Eastern Marathon County Lakes Study

Mud Lake

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EASTERN MARATHON COUNTY LAKES STUDY BACKGROUND

Lakes and rivers contribute to the way of life in Marathon County. Locals and tourists alike enjoy fishing, swimming, boating, wildlife viewing, and the peaceful nature of the lakes. Healthy lakes add value to our communities by providing places to relax and recreate, and by stimulating tourism. Just like other infrastructure in our communities, lakes require attention and management to remain healthy in our developed watersheds.

Eleven lakes in eastern Marathon County were selected for this study, which focused on obtaining a better understanding of the current conditions of the lakes' water quality, fisheries, habitat, and aquatic ecosystems. This information will help lake users, residents and municipalities by identifying ways to improve existing problems and make informed decisions to preserve and protect the lake from future issues. Data collected between fall 2010 and fall 2012 focused on fisheries, water quality, groundwater, algae, zooplankton, lake histories, shoreline habitats, watersheds, and resident and lake user opinions. This report contains the results of these studies for Mud Lake.

A resident survey was sent to all properties in the watersheds of the eastern Marathon County lakes. The majority of survey respondents expressed the importance of the lakes in their lives. The lakes provide special places for their families; many of their important family memories are tied to the lakes. The lakes seem to bring out the best in the respondents by providing environments where people can feel they are truly themselves and places where they can do what they most enjoy. The majority of respondents felt a sense of stewardship towards the lakes.

ABOUT MUD LAKE

To understand a lake and its potential for water quality, fish and wildlife, and recreational opportunities, we need to understand its physical characteristics and setting within the surrounding landscape. Mud Lake is located in the township of Norrie, east of County Highway Y and northeast of Hatley, with one public boat launch located on its southern side. Mud Lake is a 70 acre seepage lake with surface runoff and groundwater contributing most of its water. The maximum depth in Mud Lake is 15 feet; the lakebed has a gradual slope (Figure 1). Its bottom sediments are comprised entirely of muck.

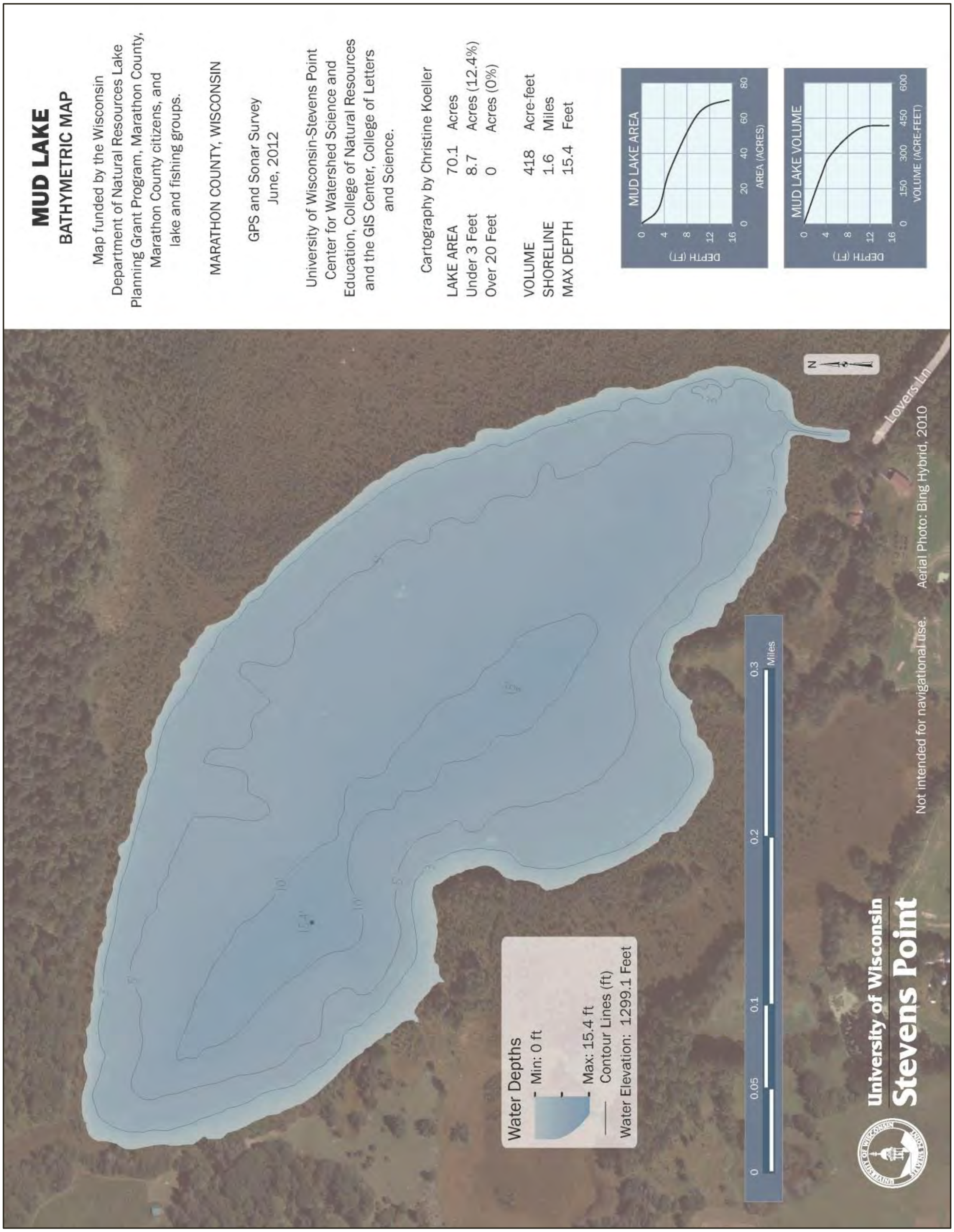


FIGURE 1. CONTOUR MAP OF THE MUD LAKE LAKEBED.

WHERE IS THE WATER COMING FROM? - WATERSHEDS AND LAND USE

The water quality in Mud Lake is a reflection of the land that drains to it. The water quality, the amount of algae and aquatic plants, the fishery and other animals in the lake are all affected by natural and man-made characteristics. The amount of land that drains to the lake, hilliness of the landscape, types of soil, extent of wetlands, and the type of lake are all natural characteristics that affect a lake. Within its watershed, alterations to the landscape, the types of land use, and the land management practices also affect the lake.

It is important to understand where Mud Lake's water originates in order to understand the lake's health. During snowmelt or a rainstorm, water moves across the surface of the landscape (runoff) towards lower elevations such as lakes, streams and wetlands. The land area that contributes runoff to Mud Lake is called a surface watershed. Groundwater also feeds Mud Lake; its land area (groundwater watershed) is different from the surface watershed.

The capacity of the landscape to shed or hold water and contribute or filter particles determines the amount of erosion that may occur, the amount of groundwater feeding a lake, and ultimately, the lake's water quality and quantity. Essentially, landscapes with a greater capacity to hold water during rain events and snowmelt help to slow the delivery of the water to the lake. Less runoff is desirable because it allows more water to recharge the groundwater which feeds the lake year round, even during dry periods or when the lake is covered with ice.

Land use and land management practices within a lake's watershed can affect both its water quantity and quality. While forests and grasslands allow a fair amount of precipitation to soak into the ground, resulting in more groundwater and better water quality, other types of land uses may result in increased runoff, less groundwater recharge, and may be sources of pollutants that can impact the lake and its inhabitants. Areas of land with exposed soil can produce soil erosion. Soil entering the lake can make the water cloudy, plug up fish spawning beds, and contains nutrients that increase the growth of algae and aquatic plants. Development often results in changes to natural drainage patterns, alterations in vegetation on the landscape, and may be a source of pollutants. Impervious (hard) surfaces such as roads, rooftops, and compacted soil prevent rainfall from soaking into the ground, which may result in more runoff carrying pollutants to the lake. Wastewater, animal waste, and fertilizers used on lawns, gardens, and agricultural fields can contribute nutrients that enhance the growth of algae and aquatic plants in our lakes.

A variety of land management practices can be put in place to help reduce impacts to our lakes. Some practices are designed to reduce runoff. These include protecting/restoring wetlands, installing rain gardens, swales and rain barrels, and routing drainage from roads and parking lots away from the lake. Some practices help reduce nutrients moving across the landscape towards the lake. Examples include manure management practices, eliminating/reducing the use of fertilizers, increasing the distance between the lake and a septic drainfield, protecting/restoring native vegetation in the shoreland, and using erosion control practices. Marathon County staff and other professionals can work with landowners to determine which practices are best suited to a particular property.

The surface watershed for Mud Lake is approximately 1,902 acres (Figure 2). The dominant land uses in the watershed are forests and agriculture. The lands closest to the lake often have the greatest impact on water quality and habitat; land uses near Mud Lake's shoreland include forests and wetlands.

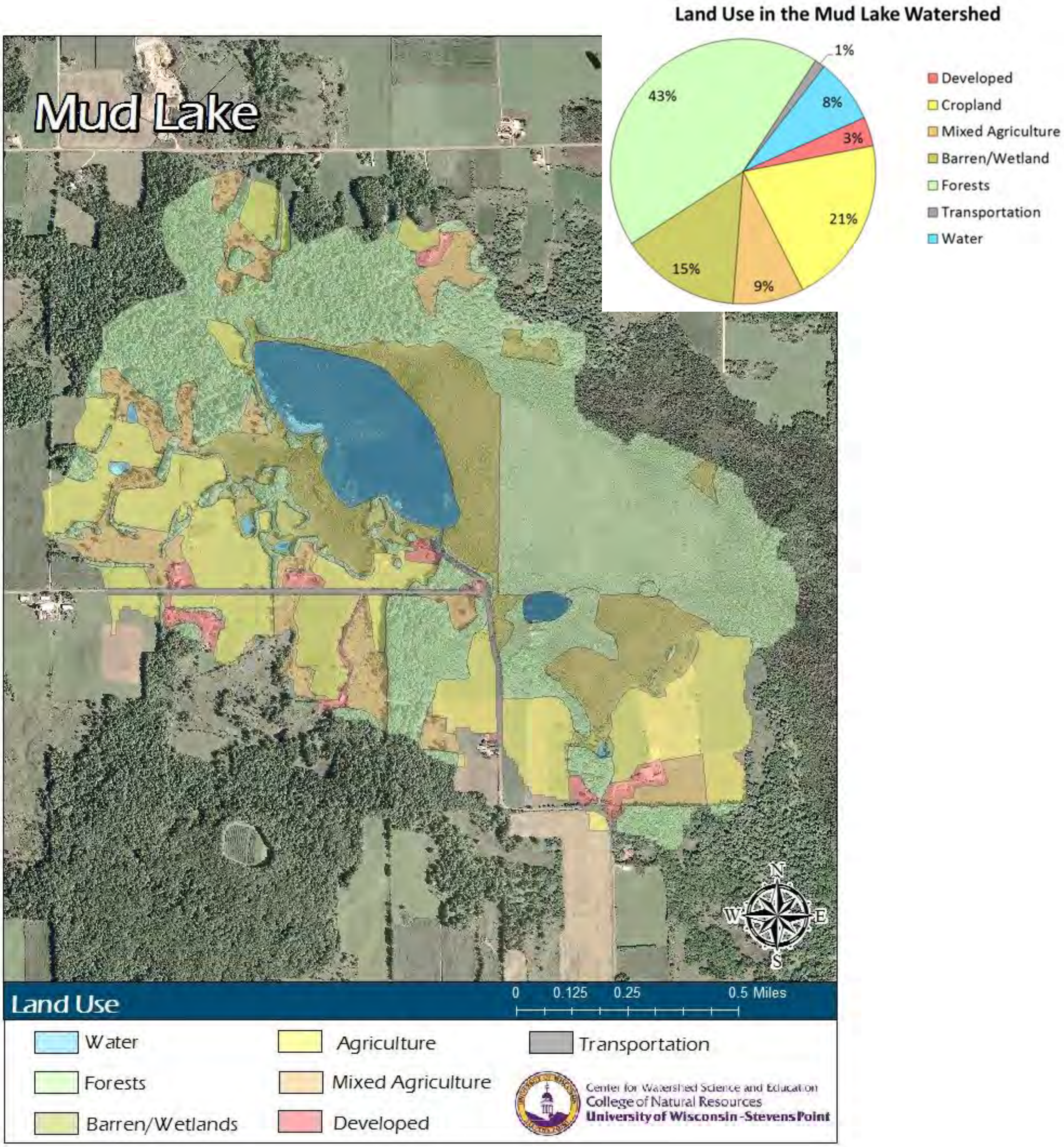
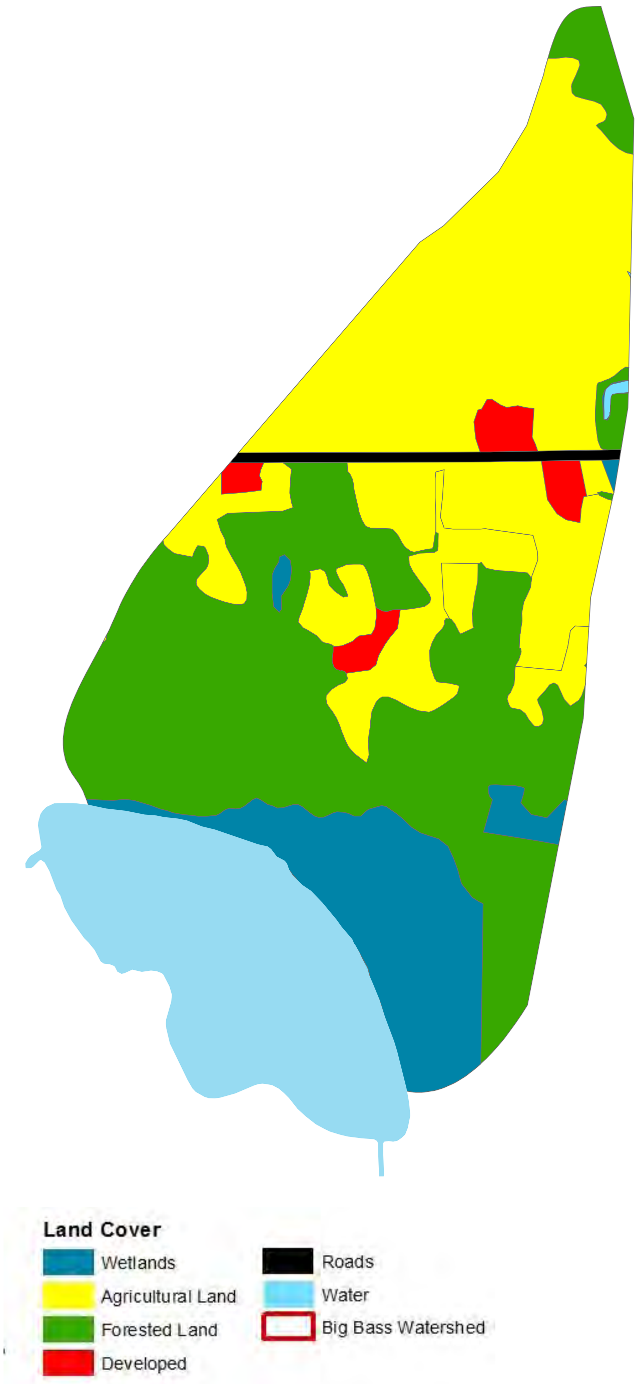


