexes had been explored in greater detail, it is likely that the total number of plant species would increase significantly.

Table 55. Plant species observed in Loon Lake on August 28, 2007.

Scientific Name	Common Name	Stratum
Asclepias incarnata	Swamp milkweed	Emergent
Ceratophyllum demersum	Coontail	Submergent
Chara species	Musk grass species	Submergent
Decodon verticillatus	Whorled loosestrife	Emergent
Filamentous algae	Filamentous algae	Algae
Iris virginica	Blue-flag iris	Emergent
Myriophyllum exalbescens	Northern watermilfoil	Submergent
Myriophyllum spicatum	Eurasian watermilfoil	Submergent
Najas guadalupensis	Southern naiad	Submergent
Nuphar advena	Spatterdock	Floating
Nuphar variegatum	Yellow pond lily	Floating
Nymphaea tuberosa	White water lily	Floating
Pontederia cordata	Pickerel weed	Emergent
Potamogeton berchtoldii	Broad-leaf small pondweed	Submergent
Sagittaria latifolia	Common arrowhead	Emergent
Scirpus acutus	Hard-stem bulrush	Emergent
Scirpus fluviatilis	River bulrush	Emergent
Scirpus pungens	Chairmaker's rush	Emergent
Sparganium eurycarpum	Giant burreed	Emergent
Typha angustifolia	Narrow-leaf cattail	Emergent
Typha x *glauca*	Blue cattail	Emergent
Typha latifolia	Broad-leaf cattail	Emergent

Of the 22 species observed in Loon Lake, one was classified as an algae, three as floating leaved, twelve as emergent, and six as submergent plant species. Of the six submergent species, nearly all of those are adapted to high nutrient environments. Two species, northern watermilfoil and broad-leaf small pondweed are typically indicative of relatively good water quality. However, both species were identified in relatively low density. Compared to other lakes in the region, this diversity of submergent species represents relatively low species richness for the submergent strata. Coontail dominated the submergent plant community and was observed throughout the lake. One exotic species, Eurasian watermilfoil, was identified within or adjacent to Loon Lake. The most common emergent species included reed canary grass, whorled loosestrife and cattails. The most common floating species were spatterdock, white water lily, and duckweed.

During the Tier II survey, coontail dominated the plant community over all depths (0-15 feet; Table 56). This species was found at the highest percentage of sites throughout the entire sampled water column (58%) and also had the highest mean (2.33) and relative densities (1.35). Throughout the entire sampled water column, no other species were relatively frequent. Eurasian watermilfoil was present at 6.5% of the sites throughout the entire sampled water column. Broad-leaf small pondweed, southern naiad, northern watermilfoil, and musk grass

were each found at 3.2% of the sites. With regards to dominance, coontail dominated the submergent plant community throughout the entire sampled water column with a dominance of 27.1. (A dominance of 150 represents a perfect score or the highest dominance possible within Loon Lake. This results from multiplying the highest density score (5) by the number of sites where plants were sampled (30). Dominance scores are reported as percentages of this maximum.) Eurasian watermilfoil recorded a dominance of 1.3. All other species had dominances less than 1. Filamentous algae were also present at 87% of the sites; however, densities are not assigned to this species.

Table 56. Frequency and dominance of submergent aquatic plant species identified during the Tier II survey of Loon Lake conducted August 28, 2007.

Occurrence and abundance of submersed aquatic plants in Loon Lake.					
Total Sites:	31	Mean species / site:	0.77	Native diversity:	0.32
Littoral Sites:	22	Maximum species / site:	5	Species diversity:	0.42
Littoral Depth (ft):	7	Number of species:	6	SE Mean natives / site:	0.15
Date:	8/28/07	Littoral sites with plants:	18	Mean natives / site:	0.71
Lake:	Loon	Secchi(ft):	4.5	SE Mean species / site:	0.18

All depths (0-15')		Frequency of	Frequency per Species				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Ceratophyllum demersum	Coontail	58.06	41.94	25.81	25.81	6.45	27.10
Myriophyllum spicatum	Eurasian watermilfoil	6.45	93.55	6.45	0.00	0.00	1.29
Potamogeton berchtoldii	Broad-leaf small pondweed	3.23	96.77	3.23	0.00	0.00	0.65
Najas guadalupensis	Southern naiad	3.23	96.77	3.23	0.00	0.00	0.65
Myriophyllum exalbescens	Northern water milfoil	3.23	96.77	3.23	0.00	0.00	0.65
Chara species	Chara species	3.23	96.77	3.23	0.00	0.00	0.65
Filamentous algae	Filamentous algae	87.10					
0-5' Stratum		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Ceratophyllum demersum	Coontail	92.86	7.14	28.57	50.00	14.29	50.00
Myriophyllum spicatum	Eurasian watermilfoil	14.29	85.71	14.29	0.00	0.00	2.86
Potamogeton berchtoldii	Broad-leaf small pondweed	7.14	92.86	7.14	0.00	0.00	1.43
Najas guadalupensis	Southern naiad	7.14	92.86	7.14	0.00	0.00	1.43
Myriophyllum exalbescens	Northern water milfoil	7.14	92.86	7.14	0.00	0.00	1.43
Chara species	Chara species	7.14	92.86	7.14	0.00	0.00	1.43
Filamentous algae	Filamentous algae	92.86					
5-10' Stratum		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Ceratophyllum demersum	Coontail	38.46	61.54	30.77	7.69	0.00	10.77
Filamentous algae	Filamentous algae	76.92					
10-15' Stratum		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Filamentous algae	Filamentous algae	100.00					

Coontail also dominated the submergent plant community in the 0-5 foot and 5-10 foot strata (Table 56). Coontail was the most frequent species as it was found at 93% of the sites in the 0-5 foot stratum and at 38.5% of the sites in the 5-10 foot stratum. Coontail generated the highest dominance rating of 50 and 10.8 in the 0-5 foot and 5-10 foot strata, respectively. Eurasian watermilfoil had a relatively low frequency (14.3) and dominance (2.9) in the 0-5 foot stratum. Eurasian watermilfoil was not identified in the 5-10 foot or the 10-15 foot strata of Loon Lake. Overall, Eurasian watermilfoil was identified at 6.5% of the sites throughout the lake.

Changes in a lake's rooted plant communities over time can illustrate unseen chemical changes in the lake. Unfortunately, limited data detailing Loon Lake's historical rooted plant community exist for comparison to the current data. In the past, IDNR fisheries biologists conducted cursory vegetation surveys as a part of their general fisheries surveys. Historical studies recorded many of the same species that currently dominate Loon Lake. In 1965, McGinty (1966d) noted the presence of 10 emergent species and 8 submergent species. McGinty noted the abundance and variety of coontail and sago pondweed and indicated that although a portion of the submergent community had 'died-off', that these species were still too abundant for Loon Lake. McGinty also noted the presence of filamentous algae throughout the water column and on vegetation throughout the lake. Further notation of the abundance of submergent vegetation from the shoreline to a depth of approximately 15 feet (4.5 m) was noted during this survey. In 1980, Braun (1981c) noted that filamentous algae was still prevalent; however, submergent vegetation was not problematic. In total, 10 emergent and 8 submergent species were identified by DNR biologists. During the 2006 assessment, Benson (2005) identified similar species but in less diversity, with coontail and sago pondweed dominating the plant community in Loon Lake. These data suggest that the plant community with Loon Lake may be shifting to one that is ubiquitous. For additional information on historical Tier II surveys see the 2007 Excerpt of Beaver Dam and Loon Lakes (JFNew, 2007a).

Although they have not yet reached the levels observed on many other regional lakes, several nuisance and/or exotic aquatic plant species grow in Loon Lake. As nuisance species, these species will continue to proliferate if unmanaged, so data collected during the plant survey will be outdated quickly and should not be used to precisely locate nuisance species individuals or stands. (Additionally, it is likely that the watershed supports many terrestrial nuisance species plant species, but this discussion will focus on the aquatic nuisance species.) The plant survey revealed the presence of one submergent, aggressive exotics: Eurasian watermilfoil (Figure 75). Although not identified during the current survey, historic assessments indicate the presence of another submergent, aggressive, exotic species, curly-leaf pondweed in Loon Lake. As nuisance species, these species have the potential to proliferate if left unmanaged. It is possible that these and other exotic species could exist within the thick emergent portions of the rooted plant community but were not observed during this survey.

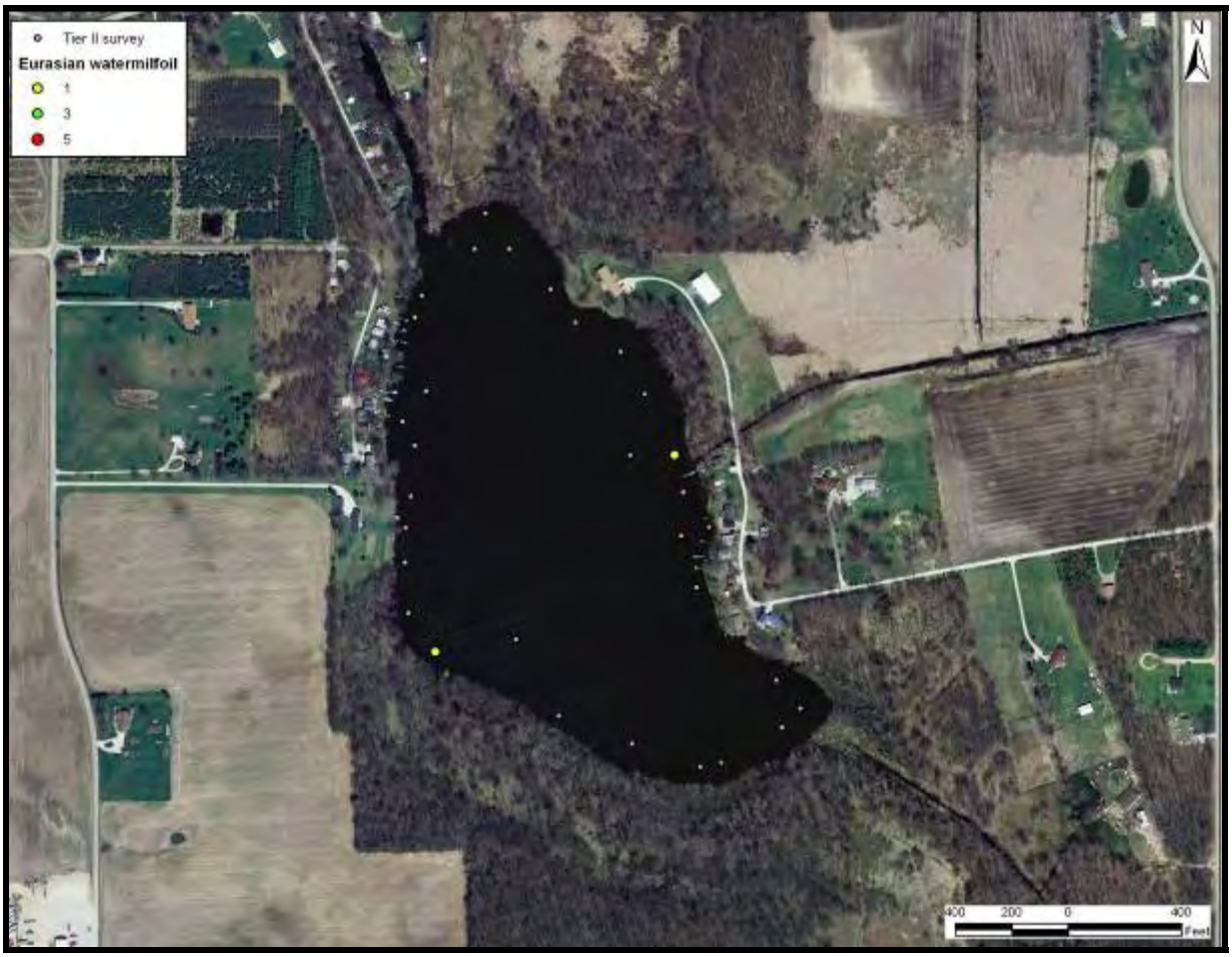


Figure 75. Location of sample points and the location/density of Eurasian watermilfoil identified in Loon Lake during the August 28, 2007 Tier II survey.

4.4.4 Loon Lake Fisheries Summary

Introduction

Loon Lake's fish community was surveyed by the IDNR in 1965, 1980 and 2006 (Table 57). Loon Lake is located downstream of Beaver Dam Lake and upstream of Yellow Creek Lake. Due to this connection the fish community in Loon Lake is likely influenced by the connection to Beaver Dam and Yellow Creek Lakes. Loon Lake can be described as a panfish-largemouth bass fishery. Additional angling for spotted gar and northern pike is available as well. According to Braun (1981), the spotted gar population in Loon Lake was the largest population the biologist had ever sampled. Braun (1981) suggested the spotted gar population was helping control the panfish population in Loon Lake by preying upon young fishes. The thinning of the number of young fish helps reduce intra-specific competition (competition within a population such as bluegill) between developing fishes and allows for healthier individuals to be recruited into the adult stock. Additionally, Braun (1981) reported that a small population of northern pike existed in Loon Lake. Northern pike utilize shallow emergent wetlands as nursery habitat, which exist on the south and east shores. The changes to the community composition of Loon Lake over time are shown is Figure 76.

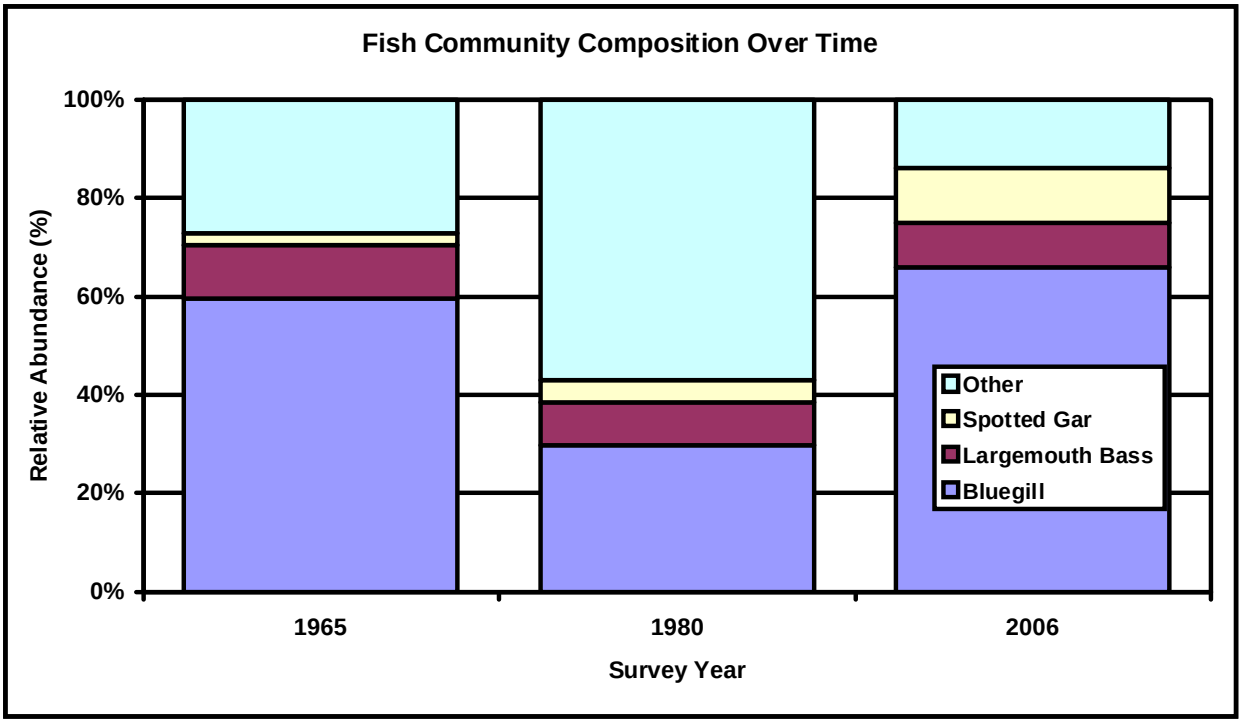


Figure 76. Fish community composition in Loon Lake for survey years 1965, 1980, and 2006. Sources: Braun, 1981; Grier, 2006; McGinty, 1966d.

Table 57. Summary Table of IDNR Fish Surveys in Loon Lake, Kosciusko County, Indiana.

Common Name	Scientific Name	1964	1980	2006
Sunfish Family				
Bluegill	*Lepomis macrochirus*	X	X	X
Black Crappie	*Pomoxis nigromaculatus*	X	X	X
Hybrid Sunfish				X
Largemouth Bass	*Micropterus salmoides*	X	X	X
Longear Sunfish	*Lepomis megalotus*	X	X	X
Pumpkinseed	*Lepomis gibbosus*	X	X	X
Redear Sunfish	*Lepomis microlophus*	X	X	X
Rock Bass	*Ambloplites rupestris*			X
Warmouth	*Lepomis gulosus*	X	X	X
Catfish Family				
Black Bullhead	*Ameiurus melas*		X	
Brown Bullhead	*Ameiurus nebulosus*	X	X	X
Channel Catfish	*Ictalurus punctatus*		X	
Yellow Bullhead	*Ameiurus natalis*	X	X	X
Minnow Family				
Common Carp	*Cyprinus carpio*	X	X	X
Golden Shiner	*Notemigonus crysoleucas*	X	X	
Sucker Family				
Golden Redhorse	*Ictiobus cyprinellus*	X		
Lake Chubsucker	*Erimyzon sucetta*	X	X	
Spotted Sucker	*Minytrema melanops*	X	X	X
White Sucker	*Catostomus commersoni*		X	X
Bowfin Family				
Bowfin	*Amia calva*	X		X
Herring Family				
Gizzard Shad	*Dorosoma cepedianum*	X	X	X
Gar Family				
Shortnose Gar	*Lepisosteus platostomus*	X		
Spotted Gar	*Lepisosteus oculatus*	X	X	X
Pike Family				
Grass Pickerel	*Esox americanus vermiculatus*		X	
Northern Pike	*Esox lucius*		X	
Perch Family				
Yellow Perch	*Perca flavescens*	X	X	X
Number Species		19	21	17/1 hybrid

Fish Community Summary

Loon Lake has not been sampled in two years; therefore, the current fish community composition is not certain. To make assumptions regarding general trends or changes within the fish community in Loon Lake is difficult due to the small working set of data available. In general, the limited data suggests that Loon Lake supports a balanced population of bluegill and

offers quality angling opportunities for largemouth bass based on the fish community in 2006. Loon Lake, like the other Yellow Creek Lakes, could benefit from smart fishing practices such as catch and release of largemouth bass and selective harvest of panfish (bluegill and black crappie). Spotted gar are important to the lake as a top predator, thinning the population of small fish in Loon Lake resulting in a balanced population. While spotted gar is not desirable to most anglers for consumption, they can provide an alternative angling opportunity to some.

4.4.5 Loon Lake Historical Water Quality

The IDNR, Division of Fish and Wildlife, the Indiana State Pollution Control Board, the Indiana Clean Lakes Program (CLP), and Grace College have conducted various water quality tests on Loon Lake. Table 58 presents some selected water quality parameters for these assessments of Loon Lake.

Table 58. Summary of historic data for Loon Lake.

Date	Secchi (ft)	% Oxic	Epi pH	TP (mg/L)	Plankton (#/L)	Chl *a* (µg/L)	ITSI Score	Source
4/18/66	8.0	37.5%	--	--	--	--	--	McGinty, 1966d
7/19/77	2.5	--	--	0.030*	--	--	52[δ]	ISPCB, 1986
7/14/80	2.2	50.0%	9.70	--	--	--	--	Braun, 1981c
8/26/91	3.3	24.5%	8.60	0.315	3,190	--	31	CLP, 1991
8/22/94	4.9	32.8%	8.60	0.359	2,316	9.1	27	CLP, 1994
8/10/98	3.0	32.8%	8.51	0.302	23,490	15.9	41	CLP, 1998
5/22/06	7.0	--	--	--	--	--	--	Grier, 2006
7/24/06	4.6	20.0%	9.96	--	--	--	--	Grier, 2006
6/26/07	4.1	--	8.94	0.027[+]	--	--	--	Lesko, 2007
7/18/07	3.8	--	8.52	0.113[+]	--	--	--	Lesko, 2007
8/6/07	4.9	--	8.69	0.010[+]	--	--	--	Lesko, 2007

*Water column average; all other values are means of epilimnion and hypolimnion values.
[+]Surface water (epilimnetic) sample only; all other values are means of epilimnion and hypolimnion values.
[δ]Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.

Based on the data presented in Table 58, water quality in Loon Lake has remained stable or even improved slightly over the past 40 years. Water clarity is relatively poor for the region. Since 1966, Secchi disk transparency (a measure of water clarity) has ranged from 2.2 feet (0.7 m) in July 1980 to 8.0 feet (2.4 m) in April 1966 (Figure 77). These measurements follow a pattern typically observed in Indiana lakes. Water clarity is generally better during the spring, early summer, and fall than clarity measurements that occur during the middle of the summer and early fall (July to September). This trend is apparent within Loon Lake as the best (deepest) transparencies occurred during April 1966 and May 2006 (8 feet (2.4 m) and 7 feet (2.1 m), respectively). During the remainder of the sampling events, transparencies ranged from 2.2 feet (0.7m) to 4.9 feet (1.5 m). These sampling events occurred during July and August when transparency is typically poorer within Indiana lakes. Overall, water clarity has been variable over the years with no distinct trend toward increasing or decreasing water clarity. All transparency measurements collected in Loon Lake with the exception of the April 1966 and may 2006 sampling events suggest that Loon Lake's water clarity is poorer than most lakes in Indiana.

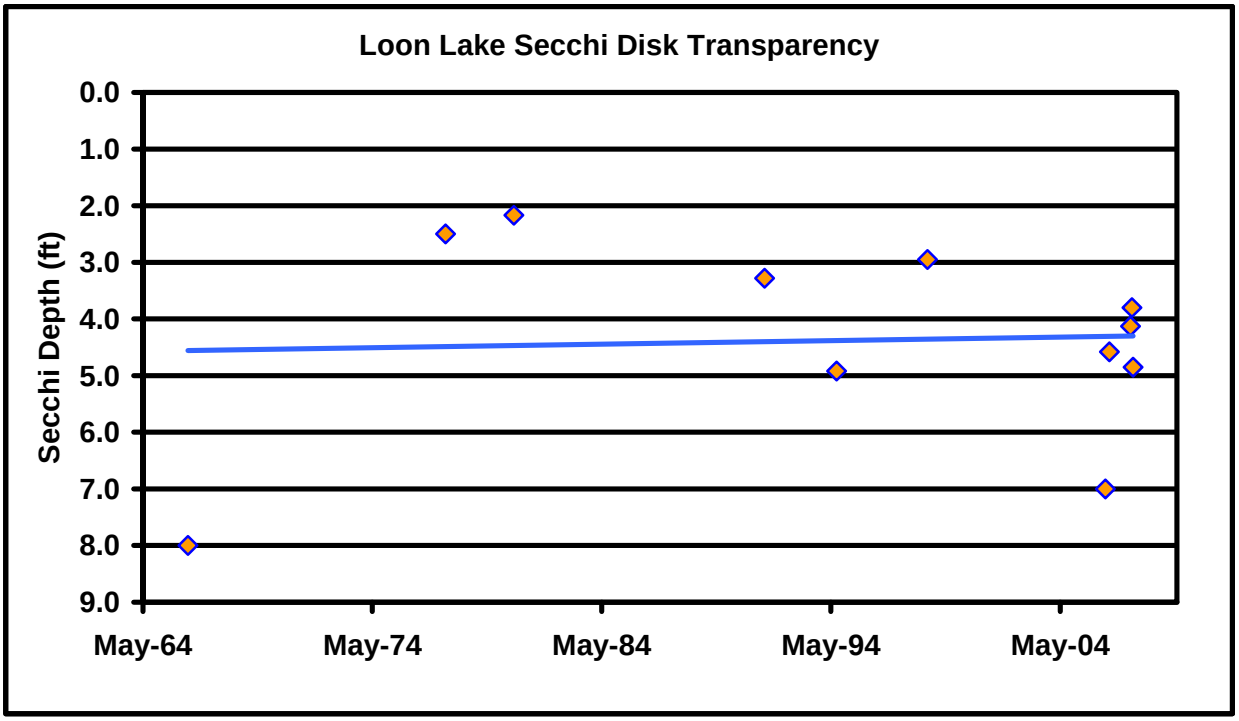


Figure 77. Historic Secchi disk transparency data for Loon Lake.
Source: Braun, 1981; CLP, 1991, 1994, 1998; Grier, 2006; ISPCB, 1986; Lesko, 2007; McGinty, 1966d.

Total phosphorus concentrations were generally elevated within Loon Lake (Figure 78). Concentrations were relatively low in 1977 measuring 0.030 mg/L but increased by an order of magnitude to range between 0.302 mg/L in 1998 and 0.359 mg/L in 1994. Concentrations in the most recently collected samples range from 0.010 mg/L to 0.113 mg/L. Samples collected in 1977 and in 2007 were collected using different protocols than those used to collect the samples from the 1990s. The 1977 sample is a water column average sample, while the 2007 samples are surface water samples only. Samples collected in the 1990s represent surface and bottom water samples which were analyzed then the concentrations were averaged. All three samples collected in the 1990s exceeded the median total phosphorus concentration measured in most Indiana lakes (0.17 mg/L). All other samples, those from 1977 and 2007 are below the median concentration for Indiana lakes.

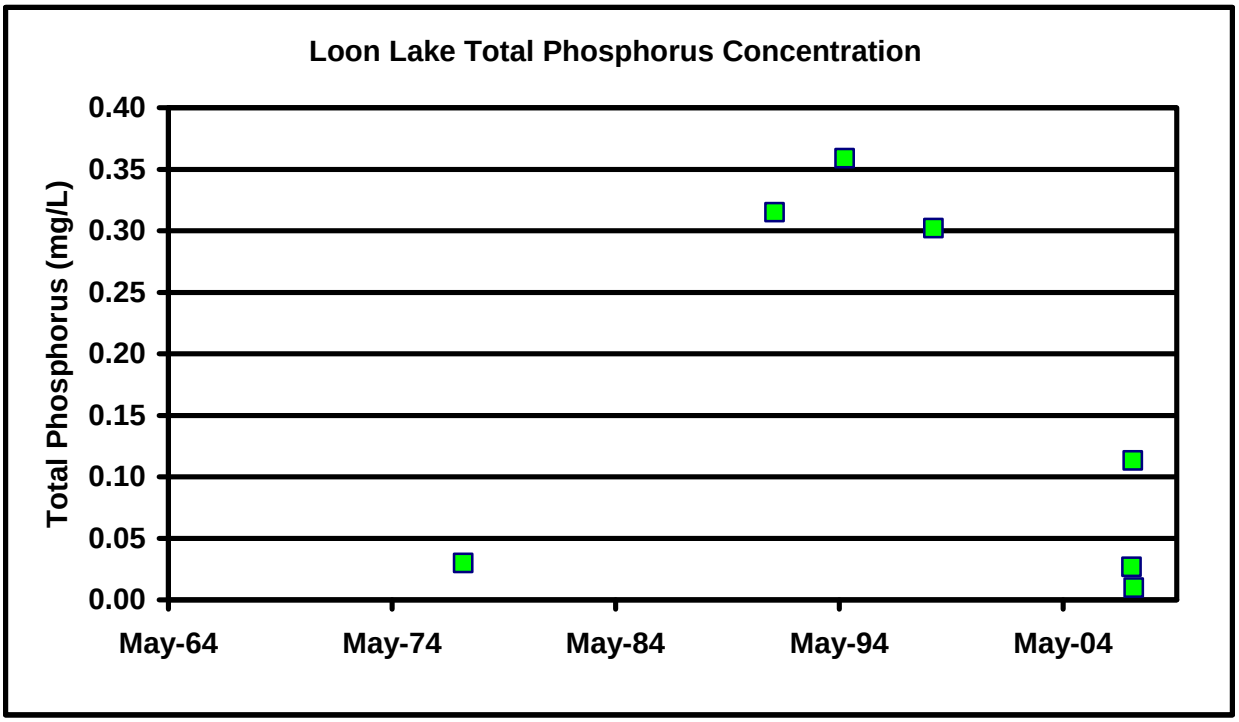


Figure 78. Historic total phosphorus concentrations measured in Loon Lake.
Source: CLP, 1991, 1994, 1998; ISPCB, 1986; Lesko, 2007.

There is not a significant trend in nutrient concentrations in Loon Lake (Figure 79). Concentrations indicate a doubling of soluble reactive phosphorus concentrations from 0.271 mg/L in 1991 to 0.548 mg/L in 1998. However, total phosphorus concentrations do not increase or decrease over time. Both soluble and total phosphorus concentrations exceed the median concentration found in Indiana lakes. Nitrogen concentrations also display little pattern between the assessments. Total nitrogen concentrations decrease from 4.573 mg/L in 1991 to 4.045 mg/L in 1998. Ammonia-nitrogen and nitrate-nitrogen concentrations also decreased from 1991 to 1998. With the exception of nitrate-nitrogen and the most recent ammonia-nitrogen, nutrient concentrations in Loon Lake are above the median concentrations measured in Indiana lakes.

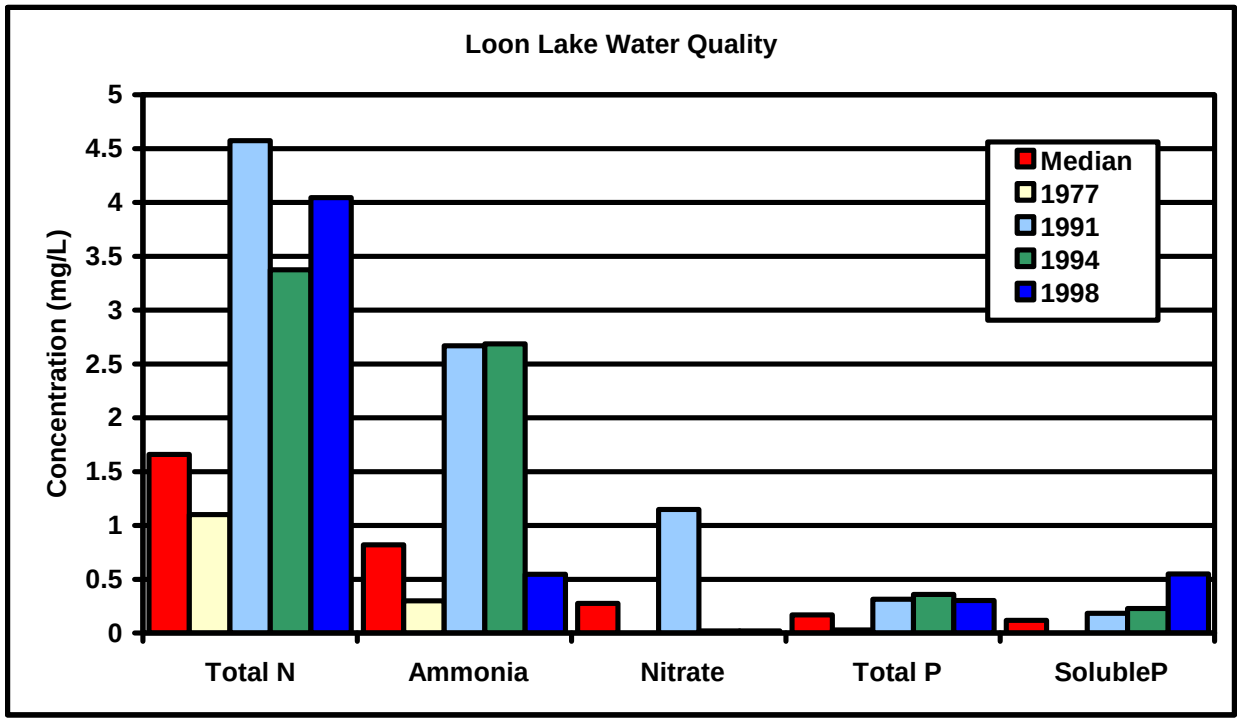


Figure 79. Variation in nutrient concentrations in Loon Lake, 1977 to 1998.
Source: CLP, 1991, 1994, 1998; ISPCB, 1986.

Despite the relatively high nutrient concentrations found in Loon Lake, the lake's algae (plankton) density remains relatively low. Nutrients (nitrogen and phosphorus) promote the growth of algae and/or rooted plant populations. Thus, lakes with high nutrient levels are expected to support dense algae and/or rooted plants. Plankton densities within Loon Lake range from 2,316/L in 1994 to 23,460/L between 1991 and 1998. These densities suggest that something other than nutrients are limiting algal productivity within Loon Lake. Low chlorophyll *a* concentrations also reflect the relatively low plankton densities found in the lake. One of the two chlorophyll *a* concentrations exceeded the median concentration measured in Indiana lakes (12.9 µg/L). However, chlorophyll *a* concentrations are relatively low for lakes in the region and within the Yellow Creek watershed. The lake's overall ITSI ranged from a high of 52 in 1977 to a low of 27 in 1994 before rising again to 41 in 1998. With the exception of the earliest sampling, these scores suggest that the lake is mesotrophic to slightly eutrophic. As all of the data are not available for the 1977 sampling event, it is difficult to determine to what the high ITSI score should be attributed. Nonetheless, Loon Lake can be classified as a moderately productive to somewhat highly productive lake with more recent data suggesting that moderate productivity is the norm in Loon Lake. (Please see the Discussion Section of this report for more detailed discussion of lake water quality parameters and trophic state indices.)

Figure 80 displays the temperature profiles recorded during IDNR fisheries surveys and Indiana CLP assessments. All of the temperature profiles show that Loon Lake was stratified at the time of sampling. The lake's metalimnion (area of highest temperature change with depth or greatest slope along the curve) extends from 10 to 20 feet below the surface. The epilimnion (or surface water) is above this point (10 feet or 3.0 m), while the hypolimnion (or bottom water) is below this level (20 feet or 6.1 m). The developed hypolimnion present during the surveys is very typical of Indiana lakes.

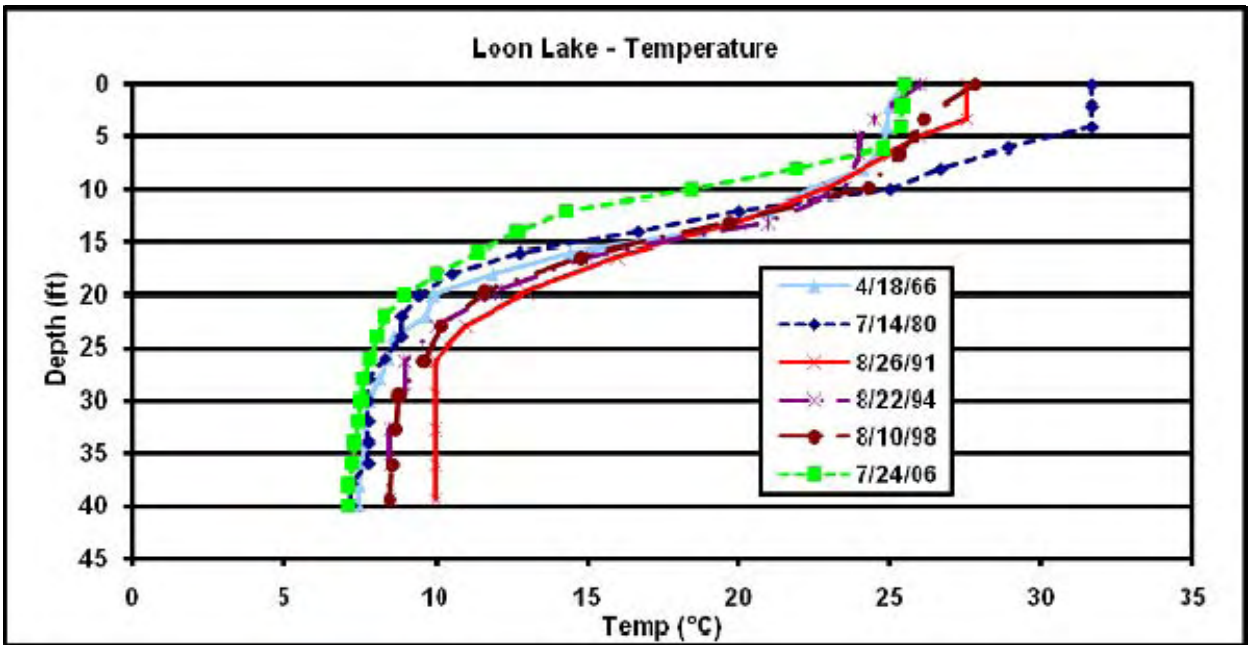


Figure 80. Historical temperature profiles for Loon Lake.
Source: Braun, 1981; CLP, 1991, 1994, 1998; Grier, 2006; McGinty, 1966d.

Much of the data presented above suggest that Loon Lake is a moderately productive to productive lake. The historical percent oxic results (Table 58) and dissolved oxygen profiles (Figure 81) are more typical of a eutrophic (productive) lake. Dissolved oxygen data indicate that the lake typically possessed dissolved oxygen greater than 1 mg/L in less than 32% of the water column. During two sampling events, April 1966 and July 1980 suggest that dissolved oxygen concentrations were better within Loon Lake. However, both of these sampling events occurred relatively early in the season when dissolved oxygen concentrations are typically better distributed and higher throughout the water column. Nonetheless, the decline in dissolved oxygen throughout the water column limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments.

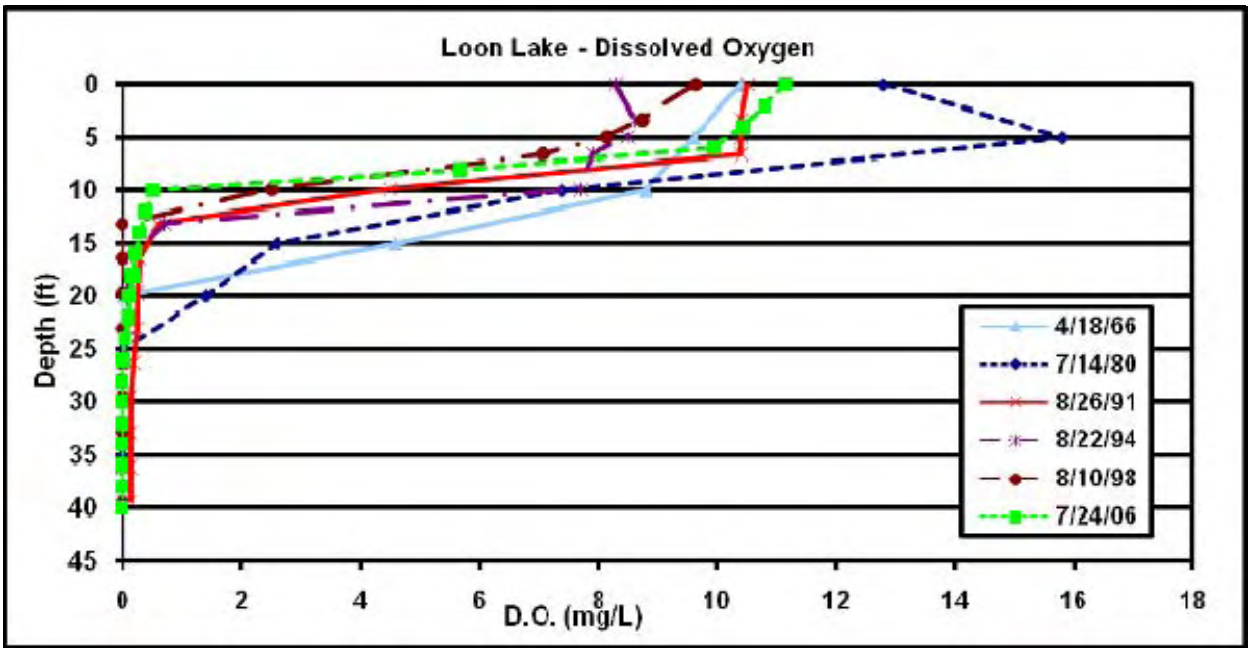


Figure 81. Historical dissolved oxygen profiles for Loon Lake.
Source: Braun, 1981; CLP, 1991, 1994, 1998; Grier, 2006; McGinty, 1966d.

The lack of oxygen in the lower part of the lake's lower water column is likely a sign of intense decomposition of plant material during the summer months. Decomposition of plant material undoubtedly occurs in the lake's deeper waters, removing oxygen from the water column. (Higher hypolimnetic ammonia concentrations suggest decomposition is occurring in the lake's bottom waters). Overall, this lack of oxygen poses a problem for the lake's inhabitants. Fish and other aquatic organisms require oxygen to live. The lack of oxygen in the lake's hypolimnion reduces the amount of habitat available to fish. Fortunately, most of the lake's volume has oxygen levels sufficient to support fish. Based on the depth-volume curve (Figure 70), approximately 84% of the lake's volume is oxygenated. (The percent oxic parameter measures the vertical percent, not volumetric percent, of the water column with oxygen.)

The lack of oxygen in Loon Lake's hypolimnion also affects the lake's chemistry. While mean total phosphorus concentrations are variable for the years 1966 through 2007 (Table 58), a more detailed evaluation shows that hypolimnetic total phosphorus concentrations are typically higher than epilimnetic total phosphorus concentrations. Under anoxic conditions, the iron in iron phosphate, a common precipitate in lake sediments, is reduced, and the phosphate ion is released into the water column. This phosphate ion is readily available to algae, and can therefore spur algal growth. Further review of historical phosphorus data indicate that much of the total phosphorus was in the dissolved form of phosphorus (SRP). This indicates that Loon Lake was releasing phosphorus from its bottom sediments. Additionally, Loon Lake exhibited higher hypolimnetic ammonia concentrations than those observed in the lake's epilimnion during all of the assessments, suggesting decomposition of organic matter was occurring in the lake's bottom waters. Overall, these data suggest that Loon Lake was a mesotrophic to moderately eutrophic lake during the 1990, 1994, and 1998 assessments.

4.4.6 Loon Lake Water Budget

The watershed or drainage area of Beaver Dam Lake is approximately 461 acres. The mean annual watershed runoff volume calculated to drain into Beaver Dam Lake is 556 acre-feet per year. Comparing the runoff to the lake volume of 719 acre-feet and factoring in evaporation and rainfall from and to the lake, results in a hydraulic residence time of about 4 months (Table 59). This residence time is on the low end of normal for Indiana Lakes. This relatively fast input and output of water means that watershed processes and practices are more important to the health of the lake than in-lake processes.

Table 59. Water Budget Calculations for Loon Lake. (See Appendix A for a graphic model of model inputs and outputs**)**

Watershed	Loon Lake - Kosciusko Co.
Direct Watershed size (ac)	461
Mean watershed runoff (ac-ft/yr)	556
Lake volume (ac-ft)	719
Closest gaged stream	Eel River @ N. Manchester
Stream watershed (mi^2)	417
Stream watershed (acres)	266880
Mean annual daily Q (cfs)	444.7
Mean annual total Q (ac-ft/yr)	321948
Mean ppt (in/yr)	37
Mean watershed ppt (ac-ft/yr)	822880
Watershed C	0.39125
Pan evaporation (in/yr)	41.80
Pan evaporation coefficient	0.70
Lake surface area (acres)	43
Estimated lake evaporation (ac-ft)	105
Direct precipitation to lake (ac-ft)	133
	= input data
	= output data
Water Budget Summary	
Direct precipitation to lake (ac-ft)	133
Runoff from watershed (ac-ft)	556
Evaporation (ac-ft)	105
Discharge from Beaver Dam Lake (ac-ft)	1621
TOTAL LAKE OUTPUT (ac-ft)	2205
Hydraulic residence time (yr)	0.33

4.4.7 Loon Lake Current Water Quality Assessment

Temperature and oxygen profiles for Loon Lake show that the lake was stratified at the time of sampling (Figure 82). Loon Lake is supersaturated in the *epilimnion* (surface waters), with 132.7% dissolved oxygen at 5 feet (1.5 m). Supersaturated dissolved oxygen is usually symptomatic of intense phytoplankton photosynthesis. The lake reaches anoxic ([D.O.] < 1.0

mg/L) conditions below 5 meters, providing little oxygen to support fish and other aquatic life. During thermal stratification, the bottom waters (*hypolimnion*) of the lake are isolated from the well-mixed epilimnion by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth is called the *metalimnion*. At the time of our sampling, the epilimnion was confined to the upper 6.5 feet (2 m) of water. The sharp decline in temperature between 6.5 feet (2 m) and about 23 feet (7 m) defines the metalimnion or transition zone. The hypolimnion occupied water deeper than 23 feet (7 m).

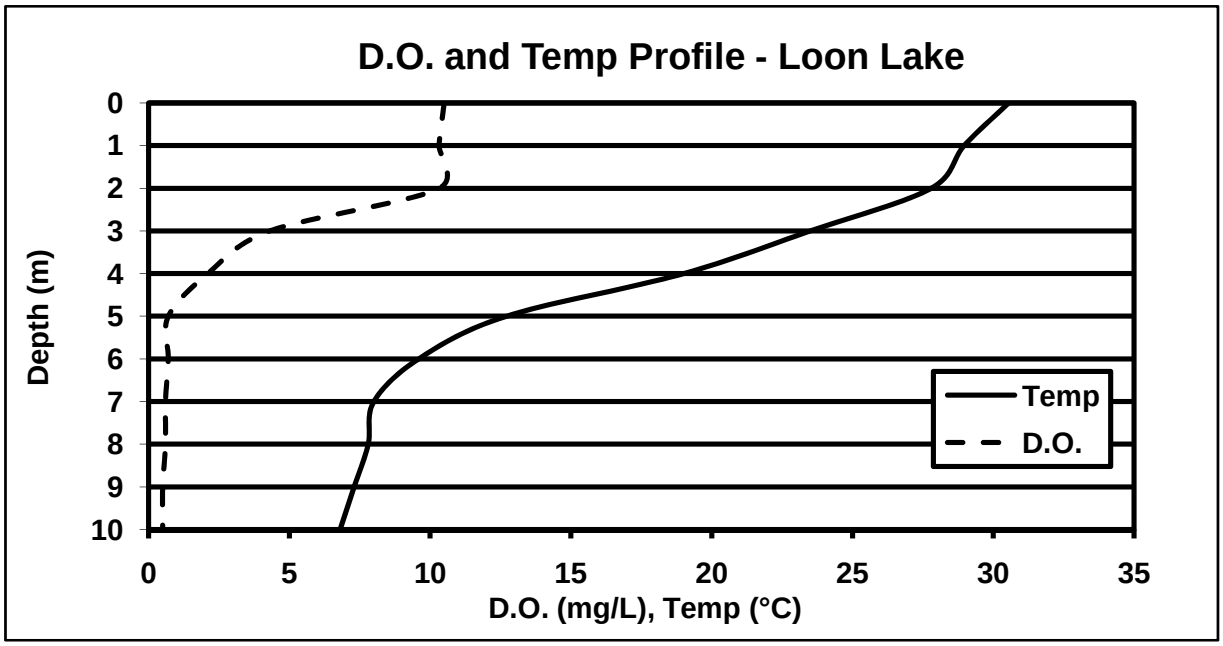


Figure 82. Temperature and dissolved oxygen profiles for Loon Lake on July 17, 2008.

The 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to 8.5 ft (2.6 m). Based on the depth-area curve (Figure 69) approximately 24% of lake bottom (approximately 10.4 acres) is shallower than 8.5 ft. This represents the area of the lake bottom with sufficient light to support rooted plants. This area is called the *littoral zone*. Furthermore, based on the depth-volume curve (Figure 70), we see that a volume of greater than 310 acre-feet of Loon Lake (43% of total lake volume) lies above the 8.5-foot 1% light level. This area, referred to as the *photic zone*, represents the amount of water with sufficient light to support algae growth.

Phosphorus and nitrogen are the primary plant nutrients in lakes. Phosphorus concentrations were relatively low in the epilimnion of Loon Lake but were considerably higher (0.526 mg/L) in the hypolimnion (Table 60). Higher phosphorus concentrations within the hypolimnion are usually associated with nutrient release from the sediments under anoxic conditions. Sedimentation of particulates and plankton also provide a source of phosphorus to the hypolimnion. The epilimnion concentration of 0.034 mg/L narrowly exceeds the 0.03 mg/L concentration that is considered high enough to support eutrophic conditions.

Nitrate nitrogen was at the lower detection limits (0.013 mg/L) of our analytical methods in the epilimnion and hypolimnion. Nitrate is used by growing algae and is reduced to ammonia when oxygen is low. Ammonia oxidizes rapidly to nitrate in the presence of adequate oxygen and nitrifying bacteria. The hypolimnetic ammonia concentrations measured (4.259 mg/L) indicate

the presence of a high biochemical oxygen demand (BOD) to produce the ammonia (NH_4) and a low amount of dissolved oxygen present to maintain these relatively high concentrations.

Table 60. Water Quality Characteristics of Loon Lake sampling on July 17, 2008.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	9.0	7.1	-
Alkalinity	130 mg/L	177.5 mg/L	-
Conductivity	338 µS/m	415 µS/m	-
Secchi depth	0.9m	-	6
Light Transmission @ 3 ft	13.0%	-	4
1% Light level	8.5ft	-	-
Total Phosphorus	0.034 mg/L	0.526 mg/L	4
Soluble Reactive Phosphorus	0.010* mg/L	0.432 mg/L	4
NO_3	0.013* mg/L	0.013* mg/L	0
NH_4	0.149 mg/L	4.259 mg/L	4
TKN	1.394 mg/L	6.461 mg/L	3
Oxygen Saturation @ 5 ft.	132.7%	-	3
% Water column oxic	33.3%	-	3
Plankton Density	15,355 N.U./L	-	2
Blue-Green Dominance	70.7%	-	10
Chl-a	12.48 µg/L	-	-
		TSI Score	**43**

*Method Detection Limit

Values for pH were within the normal range for Indiana lakes, pH 9.0 for the epilimnion and pH 7.1 for the hypolimnion. pH values for most fresh waters fall between pH 6-9 (Kalff, 2002). The high alkalinity values of 130 mg/L for the epilimnion and 177.5 mg/L for the hypolimnion, indicate that Loon Lake is a well buffered system.

Plankton enumerated from the sample collected from Loon Lake are shown in Table 61. *Limnothrix*, a blue-green alga, was the most dominant genera found, and accounted for almost half the plankton density. In addition to this particular blue-green alga, other blue-green species contributed to the overall plankton dominance by blue-greens of 70.7%. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers. This blue-green dominance is the primary reason for the higher TSI score in 2008.

Table 61. The plankton sample representing the species assemblage on July 17, 2008 in Loon Lake, Kosciusko County, Indiana.

SPECIES	ABUNDANCE (N.U./L)
Blue-Green Algae (Cyanophyta)	
Lyngbya	144
Oscillatoria	1078
Limnothrix	3305
Anabaena	2227
Aphanizomenon	503
Microcystis	1150
Green Algae (Chlorophyta)	
Mougeotia	2012
Ankistrodesmus	1868
Scenedesmus	72
Gonium	144
Diatoms (Bacillariophyta)	
Synedra	575
Gomphoneis	72
Other Algae	
Synura	503
Ceratium	431
Protozoa	216
Zooplankton	
Polyarthra	72
Nauplius	25.6
Daphnia	4.1
Calanoid Copepod	1.0
Cyclopoid Copepod	21.5

4.5 McClures Lake

4.5.1 Morphology

Figure 83 presents McClures Lake's morphology. The lake consists of one deep hole surrounded by gradually shallower water. The deepest point lies slightly south of the center of the 32-acre (12.9-ha) lake. Here, the lake extends to it maximum depth of 30 feet (9.1 m; Table 62). A large flat shelf surrounds the lake and covers much of the northern shoreline of McClures Lake. McClures Lake possesses large expanses of shallow water. According to its depth-area curve (Figure 84), nearly 22 acres (8.9 ha) of the lake is covered by water less than 5 feet (1.5 m) deep, while the entire lake is covered by water less than 30 feet (9.1 m) deep. This translates into a moderately high shallowness ratio of 0.36 (ratio of area less than 5 feet (1.5 m) deep to total lake area) and a high shoalness ratio of 0.78 (ratio of area less than 20 feet (6.1 m) deep to total lake area) (Table 62), as defined by Wagner (1990). The lake's area

gradually increases to a depth of about 5 feet (1.6 m). From 5 feet to 10 feet, little change in lake area occurs. The rate of change then continues gradually to the lakes maximum depth (30 feet or 9.1 m). McClures Lake is the shallowest of the Yellow Creek watershed lakes.

Figure 83. McClures Lake bathymetric map. Source: Kosciusko County GIS Department, digitized from 1956 IDNR contour maps.

Table 62. Morphological characteristics of McClures Lake.

Characteristic	Value
Surface Area	32 acres (12.9 ha)
Volume	713 acre-feet (879,117 m^3)
Maximum Depth	30 feet (9.1 m)
Mean Depth	22.2 feet (6.7 m)
Shallowness Ratio	0.36
Shoalness Ratio	0.78
Shoreline Length	5,523 feet (1,683 m)
Shoreline Development Ratio	1.32

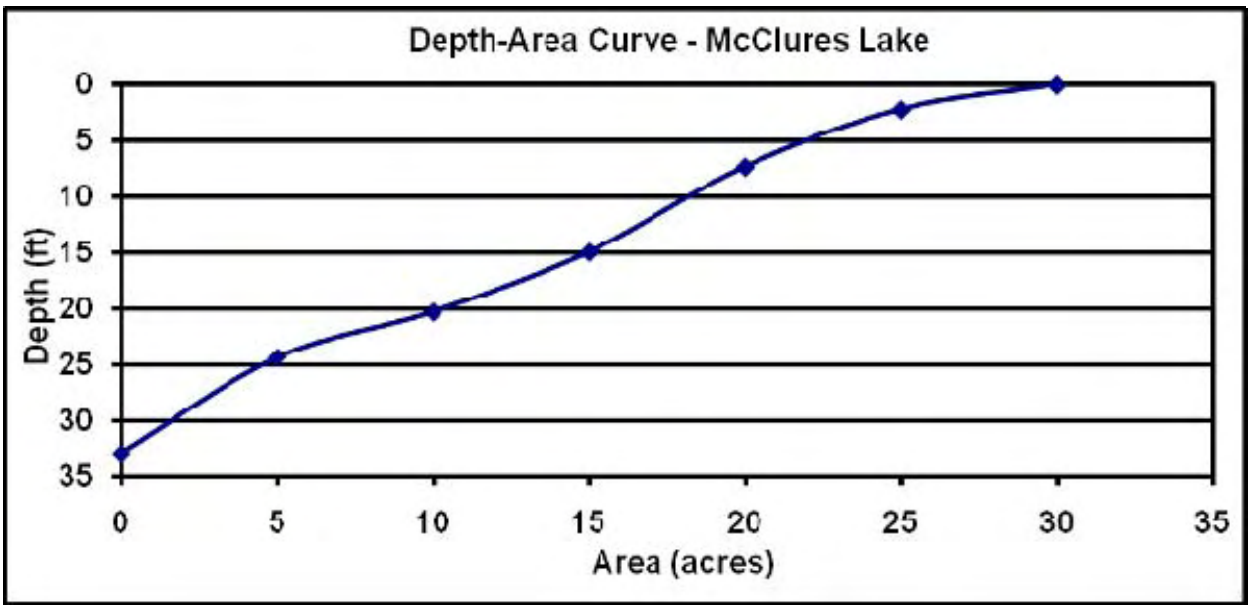


Figure 84. Depth-area curve for McClures Lake.

