Palestine Lake Watershed Diagnostic Study
Kosciusko County, Indiana

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PALESTINE LAKE WATERSHED DIAGNOSTIC STUDY
KOSCIUSKO COUNTY, INDIANA

EXECUTIVE SUMMARY

Palestine and Caldwell Lakes are 291-acre and 45-acre (117.2-ha and 18.2-ha) lakes, respectively that lie in the south central portion of Kosciusko County, Indiana. The lakes lie in the headwaters of the Tippecanoe River Basin, which carries water west and south to the Wabash River. The Palestine Lake watershed stretches out to the south and east of Palestine Lake encompassing 20,680 acres (8,246 ha). Most of the watershed (81%) is utilized for agricultural purposes (row crops, hay, and pasture). Remnants of the native landscape, including forested areas and wetlands, cover approximately 13% of the watershed, while residential and commercial land uses account for approximately 4% of the watershed's total acreage. Palestine and Caldwell lakes cover less than 1% of the total watershed.

Palestine Lake is comprised of two basins each of which receives drainage from two primary tributaries. The East Basin of Palestine Lake receives water from Ring Ditch and Magee-Robbins Ditch, while the West Basin of Palestine Lake receives water from Williamson Ditch and Sloan-Adams Ditch. Based on the diagnostic study, Williamson Ditch and Sloan-Adams Ditch routinely delivered the highest load of pollutants and the highest load per unit area to Palestine Lake. All of the watershed streams possessed poor biotic communities, with the communities' integrity scores reflecting the ditches poor water quality. All of the watershed streams' biotic communities fell in the "moderately impaired" or "severely impaired" categories using the Indiana Department of Environmental Management's scoring criteria. Of greatest concern in the streams was the elevated *E. coli*, total phosphorus, and nitrate-nitrogen concentrations, which were all outside the recommended criteria or applicable state standards during both base and storm flow monitoring events.

Palestine and Caldwell lakes themselves are productive. Historical data for the lakes suggest that water quality has changed little within Palestine Lake but may be improving within Caldwell Lake over the past 25 years. During the current assessment, Palestine Lake possessed poorer water clarity and higher nutrient levels than most Indiana lakes, while Caldwell Lake's water quality was on par with or slightly poorer than most lakes in Indiana. Evaluating the lakes using various trophic state indices suggests that Palestine Lake is eutrophic to hypereutrophic in nature, while Caldwell Lake is mesotrophic to eutrophic in nature. The lakes also support a limited submerged plant community that includes two exotic species, Eurasian water milfoil and curly-leaf pondweed. Both lakes are also ringed with exotic, emergent species: purple loosestrife surrounds much of Palestine Lake, while reed canary grass surrounds much of Caldwell Lake. Nonetheless, the lakes continue to offer good fishing opportunities.

Improving water quality in Palestine and Caldwell lakes will require both in-lake and watershed management. The lakes possess extremely short hydraulic residence times measuring 0.05 years (19 days) for Palestine Lake and 0.50 years (183 days) for Caldwell Lake. The results of the inlet sampling and the phosphorus modeling indicate that the watershed is capable of contributing significant amounts of nutrient and sediment to the lake, making good watershed management a necessity. The lakes' relatively large watershed area to lake area ratio of 70:1 for Palestine Lake and 32:1 for Caldwell Lake suggests watershed practices have substantial control over influencing the health of these lakes.

Recommended watershed management techniques include: filter strip and grassed waterway installation, streambank and shoreline stabilization and restoration, erosion control practices for existing and future developments, homeowner best management practices, wetland restoration, use of the Conservation Reserve Program and conservation tillage, and livestock restriction. Area stakeholders are encouraged to develop a comprehensive plant management plan for the lakes. This plan should include a rooted plant management section to protect the plant community's health.

ACKNOWLEDGEMENTS

The Palestine Lake Watershed Diagnostic Study was made possible with funding from the Indiana Department of Natural Resources (IDNR) Division of Fish and Wildlife and the Palestine Lake Property Owners Association. The Palestine Watershed Diagnostic Study was completed by JFNew and their subcontractor, Indiana University School of Public and Environmental Affairs. Contributors to this study included Angela Grier, Ed Braun, and Gwen White with the IDNR Division of Fish and Wildlife; Ron Hellmich with the IDNR Division of Nature Preserves; and Carol Newhouse, formerly of the Indiana Department of Environmental Management Assessment Branch. Special thanks to the dedicated members of the Palestine Lake Owners Association for their initiative and assistance in getting this study completed. Area residents who participated in the study included: Mark Whittaker, who served as the primary liaison between JFNew and the Palestine Lake Property Owners Association; Deb Hutnick, who kept an eagle eye on the finances; Mary Ann and Joseph Steininger for their assistance throughout the project, in counting boats on Palestine Lake and for providing chauffer service for the watershed tour; John Thompson, who navigated JFNew biologists around the lake during the rooted plant survey. Authors of this report included William Jones, Ted Derheimer, Aaron McMahan, and Melissa Clark at Indiana University and Sara Peel, Betsy Ewoldt, Mark Pranckus, Aaron Johnson, and John Richardson at JFNew.

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1.0 INTRODUCTION

Palestine and Caldwell Lakes are 291-acre and 45-acre (117.2-ha and 18.2-ha) lakes, respectively that lie in the south central portion of Kosciusko County, Indiana (Figure 1). Specifically, Palestine Lake is located in Sections 33 and 34, Township 32 North, Range 5 East and Sections 1 and 2, Township 31 North, Range 5 East and Caldwell Lake in Section 19 of Township 31 North, Range 6 East in Kosciusko County. The Palestine Lake watershed stretches out to the south and east of Palestine Lake encompassing 20,680 acres (8,245 ha; Figure 2). Water flows from Caldwell Lake into Adams Ditch, which flows northwest to Palestine Lake. Water exits Palestine Lake through Trimble Creek, which is located in the northwest corner of the lake and flows north to the Tippecanoe River. The Tippecanoe River transports water south and west to the Wabash River which eventually discharges water to the Ohio River in southwest Indiana. Palestine and Caldwell lake watershed runoff eventually reaches the Mississippi River in southern Illinois.

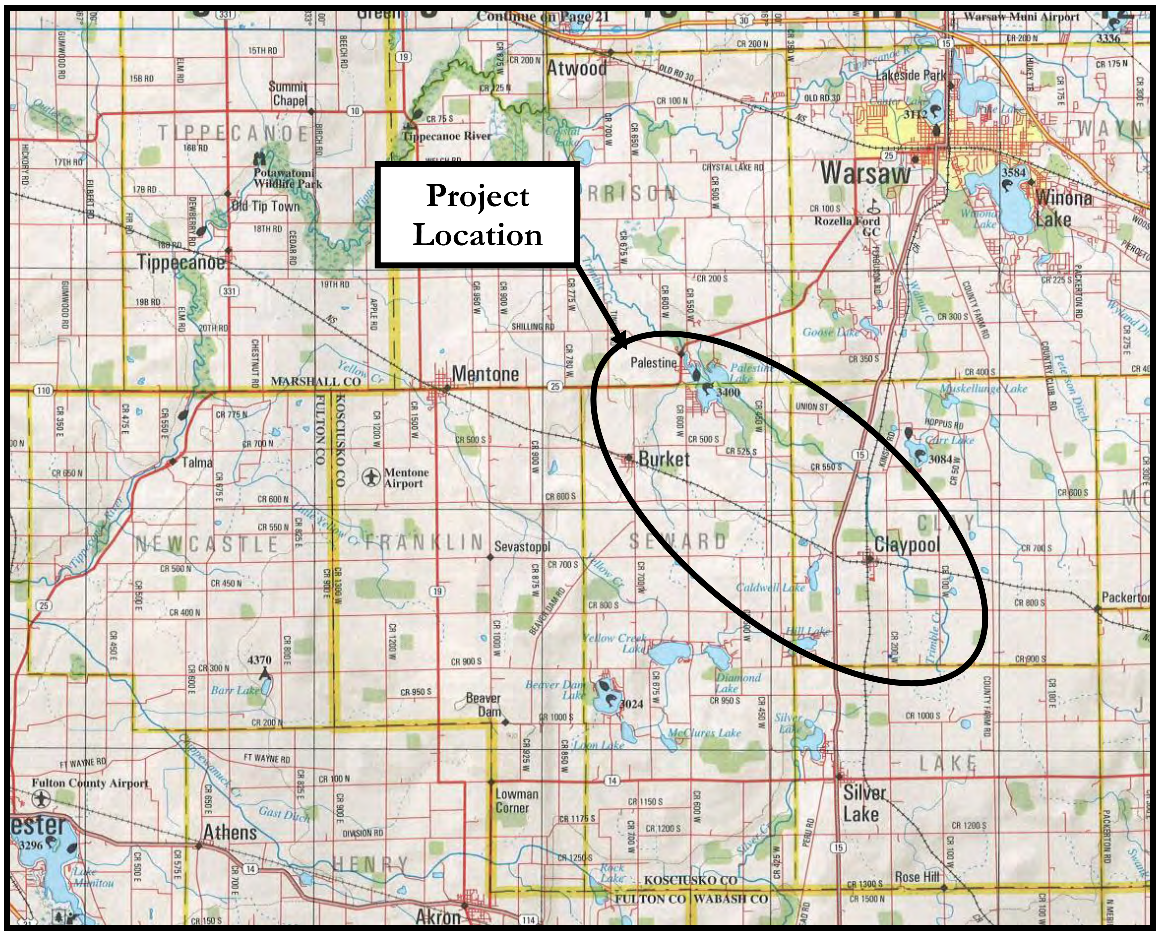

Figure 1. General location of the Palestine Lake watershed. Source: DeLorme, 1998.

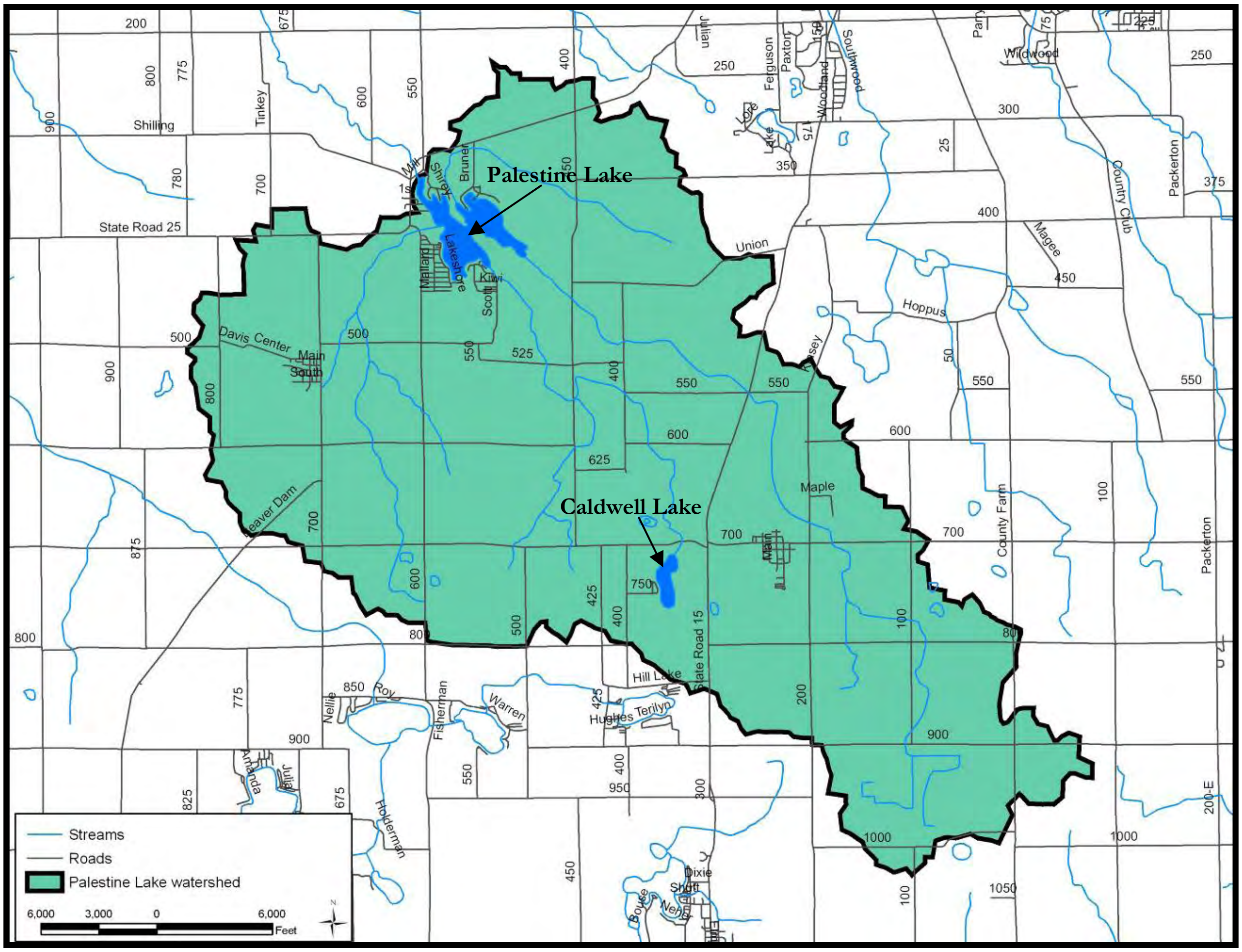

Figure 2. Palestine Lake watershed.

Palestine and Caldwell lakes have historically exhibited moderately poor water quality characteristic of highly productive (eutrophic) lakes. The lakes' water clarity has fluctuated over the past 30 to 40 years but has ultimately changed little over time. Both Palestine and Caldwell lakes possess relatively poor clarity when compared to other lakes in the region; however, more recently, Caldwell Lake's water clarity is better than that of Palestine Lake. Historical records indicated that both lakes possess Secchi disk transparencies (a measure of water clarity) poorer than 3 feet (0.9 m). More recent data indicate that current water quality in Palestine Lake is poorer than most lakes in Indiana, while Caldwell Lake's water quality is on par with lakes throughout the state. Palestine and Caldwell lakes also possess high total phosphorus concentrations measuring 0.178 mg/L and 0.257 mg/L throughout the water column, respectively. Total phosphorus concentrations are elevated compared to the statewide (0.17mg/L) and regional median (0.079mg/L) values (Clean Lakes Program data files, unpublished; CLP data files, 2007). Primary productivity of the lake (algae and plant growth) has been relatively high in Palestine Lake as well. Chlorophyll *a* concentrations (an indicator of algae production) were greater than 31 μg/L in both basins. Concentrations this high are typical of hypereutrophic lakes. The fish kill that resulted from the extremely dense algal community in late summer in Palestine Lake suggests that the lake undergoes high productivity throughout the summer. Conversely, Caldwell Lake is moderately productive, as would be expected of a mesotrophic lake.

The composition and structure of Palestine and Caldwell lakes' rooted plant communities indicate that water quality within the lakes is equitable with what the water chemistry data indicate. Both lakes are dominated by a mix of emergent, floating, and submerged species including Eurasian watermilfoil, coontail, curly-leaf pondweed, spatterdock, filamentous algae, watermeal, duckweed, and purple loosestrife. These species are common in lakes with poor water clarity and elevated nutrient concentrations. In fact, many of these species consume nutrients directly from the water column. Palestine Lake's plant community was inhibited by the dense algal mat which covered the surface of the lake throughout the summer, while Caldwell Lake's plant community reflected its better water clarity.

Shoreline residents and Palestine Lake Property Owners Association members have been proactive in protecting their lakes' health. Residents have worked on their own and with natural resource agencies to try to treat problems in the lake and its watershed. While these practices have slowed the import of sediment to Palestine and Caldwell lakes from their watershed and the conversations have sparked the interest of watershed residents, members of the Palestine Lake Property Owners Association (PLPOA) have identified additional areas of concerns. Lake residents have also expressed a desire to learn about practices that can be implemented on residential properties that might improve the lake's water quality. To achieve these goals, the PLPOA applied for and received funding from the IDNR Lake and River Enhancement Program (LARE) to complete a diagnostic study of the lake.

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

2.0 WATERSHED CHARACTERISTICS

2.1 Topography and Physical Setting

Palestine and Caldwell lakes are headwaters lakes which lie in the Mississippi River Basin. The lakes and their 20,680-acre (8,369-ha) watershed lie south of the north-south continental divide. Similar to its more famous cousin, the east-west Continental Divide, which divides the United States into two watersheds, one that drains to the Atlantic Ocean and one that drains to the Pacific Ocean. The divide separates the Mississippi River Basin (land that drains south to the Mississippi River) from the Great Lakes Basin (land that drains north to the Great Lakes). As part of the Mississippi River Basin, water exits Caldwell Lake near the lake's northeast corner and flows north then east toward Palestine Lake. Water exits Palestine Lake from its northwest corner flowing though Trimble Creek toward the Tippecanoe River. Trimble Creek combines with the Tippecanoe River west of Warsaw and south of Atwood. The Tippecanoe River eventually discharges into the Wabash River northeast of Lafayette, Indiana. The Wabash River flows southwest carrying water into the Ohio River in southeastern Illinois.

The topography of the Palestine Lake watershed reflects the geological history of the watershed. The highest areas of the watershed lie along the watershed's southern, southeastern and southwestern edges, where the Erie Lobe of the last glacial age left end moraines. Along the watershed's southern boundary, the elevation nears 950 feet (289.6 m) above mean sea level (msl). The ridges along the watershed's southeastern and southwestern boundaries are nearly as high (930 feet msl), and are equally as steep as the ridge along the southern watershed boundary. Many of the watershed streams, including Ring Ditch, Magee-Robinson Ditch, and Williamson Ditch, their floodplains, and Palestine and Caldwell lakes occupy a lower elevation valley in the watershed. Palestine Lake, elevation 917 feet (279.5 m) above mean sea level, is the lowest point in the watershed. Figure 3 presents an elevation map of the Palestine Lake watershed.

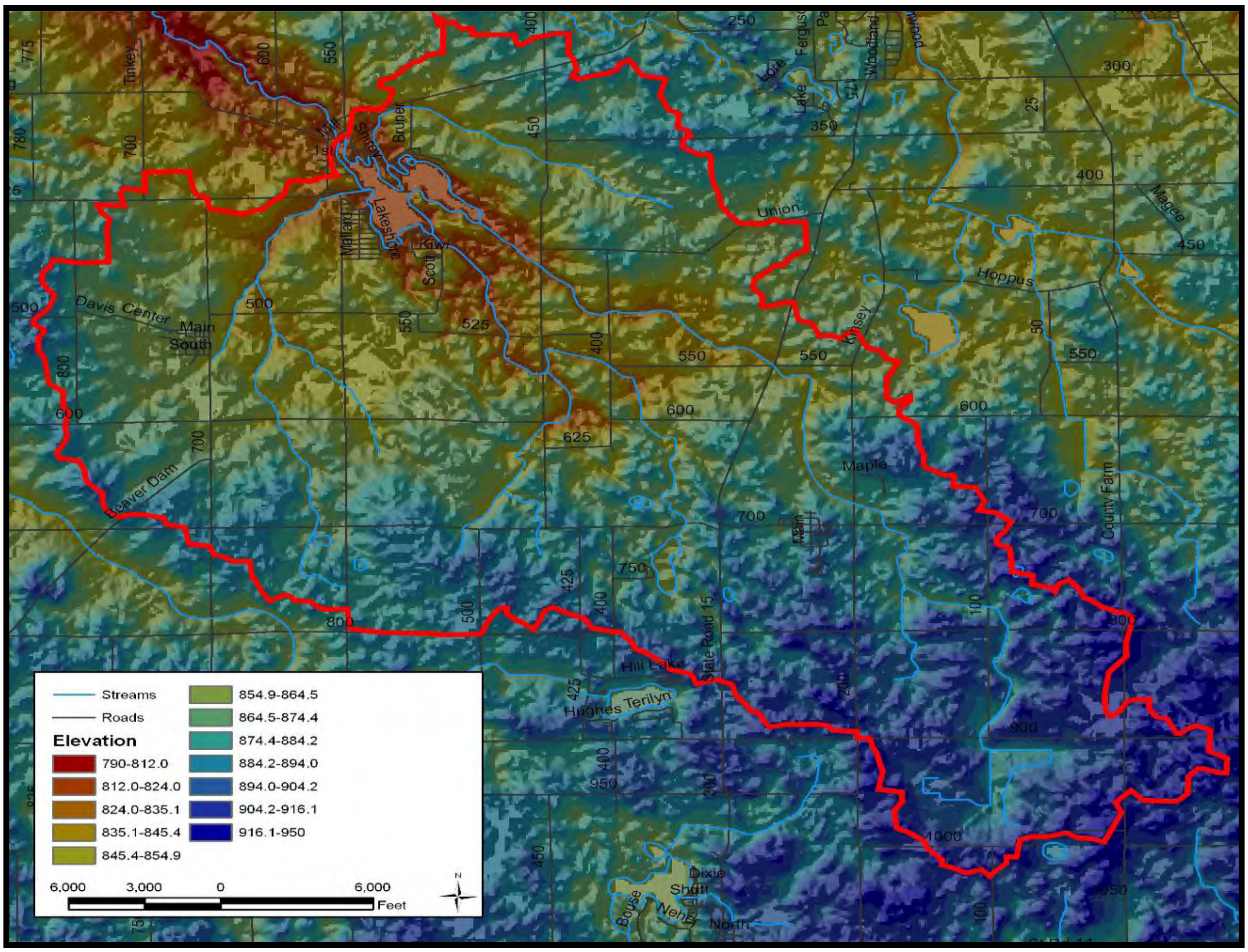

Figure 3. Elevation map of the Palestine Lake watershed.

2.1.1 Palestine Lake

Palestine Lake was created via the construction of a dam across Trimble Creek in 1893. The dam created one single surface waterbody where two previous smaller lakes existed (IDNR, no date). This resulted in the current morphology of the lake which consists of an east basin and a west basin which are connected by a narrow channel.

Surface water drains to Palestine Lake via five primary routes: through Ring Ditch, Williamson Ditch, Magee-Robbins Ditch, Sloan-Adams Ditch, and via direct drainage (Table 1). Two of these streams, Ring Ditch and Magee-Robbins Ditch drain to the lake's east basin, while the two other streams, Williamson Ditch and Sloan-Adams Ditch, drain to the west basin of Palestine Lake. Ring Ditch delivers water to Palestine Lake from the largest portion of the watershed (Figure 4). This stream drains 7,286 acres (2,948 ha) or 35% of the watershed. Ring Ditch carries water from the southernmost and easternmost portion of the watershed into the eastern basin of Palestine Lake. Magee-Robbins Ditch is the smallest of the four surface water drainages carrying water from the northeastern portion of the watershed to the eastern basin of Palestine Lake. In total, Magee-Robbins Ditch drains 1,783 acres (721 ha) or 9% of the watershed. Williamson Ditch drains nearly 5,776 acres (2,337 ha or 28%) of the Palestine Lake watershed including the town of Burket. This stream carries water from the western portion of the watershed into Palestine Lake's western basin. The final surface tributary, the Sloan-Adams Ditch, carries water from the central portion of the watershed, including Caldwell Lake, into Palestine Lake's western basin. This stream drains a total of 5,025 acres (2,033 ha) or approximately 24% of the Palestine Lake watershed. An additional 520 acres (210 ha or less than 3% of the watershed) of land drains directly to Palestine Lake via ground-water drainage or other small tributaries. Palestine Lake itself covers the remaining 290 acres or 117 ha of the watershed. Figure 4 illustrates the boundary of the four surface drainages and details the area that drains directly to Palestine Lake.

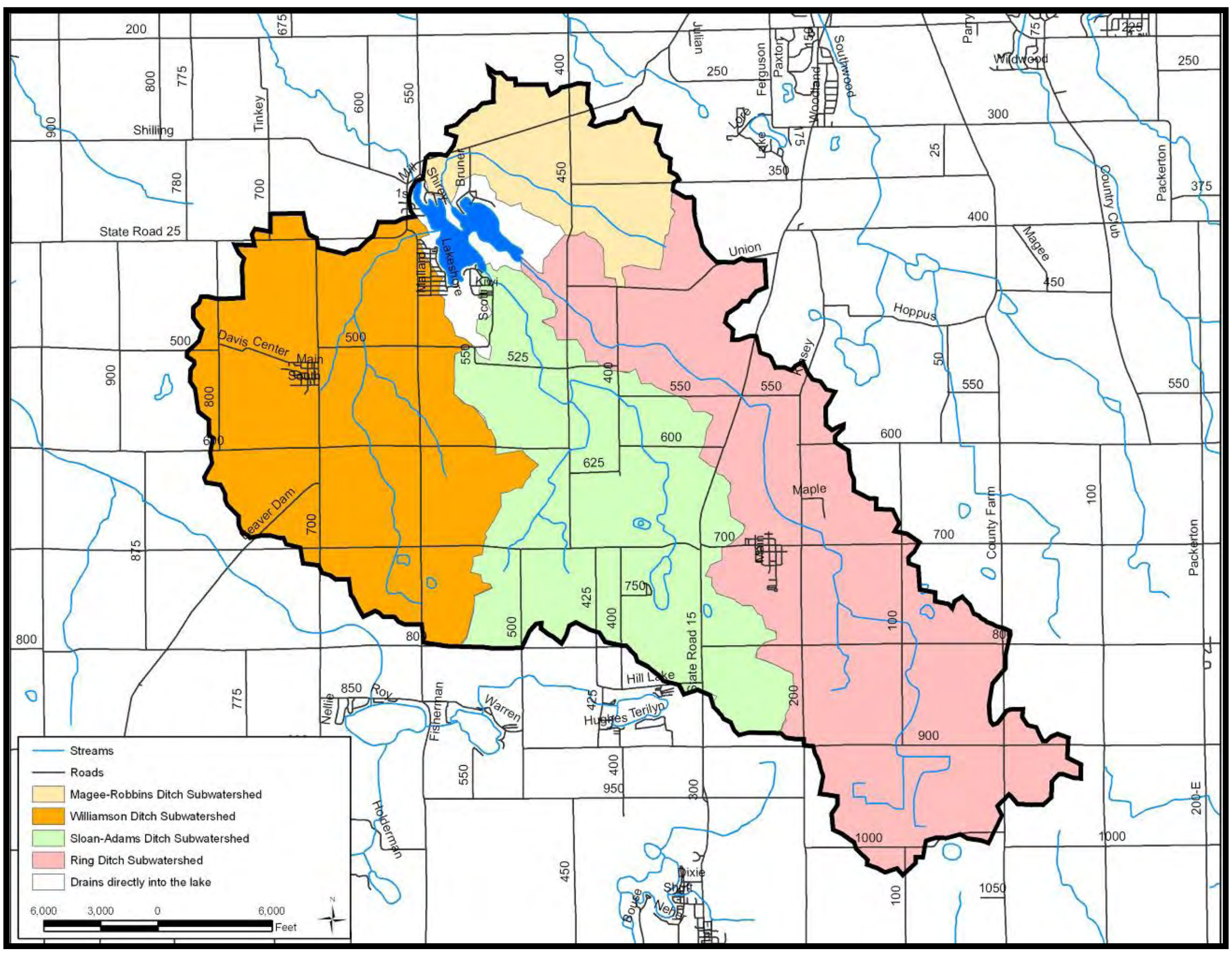

Figure 4. Palestine Lake subwatersheds.

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

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
Ring Ditch	7,286	2,948.5	35.2%
Williamson Ditch	5,776	2,337.5	27.9%
Sloan-Adams Ditch	5,025	2,033.5	24.2%
Magee-Robbins Ditch	1,783	721.5	8.6%
Drains directly to Palestine Lake	520	210.4	2.5%
Watershed Draining to Lake	**20,390**	**8,251.5**	**98.6%**
Palestine Lake	290	117.4	1.4%
Total Watershed	**20,680**	**8,245.6**	**100%**
Watershed to Lake Area Ratio	70.2:1		

Table 1 also provides the watershed area to lake area ratio for Palestine 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.

Palestine Lake possesses a watershed area to lake area ratio of approximately 70:1. This is a fairly high watershed area to lake area ratio for glacial lakes and is more typical of reservoir systems, where the watershed area to reservoir area ratio typically ranges from 100:1 to 300:1 (Vant, 1987). When compared with other lakes in the Tippecanoe River watershed, like Lake Tippecanoe, Ridinger Lake, and Smalley Lake that possess watershed area to lake area ratios of 93:1, 165:1, and 248:1, respectively, Palestine Lake's watershed area to lake area ratio appears to be relatively normal for this drainage basin. All of these lakes are natural glacial lakes which have extensive watersheds, while Palestine Lake is a reservoir.

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

2.1.2 Caldwell Lake

Surface water drains to Caldwell Lake via three primary routes. Two branches of Sloan-Adams Ditch drain into Caldwell Lake: one, the east branch, enters along the eastern shoreline carrying water from approximately 653 acres (264.3 ha) and the second, the west branch, enters along the southern shoreline of Caldwell Lake (Table 2). The west branch carries water from approximately 271 acres (109.7 ha). The remainder of the land in the Caldwell Lake watershed (470 acres or 190.2 ha) drains directly to Caldwell Lake. Figure 5 illustrates the boundaries of each of the subwatersheds of Caldwell Lake.

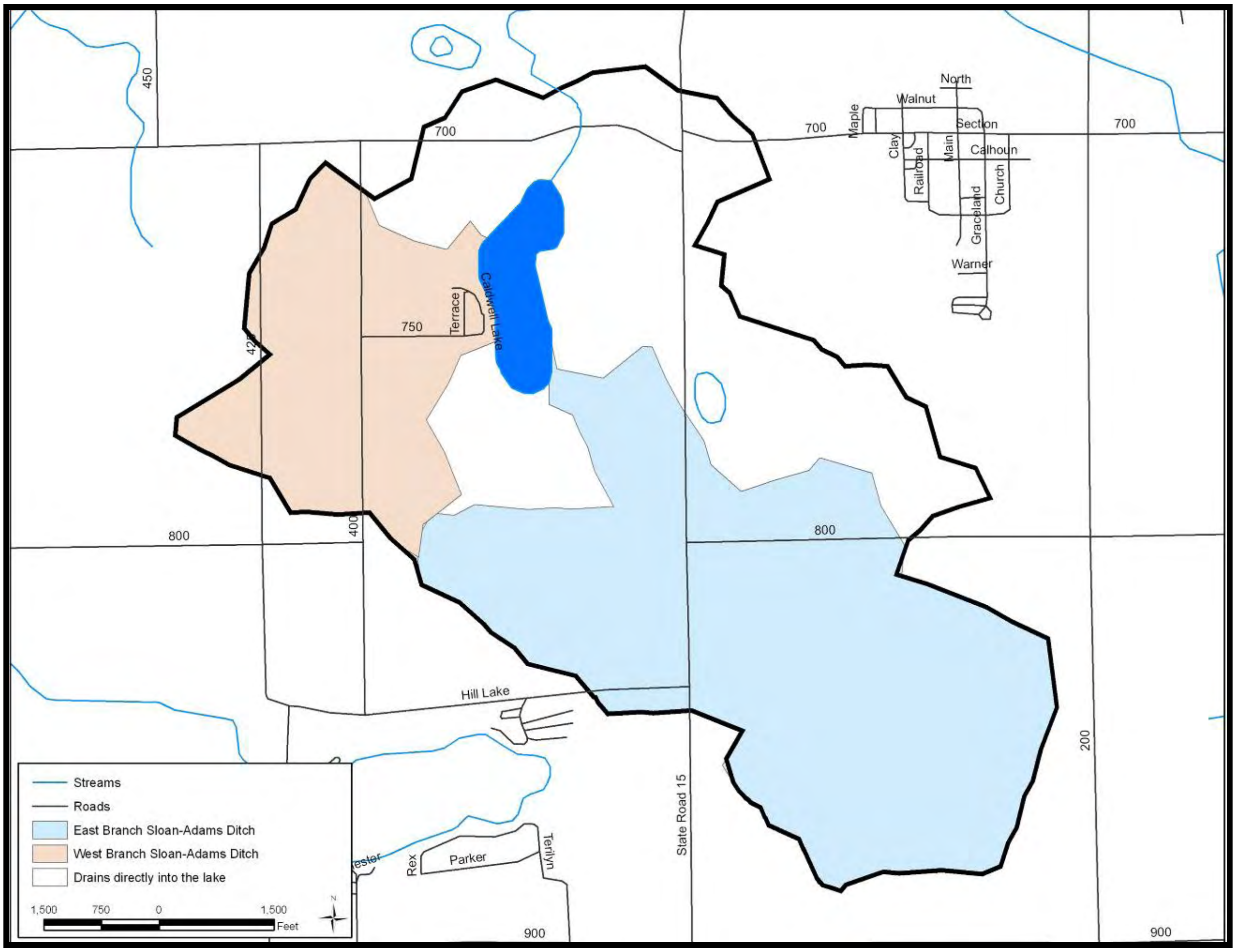

Figure 5. Caldwell Lake subwatersheds.

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

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
East Branch Sloan-Adams Ditch	653	264.3	45.4%
West Branch Sloan-Adams Ditch	271	109.7	18.8%
Directly to Caldwell Lake	470	190.2	32.7%
Watershed Draining to Lake	**1,394**	**564.1**	**96.9%**
Caldwell Lake	45	18.2	3.1%
Total Watershed	**1,439**	**582.3**	**100%**
Watershed to Lake Area Ratio	32:1		

Like Palestine Lake, Caldwell Lake possesses a relatively large watershed area to lake area ratio (32:1); however, this ratio is more in line with ratios of other glacial lakes. Many glacial lakes have watershed area to lake area ratios of less than 50:1. Watershed area to lake area ratios on the order of 10:1 are fairly common for glacial lakes (Vant, 1987). Like Palestine Lake's watershed area to lake area ratio, Caldwell Lake's ratio indicates that watershed activities and processes can potentially exert a significant influence on the health of Caldwell Lake. Again like Palestine Lake, implementing best management practices within the Caldwell Lake watershed should rank high when prioritizing management options. In-lake or near-shore management options should not be ignored, rather these alternatives should be considered of slightly lower priority when prioritizing the use of limited funds for lake management.

2.2 Climate

Indiana Climate

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

Palestine Lake Watershed Climate

The climate of the Palestine Lake watershed is characterized as having four well-defined seasons of the year. Winter temperatures average 26° F (-3.3° C), while summers are warm, with temperatures averaging 70° F (21.1° C). The growing season typically begins in early April and ends in September. Annual rainfall averages 36.65 inches (93 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, except for the annual rainfall average, were taken from Staley, 1989.) Through December 19, 2007, more than 39 inches (99.1 cm) of precipitation (Table 3) were recorded at Warsaw in Kosciusko County. When compared with the 30-year average for the area, the 2007 annual rainfall exceeded the average by approximately 5 inches (12.7 cm).

Table 3. Monthly rainfall data (in inches) for year 2007 as compared to average monthly rainfall.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2007	4.52	2.79	3.99	3.84	1.85	3.42	3.17	4.77	2.48	3.80	2.86	4.44	**41.93**
Average	1.85	1.45	2.08	3.36	3.83	4.51	3.67	4.05	3.22	3.04	2.97	2.62	**36.65**

All data were recorded at Warsaw in Kosciusko County. Averages are 30-year normals based on available weather observations taken during the years of 1971-2000 (Purdue Applied Meteorology Group, 2007).

2.3 Geology

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

The movement and stagnation of the Saginaw Lobe of the Wisconsin glacial age shaped much of the Palestine Lake watershed, although the influence of the Erie Lobe can be seen on the watershed's landscape as well. The Saginaw glacial lobe moved out of Canada to the south carrying a mixture of Canadian bedrock with it. The Packerton Moraine, an end moraine which forms the southern boundary of the Palestine Lake watershed, marks the edge of the Saginaw Lobe's advance into Indiana. The Packerton Moraine extends northeasterly along the eastern edge of the Palestine Lake watershed. Palestine and Caldwell lakes lie within the inner morainic valleys of the Burket Moraine (Wright, 1932). According to Wright (1932), the Burket Moraine formed from the stagnation of the Erie Lobe. Fragments of the Burket Moraine are scattered along the Palestine Lake watershed's western edge. These fragments form a ridge separating the Trimble Creek basin from the Yellow Creek basin. (Figure 3 – TOPO RELIEF – shows the areas of greater relief associated with the Burket Moraine along the watershed's western boundary.)

The geology and resulting physiography of the Palestine Lake watershed typify the physiographic region in which the watershed lies. The Palestine Lake watershed lies within Malott's Steuben Morainal Lake Area. Schneider (1966) notes that the landforms common in this diverse physiographic region include till knobs and ice-contact sand and gravel kames, kettle holes and lakes, meltwater channels lined with outwash deposits or organic sediment, valley trains, outwash plains, and small lacustrine plains. Specifically, kames, kettle lakes, outwash plains, and meltwater channels exist within the Palestine Lake watershed and surrounding area (Wright, 1932). Many of these landforms are visible on the Palestine Lake watershed landscape. Caldwell Lake is a good example of a moderately deep kettle lake lying in an end moraine. It is part of the "knob and kettle" topography that is characteristic of end moraines. The original ice block that formed as Caldwell Lake has undergone some modifications as sediments accumulated within the glacial drift. Till knobs and kames occur along the watershed's southwestern edge, and are quite visible.

Surficial geology indicates that Palestine Lake lies within glacial till material. Glacial drift covers the Palestine Lake watershed to a depth of 300 to 400 feet (91.2 to 122 m; Wayne, 1966). The watershed's surficial geology originates from silty clay loam and clay loam till materials. The southern portion of the watershed located in and around the vicinity of Caldwell Lake is covered by muck of lacustrine origin. This indicates that this portion of the watershed was likely once home of a larger lake basin. The bedrock immediately underlying the watershed's surficial geology includes rock from one period; Devonian shale underlies the entire Palestine Lake watershed (Gray, 1989). The underlying bedrock is a broad lowland which possesses moderate relief, the Dekalb Lowland. This lowland formed on Upper Devonian and Lower Mississippian shales (Wayne, 1966; Gutschick, 1966).

2.4 Soils

Before detailing the major soil associations covering the Palestine Lake watershed, it may be useful to examine the concept of soil associations. Major soil associations are determined at the county level. Soil scientists review the soils, relief, and drainage patterns on the county landscape to identify distinct proportional groupings of soil units. The review process typically results in the identification of eight to fifteen distinct patterns of soil units. These patterns are the major soil associations in the county. Each soil association typically consists of two or three soil units that dominate the area covered by the soil association and several soil units that occupy only a small portion of the soil association's landscape. Soil associations are named for their dominant components. For example, the 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 Palestine Lake watershed (Figure 6). These soil associations are the Wawasee-Crosier-Miami association, the Riddles-Ormas-Kosciusko Association, and the Riddles-Wawasee association. The Wawasee-Crosier-Miami soil association covers the majority of the Palestine Lake watershed including the shoreline and entire watershed for Caldwell Lake. This is the most common soil association in Kosciusko County, covering approximately 28% of the county landscape. The Riddles-Ormas-Kosciusko soil association is the second most common in the Palestine Lake watershed. This association borders the shoreline of Palestine Lake and covers the entirety of the towns of Burket and Palestine and the floodplains for Ring Ditch and Williamson Ditch from their headwaters to their mouth. The Riddles-Ormas-Kosciusko association covers approximately 6% of the county. The Riddles-Wawasee soil association covers the smallest portion of the Palestine Lake watershed covering a small area northeast of Claypool. Specifically, the Riddles-Wawasee association covers east of County Road 200 West and north of County Road 700 South. The Riddles-Wawasee soil association is the third most common soil association found in Kosciusko County, covering approximately 10% of the county landscape. The following discussion on soil associations in the Palestine Lake 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 Wawasee-Crosier-Miami soil association covers the majority of the Palestine Lake watershed including the shoreline and entirety of the Caldwell Lake watershed. 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 Palestine Lake 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.

The Riddles-Ormas-Kosciusko association is relatively uncommon in Kosciusko County, covering only 6% of the county. This association is found along the shoreline of Palestine Lake, covers the towns of Burket and Palestine, and borders the floodplains for Williamson and Ring ditches. Well drained soils with moderately well defined surface drainage patterns characterize this soil association. Soils in this association are typically found on knobs, ridges, and in deep depressional areas. Riddles soils comprise 31% of the association, while Ormas soils and Kosciusko soils comprise 25% and 24%, respectively. Riddles soils are found on the tops of ridges and on the highest points across the landscape. Surface layers of Riddles soils are fine sandy loams with even finer textured (loams and clay loams) soils below the surface layer. Ormas soils are typically found at lower elevations on south and east facing slopes. Ormas soils consist of loamy sand over loamy sand and sand substratum. Kosciusko soils are found on lower elevation ridge tops than Riddles soils and on north and west facing slopes. Kosciusko soils consist of a sandy loam surface layer over gravelly sandy clay loam and gravelly loamy sand. Minor components in the Riddles-Ormas-Kosciusko association include Boyer loamy sand, Brady sandy loam, Gilford sandy loam, and Houghton muck soils. Producers should consider the erosion potential of this soil association when cultivating crops on sloped land in this soil association. Riddles soils are moderately limited for septic system development due to permeability, while poor filtering capacity limits Ormas and Kosciusko soils.

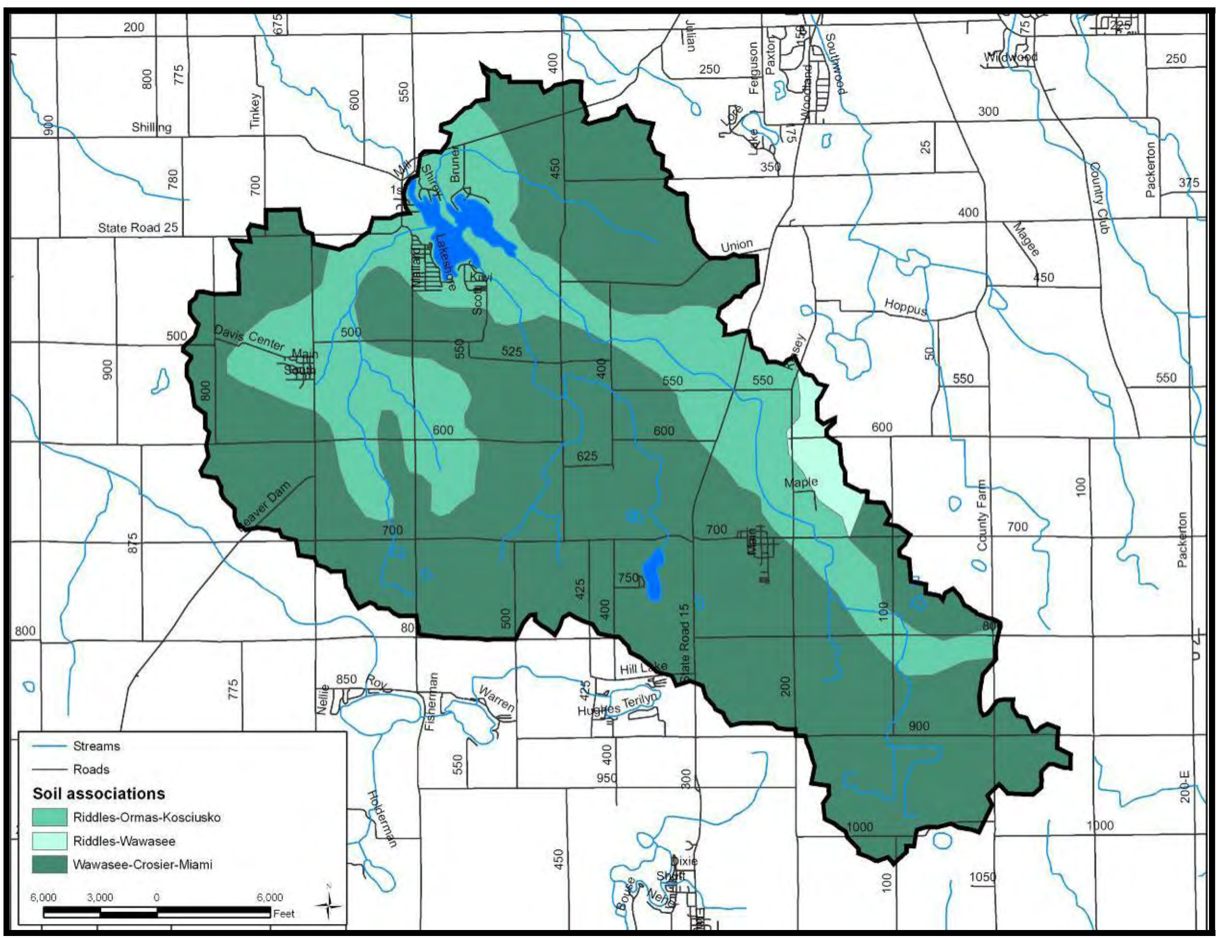

Figure 6. Soil associations present in the Palestine Lake watershed.

The Riddles-Wawasee soil association covers a minor portion of the Palestine Lake watershed northeast of Claypool. The Riddles-Wawasee soil association consists largely of Riddles (44%) and Wawasee (19%) soils. Both soils possess fine sandy loam surface layers that overlie fine sandy loam, sandy clay loam, and loam subsoil. Minor components of this association include Barry loam, Griswold loam, Martinsville sandy loam, Rensselaer loam, and Whitaker loam soils. Erosion is a concern with this soil association in sloping areas. The Riddles-Wawasee soil association is moderately limited for septic system usage.

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, and Kosciusko soils on steeply sloped areas across the Palestine Lake 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 Palestine and Caldwell lakes and their watershed streams. Similarly, many of these same soils lie under the residentially developed portions of the Palestine and Caldwell lakes shorelines and treat residential septic tank effluent. Unfortunately, these soils are moderately to severely limited in their ability to treat septic tank effluent. These limitations can impact Palestine and Caldwell lakes' water quality. A more detailed discussion how highly erodible soils and soils used to treat septic tank effluent impact Palestine and Caldwell 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 can carry attached nutrients, which further impair water quality by increasing production of plant and algae material. 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 4 lists and Figure 7 displays the soil units in the Palestine Lake watershed that the NRCS considers to be highly erodible and potentially highly erodible.

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, Morley loam and silty clay loam, Miami clay loam soils cover much of the Palestine Lake watershed. Areas of the watershed that are mapped in these soil units and have gentle slopes are considered only slightly limited for agricultural production. As slope increases, the severity of the limitation increases. Some steeply sloped Riddles and Kosciusko soils are considered unsuitable for agricultural production due to erosional hazards. The erosion hazard would also exist during residential development on these soils.

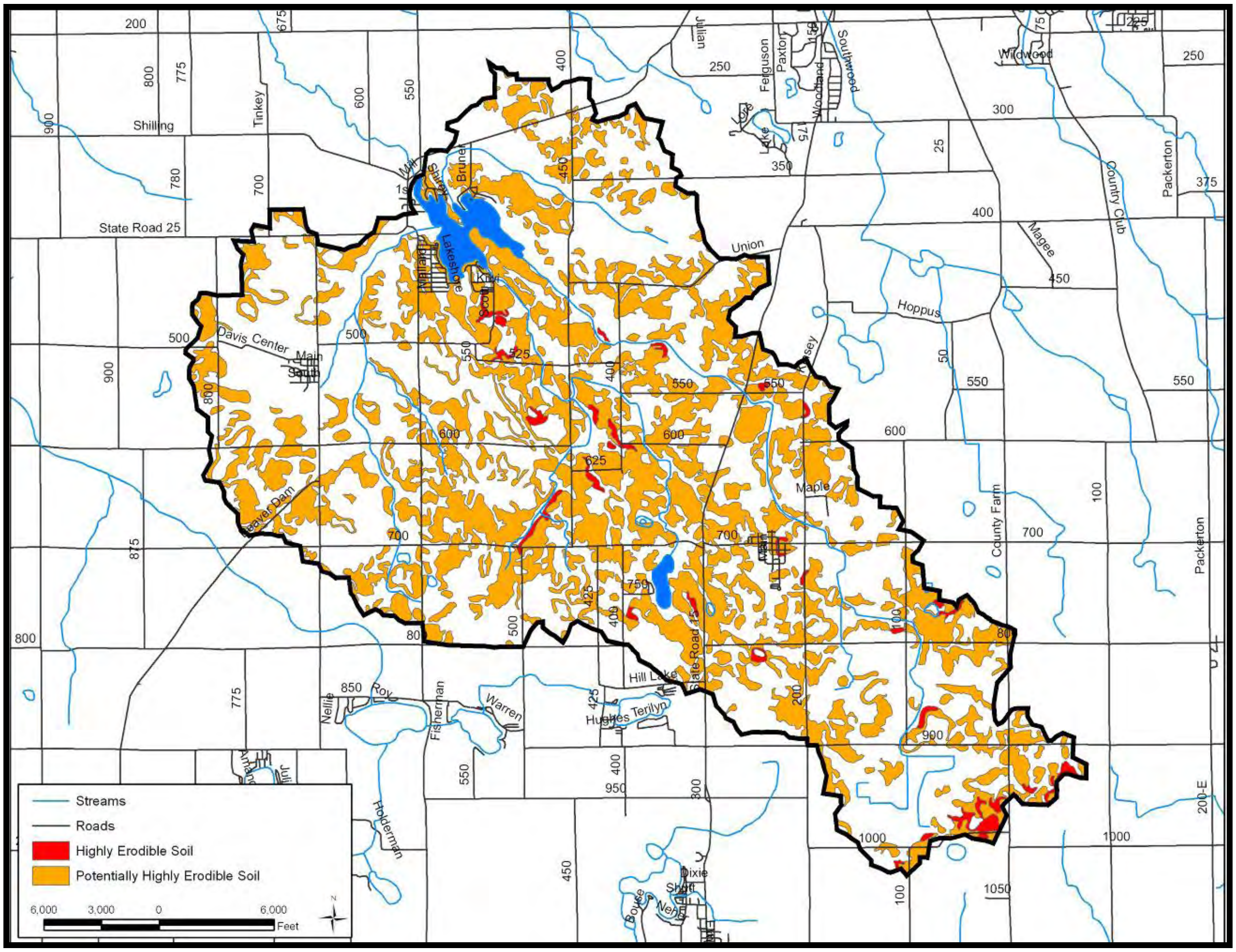

Figure 7. Highly erodible and potentially highly erodible soils within the Palestine Lake watershed.

Table 4. Highly erodible and potentially highly erodible soil units in the Palestine Lake watershed.

Soil Unit	Status	Soil Name	Soil Description
KoB	PHES	Kosciusko sandy loam	2-6% slopes
KoC	PHES	Kosciusko sandy loam	6-12% slopes
KoE	HES	Kosciusko sandy loam	18-30% slopes
KxC3	HES	Kosciusko sandy clay loam	8-15% slopes, severely eroded
MaB	PHES	Martinsville sandy loam	2-6% slopes
MaC	PHES	Martinsville sandy loam	6-12% slopes
MbC	PHES	Metea loamy sand	6-12% slopes
MrC3	HES	Miami clay loam	6-12% slopes, severely eroded
MsB	PHES	Miami-Owosso-Metea complex	2-8% slopes
MvC	HES	Morley loam	6-12% slopes
MxC3	HES	Morley silty clay loam	5-15% slopes, severely eroded
MzB	PHES	Morley-Glynwood complex	1-4% slopes
OrC	PHES	Ormas loamy sand	6-12% 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
RlD	HES	Riddles fine sandy loam	12-18% 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.

As Figure 7 indicates, erodible soils located on the most steeply sloped areas (HES) cover approximately 252 acres (102.0 ha) or 1.2% of the Palestine Lake watershed. This acreage is divided evenly over the Ring Ditch and Sloan-Adams Ditch subwatersheds. However, it should be noted that an almost equal percentage (2%) of the watershed draining directly to Palestine Lake is covered by highly erodible soils as the percentage of highly erodible soils in the Ring Ditch and Sloan-Adams Ditch subwatersheds. Approximately 7,427 acres (3,007.0 ha) of land in the Palestine Lake watershed are mapped in potentially highly erodible (PHES) units. PHES units cover 36% of the watershed including the entire shoreline of Palestine Lake. By subwatershed, the Sloan-Adams Ditch subwatershed contains the greatest percentage of land (45%) mapped as potentially highly erodible units. By area, the Ring Ditch and Sloan-Adams Ditch subwatersheds drain nearly equal areas; approximately 2,588 acres and 2,265 acres of land in each subwatershed is covered by PHES units, respectively. An additional 1,735 acres of soils mapped as PHES cover the Williamson Ditch subwatershed. A minimum of 29% of subwatershed drainage area is covered by PHES with the Magee-Robbins subwatershed containing the smallest percent PHES, while the Sloan-Adams and Ring Ditch subwatersheds contain the largest percent PHES coverage.

Table 5. Area mapped in highly erodible or potentially highly erodible map units by subwatershed.

Subwatershed	HES (acres)	HES (ha)	Percent of Subwatershed	PHES (acres)	PHES (ha)	Percent of Subwatershed
Ring Ditch	138.4	56.0	1.9%	2,588.1	1,047.8	35.5%
Williamson Ditch	0.0	0.0	0.0%	1,798.4	728.1	31.1%
Sloan-Adams Ditch	107.4	43.5	2.1%	2,265.2	917.1	45.1%
Magee-Robbins Ditch	0.0	0.0	0.0%	524.6	212.4	29.4%
Directly to the lakes	5.4	2.2	0.7%	251.0	101.6	31.0%
Watershed	**251.2**	**101.7**	**1.2%**	**7,427.3**	**3,007.0**	**35.9%**

Highly erodible and potentially highly erodible soils cover a large portion of the Caldwell Lake watershed as well. Nearly 19 acres (7.6 ha) or 1.3% of the watershed is covered by highly erodible soils, while nearly 39% of the watershed or 565 acres (228.6 ha) are demarcated as potentially highly erodible soils. Most of these soils are located south and east of Caldwell Lake. None of the soils bordering Caldwell Lake are mapped as highly erodible or potentially highly erodible.

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 Palestine Lake 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 resuspended in the soil solution and transported throughout the soil profile. Inactivation and destruction of pathogens occurs more rapidly in soils containing oxygen because sewage organisms compete poorly with the natural soil microorganisms, which are obligate aerobes requiring oxygen for life. 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 Palestine Lake watershed in terms of its limitations for use as a septic tank absorption field. Each soil series is placed in one of three categories: slightly limited, moderately limited, or severely limited. Use of septic absorption fields in moderately or severely limited soils generally requires special design, planning, and/or maintenance to overcome the limitations and ensure proper function. Figure 8 displays the septic tank suitability of soils throughout the Palestine Lake watershed, while Table 5 lists the soils located within the watershed and their associated properties. Soils that are severely limited for use as septic systems cover 11,915 acres (4,824.1 ha or 58%) of the watershed. Severely limited soils cover the Ring Ditch floodplain, border the northern and southern shorelines of Palestine Lake and the entirety of Caldwell Lake, and cover much of the western portion of the watershed in and around Burket. Soils that are moderately limited cover an additional 37% or 7,767 acres (3,144.4 ha) of the Palestine Lake watershed. These soils border the southwestern shoreline of Palestine Lake, cover much of the area west of the lake including nearly the entirety of Palestine, and are prevalent throughout the Sloan-Adams Ditch and Williamson Ditch subwatersheds. Soils that are rated as slightly limited for septic system usage cover 117 acres (47 ha or <1%) of the watershed. Soils that are not rated for septic treatment cover an additional 6%; these areas include Palestine and Caldwell lakes, other waterbodies or ponds throughout the watershed, and gravels pits.

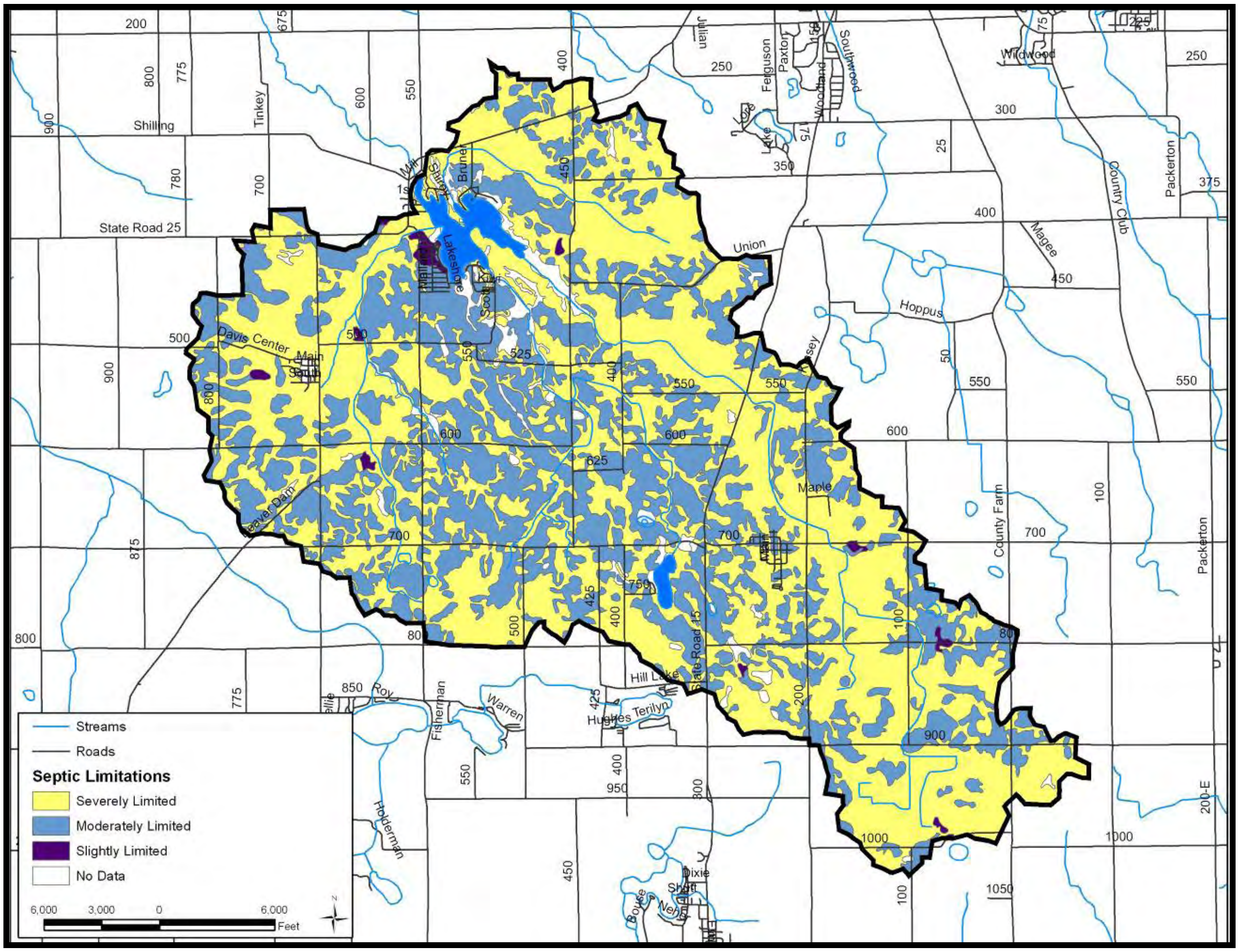

Figure 8. Soil septic tank suitability within the Palestine Lake watershed.

Table 6. Soil types in the Palestine Lake watershed and the features restrictive to their suitability to serve as a septic tank absorption field.

Soil Unit	Soil Name	Depth to High Water Table	Restrictive Features
Ab	Abscota fine sandy loam	>6 feet	Severe: flooding, poor filter
Ao	Aquents-Urban land complex	--	--
ArA	Aubbeenaubbee sandy loam	1 to 3 feet	Severe: wetness, percs slowly
AtA	Aubbeenaubbee fine sandy loam	1 to 3 feet	Severe: wetness
Bc	Barry loam	+1 to 1 feet	Severe: ponding
BlA	Blount silt loam	1 to 3 feet	Severe: wetness, percs slowly
BnB	Blount-Glynwood complex	1 to 3 feet	Severe: wetness, percs slowly
BoB-BoC	Boyer loamy sand	>6 feet	Severe: poor filter
Bp	Brady sandy loam	1 to 3 feet	Severe: wetness
BrA	Bronson sandy loam	2 to 3.5 feet	Severe: wetness
CaA	Carmi loam	>6 feet	Severe: poor filter
ClB-ClC	Coloma loamy sand	>6 feet	Severe: poor filter
CrA-CrB	Crosier loam	1 to 3 feet	Severe: percs slowly, wetness

Soil Unit	Soil Name	Depth to High Water Table	Restrictive Features
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
Go	Gravelton loamy sand	+1 to 1 feet	Severe: flooding, ponding,
Gr	Gravelton-Palms complex	+1 to 1 feet	Severe: flooding, ponding,
GtA	Griswold loam	>6 feet	Slight
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,
KoA-KoC	Kosciusko sandy loam	>6 feet	Severe: poor filter
KoE	Kosciusko sandy loam	>6 feet	Severe: poor filter, slope
KtA	Kosciusko silt loam	>6 feet	Severe: poor filter
KxC3	Kosciusko sandy clay 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-MeC	Metea loamy fine sand	>6 feet	Severe: percs slowly, poor
MlB-MlC	Miami loam	>6 feet	Severe: percs slowly
MrC3	Miami clay loam	>6 feet	Severe: percs slowly
MrD3	Miami clay loam	>6 feet	Severe: percs slowly, slope
MsB	Miami-Owosso-Metea complex	>6 feet	Severe: percs slowly
MsD	Miami-Owosso-Metea complex	>6 feet	Severe: percs slowly, slope
MvC	Morley loam	>6 feet	Severe: percs slowly
MxC3	Morley silty clay loam	>6 feet	Severe: percs slowly
MxD3	Morley silty clay loam	>6 feet	Severe: percs slowly, slope
MzB	Morely-Glynwood complex	>6 feet	Severe: percs slowly
OrA-OrC	Ormas loamy sand	>6 feet	Severe: poor filter
OtA-OtC	Ormas loamy sand, sandy substratum	>6 feet	Severe: poor filter
Pa; Pb	Palms muck, drained	+1 to 1 feet	Severe: subsides, ponding
Pe	Pewamo silty clay loam	+1 to 1 feet	Severe: percs slowly, ponding
Pg	Pits, gravel	--	--
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
RlD	Riddles fine sandy loam	>6 feet	Severe: slope
RxB	Riddles-Ormas-Kosciusko complex	>6 feet	Moderate: percs slowly;
RxC	Riddles-Ormas-Kosciusko complex	>6 feet	Moderate: percs slowly, slope;
Sa	Saranac clay loam	+0.5 to 1 feet	Severe: flooding, ponding,
Se	Sebewa loam	+1 to 1 feet	Severe: poor filter, ponding
Sf	Sebewa mucky loam	+1 to 1 feet	Severe: poor filter, ponding
ShA-ShB	Shipshe sandy loam	>6 feet	Severe: poor filter

Soil Unit	Soil Name	Depth to High Water Table	Restrictive Features
Sn	Shoals loam	1 to 3 feet	Severe: flooding, wetness
To	Toledo silty clay	+1 to 1 feet	Severe: ponding, percs slowly
Ud	Udorthents, loamy	--	--
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

Palestine Lake
While all septic system use in the Palestine Lake watershed has the potential to impact the water quality of the lake, the ability of the soil immediately adjacent to Palestine Lake to treat septic effluent has a more direct effect on Palestine Lake's water quality. Therefore the following discussion focuses on the soils adjacent to Palestine Lake. Figure 9 shows the soil units surrounding Palestine Lake. Following Table 5 provides a short description of the soils listed in the table.

Poor filtering capacity limits Boyer loamy sand (BoB-BoC) and Metea loamy sand (MbC) soils for use as septic tank adsorption fields. Groundwater well contamination can result from the use of these soils for on-site wastewater treatment.

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. This soil unit occurs primarily in the wetlands covering the northeast and southeast corners of the lake.

Rapid permeability impairs ability of the Kosciusko sandy loam soils found adjacent to Palestine Lake to serve as septic absorption fields. Kosciusko sandy loam (KoB-KoC) soils are well-drained soils. Permeability is moderate in the subsoil and very rapid 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 of the groundwater.

Martinsville sandy loam (MaB-MaC) soils are slightly limited for usage in treating septic adsorption fields. These moderately permeable soils are often found on the edges of outwash plains and terraces.

Riddles fine sandy loam (RlC) and Wawasee fine sandy loam (WlC2) soils are well-drained soils with moderately slow permeability. These soils have moderate permeability, which makes them moderately limited as a site for septic tank absorption fields. Enlarged septic fields built within this soil type will better absorb effluent.

The suitability of Udorthents (Uf) for septic tanks varies among locales. Udorthents are moderate to strongly sloping, well-drained soils typically found in disturbed areas. Septic suitability limitations can include restricted permeability, wetness, and steep slopes.

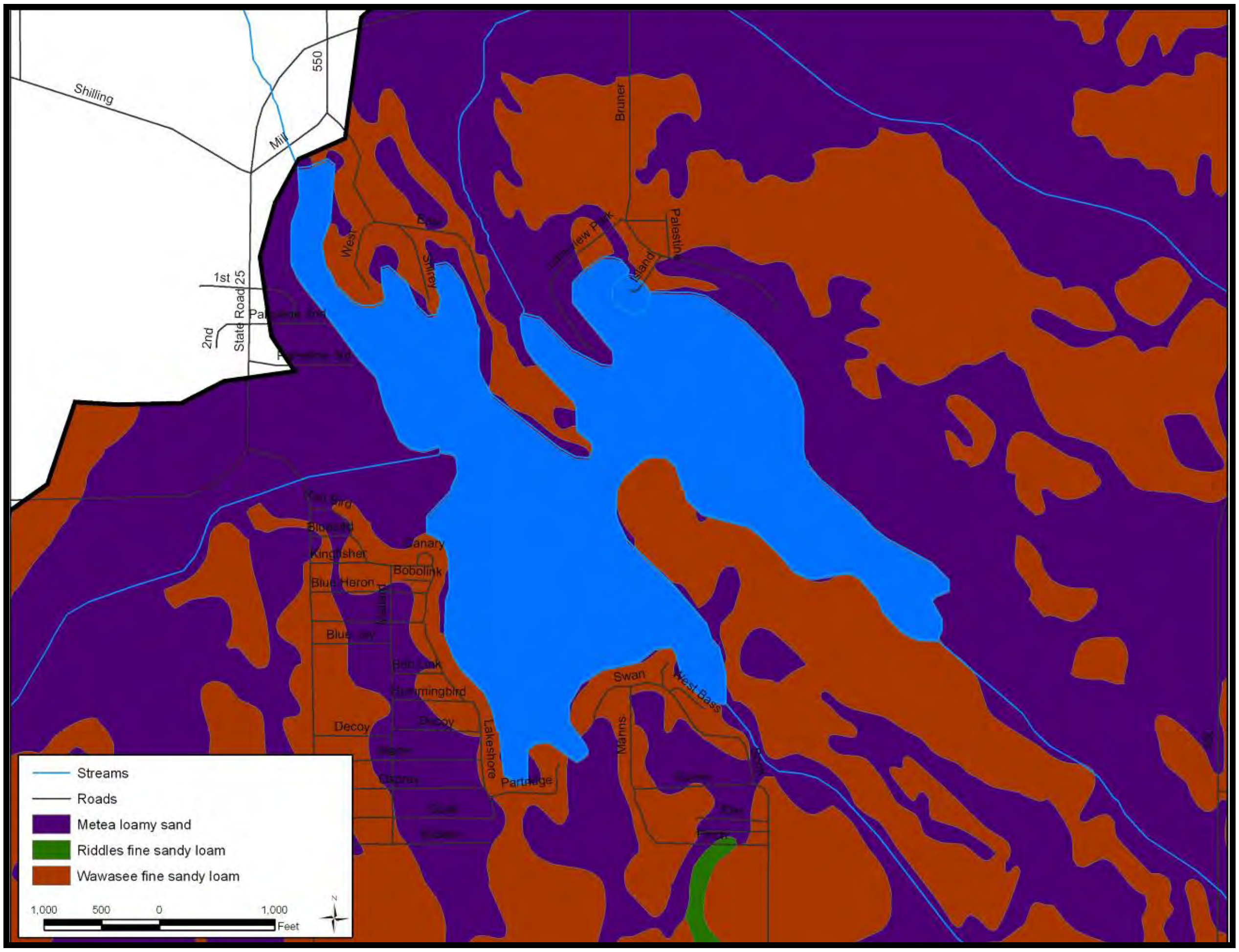

Figure 9. Soil series bordering Palestine Lake.