FIGURE 2. LAND USE IN THE MUD LAKE SURFACE WATERSHED.

The groundwater watershed is the area where precipitation soaks into the ground and travels below ground towards the lake. Mud Lake's groundwater watershed is approximately 339 acres (Figure 3). The primary land uses in the Mud Lake groundwater watershed are agriculture and forests. In general, the land adjacent to the lake where most of the groundwater is entering has the greatest immediate impact on water quality. Wetlands and forests are adjacent to Mud Lake where the groundwater enters.



Land Use	Acres
Agriculture	132
Developed	8
Forested	126
Roads	4
Water	27
Wetland	42

FIGURE 3. LAND USE IN THE MUD LAKE GROUNDWATER WATERSHED.

Locally, groundwater enters some parts of Mud Lake (inflow), has no connection to the lake in other parts, and exits the lake in other sections (outflow). Near shore, mini-wells were installed in the lakebed approximately every 200 feet around the perimeter of Mud Lake (Figure 4). Groundwater entered the lake on the northern side (green triangle). Groundwater outflow occurred on the western end of the lake (red marker). Areas with no connection between groundwater and the lake were observed around most of the lake (white circles). Additional groundwater may enter Mud Lake in areas that were deeper than the groundwater survey. It should be noted that the survey was conducted in 2011, which was a dry year with lower than normal groundwater levels. These conditions would result in less groundwater entering Mud Lake.

The more lake water interacts with groundwater (inflow and outflow), the more influence the geology has on the lake. The duration of time the water remains below ground plays a role on the temperature and chemistry of the groundwater. Groundwater temperatures are constant year round, so groundwater feeding Mud Lake will help to keep the lake water cooler during the summer months.

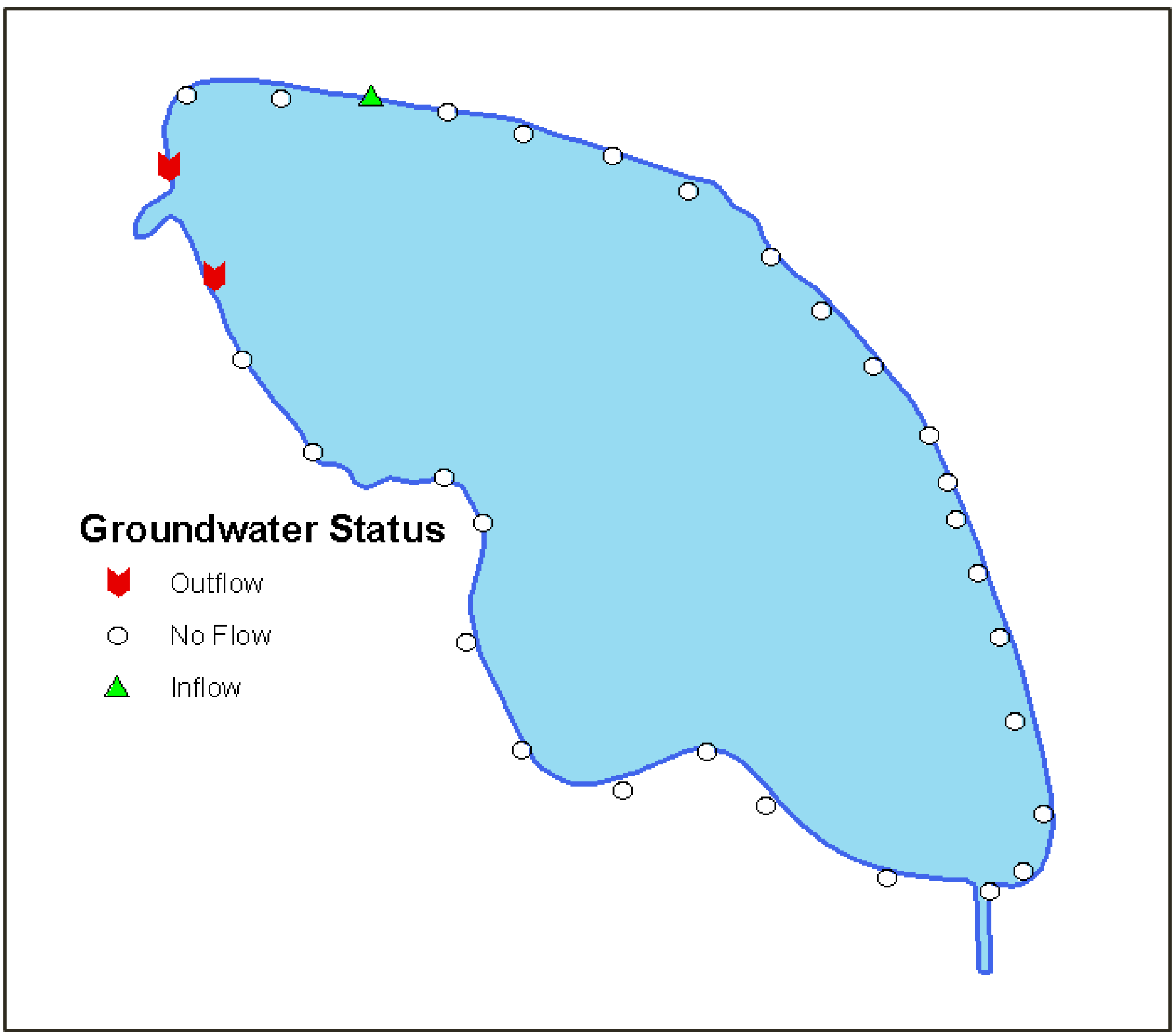
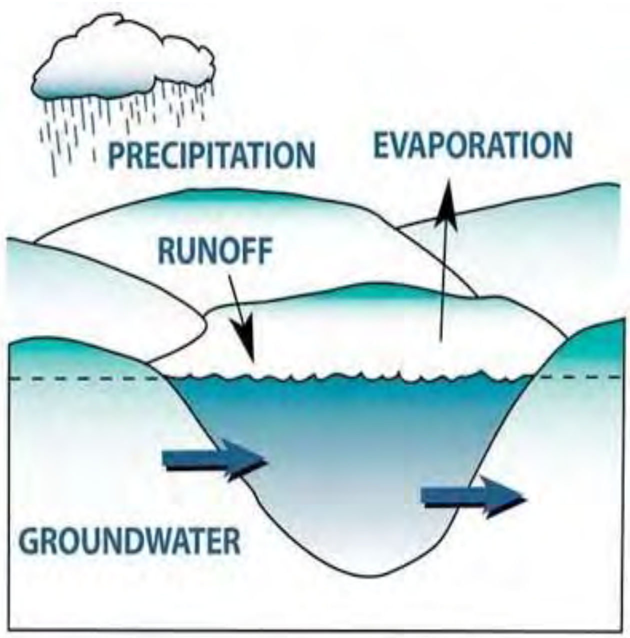


FIGURE 4. MUD LAKE GROUNDWATER INFLOW AND OUTFLOW, 2011.

Lake water quality is a result of many factors including underlying geology, climate and land use practices. Assessing lake water quality allows us to evaluate current lake health, changes from the past, and what is needed to achieve a more desirable state (or preserve an existing state) for aesthetics, recreation, wildlife and the fishery. During this study, water quality in Mud Lake was assessed by measuring different characteristics including temperature, dissolved oxygen, water clarity, water chemistry, and the algal community.



The source of a lake's water supply is important in determining its water quality and in choosing management practices to preserve or influence that quality. Mud Lake is classified as a seepage lake. Water enters and leaves the lake primarily through groundwater, and to a lesser extent, enters via surface runoff and direct precipitation (Figure 5). Seepage lakes often have higher concentrations of minerals such as calcium and magnesium, which are picked up by groundwater moving through soil and rock. Seepage lakes generally have a longer retention time (length of time water remains in the lake), which affects contact time with nutrients that feed the growth of algae and aquatic plants. This type of lake is also vulnerable to contamination moving towards the lake in the groundwater. Examples for Mud Lake may include septic systems, agriculture, and road salt.

FIGURE 5. CARTOON SHOWING INFLOW AND OUTFLOW OF WATER IN A SEEPAGE LAKE.

The geologic composition that lies beneath a lake has the ability to influence the temperature, pH, minerals, and other properties in a lake. As groundwater moves through the soil, some substances are filtered out, but other materials dissolve into the groundwater (Shaw et al., 2000). The average hardness for Mud Lake during the 2010-2012 sampling period was 6.7 mg/L, which is considered soft (Table 1). Soft water does not always provide the calcium necessary for building bones and shells for animals in the lake and limits the lake's ability to buffer acid rain and phosphorus. The average alkalinity in Mud Lake was 8 mg/L; higher alkalinity in inland lakes can support higher species productivity. Hardness and alkalinity also play roles in the types of aquatic plants that are found in a lake (Wetzel, 2001).

TABLE 1. MINERALS AND PHYSICAL MEASUREMENTS IN MUD LAKE, 2010-2012

Mud Lake	Alkalinity (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mg/L as CaCO3)	Color SU	Turbidity (NTU)
Average	8	1.3	0.9	6.7	43.5	2.0

Chloride concentrations, and to lesser degrees sodium and potassium concentrations, are commonly used as indicators of impacts from human activity. The presence of these compounds in the lake at elevated levels indicates the movement of pollutants from the landscape to the lake. Over the monitoring period, concentrations of chloride, sodium and potassium were low in Mud Lake (Table 2). Atrazine (DACT), an herbicide commonly used on corn, was below the detection limit (<0.01 ug/L) in the samples that were analyzed from Mud Lake.

TABLE 2. MUD LAKE AVERAGE WATER CHEMISTRY, 2010-2012.

Mud Lake	Average Value (mg/L)			Reference Value (mg/L)		
	Low	Medium	High	Low	Medium	High
Potassium	0.5			<.75	0.75 - 1.5	>1.5
Chloride	0.30			<3	3.0 - 10.0	>10
Sodium	0.4			<2	2.0 - 4.0	>4

Dissolved oxygen is an important measure in aquatic ecosystems because a majority of organisms in the water depend upon oxygen to survive. Oxygen is dissolved into the water from contact with the air, which is increased by wind and wave action. When sunlight enters the water, algae and aquatic plants also produce oxygen; however, the decomposition of algae and plants by bacteria after they die reduces oxygen in the lake. Some forms of iron and other metals carried by groundwater can also consume oxygen when they reach the lake.

In a lake, the water temperature changes throughout the year and may vary with depth. During winter and summer, different temperatures from the surface to the bottom cause some lakes to stratify (layer), and the amount of dissolved oxygen is often lower towards the bottom of the lake. Dissolved oxygen concentrations below 5 mg/L can stress some species of cold water fish, and over time reduce habitat for sensitive cold water species of fish and other critters.

