Eastern Marathon County Lakes Study

Mayflower Lake

Spring 2014

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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 developing watersheds.

Eleven lakes in eastern Marathon County were selected for this study. The study focused on obtaining a better understanding of the current conditions of the lakes' water quality, fisheries, habitats, 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 lakes 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 summarizes the results of the study for Mayflower 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 MAYFLOWER 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. Mayflower Lake is located in the township of Norrie, west of County Highway D. One public boat launch located on its southeastern side. Mayflower Lake is a 96 acre seepage lake with surface runoff and groundwater contributing most of its water. The maximum depth in Mayflower Lake is 19 feet; the lakebed has a gradual slope (Figure 1). Mayflower Lake has a water residence time of approximately 14 months. The residence time helps determine the potential effects of nutrients entering the lake and the length of time pollutants may stay in the lake. Mayflower Lake's bottom sediments are predominantly muck, with rock interspersed with sand around the eastern perimeter.

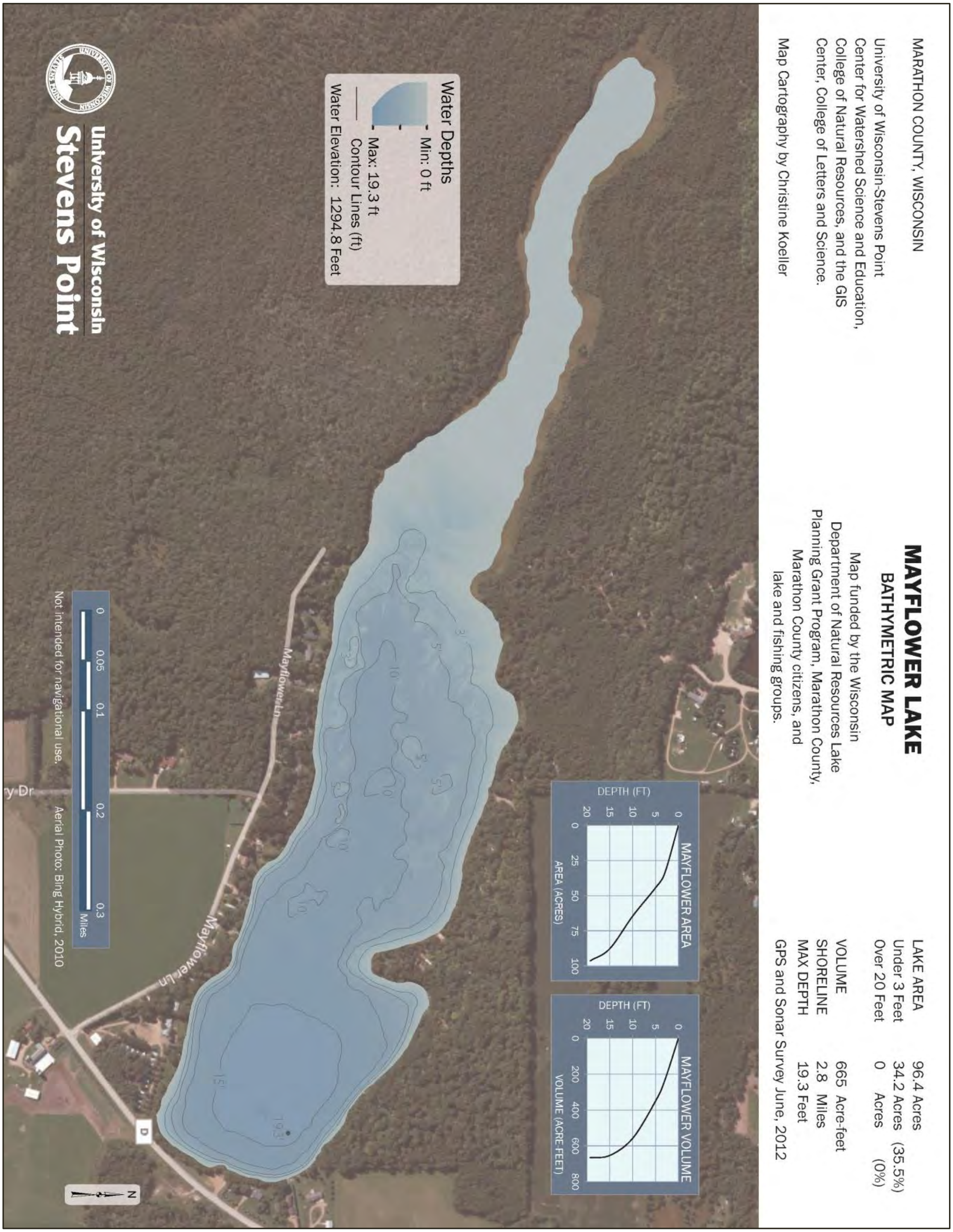


FIGURE 1. CONTOUR MAP OF THE MAYFLOWER LAKE LAKEBED.

The water quality in Mayflower Lake is a reflection of the land that drains to the lake. The water quality, the amount of algae and aquatic plants, the fishery and other animals in the lake are all affected by natural and manmade 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 Mayflower 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 Mayflower Lake is called a surface watershed. Groundwater also feeds Mayflower Lake; its land area (groundwater watershed) is different from the surface watershed (Figure 2).

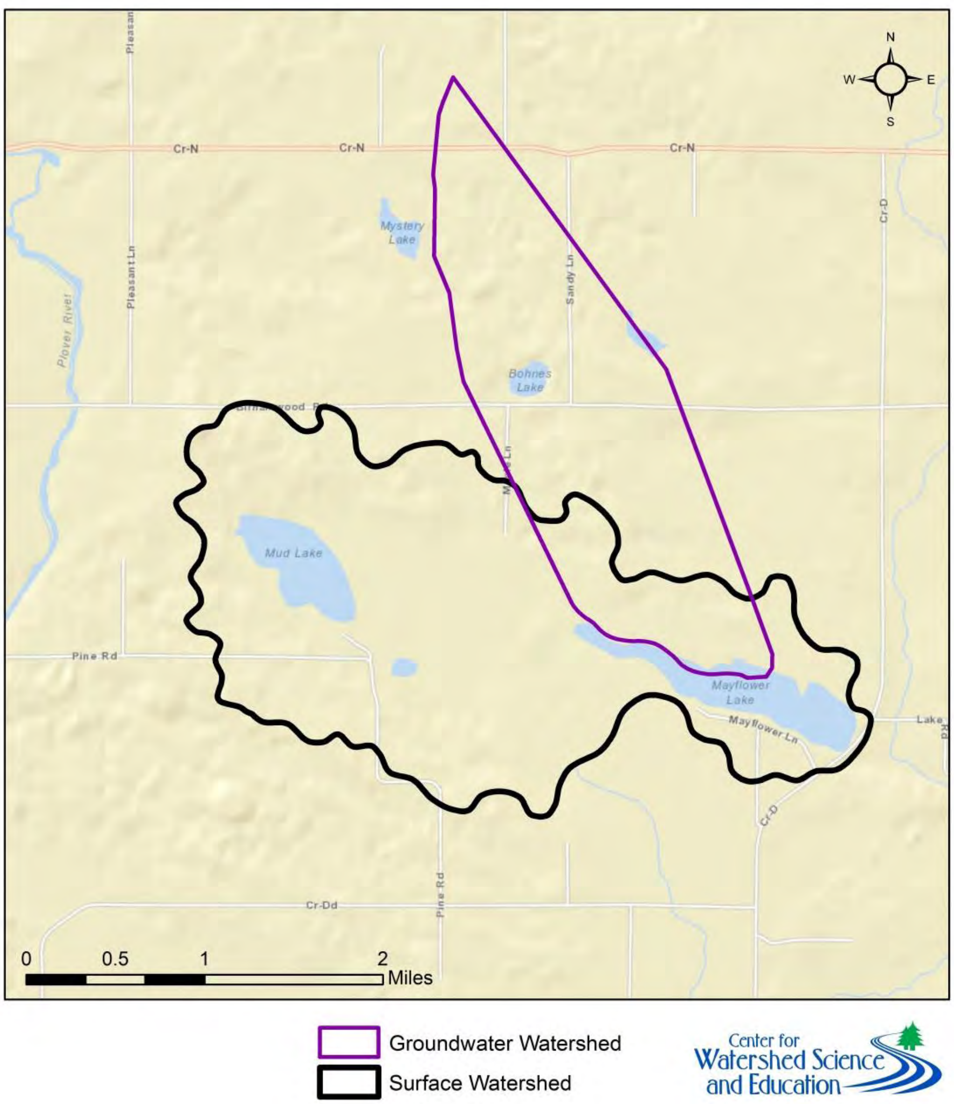


FIGURE 2. GROUNDWATER AND SURFACE WATERSHED BOUNDARIES FOR MAYFLOWER LAKE.

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 that carries pollutants to the lake. Wastewater, animal waste, and fertilizers used on lawns, gardens, and agricultural fields can contribute nutrients that can 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.

MAYFLOWER LAKE SURFACE WATERSHED

The surface watershed for Mayflower Lake is approximately 1,664 acres and includes Mud Lake (Figure 3). The dominant land uses in the watershed are forests and agriculture. The land closest to the lake often has the greatest impact on water quality and habitat; land uses near Mayflower Lake's shoreland include residential development, camps, forests, and wetlands.