McClures Lake holds approximately 713 acre-feet (879,117 m^3) of water, the smallest volume of any of the Yellow Creek watershed lakes. As illustrated in the depth-volume curve (Figure 85), most of the lake's volume is contained in the shallower areas of the lake. More than 60% of the lake's volume is contained in water that is less than 10 feet (3.1 m) deep. The lake's volume gradually increases with depth to a water depth of about 20 feet (6.1 m) before the rate of change increases. Below 20 feet (6.1 m), the steep curve indicates a greater change in depth per unit volume. This rate continues to the lakes maximum depth. The importance of this rate of increase will be discussed with regard to light penetration and the planktonic community in the Results Section.

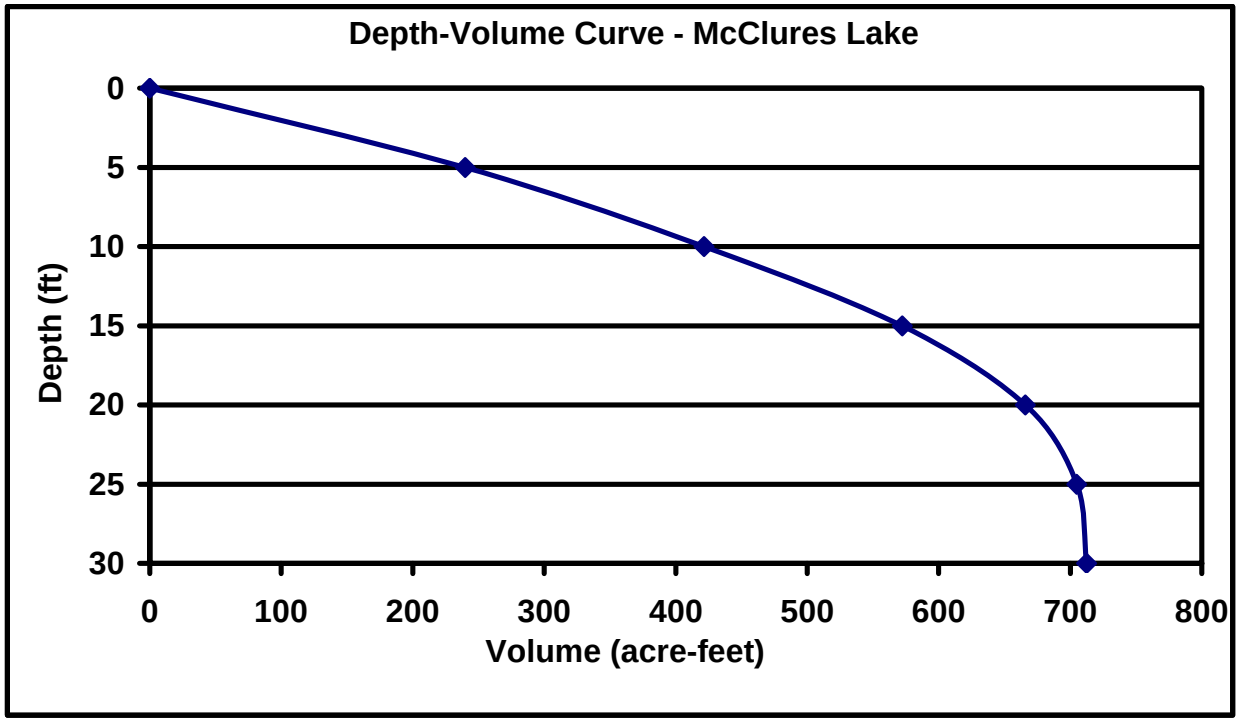


Figure 85. Depth-volume curve for McClures Lake.

A lake's morphology can play a role in shaping the lake's biotic communities. For example, McClures Lake's moderately sized shallow area and wide, shallow shelf around much of the perimeter of the lake coupled with its moderate clarity suggests the lake is capable of supporting a quality rooted plant community. Based on the lake's clarity (3 times the Secchi disk reading), McClures Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the point where water depths are approximately 4.2 feet (1.3 m). Referring to McClures Lake's depth-area curve, this means that the lake's littoral zone is approximately 22 acres (8.9 ha) in size or approximately 40% of the lake.

A lake's morphology can indirectly influence water quality by shaping the human communities around the lake. The shoreline development ratio is a measure of the development potential of a lake. It is calculated by dividing a lake's shoreline length by the circumference of a circle that has the same area as the lake. A perfectly circular lake with the same area as McClures Lake (32 acres or 12.9 ha) would have a circumference of 4,185 feet (1,275 m). Dividing McClures Lake's shoreline length (5,523 feet or 1,683 m) by 4,185 feet yields a ratio of 1.32:1. This ratio is relatively low. McClures Lake is relatively round and lacks extensive shoreline channeling. Lakes with high shoreline development ratios are often highly developed. Increased development around lakes often leads to decreased water quality.

4.5.2 McClures Lake Shoreline Development

Development of McClures Lake's shoreline is limited to the Indiana Conservation Council's (ICC) summer camp along the lakes eastern shoreline and a few residences on the western shoreline. McGinty (1966e) noted that the ICC established the conservation camp in 1948. Shoreline alternation to create a beach and allow camper access occurred shortly thereafter. Braun (1986c) also noted that nearly 75% of the shoreline was wetland. During the shoreline survey for this study it was recorded that 93% of the shoreline possesses natural vegetation

patterns (Figure 86). Wetlands abut the lake's eastern, southern, and northern shorelines, while narrow emergent and forested bands cover the lake's western shoreline (Figure 87).

Figure 86. Shoreline types observed at McClures Lake, August 27, 2007.

In 2007, an area was being cleared along the lake's western shoreline to allow new residences being built on a hill west of McClures Lake to access the lake itself (Figure 88). No erosion issues were noted during the survey conducted for this study.

Figure 87. Typical shoreline present along McClures Lake's shoreline.

Figure 88. Access clearing along the western shore of McClures Lake during the 2007 shoreline survey.

4.5.3 Macrophyte Inventory

JFNew surveyed the McClures Lake plant community on August 28, 2007. In general the submerged plant community of McClures Lake is poor; however, the emergent and floating leqaved plant community appears to be of moderately good quality compared to other lakes aquatic plant communities. The community extends from the lake's shoreline to a water depth of approximately 3 feet (0.9 m). In total, 18 aquatic plant species were identified within the water and on the shoreline of McClures Lake (Table 63). The LARE protocol used to conduct the aquatic plant survey requires surveyors to note all plant species observed from a boat. Thus, plants in the wetland complexes adjacent to the lake were only counted if they were visible from the boat. If these wetland complexes had been explored in greater detail, it is likely that the total number of plant species would increase significantly.

Table 63. Plant species observed in McClures Lake as identified on August 28, 2007.

Scientific Name	Common Name	Stratum
Asclepias incarnata	Swamp milkweed	Emergent
Ceratophyllum demersum	Coontail	Submergent
Decodon verticillatus	Whorled loosestrife	Emergent
Filamentous algae	Filamentous algae	Algae
Iris virginica	Blue-flag iris	Emergent
Leersia oryzoides	Rice cut grass	Emergent
Lemna minor	Common duckweed	Floating
Lythrum salicaria	Purple loosestrife	Emergent
Nuphar advena	Spatterdock	Floating
Nuphar variegatum	Yellow pond lily	Floating
Nymphaea tuberosa	White water lily	Floating
Phalarus arundinacaea	Reed canary grass	Emergent
Pontederia cordata	Pickerel weed	Emergent
Scirpus acutus	Hard-stem bulrush	Emergent
Scirpus pungens	Chairmaker's rush	Emergent

Scientific Name	Common Name	Stratum
Typha angustifolia	Narrow-leaf cattail	Emergent
Typha x *glauca*	Blue cattail	Emergent
Typha latifolia	Broad-leaf cattail	Emergent

Of the 18 plant species observed in McClures Lake, one was an algae, four were floating leaved, 12 were emergent, and only one was a submergent plant species. Coontail was the only submergent plant species and was observed throughout the lake. The most common emergent species were reed canary grass, whorled loosestrife, and cattails, including narrow-leaf, broad-leaf, and blue cattail. The most common floating species were spatterdock, white water lily, and duckweed (Figure 89).

Figure 89. Typical shoreline of McClures Lake during the August 28, 2007 aquatic plant survey, with reed canary grass present along the shoreline.

Coontail dominated the submergent plant community over all depths (0-15 feet; Table 64). This species was found at the highest percentage of sites throughout the water column and also had the highest mean (1.0) and relative densities (0.1). Throughout the water column, no other species were found with the exception of filamentous algae, which was present at 79% of sites. No Eurasian watermilfoil was noted within McClures Lake during this survey (Figure 90).

Table 64. Frequency and dominance of submergent aquatic plant species identified during the Tier II survey of McClures Lake conducted August 28, 2007.

Occurrence and abundance of submersed aquatic plants in McClures Lake.							
Total Sites:	29	Mean species / site:	0.10	Native diversity:			0.00
Littoral Sites:	5	Maximum species / site:	1	Species diversity:			0.00
Littoral Depth (ft):	3	Number of species:	1	SE Mean natives / site:			0.06
Date:	8/28/2007	Littoral sites with plants:	3	Mean natives / site:			0.10
Lake:	McClures	Secchi(ft):	1.4	SE Mean species / site:			0.06
Entire Water Column (0-15 ft.)			**Frequency per Species**				
Scientific Name	**Common Name**	**Frequency of Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Ceratophyllum demersum	Coontail	10.34	89.66	10.34	0.00	0.00	2.07
Filamentous algae	Filamentous algae	79.31					
0-5 ft. Stratum							
Ceratophyllum demersum	Coontail	25.00	75.00	25.00	0.00	0.00	5.00
Filamentous algae	Filamentous algae	91.67					
5-10 ft. Stratum							
Filamentous algae	Filamentous algae	78.57					
10-15 ft. Stratum							
Filamentous algae	Filamentous algae	50.00					

Changes in a lake's rooted plant communities over time can illustrate unseen chemical changes in the lake. Unfortunately, limited data detailing McClures Lake's historical rooted plant community exist for comparison to the current data. In the past, IDNR fisheries biologists conducted cursory vegetation surveys as a part of their general fisheries surveys. Historical studies recorded both greater density and diversity than was recorded during the current assessment. In 1964, McGinty (1966e) noted the presence of seven emergent species and seven submergent species. The dominance of coontail and watermilfoil were noted during this survey. Additionally, the largely natural wetland shoreline was also detailed. Overall, the plant community present in McClures Lake suggests that water quality has changed over time as the submergent vegetation was very limited in both density and diversity during the most recent assessment. However, given the fact that only one recorded list of vegetation is available, it is difficult to draw conclusions about changes in water clarity given the limited information.

For the most part, exotic species are not a problem within McClures Lake. Only one exotic species, reed canary grass, was identified within or adjacent to McClures Lake. Reed canary grass is native to Eurasia. Farmers used (and many likely still use) the species for erosion control along ditch banks or as marsh hay. The species escaped via ditches and has spread to many of the wetlands in the area. Swink and Wilhelm (1994) indicate that reed canary grass commonly occurs at the toe of the upland slope around a wetland. Reed canary grass was often observed above the ordinary high water mark around McClures Lake. Like other nuisance species, reed canary grass forms a monoculture excluding native plants

Figure 90. Location of sample points and the location/density of Eurasian watermilfoil identified in McClures Lake during the August 28, 2007 Tier II survey. Note: there was no milfoil found in the lake during this survey.

4.5.4 McClures Lake Fisheries Summary

Introduction

The IDNR surveyed McClures Lake in 1965 and 1985 (Table 65). Figure 91 presents the fish community composition during both sample events. McClures Lake can be described as a bluegill-largemouth bass fishery. The following paragraphs provide a brief summary of the IDNR fishery management survey findings for each given survey year. A table of the IDNR reports used in the following summaries can be found in the Methods Section of this report.

Fish Community Summary

Since McClures Lake has not been sampled in over twenty years, it is difficult to assess the current state of the fish community and identify any trends associated with the fishery. To identify trends associated with the McClures Lake fishery, a larger working set of data needs to be available and a general survey or angler creel survey should be conducted. It is important to note that in 1990, Indiana imposed a state minimum size limit of 12 inches on largemouth bass and later increased the minimum size to 14 inches in 1998. The goal of the state minimum size limit was to increase both the size of individual and populations of largemouth bass. While the current fish community is not known for certain, angler practices such as selective harvest of panfish and catch and release of largemouth bass beyond that required by law is encouraged.

Table 65. Summary of IDNR Fish sampling results McClures Lake, Indiana

Common Name	Scientific Name	1965	1985
Sunfish Family			
Bluegill	*Lepomis macrochirus*	X	X
Black Crappie	*Pomoxis nigromaculatus*	X	X
Hybrid Sunfish			X
Largemouth Bass	*Micropterus salmoides*	X	X
Longear Sunfish	*Lepomis mega lotus*	X	
Pumpkinseed	*Lepomis gibbosus*	X	X
Redear Sunfish	*Lepomis microlophus*	X	X
Warmouth	*Lepomis gulosus*	X	X
Catfish Family			
Black Bullhead	*Ameiurus melas*		X
Brown Bullhead	*Ameiurus nebulosus*	X	X
Yellow Bullhead	*Ameiurus natalis*	X	X
Minnow Family			
Common Carp	*Cyprinus carpio*	X	X
Golden Shiner	*Notemigonus crysoleucas*	X	X
Sucker Family			
Golden Redhorse	*Moxostoma erythrurum*	X	
Lake Chubsucker	*Erimyzon sucetta*	X	X
White Sucker	*Catostomus commersoni*	X	X
Bowfin Family			
Bowfin	*Amia calva*	X	X
Herring Family			
Gizzard Shad	*Dorosoma cepedianum*	X	X
Gar Family			
Spotted Gar	*Lepisosteus oculatus*	X	X
Pike Family			
Grass Pickeral	*Esox americanus vermiculatus*	X	
Perch Family			
Yellow Perch	*Perca flavescens*	X	X
Number Species		19	17/1 hybrid

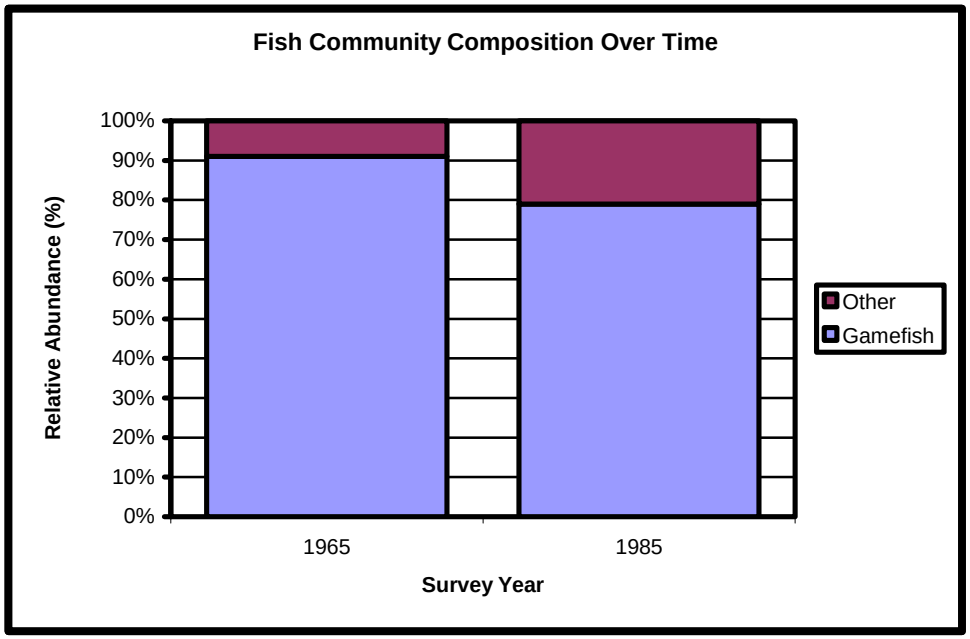


Figure 91. McClures Lake fish community composition, 1965-1985.

4.5.5 McClures Lake Historical Water Quality

The IDNR, Division of Fish and Wildlife, the Indiana State Pollution Control Board, the Indiana Clean Lakes Program (CLP), and Grace College have conducted various water quality tests on McClures Lake. Table 66 presents some selected water quality parameters for these assessments of McClure Lake.

Table 66. Summary of historic data for McClures Lake.

Date	Secchi (ft)	% Oxic	Epi pH	TP (mg/L)	Plankton (#/L)	Chl *a* (µg/L)	ITSI Score	Source
4/18/66	3.5	33.3%	8.00	--	--	--	--	McGinty, 1966e
7/19/77	2.5	--	9.26	0.070*	--	--	51$^{\delta}$	ISPCB, 1986
7/22/85	2.3	33.3%	9.00	--	--	--	--	Braun, 1986b
8/26/91	2.3	43.7%	8.70	0.163	18,332	--	32	CLP, 1991
8/22/94	4.6	43.7%	8.50	0.126	4,251	8.3	23	CLP, 1994
7/20/04	1.6	22.0%	9.30	0.089	32,134	56.2	41	CLP, 2004
6/26/07	1.3	--	8.99	0.023^{+}	--	--	--	Lesko, 2007
7/18/07	1.6	--	8.99	0.017^{+}	--	--	--	Lesko, 2007
8/6/07	1.5	--	--	0.143^{+}	--	--	--	Lesko, 2007

*Water column average; all other values are means of epilimnion and hypolimnion values.
$^{+}$Surface water (epilimnetic) sample only; all other values are means of epilimnion and hypolimnion values.
$^{\delta}$Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.

Based on the data presented in Table 66, water quality in McClures Lake has remained stable or declined slightly over the past 40 years. Since 1966, Secchi disk transparency (a measure of water clarity) declined from a depth of 4.6 feet (1.4 m) in August 1994 to 1.3 feet (0.4 m) in June 2007. The trend line of data suggests a decline in water clarity over time (Figure 92). However, this is likely due to a combination of factors including the limited number of measurements which occurred historically in McClures Lake coupled with the high number of recent measurements and the timing of the historic measurements. The one and only measurement

collected prior to 1977 occurred in April when water clarity in Indiana lakes is typically better than that observed in mid-summer. Conversely, the most recent samplings included three clarity measurements in the last year all of which occurred in mid-summer when water clarity is typically poorer in Indiana's lakes. Overall, water clarity is generally poor in McClures Lake compared to the median clarity measured in other Indiana lakes.

Total phosphorus concentrations have generally remained low within McClures Lake. Concentrations ranged from a high of 0.163 mg/L in 1991 to a low of 0.017 mg/L during 2007. It should be noted that the 2007 samples were collected from the lake's surface water only, while other samples were collected from both the surface (epilimnion) and bottom (hypolimnion) waters of the lake. Therefore, the 2007 samples likely underestimate the total phosphorus concentration present within the lake. Nonetheless, all samples collected from McClures Lake contain total phosphorus concentrations below the median concentration (0.17 mg/L) measured in Indiana lakes. As shown in Figure 93, total phosphorus concentrations measured in McClure Lake vary over time but generally remain low.

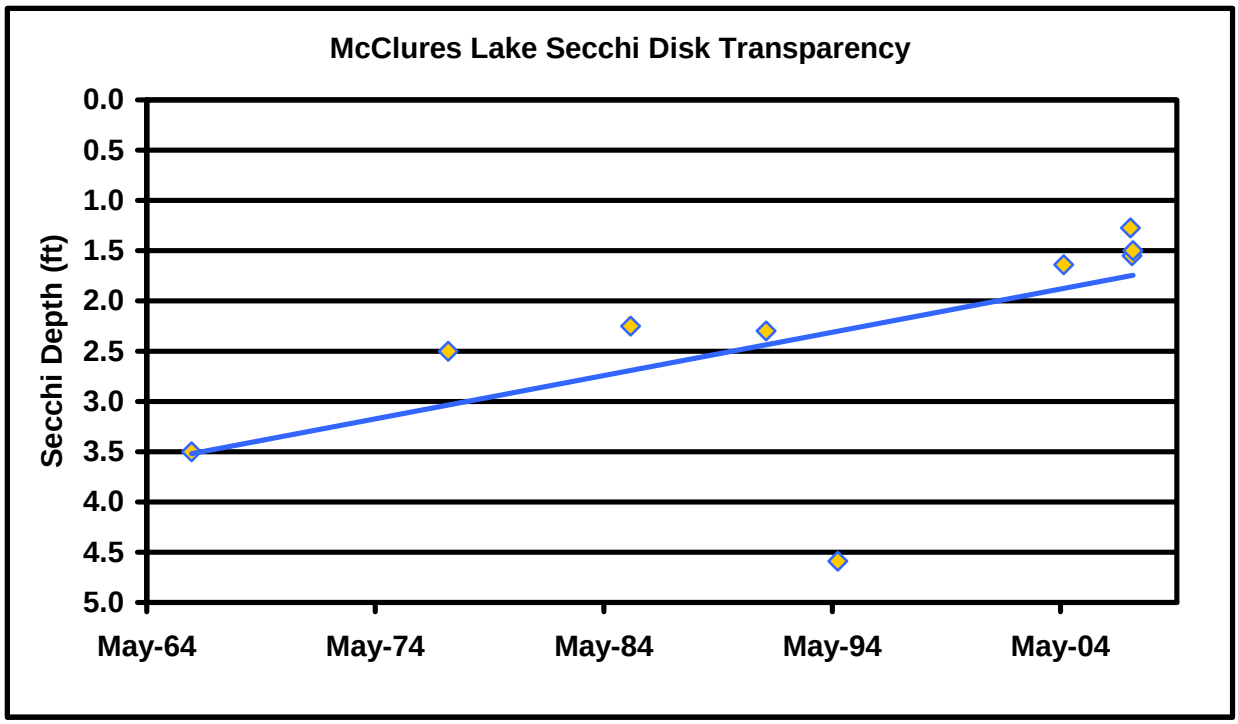


Figure 92. Historic Secchi disk transparency data for McClures Lake.
Source: Braun, 1986b; CLP, 1991, 1994, 2004; ISPCB, 1986; Lesko, 2007; McGinty, 1966e.

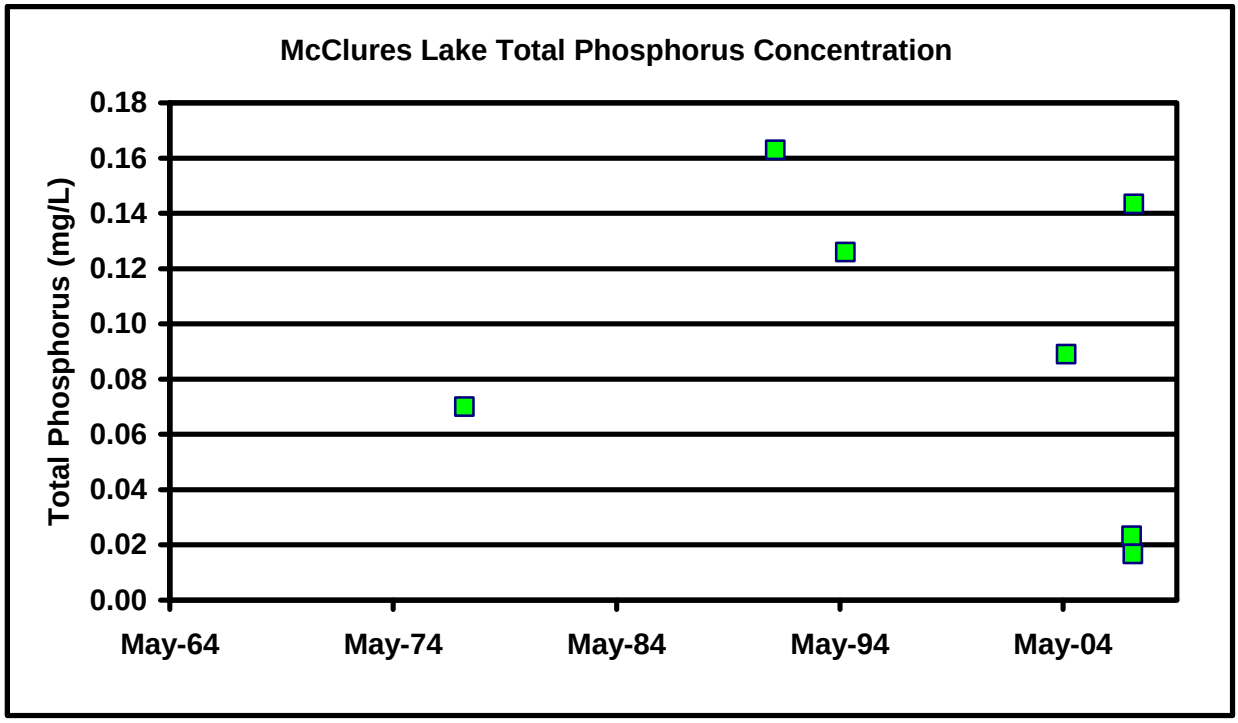


Figure 93. Historic total phosphorus concentrations measured in McClures Lake.
Source: CLP, 1991, 1994, 2004; ISPCB, 1986; Lesko, 2007.

There is not a significant trend in nutrient concentrations in McClures Lake (Figure 94). SRP concentrations are relatively low in McClure Lake with all concentrations measuring less than the median concentration (0.12 mg/L) for Indiana lakes. Conversely, nitrogen concentrations exceed the Indiana median concentrations by nearly double for McClures Lake; however, concentrations do appear to decline from historic to the most recent assessment. Total nitrogen concentrations decrease from 6.612 mg/L in 1991 to 3.465 mg/L in 2004. Ammonia-nitrogen and nitrate-nitrogen concentrations also decreased from 1991 to 2004. Concentrations were the lowest during the 1994 assessment; however, overall decreases in nitrate-nitrogen, ammonia-nitrogen, and total nitrogen were observed in McClures Lake from 1991 to 2004.

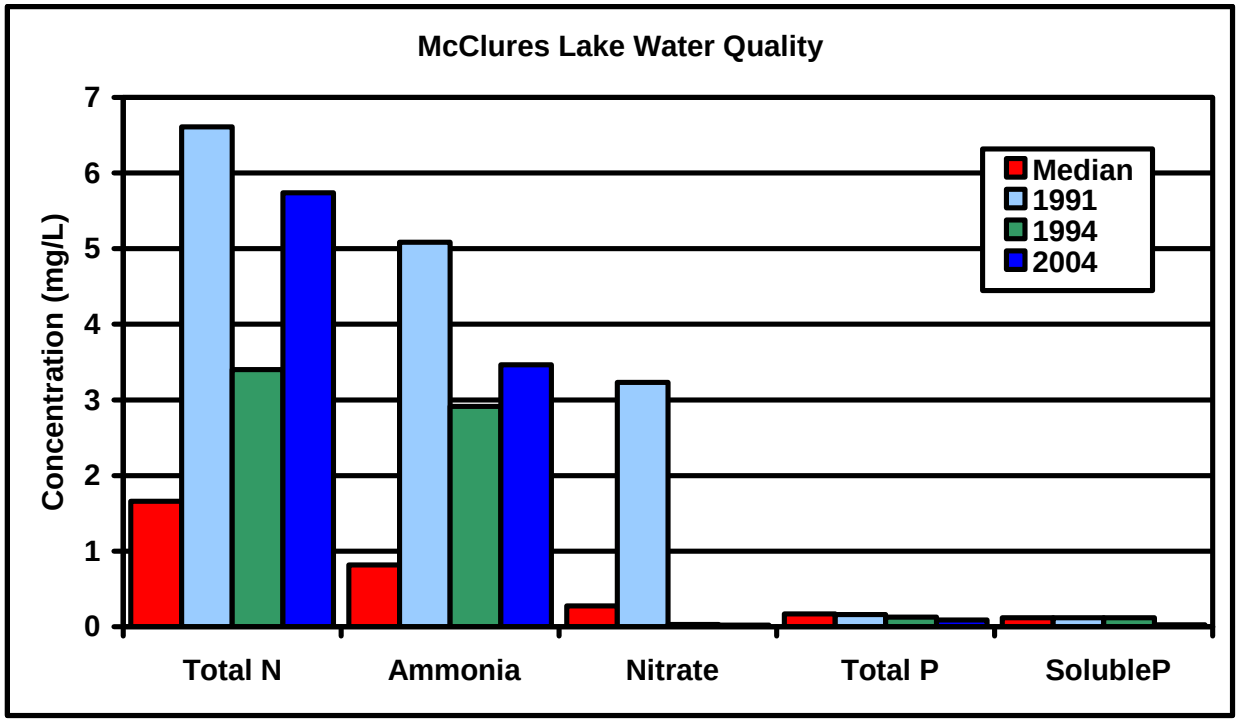


Figure 94. Variation in nutrient concentrations in McClures Lake, 1991 to 2004.
Source: CLP, 1991, 1998, 2004.

The lake's algae (plankton) density reflects the relatively moderate phosphorus levels typically present in McClures Lake. Nutrients (nitrogen and phosphorus) promote the growth of algae and/or rooted plant populations. Thus, lakes with high nutrient levels are expected to support dense algae and/or rooted plants. Plankton densities are relatively moderate within McClure Lake, reflecting the relatively moderate phosphorus concentrations present within the lake. Plankton densities ranged from 4,250/L in 1994 to 32,134/L in 2004. Chlorophyll *a* concentrations reflect the moderate plankton densities and low total phosphorus concentrations found in the lake. When plankton densities are low, chlorophyll *a* concentrations are also low. Conversely, when plankton densities are elevated, chlorophyll *a* concentrations are also elevated. Only during the highest plankton density does McClures Lake's chlorophyll *a* concentration exceed the median concentration measured in Indiana lakes (12.9 µg/L). The lake's overall ITSI scores reflect changes in the lake's plankton density. ITSI scores ranged from a high if 51 in 1977 to a low of 23 in 1994. The 2004 ITSI score of 40 reflects the productivity level suggested by the lake's plankton density. Overall, these scores suggest that the lake is mesotrophic (moderately productive) to eutrophic (productive).

A graph of the temperature profiles recorded during IDNR fisheries surveys and Indiana CLP assessments is shown in Figure 95. All of the temperature profiles show that McClures Lake was stratified at the time of the assessments. The developed hypolimnion (bottom water) present during the surveys is very typical of Indiana lakes. The metalimnion, or area of rapidly changing water temperature, typically extends from 4 feet (1.2 m) to approximately 22 feet (6.7 m). The epilimnion (surface water) is located above the metalimnion, while the hypolimnion (bottom water) is located below the metalimnion. Water within the epilimnion and hypolimnion are typically separated during the summer in stratified lakes and do not mix.

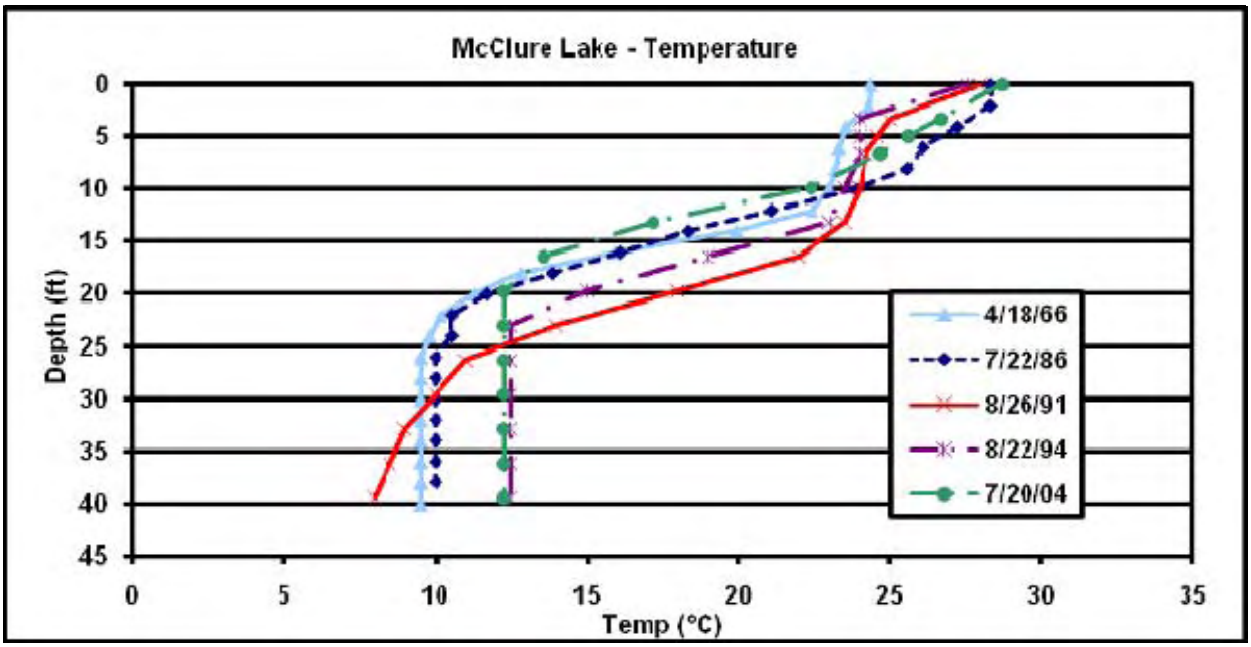


Figure 95. Historical temperature profiles for McClures Lake.
Source: Braun, 1986b; CLP, 1991, 1994, 2004; McGinty, 1966e.

While much of the data presented above suggest that McClures Lake is moderately productive, the historical percent oxic results (Table 66) and dissolved oxygen profiles (Figure 96) are more typical of a eutrophic (productive) lake. Dissolved oxygen data indicate that the lake possessed dissolved oxygen greater than 1 mg/L in less than 40% of the water column. This decline in dissolved oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments. Furthermore, the 2004 dissolved oxygen profile indicates a sharp increase in dissolved oxygen in the lake's metalimnion. This results in a positive-heterograde profile. Positive-heterograde profiles are characterized by a peak in oxygen concentration at a depth below the water surface, such as the peak in the 2004 profile beginning at 4 feet (1.6 m) below the water's surface. The peak is likely associated with a higher concentration in phytoplankton at that particular depth layer. Called a ***metalimnetic oxygen maximum***, the peak results when the rate of settling plankton slows in the denser waters of the metalimnion. At this depth, the plankton can take advantage of nutrients diffusing from the nutrient-enriched hypolimnion. As the plankton at this depth photosynthesize, they release oxygen into the water column, creating a peak in oxygen at that level.

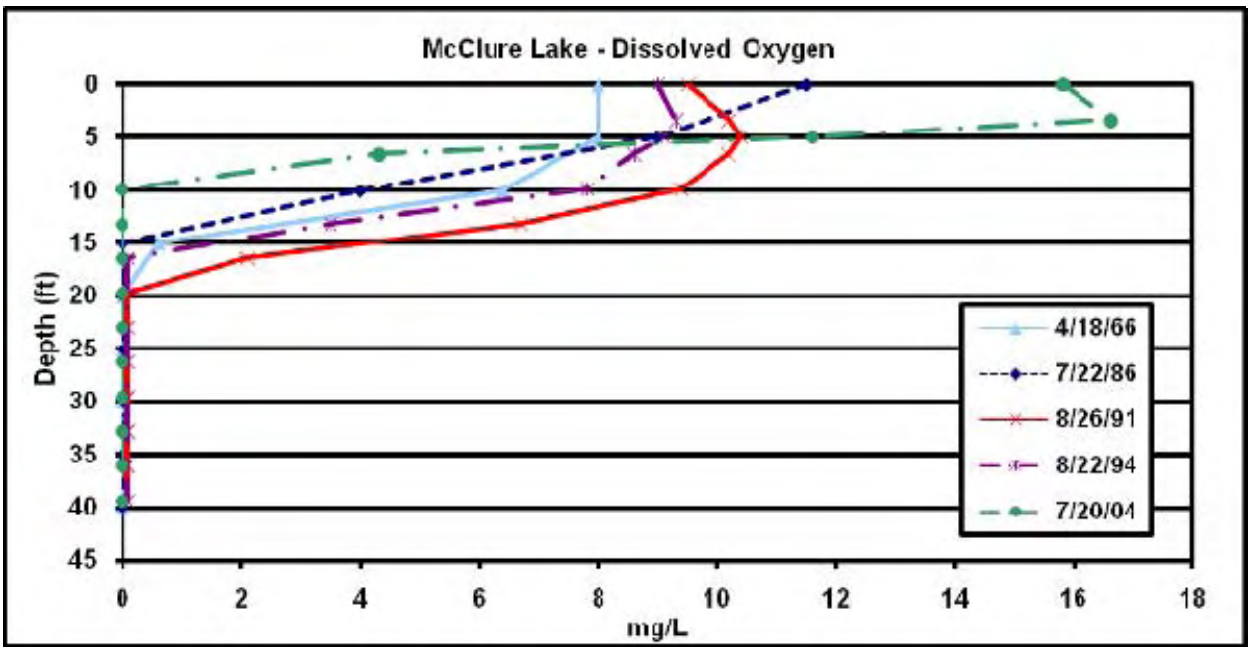


Figure 96. Historical dissolved oxygen profiles for McClures Lake.
Source: Braun, 1986b; CLP, 1991, 1994, 2004; McGinty, 1966e.

The lack of oxygen in the lake's water column likely reflects intense decomposition of plant material within McClures Lake during the summer months. Decomposition of plant material undoubtedly occurs in the lake's deeper waters, removing oxygen from the water column. Higher hypolimnetic ammonia concentrations suggest decomposition is occurring in the lake's bottom waters. This lack of oxygen poses a problem for the lake's inhabitants. Fish and other aquatic organisms require oxygen to live. The lack of oxygen in the lake's hypolimnion reduces the amount of habitat available to fish. Fortunately, most of the lake's volume has oxygen levels sufficient to support fish. Based on the depth-volume curve (Figure 84), approximately 93% of the lake's volume is oxygenated. (The percent oxic parameter measures the vertical percent, not volumetric percent, of the water column with oxygen.)

The lack of oxygen in McClures Lake's hypolimnion also affects the lake's chemistry. While mean total phosphorus concentrations are variable for the years 1966 through 2007, a more detailed evaluation shows that hypolimnetic total phosphorus concentrations are typically higher than epilimnetic total phosphorus concentrations. Further review of historical phosphorus data indicate that much of the total phosphorus was in the dissolved form of phosphorus (SRP). This indicates that McClures Lake was releasing phosphorus from its bottom sediments. McClures Lake exhibited higher hypolimnetic ammonia concentrations than in the epilimnion during all of the assessments, suggesting decomposition of organic matter was occurring in the lake's bottom waters. In fact, ammonia-nitrogen concentrations were typically an order of magnitude higher in McClures Lake's hypolimnion during historic assessments. Despite these high nitrogen concentrations, something other than nutrients may be limiting productivity within McClures Lake. Overall, these data suggest that McClures Lake was a moderately productive (mesotrophic) to productive (eutrophic) lake during the 1991, 1994, and 2004 assessments.

4.5.6 McClures Lake Water Budget

The watershed or drainage area of McClures Lake is approximately 614 acres. The mean annual watershed runoff volume calculated to drain into McClures Lake is 741 acre-feet per year. Comparing the runoff to a lake volume of 713 acre-feet, and factoring in evaporation and rainfall from and to the lake, results in a hydraulic residence time of approximately 11 months (Table 67). This residence time is about normal for Indiana Lakes.

Table 67. Water Budget Calculations for McClures Lake. (See Appendix A for a graphic model of model inputs and outputs**)**

Watershed	McClures Lake - Kosciusko Co.
Watershed size (ac)	614
Mean watershed runoff (ac-ft/yr)	741
Lake volume (ac-ft)	713
Closest gaged stream	Eel River @ N. Manchester
Stream watershed (mi^2)	417
Stream watershed (acres)	266880
Mean annual daily Q (cfs)	444.7
Mean annual total Q (ac-ft/yr)	321948
Mean ppt (in/yr)	37
Mean watershed ppt (ac-ft/yr)	822880
Watershed C	0.39125
Pan evaporation (in/yr)	41.80
Pan evaporation coefficient	0.70
Lake surface area (acres)	59
Estimated lake evaporation (ac-ft)	144
Direct precipitation to lake (ac-ft)	182
	= input data
	= output data
Water Budget Summary	
Direct precipitation to lake (ac-ft)	182
Runoff from watershed (ac-ft)	741
Evaporation (ac-ft)	144
TOTAL LAKE OUTPUT (ac-ft)	779
Hydraulic residence time (yr)	0.92

4.5.8 McClures Lake Current Water Quality Assessment

Temperature and oxygen profiles for McClures Lake show that the lake was stratified at the time of sampling (Figure 97). McClures Lake is supersaturated in the *epilimnion* (surface waters), with 122.50 % dissolved oxygen at 5 feet (1.5 m). Supersaturated dissolved oxygen is usually symptomatic of intense phytoplankton photosynthesis. McClures Lake reached anoxic ([D.O.] < 1.0 mg/L) conditions below 6.5 feet (2 m) where little oxygen was available to support fish and other aquatic life. During thermal stratification, the bottom waters (*hypolimnion*) of the lake are isolated from the well-mixed epilimnion by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth is

called the *metalimnion*. At the time of our sampling, the epilimnion was confined to the upper 6.5 feet (2 m) of water. The decline in temperature from 6.5 to 16.5 feet (2 to 5 m) defines the metalimnion or transition zone. The hypolimnion occupied water deeper than 16.5 feet (5 m).

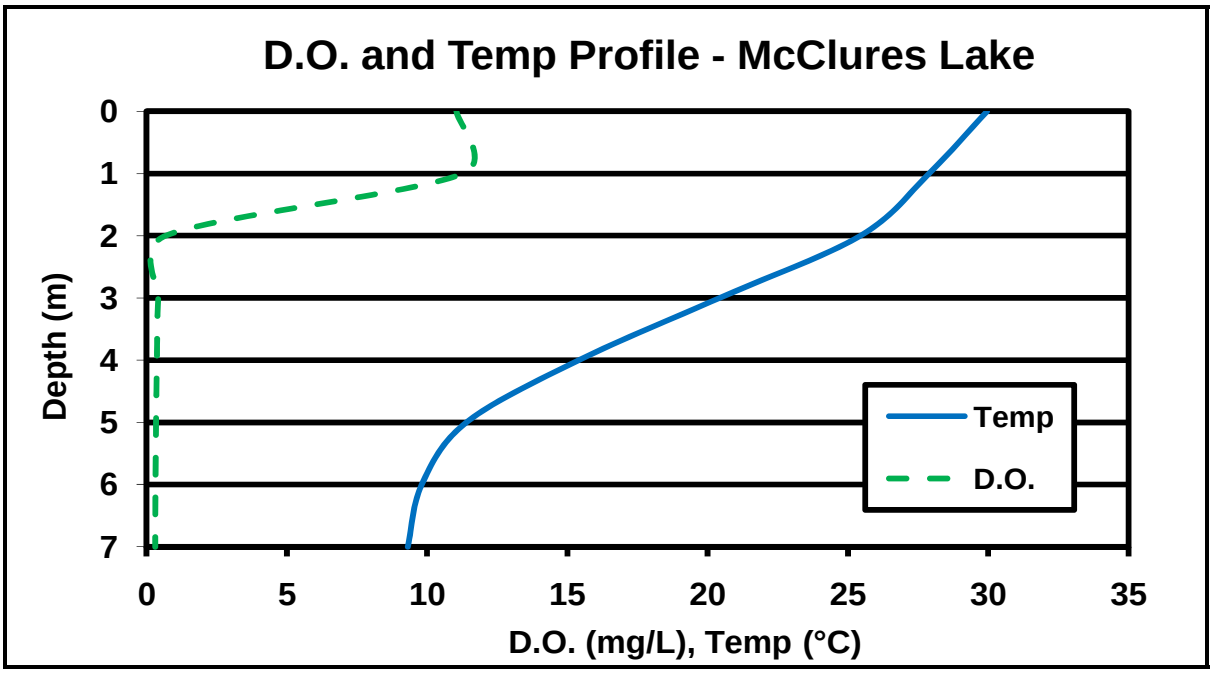


Figure 97. Temperature and dissolved oxygen profiles for McClures Lake on July 17, 2008.

The 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to 4.2 ft (1.3 m). Based on the depth-area curve in Figure 84 approximately 29.2 % of lake bottom (approximately 17.5 acres or 7 ha) is shallower than 4.2 ft. This represents the area of the lake bottom with sufficient light to support rooted plants. This area is called the *littoral zone*. Furthermore, based on the depth-volume curve (Figure 85), we see that a volume of greater than 150 acre-feet of McClures Lake (21% of total lake volume) lies above the 4.2-foot 1% light level. This area, referred to as the *photic zone*, represents the amount of water with sufficient light to support algae growth.

Phosphorus and nitrogen are the primary plant nutrients in lakes. Phosphorus concentrations were lower in the epilimnion (0.084 mg/L) of McClures Lake but were higher (0.227 mg/L) in the hypolimnion (Table 68). Higher phosphorus concentrations within the hypolimnion are usually associated with nutrient release from the sediments under these anoxic conditions. Sedimentation of particulates and plankton also provide a source of phosphorus to the hypolimnion. Both concentrations exceeded 0.03 mg/L, which is sufficient to cause eutrophic conditions.

Table 68. Water Quality Characteristics of McClures Lake from sampling conducted on July 17, 2008.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	9.0	7.3	-
Alkalinity	140 mg/L	236 mg/L	-
Conductivity	358 µS/m	533 µS/m	-
Secchi depth	0.45m	-	6
Light Transmission @ 3 ft	2.5%	-	4
1% Light level	4.2 ft	-	-
Total Phosphorus	0.084 mg/L	0.227 mg/L	4
Soluble Reactive Phosphorus	0.010* mg/L	0.171 mg/L	3
NO_3	0.013* mg/L	0.013* mg/L	0
NH_4	0.133 mg/L	6.952 mg/L	4
TKN	2.015 mg/L	7.630 mg/L	3
Oxygen Saturation @ 5 ft.	122.5%	-	0
% Water column oxic	55.5%	-	4
Plankton Density	14,443 N.U./L	-	2
Blue-Green Dominance	87.8%	-	10
Chl-a	53.72 µg/L	-	-
		TSI Score	**40**

*Method Detection Limit

Nitrate nitrogen (NO_3) was at the detection limits (0.013 mg/L) of our analytical methods in the epilimnion and hypolimnion. Nitrate is used by growing algae and can be reduced to ammonia (NH_4) when oxygen is low. The high hypolimnetic ammonia concentrations measured (6.952 mg/L) indicate the presence of a high biochemical oxygen demand (BOD) and low dissolved oxygen levels to produce and maintain these relatively high concentrations.

Values for pH were within the normal range for Indiana lakes, pH 9.0 for the epilimnion and pH 7.3 for the hypolimnion. pH values for most fresh waters fall between pH 6-9 (Kalff, 2002). The high alkalinity values of 140 mg/L and 236 mg/L, for the epilimnion and hypolimnion, indicate that McClures Lake is a well buffered system.

Plankton enumerated from the sample collected from McClures Lake are shown in Table 69. *Oscillatoria*, a blue-green alga, was the most dominant genera found, and accounted for almost half the plankton density. In addition to this particular blue-green alga, other blue-green species contributed to the overall plankton dominance by blue-greens of 87.8%. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor

problems; and 3) are unpalatable as food for many zooplankton grazers. This blue-green dominance is the primary reason for the higher TSI score in 2008. The concentration of chlorophyll a (the primary pigment of algae) was a very high 53.7 µg/L, which further illustrates the excessive algae we found in this lake.

Table 69. The plankton sample representing the species assemblage in McCLures Lake on July 17, 2008.

SPECIES	ABUNDANCE (N.U./L)
Blue-Green Algae (Cyanophyta)	
Oscillatoria	10242
Aphanizomenon	2138
Merismopedia	199
Microcystis	50
Chroococcus	50
Green Algae (Chlorophyta)	
Polyedriopsis	99
Desmodesmus	50
Scenedesmus	50
Diatoms (Bacillariophyta)	
Synedra	1243
Other Algae	
Ceratium	99
Zooplankton	
Nauplius	18.3
Cyclopoid Copepod	4.2
Calanoid Copepod	2.8

4.6 Yellow Creek Lake

4.6.1 Morphology

Yellow Creek Lake's morphology is moderately complex (Figure 98). The lake consists of two deep holes surrounded by shallower water. The lake's deepest point lies in the western portion of the 151-acre (61.1-ha) lake. Here, the lake extends to it maximum depth of 67 feet (20.4 m; Table 70). One shallower, but much larger, hole lies in the center of the lake and reaches a maximum depth of 60 feet (18.3 m). Yellow Creek Lake is the deepest of the lakes in the Yellow Creek watershed.

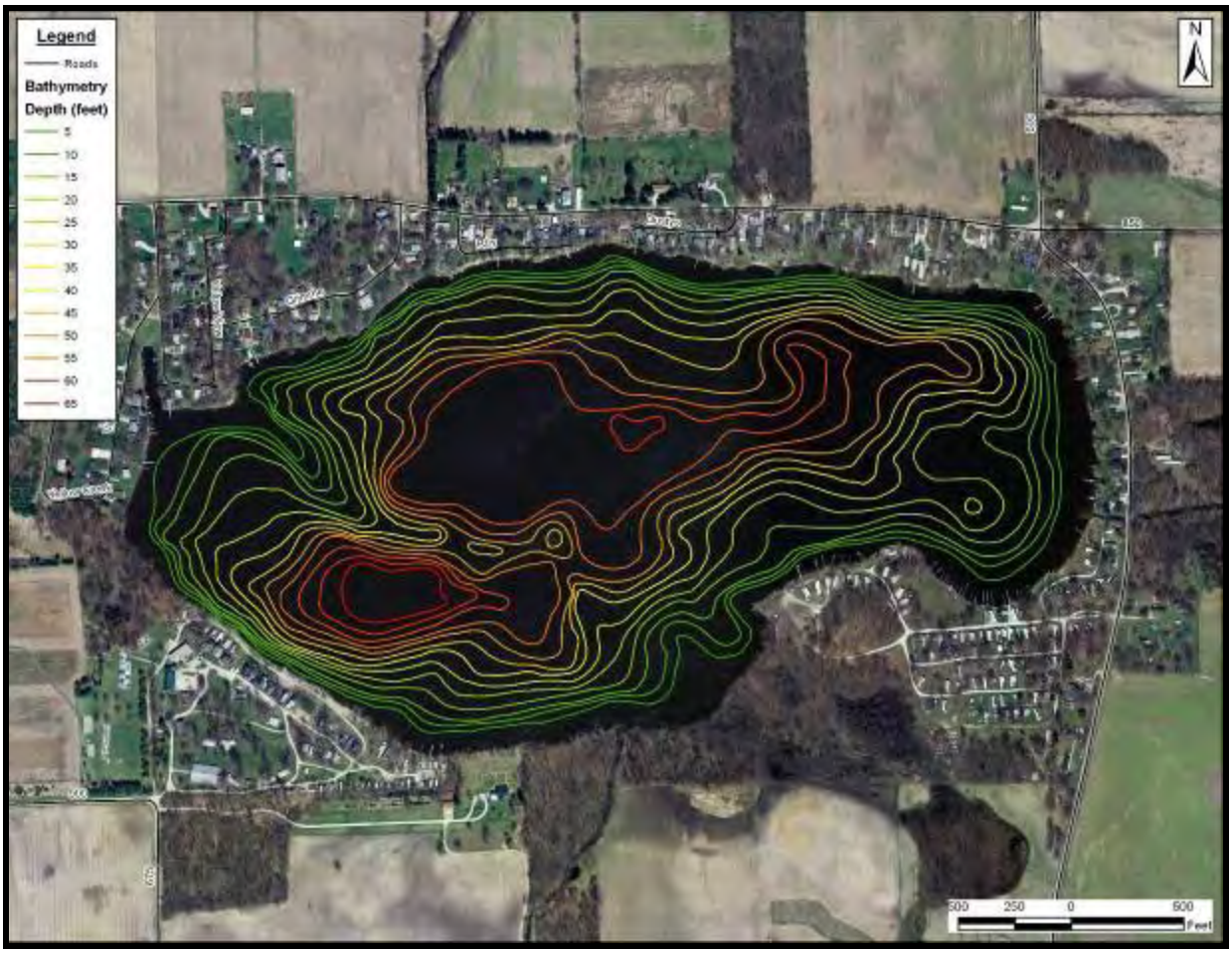


Figure 98. Yellow Creek Lake bathymetric map. Source: Kosciusko County GIS Department, digitized from 1956 IDNR contour maps.

Table 70. Morphological characteristics of Yellow Creek Lake.

Characteristic	Value
Surface Area	151 acres (61.1 ha)
Volume	4,772 acre-feet (5,886,601 m^3)
Maximum Depth	67 feet (20.4 m)
Mean Depth	31.6 feet (9.6 m)
Shallowness Ratio	0.12
Shoalness Ratio	0.27
Shoreline Length	12,096 feet (3,687 m)
Shoreline Development Ratio	1.33

Yellow Creek Lake possesses limited expanses of shallow water. According to its depth-area curve (Figure 99), nearly 20 acres (6.1 ha) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 42 acres (17 ha) is covered by water less than 20 feet (6.1 m) deep. This translates into a very low shallowness ratio of 0.12 (ratio of area less than 5 feet (1.5 m) deep to total lake area) and a moderate shoalness ratio of 0.27 (ratio of area less than 20 feet (6.1 m) deep to total lake area), as defined by Wagner (1990). The lake's area gradually increases to a water depth of about 10 feet (3.1 m). Between 10 and 15 feet (3.1 and 4.6 m) relatively little

change in area occurs. At 15 feet (4.6 m), the rate of change continues as in the shallow portion of the lake to a depth of 60 feet (18.3 m) before the rate of change increases. This rate (slope of lake bottom) continues to the lakes maximum depth (67 feet or 20.4 m).