Water temperature and dissolved oxygen were measured in Mud Lake from the surface to the bottom at the time of sample collection. As would be expected, late winter profiles (February 2011 and February 2012) showed freezing temperatures near the surface with slight gradual warming with depth (Figure 6). Below about 2 feet of depth, water temperature remained fairly constant at 4C (39°F), indicating a lack of any significant winter stratification. Temperatures ranged from 1C (34°F) at the surface in February 2012 to 28 degrees Celsius (82°F) at a depth of 4 feet in July 2012.

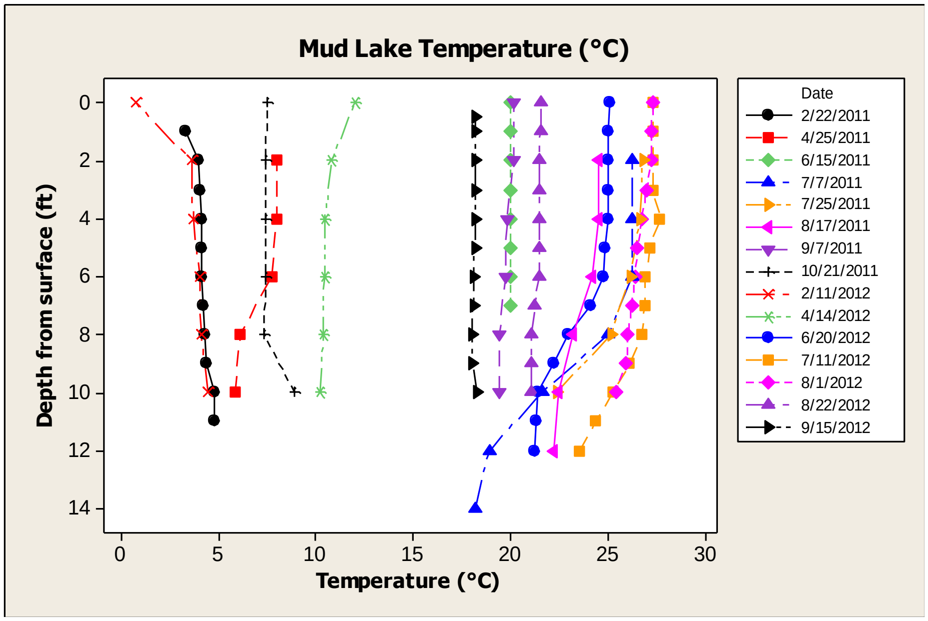


FIGURE 6. TEMPERATURE PROFILES IN MUD LAKE, 2011-2012.

Dissolved oxygen concentrations in Mud Lake ranged from plentiful to limited depending upon depth and time of year (Figure 7). Unlike other lakes in the Eastern Marathon County Lakes Study, dissolved oxygen was not uniform throughout the water column during the spring and fall sampling events. During the winter of both years, the dissolved oxygen fell below concentrations needed to support many fish species. There were times during this ice-covered period that only the upper 2 feet of water had concentrations above 5 mg/L. During summer months, algae blooms produced periodic spikes in dissolved oxygen concentrations at depths typically between 6 and 8 feet.

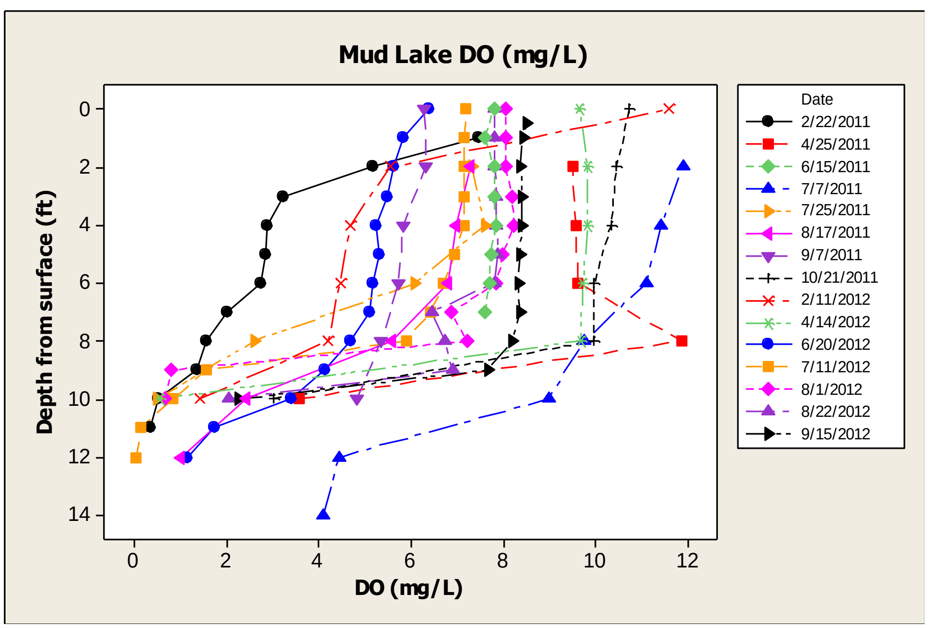


FIGURE 7. DISSOLVED OXYGEN PROFILES IN MUD LAKE, 2011-2012.

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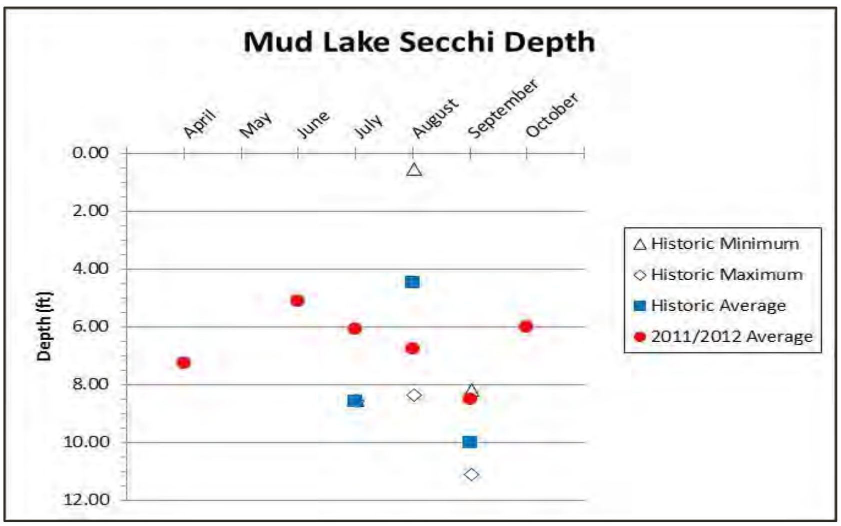
Water clarity is a measure of the depth that light can penetrate into the water. It is an aesthetic measure and is also related to the depth that rooted aquatic plants can grow due to penetration of sunlight. Water clarity is affected by water color, turbidity (suspended sediment), and algae (chlorophyll *a*), so it is normal for water clarity to change throughout the year and from year to year.

In Mud Lake, the color index was moderate (Table 1). Brown staining from tannins in the surrounding wetlands and forest is the natural source of the slightly elevated color index.

The variability in water clarity throughout the year in Mud Lake was primarily due to fluctuating algae concentrations and re-suspended sediment following storms. The water clarity in Mud Lake is considered fair. The average water clarity measurements in Mud Lake during the study were poorest in June and best in September (Figure 8). When compared with limited past data (1999-2010), the average water clarity measured during the study was better in August and poorer in July and September.



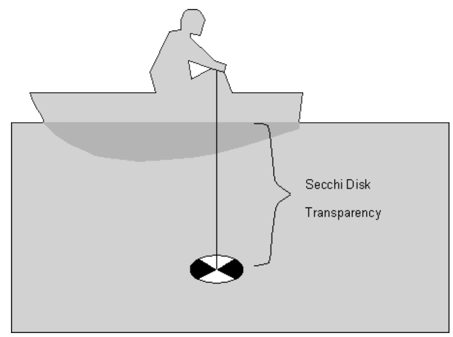


FIGURE 8. AVERAGE MONTHLY WATER CLARITY IN MUD LAKE, 2010-2012 AND HISTORIC.

Nutrients (phosphorus and nitrogen) are used by algae and aquatic plants for growth much like houseplants or crops. Phosphorus is present naturally throughout the watershed in soil, plants, animals and wetlands. Common sources from human activities include soil erosion, animal waste, fertilizers and septic systems.

The most common mechanism for the transport of phosphorus from the land to the water is through surface runoff, but it can also travel to the lake in groundwater. Once in a lake, a portion of the phosphorus becomes part of the aquatic system in the form of plant tissue, animal tissue and sediment. The phosphorus continues to cycle within the lake for many years.

Total phosphorus concentrations in Mud Lake ranged from a high of 44 µg/L in June 2011 to a low of 12 µg/L in February 2011 and June 2012 (Table 3). Summer median total phosphorus was 20.5 ug/L and 16.5 ug/L in 2011 and 2012, respectively. This is below Wisconsin's phosphorus standard of 40 ug/L for shallow seepage lakes, but above the proposed flag value of 15 ug/L.

During the study, inorganic nitrogen concentrations in samples collected from Mud Lake during the spring averaged 0.72 mg/L (Table 3). Concentrations above 0.3 mg/L are sufficient to enhance algal blooms throughout the summer (Shaw et al., 2000). Inorganic nitrogen typically moves to lakes with groundwater. Common sources include fertilizers, animal waste, and septic systems.

TABLE 3. SUMMARY OF SEASONAL NUTRIENT CONCENTRATIONS IN MUD LAKE, 2010-2012.

Mud Lake	Total Phosphorus (µg/L)			Dissolved Reactive Phosphorus (µg/L)			Total Nitrogen (mg/L)			Inorganic Nitrogen (mg/L)			Organic Nitrogen (mg/L)		
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
Fall	13	16	18	1	2	2	0.70	0.92	1.13	0.02	0.04	0.06	0.69	0.88	1.07
Spring	21	25	28	7	12	17	0.86	0.99	1.12	0.19	0.27	0.35	0.67	0.72	0.77
Summer	12	21	44												
Winter	12	15	18	1	4	7	1.07	1.08	1.09	0.14	0.26	0.38	0.71	0.82	0.93

Estimates of phosphorus from the landscape can help to understand the phosphorus sources to Mud Lake. Land use in the surface watershed was evaluated and used to populate the Wisconsin Lakes Modeling Suite (WILMS) model. In general, each type of land use contributes different amounts of phosphorus in runoff and through groundwater. The types of land management practices that are used and their distances from the lake also affect the contributions to the lake from a parcel of land. While forests comprised the greatest amount of land in the watershed, modeling results indicated that agriculture had the greatest percentage of phosphorus contributions from the watershed to Mud Lake (Figure 9). The phosphorus contributions by land use category, called phosphorus export coefficients, are shown in Table 4. The phosphorus export coefficients have been obtained from studies throughout Wisconsin (Panuska and Lillie, 1995).

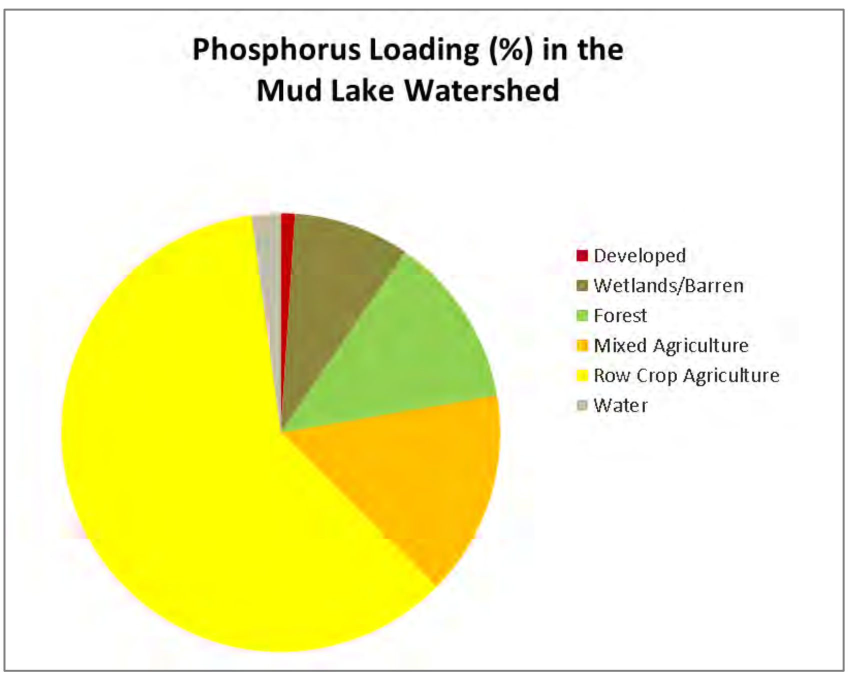


FIGURE 9. ESTIMATED PHOSPHORUS LOADS FROM LAND USES IN THE MUD LAKE WATERSHED.

TABLE 4. MODELING DATA USED TO ESTIMATE PHOSPHORUS INPUTS FROM LAND USES IN THE MUD LAKE WATERSHED (LOW AND MOST LIKELY COEFFICIENTS USED TO CALCULATE RANGE IN POUNDS).