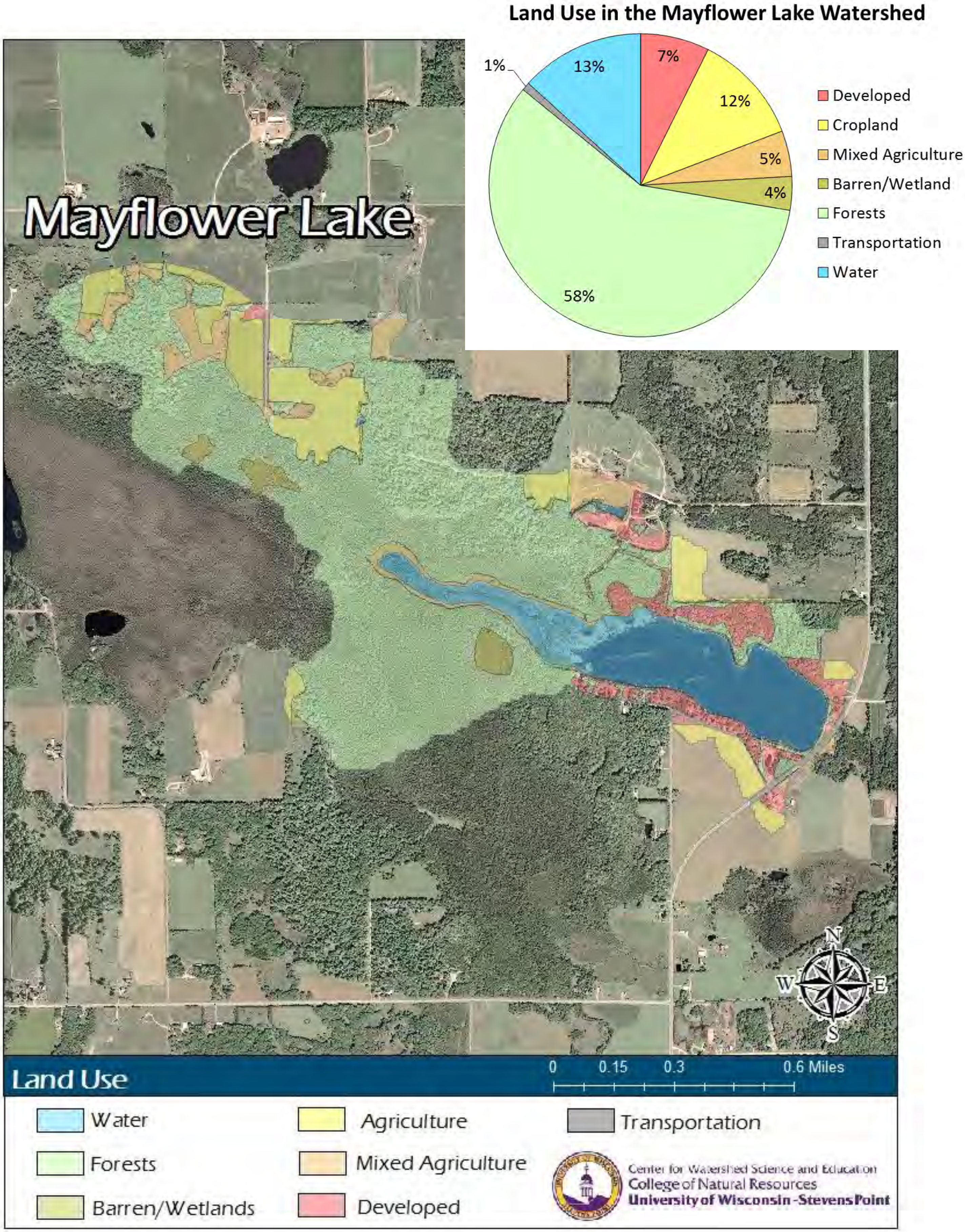


FIGURE 3. LAND USE IN THE MAYFLOWER LAKE SURFACE WATERSHED.

The groundwater watershed is the area where rain and snowmelt soak into the ground and travel below ground towards the lake. Mayflower Lake's groundwater watershed is approximately 905 acres (Figure 4). The primary land uses in the Mayflower Lake groundwater watershed are agriculture and forests. In general, the land adjacent to the lake where most of the groundwater is entering may have the greatest immediate impact on water quality. Residential development, a camp, and forests are all adjacent to Mayflower Lake where most of the groundwater enters.

Land Use	Acres
Agriculture	551
Developed	40
Forested	249
Roads	16
Water	27
Wetland	19

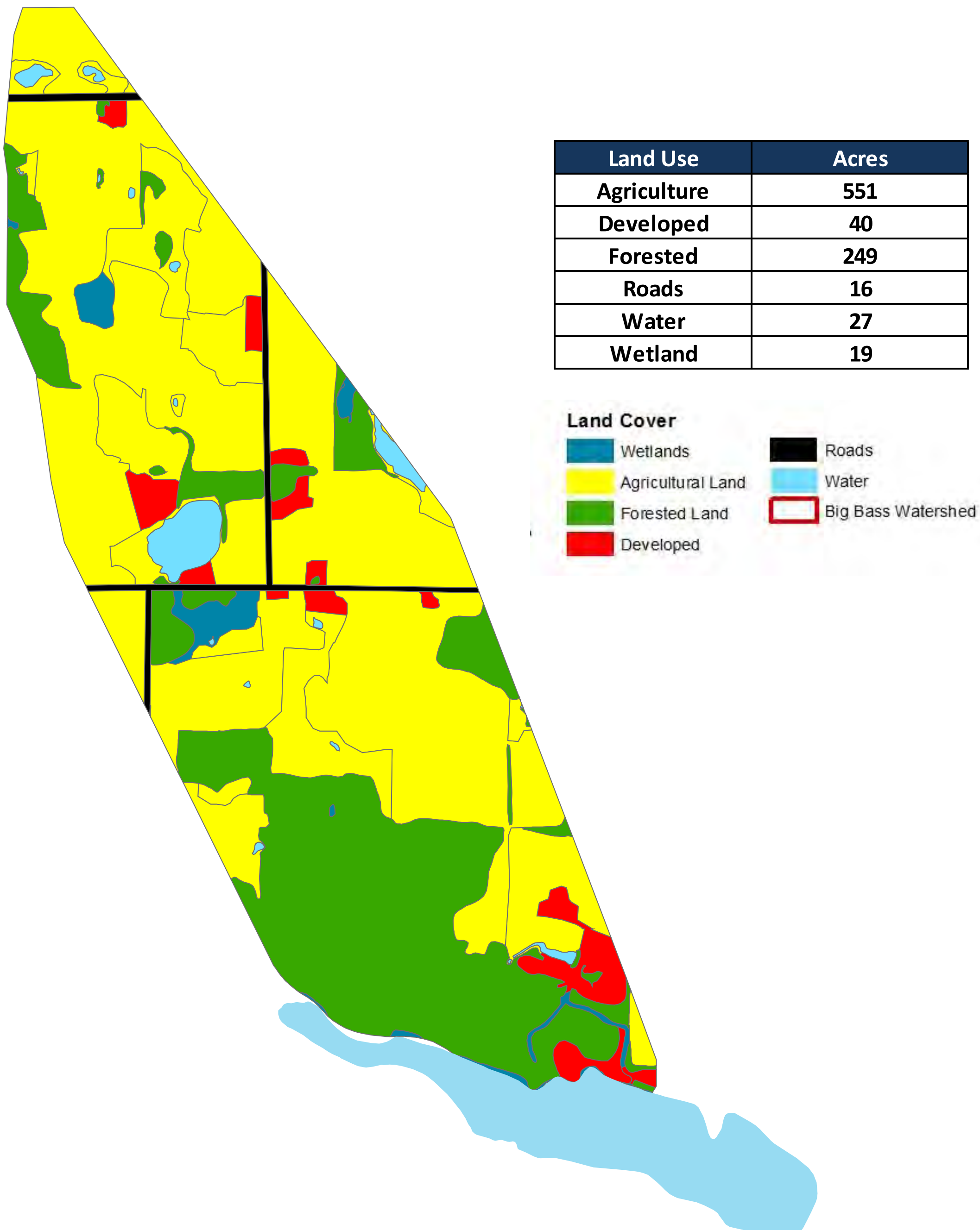


FIGURE 4. LAND USE IN THE MAYFLOWER LAKE GROUNDWATER WATERSHED.

Locally, groundwater enters some areas of the Mayflower lakebed (inflow), has no connection to the lake in other regions, and exits the lake in other areas (outflow). Near shore, mini-wells were installed in the lakebed approximately every 200 feet around the perimeter of Mayflower Lake (Figure 5). Most of the groundwater entered the lake on the northern side (green triangles). Groundwater outflow occurred on the eastern end and sporadically on the southern side of the lake (red flags). Areas with no connection between groundwater and the lake were mostly observed on the western side of the lake and sporadically around the rest of the lake (white circles). Additional groundwater may enter Mayflower 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 may result in less groundwater entering Mayflower 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 impacts the temperature and chemistry of the groundwater. Groundwater temperatures are constant year round, so groundwater feeding Mayflower Lake will help to keep the lake water cooler during the summer months.