As shown in Table 6, all of the soils surrounding Palestine Lake, except Riddles fine sandy loam (RlC) and Wawasee fine sandy loam (WlC2) soils, are severely limited in their use as a septic tank absorption field. Even the Riddles and Wawasee fine sandy loam soils are moderately limited in their 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, the county zoning department, and developers 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.

Caldwell Lake

Just as septic system use adjacent to Palestine Lake provides high potential impact to the water quality of Palestine Lake, the ability of the soil immediately adjacent to Caldwell Lake to treat septic effluent has a direct effect on Caldwell Lake's water quality. Therefore the following discussion focuses on the soils adjacent to Caldwell Lake. Figure 10 shows the soil units surrounding Caldwell Lake. Following Figure 10 is a short description of the soils listed in the table.

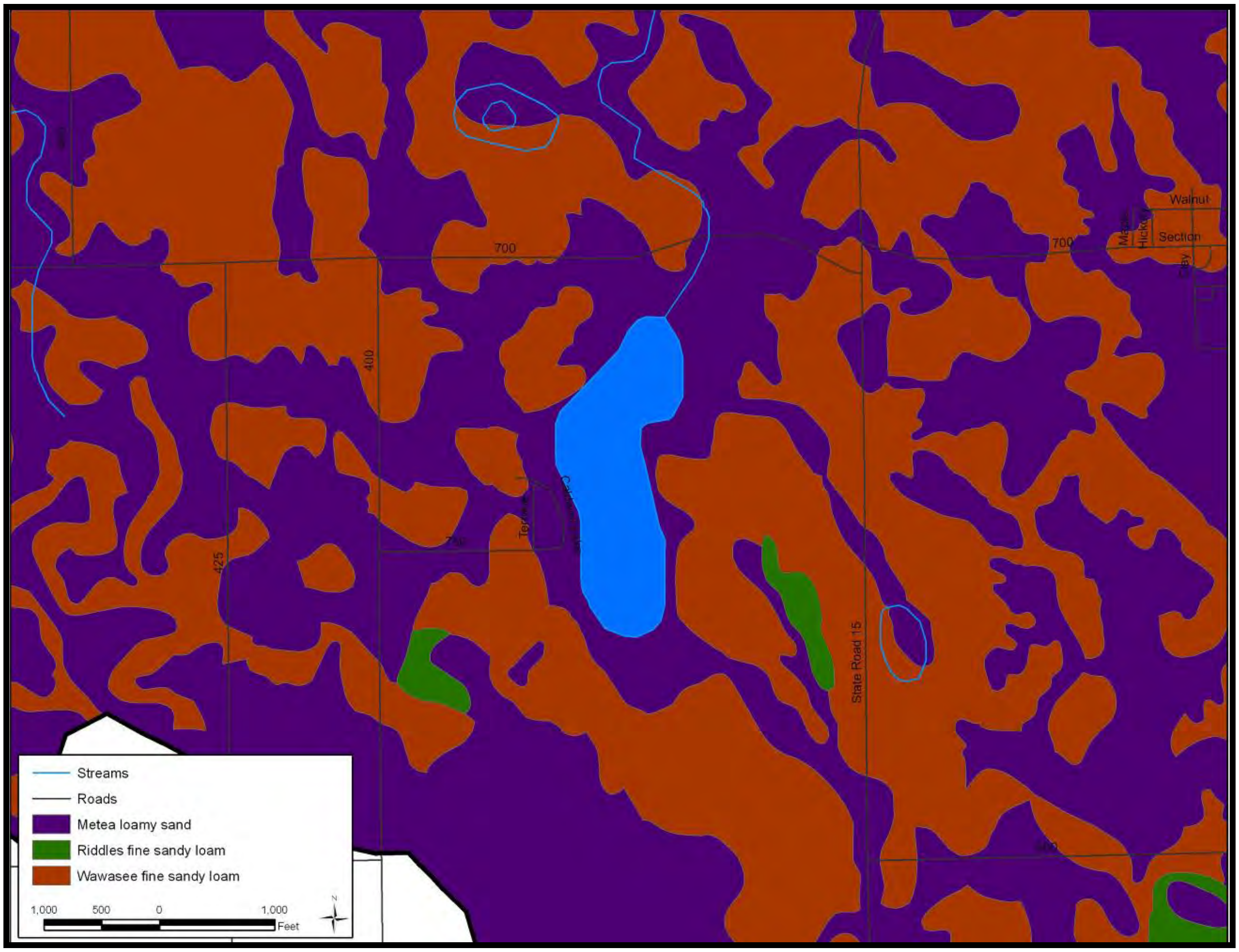

Figure 10. Soil series bordering Caldwell Lake.

Ponding limits the use of Barry loam (Bc) soils for on-site wastewater treatment. These soils border much of the undeveloped, eastern shoreline of Caldwell Lake. If this area is developed in the future, special effort must be made to ensure that adequate septic treatment occurs for these dwellings.

Edwards muck (Ed) 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. Staley (1989) 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.

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. This soil unit occurs primarily in the wetlands covering the northeast and southeast corners of the lake.

The suitability of Udorthents (Uf) for septic tanks varies among locales. Udorthents are moderate to strongly sloping, well-drained soils typically found in disturbed areas. Septic suitability limitations can include restricted permeability, wetness, and steep slopes. As these soils cover the entire western shoreline of Caldwell Lake, residents should take care in maintaining their septic systems to ensure adequate treatment of effluent.

Washtenaw silt loam (Wc) soils are limited for on-site sanitary facilities for many of the same reasons already discussed. The soil tends to occupy low-lying areas and tends to be ponded with runoff following rain events. Additionally, slow permeability may limit the proper treatment of liquid waste.

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 Palestine Lake watershed lies within Homoya's Northern Lakes Natural Region. Similarly, the Palestine Lake 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 Palestine Lake 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 Palestine Lake watershed likely consisted of components of neighboring natural areas and ecoregions in addition to components characteristic of the natural area and ecoregion in which it is mapped.

Homoya et al. (1985) noted that prior to European settlement, the region was a mixture of numerous natural community types, including bog, fen, marsh, prairie, sedge meadow, swamp, seep spring, lake, and deciduous forest. The dry to dry-mesic uplands were likely forested with red oak, white oak, black oak, shagbark hickory, and pignut hickory. More mesic areas probably harbored beech, sugar maple, black maple, and tulip poplar. 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 Palestine Lake 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 Palestine Lake watershed. The hydric soils map and an 1876 map of Kosciusko

County indicate that wetland habitat existed throughout the Palestine Lake watershed including areas south and west of Palestine Lake and surrounding much of Caldwell Lake. These wet habitats supported very different vegetative communities than the drier portions of the landscape (Homoya et. al, 1985). Sycamore, American elm, red elm, green ash, silver maple, red maple, cottonwood, hackberry, and honey locust likely dominated the floodplain forests. Swamp communities bordering lakes typically consisted of red maple, silver maple, green ash, American elm, black ash, and yellow birch. Marshes associated with lake communities typically contained swamp loosestrife, cattails, bulrush, marsh fern, marsh cinquefoil, and sedges. Aquatic species within the lake 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. Different land uses have the potential to contribute different amounts of nutrients, sediment, and toxins to receiving water bodies. For example, Reckhow and Simpson (1980) compiled phosphorus export coefficients (amount of phosphorus lost per unit of land area) for various land uses by examining the rate at which phosphorus loss occurred on various types of land. (The Phosphorus Modeling Section of the report contains more detailed information on this work and its impact on Palestine and Caldwell lakes and their watershed.) Several researchers have also examined the impact of specific urban and suburban land uses on water quality (Bannerman et. al, 1992; Steuer et al., 1997; Waschbusch et al., 2000). Bannerman et al. (1992) and Steuer et al. (1997) found high mean phosphorus concentrations in runoff from residential lawns (2.33 to 2.67 mg/L) and residential streets (0.14 to 1.31 mg/L). These concentrations are well above the threshold at which lakes might begin to experience algal blooms. (Lakes with total phosphorus concentrations greater than 0.03 mg/L will likely experience algal blooms.) Finally, the Center for Watershed Protection has estimated the association of increased levels of impervious surface in a watershed with increased delivery of phosphorus to receiving waterbodies (Caraco and Brown, 2001). Land use directly affects the amount of impervious surface in a watershed. Because of the effect watershed land use has on water quality of the receiving lakes, mapping and understanding a watershed's land use is critical in directing water quality improvement efforts.

2.6.1 Palestine Lake Watershed

Figure 11 and Table 7 present current land use information for the Palestine Lake watershed. (Land use data from the U.S. Geological Survey (USGS) form the basis of Figure 11.) Like many Indiana watersheds, agricultural land use dominates the Palestine Lake watershed, accounting for approximately 84% of the watershed. Row crop agriculture comprises the greatest percentage of agricultural land use at 68%, while pasture land or hay vegetate another 16%. Land uses other than agriculture account for the remaining 16% of the watershed. Natural landscapes, including forests and wetland, cover approximately 13% of the watershed. Most of the natural acreage in the watershed is associated with forested and emergent and woody wetland area southeast of Palestine Lake, forest along Williamson Ditch, and emergent wetland and forest adjacent to Caldwell Lake. Additional smaller tracts are located near the headwaters or adjacent to many of the watershed's streams. These natural areas consist of small tracts of wooded or emergent wetlands or deciduous forest, and are scattered throughout the watershed. Open water, including Palestine and Caldwell lakes and several small ponds, accounts for another 1.5% of the watershed. Most of the remaining 1.5% of the watershed is occupied by low intensity residential land, with less than 1% of the entire watershed classified as high intensity residential or commercial land uses. Impervious surface coverage was calculated by using adapted impervious values for selected land used in Lee and Toonkel (2003), but does not include road surfaces. Impervious surfaces cover approximately 1.8% of the watershed. This estimate of impervious surface coverage is below the threshold at which the Center for Watershed Protection has found an associated decline in water quality. The land uses contributing to the impervious surface coverage in the Palestine Lake watershed are agricultural (1.7%) and residential (0.1%).

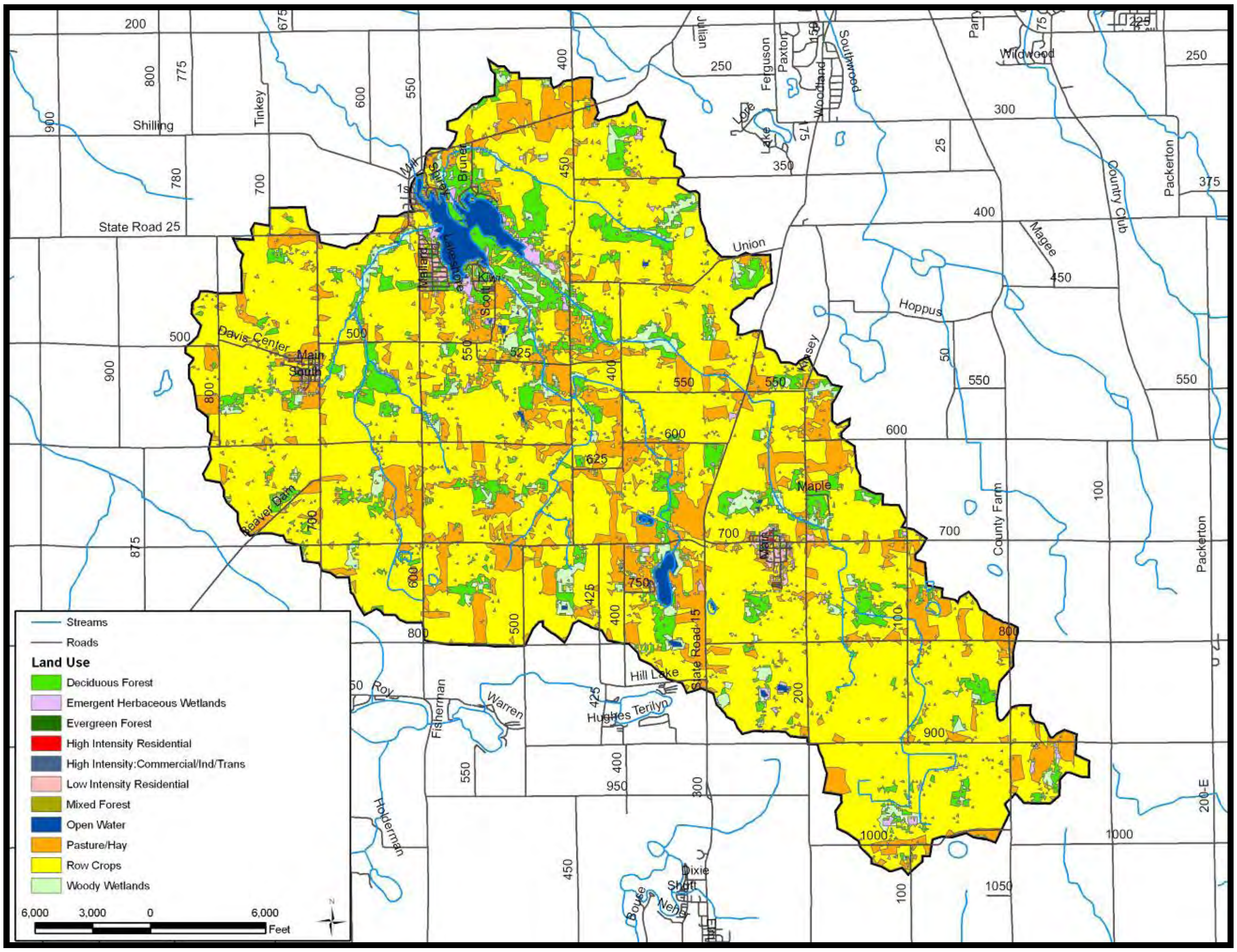

Figure 11. Land use in the Palestine Lake watershed.

Table 7. Detailed land use in the Palestine Lake watershed.

Land Use	Area (acres)	Area (hectares)	% of Watershed
Row Crops	14,118.2	5,713.6	68.3%
Pasture/Hay	3,373.1	1,365.1	16.3%
Deciduous Forest	1,842.1	745.5	8.9%
Woody Wetlands	745.2	301.6	3.6%
Open Water	318.4	128.9	1.5%
Low Intensity Residential	126.9	51.4	0.6%
Emergent Herbaceous Wetlands	137.5	55.6	0.7%
Evergreen Forest	1.9	0.8	<0.1%
High Intensity Commercial	8.7	3.5	<0.1%
High Intensity Residential	7.5	3.0	<0.1%
Mixed Forest	0.7	0.3	<0.1%
	20,680.2	**8,369.2**	**100%**

Agricultural Land Uses

Most of the agricultural land in the Palestine Lake 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 Palestine Lake 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 (IDNR, 2004b). 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 (IDNR, 2004a). 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.

The Palestine Lake watershed is also home to a number of animal operations. Six of these operations qualify as Concentrated Animal Feeding Operations (CAFO) or as Confined Feeding Operations (CFO). Three of the operations qualify as large size farms as determined by the IDEM, while two qualify as medium size and one is rated as a small CAFO. These two types of operations are defined as follows:

- CFO (Confined Feeding Operation) is any animal feeding operation engaged in the confined feeding of a minimum of 300 cattle, 600 swine or sheep, or 30,000 fowl for a minimum of 45 days per year. According to the Indiana Administrative Code (IAC 16), these operations require a permit for operation or expansion.
- CAFO (Concentrated Animal Feeding Operation) is defined as a point source and is any animal feeding operation consisting of 700 mature dairy cows; 1,000 veal calves or cattle other than mature dairy cows; 2,500 swine (>55 pounds); 10,000 swine (<55 pounds), sheep, or lambs; 500 horses; 55,000 turkeys; 30,000 hens or broilers (liquid manures system) or duck (solid manure system); 125,000 broilers (solid manure system); 82,000 hens; or 5,000 ducks (liquid manure system). As defined by the Indiana Administrative Code (327 IAC 15), these areas require a point source permit prior to construction or expansion.

Four of the operations present in the Palestine Lake watershed operate under the CFO requirements, while 2 operations operate as CAFOs (Figure 12). In total, operations for 160,000 chickens, 1,120 veal calves, 1,320 beef cattle, and 5,547 swine are permitted within the Palestine Lake watershed. CFOs and CAFOs must operate within predetermined performance standards. The standards have four main targets: to avoid management practices which discharge pollutants to state's waters; to minimize non-point source pollution to state's waters; to design, construct, and maintain waste management systems to prevent the discharge of manure and other controlled waste; and to stage and apply manure in a manner which prevents nutrient runoff, ponding, or spills and minimizes nutrient leaching beyond the root zone. All six facilities present within the Palestine Lake watershed are meeting their permit requirements. However, the potential for environmental impacts related to these facilities not following their permit requirements should be noted.

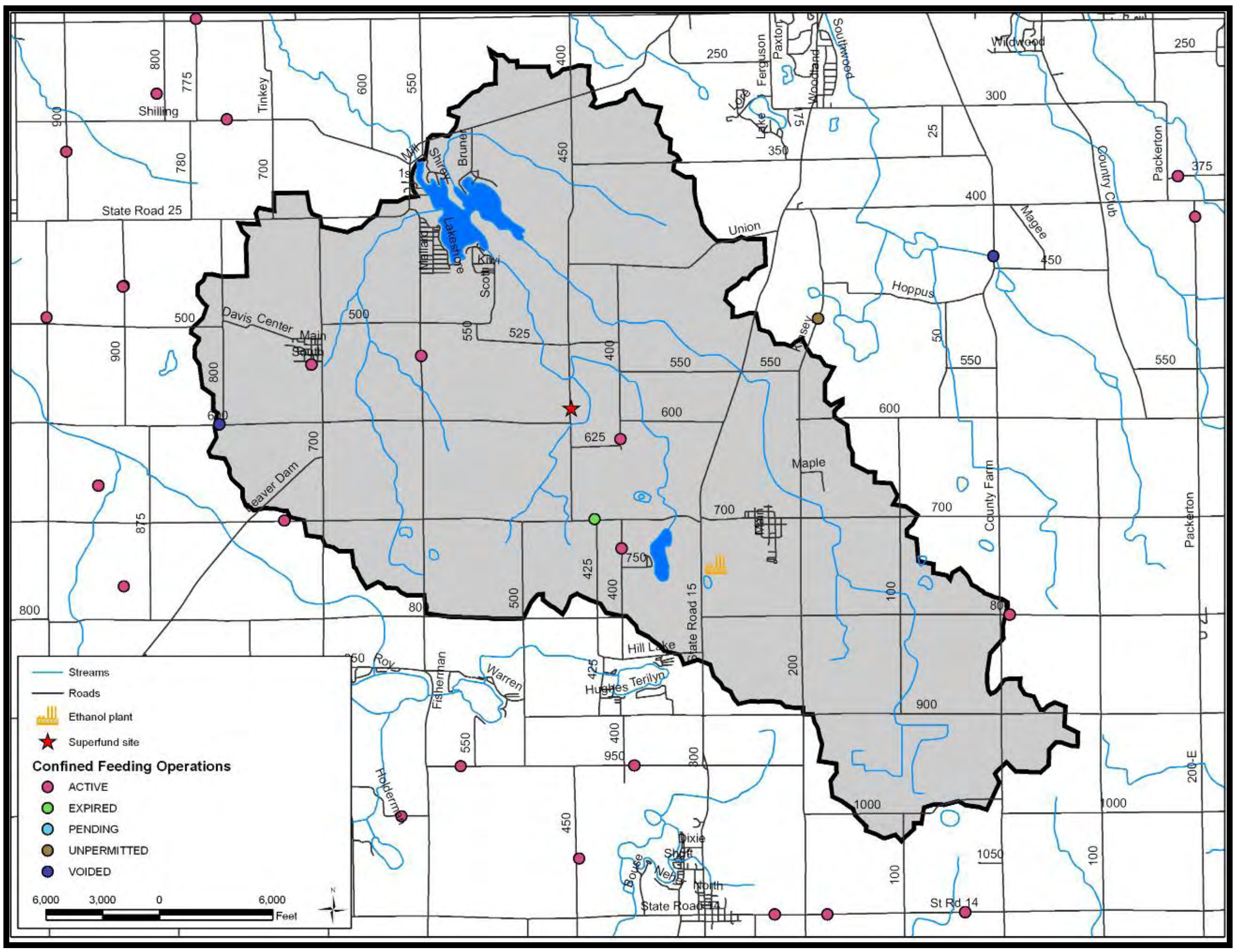

Figure 12. Confined feeding operation (CFO) and residential and commercial development locations within the Palestine Lake watershed.

Residential and Commercial Development

Much of the residential land lies directly adjacent to Palestine Lake or within Palestine, Burket, or Claypool. Nye (1938) describes Palestine as a beloved community, which was surveyed in 1827 on the banks of Trumble's Creek (now known as Trimble Creek). The plat of Palestine originally contained 96 lots with three north-south streets. Nye details the selection for the location of

Palestine, and ultimately the size of Palestine Lake, as being based on finding a point along the creek where fall was sufficient to maintain a head of water capable of supplying water for the grist mill located at the lake's outlet. This mill, which was constructed in 1877, was the first grist mill built in Harrison Township (Kingman Brothers, 1879). The dam was constructed of stone and concrete, which subsequently failed in 1990 (IDNR, no date). During World War II, the mill was converted from hydropower to electric; the mill race and turbine were subsequently dismantled, but the dam structure remains (IDNR, no date).

Much of the industry within the watershed historically centered around the town of Burket. Several industries thrived within Burket, the most well-known of these was Black Oxide, which manufactured zinc, cadmium, steel, zinc oxide steel, and black oxide steel; completed zinc and cadmium electroplating; zinc phosphating; and black oxidizing (Stallsmith, 1984). In the mid-1980s, this plant was cited for releasing large amounts of metals into the effluent's outlet stream, Williamson Ditch. (Impacts of these metals will be addressed in the stream water quality section of the report.) Additionally, waste materials from this facility were deposited within the Lakeland Disposal Service sanitary landfill located 3 miles northwest of Claypool (Figure 12; USEPA, 2007a). This, along with waste from several other facilities, subsequently known as the UAO Group, resulted in the landfill being closed and subsequently declared a Superfund site.

According to the USEPA records, at least 18,000 drums of paint sludge, 8,900 tons of plating sludge, and two million gallons of plating sludge were identified on-site (USEPA, 2007a). Additionally, soils located within the landfill were contaminated with heavy metals. In 1989, the UAO Group signed a consent decree with the USEPA to allow the USEPA to conduct an investigation of site contamination and develop a list of clean-up alternatives. According to the 1993 Record of Decision the following remedies were selected:

- Fencing and security to prevent unauthorized access;
- Deed restriction;
- Removal and disposal of buried waste;
- Construction and maintenance of a landfill cap and slurry wall to prevent stormwater intrusion or groundwater contamination;
- Monitoring program to determine operation efficiency;
- And wetland restoration or replacement for those wetland effected by waste (USEPA, 2007b).

Construction for these activities was completed in 2002 and the final inspection was conducted in 2004. Figure 13 depicts the site as it appears today. As of its last inspection, which occurred in August 2005, the site meets all requirements and operates within operation and maintenance standards established by the USEPA (USEPA, 2005).

Figure 13. Former superfund site located within the Palestine Lake watershed.

Another large industrial land use development recently occurred within the Palestine Lake watershed. Louis Dreyfus recently completed construction at the Claypool biodiesel plant south of Claypool adjacent to State Road 15 (Figures 12 and 14). The plant is slated to process approximately 260,000 metric tons of soybean oil from the on-site soybean processing plant to create biodiesel (Smith, 2006). The remnant protein-rich soybean meal will be used by the livestock and poultry industry off-site. The biodiesel plant will produce up to 250,000 gallons of biodiesel per day or up to 80 million gallons of biodiesel per year (Dick, 2006). This will be the largest biodiesel plant in the world (Alexander, 2006); the official opening of the plant occurred in August 2007, and processing of the 2007 soybean crop will begin early in 2008.

Figure 14. Claypool biodiesel plant during construction, May 2007.

2.6.2 Caldwell Lake Watershed

Figure 15 and Table 8 present current land use information for the Caldwell Lake watershed. Like the larger Palestine Lake watershed, agricultural land use dominates the Caldwell Lake watershed, accounting for approximately 81% of the watershed. Row crop agriculture makes up the greatest percentage of agricultural land use at 59%, while pastures or hay vegetate another 22%. Land uses other than agriculture account for the remaining 19% of the watershed. Natural landscapes, including forests and wetland, cover approximately 13% of the watershed. Most of the natural acreage in the watershed is associated with forested and emergent and woody wetland area adjacent to Caldwell Lake. Additional smaller tracts are located near the headwaters. Open water, Caldwell lakes and several small ponds, accounts for another 4% of the watershed. Most of the remaining 0.7% of the watershed is occupied by low intensity residential land, with less than 0.1% of high intensity residential or commercial land.

Table 8. Detailed land use in the Caldwell Lake watershed.

Land Use	Area (acres)	Area (hectares)	% of Watershed
Row Crops	853.4	345.7	59.3%
Pasture/Hay	312.6	126.6	21.7%
Deciduous Forest	111.7	45.2	7.8%
Woody Wetlands	80.6	32.6	5.6%
Open Water	57.6	23.3	4.0%
Emergent Herbaceous Wetlands	12.3	5.1	0.9%
Low Intensity Residential	9.5	3.8	0.7%
High Intensity Commercial	0.2	0.1	<0.1%
Mixed Forest	0.2	0.1	<0.1%
	1,438.1	**582.5**	**100.0%**

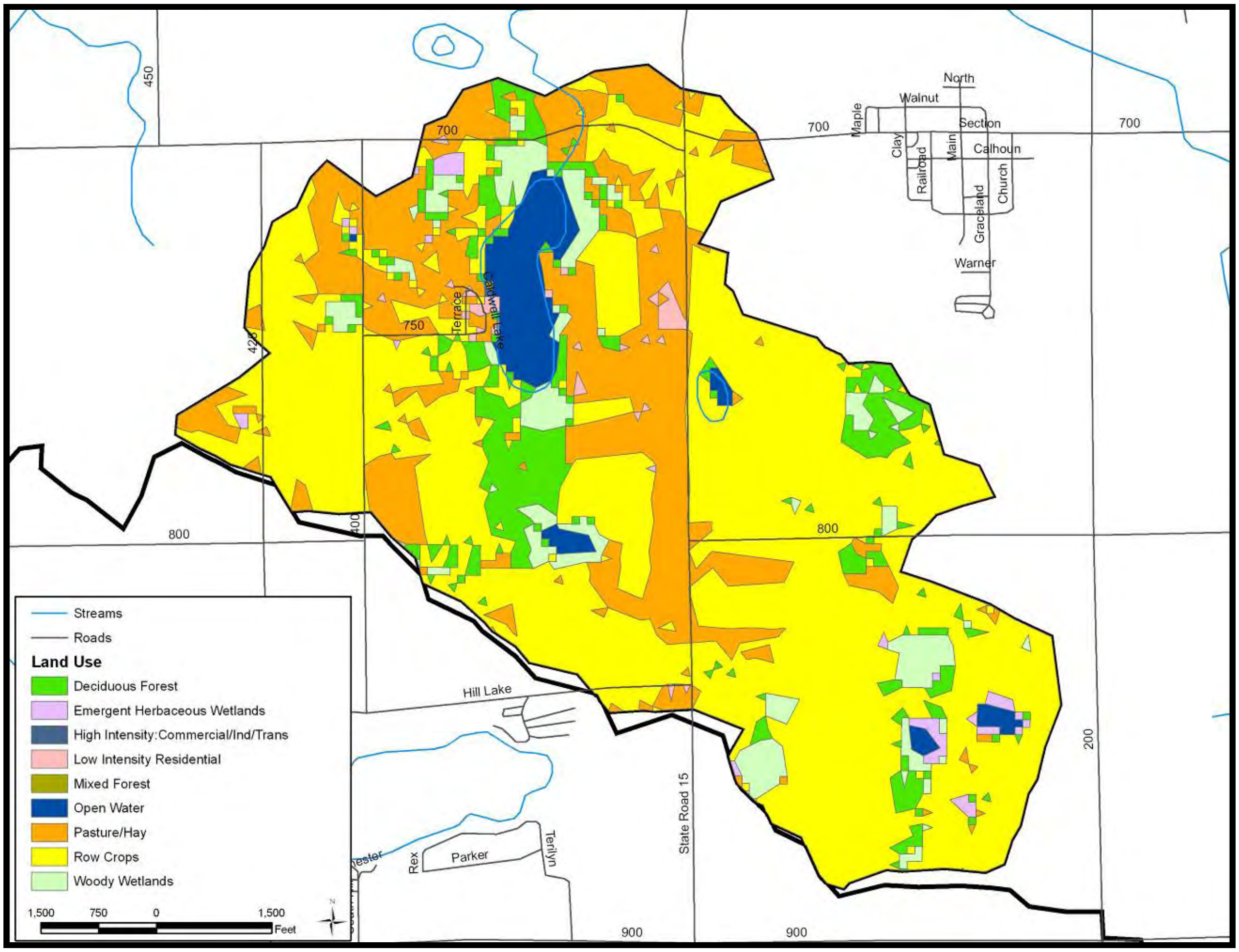

Figure 15. Land use in the Caldwell Lake watershed.

Impervious surface coverage was calculated by using adapted impervious values for selected land used in Lee and Toonkel (2003), but does not include road surfaces. Impervious surfaces cover approximately 1.7% of the watershed. This estimate of impervious surface coverage is below the threshold at which the Center for Watershed Protection has found an associated decline in water quality. The land uses contributing to the impervious surface coverage in the Caldwell Lake watershed are agricultural (1.6%) and residential (0.1%).

2.7 <u>Wetlands</u>

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 16) shows that wetlands cover approximately 10% of the Palestine Lake watershed. (Table 9 presents the acreage of wetlands by type according to the National Wetland Inventory.) Forested

(4.5%), scrub-shrub (0.5%), and herbaceous (3.2%) wetlands cover approximately 8.7% of the watershed. The largest contiguous tracts of wetland habitat lie in the southeast of Palestine Lake, north and east of Caldwell Lake, and adjacent to the watershed's streams. Palestine and Caldwell lakes and several ponds account for the remaining wetland acreage (1.5%).

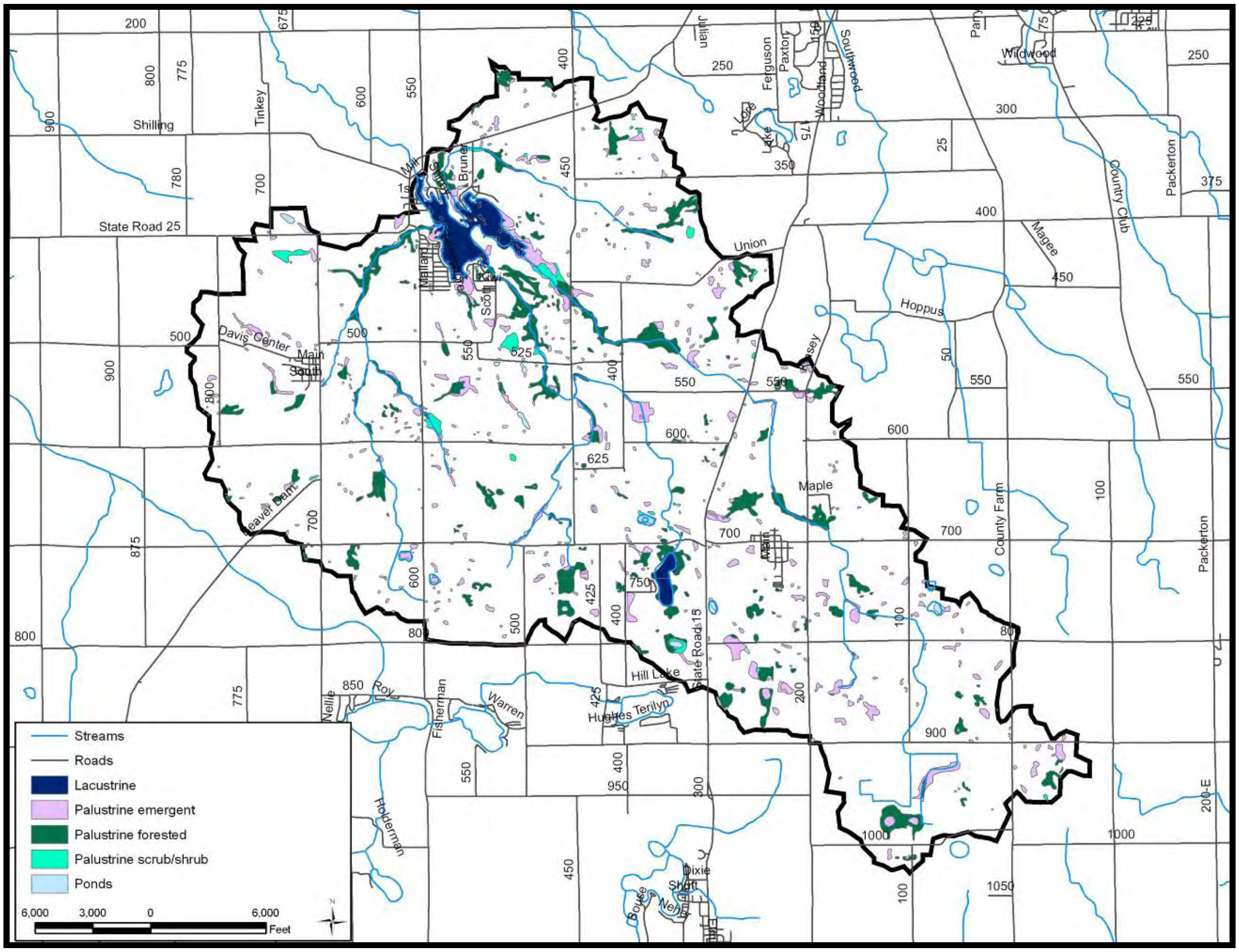

Figure 16. National wetland inventory wetlands in the Palestine Lake watershed.

Table 9. Acreage and classification of wetland habitat in the Palestine Lake watershed.

Wetland Type	Area (acres)	Area (hectares)	Percent of Watershed
Palustrine forested	940.6	380.8	4.5%
Palustrine emergent	646.8	261.8	3.1%
Lacustrine	279.8	113.3	1.4%
Palustrine scrub/shrub	102.8	41.6	0.5%
Ponds	26.1	10.6	0.1%
Wetland Total	**1,996.2**	**808.2**	**9.7%**

Source: National Wetlands Inventory.

The USFWS NWI data differ in their estimate of wetland habitat acreage in the watershed from the USGS data presented in Table 10 and Figure 17. The USGS Land Cover Data Set suggests that wetlands cover approximately 4.5% of the Palestine Lake watershed and open water covers an additional 1.6% of the watershed (Table 9). The primary difference between the two data sets is the acreage of emergent wetland. The USFWS reports nearly 650 acres of emergent wetland habitat exists in the Palestine Lake watershed compared to slightly more than 137 acres of emergent wetland habitat reported by the USGS. Additionally, the USFWS reports nearly 1,043 acres of shrub-scrub and forested wetlands, while the USGS reports only 745 acres of woody wetland. The differences in reported wetland acreage in the Palestine Lake watershed reflect the differences in project goals and methodology used by the different agencies to collect land use data.

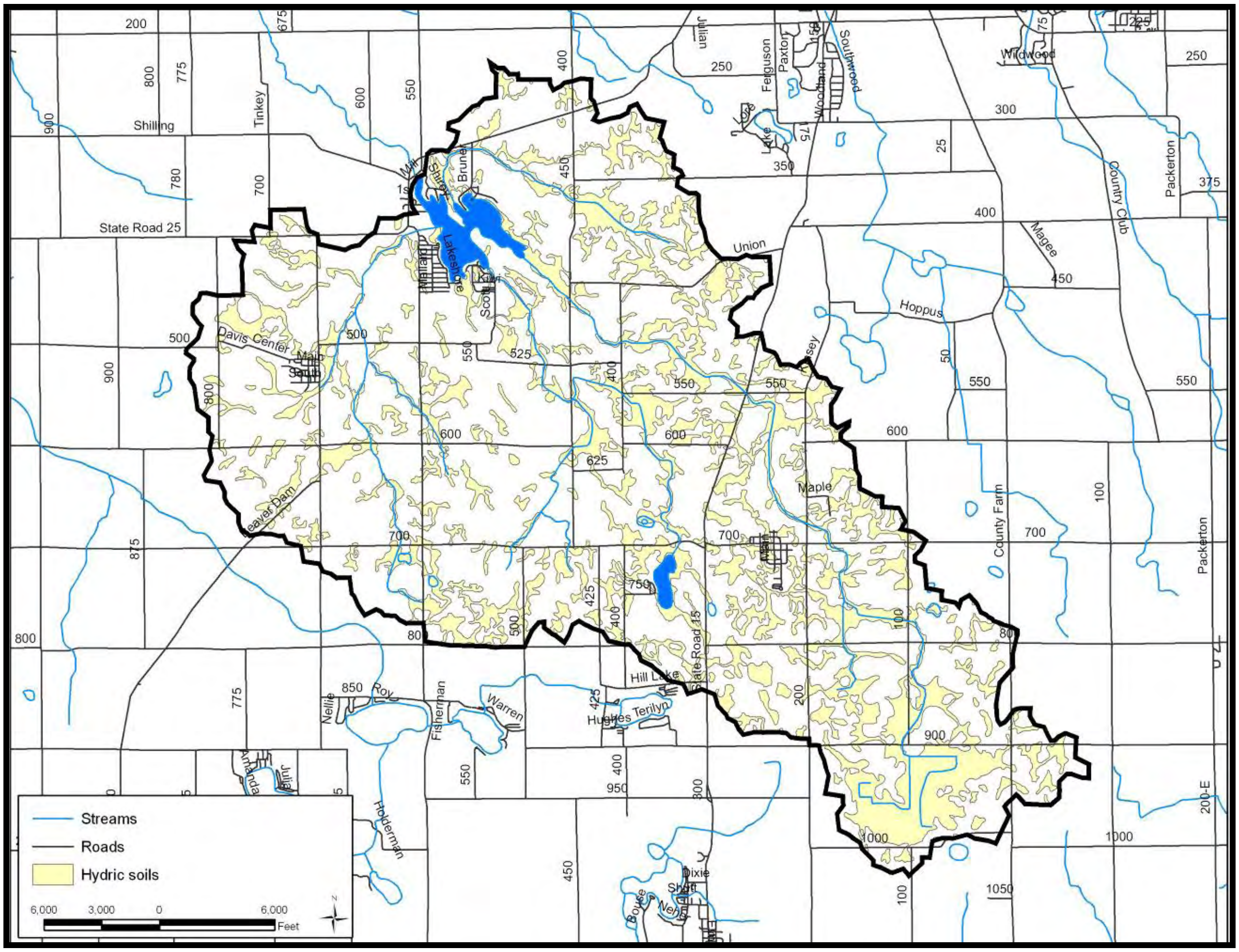

Figure 17. Hydric soils in the Palestine Lake watershed.

The U.S. Fish and Wildlife Service estimates an average of 2.6% of the nation's wetlands were lost annually from 1986 to 1997 (Zinn and Copeland, 2005). The IDNR estimates that approximately 85% of the state's wetlands have been filled (IDNR, 1996). The greatest loss has occurred in the northern counties of the state such as 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 (cited in Hudak, 1995). Shoreline development around lakes has also significantly reduced wetland acreage.

Development within the Palestine Lake watershed has undoubtedly reduced wetland acreage in the watershed as well. Hydric soils, which form under anaerobic and saturated conditions, cover nearly the entire headwaters of Ring Ditch, border the southern and eastern shorelines of Palestine Lake and nearly the entire shoreline of Caldwell Lake, and are dotted throughout the watershed (Figure 17). Areas mapped in the wettest of hydric soils, such as Houghton muck, Rensselaer loam, and Wallkill silt loam, have largely remained undeveloped. Overall, hydric soils cover approximately 5,222 acres (2,113 ha or 26%) of the Palestine Lake watershed. When compared to the acreage of wetland mapped by the USFWS NWI map (2025 acres or 820 ha), nearly 40% of wetlands remain in the Palestine Lake watershed.

2.8 <u>Natural Communities and Endangered, Threatened, and Rare Species</u>

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 federally listed endangered, threatened, and rare species are known to exist in the watershed. One state rare insect and one state rare freshwater mussel and one freshwater mussel of special concern inhabit the Palestine Lake watershed. Appendix B provides a listing of endangered, threatened, and rare species (ETR) documented in Kosciusko County. 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 three records for the area included within the Palestine Lake watershed. The ETR species identified within the watershed include two freshwater mollusks and an insect. The state rare insect (the Checkerspot butterfly) was last sighted near the southwest corner of Palestine Lake (Township 31 North, Range 5 East, Section 2). The two freshwater mussels were identified during a survey of the entire Tippecanoe River basin which was conducted in 1992. These mussels (slippershell mussel and the purple lilliput) were identified in the western basin of Palestine Lake (Township 31 North, Range 5 East, Section 2.) The purple lilliput is considered a species of special concern.

No other records exist for the Palestine Lake 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.

3.0 STREAM ASSESSMENT

3.1 Stream Assessment Introduction

To better understand the transport of nutrients and other pollutants to Palestine Lake from its watershed, this study included an evaluation of the water quality in each of Palestine Lake's four main tributaries: Williamson Ditch, Sloan-Adams Ditch, Magee-Robbins Ditch, and Ring Ditch. Additional sample sites occurred along each of the tributaries these four streams. The water quality evaluation consisted of the collection of water samples, assessment of instream habitat, and determination of macroinvertebrate communities within the streams. These samples were analyzed for an array of physical and chemical parameters and results of the analysis were compared to historical data, state standards (if available), and other known measures of stream water quality.

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

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

To provide a complete assessment of water quality within the inlet stream, the study included the collection of water chemistry and biological (macroinvertebrate) samples. Water quality samples were collected twice, once during base flow or normal conditions and once following a storm event, at the location indicated in Figure 18. The biological community of the streams were sampled during base flow conditions as required by standard protocol. Sampling occurred in mid-summer to avoid the May and October macroinvertebrate diversity peaks. The in-stream and riparian habitat along all stream reaches was also evaluated to help in isolating which factors are responsible for shaping the creek's biotic communities. The following section outlines the stream sampling methods in greater detail.

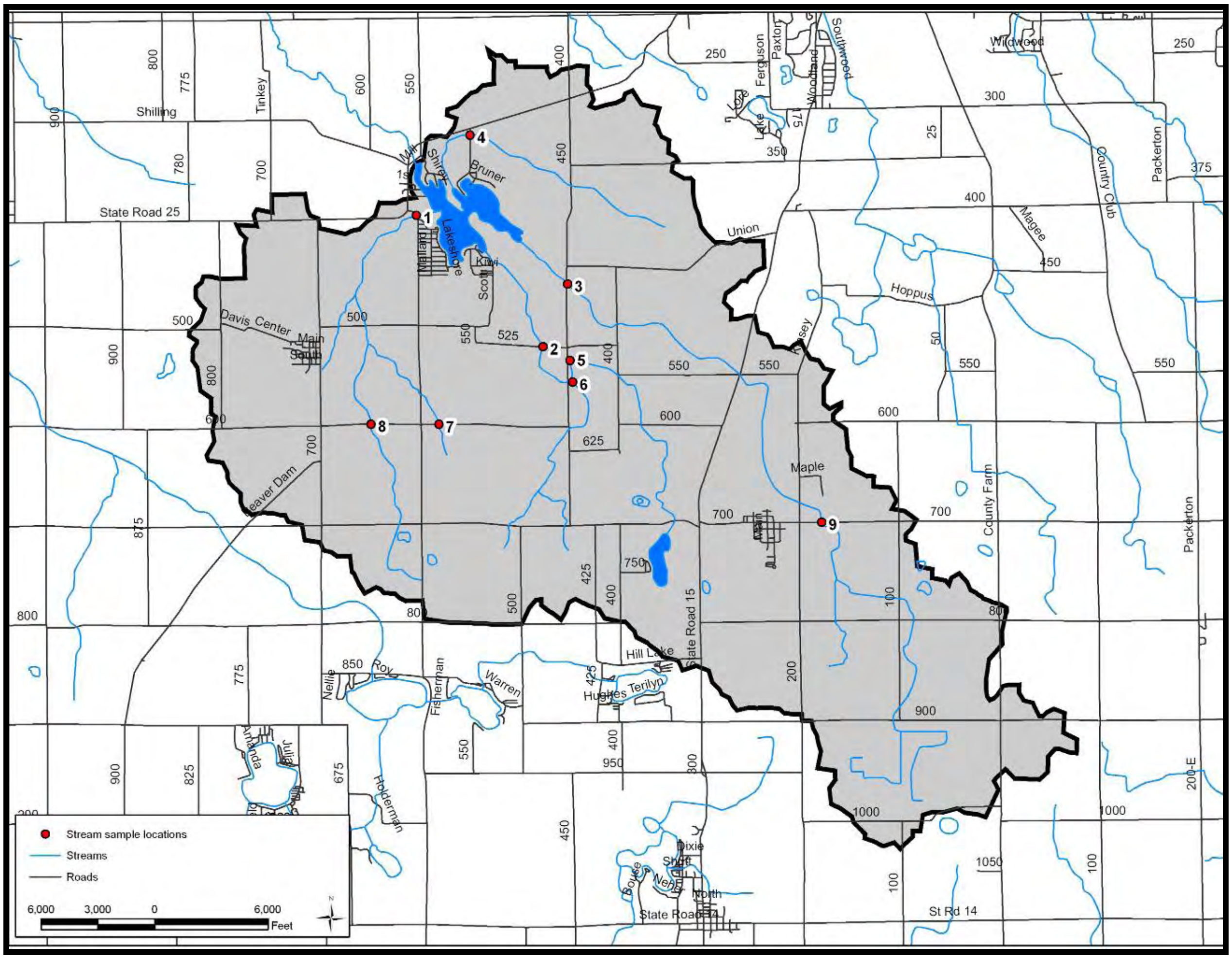

Figure 18. Stream sampling locations in the Palestine Lake watershed.

3.2 <u>Stream Assessment Methods</u>

3.2.1 Water Chemistry

Water samples were collected and analyzed for various parameters from the nine sample sites within the Palestine Lake watershed (Table 10 and Figure 18). The LARE sampling protocol requires assessing the 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 landscape and usually contains higher concentrations of soil and soil-associated nutrients. A base flow sample represents the 'usual' water characteristics of the stream. Storm flow samples were collected on May 29, 2007, following more than 1 inch (2.5 cm) of rain. Base flow samples were collected on June 19, 2007 following a period of little precipitation.

Table 10. Location of stream sampling sites in the Palestine Lake watershed.

Site	Stream Name	Sampling Location	Latitude	Longitude
1	Williamson Ditch	County Road 600 West	N41° 10.499'	W85° 56.899'
2	Sloan-Adams Ditch	Scott Road	N41° 9.346'	W85° 55.421'
3	Ring Ditch	County Road 450 West	N41° 9.918'	W85° 55.140'
4	Magee-Robbins Ditch	Bruner Road	N41° 11.221'	W85° 56.264'
5	Adams Ditch	County Road 450 West	N41° 9.213'	W85° 55.123'
6	Sloan Ditch	County Road 450 West	N41° 9.051'	W85° 55.127'
7	Kuhn Ditch	County Road 600 South	N41° 8.668'	W85° 57.603'
8	Merritt Ditch	County Road 600 South	N41° 8.666'	W85° 57.401'
9	Trimble Creek	County Road 700 South	N41° 7.818'	W85° 52.212'

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

All water samples were placed in the appropriate bottle (with preservative if needed) and stored in an ice chest until analysis at Indiana University School of Public and Environmental Affair's (SPEA) laboratory in Bloomington. Soluble reactive phosphorus samples were filtered in the field through a Whatman GF-C filter. The *E. coli* bacteria samples were taken to 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*, 20th Edition (APHA, 1998).

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

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

Dissolved Oxygen (DO). DO is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3 to 5 mg/L of DO. Coldwater fish such as trout generally require higher concentrations of DO than warmwater fish such as bass or bluegill. The Indiana Administrative Code (IAC) sets minimum DO concentrations at 4 mg/L, but all waters must have a daily average of 5 mg/L. DO enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algae growth can over-saturate (greater than 100% saturation) the water with DO. Conversely, dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

Conductivity. Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions: on their total concentration, mobility, and valence (APHA, 1998). During low discharge, conductivity is higher than during high discharge because the water moves more slowly across or through ion containing soils and substrates during base flow. Carbonates and other charged particles (ions) dissolve into the slow-moving water, thereby increasing conductivity measurements.

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

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

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

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

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

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

Researchers have recommended various thresholds and criteria for nutrients in streams. The USEPA's recommended targets for nutrient levels in streams are fairly low. The agency recommends a target total phosphorus concentration of 0.076 mg/L in streams (USEPA, 2000b). Dodd et al. (1998) suggest the dividing line between moderately (mesotrophic) and highly (eutrophic) productive streams is a total phosphorus concentration of 0.07 mg/L. The Ohio EPA recommended a total phosphorus concentration of 0.08 mg/L in headwater streams to protect the streams' aquatic biotic integrity (Ohio EPA, 1999). (This criterion is for Ohio streams classified as Warmwater Habitat, or WWH, meaning the stream is capable of supporting a healthy, diverse warmwater fauna. Ohio streams that cannot support a healthy, diverse community of warmwater fauna due to "irretrievable, extensive, man-induced modification" are classified as Modified Warmwater Habitat (MWH) streams and have a different criterion.) While the entire length of streams within the Palestine Lake watershed may not fit the WWH definition for Ohio streams, 0.08 to 0.1 mg/L is a good goal for the stream.

The USEPA sets aggressive nitrogen criteria recommendations for streams compared to the Ohio EPA. The USEPA's recommended criteria for nitrate-nitrogen and total Kjeldahl nitrogen concentrations for streams in Aggregate Nutrient Ecoregion VII are 0.633 mg/L and 0.591 mg/L, respectively (USEPA, 2000b). In contrast, the Ohio EPA suggests using nitrate-nitrogen criteria of 1.0 mg/L in WWH wadeable and headwater streams and MWH headwater streams to protect aquatic life. Dodd et al. (1998) suggests the dividing line between moderately and highly productive streams using nitrate-nitrogen concentrations is approximately 1.5 mg/L.

It is important to remember that none of the threshold or recommended concentrations listed above are state standards for water quality. They are presented here to provide a frame of reference for the concentrations found in streams in the Palestine Lake watershed. The IAC sets only nitrate-nitrogen and ammonia-nitrogen standards for waterbodies in Indiana. The Indiana Administrative Code requires that drinking water source waters of the state have a nitrate-nitrogen concentration of less than 10 mg/L, which is the drinking water standard for the state. IDEM also uses this concentration as a decision-base for water quality impairment of all Indiana waters. The IAC standard for ammonia-nitrogen depends upon the water's pH and temperature, since both can affect ammonia-nitrogen's toxicity. The 2008 303(d) list of impaired waterbodies listing criteria indicates that the IDEM will include waterbodies with total phosphorus concentrations greater than 0.3 mg/L on Indiana's list of impaired waterbodies (IDEM, 2007). Inclusion on Indiana's list of impaired waterbodies will occur only if the stream reach does not meet two or more requirements for dissolved oxygen, pH, total phosphorus, and/or nitrogen (nitrate+nitrite).

Turbidity. Turbidity (measured in Nephelometric Turbidity Units) is a measure of particles suspended in the water itself. It is generally related to suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. According to the Hoosier Riverwatch, the average turbidity of an Indiana stream is 11 NTU with a typical range of 4.5 to 17.5 NTU (Crighton and Hosier, 2004). Turbidity measurements >20 NTU have been found to cause undesirable changes in aquatic life (Walker, 1978). As part of their effort to make numeric nutrient criteria recommendations, the USEPA set 9.9 NTUs as a target for turbidity in stream ecosystems (USEPA, 2000b).

Total Suspended Solids (TSS). A TSS measurement quantifies all particles suspended and dissolved particles > 0.45 microns in water. Closely related to turbidity, this parameter quantifies sediment particles and other solid compounds typically found in water. In general, the concentration of suspended solids is greater in streams during high flow events due to increased overland flow. The increased overland flow erodes and carries more soil and other particulates to the stream. The sediment in water originates from many sources, but a large portion of sediment entering streams comes from active construction sites or other disturbed areas such as unvegetated stream banks and poorly managed farm fields.

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

***E. coli* Bacteria.** *E. coli* is one member of a group of bacteria that comprise the fecal coliform bacteria and is used as an indicator organism to identify the potential for the presence of pathogenic organisms in a water sample. Pathogenic organisms can present a threat to human health by causing a variety of serious diseases, including infectious hepatitis, typhoid, gastroenteritis, and other gastrointestinal illnesses. *E. coli* can come from the feces of any warm-blooded animal. Wildlife, livestock, and/or domestic animal defecation, manure fertilizers, previously contaminated sediments, and failing or improperly sited septic systems are common sources of the bacteria. The IAC sets the maximum concentration of *E. coli* at 235 colonies/100 mL in any one sample within a 30-day period or a geometric mean of 125 colonies per 100 mL for five samples equally spaced throughout a 30-day period.

3.2.2 Macroinvertebrates

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

To help evaluate the water quality flowing into Palestine Lake, macroinvertebrates were collected during base flow conditions on June 19, 2007 from each of the nine sampling sites using the multihabitat approach detailed in the USEPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers, 2nd ed. (Barbour et al., 1999). Organisms were identified to the family level. Peckarsky et al. (1990) was used for identification purposes. All nomenclature follows Peckarsky et al (1990). The family-level approach was used: 1) because it allows collection in a manner comparable to that collected by IDEM in the state; 2) it allows for increased organism identification accuracy; and 3) several studies support the adequacy of family-level analysis (Furse et al., 1984; Ferraro and Cole, 1995; Marchant, 1995; Bowman and Bailey, 1997; Waite et al., 2000). Voucher specimens are maintained on file in the Indiana University laboratory and were not forwarded to Purdue University.

The benthic community in the streams was evaluated using IDEM's macroinvertebrate Index of Biotic Integrity (mIBI). The mIBI is a multi-metric index that combines several aspects of the benthic community composition. As such, it is designed to provide a complete assessment of a creek's biological integrity. Karr and Dudley (1981) define biological integrity as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to the best natural habitats within a region". It is likely that this definition of biological integrity is what IDEM means by biological integrity as well. The mIBI consists of ten metrics (Table 11) which measure the species richness, evenness, composition, and density of the benthic community at a given site. The metrics include family-level HBI (Hilsenhoff's FBI or family level biotic index; Hilsenhoff, 1988), number of taxa, number of individuals, percent dominant taxa, EPT Index, EPT count, EPT count to total number of individuals, EPT count to Chironomid count, Chironomid count, and total number of individuals to number of squares sorted. (EPT stands for the *Ephemeroptera, Plecoptera*, and *Trichoptera* orders.) A classification score of 0, 2, 4, 6, or 8 is assigned to specific ranges for metric values. For example, if the benthic community being assessed supports nine different families, that community would receive a classification score of 2 for the "Number of Taxa" metric. The mIBI is calculated by averaging the classification scores for the ten metrics. The 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.

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

Table 11. Benthic macroinvertebrate scoring criteria used by IDEM in the evaluation of pool-riffle streams in Indiana.

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

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

Although the Indiana Administrative Code does not include mIBI scores as numeric criteria for establishing whether streams meet their aquatic life use designation, the IDEM indicated that they use mIBI scores to make this determination. (Under state law, all waters of the state, except for those noted as Limited Use in the Indiana Administrative Code, must be capable of supporting recreational and aquatic life uses.) In the 2008 303(d) listing methodology, the IDEM suggests that those waterbodies with mIBI scores less than 2.2 when using the multi-habitat approach are considered non-supporting for aquatic life use. Similarly, waterbodies with mIBI scores greater than 2.2 when assessed using the multi-habitat approach are considered fully supporting for aquatic life use (IDEM, 2007). IDEM staff are required to make these determinations; therefore, data collected during this project may or may not be used by IDEM for future impairment assessments by IDEM. Under federal law, waters that do not meet their designated uses must be placed on the 303(d) list and remediation/restoration plans (Total Maximum Daily Load plans) must be developed for these waters.

3.2.3 Habitat

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

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

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

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

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

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

The QHEI evaluates the characteristics of a stream segment, as opposed to the characteristics of a single sampling site. As such, individual sites may have poorer physical habitat due to a localized disturbance yet still support aquatic communities closely resembling those sampled at adjacent sites with better habitat, provided water quality conditions are similar. QHEI scores from hundreds of stream segments in Ohio have indicated that values greater than 60 are *generally* conducive to the existence of warmwater faunas. Scores greater than 75 typify habitat conditions that have the ability to support exceptional warmwater faunas (Ohio EPA, 1999). IDEM indicates that higher QHEI scores represents more diverse habitat for colonization by macroinvertebrates. Scores below 51 suggest that poor habitat may be limiting biota within the associated stream. IDEM habitat assessment must occur in concert with the biotic assessment.

3.3 Stream Assessment Results

3.3.1 Water Chemistry

Physical Concentrations and Characteristics

Physical parameter results measured during base and storm flow sampling of the Palestine Lake watershed stream are presented in Table 12. Stream discharges measured during base and storm flow conditions are shown in Figure 19.

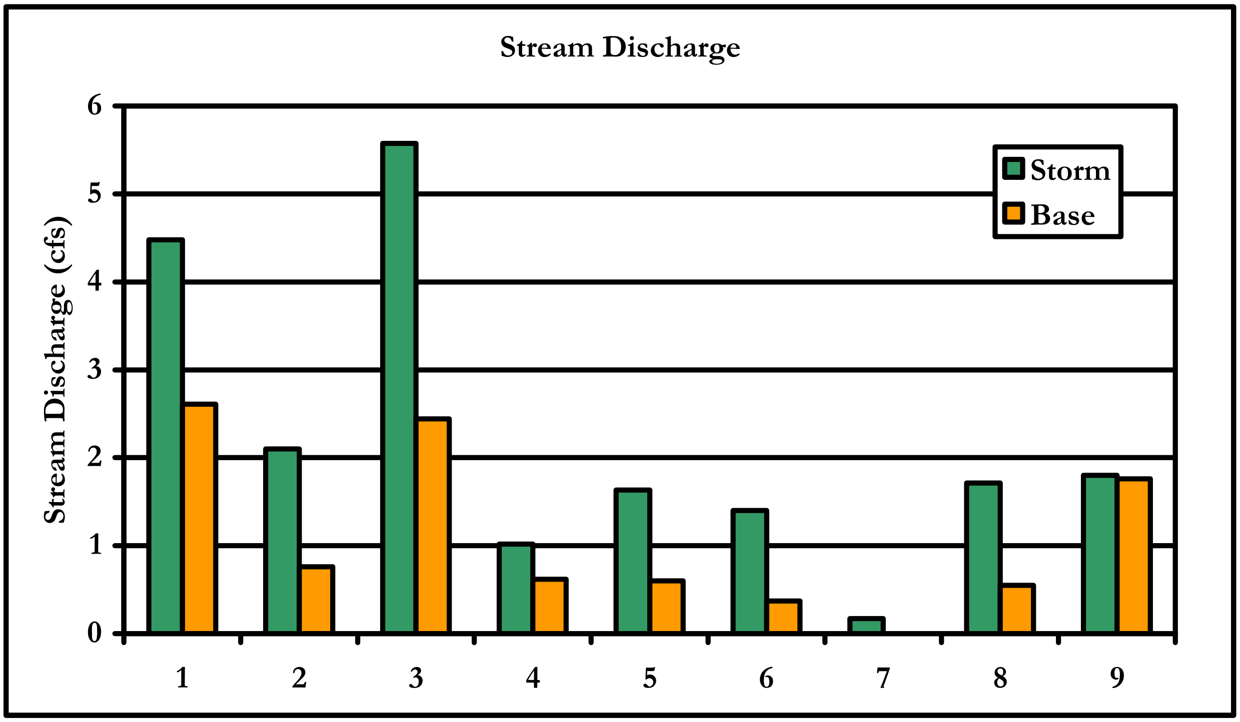

Figure 19. Discharge measurements during storm flow and base flow sampling of Palestine Lake watershed streams on May 29, 2007 (storm) and June 19, 2007 (base).

Table 12. Physical characteristics of the Palestine Lake watershed stream on May 29, 2007 (storm flow) and June 19, 2007 (base flow).

Site	Date	Timing	Flow (cfs)	Temp (°C)	DO (mg/L)	% Sat.	Cond (μmhos)	pH	TSS (mg/L)	Turb (NTU)
1	5/29/07	Storm	4.48	15.9	7.9	79.7	648	8.0	3.3	1.9
	6/19/07	Base	2.61	20.6	7.2	85.6	649	7.7	2.5	3.4
2	5/29/07	Storm	2.10	18.3	7.8	83.3	578	8.1	4.0	4.6
	6/19/07	Base	0.76	23.7	6.4	76.5	644	8.0	2.5	3.5
3	5/29/07	Storm	5.57	17.4	7.6	79.5	622	8.1	3.0	2.6
	6/19/07	Base	2.44	22.9	6.4	77.0	643	7.9	2.3	2.4
4	5/29/07	Storm	1.02	15.8	8.2	82.8	643	8.0	2.1	1.5
	6/19/07	Base	0.62	19.4	8.5	91.1	611	7.8	1.7	1.6
5	5/29/07	Storm	1.63	18.2	9.6	101.5	582	8.1	2.7	4.0
	6/19/07	Base	0.60	22.6	7.0	81	622	7.8	2.5	5.7
6	5/29/07	Storm	1.40	17.7	8.4	88	582	8.0	2.8	3.9
	6/19/07	Base	0.37	23.2	7.1	86.2	631	7.9	5.6	5.2
7	5/29/07	Storm	0.17	17.5	7.4	76.7	527	7.7	3.8	1.9
	6/19/07	Base*	--	--	--	--	--	--	--	--
8	5/29/07	Storm	1.71	17.3	8.8	91.3	605	7.8	2.5	1.6
	6/19/07	Base	0.55	23	9.3	108.6	640	7.8	0.7	1.4
9	5/29/07	Storm	1.80	17	7.5	78	607	8.0	8.5	3.8
	6/19/07	Base	1.76	21.9	7.9	90.2	294	7.9	4.7	3.3

*No samples collected due to lack of flow.

Conductivity and pH values were within normal ranges for Indiana streams (Table 12). The watershed streams' pH values ranged from 7.0 in Adams Ditch (Site 5) at base flow to 9.3 in Merritt Ditch (Site 8) during base flow. All of the pH values were within the range that is appropriate for supporting aquatic life. Conductivity values ranged from 294 μmhos in Trimble Creek (Site 9) to 649 μmhos in Williamson Ditch (Site 1) during base flow and from 527 μmhos in Kuhn Ditch (Site 7) to 648 μmhos in Williamson Ditch (Site 1) during storm flow. None of the conductivity values exceeded the Indiana state water quality standard.

Water temperatures in the Palestine Lake watershed streams varied slightly between storm and base flow sampling events (Table 12). Generally, stream temperatures during storm flow conditions were lower than stream temperatures measured during base flow conditions. Water temperatures during the base flow ranged from 19.4 °C in Magee-Robbins Ditch (Site 4) to 23.7 °C in Sloan-Adams Ditch (Site 2). Similar variation was observed during storm flow when stream temperatures ranged from 15.8 °C in Williamson Ditch (Site 1) to 18.2 °C in Sloan-Adams Ditch (Site 2). None of the observed water temperatures exceeded the Indiana Administrative Code standard for the protection of aquatic life.

Total suspended solids concentrations in the Palestine Lake watershed streams ranged from 0.7 mg/L in Merritt Ditch (Site 8) to 5.6 mg/L in Sloan Ditch (Site 6) during base flow and from 2.1 mg/L in Magee-Robbins Ditch (Site 4) to 8.5 mg/L in Trimble Creek (Site 9) during storm flow (Table 12; Figure 20). Total suspended solids concentrations are lower than is typical for Indiana streams. This is likely due to the relatively slow flow within the streams. Total suspended solids concentrations usually increase with increased stream flow because of in-stream scouring and inputs from overland flow from surrounding lands. This relationship occurred in all streams in the Palestine Lake watershed with the exception of Sloan Ditch (Site 6), where TSS concentrations were greater during base flow than those measured during storm flow. Overall, there is not much difference between the TSS concentrations measured during the base and storm flow sampling events in the Palestine Lake streams. Furthermore, none of the concentrations exceeded 80 mg/L, the threshold at which Waters (1995) found to be deleterious to aquatic life.

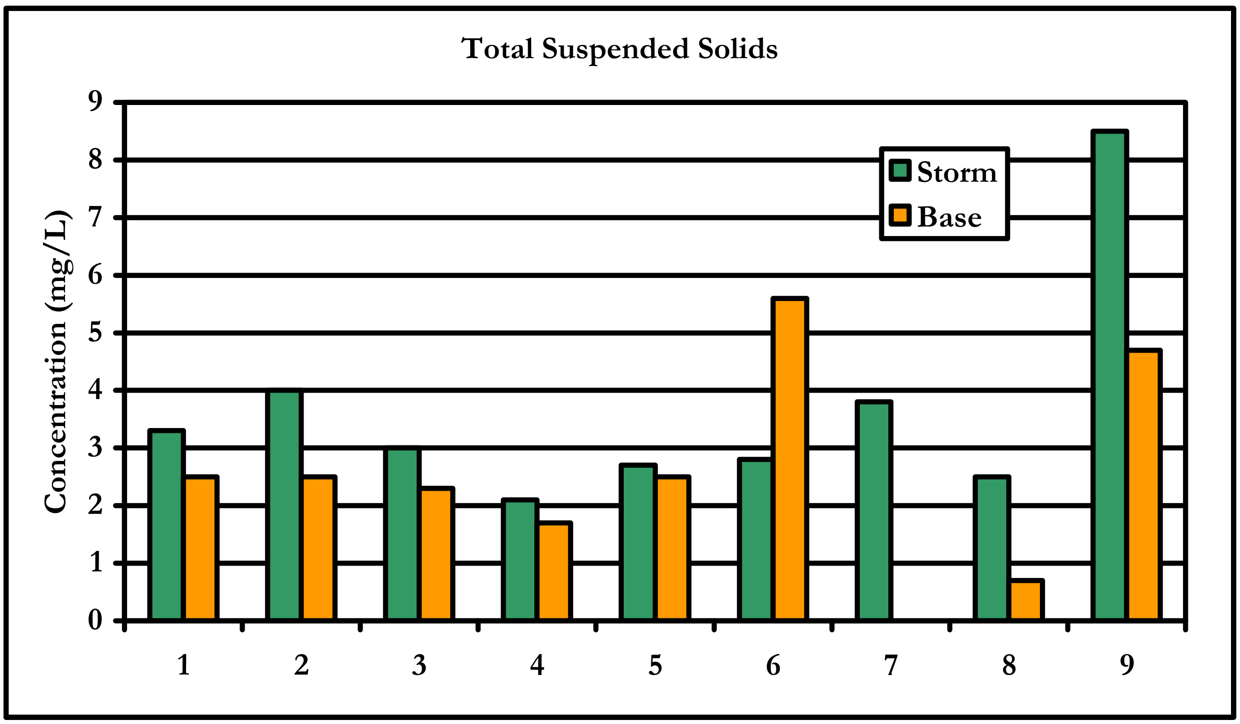

Figure 20. Total suspended solids during storm flow and base flow sampling of Palestine Lake watershed streams on May 29, 2007 (storm) and June 19, 2007 (base).