Mud Lake Land Use	Phosphorus Export Coefficient (lbs/acre-yr)	Land Use Area Within the Watershed		Phosphorus Load	
		Acres	Percent	Pounds	Percent
Water	0.10	152	**8**	6-19	**2**
Developed	0.04	69	**4**	3-6	**1**
Wetland/Barren	0.09	282	**15**	25-76	**9**
Forest	0.04	835	**44**	37-67	**13**
Mixed Agriculture	0.27	167	**9**	45-119	**15**
Row Crop Agriculture	0.45	398	**21**	178-355	**62**

*Values are not exact due to rounding and conversion

Chlorophyll *a* is an indirect measurement of algae in the water. Concentrations greater than 10 µg/L are often perceived as a mild algae bloom, while concentrations greater than 20 µg/L are frequently perceived as a nuisance. In samples collected from Mud Lake, chlorophyll *a* concentrations were generally low, ranging from a high of 20 µg/L in July 2011 to a low of 2 µg/L in June 2012 and August 2012, with average concentrations of 7 µg/L.

Algae are microscopic, photosynthetic organisms that are important food items in all aquatic ecosystems. Different algal groups increase or decrease during the year and they can be used to analyze a lake's water quality because there are more varieties of algae than fish or aquatic plants. Conclusions can be drawn about water temperature, nutrient availability, and overall water quality of a lake using algal populations.

In Marathon County lakes, there are three dominant groups of algae: blue-green algae (Cyanobacteria), green algae (Chlorophyta), and diatoms (Bacillariophyceae). The algal communities in Mud Lake during 2011 and 2012 were similar in composition and seasonal patterns. The community compositions and patterns are like those often found in eutrophic water bodies. The blue-green algae dominated both years (45-55% average community composition), with the green algae contributing 25-35%. Diatoms were of only minor significance, adding 5-10% to the algal community (Figure 10).

The abundance of small filamentous and colonial blue-green species is potentially problematic due to the inability of most planktivorous species to ingest and digest them. Dense growth of these species can decrease water clarity and they can shade out submerged aquatic plants. The total phosphorus concentrations indicated mildly mesotrophic conditions, but the algal community indicated a much more mesotrophic lake that might be beginning a transition to eutrophic status.

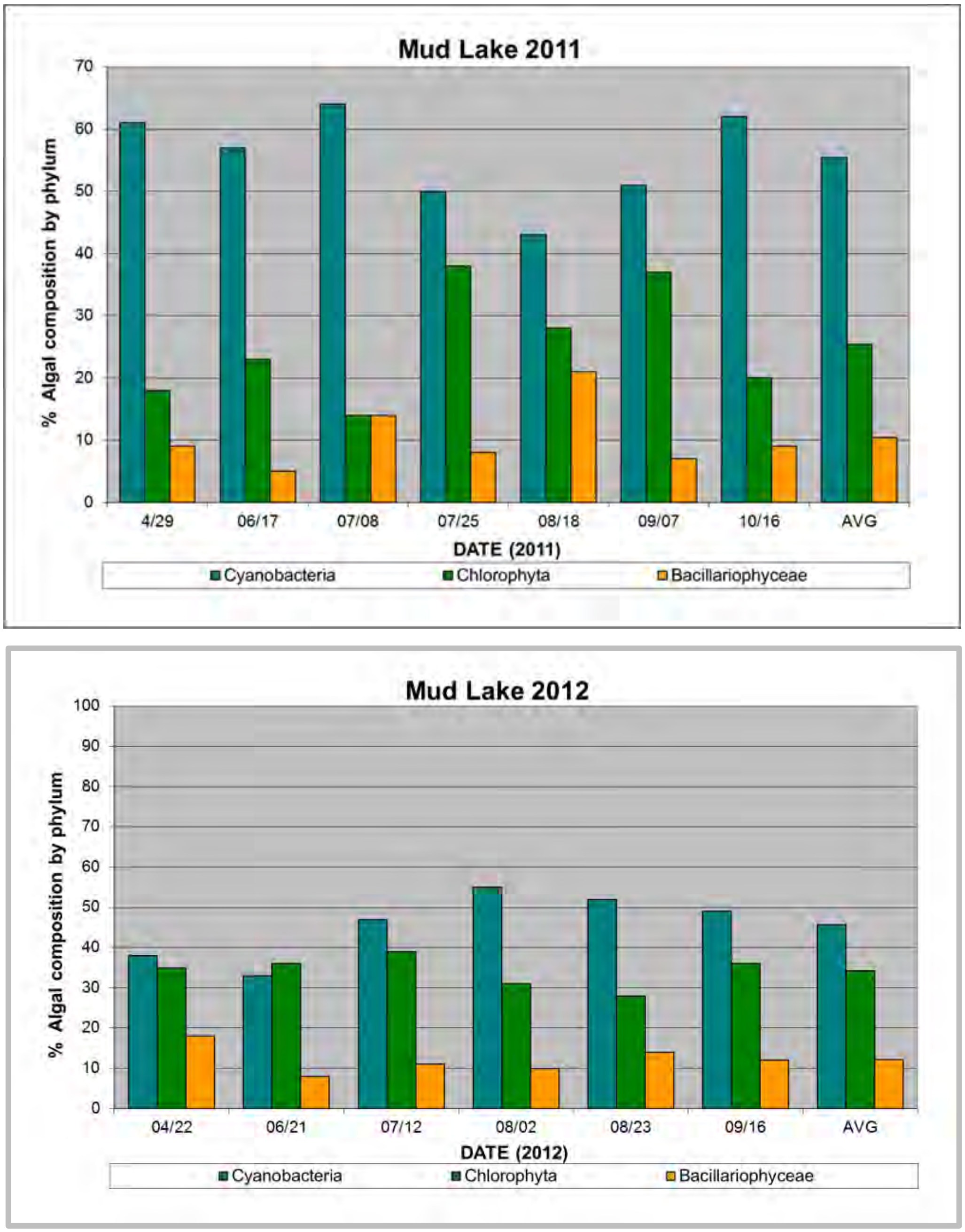


FIGURE 10. PERCENT ALGAL COMPOSITION IN MUD LAKE, 2011 AND 2012.

SHORELAND HEALTH

Shoreland vegetation is critical to a healthy lake's ecosystem. It provides habitat for many aquatic and terrestrial animals including birds, frogs, turtles, and many small and large mammals. It also helps to improve the quality of the runoff that is flowing across the landscape towards that lake. Healthy natural vegetation includes a mix of layers such as tall grasses/forbs, shrubs, and trees.

The addition of manmade features near the shoreland area can lead to more impervious surfaces. Runoff from driveways, rooftops, and buildings carries pollutants and sediments into the nearby lake. Minimizing the presence of impervious surfaces in the shoreland area can help reduce the amount of phosphorus and sediment transported to the lake. Overdeveloped shorelines cannot support the fish, wildlife and clean water that may have attracted people to the lake in the first place. Rip-rap, seawalls and docks also contribute to an unhealthy shoreline. While it might seem that one lot's development may not have a quantifiable impact on the lake's water quality, the collective effect of many properties can be significant.

The results of the shoreline survey conducted on the eastern Marathon County lakes will serve as a tool for citizens and Marathon County staff to identify locations of shoreland areas in need of restoration, as well as recognize natural shorelands for protection. In addition, this information will provide a baseline database from which to measure and monitor success.

MUD LAKE SHORELAND SURVEY RESULTS

The survey assessed the vegetation present around the lake's shoreland and identified buildings at or near the water's edge. This information can be used to assess lakeshore development's potential impact on in-lake and shoreland habitat, which may affect fish spawning grounds, shoreland wildlife habitats, and shoreline beauty.

In 2011, shoreland vegetation was recorded by mapping and estimating the depth of three categories of vegetation and the length of shoreline. Researchers in a boat navigated the shoreline and recorded the classifications of vegetation observed from the lake. The three rings surrounding Mud Lake in Figure 12 depict the depth of vegetation along Mud Lake's shore. The first ring represents the depth inland where plants occur that are 0.5 to 3 feet tall (native grasses/forbs). The second ring represents plants ranging from 3 to 15 feet tall (shrubs). The outermost ring represents all plants taller than 15 feet (trees). A greater vegetative shoreland "buffer" provides more habitat, protection from soil erosion, and improved water quality of runoff. A healthy vegetative "buffer" extends at least 35 feet inland from the water's edge and includes a mixture of grasses, forbs, shrubs and trees.

Mud Lake has 1.5 miles of shoreline. The lake's shoreland vegetation was primarily in a natural state. The overall findings showed that shorter vegetation is the most prominent vegetative layer near the water's edge. Much of this is due to the abundance of wetlands adjacent to Mud Lake, but also may be a result of lower than normal lake levels in 2011. The shoreland vegetation survey results are displayed in Figure 11. Although Mud Lake's shoreland is in natural condition right now, changes can easily occur as development takes place. In order to minimize impacts from future development, prospective developers should have the information needed to make good decisions, and zoning should be in place to achieve habitat, water quality, and aesthetic goals for Mud Lake.

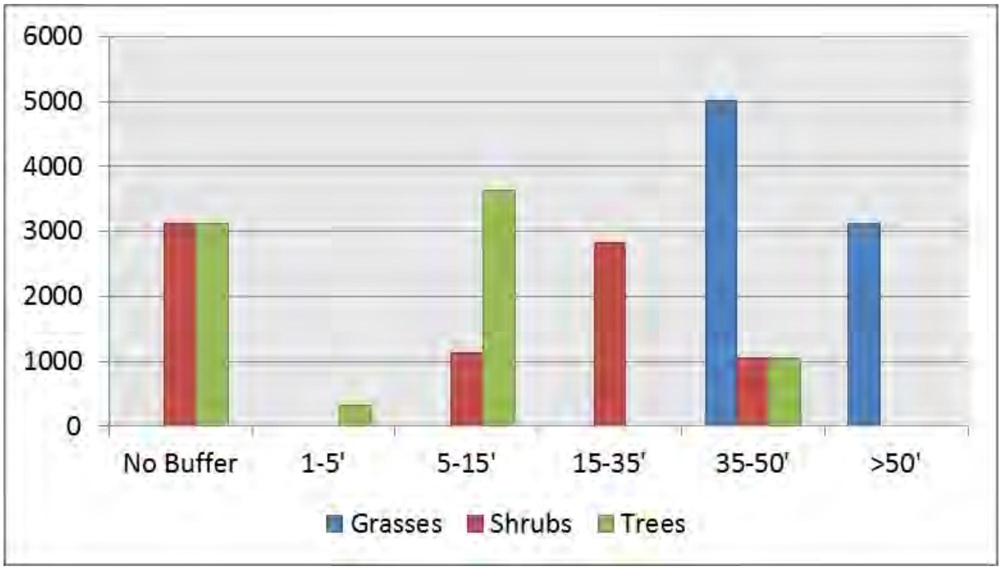


FIGURE 11. SHORELAND VEGETATION SURVEY RESULTS BY BUFFER DEPTH AROUND MUD LAKE, 2011.

On the same day the vegetation surveys were conducted, an assessment of manmade disturbances was conducted around Mud Lake. Surveyors paddled along the shoreline and documented artificial beaches, docks, riprap, seawalls, erosion, and any structures built near the water's edge. Table 5 documents the disturbances that were observed on Mud Lake and Figure 13 displays their locations. Structures such as seawalls, rip-rap (rocked shoreline), and artificial beach often result in reduction of habitat. Docks and artificial beaches can result in altered in-lake habitat with denuded lakebeds that provide good opportunities for invasive species to become established and reduce habitat that is important to fish and other lake inhabitants. Erosion can contribute sediment to the lake, which can alter spawning habitat and carry nutrients into the lake. Unmanaged runoff from the rooftops of structures located near shore can also contribute more sediment to the lake. Alone, each human-made feature may not pose a large problem for a lake, but on developed lakes their collective impact can be a problem for lake habitat and water quality.

TABLE 5. DISTURBANCES IDENTIFIED ON MUD LAKE, 2011.