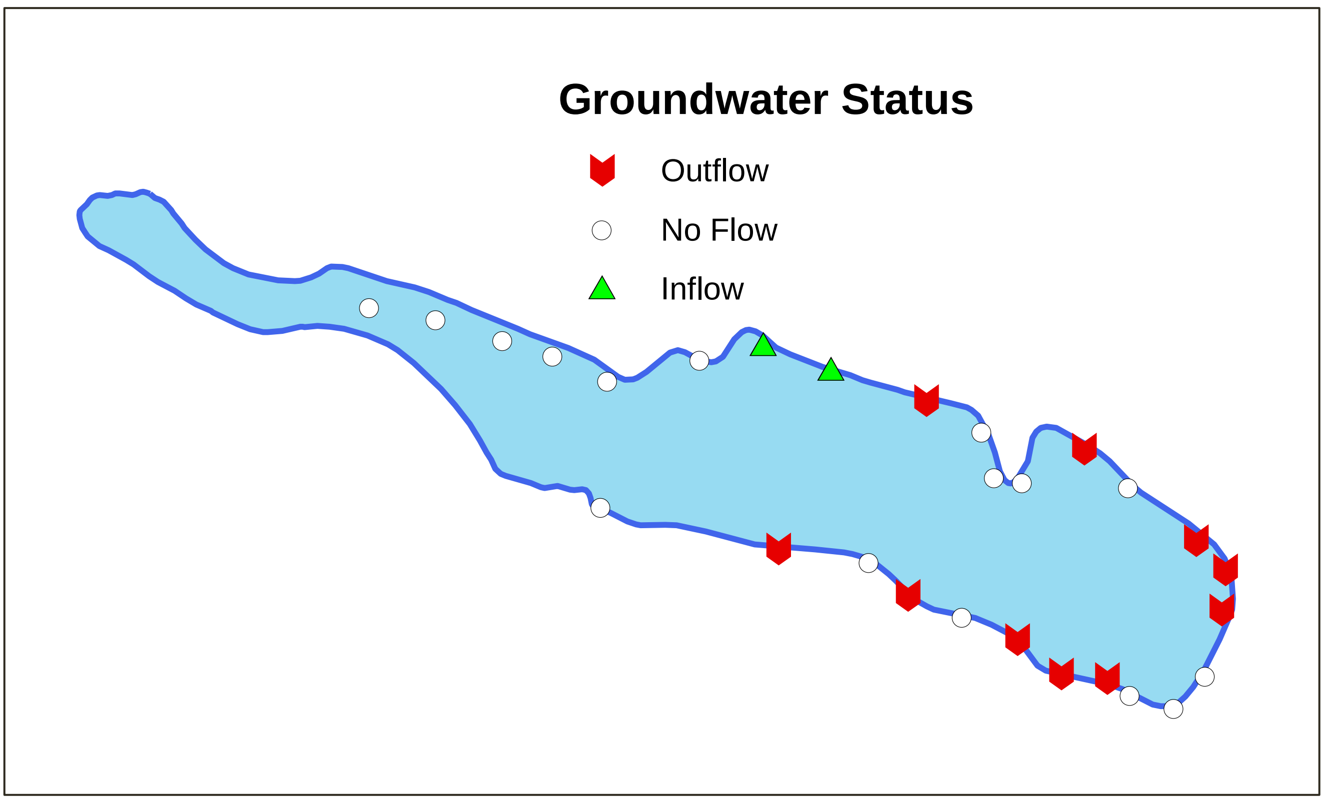
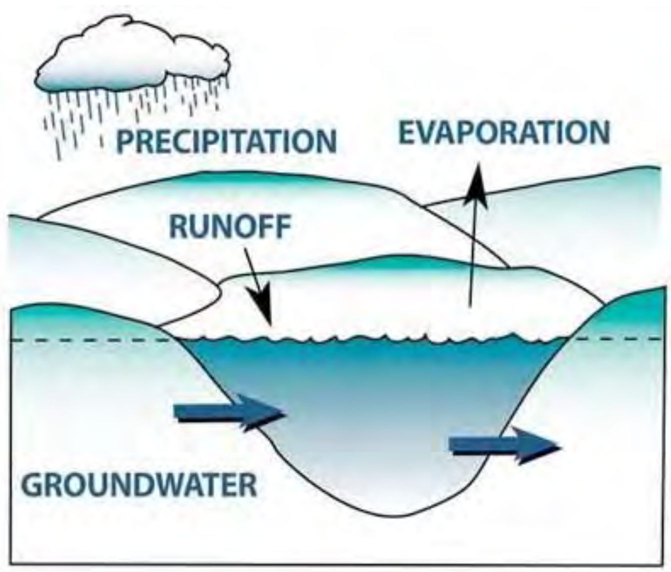


FIGURE 5. MAYFLOWER LAKE GROUNDWATER INFLOW AND OUTFLOW, 2011.

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 Mayflower 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 evaluating its water quality and quantity, and in choosing management practices to preserve or influence that quality or quantity. Mayflower Lake is classified as a seepage lake. Water enters this type of lake primarily through groundwater, and to lesser extents, via surface runoff and direct precipitation (Figure 6). 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. These lakes are vulnerable to contamination moving towards the lake in the groundwater. Examples for Mayflower Lake may include septic systems, agriculture, and road salt.

FIGURE 6. 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). Minerals such as calcium and magnesium in the soil around Mayflower Lake dissolve, making the water hard. The average hardness for Mayflower Lake during the 2010-2012 sampling period was 106 mg/L, which is considered moderately hard (Table 1). Hard water provides the calcium necessary for building bones and shells for animals in the lake. The average alkalinity concentration in Mayflower Lake was 122 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 MAYFLOWER LAKE, 2010-2012.

Mayflower Lake	Alkalinity (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mg/L as CaCO3)	Color SU	Turbidity (NTU)
Average	122	19.4	13.1	106	47.5	2.3

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 at elevated levels in the lake indicates the movement of pollutants from the landscape to the lake.

Over the monitoring period, average sodium concentrations were observed at natural levels for central Wisconsin lakes, and average concentrations of chloride and potassium were slightly elevated (Table 2). These concentrations are not harmful to aquatic organisms, but indicate that pollutants are entering the lake. Common sources of chloride and potassium include animal waste, septic systems, and fertilizer. Atrazine (DACT), an herbicide commonly used on corn, was below the detection limit (<0.01 ug/L) in the samples that were analyzed from Mayflower Lake.

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

Mayflower Lake	Average Value (mg/L)			Reference Value (mg/L)		
	Low	Medium	High	Low	Medium	High
Potassium		1.1		<.75	0.75-1.5	>1.5
Chloride		3.6		<3	3.0-10.0	>10
Sodium	0.8			<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 Wisconsin lakes, the water temperature changes throughout the year and may vary with depth. During winter and summer when lakes stratify (layer), 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 can reduce habitat for sensitive cold water species of fish and other critters.

Water temperature and dissolved oxygen were measured in Mayflower Lake from top to bottom at the time of sample collection during the 2010-2012 study. As would be expected, near-freezing temperatures existed near the surface with slight gradual warming towards the bottom of the lake in late winter (February 2011). Data collected in spring and fall indicated the lake had mixed from top to bottom, thereby replenishing oxygen throughout the lake. Based on temperature, the lake was somewhat stratified during the growing season (May-September) as surface water warmed. The stratification was weak enough that strong winds or boating activity could have mixed the water. This is not ideal during the summer as the bottom water is often rich with nutrients from the sediment, and bringing this water into warmer conditions near the surface may result in algal blooms. Water temperatures near the bottom of the lake ranged by 14 degrees (reaching a high of 66.2°F or 19 C in summer), while surface temperatures ranged by nearly 28 degrees (Figure 7).

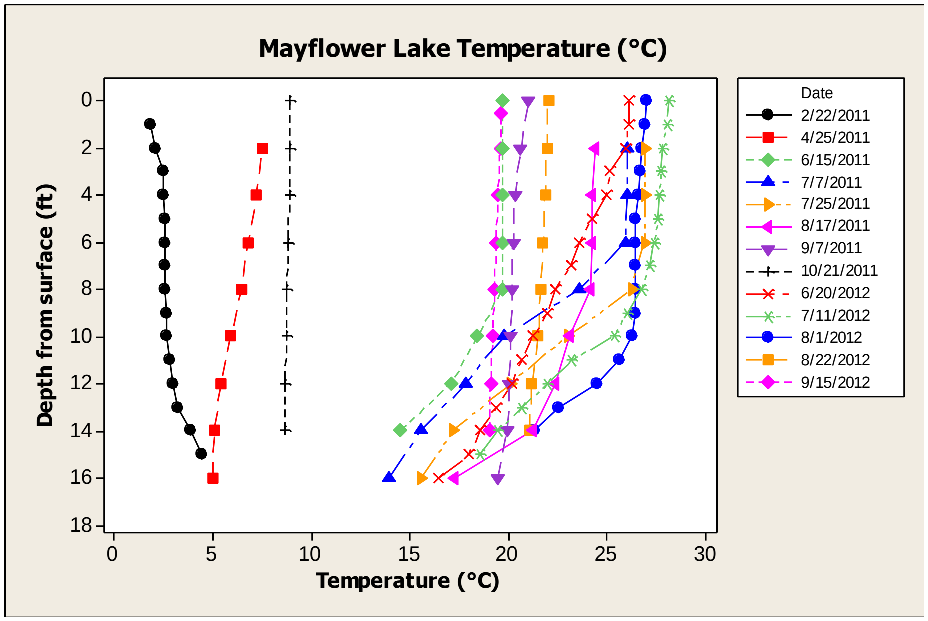


FIGURE 7. TEMPERATURE PROFILES IN MAYFLOWER LAKE, 2011-2012.

Dissolved oxygen concentrations in Mayflower Lake ranged from plentiful to limited, depending upon depth and time of year. Like temperature, dissolved oxygen was mixed from the lake surface to the lake bottom during spring and fall. In winter of both years, at the deep hole, dissolved oxygen concentrations fell below levels needed to support many fish species (Figure 8). Following spring overturn, dissolved oxygen concentrations varied with depth as biological processes in the lake consumed or generated oxygen. Algal blooms produced periodic spikes in dissolved oxygen concentrations at depths typically between 2 and 8 feet.