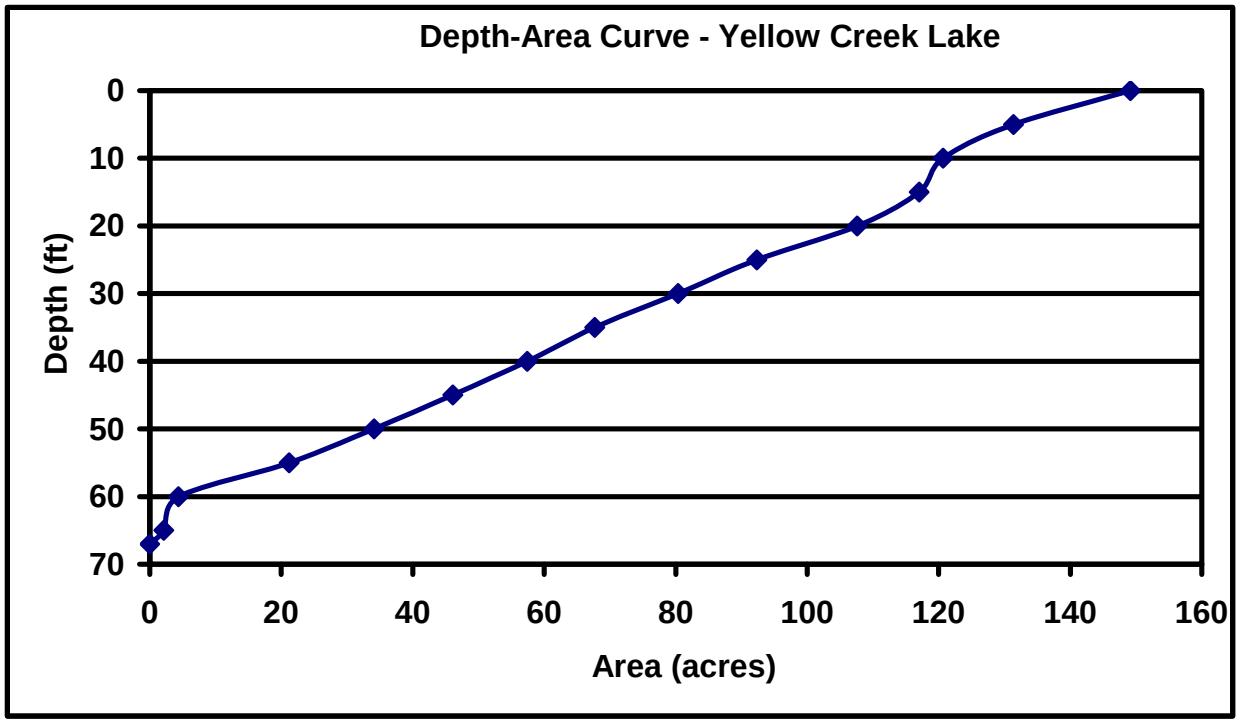


Figure 99. Depth-area curve for Yellow Creek Lake.

Yellow Creek Lake holds approximately 4,772 acre-feet (5,886,601 m^3) of water, the largest volume of water held by Yellow Creek watershed lakes. As illustrated in the depth-volume curve (Figure 100), most of the lake's volume is contained in the shallower areas of the lake. More than 85% of the lake's volume is contained in water that is less than 35 feet (10.7 m) deep. The lake's volume gradually increases to a water depth of about 50 feet (15.2 m) before the rate of change increases. Below 50 feet (15.2 m), the steep curve indicates a greater change in depth per unit volume. This rate continues to the lakes maximum depth (67 feet or 20.4 m). The importance of this rate of increase will be discussed with regard to light penetration and the planktonic community in the Results Section.

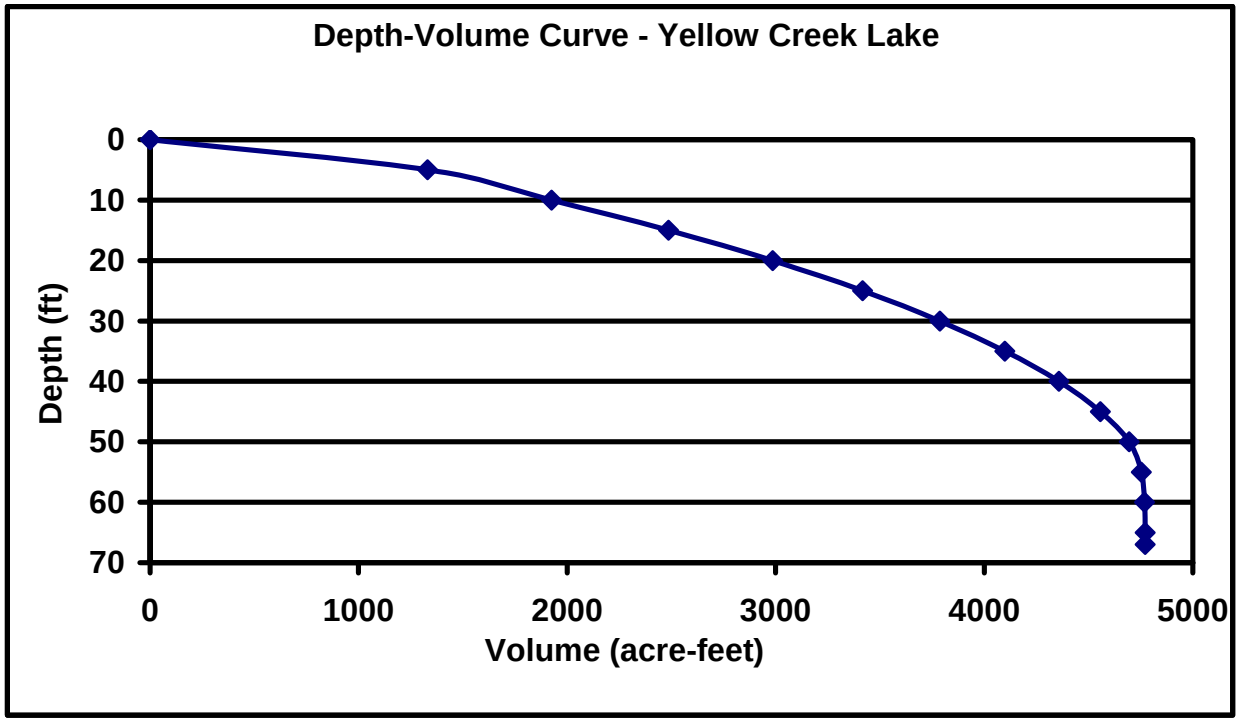


Figure 100. Depth-volume curve for Yellow Creek Lake.

A lake's morphology can play a role in shaping the lake's biotic communities. For example, Yellow Creek Lake's moderately sized shallow area and shallow shelf around much of the perimeter of the lake coupled with its moderate clarity suggests the lake is capable of supporting a quality rooted plant community. Based on the lake's clarity, Yellow Creek Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the point where water depths are approximately 12.6 feet (3.8 m). Referring to Yellow Creek Lake's depth-area curve, this means that the lake's littoral zone is approximately 30 acres (12.1 ha) in size or approximately 20% of the lake. This size littoral zone can impact other biotic communities in the lake such as fish that use the plant community for forage, spawning, cover, and resting habitat.

A lake's morphology can indirectly influence water quality by shaping the human communities around the lake. The shoreline development ratio is a measure of the development potential of a lake. It is calculated by dividing a lake's shoreline length by the circumference of a circle that has the same area as the lake. A perfectly circular lake with the same area as Yellow Creek Lake (151 acres or 61.1 ha) would have a circumference of 9,091 feet (2,771 m). Dividing Yellow Creek Lake's shoreline length (12,096 feet or 3,687 m) by 9,091 feet yields a ratio of 1.33:1. This ratio is relatively low and, along with Loon and McClures lakes, is one of the lowest shoreline development ratios calculated for Yellow Creek watershed lakes. Yellow Creek Lake lacks extensive shoreline channeling observed on other popular Indiana lakes. This lack of channeling results in less development and therefore, less pollutant loading on the lake.

4.6.2 Yellow Creek Lake Shoreline Development

Development around Yellow Creek Lake began in the early 1900's and by 1964 approximately 125 cottages and 164 trailers were located along the lake's shoreline (McGinty, 1967). McGinty noted that most of the trailers were located in a single, large trailer park at the lake's southeast corner and that additional clearing of the shoreline and surrounding area was occurring to

increase the footprint of the park. In 1964, a large private beach for the Church of Christ campground was also present along the lake's southern shoreline. Biologists counted 231 boats, 23 pontoons, and 16 rafts (McGinty, 1966e). Most of the houses were scattered around the lake with the exception of the southern shoreline, which remained largely undeveloped. Over the next 30 years, development around the shores of Yellow Creek Lake increased. Residential and boat densities increased and nearly 80% of the shoreline had been developed at the time of the IDNR 1972 survey (Pearson, 1973).

Figure 101. Shoreline survey of Yellow Creek Lake, Kosciusko County, IN, August 27, 2007.

During this study it was calculated that nearly 85% of the shoreline is developed for residential or commercial (camp) uses (Figure 101). Approximately half of the developed shoreline (43%) has been significantly modified (Figure 102), while the remainder of the developed shoreline is classified as modified natural.

Figure 102. Modified shoreline present along Yellow Creek Lake's southern shoreline.

Modified natural areas remain scattered around the lake and total approximately 40% of the shoreline (Figure 103). These areas are mapped as modified natural shoreline because they still possess at least some portion of submergent, emergent, or floating vegetation.

Figure 103. Modified natural shoreline present within Yellow Creek Lake. Note that vegetation was removed in areas required to place the dock for access to the lake. The remaining vegetation along the shoreline acts as a natural buffer.

Natural shoreline remains along approximately 8% of Yellow Creek Lake's shoreline where bands of plants like those described by McGinty (1967) are present with trees, emergent vegetation, floating vegetation, and submergent vegetation located in distinct zones along the lakeshore (Figure 104). In these areas, the submergent, floating, emergent, and shoreline canopy layers all remain intact. However, the 1,400 foot long (426 m) natural area along the south shoreline is experiencing erosion at an abnormal rate with trees continuing to tip over along the shoreline (David Patterson, Personal Communication). This erosion may be due to increased boat traffic on the lake (it is on the leeward side of the lake and thus is not subject to frequent wind driven waves). Ice damage may be another possible explanation. Either way, it is likely possible to restore a healthy native vegetative community and reduce the erosion rate.

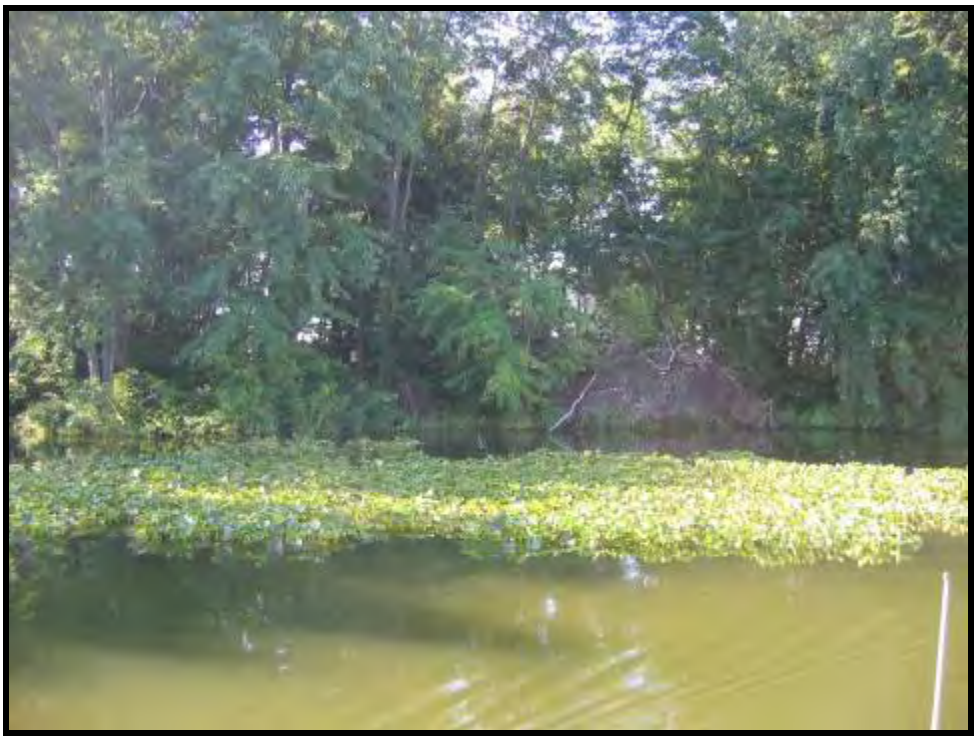


Figure 104. Natural shoreline present along Yellow Creek Lake's southern shoreline.

4.6.3 Yellow Creek Lake Aquatic Macrophyte Assessment

Changes in a lake's rooted plant communities over time can illustrate unseen chemical changes in the lake. Unfortunately, limited data detailing Yellow Creek Lake's historical rooted plant community exist for comparison to the current data. In the past, IDNR fisheries biologists conducted cursory vegetation surveys as a part of their general fisheries surveys. Historical studies recorded many of the same species that currently dominate Yellow Creek Lake. In 1965, McGinty (1966f) noted the presence of 10 emergent species and 13 submergent species. McGinty noted the abundance and variety of pondweed species, including leafy, Illinois, fine-leaf, sago, floating-leaf, and clasping-leaf pondweeds. Further notation of the abundance of submergent vegetation and problematic density of pondweeds and coontail was noted during this survey. By 1969, the aquatic plant community within Yellow Creek Lake changed significantly. Nine submergent and emergent species were identified during the survey (Hudson, 1970). Both the predominance of Eurasian watermilfoil (to a depth of 7 feet) and extensive algal blooms were noted during this survey. Hudson (1970) recommended implementation of a vegetation control program to bring watermilfoil and filamentous algae under control. By 1977, submergent vegetation was limited to two species, Eurasian watermilfoil and leafy pondweed, and the notation that no control should be enacted except for access around docks and beaches was made. No surveys of the plant community occurred between 1977 and the most recent assessment (2007).

JFNew surveyed Yellow Creek Lake for aquatic macrophytes on August 27, 2007. Yellow Creek Lake supports a good rooted aquatic plant community. The community extends from the lake's shoreline to water that is just over 7 feet (2.3 m) deep. In total, 31 aquatic plant species inhabit the water and shoreline of Yellow Creek Lake (Table 71). The LARE protocol used to conduct the aquatic plant survey requires surveyors to note all plant species observed from a boat. Thus, plants in the wetland complexes adjacent to the lake were only counted if they were

visible from the boat. If these wetland complexes had been explored in greater detail, it is likely that the total number of plant species would increase significantly.

Table 71. Plant species observed in Yellow Creek Lake as identified on August 27, 2007.

Scientific Name	Common Name	Stratum
Asclepias incarnata	Swamp milkweed	Emergent
Ceratophyllum demersum	Coontail	Submergent
Chara species	Musk grass species	Submergent
Decodon verticillatus	Whorled loosestrife	Emergent
Filamentous algae	Filamentous algae	Algae
Hibiscus species	Hibiscus species	Emergent
Impatiens capensis	Jewel weed	Emergent
Iris virginica	Blue-flag iris	Emergent
Lemna minor	Common duckweed	Floating
Lythrum salicaria	Purple loosestrife	Emergent
Myriophyllum exalbescens	Northern watermilfoil	Submergent
Myriophyllum heterophyllum	Various-leaf water milfoil	Submergent
Myriophyllum spicatum	Eurasian watermilfoil	Submergent
Najas guadalupensis	Southern naiad	Submergent
Nuphar advena	Spatterdock	Floating
Nymphaea tuberosa	White water lily	Floating
Polygonum amphibium stipulaceum	Water knotweed	Emergent
Polygonum coccineum	Water heartsease	Emergent
Polygonum lapathifolium	Willow-weed	Emergent
Potamogeton amplifolius	Large-leaf pondweed	Submergent
Potamogeton berchtoldii	Broad-leaf small pondweed	Submergent
Potamogeton illinoensis	Illinois pondweed	Submergent
Potamogeton praelongus	White-stem pondweed	Submergent
Scirpus acutus	Hard-stem bulrush	Emergent
Scirpus pungens	Chairmaker's rush	Emergent
Sparganium eurycarpum	Giant burred	Emergent
Stuckenia pectinatus	Sago pondweed	Submergent
Typha x *glauca*	Blue cattail	Emergent
Typha latifolia	Broad-leaf cattail	Emergent
Vallisneria americana	Eel grass	Submergent
Wolffia columbiana	Columbia watermeal	Floating

Yellow Creek Lake's rooted plant communities highlight the differences among various areas of the lake. For example, rooted plant beds inhabiting water in front of developed portions of the lake generally had lower submergent species diversity than rooted plant beds in front of undeveloped portions of the lake. This lack of diversity may be due to efforts to remove (either mechanically or chemically) submergent plants to improve access to and recreational use of the lake. Alternatively, submergent plants in the developed areas may be subjected to more damage from boat propellers or wash from speeding boats. These pressures may prevent more sensitive species from becoming established in front of developed shoreline.

Of the 31 species observed in Yellow Creek Lake, one was an algae, four were floating leaved, 14 were emergent, and 12 were submergent plant species. Of the twelve submergent species,

nearly all of those are adapted to high nutrient environments. Five of the submergent species were pondweeds (i.e. belonging to the *Potamogeton* genus), which are typically adapted to better water quality conditions. Sago pondweed, northern watermilfoil, and Eurasian watermilfoil dominated the submergent plant community and were observed throughout the lake. Two exotic species, including Eurasian watermilfoil and purple loosestrife, were identified within or adjacent to Yellow Creek Lake. Purple loosestrife and reed canary grass were the most common emergent species. The most common floating leaved species were spatterdock and duckweed.

During the Tier II survey, Eurasian watermilfoil, sago pondweed, and northern watermilfoil dominated the plant community over all sampled depths (0-10 feet; Table 72.) These species were found at the highest percentage of sites throughout the entire sampled water column (13.7%). Other species were somewhat frequent with southern naiad and coontail present at 9.8% of the sites. With regards to dominance, Eurasian watermilfoil, coontail, northern watermilfoil, and sago pondweed dominated the submergent plant community throughout the entire sampled water column with a dominance of 3.5. (A dominance of 250 represents a perfect score or the highest dominance possible within Yellow Creek Lake. This results from multiplying the highest density score (5) by the number of sites where plants were sampled (50). Dominance scores are reported as percentages of this maximum.) All other species were relatively sparse throughout the water column, with Illinois pondweed possessing a dominance of 3.1. All other species had dominances less than 2. Filamentous algae were also present at 13.7% of sites; however, densities are not assigned to this species.

Table 72. Frequency and dominance of submergent aquatic plant species identified during the Tier II survey of Yellow Creek Lake conducted August 27, 2007.

Occurrence and abundance of submersed aquatic plant species in Yellow Creek Lake.					
Total Sites:	51	Mean species / site:	0.90	Native diversity:	0.88
Littoral Sites:	33	Maximum species / site:	5	Species diversity:	0.89
Littoral Depth (ft):	7	Number of species:	12	SE Mean natives / site:	0.18
Date:	8/27/2007	Littoral sites with plants:	19	Mean natives / site:	0.76
Lake:	Yellow Creek	Secchi(ft):	4.2	SE Mean species / site:	0.20

All depths (0-10')		Frequency of	Frequency per Species				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Myriophyllum spicatum	Eurasian watermilfoil	13.73	86.27	11.76	1.96	0.00	3.53
Stuckenia pectinatus	Sago pondweed	13.73	86.27	11.76	1.96	0.00	3.53
Myriophyllum exalbescens	Northern watermilfoil	13.73	86.27	11.76	1.96	0.00	3.53
Najas guadalupensis	Southern naiad	9.80	90.20	9.80	0.00	0.00	1.96
Ceratophyllum demersum	Coontail	9.80	90.20	5.88	3.92	0.00	3.53
Potamogeton illinoensis	Illinois pondweed	7.84	92.16	3.92	3.92	0.00	3.14
Vallisneria americana	Eel grass	5.88	94.12	5.88	0.00	0.00	1.18
Potamogeton praelongus	White-stem pondweed	5.88	94.12	5.88	0.00	0.00	1.18
Chara species	Musk grass species	3.92	96.08	1.96	1.96	0.00	1.57
Potamogeton berchtoldii	Broad-leaf small pondweed	1.96	98.04	1.96	0.00	0.00	0.39
Potamogeton amplifolius	Large-leaf pondweed	1.96	98.04	1.96	0.00	0.00	0.39
Myriophyllum heterophyllum	Various-leaf water milfoil	1.96	98.04	1.96	0.00	0.00	0.39
Filamentous algae	Filamentous algae	13.73					
0-5' Stratum		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Myriophyllum spicatum	Eurasian watermilfoil	24.00	76.00	20.00	4.00	0.00	6.40
Stuckenia pectinatus	Sago pondweed	24.00	76.00	20.00	4.00	0.00	6.40
Myriophyllum exalbescens	Northern watermilfoil	20.00	80.00	16.00	4.00	0.00	5.60
Potamogeton illinoensis	Illinois pondweed	16.00	84.00	8.00	8.00	0.00	6.40
Najas guadalupensis	Southern naiad	16.00	84.00	16.00	0.00	0.00	3.20
Ceratophyllum demersum	Coontail	16.00	84.00	12.00	4.00	0.00	4.80
Potamogeton praelongus	White-stem pondweed	12.00	88.00	12.00	0.00	0.00	2.40
Chara species	Musk grass species	8.00	92.00	4.00	4.00	0.00	3.20
Vallisneria americana	Eel grass	8.00	92.00	8.00	0.00	0.00	1.60
Potamogeton berchtoldii	Broad-leaf small pondweed	4.00	96.00	4.00	0.00	0.00	0.80
Potamogeton amplifolius	Large-leaf pondweed	4.00	96.00	4.00	0.00	0.00	0.80
Myriophyllum heterophyllum	Various-leaf water milfoil	4.00	96.00	4.00	0.00	0.00	0.80
Filamentous algae	Filamentous algae	16.00					
5-10' Stratum		**Frequency of**	**Frequency per Species**				
Scientific Name	**Common Name**	**Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Myriophyllum exalbescens	Northern watermilfoil	9.52	90.48	9.52	0.00	0.00	1.90
Myriophyllum spicatum	Eurasian watermilfoil	4.76	95.24	4.76	0.00	0.00	0.95
Stuckenia pectinatus	Sago pondweed	4.76	95.24	4.76	0.00	0.00	0.95
Najas guadalupensis	Southern naiad	4.76	95.24	4.76	0.00	0.00	0.95
Vallisneria americana	Eel grass	4.76	95.24	4.76	0.00	0.00	0.95
Ceratophyllum demersum	Coontail	4.76	95.24	0.00	4.76	0.00	2.86
Filamentous algae	Filamentous algae	14.29					

Eurasian watermilfoil and sago pondweed also dominated the submergent plant community in the 0-5 foot stratum. Eurasian watermilfoil and sago pondweed were the most frequent species as they were each found at 24% of the sites in the 0-5 foot stratum. Eurasian watermilfoil and sago pondweed generated the highest dominance rating (6.4) in the 0-5 foot stratum. In this same stratum, northern watermilfoil was identified at 20% of the sites and scored a dominance of 5.6. Illinois pondweed, southern naiad, and coontail were found at 16% of the sites in the 0-5 foot stratum and possessed a dominance of 6.4, 3.2, and 4.8, respectively. White-stem pondweed was found at only 12% of the sites in the 0-5 foot stratum and possessed a

dominance of 2.4. Musk grass was found at only 8% of the sites in the 0-5 foot stratum, but possessed a dominance of 3.2. All other species were relatively infrequent occurring at less than 8% of sites and possessing dominances of 2.0 or less. Northern watermilfoil was the most dominant species in the 5-10 foot stratum. This species was found at 9.5% of the sites and measured a dominance of 1.9 in the 5-10 foot stratum. Coontail was found at only 4.8% of the sites, but scored dominance of 2.9. All the other species found in the 5-10 foot stratum were found at 4.8% or less of the sites and all scored a dominance of less than 0.95. Filamentous algae were found at 14% of the sites in the 5-10 foot stratum. As previously mentioned, one exotic submergent species was identified within Yellow Creek Lake during the assessment; Eurasian watermilfoil was identified at 13.7% of sampled sites throughout the lake (Figure 105).

Although they have not yet reached the levels observed on many other regional lakes, several nuisance and/or exotic aquatic plant species grow in and adjacent to Yellow Creek Lake. The plant survey revealed the presence of only one submergent, aggressive exotic: Eurasian watermilfoil. Although not identified during the current survey, historic assessments indicate the presence of another submergent, aggressive, exotic species, curly-leaf pondweed in Yellow Creek Lake. The recent survey also documented one emergent exotic plant species: purple loosestrife. These species will continue to proliferate if unmanaged, so data collected during the plant survey will be outdated quickly and should not be used to precisely locate individuals. It is also possible that these or other exotic species could exist within the thick emergent portions of the rooted plant community near the east and west ends of the lake; however, they were not observed during this survey.

Figure 105. Location of sample points and the location/density of Eurasian watermilfoil identified in Yellow Creek Lake during the August 28, 2007 Tier II survey

Yellow Creek Lake's rooted plant community reflects the lake's clarity. Despite the relatively poor water clarity, Yellow Creek Lake contains a mix of species that thrive in clear water, including four pondweed species (Davis and Brinson, 1980; Borman et al., 1997; Curtis, 1998). However, Yellow Creek Lake also has a variety of plants that are very tolerant of lower light conditions such as coontail, Eurasian watermilfoil, and southern naiad, which are ubiquitous in northeastern lakes.

4.6.4 Yellow Creek Lake Fisheries Summary

Introduction

The IDNR initially surveyed Yellow Creek Lake in 1965. Subsequent general fish surveys occurred in 1965, 1967, 1969, 1977, and 1986 (Table 73). Yellow Creek Lake is connected to five other lakes: Hill and Diamond Lake, via the Michaels Arm of Swick-Meredith Drain and to Beaver Dam, Loon, and McClure Lake via the Meredith Arm of Swick-Meredith Drain. As a result, the fish community in Yellow Creek Lake is influenced by fish communities present in the five other lakes. Braun (1986) suggested Yellow Creek Lake could benefit from a renovation effort to reduce the abundance of gizzard shad, rough fish, and small bluegills. However, Braun (1986) concluded that due to the connection of Yellow Creek Lake to the five other lakes and an insufficient drop from the top of the outlet dam to the outlet water level, the re-entry of undesirable fish species would contaminate Yellow Creek Lake eventually. To control the fish community composition within Yellow Creek Lake a fisheries management plan would have to

be developed that involved all six lakes. The changes to the community composition of Yellow Creek Lake over time are shown is Figure 106.

Table 73. Summary Table of IDNR Fish Surveys in Yellow Creek Lake, Indiana.

Common Name	Scientific Name	1965	1967	1969	1977	1986
Sunfish Family						
Bluegill	*Lepomis macrochirus*	X	X	X	X	X
Black Crappie	*Pomoxis nigromaculatus*	X	X		X	X
Green Sunfish	*Lepomis cyanellus*	X		X	X	X
Hybrid Sunfish			X			
Largemouth Bass	*Micropterus salmoides*	X	X	X	X	X
Longear Sunfish	*Lepomis megalotus*	X	X	X	X	X
Pumpkinseed	*Lepomis gibbosus*	X	X	X	X	X
Redear Sunfish	*Lepomis microlophus*	X	X	X	X	
Rock Bass	*Ambloplites rupestris*	X	X	X		
Warmouth	*Lepomis gulosus*	X	X	X	X	X
White Crappie	*Pomoxis annularis*	X	X		X	
Catfish Family						
Black Bullhead	*Ameiurus melas*				X	X
Brown Bullhead	*Ameiurus nebulosus*	X		X	X	X
Channel Catfish	*Ictalurus punctatus*	X				X
Yellow Bullhead	*Ameiurus natalis*	X			X	X
Minnow Family						
Common Carp	*Cyprinus carpio*	X	X	X	X	X
Golden Shiner	*Notemigonus crysoleucas*	X	X	X	X	X
Sucker Family						
Golden Redhorse	*Moxostoma erythrurum*	X				
Lake Chubsucker	*Erimyzon sucetta*	X	X	X	X	X
Northern Hog Sucker	*Hypentelium nigricans*				X	
Quillback	*Carpiodes cyprinus*		X	X	X	
Spotted sucker	*Minytrema melanops*	X	X	X	X	X
White Sucker	*Catostomus commersoni*		X	X	X	X
Bowfin Family						
Bowfin	*Amia calva*				X	
Herring Family						
Gizzard Shad	*Dorosoma cepedianum*	X	X	X	X	X
Silversides Family						
Brook Silverside	*Labidesthes sicculus*			X	X	
Gar Family						
Shortnose Gar	*Lepisosteus platostomus*	X				
Spotted Gar	*Lepisosteus oculatus*	X		X	X	X
Temperate Basses						
White Bass	*Morone chrysops*	X	X		X	X
Pike Family						
Grass Pickeral	*Esox americanus vermiculatus*	X	X	X		

Common Name	Scientific Name	1965	1967	1969	1977	1986
Northern Pike	*Esox lucius*					X
Trout and Salmon Family						
Rainbow Trout	*Oncorhynchus mykiss*	X				
Perch Family						
Johnny Darter	*Etheostoma nigrum*			X		
Yellow Perch	*Perca flavescens*	X	X	X	X	X
Number Species		25	19/1 hybrid	21	25	21

Yellow Creek Lake can be described as a bluegill, yellow perch, and largemouth bass fishery. According to the 1965 fishery management report, the lake has a history of stocking for bluegill, redear sunfish, largemouth bass, smallmouth bass, and rainbow trout (McGinty, 1967). All of these efforts occurred between 1954 and 1965.

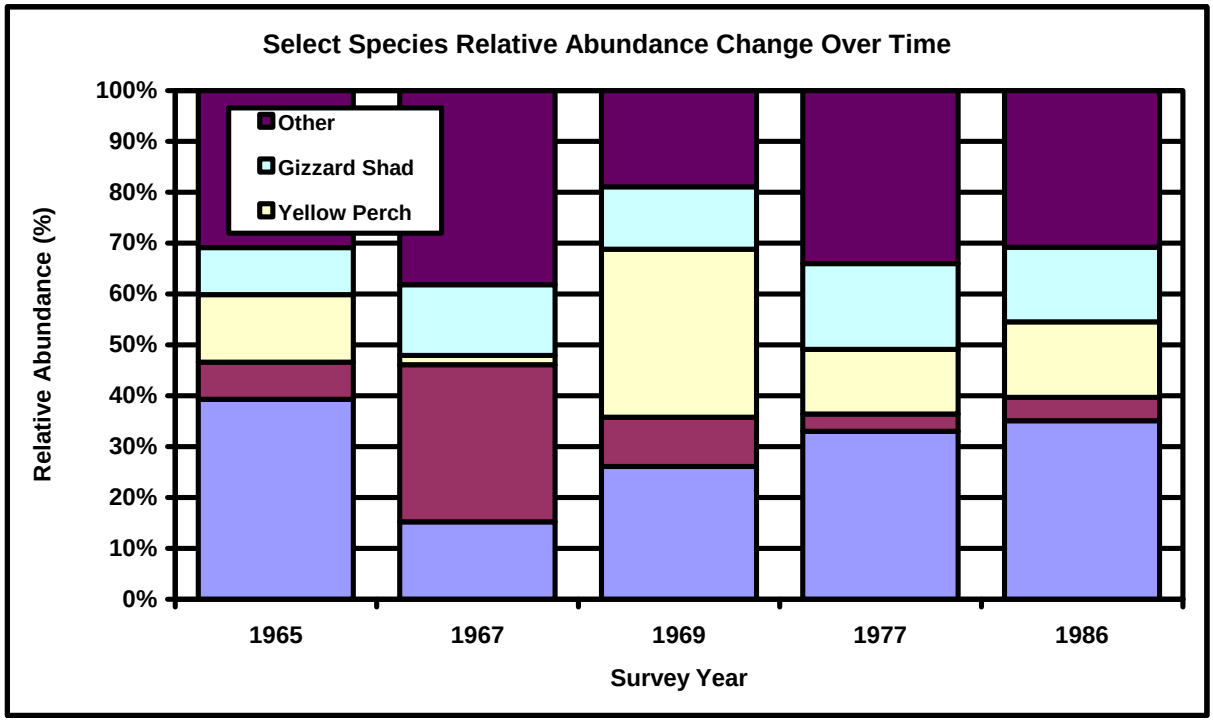


Figure 106. Historical fish community composition in Yellow Creek Lake based on IDNR surveys from 1965 to 1986. Sources: Braun, 1986; Hudson, 1968, 1970; McGinty, 1967; Pearson, 1977.

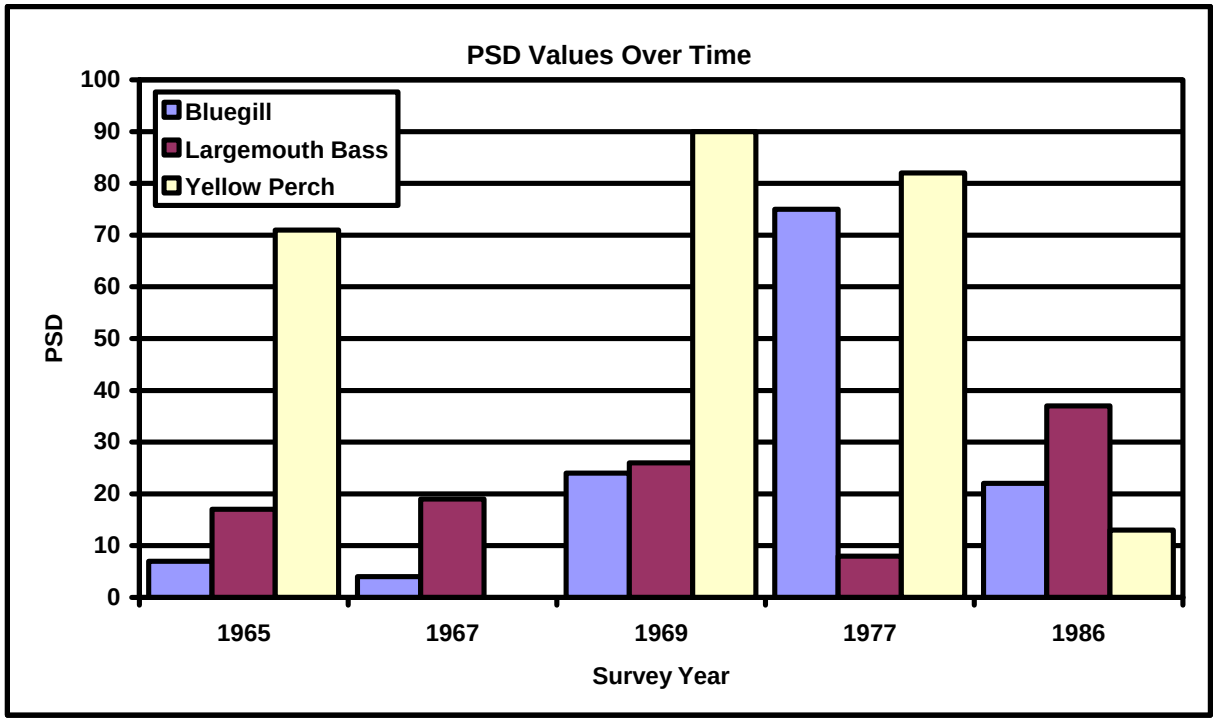


Figure 107. Proportional stock densities (PSD) of select species in Yellow Creek Lake calculated from IDNR surveys 1965 to 1986. Sources: Braun, 1986; Hudson, 1968; Hudson, 1970; McGinty, 1967; Pearson, 1977.

Fish Community Summary

Yellow Creek Lake has not been surveyed in 22 years; therefore, a survey needs to be conducted to evaluate the current state of the fishery. Historically, bluegill and yellow perch dominated the gamefish population in Yellow Creek Lake. The size structure of the bluegill population has been less than desirable, although, in 1977 the population was dominated by quality size individuals. The size structure of the yellow perch population had been dominated by larger individuals; however, that may no longer be true (Figure 107). The largemouth bass population has been small in Yellow Creek Lake and exhibited poor size structure. Indiana adopted a minimum size limit of 12 inches for largemouth bass in 1990 and increased it to 14 inches in 1998. The adoption of a minimum size limit for largemouth bass could have altered the size structure of bluegill and largemouth bass and reduced the abundance of gizzard shad in Yellow Creek Lake. Largemouth bass play an important role in controlling the population of desirable game-fish, such as bluegill, and undesirable fish species, such as gizzard shad. This occurs in two ways: 1) by helping to reduce intra-specific competition between young bluegill through limitation of their numbers; and 2) by reducing inter-specific competition of resources between young gizzard shad and young bluegill through the control of gizzard shad numbers. Catch and release of largemouth bass by anglers beyond that required by law is encouraged.

4.6.5 Yellow Creek Lake Historical Water Quality

The IDNR, Division of Fish and Wildlife, the Indiana State Pollution Control Board, the Indiana Clean Lakes Program (CLP), and Grace College have conducted various water quality tests on Yellow Creek Lake. Table 74 presents some selected water quality parameters for these assessments of Yellow Creek Lake.

Table 74. Summary of historic data for Yellow Creek Lake.

Date	Secchi (ft)	% Oxic	Epi pH	TP (mg/L)	Plankton (#/L)	Chl *a* (µg/L)	ITSI Score	Source
4/18/66	3.5	23.1%	8.30	--	--	--	--	McGinty, 1967
7/14/69	3.0	23.1%	--	--	--	--	--	Hudson, 1970
7/27/76	2.5	24.6%	--	0.090*	--	--	67[δ]	ISPCB, 1986
6/5/77	4.5	23.1%	9.00	--	--	--	--	Pearson, 1977c
7/28/86	3.8	53.8%	8.50	--	--	--	--	Braun, 1986d
1988	--	--	--	0.120	--	--	--	Hippensteel, 1989
8/22/94	3.9	25.2%	8.70	--	--	--	--	CLP, 1994
8/10/98	3.3	20.8%	8.65	0.131	23,578	--	38	CLP, 1998
7/13/04	4.6	25.2%	8.80	0.148	2,225	4.9	37	CLP, 2004
6/27/07	2.8	--	8.76	0.300[+]	--	--	--	Lesko, 2007
7/18/07	5.6	--	8.72	0.133[+]	--	--	--	Lesko, 2007
8/6/07	4.0	--	8.76	0.167[+]	--	--	--	Lesko, 2007

*Water column average; all other values are means of epilimnion and hypolimnion values.
[+]Surface water (epilimnetic) sample only; all other values are means of epilimnion and hypolimnion values.
[δ]Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.

Based on the data presented in Table 74, water quality in Yellow Creek Lake has remained stable over the past 40 years. Water clarity is relatively moderate for the region. Since 1966, Secchi disk transparency (a measure of water clarity) has ranged from 2.5 feet (0.7 m) in July 1976 to 5.6 feet (1.7 m) in July 2007. The trendline displayed in Figure 108 suggests an improvement in water clarity in Yellow Creek Lake over time. However, this suggested trend is likely due to the limited number of measurements which occurred historically in Yellow Creek Lake and the timing of those measurements, coupled with the high number of recent measurements. The most recent sampling included three clarity measurements in the last year, all of which occurred in mid-summer when water clarity is typically poorer in Indiana's lakes. During one of these sampling events, transparency measured greater than 1 foot (0.3 m) deeper than any other measurement. However, the limited data set and spread of collected data limits the determination of a significant change in water clarity. Nonetheless, water clarity is generally poor in Yellow Creek Lake and is generally poorer than the median clarity measured in 456 Indiana lakes (Jones, 2004).

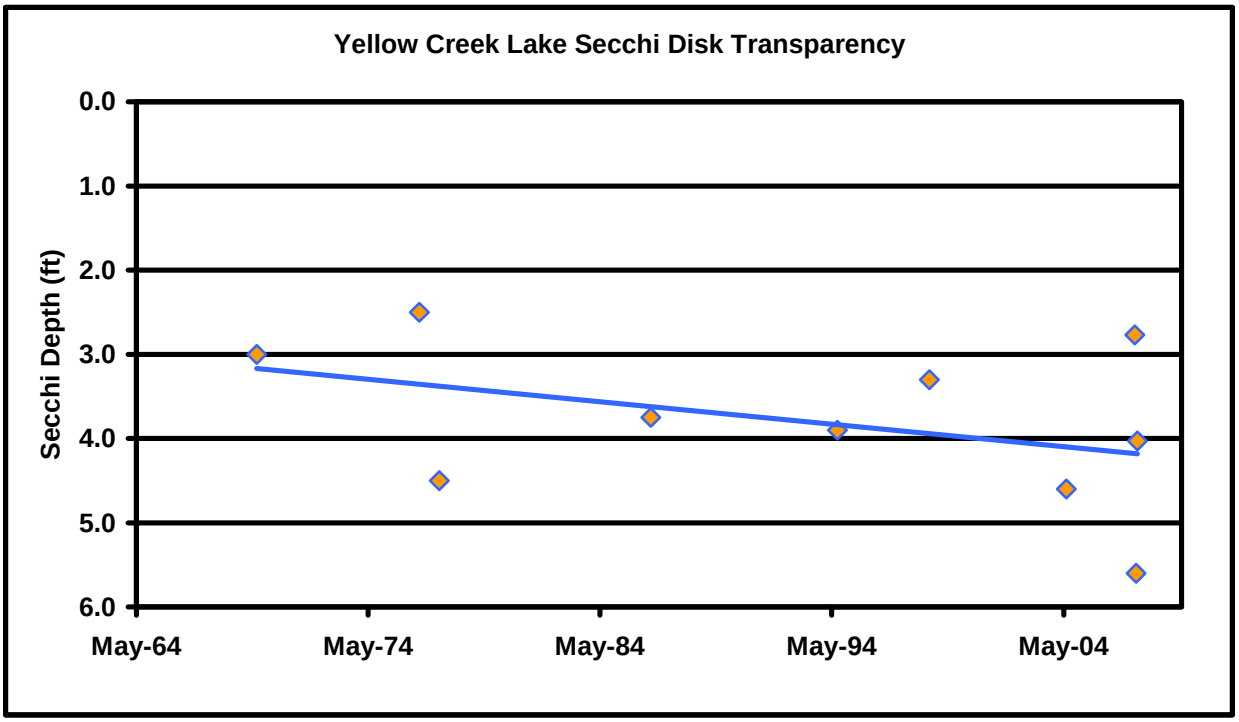


Figure 108. Historic Secchi disk transparency data for Yellow Creek Lake.
Source: Braun, 1986d; CLP, 1994, 1998, 2004; Hudson, 1970; ISPCB, 1986; Lesko 2007; McGinty, 1967; Pearson, 1977c.

Total phosphorus concentrations have varied within Yellow Creek Lake, increasing from a low of 0.090 mg/L in 1976 to a high of 0.148 mg/L in 2004 (Figure 109). More recent samples suggest that Yellow Creek Lake's total phosphorous concentration has continued to increase, reaching levels as high as 0.300 mg/L in 2007. However, it should be noted that samples collected during 2007 represent surface water samples only. Additionally, these samples were collected from various locations around the lake, not from the deepest point as historic samples were collected. Therefore, other factors including sediment resuspension, phosphorus from the lake's inlet, and additional algae or other materials that may be in the lake's surface waters could increase the total phosphorus concentration that is typical of Yellow Creek Lake. For these reasons, the steep increase in total phosphorus indicated in Figure 109 likely over exaggerates the increase in total phosphorus concentration over time. Historic total phosphorus concentrations were below the median concentration measured in Indiana lakes; however, more recent sample concentrations exceed this median (0.17 mg/L).

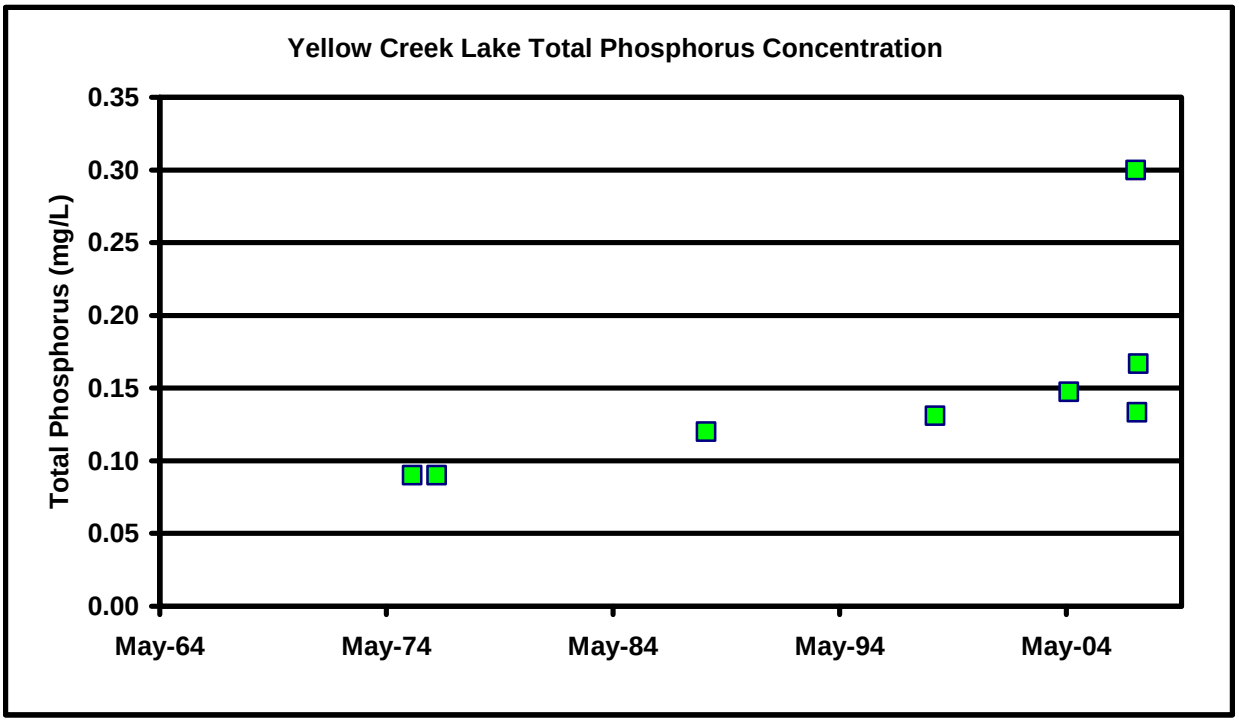


Figure 109. Historic total phosphorus concentrations measured in Yellow Creek Lake.
Source: CLP, 1994, 1998, 2004; ISPCB, 1986; Hippensteel, 1989; Lesko, 2007.

There is not a significant trend in nutrient concentrations in Yellow Creek Lake (Figure 110). As previously detailed for total phosphorus, soluble reactive phosphorus concentrations are relatively normal in Yellow Creek Lake with all concentrations measuring near or less than the median concentration (0.12 mg/L) for Indiana lakes. With the exception of the most recent nitrate-nitrogen concentration, all nitrogen concentrations are below the median concentration measured for Indiana lakes. Additionally, no apparent pattern is observable with relation to nitrogen concentrations within Yellow Creek Lake. Total nitrogen concentrations increased from 1.250 mg/L in 1976 to 1.658 mg/L in 2004. Ammonia-nitrogen and nitrate-nitrogen concentrations also increased from 1976 to 2004. Despite these increases, nitrogen concentrations remain below the median concentration found in Indiana lakes.

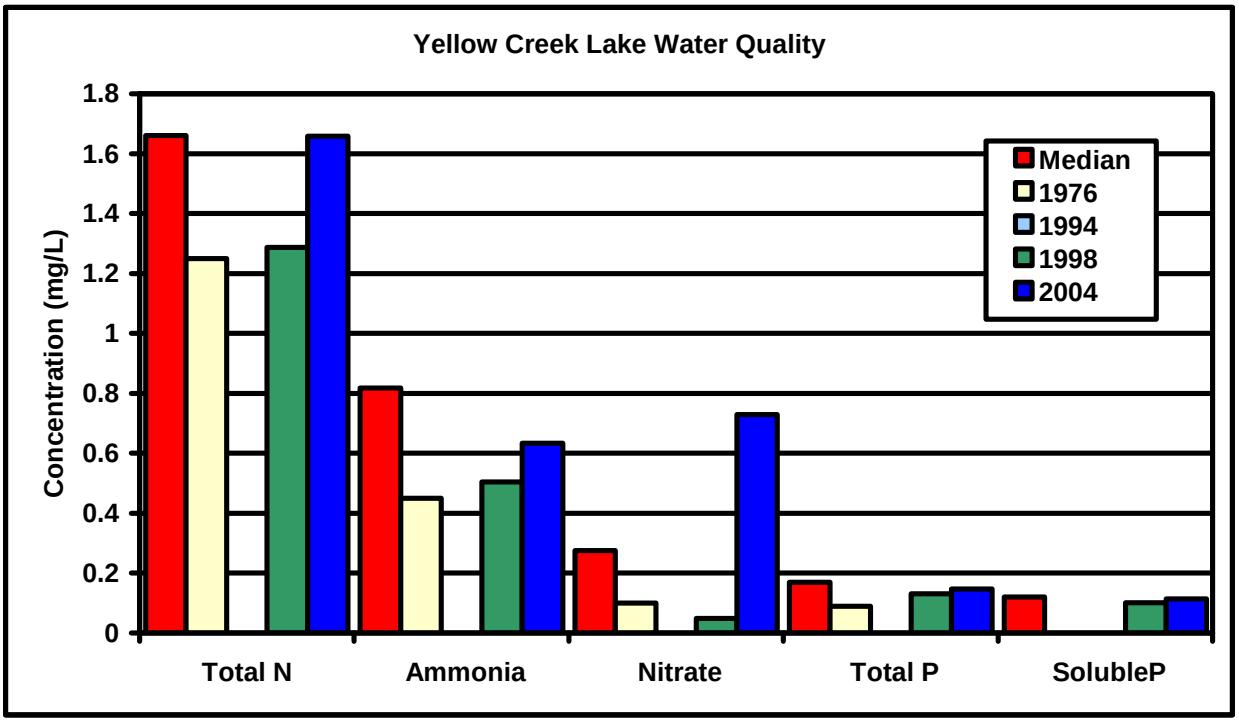


Figure 110. Variation in nutrient concentrations in Yellow Creek Lake, 1976 to 2004.
Source: CLP, 1994, 1998, 2004; ISPCB, 1986.

The lake's algae (plankton) density reflects the moderate nutrient levels typically present in Yellow Creek Lake. Nutrients (nitrogen and phosphorus) promote the growth of algae and/or rooted plant populations. Thus, lakes with high nutrient levels are expected to support dense algae and/or rooted plants. Plankton densities are relatively moderate within Yellow Creek Lake, reflecting the relatively moderate nutrient concentrations present within the lake. Plankton densities vary over time with the lowest concentration observed in 2004 measuring 2,225/L to the highest concentration of 23,578/L measured in 1998. Plankton density changes appear to be independent of nutrient concentration. Low chlorophyll *a* concentrations also reflect the relatively low plankton densities and total phosphorus concentrations found in the lake. None of the chlorophyll *a* concentrations exceed the median concentration measured in Indiana lakes (12.9 µg/L). The lake's overall ITSI score ranged from a high of 67 in 1976 to a low of 37 in 2004. These scores suggest that historically, the lake rated as highly productive (hypereutrophic), while more recent assessments indicate that the lake moderately productive (mesotrophic) to productive (eutrophic). (Please see the Discussion Section for more detailed discussion of lake water quality parameters and trophic state indices.)

Figure 111 displays the temperature profiles recorded during IDNR fisheries surveys and Indiana CLP assessments. All of the temperature profiles show that Yellow Creek Lake was stratified at the time of the assessments. The developed hypolimnion (bottom water) present during the surveys is very typical of Indiana lakes. The metalimnion, or area of rapidly changing water temperature, typically extends from 10 feet (3.0 m) to approximately 30 feet (9.1 m). The epilimnion (surface water) is located above the metalimnion, while the hypolimnion (bottom water) is located below the metalimnion. Water within the epilimnion and hypolimnion are typically separated during the summer in stratified lakes and do not mix.

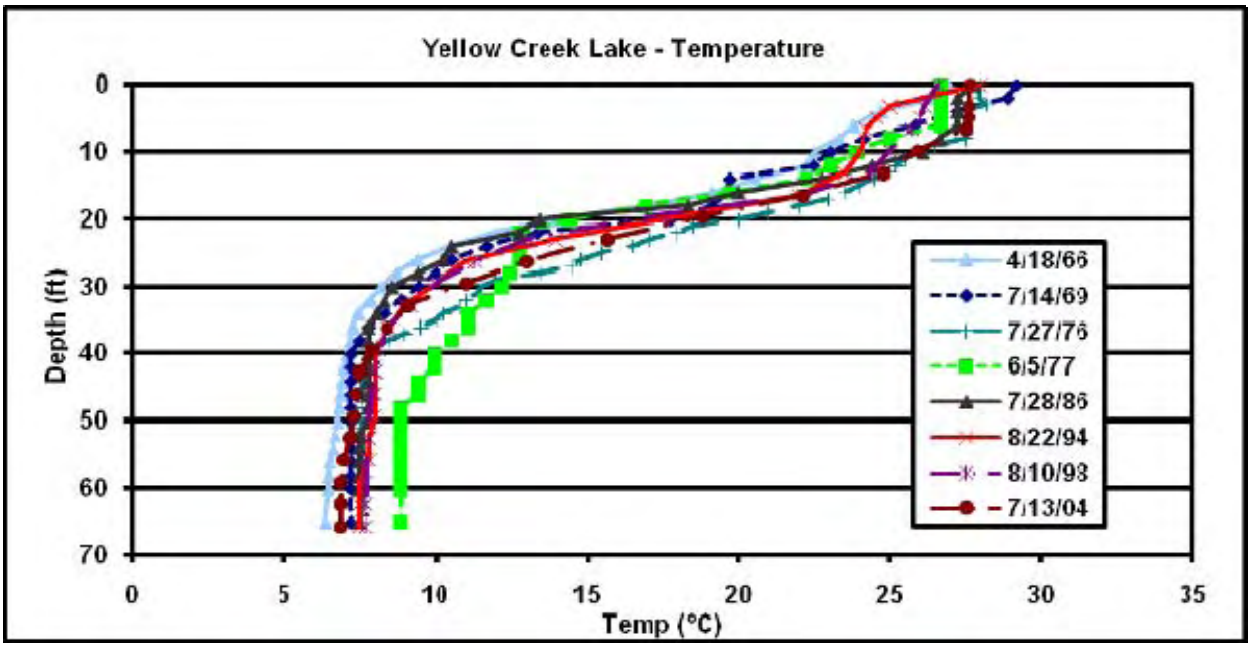


Figure 111. Historical temperature profiles for Yellow Creek Lake.
Source: Braun, 1986d; CLP, 1994, 1998, 2004; Hudson, 1970; McGinty, 1967; Pearson, 1977c.

Much of the data presented above suggest that Yellow Creek Lake is moderately to highly productive. The historical percent oxic results (Table 74) and dissolved oxygen profiles (Figure 112) support this idea and are in fact more typical of a eutrophic (productive) lake. Dissolved oxygen data indicate that the lake possessed dissolved oxygen greater than 1 mg/L in less than 25% of the water column. This decline in dissolved oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments.