Disturbance	No. of Occurrences
Artificial Beach	0
Dock	2
Riprap	0
Seawall	0
Erosion	0
Structures w/in 35'	0
Structures 35-75'	0

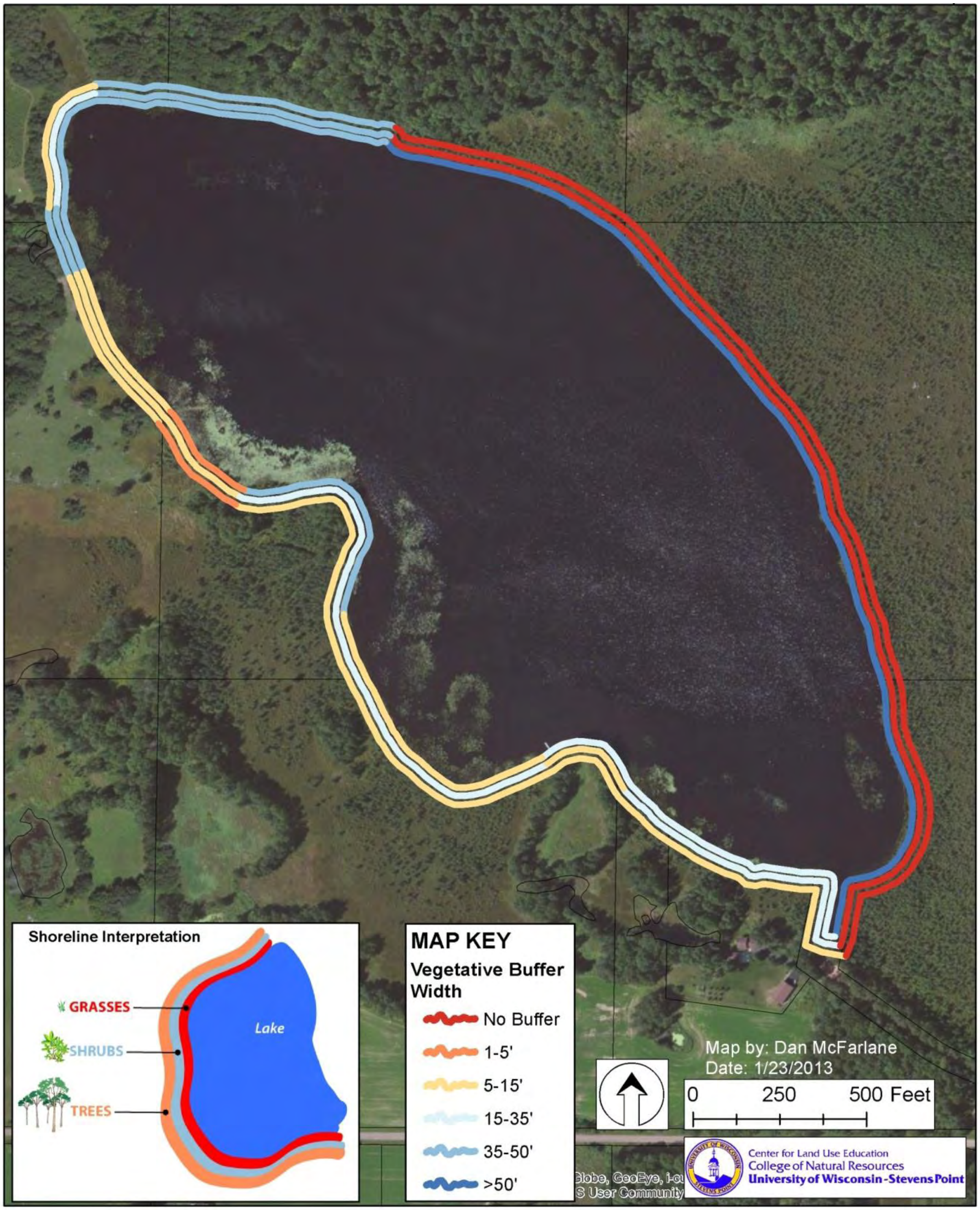


FIGURE 12. SHORELAND VEGETATION AROUND MUD LAKE, 2011.

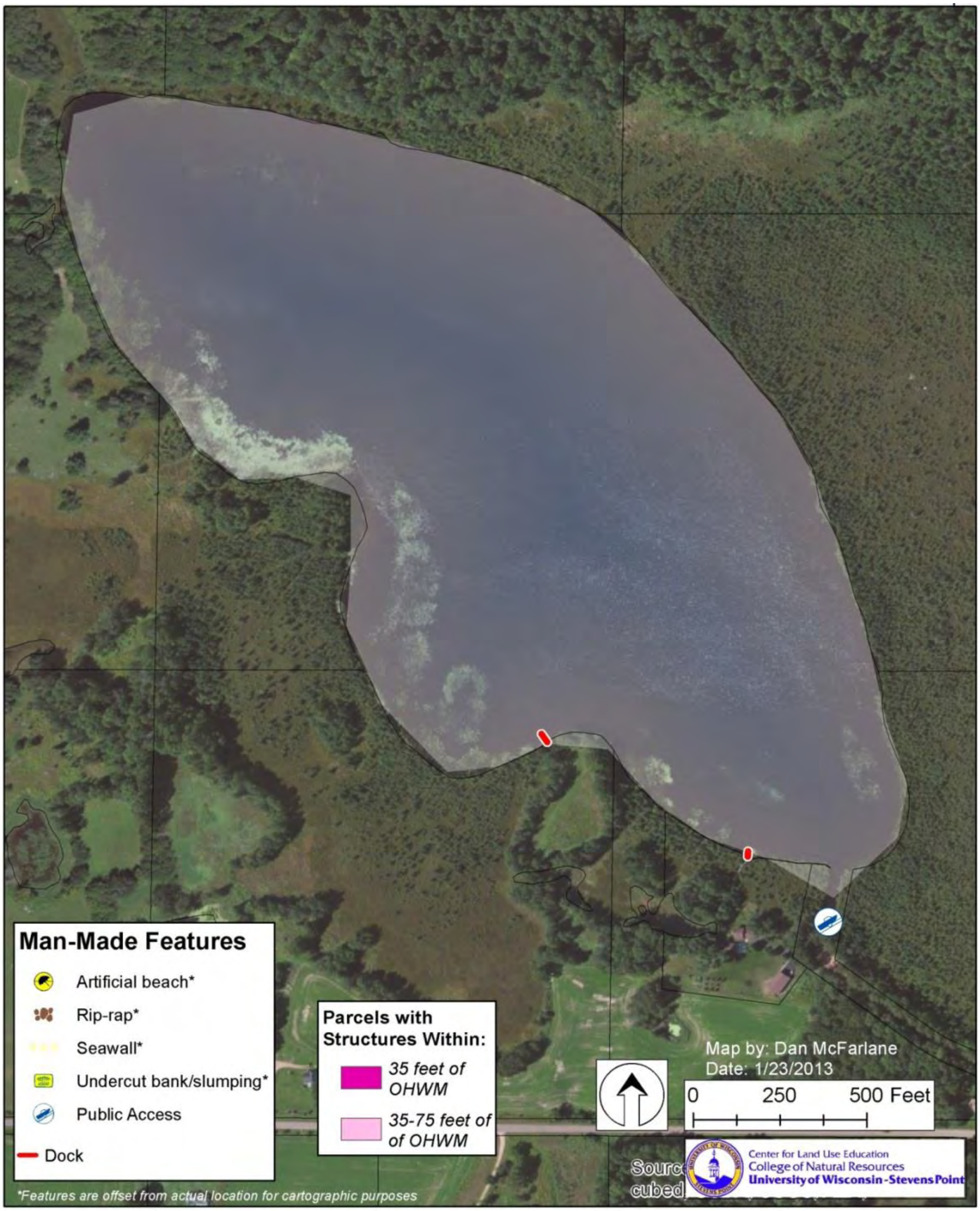


FIGURE 13. SHORELINE DISTURBANCE SURVEY OF MUD LAKE, 2011.

A healthy fishery is one that is in balance with the lake's natural ability to support the fish community, and is adaptable to fishing practices that do not cause declines in fish populations. A healthy fish community has a balance between predator and prey species, and each fish species has different needs to be met in order to flourish, including adequate food sources, habitat, appropriate spawning substrate, and water quality.

People are also an important part of a healthy fishery, as they can both remove fish and add fish. The numbers and sizes of fish taken out of the lake can influence the entire ecosystem, so it is important to adhere to appropriate fishing regulations to help maintain a healthy balance of prey and predatory species, and to adjust the regulations as the fish community changes and adapts. If stocking does occur, choosing the wrong fish species for a lake's conditions will result in a less sustainable fishery and may require outside inputs such as aeration or further stocking. Each fish species has different water quality requirements, with preferred tolerance ranges for dissolved oxygen, pH, water clarity, temperature, and hardness. A few predatory species such as largemouth bass prefer good water clarity to effectively hunt prey; other species such as walleye prefer more turbid waters. Even within a species, water quality preferences may vary during different stages of reproduction.

Mud Lake supports a warm water fish community. In 2012, three fish species were caught and identified out of the ten total species that have been recorded in surveys dating back to 1964 obtained from the Wisconsin Department of Natural Resources (Table 6). Fish diversity was low in Mud Lake compared to other lakes in the Eastern Marathon County Lakes Study. No new fish species were documented during the 2012 sampling period. The species documented previously but not detected during the 2012 survey were black bullhead (*Ameiurus melas*), common shiner (*Luxilus cornutus*), golden shiner (*Notemigonus crysoleucas*), mudminnow (*Umbra lima*), northern pike (*Esox lucius*), pumpkinseed (*Lepomis gibbosus*), and yellow perch (*Perca flavescens*). Bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*) were most abundant during the 2012 survey. As shown in Table 7, bluegill reached a maximum size of 10.1 inches. Only young-of-year largemouth bass were caught and did not exceed 2 inches in the sample. Black crappie (*Pomoxis nigromaculatus*) were the largest fish caught in Mud Lake, with individuals reaching a maximum length of 12.8 inches. Crayfish were not encountered during the sampling period.

TABLE 6. FISH SPECIES IN MUD LAKE, 2012 SURVEY AND HISTORICAL WISCONSIN DEPARTMENT OF NATURAL RESOURCES RECORDS.

Species	1964	1971	1972	1975	1979	1980	1982	1985	2005	2008	2012
Black Bullhead	x	x	x	x	x						
Black Crappie								x	x	x	x
Bluegill	x					x	x	x		x	x
Common Shiner		x	x								
Golden Shiner				x							
Largemouth Bass						x	x	x	x		x
Mudminnow						x		x			
Northern Pike	x	x	x	x	x			x		x	
Pumpkinseed				x	x		x				
Yellow Perch	x	x	x	x	x						

TABLE 7. TOTAL CATCH AND LENGTHS (MIN/MAX/AVERAGE) OF FISH SPECIES IN MUD LAKE, 2012 SURVEY.

Species	Min Length (in)	Max Length (in)	Average Length (in)	Total Catch
Bluegill	1.7	10.1	2.6	113
Largemouth Bass	0.9	1.9	1.2	26
Black Crappie	5.6	12.8	8.3	10

A variety of fish management techniques were attempted historically on Mud Lake. Due to winterkill events from low dissolved oxygen, a recommendation was made in 1958 to stock northern pike since they were more likely to survive low dissolved oxygen conditions. In the same year, yellow perch were noted to range in size from 3-11 inches. In 1964, yellow perch size was also noted as desirable, and a recommendation was made to develop public access to the lake, which was later constructed. Several years later (1972), yellow perch populations were severely stunted and a recommendation was made to poison the lake to eliminate yellow perch, northern pike, and black bullhead. In 1979, a chemical fish kill (known as the Mud Lake Fisheries Reclamation Project) was carried out with Rotenone; subsequent management was focused on producing desirable populations of largemouth bass, bluegill, and black crappie. Prior to the Rotenone treatment, the lake was shocked and 30 northern pike were transferred to nearby Norrie Lake. In 1980, Mud Lake was stocked with largemouth bass, bluegill, and minnows. Since the treatment, black bullhead and yellow perch have not been reported; northern pike were documented in 1985. Fish stocking records for Mud Lake date back to 1960 in Wisconsin Department of Natural Resources files (Table 8).

TABLE 8. WISCONSIN DEPARTMENT OF NATURAL RESOURCES FISH STOCKING SUMMARY FOR MUD LAKE, INCLUDING SPECIES, AGE CLASS, NUMBER STOCKED, AND AVERAGE LENGTH IN INCHES.

Year	Species	Age Class	Number Fish Stocked	Avg Fish Length (in)
1960	Northern Pike	Fry	248,575	
1980	Largemouth Bass	Fingerling	7,000	1"
1980	Fathead minnow	Fingerling	7,000	1-2"
1980	Bluegill	Fingerling	736	3-6"

To successfully sustain a healthy fish population, a lake must have the habitat to support it. Habitat needs of fish include healthy aquatic plants and woody structure such as logs, fallen trees, and stumps. Woody structure provides places for fish to hide, as well as habitat for invertebrates that many fish species use as food sources. Many fish use lily pads and bulrushes, as well as gravel and cobble substrates, for spawning habitat.

Bottom substrate was examined from the shoreline out to a distance of 90 feet. Substrate distribution in Mud Lake primarily consisted of a soft bottom (95% muck) (Figure 14); however, points on the southern shoreline contain areas where hard substrates are present, including mixtures of sand/gravel/cobble (1.6%). Sand is also interspersed along the southern shoreline (3.4%). Gravel areas are utilized by many fish for spawning habitat, including sunfish (bluegill, pumpkinseed, black bass), where males will construct nests and guard their young. Yellow perch and walleye utilize near-shore cobble in oxygen-rich environments for spawning activity; parents do not offer parental care. Sand can be important habitat for reproduction of non-game minnows.