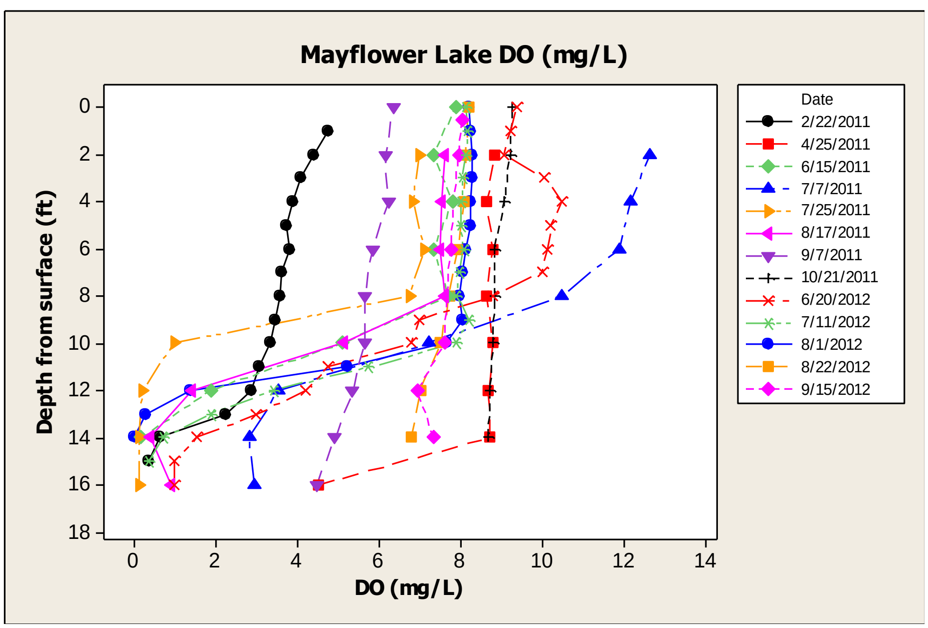
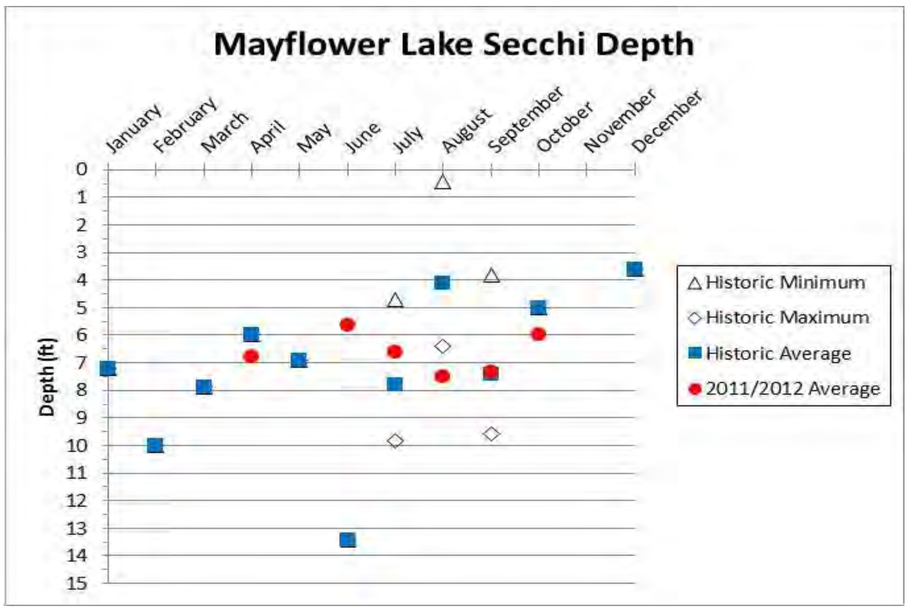


FIGURE 8. DISSOLVED OXYGEN PROFILES IN MAYFLOWER LAKE, 2011-2012.

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. Water clarity is affected by water color, turbidity (suspended sediment), and algae, so it is normal for water clarity to change throughout the year and from year-to-year. In Mayflower Lake, the color was moderately stained (Table 1). Brown staining from tannins in the surrounding wetlands and forest were the natural source of the slightly elevated color index.

The variability in water clarity throughout the year in Mayflower Lake was primarily due to fluctuating algal concentrations and re-suspended sediment following strong winds. The water clarity in Mayflower Lake was considered fair. The average water clarity measurements in Mayflower Lake during the study were poorest in June and October and best in August (Figure 9). When compared with historic data (1973-1974 and 2000), the average water clarity measured during the study was better in April, August, and October, was similar in September, and was poorer during the months of June and July.



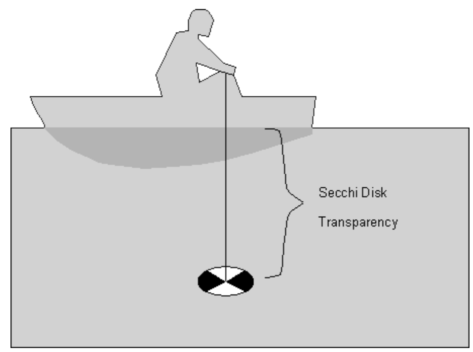


FIGURE 9. AVERAGE MONTHLY WATER CLARITY IN MAYFLOWER LAKE, 2010-2012 AND HISTORIC.

Nutrients (phosphorus and nitrogen) are used by algae and aquatic plants for growth. Phosphorus is present naturally throughout the watershed in soil, plants, animals and wetlands. Additional 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 Mayflower Lake ranged from a high of 34 µg/L in June 2011 to a low of 10 µg/L in August 2012, with median growing season concentrations of 22.5 µg/L and 18 ug/L in 2011 and 2012, respectively (Table 3). These were below Wisconsin's phosphorus standard of 40 ug/L for shallow seepage lakes. Average concentrations of inorganic nitrogen were 0.3 during the spring, a level which can result in increased algal blooms throughout the summer.

TABLE 3. SUMMARY OF SEASONAL NUTRIENTS IN MAYFLOWER LAKE, 2010-2012.

Mayflower 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	21	24	28	3	4	5	0.90	1.22	1.53	0.04	0.13	0.21	0.86	1.09	1.32
Spring	25	28	31	8	10	11	1.16	1.22	1.28	0.27	0.30	0.33	0.89	0.92	0.95
Summer	10	20	34												
Winter	16	19	22	4	5	5	1.34	1.46	1.58	0.42	0.49	0.56	0.92	0.97	1.02

Data on water clarity and phosphorus in Mayflower Lake were collected during the summers dating back to 1973, and were graphed to evaluate their relationship. As phosphorus concentrations increased, water clarity decreased, suggesting that algae abundance increases with increasing phosphorus during the summer (Figure 10).

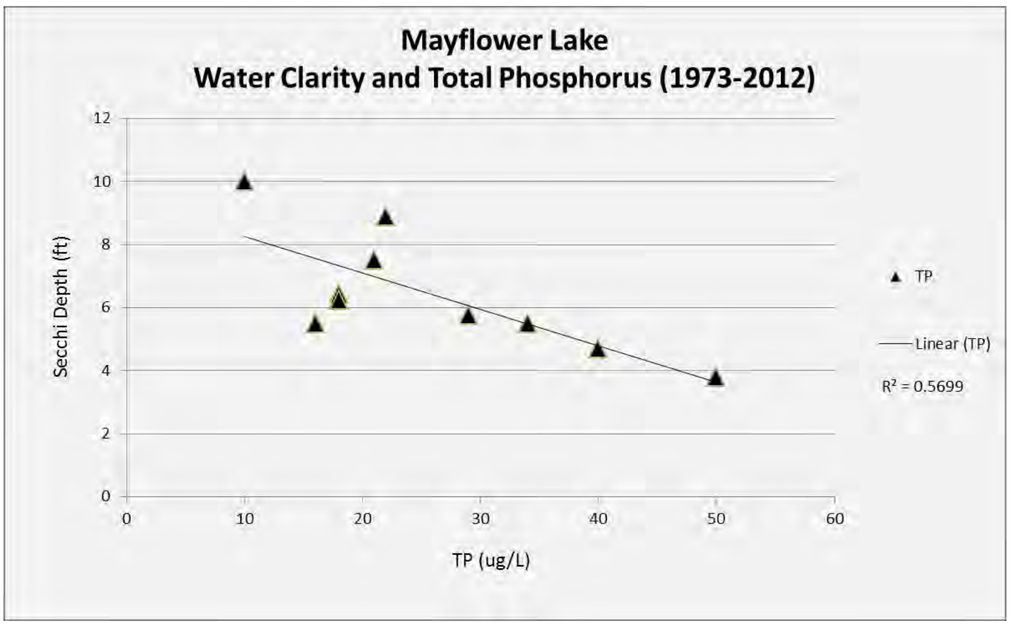


FIGURE 10. RELATIONSHIP BETWEEN WATER CLARITY AND TOTAL PHOSPHORUS CONCENTRATIONS IN MAYFLOWER LAKE, 1973-2012.

Estimates of phosphorus from the landscape can help to understand the phosphorus sources to Mayflower 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. Agriculture comprised the greatest amount of land in the watershed and modeling results indicated that it also had the greatest percentage of phosphorus contributions from the watershed to Mayflower Lake (Figure 11). 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).

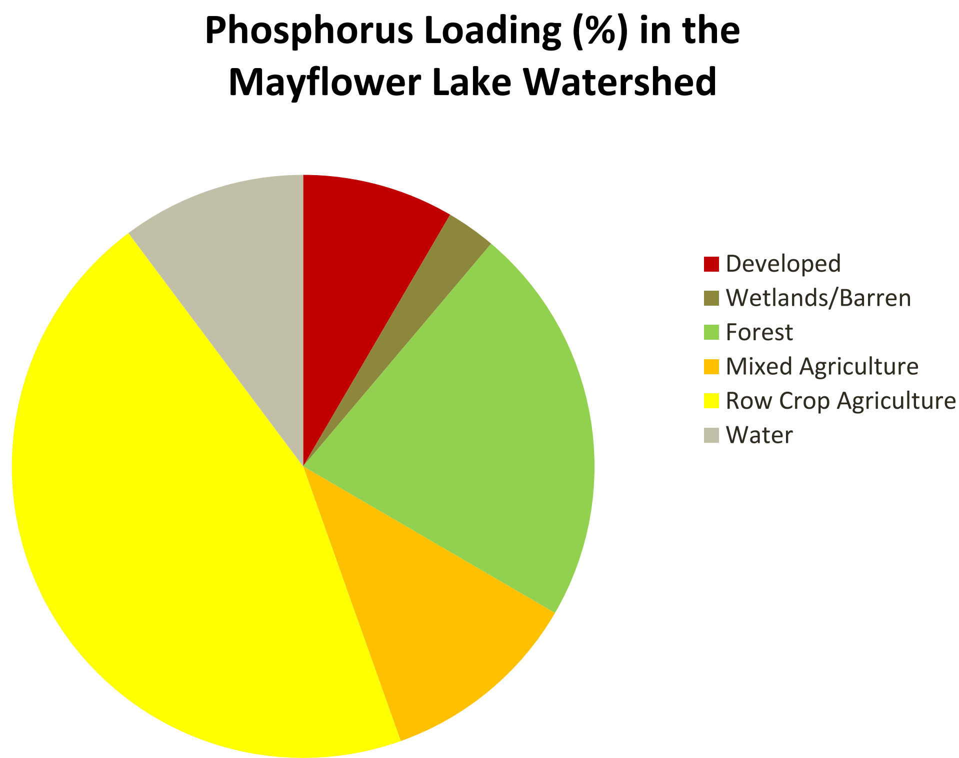


FIGURE 11. ESTIMATED PHOSPHORUS LOADS FROM LAND USES IN THE MAYFLOWER LAKE WATERSHED.