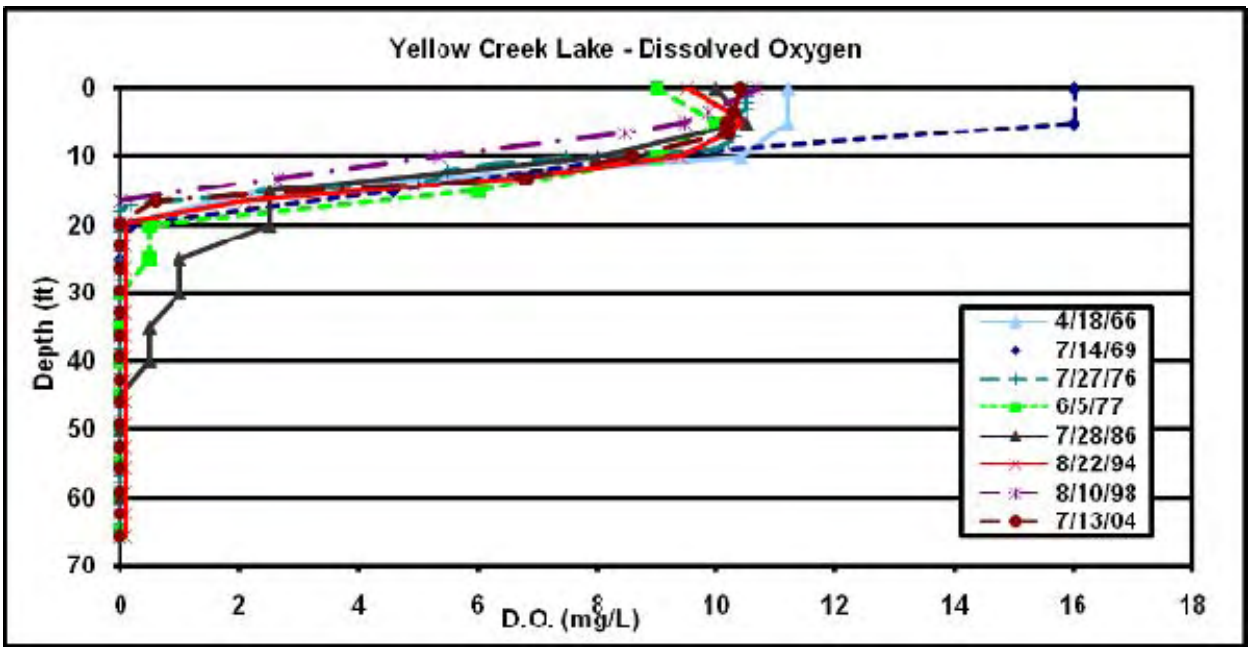


Figure 112. Historical dissolved oxygen profiles for Yellow Creek Lake.
Source: Braun, 1986d; CLP, 1994, 1998, 2004; Hudson, 1970; McGinty, 1967; Pearson, 1977c.

The lack of oxygen in the lake's water column likely reflects intense decomposition of plant material within Yellow Creek Lake during the summer months. Decomposition of plant material undoubtedly occurs in the lake's deeper waters, removing oxygen from the water column. Higher hypolimnetic ammonia concentrations suggest decomposition is occurring in the lake's bottom waters. Additionally, this lack of oxygen poses a problem for the lake's inhabitants. Fish and other aquatic organisms require oxygen to live. The lack of oxygen in the lake's hypolimnion reduces the amount of habitat available to fish. Fortunately, most of the lake's volume has oxygen levels sufficient to support fish. Based on the depth-volume curve (Figure 100), approximately 62% of the lake's volume is oxygenated.

The lack of oxygen in Yellow Creek Lake's hypolimnion also affects the lake's chemistry. While mean total phosphorus concentrations are variable for the years 1966-2007, a more detailed evaluation shows that hypolimnetic total phosphorus concentrations are typically higher than epilimnetic total phosphorus concentrations. Under anoxic conditions, the iron in iron phosphate, a common precipitate in lake sediments, is reduced, and the phosphate ion is released into the water column. This phosphate ion is readily available to algae, and can therefore spur algal growth. Further review of historical phosphorus data indicate that much of the total phosphorus was in the dissolved form of phosphorus (SRP). This indicates that Yellow Creek Lake was releasing phosphorus from its bottom sediments. Additionally, Yellow Creek Lake exhibited higher hypolimnetic ammonia concentrations than those observed in the lake's epilimnion during all of the assessments, suggesting decomposition of organic matter was occurring in the lake's bottom waters. Despite these high nitrogen concentrations, something other than nutrients are limiting productivity within Yellow Creek Lake. Overall, these data suggest that Yellow Creek Lake was a moderately productive (mesotrophic) to productive (eutrophic) lake during the 1998 and 2004 assessments.

Yellow Creek Lake Water Budget

The watershed or drainage area of Yellow Creek Lake is approximately 2,160 acres. The mean annual watershed runoff volume calculated to drain into Yellow Creek Lake is 2,606 acre-feet per year. Comparing the runoff to a lake volume of 4,772 acre-feet, and factoring in evaporation and rainfall from and to the lake, results in a hydraulic residence time of approximately seven months (Table 75). This residence time is about normal for Indiana Lakes and means that in-lake processes and management actions may not be as important as watershed processes in affecting water quality.

Table 75. Water Budget Calculations for Yellow Creek Lake. (See Appendix A for a graphic model of model inputs and outputs**)**

Watershed	Yellow Cr Lake - Kosciusko Co.
Direct Watershed size (ac)	2160
Mean watershed runoff (ac-ft/yr)	2606
Lake volume (ac-ft)	4772
Closest gaged stream	Eel River @ N. Manchester
Stream watershed (mi^2)	417
Stream watershed (acres)	266880
Mean annual daily Q (cfs)	444.7
Mean annual total Q (ac-ft/yr)	321948
Mean ppt (in/yr)	37
Mean watershed ppt (ac-ft/yr)	822880
Watershed C	0.39125
Pan evaporation (in/yr)	41.80
Pan evaporation coefficient	0.70
Lake surface area (acres)	149
Estimated lake evaporation (ac-ft)	363
Direct precipitation to lake (ac-ft)	459
	= input data
	= output data
Water Budget Summary	
Direct precipitation to lake (ac-ft)	459
Runoff from watershed (ac-ft)	2606
Evaporation (ac-ft)	363
Discharge from Diamond Lake (ac-ft)	2545
Discharge from Loon Lake (ac-ft)	2205
Discharge from McClures Lake (ac-ft)	779
TOTAL LAKE OUTPUT (ac-ft)	8231
Hydraulic residence time (yr)	0.58

4.6.7 Yellow Creek Lake Current Water Quality Assessment

Temperature and oxygen profiles for Yellow Creek Lake show that the lake was stratified at the time of July 17, 2008 sampling (Figure 113). Yellow Creek was supersaturated in the *epilimnion*

(surface waters), with 120.8 % dissolved oxygen at 5 feet (1.5 m). Supersaturated dissolved oxygen is symptomatic of intense phytoplankton photosynthesis. Below the 16.5 foot (5 m) depth, there is virtually no oxygen to support fish and other aquatic life. Bacterial decomposition of excessive organic waste on the sediment consumes oxygen and is most likely the cause of the anoxic conditions in the deeper waters of Yellow Creek Lake. During thermal stratification, the bottom waters (*hypolimnion*) of the lake are isolated from the well-mixed epilimnion by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth is called the *metalimnion*. At the time of our sampling, the epilimnion was confined to the upper 6.5 feet (2 m) of water. The sharp decline in temperature between 6.5 and 26 feet (2 and 8 m) defines the metalimnion or transition zone. The hypolimnion occupied water deeper than 26 feet (8 m).

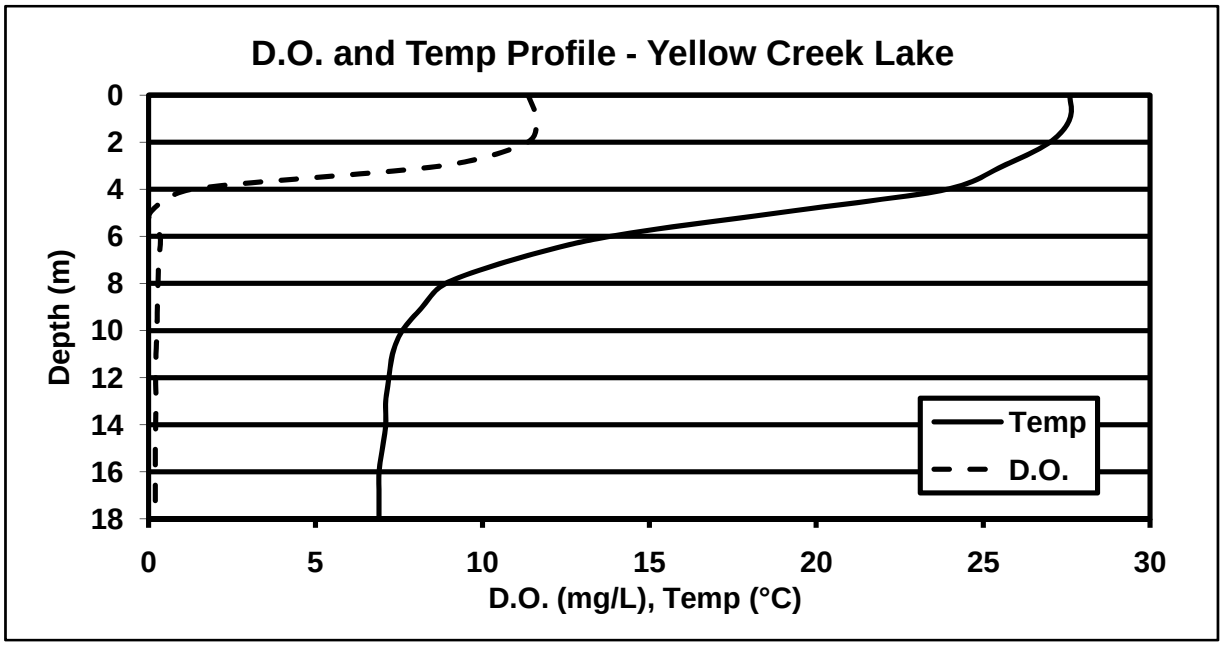


Figure 113. Temperature and dissolved oxygen profiles for Yellow Creek Lake on July 17, 2008.

The 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to 2.1 ft (0.64 m). Based on the depth-area curve in Figure 99 approximately 4.8% of lake bottom (approximately 7 acres or 2.8 ha) is shallower than 2.1 feet (0.64 m). This represents the area of the lake bottom with sufficient light to support rooted plants. This area is called the *littoral zone*. Furthermore, based on the depth-volume curve (Figure 100), a volume of greater than 400 acre-feet of Yellow Creek Lake (8.4% of total lake volume) lies above the 4.8-foot 1% light level. This area, referred to as the *photic zone*, represents the amount of water with sufficient light to support algae growth.

Phosphorus and nitrogen are the primary plant nutrients in lakes. Phosphorus concentrations were relatively low in the epilimnion (0.026 mg/L) of Yellow Creek Lake but were higher (0.218 mg/L) in the hypolimnion (Table 76). Higher phosphorus concentrations within the hypolimnion are usually associated with nutrient release from the sediments. Sedimentation of particulates and plankton also provide a source of phosphorus to the hypolimnion. The lower epilimnion concentration is close to the 0.03 mg/L concentration that is considered high enough to support eutrophic conditions.

Table 76. Water Quality Characteristics of Yellow Creek Lake, July 17, 2008.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.9	7.3	-
Alkalinity	123 mg/L	152 mg/L	-
Conductivity	327 µS/m	410 µS/m	-
Secchi depth	0.7m	-	6
Light Transmission @ 3 ft	6.4%	-	4
1% Light level	2.1 ft	-	-
Total Phosphorus	0.026 mg/L	0.218 mg/L	3
Soluble Reactive Phosphorus	0.010* mg/L	0.179 mg/L	3
NO_3	0.068 mg/L	0.406 mg/L	0
NH_4	0.060 mg/L	1.336 mg/L	3
TKN	1.069 mg/L	1.922 mg/L	2
Oxygen Saturation @ 5 ft.	120.8%	-	4
% Water column oxic	16.6%	-	4
Plankton Density	7850 N.U./L	-	2
Blue-Green Dominance	68.2%	-	10
Chl-a	15.14 µg/L	-	-
		ITSI Score	**41**

*Method Detection Limit

The concentration of nitrate nitrogen (NO_3) was 0.068 mg/L in the epilimnion. Typically nitrate is reduced to ammonia (NH_4) when oxygen is low. However, nitrate increased to 0.406 mg/L in the hypolimnion. Some nitrifying bacteria that are adapted to low DO concentrations could explain the spiked hypolimnetic nitrate concentrations. Hypolimnetic ammonia concentrations were 1.336 mg/L, indicating the presence of a high amount of biochemical oxygen demand (BOD) to produce the ammonia, and a low amount of dissolved oxygen present to maintain these relatively high concentrations.

Values for pH were within the normal range for Indiana lakes, pH 8.9 for the epilimnion and pH 7.3 for the hypolimnion. pH values for most fresh waters fall between pH 6-9 (Kalff, 2002). The high alkalinity values of 123 mg/L and 152 mg/L, for the epilimnion and hypolimnion, indicate that Yellow Creek Lake is a well buffered system.

Plankton enumerated from the sample collected from Yellow Creek Lake are shown in Table 77. *Chroococcus*, a blue-green alga, was the most dominant genera found. In addition to this particular blue-green alga, other blue-green species contributed to the overall plankton dominance by blue-greens of 68.2%. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers. This blue-green dominance is the primary reason for the higher TSI score in 2008.

Table 77. Plankton representing the Yellow Creek Lake species assemblage sampled on July 17, 2008.

SPECIES	ABUNDANCE (N.U./L)
Blue-Green Algae (Cyanophyta)	
Lyngbya	1813
Anabaena	793
Microcystis	708
Chroococcus	2040
Green Algae (Chlorophyta)	
Scenedesmus	57
Ulothrix	312
Diatoms (Bacillariophyta)	
Synedra	991
Tabellaria	28
Other Algae	
Miscellaneous Protozoa	283
Dinobryon	28
Zooplankton	
Nauplius	1.6
Cyclopoid Copepod	0.4
Calanoid Copepod	0.4
Daphnia	1.2

5.0 WATERSHED PHOSPHORUS MODELING

Since phosphorus is the limiting nutrient in the Yellow Creek watershed lakes, we have used a phosphorus model to estimate the dynamics of this important nutrient. With its role as the limiting nutrient, phosphorus should be the target of management activities to lower the biological productivity of these lakes.

The limited scope of this LARE study did not allow us to determine phosphorus inputs and outputs outright. Therefore, we have used a standard phosphorus model to estimate the phosphorus budget. Reckhow et al. (1979) compiled phosphorus loss rates from various land use activities as determined by a number of different studies, and from this, they calculated phosphorus export coefficients for various land uses. We used mid-range estimates of these phosphorus export coefficient values for all watershed land uses (Table 78). Phosphorus export coefficients are expressed as kilograms of phosphorus lost per hectare of land per year. The export coefficient for a particular land use was multiplied by the area of land in that land use category to derive an estimate of annual phosphorus export (as kg/year) for each land use.

Table 78. Phosphorus Export Coefficients (units are kg/hectare except the septic category, which are kg/capita-yr).

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

Source: Reckhow and Simpson (1980)

We estimated direct phosphorus input via precipitation to the lakes by multiplying mean annual precipitation in Kosciusko County (0.9 m/yr) times the surface area of the lake times a typical phosphorus concentration in Indiana precipitation (0.03 mg/L). For septic system inputs, we multiplied the number of permanent homes on the lakeshore times an average of 3 residents per home to calculate per capita years. These shoreline homes could leach phosphorus and other contaminants into the lake from septic systems. For these lakes, we assumed that all homes on septic were occupied year-round. We used a mid-range phosphorus export of 0.5 kg/capita-yr and a soil retention coefficient of 0.75 (this assumes that the drain field retains 75% of the phosphorus applied to it). Of course, failing septic systems or group systems serving camps, can't be modeled this way and could be underestimated.

The results, shown in Table 79, yielded an estimated 710 kg of phosphorus loading to Yellow Creek Lake from its direct watershed, septic systems, from precipitation, and an additional 1,033 kg of phosphorus from discharge from Loon, McClures and Diamond lakes' outlets annually. Discharge from upstream lakes represents more than 59 percent of the total phosphorus loading annually to Yellow Creek Lake. This, more than anything else, illustrates the importance of upstream nutrient management to improve downstream water quality.

Table 79. Estimated External Phosphorus Loads (kg/yr) from Various Sources.

Watershed	Direct Watershed Loading	Precip.	Septic	From Lakes Upstream	TOTAL
Beaver Dam	390.9	16.0	37.9	NA	444.7
Diamond	573.4	8.4	22.9	26.1[a]	630.8
Hill	141.7	7.1	7.9	NA	156.7
Loon	116.7	4.7	12.0	301.8[b]	435.1
McClure	216.3	6.5	1.7	NA	224.5
Yellow Creek	656.3	16.3	37.9	1033.2[c]	1743.7

[a]Discharge from Loon Lake
[b]Discharge from Beaver Dam Lake
[c]Discharge from Loon, McClures and Diamond lakes

The bulk of the land use within the Yellow Creek lakes watershed is cultivated cropland. Cultivated cropland makes up between 50 and 81 percent of land use in the watersheds of the six lakes (Table 80). The percentage of phosphorus loading to the lakes from cultivated cropland exceeds that of all other land uses and exceeds the percentage of cropland itself.

Table 80. Estimated Total Phosphorus Loading from Cultivated Crops as a Percent of Total Direct Watershed Loading.

Watershed	% of crop land in the watershed	% P from crop land
Beaver Dam	67.0	87.8
Diamond	81.8	91.5
Hill	58.5	80.1
Loon	50.2	80.2
McClure	79.7	91.7
Yellow Creek	65.5	87.2

We can examine the relationships among the primary parameters that affect a lake's phosphorus concentration by using a phosphorus-loading model such as the widely used

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

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

During our July 17, 2008 sampling of Beaver Dam Lake, the mean volume weighted phosphorus concentration in the lake was 0.151 mg/L. Now it is useful to ask the question, "How much phosphorus loading from all sources is required to yield a mean phosphorus concentration of 0.151 mg/L in Beaver Dam Lake?" By plugging this mean concentration along with the mean depth and flushing rate into Vollenweider's phosphorus loading model and solving for L, we get an areal phosphorus loading rate (mass of phosphorus per unit area of lake) of 2.021 g/m^2-yr. This means that in order to get a mean phosphorus concentration of 0.151 mg/L in Beaver Dam Lake, a total of 2.021 grams of phosphorus must be delivered to each square meter of lake surface area per year.

Total phosphorus loading (L_T) is composed of external phosphorus loading (L_E) from outside the lake (watershed, septics, precipitation, and upstream lakes) and internal phosphorus loading (L_I). Since L_T = 2.021 g/m^2-yr and L_E = 0.753 g/m^2-yr (estimated from the watershed loading in Table 79), than internal phosphorus loading (L_I) equals 1.269 g/m^2-yr. Thus, internal loading accounts for about 63 percent of total phosphorus loading to Beaver Dam Lake.

How reasonable is this conclusion that internal phosphorus loading accounts for 63% of total phosphorus loading to Beaver Dam Lake? Where does this internal phosphorus come from? There is evidence in Beaver Dam Lake that soluble phosphorus is being released from the sediments during periods of anoxia. For example, the concentration of soluble phosphorus in Beaver Dam's hypolimnion on 7/17/08 was 3.5 times higher than concentrations in the epilimnion (0.367 mg/L vs. 0.104 mg/L). The source of this hypolimnetic total phosphorus is primarily internal loading in most lakes. This internal loading can be a major source of phosphorus in many productive lakes. Our modeled estimate of 63 percent of annual phosphorus loading originating from internal sources is expected, given the large difference between summertime epilimnetic and hypolimnetic phosphorus concentrations.

Likewise, we ran the Vollenweider phosphorus loading model for the other five lakes. Results for all six lakes are included in Tables 81 and 82. For purposes of modeling, we assumed that 100% of the phosphorus discharged from upstream lakes was delivered to the downstream lake. It is likely that some small amount was utilized by stream biota and processes before it reached the downstream lake. There are no reliable ways to calculate this.

Table 81. Areal Phosphorus Loading Rates Determined from Models.

Lake	Total Areal P Loading (g/m^2 – yr)[1]	External Areal P Loading (g/m^2 – yr)[2]	Internal Areal P Loading (g/m^2 – yr)	% Internal
Beaver Dam	2.021	0.753	1.269	62.8
Diamond	2.617	2.035	0.582	22.2
Hill	0.441	0.596	-0.155	-35.1
Loon	4.678	2.500	2.178	46.6
McClures	1.845	0.940	0.905	49.0
Yellow Creek	2.611	2.892	-0.281	-10.8

[1]estimated from Vollenweider's lake response model
[2]estimated from Reckhow's phosphorus export model and precipitation estimates

From these data, we see an apparent anomaly with Hill and Yellow Creek lakes. The phosphorus export model estimated much more phosphorus delivered to Hill Lake (0.596 g/m^2-yr) than is accounted for by the phosphorus concentration in the lake (0.441 g/m^2-yr), hence the negative value for internal loading. Where did all of this excess phosphorus go? Without additional testing, it is difficult to say with certainty. But possible reasons could include: a) the lakes are phosphorus sinks or b) more of the phosphorus flows directly out the lake rather than accumulating in the sediments.

The significance of areal phosphorus loading rates is better illustrated in Figure 114 in which areal phosphorus loading is plotted against the product of mean depth times flushing rate. Overlain on this graph is a curve, based on Vollenweider's model, which represent an acceptable loading rate that yields a phosphorus concentration in lake water of 30 µg/L (0.03 mg/L). The areal phosphorus loading rate for each lake except Hill Lake is well above the acceptable line.

This figure can also be used to evaluate management needs. For example, areal phosphorus loading to Beaver Dam Lake would have to be reduced from 2.021 g/m^2-yr to 0.40 g/m^2-yr (the downward vertical intercept with the line) to yield a mean lake water concentration of 0.030 mg/L. This represents a reduction in areal phosphorus loading of 1.62 g/m^2-yr to the lake (80%), which is equivalent to a total phosphorus mass loading reduction of 956.9 kg P/yr. This mass can be used as a target to reduce phosphorus loadings from Beaver Dam Lake's watershed by implementing various best management practices. Similar calculations are shown in Table for the other lakes. Overall phosphorus loading reductions for the six lakes vary from a low of 12.2 percent of current loading at Hill Lake to a high of 83.7 percent loading reduction at Loon Lake.

Table 82. Phosphorus Reduction Required to Achieve Acceptable Phosphorus Loading Rate and a Mean Lake Concentration of 0.03 mg/L

Lake	Current Total Areal P Loading (g/m^2-yr)	Acceptable Areal P Loading (g/m^2-yr)	Reduction Needed (kg P/yr and %)
Beaver Dam	2.021	0.400	956.9 (80.1)
Diamond	2.617	0.610	623.1 (76.8)
Hill	0.441	0.390	14.2 (12.2)
Loon	4.678	0.760	681.3 (83.7)
McClures	1.845	0.420	340.2 (77.2)
Yellow Creek	2.611	0.800	1088.8 (69.2)

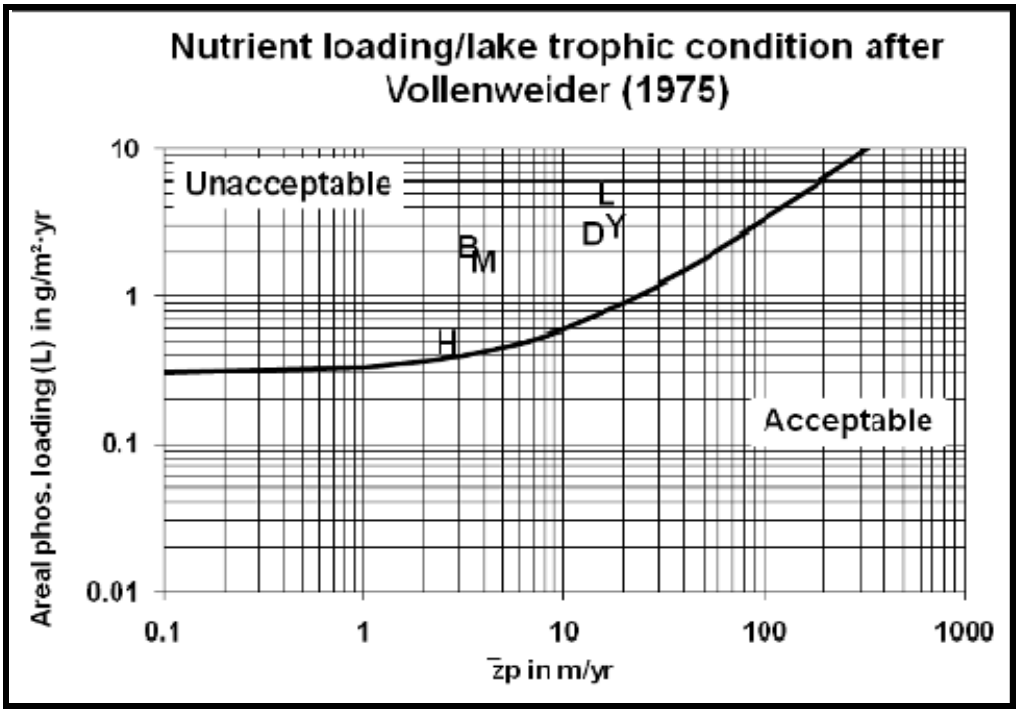


Figure 114. Phosphorus loadings to Yellow Creek watershed lakes compared to acceptable loadings determined from Vollenweider's model. The dark line represents the upper limit for acceptable loading. B=Beaver Dam; D = Diamond; H = Hill; L = Loon; M = McClures; Y = Yellow Creek.

6.0 STREAM ASSESSMENT RESULTS

A windshield and walking tour of the watershed and drains was conducted on November 21, 2007 and April 25, 2008 respectively. Please see Appendix F for a detailed summary of the walking tour. Erosion and other potential pollution sources were noted and included in the Summary and Discussion, as well as the Recommendations section of this report.

Stream sampling was conducted during storm water flows on June 5, 2008 and during base flows on July 16, 2008 at seven sample sites in the Yellow Creek Lakes watershed (Figure 115 and 116). Storm flow discharge was higher than base flow at all sampled streams. Fourteen

physical, chemical and biological measurements were taken during the base and storm flows (Table 83-85). Water quality parameters for each individual stream are discussed separately below.

The habitat or Qualitative Habitat Evaluation Index (QHEI) and aquatic macroinvertebrate surveys (resulting in mIBI values; Table 86) were completed on the same day as the base flow measurements. (See Appendix D for a description of the scoring metrics used in the QHEI). QHEI scores below 51 are considered "non-supporting" and are indicators of poor habitat, scores from 51 to 64 are partially supporting, and scores over 64 are fully supporting (IDEM, 2002). All seven sites fall below the score of 51. The low substrate stability, heavy siltation, and extensive embeddedness at these sites generally resulted in very few QHEI points.

The macroinvertebrate Index of Biotic integrity (mIBI) uses the information obtained during the survey to score the stream invertebrate population using a universal index similar to the QHEI. These scores can then be compared with other streams. The aquatic macroinvertebrate sampling resulted in mIBI scores ranging from 0.8 to 3.8 (Table 87). Scores for mIBI below 2 are considered severely impaired, scores from 2 to less than 4 are partially impaired, and scores over 4 are fully supporting (IDEM, 2002). All of the streams in this watershed had scores below 2 (non-supporting) except for one stream which scored in the partially supporting range.

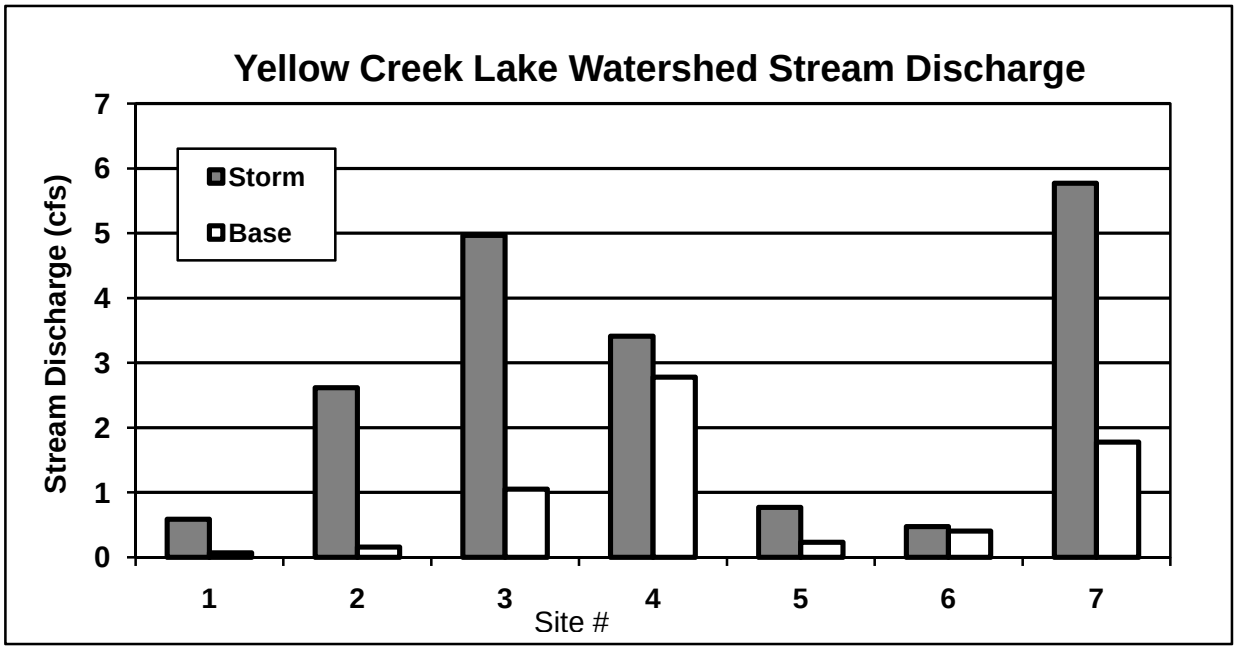


Figure 115. Discharge measurements during base flow and storm flow sampling of Yellow Creek Lake tributaries. See Figure 116.

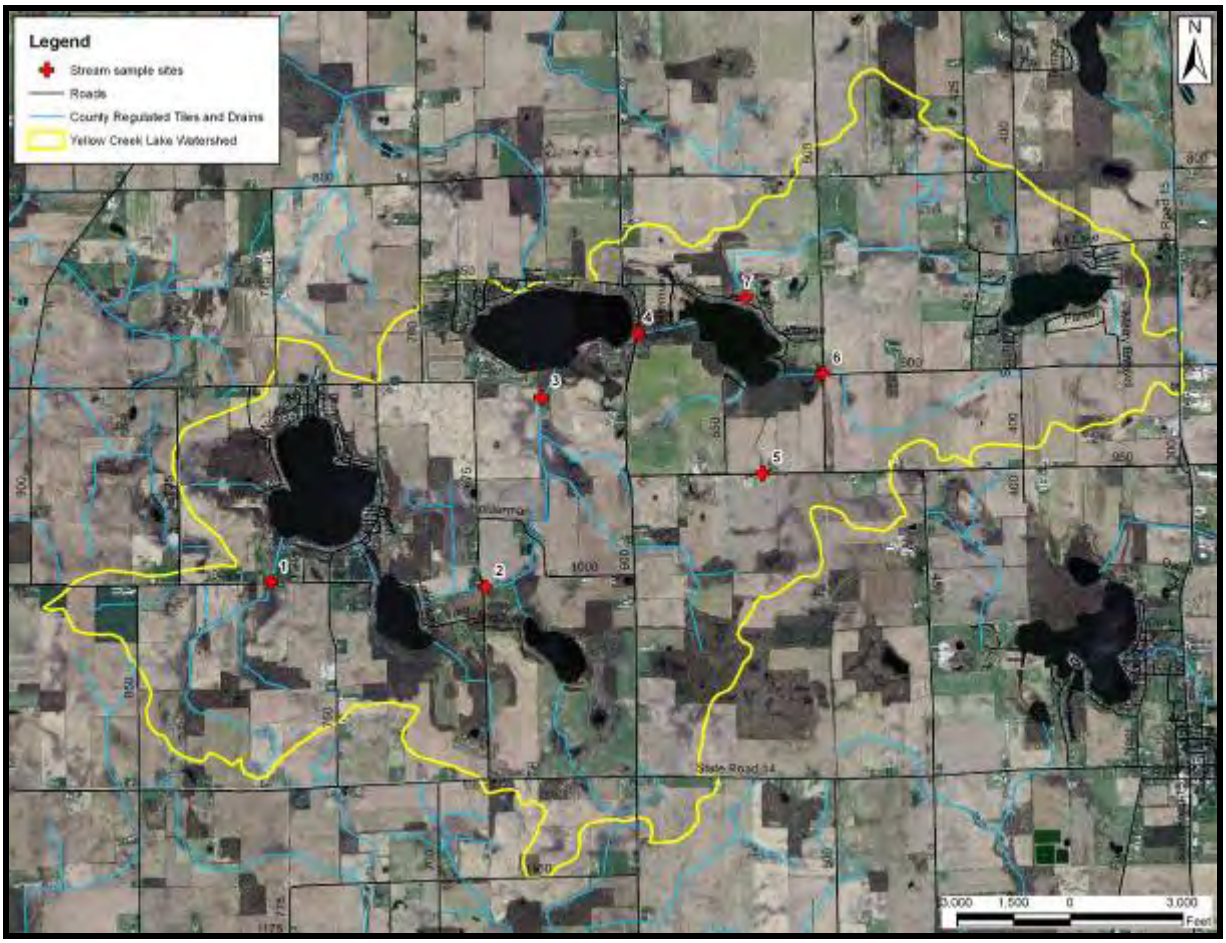


Figure 116. Location of stream samples in the Yellow Creek Lakes watershed.

6.1 Site 1: Eaton Arm Swick-Meredith Drain

This drainage flows into the south end of Beaver Dam Lake. At the location of the sample site, the drainage area is approximately 800 acres (324 ha) of recovering wetland (50%) and active agricultural fields (50%). Access to the site is off CR 1000 S approximately ¼ mile (400 m) west of CR 750 W. The sample site was located north of CR 1000 S (Figure 117).

The predominant surrounding land use at this site was row crop agriculture and residential. The riparian zone extended between 3 and 16.5 feet (1 and 5 m) on the left downstream bank; the right bank had a negligible riparian zone. The riparian vegetation was dominated by grasses. Overhanging vegetation and, to a lesser extent, shallows provided extensive instream cover. Bank stability was low and was mainly comprised of a silty muck. Substrate composition at this site was 95% silt/muck and 5% detritus.

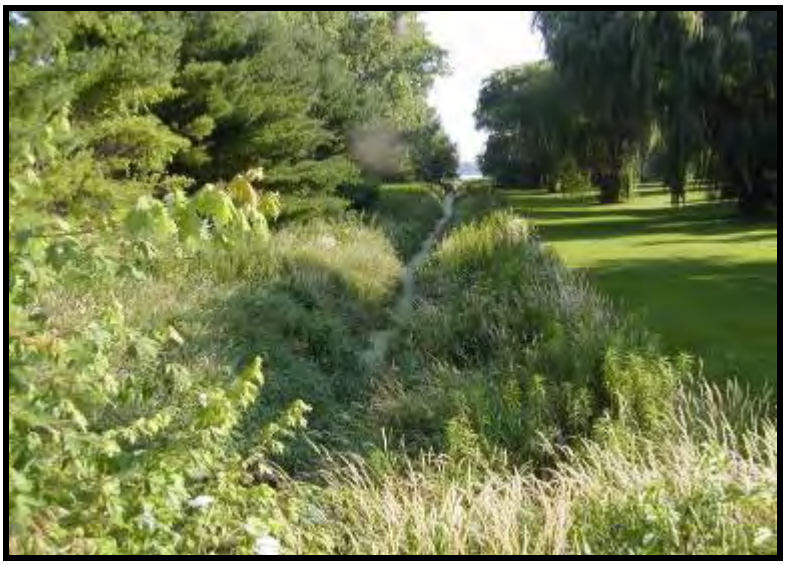


Figure 117. Effie Eaton Arm Swick-Meredith Drain, July 16, 2008, facing north off CR 1000

The water sampling results from Site 1 included several indicators of poor water quality. Oxygen was at 0.9 mg/l at base flow, which is below that required for aerobic respiration. Not surprisingly the result is dominance of the tubificid worms in the substrate. Nitrate (NO_3^-) concentrations were at 4.1 mg/l during storm flows and 1.83 mg/l during base flows. The Ohio EPA standard for nitrate is 1.6 mg/l for warmwater streams. Total phosphorus was 0.199 mg/l during diluted storm flows but 0.305 mg/l at base flow. The base flow concentration is 10 times the recommended concentration of phosphorus for eutrophic conditions. This stream is a nutrient source for Beaver Dam Lake and as such is contributing to the algae production.

Poor instream conditions: low substrate stability, extensive embeddedness and poor pool/riffle development contributed to the low QHEI score of 32 out of 100 points. The mIBI for site 1 was a 0.8 indicating that the stream was severely impaired. The prominent macroinvertebrates collected (70%) were Oligochaeta: *Tubificidae*, a family tolerant to poor water conditions.

6.2 Site 2: Swick-Meredith Drain

This drainage brings water from Loon Lake toward Yellow Creek Lake; however, this sample site location is prior to its junction with the McClure Lake Drainage. The drainage area at the location of the sample is approximately 2,450 acres (992 ha) and includes the entire drainage area of Beaver Dam Lake and Loon Lake. The sample site was on the east side of CR 675 W approximately one mile (1.6 km) south of CR 900 S (Figure 118).

The predominant land use at this site was row crop agriculture. The riparian zone extended between 16.5 and 33 feet (5 and 10 m) on the left bank, and between 3 and 16.5 feet (1 and 5 m) on the right banks. Riparian vegetation was dominated by trees and shrubs. Overhanging vegetation, and to a lesser extent woody debris, shallows, and rootwads provided instream cover. Bank stability was low comprised of a silty muck. Substrate composition at this site was 95% muck with 5% detritus. Poor instream conditions: low substrate stability, heavy siltation, and extensive embeddedness, contributed to the low QHEI score of 38 out of 100 points. Site 2 from the macroinvertebrate survey is considered severely impaired with a mIBI of 1.2. The prominent macroinvertebrates collected at the site were Amphipoda (21%), a family moderately tolerant of poor water conditions, and Diptera:*Chironomidae* (37%), a large genus, with many

species notable as being excellent indicators of organic pollution and having moderate tolerance to organic wastes.

Figure 118. Swick-Meredith Drain facing west at CR 675 W.

The water sampling results from Site 2 included several indicators of poor water quality. Oxygen was at 3.9 mg/l at base flow with only 41.4% saturation, which is at the low end of what is required for aerobic respiration. The result is a dominance of amphipods and Chironomids which are tolerant of poor water quality. Nitrate (NO_3^-) concentrations were at 4.4 mg/l during storm flows and 1.79 mg/l during base flows. Ammonia (NH_4) concentrations were also high at 0.281 mg/l during storm flows and 0.447 mg/l during base flows. The Ohio EPA standard for nitrate is 1.6 mg/l for warmwater streams. Total phosphorus was 0.06 mg/l during diluted storm flows but 0.09 mg/l at base flow. The base flow concentration is 3 times the recommended concentration of phosphorus for eutrophic conditions. This stream is a nutrient source for Yellow Creek Lake, but may also be transporting nutrients from Loon Lake.

6.3 Site 3: Meredith Arm Swick-Meredith Drain

This drainage brings water from Loon Lake and McClures Lake toward yellow Creek Lake. The drainage area at the location of the sample is approximately 3,720 acres (1,505 ha) and includes the entire drainage area of Beaver Dam Lake, Loon Lake and McClures Lake. The sample site was on the north side of a private culverted crossing of the drain, located approximately ¼ mile (400 m) upstream from Yellow Creek Lake and ½ mile west of CR 600 W (Figure 119).

The predominant land use at this site was row crop agriculture. The riparian zone extended between 3 and 16.5 feet (1 and 5 m) on the both banks. Riparian vegetation was dominated by trees and shrubs on the left downstream bank, and grasses and shrubs on the right bank. Overhanging vegetation, aquatic macrophytes, and to a lesser extent woody debris provided extensive instream cover. The bank stability was low and comprised of a silty muck. The substrate composition at this site was 95% muck with 5% hardpan and detritus. Poor instream conditions: low substrate stability, heavy siltation, and extensive embeddedness, contributed to the low QHEI score of 38 points out of 100. Site 3 from the macroinvertebrate survey is considered severely impaired with a mIBI of 0.6. The prominent macroinvertebrate genus

collected at the site was Diptera:*Chironomidae*, a genus with many species, many of which are notable as being excellent indicators of organic pollution and having moderate tolerance to organic wastes.

Figure 119. Meredith Arm Swick-Meredith Drain facing north from private crossing of drain midway between CR 600 W and CR 675 W.

The water sampling results from Site 3 were better in some ways than Site 2 upstream, but in other ways reflected the poor streamside buffer upstream. Oxygen was at 6.2 mg/l at base flow with 74.2% saturation. Total suspended solids increased significantly during storm flows from 2.67 mg/l to 36.33 mg/l and the corresponding turbidity measurement also increased (4.2 NTU to 8.6 NTU), reflecting the erosion of the adjacent agricultural field noted during the walking tour. The result is a dominance of Chironomids which are tolerant of poor water quality. Nitrate (NO_3) concentrations exceeded the Ohio EPA standard of 1.6 mg/l for warmwater streams at baseflow (2.64 mg/l) but was diluted during storm flows (0.980 mg/l). Ammonia (NH_4) concentrations increased from 0.105 mg/l during base flow to 0.324 mg/l during storm flows. This was similar to total phosphorus which increased from 0.83 mg/l during base flows but 0.155 mg/l during storm flows. The increase in solids and nutrients during the storm flows is likely caused by surface runoff and erosion of sediments into the stream. This stream is a nutrient and sediment source for Yellow Creek Lake.

6.4 Site 4: Johnson Arm 2 Swick-Meredith Drain

Located on the east side of Yellow Creek Lake, this drain brings water from Diamond Lake into Yellow Creek Lake. The drainage area at the location of the sample is approximately 2,690 acres (1,088 ha) and includes the entire drainage area of Diamond and Hill Lake. The sample site was on the west side of CR 675 W approximately 3/4 mile (1,200 m) south of CR 800 W (Figure 120).

The predominant land use at this site was forest. The riparian zone extended over 165 feet (50 m) on both banks. Riparian vegetation was dominated by trees and shrubs. Overhanging vegetation, shallows, rootwads, and aquatic macrophytes provided extensive instream cover. Bank stability was low and comprised of a silty muck. Substrate composition at this site was 95% muck with 5% detritus. Poor instream conditions: low substrate stability, heavy siltation,

and extensive embeddedness, contributed to the relatively low QHEI score of 49 out of 100 points. This site resulted in the highest scoring site of the watershed as a result of the higher instream cover score (18 points). The mIBI metric for this site was 0.6. This score indicates that the stream reach is severely impaired. The macroinvertebrate composition at this site included mostly Diptera:*Chironomidae* (45%), a large genus, with many species notable as being excellent indicators of organic pollution and having moderate tolerance to organic waste; with the presence of other pollution tolerant families: *Sphaeridae* (25%) and Oligochaeta:*Tubificidae* (23%). The site is likely influenced more by its upstream riparian influences than local habitat.

Figure 120. Johnson Arm 2 of the Swick-Meredith Drain facing east from CR 675W.

The water sampling results from Site 4 demonstrated the influence of Diamond Lake upstream. Oxygen was at a healthy 6.1 mg/l at base flow with only 77.1% saturation, but during storm flows surged to 12.1 mg/l and 142% saturation. Since the 142% is considered supersaturation and is only gained from intense algae production, it is likely that the storm flows measurements reflected Diamond Lakes epilimnion more than the natural stream condition. Chironomids were still the dominant invertebrate taxa which represents poor water quality and substrate. Nitrate (NO_3^-) concentrations were relatively low at 1.31 mg/l during storm flows and 0.27 mg/l during base flows. Ammonia (NH_4) concentrations were also normal at 0.344 mg/l during storm flows and 0.238 mg/l during base flows. The Ohio EPA standard for nitrate is 1.6 mg/l for warmwater streams. Total phosphorus was 0.08 mg/l during diluted storm flows but 0.04 mg/l at base flow. The base flow concentration is more than the recommended concentration of phosphorus for developing eutrophic conditions (0.03 mg/L). Total suspended solids increased significantly during storm flows from 5.0 mg/l to 18.5 mg/l and the corresponding turbidity measurement also increased (4.9 NTU to 16.5 NTU), reflecting upstream erosion or plankton. This stream is a nutrient source for Yellow Creek Lake and is transporting nutrients from Diamond Lake.

6.5 Site 5: Hanes William Arm Swick-Meredith Drain

This sample is located on the south side of Diamond Lake and at the point of the sample drains water from approximately 162 acres (65.5 ha) of an agricultural watershed (the unsampled and mostly tiled tributary to Hill Lake from the west is 283 acres or 114.5 ha). The sample site was on the north side of CR 950 S approximately 900 feet (275 m) east of CR 550 W (Figure 121).

The predominant land use at this site was row crop agriculture. The riparian zone extended between 16.5 and 33 feet (5 and 10 m) on both banks. Riparian vegetation was dominated by grasses and trees. Overhanging vegetation, shallows, aquatic macrophytes, and woody debris provided moderate instream cover. The bank stability was low comprised of a silty muck. Substrate composition at this site was 95% muck with 5% sand and detritus. Poor instream conditions: low substrate stability, heavy siltation, and extensive embeddedness, contribute to the low QHEI score of 32 out of 100 points. The mIBI for site 5 was a 1.0 indicating that the stream was severely impaired. The prominent macroinvertebrates collected (46%) were Oligochaeta: *Tubificidae*, a family tolerant to poor water conditions, and Diptera:*Chironomidae* (33%), a species notable as being excellent indicators of organic pollution and having moderate tolerance to organic wastes.

Figure 121. Hanes William Arm of Swick-Meredith Drain facing north from CR 950 S.

The water sampling results from Site 5 reflects its small agricultural watershed. Oxygen was relatively high at 7.9 mg/l at base flow with 84.6% saturation and similar during storm flow (7.6 mg/l at 79.2% saturation). Total suspended solids increased significantly during storm flows from 7.89 mg/l to 121.7 mg/l, and the corresponding turbidity measurement also increased (2.0 NTU to 3.7 NTU), reflecting the erosion of adjacent agricultural fields. The result is a dominance of tubificid worms, which are tolerant of extremely poor water quality. Nitrate (NO_3) concentrations exceeded the Ohio EPA standard of 1.6 mg/l for warmwater streams at baseflow (4.9 mg/l) and increased further during storm flows (5.72 mg/l). Ammonia (NH_4) concentrations were diluted during high flows, decreasing from 0.155 mg/l during base flow to 0.082 mg/l during storm flows. Total phosphorus, increased from 0.0.17 mg/l during base flows to 0.23 mg/l during storm flows. This stream is a sediment and nutrient source for Diamond Lake.

6.6 Site 6: Johnson Arm Swick-Meredith Drain

The location of the sample site is a small drainage on the southeast side of Diamond Lake. The drainage area at the sample location carries water from approximately 458 acres (185 ha) of agricultural ground. The sample site was on the west side of CR 675 W approximately 3/4 mile (1,200 m) south of CR 800 W (Figure 122).

The predominant land use at this site was row crop agriculture. The riparian zone extended between 3 and 16.5 feet (1 and 5 m) on the left downstream bank, and is negligible on the right bank. Riparian vegetation was dominated by grasses and shrubs. Aquatic macrophytes and to a lesser extent overhanging vegetation provided extensive instream cover. Bank stability was moderate comprised predominantly of a silty muck with coble and gravel. Substrate composition at this site was 90% muck with 10% coble, gravel, and hardpan. Poor instream conditions: moderate substrate stability, heavy siltation, and extensive embeddedness, contributed to the low QHEI score of 33.5 out of 100 points. The highest mIBI score of 3.8 was recorded at Site 6, indicating that this stream reach is moderately impaired. The prominent macroinvertebrate collected at the site was Ephemeroptera: *Baetidae* (85%) which is a family intolerant of poor water conditions.

Figure 122. Johnson Arm Swick-Meredith Drain facing east from CR 675 W.

The results from Site 6 did not entirely reflect the agricultural watershed and poor streamside buffer. Oxygen was at 8.2 mg/l at base flow with 92.3% saturation and similar during storm flows (8.1 mg/L, 84.6% saturation). Total suspended solids increased significantly during storm flows from 0.88 mg/l to 5.02 mg/l and the corresponding turbidity measurement also increased (3.4 NTU to 6.6 NTU), reflecting some erosion or other source of solids. A mayfly species (Baetidae family) was the dominant taxa which does not generally tolerate poor water quality, but may be reflecting the groundwater discharge that this drainage is intercepting. Nitrate (NO_3)

concentrations exceeded the Ohio EPA standard of 1.6 mg/l for warmwater streams at baseflow (5.24 mg/l) but was diluted during storm flows (0.06 mg/l). Ammonia (NH_4) concentrations also were diluted from 0.152 mg/l during base flow to 0.077 mg/l during storm flows. This was th opposite of total phosphorus which increased from 0.015 mg/l during base flows to 0.056 mg/l during storm flows. The increase in solids during the storm flows is likely caused by surface runoff and erosion of sediments, but the nitrate and ammonia source is local groundwater leaching. This stream is a nutrient and sediment source for Diamond Lake.

6.7 Site 7: Michael Arm Swick-Meredith Drain

Located on the north side of Diamond Lake, this drain brings water from Hill Lake and its watershed into Diamond Lake. The drainage area at the location of the sample is approximately 1,300 acres (526 ha). The sample site included both sides of a private road crossing at West High Street (approximately CR 850 S) (Figure 123).

The predominant land use at this site was residential with old fields upstream. The riparian zone extended from 16.5 to 33 feet (5 to 10 m) on the left downstream bank, and between 33 to 165 feet (10 to 50 m) on the right bank. Riparian vegetation was dominated by trees and shrubs upstream, and grasses downstream. Overhanging vegetation, rootwads, woody debris, and undercut banks provided moderate instream cover. Bank stability was low comprised of a silty muck. Substrate composition at this site was 95% muck with 5% detritus. Poor instream conditions: low substrate stability, heavy siltation, and extensive embeddedness, contributed to the low QHEI score of 32 out of 100 points. A score of 0.8 indicates that the stream reach is severely impaired. The macroinvertebrate composition at this site included mostly Diptera:*Chironomidae* (58%), a species notable as being excellent indicators of organic pollution and having moderate tolerance to organic wastes.

Figure 123. Michael Arm Swick-Meredith Drain facing downstream (left) and upstream (right) from West High Street.

The water sampling results from Site 7 are similar to the other Yellow Creek Lakes streams and reflects the condition of its watershed. Oxygen was at 5.1 mg/l at base flow with only 58% saturation, and similar during storm flows (5.5 mg/L, 61% saturation). Chironomids were still the dominant invertebrate taxa which represents poor water quality and substrate. Nitrate (NO_3^-)

concentrations were similar at base flow (2.27) mg/l and storm flow (2.87 mg/l). Ammonia (NH_4) concentrations were diluted during storm flows from 0.327 mg/l at base flow to 0.15 mg/l during storm flow. Total phosphorus was 0.38 mg/l during base flows and increased to 0.094 mg/l during the storm flow. The base flow concentration is more than 10 times the recommended concentration of phosphorus for developing eutrophic conditions (0.03 mg/L). Total suspended solids increased significantly during storm flows from 2.0 mg/l to 19.64 mg/l and the corresponding turbidity measurement also increased (3.3 NTU to 7.7 NTU), reflecting organic debris, upstream erosion or plankton. This site had the highest storm flow bacteria counts at 5,170 colonies per 100 ml., which is likely due to livestock grazing upstream. This stream is a nutrient source for Diamond Lake.

Table 83. Physical Characteristics of the Yellow Creek Lake watershed stream samplings on June 5, 2008 (storm flow) and July 16, 2008 (base flow).

Site	Date	Timing	Flow (cfs)	Temp (°C)	D.O. (mg/L)	D.O. Sat. (%)	Cond. (µS/m)	TSS (mg/L)	Turbidity (NTU)
1	6/5/08	Storm	0.589	17.5	2.5	25.7	483	0.84	1.6
	7/16/08	Base	0.071	21.8	0.9	8.7	666	10.22	3.4
2	6/5/08	Storm	2.616	23.9	5.0	58.1	373	2.35	2.0
	7/16/08	Base	0.156	24.6	3.9	41.4	527	3.10	1.8
3	6/5/08	Storm	4.967	22.7	4.6	52.3	382	36.33	8.6
	7/16/08	Base	1.054	25.1	6.2	74.2	466	2.67	4.2
4	6/5/08	Storm	3.412	24.0	12.1	142.0	383	18.53	16.5
	7/16/08	Base	2.781	27.9	6.1	77.1	338	5.00	4.9
5	6/5/08	Storm	0.770	13.7	7.6	72.6	522	121.67	3.7
	7/16/08	Base	0.230	13.4	7.9	79.2	648	7.89	2.0
6	6/5/08	Storm	0.472	16.3	8.1	84.6	553	5.02	6.6
	7/16/08	Base	0.404	19.2	8.2	92.3	620	0.88	3.4
7	6/5/08	Storm	5.770	19.8	5.5	61.0	407	19.64	7.7
	7/16/08	Base	1.776	20.1	5.1	58.0	525	2.00	3.3

Table 84. Chemical and bacterial characteristics of the Yellow Creek Lake watershed stream samplings on June 5, 2008 (storm flow) and July 16, 2008 (base flow).