Turbidity concentrations in the Palestine Lake watershed streams were generally low. During storm flow, turbidity concentrations ranged from 1.6 NTU in the Merritt Ditch (Site 8) to 4.6 NTU in Sloan-Adams Ditch (Site 2). During base flow, turbidity concentrations ranged from 1.4 NTU in Merritt Ditch to 5.7 NTU in Adams Ditch (Site 2). As with the total suspended solids concentrations, turbidity concentrations in streams are expected to be higher during storm flow conditions. Storms tend to wash soil and other particulates from the landscape into streams, resulting in higher turbidity concentrations. However, this did not occur in the Palestine Lake watershed streams. In these streams, differences in turbidity concentrations between the storm and base flow samples were negligible (Table 12).

Base flow dissolved oxygen concentrations in the Palestine Lake watershed streams ranged from 6.4 mg/L in Sloan-Adams Ditch (Site 2) to 9.3 mg/L in the Merritt Ditch (Site 8) (Table 12). During storm flow, dissolved oxygen concentrations ranged from 7.4 mg/L in Kuhn Ditch (Site 7) to 9.6 in Sloan Ditch (Site 5). All of the streams possessed dissolved oxygen levels above the minimum IAC level of 5 mg/L set to protect aquatic life. Dissolved oxygen saturation levels at base flow were also relatively normal for Indiana streams ranging from 77% in Kuhn Ditch under storm flow conditions and Ring Ditch during base flow conditions to 109% in Merritt Ditch during base flow conditions. DO saturation refers to the amount of oxygen dissolved in water compared to the total amount possible when equilibrium between the stream water and the atmosphere is maximized. When a stream is less than 100% saturated with oxygen, decomposition processes within the stream may be consuming oxygen more quickly than it can be replaced and/or flow in the stream is not turbulent enough to entrain sufficient oxygen.

Chemical and Bacterial Characteristics

The chemical and bacterial characteristics of the Palestine Lake watershed streams during base and storm flow conditions are shown in Table 13. 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), total nitrogen (0.26 mg/L), soluble reactive phosphorus (0.010 mg/L), and total phosphorus (0.022 mg/L) (Clark et al., 2000). Nutrient concentrations in the Palestine Lake watershed streams exceeded all of these median concentrations.

Table 13. Chemical and bacterial characteristics of the Palestine Lake watershed streams on May 29, 2007 (storm flow) and June 19, 2007 (base flow).

Site	Date	Timing	Nitrate (mg/L)	Ammonia (mg/L)	TKN (mg/L)	TP (mg/L)	SRP (mg/L)	*E. coli* (#/100mL)
1	5/29/2007	Storm	8.085	0.155	0.621	0.103	0.059	3,250
	6/19/2007	Base	6.380	0.087	0.272	0.088	0.063	1,720
2	5/29/2007	Storm	1.559	0.128	0.906	0.086	0.034	1,110
	6/19/2007	Base	0.273	0.048	0.480	0.075	0.046	350
3	5/29/2007	Storm	3.776	0.125	0.780	0.101	0.051	2,360
	6/19/2007	Base	3.177	0.076	0.598	0.095	0.064	1,730
4	5/29/2007	Storm	6.427	0.058	0.369	0.072	0.045	2,910
	6/19/2007	Base	6.496	0.036	0.230	0.069	0.050	1,620
5	5/29/2007	Storm	1.345	0.066	0.792	0.067	0.021	110
	6/19/2007	Base	0.256	0.080	0.367	0.056	0.019	110
6	5/29/2007	Storm	1.379	0.073	0.781	0.065	0.035	5,170
	6/19/2007	Base	0.256	0.044	0.413	0.059	0.025	440
7	5/29/2007	Storm	6.569	0.048	0.588	0.089	0.051	30
	6/19/2007	Base*	--	--	--	--	--	24,190
8	5/29/2007	Storm	7.802	0.209	0.230	0.079	0.046	6,130
	6/19/2007	Base	5.737	0.049	0.470	0.075	0.053	1,330
9	5/29/2007	Storm	3.405	0.147	0.862	0.079	0.040	1,040
	6/19/2007	Base	3.436	0.072	0.618	0.079	0.042	2,610

*No samples collected due to lack of flow.

Nitrate-nitrogen concentrations in the Palestine Lake watershed streams were relatively high for Indiana streams during both base and storm flow. During base flow, nitrate-nitrogen concentrations ranged from a low of 0.256 mg/L in Adams Ditch (Site 5) and Sloan Ditch (Site 6) to a high of 6.496 mg/L in the Magee-Robbins Ditch (Site 4). During storm flow, nitrate-nitrogen concentrations ranged a low of 1.345 mg/L in Adams Ditch (Site 5) to a high of 8.085 mg/L in the Williamson Ditch (Site 1). All sites except Sloan-Adams Ditch (Site 2), Adams Ditch (Site 5), Sloan Ditch (Site 6), and Kuhn Ditch (Site 7) during base flow and all sites during storm flow exceeded the USEPA recommended criteria (0.03 mg/L). Additionally, nitrate-nitrogen concentrations in these same streams during both base and storm flow conditions exceeded the Ohio EPA criteria (1 mg/L) recommended to support aquatic biota in warmwater habitat. Furthermore, all sites except Sloan-Adams Ditch (Site 2), Adams Ditch (Site 5), and Sloan Ditch (Site 6) during storm flow and these same sites plus Kuhn Ditch (Site 7) during base flow exhibited nitrate-nitrogen concentrations above the level recommended by the Ohio EPA (1.6 mg/L) for the protection of aquatic biota in a modified warmwater habitat stream. Williamson Ditch (Site 1), Ring Ditch (Site 3), Magee-Robbins Ditch (Site 4), Merritt Ditch (Site 8), and Trimble Creek (Site 9) possessed nitrate-nitrogen concentrations in excess of the productive to highly-productive threshold (1.5 mg/L) identified by Dodd et al. (1998). Additionally, these same five streams possessed nitrate-nitrogen concentrations of 3-4 mg/L, the threshold at which Ohio EPA found to definitively impair biotic communities (Ohio EPA, 1999). However, none of the watershed streams possessed nitrate-nitrogen concentrations that violated the Indiana state water quality standards.

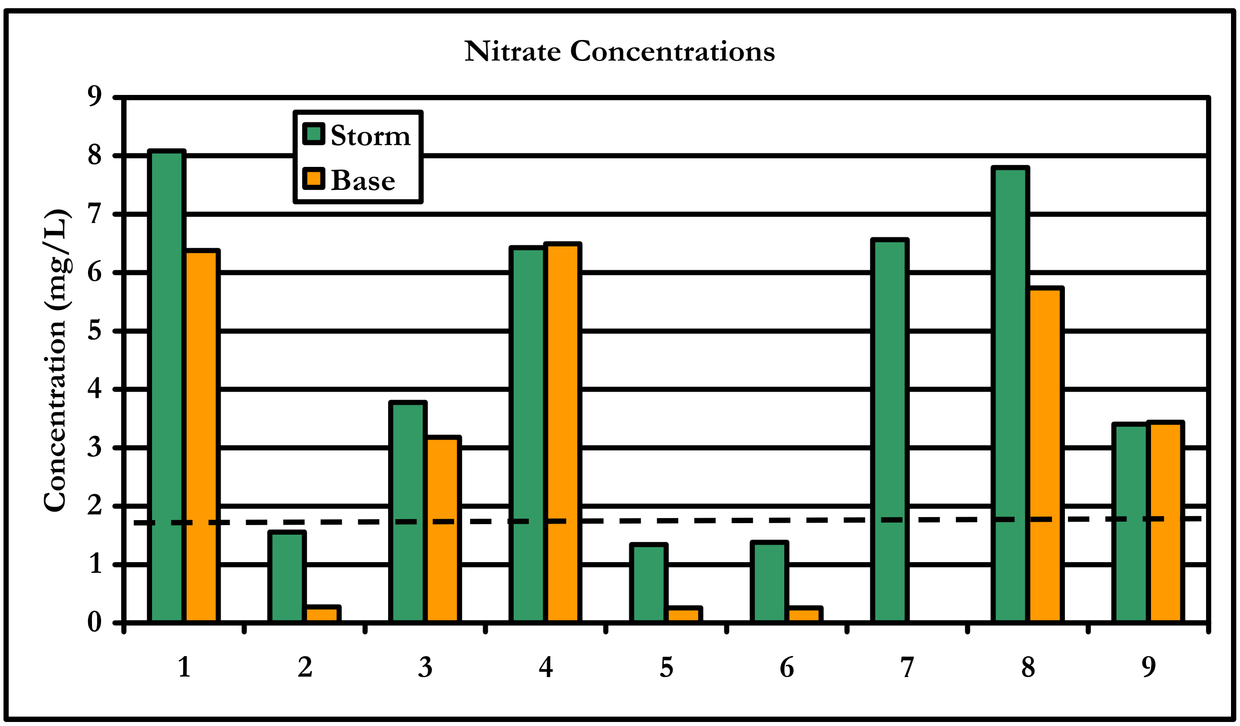

Figure 21. Nitrate concentrations during storm flow and base flow sampling of Palestine Lake watershed streams on May 29, 2007 (storm) and June 19, 2007 (base). The dashed line represents the Ohio EPA median concentration of wadeable stream to support modified warmwater habitat (1.8mg/L; Ohio EPA, 1999).

Ammonia concentrations ranged from 0.048 mg/L in Kuhn Ditch (Site 7) to 0.209 mg/L in Merritt Ditch (Site 8) during storm flow and from 0.036 mg/L in Magee-Robbins Ditch (Site 4) to 0.087 mg/L in Williamson Ditch (Site 1) during base flow. Overall, ammonia-nitrogen concentrations in Palestine Lake watershed streams were relatively low during both base and storm flow sampling. Ammonia is a by-product of decomposition and therefore streams with high levels of organic material are expected to have higher ammonia concentrations. The majority of the Palestine Lake watershed streams are physically characterized with extensive embeddedness, high percentages of muck, and significant detritus. This high level of particulate matter within the stream substrate provides conditions for ammonia-nitrogen to accumulate within the stream due to decomposition. Additionally, under low dissolved oxygen conditions, nitrogen is present in its reduced form, which is ammonia-nitrogen. Based on pH and temperature, total ammonia levels, which can be toxic to fish, were below those which cause toxicity. However, all of the watershed streams are well oxygenated. Therefore, ammonia-nitrogen is rapidly converted from ammonia-nitrogen to nitrate-nitrogen within this stream system.

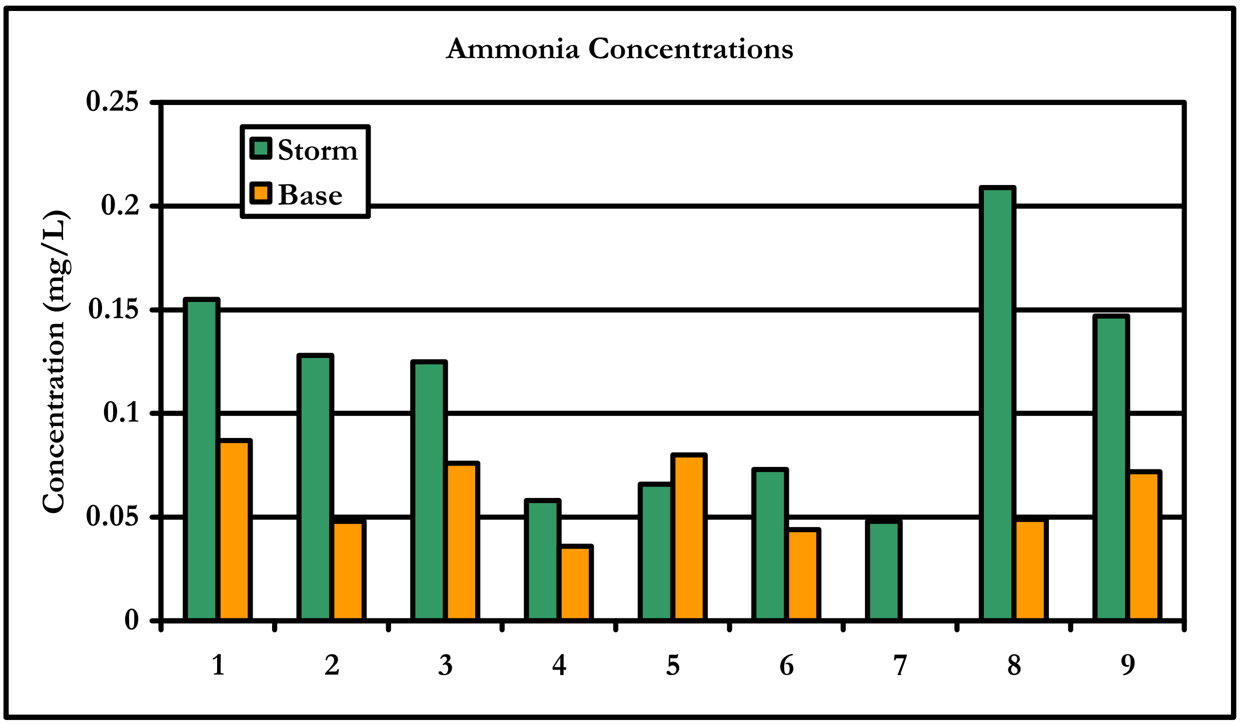

Figure 22. Ammonia concentrations during storm flow and base flow sampling of Palestine Lake watershed streams on May 29, 2007 (storm) and June 19, 2007 (base).

Total Kjeldahl nitrogen levels in the Palestine Lake watershed streams were relatively normal for northern Indiana streams. TKN concentrations ranged from 0.230 mg/L in Merritt Ditch (Site 8) to 0.906 mg/L in Sloan-Adams Ditch (Site 2) during storm flow and from 0.230 mg/L in Magee-Robbins Ditch (Site 4) to 0.618 mg/L in Trimble Creek (Site 9) during base flow. Typically storm flow concentrations of TKN exceed base flow concentrations since runoff liberates significant organic material stored within the stream and in riparian areas adjacent to the stream. This relationship occurred at all sampling sites except Merritt Ditch (Site 8). Ring Ditch (Site 3) and Trimble Creek (Site 9) during base flow and Williamson Ditch (Site 1), Sloan-Adams Ditch (Site 2), Ring Ditch (Site 3), Adams Ditch (Site 5), Sloan Ditch (Site 6), and Trimble Creek (Site 9) during storm flow possessed TKN concentrations greater than the target concentration of 0.591 mg/L recommended by the USEPA (2000a).

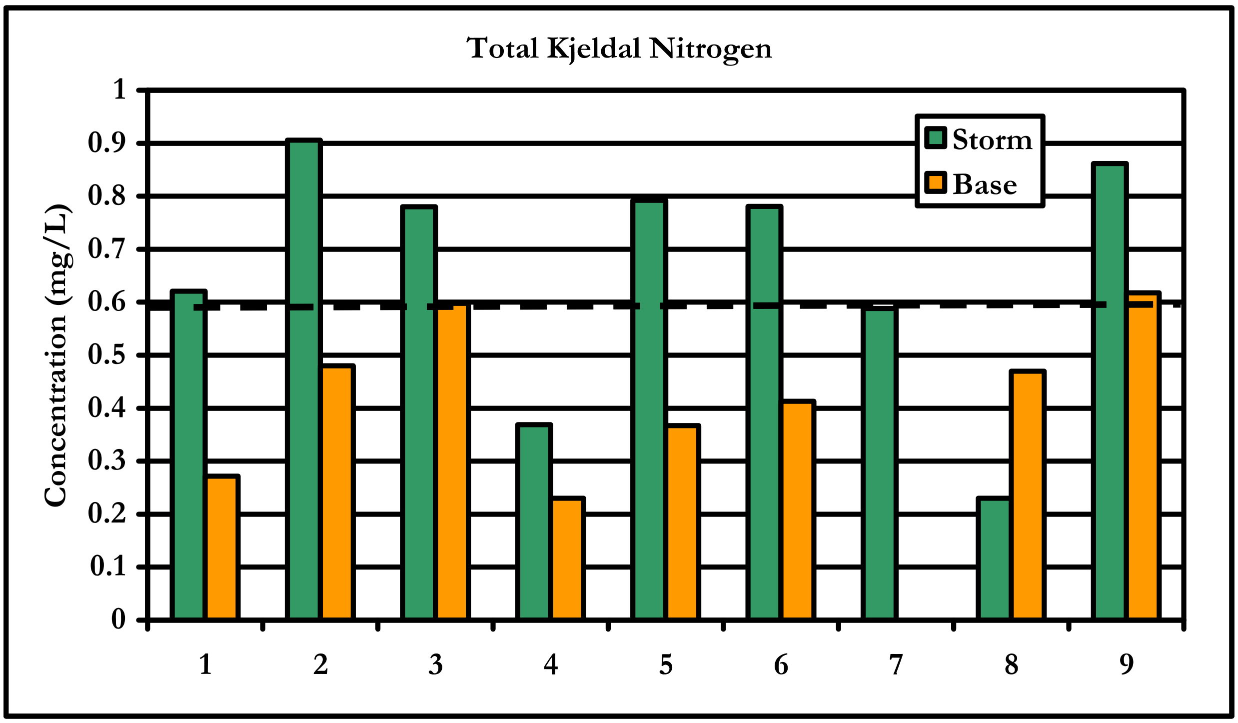

Figure 23. Total Kjeldahl nitrogen concentrations in Palestine Lake watershed streams as sampled May 29, 2007 (storm flow) and June 19, 2007 (base flow). The dashed line represents the USEPA recommended criteria for Ecoregion VI streams (0.591mg/L; USEPA, 2000b).

Soluble reactive phosphorus (SRP) is the dissolved component of total phosphorus. Understanding what portion of the total phosphorus concentration is dissolved aids in directing management efforts. Dissolved phosphorus usually comes from fertilizer and waste (wildlife and human). Chemical reactions within the stream can also contribute to the dissolved phosphorus levels in the stream. SRP concentrations in the Palestine Lake watershed streams were higher than desired for headwater streams. SRP concentrations in the Palestine Lake watershed streams ranged from 0.019 mg/L in Adams Ditch (Site 5) to 0.095 mg/L in Ring Ditch (Site 3) during base flow, while SRP concentrations ranged from 0.021 mg/L at Adams Ditch (Site 5) to 0.059 mg/L in Williamson Ditch (Site 5) during storm flow. Management efforts should focus on reducing the waste reaching these streams. Nutrient (fertilizer) management should also be a priority on agricultural and residential land in these subwatersheds.

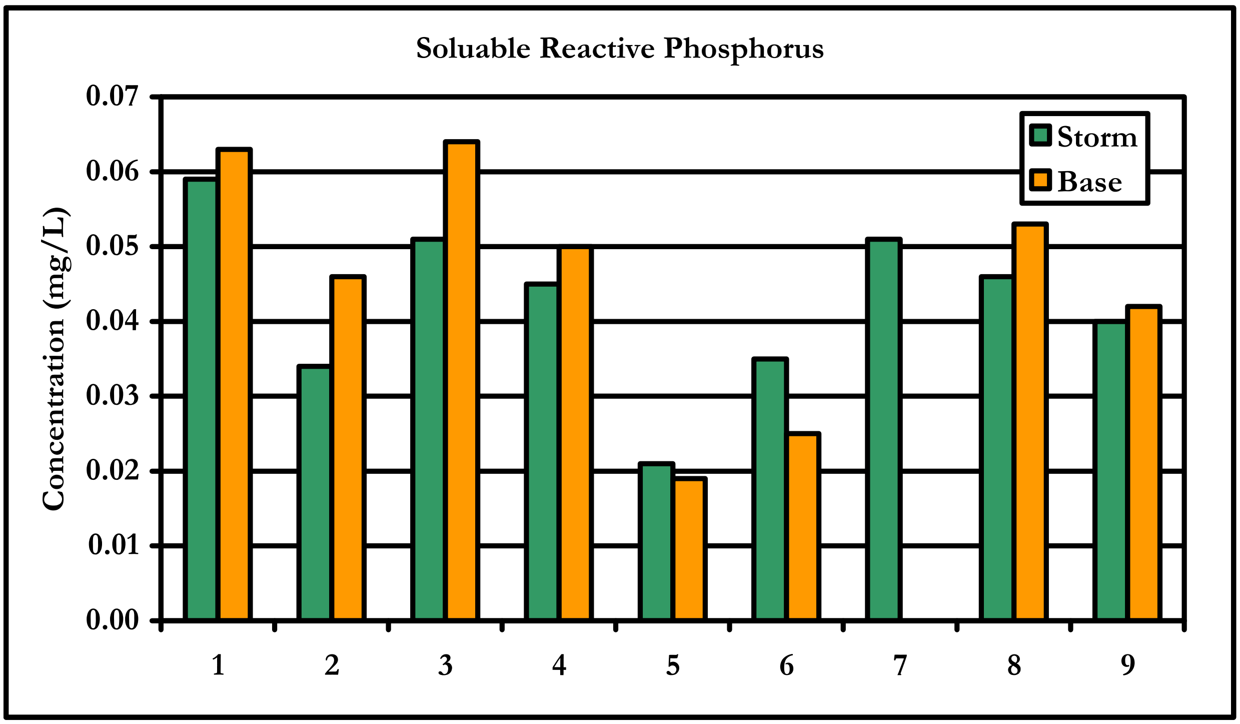

Figure 24. Soluble reactive phosphorus concentrations in Palestine Lake watershed streams as sampled May 29, 2007 (storm) and June 19, 2007 (base).

Like the TKN levels, total phosphorus concentrations in the Palestine Lake watershed streams were high for northern Indiana streams (Figure 25). Under base flow conditions, total phosphorus concentrations ranged from 0.056 mg/L in Sloan Ditch (Site 5) to 0.095 mg/L in Ring Ditch (Site 3). During storm flow, total phosphorus concentrations ranged from 0.065 mg/L in Sloan Ditch (Site 5) to 0.103 mg/L in Ring Ditch (Site 3). Ring Ditch during both base and storm flow also possessed the highest soluble reactive phosphorus concentrations. Based on the elevated total phosphorus concentrations in the watershed streams, these streams were fairly productive streams. Furthermore, this high productivity has the potential to impair the streams' biotic communities. All of the streams except Magee-Robbins Ditch (Site 4), Adams Ditch (Site 5), and Sloan Ditch (Site 6) possessed base and/or storm flow total phosphorus concentrations that would place the streams in the eutrophic, or highly productive, category using Dodd et al.'s (1998) criteria. Total phosphorus concentrations in Williamson Ditch (Site 1), Sloan-Adams Ditch (Site 3), Ring Ditch (Site 3), Kuhn Ditch (Site 7), Merritt Ditch (Site 8), and Trimble Creek (Site 9) at base and/or storm flow conditions exceeded the USEPA recommended target criterion of 0.076 mg/L (USEPA, 2000a). However, total phosphorus concentrations in Williamson Ditch (Site 1) and Ring Ditch (Site 3) were the only ones that exceeded the Ohio EPA's recommended total phosphorus criterion to protect aquatic life of 0.1 mg/L in wadeable warmwater habitat streams (Ohio EPA, 1999). None of the streams exceeded the total phosphorus criterion (0.34 mg/L) suggested by the Ohio EPA for modified warmwater habitat streams. The high total phosphorus concentrations observed in the watershed streams, particularly in Williamson Ditch, Ring Ditch, and Sloan-Adams Ditch, may be impairing the streams' biotic communities.

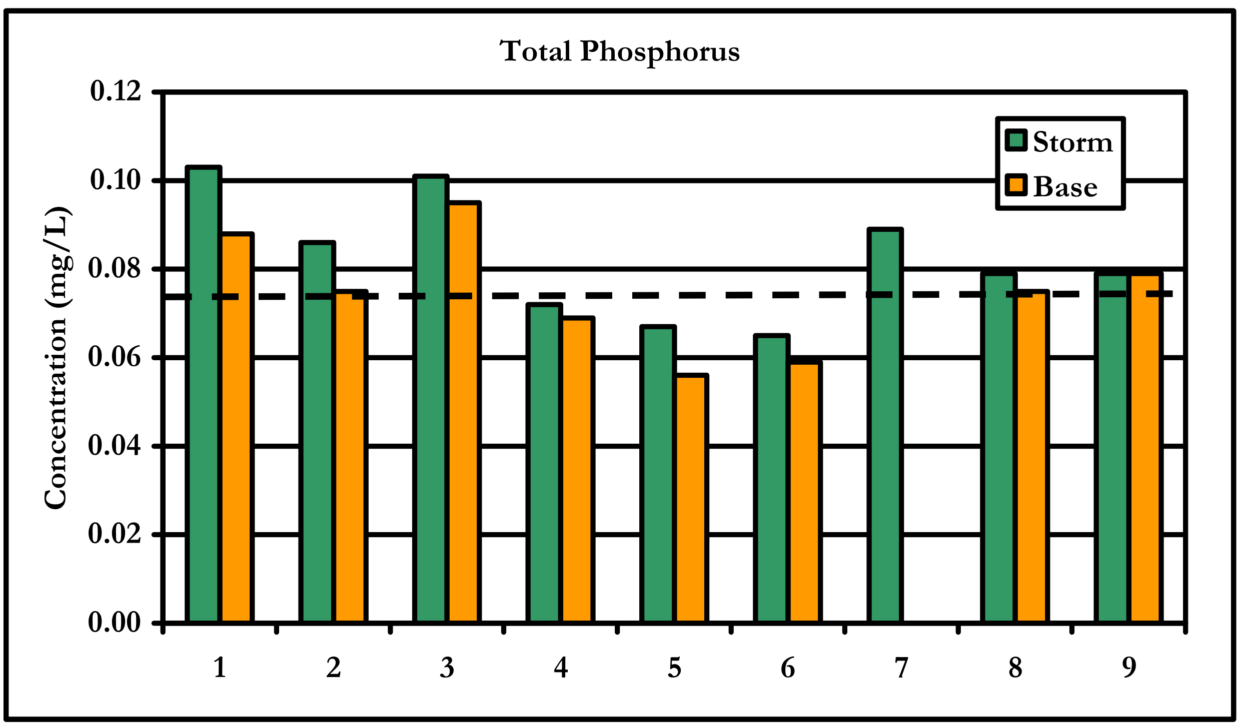

Figure 25. Total phosphorus concentrations in Palestine Lake watershed streams as sampled May 29, 2007 (storm) and June 19, 2007 (base). The dashed line represents the Ohio EPA median concentration of wadeable stream to support modified warmwater habitat (0.075 mg/L; Ohio EPA, 1999).

E. coli concentrations in the Palestine Lake watershed streams were relatively high. During base flow, all sites except Adams Ditch (Site 5) contained *E. coli* concentrations that violated state water quality standards (Figure 26). In addition to violating the state standard, *E. coli* concentrations at all sites except Sloan-Adams Ditch (Site 2), Adams Ditch (Site 5), and Sloan Ditch (Site 6) were above the average *E. coli* concentration of 650 col/100mL found in Indiana waters (White, unpublished data). During storm flow, all streams except Sloan Ditch (Site 5) and Kuhn Ditch (Site 7) exceeded the Indiana state standard during storm flow. All of the other sites were also in excess of the average concentration measured in Indiana streams. *E. coli* concentrations in the Palestine Lake watershed streams ranged from 130 col/100mL in the Kuhn Ditch (Site 7) during storm flow to 24,190 col/100 mL in Kuhn Ditch (Site 7) during base flow. However, it should be noted that this bsae from sample at this site was collected during ponded water conditions and may not represent true conditions in the stream. Throughout the watershed, *E. coli* concentrations in excess of the standard measured 1.8 to 103 times the state standard. High *E. coli* concentrations suggest the presence of other pathogens. These pathogens may impair the tributaries biota and limit human use of the streams.

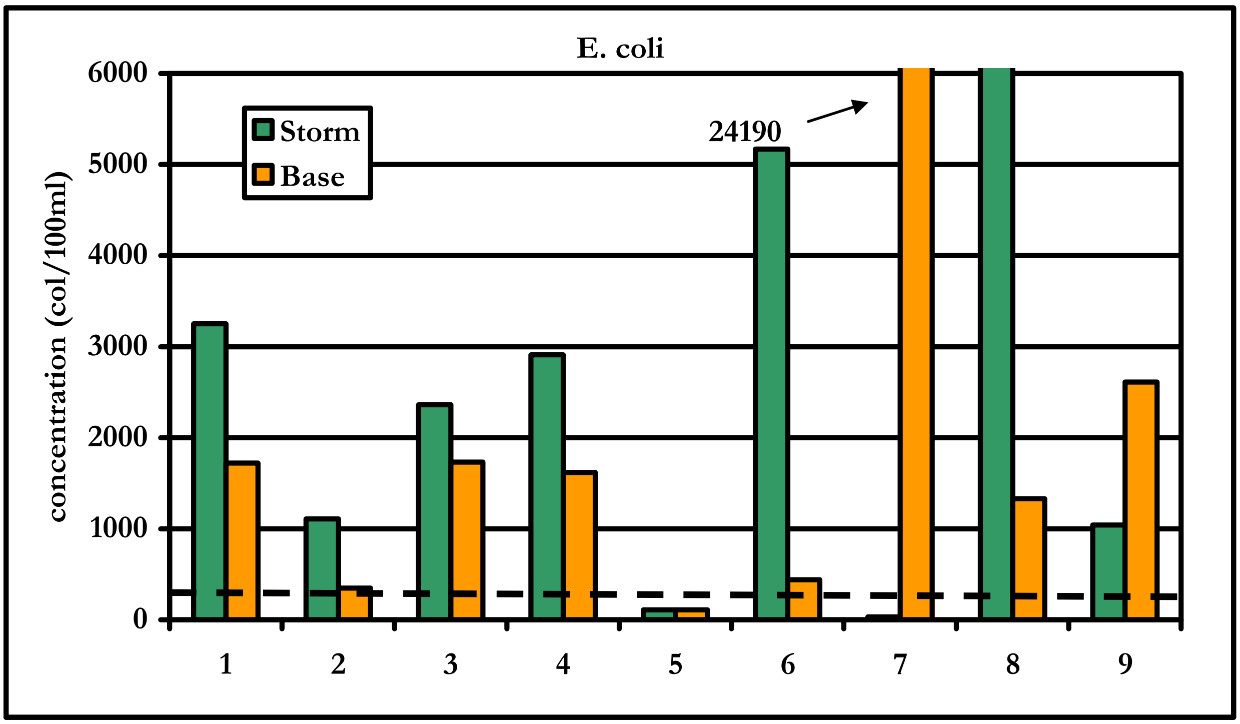

Figure 26. *E. coli* concentrations in Palestine Lake watershed streams as sampled May 29, 2007 (stream) and June 19, 2007 (base). The dashed line represents the Indiana state criteria for *E. coli*. (235 col/100ml; IAC, 2000).

Chemical and Sediment Loading

Table 14 lists the chemical and sediment loading data for the Palestine Lake watershed streams. Figures 27 to 32 present mass loading information graphically.

Table 14. Chemical and sediment load characteristics of the Palestine Lake watershed streams on May 29, 2007 (storm flow) and June 19, 2007 (base flow).

Site	Date	Timing	Nitrate Load (kg/d)	Ammonia Load (kg/d)	TKN Load (kg/d)	TP Load (kg/d)	SRP Load (kg/d)	TSS Load (kg/d)
1	5/29/2007	Storm	88.52	1.70	6.80	1.13	0.65	36.13
	6/19/2007	Base	40.72	0.56	1.74	0.56	0.40	15.95
2	5/29/2007	Storm	8.01	0.66	4.65	0.44	0.17	20.55
	6/19/2007	Base	0.51	0.09	0.89	0.14	0.09	4.65
3	5/29/2007	Storm	51.45	1.70	10.63	1.38	0.69	40.88
	6/19/2007	Base	18.95	0.45	3.57	0.57	0.38	13.72
4	5/29/2007	Storm	16.03	0.14	0.92	0.18	0.11	5.24
	6/19/2007	Base	9.85	0.05	0.35	0.10	0.08	2.58
5	5/29/2007	Storm	5.37	0.26	3.16	0.27	0.08	10.78
	6/19/2007	Base	0.38	0.12	0.54	0.08	0.03	3.67
6	5/29/2007	Storm	4.73	0.25	2.68	0.22	0.12	9.60
	6/19/2007	Base	0.23	0.04	0.37	0.05	0.02	5.07
7	5/29/2007	Storm	2.73	0.02	0.24	0.04	0.02	1.58
	6/19/2007	Base	--	--	--	--	--	--
8	5/29/2007	Storm	32.66	0.87	0.96	0.33	0.19	10.47
	6/19/2007	Base	7.72	0.07	0.63	0.10	0.07	0.94
9	5/29/2007	Storm	14.99	0.65	3.80	0.35	0.18	37.43
	6/19/2007	Base	14.79	0.31	2.66	0.34	0.18	20.23

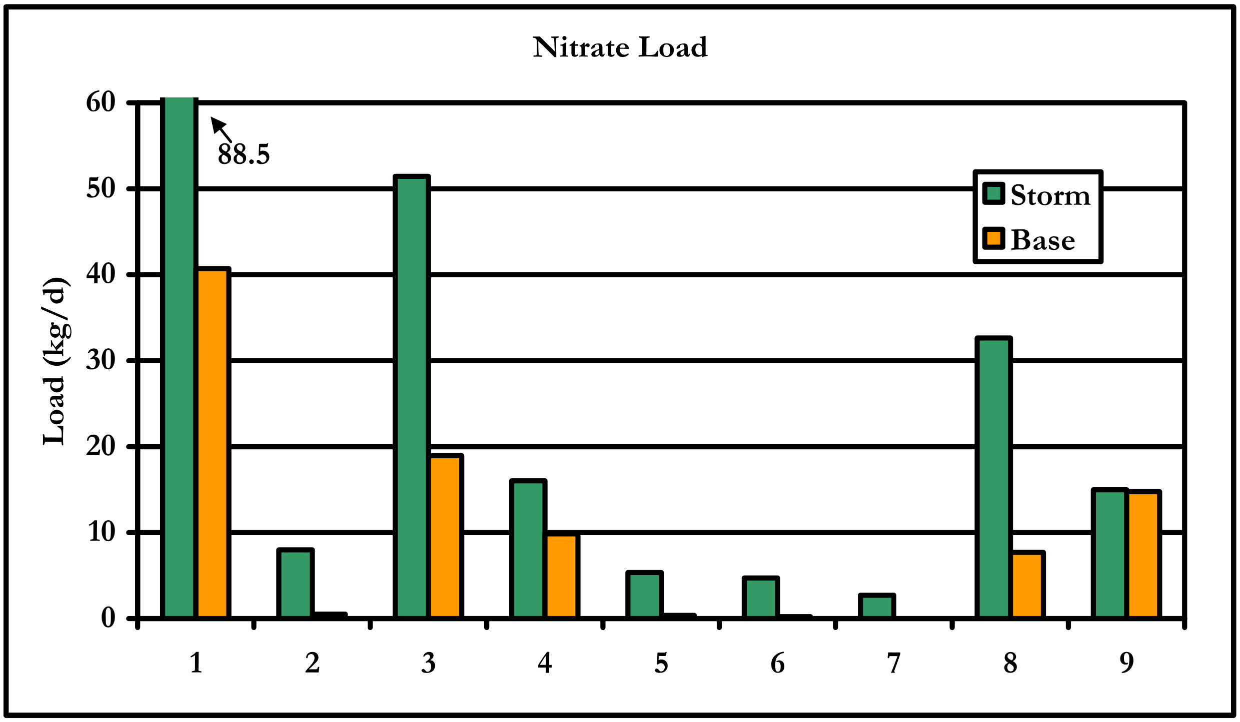

Figure 27. Nitrate loads in Palestine Lake watershed streams as sampled May 29, 2007 (storm) and July 19, 2007 (base).

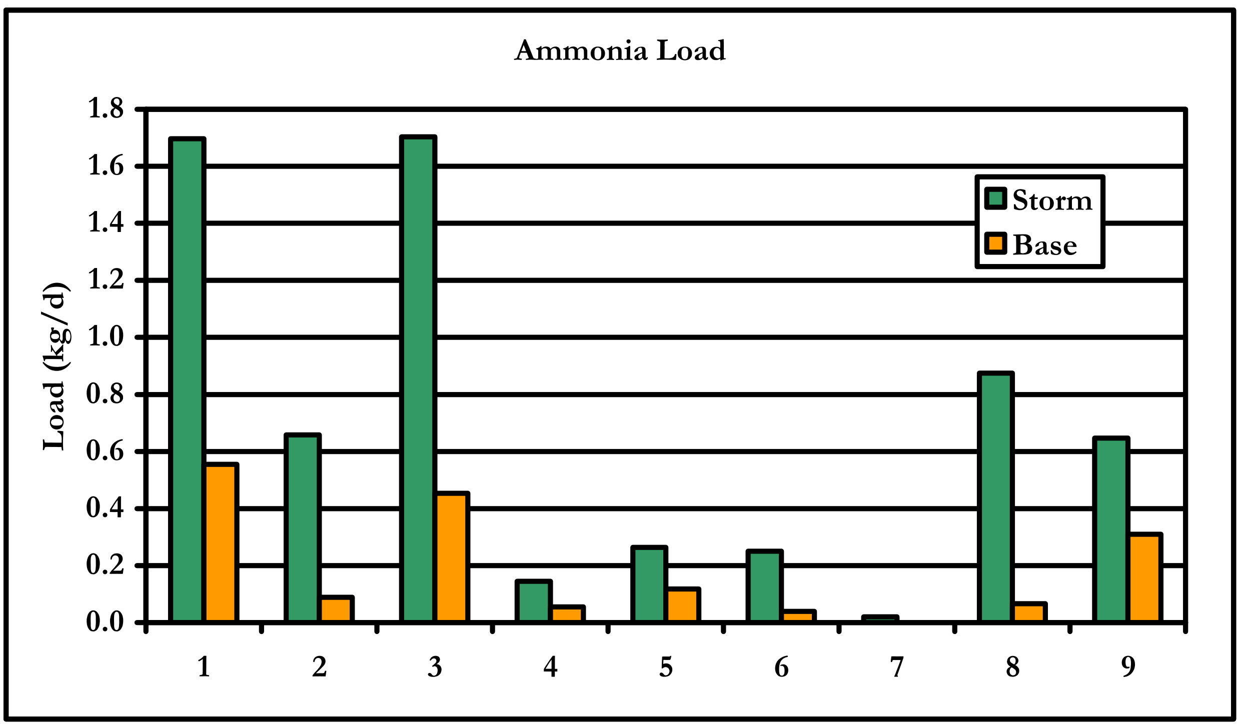

Figure 28. Ammonia loads in Palestine Lake watershed streams as sampled May 29, 2007 (storm) and June 19, 2007 (base).

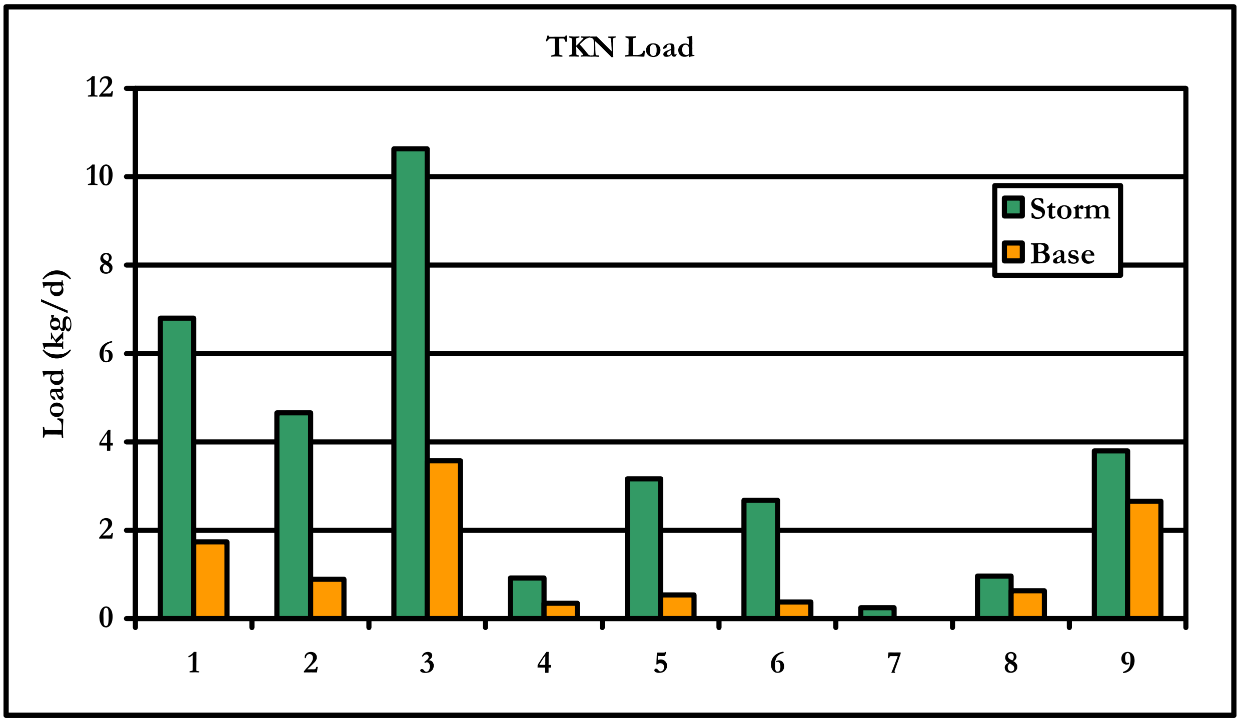

Figure 29. Total Kjeldahl nitrogen loads in Palestine Lake watershed streams as sampled May 29, 2007 (storm) and June 19, 2007 (base).

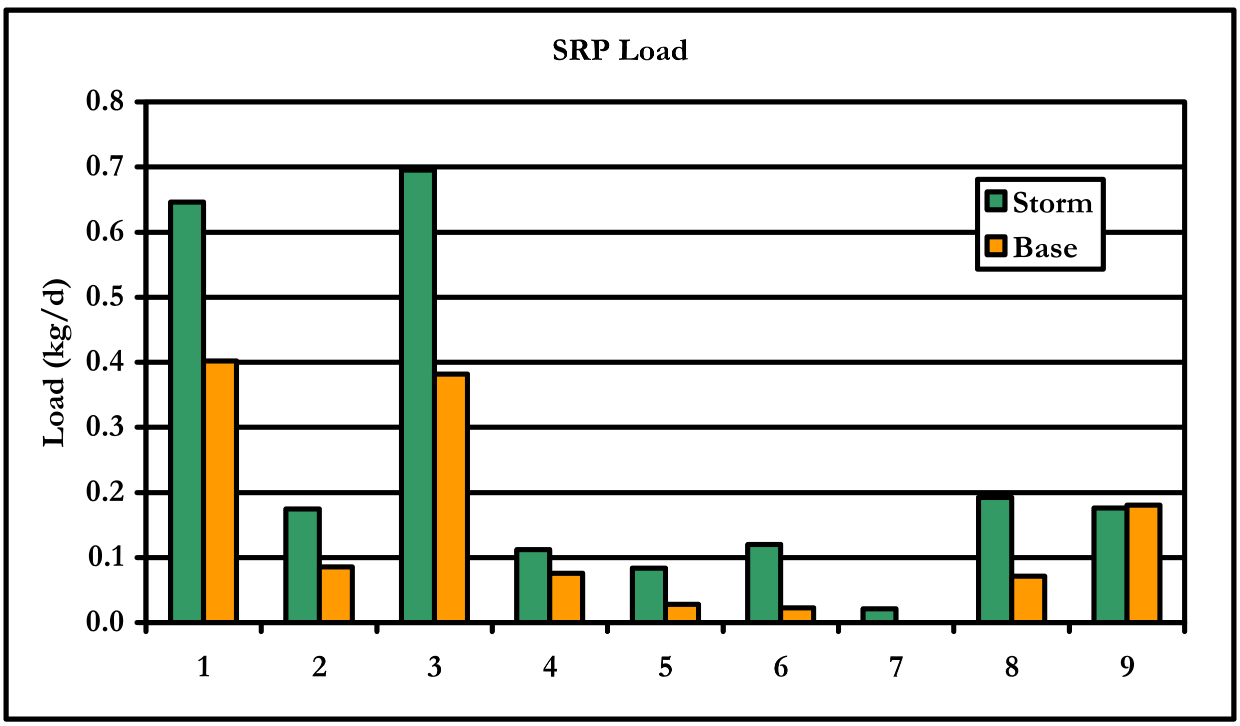

Figure 30. Soluble reactive phosphorus loads in Palestine Lake watershed streams as sampled May 29, 2007 (storm) and June 19, 2007 (base).

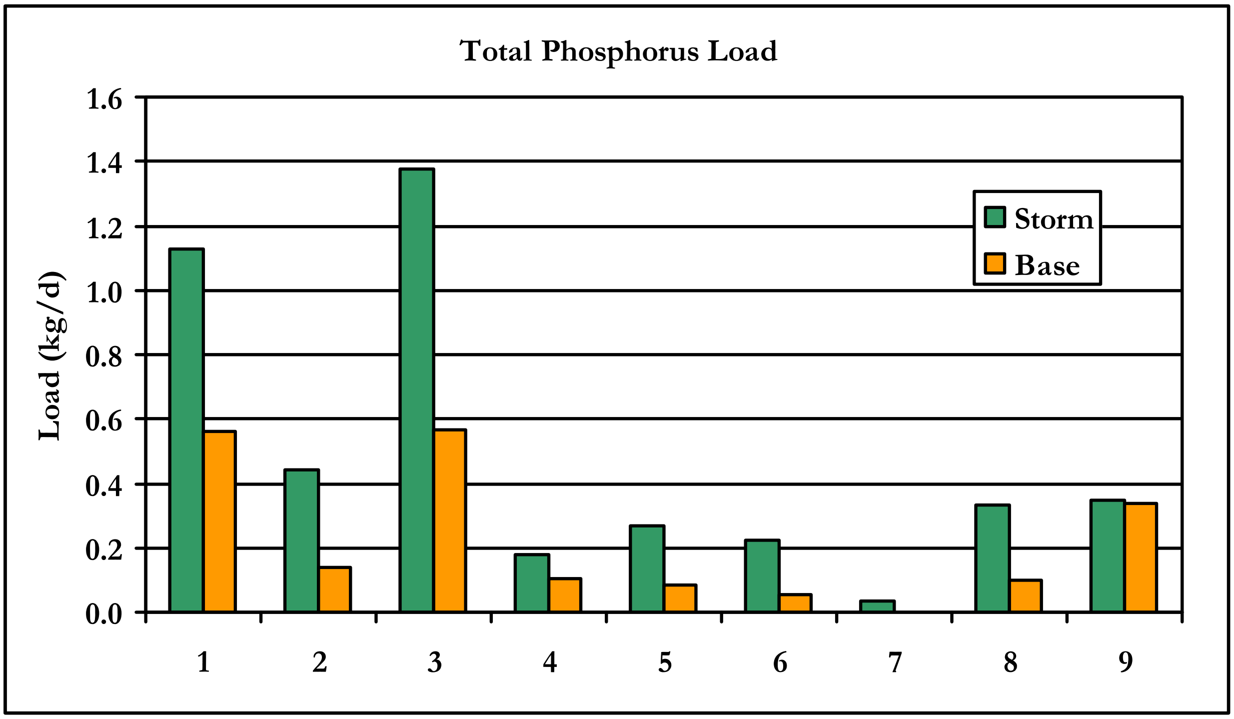

Figure 31. Total phosphorus loads in Palestine Lake watershed streams as sampled May 29, 2007 (storm) and June 19, 2007 (base).

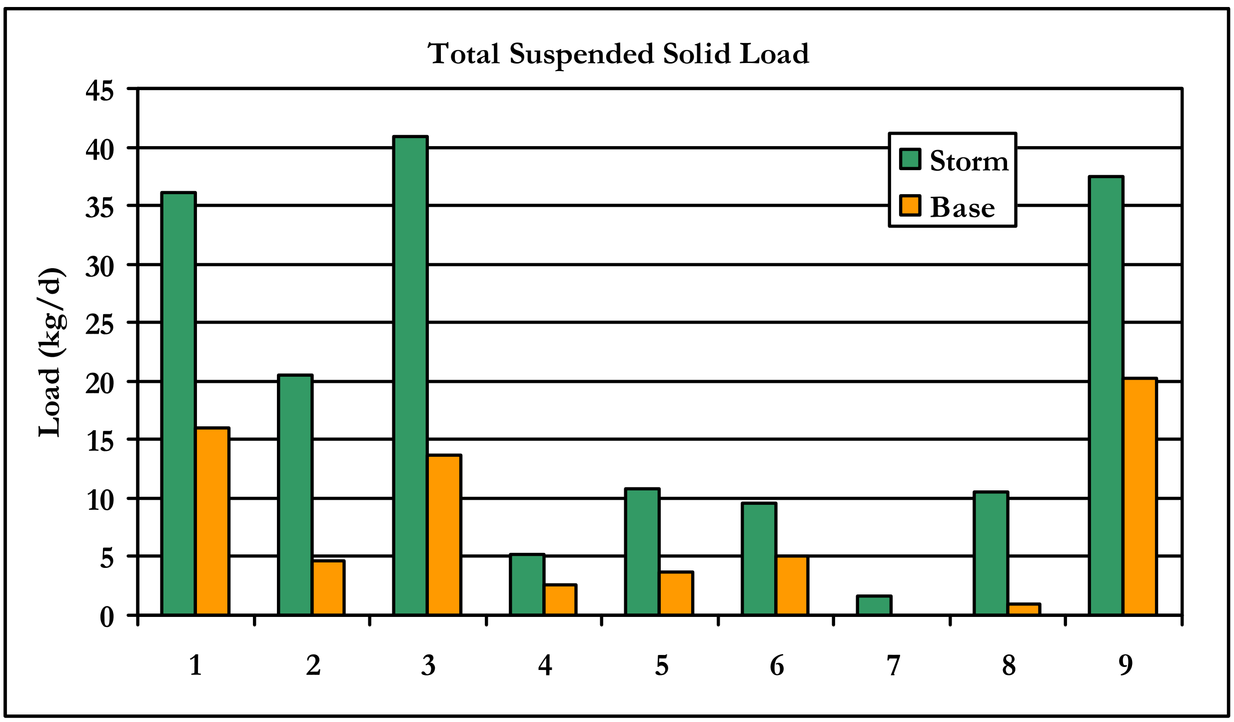

Figure 32. Total suspended solids loads in Palestine Lake watershed streams as sampled May 29, 2007 (storm flow) and June 19, 2007 (base flow).

While pollutant concentration data provides an understanding of the water quality at a given time and the conditions to which stream biota are subjected, pollutant loading data provides an understanding of how much actual pollutant (mass) is delivered to a downstream waterbody per unit of time. For example, an inlet stream that has high pollutant concentrations does not necessarily contribute the greatest amount of pollutants to its downstream lake. If the inlet stream possesses a very low discharge (i.e. water flow), it likely does not transport as much pollution to the lake as other inlets to the lake that have higher discharge levels. Thus, is it important to evaluate inlet streams' pollutant loading rates to fully understand which inlet is contributing the greatest amount of pollutants to a lake. This information is essential to prioritizing watershed management options.

When each of the watershed streams is compared to one another (Figures 33 to 41), one notices that Williamson Ditch (Site 1) and Sloan-Adams Ditch (Site 2) possessed the highest loading rate for most of the pollutants measured during both base and storm flow. The only exceptions to this are Merritt Ditch (Site 8) which possessed the second highest ammonia-nitrogen load during the storm event and Trimble Creek (Site 9) which possessed the second highest total suspended solids load during the storm event. Of concern is the elevated loading values observed in Williamson Ditch during both base and storm flow. This stream possesses a moderately-sized drainage area, yet contained the highest nutrient and sediment loading rates. This indicates that anthropogenic forces are likely impacting water quality in the Williamson Ditch subwatershed.

Knowing that Williamson Ditch and Sloan-Adams Ditch possessed the greatest pollutant loading rates does little to help direct watershed management efforts, so it is useful to consider which streams possessed the highest pollutant loading rates based on watershed size. It is also important to evaluate ***areal pollutant loading rates*** of the streams in determining prioritization of watershed management efforts. The areal pollutant loading rate normalizes the pollutant loading rates by drainage size. By dividing the pollutant loading rate of a stream by the drainage (or watershed) size of the stream, one obtains a *per acre pollutant loading rate*. Thus, pollutant loading rates in streams with large drainages, which are expected to have high pollutant loading rates, are directly comparable to pollutant loading rates in streams with small drainages, which are expected to have lower pollutant loading rates.

Examination of the areal pollutant loading rates for each of the inlet streams (Table 15) shows that, in general, Williamson Ditch (Site 1) and Ring Ditch (Site 3) delivered more pollutants per acre of watershed than the other Palestine Lake watershed streams. Pollutant delivery rates per acre of watershed in Merritt Ditch (Site 8) and Trimble Creek (Site 9) are also of concern, but they generally were not as high as the areal loading rates observed in Williamson Ditch and Ring Ditch. These results suggest that management efforts to reduce pollutant loading to the watershed lakes should focus on the Williamson Ditch and Ring Ditch subwatersheds. Theoretically, treatment efforts in these subwatersheds will provide the greatest benefit per acre of treatment.

Table 15. Area pollutant loading rates for the Palestine Lake watershed streams on May 29, 2007 (storm flow) and June 19, 2007 (base flow).

Site	Date	Timing	Nitrate Load (kg/ha-yr)	Ammonia Load (kg/ha-yr)	TKN Load (kg/ha-yr)	TP Load (kg/ha-yr)	SRP Load (kg/ha-yr)	TSS Load (kg/ha-yr)
1	5/29/2007	Storm	14.19	0.27	1.09	0.181	0.104	5.79
	6/19/2007	Base	6.53	0.09	0.28	0.090	0.064	2.56
2	5/29/2007	Storm	1.78	0.15	1.04	0.098	0.039	4.58
	6/19/2007	Base	0.11	0.02	0.20	0.031	0.019	1.04
3	5/29/2007	Storm	6.38	0.21	1.32	0.171	0.086	5.07
	6/19/2007	Base	2.35	0.06	0.44	0.070	0.047	1.70
4	5/29/2007	Storm	7.79	0.07	0.45	0.087	0.055	2.55
	6/19/2007	Base	4.79	0.03	0.17	0.051	0.037	1.25
5	5/29/2007	Storm	2.03	0.10	1.19	0.101	0.032	4.07
	6/19/2007	Base	0.14	0.04	0.20	0.031	0.011	1.38
6	5/29/2007	Storm	1.08	0.06	0.61	0.051	0.027	2.19
	6/19/2007	Base	0.05	0.01	0.09	0.012	0.005	1.16
7	5/29/2007	Storm	6.07	0.04	0.54	0.082	0.047	3.51
	6/19/2007	Base	--	--	--	--	--	--
8	5/29/2007	Storm	16.34	0.44	0.48	0.165	0.096	5.24
	6/19/2007	Base	3.86	0.03	0.32	0.050	0.036	0.47
9	5/29/2007	Storm	3.42	0.15	0.87	0.079	0.040	8.54
	6/19/2007	Base	3.38	0.07	0.61	0.078	0.041	4.62

3.3.2 Macroinvertebrates and Habitat

Typically, the results of the macroinvertebrate survey assist with directing watershed management decisions. However, streams within the Palestine Lake watershed all possessed poor quality macroinvertebrate communities with mIBI scores ranging from a low of 1.1 in Merritt Ditch to a high of 3.1 in Sloan Ditch (Table 16). Overall, the streams' macroinvertebrate communities were dominated by a mix of moderately tolerant and highly tolerant species. All streams within the Palestine Lake watershed rated as moderately to severely impaired. (Appendix C presents a list of macroinvertebrate families collected at each site.) Streams fall into two integrity classes with Sloan Ditch, Williamson Ditch, Adams Ditch, and Sloan-Adams Ditch rating as moderately impaired, while Ring Ditch, Magee-Robbins Ditch, Merritt Ditch, and Trimble Creek rated as severely impaired. Although these streams' scores differ slightly, the two sets of streams fell into similar biotic integrity classes. Karr and Chu (1999) indicate that differences between scores *within* an integrity class are not statistically significant; these differences within integrity classes often reflect the large variability associated with sampling natural biological communities rather than true differences in community quality.

Table 16. Summary of classification scores and mIBI scores for each stream sampling site within the Palestine Lake watershed streams.

Metric	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 8
HBI	0	0	0	2	0	0	0
Number of Taxa (families)	8	0	4	2	2	6	4
Number of Individuals	0	2	2	0	2	2	0
Percent Dominant Taxa	4	2	2	4	0	4	0
EPT Index	4	0	0	0	2	0	0
EPT Count	0	0	0	0	0	0	0
EPT Count/Total Count	0	0	0	0	2	0	0
EPT Abundance/Chironomid Abundance	0	8	0	0	8	8	0
Chironomid Count	8	8	8	8	8	8	6
mIBI Score	**2.67**	**2.22**	**1.78**	**1.78**	**2.67**	**3.11**	**1.11**

The individual metrics that make up the mIBI highlight the differences between the macroinvertebrate communities in the watershed stream. The Hilsenhoff Family Biotic Index (HBI), which uses tolerance values for each family, varies between Williamson Ditch (Site 1), Magee-Robbins Ditch (Site 4), Adams Ditch (Site 5), Merritt Ditch (Site 8), and Trimble Creek (Site 9) and Sloan-Adams Ditch (Site 2), Ring Ditch (Site 3), and Sloan Ditch (Site 6) (see individual tables for HBI scores). In Williamson, Magee-Robbins, Adams, and Merritt ditches and Trimble Creek, the presence of more intolerant families generates lower HBI scores, which range from 5.5 to 6.4 compared to the HBI scores for Ring, Sloan-Adams, and Sloan ditches (7.7 to 7.9). The presence of large numbers of tolerant members of the Hemipteran family *Corixidae* and the Isopod family *Assilidae* in Ring, Sloan-Adams, and Sloan ditches and the Amphipod family *Gammaridae* in Williamson Ditch indicates that these ditches possess more tolerant species than those present in streams throughout the rest of the watershed. The poor mIBI scores calculated for macroinvertebrate communities that are present in streams throughout the watershed indicates that more than the HBI weigh into the poor ratings for the Palestine Lake watershed streams. The evenness of the taxa was relatively high among all streams. In Trimble Creek, members of the *Hirudinea* family comprised 30% of the total macroinvertebrates collected, while in Sloan-Adams Ditch and Merritt Ditch, members of the order Isopod family *Asillidae* account for 60 to 64% of the total macroinvertebrates collected. The streams supported varying number of EPT (*Ephemeroptera, Plecoptera*, and *Trichoptera*) taxa. Ring Ditch and Trimble Creek were home to zero EPT taxon, while Williamson Ditch supported four EPT taxa. Densities of EPT individuals were also different among the streams. Adams Ditch possessed a total of 14 EPT individuals, while Sloan-Adams Ditch possessed a total of seven EPT individuals. All other streams contained three or less individuals Given these differences in individual metrics among the watershed streams, it may be useful to consider each of the streams' macroinvertebrate communities individually. Additionally, it should be noted that overall, the macroinvertebrate communities within the Palestine Lake watershed streams rate relatively poorly.

Williamson Ditch (Site 1)

Low numbers of individuals, a high HBI score, low density of EPT individuals, and low EPT count to total count and EPT count to Chironomid count characterize the macroinvertebrate community in Williamson Ditch (Table 17). Four members of the EPT taxa were identified within Williamson

Ditch; however, only one individual represents each of the EPT taxa. The EPT taxa that were present within Williamson Ditch represent moderately tolerant families. Members of the *Decopod* family, in the order *Camberidae*, or crayfish dominate the stream's macroinvertebrate community accounting for 32% of the community. This family is considered ubiquitous and is silt tolerant; therefore, its presence in Williamson Ditch is not surprising. Members of the very tolerant *Chironomidae* family and the order *Oligochete* were subdominant components of Williamson Ditch's macroinvertebrate community. The stream's Hilsenhoff family biotic index (HBI) was 6.16 indicating moderate organic pollution is likely in the stream. The water chemistry results agree with this assessment. Habitat impairment may also be influencing the biotic community at this. Overall, the stream's mIBI score was 2.7, suggesting its macroinvertebrate community is moderately impaired.

Table 17. Raw metric scores, classification scores, and mIBI score for Williamson Ditch (Site 1), June 17, 2007.

mIBI Metric	Raw Score	Metric Score
HBI	6.16	0
Number of Taxa (family)	20	8
Number of Individuals	37	0
% Dominant Taxa	32.4	4
EPT Index	4	4
EPT Count	4	0
EPT Count/Total Count	0.11	0
EPA Abundance/Chironomid Abundance	0.44	0
Chironomid Count	9	8
	mIBI Score	**2.7**

Sloan-Adams Ditch (Site 2)

The very tolerant (*Asillidae*) family dominates Sloan-Adams Ditch's macroinvertebrate community. Individuals from this family accounts for 61% of the stream's total macroinvertebrate population. The stream's HBI score reflects the dominance of extremely tolerant families (Table 18). The stream's elevated HBI score of 7.94 is indicative of substantial organic pollution. The water chemistry sampling supports this. Sloan-Adams Ditch exhibited relatively high total phosphorus and total organic nitrogen concentrations at base and storm flow. The stream supports one EPT family: the moderately tolerant mayfly family *Heptigeniidae*. Overall, the stream's mIBI score was 2.2, suggesting its macroinvertebrate community is moderately impaired.

Table 18. Raw metric scores, classification scores, and mIBI score for Sloan-Adams Ditch (Site 2), June 17, 2007.

mIBI Metric	Raw Score	Metric Score
HBI	7.94	0
Number of Taxa (family)	7	0
Number of Individuals	104	2
% Dominant Taxa	60.6	2
EPT Index	1	0
EPT Count	3	0
EPT Count/Total Count	0.03	0
EPA Abundance/Chironomid Abundance	MAX	8
Chironomid Count	0	8
	mIBI Score	**2.2**

Ring Ditch (Site 3)

Like the other watershed streams, Ring Ditch contains a relatively poor macroinvertebrate community. Ring Ditch's community is dominated by the tolerant Hemipteran family *Corixidae*. The highly tolerant Dipteran family *Chironomidae* and Isopod family *Asillidae* were subdominant within Ring Ditch. Ring Ditch does not contain any families representing EPT taxa (Table 19). The ditch's HBI score was 7.68, indicating that substantial organic pollution was likely in the stream. The results of the water chemistry assessment showed the ditch contained moderate total organic nitrogen levels relative to the other watershed streams. Habitat may also play a role in the observed severely impaired mIBI score of 1.8.

Table 19. Raw metric scores, classification scores, and mIBI score for Ring Ditch (Site 3), June 17, 2007.

mIBI Metric	Raw Score	Metric Score
HBI	7.68	0
Number of Taxa (family)	12	4
Number of Individuals	100	2
% Dominant Taxa	44.0	2
EPT Index	0	0
EPT Count	0	0
EPT Count/Total Count	0.00	0
EPA Abundance/Chironomid Abundance	0.00	0
Chironomid Count	19	8
	mIBI Score	**1.8**

Magee-Robbins Ditch (Site 4)

Low individual density and low taxa diversity characterize Magee-Robbins Ditch's macroinvertebrate community (Table 20). Two members of the EPT taxa were identified within Magee-Robbins Ditch, members of the Ephemeroptera family *Heptigeniidae* and members of the Trichopteran family *Hydropsyidae*. These families are considered silt tolerant; therefore, their presence in Magee-Robbins Ditch is not surprising. Members of the *Chironomidae* family dominate the stream's macroinvertebrate community accounting for 39% of the community. The silty substrate present at the Magee-

Robbins Ditch sampling site is ideal habitat for *Chironomidae*, so the dominance of this family at this sampling site is not surprising. The stream's Hilsenhoff family biotic index (HBI) was 5.46 indicating moderate organic pollution is likely in the stream. The water chemistry results agree with this assessment. Habitat impairment may be influencing the biotic community at this site. Overall, the stream's mIBI score was 1.8, suggesting its macroinvertebrate community is severely impaired.

Table 20. Raw metric scores, classification scores, and mIBI score for Magee-Robbins Ditch (Site 4), June 17, 2007.

mIBI Metric	Raw Score	Metric Score
HBI	5.46	2
Number of Taxa (family)	9	2
Number of Individuals	51	0
% Dominant Taxa	39.2	4
EPT Index	2	0
EPT Count	7	0
EPT Count/Total Count	0.14	0
EPA Abundance/Chironomid Abundance	0.35	0
Chironomid Count	20	8
	mIBI Score	**1.8**

Adams Ditch (Site 5)
Highly tolerant (*Asillidae*) and moderately tolerant (*Elmidae*) families dominate Adams Ditch's macroinvertebrate community. Individuals from the *Asillidae* family account for 64% of the stream's total macroinvertebrate population. The stream's HBI score reflects the dominance of extremely tolerant families (Table 21). The stream's elevated HBI score of 6.39 is indicative of moderate organic pollution. The stream did support three EPT families including two moderately and severely tolerant mayfly and caddisfly families and one intolerant stone fly family. Overall, the stream's mIBI score was 2.7, suggesting its macroinvertebrate community is moderately impaired.

Table 21. Raw metric scores, classification scores, and mIBI score for Adams Ditch (Site 5), June 17, 2007.

mIBI Metric	Raw Score	Metric Score
HBI	6.39	0
Number of Taxa (family)	8	2
Number of Individuals	102	2
% Dominant Taxa	63.7	0
EPT Index	3	2
EPT Count	18	0
EPT Count/Total Count	0.18	2
EPA Abundance/Chironomid Abundance	MAX	8
Chironomid Count	0	8
	mIBI Score	**2.7**

Sloan Ditch (Site 6)

Like the other watershed streams, tolerant (*Corixidae* and *Asselidae*) families dominate Sloan Ditch. The ditch possessed the highest diversity with 15 families represented in the macroinvertebrate community (Table 22). Two of the families found in Sloan Ditch were EPT families; however, these families were present in low density. The ditch's HBI score was 7.91, indicating that high amounts of organic pollution was likely in the stream. Habitat may also play a role in the observed moderately impaired macroinvertebrate community which rated a mIBI score of 3.1.

Table 22. Raw metric scores, classification scores, and mIBI score for Sloan Ditch (Site 6), June 17, 2007.

mIBI Metric	Raw Score	Metric Score
HBI	7.91	0
Number of Taxa (family)	15	6
Number of Individuals	103	2
% Dominant Taxa	35.9	4
EPT Index	2	0
EPT Count	3	0
EPT Count/Total Count	0.03	0
EPA Abundance/Chironomid Abundance	MAX	8
Chironomid Count	0	8
	mIBI Score	**3.1**

Merritt Ditch (Site 8)

Low individual density and low density and diversity of EPT taxa and individuals characterize Merritt Ditch's macroinvertebrate community (Table 23). Only two members of the EPT taxa were identified within Merritt Ditch, members of the Ephemeroptera family *Siphlonuridae* and of the Plecopteran family *Chloroperlidae*. These families are considered moderately tolerant to intolerant; therefore, their presence in Merritt Ditch is somewhat surprising. Members of the *Chironomidae* family dominate the stream's macroinvertebrate community accounting for 63% of the community. The silty substrate present at the Merritt Ditch sampling site is ideal habitat for *Chironomidae*, so the dominance of this family at this sampling site is not surprising. The stream's Hilsenhoff family biotic index (HBI) was 5.72 indicating moderate organic pollution is likely in the stream. Overall, the stream's mIBI score was 1.1, suggesting its macroinvertebrate community is severely impaired.