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

Mayflower Lake Land Use	Phosphorus Export Coefficient (lbs/acre-yr)	Land Use Area Within the Watershed		Phosphorus Load	
		Acres	Percent	Pounds	Percent
Water	0.10	95	13	9-26	11
Developed	0.13	53	7	7-14	**9**
Wetland/Barren	0.09	26	4	2-7	**3**
Forest	0.04	419	59	19-34	**25**
Mixed Agriculture	0.27	35	5	9-25	**12**
Row Crop Agriculture	0.45	85	12	38-76	**50**

*Values are not exact due to rounding and conversion.

Chlorophyll *a* is a measurement of algae in the water. Concentrations greater than 20 μg/L are perceived by many as problem blooms. In general, chlorophyll *a* concentrations in Mayflower Lake were low, ranging from a high of 12 μg/L in September 2011 to a low of 2 μg/L in September 2011. Concentrations averaged 5.2 μg/L during the two year study.

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 enhance the analysis of a lake's water quality because there are more species of algae than fish or aquatic plant species. 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 community in Mayflower Lake displayed very similar patterns in both 2011 and 2012 (Figure 12). Several species of diatoms dominated in the early season (April through July), while the blue-green algae dominated from August through the end of the season. In both years, the diatoms were the most common group found (averaging about 40%), followed closely by the blue-green algae (averaging about 30%). The green algae were never the dominant group, averaging about 20% across the seasons.

Based on the heavy midsummer algal growth, the common species of the dominant groups, water clarity depths, and nutrient loads, Mayflower Lake appeared to be moderately mesotrophic. The significant diatom populations were a positive sign, while the increasing blue-green populations were a potentially negative sign. The relatively low green algae populations indicated heavy consumption by the fishery. Conditions did not support a prediction of Mayflower Lake sliding into a eutrophic state.

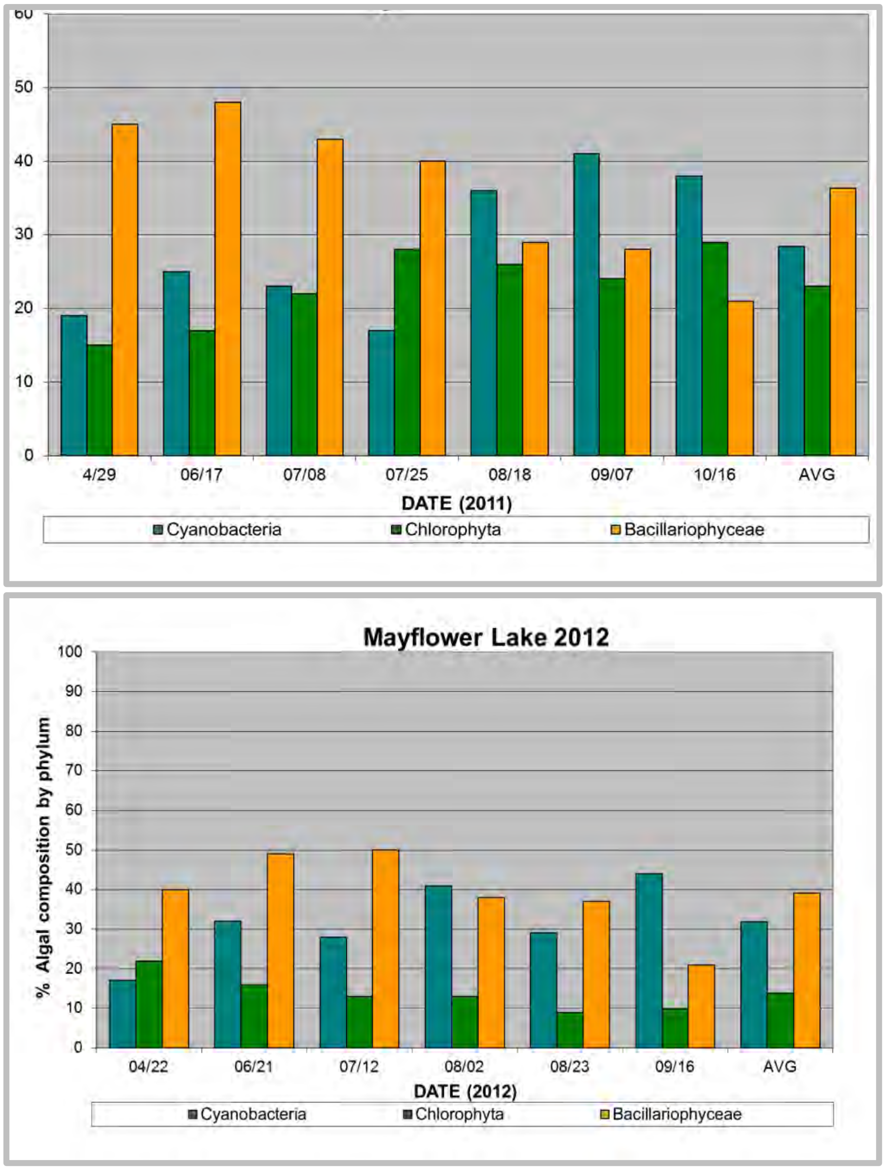


FIGURE 12. PERCENT ALGAL COMPOSITION OF MAYFLOWER LAKE, 2011 AND 2012.

SHORELAND HEALTH

Shoreland vegetation is critical to a healthy lake 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 shoreland areas in need of restoration, as well as shorelands in need of protection. In addition, this information will provide a baseline database from which to measure and monitor success.

MAYFLOWER LAKE SHORELAND SURVEY RESULTS

The survey collected data on 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 water. The three rings surrounding Mayflower Lake in Figure 14 depict the depth of vegetation along Mayflower 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 from the water's edge and includes a mixture of grasses, forbs, shrubs and trees.

Mayflower Lake has 2.8 miles of shoreline. The overall findings showed that 3,872 linear feet of shoreline were classified as having a grass/forb buffer depth of less than 35 feet inland from the water's edge. Similar results were observed for the shrubs layer. The minimum depth required by state and county shoreland zoning ordinances for the grasses, forbs, and shrubs vegetation buffer is 35 feet. The tree layer was found to be abundant, but 5,709 linear feet were classified as having a buffer depth of only 5-15 feet inland from the water's edge. These shoreland survey results are displayed in Figure 13.

Mayflower Lake's shoreland vegetation has been significantly altered by development, especially along the southern and eastern shorelines. Most of the grasses, forbs, and shrubs have been removed from these portions of the lake, leaving very narrow buffers for stormwater infiltration, erosion protection, and wildlife habitat. The western shoreline vegetation remains in a natural state with adequate vegetative buffers. If more development occurs on Mayflower Lake, changes can easily occur as development takes place. Minimizing impacts to Mayflower Lake from future development should include planning to ensure that prospective developers have information to make informed decisions and that zoning is in place to achieve habitat, water quality, and aesthetic goals.

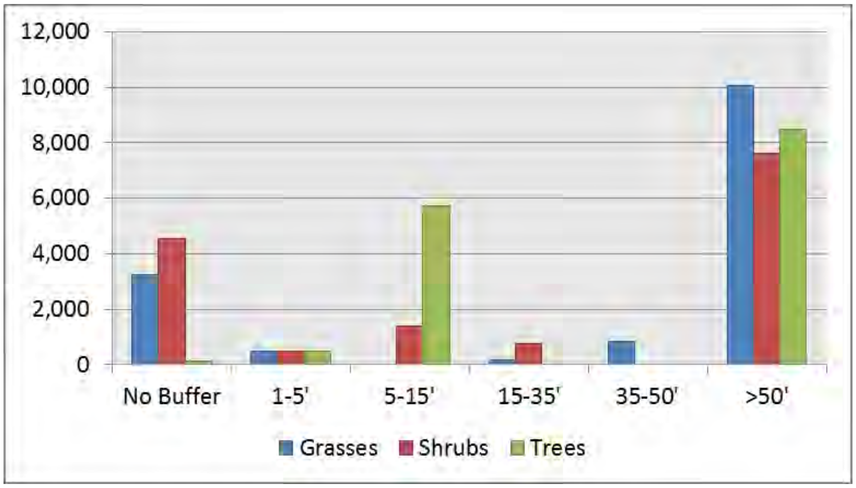


FIGURE 13. DEPTH OF SHORELAND VEGETATION INLANDFROM THE WATER'S EDGE FOR MAYFLOWER LAKE, 2011.

On the same day the vegetation survey was conducted, an assessment of disturbances was conducted around Mayflower Lake. Surveyors paddled along the shoreline and documented artificial beaches, docks, rip-rap, seawalls, erosion, and any structures built near the water's edge. Table 5 summarizes the disturbances identified around Mayflower Lake's shoreland, and Figure 15 displays the locations of the disturbances. Structures such as seawalls, rip-rap (rocked shoreline), and artificial beach result in reduction of habitat. Docks and artificial beaches can result in altered in-lake habitat; denuded lakebeds provide opportunities for invasive species to become established and reduce habitat that is important to fish and other lake inhabitants. Erosion contributes 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 manmade feature is unlikely to pose a large problem to a lake, but on developed lakes their collective impact can be a problem for lake habitat and water quality.

TABLE 5. DISTURBANCES LOCATED ALONG THE MAYFLOWER LAKE SHORELAND, 2011.