Site	Date	Timing	pH	NH_3 (mg/L)	NO_3^- (mg/L)	TKN (mg/L)	TP (mg/L)	SRP (mg/L)	*E. coli* (CFU/100 ml)
1	6/5/08	Storm	7.1	0.470	4.100	2.700	0.199	0.198	305
	7/16/08	Base	7.2	0.468	1.829	1.362	0.305	0.221	810
2	6/5/08	Storm	8.0	0.281	0.440	2.604	0.060	0.031	230
	7/16/08	Base	6.9	0.447	0.179	1.316	0.090	0.063	910
3	6/5/08	Storm	7.7	0.324	0.980	2.809	0.155	0.010*	240
	7/16/08	Base	7.0	0.105	2.624	1.183	0.083	0.033	470
4	6/5/08	Storm	8.7	0.344	1.311	1.907	0.081	0.010*	110
	7/16/08	Base	7.1	0.238	0.427	0.983	0.041	0.010*	310
5	6/5/08	Storm	7.3	0.082	5.719	0.877	0.230	0.064	770
	7/16/08	Base	7.9	0.155	4.900	0.230*	0.017	0.012	2250
6	6/5/08	Storm	7.3	0.077	0.060	1.305	0.056	0.034	4350
	7/16/08	Base	7.1	0.152	5.240	0.271	0.015	0.010*	247
7	6/5/08	Storm	7.5	0.150	2.871	1.612	0.094	0.061	5170
	7/16/08	Base	7.1	0.327	2.274	0.621	0.038	0.027	460

* Method Detection Limit

Table 85. QHEI Scores for the Yellow Creek Lake inlet and outlet sampling sites, July 16, 2008.

Site	Substrate Score	Cover Score	Channel Score	Riparian Score	Pool Score	Riffle Score	Gradient Score	Total Score
Maximum Possible Score	20	20	20	10	12	8	10	**100**
Site 1	0	14	6	4.0	4	0	4	**32.0**
Site 2	0	18	7	4	5	0	4	**38**
Site 3	2	16	6	3	5	0	6	**38**
Site 4	0	18	7	9	7	0	8	**49**
Site 5	0	11	4	5	6	0	6	**32**
Site 6	5	13	5	3.5	3	0	4	**33.5**
Site 7	2	11	7	6	0	0	6	**32**

Table 86. Tributary macroinvertebrate index of Biotic Integrity (mIBI) values for each stream sampled in the Yellow Creek Watershed on July 16, 2008.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
HBI	9.3	7.9	6.6	7.9	8.0	4.5	6.1
No. Taxa (family)	6	5	7	5	8	6	7
Total Count (# of individuals)	68	19	96	56	48	100	24
% Dominant Taxa	71	37	68	45	46	85	67
EPT Index	0	3	1	0	0	1	2
EPT Count	0	0	1	0	0	85	4
EPT Count/Total Count	0	0	0.01	0	0	0.85	0.17
EPT Abun./Chir. Abun.	0	0	0.1	0	0	17.2	0.25
Chironomid Count	9	7	65	25	15	5	16
Individuals per Square	20	6	30	16	12	33	7

Table 87. Classification Scores and mIBI Score for each sampling site in the Yellow Creek Watershed on July 16, 2008.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
HBI	0	0	0	0	0	6	0
No. Taxa (family)	0	0	0	0	2	0	0
No. of Individuals	0	0	2	0	0	2	0
% Dominant Taxa	0	4	0	0	2	0	0
EPT Index	0	0	0	2	0	0	0
EPT Count	0	0	0	0	0	4	0
EPT Count/Total Count	0	0	0	0	0	8	2
EPT Abun./Chir. Abun.	0	0	0	0	0	8	0
Chironomid Count	8	8	2	4	6	8	6
Individuals per Square	0	0	2	0	0	2	0
mIBI Score	**0.8**	**1.2**	**0.6**	**0.6**	**1.0**	**3.8**	**0.8**

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

7.0 SUMMARY AND DISCUSSION

7.1 General Watershed Issues

The six Yellow Creek Lakes combined equal approximately 515 acres of open water in a drainage basin of approximately 6535 acres. On average, 8,231 ac-ft of water is discharged from this drainage basin through the Yellow Creek Lake outlet annually. This water originates as rainfall throughout the watershed. The Yellow Creek Lakes overall watershed to lake ratio is approximately 12.6:1. This means that for every acre of open water there is over 12 acres of the landscape draining to that water. While this in the median range of most Indiana glacial lakes it means that lake water quality may be affected more by actions and processes in the watershed than by in-lake processes and actions (most glacial lakes have a watershed area to

lake surface area ratio of around 10:1). At the very least, the landscape that drains to these lakes cannot be ignored if the residents want to improve water quality.

An examination of the historic data reveals that all of the Yellow Creek Lakes have had relatively stable water quality values for the last 40 years of testing. However, with the exception of Hill Lake, they have historically exhibited below average water quality for Indiana lakes. Hippensteel (1989) reported Secchi disk readings (a measure of water clarity) of only 2-4 feet (0.61 to 1.2 m) from Beaver Dam, Diamond, and Yellow Creek Lake in his work conducted during 1988. Out of all six lakes Hill Lake has the highest recorded Secchi disk reading of 15 feet (4.6 m) (Taylor, 1974), while McClures Lake had the lowest reading at 1.3 feet (0.4 m) (Lesko, 2007). The median Secchi disk measurement from 456 Indiana Lakes sampled from 1994-2004 is 6.9 feet (2.1 m) (CLP, 2004).

Total phosphorus concentrations ranged from 0.010 mg/l in Hill Lake and Loon Lake epilimnion samples (Lesko, 2007) to 0.392 mg/l in Diamond Lake (CLP, 1998). The median concentration of total phosphorus in 456 Indiana Lakes sampled from 1994-2004 is 0.17 mg/l (CLP, 2004). Indiana Trophic Index scores (a measure that takes into account a number of water quality factors) were in the mesotrophic to eutrophic range for Hill Lake, mesotrophic to hypereutrophic range for Loon and McClures Lakes, and eutrophic to hypereutrophic for Beaver Dam, Diamond and Yellow Creek Lake considering data from 1966-2004.

When comparing the individual lakes in the watershed to each other for management decisions it is useful to look at their individual hydraulic residence times (how long it takes water in each lake to be replaced or move through the system). Of the six lakes, Hill Lake had the longest hydraulic residence time (2.05 years) and Loon Lake had the shortest (0.33 years) (Table 88). In a study of 95 north temperate lakes in the U.S., the mean hydraulic residence time of the lakes was 2.12 years (Reckhow, 1979). There are more than 40 acres of watershed surface draining into each acre of Loon Lake and Yellow Creek Lake, while Hill Lake has only 7.5 acres of landscape drainage for each acre of water. As a general rule the management implications of these ratios mean that to improve water quality in Loon Lake and Yellow Creek Lake, we need to focus on the watershed, while in Hill Lake we need to focus more efforts on in-lake or shoreline practices. However, that does not mean that obvious pollutant issues should be ignored in either the lake or the watershed.

Table 88. Water Budget Summaries for Yellow Creek watershed lakes.

Lake	Volume (V, in acre-ft)	Discharge (Q) (in acre-feet per yr)	Residence Time (V/Q) (in years)	Watershed Area: Lake Area
Beaver Dam	2276	1621	1.40	8.7:1
Diamond	1257	2545	0.49	31.8:1
Hill	1267	620	2.05	7.1:1
Loon	719	2205	0.33	40.1:1
McClures	713	779	0.92	19.2:1
Yellow Creek	4772	8231	0.58	43.3:1

The Yellow Creek Lakes Watershed lies in Tipton Till plain and has approximately 50 feet of relief from the highest point in the watershed to the outlet of Yellow Creek Lake. The soils of the watershed are largely muck, loamy sands, or loam. While only 38% of the watershed is classified as having highly erodible soils, 58% of the soils are severely limited, and another 29% are moderately limited for septic systems due to poor drainage or drainage that is too rapid. Approximately 980 residences, trailers, and farms were counted on the 2005 aerials as being

within the watershed. This is a density of one residence for each 6.67 acres (2.7 ha). While these densities do not warrant concern on a watershed wide scale, approximately 83% of the residences are clustered within 400 feet of the lakeshores, far exceeding the EPA recommended densities of no more than one system per 20 acres. Combine the lake shore home densities with severely limited soils and there is bound to be nitrate and phosphorus runoff or leaching to the lakes from failed or overloaded septic leach fields. Cleaning and regular maintenance of septic tanks and leach fields should be a priority for lakeshore property owners.

Wetland loss in the Yellow Creek watershed is estimated at 85%, mostly due to agricultural drainage but also due to lakeshore development. Wetlands are important nutrient sinks and serve to filter pollutants from runoff before they reach lakes and streams. Combining the septic suitability issue of the soils with the loss of wetlands, and it is not surprising that the Yellow Creek lakes and streams have above average levels of nutrients.

As is typical for nutrient rich lakes, the fish populations of the six Yellow Creek Lakes are in relatively good health. In general, there is a good bass-bluegill fishery in all the lakes. The size of the game fish have generally increased from 1965 to 2006 based on IDNR fisheries surveys. Gizzard shad appear to be the largest fish management issue as they tend to overpopulate and reduce food resources available to bluegill. Largemouth bass, and in some lakes gar, are playing an important role in keeping the population of desirable game-fish, such as bluegill, and undesirable fish species, such as gizzard shad in check. Bluegill and other sunfish species typically over populate a lake and become stunted without adequate predation. The predators (bass, pike, and gar) help in two ways: 1) by helping to reduce intra-specific competition between young bluegill through limitation of their numbers; and 2) by reducing inter-specific competition of resources between young gizzard shad and young bluegill through the control of gizzard shad numbers. By continuing to manage the Yellow Creek Lakes for larger bass, and keeping the gizzard shad numbers in check, the bluegill populations will remain healthy. The discussion of Individual lakes fish communities and management follows in Section 6.2 below.

The Yellow Creek Lakes have relatively good populations of aquatic macrophytes. The diversity of species identified to date each lake ranges from18 in McClures Lake to a high of 31 in Yellow Creek Lake. This diversity does not include all shoreline emergent species which could not be seen from the lake. It is important to manage lakes for a diversity of aquatic macrophytes for several reasons: 1) A diverse native, rooted aquatic plant community supports a healthy fish population with habitat, cover, and the release of oxygen into the water column; 2) a band of rooted vegetation along the shoreline significantly reduces shoreline erosion; 3) plants roots bind the sediments that would otherwise be disturbed by wave action; and 4) the plants take up nutrients from the sediment and the water column making them less available to undesirable algae, thereby improving water quality.

Like other biota in a lake ecosystem (e.g. fish, microscopic plants and animals, etc.), the composition and structure of the lake's rooted plant community often provide insight into the long term water quality of a lake. Because rooted plants live for many years in a lake, the composition and structure of this community reflects the water quality of the lake over a longer term. The composition and structure of a lake's rooted plant community also help determine the lake's fish community composition and structure. Submergent aquatic vegetation provides cover from predators and is a source of forage for many different species of fish (Valley et al., 2004). However, extensive and dense stands of exotic aquatic vegetation can have a negative impact on the fish community. For example, a lake's bluegill population can become stunted because dense vegetation reduces their foraging ability, resulting in slower growth. Conversely,

lakes with limited plant communities may have difficulty supporting some top predators that require emergent vegetation for spawning. In these and other ways, the lake's rooted plant community plays a key role in the fish community composition and structure.

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

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

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

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

The presence of the exotic invasive plants Eurasian watermilfoil, curly-leaf pondweed (Figure 124) and purple loosestrife (Figure 125) is typical in northern Indiana lakes and these plants are found in most of the Yellow Creek Lakes. Of the lakes surveyed in northern Indiana by Aquatic Control, Inc., and IDNR Fisheries Biologists, nearly every lake supported at least one exotic species (White, 1998a). Despite the ubiquitous presence of nuisance species, lakeshore property owners should continue management efforts to limit nuisance species populations where possible. A description of each of these species follows.

Figure 124. Eurasian watermilfoil (*Myriophyllum spicatum*) and Curly leaf pondweed (*Potamogeton crispus*).

Figure 125. Purple loosestrife (*Lythrum salicaria*).

Eurasian watermilfoil is an aggressive, non-native species common in northern Indiana lakes. It often grows in dense mats excluding the establishment of other plants. For example, once the plant reaches the water's surface, it will continue growing horizontally across the water's surface. This growth pattern has the potential to shade other submergent species preventing their growth and establishment. In addition, Eurasian watermilfoil does not provide the same habitat potential for aquatic fauna as many native pondweeds. Its leaflets serve as poor substrate for aquatic insect larva, the primary food source of many panfish.

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

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

7.2 Lakes

A wide variety of conditions, including geography, morphometry, time of year, and watershed characteristics, can influence the water quality of lakes. Thus, it is difficult to predict and explain the reasons for the water quality of a given lake. To help place lake data into perspective, consider the following data for 456 Indiana lakes collected during July and August 1994-2004 under the Indiana Clean Lakes Program (Table 95). The set of data summarized in the table represent mean values of epilimnetic and hypolimnetic samples for each of the 456 lakes.

Table 89. Water Quality Characteristics of 456 Indiana Lakes Sampled From 1994 through 2004 by the Indiana Clean Lakes Program. Means of epilimnion and hypolimnion samples were used.

	Secchi Disk (ft)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	Chl *a*	Plankton	Bl-Green Dominance (%)
Median	6.9	0.275	0.818	1.66	0.12	0.17	12.9	35570	53.8
Maximum	32.8	9.4	22.5	27.05	2.84	2.81	380.4	753170	100
Minimum	0.3	0.01	0.004	0.230	0.01	0.01	0.013	39	0.08

Table 90 shows mean concentrations of total phosphorus, total nitrogen, and chlorophyll *a* for the Yellow Creek watershed lakes for the July 16, 2008 samples. Total nitrogen includes TKN + nitrate-nitrogen. All of the lakes were within the eutrophic and mesotrophic ranges for the three water quality parameters. All lakes except Hill showed evidence of substantial internal loading of phosphorus from the sediments.

Table 90. Summary of mean total phosphorus, total nitrogen, Secchi disk transparency, and Chlorophyll *a* results for Beaver Dam, Diamond, Hill, Loon, McClures, and Yellow Creek Lakes.

Parameter	Beaver Dam	Diamond	Hill	Loon	McClures	Yellow Creek
Total Phosphorus (mg/L or PPM)	0.236	0.230	0.040	0.280	0.156	0.122
Total Nitrogen (mg/L or PPM)	2.424	2.650	1.808	3.940	4.836	1.732
Secchi disk transparency (ft)	2.8	2.3	5.9	3.0	1.5	2.3
Chlorophyll *a* (µg/L or PPB)	20.8	20.8	2.78	12.48	53.7	15.1
Sediment phosphorus release factor[1]	19.2	37.6	1	43.2	17.1	17.9

[1]Hypo SRP concentration/Epi SRP concentration. For example, Diamond's hypolimnetic SRP concentration is 37.6 times that in the epilimnion. This difference is strong evidence of substantial internal loading of phosphorus.

Table 91 compares the mean of selected water quality parameters for the Yellow Creek watershed lakes to the median value for all Indiana lakes. The Yellow Creek watershed lakes generally had worse transparency, ammonia, TKN and were more likely to be dominated by Blue-green algae than the 456 Indiana lakes sampled between 1994 and 2004. The Yellow Creek watershed lakes had lower nitrate concentrations and generally lower plankton densities than the group of Indiana lakes. Of the Yellow Creek watershed lakes, Yellow Creek Lake was more likely to be better than the 456 Indiana lakes for most water quality parameters.

Table 91. Comparison of Beaver Dam, Diamond, Hill, Loon, McClures, and Yellow Creek lakes to the Median for all Indiana Lakes for selected water parameters.

Lake	Secchi Disk	NO_3	NH_4	TKN	SRP	Total Phos.	Chl *a*	Plankton	Bl-green Dominance
Beaver Dam	worse	better	worse	worse	better	worse	worse	better	worse
Diamond	worse	better	worse	worse	worse	worse	worse	worse	worse
Hill	worse	better	worse	worse	better	better	better	better	worse
Loon	worse	better	worse	worse	worse	worse	better	better	worse
McClures	worse	better	worse	worse	better	better	worse	better	worse
Yellow Creek	worse	better	better	better	better	better	worse	better	worse

Table 92 presents typical concentrations of key nutrients in lakes and their relationship to trophic levels typically found in lakes (Vollenweider, 1975).

Table 92. 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	-

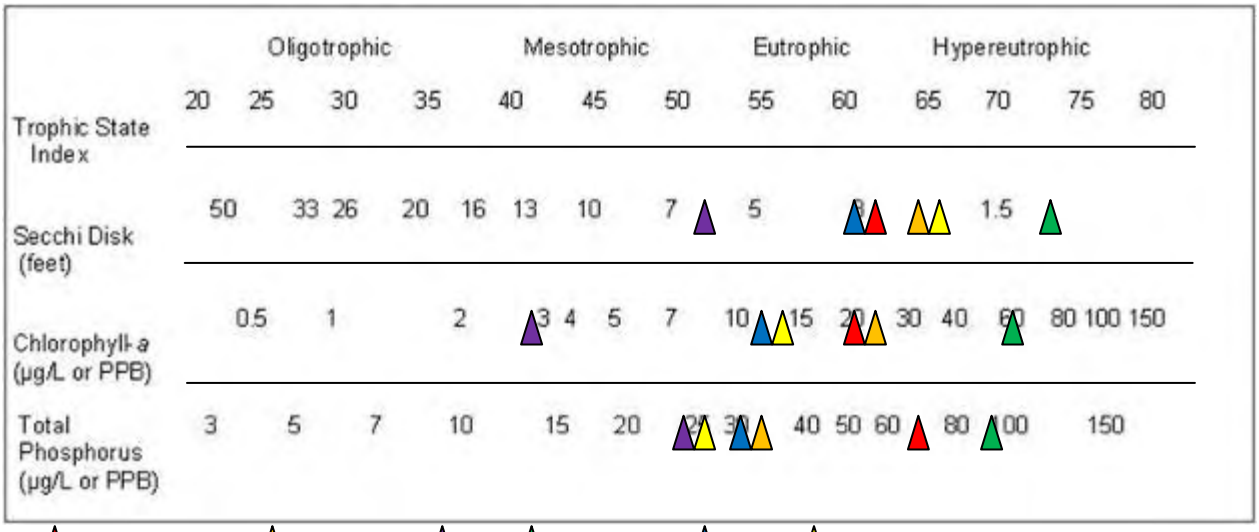
The Indiana Trophic State Index values calculated for Beaver Dam, Diamond, Hill, Loon, McClures and Yellow Creek lakes over the years are shown in Table 93. Diamond, Loon, McClures, and Yellow Creek lakes were all classified as eutrophic based on our current data. Each of these lakes had steady or worsening Indiana TSI scores over the past three sampling periods (1998, 2004, and 2008). Hill and Beaver Dam lakes were classified as mesotrophic. Hill and Beaver Dam lakes are both headwaters lakes with small watersheds relative to their lake area. Both of these lakes showed improvement in Indiana TSI scores over the past three sampling periods.

Table 93. The Indiana Trophic Index 1991, 1994, 1998, 2004 and 2008 for all six Yellow Creek watershed lakes

	1991	1994	1998	2004	2008
Diamond Lake	-	-	44	42	44
Loon Lake	31	27	42	-	43
McClures Lake	32	23	-	41	40
Yellow Creek Lake	-	-	38	37	41
Hill Lake	-	27	33	29	27
Beaver Dam Lake	-	39	52	40	33

Source: Indiana Department of Environmental Management. “Clean Lakes Program.” 1990-2008.

CARLSON'S TROPHIC STATE INDEX



Beaver Dam, Diamond, Hill, McClures, Loon, Yellow Creek

Figure 126. Carlson's Trophic State Index showing the positions of the Yellow Creek watershed lakes.

Table 94. Carlson TSI Results for Yellow Creek Watershed Lakes

Lake	TSI – Secchi Disk	TSI - CHL	TSI – TOTAL P
Beaver Dam	62	60	71
Diamond	65	60	55
Hill	52	41	49
Loon	62	55	55
McClures	73	70	68
Yellow Creek	65	57	51

When compared to Carlson's Secchi Disk TSI in Figure 126, Beaver Dam, Diamond, Hill, Loon, McClures and Yellow Creek lakes fell into the eutrophic and hypereutrophic classes. Only Hill Lake was classified as mesotrophic according to Carlson's TSI. McClures Lake had the highest Carlson TSI scores for each parameter.

The following discussion for each lake summarizes the parameters documented throughout this study. The overall theme from each lake is that excess plant productivity and organic matter promote high BOD, which in turn consumes dissolved oxygen, which leads to the chemically-reducing conditions permitting internal phosphorus release from the sediments.

7.2.1 Beaver Dam Lake

Beaver Dam Lake is 146 acres with a maximum depth of 61 feet, a mean depth of 15.6 feet, and contains 2276 acre feet of water. The residence time of water in the lake is about 1.4 years from a watershed of 1266 acres. There are only two defined drainages to the lake, the smaller of the two on the west side of the lake and the larger on the southwest end of the lake. Water leaves Beaver Dam Lake and flows south through a culvert and into a ditch toward Loon Lake. Nearly 90 percent of the shoreline has been developed for residential use with over 324 homes present within 400 feet of the lakeshore. This represents about 33% of the homes in the Yellow

Creek Lakes watershed. The residents are all on private septic systems and have private wells. Thirty acres (12.1 ha) of the lake are less than five feet (1.5 m) deep and 70 acres (28.3 ha) are less than 20 feet (6.1 m) deep. This zone of shallow water known as the littoral zone is capable of supporting rooted plants. The Secchi disk depth measured during the plant survey at Beaver Dam Lake was 4.5 feet (1.4 m). As a general rule of thumb, rooted plant growth is restricted to the portion of the lake where water depth is less than or equal to 2 to 3 times the lake's Secchi disk depth. This was not the case in Beaver Dam Lake where plants were observed to a depth of only 8 feet (2.4 m), which is about the same depth as the 1% light level penetration that was measured during the July 2008 water sampling. In previous reports rooted submergent plants have been noted as deep as 15 feet (4.6 m) which represents about one-third of the lake surface.

Twenty-six species of plants were documented in Beaver Dam Lake including four pondweed species that prefer clear water (Davis and Brinson, 1980; Borman et al., 1997; Curtis, 1998). However, Beaver Dam Lake also possesses a variety of plants that are tolerant of lower light conditions, such as coontail, Eurasian watermilfoil, and southern naiad. Sago pondweed, musk grass, and coontail were the dominant submergent species while purple loosestrife and reed canary grass were the dominant emergent shoreline plants. Eurasian watermilfoil was found just west of the public boat landing but was not a dominant species. The dominance of Sago pondweed is an indicator of long term eutrophic conditions. The historic plant survey data suggests that Beaver Dam Lake shifted from a high quality aquatic plant community in 1966 to a relatively turbid system dominated by algae in 1977. The partial fish eradication program enacted in 1966 may have created some of this shift. The winter kill of shad in 1962-1963 and again in 1970-1971 indicates that a shift in community structure occurred within this time frame.

Fisheries surveys of Beaver Dam Lake were conducted 12 times between 1965 and 2005 by the IDNR. Surveys have identified 29 species of fish in the lake and it has consistently been a relatively good largemouth bass and bluegill fishery. In 1966, the IDNR conducted a partial fish kill to reduce the stunted panfish population and subsequently restocked the lake with largemouth bass and a number of other species. Tiger muskie were stocked as an additional predator on the panfish in 1981 but never reproduced. Channel catfish were stocked in 1973, 1981 and again in 1992 without success. Walleye and northern pike were also stocked in 1973 without success. Subsequent studies suggested that fishing pressure on the lake, and the subsequent over harvest of larger panfish was the cause of the stunted population. In 2005 it was recommended that panfish bag limits be established to allow more fish to reach maturity and increase the average size of the harvest. The IDNR report also recommended that Eurasian watermilfoil be treated.

The water quality of Beaver Dam Lake has been below the median of most Indiana Lakes since monitoring began in 1966 but is showing signs of improvement. Secchi disk transparency measurements have ranged from a water depth of 2.3 to 7 feet (0.7 to 2.1 m) with an average of 4 feet (1.2 m) from 1966 to 2008 with no apparent trend. The water column has been thermally stratified during all sampling events with 8-12 ppm oxygen at the surface; however, at depths ranging from 12 to 25 feet (3-7 m) over those same sampling events the water column becomes anoxic. There is not enough oxygen below a depth of 25 feet in most summers to sustain fish. Fortunately that only equates to a loss of about 8 percent of the lakes water volume because most of the lake is shallower. While there is an apparent decline in total nitrogen from a high of 3.7 mg/l (1.66 mg/l is the Indiana Median; Table 95) to recent epilimnion measurements as low as 1.36 mg/L, this may be deceptive as recent hypolimnion measurements are still at 3.40 mg/L. Ammonia nitrogen follows the same general pattern with recent measurements of 0.04 mg/l in the epilimnion and 2.5 mg/L in the hypolimnion. Total phosphorus recordings average

approximately 0.3mg/l with recent measurements of 0.1 mg/l in the epilimnion and 0.367 mg/l in the hypolimnion. That is 10 times the recommended concentration of phosphorus for mesotrophic lakes (0.03 mg/l). The soluble reactive phosphorus which is the nutrient available for algae is being used for plankton production as it was measured at 0.01 mg/L in the epilimnion but 0.192 mg/l in the hypolimnion. As plankton settle in the water column they decompose. Bacteria use oxygen to decompose the plankton which is the most likely cause of the anoxic zone below the level at which light can sustain the plankton. As the nutrients also settle with the decomposing plankton, other organic matter or attached to sediment, they are released into the water column by chemical reactions with the anoxic water. Thus, the bottom of the lake is contributing to the over abundance of nutrients available for algae production. Unfortunately, the algae is dominated by blue-green algae, a type less preferred by zooplankton, mussels, and other plankton feeders. Summarizing the water quality using the Indiana Trophic State Index (ITSI), Beaver Dam lake has scored as poorly as 55 (hyper-eutrophic) back in 1972 to a relatively good 33 (low end of eutrophic) in the 2008 sampling.

Table 95. Water quality characteristics of 456 Indiana Lakes sampled from 1994-2004 by the Indiana Clean Lakes Program (Epilimnion and hypolimnion data averaged).

	Secchi Disk (ft)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	Chl *a* (µg/L)	Plankton (NU/L)	Bl-Green Dominance (%)
Median	6.9	0.275	0.818	1.66	0.12	0.17	12.9	35,570	53.8
Maximum	32.8	9.4	22.5	27.05	2.84	2.81	380.4	753,170	100
Minimum	0.3	0.01	0.004	0.230	0.01	0.01	0.013	39	0.08

7.2.2 Diamond Lake

Diamond Lake is 79 acres (32 ha) with a maximum depth of 39 feet (11.9 m), a mean depth of 16.4 feet (5 m), and contains 1257 acre-feet of water. The residence time of water in the lake is about six months from a watershed of 1555 acres. Water flows into Diamond Lake primarily from Hill Lake through a ditch entering the lake on the north side, but also has two minor drainages, one on the southwest side and one on the southeast side of the lake. Water leaves Diamond Lake on the northeast side and flows to Yellow Creek Lake. Approximately 60 percent of the Diamond Lake shoreline has been developed for residential use with 105 homes present within 400 feet of the lakeshore. This represents about 10% of the homes in the Yellow creek Lakes watershed. The residents are all on private septic systems and have private wells. Eleven acres (4.5 m) of the lake are less than five feet (1.5 m) deep and 56 acres (22.6 ha) are less than 20 feet deep. This zone of shallow water known as the littoral zone is capable of supporting rooted plants. The Secchi disk depth measured during the plant survey at Diamond Lake was 3.5 feet (1.1 m). As a general rule of thumb, rooted plant growth is restricted to the portion of the lake where water depth is less than or equal to 2 to 3 times the lake's Secchi disk depth. This is true in Diamond Lake where plants were observed to a depth of 10 feet (3.05 m), which is greater than the observed 1% light level penetration of 6.4 feet (1.95 m) measured during the July 2008 water sampling. Ten feet of depth represents about one-fourth of the lake surface that is likely to be vegetated in an undisturbed condition. This is important, because if you choose to improve water quality (clarity), then light will penetrate deeper and make more of the lake available for aquatic macrophyte growth. Just by obtaining the average Secchi disk transparency of Indiana lakes (6.9 feet), rooted aquatic macrophytes could reasonably inhabit 71 percent of the lake.

Twenty-five species of plants were documented including 11 submergent species in Diamond Lake. The submergent plant community was dominated by southern naiad, Eurasian watermilfoil, muskgrass, and sago pondweed; all of which are tolerant of lower light conditions and poor water quality. Whorled loosestrife, reed canary grass, and cattails were the dominant emergent shoreline plants. Floating leaved dominants included spatterdock, white water lily, and duckweed. The Diamond Lake Conservation Club began treating Eurasian watermilfoil using 2,4-D in 2006 with immediate results, and is planning additional herbicide treatments in the future in an attempt to eradicate the species from Diamond Lake as well as Hill Lake upstream. Although not identified during the current survey, historic assessments indicate the presence of curly-leaf pondweed in Diamond Lake, another submergent, aggressive, exotic species.

Fisheries surveys of Diamond Lake were conducted 12 times between 1964 and 2006 by the IDNR. Surveys have identified 33 species of fish in the lake and it has been a relatively good largemouth bass, yellow perch and bluegill fishery. In 1967, the IDNR conducted a fish kill to reduce dominant longear sunfish and gizzard shad as well as the stunted bluegill. They repeated the fish kill in 1973. Subsequent restocking included largemouth bass, bluegills, channel catfish, black crappie, walleye, and northern pike. The size (as PSD) of game fish in the IDNR surveys has increased steadily from 1985 to the 2006 survey; however, the percentage of gizzard shad in the population also continues to increase. Predators such as walleye and northern pike (which have not established themselves in Diamond Lake) and Largemouth bass are extremely important management tools for controlling shad numbers and keeping panfish populations from becoming stunted. The 14-inch minimum size limit has helped raise the average PSD value of bass, perch, and bluegill in Diamond Lake. This will continue as long as anglers support the minimum size limits on bass and do not over harvest the larger perch and bluegills.

The water quality of Diamond Lake has been below the median of most Indiana Lakes (Table 95) since monitoring began in 1964. Secchi disk transparency measurements have generally ranged from a water depth of 2 to 4 feet (0.6 to 1.2 m) from 1964 to 2008 with no apparent trend. The water column has been thermally stratified during all sampling events with 6-20 mg/l oxygen at the surface; however, at depths ranging from 12 to 20 feet (3 to 6 m) over those same sampling events the water column becomes anoxic. There is not enough oxygen below a depth of 12 feet (3.7 m) in most summers to sustain fish. Fortunately that only equates to a loss of about 25 percent of the lakes water volume because most of the lake is shallower. There is a general increase in nutrients (total nitrogen and total phosphorus) from 1990 to 2008. Total nitrogen was recently recorded as high as 4.02 mg/l in the hypolimnion (about 2.5 times the Indiana median; Table 95). Total phosphorus was recently recorded as high as 0.425 mg/l in the hypolimnion (also about 2.5 the Indiana median), although the recent epilimnion measurement was 0.34 mg/L. Ammonia nitrogen follows the same general pattern with recent measurements of 0.43 mg/l in the epilimnion and 2.5 mg/L in the hypolimnion. Soluble reactive phosphorus, which is the nutrient available for algae, is being used for plankton production as it was measured at 0.01 mg/L in the epilimnion but 0.376 mg/l in the hypolimnion (10 times the amount associated with eutrophic lakes). Similar to Beaver Dam Lake, the plankton are settling in the water column and decomposing. The anoxic conditions in the hypolimnion are causing the sediment to release nutrients back into the water column. Annual mixing of the epilimnion with the hypolimnion (fall turnover) makes the nutrients available for algae production. Like Beaver Dam Lake, the algae in Diamond Lake is dominated by blue-green algae. Diamond Lake shows some signs of improvement, with ITSI scores as poor as 60 (hyper-eutrophic) back in 1977 and improving to a score of 44 (eutrophic) in 2008 sampling.

7.2.3 Hill Lake

Hill Lake is 67 acres (27 ha) with a maximum depth of 35 feet (10.7 m), a mean depth of 18.9 feet (5.8 m), and contains 1267 acre-feet of water. Water flows into Hill Lake from its 479 acre (194 ha) watershed; there are no natural drainages entering the lake and it has a residence time of about 2 years. Water leaves Hill Lake on the west side and flows to Diamond Lake. Approximately 30 percent of the Hill Lake shoreline has been developed for residential use with about 115 homes and cottages present within 400 feet of the lakeshore. This represents about 12% of the homes in the Yellow creek Lakes watershed. The residents are all on private septic systems and have private wells (the private communities have a common system). Ten acres (4 ha) of the lake are less than five feet (1.5 m) deep and approximately 20 acres (8 ha) or 31 percent of the lake is less than 15.7 feet (4.8 m), which is the 1% light level. This zone of shallow water known as the littoral zone is capable of supporting rooted plants. The Secchi disk depth measured during the plant survey at Hill Lake was 8.5 feet (2.6 m) which would predict the growth of rooted vegetation to a depth of 25 feet (7.6 m). However, rooted aquatic macrophytes were documented at a maximum depth of 14 feet (4.3 m) during this study.

Twenty-three species of plants were documented including nine submergent species in Hill Lake. The submergent plant community was dominated by coontail, Eurasian watermilfoil, and muskgrass; all of which are tolerant of high nutrient concentrations. Reed canary grass, whorled loosestrife, and cattails were the dominant emergent shoreline plants. Floating leaved dominants included spatterdock, white water lily, and duckweed. A whole lake flouridone treatment for EWM is planned for 2009.

Fisheries surveys on Hill Lake were conducted nine times between 1965 and 1994 by the IDNR. Surveys have identified 27 species of fish in the lake and it is considered a good largemouth bass-Yellow Perch-bluegill fishery. In 1973, the IDNR conducted a fish kill to reduce stunted panfish and gizzard shad. Subsequent restocking included largemouth bass, bluegills, channel catfish, black crappie, walleye, and northern pike. Channel catfish remained in the population in 1994, as did northern pike, which are believed to be reproducing. Gizzard shad control using largemouth bass minimum size harvest regulations (14 inches) remains a successful management tool. The increased bass size should help reduce the stunted panfish populations. Secchi disk transparency depths measured historically, and as part of this study, indicate that Hill Lake has relatively good water clarity compared to most Indiana Lakes ranging from 3.3 to 12 feet (1 to 3.7 m). The Secchi disk transparency depth of 6 feet (1.8 m) recorded in 2008 is nearly the same as the statewide median of 6.9 feet (2.1 m) and is better than all the other Yellow Creek Lakes. The water column has been thermally stratified during all sampling events with 7-20 mg/l oxygen at the surface; however, at depths ranging from 10 to 20 feet (3 to 6 m) over those same sampling events the water column becomes anoxic. There is not enough oxygen below a depth of 10 feet (3 m) in most summers to sustain fish. Fortunately that only equates to a loss of about 20 percent of the lakes water volume available to the fish because most of the lake is shallower. There is no general trend in nutrient concentrations from 1966 to 2008. Total phosphorus has remained rather low for Indiana Lakes at 0.13mg/l or less (median 0.17 mg/l; Table 95). Total Nitrogen has also remained near or below the Indiana median of 0.166 mg/l. There is strong evidence of organic matter decomposition in the hypolimnion: Ammonia concentrations are 20 times greater in the hypolimnion than in the epilimnion (from 0.116 mg/l to 2.922 mg/l). Phosphorus is likely being released from the bottom sediments as a result of the anoxic conditions created by this decomposition. Algae are the primary users of nutrients, including nitrate and soluble reactive phosphorus. Ammonia oxidizes to nitrate in the presence of oxygen and allows the algae and other aquatic plants to uptake these nutrients. As algae die and sink to the bottom this cycle is repeated. Sequestering these nutrients in rooted macrophytes removes them from the water column for longer periods than algae. During the

July 2008 survey, blue-green algae made up 87.5% of the algae population. Despite the negative influence these algae have on the trophic index scores, Hill Lake still scored 27 points on the ITSI, putting it within the category of a mesotrophic lake.

7.2.4 Loon Lake

Loon Lake is 43 acres (17.4 ha) with a maximum depth of 40 feet (12.2 m), a mean depth of 16.7 feet (5.1 m), and contains 719 acre-feet of water. The residence time of water in the lake is about 4 months from a watershed of 461 acres. Water flows into Loon Lake primarily from Beaver Dam Lake through a ditch entering the lake on the north side, but also from a minor drainage on the south side of the lake. Water leaves Loon Lake on the east side and flows to Yellow Creek Lake. Approximately 50 percent of the Loon Lake shoreline has been developed for residential use with 24 homes present within 400 feet of the lakeshore. This represents 2% of the homes in the Yellow creek Lakes watershed. The residents are all on private septic systems and have private wells. Seven acres of the lake are less than five feet (1.5 m) deep and 27 acres (10.9 ha) are less than 20 feet deep. In mesotrophic lakes, this zone of shallow water, or littoral zone, is normally capable of supporting rooted plants. Aquatic vegetation was only growing at an observed maximum depth of 7 feet (2.1 m), which was slightly less than the 1% light level penetration of 8.5 feet (2.6 m) measured during the July 2008 water sampling. The 7-foot depth represents about 9 acres (3.6 ha) or 20 percent of the lake surface that is likely to be currently vegetated. If water quality were improved to increase clarity to the Indiana average Secchi disk measurement of 6.9 feet, then light penetration, and subsequent plant growth, could reach 20 feet, or 60 percent of the lakes surface area.

The shoreline inventory documented 56 percent of the shoreline remaining in its natural state. Loon Lake's rooted plant communities adjacent to the natural shorelines had greater plant diversity than those areas adjacent to developed portions of the shoreline. Twenty-two species of plants were documented during the Loon Lake surveys, including six submergent species. The submergent plant community was dominated by coontail. Eurasian watermilfoil was located on both the east and west shore, but in low densities. Reed canary grass, whorled loosestrife, and cattails were the dominant emergent shoreline plants. Floating leaved dominants included spatterdock, white water lily, and duckweed. Filamentous algae were documented at 87% of the sample sites. It is likely that curly-leaved pondweed also exists in Loon Lake.

Only three fisheries surveys of Loon Lake were conducted between 1965 and 2006 by the IDNR. Surveys have identified 26 species of fish in the lake including one hybrid. Loon Lake is considered to be a good panfish and largemouth bass fishery with a plentiful gar population. The bluegill and bass tend to be fewer in number but larger in Loon Lake. According to the IDNR, this is likely due to the presence of gar, which keep the populations in check.

The water quality of Loon Lake has been historically below the median of most Indiana Lakes. Except for spring readings, Secchi disk transparency measurements have ranged from a water depth of 2 to 5 feet (0.6 to 1.5 m) with no apparent trend from 1966 to present. The water column has been thermally stratified during all sampling events with 8-14 mg/l oxygen at the surface; however, at depths ranging from 10 to 15 feet (3.1 to 4.6 m) over those same sampling events the water column becomes anoxic. There is not enough oxygen below a depth of 12 feet (3.6 m) in most summers to sustain fish. When anoxia is present at 10 feet (3.2 m) this equates to a loss of 48% percent of the lakes water volume for fish habitat. At 20 feet, only 16% of the lake volume would anoxic. Loon Lake, like many of the Yellow Creek Lakes, is releasing phosphorus from its sediment, which is helping fuel algae production. Total phosphorus has been below the Indiana mean during most measurements (Table 95) but measurements in the hypolimnion alone are three times higher than the average (0.53 mg/L in 2008). Of the total

phosphorus measurement in the hypolimnion, soluble reactive phosphorus, which is the form available for nutrient uptake in plants, accounts for 0.43 mg/l. Total nitrogen, averaging about 4 mg/l is about 2.5 times the Indiana median, with the majority of that in the form of ammonia in the hypolimnion. As algae die and settle to the lake bottom along with other organic debris, the bacteria that decompose them use up the available oxygen continuing the cycle of nutrient release, and with fall turnover, nutrient availability for more algae (plankton) production. The plankton community is dominated by blue-green algae (70%), and accounts for 10 points of the 2008 ITSI score of 43 (highly eutrophic). This compares to a score of 27 (mesotrophic) in 1994.

7.2.5 McClures Lake

McClures Lake is 32 acres (17.4 ha) with a maximum depth of 30 feet (9.1 m), a mean depth of 22.2 feet (6.7 m), and contains 713 acre-feet of water. The residence time of water in the lake is about 11 months from a watershed of 614 acres. Water flows into McClures Lake from two small drainages, one on the south end of the lake and one entering on the northeast corner. Water leaves McClures Lake on the north end and joins with the water from Loon Lake flowing north to Yellow Creek Lake. There is less than 10 percent development of McClures Lake shoreline with a seasonal use camp on the east side and a one home on the west side. The camp and residence are on private septic systems and wells. Thirty six percent (11.5 acres or 4.7 ha) of the lake is less than five feet (1.5 m) deep and 78 percent (25 acres or 10.1 ha) is less than 20 feet (6.1 m) deep. This littoral zone is normally capable of supporting rooted plants in Midwestern glacial lakes. However; the median Secchi disk reading of 2.0 feet in McClures Lake (range 1.5 to 2.5 or 0.46 to 0.76 m) suggests that rooted aquatic macrophytes can only grow to a depth of 6 feet (1.8 m). In fact, during the study it was noted aquatic vegetation was only growing at a maximum observed depth of 3 feet (0.9 m), which was even less than the 1% light level penetration of 4.2 feet (1.3 m) measured during the July 2008 water sampling. This is likely due to dense algae blooms limiting light penetration and macrophyte growth. If water quality were improved to the Indiana average Secchi disk reading of 6.9 feet, then light penetration, and subsequent rooted plant growth, could reach 20 feet. Nearly 80 percent of the lakes surface area would support rooted macrophytes at a light penetration of 20 feet.

Natural plant communities existed adjacent to 93 percent of McClures Lake shoreline in 2007. Eighteen species of plants were documented during the vegetation surveys, including one submergent species, coontail, which dominated the water column. Eurasian watermilfoil was not documented during this survey. Reed canary grass, whorled loosestrife, and cattails were the dominant emergent shoreline plants. Floating leaved dominants included spatterdock, white water lily, and duckweed. Filamentous algae were documented at 79% of the sample sites.

Just two fisheries surveys have been conducted by the IDNR on McClures Lake during 1965 and 1985. Surveys have identified 21 species of fish in the lake including one hybrid. The most abundant fish in McClures Lake has been bluegill, followed by Largemouth bass. Game fish species accounted for 91 and 79 percent of the catch in respective IDNR sampling events. This may be due to the fact that over 93 percent of the lake volume is well oxygenated.

McClures Lake, despite it undeveloped nature, has high concentrations of nitrogen driving a plankton cycle. Secchi disk transparency measurements show a worsening trend, decreasing from a 1965 depth of 3.5 (1.1 m) to more recent cluster of measurements around 1.5 feet (0.45 m). The water column has been thermally stratified during all sampling events with 8 to 17 mg/l oxygen at the surface; however, at depths ranging from 10 to 20 feet (3.1 to 6.2 m) over those same sampling events the water column becomes anoxic. There is not enough oxygen below a depth of 15 feet (4.5 m) in most summers to sustain fish. When anoxia is present at 15 feet (4.5 m) this means a loss of 20% percent of the lakes water volume for fish habitat.

McClures Lake, like the other Yellow Creek Lakes, is releasing phosphorus from its sediment, which is helping fuel algae production. Total phosphorus has been below the Indiana mean during most measurements (0.07 to 0.16 mg/l), but measurements in the hypolimnion are two times higher than the Indiana median (0.17 mg/L). Soluble reactive phosphorus in the hypolimnion accounts for half of the total phosphorus, which is the form available for nutrient uptake in plants. Total nitrogen, has been 2 to 3 times (3.3 to 6.6 mg/l) the Indiana median (1.7 mg/l), with the majority of that in the form of ammonia in the hypolimnion. Ammonia is the reduced form of nitrate nitrogen (the reduction occurs when nitrate nitrogen encounters low oxygen conditions). There was a significant nitrate spike recorded in the 1991 sample. Algae utilize nitrates as food, but then die, settle to the lake bottom, decompose, and then the nutrients are released. A mixing of the water column on windy days or during fall turnover, allows the nutrients to cycle back up to the epilimnion and become available for more algae (plankton) production. The plankton community is dominated by blue-green algae (87.8%), and accounts for 10 points of the 2008 ITSI score of 40 (eutrophic). This compares to a score of 23 (mesotrophic) in 1994. McClures Lake productivity is limited by the phosphorus received.

7.2.6 Yellow Creek Lake

Yellow Creek Lake is 151 acres (61.1 ha) with a maximum depth of 67 feet (20.4 m), a mean depth of 31.6 feet (9.6 m), and contains 4,472 acre-feet of water. The residence time of water in the lake is about 7 months from a watershed of 2,160 acres. Water flows into Yellow Creek Lake about equally from the south and east in respective branches of the Swick-Meredith Drain. Water leaves Yellow Creek Lake on the north side and flows toward the Tippecanoe River. Approximately 85 percent of the Yellow Creek Lake shoreline has been developed for residential or camp use with 286 homes present within 400 feet of the lakeshore. This represents 29% of the homes in the Yellow creek Lakes watershed. The residents are all on private septic systems and have private wells with the exception of the camp. The camp has a private sewage treatment plant that discharges treated water directly into Yellow Creek Lake.

Twenty acres (6.1 ha) of the lake are less than five feet (1.5 m) deep and 42 acres (17 ha) are less than 20 feet deep. This zone of shallow water known as the littoral zone is capable of supporting rooted plants. The Secchi disk depth measured during the plant survey at Yellow Creek Lake was 4.2 feet (1.3 m). As a general rule of thumb, rooted plant growth is restricted to the portion of the lake where water depth is less than or equal to 2 to 3 times the lake's Secchi disk depth. This is true in Yellow Creek Lake where plants were observed to a depth of nearly 8 feet (2.4 m), which is greater than the observed 1% light level penetration of 2.1 feet (0.64 m) measured during the July 2008 water sampling. Eight feet of depth represents about 15 percent of the lake surface (23 aces or 9.3 ha) that is likely to be vegetated in an undisturbed condition with existing lake water quality. If water quality (clarity) is improved to the statewide median of 6.9 feet (Table 95), then light will penetrate deeper and make approximately 28 percent of the lake available for aquatic macrophyte growth.

Yellow Creek Lake has one of the most diverse plant communities of this lake chain. Thirty-one species of plants were documented including 12 submergent species. The submergent plant community was dominated by Sago pondweed, northern watermilfoil, and Eurasian watermilfoil; all of which are tolerant of lower light conditions and poor water quality. Purple Loosestrife and reed canary grass were the dominant emergent shoreline plants. Floating leaved dominants included spatterdock and duckweed. Although not identified during the current survey, historic assessments indicate the presence of curly-leaf pondweed in Yellow Creek Lake, another submergent, aggressive, exotic species. No organized lake wide chemical control has been undertaken or proposed to date.

Fisheries surveys of Yellow Creek Lake were conducted 5 times between 1965 and 1986 by the IDNR. Surveys have identified 34 species of fish in the lake and it has been a relatively good bluegill, yellow perch, and largemouth bass fishery. Prior to the first IDNR survey, the lake had been stocked with bluegill, redear sunfish, largemouth bass, and rainbow trout. White sucker and gizzard shad made up 41 percent of the IDNR catch in 1986. Since that time it is believed that the increases in minimum sizes for largemouth bass (12 inches in 1990 and 14 inches in 1998) may have altered the size structure such that the bass are now limiting the gizzard shad numbers and allowing game species to increase their growth rates.

The water quality of Yellow Creek Lake has historically below the median of most Indiana Lake and continues to be stable. Secchi disk transparency measurements have ranged from a water depth of 2.5 to 5.6 feet (0.76 to 1.7 m) from 1966 to 2008 with no apparent trend. The water column has been thermally stratified during all sampling events with 9-12 mg/l oxygen at the surface; however, at depths ranging from 16 to 20 feet (4.9 to 6 m) over those same sampling events the water column becomes anoxic. There is not enough oxygen below a depth of 16 feet in most summers to sustain fish. When anoxia occurs at 16 feet, fish can not live in approximately 43 percent of the lakes water volume that is below that depth.

There is a general increase in nutrients (total nitrogen and total phosphorus) from 1990 to 2008. Total nitrogen was recently recorded as high as 4.02 mg/l in the hypolimnion (about 2.5 times the Indiana median; Table 95). Total phosphorus appears to be increasing with 1976 values of 0.09 mg/l to 2007 values of 0.15 mg/l. However, the 1998 and 2004 CLP data, and the 2008 data, collected by the same methods, ranges from 0.122 to 0.148 mg/l without any apparent trends. The total phosphorus is concentrated in the hypolimnion (0.281 mg/l) and is about half soluble reactive phosphorus. Total nitrogen remains relatively stable at or lower than the Indiana median ranging from 1.25 mg/l in 1976 to 1.66 mg/l in 2004 and 1.5 mg/l in 2008. There was an unusual increase in nitrate concentrations from the epilimnion (0.068 mg/l) to the hypolimnion (0.406 mg/l) and a smaller increase in ammonia concentration from (0.06 mg/l to 1.92 mg/l) but denitrifying bacteria may adapt to low oxygenated conditions. Regardless, the increase in ammonia and phosphorus concentrations in the hypolimnion, mean that the sediments are releasing nutrients.

Similar to the other lakes in the Yellow Creek chain of lakes, the algae in Yellow Creek Lake is dominated by blue-green algae (68.2%). Blue-green algae are less desirable than green algae because they are less palatable to zooplankton and other filter feeders, may cause taste and odor problems, and can cause dense algae blooms, detracting from the use and enjoyment of the lake. The 2008 sampling resulted in an ITSI score of 41, similar to the 1998 and 2004 scores of 38 and 37 respectively. These scores are all within the eutrophic category for Indiana Lakes.

7.3 Streams

The streams in the Yellow Creek Lakes watershed have poor habitat, likely due to the fact they are legal drains. All seven streams had QHEI scores of less than 51, which are considered non-supporting of aquatic life. All stream sites sampled within the Yellow Creek Lakes watershed (with the exception of site 6, which flows into the east side of Diamond Lake) are considered severely impaired for aquatic macroinvertebrates. Site 6 was considered moderately impaired. The lack of available habitat likely plays a significant role in the low aquatic macroinvertebrate diversity. The watershed streams sampled serve as agricultural drains. As such these drains are periodically cleaned of sediment and organic matter that has accumulated on the bottom of the stream. In addition to direct disturbance to the stream fauna by dredging, removing organic

matter takes away the food source and shelter (the invertebrates typically cling to or build shelter with or on the organic matter) for the macroinvertebrates.

Dissolved oxygen (DO) concentrations in the Yellow Creek Lake watershed streams ranged from a low of 0.9 mg/L to 8.2 mg/L at base flow, and a low of 2.5 mg/L to 12.1 mg/L at storm flow. The low DO in certain streams, such as site 1, which flows into the south end of Beaver Dam Lake, may be due to decomposition of organic matter and stagnant water. Oxygen is usually at saturation in flowing water because the turbulence helps equilibrate oxygen concentrations with the atmosphere, resulting in 100% saturation. Supersaturation (>100%) results from intense photosynthesis which, in a stream, comes primarily from periphyton (algae attached to rocks) and from rooted aquatic plants. Under saturated (<100%) stream water is indicative of excessive oxygen consumption, usually from biological oxygen demand (BOD). Site 4 (between Diamond and Yellow Creek Lake) was the only watershed site where supersaturation was recorded. This may have been from the storm water flushing out the supersaturated water from Diamond Lake. During storm flow 142% dissolved oxygen saturation was recorded at this site. However, the low DO saturation percentage at most sites was between 8.7% and 85%, which is indicative of a high BOD throughout the watershed.

Temperatures were warmer during base flow than during storm flow. This is largely due to the time of year when sampling took place. The lower temperature of rainfall also contributes to lower storm flow water temperatures. Rainfall is generally low in turbidity. However, the erosive force of storm runoff often washes soil and other particulates from the land into streams, resulting in higher turbidity and total suspended solid (TSS) concentrations. Higher turbidity was recorded at all but one of the seven sites (Site 1) during storm flow as compared to base flow turbidity. When we see lower storm flow turbidities, one of several things may be happening: 1) The watershed might be relatively undisturbed, especially in the riparian zone, limiting the availability of erodible materials, or 2) Pollen, phytoplankton, and/or localized disturbances may cause temporary increases in base flow turbidities. In the case of Site 1, both are likely occurring. The watershed of Site 1 is 50% wetland, and the stream had a lot of organic matter.

Similarly, TSS concentrations usually increase with increased stream flow because of instream scouring and inputs from overland flow from surrounding lands. Sites 3, 4, 5, 6 and 7 had higher storm flow TSS concentrations. The narrow riparian buffers at these sites likely contributed to higher storm flow TSS by not trapping eroded material. Since Site 2 is the outlet from Loon Lake, stream water quality is modified by settling, uptake, and other processes occurring within Loon Lake. At Site 4, the base flow TSS was higher because of ditch cleaning at the time of sampling. Wide vegetated filter strips are beneficial in trapping sediment and nutrients from landscape runoff.

In a recent study of 85 relatively undeveloped basins across the United States, the USGS reported the following median concentrations: ammonia (0.020 mg/L), nitrate (0.087 mg/L), soluble reactive phosphorus (0.010 mg/L), and total phosphorus (0.022 mg/L) (Clark et al. 2000). Except for two instances, nutrient concentrations within the Yellow Creek Lake streams all exceeded these median concentrations, some parameters by an order of magnitude. The pH values were on the alkaline side of neutrality, ranging from 6.9 to 8.7.

The median nitrate concentration of wadeable streams found by the Ohio EPA to support modified warmwater habitat (MWH) is 1.6 mg/L (Ohio EPA 1999). The concentrations at Site 1, Site 5 and Site 7 exceeded the Ohio EPA median for both flow regimes. Site 3 and Site 7 exceeded this criterion during base flow. Site 4 exceeded this criterion during storm flow. Site 5, at the south end of Diamond Lake, had the highest nitrate concentrations of the four streams.

Land use in the Yellow Creek Lake watershed is predominantly row crop agriculture; this could contribute to the high nitrate concentrations as runoff from fertilized fields often carries nitrates. Typically, storm flow concentrations of Total Kjeldahl Nitrogen (TKN) exceed base flow concentrations because runoff releases significant organic material stored within the stream and in riparian areas adjacent to the stream. This occurred at all seven sites.

Small streams are typically well oxygenated because of the turbulent flow; therefore, ammonia is usually oxidized to nitrate. However, flows recorded (both during storm and base) for all sites were insufficient to allow for this oxidation. The relatively high ammonia concentrations at Sites 1, 2, and 7 during base flow suggest a nearby source of this nutrient. Site 1 is on the south end of Beaver Dam Lake, Site 2 between Loon Lake and Yellow Creek Lake, and Site 7 is between Diamond and Yellow Creek Lake.

Since phosphorus readily adsorbs onto soil particles and organic matter, eroded soil carried by overland flow can contain a significant amount of phosphorus. Consequently, total phosphorus (TP) concentrations typically increase during storm events in disturbed watersheds. This occurred at Sites 3, 4, 5, 6 and 7. The narrow riparian zone and surrounding agricultural land use likely contributed to this. Lower storm flow TP concentrations at Sites 1 and 2 suggest less availability of this nutrient and possible interception by the vegetated stream riparian zone.