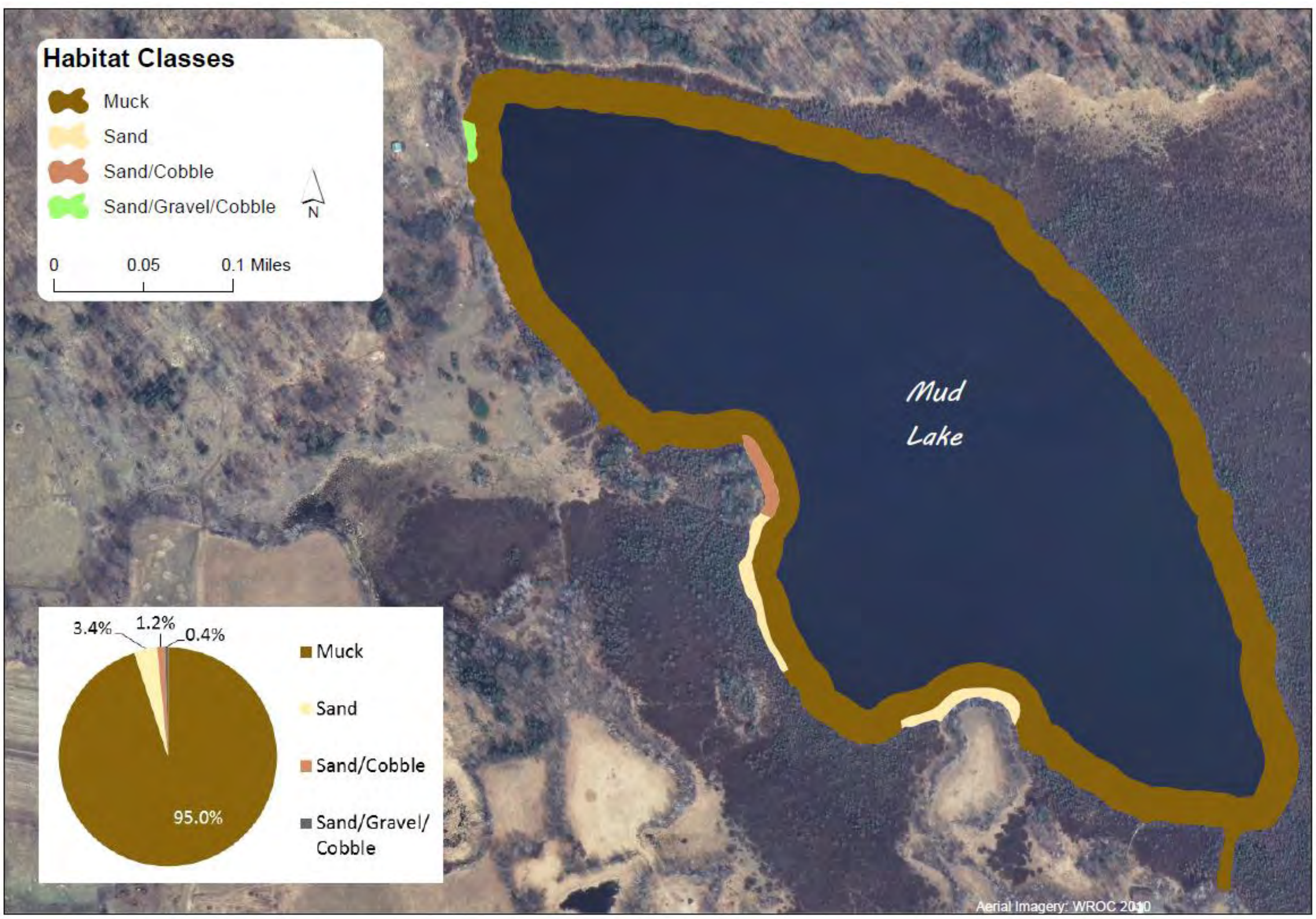


FIGURE 14. DISTRIBUTION OF SUBSTRATE HABITAT IN MUD LAKE, 2012.

Sparse areas of bulrush are present in Mud Lake (Figure 15). Northern pike, which do not offer parental care, utilize areas with emergent and floating-leaf vegetation in shallow or flooded areas for spawning. Black crappie utilize bulrush habitat on gravel or sand substrates where they construct nests and guard young. The absence of young northern pike in the 2012 sampling may be an indicator of poor reproduction, although more intense population sampling over several seasons would be required to determine the reproductive success for individual fish species. The presence of young bass and sunfish sampling indicated successful reproduction of these species.

Coarse woody habitat (CWH), including downed trees and logs, is present in Mud Lake (Figure 15). This structure is utilized by young prey fish and other aquatic organisms for spawning, foraging, and protective cover. The addition of CWH cover would benefit the fish community.

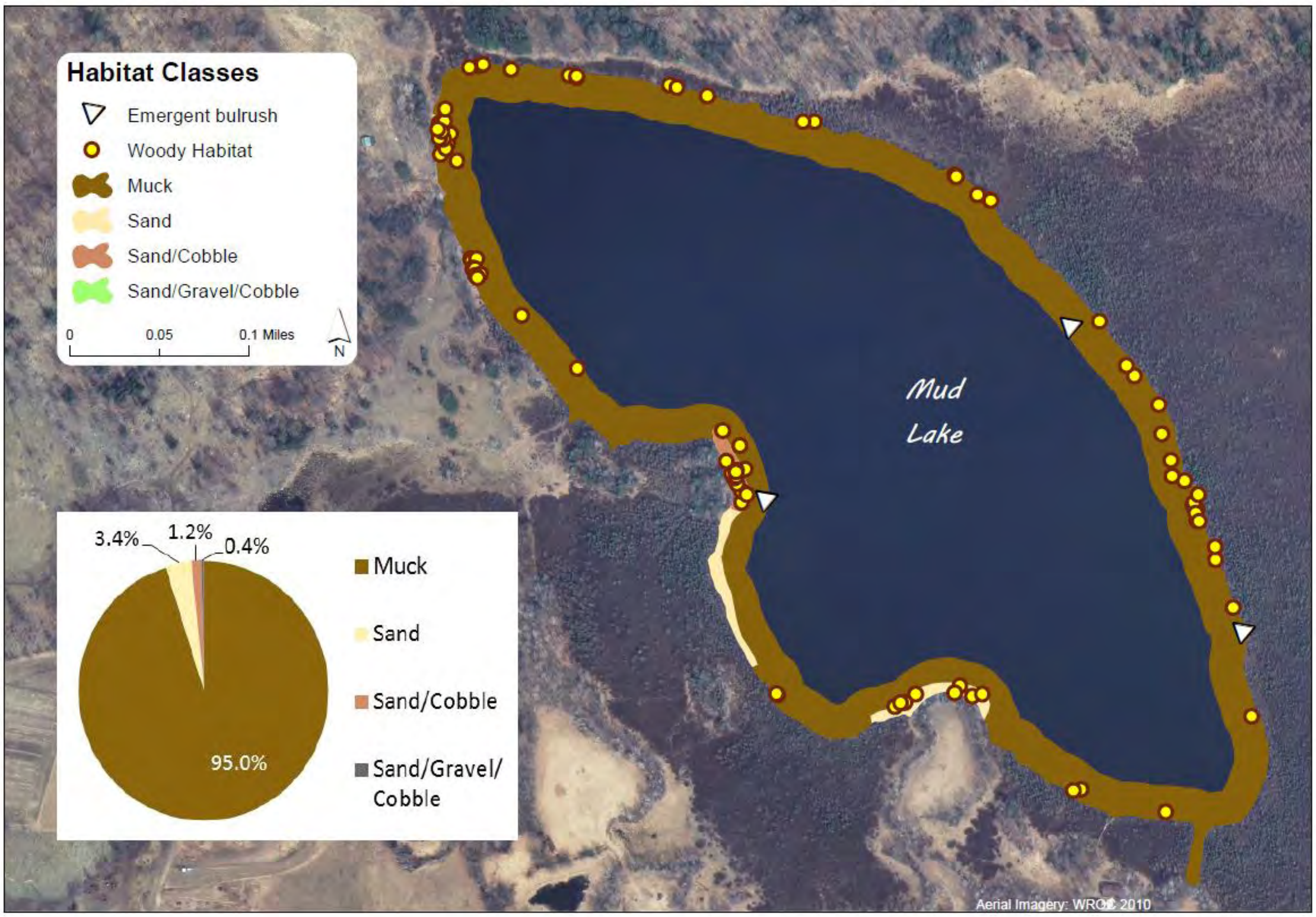
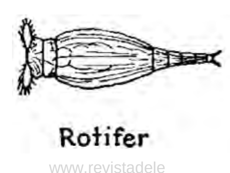


FIGURE 15. DISTRIBUTION OF COARSE WOODY HABITAT IN MUD LAKE, 2012.

Zooplankton are microscopic invertebrate animals that swim or drift in water. They are the primary consumers at the base of the food chain in our lakes and are an important food for many fish. Most zooplankton are filter feeders, using their appendages to strain bacteria and algae from water, so they help to keep algae populations under control. While zooplankton can reproduce rapidly, with populations capable of doubling in a few days, they live short and productive lives. Food (bacteria and algae), temperature, and water chemistry are important in determining the type of zooplankton that can live in a particular lake, along with fish predation which can have a profound impact on zooplankton abundance and community composition.

While the semi-transparency and small size (0.01 – 4.0 mm) of zooplankton are effective deterrents to fish predation, it is the timing of zooplankton abundance that frequently determines the success of a lake's larval fish community. The abundance and slow-moving nature of zooplankton make them the primary food of young fish (fry). The interdependence of algae, zooplankton, and young fish as predators and prey forms the primary food web in most lakes. Some of the non-native and invasive zooplankton species are much larger in size than native zooplankton. The non-native zooplankton can disturb the fishery in a lake because they are often too large to fit in the mouth of young fish.

In Marathon County lakes, three dominant groups of zooplankton were observed – **Rotifers** (microscopic wheel organisms), **Cladocerans** (water fleas), and **Copepods**. The various zooplankton groups and species within these groups wax and wane during the ice-free season as algae, temperature and fish predation change.

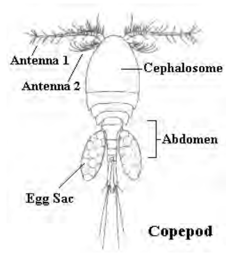


Rotifers are small invertebrate animals with simple body designs. They are usually not found uniformly throughout lakes, but congregate in areas of high food abundance (bacteria, algae, and other rotifers). Generally, a lake's trophic status influences, or can be predicted by, the abundance and diversity of rotifers. Eutrophic lakes show greater abundance and diversity of rotifers than oligotrophic systems.

Cladocerans, commonly called water fleas, are a widespread group occurring in all but a few of the most extreme freshwater habitats. Cladoceran richness in a lake depends on several factors such as water chemistry, lake size, productivity, the number of adjacent lakes, and biological interactions.

Cladoceran populations usually peak in early summer and fall immediately after algal population peaks, since algae are the preferred food of cladocerans. It is the cladocerans that are responsible for increasing water clarity in mid-summer by filtering algae that cause summertime blooms.

Many cladocerans exhibit a behavior called diel vertical migration, swimming to deep water during the day and rising to the surface at night. This is an avoidance response to heavy fish predation and can result in lower than expected cladoceran numbers during daytime collections.



Copepods, like cladocerans, can fluctuate in abundance and composition due to food limitation, temperature and predation within a lake. They can occur in high densities and populations can double in 1 to 2 weeks. There is a documented positive relationship between copepod numbers and increased eutrophy; as lakes become more nutrient rich copepod numbers increase. Also, like cladocerans, native copepods are a favorite prey to young fish.

The zooplankton community of Mud Lake was diverse (Table 9 and Table 10). Zooplankton were classified based on two general size categories: nano-plankton (80 um or less) or net plankton (210 um or less).

The dominant groups of nano-plankton were copepods and rotifers, with rotifer and cladoceran subdominants.

- There were 857 individuals counted during this period:
    - 323 rotifers, 91 cladocerans, 443 copepods.

The dominant groups of net plankton were the cladocerans and copepods, with copepod and cladoceran subdominants.

- There were 264 individuals counted during this period:
    - 130 cladocerans, 134 copepods.

Rotifers and copepods were the dominant taxa in two of four sample periods during the 2011-2012 season. These taxa dominated from early summer though late fall before falling into subdominant positions in winter and early spring. Immature copepods were dominant in winter and early spring in nano-plankton samples. Cladocerans were most abundant spring through summer in net plankton samples but faded from abundance in fall and winter. Several other species of copepods and rotifers were present throughout the year, dependent on species and season.

The zooplankton community presented a picture of a lake transitioning to mesotrophic when considered relative to the algal, phosphorus, and nitrogen values for Mud Lake. The 4 genera of rotifers, 4 genera of cladocerans, and 7 genera of copepods identified during the sample periods were relatively common and none of those that reached numerical dominance in the sample counts were associated as invasive or exotic. A stable, little changing zooplankton community dominated by cladocerans and copepods in both the nano and net-plankton suggest that Mud Lake is fairly mesotrophic.

TABLE 9. MOST COMMON (NANO) ZOOPLANKTON BY DATE IN MUD LAKE, APRIL 2011 TO MARCH 2012.