Type of Disturbance	No. of Occurrences
Artificial Beach	1
Dock	73
Rip-rap	8
Seawall	7
Erosion	0
Structures w/in 35'	4
Structures 35-75'	26

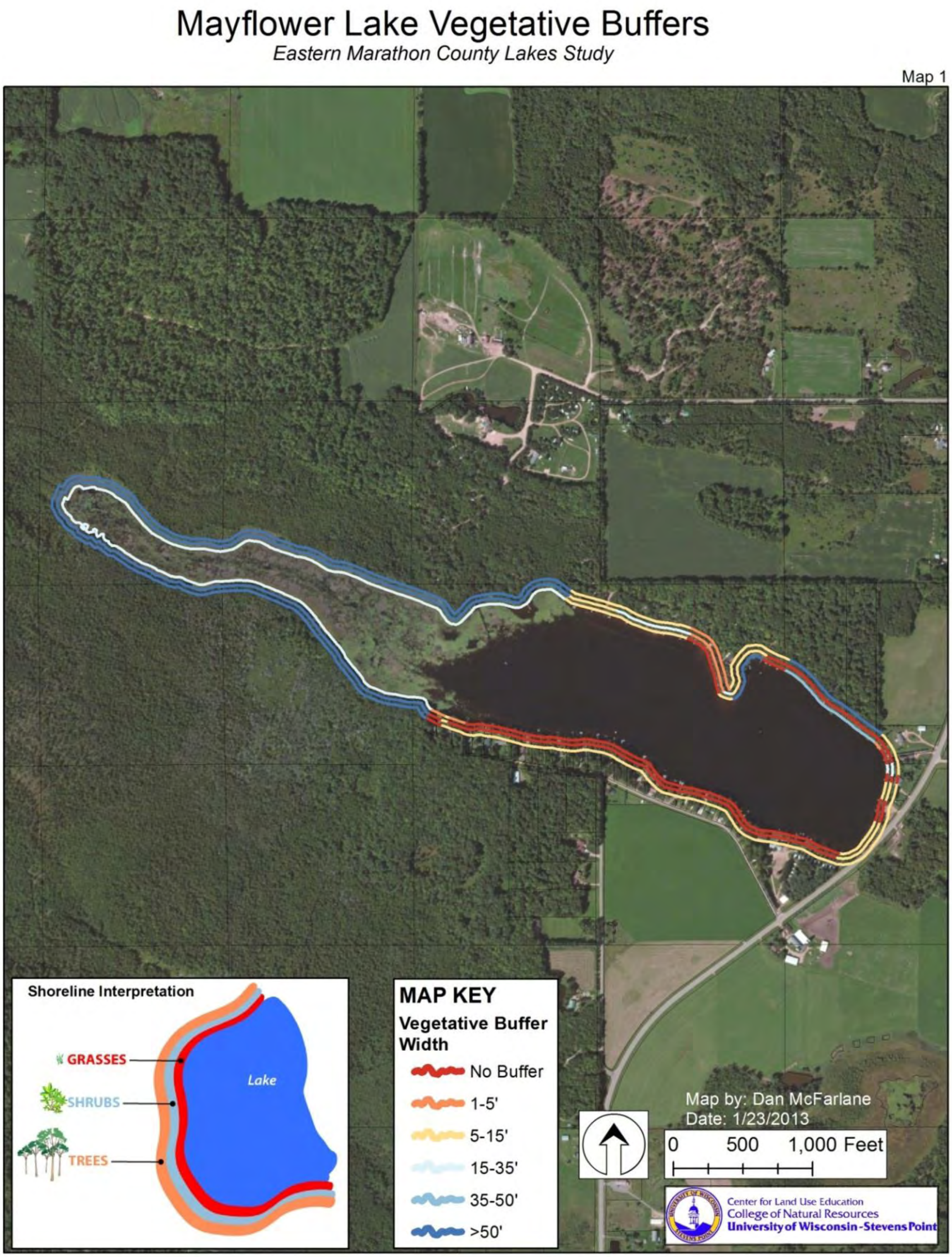


FIGURE 14. SHORELAND VEGETATION SURVEY OF MAYFLOWER LAKE, 2011.

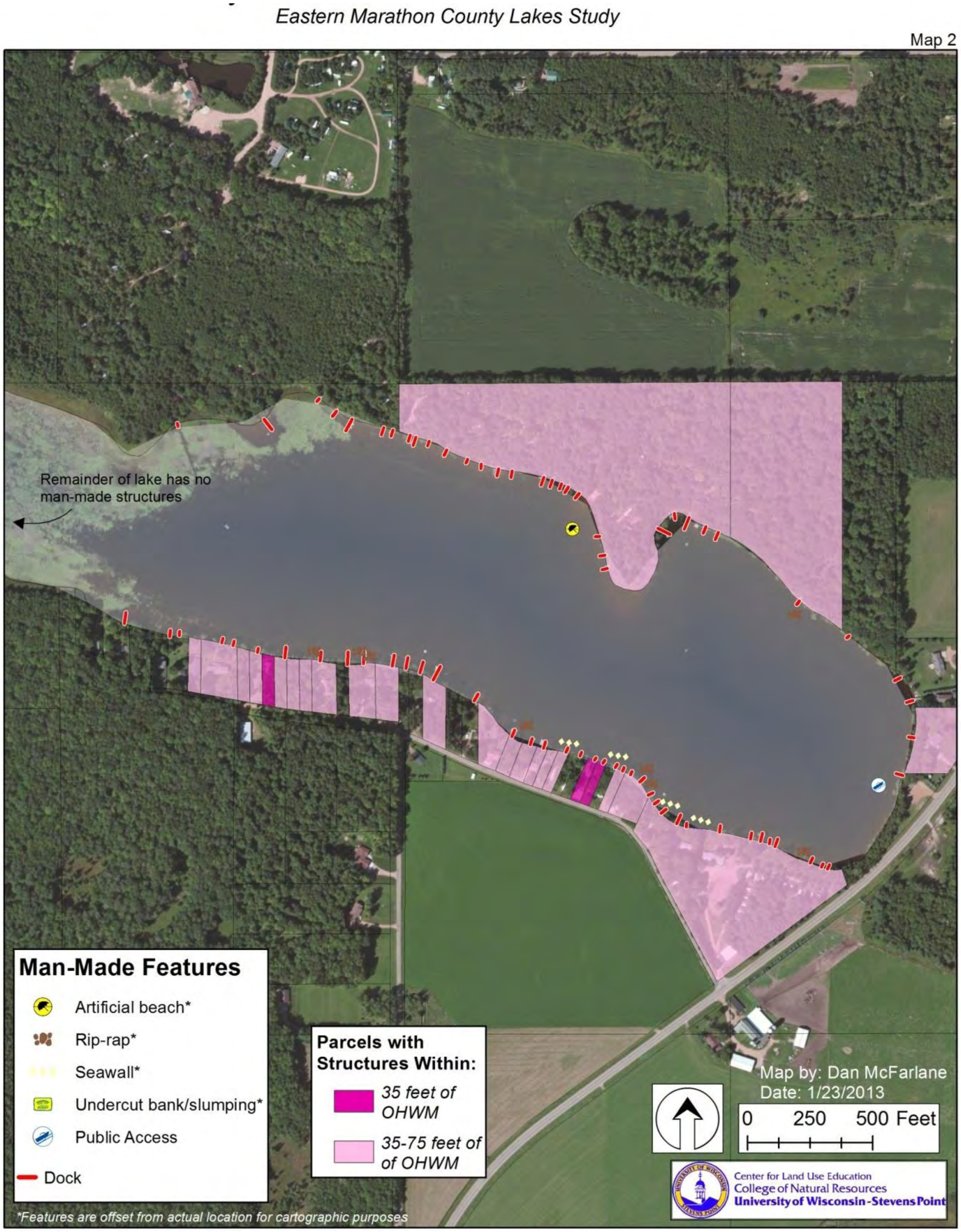


FIGURE 15. SHORELAND DISTURBANCE SURVEY OF MAYFLOWER LAKE, 2011.

A sustainable 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 nesting substrate, and water quality.

People are also an important part of a sustainable 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.

Mayflower Lake supports a warm water fish community. In 2012, nine fish species were sampled and identified out of the fourteen total species that have been recorded in surveys dating back to 1958 obtained from the Wisconsin Department of Natural Resources (Table 6). Although most species identified in 2012 had been previously reported, the black bullhead (*Ameiurus melas*) and the bluegill x pumpkinseed hybrid were newly documented. Species documented previously, but not detected during the 2012 survey were: common shiner (*Luxilus cornutus*), golden shiner (*Notemigonus crysoleucas*), green sunfish (*Lepomis cyanellus*), central mudminnow (*Umbra lima*), and white sucker (*Catostomus commersoni*). Bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*) were most abundant during the 2012 survey.

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

Species	1958	1962	1964	1970	1972	1983	1985	1988	1989	2000	2012
Black Bullhead											x
Black Crappie	x	x		x	x			x	x	x	x
Bluegill		x	x	x	x		x		x	x	x
Bluegill x Pumpkinseed hybrid											x
Bullhead	x	x		x	x		x	x	x		
Common Shiner								x			
Golden Shiner				x				x			
Green Sunfish										x	
Largemouth Bass				x		x	x	x	x	x	x
Central Mudminnow				x							
Northern pike				x	x	x	x	x	x		x
Pumpkinseed		x			x		x		x	x	x
Walleye	x	x	x	x	x	x	x	x	x	x	x
White Sucker	x			x			x	x		x	
Yellow Perch	x	x	x	x	x		x		x		x

Although infrequently encountered, walleye (Sander vitreus) and northern pike (Esox lucius) were the largest sampled fish in Mayflower Lake, with walleye reaching over 25 inches and pike exceeding 28 inches. Bluegill caught during the survey reached a maximum size of 7 inches and largemouth bass did not exceed 7.3 inches in the sample (Table 7). Crayfish were not encountered during the sampling.

TABLE 7. TOTAL CATCH AND LENGTHS OF FISH SPECIES IN MAYFLOWER LAKE, 2012 SURVEY.