Table 23. Raw metric scores, classification scores, and mIBI score for Merritt Ditch (Site 8), June 17, 2007.

mIBI Metric	Raw Score	Metric Score
HBI	5.72	0
Number of Taxa (family)	13	4
Number of Individuals	67	0
% Dominant Taxa	62.7	0
EPT Index	2	0
EPT Count	5	0
EPT Count/Total Count	0.07	0
EPA Abundance/Chironomid Abundance	0.12	0
Chironomid Count	42	6
	mIBI Score	**1.1**

Trimble Creek (Site 9)
Moderately tolerant (*Geridae*) and very tolerant (*Asillidae*) families dominate Trimble Creek's macroinvertebrate community. Individuals from the two most tolerant families account for more than half (57%) of the stream's total macroinvertebrate population. The stream's HBI score reflects the dominance of extremely tolerant families (Table 24). The stream's elevated HBI score of 6.15 is indicative of moderate organic pollution. The water chemistry sampling supports this. The stream did not support any EPT families. Overall, the stream's mIBI score was 1.6, suggesting its macroinvertebrate community is severely impaired.

Table 24. Raw metric scores, classification scores, and mIBI score for Trimble Creek (Site 9), June 17, 2007.

mIBI Metric	Raw Score	Metric Score
HBI	6.15	0
Number of Taxa (family)	7	0
Number of Individuals	63	0
% Dominant Taxa	30.2	6
EPT Index	0	0
EPT Count	0	0
EPT Count/Total Count	0.00	0
EPA Abundance/Chironomid Abundance	0.00	0
Chironomid Count	9	8
	mIBI Score	**1.6**

3.2.3 Habitat

In addition to a stream's water chemistry, habitat quality also influences the quality of the biotic community inhabiting the stream. Thus, it is useful to examine the habitat quality of the stream in the Palestine Lake watershed. Table 25 presents the results of the QHEI calculated at each of the nine study sites. (Appendix D presents the QHEI data sheets for each of the nine study sites.) The following paragraphs provide a short description of the in-stream and riparian characteristics observed at each of the study sites.

Table 25. QHEI scores for the Palestine Lake watershed streams, June 17, 2007.

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**
Williamson Ditch (1)	3	6	10	6.3	5	3	6	**39.3**
Sloan-Adams Ditch (2)	1	6	10	9	0	2	6	**34**
Ring Ditch (3)	1	6	10	7	3	2	6	**35**
Magee-Robbins Ditch (4)	6	12	9	7.5	5	2	10	**51.5**
Adams Ditch (5)	15	15	15	7.3	0	3	6	**61.3**
Sloan Ditch (6)	1	6	10	7	3	2	6	**35**
Kuhn Ditch (7)	2	10	9	3	0	0	10	**34**
Merritt Ditch (8)	12	10	7	7	0	3	8	**47**
Trimble Creek (9)	12	13	11	6	5	3	8	**58**

Williamson Ditch (Site 1)

The predominant land use along this reach of Williamson Ditch were forest and residential (Figure 33). The riparian zone extended between 30 and 50 feet (9.1 and 15.2 m) on the right bank and between 15 and 30 feet (4.6 and 9.1 m) on the left bank. Riparian vegetation was dominated by trees. Overhanging vegetation, and to a lesser extent woody debris and rootwads, provided sparse instream cover. Bank stability was low and the streambanks were comprised of silty muck soils. Sinuosity was low, but no evidence of channelization was present. Substrate composition at this site was 90% muck and 10% gravel; detritus and artificial substrates were also present. The organic composition consisted of 10% coarse particulate organic matter (CPOM) and 90% fine particulate organic matter (FPOM) or muck. Instream conditions were quite poor with low substrate stability, heavy siltation, and extensive embeddedness. This reach of Williamson Ditch scored relatively low when compared with other streams within the Palestine Lake watershed with a QHEI score of 39.3 out of 100.

Figure 33. Williamson Ditch (Site 1) sampling site.

Sloan-Adams Ditch (Site 2)

The predominant land use at this site was forest (Figure 34). The riparian zone extended beyond 150 feet (45.7 m) on both banks. Riparian vegetation was dominated by trees and shrubs. Overhanging vegetation, and to a lesser extent woody debris and shallows, provided sparse instream cover. Bank stability was low and streambanks were comprised of a silty muck. Sinuosity was low, but no evidence of channelization was present. Substrate composition at this site was 95% muck with some detritus and artificial substrate. The organic composition consisted of 20% CPOM and 80% FPOM or muck. Instream conditions were quite poor with low substrate stability, heavy siltation, and extensive embeddedness. Along this reach, Sloan-Adams Ditch scored the lowest of the Palestine Lake watershed streams with a QHEI score of 34 out of 100.

Figure 34. Sloan-Adams Ditch (Site 2) sample site.

Ring Ditch (Site 3)

The dominant land use types at this site were row crop agriculture (left) and forested floodplain wetland with forest (right) (Figure 35). The riparian zone extended approximately 30 to 50 feet (9.1 to 15.2 m) on the left side of the stream and over 150 feet (45.7 m) on the right side. Riparian vegetation was dominated by trees and tall forbs. Sparse instream cover was provided by overhanging vegetation, undercut banks, woody debris, and artificial substrate. Bank stability was low and comprised of a silty muck. Sinuosity was low, but no evidence of channelization was present. The substrate composition at this site was 95% muck, 5% detritus and artificial. The organic composition consisted of 90% FPOM and 10% CPOM. Instream conditions were quite poor with low substrate stability, heavy siltation, and extensive embeddedness. This reach of Ring Ditch scored the second lowest of the Palestine Lake watershed streams with a QHEI score of 35 out of 100.

Figure 35. Ring Ditch (Site 3) sample site.

Magee-Robbins Ditch (Site 4)

The predominant surrounding land use at this site was residential (Figure 36). The riparian zone extended over 150 feet (45.7 m) on each bank. Riparian vegetation was dominated by grasses with some trees. Undercut banks, shallows, boulders, aquatic macrophytes, and woody debris combined to provide moderate instream cover. Bank stability was low and the streambanks were comprised of fine sediments. Sinuosity was low along this reach of Magee-Robbins Ditch and shows signs of recovering from channelization. Substrate composition at this site was 60% sand; 30% silt and muck; and 10% boulders, gravel, and detritus. The organic composition consisted of 35% CPOM and 65% FPOM or muck. Instream conditions were moderate with low substrate stability, extensive embeddedness and moderate pool/riffle development. This reach of Magee-Robbins Ditch scored relatively high when compared with Palestine Lake watershed streams with a QHEI score of 51.5 out of 100.

Figure 36. Magee-Robbins Ditch (Site 4) sample site.

Adams Ditch (Site 5)
The predominant surrounding land use at this reach was forest (Figure 37). The riparian zone extended over 150 feet (45.7 m) on the left side, and 15 to 30 feet (4.5 to 9.1 m) on the right side. Riparian vegetation was dominated by trees. Overhanging vegetation, undercut banks, woody debris, and rootwads provided extensive instream cover. Bank stability was moderate. Sinuosity was low, but no evidence of channelization was present. Substrate composition at this site was 60% sand, 35% gravel, and 5% detritus and muck. The organic composition consisted of 55% CPOM and 45% FPOM or muck. Instream conditions were good with moderate substrate stability, moderate embeddedness and moderate pool/riffle development. Adams Ditch along this reach scored the highest of the Palestine Lake watershed streams with a QHEI score of 61.3 out of 100.

Figure 37. Adams Ditch (Site 5) sample site.

Sloan Ditch (Site 6)
The predominant surrounding land use at this site was residential (Figure 28). The riparian zone extended over 150 feet (45.7 m) on each side. Riparian vegetation was dominated by trees and grasses. Overhanging vegetation, woody debris, and aquatic macrophytes provide sparse instream cover. Bank stability was low with the streambanks comprised of a silty muck. Sinuosity was low, but no evidence of channelization was present. Substrate composition at this site was 90% muck and 5% detritus and artificial. The organic composition consisted of 35% CPOM and 65% FPOM or muck. Instream conditions were poor with low substrate stability, extensive embeddedness, and poor pool/riffle development. This reach of Sloan Ditch scored the second lowest of the Palestine Lake watershed streams with a QHEI score of 35 out of 100.

Figure 38. Sloan Ditch (Site 6) sampling site.

Kuhn Ditch (Site 7)

The predominant surrounding land uses at this site were agriculture and forest (Figure 39). The riparian zone extended 3 to 15 feet (0.9 to 4.6 m) on both sides. Riparian vegetation was dominated upstream by agricultural crops and downstream by grasses and small trees. Instream cover included overhanging vegetation, shallows, and logs or woody debris. Bank stability was moderate. No sinuosity was present, but the site is recovering from channelization. Substrate composition at this site was 75% silt and muck and 25% artificial. The organic composition consisted of 40 CPOM and 60% FPOM or muck. Instream conditions were moderate with moderate substrate stability, low embeddedness and no pool/riffle development. This reach of Kuhn Ditch earned the lowest score when compared to Palestine Lake watershed streams; this site's score was 34 out of 100.

Figure 39. Kuhn Ditch (Site 7) sampling site downstream of the sample site.

Merritt Ditch (Site 8)
The predominant surrounding land use at this site was agriculture (Figure 40). The riparian zone extended over 150 feet (45.7 m) on both sides. Riparian vegetation was dominated by grasses and sparse shrubs. Instream cover included overhanging vegetation, shallows, and aquatic macrophytes. Bank stability was moderate. No sinuosity was present, but the site is recovering from channelization. Substrate composition at this site was 75% sand, 20% gravel, and 5% silt and muck. The organic composition consisted of 40% CPOM and 60% FPOM or muck. Instream conditions were moderate with moderate substrate stability, moderate embeddedness and no pool/riffle development. This reach of Merritt Ditch scored relatively high when compared with Palestine Lake watershed streams; this site's scored 47 out of 100.

Figure 40. Merritt Ditch (Site 8) sampling site.

Trimble Creek (Site 9)
The predominant surrounding land use at this site was agriculture (Figure 41). The riparian zone extended beyond 150 feet (45.7 m) on both banks. Riparian vegetation was dominated by trees. Overhanging vegetation, woody debris, undercut banks, shallows, aquatic macrophytes, and rootwads provided moderate instream cover. Bank stability was moderate with moderate bank erosion. Sinuosity was low, but no evidence of channelization was present. Substrate composition at this site was 85% sand, 10% gravel, and 5% silt and muck. The organic composition consisted of 35% CPOM and 65% FPOM or muck. Instream conditions were moderate with moderate substrate stability, low embeddedness, and moderate pool/riffle development. This reach of Trimble Creek scored the second highest of the Palestine Lake watershed streams with a QHEI score of 58 out of 100.

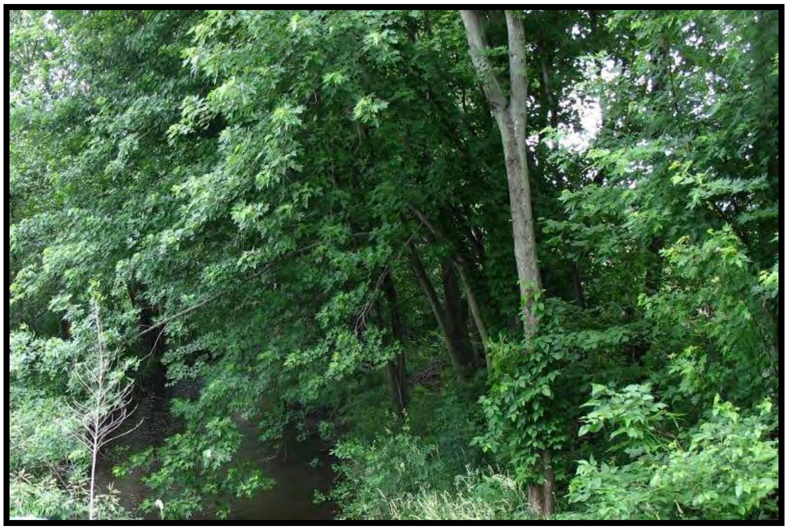

Figure 41. Trimble Creek (Site 9) sampling location.

The QHEI scores help explain the low biotic integrity scores observed in the Palestine Lake watershed streams. The QHEI scores indicate that instream and riparian habitat is impaired at all sites. Magee-Robbins Ditch, Trimble Creek, and Adams Ditch reaches possessed the highest QHEI scores of 61.3, 58, and 51.5 respectively (Table 26). These scores suggest that these streams should be capable of supporting a moderately healthy warmwater fauna. Both Adams Ditch and Trimble Creek possessed QHEI scores in IDEM's "partially supportive" range. However, these streams' macroinvertebrate communities rated as moderately to severely impaired. Thus, it is likely that water quality played a greater role in impairing the biotic community in these streams than habitat quality. QHEI scores of the remaining watershed streams indicate severe habitat impairment. In these streams, both poor water quality and poor habitat quality play a role in impairing the streams' biotic communities.

Many of the sites share some common characteristics. Pools and riffles are absent or poorly developed in each of the watershed streams. Many of the streams offer only run habitat to aquatic biota. This lack of habitat diversity leads to a lack of biotic diversity since different organisms occupy different habitat types, or ***niches***, within a stream. The watershed streams also lack in-stream cover. This is especially true in the Williamson Ditch, Sloan-Adams Ditch, Ring Ditch, and Sloan Ditch. Substrate quality is relatively poor in each of the watershed streams, specifically in Williamson Ditch, Sloan-Adams Ditch, Ring Ditch, Sloan Ditch, and Merritt Ditch. The dominance of muck/silt substrate, heavy silt covering, and embeddedness of the substrate resulted in exceptionally poor substrate quality scores in these streams. Overall, habitat quality is generally poor in the Palestine Lake watershed streams and restoration measures are necessary to ensure healthy, functioning stream systems.

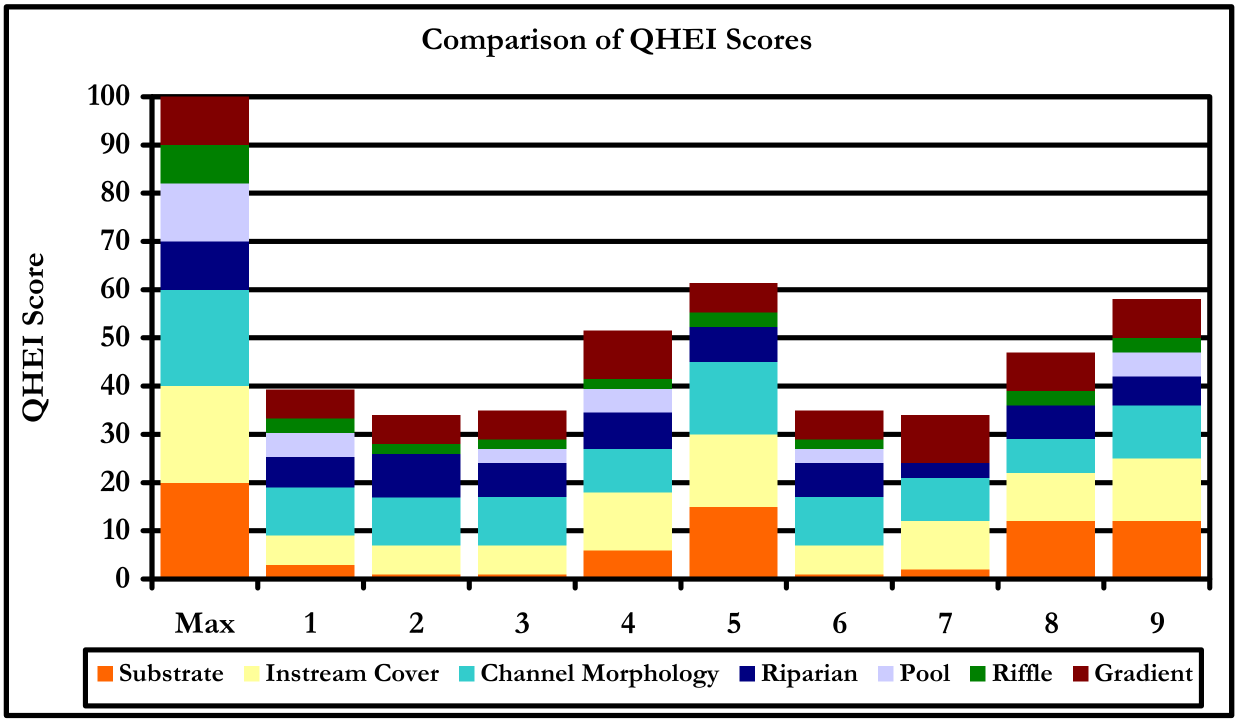

Table 26. QHEI metric scores for the Palestine Lake watershed streams, June 19, 2007.

3.4 <u>Stream Assessment Discussion</u>

The overall assessment of habitat quality for this study of the Palestine Lake watershed indicates that these streams are moderately to severely degraded. Each of the sites studied lack key elements of natural, healthy stream habitats, which in turn limits the processes and functions of these ecological systems. QHEI is used as a screening tool for regional variation in habitat quality (Rankin, 1989). The QHEI evaluations from each site indicate that the streams are lacking adequate substrate. Stream bottoms are dominated by silty materials that offer little habitat for stream macroinvertebrates. In addition, many of the streams are lacking sufficient pool and riffle development, and generally have poor in stream cover. The Palestine watershed is composed primarily of agricultural fields, and the riparian buffer is not adequate to filter sufficiently the agricultural runoff. The mIBI scores reflect the moderate to severely impaired habitat quality at each site.

Heavy sediment loading is an apparent factor in the degradation of the study sites, and several of the sites have accumulated a considerable amount of silt. This sedimentation leads to extensive substrate embeddedness severely limits habitat diversity within the stream channel by filling in gaps among rocks and gravel that benthic organisms would inhabit. This heavy sediment loading is reflected in the poor substrate scores of the QHEI evaluations. The range of substrate scores was 1 to 15 out of a possible 20, with the majority of the sites scoring poorly. Most of the sites show moderate streambank erosion which can be a source for some of the sediment, however, the surrounding land use most likely plays the dominant role in sediment loading.

Watersheds that are dominated by agricultural activity typically contain streams that have had their stream channel morphology greatly manipulated through bank shaping, dredging, and straightening. In addition, their very headwaters are likely disturbed or turned into agricultural land. Therefore, any filtering associated headwater habitat is lost. This puts to risk the integrity of the biological communities. Riffles and pools are important habitats in streams that provide greater habitat diversity and thus, greater macroinvertebrate and fish diversity. The lack of pool development is likely associated with land use alterations, past stream channelization, and the heavy sedimentation. These combined activities interfere with typical sorting of particles that forms both riffles and pools (Allan, 1995).

The mIBI scores in the Palestine watershed indicate moderate to severe impairment at each of the nine sites sampled. Healthy streams contain a diverse community of both species that are tolerant and intolerant to pollution. Streams which become impaired or polluted will tend to have few intolerant organisms, and will be largely comprised of tolerant species. Within the metrics of the mIBI, the Hilsenhoff Biotic Index (HBI) is calculated to rate the tolerance of the species found. Individual taxa are assigned values between 0 and 10 with 0 being least tolerant and 10 being the most tolerant (USGS, 2002). The lowest score among the nine sites was 5.46, with six out of the eight sites scoring over 6, suggesting the streams are largely comprised of pollution tolerant species. Ephemeroptera, Plecoptera, and Trichoptera (EPT) represent "pollution sensitive" orders, and their presence is often associated with healthy streams. Adams Ditch contained the highest count of 18 EPT individuals from three families, but that value is not high enough to garner additional points to the mIBI. This general lack of EPT taxa also suggests the presence of pollution in the Palestine watershed.

Along with suitable habitat in which to live, benthic communities also need sufficient water quality. The Ohio EPA found degraded biotic communities to be present when median nitrate-nitrogen concentrations exceeded 3-4 mg/L. (Base flow data should be used because base flow conditions will represent the residual nutrient concentrations in the stream (Ohio EPA, 1999)). Although not all of the sites exceeded 3 mg/L, nitrate-nitrogen concentrations and mIBI scores indicate a trend supportive of the Ohio EPA's conclusion that elevated nitrate levels can lead to degraded biotic communities.

According to QHEI and mIBI scores, the Palestine watershed streams are moderately to severely impaired. Only the best performing streams in the watershed were partially supportive of aquatic life by the QHEI standards set by IDEM. All of the mIBI scores recorded in the streams also indicate moderate to severe impairment based on the macroinvertebrate assemblages. These scores indicate that there is excessive sedimentation in the watershed causing QHEI scores to be low.

4.0 LAKE ASSESSMENT

4.1 Morphology

Morphology, or the size, depth, and shape of a lake, greatly influences the biotic (algae, plant, fish, etc.), and chemical and physical (nutrient concentrations, light penetration, wave speed, etc.) factors within a lake. As both biotic and chemical and physical factors influence water quality, morphology plays an important and overriding role in all aspects of a lake's quality. For this reason, Palestine and Caldwell lakes' morphologies are reviewed below.

4.1.1 Palestine Lake

Figure 42 presents Palestine Lake's complex morphology. The lake, which was created by damming Trimble Creek in 1893, consists of two separate basins. These basins each contain a deep hole that represents the original size and morphology of the two smaller lakes that were historically present within this location. These lakes were flooded to form the larger Palestine Lake as it exists today. The lake's west basin is the larger of the two basins and also contains the lake's deepest point. Palestine Lake reaches a depth of 31 feet (9.4 m) within the southwestern portion of this basin (Figure 40). With the exception of this deep hole, this basin is quite shallow with much of the lake's west basin covered by water measuring less than 8 feet (2.4 m). Palestine Lake's east basin follows a similar pattern. It contains one deep hole which reaches a depth of 21 feet (6.4 m) near the lake's northeastern edge. The east basin is, however, shallower than the west basin. Much of the east basin is covered by water with a maximum depth of 6 feet (1.8 m).

Figure 42. Palestine Lake bathymetric map. Source: IDNR, 1964.

Table 27. Morphological characteristics of Palestine Lake.

Characteristic	Value
Surface Area	291 acres (117.3 ha)
Volume	1,170 acre-feet (50,965,200 m^3)
Maximum Depth	31 feet (9.4 m)
Mean Depth	4 feet (13.2 m)
Shallowness Ratio	0.8
Shoalness Ratio	0.98
Shoreline Length	49,569 feet (15,109 m)
Shoreline Development Ratio	3.93:1

Palestine Lake possesses large expanses of shallow water. According to its depth-area curve (Figure 43), nearly 235 acres (95.1 ha) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 285 acres (114.6 ha) is covered by water less than 20 feet (6.1 m) deep. This translates into a very high shallowness ratio of 0.8 (ratio of area less than 5 feet (1.5 m) deep to total lake area) and an extremely high shoalness ratio of 0.98 (ratio of area less than 20 feet (6.1 m) deep to total lake area) (Table 27), as defined by Wagner (1990). Wagner (1990) indicates that lakes with shallowness ratios less than 0.1 (or 10% of the lake bottom) are very unlikely to be directly impacted by motor boat activity, while lake with shallowness ratios greater than 0.5 (or 50% of the lake bottom) are likely to be highly affected by motor boat activity. Given its extremely high shallowness ratio (0.8), Palestine Lake is likely very sensitive to impacts associated with motor boating. A large portion (90%) of the lake's acreage (approximately 46 acres or 32.5 ha) includes water shallower than 6 feet (1.8 m). The lake's area gradually increases with depth to a water depth of about 6 feet (1.8 m) before the rate of change increases. This rate (slope of lake bottom) continues to the lakes maximum depth (31 feet or 9.4 m).

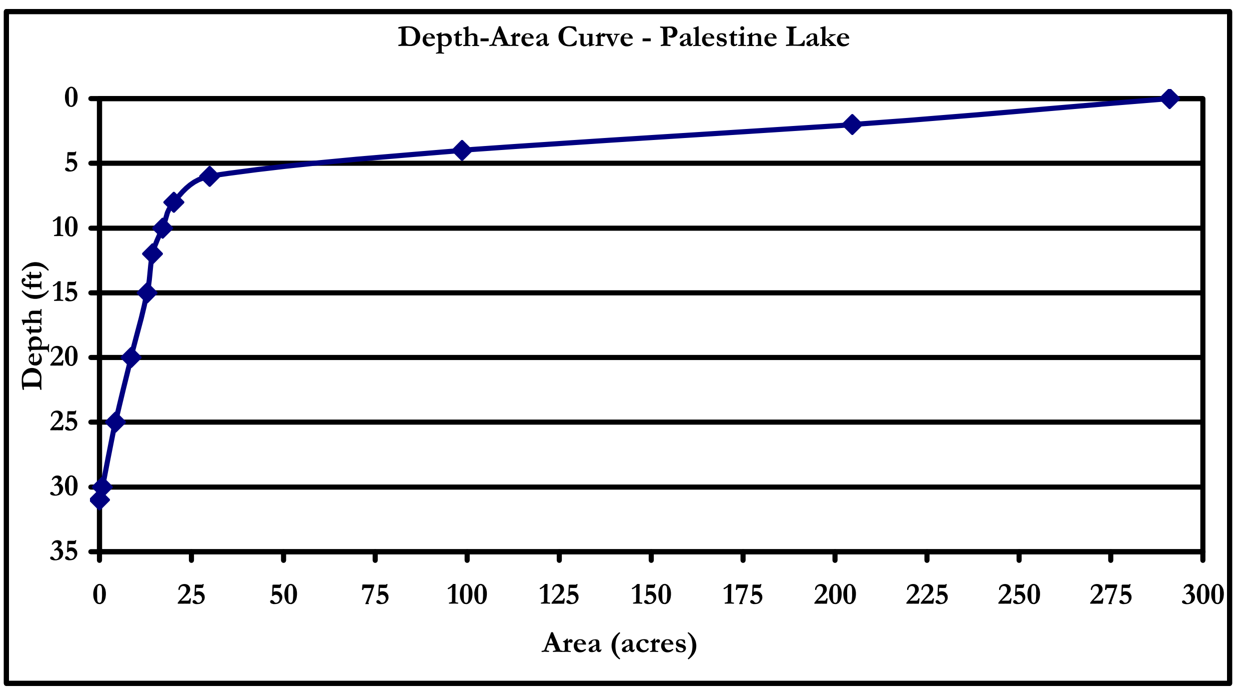

Figure 43. Depth-area curve for Palestine Lake.

Palestine Lake holds approximately 4,717 acre-feet (50,965,200 m^3) of water. As illustrated in the depth-volume curve (Figure 44), most of the lake's volume is contained in the shallower areas of the lake. More than 75% of the lake's volume is contained in water that is less than 6 feet (1.8m) deep. The lake's volume gradually increases with depth to a water depth of about 6 feet (1.8 m) before the rate of change increases. Below 6 feet (9.4 m), the steep curve indicates a greater change in depth per unit volume. This rate continues to the lakes maximum depth (31 feet or 9.4 m). The importance of this rate of increase will be discussed with regard to light penetration and the planktonic community in the Results Section.

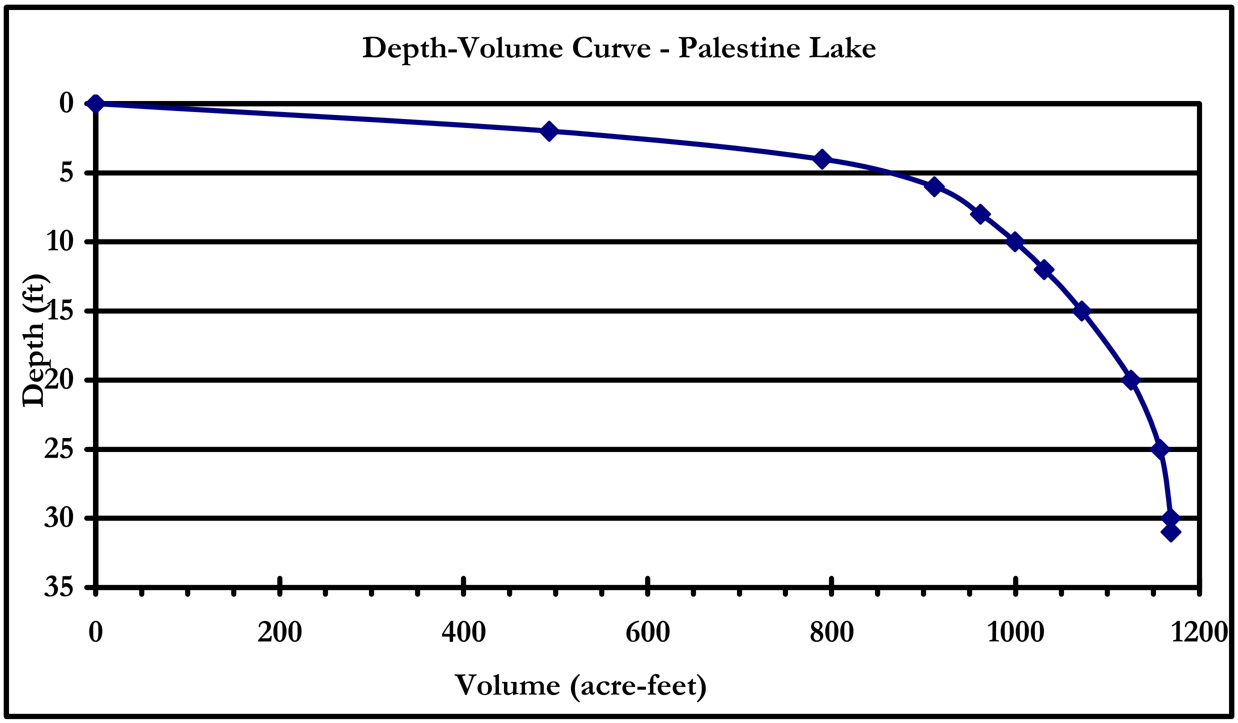

Figure 44. Depth-volume curve for Palestine Lake.

A lake's morphology can play a role in shaping the lake's biotic communities. For example, Palestine Lake's large shallow area and wide, shallow shelf around much of the perimeter of both basins 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, Palestine 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 feet (3.2 m). Referring to Palestine Lake's depth-area curve (Figure 43), this means that the lake's littoral zone is approximately 270 acres (109.3 ha) in size or approximately 94% of the lake. The lake's 1% light level (or the depth at which only 1% of available surface light penetrates) is less than the littoral zone calculated by multiplying the transparency by a factor of three. Using the second method, Palestine Lake's littoral zone reaches a depth of 8.5 feet (2.6 m) and covers 260 acres (105.2 h) or 89% of the lakes surface area. 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 Palestine Lake (291 acres or 117.3 ha) would have a circumference of 12,599 feet (3,840 m). Dividing Palestine Lake's shoreline length (49,569 feet or 15,108 m) by 12,599 feet yields a ratio of 3.93:1. This ratio is extremely high. Palestine Lake is very convoluted and possesses two basins. Its shape is very similar other reservoirs located throughout the state. Despite the extremely high shoreline development ratio it should be noted that Palestine Lake lacks extensive shoreline channeling observed on other popular Indiana lakes such as the Barbee Chain Lakes 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. Despite its extremely high shoreline development ratio, Palestine Lake actually possesses a relatively small overall length of shoreline covered by residential development, which often leads to decreased water quality. Nonetheless, Palestine Lake's large shoreline development ratio suggests that shoreline activities have a large impact on the water quality of the lake.

4.1.2 Caldwell Lake

Figure 45 presents Caldwell Lake's relatively simplistic morphology. The lake contains one deep hole surrounded by gradually shallower water. The lake's deepest point lies slightly north of the center of the 45-acre (18.2-ha) lake. Here, the lake extends to it maximum depth of 42 feet (12.8 m; Table 28). The northern half of the lake is shallower than the southern half; however, no other deep holes or islands are present within Caldwell Lake (Figure 45).

Table 28. Morphological characteristics of Caldwell Lake.

Characteristic	Value
Surface Area	45 acres (18.2 ha)
Volume	805 acre-feet (992,953 m^3)
Maximum Depth	42 feet (12.8 m)
Mean Depth	17.8 feet (5.4 m)
Shallowness Ratio	0.2
Shoalness Ratio	0.6
Shoreline Length	8,306 feet (2,531 m)
Shoreline Development Ratio	1.67:1

Caldwell Lake possesses limited expanses of shallow water. According to its depth-area curve (Figure 46), nearly 9 acres (3.7 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 0.2 (ratio of area less than 5 feet (1.5 m) deep to total lake area) and a high shoalness ratio of 0.6 (ratio of area less than 20 feet (6.1 m) deep to total lake area) (Table 13), as defined by Wagner (1990). The lake's area gradually increases with depth from the lake's surface to the lake's maximum depth (42 feet or 12.8 m) with a relatively steady rate of change (representing the slope of lake bottom). Overall, the relatively proportionate distribution of water depths in Caldwell Lake should be noted.

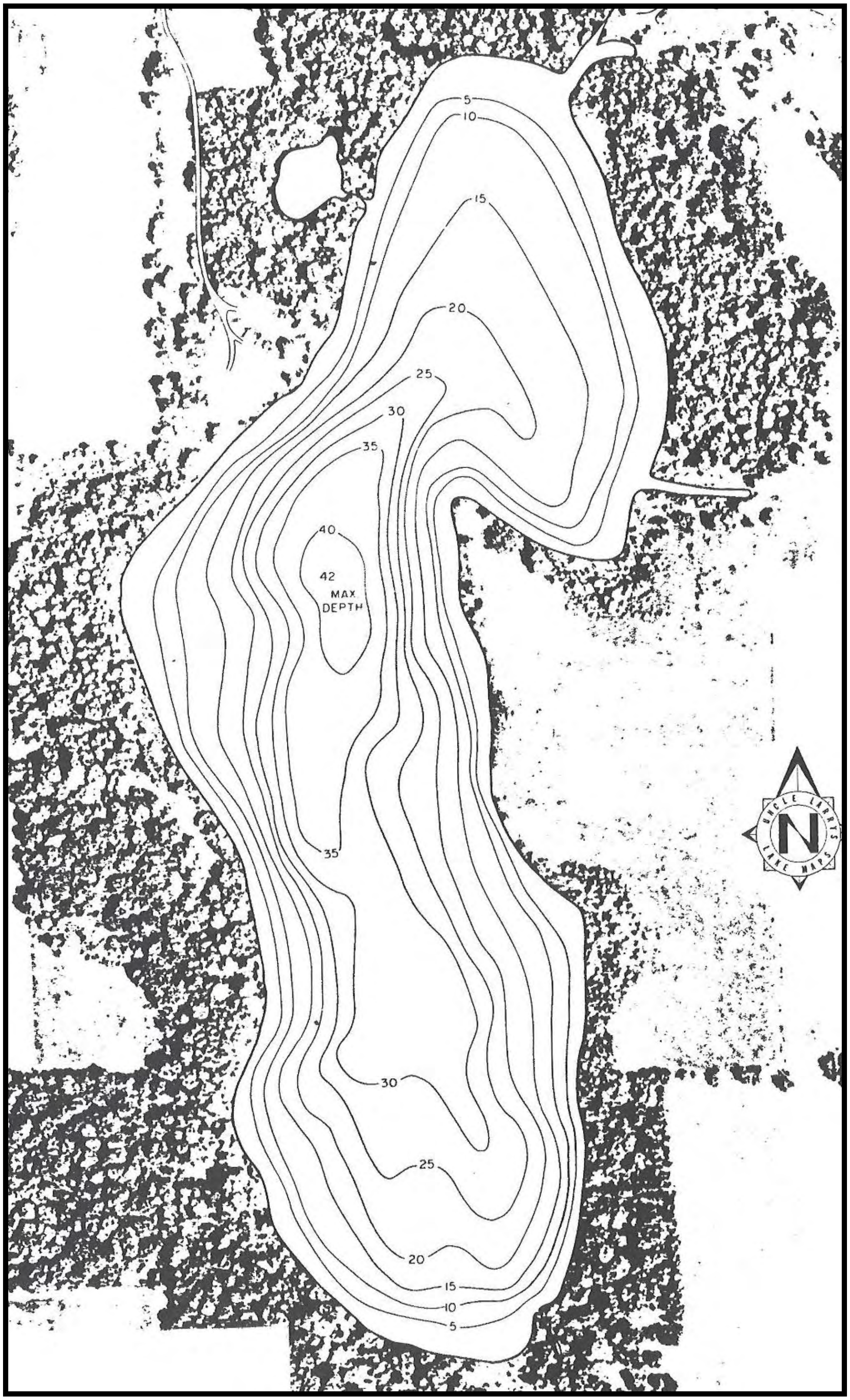

Figure 45. Caldwell Lake bathymetric map. Source: IDNR, 1960.

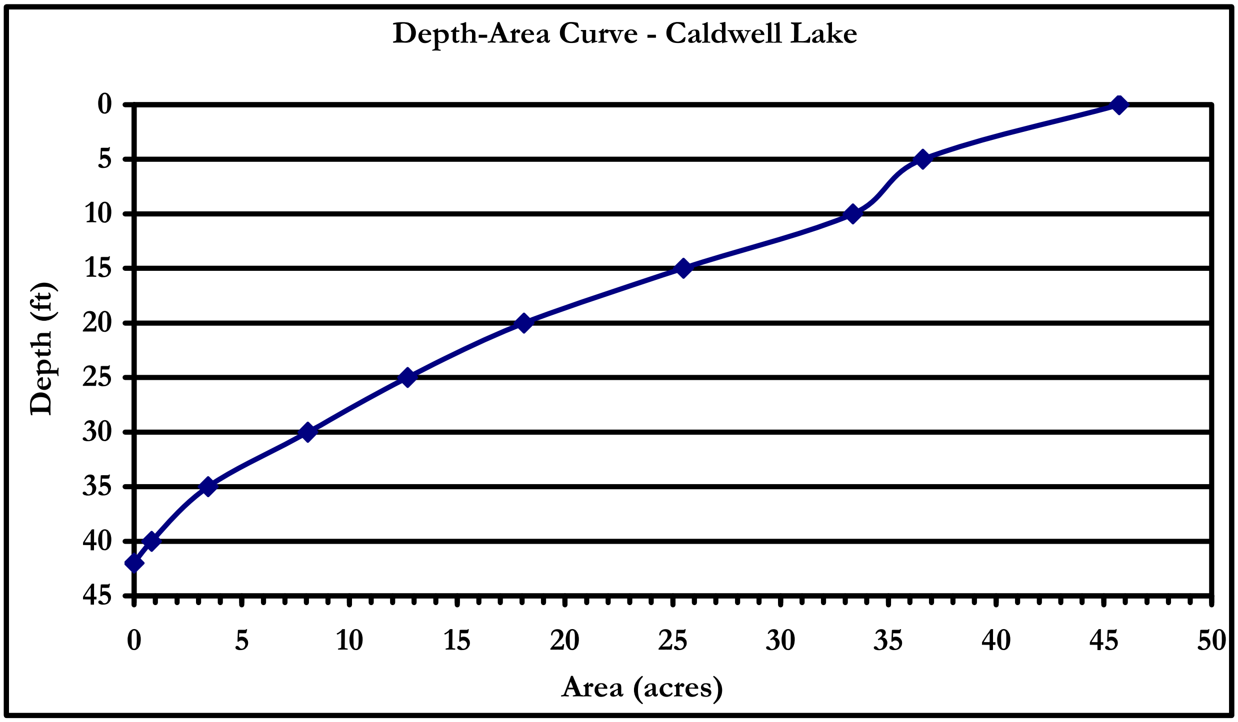

Figure 46. Depth-area curve for Caldwell Lake.

Caldwell Lake holds approximately 805 acre-feet (992,953 m^3) of water. As illustrated in the depth-volume curve (Figure 47), 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 20 feet (6.1m) deep. The lake's volume gradually increases with depth to a water depth of about 30 feet (9.1 m) before the rate of change increases. Below 30 feet (9.1 m), the steep curve indicates a greater change in depth per unit volume. This rate continues to the lakes maximum depth (42 feet or 12.8 m). The importance of this rate of increase will be discussed with regard to light penetration and the planktonic community in the Results Section.

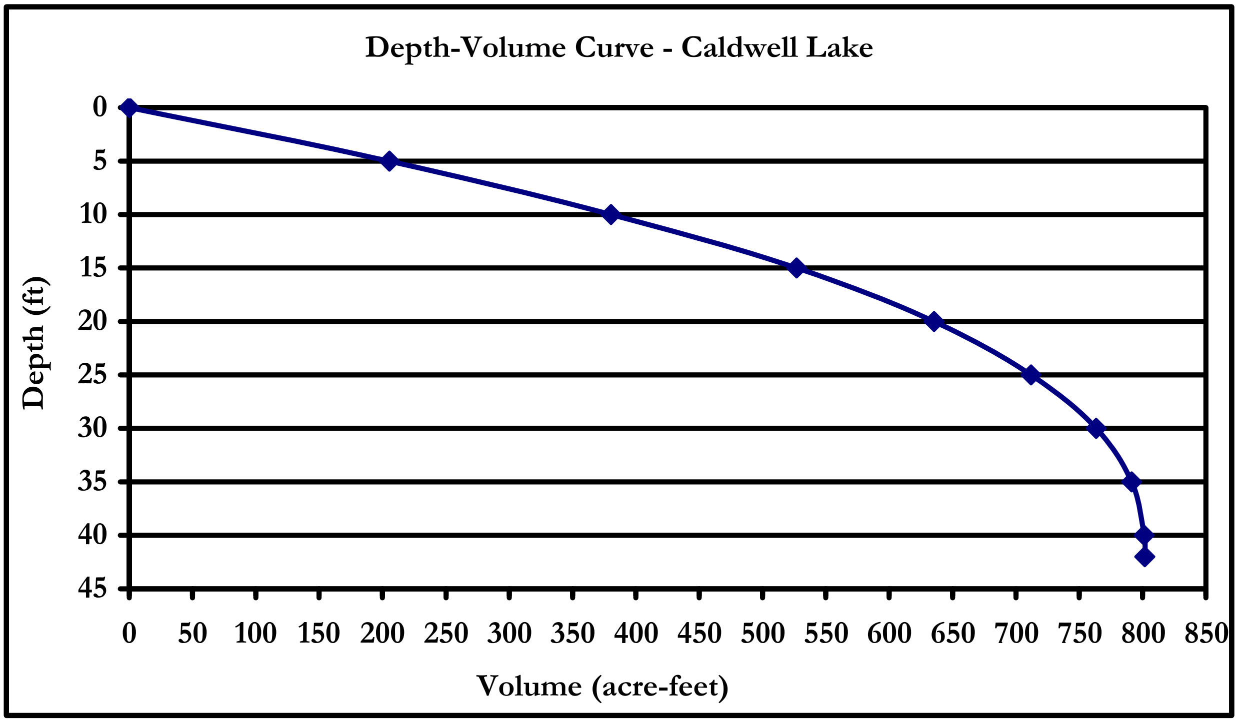

Figure 47. Depth-volume curve for Caldwell Lake.

As stated above, a lake's morphology can play a role in shaping the lake's biotic communities. For example, Caldwell Lake's limited shallow area and narrow, shallow shelf around much of the perimeter of the lake suggests that the lake is somewhat limited in its ability to support a quality rooted plant community. Based on the lake's clarity, Caldwell 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 31.5 feet (9.6 m). Referring to Caldwell Lake's depth-area curve (Figure 46), this means that the lake's littoral zone is approximately 36 acres (14.5 ha) in size or approximately 86% of the lake. The lake's 1% light level (or the depth at which only 1% of available surface light penetrates) is less than the littoral zone calculated by multiplying the transparency by a factor of three. Using the second method, Caldwell Lake's littoral zone reaches a depth of 19.7 feet (6 m) and covers 27 acres (10.9 h) or 60% of the lakes surface area. 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 Caldwell Lake (45 acres or 21.8 ha) would have a circumference of 4,963 feet (1,430.4 m). Dividing Caldwell Lake's shoreline length (8,306 feet or 2,531.7m) by 4,963 feet yields a ratio of 1.67:1. This ratio is relatively normal for most lakes in Indiana and is much lower than Palestine Lake's ratio. Caldwell Lake's shoreline is very regular and lacks inlets, bays, or channels that are typical of lakes in northern Indiana. Based on its shoreline development ratio, which suggests that shoreline and in-lake issues have a minimal effect on water quality within the lake, water quality improvement efforts should focus on watershed issues first before working to improve shoreline and in-lake issues.

4.2 Shoreline Development

4.2.1 Palestine Lake

Development along Palestine Lake's shoreline began relatively late with much of the housing construction beginning sometime between 1939 and 1957 (Figures 48 and 49). An aerial photograph from 1939 shows few houses around Palestine Lake. The lone residence was situated at the northwestern edge of the lake, along the bay leading to the outlet. Agricultural fields and wetland bordered a majority of the rest of the western basin shoreline. Most of the agricultural fields were separated from the lake by a narrow forested buffer. This indicates that the actual shoreline may not have been altered even though the adjacent land had been developed. In 1939, the shoreline of the eastern basin remained largely undeveloped with forest bordering a majority of the shoreline. Along the remainder of the shoreline, agriculture dominated the use of nearby land; however, forested buffers were generally wider than those on the western basin. During this time frame, open water appears to dominate Palestine Lake. However, it should be noted that photographs were taken in October, which is outside the growing season.

Figure 48. Aerial photograph of Palestine Lake circa October 1939.

Figure 49. Aerial photograph of Palestine Lake circa June 1957.

Much of the residential development along the shoreline of Palestine Lake began in the mid-1950's. The DNR established a public boat launch on the lake in 1953 (IDNR, no date). In 1957, aerial photographs show residential land at the north and south ends of the western basin. (Farm fields were previously present in these areas in the 1939 aerial photograph.) This residential land was likely newly built or in the process of development since the land had already been sectioned and roads had been installed but few houses had been built. The eastern basin remained undeveloped with little change between the 1939 and 1957 aerial photographs. A close look at the 1957 aerial suggests that much of Palestine Lake was covered by aquatic vegetation, likely water lilies or spatterdock, or algae mats. As the photograph was taken during June, this growth, and subsequent limited open water, are not surprising.

Development slowed after 1957. Aerial photography from 1965 shows little change in the shoreline of both basins of Palestine Lake after 1957. Between 1965 and 2005, housing density increased although the total amount of developed shoreline remained constant. No new areas of shoreline were developed between 1965 and 2005, as observed in aerial photographs taken during those years. However, the existing residential areas grew substantially between 1965 and 2005. In 1965, housing developments contained few houses (low housing density), although roads and infrastructure had already been constructed. In 2005, housing densities increased with the highest density occurring along the southwest corner of the lake (Figure 50).

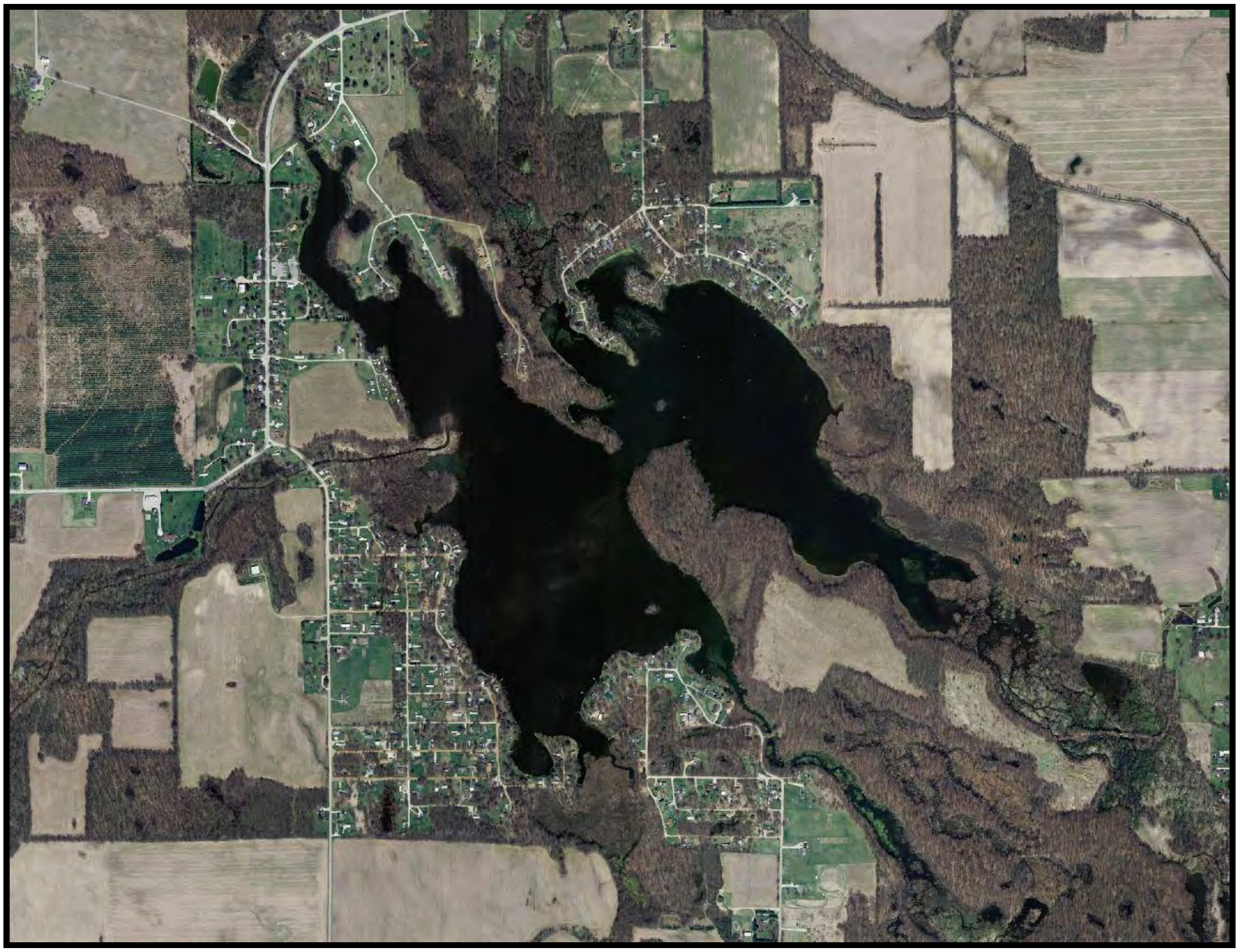

Figure 50. Aerial photograph of Palestine Lake circa 2005.

Based on recorded observations, it is like that much of the increase in housing density likely occurred prior to 1994. This idea is further supported by IDNR fisheries biologist's observations. In 1975, IDNR biologists noted the presence of 109 homes, 27 boats, 1 camp, and 1 marina along Palestine Lake (Shipman, 1976). DNR biologists estimated that 40% of the shoreline was developed. In 1994 and 1998, Indiana Clean Lakes Program field biologists estimated that residential land comprised approximately 60 and 65% of the shoreline, respectively. Both of these estimates occurred on the western basin of Palestine Lake. In 2006, CLP field biologists conducted surveys on both the western and eastern basins of Palestine Lake. They estimated that residential land comprised 40% of the shoreline of the western basin and 5% of the shoreline of the eastern basin. Wetlands and forested land comprised the rest of the shoreline of both basins.

More than 53% of Palestine Lake's shoreline (5,993 feet or 1827 meters) remains undeveloped and undisturbed (Figures 50 and 51). The rest of the shoreline has been developed with residential housing. Most of the residential land retains a natural or modified natural shoreline. However, seawalls have been installed along approximately 14.4% of the shoreline (1,845 feet or 562 meters).

Seawalls can diminish lake quality since they do not provide habitat for aquatic biota. Additionally, while seawalls protect shoreline in the area where they are installed, they can cause erosion and stability problems in adjacent sections of shoreline. This is due to the fact that seawalls divert wave energy but do not diminish it.

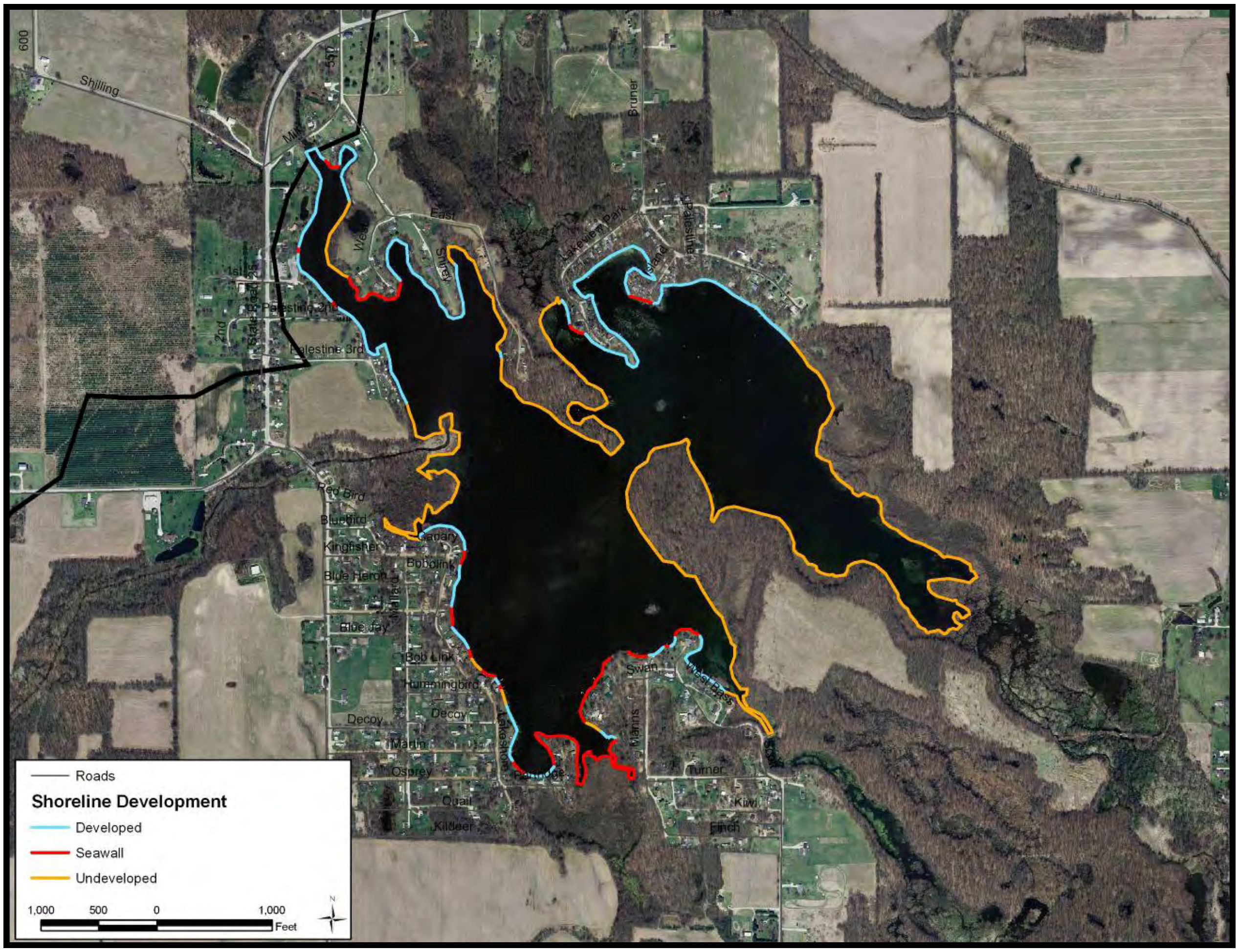

Figure 51. Shoreline development of Palestine Lake based on the shoreline survey completed August 3, 2007.

Figure 52. Natural shoreline observed at Palestine Lake on August 3, 2007.

Figure 53. Modified natural shoreline observed at Palestine Lake on August 3, 2007.

Figure 54. Modified shoreline present at Palestine Lake on August 3, 2007.

4.2.2 Caldwell Lake

Like the shoreline of Palestine Lake, the shoreline of Caldwell Lake has not been developed to the extent of most Indiana lakes. Two residential communities line the western shore of Caldwell Lake, comprising less than 24% (576 feet or 177 m) of the total shoreline (Figure 55). Seawalls have been installed along less than 6% (135 feet or 41 m) of the lake's shoreline. Forested land abuts a majority of the remaining shoreline. An old field lies next to part of the eastern shoreline with a narrow forested buffer separating the field from the lake. The presence of a forested buffer suggests that the actual shoreline has not been modified; however, evidence of livestock grazing in the forested area and the lake itself is present (Figure 52).

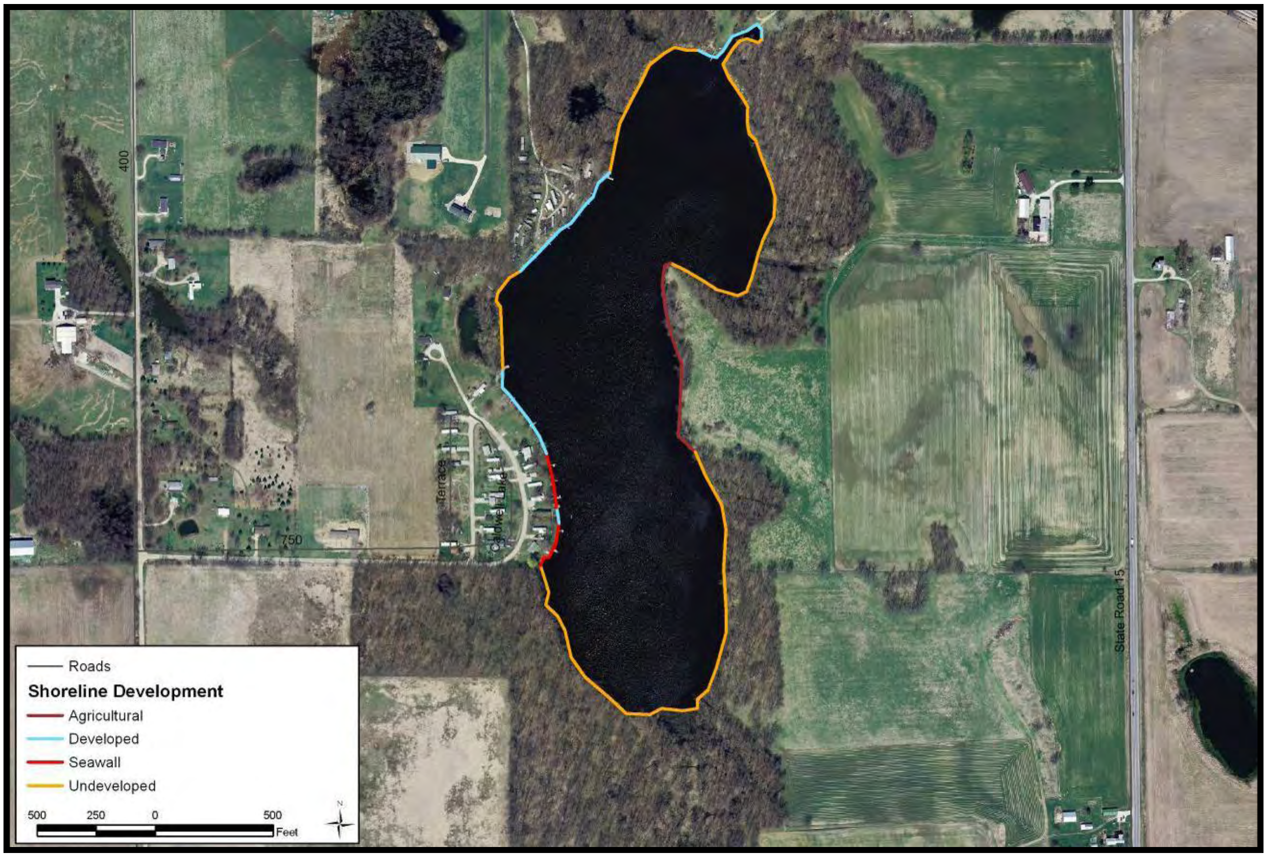

Figure 55. Shoreline development of Caldwell Lake based on the shoreline survey completed August 3, 2007.

4.3 Boat Usage

One of the most common impacts associated with motor boating is a decrease in water quality. As motor boats travel through shallow water, the energy from movement of the boat propeller may be sufficient to resuspend sediment from the lake bottom, decreasing the lake's water clarity. Several researchers have documented either an increase in turbidity or a decrease in Secchi disk transparency during and following motor boat activity (Wagner, 1991; Asplund, 1996; Yousef et al., 1980). Crisman (1986) reported a decrease in Secchi disk transparency following holiday weekend use of Lake Maxinkuckee in Culver, Indiana.

Depth, substrate composition, and vegetative cover can all influence how boating activity impacts a lake. Motor boating will typically degrade water clarity more in shallower lakes than it will in deeper lakes. Wagner (1991) suggests little impacts from motor boating are likely in water deeper than 10-15 feet (3.0-4.6 m). Lakes with soft fine sediments are more likely to suffer from sediment resuspension than lakes with coarser substrates. Lakes with extensive rooted plant coverage throughout the littoral zone are less prone to motor boat related resuspension problems than lakes with sparse vegetation since plants help hold the lake's bottom substrate in place. Additionally, plant coverage can limit the amount of area accessible to boats, reducing the area of impact by boats.

Based on this information, some of Palestine Lake's physical characteristics predispose it to water clarity problems associated with motor boating. As discussed above, boats are likely to impact Palestine Lake due to its shallowness. Approximately 80% of the lake contains depths of 5 feet (1.5

m) or less. Thus, a large portion of Palestine Lake could be potentially subject to impacts due to motor boating.

Historical studies and observations suggest an abundance of aquatic vegetation within the lake during the summer. The Indiana State Department of Health (1976) observed large beds of spatterdock (*Nuphar advena*) and coontail (*Ceratophyllum demersum*) in many shallow areas around the lake. Multiple IDNR surveys detail extensive submergent vegetation along much of the shoreline. Current aquatic plant surveys also lend credence to the presence of aquatic vegetation (Figure 56). (See the **Aquatic Plant Discussion** for further detail.)

Figure 56. Photo of aquatic vegetation growth in Palestine Lake during August 2 and 3, 2007 surveys.

While these factors suggest that Palestine Lake may be susceptible to impacts on water clarity due to motor boating, the actual impact of boating may be less. With a surface area less than 300 acres, a 10 mile-per-hour speed limit applies to all boating activity on Palestine Lake. Therefore, actual use of the lake by motor boats and their associated impacts are likely limited. Observations recorded in July 2007 support this assessment. Table 29 presents boat counts as observed during July 2007. For each day, counts were conducted over a period of at least 7 hours. The count recorded on July 11, 2007 was thought to reflect normal usage conditions on the lake while the July 21, 2007 count (a Saturday) was chosen to document peak weekend use. The total number of boats on the lake during peak usage (17) increased by approximately 31% as compared to that during normal usage (13). However, under both peak and normal usage times the total number of boats on the lake was relatively low. Fishing boats comprised a majority of the usage during both boat counts. The largest single category of boats, motorized fishing boats, comprised 54% of all boats during normal usage periods and 59% during peak usage. Non-motorized fishing or recreational boats (jon boats and rowboats) together comprised 38% of all boats during normal usage. The number of people using jon boats or rowboats decreased during peak usage to 24%. While fishing still comprised the largest category of users on the lake during both normal and peak usage, recreational use did increase during peak usage. The percentage of people using pontoon boats increased during peak usage times to 18%, as compared to 8% of users during normal usage times.

Table 29. Boat counts completed on Palestine Lake during July 2007.

Date	Period	Bass Boats		Jon Boats		Rowboats		Pontoon		Total Count
		Count	Percent	Count	Percent	Count	Percent	Count	Percent	
7/11/07	Normal	7	53.85%	2	15.38%	3	23.08%	1	7.69%	13
7/21/07	Peak	10	58.82%	1	5.88%	3	17.65%	3	17.65%	17

With a 10 mph speed limit in place, boats likely impact Palestine Lakes less than most Indiana lakes. This does not mean that boats will have no effect on water clarity. The ability of a motor boat to resuspend sediment from the lake bottom depends on several factors. Yousef et al. (1978) found that while 50 horsepower (hp) motors were capable of mixing the water column to a depth of 15 feet (4.6 m), 10 hp motors were still capable of mixing the water column to a depth of 6 feet (1.8 m). In Palestine Lake, then, a 10 hp motor would still be capable of resuspending sediment in more than 80% of the lake. Additionally, the velocity of water at the lake bottom created by a motor boat depends on the boat's displacement, which is a function of boat length and speed. As a result of this relationship, boats at higher speeds do not automatically translate to a greater ability to resuspend sediments. Beachler and Hill (2003) suggest that boat speeds in the range of 7 to 12 mph may have the greatest potential to resuspend sediment from the lake bottom. While this range lies on the upper end of that allowed on Palestine Lake, it demonstrates that even these low speeds can affect water clarity.

It is important to note that the decrease in water clarity is not usually permanent. Once motor boating activity ceases, resuspended materials will sink to the lake bottom again. However, this process can take several days. Wagner (1991) found that while turbidity levels steadily decreased following boating activity in his shallow study lakes, the turbidity had not returned to baseline levels even two days after the activity. Crisman (1986) found similar lags on Lake Maxinkuckee. Thus, Palestine Lake residents may need to wait several days before their lake returns to its baseline clarity following use.

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

4.4 <u>Historical Water Quality</u>

4.4.1 Palestine Lake Historical Water Quality

The Indiana State Board of Health, Indiana Department of Natural Resources, Division of Fish and Wildlife, the Indiana Clean Lakes Program, and independent researchers conducted various water quality tests on the two basins of Palestine Lake. Much of the research has focused on the west basin but a number of assessments have also been completed on the east basin. Tables 30 and 31 present selected water quality parameters for these assessments of the west basin and east basin of Palestine Lake, respectively. Additional water quality data are included in Appendix E.

Table 30. Summary of historic data for the west basin of Palestine Lake.

Date	Secchi (ft)	Percent Oxic	epi pH	Mean TP (mg/L)	Plankton Density (#/L)	ITSI Score (based on means)	Data Source
1975	0.50	--	--	0.91*	--	--	Hippensteel, 1989
7/10/75	--	--	--	0.190	--	--	ISBH, 1976
8/4/75	2.5	33.3%	9.0	--	--	--	Shipman, 1976
6/8/76	3.3	25.0%	8.0	0.150	1,386	--	ISBH, 1976
7/6/76	2.5	25.0%	8.3	0.240	17160	28	ISBH, 1976
8/3/76	1.6	50.0%	8.3	0.480	23,892	39	ISBH, 1976
4/19/77	--	60.0%	--	0.060	--	--	Michaud et al., 1979
5/3/77	--	100.0%	--	0.068	--	--	Michaud et al., 1979
5/10/77	--	80.0%	--	0.088	--	--	Michaud et al., 1979
5/11/77	--	80.0%	--	0.062	--	--	Michaud et al., 1979
5/12/77	--	60.0%	--	0.130	--	--	Michaud et al., 1979
5/17/77	--	60.0%	--	0.099	--	--	Michaud et al., 1979
5/24/77	--	80.0%	--	0.071	--	--	Michaud et al., 1979
6/28/77	--	40.0%	--	0.291	--	--	Michaud et al., 1979
7/15/77	--	--	--	0.243	--	--	Michaud et al., 1979
8/3/77	--	40.0%	--	0.425	--	--	Michaud et al., 1979
7/4/78	3.3	50.0%	9.0	--	--	--	Braun, 1978
1988	1.7	--	--	0.310*	--	55	Hippensteel, 1989
7/24/89	15.0	71.4%	--	--	--	--	Braun, 1990
6/11/90	13.1	53.6%	8.5	--	--	--	Braun, 1991a
6/3/91	3.0	89.3%	8.4	--	--	--	Braun, 1991b
7/19/93	2.5	37.0%	8.5	--	--	--	Kittaka, 1993
8/23/94	2.6	75.0%	8.2	0.691	27,447	31	CLP, 1994
7/17/95	2.5	37.0%	7.6	--	--	--	Braun, 1996
7/21/97	2.5	38.5%	8.2	--	--	--	Braun, 1998
7/28/98	1.6	42.9%	8.5	0.395	55,255	34	CLP, 1998
6/7/00	3.0	36.4%	8.5	--	--	--	Kittaka, 2000
7/14/03	3.3	23.1%	9.0	--	--	--	Benson, 2004
7/12/04	5.9	38.0%	8.4	0.211	1,490	19	CLP, 2004
7/31/06	3.2	25.0%	8.2	0.394	22,117	32	CLP, 2006

*Total phosphorus concentrations from 1975 and 1988 are reported as given in Hippensteel, 1989. Whether samples were collected from the epilimnion, hypolimnion, or both could not be verified. All other concentrations are reported as an average of epilimnetic and hypolimnetic samples.