Date	Primary dominant	Species	Secondary dominant	Species	Tertiary dominant	Species
April 29	Copepod	Nauplii	Copepod	*Diacyclops nanus*	Rotifer	*Keratella cochlearis*
June 20	Rotifer	*Kertella cochlearis*	Rotifer	*Polyarthra vulgaris*	Cladoceran	*Bosmina longirostris*
October 19	Copepod	*Diacyclops nanus*	Rotifer	*Keratella cochlearis*	Rotifer	*Notholca* spp.
March 4	Copepod	Nauplii	Copepod	*Diacyclops nanus*		

TABLE 10. MOST COMMON (NET) ZOOPLANKTON BY DATE IN MUD LAKE FROM APRIL 2011 TO MARCH 2012.

Date	Primary dominant	Species	Secondary dominant	Species	Tertiary dominant	Species
April 29	Cladoceran	*Bosmina longirostris*	Copepod	*Diacyclops nanus*	Rotifer	*Keratella cochlearis*
June 20	Cladoceran	*Bosmina longirostris*	Rotifer	*Polyarthra vulgaris*	Cladoceran	*Bosmina longirostris*
October 19	Copepod	*Diacyclops nanus*	Rotifer	*Keratella cochlearis*	Rotifer	*Notholca* spp.
March 4	Copepod	*Diacyclops nanus*	Copepod	*Diacyclops nanus*		

AQUATIC PLANTS

Aquatic plants are the forested landscape within a lake. They provide food and habitat for a wide range of species including fish, waterfowl, turtles, and amphibians, as well as invertebrates and other aquatic animals. They improve water quality by releasing oxygen into the water and utilizing nutrients that would otherwise be used by algae. A healthy lake typically has a variety of aquatic plant species which creates diversity that makes the aquatic plant community more resilient and can help to prevent the establishment of non-native aquatic species.

During the 2012 aquatic plant survey of Mud Lake, 19 species of aquatic plants were observed (Table 11), with the greatest diversity located on the northwestern shore of the lake (Figure 16). The nineteen total species within Mud Lake were low compared with the other lakes in the Eastern Marathon County Lakes Study. Eighty-nine percent (171 of 193) of the sampled sites had vegetative growth, with an average depth of 6 feet and a maximum depth of 13 feet.

The dominant plant species in the survey were large purple bladderwort (*Utricularia purpea*), small purple bladderwort (*Utricularia resupinata*) and arrowheads (*Sagitteria* spp.). Both large and small purple bladderwort are species of special concern in Wisconsin and offer invertebrate habitat as well as foraging sites for fish. Bladderworts are carnivorous plants, using vacuums in their bladders to catch tiny insects. Arrowhead is one of the highest valued aquatic plants for wildlife. Waterfowl depend on the high-energy tubers during migration. Beds of arrowhead offer shade and shelter for young fish (Borman et al., 2001).

The Floristic Quality Index (FQI) evaluates the closeness of a plant community to undisturbed conditions. Each plant is assigned a coefficient of conservatism (C value) that reflects its sensitivity to disturbance. These numbers are used to calculate the FQI. C values range from 0 to 10, with higher values designating species that are more intolerant of disturbance. The FQI for Mud Lake was 31.5, which was above average and made Mud Lake the third highest ranked lake in the Eastern Marathon County Lakes Study.

Ten of the 19 aquatic plant species in Mud Lake had a C value of eight or greater (Table 11), making Mud Lake second only to Norrie Lake for the greatest number of high quality aquatic plants in the Eastern Marathon County Lakes Study. Out of these ten species, three are designated as species of special concern in Wisconsin: waterthread pondweed (*Potamogeton diversifolius*), large purple bladderwort, and small purple bladderwort. Mud Lake was one of only four lakes in the Eastern Marathon County Lakes Study containing species of special concern.

The Simpson Diversity Index (SDI) quantifies biodiversity based on a formula that uses the number of species surveyed and the number of individuals per site. The SDI uses a decimal scale of zero to one with values closer to one representing higher amounts of biodiversity. Mud Lake had a SDI value of 0.84. This represents average biodiversity when compared to other lakes in the Eastern Marathon County Lakes Study.

During the aquatic plant survey of Mud Lake, no non-native species were observed. This is a good indicator of overall aquatic health within the lake. The lack of non-native species may also demonstrate diligence by lake users in cleaning watercraft before entering the lake to prevent non-native species transfer.

Overall, the aquatic plant community in Mud Lake can be characterized as having excellent quality species with a number of relatively uncommon species for central Wisconsin. The habitat, food source, and water quality benefits of this diverse plant community should be focal points in future lake management strategies.

TABLE 11. AQUATIC PLANTS IDENTIFIED IN THE AQUATIC PLANT SURVEY OF MUD LAKE, 2012.

Common Name	**Scientific Name**	**Coefficient of Conservatism Value (C Value)**
Emergent Species		
three-way sedge	*Dulichium arundinaceum*	9
creeping spikerush	*Eleocharis palustris*	6
common arrowhead	*Sagittaria latifolia*	3
pickerelweed	*Pontederia cordata*	8
Floating Leaf Species		
watershield	*Brasenia schreberi*	6
spatterdock	*Nuphar variegata*	6
white water lily	*Nymphaea odorata*	6
Submergent Species		
needle spikerush	*Eleocharis acicularis*	5
pipewort	*Eriocaulon aquaticum*	9
water star-grass	*Heteranthera dubia*	6
spiny spored quillwort	*Isoetes echinospora*	8
brown fruited rush	*Juncus pelocarpus f. submersus*	8
Nitella	*Nitella* spp.	7
waterthread pondweed*	*Potamogeton diversifolius*	8
ribbon leaved pondweed	*Potamogeton epihydrus*	8
water bulrush	*Schoenoplectus subterminalis*	9
large purple bladderwort*	*Utricularia purpurea*	9
small purple bladderwort*	*Utricularia resupinata*	9
common bladderwort	*Utricularia vulgaris*	7

*Species of special concern in Wisconsin.

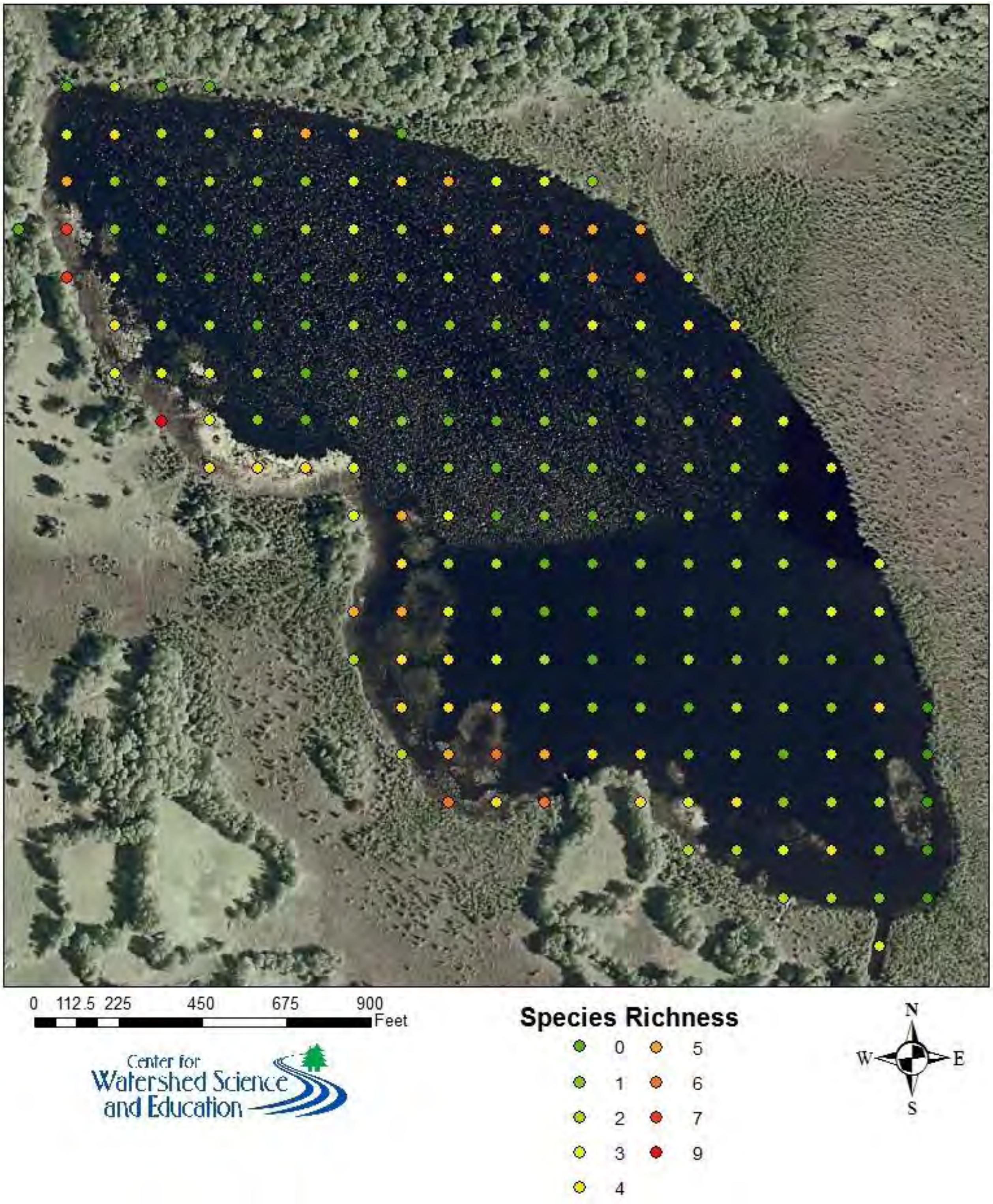


FIGURE 16. SPECIES RICHNESS AT SAMPLE SITES IN MUD LAKE, 2012.

CONCLUSIONS & RECOMMENDATIONS

Overall, many of the measures indicated that Mud Lake had good water quality; however, inorganic nitrogen was elevated and the dominance of blue-green algae suggested some problems. Mud Lake has a history of low dissolved oxygen and winter fish kills. The lake appears to be transitioning towards more nutrient-rich conditions, so efforts should be made to prevent additional inputs from reaching the lake.

- Mud Lake is a soft water lake. Soft water does not always provide the calcium necessary for building bones and shells for animals in the lake and limits the lake's ability to buffer acid rain and phosphorus.
- Over the monitoring period, concentrations of chloride, sodium and potassium were low in Mud Lake. Atrazine (DACT), an herbicide commonly used on corn, was below the detection limit in the samples that were analyzed from Mud Lake.
- Dissolved oxygen concentrations in Mud Lake ranged from plentiful to limited depending upon depth and time of year. In the winters during the study, the dissolved oxygen fell below concentrations needed to support many fish species. At times, only the upper 2 feet of water had concentrations above 5 mg/L. During summer months, algae blooms produced periodic spikes in dissolved oxygen concentrations at depths typically between 6 and 8 feet.
- Total phosphorus concentrations in Mud Lake ranged from a high of 44 μg/L in June 2011 to a low of 12 μg/L in February 2011 and June 2012. Summer median total phosphorus was 20.5 ug/L and 16.5 ug/L in 2011 and 2012, respectively. This is below Wisconsin's phosphorus standard of 40 ug/L for shallow seepage lakes, but above the proposed flag value of 15 ug/L.
- During the study, concentrations of inorganic nitrogen in samples collected from Mud Lake during the spring averaged 0.72 mg/L. Concentrations above 0.3 mg/L are sufficient to enhance algal blooms throughout the summer. Inorganic nitrogen typically moves to lakes with groundwater. Common sources are fertilizers, animal waste, and septic systems.

Algae are microscopic, photosynthetic organisms that are important food items in all aquatic ecosystems. Different algal groups increase or decrease during the year and they can be used to analyze a lake's water quality because there are more varieties of algae than fish or aquatic plants. Conclusions can be drawn about water temperature, nutrient availability, and overall water quality of a lake using algal populations.

- The algal communities in Mud Lake were similar in composition and seasonal patterns during 2011 and 2012. The community composition and patterns were similar to those often found in eutrophic water bodies.
- The blue-green algae dominated both years (45-55% average community composition), with the green algae comprising 25-35%. Diatoms were of only minor significance, adding 5-10% to the algal community.
- The abundance of small filamentous and colonial blue-green species is potentially problematic due to the inability of most zooplankton species to ingest and digest them. Dense growth of these algal species can decrease water clarity and can shade out submerged aquatic plants.
- The total phosphorus concentrations indicated mildly mesotrophic conditions, but the algal community indicated a much more mesotrophic lake that might be transitioning to eutrophic status.

The interdependence of algae, zooplankton, and young fish as predators and prey form the primary food web in most lakes. Zooplankton are microscopic invertebrate animals that swim or drift in water. They are the primary consumers at the base of the food chain in our lakes and are an important food for many fish. Most zooplankton are filter feeders, using their appendages to strain bacteria and algae from water, so they help to keep algal populations under control. It is the timing of zooplankton abundance that frequently determines the success of a lake's larval fish community. The abundance and slow-moving nature of zooplankton make them the primary food of young fish (fry).