Species	Min Length (in)	Max Length (in)	Average Length (in)	Total Catch
Bluegill	0.4	7.0	3.3	159
Largemouth Bass	0.7	7.3	1.2	95
Pumpkinseed	2.4	7.2	3.6	55
Bluegill x Pumpkinseed Hybrid	1.9	7.4	3.0	38
Yellow Perch	1.3	6.3	2.2	6
Black Crappie	6.8	9.6	8.0	4
Walleye	16.3	25.5	19.6	3
Black Bullhead	10.8	14.3	12.6	2
Northern Pike	24.2	28.4	26.3	2

A variety of management techniques were attempted to maintain fisheries in Mayflower Lake. In 1959, Wisconsin Department of Natural Resources staff noted the potential to manage populations of northern pike, largemouth bass, and bluegill. In 1957 and 1958, adult northern pike were stocked, and public opinion noted an increase in catchable-sized bluegill with the introduction of predator fish. Due to this success, a complete renovation program with chemical treatment was proposed; however, the proposal was declined. In 1972, basic management focused on populations of northern pike, largemouth bass, and panfish. Due to several winter fish kill events resulting from low dissolved oxygen concentrations, dip netting permits were approved in 1972, 1975, and 1979. As a result of these frequent winterkill events, a permanent aeration system was installed on Mayflower Lake in 1979. A 1989 fisheries report indicated largemouth bass were abundant, yet growth was slow. Walleye recruitment was noted as variable across years leading up to the 1989 report.

Chemical and mechanical controls were used to address concerns about excessive aquatic plant growth in Mayflower Lake. Chemical treatments were noted in 1971 and 1988, and mechanical harvesting was noted in 1988 and 2009.

Fish stocking records for Mayflower Lake date back to 1938 according to Wisconsin Department of Natural Resources files (Table 8). Stocking efforts have focused mainly on walleye; however, largemouth bass, yellow perch (*Perca flavescens*), and smallmouth bass (*Micropterus dolomieu*) have also been stocked. In spite of stocking efforts, walleye reproduction was not observed in the 2012 survey.

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

Year	Species	Age Class	Number Fish Stocked	Avg Fish Length (in)	Year	Species	Age Class	Number Fish Stocked	Avg Fish Length (in)
1938	Walleye	Fry	266,390		1983	Walleye	Fingerling	5,000	
1939	Walleye	Fry	575,000		1985	Walleye	Fingerling	5,000	
1940	Walleye	Fry	200,000		1987	Walleye	Fingerling	15,000	
1943	Largemouth Bass	Fingerling	400		1989	Walleye	Fingerling	11,335	
1943	Smallmouth Bass	Fingerling	300		1991	Walleye	Fingerling	5,000	
1944	Smallmouth Bass	Fingerling	50		1995	Walleye	Fingerling	2,544	
1945	Largemouth Bass	Fingerling	400		1997	Walleye	Fingerling	4,900	
1950	Walleye	Fry	3,478,000		1999	Walleye	Fingerling	4,900	
1956	Walleye	Fry	1,054,000		2001	Walleye	Fingerling		
1959	Walleye	Fry	2,000,000		2001	Walleye	Fingerling	4,900	
1961	Walleye		4,000		2003	Walleye	Fingerling	4,840	
1962	Walleye	Fry	2,000,000		2005	Walleye	Fingerling	4,860	
1965	Walleye	Fingerling	40,000		2006	Largemouth bass	Fingerling	900	
1969	Walleye	Fingerling	5,320		2006	Yellow perch	Fingerling	200	
1969	Walleye	Fingerling	240		2008	Smallmouth bass	Fingerling	200	
1972	Walleye	Fingerling	5,000		2008	Walleye	Fingerling	750	
1972	Walleye	Fry	999,999		2009	Smallmouth bass	Yearling	200	
1973	Walleye	Fingerling	4,992		2009	Walleye	Fingerling	3,520	
1974	Walleye	Fingerling	10,272		2009	Walleye	Fingerling	600	
1975	Walleye	Fingerling	5,000		2010	Smallmouth bass	Fingerling	250	
1975	Walleye	Fry	250,000		2010	Walleye	Fingerling	750	
1976	Walleye	Fingerling	5,000		2011	Walleye	Fingerling	3,500	
1976	Walleye	Fry	250,000		2011	Walleye	Fingerling	900	
1977	Walleye	Fingerling	5,000		2011	Walleye	Yearling	1,000	

BOTTOM SUBSTRATE AND COARSE WOODY HABITAT

To successfully sustain a healthy fish community, a lake must have the habitat to support it. Habitat needs of fish include aquatic plants (not too many and not too few) and woody structure such as logs, fallen trees, and stumps. Woody structure provides cover for fish to hide, as well as habitat for invertebrates that are food for many fish species. Invertebrates, zooplankton and algae are the main food sources for many fish. These organisms often live on or around aquatic plants or woody structure. Many fish use floating vegetation like lily pads or near-shore emergent vegetation like bulrushes for spawning habitat. Cobble and gravel substrates also provide excellent spawning beds for numerous species. Many young fish prefer to dwell in adjacent wetlands that provide plenty of food, cover, and fewer large predators.

Bottom substrate and woody habitat were evaluated with side-scan sonar from the shoreline lakeward for a distance of 90 feet. Substrate distribution in Mayflower Lake varied (Figure 16). In the western portion of the lake, sediments were generally soft, and muck dominated (82.4%). In the southern and eastern portions of the lake, large areas of hard substrate were present, including boulder beds, cobble, and mixed substrates that are used by many fish for spawning habitat.

Gravel areas are used as spawning habitat for many sunfish (bluegill, pumpkinseed (*Lepomis gibbosus*), black bass), where males will construct nests and guard their young. Northern pike, which do not offer parental care, use areas with emergent and floating-leaf vegetation in shallow or flooded areas for spawning. Black crappie (*Pomoxis nigromaculatus*) use bulrush habitat on gravel or sand substrates where they construct nests and guard young. Bulrush was present along areas of the western shoreline in Mayflower Lake and randomly along the northern shoreline (Figure 16). Yellow perch and walleye use near-shore cobble in oxygen-rich environments for spawning activity and offer no parental care. Sand can be important habitat for reproduction of non-game minnow. The presence of young bass and abundant sunfish during sampling indicated successful reproduction of these species. The absence of young northern pike and walleye may indicate poor natural reproduction; however, more intensive sampling efforts would be required to properly assess reproductive success of any individual fish species.

Coarse woody habitat (CWH), including downed trees and logs, were abundant along the eastern end of Mayflower Lake and was lacking along most of the shoreland (Figure 17). This structure is used by young prey fish and other aquatic organisms for spawning, foraging, and protective cover. The addition of CWH cover in sparse areas of Mayflower Lake would benefit the fish community.

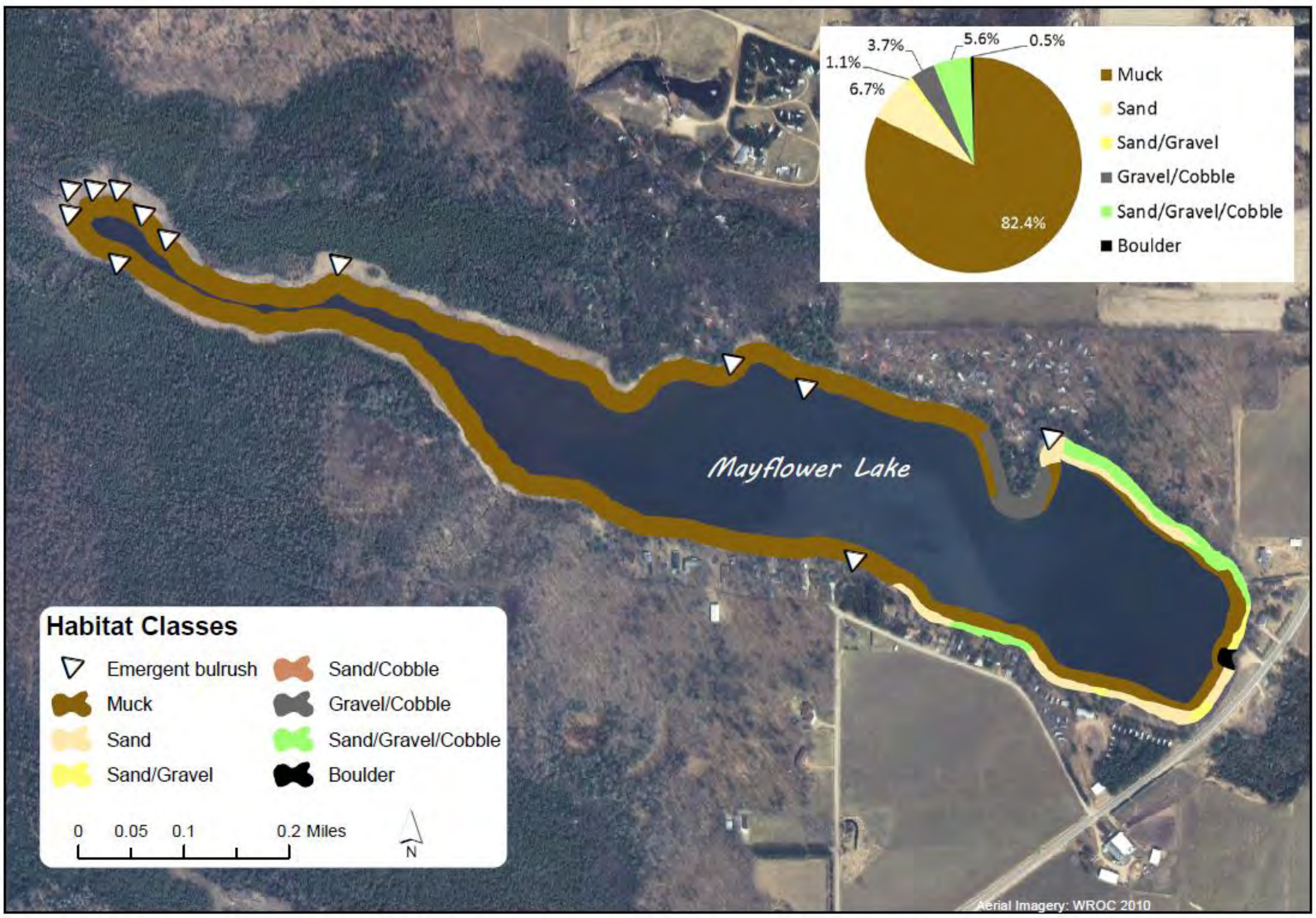


FIGURE 16. DISTRIBUTION OF SUBSTRATE HABITAT AND BULRUSH NEAR THE SHORES OF MAYFLOWER LAKE, 2012.