Table 31. Summary of historic data for the east basin of Palestine Lake.

Date	Secchi (ft)	Percent Oxic	epi pH	Mean TP (mg/L)	Plankton Density (#/L)	ITSI Score (based on means)	Data Source
7/10/75	--	--	--	0.220	--	--	ISBH, 1976
8/4/75	4.0	22.7%	8.5	--	--	--	Shipman, 1976
6/8/76	4.9	--	--	--	198	--	ISBH, 1976
7/6/76	1.6	--	--	0.280	14,190	--	ISBH, 1976
8/3/76	0.8	--	--	0.450	27,984	--	ISBH, 1976
4/19/77	--	100.0%	--	0.063	--	--	Michaud et al., 1979
5/3/77	--	100.0%	--	0.142	--	--	Michaud et al., 1979
5/10/77	--	85.7%	--	0.062	--	--	Michaud et al., 1979
5/11/77	--	100.0%	--	0.059	--	--	Michaud et al., 1979
5/12/77	--	85.7%	--	0.087	--	--	Michaud et al., 1979
5/17/77	--	57.1%	--	0.113	--	--	Michaud et al., 1979
5/24/77	--	57.1%	--	0.149	--	--	Michaud et al., 1979
6/28/77	--	57.1%	--	0.258	--	--	Michaud et al., 1979
7/15/77	--	--	--	0.243	--	--	Michaud et al., 1979
8/3/77	--	28.6%	--	0.711	--	--	Michaud et al., 1979
7/24/89	13.2	55.6%	--	--	--	--	Braun, 1990
6/11/90	4.0	27.8%	8.5	--	--	--	Braun, 1991a
6/3/91	2.8	50.0%	7.8	--	--	--	Braun, 1991b
7/19/93	2.5	27.8%	8.5	--	--	--	Kittaka, 1993
7/17/95	3.5	55.6%	8.1	--	--	--	Braun, 1996
7/21/97	2.5	83.3%	8.2	--	--	--	Braun, 1998
6/7/00	5.8	55.6%	8.5	--	--	--	Kittaka, 2000
7/14/03	3.3	33.3%	8.5	--	--	--	Benson, 2004
7/31/06	3.3	30.0%	8.1	0.125	2,997	21	CLP, 2006

The data in Tables 30 and 31 indicate that water quality in both basins of Palestine Lake is generally poorer than most Indiana lakes. Palestine Lake routinely contains elevated nutrient concentrations and manifests evidence of high productivity. Secchi disk transparencies in both basins were consistently measured at levels less than that found at most Indiana lakes (6.5 feet). In the west basin, Secchi depths typically ranged from 0.5 feet (0.2 meters) in 1975 to 3.3 feet (1.0 meters) in 1978 and 2003. The median transparency of Palestine Lake's west basin measured 2.5 feet (0.8 meters). Secchi depths in the east basin generally measured greater than those in the west basin. In the east basin, transparencies ranged from 0.8 feet (0.2 meters) in 1976 to 5.8 feet (1.8 meters) in 2000. The median transparency of Palestine Lake's east basin measured 3.3 feet (1.0 meters), which is nearly 1 foot (0.3 meters) more than the median transparency in the west basin.

Shallow lakes, like Palestine Lake, typically contain greater turbidities than deeper lakes. This can be attributed to wind-driven surface currents, which can disturb and resuspend bottom sediments in shallow lakes. With an average depth of 4 feet (1.2 meters), Palestine Lake falls into the shallow lake category, meaning that a greater than average turbidity is expected. This naturally higher turbidity is likely exacerbated by disturbances within the lake and from sediment loading from the watershed. Historically, one factor affecting transparency within Palestine Lake was the fish community. Prior to 1988, carp comprised a majority of the fish community present in Palestine Lake as measured by both number and weight. (See the **Fisheries Section** for more details regarding Palestine Lake's fish community.) As bottom-feeders, carp resuspend bottom material while scavenging. This results in increased turbidity in the lake. Additionally, resuspension facilitates the release of nutrients from the sediment to the water column. The presence of higher concentrations of nutrients in the water column increases the nutrient levels available for algae, ultimately leading to increased algal productivity. To control the amount of nutrients present in the water column and to revitalize the game fish population, the IDNR implemented a fish management project in 1988 to remove carp from the watershed and restock the lake with gamefish. Fisheries assessments in 1989 and 1990 documented transparencies measuring more than five times the median concentration in the west basin and more than four times transparencies observed in the east basin through the lifetime of sampling (Tables 30 and 31). These transparencies suggest that carp exacerbated the turbidity within the lake. Once the carp population was removed, transparencies improved thereby lending weight to the idea that carp increased sediment resuspension within the west basin of Palestine Lake. While the carp did not return in high numbers, transparency decreased again after 1990. IDNR fisheries reports indicated sediment loading issues from the drainages, which likely contributed to poor transparency in subsequent years.

Both algal and non-algal (sediment, organic material) elements contribute to lake transparency in Palestine Lake. Plankton density exhibited an inverse relationship with Secchi disk transparency. The highest plankton density measured in the west basin (55,255/L) corresponds with the transparency (1.6 feet or 0.5 meters). Conversely, the lowest plankton density in the west basin (1,386 /L) corresponds with the second-highest transparency (3.3 feet or 1.0 meters) recorded. The same trend can be seen in the east basin. The highest plankton density (27,984/L) corresponds with the poorest transparency (0.8 feet or 0.2 meters). The lowest plankton density (198/L) corresponds with the second-highest transparency (4.9 feet or 1.5 meters). Plankton densities in both basins measured below the Indiana median (35,570 /L) during all but one study. However, chlorophyll *a* concentrations, a better estimate of algal biomass than plankton density, routinely measured in both basins at levels six times higher than the Indiana median concentration (12.9 μg/L). Additionally, both basins contained elevated epilimnetic pHs during most of the studies. 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. This suggests that algal productivity was high during much of the study period and could increase turbidity. Historical aerial photographs support this conclusion. The 1957 aerial photograph indicated the presence of algal blooms during the summer. Floating debris (likely algal growth) shown is this photograph reduced the area of open water to less than half its normal size. Aerial photographs taken after 1957 do not display the same amount of algal productivity observed in 1957. However, in 1965 large blooms of algae were still observable along much of the lake shoreline with extensive cover of the water surface in the south part of the eastern basin. Despite the evidence for high algal productivity, IDNR observations suggest that non-algal turbidity also influences the turbidity in Palestine Lake. In most years surveyed, IDNR biologists noted brown or muddy water in both basins of Palestine Lake.

Total phosphorus concentrations also indicate generally poor water quality in Palestine Lake. Concentrations in the west basin ranged from 0.06 mg/L in April 1977 to 0.91 mg/L in 1975. The median total phosphorus concentration of Palestine Lake's west basin measured 0.19 mg/L. Concentrations in the east basin ranged from 0.06 mg/L in May 1977 to 0.71 mg/L in August 1977. The median total phosphorus concentration of Palestine Lake's east basin measured 0.149 mg/L. With the exception of samples collected between March and May in 1977, total phosphorus concentrations in both basins exceeded the concentration typically measured in Indiana lakes (0.17 mg/L) during all sampling events. Total phosphorus concentrations measuring less than a third of typical values observed in the lake were observed between March and May 1977 with concentrations ranging from 0.060 to 0.088 mg/L in the west basin and from 0.059 to 0.149 mg/L in the east basin. These differences can be attributed more to the sampling time (early spring) than the quality of the lake. Land fertilizer applications typically do not begin until late spring, at the beginning of the growing season. Additionally, lower water temperatures and shorter days limit the amount of algal growth in lakes during the spring. Therefore, samples taken during this period will collect less algal material and the phosphorus associated with it.

Nitrogen concentrations are similarly high compared to the Indiana average. Total nitrogen concentrations in the west basin ranged from 0.9 mg/L in July 1976 to 3.34 mg/L in August 1994. The median total nitrogen concentration of Palestine Lake's west basin measured 1.9 mg/L. Total nitrogen concentrations in the east basin ranged from 1.1 mg/L in July 1976 to 2.8 mg/L in August 1976. The median total nitrogen concentration of Palestine Lake's east basin measured 1.381 mg/L. Total nitrogen in Palestine's east basin exceeded the concentration typically measured in Indiana lakes (1.7 mg/L) only once out of the four samples collected. Total nitrogen in Palestine's west basin was measured at similar levels during the 1970's but increased in recent years. All samples collected from the east basin since 1994 exceeded the Indiana median concentration and were measured at twice the concentration found in the 1970s. No data were collected in the 1980's to determine when this increase in total nitrogen occurred.

Ammonia and nitrate, two specific compounds of nitrogen, are typically examined because of their availability to plants and algae. Ammonia exhibited a similar trend over time to total nitrogen in the west basin. Concentrations ranged from 0.3 mg/L in June 1976 to 2.840 mg/L in July 2004. The median ammonia concentration in Palestine Lake's west basin measured 1.272 mg/L. Like total nitrogen, ammonia concentrations exceeded the Indiana median (0.818 mg/L) for half of the samples collected during the 1970s. More recent samples suggest an increase in ammonia concentrations, with all samples collected since 1994 exceeding the Indiana median and concentrations measuring more than twice concentrations observed in the 1970s. Ammonia concentrations in the east basin ranged from 0.106 mg/L in July 2006 to 1.000 mg/L in July 1976. The median ammonia concentration in Palestine's east basin measured 0.403 mg/L. Ammonia concentrations exceeded the Indiana median once out of four samples collected since 1975. For all assessments that included samples from both the epilimnion (surface waters) and hypolimnion (deeper waters), ammonia concentrations were between eight and 275 times higher at the bottom of the lake than at the surface of the lake. Ammonia typically accumulates in the hypolimnion when the decomposition of organic matter occurs in the deeper waters of a lake.

Nitrate concentrations in the west basin ranged from 0.022 mg/L in August 1994 and July 1998 to 1.100 mg/L in June 1976. The median nitrate concentration in the west basin measured 0.206 mg/L. The data suggest concentrations may have decreased over the past thirty years. Concentrations in samples collected in the 1970s ranged between 0.1 mg/L and 1.1 mg/L. Generally, concentrations increased during the summer. All concentrations measured during this time period exceeded the concentration measured in most Indiana lakes (0.28 mg/L). Samples collected after 1994 have not exceeded the state median; all concentrations measured below 0.221 mg/L. Nitrate concentrations in the east basin ranged from 0.1 mg/L in August 1976 to 1.000 mg/L in July 1976. The median nitrate concentration in the east basin measured 0.582 mg/L.

Nitrate concentrations exceeded the Indiana median for three of four samples collected since 1975 (Appendix E).

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. While actual plankton densities did not exceed the level typically observed in Indiana lakes, chlorophyll *a* (a better measure of algal biomass) was observed at concentrations considerably higher than the Indiana median (12.9 mg/m^3) and greater than the range (3-78 mg/m^3) typically associated with eutrophic lakes (Wetzel, 2001). Since blue-green algae have competitive advantages over other algae in nutrient-rich water, high nutrient levels can also lead to dominance of the algal community by blue-green algae. This phenomenon has not been observed in Palestine Lake as blue-green algae have accounted for less than 25% of the plankton population during all assessments (Appendix E).

The Indiana Trophic State Index (ITSI) scores reflect the moderate to high productivity level suggested by Palestine Lake's nutrient concentrations and transparencies. The ITSI scores displayed in Table 30 place the west basin of Palestine Lake in the mesotrophic (moderately productive) to eutrophic (excessively productive) productivity class. Scores were similar between the years of record, with a general increase in scores between 1976 and 1988. Subsequent scores were similar to those observed in 1976. Comparatively, less data exist for the east basin with only one ITSI score (21 in July 2006) available. This score is less than all but one of the scores calculated for the west basin and place the east basin in the mesotrophic productivity class. The ITSI uses plankton density to measure algal productivity in lakes. As discussed above, plankton density may not be an accurate measure of algal productivity in Palestine Lake. As a result, the ITSI may actually understate the lake's productivity. Later sections will discuss this more fully. Despite its shortcomings, this classification indicates that the lake is productive and will typically support dense plant or plankton populations and have poor transparency.

Figure 57 displays temperature profiles for the west basin recorded during IDNR fisheries surveys and CLP assessments. All of the temperature profiles indicate that the west basin of Palestine Lake was stratified at the time of sampling, with a moderately well to well-developed metalimnion (layer of temperature change between the epilimnion and hypolimnion), as is typical of most Indiana lakes during the summer months.

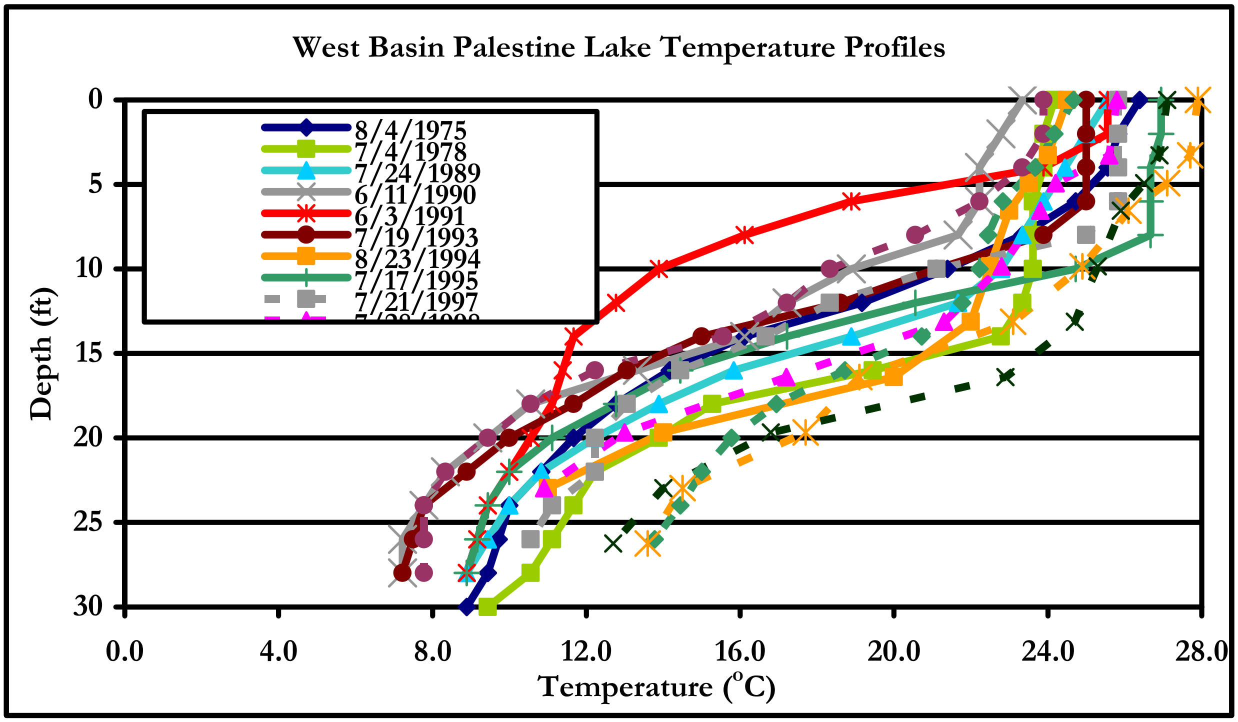

Figure 57. Historical temperature profiles for the west basin of Palestine Lake.
Source: Shipman, 1976; Braun, 1978; Braun, 1990; Braun, 1991; Kittaka, 1993; CLP, 1994; Braun, 1996; Braun, 1998; CLP, 1998; Kittaka, 2000; Benson, 2004; CLP, 2004; CLP, 2006

Much of the data above suggest that the west basin of Palestine Lake is relatively productive. The historical dissolved oxygen profiles lend additional evidence to this suggestion (Figure 58). Typically, the lake was anoxic (without dissolved oxygen) below 10 feet (3 m). This decline in dissolved oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments. Generally, less than 50% of the water column contained sufficient oxygen to support aquatic biota (Figure 58). Additionally, in two years (1998 and 2003) the surface waters were supersaturated with respect to oxygen. Without any biological activity, dissolved oxygen concentrations will tend toward an equilibrium value dependent on the water temperature. When photosynthetic activity exceeds the rate that oxygen can escape water, dissolved oxygen concentrations can temporarily exceed this value and supersaturated conditions will be observed. While not a concern for aquatic biota, supersaturated oxygen concentrations typically indicate high levels of productivity within a lake.

Exceptions to this assessment occurred in 1989 and 1991 when dissolved oxygen decreased in the hypolimnion but did not reach anoxia. As was discussed above, these profiles were measured after a fish restocking project by IDNR. During this project, rotenone was applied to the lake to remove carp populations. Once carp populations were removed, the lake was restocked with gamefish. Because of the effects of these measures down the food chain, restocking often leads to decreased plankton populations and increased transparency. Most gamefish feed on other fish. Restocking these predators leads to a decrease in fish that typically eat zooplankton. With decreased predation, the zooplankton populations increase, adding predation pressure on the phytoplankton. As a result, phytoplankton populations decrease. Since phytoplankton form the base of the late ecosystem, a decrease to their populations leads to an overall decrease in biomass within the lake. With less biomass, decomposition rates decrease, leading to a reduced requirement of oxygen in the hypolimnion to fuel respiration. In Palestine Lake, it seems likely that this chain of events reduced oxygen demand enough to prevent anoxia in the hypolimnion in 1989 and 1991. As the fish community adjusted to include less predators, anoxic conditions were observed again in the hypolimnion.

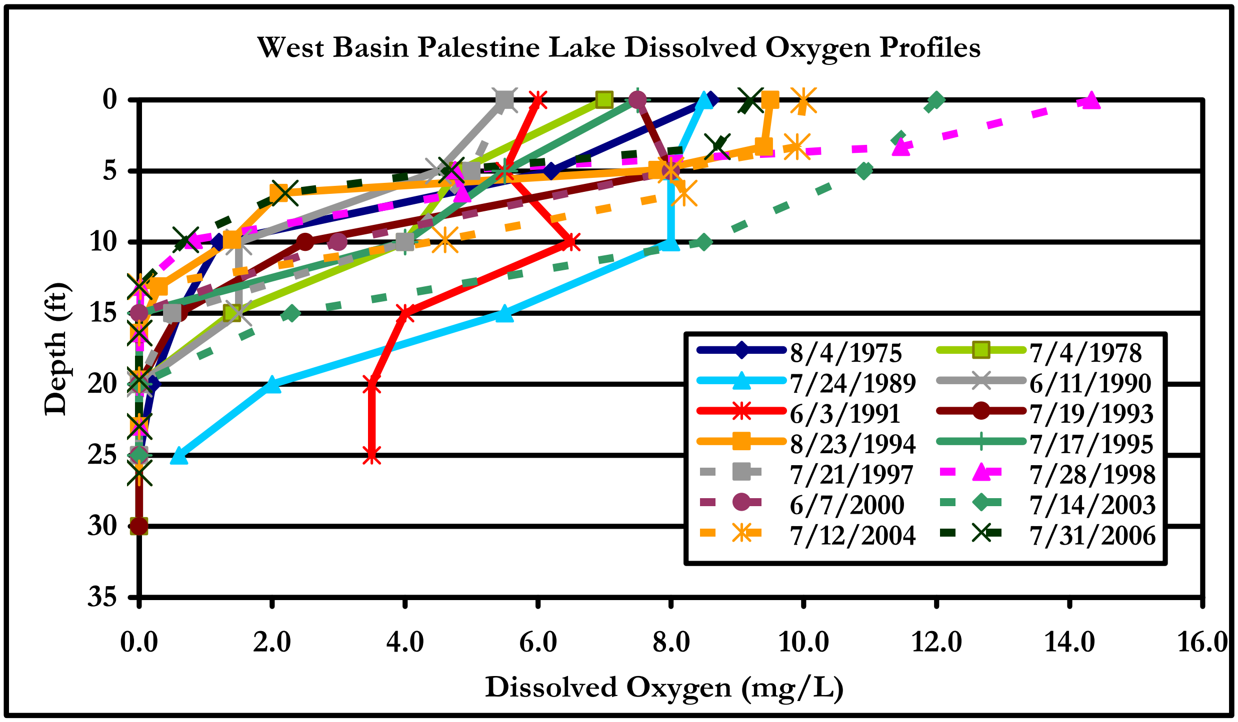

Figure 58. Historical dissolved oxygen profiles for the west basin of Palestine Lake.
Source: Shipman, 1976; Braun, 1978; Braun, 1990; Braun, 1991; Kittaka, 1993; CLP, 1994; Braun, 1996; Braun, 1998; CLP, 1998; Kittaka, 2000; Benson, 2004; CLP, 2004; CLP, 2006

The lack of oxygen in the west basin of Palestine Lake's hypolimnion also affects the lake's chemistry. For all years in which samples were collected from both the epilimnion (surface waters) and the hypolimnion (deeper waters), the hypolimnetic total phosphorus concentrations were much higher than concentrations measured in the epilimnion. 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), supporting the idea that phosphorus is readily available for algae. Additionally, the west basin of Palestine 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 during these assessments. Overall, these data suggest that the west basin of Palestine Lake was a eutrophic lake during the 1994, 1998, and 2006 assessments.

Figure 59 displays temperature profiles for the east basin recorded during IDNR fisheries surveys and CLP assessments. All of the temperature profiles indicate that the east basin of Palestine Lake was stratified at the time of sampling, with a moderately well to well-developed metalimnion as is typical of most Indiana lakes during the summer months.

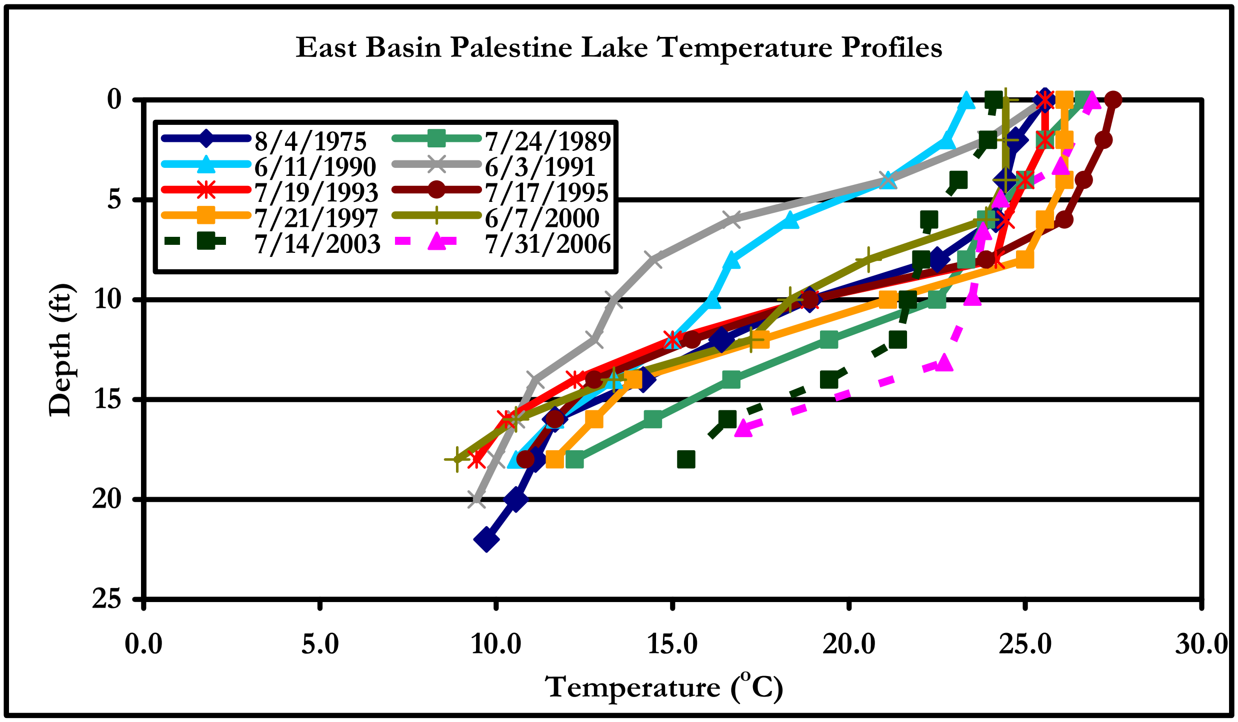

Figure 59. Historical temperature profiles for the east basin of Palestine Lake.
Source: Shipman, 1976; Braun, 1990; Braun, 1991; Kittaka, 1993; Braun, 1996; Braun, 1998; Kittaka, 2000; Benson, 2004; CLP, 2006

The data for the east basin of Palestine Lake suggest relatively high productivity levels, though lower than those in the west basin of Palestine Lake. The historical dissolved oxygen profiles lend additional evidence to this suggestion (Figure 60). Typically, the lake was anoxic below 15 feet (4.5 m). This decline in dissolved oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments. Generally, less than 55% of the water column contained sufficient oxygen to support aquatic biota (Table 32). Additionally, supersaturated oxygen levels were measured in the surface waters during one assessment.

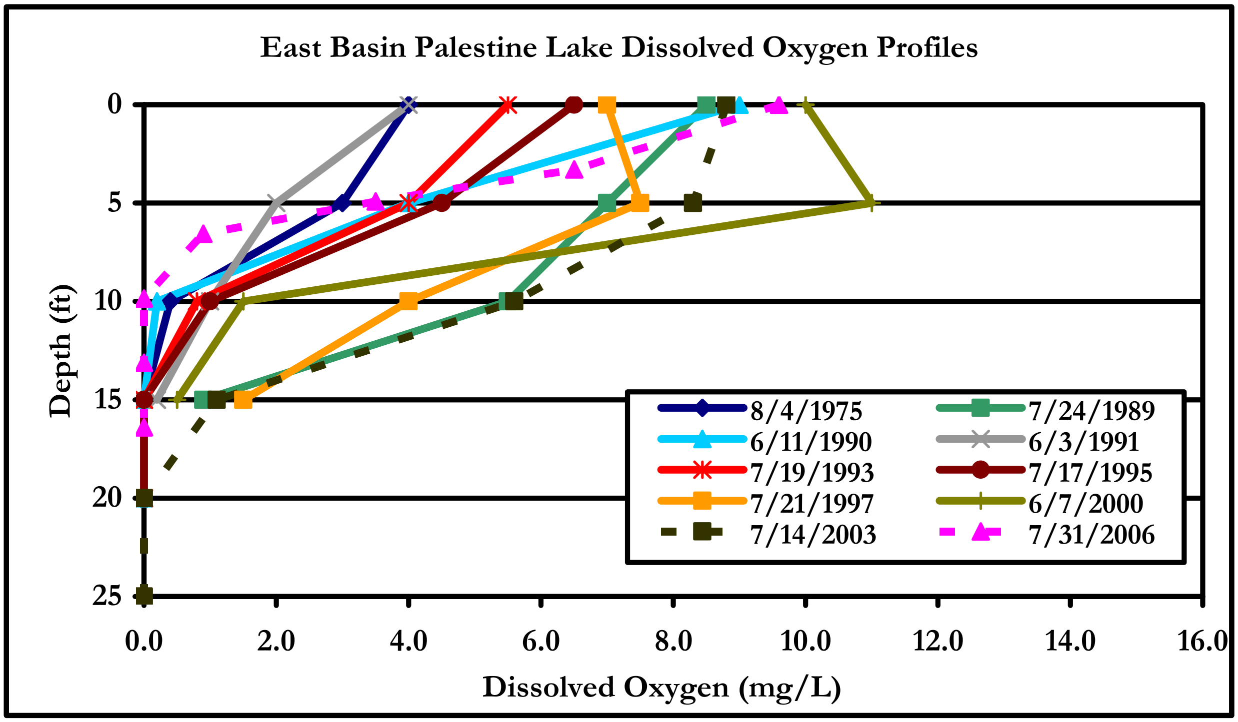

Figure 60. Historical dissolved oxygen profiles for the east basin of Palestine Lake.
Source: Shipman, 1976; Braun, 1990; Braun, 1991; Kittaka, 1993; Braun, 1996; Braun, 1998; Kittaka, 2000; Benson, 2004; CLP, 2006

Only one study (CLP, 2006) has released data for samples collected from both the epilmnion and hypolimnion of the east basin of Palestine Lake. Therefore, there is less evidence for release of phosphorus and ammonia from the sediment than there is in the west basin; however, the data suggest that these processes may be occurring in the east basin as well. Samples collected between April and August 1977 measured increasing mean total phosphorus concentrations in the water column after anoxic conditions began to develop in the hypolimnion. These increases in total phosphorus corresponded with increases in the average soluble reactive phosphorus concentrations in the water column. While it is difficult to determine if these were the result of dissolution of phosphorus in the hypolimnion, this explanation seems likely since the accumulation of soluble phosphorus in the epilimnion is rare.

Overall, these data suggest that the east basin of Palestine Lake exhibited slightly better water quality than the west basin of Palestine Lake but would still be considered a eutrophic lake.

4.4.2 Caldwell Lake Historical Water Quality

The Indiana Department of Natural Resources, Division of Fish and Wildlife and the Indiana Clean Lakes Program have conducted various water quality studies on Caldwell Lake. Table 32 presents some selected water quality parameters for these assessments of Caldwell Lake. In addition, water clarity was measured by a volunteer between July 1993 and June 1997 as part of the Clean Lakes Program. No volunteer monitoring occurred in Caldwell Lake since 1997. Table 33 presents a summary of volunteer data for water clarity.

Table 32. Summary of historic data for Caldwell Lake.

Date	Secchi (ft)	Percent Oxic	epi pH	Mean TP (mg/L)	Plankton Density (#/L)	TSI Score (based on means)	Data Source
7/9/75	6.0	--	--	0.120	31,000	--	IDEM, 1975
6/25/79	11.2	62.5%	9.4	--	--	--	Braun, 1980
7/24/89	17.1	52.6%	--	--	--	--	Braun, 1990
7/23/90	6.5	37.5%	9.0	--	--	--	Braun, 1991
8/22/90	4.3	44.0%	--	0.261	1,507,865	66	CLP, 1990
8/23/94	5.6	27.0%	8.6	0.037	200,547	44	CLP, 1994
7/28/98	3.6	27.3%	8.7	0.335	48,974	48	CLP, 1998
7/13/04	5.3	27.0%	8.7	0.206	30,444	40	CLP, 2004

Table 33. Summary of historic data collected as part of the CLP volunteer monitoring program for Caldwell Lake.

1993		1994		1995		1996		1997	
Date	Secchi (ft)	Date	Secchi (ft)	Date	Secchi (ft)	Date	Secchi (ft)	Date	Secchi (ft)
7/5/93	4.0	5/12/94	6.3	5/7/95	7.5	4/14/96	1.3	6/27/97	3.0
7/11/93	5.5	5/28/94	4.0	5/14/95	6.3	4/21/96	1.0		
7/20/93	8.3	6/3/94	7.0	5/21/95	5.8	5/5/96	0.5		
7/29/93	7.0	6/22/94	7.5	5/30/95	4.8	5/12/96	0.3		
8/5/93	7.3	7/4/94	1.8	6/4/95	2.5	5/26/96	0.3		
8/29/93	5.3	7/5/94	6.9	6/11/95	7.5	6/2/96	0.3		
		7/16/94	3.5	6/17/95	8.3	6/9/96	0.3		
		7/31/94	2.5	6/25/95	6.5	6/16/96	1.3		
		8/10/94	4.5	7/9/95	2.8	6/23/96	3.0		
		8/23/94	6.7	7/15/95	4.8	6/29/96	2.3		
		9/2/94	8.5	7/22/95	3.0	7/7/96	5.3		
		9/23/94	7.0	7/30/95	4.0	7/28/96	2.3		
				8/6/95	4.0	8/4/96	2.3		
				8/13/95	4.5	12/7/96	6.0		
				8/26/95	5.0				
				9/4/95	4.0				
				9/10/95	4.0				
				9/24/95	3.5				

The data in Table 32 indicates that water quality in Caldwell Lake is poorer than in most Indiana lakes. Caldwell Lake contains elevated nutrient concentrations and high algal productivity. Secchi depths ranged between 0.3 feet (0.1 meters) in May and June 1996 and 17.1 feet (5.2 meters) in July 1989. Median water transparency in Caldwell Lake measured 4.5 feet (1.4 meters). Water clarity was better on average than that found in Palestine Lake (2.5 feet or 0.8 meters in the west basin and 3.3 feet or 1.0 meters in the east basin) but was typically poorer than the Indiana average (6.9 feet or 2.1 meters). Water clarity was measured at levels nearly 4 times the median transparency during the 1979 and 1989 assessments. The 1989 assessment occurred after the fish management project, which included Caldwell Lake. It is not known what caused the 1979 increase in water clarity.

Figure 61 and Table 33 shows the change in Secchi disk transparencies seasonally. When algal productivity affects water clarity, transparencies typically decrease toward the middle of the summer and increase at the end of the summer. No such trend was noticed in the volunteer data. This is especially apparent during the 1996 assessments. Transparency measured extremely poor compared with average transparencies measured in Caldwell Lake. This suggests that other stressors other than algal productivity, like sediment or silt from the watershed, were impacting water clarity more than algal productivity.

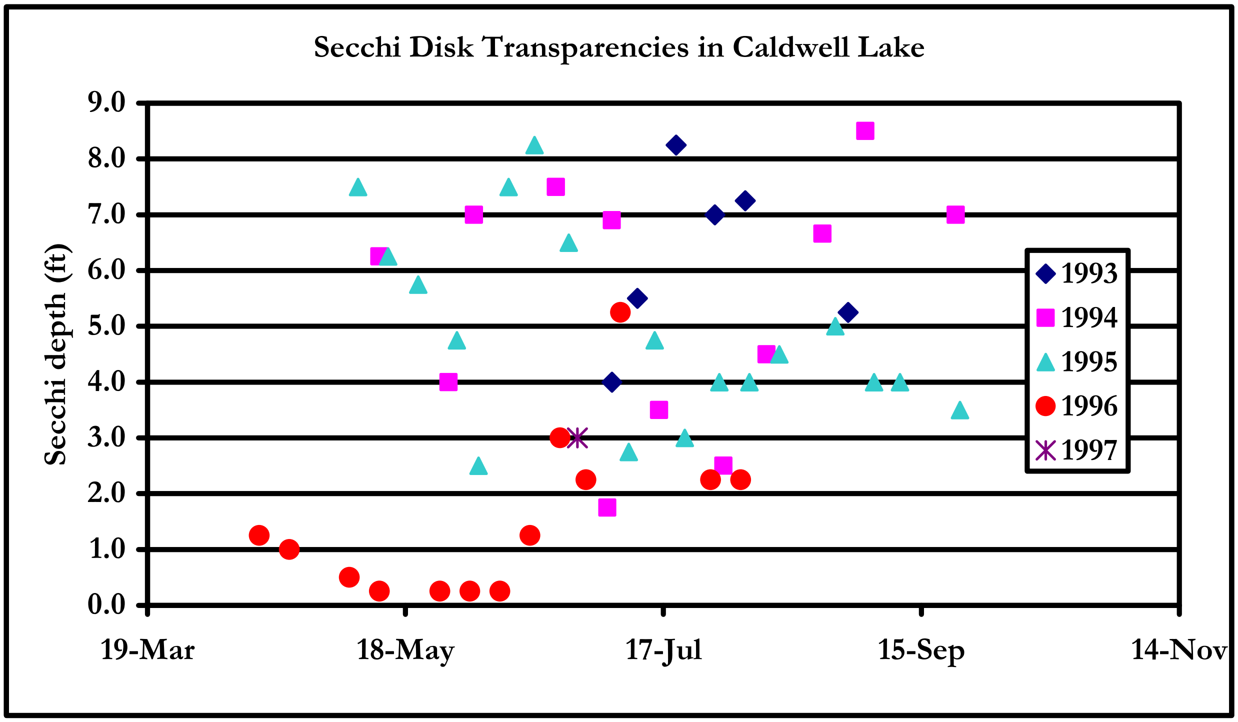

Figure 61. Historical variation in Secchi disk transparency based on seasonality.
Source: CLP, 1993-1997.

Total phosphorus concentrations ranged from 0.037 mg/L in August 1994 to 0.335 in July 1998. The median total phosphorus concentration of Caldwell Lake measured 0.206 mg/L. Total phosphorus concentrations generally exceeded the concentration observed in most Indiana lakes (0.17 mg/L). Samples collected in 1975 and 1994 provided two exceptions to this trend. Phosphorus was consistently higher in the hypolimnion (median of 0.42 mg/L) than in the epilimnion (median of 0.05 mg/L). A majority of the phosphorus in the hypolimnion was in the dissolved form. Concentrations measured during recent samples were generally higher than those collected historically, suggesting a gradual decline in water quality. Sufficient data to make a proper assessment were not available.

Nitrogen concentrations in Caldwell Lake were similarly elevated compared to most Indiana lakes. Total nitrogen concentrations ranged from 1.00 mg/L in July 1975 to 2.517 mg/L in July 1998. The median total nitrogen concentration measured 1.112 mg/L. Samples collected in 1998 and 2004 exceeded the Indiana median (1.7 mg/L) while samples collected prior to 1998 measured below the average. Total nitrogen generally increased over the period of record with the highest observed concentrations occurring since 1998.

Ammonia-nitrogen concentrations ranged from 0.576 mg/L in August 1994 to 1.524 mg/L in 1990. The median ammonia-nitrogen concentration measured 1.254 mg/L. More than half the collected samples exceeded the Indiana median concentration (0.818 mg/L). Like total phosphorus, recent samples were generally higher than those collected in the past, with high ammonia concentrations coinciding with high total phosphorus values. For all samples collected, hypolimnetic samples contained higher ammonia-nitrogen concentrations than samples from the epilimnion. Like the data collected from Palestine Lake, these concentrations suggest that decomposition is occurring in Caldwell lake's hypolimnion. Nitrate concentrations ranged from 0.022 mg/L in August 1994 to 1.466 mg/L in 1990. The median nitrate concentration measured 0.600 mg/L. A majority of the samples exceeded the Indiana median for nitrate (0.28 mg/L) but concentrations displayed a decreasing trend over time.

Plankton densities measured in Caldwell Lake were generally higher than those measured in most Indiana lakes (35,570/L). Blue-green algae dominated the plankton samples collected during all years sampled. Algal densities measured during the 1990 and 1994 assessments indicate that algal blooms occurred during the assessments. Some of the high plankton density could be attributed to the rotenone treatment which occurred in both Palestine and Caldwell lakes in 1989. However, it is likely that environmental factors (climate) likely affected algal populations during these assessments. Plankton densities vary throughout the season. Densities are often dependent upon temperature, available sunlight, and precipitation. Low cloud cover, long periods of sunny skies, low precipitation, and readily available nutrients could all play a part in these higher than normal (two to four orders of magnitude) plankton densities observed in Caldwell Lake during these assessments.

The Indiana Trophic State Index (ITSI) scores displayed in Table 32 place Caldwell Lake in the eutrophic to hypereutrophic productivity class (highly productive). Scores have generally declined since 1990. Much of the score change can be attributed to variations in plankton densities. Nonetheless, scores remained within the eutrophic class suggesting high productivity in Caldwell Lake.

Figure 62 displays the temperature profiles recorded during IDNR fisheries surveys and Indiana CLP assessments. Caldwell Lake was strongly stratified during all sampling events. There was very little change in profile for all sampling events with a five-foot range in the depth of the metalimnion over the years assessed. The developed hypolimnion present during all seven assessments is very typical of Indiana lakes.

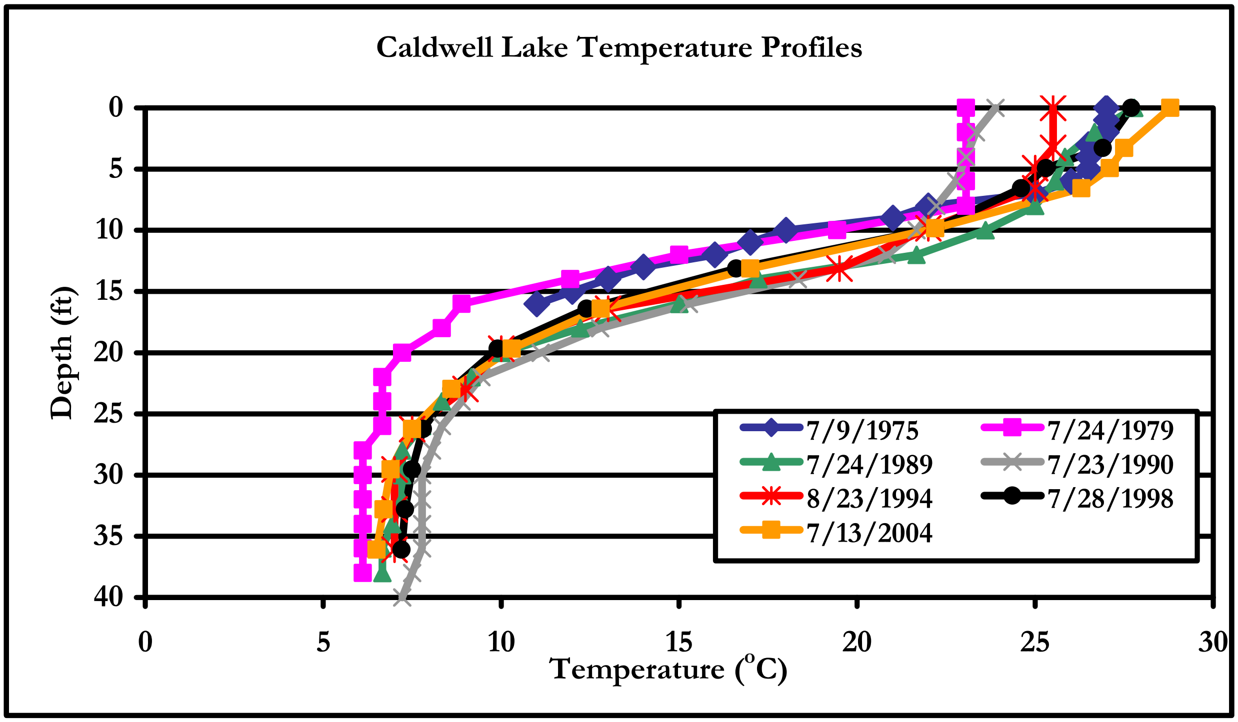

Figure 62. Historical temperature profiles for Caldwell Lake.
Source: IDEM, 1975; Braun, 1980; Braun, 1990; Braun, 1991; CLP, 1994; CLP, 1998; CLP, 2004

Much of the data presented above suggest that Caldwell Lake is relatively productive. The historical dissolved oxygen results lend further evidence to this suggestion (Figure 63). Typically, the lake was anoxic (without dissolved oxygen) below 15 feet (4.6 meters). Exceptions to this occurred in 1979, 1989, and 1990 when dissolved oxygen was present in Caldwell Lake as low as 25 feet below the surface. This decline in dissolved oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments. Generally, between 30 and 64% of the water column contained sufficient oxygen to support aquatic biota. The amount of the water column that goes anoxic can vary depending on the productivity and clarity of the lake. The increased biomass produced in more productive lakes requires higher decomposition rates, which uses more oxygen in the hypolimnion. In lakes with higher transparency, photosynthesis can counteract this process in the upper depths of the hypolimnion, adding oxygen to the hypolimnion. Oxic conditions were observed in higher percentages of the water column during 1979, 1989, and 1990. The oxygen profiles for these years suggest that photosynthesis in deeper waters may have caused this increase in the availability of oxygen. In 1989 and 1990, increases in oxygen were observed in the lake's metalimnion. These peaks are likely associated with a higher concentration in phytoplankton at that particular depth layer. Called a metalimnetic oxygen maximum, the peaks observed in 1989 and 1990 resulted when the settling rate of plankton slows in the denser waters of the metalimnion. At this depth, the plankton can take advantage of nutrients diffusing from the nutrient-rich hypolimnion as long as there is sufficient light penetration to support photosynthesis. As the plankton at this depth photosynthesize, they release oxygen into the water column, creating a peak in oxygen at that level. A decrease in oxygen was observed in the lake's metalimnion in 1975. This decline is likely associated with a higher concentration in decomposing material at that particular depth. Called a metalimnetic oxygen minimum, the decline results when the settling rate of decaying organic matter slows in the denser waters of the metalimnion. As microbes decompose the organic matter, they use the oxygen at that depth, creating a decline in oxygen at that level.

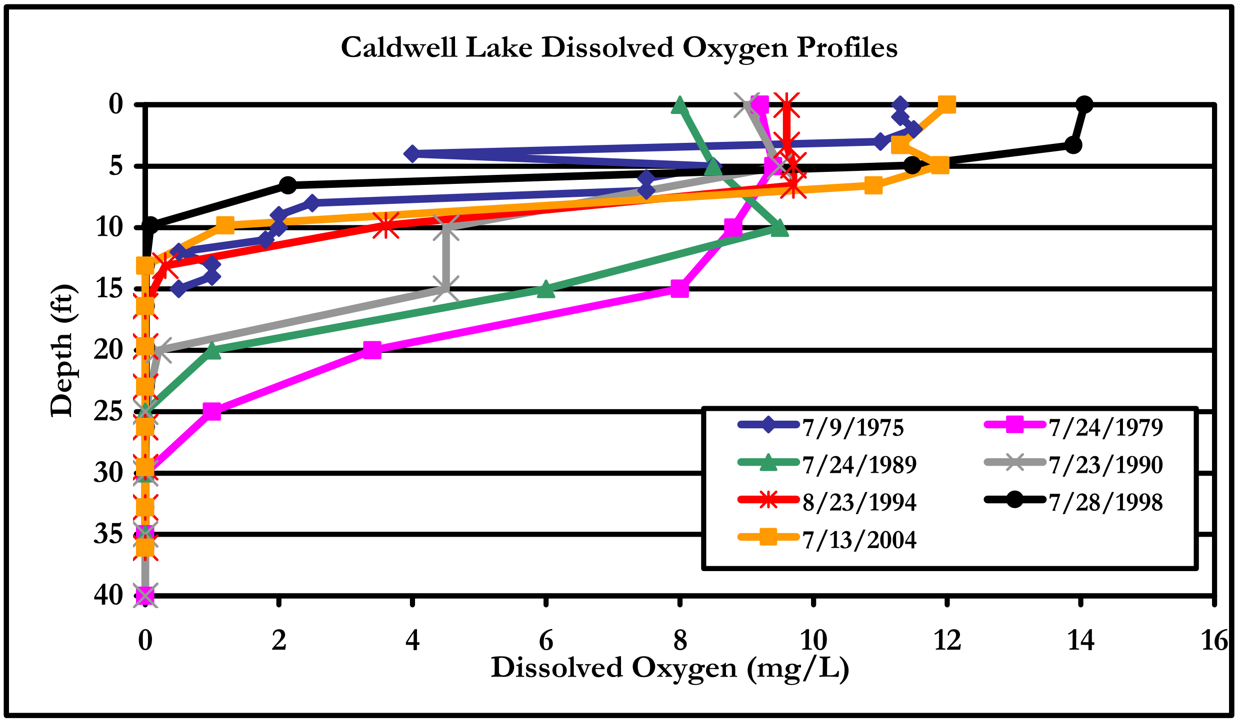

Figure 63. Historical dissolved oxygen profiles for Caldwell Lake.
Source: IDEM, 1975; Braun, 1980; Braun, 1990; Braun, 1991; CLP, 1994; CLP, 1998; CLP, 2004

Like Palestine Lake, the lack of oxygen in Caldwell Lake's hypolimnion also affects the lake's chemistry. 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. For all years in which samples were collected from both the epilimnion and the hypolimnion, the hypolimnetic total phosphorus concentrations were much higher than concentrations measured in the epilimnion. Much of the total phosphorus was in the dissolved form of phosphorus (SRP), supporting the idea that phosphorus is readily available for algae. Additionally, Caldwell Lake exhibited higher hypolimnetic ammonia concentrations than those observed in the lake's epilimnion during all of the assessments. This suggests that decomposition of organic matter was occurring in the lake's bottom waters during these assessments. Overall, these data suggest that Caldwell Lake was a eutrophic to hypereutrophic lake during the 1994, 1998, and 2006 assessments.

4.5 Lake Water Quality Assessment

4.5.1 Lake Water Quality Assessment Methods

The water sampling and analytical methods used for Palestine and Caldwell lakes were consistent with those used in IDEM's Indiana Clean Lakes Program and IDNR's Lake and River Enhancement Program. Water samples were collected and analyzed for various parameters from Palestine and Caldwell lakes on June 19, 2007 from the surface waters (***epilimnion***) and from the bottom waters (***hypolimnion***) of the lakes at a location over the deepest water. In Palestine Lake, sampling occurred at the deepest point within each basin for a total of two sampling points within the lake. These parameters include conductivity, total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, and organic nitrogen. In addition to these parameters, several other measurements of lake health were recorded. Secchi disk, light transmission, and oxygen saturation are single measurements made in the epilimnion. Chlorophyll *a* was determined only for an epilimnetic sample. Dissolved oxygen and temperature were measured at one-meter intervals from the surface to the bottom. A tow to collect plankton was made from the 1% light level depth up to the water surface. Conductivity, temperature, and dissolved oxygen were measured *in situ* with an YSI Model 85 meter.

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

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

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

Temperature. Temperature can determine the form, solubility, and toxicity of a broad range of aqueous compounds. For example, water temperature affects the amount of dissolved oxygen in the water column. Likewise, life associated with the aquatic environment in any location has its species composition and activity regulated by water temperature. Since essentially all aquatic organisms are 'cold-blooded' the temperature of the water regulates their metabolism and ability to survive and reproduce effectively (USEPA, 1976). The Indiana Administrative Code (327 IAC 2-1-6) sets maximum temperature limits to protect aquatic life for Indiana waters. For example, temperatures during the summer months should not exceed 90 °F (32.2 °C).

Dissolved Oxygen (DO). DO is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3 to 5 mg/L of DO. Coldwater fish such as trout generally require higher concentrations of DO than warmwater fish such as bass or bluegill. The IAC sets minimum DO concentrations at 4 mg/L for warmwater fish, but all waters must have a daily average of 5 mg/L. DO enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algal growth can over-saturate (greater than 100% saturation) the water with DO. Conversely, dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

Conductivity. Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions: on their total concentration, mobility, and valence (APHA, 1998). Rather than setting a conductivity standard, the Indiana Administrative Code sets a standard for dissolved solids (750 mg/L). Multiplying a dissolved solids concentration by a conversion factor of 0.55 to 0.75 μmhos per mg/L of dissolved solids roughly converts a dissolved solids concentration to specific conductance (Allan, 1995). Thus, converting the IAC dissolved solids concentration standard to specific conductance by multiplying 750 mg/L by 0.55 to

0.75 μmhos per mg/L yields a specific conductance range of approximately 1000 to 1360 μmhos. This report presents conductivity measurements at each site in μmhos.

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

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

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

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

With respect to lakes, limnologists have determined the existence of certain thresholds for nutrients above which changes in the lake's biological integrity can be expected. For example, Correll (1998) found that soluble reactive phosphorus concentrations of 0.005 mg/L are enough to maintain eutrophic or highly productive conditions in lake systems. For total phosphorus concentrations, 0.03 mg/L (0.03 ppm – parts per million or 30 ppb – parts per billion) is the generally accepted threshold. Total phosphorus concentrations above this level can promote nuisance algae blooms in lakes. The USEPA's recommended nutrient criterion for total phosphorus is fairly low, 14.75 μg/L (USEPA, 2000a). This is an unrealistic target for many Indiana lakes. It is unlikely that IDEM will recommend a total phosphorus criterion this low for incorporation in the IAC. Similarly, the USEPA's recommended nutrient criterion for nitrate-nitrogen in lakes is low at 8 μg/L (0.008 mg/L). This is below the detection limit of most laboratories. In general, levels of inorganic nitrogen (which includes nitrate-nitrogen) that exceed 0.3 mg/L may also promote algae blooms in lakes. High levels of nitrate-nitrogen can be lethal to fish. The nitrate LC_{50} is 5 mg/L for logperch, 40 mg/L for carp, and 100 mg/L for white sucker. (Determined by performing a bioassay in the laboratory, the LC_{50} is the concentration of the pollutant being tested, in this case nitrogen, at which 50% of the test population died in the bioassay.) The USEPA's recommended criterion for total Kjeldahl nitrogen in lakes is 0.56 mg/L.

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

Secchi Disk Transparency. This refers to the depth to which the black and white Secchi disk can be seen in the lake water. Water clarity, as determined by a Secchi disk, is affected by two primary factors: algae and suspended particulate matter. Particulates (for example, soil or dead leaves) may be introduced into the water by either runoff from the land or from sediments already on the bottom of the lake. Many processes may introduce sediments from runoff; examples include erosion from construction sites, agricultural land, and riverbanks. Bottom sediments may be resuspended by bottom feeding fish such as carp, or in shallow lakes, by motorboats or strong winds. In general, lakes possessing Secchi disk transparency depths greater than 15 feet (4.5 m) have outstanding clarity. Lakes with Secchi disk transparency depths less than 5 feet (1.5 m) possess poor water clarity (ISPCB, 1976; Carlson, 1977). The USEPA recommended a numeric criterion of 10.9 feet (3.3 m) for Secchi disk depth in lakes (USEPA, 2000a).

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

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

Chlorophyll *a*. The plant pigments in algae consist of the chlorophylls (green color) and carotenoids (yellow color). Chlorophyll *a* is by far the most dominant chlorophyll pigment and occurs in great abundance. Thus, chlorophyll *a* is often used as a direct estimate of algal biomass. In general, chlorophyll *a* concentrations below 2 μg/L are considered low, while those exceeding 10 μg/L are considered high and indicative of poor water quality. The USEPA recommended a numeric criterion of 2.6 μg/L as a target concentration for lakes in Aggregate Nutrient Ecoregion VII (USEPA, 2000a).

4.5.2 Lake Water Quality Assessment Results

Palestine Lake

Results from the Palestine Lake water quality assessment are included in Figures 64 and 65 and Tables 34 to 37. Data collected within the West Basin of Palestine Lake are shown in Figure 64 and Tables 34 and 35, while Figure 65 and Tables 36 and 37 display data collected in the East Basin of Palestine Lake.

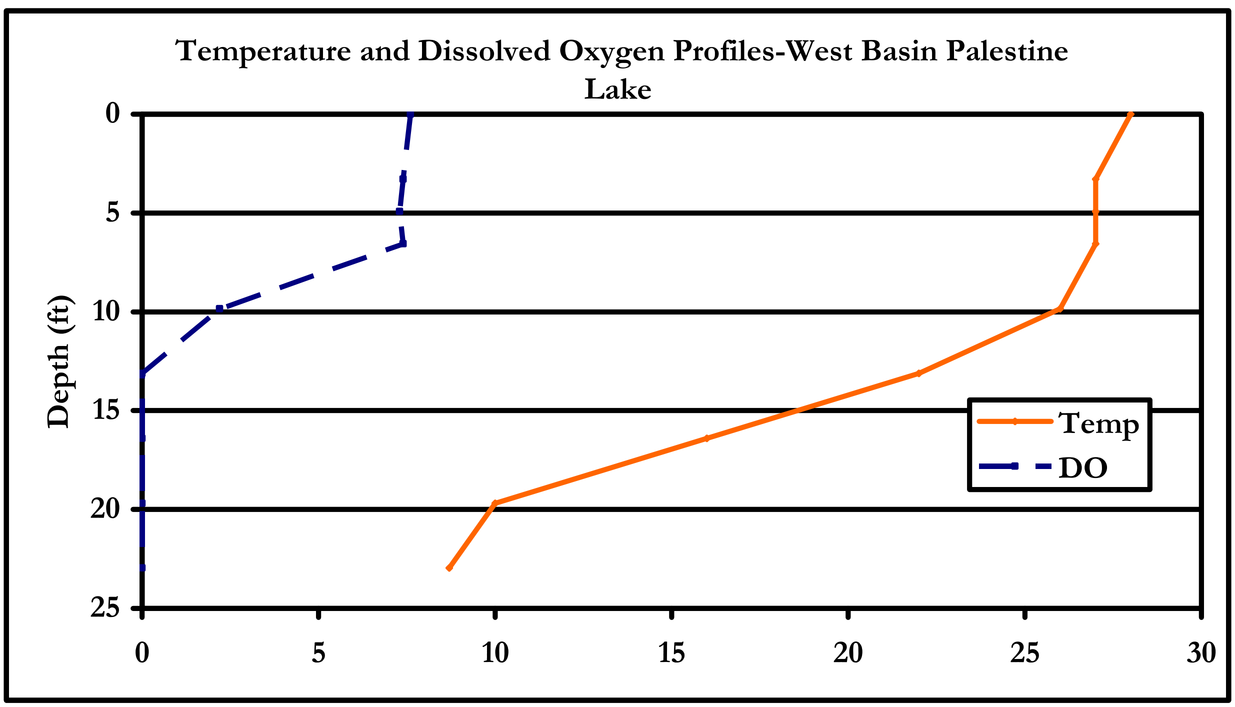

Figure 64. Temperature and dissolved oxygen profiles for West Basin Palestine Lake on June 19, 2007.

Table 34. Water quality characteristics of West Basin Palestine Lake, June 19, 2007.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.2	7.5	-
Alkalinity	200 mg/L	239 mg/L	-
Conductivity	518 μmhos	375 μmhos	-
Secchi Depth Transparency	0.8 meters	-	6
Light Transmission @ 3 ft.	8.3 %	-	4
1% Light Level	8.5 feet	-	-
Total Phosphorous	0.087 mg/L	0.340 mg/L	4
Soluble Reactive Phosphorous	0.010* mg/L	0.405 mg/L	4
Nitrate-Nitrogen	0.049 mg/L	0.072 mg/L	0
Ammonia-Nitrogen	0.150 mg/L	1.651 mg/L	3
Organic Nitrogen	1.256 mg/L	1.289 mg/L	3
Turbidity	3.0 NTU	-	-
Oxygen Saturation @ 5ft.	94%	-	0
% Water Column Oxic	43%	-	3
Plankton Density	10,955/L	-	2
Blue-Green Dominance	23.3%	-	0
Chlorophyll *a*	31.15 μg/L	-	-
		TSI score	**29**

*Method detection limit

Table 35. The plankton sample representing the species assemblage of West Basin Palestine Lake on June 19, 2007.

Species	Abundance (#/L)
Blue-Green Algae (Cyanophyta)	
Aphanothece	1989
Oscillatoria	331
Aphanizomenon	133
Lyngbya	99
Coelosphaerium	66
Microcystis	33
Green Algae (Chlorophyta)	
Desmodesmus	1425
Ankistrodesmus	729
Miscellaneous green	729
Closteriopsis	497
Coelastrum	265
Arthrospira	265
Ulothrix	232
Gonium	199
Pandorina	166
Scenedesmus	99
Micractinium	99

Species	Abundance (#/L)
Actinastrum	66
Treubarra	66
Pediastrum	33
Closterium	33
Gloeocapsa	33
Cosmarium	33
Errerella	33
Mougeotia	33
Diatoms (Bacillariophyta)	
Synedra	1392
Other Algae	
Dinobryon	1525
Miscellaneous protozoan	133
Peridinium	99
Ceratium	33
Zooplankton	
Polyarthra	166
Nauplius	14
Cyclopoid Copepod	2.3
Daphnia	0.9
Calanoid Copepod	0.5

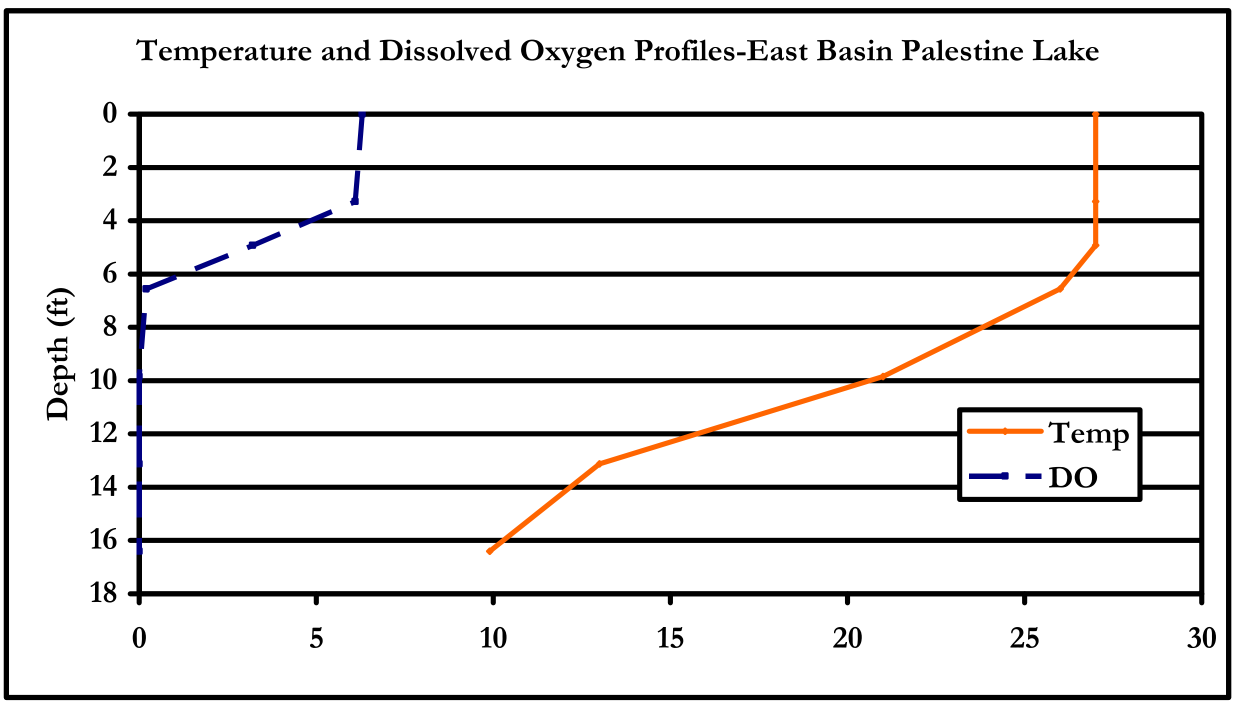

Figure 65. Temperature and dissolved oxygen profiles for East Basin Palestine Lake on June 19, 2007.

Table 36. Water quality characteristics of East Basin Palestine Lake, June 19, 2007.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	7.4	7.9	-
Alkalinity	227 mg/L	224 mg/L	-
Conductivity	557 µmhos	394 µmhos	-
Secchi Depth Transparency	0.65 meters	-	6
Light Transmission @ 3 ft.	4.6%	-	4
1% Light Level	5.5 feet	-	-
Total Phosphorous	0.144 mg/L	0.139 mg/L	3
Soluble Reactive Phosphorous	0.010* mg/L	0.064 mg/L	1
Nitrate-Nitrogen	0.029 mg/L	0.027 mg/L	0
Ammonia-Nitrogen	0.027 mg/L	0.633 mg/L	1
Organic Nitrogen	1.491 mg/L	1.127 mg/L	3
Turbidity	3.8 NTU	-	-
Oxygen Saturation @ 5ft.	48%	-	0
% Water Column Oxic	30%	-	3
Plankton Density	30,825/L	-	4
Blue-Green Dominance	14.4 %	-	0
Chlorophyll *a*	43.48 µg/L	-	-
		TSI score	**25**

*Method detection limit

Table 37. The plankton sample representing the species assemblage of East Basin Palestine Lake on June 19, 2007.

Species	Abundance (#/L)
Blue-Green Algae (Cyanophyta)	
Oscillatoria	2,078
Lyngbya	1,692
Aphanizomenon	386
Aphanothece	119
Microcystis	89
Anabaena	30
Aphanocapsa	30
Coelosphaerium	30
Green Algae (Chlorophyta)	
Actinastrum	950
Miscellaneous green	861
Dictyosphaerium	386
Ankistrodesmus	356
Coelastrum	238
Scenedesmus	238
Spirulina	238
Desmodesmus	178
Ulothrix	30

Species	Abundance (#/L)
Staurastrum	30
Polyedriopsis	30
Gloeocyslis	30
Closterium	30
Diatoms (Bacillariophyta)	
Synedra	19,507
Miscellaneous diatom	534
Fragillaria	178
Navicula	30
Other Algae	
Miscellaneous protozoan	505
Ceratium	475
Zooplankton	
Keratella	356
Nauplius	31
Filinia	30
Cyclopoid Copepod	2.9
Daphnia	0.4

Temperature profiles for both basins of Palestine Lake show that the lake was stratified at the time of sampling (Figures 64 and 65). During thermal stratification, the bottom waters (*hypolimnion*) of the lake are isolated from the well-mixed *epilimnion* (surface waters) by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth, is called the *metalimnion.* At the time of sampling, the epilimnion was confined to the upper 6.5 to 9.8 feet (2 to 3 m) of water. The decline in temperature between 9.8 and 19.6 feet (3 and 6 m) in the West Basin and between 6.5 and 13.0 feet (2 and 4 m) in the East Basin defines the metalimnion or transition zone within each basin of Palestine Lake. The hypolimnion occupied water deeper than this transition zone (19.6 feet (6 m) in the West Basin and 13.0 feet (4 m) in the East Basin).

The dissolved oxygen profiles mirror the temperature profiles and are generally consistent with historical dissolved oxygen profiles for the lake (Figures 58 and 59). In the West Basin, the lake was slightly undersaturated maintaining a dissolved oxygen concentration of 7.5 mg/L from the water surface to a depth of 6.5 feet (2 m) before concentrations declined to anoxic conditions at a depth of 13.0 feet (4 m). The depth at which dissolved oxygen rapidly declines (6.5 to 13.0 feet (2 to 4 m)) corresponds with the top edge of the *euphotic zone*, or the locations where insufficient light limits photosynthesis by phytoplankton. In this portion of the lake, aquatic fauna are respiring, or using available oxygen, while bacteria are consuming oxygen during decomposition. All of this results in declining dissolved oxygen concentrations. Below this (13.0 feet or 4 m), DO levels decline until there is no dissolved oxygen remaining in the West Basin of Palestine Lake. This is likely due to biological oxygen demand (BOD) from excess organic detritus in the lake's deeper waters. Respiration by aquatic fauna and decomposition of organic matter likely depleted the oxygen supply in the lake's deeper waters. Water below 13.0 feet (4 m) did not contain sufficient dissolved oxygen to support fish and other aquatic organisms. The lack of oxygen at the lake-sediment interface created conditions conducive to the release of phosphorus from the lake's sediments. Only 43% of the basin's water column was oxic, limiting the amount of habitat available for aquatic fauna.