All but one of the samples from the Yellow Creek Lake streams exceeded the Indiana state *E. coli* standard for recreational waterbodies of 235 col/100ml. The *E. coli* concentrations ranged from 110 col/100ml at Site 4 (storm flow) to 5170 col/100ml at Site 7 (storm flow). These high *E. coli* concentrations likely resulted from land use activities associated with livestock and/or inadequate septic systems. While *E. coli* sources should be addressed, caution is advised in drawing conclusions from just two samples. Site 6 and 7 exhibited the two highest *E. coli* concentrations during storm flows (4350 and 5170 respectively), but even these number pale in comparison to colony counts in the 10's or 100's of thousands observed in some Indiana streams that have known fecal contamination.

In summary, the streams in the Yellow Creek subwatershed are relatively normal for Indiana agricultural streams. The high ammonia nitrogen in several of the streams should be addressed at the sources of contamination. Reducing nitrate runoff to the streams through vegetated filter strips will also reduce phosphorus. Developing or restoring wetlands or artificial filters directly in the path of surface flow to the streams or in the streams themselves may also reduce nitrogen and associated phosphorus.

7.4 Watershed Restoration Priorities and Institutional Resources

Having documented the state of the six lakes and interconnected streams in the upper Yellow Creek watershed, attention must now be focused on prioritizing which issues should be addressed and in what order. Changing land use from crop land back to permanent vegetation adjacent to the lakeshores and streams is one of the most valuable restoration tools available. As is true of most northern Indiana lakes, the pollutant of concern is phosphorus. Specifically phosphorus entering the waterways from the adjacent landscape (along with high nitrogen) continues to be an issue. The phosphorrus modeling conducted for this study showed that from 80 to 90 percent of the total phosphorus loading to each lake was from agricultural sources. While the phosphorus model tells us that we need to reduce phosphorus inputs by an average of 80% to bring the Yellow Creek Lakes back to a mesotrophic status, this may be an unreasonable goal. If the goal is set at a 20% reduction over the next 10 year period, and met, then reasonable progress will have been made. There are many governmental agencies, university researchers, and private consultants that can help the Yellow Creek Lakes to reach

that goal. Appendix G lists some of the individual contacts at those agencies and potential grant resources to help you work toward that goal. Steps to reach that goal include:

1) From a separate non-profit 501 C(3) Association that represents all six of the lakes.
2) Continue utilizing the LARE program for pursuing sediment and nutrient reduction projects in the watershed detailed in the Recommendations section of this report.
3) Consider using the 319 Program for additional monetary resources.
4) Educate watershed stakeholders who we did not reach with this initial effort (use the brochure contained in Appendix E to assist with passive education, but also consider sponsoring workshops each summer and inviting DNR, IDEM, SWCD, as well as lake related vendors and consultants to present their expertise to interested groups.
5) Choose one water quality improvement project per year to pursue and appoint a Conservation Club member to lead the project.
6) Contact the appropriate resources to pursue the project.

8.0 CONCLUSIONS

The lakes located in the upper or headwaters region of the Yellow Creek watershed generally have better overall water quality than the lakes downstream. This is likely due to smaller watershed areas. Hill and Beaver Dam lakes have watershed area to lake area ratios of 7.4:1 and 8.7:1 respectively. Smaller watersheds mean less area to transport nutrients, sediments, and other contaminants into the lakes downstream. Runoff from even small watersheds can overwhelm lakes with excessive nutrients and sediments, so efforts should be made to implement best management practices on the watersheds of Hill and Beaver Dam lakes.

McClures Lake is also a headwaters lake and has the next smallest watershed area: lake area ratio of 10.4:1. However, McClures Lake had a massive algal bloom on our July 17, 2008 sampling event so there must be some other significant source of nutrients contaminating this lake. There are only two potential sources of nutrients from the watershed due to the very limited development around the lake: the agricultural field immediately south of the lake and the camp on east side of the lake. Additional investigation of both these potential sources may be necessary before project resources are allocated.

Diamond, Loon, and Yellow Creek lakes all had larger watersheds, with watershed area to lake area ratios of more than 26:1. In addition to runoff from their immediate watersheds, each of these lakes receives discharge from an upstream lake. This all contributes to the high loading of nutrients into these lakes. As a result, these lakes were all classified as eutrophic according to Carlson's TSI. Cleaning up the watershed inputs to these lakes should be prioritized.

Beaver Dam, Diamond, Hill, Loon, McClures and Yellow Creek lakes all have more phosphorus than is ideal. Internal release of phosphorus from the sediments is an important source of this limiting nutrient. That these lakes suffer from internal phosphorus loading suggests that excessive production of plants (algae and rooted plants) within the lakes, as well as possible runoff of organic materials from the watershed, have created high sediment BOD. The high BOD, in turn, consumes dissolved oxygen and produces excessive ammonia-nitrogen concentrations. Cleaning up the watershed inputs to these lakes should be prioritized.

The potential is there for excessive algae production and this occurs periodically in the lakes, however, there wasn't a good relationship between concentrations of total phosphorus and chlorophyll *a* in the lakes when we sampled them. In most lakes, increases in total phosphorus

concentration results in increases in chlorophyll. There isn't a clear pattern of this in the study lakes (Figure 127). This suggests that something else limits the growth of algae to its full potential in these lakes.

Secchi disk transparency in the six lakes appeared to be controlled by algae, rather than by suspended sediments at the time of sampling. Lakes with the highest amount of chlorophyll had the lowest Secchi disk transparency (Figure 128). This relationship has a correlation coefficient of 0.541 which means that about 54% of the variation in Secchi disk transparency can be explained by the chlorophyll concentration.

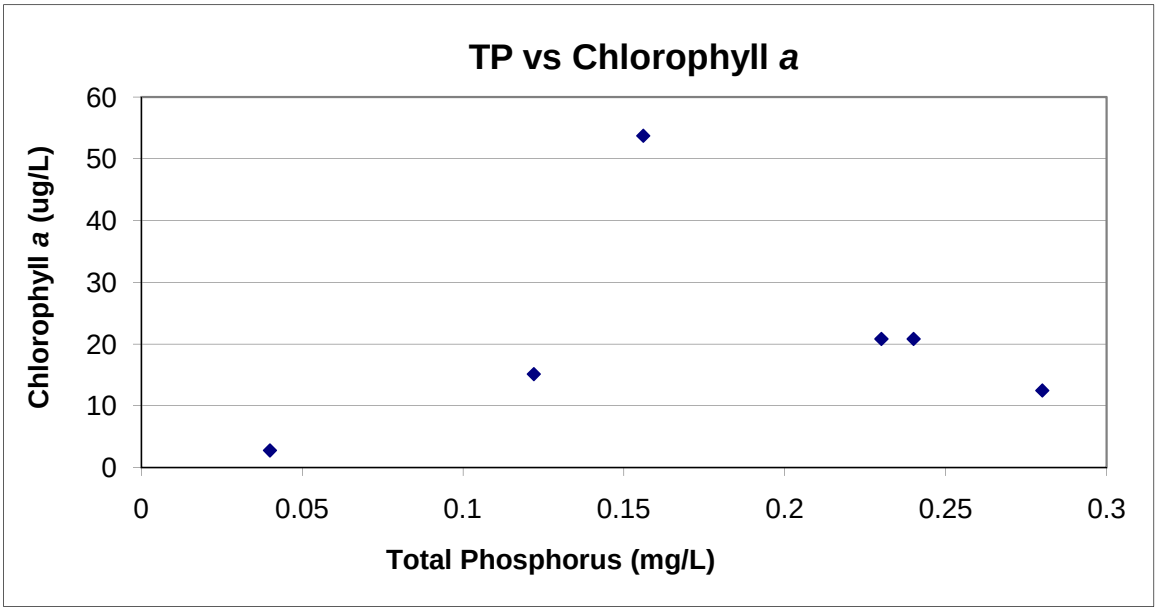


Figure 127. Relationship between total phosphorus and chlorophyll *a* in Beaver Dam, Diamond, Hill, Loon, McClures and Yellow Creek lakes.

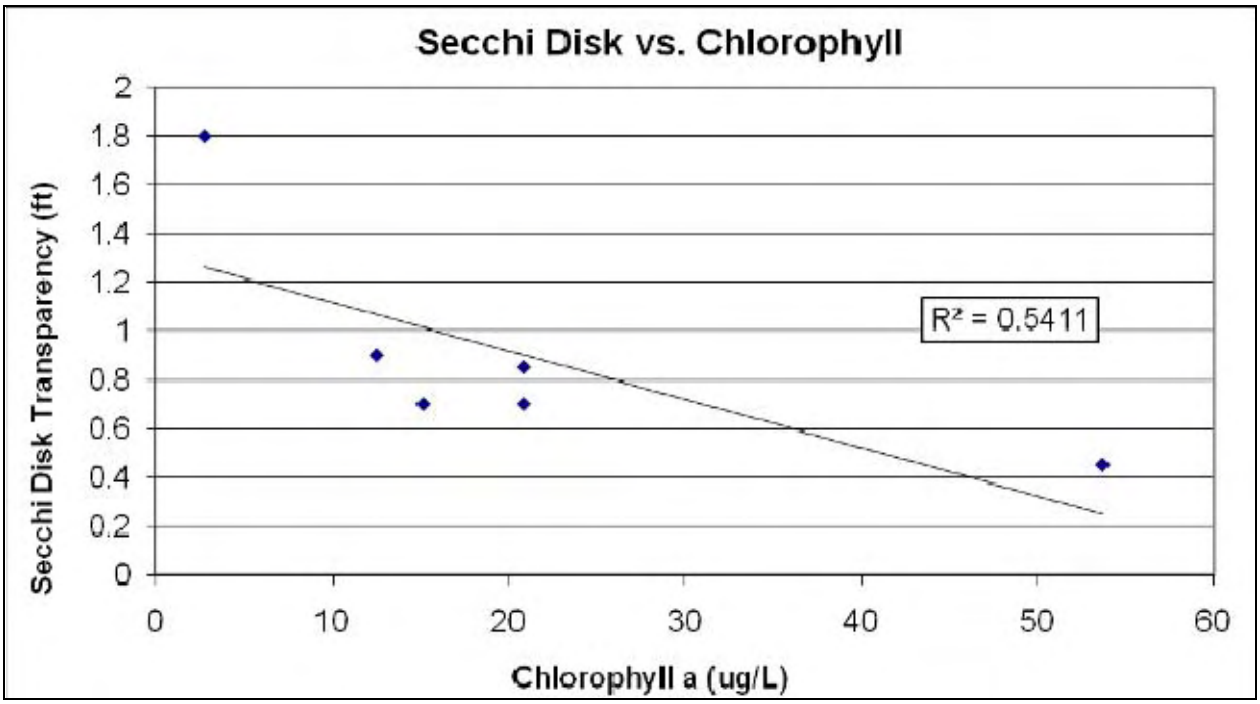


Figure 128. Relationship between Secchi disk transparency and chlorophyll *a* in Beaver Dam, Diamond, Hill, Loon, McClures and Yellow Creek lakes.

The lake water quality in all of the lakes will be improved by reducing plant productivity (algae) within the lakes and preventing organic matter (dissolved and particulate) from entering the lakes. The most efficient way to reduce plant productivity in the lake is to reduce the nutrient supply from the watershed. Once watershed phosphorus inputs are reduced, internal phosphorus loading can be controlled.

The Yellow Creek Lakes provide an outstanding natural resource capable of supporting a wide variety of uses. Improving water quality, while maintaining the relatively good fishery, will increase enjoyment of the lakes and property values around the lake. Because it is usually less costly to maintain lake water quality than it is to restore it once it becomes degraded, and because it often takes a long period of time to restore a degraded lake, efforts to maintain the water quality of Yellow Creek lakes at their present state should receive the highest priority in any watershed management plan. Specifically, management efforts should focus on reducing the nutrient supply to each lake and controlling the spread of Eurasian watermilfoil. Management efforts applied to upstream lakes like Beaver Dam, Loon, Hill, and Diamond will improve water quality downstream in Yellow Creek Lake as well.

9.0 RECOMMENDATIONS

The preceding discussion and conclusions provides a basis for management recommendations to improve the general health of Yellow Creek Lakes. Before undertaking management actions to improve lake water quality, it should be understood what the response of the lake will be by reducing the targeted pollutant. For example, by reducing phosphorus, algae production decreases, which improves water clarity in summer, which leads to more macrophyte growth. Alternatively, reducing nitrogen may limit filamentous algae growth but do nothing for water clarity. Limited time and financial resources of the organization make it nearly impossible to

implement all of the recommendations. Thus, it is necessary to prioritize the recommendations. The following priorities were discussed and rearranged during a meeting with the project sponsor. The list is not absolute. It is recommended that the conservation clubs get together annually and review the list to decide what is practical to pursue.

Priority should be given to treating the pollutants (sediment, nutrients, and bacteria) at or as close to their sources as possible because in the long run that is the most efficient way to improve water quality. This is not always possible, because landowners may not be willing to cooperate, and are often under no legal obligation to do so. The pollutants we need to address are often delivered to the waterways at levels that negatively affect the lake, but that below state standards. Fortunately, many of the Yellow Creek Lakes have short residence times (Hill Lake is an exception). This allows us to focus on watershed pollution, and once addressed, the lakes will have a shorter recovery response time than a lake with a longer residence time. To improve water quality in Hill Lake, it is necessary to focus on in-lake or near shore management.

Based on the above rationale, a prioritized list of management recommendations is presented below (the numbered recommendation correspond to numbers in Figure 129 where applicable). These should be considered guidelines based on the current ecological condition of the lakes and their watershed. These conditions may change as land and lake uses change. Individual lakes may wish to prioritize the management effort differently to accommodate their specific desired uses of the lake. To ensure maximum participation in the any management effort, as many lakes side property owners and lake users should participate in prioritizing the management efforts.

It is also important to note that even if all stakeholders agree this is the best prioritization to meet their needs, action need not be taken in this order. Some of the smaller, less expensive recommendations, such as the homeowner recommendations, may be implemented while funds are raised to implement some of the larger projects. Many of larger projects will require feasibility studies to ensure landowner willingness to participate in the project and regulatory approval of the project. Regulatory approval and landowner cooperation ultimately determine the prioritization of management efforts. Please see Appendix I for a reference list of the recommended projects with potential timelines, costs, institutional resources, expected benefits, and other factors that may affect project success.

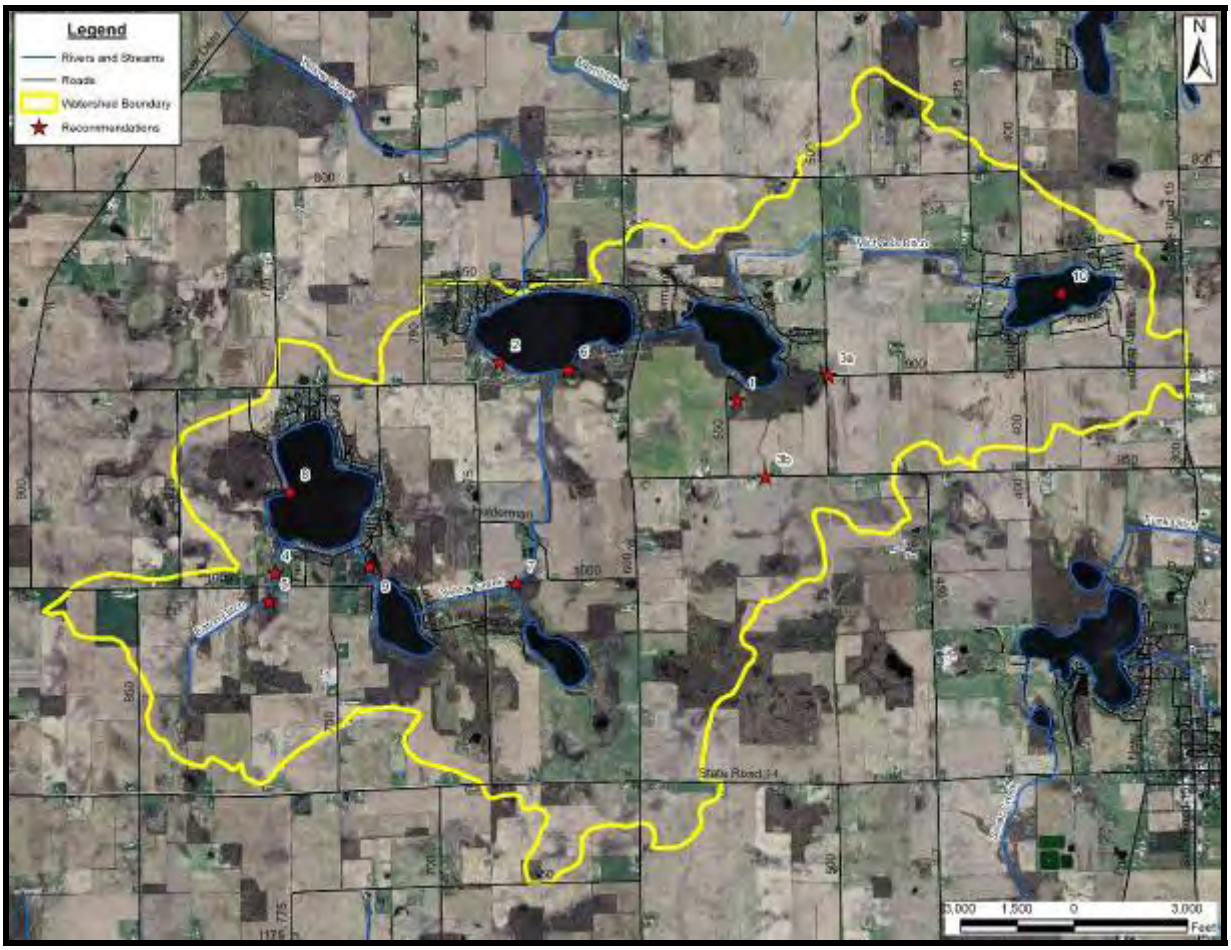


Figure 129. Locations of select project recommendations for reducing sediment and nutrient loading to the Yellow Creek lakes.

1) On the west side of Diamond Lake, off 550 W Road and north of 950 S. Road, there is an open ditch (not visible from the road because it is in tile for the first 300 feet) that is choked with filamentous algae and reed canary grass and had a strong odor. A liquid manure application was observed while stream sampling in the vicinity. This stream drains into Diamond Lake. Liquid manure should be applied only after a nutrient test shows a phosphorus deficiency. An adequate (100 feet) vegetated buffer between application sites and streams or other drainage channels should be maintained.

2) A camp on Yellow Creek Lake has a private treatment plant system that discharges directly to the lake. Work with the camp to examine the potential of locating an alternative discharge point downstream from the lake and upgrading their system.

3) On the southeast corner of Diamond Lake two separate drainages flow into Diamond Lake. The drains both have narrow buffers from the adjacent agricultural activities. Both drains should have wider filter strips installed. The source of ammonia nitrogen should also be addressed or a filter developed to intercept the nitrogen.

4) Entering the south end of Beaver Dam Lake is a branch of the Swick-Meredith Drain. The embankments along the east side of the ditch from the lake south to 1000 S. are eroding due to attempted maintenance of ornamental grasses and severe damage by muskrats. At the drain

outlet into the lake, the there is a lot of tires and other debris in thte wetland adjacent to the stream and lake. The bank erosion, debris and the source of ammonia nitrogen should be addressed.

5) Upstream from 1000 S. the Swick Meredith Drain is well maintained and relatively stable except that the grass buffer is relatively narrow (five feet or less) and several rill erosion areas were noted from the adjacent farm fields. A wider filter strip and/or embankment protection should be implemented.

6) Approximately 1400 feet of shoreline on the south side of Yellow Creek Lake is well buffered with wetland forest several hundred feet wide. However, the shoreline is receding at a rapid pace with trees falling into the lake. A bioengineering solution for reducing erosion along this shoreline should be implemented.

7) The channel from Loon Lake toward Yellow Creek Lake beginning at CR 675 W has a narrow grass filter between the agricultural field and the stream. There were several locations along this reach where sediment deltas in the stream were present from rill erosion in the fields. This erosion resulted in poor water quality downstream. A wider filterstrip should be implemented along this reach.

8) The Beaver Dam Lake shoreline at the south end of Amanda Drive has approximately 150 feet of shoreline eroding at a moderate rate around a southward facing point (Amanda Point). The erosion is about 16-18 inches in height and is undercutting trees and the lawn. The shoreline should be stabilized with bioengineering methods.

9) The ditch between Loon Lake and Beaver Dam Lake (not a natural waterway) is under consideration for cleaning by the Kosciusko County Drainage Board at the request of the adjacent residents. Need to consider bank stabilization or other alternatives and work with county surveyor.

10) Hill Lake has a significant problem with Eurasian watermilfoil (EWM) and internal nutrient cycling. A whole lake EWM treatment for 2009 is scheduled, Monitoring surveys should be conducted in subsequent years.

11) Fence the cows out of Hill Lake and provide an alternative water supply.

12) Controlling EWM within Diamond, Yellow Creek, Beaver Dam, and Loon Lake should also be a priority. McClure Lake should be surveyed occasionally to make sure a population of EWM does not develop.

13) Follow the recommendations of the Aquatic Vegetation Management Plan recently developed for Diamond and Hill Lake, and soon to be developed for Beaver Dam and Loon Lake. Consider developing a similar plan for Yellow Creek Lake.

14) Additional recommendations for all lake side or near lake residents:

a) Reduce fertilizer use in general, and then use only phosphorus-free fertilizers on lawns, gardens, and ornamental plants as the excess fertilizer washes to the lake and feeds the algae as well.

b) Consider natural stone in combination with 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; consider alternate routes for these drains that would filter pollutants before they reach the lake.

d) Keep organic debris such as lawn clippings, leaves, and animal waste out of the water and adjacent areas where the water drains to the lake.

e) Use idle speeds in shallow water to limit prop wash and mark those areas with buoys.

f) Consider planning for future growth in the Yellow Creeks area. At some point, a sanitary sewer system around the lakes will become necessary to reduce the nutrient level in the lakes. At a minimum, maintain existing septic systems and, when improving existing homes, upgrade septic systems to the best available technology.

g) Anglers are encouraged to practice selective harvest of panfish (especially bluegill and black crappie). This would be beneficial to the bluegill population for a couple of reasons: 1) the release of most large adults would help develop a large, healthy stock of breeding individuals capable of producing many offspring, which would young fish into the population each year and 2) the increased harvest of smaller individuals would decrease the amount of intra-specific competition for space and food resources between young bluegill resulting in a healthy recruitment of individuals into the larger sized breeding population. The goal should be to develop a distribution of sizes within the population that allows for the harvest of quality size fish while ensuring the replacement of those individuals the following year.

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APPENDIX A:

GLOSSARY OF KEY TERMS, TSI METRICS, AND WATER BUDGET DETAILS

YELLOW CREEK LAKES WATERSHED DIAGNOSTIC STUDY

KOSCIUSKO COUNTY, INDIANA

JFNew

Glossary of Key Terms and Concepts

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

Alkalinity. Alkalinity is a measure of the acid-neutralizing (or buffering) capacity of water. Certain substances, if present in water, like carbonates, bicarbonates, and sulfates can cause the water to resist changes in pH. A lower alkalinity indicates a lower buffering capacity or a decreased ability to resist changes in pH. During base flow conditions, alkalinity is usually high because the water picks up carbonates from the bedrock. Alkalinity measurements are usually lower during storm flow conditions because buffering compounds are diluted by rainwater and the runoff water moves across carbonate-containing bedrock materials so quickly that little carbonate is dissolved to add additional buffering capacity.

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.

Conductivity. Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions: on their total concentration, mobility, and valence (APHA, 2005). During low discharge, conductivity is higher than during storm water runoff because the water moves more slowly across or through ion containing soils and substrates during base flow. Carbonates and other charged particles (ions) dissolve into the slow-moving water, thereby increasing conductivity measurements.

Dissolved Oxygen (D.O). D.O. is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3-5 mg/L of D.O. Cold-water fish such as trout generally require higher concentrations of D.O. than warm water fish such as bass or Bluegill. The IAC sets minimum D.O. concentrations at 6 mg/L for cold-water fish. D.O. enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algae growth can over-saturate (greater than 100% saturation) the water with D.O. Conversely, dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

***E. coli* Bacteria.** *E. coli* is one member of a group of bacteria that comprise the Fecal Coliform Bacteria and is used as an indicator organism to identify the potential for the presence of pathogenic organisms in a water sample. Pathogenic organisms can present a threat to human health by causing a variety of serious diseases, including infectious hepatitis, typhoid, gastroenteritis, and other gastrointestinal illnesses. *E. coli* can come from the feces of any warm-blooded animal. Wildlife, livestock, and/or domestic animal defecation, manure fertilizers, previously contaminated sediments, and failing or improperly sited septic systems are common sources of the bacteria. The IAC sets the maximum standard at 235 colonies/100 ml in any one sample within a 30-day period or a geometric mean of 125 colonies per 100 ml for five samples collected in any 30-day period. A study conducted by students at IU SPEA in the spring of 2000 found average fecal coliform levels of <200 colonies/100 ml in unglaciated, gravel-bottom creeks in the Stephen's Creek Watershed in Monroe County, Indiana (Klumpp et al., 2000). In general, fecal coliform bacteria have a life expectancy of less than 24 hours.

Epilimnion Lake surface waters, generally warmer and better oxygenated

Hydraulic residence time The theoretical time it takes a lakes' entire volume of water to replace itself with water from direct precipitation, groundwater discharge and watershed runoff (including incoming streams). Given a lakes residence time of 2 years for example, means that within periods of average rainfall, the lake receives enough water to replace itself completely. This does not mean every molecule of water is automatically replaced every 2 years, as much of the water that enters a lake often passes through the system quickly (especially in smaller lakes like these).

Hypolimnion bottom waters, characterized by cooler temperatures and less oxygen

IDEM Indiana Department of Environmental Management

IDNR Indiana Department of Natural Resources

In situ Means at the location of, the water sample was collected *in-situ*

LARE Lake and River Enhancement, a program within the Division of Wildlife, IDNR

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

Macroinvertebrates Worms, and larval and adult insects that are visible to the naked eye. Note: periphyton and zooplankton excluded. The insects, including beetles, flies, dragonflies, worms, are found as larvae and or adults living within or on the substrate of most streams.

Macrophytes Plants that can be seen with the naked eye. In aquatic pplant surveys, these are often divided into submergent (underwater) species, floating-leaved (plants whose leaves grow to and rest on the surface of water under natural conditions), and emergents (plants whose roots are in water but the stems break the water surface and the form the majority of the plant above water).

Metalimnion The zone of temperature change between surface and bottom waters.

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

> ***Nitrate (NO_3^-)*** – Nitrate is an oxidized form of dissolved nitrogen that is converted to ammonia by algae. It is found in streams and runoff when dissolved oxygen is present, usually in the surface waters. Ammonia applied to farmland is rapidly oxidized or converted to nitrate and usually enters surface and groundwater as nitrate. The Ohio EPA (1999) found that the median nitrate-nitrogen concentration in wadeable streams that support modified warmwater habitat (MWH) was 1.6 mg/L. Modified warmwater habitat was defined as: aquatic life use assigned to streams that have irretrievable,

extensive, man-induced modification that preclude attainment of the warmwater habitat use (WWH) designation; such streams are characterized by species that are tolerant of poor chemical quality (fluctuating dissolved oxygen) and habitat conditions (siltation, habitat amplification) that often occur in modified streams (Ohio EPA, 1999). Nitrate concentrations exceeding 10 mg/1 in drinking water are considered hazardous to human health (Indiana Administrative Code IAC 2-1-6).

Ammonia (NH_4^+) – Ammonia is a form of dissolved nitrogen that is the preferred form for algae use. It is the reduced form of nitrogen and is found in water where dissolved oxygen is lacking. Important sources of ammonia include fertilizers and animal manure. In addition, bacteria produce ammonia as a by-product as they decompose dead plant and animal matter. Both temperature and pH govern the toxicity of ammonia for aquatic life.

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

pH. The pH of water is a measure of the concentration of acidic ions (specifically H^+) present in the water. The pH also determines the form, solubility, and toxicity of a wide range of other aqueous compounds. The IAC establishes a range of 6-9 pH units for the protection of aquatic life.

Phosphorus. Phosphorus is an essential plant nutrient, and the one that most often controls aquatic plant (algae and macrophyte) growth in freshwater. It is found in fertilizers, human and animal wastes, and yard waste. There are few natural sources of phosphorus to streams other than what is attached to soil particles, and there is no atmospheric (vapor) form of phosphorus. For this reason, phosphorus is often a ***limiting nutrient*** in aquatic systems. This means that the relative scarcity of phosphorus may limit the ultimate growth and production of algae and rooted aquatic plants. Therefore, management efforts often focus on reducing phosphorus inputs to receiving waterways because: (a) it can be managed and (b) reducing phosphorus can reduce algae production. Two common forms of phosphorus are:

Soluble reactive phosphorus (SRP) – SRP is dissolved phosphorus readily usable by algae. SRP is often found in very low concentrations in phosphorus-limited systems where the phosphorus is tied up in the algae themselves. Because phosphorus is cycled so rapidly through biota, SRP concentrations as low as 0.005 mg/L are enough to maintain eutrophic or highly productive conditions in lake systems (Correll, 1998). Sources of SRP include fertilizers, animal wastes, and septic systems.

Total phosphorus (TP) – TP includes dissolved and particulate phosphorus. TP concentrations greater than 0.03 mg/L (or 30μg/L) can cause algal blooms in lakes and reservoirs. The Ohio EPA (1999) found that the median TP in wadeable streams that support MWH for fish was 0.28 mg/L.

Plankton. Plankton are important members of the aquatic food web. The plankton include the algae (microscopic plants) and the zooplankton (tiny shrimp-like animals that eat algae). Determined by filtering water through a net having a very fine mesh (63-micron openings = 63/1000 millimeter). The plankton net is towed up through the lake's water column from the one percent light level to the surface. Algae are reported as *natural units*, which records one

colonial filament of multiple cells as one natural unit and one cell of a singular alga also as one natural unit. Of the many different algal species present in the water, we are particularly interested in the Blue-green algae. Blue-green algae are those that most often form nuisance blooms and their dominance in lakes may indicate poor water conditions.

QHEI Qualitative Habitat Evaluation Index, an objective method of assigning a numeric value to habitat features in order to compare one stream reach to another. Various attributes of the habitat are scored based on the overall importance of each to the maintenance of viable, diverse, and functional aquatic faunas. The type(s) and quality of substrates, amount and quality of in-stream cover, channel morphology, extent and quality of riparian vegetation, pool, run, and riffle development and quality, and gradient are some of the metrics used to determine the QHEI score which generally ranges from 20 to 100. The QHEI is used to evaluate the characteristics of a stream segment, as opposed to the characteristics of a single sampling site. As such, individual sites may have poorer physical habitat due to a localized disturbance yet still support aquatic communities closely resembling those sampled at adjacent sites with better habitat, provided water quality conditions are similar. QHEI scores from hundreds of segments around Indiana have indicated that values greater than 64 are considered *fully supporting* of aquatic life use, scores between 51–64 are *partially supporting*, and scores less than 51 are *non-supporting* (IDEM, 2002).

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

Temperature. Temperature can determine the form, solubility, and toxicity of a broad range of aqueous compounds. Likewise, life associated with the aquatic environment in any location has its species composition and activity regulated by water temperature. Since essentially all aquatic organisms are 'cold-blooded' the temperature of the water regulates their metabolism and ability to survive and reproduce effectively (EPA, 1976). The Indiana Administrative Code (327 IAC 2-1-6) sets maximum temperature limits to protect aquatic life for Indiana streams. For example, temperatures during the month of May should not exceed 80 ^{o}F (23.7 ^{o}C) by more than 3 ^{o}F (1.7 ^{o}C). June temperatures should not exceed 90 ^{o}F (32.2 ^{o}C).

Total Suspended Solids (TSS). A TSS measurement quantifies all particles suspended and dissolved in stream water. Closely related to turbidity, this parameter quantifies sediment particles and other solid compounds typically found in stream water. In general, the concentration of suspended solids is greater during high flow events due to increased overland flow. The increased overland flow erodes and carries more soil and other particulates to the stream. Although the State of Indiana sets no standard for TSS, total dissolved solids should not exceed 750 mg/L. In general, TSS concentrations >80 mg/L have been found to be deleterious to aquatic life (Waters, 1995).

Trophic State Index An objective scoring mechanism for assessing multiple chemical and physical water quality parameters in lakes so that they can be compared to one another. Indiana and many other states use a trophic state index (TSI) to help evaluate water quality data. A TSI condenses water quality data into a single, numeric index. Different index (or

eutrophy) points are assigned for various water quality concentrations. The index total, or TSI, is the sum of individual eutrophy points for a lake. The Indiana TSI (ITSI) was developed by the Indiana State Pollution Control Board and published in 1986 (IDEM, 1986). The original ITSI differed slightly from the one in use today. Today's ITSI uses ten different water quality parameters to calculate a score. Indiana typically uses its own index developed by IDEM. The Indiana TSI scoring matrix and Carlson's TSI graphic follows this glossary.

Because the Indiana TSI has not been statistically validated and because of its heavy reliance on algal parameters, the Carlson TSI may be more appropriate for 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. The Carlson TSI scoring metric follows the Indiana TSI at the end of this glossary.

Both TSI tables result in the classification of the lake in one of the following 4 categories: oligotrophic (least productive), mesotrophic (moderately productive), eutrophic (very productive), and hypereutrophic (extremely productive).

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

Water Budget. A lake's water budget is the amount of water that enters the lake and how fast it leaves. This is an important parameter as it results in a 'residence time" estimate or how long water remains in the lake. Knowing the residence time helps with chemical dosing for aquatic plant management and helps determine lake restoration strategies. Shorter residence times mean watershed impacts have a larger role in lake water quality and should be targeted. Alternately, long residence times mean that in-lake treatments may be more effective management strategies. The flow path for water in this study follows this glossary.

The Indiana Trophic State Index.

Parameter and Range		Eutrophy Points
I.	Total Phosphorus (ppm)	
A.	At least 0.03	1
B.	0.04 to 0.05	2
C.	0.06 to 0.19	3
D.	0.2 to 0.99	4
E.	1.0 or more	5

II. Soluble Phosphorus (ppm)

A.	At least 0.03	1
B.	0.04 to 0.05	2
C.	0.06 to 0.19	3
D.	0.2 to 0.99	4
E.	1.0 or more	5

III. Organic Nitrogen (ppm)

A.	At least 0.5	1
B.	0.6 to 0.8	2
C.	0.9 to 1.9	3
D.	2.0 or more	4

IV. Nitrate (ppm)

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

V. Ammonia (ppm)

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

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

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

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

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

VIII. Light Penetration (Secchi Disk)

A.	Five feet or under	6

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

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

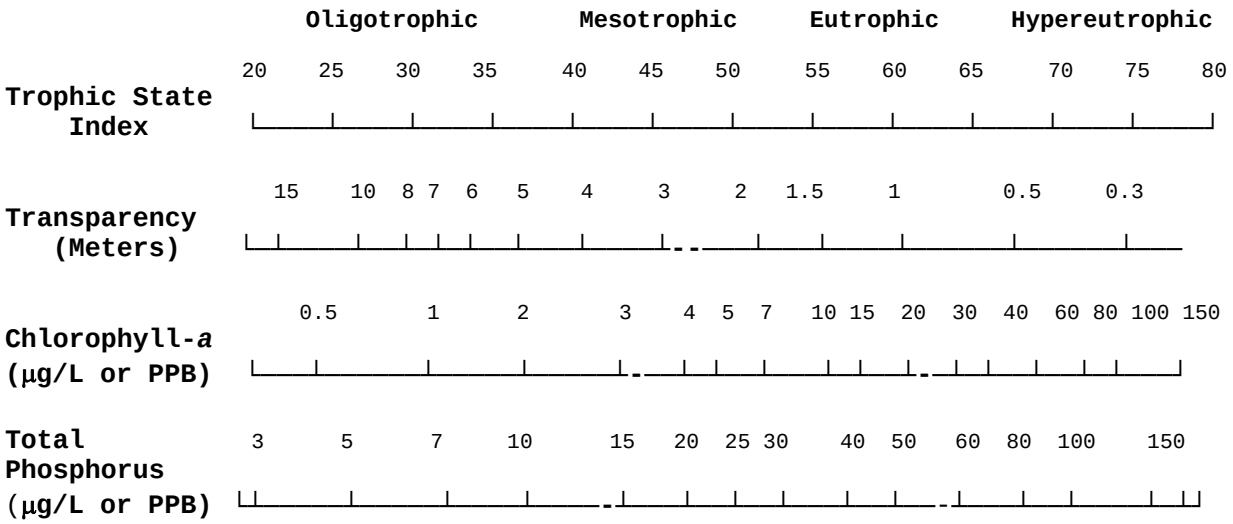
X. Total Plankton per liter of water sampled from a single vertical tow between the 1% light level and the surface:

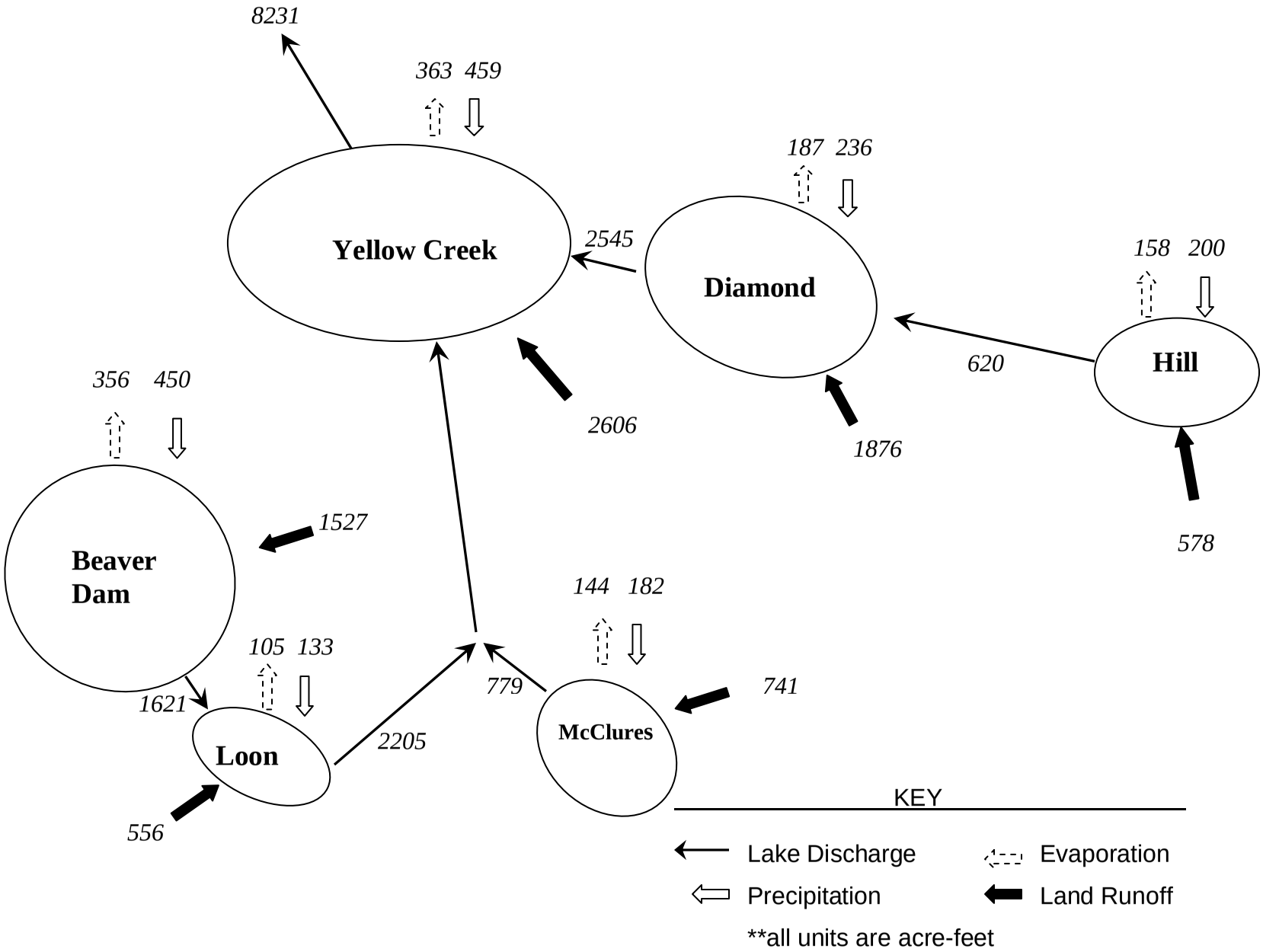
A.	less than 3,000 organisms/L	0
B.	3,000 - 6,000 organisms/L	1
C.	6,001 - 16,000 organisms/L	2
D.	16,001 - 26,000 organisms/L	3
E.	26,001 - 36,000 organisms/L	4
F.	36,001 - 60,000 organisms/L	5
G.	60,001 - 95,000 organisms/L	10
H.	95,001 - 150,000 organisms/L	15
I.	150,001 - 5000,000 organisms/L	20
J.	greater than 500,000 organisms/L	25
K.	Blue-Green Dominance: additional points	10

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

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

CARLSON'S TROPHIC STATE INDEX





Water Budget Flow Chart for the Yellow Creek Watershed Lakes.

APPENDIX B:

ENDANGERED, THREATENED, AND RARE SPECIES

YELLOW CREEK LAKES WATERSHED DIAGNOSTIC STUDY

KOSCIUSKO COUNTY, INDIANA

JFNew

JFNew
From Native Seed to Ecological Solutions

708 Roosevelt Road
Walkerton, Indiana 46574
Phone: 574-586-3400 ext. 313
Fax: 574-586-3446

Aaron Johnson
Aquatic Ecologist
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Indianapolis, Indiana

Ann Arbor, Michigan

Grand Haven, Michigan

Cincinnati, Ohio

Madison, Wisconsin

Native Plant Nursery:
Walkerton, Indiana

www.jfnew.com

October 2, 2007

Mr. Ronald Hellmich
Indiana Department of Natural Resources
Division of Nature Preserves
402 West Washington Street Rm 267
Indianapolis, Indiana 46204

Re: Endangered, Threatened, and Rare Species Database Review Request

Dear Mr. Hellmich:

I am writing to request an ETR, high quality natural communities, and natural areas database review for the following areas:

Yellow Creek Watershed:
The site is located in Kosciusko County southwest of Claypool, Indiana. It includes:

- Township 31N Range 5E Sections 23-28, 32-36
- Township 31N Range 6E Sections 30, 31
- Township 30N Range 5E Sections 2-5, 10, 11

Rock Lake Watershed:
The site is located in Kosciusko and Fulton Counties east of Albion, Indiana. It includes:

- Township 30N Range 5E Sections 15-17, 20-22, 27, 28, 33, 34

Pretty Lake Watershed:
The site is located in Marshall County east of Albion, Indiana. It includes:

- Township 30N Range 5E Sections 15-17, 20-22, 27, 28, 33, 34

Please bill each area separately. If you have any questions, please call me at (574) 586-3400. Thank you for your attention to this request.

Sincerely,

Aaron Johnson
Aquatic Ecologist
JFNew

Cc. JFN #07-07-44/07-07-72/07-08-93

DNR Indiana Department of Natural Resources

Mitchell E. Daniels, Jr., Governor
Kyle J. Hupfer, Director

October 10, 2007

Mr. Aaron Johnson
J.F. New and Associates
708 Roosevelt Road
Walkerton, IN 46574

Dear Mr. Johnson:

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

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

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

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

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

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

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

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

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

Sincerely,

Ronald P. Hellmich

Ronald P. Hellmich
Indiana Natural Heritage Data Center

enclosure: data sheet
invoice

10/16/2007

Endangered, Threatened and Rare Species, and High Quality Natural Communities from the Yellow Creek Watershed, Indiana

TYPE	SPECIES NAME	COMMON NAME	FED	STATE	TRS	LASTOBS	COMMENTS
Vascular Plant	Carex aurea	Golden-fruited Sedge		SR	031N005E 33	1939-06-10	
Vascular Plant	Carex aurea	Golden-fruited Sedge		SR	031N005E 33 CENTER WH WH	1982	
Vascular Plant	Carex bebbii	Bebb's Sedge		ST	030N005E 04	1939-06-10	
Vascular Plant	Carex flava	Yellow Sedge		ST	031N005E 33	1939-06-10	
Vascular Plant	Carex flava	Yellow Sedge		ST	031N005E 33 CENTER WH WH	1982	
Vascular Plant	Juglans cinerea	Butternut		WL	030N005E 13	1975-01-28	
Vascular Plant	Potamogeton strictifolius	Straight-leaf Pondweed		ST	031N005E 33	2000-07-27	
Vascular Plant	Spiranthes lucida	Shining Ladies'-tresses		SR	031N005E 33	1939-06-10	
Vascular Plant	Spiranthes lucida	Shining Ladies'-tresses		SR	031N005E 33 CENTER WH WH	1982	

Fed: LE = listed federal endangered; C = federal candidate species

State: SE = state endangered; ST = state threatened; SR = state rare; SSC = state species of special concern; SG = state significant; WL = watch list; no rank = not ranked but tracked to monitor status

Grank: Heritage Global Rank: G1 = critically imperiled; G2 = imperiled; G3 = rare or uncommon; G4 = widespread but with long term concerns; G5 = widespread and secure; GU = unranked

Srank: State Heritage Rank: S1 = critically imperiled; S2 = imperiled; S3 = rare or uncommon; S4 = widespread but with long term concerns SNR = not ranked; B = breeding rank; SNA = not resident in state in non-breeding season

APPENDIX C:

IDNR FISH REPORT SUMMARIES AND PROPORTIONAL STOCK DENSITY EXPLAINED

YELLOW CREEK LAKES WATERSHED DIAGNOSTIC STUDY

KOSCIUSKO COUNTY, INDIANA

JFNew

JFNew

Fish Data Summaries for Each of the Yellow Creek Lakes

When reviewing the summaries below, and to some extent the IDNR reports themselves, it is important for the reader to understand that the collection methodologies and procedures used by the IDNR have changed over time. Therefore, any information below should be viewed for trends over time rather than direct comparisons from study year to year. In 2001, the IDNR addressed this by adopting a set of standardized sampling protocol for future studies.

Beaver Dam Lake

Fish Community Composition

During the initial survey of Beaver Dam Lake in 1965, the DNR collected eighteen species of fish (McGinty, 1966a). Bluegill was the most abundant fish species collected by number (42.6%), followed by longear sunfish (20%), yellow perch (11.1%), and largemouth bass (8.8%; Figure 27). Both bluegill and largemouth bass had low Proportional Stock Density (PSD) values, 9 and 29, respectively, suggesting there were a disproportionate number of small individuals in their populations (Figure 28). (Appendix D describes PSD values, their calculation, and factors that affect them.) All longear sunfish collected measured less than six inches in length except for one; therefore, this species was generally assumed to be undesirable to anglers. Black crappie comprised 4.7% of fish collected by number and had a PSD value of 32 suggesting the population was in balance. Gizzard shad accounted for 2.4% of fish collected by number; however, DNR biologists noted the presence of thousands more observed during electrofishing. The gizzard shad population in Beaver Dam Lake was suggested as a potential problem by IDNR in 1965. Gizzard shad can be important as a forage species in many fisheries; however, due to their fast growth rates, gizzard shad can become too large for predators to consume and can quickly account for too large of a portion of the carrying capacity of a lake. When overly abundant, gizzard shad can negatively affect more desirable species, such as bluegill, through increased competition for food and space. This competition can result in decreased survival of young bluegill.

A partial fish eradication occurred in Beaver Dam Lake in 1966 to reduce the number of small bluegill and population of undesirable sunfish (longear sunfish); a follow-up survey was conducted in 1968 to evaluate the partial fish eradication effort. Fourteen fish species were collected during the 1968 survey of Beaver Dam Lake (Hudson, 1969). Largemouth bass was the most abundant fish species collected (24.9%), followed by lake chubsucker (22.0%), yellow perch (15.1%), and carp (11.8%). Bluegill was the most abundant species collected in 1965 accounting for 42.6% of fish collected by number compared to 11.4% in 1968. (The absence of trap nets as a collection method for the 1968 survey accounts for the reduced number of bluegill collected.) Of the 61 largemouth bass collected in 1968, only three measured twelve inches or larger. A PSD was not calculated due to the small number of stock size (8-12 in; 20.3-30.5 cm) individuals collected. Yellow perch abundance was similar to that collected during the 1965 survey; however, only one individual was of quality size (8-10 in; 20.3-25.4 cm). Notably, carp relative abundance increased from 0.4% in 1965 to 11.8% in 1968 and was suggested by Hudson (1969) as the only negative result of the partial fish eradication.

From 1970 to 1971, Beaver Dam Lake was involved in a study involving destratification, which is a method used to increase the percentage of a lake's water column that fish can

inhabit. During the summer, Beaver Dam Lake, like most moderately deep, eutrophic lakes, becomes thermally stratified. This results in low dissolved oxygen (DO) concentrations in the moderately deep to deep areas of the lake. During these conditions, DO concentrations occur at concentrations below which fish can survive. This results in a reduced area within the lake for fish to occupy and can lead to increased competition between species for food and space. The 1970-1971 study represented the preliminary collection of data to determine if Beaver Dam Lake would be a good candidate for destratification as a management practice. During the study, biologists recorded DO concentrations in the water column throughout the two years, surveyed the fish population, and conducted a creel survey to document angler harvest effort.

In 1970, 17 species of fish were collected during the sampling effort (Gulish, 1972). Yellow perch was the most abundant species collected by number (24.1%), followed by largemouth bass (15.8%), gizzard shad (12.4%), and bluegill (12.1%). IDNR biologists reported few fish were collected during the 1970 sampling due to an inadequate level of sampling effort. This resulted in an increased sampling effort during the 1971 assessment. Because of this increased effort, nineteen fish species were collected during the 1971 sampling effort. Bluegill was the most abundant species collected by number (35.5%), followed by largemouth bass (25.7%), yellow perch (11.4%), and gizzard shad (7.6%). The increase in sampling effort increased the number of fish collected from 348 in 1970 to 1,123 in 1971. The calculated PSD for bluegill in 1971 was 20 and was within the range of a balanced population (Anderson 1980). However it was noted that the 1969 year class dominated the population. Anderson (1980) suggested that a balanced largemouth bass population should have a PSD value between 40-70 and in 1971 the PSD was 27 suggesting the population was not balanced and was dominated by smaller individuals. The calculated PSD for yellow perch in 1971 was 73 suggesting the population was dominated by larger individuals.

The creel survey involved interviewing both bank and boat anglers. Information on total effort, catch per unit effort (CPUE), were determined from data taken by creel clerks. Results of the survey concluded that from 1970 to 1971 there was a 30% decrease in the total number of angler trips and a 70% decrease in hours fished; however, catch and harvest rates increased significantly within this time period. The 1971 catch rate measured six times higher than the 1970 rate, while the total number of fish harvested increased by 81%. This was contributed to the bluegill fishery as bluegill harvest increased by 141% from 1970 to 1971.

At the completion of the sampling effort, DNR biologists concluded that Beaver Dam Lake was not a good candidate for a destratification project due to the unstable fish population. IDNR biologists suggested that a partial fish kill in 1966 caused Beaver Dam Lake's fish community to become unstable, and that in 1970-1971, the lake was still recovering from the fish kill. IDNR biologists suggested that a lake containing a stable fish community would be a better candidate for a destratification project because the results would be more conclusive.

Beaver Dam Lake was next surveyed in 1977. Due to bad weather during sampling in June another sampling effort was conducted in August to collect more fish. Collectively, twenty species of fish were identified during the 1977 survey (Braun, 1978). Golden shiner was the most abundant fish species collected by number (19.2%), followed by bluegill (17.8%), gizzard shad (15.8%), and largemouth bass (12.4%). Bluegill PSD

increased from 20 in 1971 to 53 in 1977. The largemouth bass PSD increased from 27 in 1971 to 41 in 1977. Black crappie had a PSD value of 85 and accounted for 9.9% of the total number of fish collected. Yellow perch relative abundance by number decreased from 11.4% in 1971 to 5.5% in 1977. Both yellow perch and black crappie are cyclic species, resulting in very strong and weak year classes, which accounts for their fluctuations in PSD and relative abundance values. Collectively, gizzard shad and carp accounted for 19.1% of the sample by number and 48.9% by weight. IDNR biologists suggested that the Beaver Dam Lake gizzard shad population was large enough to supply another top predator and suggested the stocking of white bass.

During the 1978 survey of Beaver Dam Lake, IDNR biologists collected 18 species of fish and 1 hybrid (Braun, 1978). Black crappie was the most abundant species collected by number (19.9%) followed by largemouth bass (13.4%), bluegill (13.3%), and longear sunfish (10.1%). Noticeable changes occurred between the 1977 and 1978 surveys. Most notably, gizzard shad's relative abundance by number decreased from 15.8% in 1977 to 2.8% in 1978 and black crappie relative abundance by number increased from 9.9% in 1977 to 19.9% in 1978. Additionally, longear sunfish, whose population declined to minimal numbers after the partial fish eradication in 1966, increased from 1.3% in 1977 to 10.1% in 1978. Bluegill and largemouth bass relative abundance by number and PSD were similar to those measured in 1977. Black crappie had a very high PSD of 92. The same number of yellow perch were collected during both the 1977 and 1978 surveys; the PSD was also very high (98) during those assessments. Carp again accounted for a large percentage of the community by weight (39.5%), but were not considered a problem by IDNR.

In September 1981, 746 tiger muskie fingerlings were stocked in Beaver Dam Lake. A follow up survey was conducted in 1982 to evaluate the success of the stocking. Fifteen species of fish and one hybrid were collected in the 1982 survey (Braun, 1982). Black crappie was the most abundant species collected by number (43.0%), followed by bluegill (35%), yellow perch (6.7%), and golden shiner (4.7%). No tiger muskie were collected. All black crappie collected were age three plus and growth was average during the first year and below average during the next two. Black crappie had a PSD value of zero indicating no individuals collected were considered harvestable size (8 in; 20.3 cm); however, 91% measured between 6 and 7 inches (15.2-17.8 cm). Bluegill PSD decreased from 51 in 1978 to 20 in 1982). Largemouth bass relative abundance by number decreased from 13.4% in 1978 to 1.7% in 1982 and the calculated PSD for largemouth rated approximately the same (46 and 40, respectively). Yellow perch collected ranged in size from 5-11.5 inches (12.7-29.2 cm) and had a low PSD value of 9. IDNR suggested Beaver Dam Lake be surveyed the following year to monitor largemouth bass and black crappie populations.