- The zooplankton community presented a picture of a lake transitioning to mesotrophic when considered relative to the algal, phosphorus, and nitrogen values for Mud Lake.
- The four genera of rotifers, four genera of cladocerans, and seven genera of copepods identified during the sample periods were relatively common and none of those that reached numerical dominance in the sample counts were associated as invasive or exotic.
- A stable, little-changing zooplankton community dominated by cladocerans and copepods in both the nano and net-plankton suggest that Mud Lake is fairly mesotrophic.

A healthy fishery is one that is in balance with the lake's natural ability to support the fish community, and is adaptable to fishing practices that do not cause declines in fish populations. A healthy fish community has a balance between predator and prey species, and each fish species has different needs to be met in order to flourish, including adequate food sources, habitat, appropriate spawning substrate, and water quality.

- Mud Lake supports a warm water fish community. Fish diversity was low in Mud Lake compared to other lakes in the Eastern Marathon County Lakes Study. This may suggest fish kills during recent winters.
- Bluegill and largemouth bass were most abundant during the 2012 survey. Bluegill reached a maximum size of 10.1 inches. Only young-of-year largemouth bass were caught and did not exceed 2 inches in the 2012 sample. Black crappie were the largest fish caught in Mud Lake, with individuals reaching a maximum length of 12.8 inches.
- No new fish species were documented during the 2012 sampling period and crayfish were not encountered.
- In 2012, three fish species were caught and identified out of the ten total species that have been recorded in surveys dating back to 1964 obtained from the Wisconsin Department of Natural Resources. The species documented previously but not detected during the 2012 survey were black bullhead, common shiner, golden shiner, mudminnow, northern pike, pumpkinseed, and yellow perch.

To successfully sustain a healthy fish population, a lake must have the habitat to support it. Habitat needs of fish include healthy aquatic plants and woody structure such as logs, fallen trees, and stumps. Woody structure provides places for fish to hide, as well as habitat for invertebrates that many fish species use as food sources. Many fish use lily pads and bulrushes, as well as gravel and cobble substrates, for spawning habitat.

- Substrate distribution in Mud Lake primarily consisted of a soft bottom (95% muck) with mixtures of sand/gravel/cobble (1.6%) and sand (3.4%) on the southern shoreline.
- Gravel areas are utilized by many fish for spawning habitat, including sunfish (bluegill, pumpkinseed, black bass), where males will construct nests and guard their young. Sand can be

important habitat for reproduction of non-game minnows. The presence of young bass and sunfish sampling indicates successful reproduction of these species.

- Sparse areas of bulrush were present in Mud Lake. Northern pike, which do not offer parental care, utilize areas with emergent and floating-leaf vegetation in shallow or flooded areas for spawning. Black crappie utilize bulrush habitat on gravel or sand substrates where they construct nests and guard young.
- Coarse woody habitat (CWH), including downed trees and logs, are present in Mud Lake. This structure is utilized by young prey fish and other aquatic organisms for spawning, foraging, and protective cover. The addition of CWH cover would benefit the fish community.

Aquatic plants are the forested landscape within a lake. They provide food and habitat for a wide range of species including fish, waterfowl, turtles, and amphibians, as well as invertebrates and other aquatic animals. They improve water quality by releasing oxygen into the water and utilizing nutrients that would otherwise be used by algae. A healthy lake typically has a variety of aquatic plant species which creates diversity that makes the aquatic plant community more resilient and can help to prevent the establishment of non-native aquatic species.

- Nineteen species of aquatic plants were identified in Mud Lake. This was lower than average compared with other lakes in the study.
- The dominant plant species in the survey were large purple bladderwort, small purple bladderwort, and arrowhead . Both large and small purple bladderwort are species of special concern in Wisconsin and offer invertebrate habitat as well as foraging sites for fish. Bladderworts are carnivorous plants, using vacuums in their bladders to catch tiny insects. Arrowhead is one of the highest valued aquatic plants for wildlife. Waterfowl depend on the high-energy tubers during migration. Beds of arrowhead offer shade and shelter for young fish.
- The Floristic Quality Index (FQI) evaluates the closeness of a plant community to undisturbed conditions. The FQI for Mud Lake was 31.5, which was above-average and the third highest in the study.
- Mud Lake was second only to Norrie Lake for the greatest number of high quality aquatic plants in the study. Ten of the 19 aquatic plant species within Mud Lake were high quality plants (with a C value of eight or greater). Out of these ten species, three are species of special concern in Wisconsin: waterthread pondweed, large purple bladderwort, and small purple bladderwort. Mud Lake was one of only four lakes within the Eastern Marathon County Lakes Study hosting species of special concern.
- No non-native aquatic plant species were observed during the survey in 2012. Keeping aquatic invasive species (AIS) out of a lake and identifying early infestations requires on-going effort.
- The amount of disturbed lakebed from raking or pulling plants should be minimized, since these open spaces are “open real estate” for aquatic invasive plants to establish.
- Early detection of aquatic invasive species (AIS) can help to prevent their establishment should they be introduced into the lake. Boats and trailers that have visited other lakes can be a primary vector for the transport of AIS.
- Programs are available to help volunteers learn to monitor for AIS and to educate lake users at the boat launch about how they can prevent the spread of AIS.

In general, each type of land use contributes different amounts of phosphorus, nitrogen, and pollutants in runoff and through groundwater. The types of land management practices that are used and their distances from the lake affect the contributions to the lake from a parcel of land. Mud Lake's surface and groundwater watersheds provided most of the water to the lake. Forests comprised 43% of the 1,902 acre surface watershed, followed by agriculture which comprised about 30% of the watershed. In the groundwater watershed, agriculture has the greatest percent land use (39%), followed by forests (37%).

- While forests comprised the greatest amount of land in Mud Lake's surface watershed, water quality modeling results indicated that agriculture had the greatest percentage of phosphorus contributions from the watershed to Mud Lake.
- Over-application of chemicals and nutrients should be avoided. Landowners in the watershed should be made aware of their connection to the lake and should work to reduce their impacts through the implementation of water quality-based best management practices.
- The Marathon County Conservation Department and Natural Resources Conservation Service (NRCS) have professional staff available to assist landowners interested in learning how they can improve water quality through adjustments in land management practices.

Shoreland vegetation is critical to a healthy lake's ecosystem. It provides habitat for many aquatic and terrestrial animals including birds, frogs, turtles, and many small and large mammals. It also helps to improve the quality of the runoff that is flowing across the landscape towards that lake. Healthy natural vegetation includes a mix of layers such as tall grasses/forbs, shrubs, and trees.

- Mud Lake has 1.5 miles of shoreline. During the 2011 survey, the lake's shoreland vegetation was primarily in a natural state.
- The overall findings showed that shorter vegetation is the most prominent vegetative layer near the water's edge. Much of this is due to the abundance of wetlands adjacent to Mud Lake, but also may be a result of lower than normal lake levels in 2011.
- Although Mud Lake's shoreland is in natural condition right now, changes can easily occur as development takes place. Minimizing impacts to Mud Lake from future development should include planning to ensure that prospective developers have information to make good decisions and that zoning is in place to achieve habitat, water quality, and aesthetic goals.
- Distributing information about the importance of healthy shorelands to property owners is a good first step.

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GLOSSARY OF TERMS

Algae: One-celled (phytoplankton) or multicellular plants either suspended in water (plankton) or attached to rocks and other substrates (periphyton). Their abundance, as measured by the amount of chlorophyll a (green pigment) in an open water sample, is commonly used to classify the trophic status of a lake. Numerous species occur. Algae are an essential part of the lake ecosystem and provide the food base for most lake organisms, including fish. Phytoplankton populations vary widely from day to day, as life cycles are short.

Atrazine: A commonly used herbicide. Transports to lakes and rivers by groundwater or runoff. Has been shown to have toxic effects on amphibians.

Blue-Green Algae: Algae that are often associated with problem blooms in lakes. Some produce chemicals toxic to other organisms, including humans. They often form floating scum as they die. Many can fix nitrogen (N2) from the air to provide their own nutrient.

Calcium (Ca++): The most abundant cation found in Wisconsin lakes. Its abundance is related to the presence of calcium-bearing minerals in the lake watershed. Reported as milligrams per liter (mg/1) as calcium carbonate (CaCO3), or milligrams per liter as calcium ion (Ca++).

Chloride (Cl-): The chloride ion (Cl-) in lake water is commonly considered an indicator of human activity. Agricultural chemicals, human and animal wastes, and road salt are the major sources of chloride in lake water.

Chlorophyll *a*: Green pigment present in all plant life and necessary for photosynthesis. The amount present in lake water depends on the amount of algae, and is therefore used as a common indicator of algae and water quality.

Clarity: See "Secchi disk."

Color: Color affects light penetration and therefore the depth at which plants can grow. A yellow-brown natural color is associated with lakes or rivers receiving wetland drainage. Measured in color units that relate to a standard. The average color value for Wisconsin lakes is 39 units, with the color of state lakes ranging from zero to 320 units.

Concentration units: Express the amount of a chemical dissolved in water. The most common ways chemical data is expressed is in milligrams per liter (mg/l) and micrograms per liter (ug/l). One milligram per liter is equal to one part per million (ppm). To convert micrograms per liter (ug/l) to milligrams per liter (mg/l), divide by 1000 (e.g. 30 ug/l = 0.03 mg/1). To convert milligrams per liter (mg/l) to micrograms per liter (ug/l), multiply by 1000 (e.g. 0.5 mg/l = 500 ug/l).

Cyanobacteria: See "Blue-Green Algae."

Dissolved oxygen: The amount of oxygen dissolved or carried in the water. Essential for a healthy aquatic ecosystem in Wisconsin lakes.

Drainage basin: The total land area that drains runoff towards a lake.

Drainage lakes: Lakes fed primarily by streams and with outlets into streams or rivers. They are more subject to surface runoff problems, but generally have shorter residence times than seepage lakes.

Emergent: A plant rooted in shallow water and having most of its vegetative growth above water.

Eutrophication: The process by which lakes and streams are enriched by nutrients, and the resulting increase in plant and algae. The extent to which this process has occurred is reflected in a lake's trophic classification: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Groundwater drainage lake: Often referred to as a spring-fed lake, it has large amounts of groundwater as its source and a surface outlet. Areas of high groundwater inflow may be visible as springs or sand boils. Groundwater drainage lakes often have intermediate retention times with water quality dependent on groundwater quality.

Hardness: The quantity of multivalent cations (cations with more than one +), primarily calcium (Ca^{++}) and magnesium (Mg^{++}) in the water expressed as milligrams per liter of $CaCO_3$. Amount of hardness relates to the presence of soluble minerals, especially limestone or dolomite, in the lake watershed.

Intermittent: Coming and going at intervals, not continuous.

Macrophytes: See "Rooted aquatic plants."

Marl: White to gray accumulation on lake bottoms caused by precipitation of calcium carbonate ($CaCO_3$) in hard water lakes. Marl may contain many snail and clam shells. While it gradually fills in lakes, marl also precipitates phosphorus, resulting in low algae populations and good water clarity. In the past, marl was recovered and used to lime agricultural fields.

Mesotrophic: A lake with an intermediate level of productivity. Commonly clear water lakes and ponds with beds of submerged aquatic plants and mediums levels of nutrients. See also "eutrophication".

Nitrate (NO_3^-): An inorganic form of nitrogen important for plant growth. Nitrate often contaminates groundwater when water originates from manure, fertilized fields, lawns or septic systems. In drinking water, high levels (over 10 mg/L) are dangerous to infants and expectant mothers. A concentration of nitrate-nitrogen (NO_3-N) plus ammonium-nitrogen (NH_4-N) of 0.3 mg/L in spring will support summer algae blooms if enough phosphorus is present.

Oligotrophic: Lakes with low productivity, the result of low nutrients. Often these lakes have very clear waters with lots of oxygen and little vegetative growth. See also "eutrophication".

Overturn: Fall cooling and spring warming of surface water increases density, and gradually makes lake temperatures and density uniform from top to bottom. This allows wind and wave action to mix the entire lake. Mixing allows bottom waters to contact the atmosphere, raising the water's oxygen content. Common in many lakes in Wisconsin.

Phosphorus: Key nutrient influencing plant growth in more than 80% of Wisconsin lakes. Soluble reactive phosphorus is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.

Rooted aquatic plants (macrophytes): Refers to higher (multi-celled) plants growing in or near water. Macrophytes are beneficial to lakes because they produce oxygen and provide substrate for fish habitat and aquatic insects and provide food for many aquatic and terrestrial animals. Overabundance of such plants, especially problem species, is related to shallow water depth and high nutrient levels.

Secchi disk: An 8-inch diameter plate with alternating quadrants painted black and white that is used to measure water clarity (light penetration).

Sedimentation: Materials that are deposited after settling out of the water.

Stratification: The layering of water due to differences in density. As water warms during the summer, it remains near the surface while colder water remains near the bottom. Wind mixing determines the thickness of the warm surface water layer (epilimnion), which usually extends to a depth of about 20 feet. The narrow transition zone between the epilimnion and cold bottom water (hypolimnion) is called the metalimnion. Common in many deeper lakes in Wisconsin.

Watershed: See "Drainage basin."