A similar pattern occurs in the East Basin of Palestine Lake. However, the decline occurs much higher in the water column. In the East Basin, the lake was undersaturated maintaining a dissolved oxygen concentration of 6 mg/L from the water surface to a depth of 3.1 feet (1 m) before concentrations declined to anoxic conditions at a depth of 6.2 feet (2 m). Similar to the West Basin, this range (3.1 to 6.2 feet (1 to 2 m)) corresponds with the top edge of the *euphotic zone*. Below 6.2 feet (2 m), DO levels decline until no dissolved oxygen remains in the East Basin of Palestine Lake.

Values for pH are within the normal range for Indiana lakes, ranging from pH 7.4 in the East Basin to pH 8.2 in the West Basin. These pH values are typical for most fresh waters as pH values typically fall between pH 6-9 (Kalff, 2002). The alkalinity values, a measure of buffering capacity, indicate that Palestine Lake is well buffered against large changes in pH. Conductivity values, a measure of dissolved ions, were within the normal range for Indiana lakes.

Palestine Lake continues to exhibit poor water clarity. The lake's Secchi disk transparency depths at the time of sampling ranged from 2.1 feet (0.65 m) in the East Basin to 2.6 feet (0.8 m) in the West Basin. These results are generally poorer than the measurement taken during the aquatic macrophyte survey on August 2, 2007. However, the results recorded during the water quality assessment of the lake are consistent with historic water quality measurements. Light transmission at 3 feet (0.9 m) was also generally poor ranging from 4.6% in the East Basin to 8.3% in the West Basin.

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

Despite Palestine Lake's relatively poor transparency and light transmission, the lake's 1% light level extended to 5.5 feet (1.7 m) in the East basin and 8.5 feet (2.6 m) in the West basin. Based on the depth-area curve in Figure 43, approximately 92% of lake bottom (approximately 269 acres (108.8 ha)) is shallower than 7 feet (2.1 m). This represents the approximate <u>area</u> 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 44), we see that a <u>volume</u> of greater than 912 acre-feet (1,124,935 m^3) of Palestine Lake (78% of total lake volume) lies above the mean 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 and therefore are measured in lake water quality analyses. In the summer, Indiana lakes typically possess lower nutrient concentrations in their epilimnia compared to nutrient concentrations present in their hypolimnia. Algae in the lake's epilimnion often utilize a large portion of the readily available nutrients for growth. When the algae die and settle to the bottom sediments, nutrients are relocated to the hypolimnion. Higher concentrations of phosphorus in the hypolimnion may also result from chemical processes occurring at the sediment-water interface.

Nutrient concentrations in Palestine Lake are low relative to other regional lakes and are on par with assessments completed in Palestine Lake in the past. At the time of sampling, nitrate-nitrogen concentrations in Palestine Lake were low in both the epilimnion and hypolimnion of both basins. Nitrate-nitrogen concentrations ranged from 0.029 mg/L and 0.027 mg/L in the epilimnion and hypolimnion of the East Basin, respectively to 0.049 mg/L and 0.072 mg/L in the epilimnion and hypolimnion of the West Basin. Despite measuring relatively normal for Indiana lakes, nitrate-nitrogen concentrations were higher than the USEPA target concentration of 0.008 mg/L (USEPA, 2000a). Ammonia-nitrogen concentrations measured in the lake's epilimnion were lower than the corresponding hypolimnetic concentrations. Concentrations measured 0.027 mg/L and 0.633 mg/L in the East Basin's epilimnion and hypolimnion, respectively and 0.150 mg/L and 1.651 mg/L in the West Basin's epilimnion and hypolimnion, respectively. Since ammonia-nitrogen is a byproduct of decomposition, a higher hypolimnetic concentration of ammonia-nitrogen suggests decomposition is occurring in the lake's bottom waters. The hypolimnetic concentration of ammonia-nitrogen observed during this sampling effort is similar to the hypolimnetic concentrations of ammonia-nitrogen observed during the most recent assessments indicating that the rate or amount of decomposition has not changed significantly over the years. Despite the relatively limited change in decomposition over time, hypolimnetic ammonia-nitrogen concentrations indicate the presence of a high amount of biochemical oxygen demand (BOD) to produce the NH_4 and a low amount of dissolved oxygen present to maintain these relatively high concentrations. Both the East and West basin hypolimnia exceed the USEPA ambient water quality criteria recommendations for regional lakes, which is 0.525 mg/L for ammonia (USEPA, 2000a). However, only the West Basin contained ammonia-nitrogen concentrations in excess of the median concentrations for Indiana lakes.

Additionally, Palestine Lake's total phosphorus and soluble reactive phosphorus concentrations were normal to elevated when compared to other regional lakes. The lake's epilimnetic soluble reactive phosphorus concentrations were below the detection limit (0.010 mg/L) in both basins, which is below the threshold at which algal blooms can occur. Epilimnetic soluble reactive phosphorus concentrations in Indiana lakes are often below the laboratory detection limit because this form of phosphorus is readily consumed by algae. Palestine Lake's hypolimnetic soluble reactive phosphorus concentrations measured 0.064 mg/L in the East Basin and 0.405 mg/L in the West Basin. This suggests that the lake is releasing phosphorus from its bottom sediments within both basins. Higher phosphorus concentrations within the hypolimnion are usually associated with phosphorus release from the sediments under these anoxic conditions. Sedimentation of particulates and plankton also provide a source of phosphorus to the hypolimnion.

Palestine Lake's total phosphorus concentrations further support this theory. In the East Basin, total phosphorus concentrations are almost equal between the epilimnion and hypolimnion. This suggests that not only is phosphorus routinely released from the lake's sediment, but that regular mixing between the lake's surface and deep waters occurs. This creates the relatively high total phosphorus concentration observed throughout the water column. In the West Basin, concentrations are similarly high within both the epilimnion and hypolimnion. However, concentrations measured in the lake's bottom waters are nearly four times higher than those observed in the basin's surface waters. This results in overall soluble reactive and total phosphorus concentrations in excess of the median concentration measured in Indiana lakes. All total phosphorus concentrations measured higher than the USEPA recommended nutrient criteria (0.075mg/L; USEPA, 2000a).

Palestine Lake's plankton density reflects the nutrient concentrations in the lake. Palestine Lake exhibited a chlorophyll *a* concentration of 31 μg/L in the West Basin and a concentration of 44 μg/L in the East Basin. These concentrations are lower than the chlorophyll *a* concentrations observed in previous assessments. However, concentrations measure approximately three times higher than other lakes in the region and are much higher than the USEPA's recommended target concentration of 2.6 μg/L (USEPA, 2000a).

Plankton enumerated from the sample collected from Palestine Lake are shown in Tables 38 and 39. Both basins had a rich diversity of plankton genera with 32 different genera observed in the East Basin and 35 different genera observed in the West Basin. *Synedra*, a diatom, was the most dominant genera found in the East basin, and accounted for two-thirds the plankton density. The West Basin, however, was more equally distributed between the genera found. Green algae dominated and represented approximately half of the species found. Diatoms comprised approximately 13% of the total assemblage observed in the West Basin. Diatoms typically have higher concentrations early in the sampling season; yet diatom concentrations typically decline closer to spring turnover. Diatom numbers increase with and after turnover because of the increased supply of available dissolved silica (Kalff and Watson, 1986).

Blue-green species only represent 14.4% and 23.3% in the East and West basin plankton populations, respectively. Most likely, a late summer sampling would show a very different scenario. Diatom populations generally decrease throughout the growing season, as silica becomes limiting, while blue-greens tend to flourish in the warm, nutrient rich waters of summer. A plankton sample was collected by the DNR District Fisheries biologist during a summer algal bloom which occurred in August 2007. The plankton sample was collected August 27, 2007 and sent to IUPUI for assessment. Results were as anticipated with blue-green and green algae dominating the sample. Pithophora, a matte-forming green algae, and Oscillatria, a potential algal-toxin producing blue-green algae were the most prevalent species. Additionally, a number of diatom species were also present (Lenore Tedesco, IUPUI, personal communication). 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.

Caldwell Lake

Results from the Caldwell Lake water quality assessment are included in Tables 38 and 39 and Figure 66.

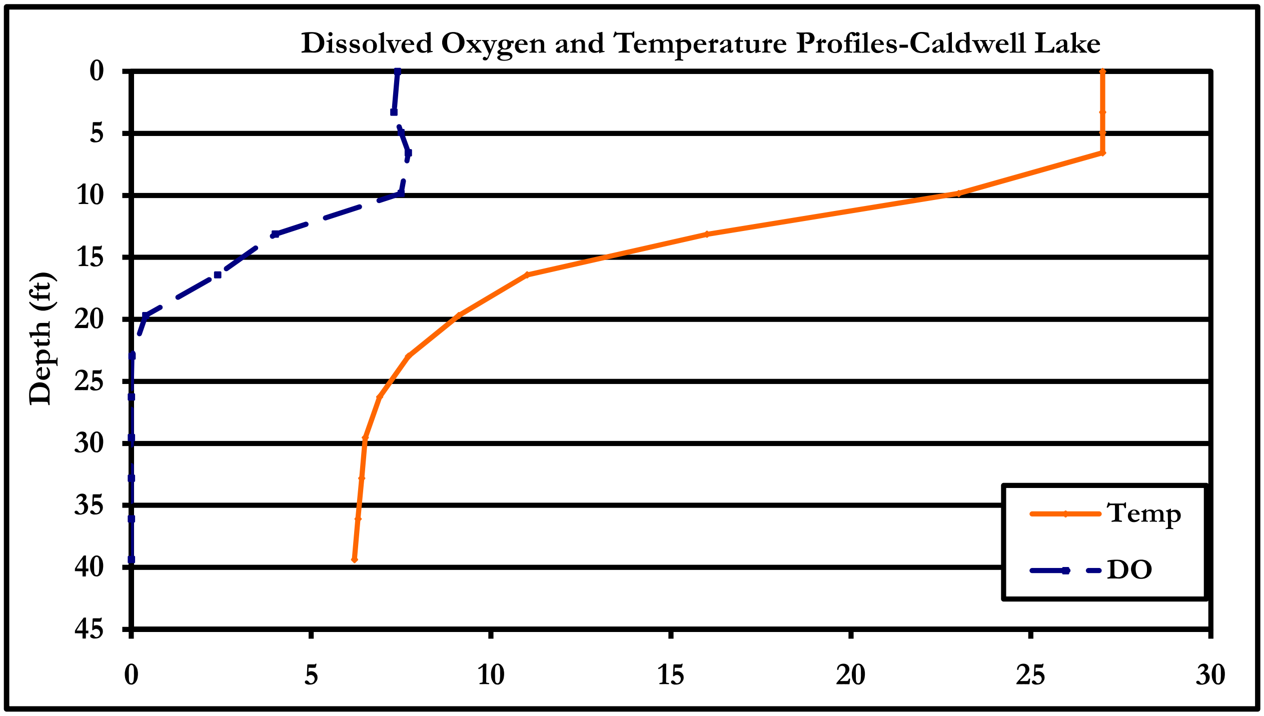

Figure 66. Temperature and dissolved oxygen profiles for Caldwell Lake on June 19, 2007.

Table 38. Water quality characteristics of Caldwell Lake, June 19, 2007.

Parameter	**Epilimnetic Sample**	**Hypolimnetic Sample**	**Indiana TSI Points (based on mean values)**
pH	8.2	7.3	-
Alkalinity	201 mg/L	262 mg/L	-
Conductivity	487 μmhos	348 μmhos	-
Secchi Depth Transparency	4.1 meters	-	0
Light Transmission @ 3 ft.	15.4%	-	4
1% Light Level	19.7 feet	-	-
Total Phosphorous	0.02 mg/L	0.494 mg/L	4
Soluble Reactive Phosphorous	0.010* mg/L	0.425 mg/L	4
Nitrate-Nitrogen	0.835 mg/L	0.103 mg/L	2
Ammonia-Nitrogen	0.040 mg/L	1.296 mg/L	3
Organic Nitrogen	0.804 mg/L	1.359 mg/L	3
Turbidity	1.1 NTU	-	-
Oxygen Saturation @ 5ft.	91%	-	0
% Water Column Oxic	42%	-	3
Plankton Density	6,416/L	-	2
Blue-Green Dominance	44.5 %	-	0
Chlorophyll *a*	3.48 μg/L	-	-
		TSI score	**25**

*Method detection limit

Table 39. The plankton sample representing the species assemblage of Caldwell Lake on June 19, 2007.

Species	Abundance (#/L)
Blue-Green Algae (Cyanophyta)	
Aphanizomenon	2,679
Aphanothece	132
Aphanocapsa	26
Green Algae (Chlorophyta)	
Ulothrix	145
Miscellaneous flagellated green	132
Eudorina	119
Miscellaneous coccoid green	66
Schroederia	26
Dictyosphaerium	13
Diatoms (Bacillariophyta)	
Asterionella	238
Synedra	13
Other Algae	
Ceratium	897
Dinobryon	185
Zooplankton	
Keratella	53
Mallamonas	13
Polyarthra	13
Nauplius	4.1
Daphnia	3
Calanoid Copepod	2.3
Cyclopoid Copepod	0.2

The temperature profile for Caldwell Lake shows that the lake was stratified at the time of sampling (Figure 66). During thermal stratification, the bottom waters (*hypolimnion*) of the lake are isolated from the well-mixed *epilimnion* (surface waters) by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth, is called the *metalimnion*. At the time of sampling, the epilimnion was confined to the upper 6.5 feet (2 m) of water. The decline in temperature between 6.5 and 22.9 feet (2 and 7 m) defines the metalimnion or transition zone. The hypolimnion occupied water deeper than 7 meters (22.9 feet).

The dissolved oxygen profile mirrors the temperature profile and is consistent with historical dissolved oxygen profiles for the lake (Figure 63). The lake was slightly undersaturated maintaining a dissolved oxygen concentration of 7 mg/L from the water surface to a depth of 3.2 feet (1 m) before concentrations increased to form a small peak at a depth of 6.5 feet (2 m). Although the peak is not as large as that present during previous assessments, this supersaturation represents a *metalimnetic oxygen maximum* and is likely associated with a higher concentrations of phytoplankton at that particular depth layer. A peak like this typically results when the rate of settling plankton slows in the denser waters of the metalimnion. As the plankton at this depth photosynthesize, they release oxygen into the water column, creating a peak in oxygen at that level. The oxygen concentration decreases rapidly within the epilimnion to a depth of 19.7 feet (6 m). The area from 6.5 to 19.7 feet (2 to 6 m) corresponds with the top edge of the *euphotic zone*, or the locations where insufficient light limits photosynthesis by phytoplankton. In this portion of the lake, aquatic fauna are respiring, or using available oxygen, while bacteria are consuming oxygen during decomposition. All of this results in declining dissolved oxygen concentrations. Below 19.7 feet (6 m), DO levels decline until there is no dissolved oxygen remaining in the lake. This is likely due to biological oxygen demand (BOD) from excess organic detritus in the lake's deeper waters. Respiration by aquatic fauna and decomposition of organic matter likely depleted the oxygen supply in the lake's deeper waters. Water below 19.7 feet (7 m) did not contain sufficient dissolved oxygen to support fish and other aquatic organisms. The lack of oxygen at the lake-sediment interface created conditions conducive to the release of phosphorus from the lake's sediments. Only 42% of the lake's water column was oxic, limiting the amount of habitat available for aquatic fauna.

Values for pH were within the normal range for Indiana lakes and typical of most fresh waters (Kalff, 2002). The alkalinity values, a measure of buffering capacity, indicate that Caldwell Lake is well buffered against large changes in pH. Conductivity values, a measure of dissolved ions, were within the normal range for Indiana lakes.

Caldwell Lake exhibited better than normal water clarity during the water quality assessment. The lake's Secchi disk transparency depth at the time of sampling was 13.4 feet (4.1 m). This result is consistent with the measurement taken during the aquatic macrophyte survey on August 2, 2007. Despite the better than average transparency, light transmission at 3 feet (0.9 m) was relatively poor measuring only 15.4%.

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

Because of the lake's good water clarity, Caldwell Lake's 1% light level is relatively deep, extending to a depth of 19.7 feet (6 m). Using the definition of littoral zone provided above, Caldwell Lake's littoral zone is that portion of the lake with water depths less than 19.7 feet (6 m). Based on the depth-area curve in Figure 44, this would mean that Palestine Lake's littoral zone is approximately 27 acres (10.9 ha) in size and covers 60% of the lake's surface area. A previous section of this document suggests Caldwell Lake's littoral zone is the same area. (This estimate was based on the lake's Secchi disk transparency.)

The lake's 1% light level also defines the lake's *photic zone*. A lake's *photic zone* is the volume of water with sufficient light to support algae growth. Based on Caldwell Lake's depth-volume curve (Figure 47), more than 635 acre-feet of Caldwell Lake (80% of total lake volume) lies above the 19.7-foot 1% light level. This volume constitutes the lake's photic zone.

As previously described, phosphorus and nitrogen are the primary plant nutrients in lakes and therefore are measured in lake water quality analyses.

Nutrient concentrations in Caldwell Lake measured relatively high when compared to other regional lakes and are on par with assessments completed in Caldwell Lake in the past. At the time of sampling, nitrate-nitrogen concentrations in Caldwell Lake were relatively high measuring 0.835 mg/L in the epilimnion and 0.103 mg/L in the lake's hypolimnion. Ammonia-nitrogen oxidizes rapidly to nitrate-nitrogen in the presence of adequate oxygen and nitrifying bacteria, which partially explains the presence of the extremely high surface nitrate-nitrogen concentration. However, as the concentration remains high throughout the water column, the data suggest that there is a source of nitrate-nitrogen routinely entering the lake. Because nitrate-nitrogen concentrations are elevated within the surface water of Caldwell Lake, it is not surprising that nitrate-nitrogen concentrations were higher than the USEPA target concentration of 0.008 mg/L (USEPA, 2000a). The ammonia-nitrogen concentration in the lake's epilimnion measured lower than the corresponding hypolimnetic concentrations. Since ammonia-nitrogen is a byproduct of decomposition, a higher hypolimnetic concentration of ammonia-nitrogen suggests decomposition is occurring in the lake's bottom waters. The hypolimnetic concentration of ammonia-nitrogen observed during this sampling effort is similar to the hypolimnetic concentrations of ammonia-nitrogen observed during the most recent assessments indicating that the rate or amount of decomposition has not changed significantly over the years.

Additionally, Caldwell Lake's total phosphorus and soluble reactive phosphorus concentrations were high measuring on par with the epilimnion and hypolimnion concentrations observed in previous assessments. The lake's epilimnetic soluble reactive phosphorus concentration was below the detection limit (0.010 mg/L), which is below the threshold at which algal blooms can occur. Epilimnetic soluble reactive phosphorus concentrations in Indiana lakes are often below the laboratory detection limit because this form of phosphorus is readily consumed by algae. The lake's relatively low epilimnetic soluble reactive phosphorus concentration coupled with its relatively low plankton density suggest that nutrients may be limiting algal growth in the lake. Caldwell Lake's hypolimnetic soluble reactive phosphorus concentration measured more than 40 times the lake's epilimnetic concentration suggesting that the lake is releasing phosphorus from its bottom sediments. Total phosphorus concentrations follow a similar pattern with the epilimnetic concentration measuring 0.020 mg/L and the hypolimnetic concentration measuring 0.494 mg/L. When comparing soluble reactive and total phosphorus concentrations, the data suggest that a majority of the phosphorus present in Caldwell Lake occurs in the soluble, easily usable form. Additionally, both soluble reactive and total phosphorus concentrations present in Caldwell Lake exceed the concentration present in most Indiana lakes.

Caldwell Lake's relatively low plankton density (6,416/L) suggests that something other than nutrients are limiting the productivity of the lake. Caldwell Lake exhibited a chlorophyll *a* concentration of 3.48 μg/L. This concentration is slightly lower than the chlorophyll *a* concentrations previously observed in the lake. Additionally, it is low relative to other lakes in the region (median concentration measures 12.9 μg/L) but is higher than the USEPA's recommended target concentration of 2.6 μg/L.

Caldwell Lake's plankton density was lower than the density observed during all previous assessments (Table 37). At the time of the current sampling effort, *Aphaizomenon*, a blue-green algae, dominated the sample, accounting for 40% of the community. In total, 45% of the Caldwell Lake plankton community consisted of blue-green algae. This is consistent with the findings of previous assessments on Caldwell Lake. In four comprehensive examinations of the lake (CLP, 1990, 1994 1998, and 2004), blue-green algae accounted for 87% to 99% of the lake's plankton density.

4.5.3 Lake Water Quality Assessment Discussion

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

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

Comparison with Vollenweider's Data

Results of studies conducted by Richard Vollenweider in the 1970's are often used as guidelines for evaluating concentrations of water quality parameters. His results are given in Table 40. Vollenweider relates the concentrations of selected water quality parameters to a lake's *trophic state*. The trophic state of a lake refers to its overall level of nutrition or biological productivity. Trophic categories include: ***oligotrophic***, ***mesotrophic***, ***eutrophic*** and ***hypereutrophic***. Lake conditions characteristic of these trophic states are:

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

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

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

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

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

Table 40. Mean values of some water quality parameters and their relationship to lake production (after Vollenweider, 1975).

	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Chlorophyll *a* (µg/L)
Oligotrophic	0.008	0.661	1.7
Mesotrophic	0.027	0.753	4.7
Eutrophic	0.084	1.875	14.3
Hypereutrophic	>0.750	-	-
East Basin Palestine Lake	0.141	1.209	43.5
West Basin Palestine Lake	0.214	1.273	31.2
Caldwell Lake	0.257	1.082	3.5

Regarding to nutrient concentrations, both lakes range from mesotrophic to eutrophic when compared with Vollenweider's data (Table 40). Specifically, all three lake's total phosphorus concentration measure higher than lakes in Vollenweider's eutrophic category; however, the total phosphorus concentrations were lower than lakes that rated hypereutrophic during Vollenweider's assessment. The lake's nitrogen concentrations place the lakes in the mesotrophic to eutrophic range. However, when chlorophyll *a* concentrations are reviewed, concentrations present in the lakes suggest that Palestine Lake would rate as eutrophic, while Caldwell Lake would rate as oligotrophic. With relation to nutrients, Caldwell Lake would rate as eutrophic. The data suggest that despite the elevated nutrient concentrations present in Caldwell Lake, the lake may not be fully utilizing the available nutrients. This further suggests that something other than nutrients are limiting productivity within Caldwell Lake.

Comparison with Other Indiana Lakes

The Palestine and Caldwell lakes' results can also be compared with other Indiana lakes. Table 41 presents data from 456 Indiana lakes collected during July and August from 1994 to 2004 under the Indiana Clean Lakes Program. The set of data summarized in the table are mean values obtained by averaging the epilimnetic and hypolimnetic pollutant concentrations in samples from each of the 456 lakes. It should be noted that a wide variety of conditions, including geography, morphometry, time of year, and watershed characteristics, can influence the water quality of lakes. Thus, it is difficult to predict and even explain the reasons for the water quality of a given lake.

Overall, Palestine Lake possessed water quality on par with or poorer than most lakes in Indiana (Table 41) during the June 19, 2007 assessment. Palestine Lake's Secchi disk transparency depth measured less than half that found in most lakes in Indiana. Nitrogen and phosphorus concentrations measured in the East Basin suggest that the lake possesses better water quality than most lakes in the state, while nutrient data from the West Basin suggests that the lake possesses poorer water quality than most lakes in the state (Figure 67). Only one of the nutrient concentrations (total Kjeldahl nitrogen) measured in the East Basin of Palestine Lake exceeded the median concentration observed in Indiana lakes. However, soluble reactive and total phosphorus and total Kjeldahl and ammonia-nitrogen concentrations measured in the West Basin were in excess of concentrations found in most Indiana lakes. Despite the differences in nutrient concentrations, both basins contain relatively high chlorophyll *a* concentrations. These concentrations measure nearly three times the concentration found in most Indiana lakes. In Caldwell Lake, nitrate-nitrogen, total Kjeldahl nitrogen, soluble reactive phosphorus, and total phosphorus concentrations were in excess of concentrations observed in most Indiana lakes. Despite these relatively high nutrient concentrations, Caldwell Lake was less productive, as measured by chlorophyll *a* concentration and plankton density, than most Indiana lakes.

Table 41. 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 for all nitrogen and phosphorus parameters. Squares shaded yellow denote those values in excess of the median concentration.

	Secchi Disk (ft)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	Chl *a* (µg/L)	Plankton (#/L)	Blue-Green Dominance
Minimum	0.3	0.01	0.004	0.230	0.01	0.01	0.013	39	0.08%
Maximum	32.8	9.4	22.5	27.05	2.84	2.81	380.4	753,170	100%
Median	6.9	0.275	0.818	1.66	0.12	0.17	12.9	35,570	53.8%
East Palestine	2.1	0.028	0.330	1.639	0.037	0.142	43.48	30,825	14.4%
West Palestine	2.6	0.061	0.901	2.173	0.208	0.214	31.15	10,955	23.3%
Caldwell	13.5	0.469	0.668	1.749	0.252	0.257	3.48	6,416	44.5%

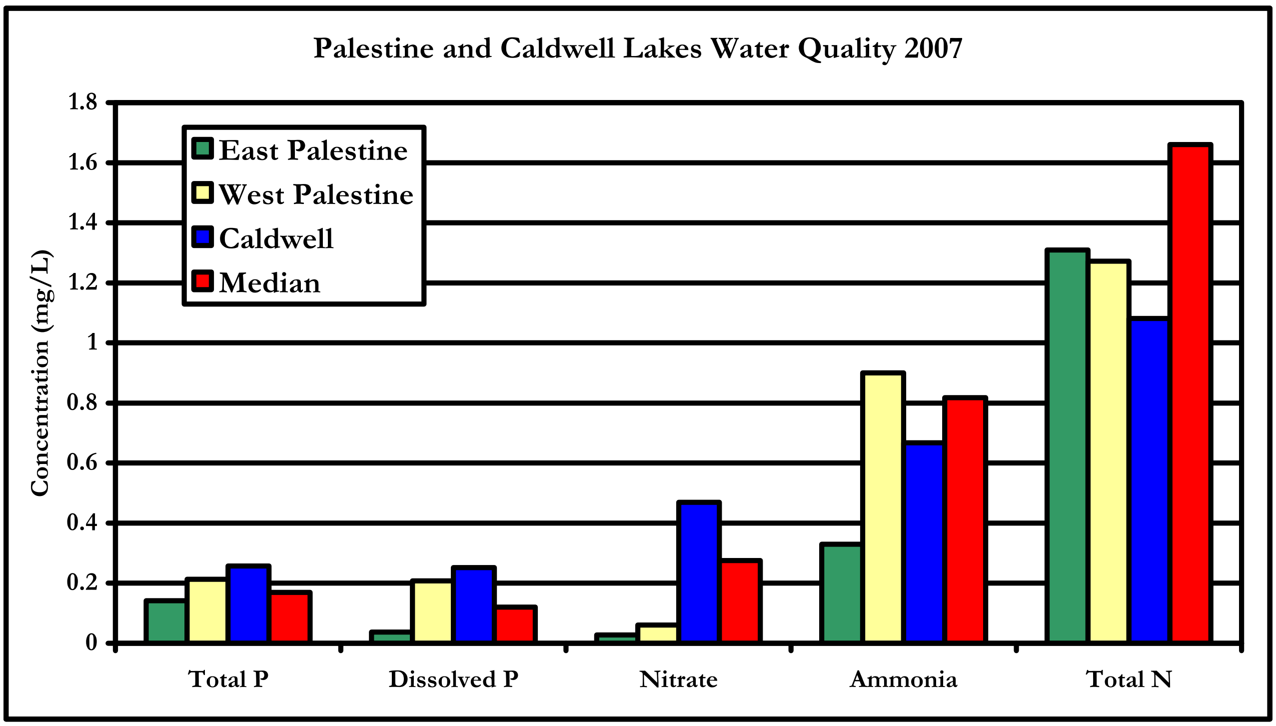

Figure 67. Selected nutrient concentrations within Palestine and Caldwell lakes compared to concentrations present in most lakes in Indiana (shown in red).

Based on data collected in the five-year rotating basin cycle which occurred from 1999 to 2003, water quality within Palestine Lake is poorer than lakes throughout its ecoregion, while water quality in Caldwell Lake is better than lakes throughout the same ecoregion (SPEA, 2006). As previously discussed, Palestine Lake and its watershed lie entirely within the Southern Michigan/Northern

Indiana Till Plains Ecoregion (Ecoregion 56). This ecoregion contains the largest number of lakes (239) found within any of Indiana's ecoregions (SPEA, 2006). Lakes within this ecoregion possessed a median Secchi depth of 5.9 feet (1.8 m), a median total phosphorus concentration of 0.079 mg/L, and a chlorophyll *a* concentration of 17.1 μg/L (SPEA, 2006). Lakes in this ecoregion rank third highest for Secchi disk transparency and total phosphorus concentration and possess the highest chlorophyll *a* concentration of any of Indiana's ecoregions. In comparison, both Palestine and Caldwell lakes contained higher total phosphorus concentrations and Palestine Lake contained higher chlorophyll *a* concentrations and possessed poorer water transparency. Caldwell Lake's chlorophyll *a* concentration and water transparency were better than the average lake in this ecoregion. All of these translate to Palestine Lake containing poorer water quality and Caldwell Lake containing better water quality than lakes throughout its ecoregion. Additionally, both lakes possessed higher nitrate-nitrogen concentrations (compared to 0.057 mg/L), ammonia-nitrogen concentrations (compared to 0.437 mg/L), and similar total Kjeldahl nitrogen concentrations (compared to 1.341 mg/L) than most lakes in the ecoregion.

Using a Trophic State Index

In addition to simple comparisons with other lakes, lake water quality data can be evaluated through the use of a trophic state index or TSI. Indiana and many other states use a trophic state index (TSI) to help evaluate water quality data. A TSI condenses water quality data into a single, numeric index. Different index (or eutrophy) points are assigned for various water quality concentrations. The index total, or TSI, is the sum of individual eutrophy points for a lake.

The Indiana TSI

The Indiana TSI (ITSI) was developed by the Indiana Stream Pollution Control Board and published in 1986 (IDEM, 1986). The original ITSI differed slightly from the one in use today. Today's ITSI uses ten different water quality parameters to calculate a score. Table 42 shows the point values assigned to each parameter.

Table 42. The Indiana Trophic State Index.

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

III. Organic Nitrogen (ppm)

A.	At least 0.5	1
B.	0.6 to 0.8	2
C.	0.9 to 1.9	3
D.	2.0 or more	4

IV. Nitrate (ppm)

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

V. Ammonia (ppm)

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

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

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

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

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

VIII. Light Penetration (Secchi Disk)

A.	Five feet or under	6

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

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

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

A.	less than 3,000 organisms/L	0
B.	3,000 - 6,000 organisms/L	1
C.	6,001 - 16,000 organisms/L	2
D.	16,001 - 26,000 organisms/L	3
E.	26,001 - 36,000 organisms/L	4
F.	36,001 - 60,000 organisms/L	5
G.	60,001 - 95,000 organisms/L	10
H.	95,001 - 150,000 organisms/L	15
I.	150,001 - 5000,000 organisms/L	20
J.	greater than 500,000 organisms/L	25
K.	Blue-Green Dominance: additional points	10

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

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

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

At the time of the June 19, 2007 sampling, Palestine Lake's East Basin possessed an Indiana Trophic State Index value of 25, while the West Basin Palestine Lake scored a 29. Caldwell Lake scored an ITSI value of 25. These values place both lakes in the mesotrophic category. For Caldwell Lake, this conclusion is generally consistent with results obtained from the comparison of the lake data to Vollenweider's data (Table 40), where nutrient parameters suggested the lake was mesotrophic to eutrophic in nature. However, when compared with results obtained for Palestine Lake, the Indiana TSI score under-represents the findings in comparison to Vollenweider's data. The previous assessment suggested that Palestine Lake was eutrophic to hypereutrophic in nature, while the current assessment suggests that Palestine Lake rates as mesotrophic. Further assessment and comparison of these two scoring methodologies will be discussed in subsequent sections.

Because the ITSI captures one snapshot of a lake in time, using the ITSI to track trends in lake productivity may be the best use of the ITSI. Figure 68 illustrates the change in Palestine and Caldwell lakes' ITSI scores over time. Figure 70 shows relatively little change in regards to Palestine Lake's ITSI score over time. (Only one ITSI score has been calculated for the East Basin of Palestine Lake; therefore, this discussion refers only to the West Basin of Palestine Lake.) The highest score (33) was recorded in 1998, while the lowest score (19) was recorded in 2004. Overall, ITSI scores generally varied between this high and low and were typically in the range of 29 to 33 points. Conversely, a general decline in Caldwell Lake's ITSI scores can be observed over time. The highest score calculated for Caldwell Lake occurred in 1990 (66 points). Scores generally declined from this high to the current score of 25. The only exception to this occurred in 1998. Based on data from Jones (1996), a change ITSI score of 10 or more points indicates a change in water quality. If this holds true for Caldwell Lake, water quality has improved within Caldwell Lake in the last 27 years.

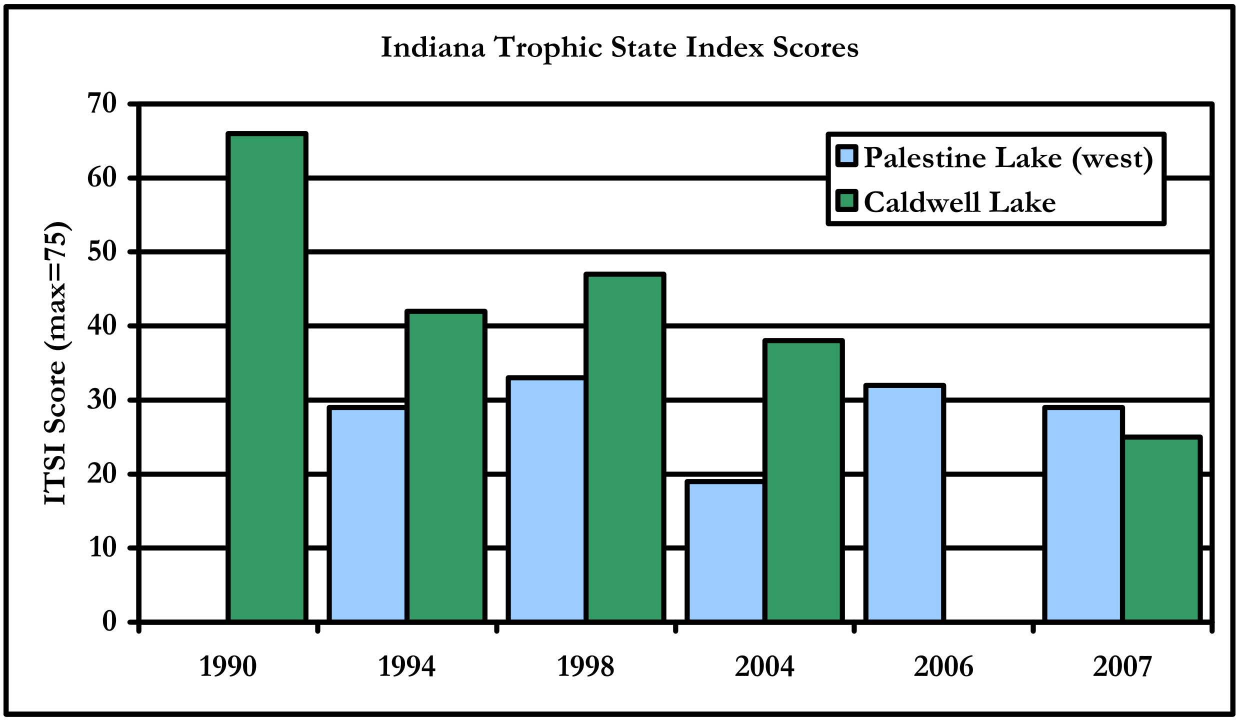

Figure 68. Indiana Trophic Index State scores for Palestine and Caldwell lakes from 1990 to 2007.

Using the ITSI to compare Palestine and Caldwell lakes to other lakes in the region, both lakes' water quality is on par with other lakes in the region. Based on data collected by the Indiana Clean Lakes Program during their 2000 to 2004 assessment cycle, approximately 12.5% of the lakes in the Tippecanoe River Basin (which includes the Palestine Lake watershed) were classified as oligotrophic (IDEM, 2006). Another 36% rated as mesotrophic. Forty percent fell in the eutrophic category, while 9% fell in the hypereutrophic category. Palestine and Caldwell lakes' placement in the mesotrophic category based on the ITSI suggests its water quality is among the upper 38% of lakes in the region when ranked by water quality. Palestine and Caldwell lakes' water quality rates better than 52% of the lakes in the Tippecanoe River Basin. This evaluation is consistent with the comparison of raw data scores for the lake to those for all lakes in Indiana (Table 42).

The Carlson TSI

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 (Figure 69).

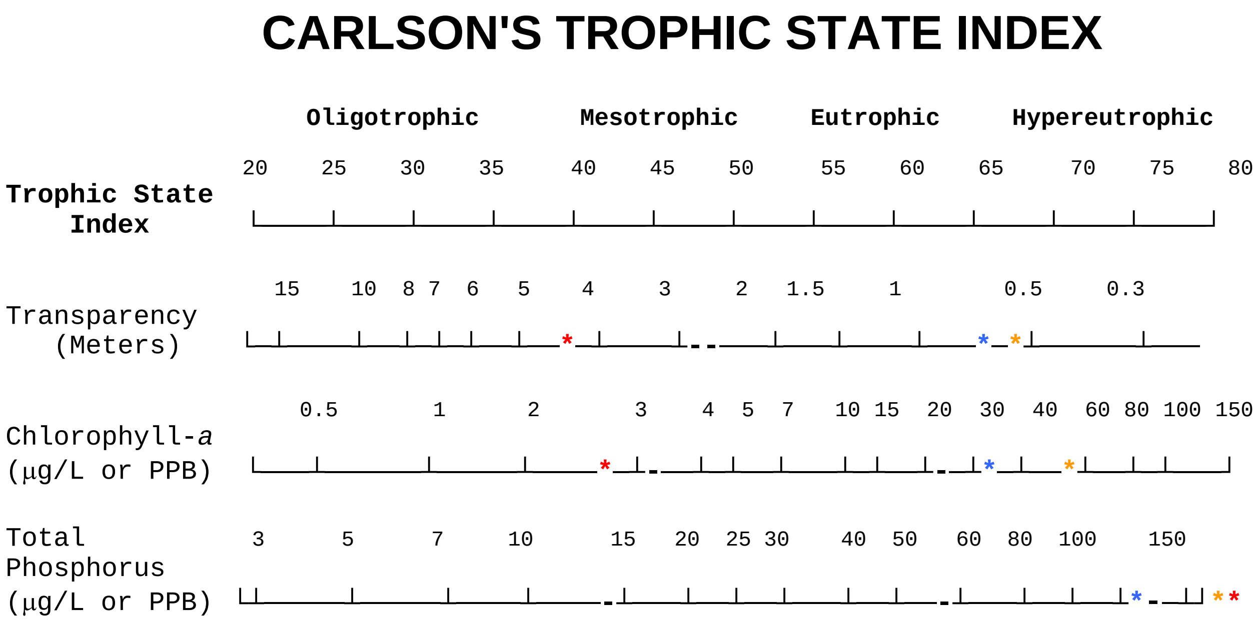

Figure 69. Carlson's Trophic State Index with Palestine East (*), Palestine West (*), and Caldwell Lake (*) results indicated by asterisks.

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

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

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

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

Analysis of Palestine Lake's total phosphorus, transparency, and chlorophyll *a* data using to Carlson's TSI suggests that the lake is eutrophic to hypereutrophic (Figure 69). In both basins, Palestine Lake's transparency and chlorophyll *a* concentration place the lake in the eutrophic category, while its total phosphorus concentration places it off of the scale above the hypereutrophic categories. This analysis is basically consistent with the results obtained when comparing the Palestine Lake data to Vollenweider's data. Both analyses suggest that Palestine Lake possesses sufficient phosphorus to support a greater level of productivity than the level suggested by the lake's chlorophyll *a* concentration.

Similar analysis of Caldwell Lake's total phosphorus, transparency, and chlorophyll *a* data using to Carlson's TSI suggests that the lake is mesotrophic (Figure 69). Caldwell Lake's transparency and chlorophyll *a* concentration place the lake in the mesotrophic category, while its total phosphorus concentration places it off of the scale above the hypereutrophic categories. This analysis is basically consistent with the results obtained when comparing the Caldwell Lake data to Vollenweider's data. Both analyses suggest that Caldwell Lake possesses sufficient phosphorus to support a greater level of productivity than the level suggested by the lake's chlorophyll *a* concentration.

As described above, the expected relationship between transparency, chlorophyll *a* concentration, and total phosphorus concentration is that Carlson's TSI score for each is the same. For both Palestine and Caldwell lakes, Carlson's TSI scores using transparency and chlorophyll *a* concentrations are roughly equal. In Palestine Lake, TSI (Secchi disk) equals 63 and 66 and TSI (total phosphorus) equals 64 and 68. In Caldwell Lake, TSI (Secchi disk) equals 40, while TSI (chlorophyll *a*) equals 43. However, Carlson's TSI score for total phosphorus concentration is much higher: TSI (total phosphorus) equals 76 and 82 in Palestine Lake and 84 in Caldwell Lake. When TSI (SD) = TSI (chl *a*) < TSI (TP), something other than phosphorus is limiting algae growth. Potential limiting factors include zooplankton grazing and/or aquatic macrophyte dominance. In the case of both lakes, zooplankton grazing may affect the lake's algal community. (Further studies would be needed to confirm this.) Additionally, the lake's extensive rooted plant community likely plays a role in limiting algae growth. Rooted plants have been shown to secrete alleopathic chemicals preventing algae growth. Again, more research (i.e. year round evaluation of the lake's temperature profile) is needed to determine if this is a factor in limiting algae production.

4.5.4 Lake Water Quality Assessment Summary

Both Palestine and Caldwell lakes contain more phosphorus than is ideal. The potential exists for excessive algal production to occur in these lakes. Both lakes are considered hypereutrophic when evaluated with Carlson's total phosphorus TSI. When compared with Vollenweider's phosphorus data, the lakes rate as eutrophic to hypereutrophic. While conditions visible on the surface of Caldwell Lake may not appear overly bad, conditions in the lake's hypolimnion are of concern. Years of excessive plant and algae production and transport of organic material into Caldwell Lake from its watershed have led to the build-up of decaying organic matter in the sediments of Caldwell Lake (Table 43). As bacteria decompose this material, they consume oxygen and leave the bottom waters *anoxic* (dissolved oxygen concentrations < 1.0 mg/L). Currently, the lake becomes anoxic below 22.9 feet (7 m).

Table 43. Summary of mean total phosphorus, total nitrogen, Secchi disk transparency, and chlorophyll *a* results for Palestine and Caldwell lakes.

Parameter	East Palestine Lake	West Palestine Lake	Caldwell Lake
Mean total phosphorus (mg/L)	0.142	0.214	0.257
Mean soluble reactive phosphorus (mg/L)	0.037	0.208	0.252
Hypolimnetic ammonia-nitrogen (mg/L)	0.633	1.651	1.296
Total nitrogen:Total phosphorus[1]	10.35	14.44	40.2
Mean total nitrogen (mg/L)	1.309	1.273	1.082
Secchi disk transparency (ft)	2.1	2.6	13.5
Chlorophyll *a* (μg/L)	43.5	31.2	3.5
Sediment phosphorus release factor[2]	6.4	40.5	42.5

[1]Total nitrogen:Total phosphorus ratio is calculated based on epilimnetic concentrations.
[2]Hypo SRP concentration/Epi SRP concentration. For example, Palestine Lake's hypolimnetic SRP concentration is equal to the SRP concentration present in the epilimnion. This similarity is evidence of limited internal loading of phosphorus.

Conversely, conditions within Palestine Lake reflect production from the lake's watershed. Palestine Lake is an over productive system. Excessive nutrients in the lake support abundant rooted plant and suspended algae growth. The excessive plant and algae productivity within the lake is a large source of biological oxygen demand (BOD). When algae dies and settles down through the water column, decomposition occurs. Bacteria decomposing this organic matter consume oxygen in the process and this creates a substantial anoxic zone in both basins of Palestine Lake. This occurs despite the weak thermal stratification in the lake. Anoxia creates chemically-reducing conditions in the hypolimnion which, in turn, allows sediment-bound phosphorus to re-solublize and re-enter the water column. This internal loading further adds to the nutrient loading burden in the lake. Anoxia also allows ammonia to build up in the hypolimnion because without oxygen, nitrification cannot convert the ammonia to nitrate.

Anoxia is not limited to the hypolimnion of Palestine Lake. On August 16, 2007, a massive algal bloom and die-off throughout the lake caused a large fish kill (300+ fish) due to the resulting low dissolved oxygen concentrations (Angela Grier, DNR Fisheries Biologist, personal communication). The algal biomass was so large and sudden that bacterial decomposition of the dying algae caused anoxic conditions even in the lake's surface waters (Figures 70 and 71). This condition was worse in the East Basin where dissolved oxygen fell to less than 1 mg/L throughout the water column. There was more dissolved oxygen in the West Basin; however, concentrations were not sufficient for many fish within the lakes as most fish begin to suffer at dissolved oxygen concentrations that measure less than 5 mg/L. Both basins of Palestine Lake remained thermally stratified during the algae die-off and fish kill.

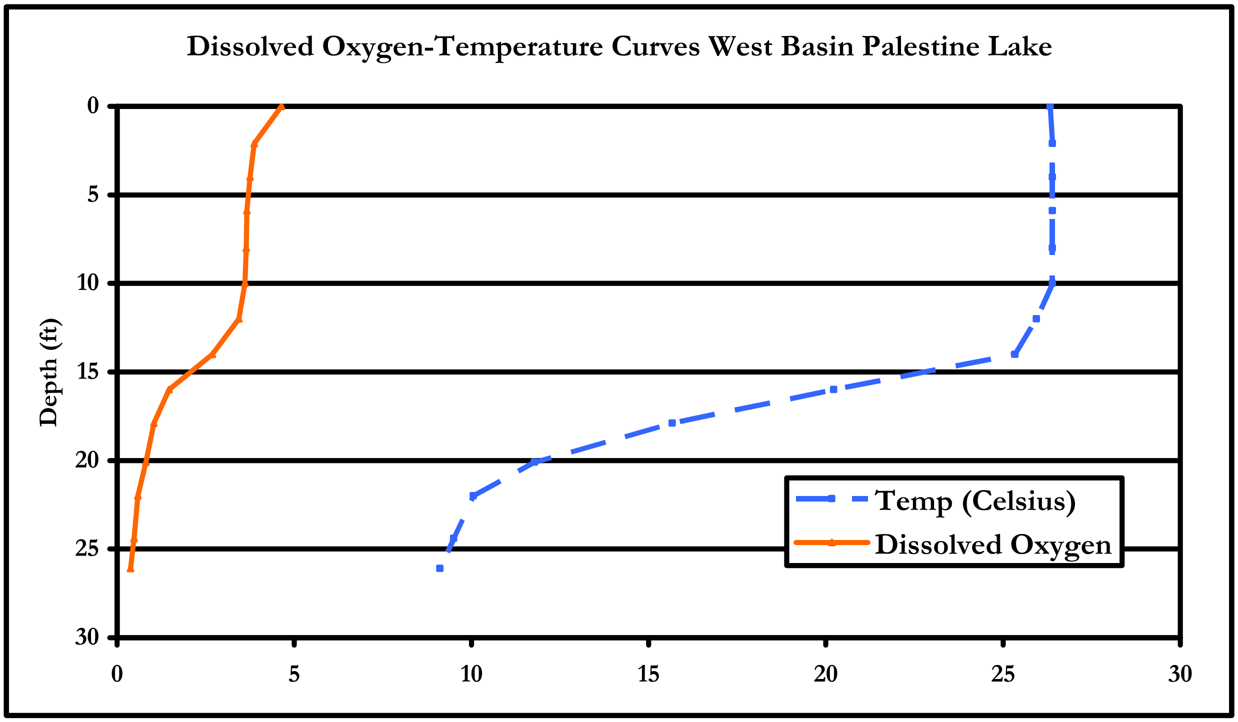

Figure 70. West Basin Palestine Lake temperature and dissolved profiles on 8/16/07.
Source: DNR Fisheries Biologist, unpublished.

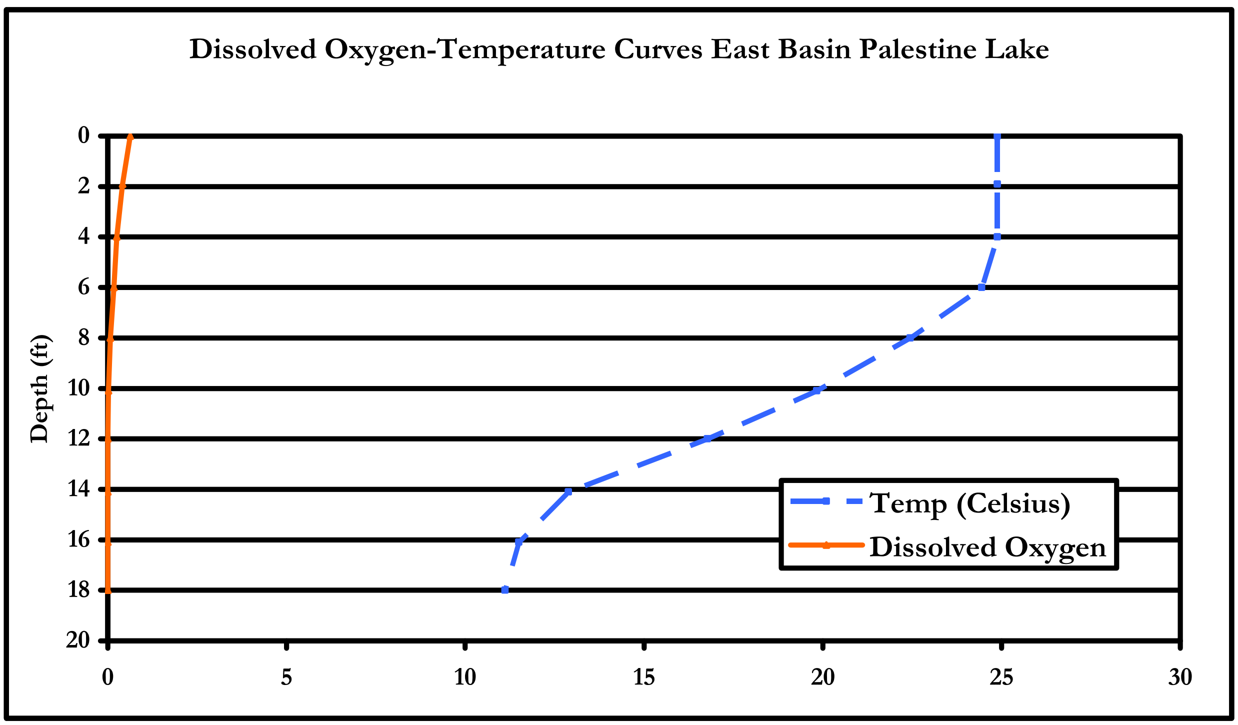

Figure 71. East Basin Palestine Lake temperature and dissolved profiles on 8/16/07.
Source: DNR Fisheries Biologist, unpublished.

Additionally, there is evidence of internal phosphorus release from both Palestine and Caldwell lakes' sediment (Table 43). There is considerably more soluble phosphorus in the hypolimnia (bottom waters) of both lakes when compared to the lakes' epilimnetic concentration. This is strong evidence that phosphorus is being liberated from the sediments when oxygen is depleted or the lake is *anoxic*. The column headed "Sediment Phosphorus Release" details the amount of soluble phosphorus (the form of phosphorus that can be released from the sediments) in the deepwater (hypolimnetic) sample to the surface (epilimnetic) sample. In the West Basin of Palestine Lake, the ratio is 40.5, while the East Basin Palestine Lake measure 6.4 and Caldwell Lake measure 42.5, which indicates that sediment phosphorus release is occurring. Phosphorus release from the sediments is an additional and important source of phosphorus to both lakes that must be addressed along with watershed practices when designing a management plan to reduce nutrient loading to the lake. This *internal loading* of phosphorus is another source of phosphorus to these lakes that can promote excessive algae production.

Both lakes also contain relatively high ammonia nitrogen concentrations in their hypolimnion (Table 43). Ammonia is a by-product of bacterial decomposition. When ammonia occurs in high concentrations, it is evidence of high biological oxygen demand. This biological oxygen demand comes from organic waste, such as dead algae and rooted plants, within the sediments, which provides further evidence of excess algae and rooted plant growth in these lakes.

Despite the poor conditions present in Caldwell Lake, surface water quality remains fair primarily because the lake is so deep and strong thermal stratification isolates the hypolimnion, and its excessive nutrient concentration, from the euphotic zone where algae could otherwise use these nutrients. It is just a matter of time before the capacity of the lake to handle these excesses is exceeded. When that happens, the lake will likely suffer from dense algal blooms. Additionally, there has been significant improvement in Caldwell Lake's trophic state, as determined by the Indiana TSI, over the past 17 years. The severe anoxia, internal phosphorus loading, and ammonia accumulation in Caldwell Lake's hypolimnion is not healthy and indicates that serious problems still exist within the lake. Fortunately, Caldwell Lake is deep and strongly stratified so the poor water quality of the hypolimnion remains isolated from the surface waters during the summer and is not available to grow more algae. Evidence from many other lakes show that in the long run, the nutrient enrichment of the hypolimnion will eventually overwhelm the lake and will result in excessive algae blooms in the surface waters and reduced fisheries (Holdren et al. 2001).

4.6 Aquatic Macrophyte Assessment

4.6.1 Macrophyte Assessment Introduction

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

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

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

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

Conditions for Growth

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

Water clarity affects the ability of sunlight to reach plants, even those rooted in shallow water. Lakes with clearer water have an increased potential for plant growth. Caldwell Lake possesses better water clarity than the average Indiana lake, while Palestine Lake possesses poorer water clarity than the average Indiana lake. The Secchi disk depth measured during the plant survey at Caldwell Lake was 10.5 feet (3.2 m), while the transparency measured during the Palestine Lake plant survey was 6 feet (1.8 m). As a general rule of thumb, rooted plant growth is restricted to the portion of the lake where water depth is less than or equal to 2 to 3 times the lake's Secchi disk depth. This was not the case in either Palestine or Caldwell lakes. Plants were observed to a depth of only 8 feet (2.4 m) in Palestine Lake and to a depth of 14 feet (4.3 m) in Caldwell Lake. Generally, aquatic plants were observed in both lakes to a depth that measures approximately one and one-half times the Secchi disk transparency. This suggests one of two things: either something more than transparency is limiting plant growth within these lakes or these lakes do not behave as the lakes that were used to determine the relationship between Secchi disk transparency and aquatic plant growth. It is likely that both factors affect the depth at which aquatic plants can grow within Palestine and Caldwell lakes.

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

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

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

Ecosystem Roles

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

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

Aquatic vegetation also serves as substrate for aquatic insects, the primary diet of insectivorous fish. Waterfowl and shorebirds depend on aquatic vegetation for nesting and brooding areas. Numerous waterfowl were observed utilizing both lakes as habitat during 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.

4.6.2 Macrophyte Assessment Methods

JFNew surveyed Palestine Lake's plant community on August 2, 2007 and Caldwell Lake's plant community on August 3, 2007 according to the Indiana Department of Natural Resources sampling protocols (IDNR, 2007). The survey included two components: 1) a general survey to identify aquatic plants present in the lake 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. As previously discussed, the littoral zone can be estimated by multiplying the Secchi disk transparency by three. A survey crew, consisting of one aquatic ecologist, one botanist, and a citizen volunteer boat driver, surveyed both 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 density 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. Appendix D of the survey protocol was consulted to determine the number of points to be sampled. This determination was based on the lake size (surface area) and trophic status.
2. Table 3 of the survey protocol was referenced as an indicator of the number of sample points per stratum. Table 44 in this report lists the sampling strategy for Palestine and Caldwell lakes while Figures 72 and 73 display the points sampled during each survey.

Stratum refers to depth at which plants were observed. Dominance presented in subsequent tables was calculated by the IDNR protocol. The density scale presented in subsequent tables provides a measure of the density of a species. The percentage of plants found within a density measure indicates the frequency of plants found over all the sampling points.

Table 44. Tier II sampling strategy for Palestine and Caldwell lakes using the 2007 Tier II protocol.

Lake	Size	Trophic Status	Number of Points	Stratification of Points
Palestine Lake	291 acres	Hypereutrophic	60	50 pts 0-5 foot stratum 10 pts 5-10 foot stratum
Caldwell Lake	45 acres	Eutrophic	30	10 pts 0-5 foot stratum 10 pts 5-10 foot stratum 10 pts 10-15 foot stratum

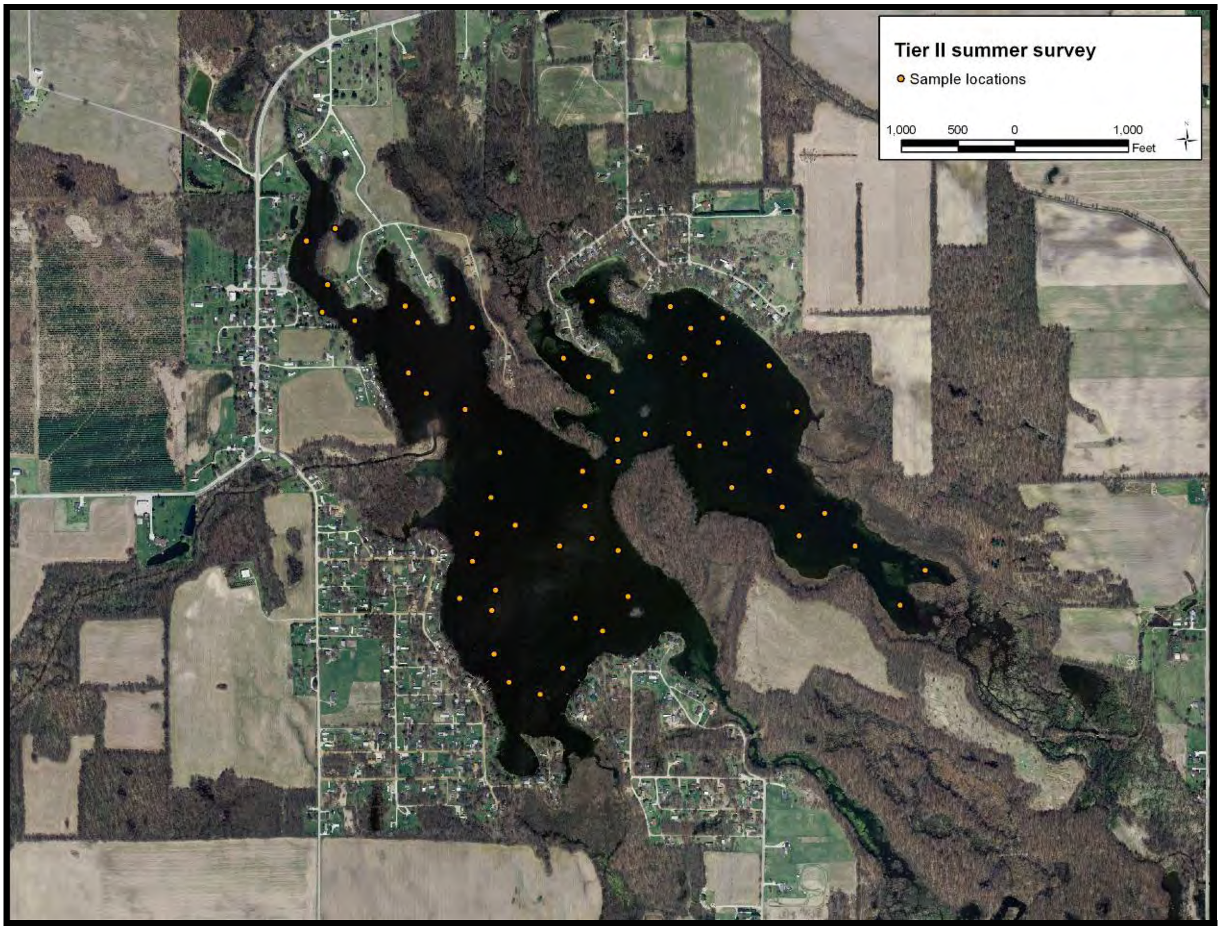

Figure 72. Points sampled during the Tier II aquatic plant assessment of Palestine Lake.

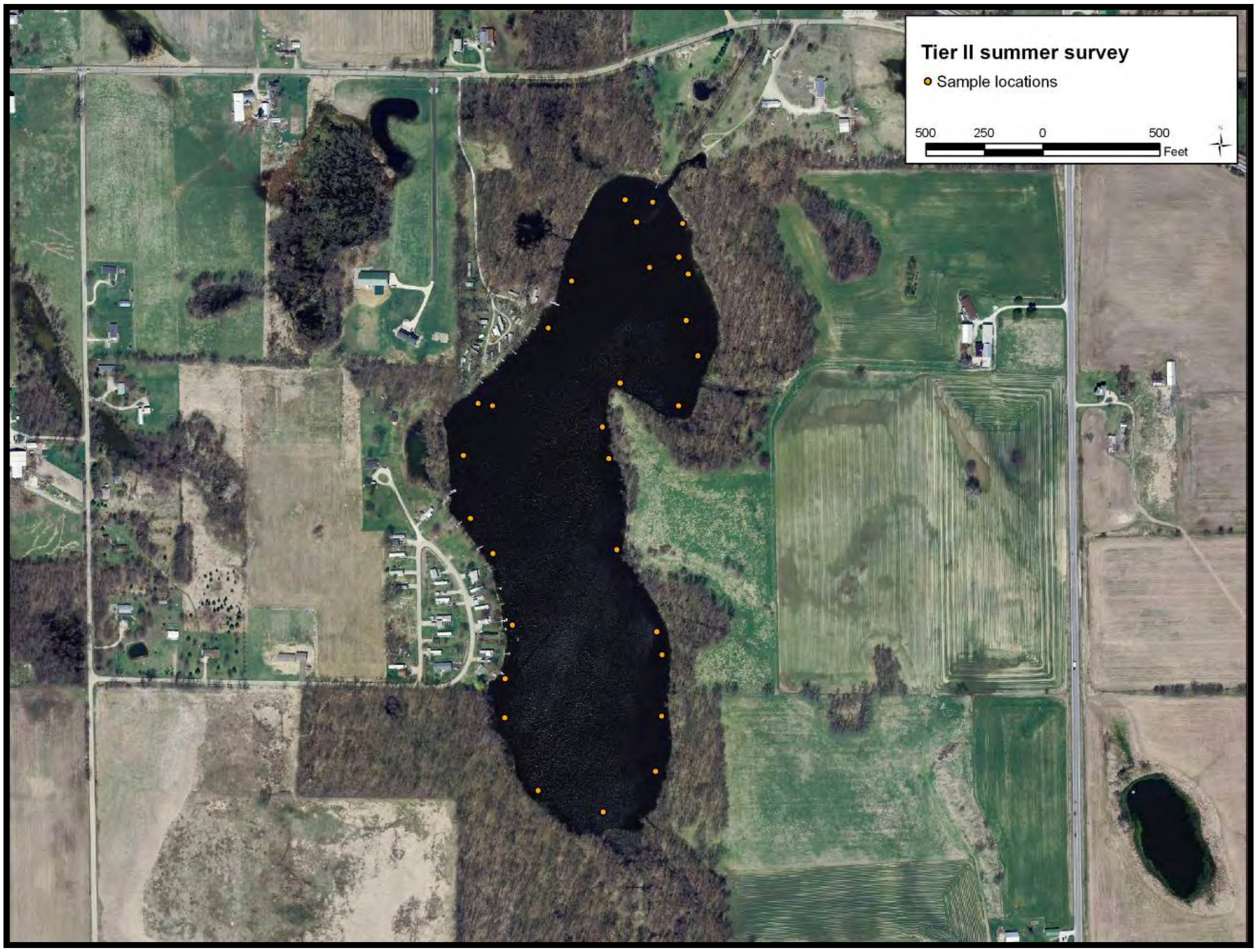

Figure 73. Points sampled during the Tier II aquatic plant assessment of Caldwell Lake.

4.6.3 Macrophyte Inventory and Tier II Results

Palestine Lake

Inventory

Palestine Lake supports a poor rooted aquatic plant community. The community extends from the lake's shoreline to water that is just over 8 feet (2.4 m) deep. This is on par with the extent of the littoral zone based on the lake's 1% light level of 8.5 feet (2.6 m), measured at the time of the in-lake water quality survey. In total, 36 aquatic plant species inhabit the water and shoreline of Palestine Lake (Table 45). 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 45. Plant species observed in Palestine Lake as identified on August 2, 2007.

Scientific Name	Common Name	Stratum
Asclepias incarnata	Swamp milkweed	emergent
Bidens cernua	Nodding beggar-ticks	emergent
Bidens comosa	Swamp tickseed	emergent
Cephalanthus occidentalis	Buttonbush	emergent
Ceratophyllum demersum	Coontail	submerged
Chara species	Chara species	submerged
Cicuta bulbifera	Bulblet-bearing water-hemlock	emergent
Decodon verticillatus	Whirled loosestrife	emergent
Eclipta prostrata	False daisy	emergent
Elodea canadensis	Common water weed	submerged
Elodea nuttallii	Nuttall's water weed	submerged
Filamentous algae	Filamentous algae	floating
Galium tinctorium	Stiff bedstraw	emergent
Impatiens capensis	Spotted touch-me-not	emergent
Leersia oryzoides	Rice cut grass	emergent
Lemna minor	Common duckweed	floating
Lythrum salicaria	Purple loosestrife	emergent
Morus alba	Mulberry	emergent
Myriophyllum spicatum	Eurasian watermilfoil	submerged
Najas guadalupensis	Southern naiad	submerged
Nuphar advena	Spatterdock	floating
Peltandra virginica	Arrow arum	emergent
Phalaris arundinacaea	Reed canary grass	emergent
Pilea pumila	Clearweed	emergent
Polygonum pensylvanicum	Pinkweed	emergent
Potamogeton crispus	Curly-leaf pondweed	submerged
Roripa palustris	Marsh cress	emergent
Rumex species	Dock species	emergent
Rumex orbiculatus	Great water dock	emergent
Sagittaria latifolia	Common arrowhead	emergent
Scirpus validus	Soft-stem bulrush	emergent
Scutellaria lateriflora	Mad-dog scullcap	emergent
Sparganium eurycarpum	Common burreed	emergent
Spirodela polyrhiza	Large duckweed	floating
Typha latifolia	Broad-leaved cattail	emergent
Wollfia columbiana	Watermeal	floating

Of the 36 species observed in Palestine Lake, only seven (7) were submerged plant species. Of the seven submerged species, nearly all of those are adapted to high nutrient environments. Only one of the submerged species was a pondweed (i.e. belonging to the *Potamogeton* genus). However, this pondweed species is also an exotic species and therefore, should not be celebrated or highly regarded as an indicator of water quality. Compared to other lakes in the region, this lack of pondweeds and low diversity of submerged species represents relatively poor species richness for the submerged strata. Much of this can likely be attributed to the high density of filamentous algae covering the lake's surface (Figure 74). Coontail, Eurasian watermilfoil, and curly-leaf pondweed dominated the submerged plant community and were observed throughout the lake. Four exotic species, including Eurasian watermilfoil, curly-leaf pondweed, purple loosestrife, and reed canary grass were identified within or adjacent to Palestine Lake.