Fifteen species of fish were collected during the 1983 survey of Beaver Dam Lake (Braun, 1983). Bluegill was the most abundant species collected by number (33.9%), followed by black crappie (27.8%), golden shiner (15.2%), and gizzard shad (7.6%). All calculated PSD values were low for most species except largemouth bass. In general, bluegill, black crappie, and yellow perch were all dominated by one year class or a size range that was below harvestable size, which explains the low PSD values. For example, the 1982 year class accounted for 88% of the bluegill collected and the 1979 year class accounted for 97.5% of black crappie collected. While the calculated PSD for largemouth bass was in the desirable range (40-70), only 36 individuals were collected. IDNR biologists suggested a northern pike stocking in Beaver Dam Lake to consume the

over abundance of forage species, such as gizzard shad and golden shiner, as well as bluegill, black crappie and pumpkinseed. In general, northern pike do not form dense populations according to the IDNR, the southwestern portion of the Beaver Dam Lake could provide spawning habitat.

In 1984, Beaver Dam Lake became one of eight lakes used in Indiana to evaluate a 14-inch minimum size limit on largemouth bass. Annually from 1984 to 1989 and in 1992, largemouth bass sampling and population estimates were made on Beaver Dam Lake. Based on these assessments, the minimum size limit went into effect in the fall of 1986. A general fisheries survey was conducted in 1992 to evaluate the possible impacts of the 14-inch minimum size limit on the fish community and to assess the fishery as a whole. Nineteen species of fish were collected in the 1992 survey of Beaver Dam Lake (Braun, 1993). Bluegill was the most abundant species collected by number (40.2%), followed by gizzard shad (24.3%), largemouth bass (11.4%), and yellow perch (8.5%). The calculated PSD for bluegill increased from 7 in 1983 to 23 in 1992. Largemouth bass PSD increased slightly from 40 in 1983 to 44 in 1992. Additionally, largemouth bass relative abundance by number increased from 1.7% in 1983 to 11.4% in 1992. Yellow perch PSD increased considerably from 3 in 1983 to 73 in 1992. In 1983, black crappie was the second most abundant fish species collected accounting for 27.8% of the sample; however, during the 1992 survey, black crappie was the ninth most abundant species collected accounting for 1.7% of the sample. Gizzard shad relative abundance increased from 7.6% in 1983 to 24.3% in 1992. Results of the survey suggested that the largemouth population had improved since the adoption of the 14-inch minimum size limit. Reinforcing this theory was an observed increase in the largemouth bass population and an increase in the size of individuals. In 1983, the largest bass collected measured 17 inches (43.2 cm) with only three individuals measuring over 14 inches (35.6 cm) collected compared to maximum largemouth bass measuring 20.6 inches (52.3 cm) and 10 individuals collected in 1992.

In 1992, IDNR biologists suggested that the largemouth bass population should be sampled on a regular basis to monitor the potential long-term impacts that the 14 inch (35.6 cm) minimum size limit might have on the fish community in Beaver Dam Lake. In 1994, Beaver Dam Lake was sampled to monitor any potential changes. Electrofishing occurred over four nights in May. The sampling targeted only largemouth bass and utilized mark-recapture methods to estimate the largemouth bass population. In June, electrofishing occurred again with effort being alternated between intensive (all species targeted) and selective (bluegill only). CPUE for largemouth bass in May was 111.3 per hour. June electrofishing collected thirteen species of fish of which bluegill, gizzard shad, and largemouth accounted for 97.3% of fish collected. Bluegill was the most abundant species collected by number (61.3%), followed by gizzard shad (30.5%), and largemouth bass (5.5%). Bluegill PSD decreased from 23 in 1992 to 11 in 1994. Largemouth bass PSD decreased from 44 in 1992 to 34 in 1994. PSDs were not calculated for yellow perch or black crappie due to only three and zero individuals collected, respectively. Average bluegill CPUE for intensive dip netting was 116 per hour and 147.8 per hour for selective dip netting. IDNR biologists suggested that the largemouth bass population had stabilized since the implementation of the 14 inch (35.6 cm) minimum size limit. This thought was based on an increased CPUE for largemouth bass: 88/hour in 1992 to 111.3/hour in 1994. IDNR biologists further suggested that bluegill fishing has improved since the adoption of the largemouth bass minimum size limit as CPUE for bluegill increased from 313/hour in 1992 to 556/hour in 1994.

Beaver Dam Lake was next sampled in 2002. Twenty-one species of fish were identified (Burlingame, 2003). Bluegill was the most abundant fish species collected by number (52.4%), followed by largemouth bass (13.9%), yellow perch (12.3%), and brook stickleback (8.4%). Bluegill PSD increased from 11 in 1994 to 19 in 2002. Largemouth bass PSD more than doubled from 1994 to 2002 rating 34 and 79, respectively. Largemouth bass ranged in size from 3.4-16.8 inches (8.6-42.7 cm); individuals 12-14 inches (30.5-35.6 cm) dominated the catch accounting for 87% of the largemouth bass collected. Yellow perch had a very high PSD of 99. Gizzard shad relative abundance decreased from 30.5% in 1994 to 4.4% in 2002. CPUE for largemouth bass increased from 111.3/hour in 1994 to 186/hour in 2002. CPUE for bluegill decreased from 556/hour in 1994 to 438/hour in 2002. IDNR reported that both bluegill and largemouth growth rated average or above average when compared to most Indiana natural lakes. The reduction of gizzard shad in Beaver Dam Lake was thought to be contributing to the improvements observed in the bluegill population. Reduced numbers of gizzard shad decrease the amount of inter-specific competition between gizzard shad and bluegill populations. Gizzard shad are a planktivorious species foraging on zooplankton, an important food source for young, developing bluegill. Increased competition for food between gizzard shad and bluegill often results in higher mortality rates among young bluegill, thereby decreasing the amount of individuals successfully being recruited into the population. Finally, efforts made by the Beaver Dam Lake Conservation Club to reduce the density of milfoil were suggested to be contributing to the observed improvements in the bluegill population as well. Reducing the density of aquatic plants allows largemouth bass to more effectively prey upon bluegill reducing the amount of intra-specific competition within the bluegill population for food and space.

Beaver Dam Lake was most recently surveyed in 2005. Electrofishing occurred in May to estimate the largemouth bass population in addition to a general survey in June, and an angler creel survey from April through September. The largemouth bass population was estimated at 3,380 fish or 23 bass per acre for any size (Benson, 2006). Stock size fish (8 in; 20.3 cm) were estimated at 2,861 fish or 20 stock size fish per acre. In contrast, the 1994 population estimate of stock size largemouth bass was 1,861 fish or 12.7 stock size bass per acre (Braun, 1995). In 2005, largemouth bass reached harvestable size (14 in; 35.6 cm) at age 5. The general fish survey collected seventeen species of fish and 1 hybrid. Bluegill was the most abundant species collected by number (65.1%) followed by largemouth bass (8.6%), yellow perch (6.8%), and gizzard shad (5.5%). In 2005, largemouth bass, yellow perch, and bluegill PSD values fell into the desired range for a balanced population; however, both yellow perch and largemouth bass PSD values decreased from the 2002 survey. Results of the creel survey indicated anglers preferred to fish for largemouth bass (45%), bluegill (39%), or both bass and bluegill (12%). Fishing pressure was the highest in July and lowest in April. The overall fishing pressure for the six month creel survey was 54 hr/acre. The overall harvest of fish from Beaver Dam Lake was 2,853 or 0.36 fish/hr. Of the 1,090 individuals that were interviewed, 85% believed the quality of fishing in Beaver Dam Lake was staying the same, while 6% believed it to be improving, and 9% indicated it was declining. When anglers were asked whether they were satisfied with their fish experience that day, 92% indicated that they were satisfied, while 8% were not satisfied. The most common reason for anglers to be unsatisfied with their fishing trip was that either no fish were caught or no fish were caught that were large enough to harvest.

Diamond Lake

Fish Community Composition

In 1964, twenty-four fish species were identified in the initial survey of Diamond Lake (McGinty, 1966b). Bluegill was the most abundant species by number (37.0%), followed by longear sunfish (21.0%), gizzard shad (12.5%), and pumpkinseed (10.5%; Figure 43). Bluegill PSD was 9 indicating the population was dominated by small individuals (Figure 44). (Appendix D describes PSD values, their calculation, and factors that affect them.) Anderson (1980) suggests a balanced bluegill population has a desired PSD value of 20-40. Largemouth bass had a very low PSD value and the population was dominated by small, young individuals. Anderson (1980) suggests a balanced largemouth population has a desired PSD value of 40-70. The calculated PSD value for yellow perch was high (71), suggesting the population had a sizable amount of quality sized individuals. The desired PSD value for yellow perch according to Anderson and Weithman (1978) is 30-50. Longear and pumpkinseed sunfish combined had a relative abundance of 31.5% by number. With the exception of two pumpkinseed sunfish that measured 6 inches (15.2 cm), nearly 100% of longear and pumpkinseed sunfish collected measured less than 6 inches (15.2 cm). Pumpkinseed and longear sunfish of this size are generally considered undesirable to anglers. Gizzard shad ranked third in abundance by number but McGinty (1966b) suggested they were the most abundant species in Diamond Lake due to a large number of individuals observed (but not captured) during the sampling period. McGinty (1966b) suggested a partial fish eradication be carried out in Diamond Lake in response to the poor size structure observed within the bluegill population and large numbers of gizzard shad and undesirable sunfish species (longear, pumpkinseed, warmouth). The partial fish eradication would target these species in areas of Diamond Lake measuring less than eight feet deep. Large numbers of gizzard shad and undesirable sunfish are a potential threat to young bluegills because they increase competition for food resources. Therefore, their removal from the fish community was necessary to stabilize and improve the bluegill population.

A survey was conducted in Diamond Lake in 1968 to evaluate the success of the partial fish eradication conducted in 1967. Eighteen fish species were identified (Hudson, 1969). Longear sunfish were the most abundant species collected by number (30.9%), followed by bluegill (28.5%), pumpkinseed (18.5%), and gizzard shad (8.5%). According to IDNR biologists, the partial fish eradication in 1967 did not improve the bluegill population in Diamond Lake. Young, small individuals still dominated the bluegill population and the bluegill PSD did not change much. The partial fish eradication in 1967 was also not successful in decreasing populations of undesirable sunfish species (longear, pumpkinseed, warmouth). Longear sunfish relative abundance increased from 21.0% in 1964 to 30.9% in 1968, while pumpkinseed sunfish relative abundance increased from 10.5% to 18.5%, respectively. One hundred percent of longear sunfish and 94.7% of pumpkinseed sunfish collected measured less than six inches. The partial fish eradication effort was successful in reducing the young gizzard shad population; only one gizzard shad collected measured less than 10.5 inches (26.7 cm). Additionally, gizzard shad relative abundance decreased from 12.5% in 1964 to 8.5% in 1968. Despite the decrease in gizzard shad relative abundance, IDNR biologists still considered gizzard shad a problem. Both yellow perch relative abundance and PSD increased from 1964 to 1968. Largemouth bass relative abundance decreased from 1964 to 1968 and PSD stayed about the same. A fall seining event occurred in Diamond Lake in 1968 where a large number of YOY (young-of-the-year) largemouth bass were collected. As stated by Hudson (1969), this collection of YOY largemouth bass was

encouraging. Based on this data, the IDNR dismissed another partial fish eradication effort for Diamond Lake and recommended a follow-up survey be conducted in 1970 to reevaluate the fish population in Diamond Lake.

The follow-up survey in 1970 identified twenty fish species (Johnson, 1971). Bluegill were the most abundant fish species collected by number (35.7%), followed by pumpkinseed sunfish (18.5%), longear sunfish (11.7%), and gizzard shad (9.7%). Bluegill PSD increased from 1968 to 1970; however, the population structure was still unsatisfactory. Collectively, longear and pumpkinseed sunfish had a relative abundance of 28.4% by number. Longear and pumpkinseed sunfish size was again undesirable with almost 100% of collected individuals from both species measuring less than six inches (15.2 cm). Gizzard shad relative abundance increased slightly from 1968 to 1970, remaining at a level that was not a problem. Largemouth bass relative abundance and PSD changed little between 1968 and 1970. Johnson (1971) suggested partial fish kills be conducted on Diamond Lake for three consecutive years to reduce the abundance of small bluegill and undesirable sunfish species. Additionally, Johnson (1971) recommended Hill Lake, Yellow Creek Lake, and McClures Lake also be sampled so a management plan could be developed for all the lakes based on their connectivity.

Diamond Lake was renovated and restocked in October 1973 by the IDNR (October 26, 1973 Fish Population Control Plan report). As detailed above, this effort was in response to an over-abundance of small individuals in the bluegill population and large numbers of small undesirable sunfish species (pumpkinseed, longear, warmouth). Rotenone was applied to the entire lake to completely eradicate the fish population; largemouth bass, black crappie, bluegill, channel catfish, walleye and northern pike were stocked concurrently. Hill Lake, which is upstream and connected to Diamond Lake via the Michaels Arm of Swick-Meredith Drain, was renovated and restocked at the same time with the same species. A fish barrier was constructed between Diamond and Yellow Creek lakes to prevent movement of undesirable fish species from Yellow Creek Lake to Diamond Lake.

Diamond Lake was surveyed in 1974 to evaluate the success of the 1973 renovation and restocking effort. Twelve species of fish were identified in the 1974 survey (Taylor, 1975). Largemouth bass was the most abundant species by number (41.7%), followed by bluegill (26.2%), white sucker (11.2%), and lake chubsucker (5.4%). Of the six species stocked in the 1973 renovation and restocking effort, all but two (walleye and northern pike) were collected. Largemouth bass and bluegill condition and growth were above average and reproductive success was evident due to the presence of Age 0 individuals. Several additional fish species re-entered Diamond Lake despite the installation of a fish barrier between Diamond and Yellow Creek lakes. None of the additional species were suggested as a problem.

Diamond Lake was surveyed again in 1975 to evaluate the success of the renovation and restocking effort of 1973. All stocked species were collected and together accounted for 62.8% of the fish collected by number (Shipman, 1976). Bluegill was the most abundant fish species collected by number (48.4%), followed by gizzard shad (13.6%), yellow perch (9.2%), and largemouth bass (8.3%). Bluegill relative abundance increased considerably from 1974 to 1975, 26.2% and 48.4% respectively. Conversely, largemouth bass relative abundance decreased considerably from 1974 to 1975, 41.7% and 8.3%, respectively. Bluegill PSD was low (6), while largemouth bass PSD (43) fell on the low end of range desired for a balanced population. Shipman (1976) offered no explanation

for the changes in bluegill and largemouth bass populations. Yellow perch relative abundance increased from 1974 to 1975, while yellow perch PSD dropped. Pumpkinseed and longear sunfish were collected, but were present in low numbers. Collectively, pumpkinseed and longear sunfish accounted for only 2.6% of fish collected by number, which represents a significant decrease from pre-renovation and restocking effort levels. These data indicate an improvement to the Diamond Lake fishery. Gizzard shad relative abundance increased from 3.2% in 1974 to 13.6% in 1975. Numerous schools of gizzard shad were observed during sampling which suggested gizzard shad were, once again, a problem. IDNR biologists suggested that Diamond Lake be surveyed again in 1977 to monitor the gizzard shad population.

Twenty-one fish species were identified in the 1977 survey of Diamond Lake (Pearson, 1977). Bluegill was the most abundant species collected by number (47.1%), followed by gizzard shad (12.8%), golden shiner (9.2%), and yellow perch (8.7%). Bluegill relative abundance remained similar to that calculated for the 1975 survey. IDNR biologists noted good recruitment of bluegill from 1974 and very poor recruitment from 1975 and 1976. Only two individuals were collected from the 1975 year class; zero individuals were collected from the 1976 year class. As a result, a large portion of the bluegill population was quality size or larger which is represented in the PSD value. In a short (ten minute) electrofishing effort conducted in August 1977, the IDNR collected some small bluegill (0.7-2.8 in; 1.8-7.1 cm) suggesting recruitment occurred in the 1976 year class. Gizzard shad relative abundance decreased slightly between 1975 and 1977 returning to pre-1973 renovation and restocking effort levels. Yellow perch relative abundance changed little, while yellow perch PSD increased. Both largemouth bass relative abundance and PSD decreased from 1975 to 1977. Eighty-five percent of black crappie measured quality size or larger (≥ 8 in; 20.3 cm) indicating very good survival of black crappie from the renovation and restocking effort of 1973. However, few young, small individuals were collected suggesting poor recruitment after 1973. Walleye, northern pike, and channel catfish were collected, but were present in low numbers. Pearson (1977), suggested walleye, northern pike, and channel catfish would disappear from Diamond Lake due to inadequate if not absent recruitment. Furthermore, Pearson (1977) suggested Diamond Lake be re-surveyed twice in 1978 (June and again in late summer) to evaluate 1977 and 1978 bluegill recruitment.

Despite recommendations for a 1978 survey, Diamond Lake was not again surveyed until 1980. Overall, nineteen fish species were identified in the 1980 survey (Braun, 1981). Yellow perch was the most abundant fish species collected by number (46.6%), followed by bluegill (28.4%), largemouth bass (5.3%), and warmouth (2.8%). From 1977 to 1980, yellow perch relative abundance increased from 8.7% to 46.6%. Bluegill relative abundance decreased considerably from 1977 to 1980 measuring 47.7% and 28.4%, respectively. Bluegill PSD also decreased from 1977 to 1980. Braun (1981) indicated that the 1975 and 1976 bluegill year classes were very weak, but that year classes following had good recruitment. Braun further suggested that the bluegill population appeared to be stabilizing. Largemouth bass relative abundance increased slightly from 1977 to 1980 and PSD remained low. Braun (1981) noted that the largemouth bass population displayed a good distribution of individuals throughout the size range and also reported many schools of young of the year bass (< 2 in; 5.1 cm) were observed during the sampling process. Black crappie relative abundance decreased from 3.9% in 1977 to 0.7% in 1980. This was not a surprise to IDNR biologist due to the small number of young individuals identified in the 1977 survey. Gizzard shad relative abundance decreased from 12.8% in 1977 to 0.7% in 1980. A winter kill of gizzard shad was

suggested as the reason for the decline in the population from 1977 to 1980. Three channel catfish were collected in the 1980 survey. Again, it was noted by IDNR biologist that channel catfish were not reproducing naturally within Diamond Lake and to maintain a fishable channel catfish population a stocking program would need to be implemented. No walleye or northern pike were collected in the 1980 survey.

Twenty-one species of fish were collected in the 1983 survey of Diamond Lake (Braun, 1983). Gizzard shad was the most abundant species collected by number (42.6%), followed by yellow perch (22.3%), bluegill (11.7%), and channel catfish (6.9%). During the 1980 and 1983 Diamond Lake surveys, IDNR biologists collected approximately the same number of fish, 1215 and 1199, respectively. However, the relative abundance of fish species changed considerably between the two assessments. By number, gizzard shad relative abundance increased from 0.7% in 1980 to 42.6% in 1983, while yellow perch and bluegill relative abundances greatly decreased. Braun (1983) suggested that the increase in the gizzard shad population could have been an explanation for the decrease in yellow perch and bluegill populations due to competition for food and space between gizzard shad and bluegill and yellow perch populations. Channel catfish were stocked in Diamond Lake in 1981 which accounted for the increase in channel catfish relative abundance. Channel catfish accounted for 6.9% of the sample by number and of those 86.7% were of legal size (≥ 10 in; 25.4 cm). Braun (1983) recommended that channel catfish be stocked every three years in Diamond Lake to provide a steady, fishable population. Largemouth bass relative abundance decreased slightly from 1980 to 1983, while largemouth PSD increased. IDNR biologists recommended Diamond Lake be surveyed in 1985 to monitor the gizzard shad population.

The 1985 survey of Diamond Lake collected twenty fish species (Braun, 1986). Bluegill was the most abundant species collected by number (27.9%), followed by gizzard shad (27.4%), largemouth bass (11.6%), and white sucker (8.4%). Bluegill relative abundance increased from 11.7% in 1983 to 27.9% in 1985; however, bluegill PSD remained unchanged. Gizzard shad was the most abundant fish species by weight accounting for 22% of the overall fish biomass collected. Gizzard shad relative abundance by number decreased from 42.6% in 1983 to 27.4% in 1985. Braun (1986) suggested that the decrease in relative abundance of gizzard shad could have explained the increase in bluegill relative abundance from 1983 to 1985. Largemouth bass relative abundance increased from 3.6% in 1983 to 11.6% in 1985; conversely, largemouth bass PSD decreased during this time period from 64 to 22. Channel catfish were stocked again in Diamond Lake in 1984. Eighty-six percent of channel catfish were of legal size (≥ 10 in; 25.4 cm) and 22.2% of channel catfish were quality size or larger (≥ 16 in; 40.6 cm). Yellow perch relative abundance decreased for the third survey year in a row. Black crappie relative abundance decreased from 4.9% in 1983 to 1.2% in 1985.

The next survey of Diamond Lake occurred in 1995. Twenty-four fish species were identified in the 1995 survey of Diamond Lake (Braun, 1996). Bluegill was the most abundant species collected by number (43.6%), followed by gizzard shad (17.2%), largemouth bass (16.4%), and yellow perch (7.6%). Bluegill relative abundance increased from 27.9% in 1985 to 43.6% in 1995. Concurrently, PSD for bluegill decreased from 23 to 14. Gizzard shad relative abundance decreased from 27.4% in 1985 to 17.2% in 1995. Both relative abundance and PSD of largemouth bass increased from 1985 to 1995. In 1990, Indiana initiated a 12-inch minimum size limit on largemouth bass. Braun (1996) suggested the change in policy coupled with an increase in acceptance of catch and release practices could have led to the larger bass population

in Diamond Lake. The yellow perch population changed little from 1985 to 1995. Additionally, the Diamond Lake Conservation Club stocked channel catfish in Diamond Lake in 1992; however, only two channel catfish were documented in the 1995 survey.

Twenty fish species were identified in the 2005 survey of Diamond Lake (Meyer, 2006). Bluegill was the most abundant species collected by number (29.2%), followed by gizzard shad (27.8%), largemouth bass (14.3%), and yellow perch (10.6%). Bluegill relative abundance decreased from 46.3% in 1995 to 29.2% in 2005, while bluegill PSD increased from 14 in 1995 to 39 in 2005. Gizzard shad relative abundance increased from 17.2% in 1995 to 27.8% in 2005. Largemouth bass relative abundance decreased from 16.4% in 1995 to 14.3% in 2005. The Indiana state legal minimum size limit for largemouth bass was increased from 12 inches to 14 inches in 1998. Despite the increase in the state minimum size limit, largemouth bass PSD decreased from 47 in 1995 to 32 in 2005. Yellow perch relative abundance and PSD both increased from 1995 to 2005. Diamond Lake was spot treated with Reward to control Eurasian watermilfoil in 2005, and again in 2006 (Weed Patrol, Inc. 2007). Meyer (2006) noted the herbicide treatment was effective in reducing the abundance of Eurasian watermilfoil in Diamond Lake.

A general fishery survey was conducted again in 2006 to collect data on the effect of the herbicide treatment on the fishery. Thirteen fish species were identified in the general survey of 2006 (Edgell, 2006). Gizzard shad was the most abundant species by number (33.3%), followed by largemouth bass (29.2%), bluegill (14.2%), and white sucker (9.7%). Gizzard shad relative abundance increased from 27.8% in 2005 to 33.3% in 2006. Both largemouth bass relative abundance and PSD increased from 2005 to 2006. Edgell (2006) noted that catch rates of largemouth bass during electrofishing almost doubled from the 2005 survey to 2006 survey. Bluegill relative abundance decreased from 29.2% in 2005 to 14.2% in 2006, while bluegill PSD increased from 39 to 54. The yellow perch population remained at levels collected in 2005. Edgell (2006) stated that the 2005 and 2006 herbicide treatments were successful in reducing the abundance of Eurasian watermilfoil and could account for the increase in growth rates between 2005 and 2006 for largemouth bass and bluegill. Reduced abundance of Eurasian watermilfoil was suggested by Edgell (2006) to increase the availability of gizzard shad and bluegill as prey items for largemouth bass and, as a result, reduce intra-specific competition between bluegill due to a lower bluegill population density.

Hill Lake

Fish Community Composition

In 1965, fourteen fish species were identified during the initial survey of Hill Lake (McGinty, 1966c). Bluegill was the most abundant species by number (46.3%), followed by longear sunfish (27.0%), yellow perch (9.3%), and largemouth bass (7.2%; Figure 59). Bluegill had a Proportional Stock Density (PSD) of 15 suggesting the population was dominated by smaller individuals (Figure 60). Appendix D describes PSD values, their calculation, and factors that affect them. Anderson (1980) suggests a balanced bluegill population has a desired PSD value of 20-40. Bluegill condition was considered slightly above average when compared to other northeastern Indiana lakes surveyed. Yellow perch had a PSD value of 84 suggesting the population was dominated by larger individuals. The desired PSD value for yellow perch according to Anderson and Weithman (1978) is 30-50. Yellow perch condition was considered very good. Largemouth bass had a PSD value of 22 which is below the desired range of 40-70 suggested by Anderson (1980). Largemouth bass condition was considered average to

above average. While longear sunfish were considered abundant, all collected longear sunfish measured smaller than 6 inches (15.2 cm). Longear sunfish of this size are generally considered undesirable to anglers. The abundance of longear sunfish was also seen as a potential threat to bluegill due to possible competition for food resources.

In 1972, eighteen fish species were identified (Taylor, 1973). Yellow perch was the most abundant species by number (24.3%), followed by bluegill (21.5%), largemouth bass (13.3%), and gizzard shad (12.4%). Yellow perch relative abundance increased from 1965 to 1972; condition, growth, and PSD of yellow perch all decreased during this period. Bluegill PSD increased from 15 in 1965 to 41 in 1972, while bluegill relative abundance decreased from 46.3% to 21.5%, respectively. Bluegill condition and growth rates also decreased from 1965 to 1972 and were considered below average. Both relative abundance and PSD of largemouth bass increased from 1965 to 1972. Largemouth bass condition and growth rates were considered average in 1972. Relative abundance of gizzard shad increased from 1.1% in 1965 to 12.4% in 1972. A large number of small (0.5-1.0 in; 1.3-2.5 cm) gizzard shad were also observed during the survey period, but were not collected. IDNR biologists suggested that had the young gizzard shad been collected, they could have comprised up 90% of the sample. Gizzard shad was suggested as a serious threat to the reproductive success of bluegill and largemouth bass and were one reason for the renovation and restocking suggestion made for 1973.

In 1974, a short survey was conducted to evaluate the success of the 1973 renovation and restocking effort. Eight fish species were identified during the 1974 survey (Taylor, 1974). Largemouth bass was the most abundant species by number (55.5%), followed by black crappie (21.9%), white sucker (14.4%), and bluegill (4.1%). The IDNR considered reproductive success of black crappie and largemouth bass excellent, while bluegill reproductive success was considered fair. Growth of northern pike and bluegill rated as excellent. PSD was not calculated for the 1974 survey due to the recent renovation and restocking effort in 1973.

In 1975, IDNR biologists identified twelve fish species during their assessment of Hill Lake (Shipman, 1976a). Bluegill was the most abundant species by number (57.1%), followed by largemouth bass (14.5%), pumpkinseed (10.0%), and black crappie (7.5%). The six species, bluegill, largemouth bass, black crappie, walleye, northern pike, and channel catfish, originally stocked as part of the 1973 renovation and restocking effort had a relative abundance of 84.7% by number and 67.5% by weight. Bluegill condition rated below average, while bluegill growth rated above average. Largemouth bass growth and condition rated average to above average during the 1975 assessment. PSD was not calculated for the 1975 survey.

In 1977, seventeen fish species were identified during the survey (Pearson, 1977b). Bluegill was the most abundant species by number (52.5%), followed by largemouth bass (16.7%), pumpkinseed (7.3%), and lake chubsucker (4.6%). Bluegill condition rated slightly above average and growth rated above average for the 1974 year-class and average for the 1975 and 1976 year-classes. Bluegill relative abundance remained similar to that sampled in 1975 and bluegill PSD was 41 suggesting the population had a balance of larger and smaller individuals. Largemouth bass numbers were good; however, growth rated below average. Below average growth rates and inadequate time to reach quality size since the renovation and restocking effort (1973) are reflected in the very low PSD value calculated for largemouth bass in 1977. All channel catfish collected

measured 13-21 inches (33.0-53.3 cm) long and were considered of harvestable size (≥10 inches; 25.4 cm). Due to the absence of young, small individuals, a naturally reproducing channel catfish population was dismissed (Pearson, 1977).

Nineteen fish species were identified during the 1980 survey (Braun, 1981b). Bluegill was the most abundant species by number (60.2%), followed by yellow perch (8.8%), largemouth bass (6.9%), and redear sunfish (4.8%). In 1980, IDNR biologists collected yellow perch for the first time since the lake renovation effort. Yellow perch growth rates were believed to be decreasing as the population increased over the previous four years due to a decline in growth rates after Age 1. Largemouth bass and bluegill had similar growth rate trends. Bluegill growth rates decreased after Age 1, while largemouth bass growth rates decreased after Age 3. Largemouth bass PSD remained low while bluegill and yellow perch PSD values were within the desired range for balanced populations. According to IDNR biologists, Hill Lake was dominated by game-fish, but was producing slow growth rates.

The 1983 survey identified twenty-two fish species (Braun, 1983c). Yellow perch was the most abundant species by number (31.3%), followed by bluegill (24.7%), warmouth (8.2%), and gizzard shad (8.1%). Yellow perch condition and growth again decreased in concert with population increases observed from 1980 to 1983. In 1980, yellow perch represented 8.8% of the sample by number and 6.1% of the sample by weight. In 1983, yellow perch represented 31.3% of the sample by number and 9.5% of the sample by weight. Yellow perch length ranges for 1980 and 1983 were the same. Only 10.8% of the perch collected in 1983 were of quality size or larger (≥ 8 inches; 20.3 cm) compared to 29.3% of yellow perch in 1980, thus the decrease in PSD. Largemouth bass relative abundance decreased slightly from 1980 to 1983; however, largemouth bass PSD increased significantly from 17 to 51 respectfully. Bluegill PSD decreased from 1980 to 1983. Ninety-two percent of channel catfish collected in 1983 were of harvestable size (≥10 inches; 25.4 cm).

The 1985 survey included identification of twenty fish species (Braun, 1986b). Bluegill was the most abundant species by number (43.2%), followed by gizzard shad (14.6%), yellow perch (10.2%), and channel catfish (8.0%). Both bluegill and largemouth bass relative abundances increased from 1983 to 1985, while yellow perch relative abundance decreased. All calculated PSD values fell below that desired for a balanced population.

Hill Lake was most recently surveyed in 1994 (Braun, 1995b). Nineteen fish species were identified of which bluegill was the most abundant species by number (57.5%), followed by largemouth bass (12.7%), yellow perch (8.2%), and redear sunfish (8.1%). Both bluegill and largemouth bass relative abundances increased from 1985 to 1994, while yellow perch relative abundance decreased. Yellow perch and bluegill rated desirable PSD values, while largemouth bass PSD was low. The number of gizzard shad collected in 1994 was 10% of that collected in 1985. The increase in the largemouth bass population since the implementation of the 12-inch size limit on Hill Lake in 1990 was suggested by Braun (1995), as one possible explanation for the decline in gizzard shad abundance from 1985 to 1994.

Loon Lake

Fish Community Composition

The initial survey of Loon Lake identified nineteen species of fish (McGinty, 1966d). Bluegill was the most abundant fish species collected by number (59.6%), followed by largemouth bass (10.8%), gizzard shad (6.9%), and redear sunfish (4.7%; Figure 75). Bluegill had a very low PSD value of 9 suggesting the bluegill population was dominated by small individuals. Anderson (1980) suggests a balanced bluegill population has a PSD value of 20-40. (Appendix D describes PSD values, their calculation, and factors that affect them.) Sufficient data to calculate a largemouth bass PSD was not available; therefore, PSD of largemouth bass was not calculated. McGinty (1966d) reported 51% of largemouth bass were catchable (≥ 10 inches; 25.4 cm) and additional adults and young of the year (YOY) were observed while sampling. Yellow perch collected had above average condition and growth; however, yellow perch were collected in low numbers and reports from anglers suggested the angling opportunity for yellow perch was low. Fourteen spotted gar were collected accounting for 2.4% of fish collected by number. Additional numbers of spotted gar were observed during sampling. Undesirable fish species such as gizzard shad and common carp were collected, but in low abundance and not considered a problem in Loon Lake during the 1965 survey.

Twenty-one fish species were collected in the 1980 survey of Loon Lake (Braun, 1981). Bluegill was the most abundant fish species collected by number (29.6%), followed by black crappie (22.5%), largemouth bass (8.8%), and golden shiner (8.4%). Bluegill relative abundance decreased from 59.6% in 1965 to 29.6% in 1980; conversely, bluegill PSD increased from 9 to 47 during the same period. Notably, black crappie relative abundance increased from 1.7% in 1965 to 22.5% in 1980. Largemouth bass relative abundance decreased slightly from 1965 to 1980. The calculated PSD for largemouth bass in 1980 was 24, suggesting that the population was not balanced. Anderson (1980) suggests a balanced largemouth bass population has a PSD value of 40-70. Yellow perch relative abundance increased from 3.2% in 1965 to 6.7% in 1980. The PSD value of yellow perch sampled in 1980 was 83. The desired PSD value for yellow perch according to Anderson and Weithman (1978) is 30-50. Spotted gar accounted for 4.9% of the sample by number and 29.3% of the sample by weight. Braun (1981) suggested the sizeable population of spotted gar could explain the well balanced fish community in Loon Lake. Again, undesirable fish species such as gizzard shad and common carp were collected, but not in abundances that were not considered a problem to the fishery.

Loon Lake was most recently surveyed in 2006. Seventeen fish species were collected in addition to one hybrid (Grier, 2006). Bluegill was the most abundant fish species collected by number (66%), followed by spotted gar (11.1%), largemouth bass (9.1%), and yellow perch (2.9%). Bluegill, despite their abundance, still exhibited good population structure. The PSD for bluegill in 2006 was 43. Largemouth bass relative abundance was similar to that sampled in 1965 and 1980 with a calculated PSD value of 79. The high PSD value would suggest that the largemouth bass population is not balanced, but does provide quality angling opportunities. The same number of spotted gar were collected in the 2006 survey as in the 1980 survey; however, due to the reduced number of all fish species collected in the 2006 survey, spotted gar accounted for a larger portion of the sample. Yellow perch had a size range of 9.5 inches to 12.5 inches (24.1 cm to 31.8 cm), but were collected in low abundance (2.9%). Black crappie relative abundance decreased considerably from 22.5% in 1980 to 1.6% in 2006.

McClures

Fish Community Composition

The initial survey of McClures Lake occurred in 1965 where 19 species of fish were identified (McGinty, 1966e). Bluegill was the most abundant species collected by number (68.4%), followed by largemouth bass (10.5%), redear sunfish (5.4%), and longear sunfish (3.5%; Figure 90). Gamefish accounted for 91% of the fish sampled by number. Both bluegill and largemouth bass had low Proportional Stock Density (PSD) values 4 and 18, respectively. (Appendix D describes PSD values, their calculation, and factors that affect them.) Anderson (1980) suggests a balanced population of bluegill should have a PSD value of 20-40 and largemouth bass should have a PSD value of 30-50. McGinty (1966e) noted that during sampling many additional largemouth bass were observed and that the largemouth bass population was considered phenomenal. A number of different sunfish species were collected during the sampling effort but due to the low abundance in which they were collected the miscellaneous sunfish population was suggested to be contributing little to the fishery. Gizzard shad accounted for 2.6% of the fish collected by number with additional numbers noted during the sampling effort. Gizzard shad can be important as a forage species within a fish community; however, when gizzard shad numbers are not kept in check they can quickly become the dominant species within a system and compete for space and resources with other species of fish such as bluegill. However, gizzard shad were not viewed as a threat to the fish community in McClures Lake in 1965.

McClures Lake was most recently surveyed in 1985. Seventeen species of fish and one hybrid were collected (Braun, 1986c). Bluegill was the most abundant species collected by number (60.8%), followed by largemouth bass (11.8%), gizzard shad (9.0%), and black crappie (3.4%). Gamefish accounted for 79% of fish collected by number. Bluegill relative abundance did not change much between 1965 and 1985; however, bluegill PSD increased tenfold from 4 in 1965 to 40 in 1985 suggesting the bluegill population was balanced in 1985. Both relative abundance and PSD of largemouth bass increased only slightly from 1965 to 1985 suggesting the largemouth bass population was similar to that sampled in 1965. Gizzard shad relative abundance increased from 2.4% in 1965 to 9% in 1985. Despite the increase in gizzard shad, relative abundance of the population was still not viewed as a major threat to the fishery. As in 1965, miscellaneous sunfish species were collected in low abundance and not viewed as a major component of the McClures Lake fishery.

Yellow Creek Lake

Fish Community Composition

In 1965, twenty-five fish species were identified in the initial survey of Yellow Creek Lake (McGinty, 1967, Table 73). Bluegill was the most abundant species collected by number (39.9%), followed by yellow perch (13.3%), longear sunfish (12.6%), and gizzard shad (9.2%; Figure 106). Bluegill had a Proportional Stock Density (PSD) value of 7 (Figure 107) indicating the population was dominated by smaller individuals. (Appendix D describes PSD values, their calculation, and factors that affect them.) Anderson (1980) suggests a balanced bluegill population has a desired PSD value of 20-40. Largemouth bass had a relative abundance of 7.3% and a PSD value of 17. Anderson (1980) suggests a balanced largemouth population has a desired PSD value of 40-70. A PSD value of 17 in Yellow Creek Lake suggests that the largemouth bass population was dominated by smaller individuals. Yellow perch rated a PSD value of 71 suggesting the population was dominated by larger individuals. The desired PSD value for yellow perch according to Anderson and Weithman (1978) is 30-50. Longear sunfish were the third

most abundant species collected in Yellow Creek Lake in the 1965 survey. The longear sunfish population was considered undesirable for two reasons: 1) because all but two individuals collected measured less than 6 inches the entire population was generally considered undesirable to anglers, and 2) the abundance of longear sunfish could negatively impact the bluegill population by increasing competition for food resources. Gizzard shad ranked fourth in relative abundance but were suggested as the most abundant species in Yellow Creek Lake due to the large number of young of the year (YOY) gizzard shad observed during sampling. A partial fish kill was suggested by McGinty (1967) to reduce the number of small bluegill and longear sunfish and number of gizzard shad within Yellow Creek Lake.

A follow up survey was conducted in Yellow Creek Lake in 1967 to re-evaluate the small, undesirable sunfish population observed in the 1965 survey. Nineteen species of fish and one hybrid species were collected in the 1967 survey of Yellow Creek Lake (Hudson, 1968). Largemouth bass was the most abundant species collected by number (30.9%), followed by bluegill (15.2%), gizzard shad (13.9%), and lake chubsucker (13.1%). The relative abundance of largemouth bass increased between 1965 and 1967, while bluegill relative abundance decreased. Both largemouth bass and bluegill PSD values remained similar to that calculated in 1965. Gizzard shad relative abundance increased between 1965 and 1967. Yellow perch relative abundance decreased from 13.3% in 1965 to 1.8% in 1967. A PSD value could not be calculated for the yellow perch population due to lack of data available. Notably, lake chubsucker relative abundance increased from 0.6% in 1965 to 13.1% in 1967. Lake chubsuckers can provide a good forage opportunity to predators when individuals are less than six inches, however, all individuals collected in the 1967 survey measured greater between 6.5 inches and 8.5 inches. Hudson (1968) suggested that the Yellow Creek Lake fish population had improved since 1965 and recommended that the lake be surveyed again in 1969 to re-evaluate the fishery.
As recommended by IDNR, Yellow Creek Lake was surveyed again in 1969. Twenty-one fish species were collected during the 1969 survey (Hudson, 1970). Yellow perch was the most abundant species collected by number (33.0%), followed by bluegill (26.1%), gizzard shad (12.3%), and largemouth bass (9.7%). Yellow perch relative abundance increased by more than an order of magnitude from 1.8% in 1967 to 33.0% in 1969 and a high PSD value (90) was calculated for the 1969 survey. Bluegill relative abundance increased from 15.2% in 1967 to 26.1% in 1969. Bluegill PSD also increased from 4 in 1967 to 24 in 1969, suggesting that the bluegill population size structure had improved. Largemouth bass relative abundance decreased from 30.0% in 1967 to 9.7% in 1969. Largemouth bass PSD increased from 19 in 1967 to 26 in 1969. Gizzard shad relative abundance remained similar to that observed in the 1967 survey.

Twenty-five fish species were collected in the 1977 survey of Yellow Creek Lake (Pearson, 1977). Bluegill was the most abundant species collected by number (33.0%), followed by gizzard shad (16.9%), yellow perch (12.7%), and golden shiner (9.9%). Bluegill relative abundance increased from 26.1% in 1969 to 33.0% in 1977, but most notably bluegill PSD more than tripled from 24 in 1969 to 75 in 1977. Yellow perch relative abundance decreased considerably from 1969 to 1977; however, yellow perch PSD remained high at a rating of 82. Largemouth bass relative abundance decreased from 9.7% in 1969 to 3.4% in 1977. Largemouth bass PSD also decreased from 1969 to 1977 and remained below the desired range. Gizzard shad relative abundance increased from 12.3% in 1969 to 16.9 % in 1977.

The most recent survey of Yellow Creek Lake occurred in 1986. Twenty-one fish species were identified (Braun, 1986d). Bluegill was the most abundant species collected by number (35.1%), followed by yellow perch (14.8%), gizzard shad (14.7%), and white sucker (6.6%). Bluegill relative abundance increased only slightly from 1977 to 1986, however, PSD decreased considerably from 75 in 1977 to 22 in 1986. The high PSD value observed in the 1977 survey was contributed to strong year classes in 1973 and 1974. Yellow perch relative abundance increased slightly from 1977 to 1986. Calculated yellow perch PSD's have historically been high, but in 1986 the calculated PSD was low rating 13. Largemouth bass relative abundance increased slightly from 3.4% in 1977 to 4.6% in 1986. Calculated PSD for largemouth bass collected was 37, just shy of the desired range of 40-60 for a balanced population. Gizzard shad relative abundance remained similar to that observed in past survey years. Gizzard shad and white sucker accounted for 41% of the biomass collected in the 1986 survey. These two species were suggested by Braun (1986) as the most limiting factor to the game fish population in Yellow Creek Lake. These species compete with game species for food and are assumed to be accounting for a large portion of the carrying capacity in the lake. Renovation of Yellow Creek Lake was suggested by Braun (1986) however, it was inferred that it was physically and economically impossible at the present time due to the connection of Yellow Creek Lake to the other five lakes located upstream coupled with an insufficient drop from the top of the outlet dam to the outlet water level, which would allow the re-entry of undesirable fish species back into Yellow Creek Lake. To control the fish community composition within Yellow Creek Lake, a fisheries management plan would have to be developed that involved all six lakes.

Proportional stock density (PSD) is an easily calculated statistic used by fisheries biologists when determining if a species population is balanced. Anderson (1976) developed PSD and its use is generally applicable to water bodies less than 500 acres. PSD relates the number of individuals in a population stock size or larger to the number of those individuals that are of quality size or larger. Stock size is generally defined as the minimum size at which a species becomes available to anglers, while quality size is generally defined as the minimum size anglers consider the species harvestable. Generally, PSDs indicative of balance in a target species population are based on sustainable harvest of sizes preferred by anglers (Hubert and Kohler, 1999). Therefore, balance depends on the density of fish of various sizes in the population; both adequate numbers of catchable size fish and sufficient numbers of smaller fish to provide replacement (Hubert and Kohler, 1999).

PSD Explained

Ranges of PSD values indicating balanced populations have been developed for a number of different fish species. For example, largemouth bass populations with PSD values between 40 and 70 and bluegill populations with PSD values between 20 and 40 are characteristic of balanced populations (Anderson, 1980). If a species PSD value is low it would suggest the population has a disproportionate number of small individuals. Conversely, if a species PSD is high it would suggest the population has a disproportionate number of large individuals. It is important to note that desired PSD values can vary depending on the management goal of a fishery. For example, a largemouth bass oriented fishery would support a low PSD value in the bluegill population and a high PSD value in the largemouth bass population. The low bluegill PSD value would provide an abundance of edible size prey demanded by the large largemouth bass population. It is important to note PSD values are usually calculated for a single collection method, such as electro-fishing; however, due to the absence of data

provided on the number of individuals collected by method in historic fishery management reports, an overall PSD was calculated for each given survey year. Additionally, it is important to recognize that PSD is not an all inclusive statistic which always correlates with the overall state of a population; rather, PSD should be used in series with other population statistics such as recruitment, mortality, growth and condition, and density, just to name a few. The PSD value should be viewed as a general assessment of the population structure.

APPENDIX D:

QHEI METRICS AND RAW DATA

YELLOW CREEK LAKES WATERSHED DIAGNOSTIC STUDY

KOSCIUSKO COUNTY, INDIANA

JFNew

QHEI

The following paragraphs describe the scoring metrics for the Qualitative Habitat Evaluation Index (QHEI). The QHEI is used to evaluate the characteristics of a stream segment, as opposed to the characteristics of a single sampling site. As such, individual sites may have poorer physical habitat due to a localized disturbance yet still support aquatic communities closely resembling those sampled at adjacent sites with better habitat, provided water quality conditions are similar. QHEI scores from hundreds of segments around Indiana have indicated that values greater than 64 are considered *fully supporting* of aquatic life use, scores between 51–64 are *partially supporting*, and scores less than 51 are *non-supporting* (IDEM, 2002).

Metric 1

Substrate type(s) and quality are important factors of habitat quality and the QHEI score is partially based on these characteristics. Sites that have greater substrate diversity receive higher scores as they can provide greater habitat diversity for benthic organisms. The quality of substrate refers to the embeddedness of the benthic zone. Small particles of soil and organic matter will settle into small pores and crevices in the stream bottom. Many organisms can colonize these microhabitats, but high levels of silt in a streambed can result in the loss of habitat within the substrate, thus sites with heavy embeddedness and siltation receive lower QHEI scores for the substrate metric.

Metric 2

In-stream cover, another metric of the QHEI, represents the type(s) and quantity of habitat provided within the stream itself. Examples of in-stream cover include woody logs and debris, aquatic and overhanging vegetation and root wads extending from the stream banks.

Metric 3

The channel morphology metric evaluates the stream's physical development with respect to habitat diversity. Pool and riffle development within the stream reach, the channel sinuosity and other factors that represent the stability and direct modification of the site are evaluated to comprise this metric score.

Metric 4

Riparian zone and bank erosion were examined at each site to evaluate the quality of the buffer zone of a stream, the land use within the floodplain that affects inputs to the waterway, and the extent of erosion in the stream, which can reflect insufficient vegetative stabilization of the stream banks. For the purposes of the QHEI, a riparian buffer is a zone that is forest, shrub, swamp, or woody old field vegetation. A wooded riparian buffer is a vital functional component of riverine ecosystems. It is instrumental in the detention, removal and assimilation of nutrients. Typically, weedy, herbaceous vegetation has higher runoff potential than woody components and does not represent an acceptable riparian zone type for the QHEI (Ohio EPA, 1989).

Metric 5 and 6

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

Metric 7

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

The following is an example score sheet for the QHEI

QHEI SCORING (Maximum = 100)

QHEI Metric	Metric Component	Component Scoring Range	Metric Max.Score
1) Substrate	a) Type	0 to 20	20
	b) Origin	-2 to 1	
	b) Quality	-4 to 2	
2) Instream Cover	a) Type	0 to 11	20
	b) Amount	1 to 11	
3) Channel Morphology	a) Sinuosity	1 to 4	20
	b) Development	1 to 7	
	c) Channelization	1 to 6	
	d) Stability	1 to 3	
4) Riparian Zone	a) Width	0 to 4	10
	b) Quality	0 to 3	
	c) Bank Erosion	1 to 3	
5) Pool Quality	a) Max. Depth	0 to 6	12
	b) Morphology	0 to 2	
	c) Current Velocity	-2 to 4	
6) Riffle Quality	a) Depth	0 to 4	8
	b) Substrate Stability	0 to 2	
	c) Substrate Embeddedness	-1 to 2	
7) Gradient		2 to 10	10
	TOTAL	Maximum Score	100

Project ID:	Yellow Creek Lakes
Sample Type	Kick Sample
Stream/Reach:	Swick Meredith Drain
Sample Date:	########
Location	Site 1 CR 1000 S

QHEI Habitat Parameters

1. Substrate	5	range (0-20)
2. Cover	4	range (0-20)
3. Channel	6	range (0-20)
4. Riparian	5	range (0-10)
5. Pool/Current Quality	4	range (0-12)
6. Riffle/Run Quality	2	range (0-8)
7. Gradient	4	range (0-10)
Total Habitat Score	30	range (0-100)

Ohio EPA Biotic Index Score - Genus/species Level

	Data	Score
1.Genus/species Taxa Richness	8	2
2.Number mayfly taxa	0	0
3.Number caddisfly taxa	0	0
4. Number dipteran taxa	3	0
5 % mayfly composition	0	0
6. % caddisfly compostion	0	0
7.% tanitarsini midge compostion	0	0
8.% Other dipteran and non-insects	99	0
9.% Tolerant organisms	84	0
10. Percent in Dominant Group	71	0
IBI		2
"Standardized" IBI		3

IDEM mIBI Score - Family Level

	Data	Score
1. Hilsenhoff Biotic Index	9.3	0
2. Number of Families	6	0
3. Number of Individuals	68	0
4. Percent Dominant	71	0
5. EPT Index	0	0
6. EPT Count	0	0
7. EPT Count / Total Count	0	0
8. EPT Count / Chironomid Count	0	0
9. Chironomid Count	9	8
10. Individuals per Square	20	0
mIBI		0.8
"Standardized" IBI		10

Diagnosis

This site is dominated by tubificid worms, indicative of high inputs of "organic" pollution or sediment. Despite the low habitat value, the biotic score could be improved with better water quality.

Raw Data

Chironomidae	Procladius sublettei	3
	Clinotanypus spp.	
	Thienemannimyia spp.	
	Natarsia baltimoreus	
	Cricotopus bicinctus	2
	Nanocladius spp.	4
	Orthocladius obumbratus	
	Parametriocnemus lundbecki	
	Rheocricotopus robacki	
	Corynoneura spp.	
	Thienemanniella xena	
	Chironomus spp.	
	Glyptotendipes lobiferus	
	Dicrotendipes nervosus	
	Paratendipes albimanus	
	Polypedilum convictum	
	Stictochironomus spp.	
	Microspectra polita	
	Rheoptanytarsus spp.	
	Tanytarsus glabrescens	
Ceratopogonidae		
Ephydridae		
Tipulidae	Pseudolimnophila spp.	
Ptychopteridae		
Baetidae	Procleon spp.	
Caenidae	Caenis spp.	
Limnephilidae	Limnephilus spp.	
Phyrganidae	Ptilostomis spp.	
Dytiscidae	Agabus spp.	1
Elmidae	Dubiraphia spp.	
	Stenelmis spp.	
Haliplidiae		
Helodidae		
Libellulidae	Plathelmis lydia	
Coenagrionidae	Argia spp.	
Amphipoda	Gammarus spp.	1
	Hyalella spp.	
Isopodae	Caecidotea spp.	2
Sphaeridae		
Physidae		7
Oligochaeta	Tubificidae	48
	Lumbriculidae	
Hirudinea		
Total		68

Project ID:	Yellow Creek Lakes
Sample Type	Kick Sample
Stream/Reach:	Swick Meredith Drain
Sample Date:	########
Location	Site 2 CR 675 W

QHEI Habitat Parameters

1. Substrate	6 range (0-20)
2. Cover	4 range (0-20)
3. Channel	6 range (0-20)
4. Riparian	6 range (0-10)
5. Pool/Current Quality	5 range (0-12)
6. Riffle/Run Quality	3 range (0-8)
7. Gradient	4 range (0-10)
Total Habitat Score	34 range (0-100)

Ohio EPA Biotic Index Score - Genus/species Level

	Data	Score
1.Genus/species Taxa Richness	8	2
2.Number mayfly taxa	0	0
3.Number caddisfly taxa	0	0
4. Number dipteran taxa	4	2
5 % mayfly composition	0	0
6. % caddisfly compostion	0	0
7.% tanitarsini midge compostion	0	0
8.% Other dipteran and non-insects	79	0
9.% Tolerant organisms	32	0
10. Percent in Dominant Group	37	2
IBI		6
"Standardized" IBI		10

IDEM mIBI Score - Family Level

	Data	Score
1. Hilsenhoff Biotic Index	7.9	0
2. Number of Families	5	0
3. Number of Individuals	19	0
4. Percent Dominant	37	4
5. EPT Index	3	0
6. EPT Count	0	0
7. EPT Count / Total Count	0	0
8. EPT Count / Chironomid Count	0	0
9. Chironomid Count	7	8
10. Individuals per Square	6	0
mIBI		1.2
"Standardized" IBI		15

Diagnosis

This site supported very little benthic life, an indication of a recent "toxic chemical" input. Despite the low habitat value, water quality at this site could be improved.

Raw Data

Chironomidae	Procladius sublettei	
	Clinotanypus spp.	
	Thienemannimyia spp.	
	Natarsia baltimoreus	
	Cricotopus bicinctus	
	Nanocladius spp.	2
	Orthocladius obumbratus	1
	Parametriocnemus lundbecki	
	Rheocricotopus robacki	
	Corynoneura spp.	
	Thienemanniella xena	
	Chironomus spp.	2
	Glyptotendipes lobiferus	
	Dicrotendipes nervosus	
	Paratendipes albimanus	
	Polypedilum convictum	2
	Stictochironomus spp.	
	Microspectra polita	
	Rheoptanytarsus spp.	
	Tanytarsus glabrescens	
Ceratopogonidae		
Ephydridae		
Tipulidae	Pseudolimnophila spp.	
Ptychopteridae		
Baetidae	Procleon spp.	
Caenidae	Caenis spp.	
Limnephilidae	Limnephilus spp.	
Phyrganidae	Ptilostomis spp.	
Dytiscidae	Agabus spp.	1
Elmidae	Dubiraphia spp.	
	Stenelmis spp.	
Haliplidiae		
Helodidae		
Libellulidae	Plathelmis lydia	
Coenagrionidae	Argia spp.	3
Amphipoda	Gammarus spp.	4
	Hyalella spp.	
Isopodae	Caecidotea spp.	
Sphaeridae		
Physidae		
Oligochaeta	Tubificidae	4
	Lumbriculidae	
Hirudinea		
Total		19

Project ID:	Yellow Creek Lakes	
Sample Type	Kick Sample	
Stream/Reach:	Swick Meredith Drain	
Sample Date:	########	
Location	Site 3	Yellow Creek Lake Inlet

QHEI Habitat Parameters

1. Substrate	9	range (0-20)
2. Cover	5	range (0-20)
3. Channel	8	range (0-20)
4. Riparian	6	range (0-10)
5. Pool/Current Quality	3	range (0-12)
6. Riffle/Run Quality	2	range (0-8)
7. Gradient	4	range (0-10)
Total Habitat Score	37	range (0-100)

Ohio EPA Biotic Index Score - Genus/species Level

	Data	Score
1.Genus/species Taxa Richness	11	2
2.Number mayfly taxa	0	0
3.Number caddisfly taxa	1	2
4. Number dipteran taxa	7	2
5 % mayfly composition	0	0
6. % caddisfly compostion	1	2
7.% tanitarsini midge compostion	0	0
8.% Other dipteran and non-insects	95	0
9.% Tolerant organisms	17	4
10. Percent in Dominant Group	68	0
IBI		12
"Standardized" IBI		20

IDEM mIBI Score - Family Level

	Data	Score
1. Hilsenhoff Biotic Index	6.6	0
2. Number of Families	7	0
3. Number of Individuals	96	2
4. Percent Dominant	68	0
5. EPT Index	1	0
6. EPT Count	1	0
7. EPT Count / Total Count	0.01	0
8. EPT Count / Chironomid Count	0.1	0
9. Chironomid Count	65	2
10. Individuals per Square	30	2
mIBI		0.6
"Standardized" IBI		8

Diagnosis

The dominant organism at this site was a midge larvae that usually thrives where periphyton are abundant. The primary water quality problem here is probably excessive nutrient inputs.
The toxic input to this tributary, as observed at site 2, was no longer affecting the biota at site 3.