Figure 74. Filamentous algae covering Palestine Lake on August 2, 2007.

The species richness of the emergent strata was much higher than the submerged strata, while the floating strata's richness was much lower than the emergent and submerged strata. Twenty-four (24) emergent species were noted bordering Palestine Lake's edges, while only four floating species were observed in the lake. (It is important to note that there are significantly fewer floating aquatic species that are native to Indiana lakes compared to the number of emergent and submerged species. Consequently, many lakes possess low numbers of floating species.) The most common emergent species include purple loosestrife and reed canary grass. The most common floating species are spatterdock and duckweed.

Tier II

During the survey, coontail dominated the plant community over all depths (0-10 feet; Table 46). (Appendix F details raw data collected during the Tier II aquatic plant survey.) This species was found at the highest percentage of sites throughout the water column (97%) and also had the highest mean (2.79) and relative densities (2.7). throughout the water column, other species were relatively frequent with curly-leaf pondweed present at 40% of sites and common waterweed present at 32% of sites. Eurasian watermilfoil, nuttall's waterweed, southern naiad, and musk grass were found at 10% or less sites. With regards to density, coontail dominated the submerged plant community throughout the water column with a dominance of 54. (A dominance of 300 represents a perfect score or the highest dominance possible within Palestine Lake. This results from multiplying the highest density score (5) by the number of sites where plants were sampled (60). Dominance scores are reported as percentages of this maximum.) All other species were relatively sparse throughout the water column, with common waterweed possessing a dominance of 13 and curly-leaf pondweed having a dominance of 8. All other species had dominances less than 2. Filamentous algae were also present at 100% of sites; however, densities are not assigned to this species.

Table 46. Frequency and dominance of submerged aquatic plant species identified during the Tier II survey of Palestine Lake conducted August 2, 2007.

Entire Water Column (0-10 feet)			**Density Scale**				
Common Name	**Scientific Name**	**Frequency of Occurrence**	**0**	**1**	**3**	**5**	**Dominance**
Coontail	*Ceratophyllum demersum*	96.67	3.33	40.00	26.67	30.00	54.00
Common waterweed	*Elodea canadensis*	31.67	68.33	18.33	10.00	3.33	13.00
Curly-leaf pondweed	*Potamogeton crispus*	40.00	60.00	40.00	0.00	0.00	8.00
Eurasian watermilfoil	*Myriophyllum spicatum*	10.00	90.00	10.00	0.00	0.00	2.00
Nuttall's waterweed	*Elodea nuttallii*	10.00	90.00	10.00	0.00	0.00	2.00
Southern naiad	*Najas guadalupensis*	6.67	93.33	6.67	0.00	0.00	1.33
Musk grass	*Chara species*	3.33	96.67	3.33	0.00	0.00	0.67
Filamentous Algae		100.00	--	--	--	--	--
0-5 Foot Stratum							
Coontail	*Ceratophyllum demerumn*	95.83	4.17	31.25	31.25	33.33	58.33
Common waterweed	*Elodea canadensis*	33.33	66.67	20.83	10.42	2.08	12.50
Curly-leaf pondweed	*Potamogeton crispus*	45.83	54.17	45.83	0.00	0.00	9.17
Nuttall's waterweed	*Elodea nuttallii*	12.50	87.50	12.50	0.00	0.00	2.50
Eurasian watermilfoil	*Myriophyllum spicatum*	10.42	89.58	10.42	0.00	0.00	2.08
Southern naiad	*Najas guadalupensis*	6.25	93.75	6.25	0.00	0.00	1.25
Musk grass	*Chara species*	4.17	95.83	4.17	0.00	0.00	0.83
Filamentous Algae		100.00	--	--	--	--	--
5-10 Foot Stratum							
Coontail	*Ceratophyllum demersum*	100.00	0.00	75.00	8.33	16.67	36.67
Common waterweed	*Elodea canadensis*	25.00	75.00	8.33	8.33	8.33	15.00
Curly-leaf pondweed	*Potamogeton crispus*	16.67	83.33	16.67	0.00	0.00	3.33
Southern naiad	*Najas guadalupensis*	8.33	91.67	8.33	0.00	0.00	1.67
Eurasian watermilfoil	*Myriophyllum spicatum*	8.33	91.67	8.33	0.00	0.00	1.67
Filamentous Algae		100.00	--	--	--	--	--

Coontail also dominated the submerged plant community in the 0-5 foot and 5-10 foot strata (Table 46). Coontail was the most frequent as it was found at nearly 96% of sites in the 0-5 foot stratum and at 100% of sites in the 5-10 foot stratum. Coontail generated the highest dominance rating of 58 in the 0-5 foot stratum and a 37 in the 5-10 foot stratum. In the 0-5 foot stratum, curly-leaf pondweed was identified at 46% of sites but was relatively sparse scoring a dominance of 9.2, while common waterweed was found at 33% of sites and possessed a dominance of 12.5. All other species were relatively infrequent occurring at less than 12.5% of sites and possessing dominances of 2.5 or less (Table 46). Similar results occurred in the 5-10 foot stratum with common waterweed occurring at 25% of sites but in relatively low density (15) and curly-leaf pondweed occurring at 17% of sites in very low density (3.3).

As previously mentioned, two exotic submerged species were identified within Palestine Lake during the Tier II assessment. Eurasian watermilfoil was identified at 10% of sites throughout the lake (Figure 75), while curly-leaf pondweed was found at 40% of sites (Figure 76). The high frequency of curly-leaf pondweed during this survey is surprising. Curly-leaf pondweed is an early-season, cold-water species that typically dies back during the recreation season. However, this did not occur in Palestine Lake in 2007. It is possible that heavy algae cover limits light transmission and keeps water temperatures low within Palestine Lake. These conditions could encourage prolonged growth of curly-leaf pondweed in Palestine Lake. It is currently unknown whether early-season curly-leaf pondweed growth is more or less frequent and/or dominant than the levels observed during this assessment. More specific information about these plants and options for their control will be discussed in subsequent sections.

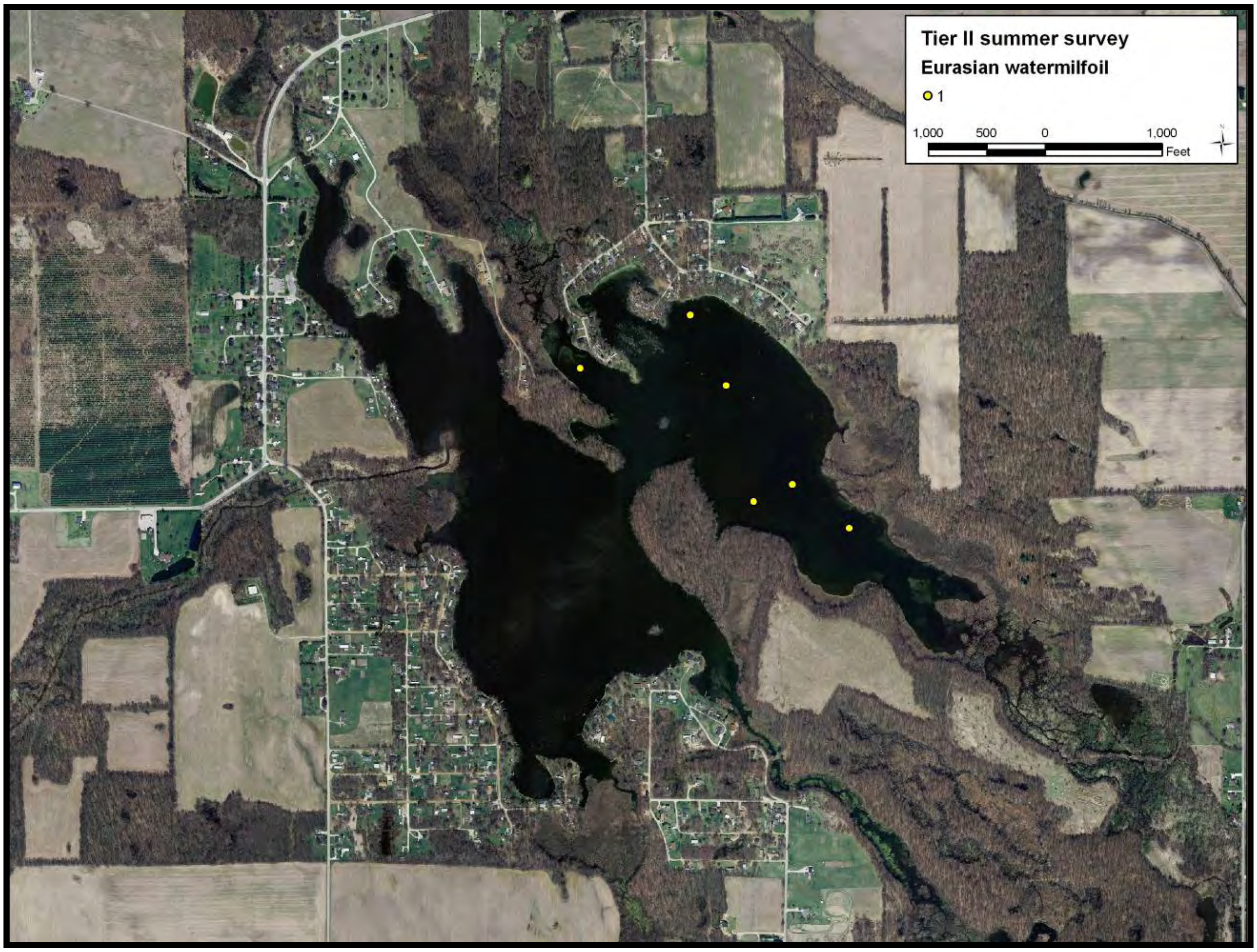

Figure 75. Location and density of Eurasian watermilfoil identified in Palestine Lake during the August 2, 2007 Tier II survey.

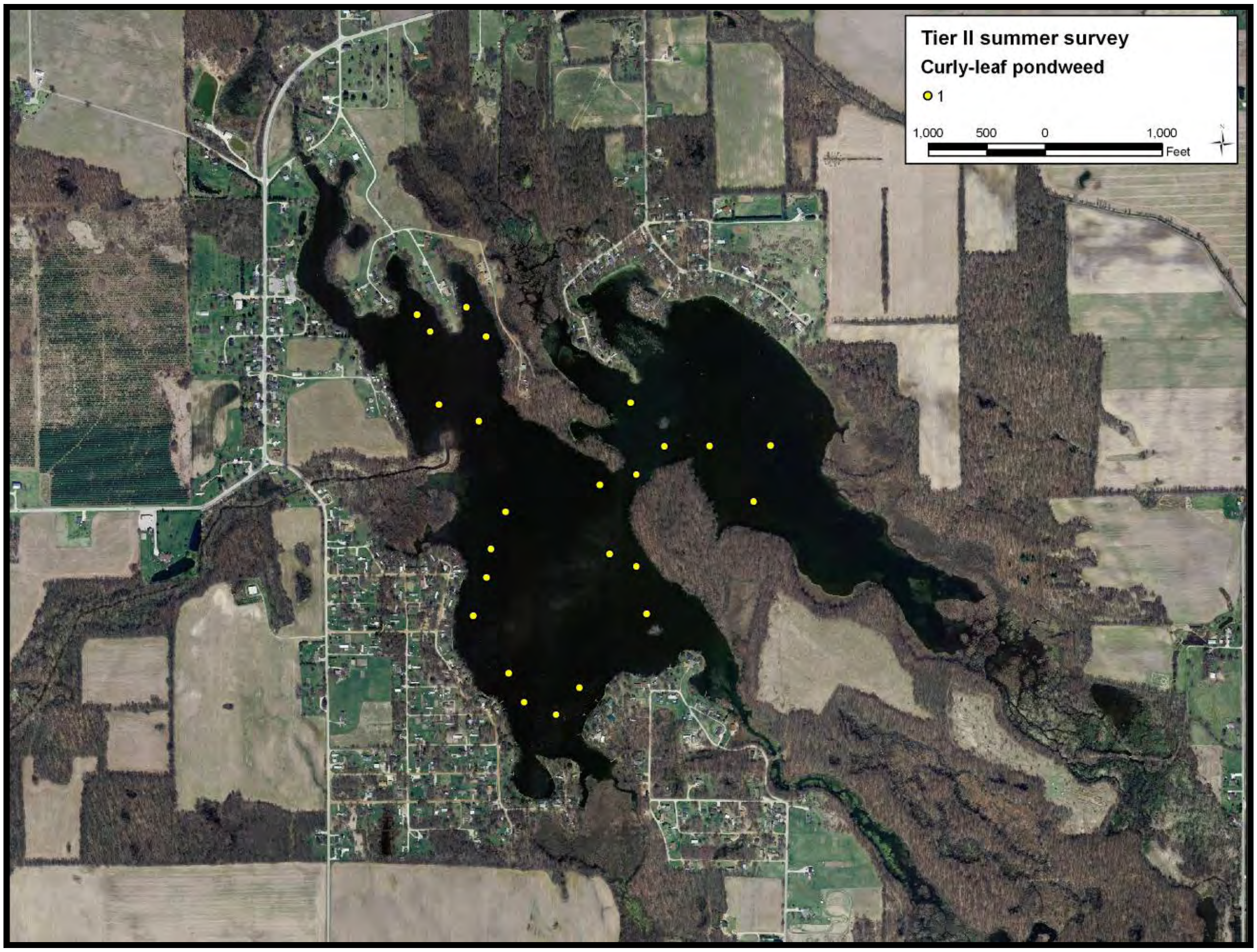

Figure 76. Location and density of curly-leaf pondweed identified in Palestine Lake during the August 2, 2007 Tier II survey.

Caldwell Lake

Inventory

Contrary to Palestine Lake, Caldwell Lake supports a good aquatic plant community. The community extends from the lake's shoreline to water that is just over 15 feet (4.6 m) deep. This is poorer than the extent of the littoral zone based on the lake's 1% light level of 19.7 feet (6 m), measured at the time of the in-lake water quality survey. In total, 35 aquatic plant species inhabit the water and shoreline of Caldwell 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.

Table 47. Plant species observed in Caldwell Lake as identified on August 3, 2007.

Scientific Name	Common Name	Stratum
Acer saccharinum	Silver maple	emergent
Alisma subcordata	Common water plantain	emergent
Asclepias incarnata	Swamp milkweed	emergent
Cephalanthus occidentalis	Buttonbush	emergent
Ceratophyllum demersum	Coontail	submerged
Chara species	Chara species	submerged
Decodon verticillatus	Whirled loosestrife	emergent
Elodea canadensis	Common water weed	submerged
Filamentous algae	Filamentous algae	floating
Heteranthera dubia	Water star grass	submerged
Iris virginica	Blue-flag iris	emergent
Leersia oryzoides	Rice cut grass	emergent
Lemna minor	Common duckweed	floating
Lobelia cardinalis	Cardinal flower	emergent
Myriophyllum exalbescens	Northern watermilfoil	submerged
Myriophyllum spicatum	Eurasian watermilfoil	submerged
Najas flexilis	Slender naiad	submerged
Najas guadalupensis	Southern naiad	submerged
Nuphar advena	Spatterdock	floating
Nymphaea tuberosa	White water lily	floating
Peltandra virginica	Arrow arum	emergent
Phalaris arundinacaea	Reed canary grass	emergent
Polygonum hydriouoeriudes	Mild water pepper	emergent
Pontederia cordata	Pickerel weed	emergent
Potamogeton berchtoldii	Broad-leaf small pondweed	emergent
Potamogeton crispus	Curly-leaf pondweed	submerged
Ranunculus longirostris	White water crowfoot	emergent
Rumex verticillatus	Swamp dock	emergent
Sagittaria latifolia	Common arrowhead	emergent
Scirpus acutus	Hard-stem bulrush	emergent
Scirpus validus	Soft-stem bulrush	emergent
Sparganium eurycarpum	Common burreed	emergent
Spirodela polyrhiza	Large duckweed	floating
Typha x glauca	Blue cattail	emergent
Typha latifolia	Broad-leaved cattail	emergent

Of the 36 species observed in Caldwell Lake, nine species were submerged plant species. Of the nine submerged species, nearly all of those are adapted to high nutrient environments. Only two of the submerged species was a pondweed (i.e. belonging to the *Potamogeton* genus). However, one of these pondweed species is also an exotic species and therefore, should not be celebrated or highly regarded as an indicator of water quality. Compared to other lakes in the region, this diversity of submerged species represents relatively normal species richness for the submerged strata. Coontail, southern naiad, and curly-leaf pondweed dominated the submerged plant community and were observed throughout the lake. Four exotic species, including Eurasian watermilfoil, curly-leaf pondweed, purple loosestrife, and reed canary grass were identified within or adjacent to Caldwell Lake.

The species richness of the emergent strata was much higher than the submerged strata, while the floating strata's richness was much lower than the emergent and submerged strata. Twenty-one (21) emergent species were noted bordering Caldwell Lake's edges, while only five floating species were observed in the lake. (It is important to note that there are significantly fewer floating aquatic species that are native to Indiana lakes compared to the number of emergent and submerged species. Consequently, many lakes possess low numbers of floating species.) The most common emergent species include reed canary grass, whirled loosestrife, and cattails. The most common floating species are spatterdock, white water lily, and duckweed.

Tier II

During the survey, coontail dominated the plant community over all depths (0-15 feet; Table 48). (Appendix F details raw data collected during the Tier II aquatic plant survey.) This species was found at the highest percentage of sites throughout the water column (59%) and also had the highest mean (3.3) and relative densities (2.97). Throughout the water column, other species were relatively frequent with southern naiad present at 53% of sites, curly-leaf pondweed present at 46% of sites, Eurasian watermilfoil present at 33% of sites, and broad-leaf small pondweed and slender naiad each present at 20% of sites. Northern watermilfoil, water star grass, common waterweed, and musk grass were each found at 3.3%. With regards to density, coontail dominated the submerged plant community throughout the water column with a dominance of 59. (A dominance of 150 represents a perfect score or the highest dominance possible within Caldwell 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.) Southern naiad recorded a dominance of 20. All other species were relatively sparse throughout the water column, with curly-leaf pondweed possessing a dominance of 9, slender naiad a dominance of 8, northern watermilfoil a dominance of 7, and broad-leaf small pondweed having a dominance of 4. All other species had dominances less than 1. Filamentous algae were also present at 100% of sites; however, densities are not assigned to this species.

Table 48. Frequency and dominance of submerged aquatic plant species identified during the Tier II survey of Caldwell Lake conducted August 3, 2007.

Species		Frequency of Occurrence	0	1	3	5	Dominance
Entire Water Column (0-15 feet)							
Coontail	*Ceratophyllum demersum*	90.00	10.00	30.00	16.67	43.33	59.33
Southern naiad	*Najas guadalupensis*	53.33	46.67	40.00	3.33	10.00	20.00
Curly-leaf pondweed	*Potamogeton crispus*	46.67	53.33	46.67	0.00	0.00	9.33
Slender naiad	*Najas flexilus*	20.00	80.00	10.00	10.00	0.00	8.00
Eurasian watermilfoil	*Myriophyllum spicatum*	33.33	66.67	33.33	0.00	0.00	6.67
Broad-leaf small pondweed	*Potamogeton berchtoldii*	20.00	80.00	20.00	0.00	0.00	4.00
Northern watermilfoil	*Myriophyllum exalbesens*	3.33	96.67	3.33	0.00	0.00	0.67
Water star grass	*Heteranthera dubia*	3.33	96.67	3.33	0.00	0.00	0.67
Common waterweed	*Elodea canadensis*	3.33	96.67	3.33	0.00	0.00	0.67
Musk grass	*Chara* species	3.33	96.67	3.33	0.00	0.00	0.67
Filamentous Algae		100.00	--	--	--	--	--
0-5 Foot Stratum							
Coontail	*Ceratophyllum demersum*	100.00	0.00	12.50	25.00	62.50	80.00
Southern naiad	*Najas guadalupensis*	62.50	37.50	50.00	0.00	12.50	22.50
Curly-leaf pondweed	*Potamogeton crispus*	75.00	25.00	75.00	0.00	0.00	15.00
Slender naiad	*Najas flexilus*	25.00	75.00	12.50	12.50	0.00	10.00
Eurasian watermilfoil	*Myriophyllum spicatum*	37.50	62.50	37.50	0.00	0.00	7.50
Broad-leaf small pondweed	*Potamogeton berchtoldii*	25.00	75.00	25.00	0.00	0.00	5.00
Northern watermilfoil	*Myriophyllum exalbesens*	12.50	87.50	12.50	0.00	0.00	2.50
Filamentous Algae		100.00	--	--	--	--	--
5-10 Foot Stratum							
Coontail	*Ceratophyllum demersum*	100.00	0.00	42.86	14.29	42.86	60.00
Southern naiad	*Najas guadalupensis*	64.29	35.71	42.86	7.14	14.29	27.14
Curly-leaf pondweed	*Potamogeton crispus*	21.43	78.57	7.14	14.29	0.00	10.00
Slender naiad	*Najas flexilus*	50.00	50.00	50.00	0.00	0.00	10.00
Eurasian watermilfoil	*Myriophyllum spicatum*	50.00	50.00	50.00	0.00	0.00	10.00
Broad-leaf small pondweed	*Potamogeton berchtoldii*	21.43	78.57	21.43	0.00	0.00	4.29
Water star grass	*Heteranthera dubia*	7.14	92.86	7.14	0.00	0.00	1.43
Musk grass	*Chara species*	7.14	92.86	7.14	0.00	0.00	1.43
Filamentous Algae		100.00	--	--	--	--	--
10-15 Foot Stratum							
Coontail	*Ceratophyllum demersum*	62.50	37.50	25.00	12.50	25.00	37.50
Southern naiad	*Najas guadalupensis*	25.00	75.00	25.00	0.00	0.00	5.00
Curly-leaf pondweed	*Potamogeton crispus*	12.50	87.50	12.50	0.00	0.00	2.50
Broad-leaf small pondweed	*Potamogeton berchtoldii*	12.50	87.50	12.50	0.00	0.00	2.50
Slender naiad	*Najas flexilus*	12.50	87.50	12.50	0.00	0.00	2.50
Common waterweed	*Elodea canadensis*	12.50	87.50	12.50	0.00	0.00	2.50
Filamentous Algae		100.00	--	--	--	--	--

Coontail also dominated the submerged plant community in the 0-5 foot, 5-10 foot, and 10-15 foot strata (Table 48). Coontail was the most frequent as it was found at 100% of sites in the 0-5 foot and

5-10 foot strata and at 62.5% of sites in the 10-15 foot stratum. Coontail generated the highest dominance rating of 80 in the 0-5 foot stratum, 60 in the 5-10 foot stratum, and 38 in the 10-15 foot stratum. Southern naiad was also very frequent and highly dominant. This species was identified in each of the strata rating 62.5%, 64.3%, and 25% in the 0-5 foot, 5-10 foot, and 10-15 foot strata, respectfully. Curly-leaf pondweed was actually more frequent than southern naiad in the 0-5 foot stratum; however, curly-leaf pondweed was found in lower density than southern naiad. Eurasian watermilfoil followed a similar pattern with relatively high frequency but relatively low density in the 0-5 foot stratum. Both frequency and density of Eurasian watermilfoil increased in the 5-10 foot stratum. Eurasian watermilfoil was not identified in the 10-15 foot stratum of Caldwell Lake. Overall, Eurasian watermilfoil was identified at 33.3% of sites throughout the lake (Figure 77), while curly-leaf pondweed was found at 46.7% of sites (Figure 78). More specific information about these plants and options for their control will be discussed in subsequent sections.

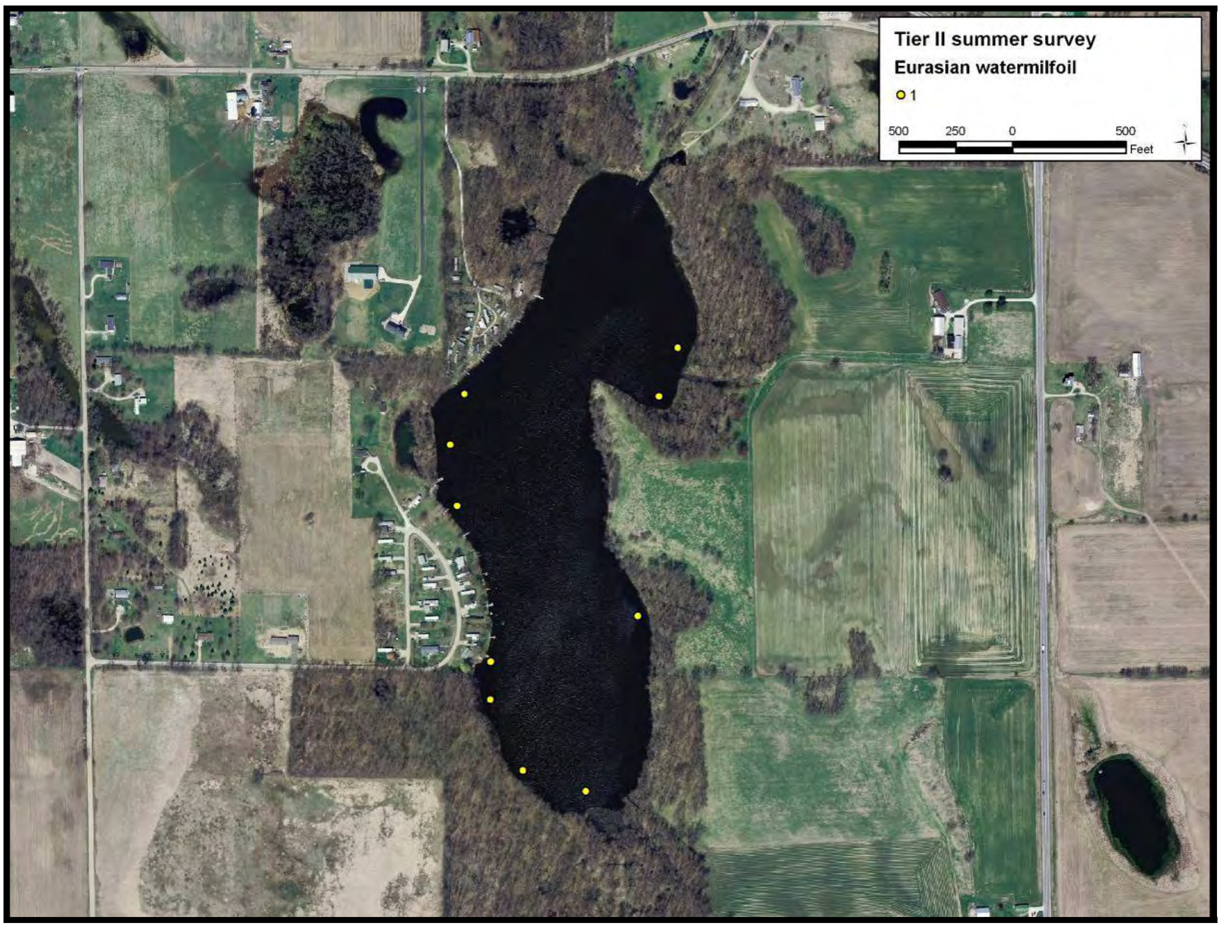

Figure 77. Location and density of Eurasian watermilfoil identified in Caldwell Lake during the August 3, 2007 Tier II survey.

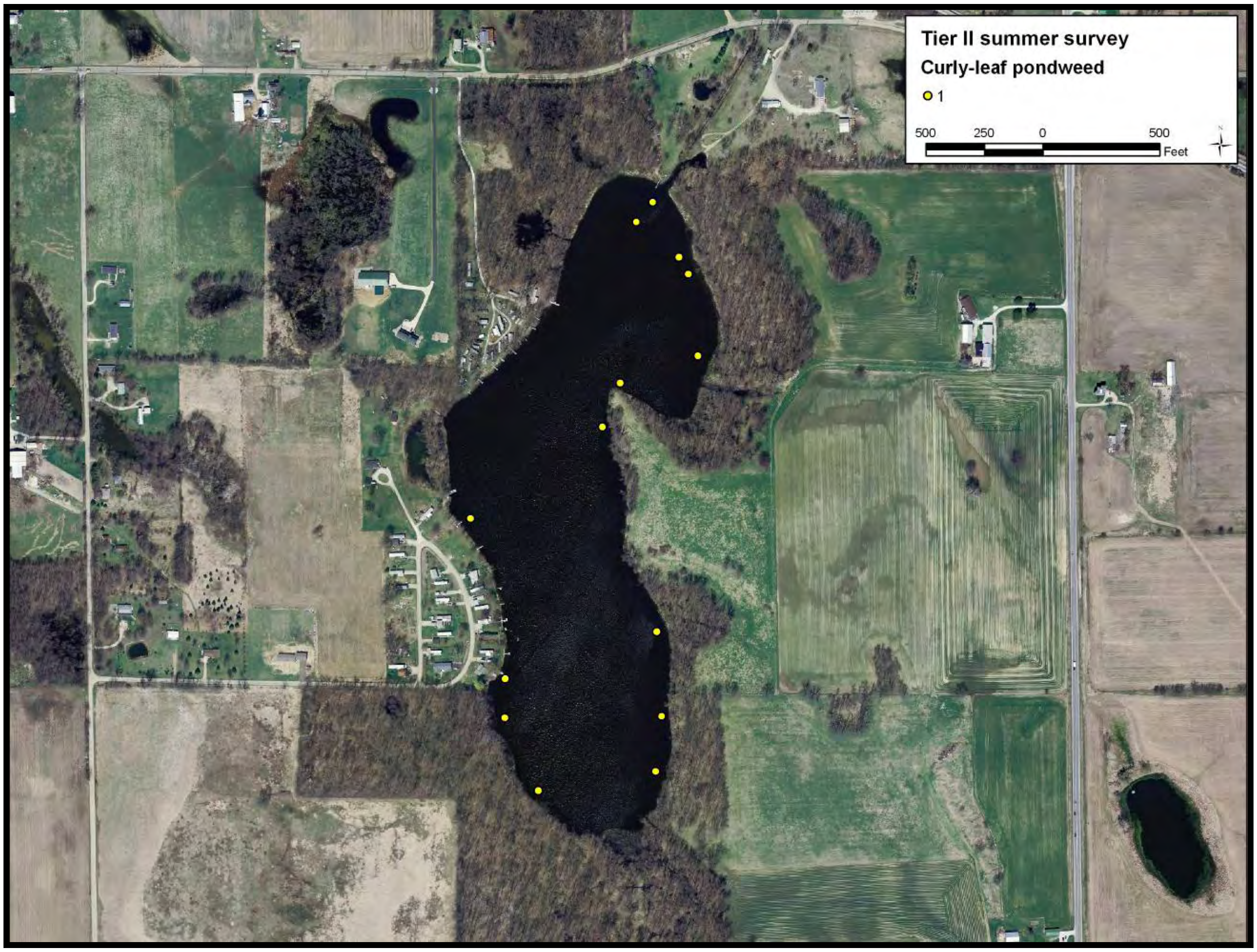

Figure 78. Location and density of curly-leaf pondweed identified in Caldwell Lake during the August 3, 2007 Tier II survey.

4.6.4 Macrophyte Inventory Discussion

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

Secchi disk transparency depths measured as part of this study indicated that Palestine Lake possessed moderate water clarity, while Caldwell Lake possessed good water clarity. The Secchi disk transparency depth recorded during the rooted plant survey extended to 6 feet and 10.5 feet, respectively. The transparency recorded in Palestine Lake is shallower than the statewide median Secchi disk transparency depth, while the value recorded in Caldwell Lake is deeper than the statewide median Secchi disk transparency depth. Historical Secchi disk data suggest that these clarity measurements are better than the typical measurements that occur in both lakes.

Both Palestine and Caldwell lakes' rooted plant communities reflect their lake's clarity; in Palestine Lake, clarity is relatively poor and the plant community reflects this. Likewise, clarity in Caldwell Lake is relatively good and the plant community reflects the higher water quality present in Caldwell Lake compared to that present in Palestine Lake. Nonetheless, neither Palestine nor Caldwell lakes possess any of the species that thrive in clear water, including large-leaf pondweed, northern watermilfoil, and flat-stem pondweed (Davis and Brinson, 1980; Borman et al., 1997; Curtis, 1998). However, Caldwell Lake possesses a variety of plants that are very tolerant of lower light conditions such as coontail and southern naiad; however, these species are ubiquitous in northeastern lakes thus, their presence is not necessarily an indication of turbid water.

Both Palestine and Caldwell lakes exhibit elevated nutrient concentrations similar to nutrient concentrations observed in many other lakes in the region. The relatively limited submerged rooted plant community indicates that water quality may have historically been on par with the quality that is currently present. Based on the elevated nutrient levels, it is anticipated that the plant community present within the lake would be of poor quality. For example, regional lakes with relatively similar total phosphorus levels, such as Silver Lake (Kosciusko County), Ridinger Lake (Kosciusko County), Robinson Lake (Whitley County), Smalley Lake (Kosciusko County), and the Four Lakes (Cook, Holem, Kreighbaum, and Mill Pond lakes, Marshall County), possess similar diversities of submerged species compared to Palestine and Caldwell lakes (JFNew, 2000b; JFNew, 2004a; JFNew, 2004b; JFNew, 2005c). Additionally, in lakes with high total phosphorus concentrations, species tolerant of eutrophic water such as Eurasian watermilfoil, Sago pondweed, and coontail tend to dominate the rooted plant communities to the exclusion of species that are more sensitive to eutrophic conditions. Two of these species dominated the plant communities present in both Palestine and Caldwell lakes.

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

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

Into the Future

Changes in a lake's rooted plant communities over time can illustrate unseen chemical changes in the lake. Unfortunately, limited data detailing Palestine and Caldwell lakes' historical rooted plant communities 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 both lakes. In 1975, Shipman noted the presence of five emergent species and three submerged species. The dominance of coontail, duckweed, and filamentous algae were noted during this survey. Shipman (1976) indicated that heavy blooms of all three species occurred annually often choking out growth of other species. Similar species were identified by IDNR biologists in 1978, 1999, and 2003. Additionally, Braun (1978) noted that the shallow and productive nature of Palestine Lake is due to residential development and farmland runoff and indicates that a "weed cutter" is in operation on the west basin and that a total weed control program should be implemented by residents. Only one previous aquatic plant survey was recorded for Caldwell Lake. During this assessment, three pondweed species, including curly-leaf pondweed, were identified. Three other submerged species, coontail, common elodea, and chara, were identified during the 1979 survey. Overall, the plant communities present in Palestine and Caldwell lakes suggest that water quality has changed little over time as many of the same species were present in the lakes. Additionally, the relatively low diversity of submerged species suggests that water clarity has been poor within these lakes.

Nuisance and Exotic Plants

Although they have not yet reached the levels observed on many other regional lakes, several nuisance and/or exotic aquatic plant species grow in both Palestine and Caldwell lakes. 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 two submerged, aggressive exotics: Eurasian water milfoil (Figure 79) and curly-leaf pondweed (Figure 80). It also supports two emergent exotic plant species: purple loosestrife (Figure 81) and reed canary grass. As nuisance species, these species have the potential to proliferate if left unmanaged. It is possible that these or other exotic species could exist within the thick emergent portions of the rooted plant community near the east and west ends of the lake but were not observed during this survey.

Figures 79. Eurasian water milfoil (*Myriophyllum spicatum*) and 80. Curly-leaf pondweed (*Potamogeton crispus*).

Figure 81. Purple loosestrife (*Lythrum salicaria*).

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

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

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

Like purple loosestrife, reed canary grass is native to Eurasia. Farmers used (and many likely still use) the species for erosion control along ditch banks or as marsh hay. The species escaped via ditches and has spread to many of the wetlands in the area. Swink and Wilhelm (1994) indicate that reed canary grass commonly occurs at the toe of the upland slope around a wetland. Reed canary grass was often observed above the ordinary high water mark around both Palestine and Caldwell lakes (Figure 82). Like other nuisance species, reed canary grass forms a monoculture mat excluding native wetland/shoreline plants. This limits a wetland's or shoreline's diversity ultimately impacting the habitat's functions.

Figure 82. Reed canary grass present along the shoreline of Caldwell Lake during the August 3, 2007 aquatic plant survey.

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

4.7 Fisheries Assessment

4.7.1 Fisheries Introduction

A fishery survey or assessment is an important tool for fishery biologists to properly manage a lake. When an assessment occurs, biologists are interested in the species present (the species richness), the number of individuals of each species (species abundance), the number of individuals of each species captured per unit of sampling effort, such as the number of fish per net (catch per unit effort or CPUE), and the size and age of important recreational species. Species abundance, or the number of fish captured, is typically converted to a relative percent abundance by dividing the number of individuals per species by the total number of individuals collected and multiplying by 100 to generate a percent of the total population. Additionally, converting abundance to relative percent abundance allows for an easier comparison of data between years especially when the goal is to look at fish species composition and community structure. Fish weight can also be used to estimate relative abundance; however, abundance by numbers generally has more intrinsic value when discussing and comparing inland lakes than abundance by weight. Individual fish size and age are particularly important because they relate directly to many population indicators including natural reproduction, growth, and survival. A fisheries biologist will use mathematical relationships between age and size to classify growth rates of different species into different classes such a Below-Average, Average, Above-Average. For natural lakes in northern Indiana, growth rates for largemouth bass, bluegill, and black crappies are calibrated based on historical data of each species' mean length per age (Pearson, 1996). Growth is influenced by many variables, including the amount of forage available, competitive interactions among members of the same population and with different species, environmental conditions and local and regional climate.

For most inland fish species, members of the population will reproduce once each year within a certain time period. Individuals born during that year are referred to as a year-class. During fishery assessments, biologists collect scales or other bony structures to determine a fish's age. These structures develop rings similar to tree rings that allow a trained observer to estimate the age of the fish. One of the results is that a biologist can track year-classes through time. Age information combined with information about a fish's length is a powerful tool to understanding the growth and survival of the individuals of a population.

The following paragraphs provide a brief summary of the IDNR fishery management survey findings for each given survey year. A list of the IDNR reports used in the following summaries can be found in the literature cited. When reviewing the summaries below, and to some extent the IDNR reports themselves, it is important 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. The relative percent abundance by numbers of fish is reported and referred to as abundance for simplicity sake.

4.7.2 Palestine Lake

Palestine Lake is an excellent example of the importance of viewing trends over time versus directly comparing data between surveys. There have been thirteen surveys or assessments performed since 1975, which is significantly more than a typical lake of its size would have during that time period. IDNR biologists surveyed the lake frequently to understand and track changes in the fish community due to both natural and human-influenced events. Each survey differs in minor ways based on the amount of effort spent on the lake, the type of gear used, and the goal of the assessment, which makes a direct comparison difficult. When the data is viewed over the entire time period, interesting and important trends appear.

The IDNR performed the first fisheries survey on Palestine Lake in 1975 (Shipman, 1976). During that survey, golden shiners were the most abundant fish in community comprising 40.1% of the total abundance (Figure 83). Bluegills were the second most abundant species surveyed and comprised 28.0% of the catch. Largemouth bass comprised 3.3% of the survey catch while carp made up 0.4% of the catch. A complete list of the fish species captured during the DNR surveys can be found in Appendix H. Fish kills occurred in Palestine Lake during the winters of 1976-77 (due to cold weather) and 1977-78 (due to record snow fall; Braun, 1978). The IDNR responded by performing surveys in August 1977 and July 1978 to assess the extent of the winterkill, the resulting fish community, and the success of a June 1977 largemouth bass stocking. In 1977, carp and golden shiner comprised 60% of the survey catch (Figure 83). In 1978, carp were again the most abundant species caught during the survey (36.7%); however, black bullheads, which were not observed during the previous year's survey, were the second most abundant species at 35.9% (Figure 83). Both species are well adapted to low oxygen conditions, such as those present during the winter of 1977-78. Following the 1980 survey, bluegill (28.1%) and black crappie (16.7%) were the most abundant species captured (Figure 83). Carp abundance in 1978 was 13.6% of the catch, which was lower than the previous survey.

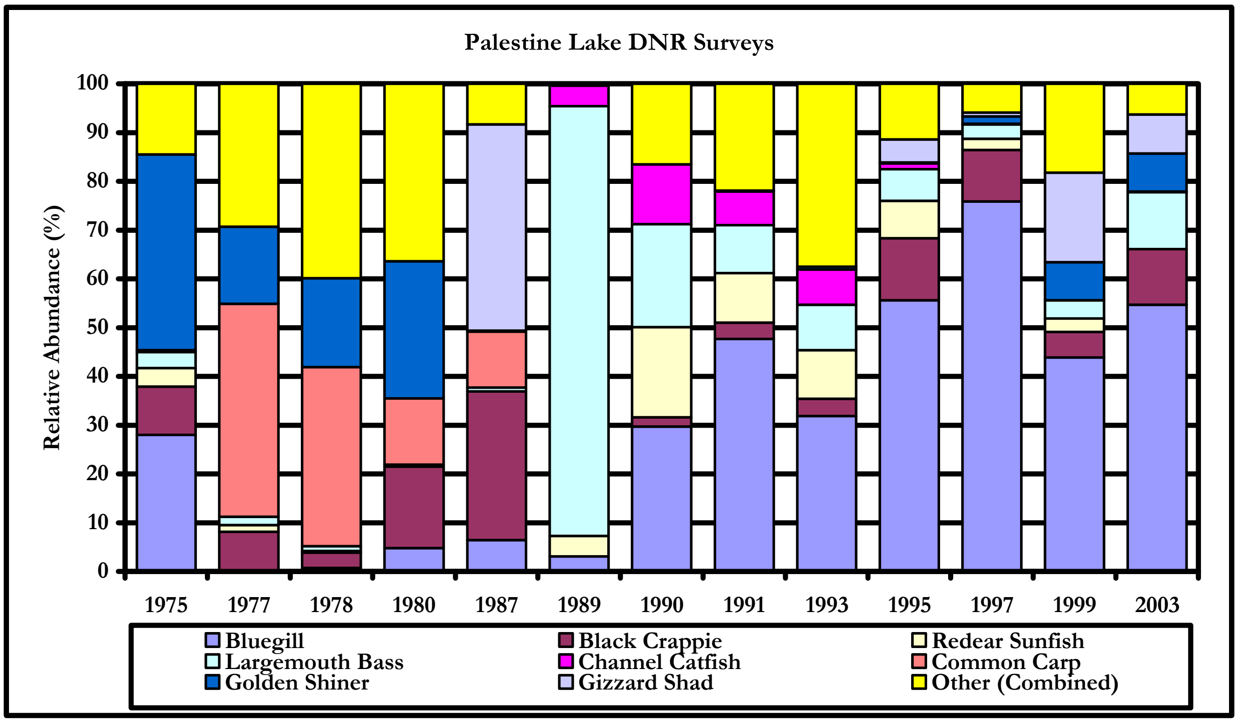

Figure 83. Relative abundance of selected fish species in Palestine Lake from IDNR fishery assessments.

At some point after 1980, gizzard shad were introduced into Palestine Lake where they became the most abundant fish species surveyed in 1987 (Braun, 1988). A narrower window of this event is unavailable at this time. It is believed that the introduction must have occurred after the 1979 survey and before the 1982. Gizzard shad were not observed in the 1980 survey; however, their abundance could have been so low that they were not collected due to the type of sampling gear used. More than likely, this introduction occurred by an angler or individual who wanted to "improve" the largemouth bass fishing by providing an additional forage base. Direct, conscious human introductions are responsible for the spread of several exotic species in the Midwest (Hrabik and Magnuson, 1999). Unfortunately, the introduction of exotic species does not usually improve the fishery over the long term as hoped because exotic species tend to disrupt the natural dynamic of the local fish community.

In 1988, the IDNR decided to renovate the fish community of Palestine Lake in conjunction with work that was occurring on the dam which required the lake level to be temporarily lowered by eight feet. The lower water level concentrated the fish and allowed for the chemical treatment to be more effective with less chemical usage because the lake volume was reduced. All waterbodies within the entire Palestine Lake watershed including the lakes and the drainages were treated with a chemical called rotenone to reduce or remove the existing fish community.

Following the dam reconstruction and rotenone treatment, the second phase of the fishery renovation began in October 1988 with fish stocking (Braun, 1989). Largemouth bass, bluegill, redear sunfish, and channel catfish were restocked into Palestine Lake in the fall of 1988 with an additional stocking of channel catfish in 1990. Northern pike were stocked into the lake in 1991, 1993, 1994, and 1997. Muskellunge were stocked in Palestine Lake in 1997, 1998, 1999, 2002, and 2003. The goal of the stocking was to renovate the fish community, offer recreational angling opportunities for lake users, and reduce or control the populations of carp and gizzard shad through the use of predator fish species.

In addition to the fish stockings, a 14-inch minimum size limit regulation was imposed on largemouth bass in Palestine Lake. The minimum size limit protects small largemouth bass from being over-harvested by the angling public. In one study of lakes without a size limit for bass, up to eighty-five percent of the fish harvested were less than 12 inches in length (Braun, 1987). Largemouth bass greater than 14 inches are important to a lake to keep the populations of forage fish such as golden shiners and gizzard shad as well as panfish such as bluegill in check.

Since the 1988 fish community renovation effort, Palestine Lake has been surveyed seven times (1989, 1990, 1991, 1993, 1995, 1997, 1999, and 2003) to assess the changes in the fish community. During the 1989 survey, four of the stocked species, largemouth bass, bluegill, redear sunfish, and channel catfish were present and comprised nearly 100% of the total abundance of the survey. Black bullhead and pumpkinseed were two other species sampled at extremely low abundance, one fish per species found in the survey (Figure 83). Young-of-the-year (YOY) largemouth bass were captured during the 1989 survey, indicating that stocked adults from the previous fall had successfully reproduced (Braun, 1990). As important as the presence of the stocked species was the absence of carp and gizzard shad during the assessment. Palestine Lake was again surveyed in 1990 and 1991 with similar results from 1989 (Braun, 1991a; Braun, 1991b). The four stocked species were present and had combined abundances that represented 82% and 75% of the survey catch, respectively (Figure 83). Carp were not sampled during the assessments and gizzard shad abundance was extremely low with one individual collected in 1991.

During the 1993 survey, thousands of YOY gizzard shad were observed, indicating the potential for the fishery to change over the next few years as the gizzard shad population matured (Kittaka, 1993). Besides the presence of gizzard shad, the fishery remained relatively unchanged with the four stocked species making up 58% of the fish captured during the survey (Figure 83). Northern pike were stocked in 1991; however, northern pike were not collected during the 1991 survey, indicating that the initial stocking was a failure. In 1995, bluegill and black crappie, a holdover species from before the renovation project, comprised 68% of the abundance in the assessment (Figure 81). Although adult gizzard shad were collected in low abundance (4.7%) during the survey, no YOY gizzard shad were sampled. This indicates that the current year-class did not survive or was subject to predation by bass and other species. In 1993, only one bass greater than the 14-inch minimum size limit was captured. During the 1995 survey, 26 fish 14-inches or greater were collected. Northern pike growth rates were classified as average for northeast Indiana lakes. The 1995 survey also marked the first time since the renovation project that carp were observed during a survey in Palestine Lake (Braun, 1996).

During the 1997 survey, bluegill and black crappie comprised 86% of the survey catch in numbers, continuing the trend since 1993 of their increased relative abundance within the fishery (Figure 83). The percentage of largemouth bass greater than 14 inches in length was less in 1997 than it was during the 1995 survey, 15% and 24%, respectively. Growth for largemouth bass age 3 or less was classified as above average, indicating that young fish were growing faster than typical northeast Indiana lakes. Northern pike were again collected during the survey and although their abundance was low (four individuals collected), their growth rates were classified as excellent. Gizzard shad and one carp were also collected during the survey (Braun, 1998).

The 1999 survey marked a shift in the fishery as gizzard shad became the second most abundant fish behind bluegill collected in the survey (Figure 83). Bluegill made up 44% of the survey catch while gizzard shad made up 18% of the catch, up from 4% in 1997. The percentage of largemouth bass greater than 14 inches in length made up 28% of the largemouth bass sampled, almost double the percentage from 1997. There was also no evidence from the survey that northern pike were naturally reproducing since no individuals born after 1995, the last year of stocking, had been observed. No muskellunge were collected after stocking efforts in 1997, 1998, and 1999 (Kittaka, 2000). In 2003, bluegill, again, was the most abundant species at 55%, however, largemouth bass replaced gizzard shad as the second most abundant species with 12% of the abundance (Figure 83). Gizzard shad abundance decreased to 8%, which was the fourth most abundant species from the survey (Benson, 2004). No northern pike, muskellunge or carp were collected during the survey indicating that there was no natural reproduction for northern pike. Success of the muskellunge stockings may be limited by available of habitat within the lake (too high of water temperatures and too low of dissolved oxygen concentrations). Carp may be present in the lake; however, they have not become as dominant as they were prior to the renovation project.

Palestine Lake has an excellent panfish fishery comprised of bluegill, redear sunfish, and black crappie. The largemouth bass population offers an additional recreational opportunity. The 1988 fishery renovation project has been relatively successful. Even though gizzard shad and carp are still present in the lake, they have not dominated the fishery. The success of the renovation project may be partially due to size harvest regulations on largemouth bass and stockings of northern pike and muskellunge, both of which increase the number of large predators to control gizzard shad and carp reproduction. Given that Palestine Lake is relatively shallow, dominated by heavy vegetation, and lies in an agricultural watershed, it is strongly recommended that water quality protection and improvement projects be pursued by the lake association to reduce the risk of having either a summer or winter fish kill due to low oxygen levels and have to restore the fishery again.

4.7.3 Caldwell Lake

Caldwell Lake was first sampled by IDNR biologists in 1979 (Braun, 1980). The fishery was composed primarily of golden shiners, 55% of relative abundance (Figure 84). Bluegill, yellow perch, and largemouth bass were abundant with average to above-average growth rates for several year classes. Interestingly, carp and gizzard shad were not sampled in Caldwell Lake. At the time, there must have been some discussion about renovating Palestine Lake due to the high abundance of carp; however, IDNR biologists felt that Caldwell could be excluded from any Palestine fishery renovation plan because they believed the ditch between Caldwell and Palestine lakes was impassible for carp due to high weed abundance. Unfortunately, in 1982 high water allowed carp and gizzard shad to move from Palestine Lake into Caldwell Lake through Adams Ditch, where they quickly became established (Braun, 1990). During a 1987 assessment, carp comprised 21% of the survey catch (Braun, 1990). When the Palestine Lake fishery was renovated in 1988, Caldwell Lake was included to reduce the potential from re-colonization back into Palestine. Following the renovation of Palestine Lake, Caldwell Lake was re-stocked with bluegill, largemouth bass, channel catfish, and redear sunfish. In addition to the fish stockings, a 14-inch minimum size limit regulation was imposed on largemouth bass in Caldwell Lake to encourage the establishment of the bass fishery (Braun, 1987). In a follow-up survey of Caldwell Lake in 1989, twelve species were sampled with largemouth bass and bluegill being the most abundant (Braun, 1990; Figure 84). More importantly, eight species including carp survived the chemical application. The surviving carp represented a potential for re-infestation back into Palestine Lake. Caldwell Lake was again surveyed in 1990 and bluegill was the most prevalent species, making up 48% of the total abundance (Figure 84; Braun, 1991a). Largemouth bass made up 22% of the total abundance while other species combined for 19% of the total abundance. Carp and gizzard shad were not sampled during the 1990 survey.

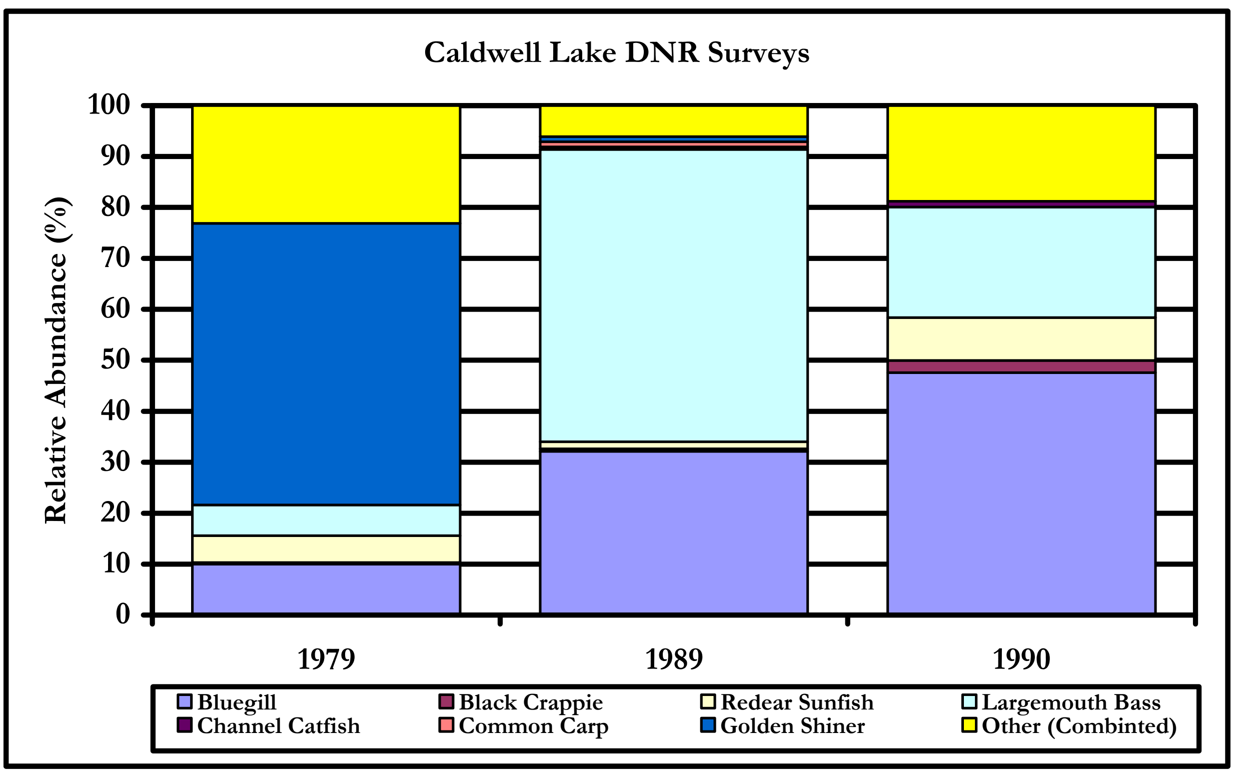

Figure 84. Relative abundance of selected fish species in Caldwell Lake from IDNR fishery assessments.

5.0 MODELING

5.1 Water Budget

5.1.1 Palestine Lake

Inputs of water to Palestine Lake are limited to:
1. direct precipitation to the lake;
2. discharge from the inlet streams, including Williamson Ditch, Sloan-Adams Ditch, Ring Ditch, and Magee-Robbins Ditch;
3. sheet runoff from land immediately adjacent to the lake; and
4. groundwater.

Water leaves the lake system from:
1. discharge from the lake's outlet channel, Trimble Creek;
2. evaporation; and
3. groundwater.

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

- Direct precipitation to the lake was calculated from mean annual precipitation falling directly on the lake's surface.
- Runoff from the lake's watershed was estimated by applying runoff coefficients. A runoff coefficient refers to the percentage of precipitation that occurs as surface runoff, as opposed to that which soaks into the ground. Runoff coefficients may be estimated by comparing discharge from a nearby gauged watershed of similar land and topographic features, to the total amount of precipitation falling on that watershed. The nearest gaged watershed is a U.S.G.S. gaging station on the Tippecanoe River at North Webster, Indiana (Morlock et al. 2005). The 33-year (1972–2005) mean annual runoff for this watershed is 13.01 inches. With mean annual precipitation of 32.99 inches (Hillis, 1980), this means that on average, 39% of the rainfall falling on this watershed runs off on the land surface.
- No groundwater records exist for the lakes, so it was assumed that groundwater inputs equal outputs or groundwater effects are insignificant when compared to surface water impacts. It is unlikely that the latter is true for these lakes. However, since no groundwater records for the lake exist we must assume that groundwater inputs equal outputs.

Evaporation losses were estimated by applying evaporation rate data to the lake. Evaporation rates are determined at six sites around Indiana by the National Oceanic and Atmospheric Administration (NOAA). The nearest site to the watershed is located in Wanatah, Indiana. Annual evaporation from a 'standard pan' at the Wanatah site averages 41.8 inches (106.2 cm) per year between 2003 and 2005 (NOAA, 2005). Because evaporation from the standard pan overestimates evaporation from a lake by about 30%, the evaporation rate was corrected by this percentage, yielding an estimated evaporation rate from the lake surface of 29.3 inches (74.4 cm) per year. Multiplying this rate times the surface area of each lake yields an estimated volume of evaporative water loss from Palestine Lake.

The water budget for Palestine Lake is based on the assumptions discussed above. (The water budget calculations are shown in Appendix I.) When the volume of water flowing out of a lake is divided by the lake's volume the result is known as the lake's *hydraulic residence time*. The hydraulic residence time for Palestine Lake is 19 days (0.05 years). This means that on average, water entering Palestine Lake stays in the lake for only 19 days before it leaves. This hydraulic flushing rate is extremely rapid for lakes in this part of the country. In a study of 95 north temperate lakes in the U.S., the mean hydraulic residence time for the lakes was 2.12 years (Reckhow and Simpson, 1980). The short hydraulic residence time for Palestine Lake is due to its very large watershed. There are approximately 71 acres (28.7 ha) of watershed draining into each acre of Palestine Lake. Most glacial lakes have a watershed area to lake surface area ratio of around 10:1. However, Palestine Lake's ratio is more typical of reservoirs, which it is. In reservoirs, the watershed area to reservoir surface area typically ranges between 100:1 and 300:1 (Vant, 1987).

5.1.2 Caldwell Lake

Inputs of water to Caldwell Lake are limited to:
1. direct precipitation to the lake;
2. discharge from the intermittent inlet streams;
3. sheet runoff from land immediately adjacent to the lake; and
4. groundwater.

Water leaves the lake system from:
1. discharge from the lake's outlet channel, Adams Ditch;
2. evaporation; and
3. groundwater.

The water budget for Caldwell Lake is based on the assumptions discussed above. (The water budget calculations are shown in Appendix I.) When the volume of water flowing out of a lake is divided by the lake's volume the result is known as the lake's *hydraulic residence time*. The hydraulic residence time for Caldwell Lake is 185 days (0.50 years). This means that on average, water entering Caldwell Lake stays in the lake for 185 days before it leaves. This hydraulic flushing rate is extremely rapid for lakes in this part of the country. In a study of 95 north temperate lakes in the U.S., the mean hydraulic residence time for the lakes was 2.12 years (Reckhow and Simpson, 1980). The relatively short hydraulic residence time for Caldwell Lake is due to its very large watershed. There are approximately 31 acres (12.5 ha) of watershed draining into each acre of Palestine Lake. Most glacial lakes have a watershed area to lake surface area ratio of around 10:1. However, like Palestine Lake, Caldwell Lake's ratio is more typical of reservoirs, where surface area typically ranges between 100:1 and 300:1 (Vant, 1987).

As previously noted, residence time estimates can be used to help guide management of the lakes. In general, lakes possessing long residence times often benefit from in-lake management techniques, while lakes possessing short residence times benefit from watershed management techniques. In lakes with short residence time, such as such as Palestine and Caldwell lakes, water is continuously moving through the lake. Thus, the lakes with short residence times would have good water quality if the water entering these lakes is clean. Conversely, water stays in lakes with long residence time for a longer period of time. As a consequence, internal processes, such as internal phosphorus release from the lake's sediments, can have a larger impact on water quality than the condition of the incoming surface water.

5.2 Phosphorus Budget

5.2.1 Palestine Lake

Since phosphorus is a limiting nutrient in lakes and because it is the easier of the two main nutrients (phosphorus and nitrogen) required for plant and algal growth to control (Lee and Jones-Lee, 1998), a phosphorus model was used to estimate the dynamics of this important nutrient in Caldwell and Palestine lakes. 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 study did not allow for the determination of phosphorus inputs and outputs outright. Therefore, a standard phosphorus model was utilized 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. Phosphorus export coefficients are expressed as kilograms of phosphorus lost per hectare of land per year. Table 49 shows the phosphorus export coefficients developed by Reckhow and Simpson (1980).

Table 49. Phosphorus export coefficients (units are kg/hectare except the septic category, which are kg/capita-yr).

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

Source: Reckhow and Simpson, 1980.

To obtain an annual estimate of the phosphorus exported to Palestine and Caldwell lakes from the lakes' watershed(s), the export coefficient for a particular land use was multiplied by the area of land in that land use category. Mid-range estimates of phosphorus export coefficient values for all watershed land uses (Table 49) were used in this calculation.

Direct phosphorus input via precipitation to the lakes was estimated by multiplying mean annual precipitation in Kosciusko County (0.93 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, the number of permanent homes on each lake was multiplied times an average of 3 residents per home to calculate per capita years. Using 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), phosphorus export from septic systems was calculated. For temporary residences, an average of 6 months per year was used to calculate septic system inputs. Likewise, for seasonal residences, 3 months per year was utilized. The results of this calculation are detailed in Appendix J.

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

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

During the June 19, 2007 sampling of Palestine Lake, the mean volume weighted phosphorus concentration in the lake was 0.274 mg/L. It is useful to determine how much phosphorus loading from all sources is required to yield a mean phosphorus concentration of 0.274 mg/L in Palestine Lake. Plugging this mean concentration along with the lake's mean depth and flushing rate into Vollenweider's phosphorus loading model and solving for L yields an areal phosphorus loading rate (mass of phosphorus per unit area of lake) of 4.15 g/m^2-yr. This means that in order to get a mean phosphorus concentration of 0.274 mg/L in Palestine Lake, a total of 11.302 grams of phosphorus must be delivered to each square meter of lake surface area per year.

This back-calculated estimate of areal phosphorus loading is smaller than that estimated from Reckhow's watershed phosphorus loading model plus the estimated phosphorus load from precipitation. This process estimated an areal loading rate of 5.67 g/m^2-yr to Palestine Lake. The difference between the two areal phosphorus loading estimates – 5.67 g/m^2-yr from a watershed loading model and 4.15 g/m^2-yr from back-calculating areal loading from Vollenweider's model – could be due to several reasons:

1. If the phosphorus loss from watershed land uses is overestimated, then the loading estimate would be too high. However, the middle to lower values for phosphorus export coefficients was used in Reckhow's model. These conservative estimates should have underestimated phosphorus loading rather than overestimated it.
2. Another, more likely possibility, is that Palestine Lake does not behave like the lakes Vollenweider used to formulate his model. The large watershed size and very short hydraulic retention time in Palestine Lake reduces the rate of phosphorus settling that is built into Vollenweider's model. Phosphorus in watershed runoff flows through and out of the lake, rather than circulating within the water and ultimately settling down into the sediments. This flow through of phosphorus actually decreases the phosphorus concentration measured in the water.

The significance of areal phosphorus loading rates is better illustrated in Figure 85 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 represents 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 Palestine Lake is well above the acceptable line. This figure can also be used to evaluate management needs. For example, areal phosphorus loading to Palestine Lake would have to be reduced from 5.650 g/m^2-yr to 2.613 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 3.037 g/m^2-yr to the lake, which is equivalent to a total phosphorus mass loading reduction of 3,576 kg P/yr or 53.7% of current total loading to the lake. Reducing phosphorus loading to Palestine Lake by 3,576 kg per year should be a target for nutrient management and BMP implementation in the lake's watershed (Table 50).

Table 50. Phosphorus reduction required in Palestine Lake 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 %)
Palestine	5.650	2.613	3,576 (53.7%)

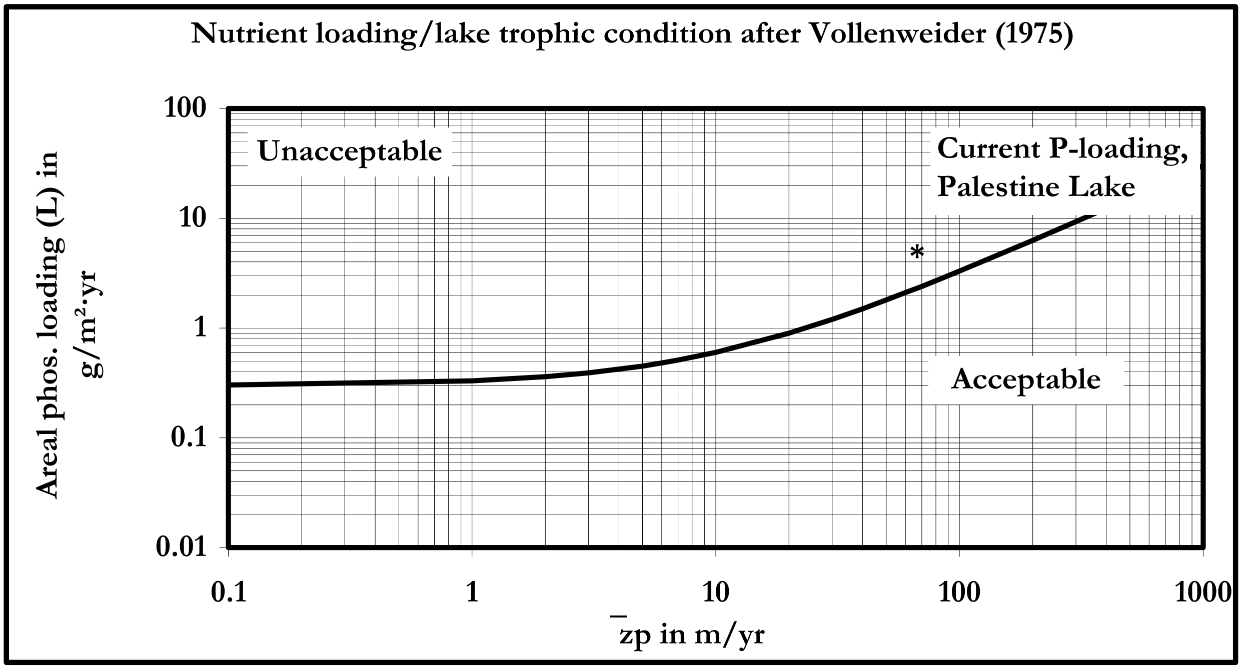

Figure 85. Phosphorus loadings to Palestine Lake (*) compared to acceptable loadings determined from Vollenweider's model. The dark line represents the upper limit for acceptable loading.

5.5.2 Caldwell Lake

A similar approach was used to estimate a phosphorus budget for Caldwell Lake. Caldwell Lake's smaller watershed size yields less phosphorus loading annually. Caldwell Lake's greater volume allows the lake to be a phosphorus *sink* whereby incoming phosphorus settles out into the sediments and does not contribute to the phosphorus concentration measured within the lake. The results yielded an estimated 429 kg of phosphorus loading to Caldwell Lake from its watershed and from precipitation annually (Appendix J). The greatest estimated source of phosphorus loading to the lake is from row crop agriculture – over 80% of total watershed loading.

Using a phosphorus-loading model such as the widely used Vollenweider (1975) model, the relationships among the primary parameters that affect a lake's phosphorus concentration can be examined. Recall that 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 (p) plus a constant (10):

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

During the June 19, 2007 sampling of Caldwell Lake, the mean volume weighted phosphorus concentration in the lake was 0.222 mg/L. Again, it is useful to ask the question, "How much phosphorus loading from all sources is required to yield a mean phosphorus concentration of 0.222 mg/L in Caldwell Lake?" By plugging this mean concentration along with the mean depth and flushing rate into Vollenweider's phosphorus loading model and solving for L, an estimated areal phosphorus loading rate (mass of phosphorus per unit area of lake) of 4.554 g/m^2-yr results. This means that in order to get a mean phosphorus concentration of 0.222 mg/L in Caldwell Lake, a total of 4.554 grams of phosphorus must be delivered to each square meter of lake surface area per year.

Total phosphorus loading (L_T) is composed of external phosphorus loading (L_E) from outside the lake (watershed runoff and precipitation) and internal phosphorus loading (L_I). Since L_T = 4.554 g/m^2-yr and L_E = 2.305 g/m^2-yr (estimated from Reckhow's watershed loading model in Table 51), then internal phosphorus loading (L_I) equals 2.249 g/m^2-yr. Thus, internal loading accounts for about 50% of total phosphorus loading to the water column Caldwell Lake.

A determination of how reasonable this conclusion is that internal phosphorus loading accounts for 44% of total phosphorus loading to Caldwell Lake is necessary. Furthermore, where the internal phosphorus come from is also necessary to determine. There is evidence in Caldwell Lake that soluble phosphorus is being released from the sediments during periods of anoxia. For example, the concentration of soluble phosphorus in Caldwell Lake's hypolimnion on June 15, 2007 was 25 times higher than concentrations in the epilimnion (0.020 mg/L vs. 0.494 mg/L). The source of this hypolimnetic total phosphorus is most likely internal loading. This internal loading can be a major source of phosphorus in many productive lakes.

The significance of areal phosphorus loading rates in Caldwell Lake is better illustrated in Figure 86 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 Caldwell Lake is well above the acceptable line. This figure can also be used to evaluate management needs. For example, areal phosphorus loading to Caldwell Lake would have to be reduced from 4.554 g/m^2-yr to 1.33 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 3.224 g/m^2-yr to the lake, which is equivalent to a total phosphorus mass loading reduction of 600 kg P/yr or 70% of current total loading to the lake. The watershed management plan for Caldwell Lake should use 600 kg P/yr as a target for phosphorus loading reduction (Table 51).

Table 51. Phosphorus reduction required in Caldwell Lake 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 %)
Caldwell	4.554	1.33	600 (70%)

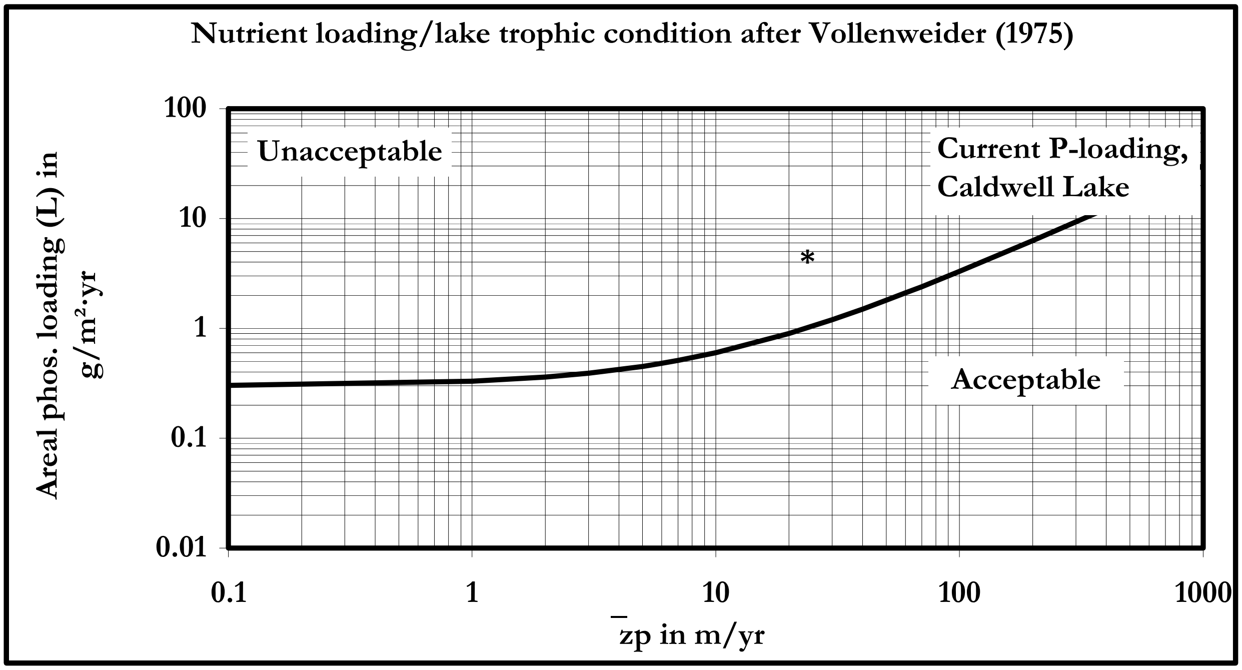

Figure 86. Phosphorus loadings to Caldwell Lake (*) compared to acceptable loadings determined from Vollenweider's model. The dark line represents the upper limit for acceptable loading.

6.0 MANAGEMENT

The preceding sections of this report detailing Palestine and Caldwell lakes' current conditions indicate that the lakes possess poor water quality in comparison to other lakes in the region and throughout the state. The lakes have moderately poor to poor clarity. Nutrient concentrations are higher than the state medians. The lakes' volume weighted total phosphorus concentration place them in the hypereutrophic category based on Carlson's TSI, but much of this phosphorus is in the lakes' hypolimnion where it is not accessible to algae. The higher than average nutrient levels present in Palestine and Caldwell lakes result in an elevated productivity level. The lakes' chlorophyll *a* concentration, Indiana TSI score, and Secchi disk depth suggest Caldwell Lake is mesotrophic to eutrophic in nature, while the same factors suggest that Palestine Lake is eutrophic to hypereutrophic in nature.

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

This high phosphorus loading resulted in the conditions that were present on the lake in August, where blue-green algae formed a mat over the surface of Palestine Lake. Once this algal mat began to decay, dissolved oxygen was consumed resulting in limited dissolved oxygen in the water column. The end result was that more than 300 fish were killed in Palestine Lake due to its high productivity. Conversely, Caldwell Lake's relatively large capacity (volume) has likely helped offset the effects of the phosphorus and organic matter loading from both the lake's watershed (external loading) and the lake's sediment (internal loading). Thus, despite relatively high phosphorus inputs, the lake's productivity (algae, plant, and fish populations) is more typical of moderately productive to productive lake. However, the lake cannot continue to absorb phosphorus and organic matter indefinitely without a concurrent change in its water quality. It is likely that Caldwell Lake will reach a "breaking point" at which the lake's biological community may begin to reflect more eutrophic conditions. The observable effects once this "breaking point" is reached could include more algal blooms, poorer water clarity, and shifts in the rooted plant and fish community to a dominance of less desirable species.

To prevent, or at least delay, degradation of Caldwell Lake's water quality and biological communities, Caldwell Lake residents and other watershed stakeholders are strongly encouraged to actively manage their lake and watershed. Managing inputs to Caldwell Lake will likely reduce phosphorus concentrations entering Palestine Lake. In both cases, management efforts should focus on reducing both external and internal phosphorus loading to the lakes. The lakes' high watershed area to lake area ratio suggests actions taken throughout the watershed will have a significant impact of the lakes' health. Finally, the lakes' relatively short hydraulic residence time means in-lake management, which can affect nutrient cycling, should receive a low priority. The following paragraphs describe the management techniques recommended for Palestine and Caldwell lakes and their watershed. For the sake of clarity, the techniques are separated into two categories: watershed management techniques and in-lake management techniques.

6.1 Historic Watershed Management

Very few watershed-based projects have been enacted in the Palestine Lake watershed. To date, the SWCD worked with some watershed landowners to implement minor Conservation Reserve Programs. Additionally, the Kosciusko County Surveyor's office maintains the legal drains throughout the watershed. However, these efforts have been focused at maintaining water flow not at improving water quality.

6.2 Watershed Management

JFNew and PLPOA representatives completed a tour of the watershed on March 27, 2007. The majority of the tour was conducted by driving the watershed roads and stopping and walking in areas of interest. Additional areas were identified during subsequent visits to the watershed (water quality sampling, plant surveys, etc.) and through landowner suggestions. The areas that would benefit most from watershed management techniques are detailed in Figure 87. Watershed management techniques are broken into a few major categories. Specifics about each of these areas are detailed below.

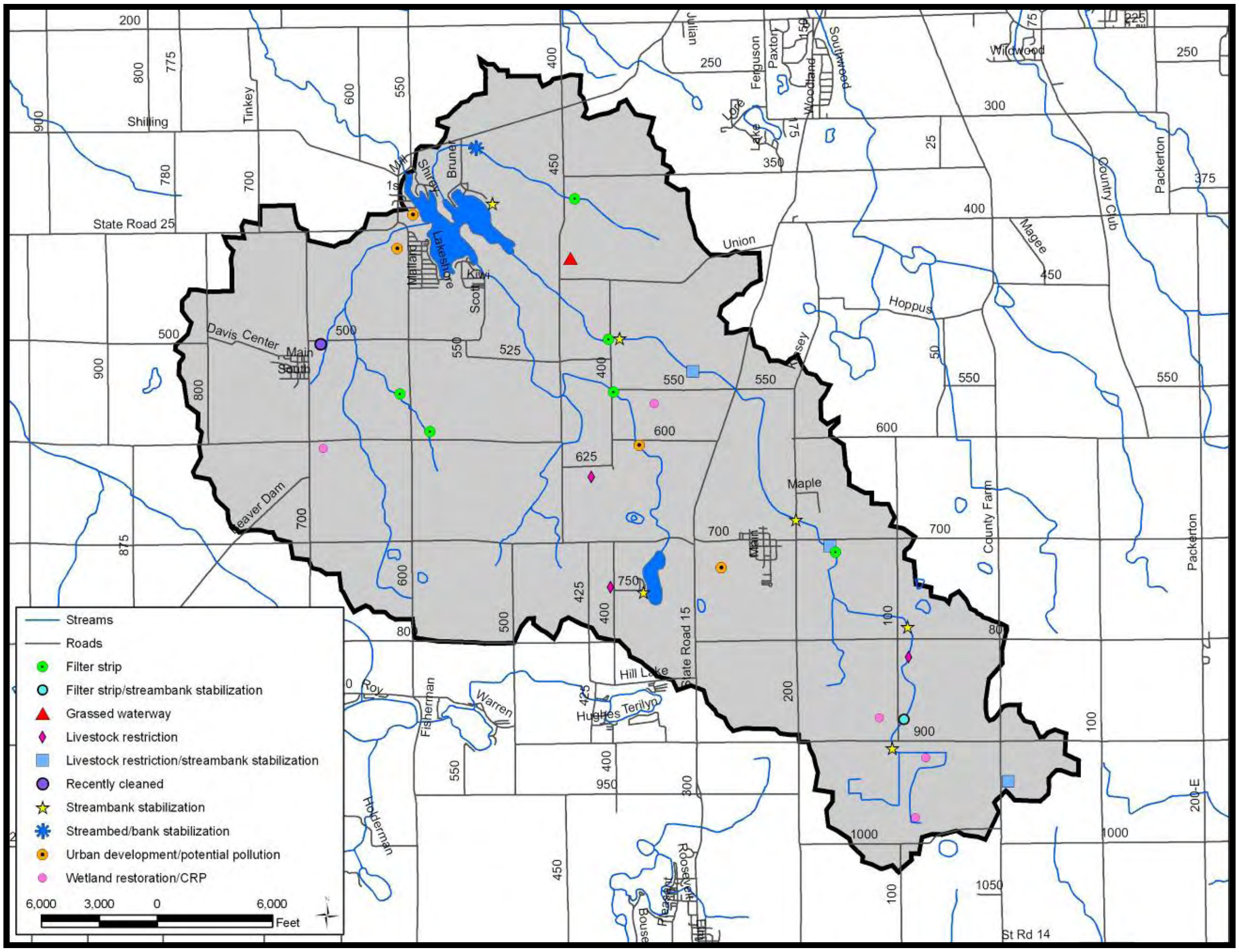

Figure 87. Areas in the Palestine Lake watershed that would benefit from watershed management technique installation.

6.2.1 Stream Channel Management

Palestine Lake possesses four major drainages, which exhibit relatively steep grades in their headwaters, but flatten out as they reach the lake. The soil units associated with the drainages are considered potentially highly erodible (Figure 7). The drains possess a mixture of stable, forested buffers (Figure 88), recently cleaned riparian areas (Figure 89), narrow herbaceous buffers (Figure 90), or are unvegetated (Figure 91). Given these site conditions, it is not surprising that portions of all of these streams are actively eroding. Palestine Lake property owners indicated that during large storm events sediment from many of the lake's drainages turn portions of Palestine Lake brown.

Figure 88. Portion of Sloan Ditch with a maintained forested buffer.

Figure 89. Portion of Williamson Ditch exhibiting a recently cleared riparian area.

Figure 90. Narrow, grass buffer adjacent to Kuhn Ditch (a tributary to Williamson Ditch).

Figure 91. Portion of Magee-Robbins Ditch which lacks an adequate buffer.

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

Some of the erosion occurring within the ravines is natural. The landscape's steep slopes coupled with the sandy and loamy soil naturally predispose the streams to erosion. However, the streams may experience greater erosion rates as explained by the following: In pre-settlement times, forest and wetlands likely covered much of the Palestine Lake watershed. Due to the structure and physical composition of forested land, very low stormwater runoff volumes and flow rates are characteristic. To understand this, it is helpful to consider the path of rain falling on a forested landscape. Some portion of the rain falling on forested land never reaches the ground. The multi-layered canopy of forested land captures this portion of rain. Of the rain that does reach the forest floor, herbaceous ground cover and decaying organic matter absorb another portion of the total rain volume. An additional portion of the total rain volume is infiltrated into the forest soil. This leaves a very small amount of rain that actually leaves the forest floor as overland runoff. This low stormwater runoff volume and consequently low flow rate translates into lower potential for soil erosion. Furthermore, once the water exited the forest as overland flow, much of it historically flowed through wetlands. Wetlands acted to slow the flow of water, which allowed sediment and nutrients to settle into the surrounding landscape before the water made its way to the historic lakes which became Palestine and Caldwell lakes.

Much of the forested canopy and wetland land uses are maintained along the two southern tributaries (Sloan-Adams Ditch and Trimble Creek). However, headwaters portions of these streams and a majority of the two northern tributaries (Magee-Robbins Ditch and Williamson Ditch) do not possess a canopy (Figure 91). The water quality impact of canopy removal and other land use alterations on watershed streams are discussed in more detail in the Stream Assessment Section. Additionally, at some point during settlement of the Palestine Lake watershed, settlers cleared much of the forested areas to allow for agricultural production. Historical aerial photography confirms that much of the land at the headwaters of Palestine Lake's tributaries have been, and in some cases still are, in agricultural production. Agricultural land has significantly higher stormwater runoff volumes and rates compared to forested land. These higher stormwater runoff volumes and rates are increased even further when agricultural land is tiled to improve drainage. The result is an increase in the volume and rate of stormwater runoff reaching the drainages as the water drains toward the lake. The increased volume and rate of stormwater runoff increases the erosion and subsequent down-cutting that occurs within the drains.

In drains where down-cutting continuously occurs, sediment is continuously eroded away from the toe of the streambank and carried down stream. Once the flow of water slows, the eroded sediment is deposited creating an area of deposition. The additional bedload created by the eroded sediment causes additional erosion downstream (Figure 92). The processes of erosion and deposition of bank material continues until the stream reaches a stable condition or enters the lake. In the case of Palestine Lake's watershed streams, the relatively steep gradient, sandy soils, and steep streambanks limit the ability of the stream to create stable conditions. Nearly continuous lateral channel migration, bed scour, and bank sloughing results from the unstable conditions observed along streams draining to Palestine Lake.

Figure 92. Heavy bedload and area of deposition observed in Magee-Robbins Ditch north of Palestine Lake.

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

Erosion control may be possible within the stream channels themselves. Depending upon the slope and soil composition, it may be possible to install a series of check dams or grade control structures within the drains. Check dams reduce erosion by pooling water behind them, slowing the velocity and erosive potential of runoff. As the water slows behind the check dam, some of the sediment in the runoff will drop out of suspension and remain trapped behind the check dam. Sediment traps may also be an option in some of the drain. Like many of the other practices described above, sediment traps slow and store water for release in the future. As water pools within a sediment trap, heavier particles drop out of suspension, reducing the sediment load that reaches the lake. Finally, inn the smaller drains, the use of a French drain or simple slope regrading, seeding, and blanketing may suffice to stabilize the channel.

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

6.2.2 Individual Property Management

Individual property owners can take several actions to maintain or improve Palestine and Caldwell lakes' existing water quality. First, shoreline landowners should seriously consider re-landscaping lakeside properties to protect their lake (Figure 93). Runoff from residential lawns can be very high in phosphorus. In a study on residential areas in Madison, Wisconsin, Bannerman et al. (1992) found extremely high total phosphorus concentrations in stormwater samples from residential lawns. The average phosphorus concentration of runoff water from residential lawns was nearly 100 times the concentration at which algal blooms are expected in lake water. While some dilution occurs as runoff water enters the lake, this source of phosphorus is not insignificant. Other researchers have found similarly high total phosphorus concentrations in lawn runoff water (Steuer et al., 1997).

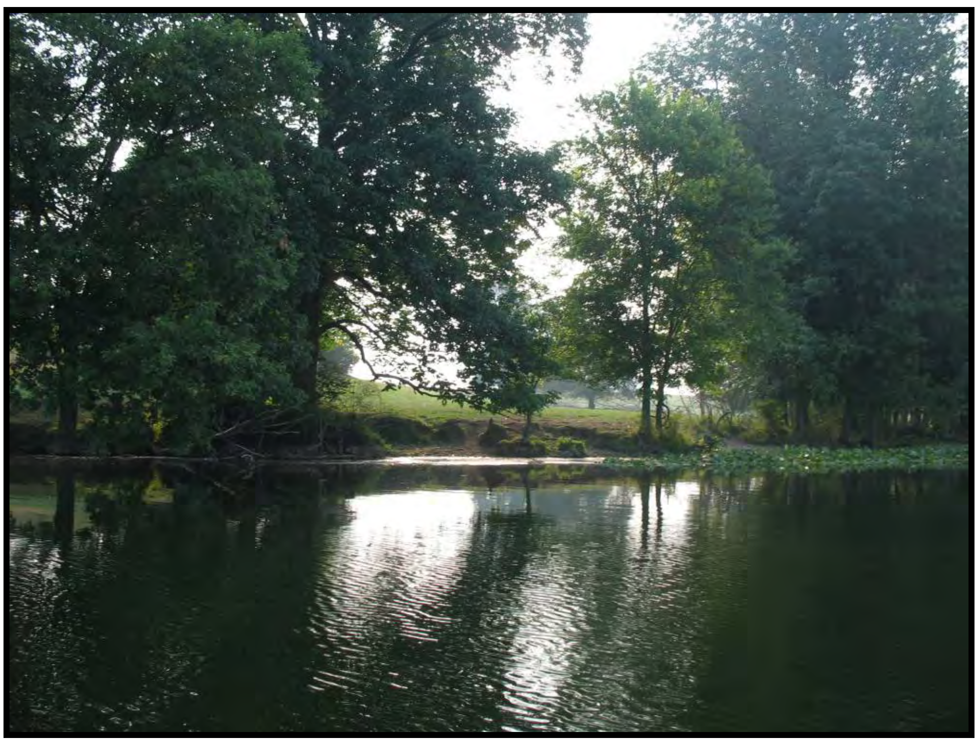

Figure 93. Shoreline erosion present along Caldwell Lake's shoreline.

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

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

Purple loosestrife and reed canary grass were identified in several locations along Palestine Lake's and Caldwell Lake's lakeshore and in adjacent lawns, respectively (Figures 94 and 95). Both of these species are introduced from Eurasia and spread rapidly through prolific seed production, vegetative growth, and cultivation. Without individual control, both species can spread along the lakeshore inhibiting boat mooring and individual access to the lake. (See the Macrophyte Discussion for more information on these plants.) Landowners should replace these plants with native species that provide equal or better quality aesthetics and are more useful to birds, butterflies, and other wildlife as habitat and a food source. Reed canary grass should be replaced with switch grass, Indian grass, or even big blue stem depending on the landowner's desired landscaping (Figure 96). Swamp blazing star, swamp milkweed, cardinal flower, blue-flag iris, or blue lobelia all offer more habitat and aesthetic variety than that offered by purple loosestrife (Figure 97). A mixture of these species will also allow for colorful blooms throughout the growing season.

Figure 94. Purple loosestrife present along Palestine Lake's shoreline.

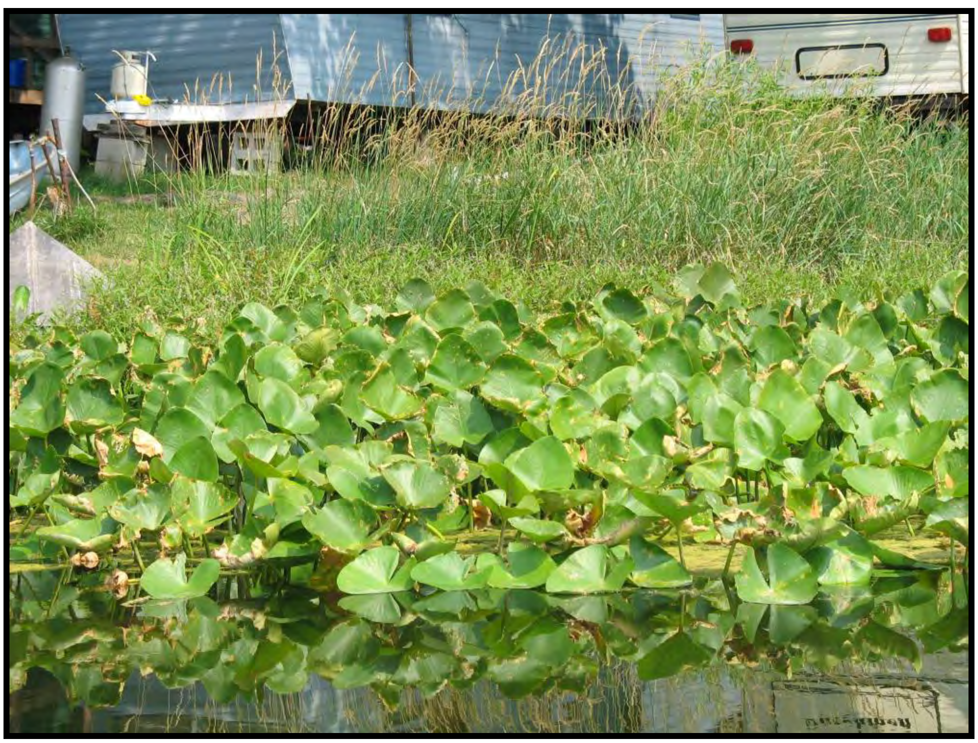

Figure 95. Reed canary grass present along Caldwell Lake's shoreline.

Figure 96. Switch grass (left), big bluestem (center), and Indian grass (right) are some of the grass species suggested for shoreline planting along Palestine and Caldwell lakes.

Figure 97. Some of the forbs suggested for shoreline planting along Palestine and Caldwell lakes are swamp blazing star (top left), swamp milkweed (top center with bumblebee top center), cardinal flower (bottom left), blue-flag iris (bottom center), and blue lobelia (bottom right).

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

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

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

Each lake property owner should investigate local drains, roads, parking areas, driveways, and roof tops. Resident surveys conducted on other northern Indiana lakes have indicated that many lakeside houses have local drains of some sort on their properties (JFNew, 2002). These drains contribute to sediment and nutrient loading and thermal pollution of the lake. Driveways transversing steep slopes adjacent to Palestine Lake should be constructed in a manner that limits the transport of sediment and nutrients to the lake. Where possible, alternatives to piping the water directly to the lake should be considered. Alternatives include French drains (gravel filled trenches), wetland filters, catch basins, and native plant overland swales. Residents might also consider the use of rain gardens or rain barrels to treat stormwater on individual lots.

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

6.2.3 Conservation Reserve Program

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

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

Given the ecological benefits that land enrolled in CRP provides, it is not surprising that removing land from production and planting it with vegetation has a positive impact on water quality. In a review of Indiana lakes sampled from 1989 to 1993 for the Indiana Clean Lakes Program, Jones (1996) showed that lakes within ecoregions reporting higher percentages of cropland in CRP had lower mean trophic state index (TSI) scores. A lower TSI score is indicative of lower productivity and better water quality.

Specific areas where enrollment in CRP is recommended are shown in Figure 87. Each of these areas shares the same common characteristics: they are mapped in a highly erodible soil unit and are currently being utilized for agricultural production. The highest priority area is shown in Figure 87. This owner may already utilize grassed waterways under the CRP, but removal of a larger portion of these fields from agricultural production should be considered. Further, there may be other areas in the watershed that were not observable from the road during the windshield tour that may warrant consideration for enrollment in CRP.

6.2.4 Conservation Tillage

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

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

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

6.2.5 Livestock Fencing

Livestock that have unrestricted access to a lake, stream, or wetland have the potential to degrade the waterbody's water quality and biotic integrity. Livestock can deliver nutrients and pathogens directly to a waterbody through defecation. Livestock also degrade stream and lake ecosystems indirectly. Trampling and removal of vegetation through grazing of riparian zones can weaken banks and increase the potential for bank erosion. Trampling can also compact soils in a wetland or riparian zone decreasing the area's ability to infiltrate water runoff. Removal of vegetation in a wetland or riparian zone also limits the area's ability to filter pollutants in runoff. The degradation of a waterbody's water quality and habitat typically results in the impairment of the biota living in the waterbody.

Livestock access to a stream or wetland adjacent to a stream was a concern noted in six spots in the Palestine Lake watershed (Figure 98). One area of concern is a wetland immediately upstream of Caldwell Lake within the West Branch Sloan-Adams Ditch near the intersection of County Road 750 South and County Road 400 West. Livestock were observed grazing in a low lying wetland area (Figure 98). Although it could not be determined from the observation point at the roads' intersection, the livestock may have direct access to the West Branch Sloan-Adams Ditch or at a minimum, access to a tile draining to the West Branch Sloan-Adams Ditch. The livestock appear to have direct access to the wetland upstream of Caldwell Lake. Excluding livestock from the wetland and revegetating the wetland to provide better treatment for runoff water before reaching Caldwell Lake is recommended at this site. A majority of the other sites are located along Trimble Creek. In most cases, livestock appear to have access to Trimble Creek or one of its tributaries. Figure 99 details one of these locations where the stream banks appear to be damaged by grazing and trampling. This area would benefit from exclusion fencing and stabilization of the stream banks.

Figure 98. Area of direct livestock access to a wetland located within the Caldwell Lake subwatershed.

Figure 99. Bank damage and trampling located within a livestock grazing area along a tributary to Trimble Creek.

Restoring areas impacting by livestock grazing often involves several steps. First, the livestock in these areas should be restricted from the wetland or stream to which they currently have access. If necessary an alternate source of water should be created for the livestock. Second, the wetland or riparian zone where the livestock have grazed should be restored. This may include stabilizing or reconstructing the banks using bioengineering techniques. Minimally, it involves installing filter strips along banks or wetland edge and replanting any denuded areas. Finally, if possible, drainage from the land where the livestock are pastured should be directed to flow through a constructed wetland to reduce pollutant loading, particularly nitrate-nitrogen loading, to the adjacent waterbody. Complete restoration of aquatic areas impacted by livestock will help reduce pollutant loading (particularly nitrate-nitrogen, sediment, and pathogens) to Palestine and Caldwell lakes.

6.2.6 Filter Strips

Just as Palestine and Caldwell lakes themselves would benefit from having the natural buffer around their shoreline restored, installing filter strips along major and minor drainages in the watershed would help reduce the pollutant load reaching these waterbodies. Many researchers have verified the effectiveness of filter strips in removing sediment from runoff with reductions ranging from 56-97% (Arora et al., 1996; Mickelson and Baker, 1993; Schmitt et al., 1999; Lee et al, 2000; Lee et al., 2003). Most of the reduction in sediment load occurs within the first 15 feet (4.6 m). Smaller additional amounts are retained and infiltration is increased by increasing the width of the strip (Dillaha et al., 1989). Filter strips have been found to reduce sediment-bound nutrients like total phosphorus but to a lesser extent than they reduce sediment load itself. Phosphorus predominately associates with finer particles like silt and clay that remain suspended longer and are more likely to reach the strip's outfall (Hayes et al., 1984). Filter strips are least effective at reducing dissolved nutrients like those of nitrate and phosphorus, and atrazine and alachlor, although reductions of dissolved phosphorus, atrazine, and alachlor of up to 50% have been documented (Conservation Technology Information Center, 2000). Simpkins et al. (2003) demonstrated 20-93% nitrate-nitrogen removal in multispecies riparian buffers. Short groundwater flow paths, long residence times, and contact with fine-textured sediments favorably increased nitrate-nitrogen removal rates. Additionally, up to 60% of pathogens contained in runoff may be effectively removed. Computer modeling also indicates that over the long run (30 years), filter strips significantly reduce amounts of pollutants entering waterways.

Filter strips are effective in reducing sediment and nutrient runoff from feedlot or pasture areas as well. This is particularly important in the Palestine Lake watershed where the need for filter strips was associated with livestock pastures. Olem and Flock (1990) report that buffer strips remove nearly 80% of the sediment, 84% of the nitrogen, and approximately 67% of the phosphorus from feedlot runoff. In addition, they found a 67% reduction in runoff volume. The reduction in runoff volume decreases the potential for erosion in any receiving stream. It is important to note that filter strips should be used as a component of an overall waste management system when addressing runoff from pastures and feed lots.

Filter strips are most effective when they: 1) are adequately sized to treat the amount of runoff reaching them (Figure 100); 2) include a diverse variety of species; 3) contain species appropriate for filter strips; and 4) are regularly maintained. Filter strip size depends on the purpose of the strip, but should ideally have at least a 30-foot flow path length (the minimum length across which water flows prior to reaching the adjacent waterbody). The variety of species planted in a filter strip depends upon the desired uses of the strip. For instance, if the filter strip will be grazed or if a landowner wishes to attract a diverse bird community, specific seed mixes should be used in the filter strip. The NRCS or an ecological consultant can help landowners adjust filter strip seed mixes to suit specific needs.

Figure 100. An example of a filter strip with excellent width to maximize the reduction of pollutant loads reaching the adjacent ditch. (Photo taken in Cass County, Indiana.)

During the windshield tour of the Palestine Lake watershed, filter strips were observed along portions of Palestine and Caldwell lakes' tributaries. However, the need for filter strips or an increase in the width of existing filter strips was noted in the areas impacted by livestock discussed above and along at least six portions of the Trimble Creek, Sloan-Adams Ditch, Williamson Ditch, and Magee-Robbins Ditch drainage systems. One example of such an area is depicted in Figure 103. Filter strips may be needed in other locations along these drainages in the Palestine Lake watershed that are not visible from roadways. Given the benefits filter strips provide, Palestine Lake watershed stakeholders should work with the Kosciusko County SWCD to ensure that tributaries in the watershed are protected with wide, functioning filter strips.

Figure 101. Portion of a tributary to Trimble Creek where the installation of a buffer strip would benefit water quality within the drain and Palestine Lake.

6.2.7 Wetland Restoration

Visual observation and historical records indicate at least a portion of the Palestine Lake watershed has been altered to increase its drainage capacity. The 1978 Census of Agriculture found that drainage is artificially enhanced on 38% of the land in Kosciusko County (cited in Hudak, 1995). Riser tiles in low spots on the landscape and tile outlets along the waterways in the Palestine Lake watershed confirm the fact that the landscape has been hydrologically altered.

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

Restoring wetlands in the Palestine Lake watershed could return many of the functions that were lost when these wetlands were drained. Figure 102 shows the locations where large wetland restoration projects were identified and that wetland restoration is recommended. While other areas of the watershed could be restored to wetland conditions, the areas shown in Figure 87 were selected because they are areas where large scale restoration is possible. Figure 102 details one such location in the headwaters of Trimble Creek.

Figure 102. Potential wetland restoration site within the headwaters of Trimble Creek.

6.2.8 Manure Management

Nutrient management has been the focus of agricultural research in many parts of the country. Studies have shown that every year about 15% of the applied nitrogen, 68% of the residual nitrogen in the non-root zone layer of the soil, and 20% of the residual nitrogen in the root zone layer are leached to the groundwater (Yadav, 1997). To address this concern, the Penn State Cooperative Extension Service designed a nutrient management plan based on: 1) crop yield goals; 2) soil type; 3) methods of manure and commercial fertilizer application; 4) nitrogen concentrations in soils; 5) nitrogen concentrations in manure to be used for fertilizer; and 6) crop rotations (Hall and Risser, 1993). With this plan in place: 1) fertilizer application as manure and commercial fertilizer decreased 33% from 22,700 lbs/year to 15,175 lbs/year; 2) nitrogen loads in groundwater decreased 30% from 292 lbs of nitrogen per 1,000,000 gallons of groundwater to 203 lbs per 1,000,000 gallons; and 3) the load of nitrogen discharged in groundwater was reduced by 11,000 lbs for the site over a three-year period (70 lbs/ac/yr).

In special areas of environmental concern, such as fields that border streams and other waterbodies, fertilizer setbacks should be utilized. Setbacks are strips or borders where fertilizer is either not applied or applied in smaller quantities. Fertilizers should not be applied directly next to streams and certainly not in them. According to the Kosciusko County Purdue Cooperative Extension Agency, fertilizer setbacks are accomplished with filter strips; most farmers are conscientious of application near tile drains and open ditch areas. Farmers are typically extremely aware of fertilizer application near streams and drainage tiles. Producers on highly erodible land in some areas of concern tend to be more conscientious with respect to fertilizer application; many of these producers are diligently following their production plans and continue to maintain highly erodible field in hay or wheat and avoid tilling these fields in the fall.

Though not a nutrient in and of itself, *E. coli* bacteria contamination of waterways is an indirect effect of applying animal waste as fertilizer. *E. coli* and other bacteria from the intestinal tracts of warm blooded animals can cause gastroenteritis in humans and pets. Symptoms of gastroenteritis include: nausea, vomiting, stomachache, diarrhea, headache, and fever. Due to high *E. coli* counts, about 81% of the assessed waters in Indiana did not support "full body contact recreation" in 1994-1995 (IDEM, 1995). Of over 800 samples collected in the St. Joseph River (Ft. Wayne) in northern Indiana during 1996-1997, the average of all samples was 2,000 col/100 ml, or about 16 times the maximum allowable level (Frankenberger, 2001). Samples collected near 19 USGS gauging stations in the St. Joseph River (South Bend) Watershed during 2002 contained *E. coli* concentrations of 7-4,600 col/100 ml. The USGS determined that 33-95% of these colonies were the pathogenic strains (O157:H7) of *E. coli* (Duris et al., 2003). During the present study, many of the Palestine Lake watershed streams were in violation of the Indiana state standard; concentrations ranged from 350-24,190 col/100 ml (Table 51). To prevent manure from entering tiles, ditches, and streams, producers can: 1) apply manure at optimal times for plant uptake; 2) apply manure when potential for plant uptake is high and runoff is low; 3) inject or incorporate manure to reduce runoff potential; 4) use filter strips; and 5) use setbacks from surface inlets to tile lines.

6.2.9 Additional Treatment of Stormwater Runoff

All hardscape within the Palestine Lake watershed are sources of urban pollutants. The urban landscape can contribute more pollutants to nearby waterbodies than some agricultural landscapes. The U.S. Environmental Protection Agency's National Urban Runoff Program (USEPA, 1983) results suggest that pollutant runoff rates, including nutrients and suspended solids, will increase as land is converted from agricultural fields to urban landscapes. Reckhow and Simpson (1980) found similar results in their review of studies of nutrient export rates from various landscapes. Bannerman et al. (1992) reported that streets and parking lots release significant amounts of stormwater contaminants. Given the potential for water pollution from typical urban landscapes, watershed stakeholders must also focus on urban watershed management.

The potential for installing stormwater Best Management Practices (BMPs) that promote infiltration should also be investigated. These issues are of particular concern in three main locations: adjacent to the gravel road in watershed tributary headwaters, in reference to the storm drains that are located within the county right-of-way adjacent to roads around Palestine Lake, and around areas within the Town of Palestine. All of these are great examples of areas where soils are appropriate for infiltration BMPs. Filtration trenches, sand filters, and biofilters (a variation of sand filters that are planted with native vegetation to allow additional nutrient uptake) provide good treatment for stormwater pollutants. Research (Winer, 2000) suggests these infiltration BMPs are particularly good for treating pollutants of concern in the Palestine Lake watershed. These BMPs also promote infiltration of stormwater rather than storing it and discharging it at a later time. This simulates the natural hydrology of the watershed by recharging the groundwater with at least a portion of the stormwater rather than sending the whole volume downstream. Unfortunately, these BMPs can be costly and difficult to maintain, factors that should be balanced with the benefits derived from these BMPs.

Residential runoff carries yard waste, fertilizer, and other debris to the lake via storm drains. Pollution from these drains was not directly categorized or quantified but varies at each drain. These drains likely carry sand, gravel, and road salt from wintertime applications of these pollutants to the adjacent roads; other storm drains likely release sediment, sediment-attached nutrients, pesticides, yard debris, and garbage. Most of the drains examined could be improved in some way to reduce their respective pollutant loads to the lake. A majority of the storm drains located during the watershed tour were constructed by individual landowners. Generally, residents designed their drains based on the location of standing water on or near their property at the time of construction. Most of these drains were sized to reduce the depth and duration of water ponding and consist of a grated metal or cement inlet structure connected to a plastic, clay, or metal pipe which conveys water directly into the lake. The general design of an inlet to a pipe flowing directly to the lake provides little to no stormwater pollutant reduction and often does not allow for drain cleaning or maintenance.

The storm drains were not sampled for pollutant export; therefore only limited conclusions can be drawn on the amount of pollutants that these drains are delivering to Palestine and Caldwell lakes and what impact the proposed solutions will have. Road salts, nutrients from adjacent lawns and leaf litter, and hydrocarbons are going directly to the lake as they are washed from the roads. Properly maintained catch basins have been found to remove 32-97% of total suspended solids (Pitt et al., 2000; Mineart and Singh, 1994). Wetland vegetated filters have been found to remove between 40-90% of hydrocarbons, nutrients, and sediment from runoff (Moustafa, 1997; Wang and Mitsch, 1996; Warwick et al., 1998). Projects vary in efficiency due to size and type of construction as well as the age of filters. Mature wetland filters absorb fewer pollutants than newly constructed filters. This study assumes that the storm drains around the lake play a minor role in the delivery of pollutants to the lakes. However, the drains are contributing pollutants and the cost of treatment is relatively low compared to some of the other issues identified throughout the watershed, therefore treatment is recommended.

6.3 <u>In-Lake Management</u>

6.3.1 Aquatic Plant Management

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

1. Palestine and Caldwell lakes' rooted plant diversity should be protected (Figure 103 and 104). Both lakes support excellent rooted plant diversity and this undoubtedly plays a role in supporting its healthy fishery. Management techniques that are not species specific or large scale harvesting should be avoided.

Figure 103. Example of Palestine Lake's rooted plant community.

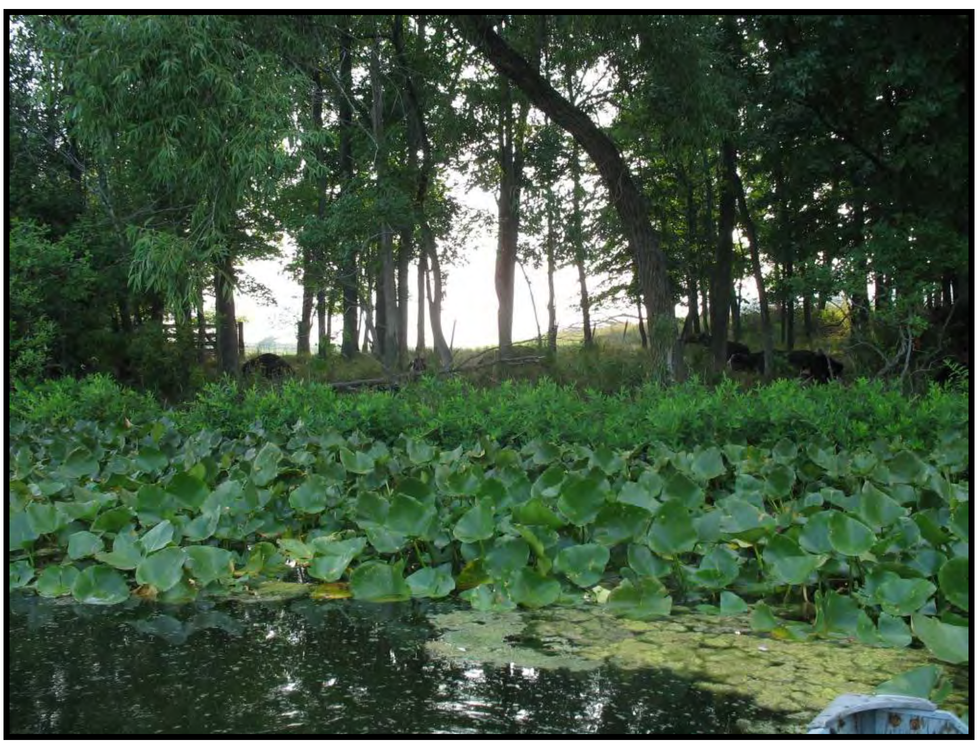

Figure 104. Example of Caldwell Lake's rooted plant community.

2. Lake residents should take steps to reduce the coverage of exotic, invasive species and restore the lakes' shoreline vegetation. Currently, much of Palestine Lake's shoreline is vegetated by purple loosestrife (Figure 94), while much of Caldwell Lake's shoreline is

vegetated by reed canary grass (Figure 95). Removal of these species and restoration of the shoreline would return many of the functions provided by healthy riparian areas. Additionally, some of the developed portion of the lake's shoreline lacks a healthy emergent plant population. A more detailed discussion of shoreline functions and restoration techniques was provided above in the Individual Property Management Section.

3. Palestine and Caldwell lakes' residents should develop an aquatic plant management plan and investigate spot treatment options for areas where aquatic plants and algae are especially dense or occur in nuisance stands. Treatment history indicates that curly-leaf pondweed and Eurasian watermilfoil reach nuisance levels in various locations within the lake. However, at the time of the current survey, curly-leaf pondweed was found in moderate density throughout the lake, while Eurasian watermilfoil was identified in relatively low densities throughout the lake. Curly-leaf pondweed typically reaches its greatest density early in the growing season; therefore, its presence at the time of the assessment is somewhat surprising. The heavy algal mat covering the lake likely kept water temperatures low enough for curly-leaf pondweed to continue to grow. If individual residents in areas with heavy aquatic plant growth feel that the amount of plant growth in front of their property is limiting the recreational potential of the lake, these residents might consider management techniques such as hand harvesting of plant material, spot treatment of aquatic vegetation, or the use of bottom covers. Please be aware that permits may be required for these activities. Residents should consult with the IDNR Division of Fish and Wildlife before implementing any of these management methods. If hand harvesting is utilized as a treatment method, residents need to remove the plant material from the lake rather than allowing it to remain in the lake, float to other areas, and re-root. Additionally, if plants are removed from the lake by hand, plants should not be left along the shoreline or piled on adjacent sea walls. The nutrients from the plants return to the water through decomposition and decay. This is an additional source of nutrient loading to the lake. An educational program highlighting the benefits of a healthy plant community, including emergent species, might help residents make informed decisions on balancing their desire for relatively plant-free water in front of their property with the desire for a healthy, productive fish community in the lakes.

4. Residents should take action to educate themselves on Eurasian watermilfoil and hydrilla. Given the high density of off-shore users, residents should be especially diligent in educating all users regarding the threat of Eurasian watermilfoil and hydrilla to Palestine and Caldwell lakes and other area lakes. These exotic invasive species offer poor habitat to the lake's biota and often interferes with recreational uses of a lake. Creating an inspection or boat washing facility would likely be the best option to prevent the infestation of the lake with Eurasian watermilfoil or hydrilla. Furthermore, lake users should also educate themselves on both species. The Stop the Hitchhikers! (www.protectyourwaters.net) campaign offers great resources on preventing the spread of exotic and/or invasive species. Taking precautionary measures such as ensuring that all plant material is removed from boat propellers following their use prevents the spread of these and other invasive species. Lake users should also refrain from boating through stands of Eurasian watermilfoil in other lakes. (Access to the only lake in Indiana containing a known population of hydrilla is currently restricted. Therefore, boating through hydrilla is unlikely within Indiana lakes.) Caution should be used if an individual observes hydrilla. This individual should contact Doug Keller, IDNR ANS coordinator, immediately if hydrilla is observed in or around any of Indiana's lakes. Pieces

of the plant as small as one inch in length that are cut by a boat propeller as it moves through a stand of Eurasian watermilfoil or hydrilla can sprout and establish a new plant. Signage at the public boat ramp informing visitors of these best management practices would also be useful. It is important to note that IDNR approval is required to post any signs at the public boat ramp.

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

Institutional Protection of Beneficial Vegetation
Invasive species often colonize disturbed areas first before moving to other areas of the lake. The protection of native and/or beneficial aquatic vegetation can prevent the growth of exotic or nuisance species. This can be accomplished in two ways: limiting user impacts to beneficial plants due to boating or recreational uses and not over-treating beneficial plant beds. Users can restrict the use of specific areas of Palestine and Caldwell lakes through the use of buoys or the establishment of user zones. The second methodology, over-treating of native plant beds, could be a concern in the lakes in the future. This issue occurs when a beneficial, native plant bed is deemed to be a nuisance and treatment of this area begins. Once the native plant community is weakened through treatment, exotic species can move into these areas colonizing open sediment. Once a foothold is established, the aggressive, exotic species can then out-compete native varieties. The PLPOA should be aware of this issue and tailor their treatment efforts to not impact beneficial native species.

Environmental Manipulation
Environmental manipulation often refers to manipulating the lake's water level to control vegetation. This occurs by raising water levels resulting in drowning the plants or lowering the water level to freeze or heat the aquatic plant community. This type of treatment is limited to lakes where water levels are easily manipulated. Neither Palestine Lake's nor Caldwell Lake's water control structures offer ease of water-level manipulation. However, this has occurred in the past when dam repair was completed and therefore, could be used again in the future.

Nutrient Reduction
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) (Aikens et al., 1979). Hydrostatic pressure rather than light often limits plant growth at deeper water depths (15-20 feet or 4.5-6 m).

Water clarity affects the ability of sunlight to reach plants, even those rooted in shallow water. Lakes with clearer water have an increased potential for plant growth. Caldwell Lake possesses better water clarity than the average Indiana lake. In this lake, aquatic plant growth can occur in greater water depths than in Palestine Lake, where the water clarity is poor. 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 generally holds true in both Palestine and Caldwell lakes.

Aquatic plants also require a steady source of nutrients for survival. Many aquatic plants, also known as aquatic macrophytes, differ from microscopic algae (which are also plants) in their uptake of nutrients. Aquatic macrophytes receive most of their nutrients from the sediments via their root systems rather than directly utilizing nutrients in the surrounding water column. Some competition with algae for nutrients in the water column does occur. The amount of nutrients taken from the water column varies for each macrophyte species. Because macrophytes obtain most of their nutrients from the sediments, lakes, which receive high watershed inputs of nutrients to the water column, will not necessarily have aquatic macrophyte problems. However, lakes with large sources of readily-available nutrients (phosphorus and nitrogen), typically contain higher density aquatic plant communities. Reductions in nutrients can both increase and decrease aquatic plant density. Increases in plant density occur due to improved water clarity, which often results in more plant growth. Both Palestine and Caldwell lakes contain relatively high nutrient levels and therefore would be expected to contain a high density aquatic plant community. The reduction of nutrient inputs to the both lakes will likely not alter the aquatic plant community as a whole. Rather, localized effects of the nutrient reduction will likely occur in the areas of the lake closest to the change in nutrient resources.

Mechanical Harvesting

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

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

Hand harvesting may be the most economical means of harvesting on both lakes. Hand harvesting is recommended in small areas where human uses are hampered by extensive growths (docks, piers, beaches, boat ramps). In these small areas, plants can be efficiently cut and removed from the lake with hand cutters such as the Aqua Weed Cutter (Figure 105). In less than one hour every 2-3 weeks, a homeowner can harvest 'weeds' from along docks and piers. Depending on the model, hand-harvesting equipment for smaller areas cost from $50 to $1500 (McComas, 1993). To reduce the cost, several homeowners can invest together in such a cutter. Alternatively, a lake association may purchase one for its members. This sharing has worked on other Indiana lakes with aquatic plant problems. Use of a hand harvester is more efficient and quick-acting, and less toxic for small areas than spot herbicide treatments. Depending on the size to be treated, a permit may be required for hand-harvesting. (The IDNR Division of Fish & Wildlife can assist lake residents in determining whether a permit is needed and how to obtain one.)

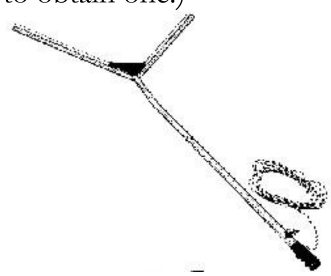

Figure 105. An aquatic weed cutter designed to cut emergent weeds along the edge of ponds. It has a 48" cutting width, uses heavy-duty stainless steel blades, can be sharpened, and comes with an attached 20' rope and blade covers.

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

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

Biological Control
Biological control involves the use of one species to control another species. Often when a plant species that is native to another part of the world is introduced to a new region with suitable habitat, it grows rapidly because its native predators have not been introduced to the new region along with the plant species. This is the case with some of the common pest plants in northeast Indiana such

as Eurasian watermilfoil and purple loosestrife. Neither of these species is native to Indiana, yet both exist in and around Kosciusko County.

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

The population of purple loosestrife around Palestine Lake is extremely large and covers much of the shoreline of the lake; therefore, biological control may be the most suitable option for control efforts. Furthermore, it is important for residents to understand the common biocontrol mechanisms for this species should the situation on the lake change. Likewise, as Eurasian watermilfoil is present in the both lakes, residents should be cognizant of infestation issues and biocontrol mechanisms for Eurasian watermilfoil. Therefore, treatment options for the plant are discussed below merely as reference material for use in case of future infestation. Residents should also be aware that under new regulations an IDNR permit is required for the implementation of a biological control program on a lake.

Biological Control of Eurasian Watermilfoil

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

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

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

Biological Control of Purple Loosestrife

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

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

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

Chemical Control

Herbicides are the most traditional means of controlling aquatic vegetation. Herbicides have been used in the past on the both Palestine and Caldwell lakes as detailed in previous sections. Additionally, it is likely that some residents may have conducted their own spot treatments around piers and swimming areas. It is important for residents to remember that any chemical herbicide treatment program should always be developed with the help of a certified applicator who is familiar with the water chemistry of the target lake. In addition, application of a chemical herbicide may require a permit from the IDNR, depending on the size and location of the treatment area. Information on permit requirements is available from the IDNR Division of Fish and Wildlife or conservation officers.

There are two major disadvantages associated with chemical control of aquatic plants. The primary concern associated with chemical use is user concerns regarding safety. Chemicals undergo rigorous testing prior to licensing. Testing is completed by the USEPA with the final registration occurring within each state. All herbicides are required to result in low toxicity to humans and wildlife and to not persist or bioaccumulate within the environment. Secondarily, users are often concerned due to water use restriction. Restrictions must be posted prior to treatment and can be in the form of irrigation or full body contact. Finally, nutrient releases can occur due to the large volume of dying plant material. This disadvantage can be controlled through correct timing of aquatic plant treatment.

Herbicides vary in their specificity to given plants, method of application, residence time in the water, and the use restrictions for the water during and after treatments. Herbicides occur in two forms: contact and systemic. There are three primary contact herbicides used for controlling submerged aquatic vegetation: diquat (trade name Reward), endothall (trade name Aquathol K), and copper-based formulations (trade names Komeen, Clearigate, and Nautique). Contact herbicides are effective for controlling submerged vegetation on the short term. Such herbicides have historically lacked selectivity resulting in killing non-target plants and sometimes even fish species in a lake. However, recent research suggests that some contact herbicides can be effective for the control of exotic species with relatively minor effects on native species (Skogerboe and Getsinger, 2002). Additionally, it should be noted that the timing and dosage of contact herbicides can improve their selectivity and control, and that this control can be extended to attempt long-term control. Reward is the typical contact herbicide used for mid-season treatment. Diquat or copper-based contact herbicides are fast-acting and, based on this, these herbicides are typically used to control nuisance vegetation around docks or in high-use areas. However, plants can recover quickly from treatments of these herbicides; recovery can occur as quickly as four to eight weeks after treatment.

Research completed by Skogerboe and Getsinger (2002) indicate that treatment rates of endothall as low as 0.5 to 1.0 mg/L can effectively control curly-leaf pondweed and Eurasian watermilfoil. However, higher application rates (1.0 mg/L) of endothall provide better long-term control of curly-leaf pondweed and are required to sustain adequate chemical concentrations within large treatment areas (UPI, no date). Further research indicates that early spring application of endothall at a rate of 1.0 mg/L provides nearly 90% reduction in root biomass production and greater than 90% reduction in turion production (Poovey et al., 2002). (Poovey et al. (2002) defined early spring treatment as March or April when water temperatures are below 60°F (15°C). Furthermore, research indicates that late spring or early summer treatment after turions have formed is ineffective at long-term control of curly-leaf pondweed and that treatment methodology does not reduce turion production. Aquathol K manufacturers recommend that treatment occur on or before temperatures reach 50 °F and suggest that early season treatment control "reduces turion production and may reduce the curly-leaf population over time" (UPI, no date). The following treatment rates are their recommendations for effective control of curly-leaf pondweed:

- Large treatment area: 0.5 to 1.5 mg/L (ppm) or 0.3 to 1.0 gallons/acre-foot
- Spot treatment: 1.5 to 3.0 mg/L (ppm) or 1.0 to 1.9 gallons/acre-foot

Systemic herbicides are those that work within the system of the plant itself. These herbicides are transported to the root system resulting in killing the entire plant. The three most common systemic herbicides used for the control of Eurasian watermilfoil are fluoridone (trade name Sonar or Avast!), 2,4-D (trade name Aqua-Kleen, DMA4, or Navigate), and triclopyr (trade name Renovate). (Additionally, imazapyr, glyphosate, and triclopyr can be used for the control of purple loosestrife.) Fluoridone is typically recommended for whole lake treatment of Eurasian watermilfoil and curly-leaf pondweed due to the lower tolerance of these species to fluoridone compared with other aquatic plant species. Smith (2002) noted control of Eurasian watermilfoil to the point of limited detectability following whole-lake treatment with fluoridone. Additionally, most Eurasian watermilfoil strains have a lower tolerance to fluoridone than most other aquatic plant species; therefore, if fluoridone is properly applied, control of Eurasian watermilfoil can occur with little harm to native species (Nate Long, Aquatic Control, personal communication).

Triclopyr and 2,4-D are typically used for spot treatment of small areas of broad-leaf plants (dicots) like coontail, watermilfoil, and waterweed. Treatment with triclopyr is a good option if Eurasian watermilfoil populations are not dense or abundant. Treatment using triclopyr must be aggressive in order to result in adequate Eurasian watermilfoil control. Neither chemical affects monocots such as eel grass or pondweeds and are not effective in the control of curly-leaf pondweed. 2,4-D is a cheaper alternative than triclopry; however, 2,4-D can impact other native species like coontail.

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

Chemical treatment should be used with caution on Palestine and Caldwell lakes since treated plants are often left to decay in the water. This will contribute nutrients to the lake's water column. Additionally, plants left to decay in the water column will consume oxygen. Water quality sampling showed that the lakes possessed moderate to high nutrient concentrations compared to many Indiana lakes. Nonetheless, as evidenced during the plant survey, the lakes' total phosphorus concentration is high enough to support filamentous algae and, based on the water chemistry samples collected during the previous in-lake assessments, the lakes may also experience algal blooms. The plankton community present in Palestine Lake illustrates this issue in that the community is dominated by blue-green algae during the height of the summer. Furthermore, the blue-green algae that comprised the largest portion of the plankton community have been known to cause taste, odor, and toxicity problems in other lakes. Chemical treatment is likely the best way to control growth and spread of Eurasian watermilfoil and curly-leaf. Herbicides (and algaecides; chara is an algae) that are non-specific or require whole lake applications to work are generally not recommended for treatment.

Preventive Measures

Preventive measures are necessary to curb the spread of nuisance aquatic vegetation. Although milfoil is thought to 'hitchhike' on the feet and feathers of waterfowl as they move from infected to uninfected waters, the greatest threat of spreading this invasive plant is humans. Plant fragments snag on boat motors and trailers as boats are hauled out of lakes (Figure 106). Milfoil, for example, can survive for up to a week in this state; it can then infect a milfoil-free lake when the boat and trailer are launched next. It is important to educate boaters to clean their boats and trailers of all plant fragments each time they retrieve them from a lake. The Stop Aquatic Hitchhikers! campaign offers information on the prevention of spreading exotic invasive species. Visit their website at for more information: www.protectyourwaters.net

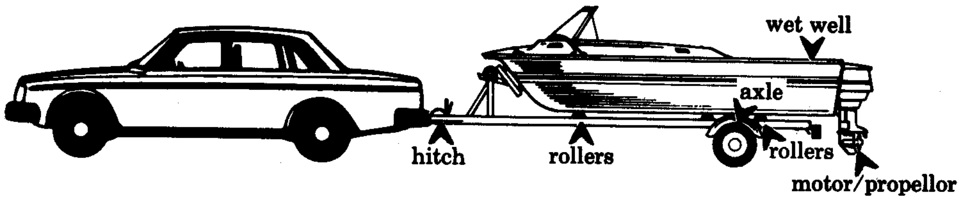

Figure 106. Locations where aquatic macrophytes are often found on boats and trailers.

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

6.3.2 Boat Management

During multiple conversations, several watershed stakeholders expressed a concern over the potential ecological impact to Palestine Lake from motor boats. Given the lake's shallow nature and the fact that more than 90% of its surface water covers depths measuring 10 feet (3.1 m) or less, the impact of motor boats on Palestine Lake can be extremely high. The stakeholders also communicated a perceived increase in the number of boats using Palestine Lake over the past few years. Although an assessment of the ecological impact of motor boating on Palestine Lake's health was beyond the scope of this study, the scientific literature contains several studies documenting the effects of motor boating on lake health in general. A review of the potential ecological impacts of motor boating on lake health may be useful to understand how Palestine Lake may be affected by this activity.

Water Clarity Concerns

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

The ability of a motor boat to resuspend sediment from the lake bottom depends on several factors. Some of these factors, such as boat length, motor size, and boat speed, are related to the boat itself and the boat's operator. Yousef et al. (1978) found that 10 horsepower (hp) motors were capable of mixing the water column to a depth of 6 feet (1.8 m), while 50 hp motors were capable of mixing the water column to a depth of 15 feet (4.6 m). While larger motor sizes have a greater potential to resuspend sediments than smaller motors, longer boats and higher speeds do not automatically translate to a greater ability to resuspend sediments. Boats that are 'planing' on the water actually have little impact on the lake's bottom. This is because the velocity of water at the lake bottom created by a motor boat depends on the boat's displacement, which is a function of boat length and speed. Beachler and Hill (2003) suggest that boat speeds in the range of 7 to 12 mph may have the greatest potential to resuspend sediment from the lake bottom. (This range is based on typical recreational boat length.) In Palestine Lake, where idle and no wake boating is the predominant form, boats that are not yet planing are present in high numbers; these boats can have a heavy, negative impact on the lake's water quality.

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

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

Other Potential Concerns

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

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

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

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

Boat Management

It is clear from the preceding discussion, the education of individuals who boat on Palestine Lake is necessary to ensure that Palestine Lake continues to be a healthy, functioning lake capable of providing recreational and aesthetic enjoyment for all users. Educating all users, both on-lake and off-lake, is often key in boat management on any lake. If education of users is not successful and boating impacts continue to increase, then further boat management techniques, including carrying capacity determination and lake use limitation, may need to be investigated and, if deemed appropriate, enacted. Boat management is often highly contentious and different user groups will undoubtedly have differing opinions on the best course of management.

6.3.3 Dredging

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

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

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

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

6.3.4 Alum Treatment

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

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

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

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

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

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

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

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

Cooke et al. (2005) outline several of the potential drawbacks to alum treatments. These include the potential for increased rooted plant growth. As phosphorus that was once available for algal growth is removed from the water column, algae growth is reduced. This may increase water transparency. Increased water clarity allows for greater light penetration which could enhance rooted plant growth.

Food chain impacts from the immediate reduction of algae could also affect a lake's fishery. Finally, the toxicity of aluminum even in neutral or basic conditions (pH >7) is of some concern to researchers.

6.3.5 Water Quality Monitoring

The Indiana Clean Lakes Volunteer Monitoring Program trains and equips citizen volunteers to measure Secchi disk transparency, water color, total phosphorus, and chlorophyll *a* in Indiana lakes. Citizen volunteers monitor over 115 lakes for transparency and 40 lakes for phosphorus and chlorophyll. Volunteers also have access to temperature and oxygen meters to track changes in these parameters throughout the year. Data collected by volunteers helps elucidate any trends in water quality and provides more timely information with which lake management decisions can be made. Neither Palestine Lake nor Caldwell Lake have participated in this program in the past and should consider options for a citizen volunteer. Participation in the Indiana Clean Lakes Volunteer Monitoring Program is highly recommended.

7.0 <u>RECOMMENDATIONS</u>

As noted in the previous section, Palestine Lake currently possesses poor water quality, while Caldwell Lake contains moderate water quality. The biotic communities (algae, plants, fish) exhibit characteristics typically observed within lakes which possess high nutrient concentrations like those present in Palestine and Caldwell lakes. It is unlikely that the lakes can continue to absorb the pollutant loads they are currently receiving. Results from the modeling and lake and stream assessments indicate that current pollutant concentrations and loads, particularly phosphorus, nitrate, organic matter, and bacteria, are of concern for the lakes' long-term health. Lake residents have already noted declines in water clarity following storm events, suggesting sediment is also of concern. Despite these conditions, Palestine Lake residents' goal is for the lake to be fishable and swimmable. Additionally, residents desire a lake where thick algae mats do not cover the water surface during the summer.

Given Palestine and Caldwell lakes' specific characteristics, both in-lake and watershed management is recommended to improve the lakes' water quality. Palestine and Caldwell lakes' high watershed area to lake area ratios suggests actions taken within the watershed will have a significant impact of the lakes' health. Thus, management of watershed issues and near shore drainages and individual residential properties should be prioritized. The lakes' relatively short hydraulic residence time means in-lake management, which can affect nutrient cycling, should receive lower priority.

The list of recommendations was briefly discussed during the first public meeting which occurred April 29, 2007. Recommendations were discussed in more detail during the final public meeting which occurred March 30, 2008. In total, 23 people attended one or both of these public meetings. The following list summarizes the recommendations for improving Palestine and Caldwell lakes' chemical, biological, and physical conditions. The recommendations are separated in two groups based on priority described above. Recommendations in the first group are of higher priority than recommendations in the second group since implementation of these recommendations would provide greatest benefit to Palestine and Caldwell lakes. Implementation of recommendations in the second group is, however, important and should not be ignored. Each of the following recommendations should be implemented and will help improve Palestine and Caldwell lake water quality.

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

Primary Recommendations

1. Complete shoreline and streambank stabilization and restoration projects throughout the watershed. Streambank stabilization projects should be coordinated with the surveyor's office as many of the streams draining to Palestine Lake are legal drains. Furthermore, stabilization efforts should focus on areas where the surveyor's office does not plan to implement any cleaning projects in the near future. Shoreline stabilization projects should focus on those areas where erosion is the most severe (Figure 87).

2. Implement an aquatic plant management program. This should start with completion of an aquatic plant management plan. This plan should include a focus on the lakes' algae community and include recommendations for lake-wide control of Palestine Lake's algae population.

3. Increase usage of the Conservation Reserve Program in the Palestine and Caldwell Lakes watershed particularly on land mapped in highly erodible soils. Areas where filter strips and/or grassed waterways could be implemented are shown in Figure 87.

4. Fence livestock out of the Palestine and Caldwell lakes watershed waterbodies. Specific locations that would benefit from livestock restriction are shown in Figure 87.

5. Work with watershed landowners who operate Confined Feeding Operations (CFOs) to establish water quality improvement projects in areas where manure is spread. CFO locations are shown in Figure 12.

6. Implement individual property owner management techniques. These apply to all watershed property owners rather than simply those who live immediately adjacent to Palestine and Caldwell lakes.
    a. Reduce the frequency and amount of fertilizer and herbicide/pesticide used for lawn care.
    b. Use only phosphorus-free fertilizer. (This means that the middle number on the fertilizer package listing the nutrient ratio, nitrogen:phosphorus:potassium is 0.)
    c. Consider re-landscaping lawn edges, particularly those along the watershed's lakes and streams, to include low profile prairie species that are capable of filtering runoff water better than turf grass. This is especially important on properties adjacent to Pleasant and Riddles lakes where exotic, invasive species are currently used as landscaping materials.
    d. Consider planting native emergent vegetation along shorelines or in front of existing seawalls to provide fish and invertebrate habitat and dampen wave energy.

e. Keep organic debris like lawn clippings, leaves, and animal waste out of the water.
f. Properly maintain septic systems. Systems should be pumped regularly and leach fields should be properly cared for.
g. Examine all drains that lead from roads, driveways, or rooftops to the watershed's lake and/or streams; consider alternate routes for these drains that would filter pollutants before they reach the water. Stabilize bare drainage ditches with vegetation where possible or rock where flow rates are too high for vegetation.
h. These lakes are no-wake lakes; boaters should obey the no-wake rules.
i. Clean boat propellers after lake use and refrain from dumping bait buckets into the lake to prevent the spread of exotic species.

7. Restore wetland habitat within the Palestine and Caldwell lakes watershed where feasible. Figure 87 shows areas that are good candidates for wetland restoration.

8. Minimize the impact of exotic species on the lakes. Eurasian watermilfoil, curly-leaf pondweed, purple loosestrife, and reed canary grass were present during the current assessment of the lakes. Special care should be taken to prevent the spread of these species and protect the diverse, native submerged rooted plant community.

Secondary Recommendations

9. Post informational signage at the boat launches on Palestine and Caldwell lakes to inform lake users of best management practices to prevent the spread of aquatic nuisance species, particularly Eurasian watermilfoil, curly-leaf pondweed, and zebra mussels. Any signage posted at a public boat launch requires permission from the IDNR Division of Fish and Wildlife. Because Caldwell Lake's boat ramp is privately owned, permission from the IDNR is not required, but instead from the property owner, for signage posted at the ramp.

10. Monitor and improve erosion control techniques on residential development sites and along Palestine Lake's shoreline. Bring areas of concern to appropriate authorities.

11. Become an active volunteer in the Indiana Clean Lakes Program volunteer monitoring program. Volunteer monitoring is easy and does not take much time. The CLP staff provides the training and equipment needed to participate in the program. The data collected by the volunteer monitor will be extremely useful in tracking long-term trends in the lake water quality and measuring the success of any restoration measures implemented in the watershed.

12. Implement an alum dosing project in Caldwell Lake to bind the phosphorus and keep the phosphorus out of the lake's water column. Like other in-lake techniques, this should be attempted only after all watershed-based projects have been implemented.

13. Once watershed issues have been addressed, complete sediment removal work as defined in the sediment removal plan. Dredging of any areas within the lake will likely extend over a number of years and could involve the creation of sediment traps at the mouths of each of the outlets. These actions should only be considered after all options for implementing watershed techniques have been addressed.

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