Raw Data

Chironomidae	Procladius sublettei	
	Clinotanypus spp.	
	Thienemannimyia spp.	
	Natarsia baltimoreus	8
	Cricotopus bicinctus	3
	Nanocladius spp.	
	Orthocladius obumbratus	8
	Parametriocnemus lundbecki	44
	Rheocricotopus robacki	
	Corynoneura spp.	
	Thienemanniella xena	
	Chironomus spp.	
	Glyptotendipes lobiferus	
	Dicrotendipes nervosus	
	Paratendipes albimanus	
	Polypedilum convictum	2
	Stictochironomus spp.	
	Microspectra polita	
	Rheoptanytarsus spp.	
	Tanytarsus glabrescens	
Ceratopogonidae		
Ephydridae		1
Tipulidae	Pseudolimnophila spp.	4
Ptychopteridae		
Baetidae	Procleon spp.	
Caenidae	Caenis spp.	
Limnephilidae	Limnephilus spp.	
Phyrganidae	Ptilostomis spp.	1
Dytiscidae	Agabus spp.	
Elmidae	Dubiraphia spp.	
	Stenelmis spp.	
Haliplidiae		
Helodidae		
Libellulidae	Plathelmis lydia	
Coenagrionidae	Argia spp.	
Amphipoda	Gammarus spp.	1
	Hyalella spp.	
Isopodae	Caecidotea spp.	9
Sphaeridae		
Physidae		
Oligochaeta	Tubificidae	15
	Lumbriculidae	
Hirudinea		
Total		96

Project ID:	Yellow Creek Lakes
Sample Type	Kick Sample
Stream/Reach:	Swick Meredith Drain
Sample Date:	########
Location	Site 4 CR 600 W

QHEI Habitat Parameters

1. Substrate	14	range (0-20)
2. Cover	6	range (0-20)
3. Channel	11	range (0-20)
4. Riparian	5	range (0-10)
5. Pool/Current Quality	6	range (0-12)
6. Riffle/Run Quality	2	range (0-8)
7. Gradient	4	range (0-10)
Total Habitat Score	53	range (0-100)

Ohio EPA Biotic Index Score - Genus/species Level

	Data	Score
1.Genus/species Taxa Richness	10	2
2.Number mayfly taxa	0	0
3.Number caddisfly taxa	0	0
4. Number dipteran taxa	6	2
5 % mayfly composition	0	0
6. % caddisfly compostion	0	0
7.% tanitarsini midge compostion	0	0
8.% Other dipteran and non-insects	93	0
9.% Tolerant organisms	23	2
10. Percent in Dominant Group	45	0
IBI		6
"Standardized" IBI		10

IDEM mIBI Score - Family Level

	Data	Score
1. Hilsenhoff Biotic Index	7.9	0
2. Number of Families	5	0
3. Number of Individuals	56	0
4. Percent Dominant	45	0
5. EPT Index	0	2
6. EPT Count	0	0
7. EPT Count / Total Count	0	0
8. EPT Count / Chironomid Count	0	0
9. Chironomid Count	25	4
10. Individuals per Square	16	0
mIBI		0.6
"Standardized" IBI		8

Diagnosis

Although this site had reasonably good habitat, the biotic index scores were quite low, indicating poor water quality. Fingernail clams and tubificids were dominant. This usually indicates excessive sediment inputs.

Raw Data

Chironomidae	Procladius sublettei	3
	Clinotanypus spp.	6
	Thienemannimyia spp.	
	Natarsia baltimoreus	
	Cricotopus bicinctus	
	Nanocladius spp.	
	Orthocladius obumbratus	
	Parametriocnemus lundbecki	8
	Rheocricotopus robacki	
	Corynoneura spp.	
	Thienemanniella xena	
	Chironomus spp.	
	Glyptotendipes lobiferus	2
	Dicrotendipes nervosus	3
	Paratendipes albimanus	
	Polypedilum convictum	3
	Stictochironomus spp.	
	Microspectra polita	
	Rheoptanytarsus spp.	
	Tanytarsus glabrescens	
Ceratopogonidae		
Ephydridae		
Tipulidae	Pseudolimnophila spp.	
Ptychopteridae		
Baetidae	Procleon spp.	
Caenidae	Caenis spp.	
Limnephilidae	Limnephilus spp.	
Phyrganidae	Ptilostomis spp.	
Dytiscidae	Agabus spp.	
Elmidae	Dubiraphia spp.	
	Stenelmis spp.	
Haliplidae		
Helodidae		
Libellulidae	Plathelmis lydia	2
Coenagrionidae	Argia spp.	2
Amphipoda	Gammarus spp.	
	Hyalella spp.	
Isopodae	Caecidotea spp.	
Sphaeridae		14
Physidae		
Oligochaeta	Tubificidae	13
	Lumbriculidae	
Hirudinea		
Total		56

Project ID:	Yellow Creek Lakes
Sample Type	Kick Sample
Stream/Reach:	Swick Meredith Drain
Sample Date:	########
Location	Site 5 CR 950 S

QHEI Habitat Parameters

1. Substrate	8	range (0-20)
2. Cover	6	range (0-20)
3. Channel	7	range (0-20)
4. Riparian	4	range (0-10)
5. Pool/Current Quality	6	range (0-12)
6. Riffle/Run Quality	2	range (0-8)
7. Gradient	4	range (0-10)
Total Habitat Score	37	range (0-100)

Ohio EPA Biotic Index Score - Genus/species Level

	Data	Score
1.Genus/species Taxa Richness	13	2
2.Number mayfly taxa	0	0
3.Number caddisfly taxa	0	0
4. Number dipteran taxa	7	2
5 % mayfly composition	12	4
6. % caddisfly compostion	0	0
7.% tanitarsini midge compostion	0	0
8.% Other dipteran and non-insects	75	0
9.% Tolerant organisms	50	0
10. Percent in Dominant Group	46	0
IBI		8
"Standardized" IBI		13

IDEM mIBI Score - Family Level

	Data	Score
1. Hilsenhoff Biotic Index	8.0	0
2. Number of Families	8	2
3. Number of Individuals	48	0
4. Percent Dominant	46	2
5. EPT Index	0	0
6. EPT Count	0	0
7. EPT Count / Total Count	0	0
8. EPT Count / Chironomid Count	0	0
9. Chironomid Count	15	6
10. Individuals per Square	12	0
mIBI		1.0
"Standardized" IBI		13

Diagnosis

This site is dominated by tubificid worms, indicative of high inputs of "organic" pollution or sediment. Despite the low habitat value, the biotic score could be improved with better water quality.

Raw Data

Chironomidae	Procladius sublettei	4
	Clinotanypus spp.	
	Thienemannimyia spp.	
	Natarsia baltimoreus	
	Cricotopus bicinctus	
	Nanocladius spp.	2
	Orthocladius obumbratus	
	Parametriocnemus lundbecki	
	Rheocricotopus robacki	
	Corynoneura spp.	
	Thienemanniella xena	
	Chironomus spp.	
	Glyptotendipes lobiferus	
	Dicrotendipes nervosus	1
	Paratendipes albimanus	
	Polypedilum convictum	
	Stictochironomus spp.	3
	Microspectra polita	
	Rheoptanytarsus spp.	3
	Tanytarsus glabrescens	3
Ceratopogonidae		1
Ephydridae		
Tipulidae	Pseudolimnophila spp.	
Ptychopteridae		
Baetidae	Procleon spp.	
Caenidae	Caenis spp.	
Limnephilidae	Limnephilus spp.	
Phyrganidae	Ptilostomis spp.	
Dytiscidae	Agabus spp.	4
Elmidae	Dubiraphia spp.	
	Stenelmis spp.	
Haliplidiae		1
Helodidae		
Libellulidae	Plathelmis lydia	
Coenagrionidae	Argia spp.	
Amphipoda	Gammarus spp.	
	Hyalella spp.	1
Isopodae	Caecidotea spp.	
Sphaeridae		2
Physidae		
Oligochaeta	Tubificidae	22
	Lumbriculidae	
Hirudinea		1
Total		48

Project ID:	Yellow Creek Lakes
Sample Type	Kick Sample
Stream/Reach:	Swick Meredith Drain
Sample Date:	########
Location	Site 6 CR 500 W

QHEI Habitat Parameters

1. Substrate	3	range (0-20)
2. Cover	3	range (0-20)
3. Channel	6	range (0-20)
4. Riparian	3	range (0-10)
5. Pool/Current Quality	6	range (0-12)
6. Riffle/Run Quality	0	range (0-8)
7. Gradient	4	range (0-10)
Total Habitat Score	25	range (0-100)

Ohio EPA Biotic Index Score - Genus/species Level

	Data	Score
1.Genus/species Taxa Richness	7	2
2.Number mayfly taxa	1	0
3.Number caddisfly taxa	0	0
4. Number dipteran taxa	2	0
5 % mayfly composition	85	6
6. % caddisfly compostion	0	0
7.% tanitarsini midge compostion	0	0
8.% Other dipteran and non-insects	8	6
9.% Tolerant organisms	3	6
10. Percent in Dominant Group	85	0
IBI		20
"Standardized" IBI		33

IDEM mIBI Score - Family Level

	Data	Score
1. Hilsenhoff Biotic Index	4.5	6
2. Number of Families	6	0
3. Number of Individuals	100	2
4. Percent Dominant	85	0
5. EPT Index	1	0
6. EPT Count	85	4
7. EPT Count / Total Count	0.85	8
8. EPT Count / Chironomid Count	17.2	8
9. Chironomid Count	5	8
10. Individuals per Square	33	2
mIBI		3.8
"Standardized" IBI		47

Diagnosis

This was by far the most ecologically healthy site in the watershed, despite the low habitat value. Water quality is probably relatively high.

Raw Data

Chironomidae	Procladius sublettei	4
	Clinotanypus spp.	
	Thienemannimyia spp.	
	Natarsia baltimoreus	
	Cricotopus bicinctus	
	Nanocladius spp.	
	Orthocladius obumbratus	
	Parametriocnemus lundbecki	1
	Rheocricotopus robacki	
	Corynoneura spp.	
	Thienemanniella xena	
	Chironomus spp.	
	Glyptotendipes lobiferus	
	Dicrotendipes nervosus	
	Paratendipes albimanus	
	Polypedilum convictum	
	Stictochironomus spp.	
	Microspectra polita	
	Rheoptanytarsus spp.	
	Tanytarsus glabrescens	
Ceratopogonidae		
Ephydridae		
Tipulidae	Pseudolimnophila spp.	
Ptychopteridae		
Baetidae	Procleon spp.	85
Caenidae	Caenis spp.	
Limnephilidae	Limnephilus spp.	
Phyrganidae	Ptilostomis spp.	
Dytiscidae	Agabus spp.	1
Elmidae	Dubiraphia spp.	
	Stenelmis spp.	1
Haliplidiae		
Helodidae		
Libellulidae	Plathelmis lydia	
Coenagrionidae	Argia spp.	5
Amphipoda	Gammarus spp.	
	Hyalella spp.	
Isopodae	Caecidotea spp.	
Sphaeridae		
Physidae		3
Oligochaeta	Tubificidae	
	Lumbriculidae	
Hirudinea		
Total		100

Site 1		
mIBI Metric		Metric Score
HBI	9.3	0
No. Taxa (family)	6	0
Total Count (# individuals)	68	0
% Dominant Taxa	70.6	0.0
EPT Index (# families)	0	0
EPT Count (# individuals)	0	0
EPT Count/Total Count	0	0
EPT Abun./Chir. Abun.	0	0
Chironomid Count	9	6
mIBI Score		0.67

Site 2		
mIBI Metric		Metric Score
HBI	7.9	0
No. Taxa (family)	5	0
Total Count (# individuals)	19	0
% Dominant Taxa	36.8	4.0
EPT Index (# families)	0	0
EPT Count (# individuals)	0	0
EPT Count/Total Count	0	0
EPT Abun./Chir. Abun.	0	0
Chironomid Count	7	6
mIBI Score		1.11

Site 3		
mIBI Metric		Metric Score
HBI	6.6	0
No. Taxa (family)	7	0
Total Count (# individuals)	96	2
% Dominant Taxa	67.7	0.0
EPT Index (# families)	0	0
EPT Count (# individuals)	0	0
EPT Count/Total Count	0	0
EPT Abun./Chir. Abun.	0	0
Chironomid Count	65	2
mIBI Score		0.44

Site 4		
mIBI Metric		Metric Score
HBI	7.9	0
No. Taxa (family)	5	0
Total Count (# individuals)	56	0
% Dominant Taxa	44.6	2.0
EPT Index (# families)	0	0
EPT Count (# individuals)	0	0
EPT Count/Total Count	0	0
EPT Abun./Chir. Abun.	0	0
Chironomid Count	25	4
mIBI Score		0.67

Site 5		
mIBI Metric		Metric Score
HBI	8	0
No. Taxa (family)	8	2
Total Count (# individuals)	48	0
% Dominant Taxa	45.8	2.0
EPT Index (# families)	0	0
EPT Count (# individuals)	0	0
EPT Count/Total Count	0	0
EPT Abun./Chir. Abun.	0	0
Chironomid Count	16	6
mIBI Score		1.11

Site 6		
mIBI Metric		Metric Score
HBI	4.5	6
No. Taxa (family)	6	0
Total Count (# individuals)	100	2
% Dominant Taxa	85.0	0.0
EPT Index (# families)	1	0
EPT Count (# individuals)	85	4
EPT Count/Total Count	0.85	8
EPT Abun./Chir. Abun.	17	8
Chironomid Count	5	8
mIBI Score		4.00

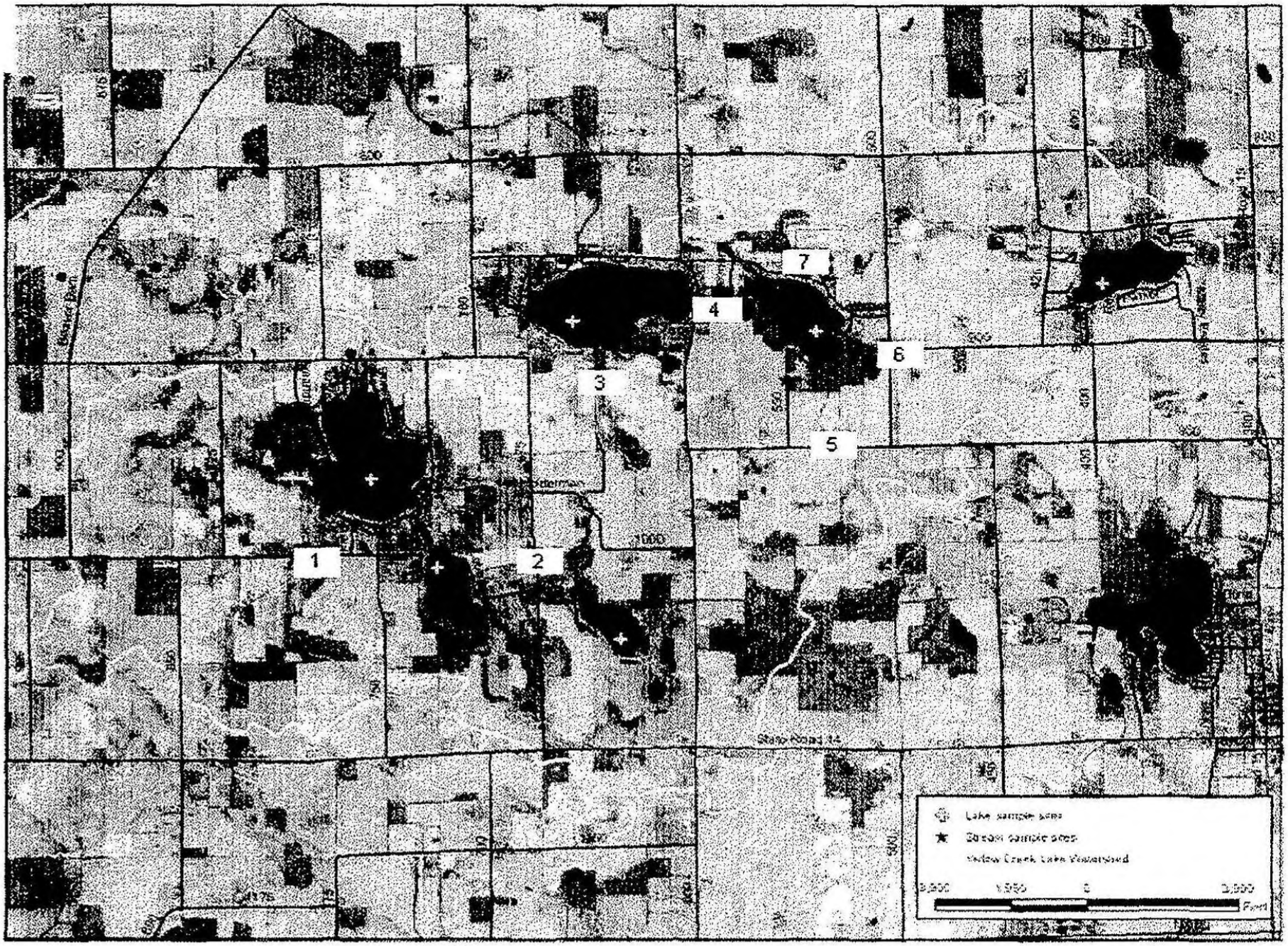
Site 7		
mIBI Metric		Metric Score
HBI	6.1	0
No. Taxa (family)	7	0
Total Count (# individuals)	24	0
% Dominant Taxa	58.3	2.0
EPT Index (# families)	2	0
EPT Count (# individuals)	4	0
EPT Count/Total Count	0.17	2
EPT Abun./Chir. Abun.	0.29	0
Chironomid Count	14	8
mIBI Score		1.33

Yellow Creek Watershed Diagnostic Study
mIBI calculations

Site 1: Swick-Meredit Drain to Beaver Lake (CR 100 S)
Site 2: Loon Lake outlet to Yellow Creek (CR 650 W)
Site 3: Yellow Creek (private road)
Site 4: Michaels Ditch (CR 600 W)
Site 5: Swick-Mereditch Drain (CR 950 S)
Site 6: Michaels Ditch (CR 500 W)
Site 7: Swick-Meredith Drain north (Hill Streer)

0-2: Severely Impaired; 2-4: Moderately Impaired; 4-6 Slightly Impaired; 6-8 Unimpaired

Sampled: 11/29/07; Commonwealth Biomonitoring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Lake sample sites
Sediment sample sites
Yellow Creek Lake Watershed
Feet

APPENDIX E:

PUBLIC INFORMATION HANDOUT

YELLOW CREEK LAKES WATERSHED DIAGNOSTIC STUDY

KOSCIUSKO COUNTY, INDIANA

JFNew

Understanding Your Watershed:

- ★ The six Yellow Creek Lakes lie in the Headwaters of the Mississippi River Basin. Water flows north from Yellow Creek Lake to the Tippecanoe River and then southwesterly to the Wabash and Ohio Rivers.
- ★ The water entering Yellow Creek Lake comes from Beaver Dam Lake, Loon and McClures to the southwest, and from Hill and Diamond to the east flowing through various branches of the Swick-Meredith Drain which eventually becomes Yellow Creek when it exits the lake.
- ★ The drainage area (watershed) containing all six lakes encompasses 6535 acres (10.2 sq. mi.) within Kosciusko county of which 515 acres is open water.
- ★ The Watershed to lake area ratio is:

Hill - 7:1	McClures - 19:1
Diamond - 32:1	Beaver Dam - 9:1
Yellow Creek - 43:1	Loon – 40:1

- ★ Land use within the watershed is about 68% Crop Land, 10% pasture or grassland, 8% open water, 8% wetlands, 5% woodland, and 1% residential.
- ★ Three major soil associations including Ormas-Kosciusko loamy sands, Wawasee Crosier-Miami loams and clay loams, and the Houghton-Palms muck soils dominate the watershed.
- ★ 58% of the soils in the watershed are severely limited for use as septic tank absorption fields but Less then 1% of the soils in the watershed are highly erodible.
- ★ 85% of the original wetland areas in the watershed have been drained or filled.
- ★ Eight Rare, Threatened, or Endangered species of plants and animals have been recorded in the Yellow Creek Lakes watershed while 109 have been recorded in Kosciusko County .

For additional information on how to keep your lakes and watershed clean and healthy contact:

Lake and River Enhancement Program
Indiana Department of Natural Resources
(IDNR) Division of Fish & Wildlife
402 West Washington Street Room W273
Indianapolis, Indiana 46204
(317) 233-3871
www.in.gov/dnr/fishwild/lare

Kosciusko County
Soil and Water Conservation District
217 E. Bell Drive
Warsaw, IN 46582
(574) 267-7445 ext. 3
http://www.kosciuskoswcd.com

This pamphlet was produced by:

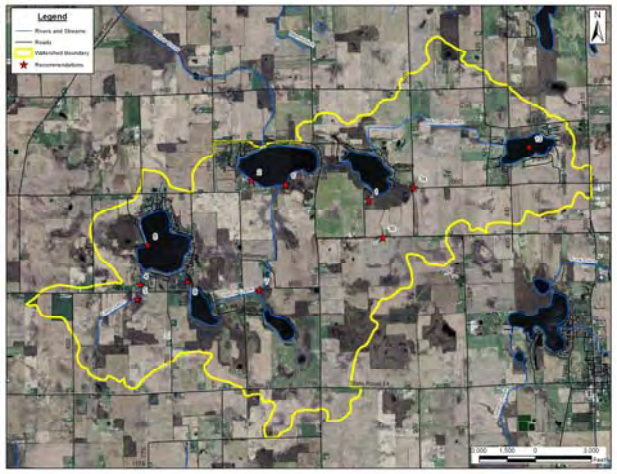
JFNew

708 Roosevelt Road
Walkerton, Indiana 46574
(574) 586-3400

If you have any questions regarding the study, please contact JFNew.

The Yellow Creek Lake's Diagnostic Study

Kosciusko County Indiana



Beaver Dam, Diamond, Hill, Loon, McClures, Yellow Creek

Facts about each lake:

★ **Beaver Dam Lake:** 146 acres, 17 month retention time, 1266 acre watershed, maximum depth of 61 feet, average clarity of 4 feet. Sago pondweed dominates the aquatic plant community of 26 species. Bluegill is the dominant fish of 26 species in the lake.

★ **Diamond Lake:** 79 acres, 6 months retention time, 1555 acre watershed, maximum depth of 29 feet and average clarity of 3 feet. Southern naiad dominates the aquatic plant community of 25 species. Shad is the dominant fish of 33 species in the lake.

★ **Hill Lake:** 67 acres, 24 month retention time, 479 acre watershed, maximum depth of 35 feet, and average clarity of 7 feet. Coontail dominates the aquatic plant community of 23 species. Bluegill is the dominant fish of 27 species in the lake.

★ **Loon Lake:** 43 acres, 4 month retention time, 461 acre watershed, maximum depth of 40 feet and average clarity of 4 feet. Coontail dominates the aquatic plant community of 22 species. Bluegill is the dominant fish of 26 species in the lake.

★ **McClures Lake:** 32 acres, 11 month retention time, 614 acre watershed, maximum depth of 30 feet and average clarity of 2 feet. Coontail dominates the aquatic plant community of 18 species. Bluegill is the dominant fish of 19 species in the lake.

★ **Yellow Creek Lake:** 151 acres, 7 month retention time, 2160 acre watershed, maximum depth of 67 feet and average clarity of 3.5 feet. Sago pondweed dominates the aquatic plant community of 26 species. Bluegill is the dominant fish of 26 species.

Concerns to be addressed:

★ **Exotic invasive species:**
- Eurasian watermilfoil
- Zebra mussels
- Purple loosestrife
- Reed canary grass

★ **Water Quality:**
- Excessive algae
- Bacterial contamination
- Excessive nutrients

★ **Fish:**
- Anoxia (loss of habitat)
- Species composition
- Size of game fish
- Abundance of game fish

★ **Development:**
- Loss of open space
- Shoreline erosion
- Additional boat traffic
- Septic system failures

How to Manage the Lakes:

★ **Education:**
- learn & share Diagnostic Study
- Participate in local watershed events
- Encourage landowners

★ **Assistance:**
- LARE program
- Kosciusko County SWCD
- Kosciusko Lakes and streams
- IDEM 319 Program
- Private and community foundations

★ **Action:**
- Implement study recommendations
- Hoosier Riverwatch Training
- Clean Lakes program volunteer

Management Actions:

In-Lake Recommendations:

★ Monitor and control invasive species.
★ Return most large fish to the lake
★ Keep motorboat speeds low to prevent churning up the bottom sediment.

Watershed Recommendations:

★ Encourage the use of wider filter strips, no-till agriculture, grassed waterways and other soil saving measures on agricultural fields.
★ Restore wetland habitat by removing drain tiles within inactive agricultural fields.
★ Implement bank stabilization measures on eroding ditch banks and shorelines.
★ Implement instream nutrient filters where upstream sources can't be addressed.
★ Consider the eventual implementation of a sewer system around the lakes.

What You Can Do:

The lakeshore residents can have substantial impacts to the health of their lakes!

★ Identify pollution pathways from the roads or your homes to the lake—then eliminate or intercept the pollutant.
★ Use phosphorus-free fertilizer
★ Maintain septic systems annually
★ Use only rock or native vegetation to protect shorelines from erosion
★ Keep lawn clippings, leaves, and animal waste out of the water
★ Keep boat speeds low
★ Harvest only the necessary and legal area (625 sq. ft.) of aquatic plants for your enjoyment of the lake.
★ Keep only a limited number of large fish

APPENDIX F:

PUBLIC MEETING DOCUMENTATION
AND
SUMMARY OF WATERSHED TOUR

YELLOW CREEK LAKES WATERSHED DIAGNOSTIC STUDY

KOSCIUSKO COUNTY, INDIANA

JFNew

Yellow Creek Lakes Watershed Meeting
Presentation - 10:00 am April 19, 2008

This was the annual meeting for the Beaver Dam-Loon Lake Conservation Club. JFNew (Sara Peel) presented a power point presentation on the LARE program and Diagnostic Study components to the audience and provided them with a general survey on lake issues. There were 14 people present at the meeting representing Hill, Diamond, Beaver Dam, and Yellow Creek Lakes.

Topics Discussed

1) Overview of the LARE program
   (Basis of funding and types of projects funded)

2) Purpose of conducting LARE Diagnostic Studies
   (Baseline information to document changes over time)

3) Aquatic Vegetation Management
   (Known treatment needs, additional surveys required, monitoring

4) Fish Management
   (Study will only address previous DNR studies, residents still desire stocking)

5) Odors from drainages into lake
   (Diamond Lake has inlet drains that have strong odors, residents on lake suspect animal waste is entering lake through the drain)

6) No public access on Loon, McClures, Diamond, Yellow Creek and Hill Lakes

Yellow Creek Lakes Watershed
Final Diagnostic Study Presentation -May 9, 2009

The meeting was held at 1 pm in the Yellow Creek Lake Conservation Club clubhouse. The following survey was handed out. Returned survey responses follow the questions.

Do you live or have a part time residence or business in the 6500 acre drainage basin (watershed) of Yellow Creek Lakes? Yes (8); No (1)

Are you a lakeshore property owner? Yes (8); No (1)

Are you currently a member of one of the Conservation Clubs? Yes (9); No (0)

How many years have you been at the lake? 2, 2, 4, 9, 10, 16, 50, 53 mean = 18.25

What do you use the lake(s) for the most? Fishing (5); boating (2); Recreation (2)

Should the Conservation Clubs continue to target aquatic plant control? Yes (7)
Unsure (2)

Do you personally get involved in aquatic plant treatment on the lake? Yes (6); No (2)

Should the Conservation Clubs get more involved in stocking and managing fish populations in the lake (for example: promoting catch and release with signage, stocking fish, petitioning the IDNR to change size limit restrictions)? Yes (9); No (0)

Is the overall water quality in your lake satisfactory? Yes (6); No (2)

Do you think the Conservation Clubs should continue to pursue LARE assistance in designing and implementing potential solutions for improving water quality? Yes (7);
Unsure (1)

Did you learn anything of personal interest or value to you today? Yes (7); No (0)

Thank you for coming, please add any comments below or on the back:

-14” minimum size bass limit is high enough
-Presentation too long and too detailed and not enough vivid color
-Presentation should have been in summer

Presenters Notes:
John Richardson of JFNew and William (Bill) Jones from IU presented the study.
There were 12 area residents who attended the presentation including Dr. Gwen White who also represented LARE. Ed Braun, the IDNR District Fisheries Biologist, and Linda Schmidt, the watershed coordinator from IDEM also attended. The presentation was two hours long and covered details about water quality, fish, and plants on each lake.

Summary of Yellow Creek Lake Watershed Walking Tour – April 25, 2008

Tom Estrem and John Richardson

West Side of Beaver Dam Lake:

1) The Swick-Meredith Drain enters the lake from the west first traveling through a small pond known locally as Piscell Lake. It is predominantly a silver maple swamp with little gradient in the ditch and draining yup to 300 acres of farm ground. There are no reported problems with sediment plumes and no issues with the ditch banks or buffers. No watershed actions needed. There is a wetland fill due to a real estate company attempting to sell lots at the end of Amanda Drive. It was related that over 40 truck loads of fill have been placed at the end of the road to facilitate potential development of this lot. The lots for sale are 100 percent wetland. The For Sale sign: Prickett's Properties 574-457-5422. They should be called directly or referred to the Corps of Engineers.
2) We examined the shoreline at the south end of Amanda Drive (owned by Amanda Pruitt) and noted the erosion reported by the owner and an adjacent fill violation from a relatively new resident. Approximately 150 feet of shoreline was eroding at a moderate rate around a southward facing point (Amanda Point). The erosion is about 16-18 inches in height and is undercutting trees and lawn. Owner will allow a natural bank treatment. Recommend stone and biolog combo. Potential to restore all or part of wetland filled recently by Petro family just west of point.
3) Entering the south end of Beaver Dam Lake is a branch of the Swick-Meredith Drain which provides drainage for about 3 square miles. The embankments along the east side of the ditch from the lake south to 1000 S. are eroding due to attempted maintenance of ornamental grasses and severe damage by muskrats. It is interesting to note that the reed canary grass dominated west bank is in relatively good shape although both sides are in the same muck soils. At the drain outlet into the lake the owner has been filling the east bank and shoreline with tires and other debris for years. Needs to be cleaned up.
4) Proceeding upstream (south) from 1000 S road the ditch is well maintained and relatively stable except that the grass buffer is relatively narrow (five feet or less) and several rill erosion areas were noted from the adjacent farm fields (parcel 025-110-002. Work with landowner/tenant to establish a wider filter strip. Proceeding upstream the open drain and several tributary ditches have all but been abandoned with the majority of ditch buffered by fallow fields (wetland) and woodland. It is doubtful that any significant water quality issues arise upstream of these areas although we did not walk the tiles to the top of the drainages where open risers may exist.
5) We examined the ditch between Loon and Beaver Dam Lake. This ditch (not a natural waterway) is usually dry has a few spots of erosion, but was flowing clear water several inches deep on the inspection date. Mr. Kemper (the Kosciusko County Surveyor) related in a phone call to me that the residents have requested maintenance on this section of drain. The drain itself does not appear to be clogged with debris or inhibiting flow in any way but there are trees and branches that have fallen on the slopes of the ditch and a few spots of formerly severe

erosion on the west bank that could be fixed. We discussed how it may be more appropriate to put the drain back into the adjacent artificial channel that the residents are wanting cleaned. The water could then be piped from Beaver Dam Lake to the end of the existing channel with a control structure to regulate Beaver Dam Lake water levels. This would also make the channel a "public" channel elgible for drain maintenance and LARE funding. The channel needs dredging to be useable. The abandoned ditch could then be filled with the dredge spoils.

6) We walked the channel flowing from Loon Lake toward Yellow Creek Lake beginning at 675 and walking west toward Loon Lake. The channel has not been maintained for drainage in this reach and therefore nothing was noted in need of erosion or water quality issues. It was well buffered with grass and accepted drainage from one crop field via a pump system. East of 675 West Road the agricultural field on the north side of the road (Clinker parcel 025-087-002) the ditch is well maintained with a very narrow (less then 3 feet) grass filter between the ag field and the ditch. There were several locations along this reach to the next property where sediment deltas were present in the ditch from rill erosion in the fields. This area needs a grass filter of at least 30 feet and preferably 60-120 feet except for 1/3 of the reach where the ditch was cut through a hill.
7) North of the Clinker property the ditch is well buffered and has relatively minor erosion along the banks with no treatment areas identified.
8) The Hoffman family owns approximately 1400 feet of shoreline on the south side of Yellow Creek Lake. The shoreline is well buffered with wetland forest several hundred feet wide. However, the shoreline is receding at a rapid pace with trees falling into the lake. The shoreline is relatively shallow (about 1 foot deep) but I was told it drops off quickly not too far from shore. We suggested that a wave break of timbers (trees) may be the best solution to reduce erosion along this shoreline.
9) Off 550 W Road north of 950 S. Road we then walked east to Diamond Lake on property owned by Bill and Nancy South (parcel 025-089-026). The open ditch on this parcel (not visible from the road because it is in tile for the first 300 feet) was choked with filamentous algae and reed canary grass and had a strong odor of animal waste. The drain originates on property to the west of 550 W. and north of 950 S. owned by Todd and Lisa Hoffman (parcel 025-090-001 and 002). The Hoffman's may be spreading waste on the fields or may have CAFO structures connected directly into this tile drainage system. The source should be addressed or a wetland filter could be developed on the South property.
10) On the southeast corner of Diamond Lake a drain flows west to Diamond adjacent to 900 S. This drain is completely buffered by wooded wetland west of 500 West. East of 500 West the drain has a narrow buffer which could be expanded but no significant erosion issues were noted. It was not walked as it could be seen from the road.
11) The Swick-Meredith Drain flowing from Hill Lake to Diamond Lake and entering on the north end of Diamond Lake was examined at various points. Near the Diamond Lake outlet, the drain was relatively stable with no erosion noted off High Street. At 500 W. we walked West for a ways but the ditch was stable with a moderate width grass buffer 15-30 feet and no eroding banks. No erosion was

noted. East of 500 W. the ditch was bordered by residential lawns and had no erosion issues. Further East, ag fields bordered the ditch, which had recovered ecologically to a meandering low flow channel in a reed canary grass dominated ditch, with no erosion issues.

12) Off Hill Lake Road we walked Lana Hunter's property with her. She has animals with grazing access to the stream (potential nutrient issues) but was in the process of fencing them out of the stream. We discussed potentially assisting her with a grass buffer on the streams where she was having difficulty establishing any non-invasive vegetation. She was actively controlling burdock and giant ragweed along the banks. Recommend assisting her with the establishment of a prairie buffer (switch grass, cordgrass, little and big bluestem, Canada rye).
13) The ditch appears well buffered from Hill Lake road to the lake although we did not walk that section.
14) There may be (hypothesis only) septic issues on Hill Lake which encourages the Eurasian milfoil issues. Hill Lake is bordered by grass land on the south and has no major drains leading to it, therefore nutrient issues if they exist are likely internal or from the high density housing on the north and west sides of the lake.

APPENDIX G:

ADDITIONAL WATERSHED RESTORATION CONTACTS AND RESOURCES

YELLOW CREEK LAKES WATERSHED DIAGNOSTIC STUDY

KOSCIUSKO COUNTY, INDIANA

JFNew

ADDITIONAL RESOURCES

The following agencies have staff members that may be useful for questions you may have about your lake and watershed or the environment in general:

Contacts:

LARE Program
Kent Tracey or Doug Nusbaum
Indiana Department of Natural Resources
1353 S Governors Drive
Columbia City, IN 46725
phone: (260) 244-7470
Fax: (260) 244-7247
ktracey@dnr.in.gov

Limnology Professor
and volunteer lake monitor coordinator
William Jones
IU-SPEA
1315 E. 10th Street
Bloomington, Indiana 47405
(812) 855-4556
joneswi@indiana.edu

Rod Edgell
IDNR -Fish Biologist
NE Regional Office
1353 S. Governors Drive
Columbia City, IN 46725
260-244-6805
redgell@dnr.in.gov

Kosciusko County SWCD
Hosier Riverwatch training
Marci Zolman
217 East Bell Drive
Warsaw, IN 46580-9362
(219) 267-7445

319 Grant program
Andrew Pelloso - IDEM
Office of Water Quality
100 N. Senate Ave. N1255
Indianapolis, IN 46204
(317) 233-8488
apelloso@idem.IN.gov

Pheasants Forever
NE Indiana Chapter
4615 CR 19 Auburn, IN 46706
260-238-4344 or
260-238-4853

Richard Kemper
Kosciusko County Surveyor
100 W Center
Warsaw, IN 46580
(574) 267-4444
rkemper@kcgov.com

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

Lake and River Enhancement Program (LARE)

LARE is administered by the Indiana Department of Natural Resources, Division of Fish and Wildlife. The program's main goals are to control sediment and nutrient inputs to lakes and streams and prevent or reverse degradation from these inputs through the implementation of corrective measures. Under present policy, the LARE program may fund Diagnostic, feasibility, and design studies with a local cost share of 10%, watershed improvement construction projects with a local cost share of 25%, Aquatic Plant management Plans at 25%, an sediment removal plans at 50%. Aquatic plant treatments and dredging projects require a local cost share of 25%. LARE also has a "watershed land treatment" component that can provide grants to SWCDs for multi-year projects. The funds are available on a cost-sharing basis with landowners who implement various BMPs. All of the LARE programs are recommended as a project funding source for your lakes's watershed. More information about the LARE program can be found at: http://www.in.gov/dnr/fishwild/3302.htm

Clean Water Act Section 319 Nonpoint Source Pollution Management Grant

The 319 Grant Program is administered by the Indiana Department of Environmental Management (IDEM), Office of Water Management, Watershed Management Section. 319 is a federal grant made available by the Environmental Protection Agency (EPA). 319 grants fund projects that target nonpoint source water pollution. Nonpoint source pollution (NPS) refers to pollution originating from general sources rather than specific discharge points (Olem and Flock, 1990). Sediment, animal and human waste, nutrients, pesticides, and other chemicals resulting from land use activities such as mining, farming, logging, construction, and septic fields are considered NPS pollution. According to the EPA, NPS pollution is the number one contributor to water pollution in the United States. To qualify for funding, the water body must meet specific criteria such as being listed in the state's 305(b) report as a high priority water body or be identified by a diagnostic study as being impacted by NPS pollution. Funds can be requested for up to $300,000 for individual projects. There is a 40% cash or in-kind match requirement. To qualify for implementation projects, there must be a watershed management plan for the receiving waterbody. This plan must meet all of the current 319 requirements. This diagnostic study serves as an n excellent foundation for developing a watershed management plan since it satisfies several, but not all, of the 319 requirements for a watershed management plan. More information about the Section 319 program can be obtained from:
http://www.in.gov/idem/water/planbr/wsm/319main.html.

Section 104(b)(3) NPDES Related State Program Grants

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

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

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

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

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

Wetlands Reserve Program
The Wetlands Reserve Program (WRP) is funded by the USDA and is administered by the NRCS. WRP is a subsection of the Conservation Reserve Program. This voluntary program provides funding for the restoration of wetlands on agricultural land. To qualify for the program, land must be restorable and suitable for wildlife benefits. This includes farmed wetlands, prior converted cropland, farmed wet pasture, farmland that has become a wetland as a result of flooding, riparian areas which link protected wetlands, and the land adjacent to protected wetlands that contribute to wetland functions and values. Landowners may place permanent or

30-year easements on land in the program. Landowners receive payment for these easement agreements. Restoration cost-share funds are also available. No match is required.

Grassland Reserve Program

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

Community Forestry Grant Program

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

Forest Land Enhancement Program (FLEP)

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

Wildlife Habitat Incentive Program

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

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

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

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

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

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

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

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

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

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

Freshwater Mussel Fund
The National Fish and Wildlife Foundation and the U.S. Fish and Wildlife Service fund the Freshwater Mussel Fund which provides funds to protect and enhance freshwater mussel resources. The program provides $100,000 in funding to approximately 5-10 applicants annually. More information can be found at http://www.nfwf.org/programs/grant_apply.htm.

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

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

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

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

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

APPENDIX H:

ANNOTATED LIST OF HISTORICAL STUDIES

YELLOW CREEK LAKES WATERSHED DIAGNOSTIC STUDY

KOSCIUSKO COUNTY, INDIANA

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Annotated bibliography

The historical reports below were utilized within the current study to present and compare data collected and conclusions drawn by these researchers with the recent efforts. The following table lists the fish reports completed on each of the Yellow Creek Lakes from the 1960's to the present. Appendix C summaries each of the fish reports in detail.

Beaver Dam	Diamond	Hill	Loon	McClures	Yellow Creek
McGinty (1965) 1964	McGinty (1966b) 1964	McGinty (1966c) 1965	McGinty (1966d) 1965	McGinty (1966e) 1965	McGinty (1967) 1965
Hudson (1969) 1968	Hudson (1969b) 1968	Taylor (1973) 1972	Braun (1981c)1980	Braun (1986c) 1985	Hudson (1968) 1967
Gulish (1972) 1971	Johnson (1971) 1970	Taylor (1974) 1974	Grier (2006) 2006		Hudson (1970) 1969
Braun (1978a) 1977	Taylor (1975) 1974	Shipman (1975a) 1975			Pearson (1977c) 1977
Braun (1978b) 1978	Shipman (1976b) 1975	Pearson (1977b) 1977			Braun (1986d) 1986
Braun (1982) 1982	Pearson (1977a) 1977	Braun (1981b) 1980			
Braun (1983a) 1983	Braun (1981a) 1980	Braun (1983c) 1983			
Braun (1993) 1992	Braun (1983b) 1983	Braun (1986b) 1985			
Braun (1995a) 1994	Braun (1986a) 1985	Braun (1995b) 1994			
Benson (2006) 2005	Braun (1996) 1995				
	Meyer (2006) 2005				
	Edgell (2006) 2006				

Peter Hippensteel, Tri-State University: A preliminary Investigation of the Lakes of Kosciusko County

Various land use activities were analyzed for their impact on water quality in Kosciusko County lakes including the Yellow Creek Lakes watershed. The activities analyzed included agriculture, residential and commercial development, sewage treatment plants and lakeshore development. The study listed four priority watersheds for further treatment including the Stonebruner-Putney Ditch that flows in Barbee Lakes, the Wyland Ditch that flows into Winona Lake, Deeds Creek which flows into Pike Lake, and Elder and Shanton Drains which flow into Ridinger Lake and then to the Barbee Lake chain.

William Jones, Indiana University Clean Lakes Program

Mr. Jones has been conducting Clean Lakes Program (CLP) data collection on Indiana Lakes since 1999 under contract with IDEM. Most of Indiana's lakes are sampled on a five year rotation including many of the Yellow Creek Lakes. The sampling includes total and dissolved phosphorus, all forms of nitrogen, plankton counts, temperature and dissolved oxygen,

conductivity, pH, Secchi disk, and light transmission. Annual reports are issued summarizing the lake data from the lakes sampled and comparing the recent data to historical data.

Jim Lesko, PhD, Grace College Water Quality Initiative
Comparative Study of Kosciusko County Lake Water Quality
The study was conducted to obtain a countywide profile of lake water quality in Kosciusko County during 2007. The goal was to identify a current average of various water quality measurements in the county, and to identify lakes that stood out from the average with regard to these measurements. Thirty lakes within the county were selected. Various water quality measurements were taken from these lakes on three different occasions during June, July, and August 2007. The 30 lakes were selected based upon the following criteria: 1) All large lakes (or limited lakes within large lake chains); 2) Small lakes which typically received less monitoring attention than the larger lakes in the county (particularly, attention was given to lakes in the southwestern part of the county). 3) Lakes from all regions of the county where lakes exist (Northeast, North, East, Center, West, Southeast, South, Southwest).

Weed Patrol, Inc. Diamond Lake Aquatic Plan Management Plan 2005-2009.
Mr. Tony Cunningham conducted an aquatic vegetation assessment of Diamond Lake in 2005 to document the plant community, especially the exotic invasive species. A five year plan was developed using herbicides to control the spread and eventually eliminate invasive species from the lake. Subsequent annual updates were then produced.

Weed Patrol, Inc., Beaver Dam and Loon Lake Aquatic Plan Management Plan 2005-2008.
Mr. Tony Cunningham conducted an aquatic vegetation assessment of Beaver Dam and Loon Lake in 2005 to document the plant community, especially the exotic invasive species. A three year plan was developed using herbicides to control the spread and eventually eliminate invasive species from the lake. A 2006 update was then produced.

APPENDIX I:

ANNOTATED LIST OF RECOMMENDED PROJECTS

YELLOW CREEK LAKES WATERSHED DIAGNOSTIC STUDY

KOSCIUSKO COUNTY, INDIANA

JFNew

Annotated Project List (not prioritized)

Beaver Dam Lake -Amanda Point: 150 feet of eroding shoreline on private property. Erosion is 12 t o18 inches high. Bioengineering would be permissible and halt erosion of several tons per year into the lake at a one time cost of approximately $24,000 for design, permitting, and construction through LARE program. Cost share is 75% for construction projects through LARE, so the final out of pocket cost to the landowner or Conservation Club if a grant is obtained is $6,000. Alternatively the landowner could complete permitting of a glacial stone seawall themselves and hire a contractor to install the work without design fees and spend about $7,000 to $8,000. This assumes that the landowner desires to stabilize the point and would cooperate with the Conservation Club to implement stabilization. The likelihood of project success is 95%. The Conservation Club should pursue this relatively easy to implement project as a demonstration in 2010.

Beaver Dam Lake - Inlet Ditch (Swick Meredith Drain from 1000 S. to lake): Approximately 1500 feet of the ditch is eroding along the east embankment where the maintained grass on muck soils has been undermined by muskrats. The other embankment is reed canary grass and does not appear to be undermined or eroding. Additionally, there is eroding embankments upstream (south) of 1000 S. Road for approximately 500 feet. There are several ways this project could be approached and therefore it should be considered for a feasibility study and not as a design or implementation project at this time. The different approaches may include an unmowed vegetated filter strip only, a native plant buffer reinforced with bioengineered products along the shoreline, or armoring the entire embankment with rock or sheet pile. The technique depends entirely upon the two separate owners' willingness to participate and their potential use of the adjacent property. The estimated cost ranges from $0 to convince the owner(s) not to mow or plant along the drain to $100 a lineal foot for sheet pile installation. The project's success in reducing the particulate matter originating from the embankments or adjacent cropland along this reach depends upon the final methodology chosen. Assistance could come from the SWCD through land treatment programs, LARE staff, or 319 program assistance. The Conservation Club should set a target of gauging the two landowner's interest in a project by the end of 2010.

Channel between Beaver Dam Lake and Loon Lake

The proposed project is on an artificial channel approximately 1,000 feet long between Beaver Dam and Loon Lake. The channel had several areas of erosion along the embankments. These areas don't amount to more than several hundred square feet and could likely be fixed using native rye seed and erosion control fabrics for about $3.00 per square yard. The owner(s) permission would be needed to access the property for these repairs, although it is a Legal Drain with an easement by the Kosciusko County Drainage Board. Therefore, any work within the ditch would also require Drainage Board approval. This project will not significantly help with nutrient reduction into the lake as the eroding areas likely emit less than 1 ton of soil per year; however, if the owner desires the project to proceed a landscape firm should be called to complete the work. This project should be pursued in 2011 or later.

Fencing of animals out of Hill Lake

Cows were observed in Hill Lake along the north side during the sampling effort. Fencing the cows so that they no longer have access to the lake would reduce the nitrogen, phosphorus and bacterial contamination to the lake. The feasibility of this project depends upon the landowner's willingness to cooperate. No attempt was made during the current project to contact the property owner. Since no access was granted to this site, no specific information regarding the project was gathered. The cost of fencing and an alternate watering station depend upon the length of the fence required but typically a project of this nature could be implemented using land treatment match money through the SWCD for less than $5,000. This project should be pursued in 2010.

Filter strip planting between Hill and Diamond

Approximately 800 feet of ditch banks along the property immediately west of Hill Lake Road was poorly vegetated due to previous animal access to the stream. The owners had begun a fencing project to eliminate the stream access but were interested in assistance with seeding the ditch banks to grass. Native warm season grasses were suggested but either warm or cool season grasses planted in a 20 to 30 foot wide buffer along the stream bank would have value for filtering runoff from their livestock pastures. The project would cost from $500 to $1,500 (cool season and warm season grasses respectively) and have value in reducing the bacterial and nutrient contamination to the stream. The SWCD land treatment program would be a good way for the owners to access financial assistance to accomplish this project. This project should be followed up on immediately in 2009 by the Diamond Lake Conservation Club.

Diamond Lake Drain filters

There are three drains entering the south side of Diamond Lake, all of which were documented as contributing excess nutrients to the lake.

Drain 1 on the southeast side of the lake needs approximately 1500 feet of filter strips on both sides of the maintained ditch east of CR 500W, along and south of CR 900S. This project should be pursued with the SWCD under land treatment programs. An estimated cost is $3,000 for a cool season grass, 60-foot wide buffer along both banks for 3,000 feet (4 acres). If warm season grasses our utilized then the cost may increase to $5,000. The project is only feasible if the landowner is willing to cooperate (they were not contacted during this project). As an incentive the filter strip could be enrolled in CRP and the landowner can receive annual payments equal to the average rental rate for the soil type. This project should be pursued by the Diamond Lake Conservation Club in 2010.

Drain number 2 on the south side of Diamond Lake from CR 950 S about 1,500 feet is in need of additional filter strips. This project should be pursued by the SWCD under land treatment programs. An estimated cost is $1,500 for a cool season grass, 60-foot wide buffer along both banks for 1,500 feet (2 acres). If warm season grasses our utilized then the cost may increase to $2,500. The project is only feasible if the landowner is willing to cooperate and they were not contacted during this project. As an incentive the filter

strip could enrolled in CRP and the landowner can receive annual payments equal to the average rental rate for the soil type. This project should be pursued by the Diamond lake Conservation Club in 2010.

Drain number 3 on the southwest side of Diamond Lake is a short open ditch (approximately 500 feet) that drains (through field tile) approximately 180 acres between CR 550 W and CR 600 W. The 180 acre agricultural field receives regular applications of liquid manure and has perforated risers directing all surface water to the tile. There are several options for reducing or eliminating this source of pollutants to Diamond Lake and it best addressed in an engineering feasibility study conducted under the LARE program or through the SWCD and NRCS within their land treatment program. Because the potential project could range from simply not applying liquid manure to creating elaborate filters, or the Conservation Club acquiring conservation easements for the property, no attempt is made here to estimate the potential cost of the project or timelines. This project should be pursued by the Diamond lake Conservation Club in 2009.

Yellow Creek Lake shoreline erosion control

The Hoffman family owns approximately 1400 hundred feet of eroding shoreline on the south side of Yellow Creek Lake. The forested lakeshore along this reach is entirely wetland, dominated by silver maple, but the lake residents and the property owner have expressed concern over the continued erosion, which his causing a loss of the trees along the shoreline. Bioengineering would be permissible and halt erosion of hundreds of tons of soil per year into the lake (assuming an erosion rate of six inches per year along the shoreline). Bioengineering practices recommended include creating a wave break or logs and additional native plants (shrubs) at the existing shoreline. The project could be pursued under a LARE design study for one time cost of approximately $20,000 for design and permitting. Cost share for design projects are 90% through LARE, so the final out of pocket cost for the design and permitting to the landowner or Conservation Club if a grant is obtained is $2,000. This estimate assumes that the landowner desires to stabilize the shoreline and would cooperate with the Conservation Club to implement stabilization. The likelihood of project success is 75%. The Conservation Club should pursue this project as a demonstration within the next five years.

Yellow Creek Lake reroute of treatment plant outfall

The camp on the south shore of Yellow Creek Lake has an NPDES permitted outfall directly into Yellow Creek Lake from their treatment system. While, this treatment plant may be meeting IDEM discharge standards, the standards for phosphorus and nitrogen exceed the existing concentrations in the lake and therefore are adding to the phosphorus loading. No estimate has been made on the total percentage of loading coming from the discharge (it likely varies greatly with campground seasonal use changes) but any reduction is phosphorus helps to meet the overall goal of an 80 percent reduction in loading based on the model completed for this study. The initial idea is that the discharge could be moved downstream of Yellow Creek lake to Yellow Creek. To begin a project such as this requires an engineering feasibility study to look at all the potential options, discuss the project with all stakeholders (including the property owner, IDEM and the County Health Department), and develop cost estimates. An estimate for a

LARE feasibility study for this project is approximately $30,000 and would be funded with a local 10% cost share.

McClures Lake Investigation

McClures Lake has abnormally high phosphorus and nitrogen concentration and no obvious source of the nutrients. There are two potential sources identified in the Diagnostic Study including an adjacent agricultural field and a limited use residential camp, but without further study neither of these two potential sources can be identified or ruled out as a definite problem. The project may require a LARE style feasibility study or investigation by the Kosciusko County SWCD and Health Department. The wastewater treatment system (septic tank and leach field) at the camp should be monitored or tested to make sure it is functioning properly during or immediately following full use of the camp (Health Department). The crop field adjacent to the lake should have soil tests to determine phosphorus and nitrogen concentrations (SWCD). If these two potential sources are ruled out, then further investigation is needed to find the source(s) of nutrients entering the lake. This project will not proceed without written permission from the owners of the properties to proceed with testing. A representative of the Loon Lake-Beaver Dam Conservation Club or Yellow Creek Lake Conservation Club should contact the camp director and the landowner of concern to discuss the issues. Perhaps the issue will be resolved privately by having the conversation. Regardless, without their permission the Conservation Club can not initiate further study of this issue.