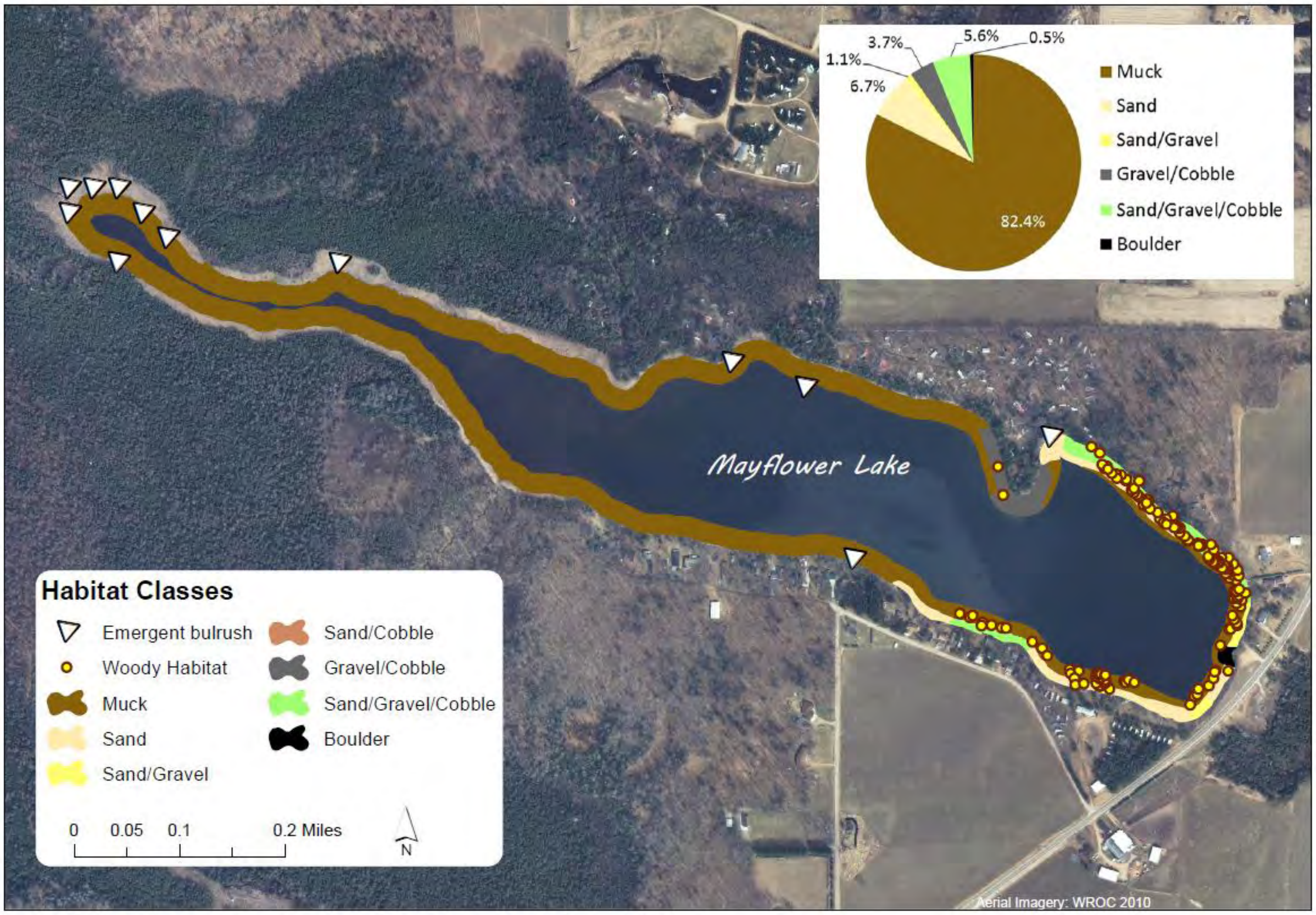
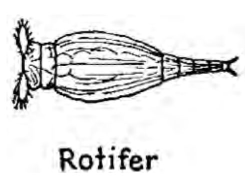


FIGURE 17. DISTRIBUTION OF COARSE WOODY HABITAT NEAR THE SHORES OF MAYFLOWER LAKE, 2012.

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 lives. Food (bacteria and algae), temperature, and water chemistry are important in determining the type of zooplankton that can live in a particular lake. Fish predation can also 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.



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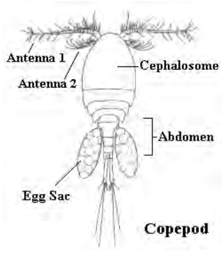
Rotifers are small invertebrate animals with simple body designs. They are usually not found uniformly throughout lakes, but congregate in areas of high food abundance (bacteria, algae, and other rotifers). Generally, a lake's trophic status influences or can be predicted based on the abundance and diversity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


http://www.oocities.org

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 the 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 Mayflower Lake was very diverse (Table 9, Table 10). Zooplanktons 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 rotifers and copepods, with rotifer and copepod subdominants.

- There were 933 individuals counted during this period:
    - 487 rotifers, 57 cladocerans, 389 copepods

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

- There were 386 individuals counted during this period:
    - 38 rotifers, 129 cladocerans, 219 copepods

Rotifers and copepods dominated three of four sample periods during 2011-2012. These taxa dominated from early summer though fall before falling into subdominant positions in late winter. A variety of copepods and cladocerans were abundant spring through fall. No net plankton were collected in late winter, indicating low productivity or a prolonged winter egg stage for many of the cladocerans and copepods.

The zooplankton community presented the picture of a mesotrophic lake when considered relative to the algal, phosphorus, and nitrogen values for Mayflower Lake. The six genera of rotifers, five genera of cladocerans, and five genera of copepods identified during the sample periods were relatively common and none of those that reached numerical dominance in the sample counts are considered invasive or exotic. The stable, little-changing zooplankton community dominated by nano-plankton rotifers and copepods suggested that Mayflower Lake is fairly mesotrophic.

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

Date	Primary dominant	Species	Secondary dominant	Species	Tertiary dominant	Species
April 25	Rotifer	*Keratella cochlearis*	Copepod	Nauplii	Rotifer	*Polyarthra dolichoptera*
June 20	Rotifer	*Keratella longispina*	Rotifer	*Keratella cochlearis*	Copepod	Nauplii
October 21	Copepod	*Diacyclops nanus*	Rotifer	*Polyarthra vulgaris*	Cladoceran	*Bosmina longirostris*
March 4	Copepod	Nauplii	Copepod	*Paracyclops fimbriatus poppei*		*Diacyclops nanus*

TABLE 10. MOST COMMON (NET) ZOOPLANKTON BY DATE IN MAYFLOWER LAKE FROM APRIL TO OCTOBER 2011.

Date	Primary dominant	Species	Secondary dominant	Species	Tertiary dominant	Species
April 25	Rotifer	*Keratella longispina*	Rotifer	*Filinia* spp.		
June 20	Copepod	*Diacyclops nanus*	Copepod	*Senecella calanoides*	Cladoceran	*Daphnia retrocurva*
October 21	Copepod	*Diacyclops nanus*	Copepod	*Tropocyclops prasinus mexicanus*	Cladoceran	*Daphnia pulex*

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 Mayflower Lake, sixty-nine percent (180 of 260) of the sampled sites had vegetative growth. Of the sampled sites within Mayflower Lake, the average depth was 8 feet and the maximum depth was 15 feet. Twenty-two species of aquatic plants were found in Mayflower Lake (Table 11), with the greatest diversity located in the shallows of the western side of the lake (Figure 18). Mayflower Lake ranked fourth highest out of the eleven lakes in the Eastern Marathon County Lakes Study for the number of aquatic plant species.

The dominant plant species was white water lily (*Nymphaea odorata*), followed by Fries' pondweed (*Potamogeton friesii*) and muskgrass (*Chara* spp.). The seeds of the white water lily provide food to waterfowl. The broad, floating leaves of this aquatic species offer shade and shelter to fish. Fries' pondweed is also an important food source for waterfowl and protective cover for fish and invertebrates. Muskgrass is a favorite food source for a wide variety of waterfowl, and is provides important cover and food for young trout, largemouth bass, and smallmouth bass (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 less tolerant of disturbance. The FQI for Mayflower Lake was 27, which was slightly above average compared with the other lakes in the Eastern Marathon County Lakes Study. Three of the high quality aquatic plant species in Mayflower Lake with a C value of eight or greater were creeping bladderwort (*Utricularia gibba*), Fries pondweed (*Potamogeton friesii*), and white-stem pondweed (*Potamogeton praelongus*). No species of special concern in Wisconsin were found in Mayflower Lake.

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 biodiversity. The aquatic plant community in Mayflower Lake had a SDI value of 0.9, which represented above-average biodiversity when compared with other lakes in the Eastern Marathon County Lakes Study.

The presence of curly-leaf pondweed (*Potamogeton crispus*), CLP, was documented in Mayflower Lake by biologists from the Wisconsin Department of Natural Resources prior to 2012. This species is often missed during late summer aquatic plant surveys because it dies back in late June, so a special survey for CLP was conducted in June 2012 to evaluate populations of this non-native species in Mayflower Lake. CLP was not identified in the lake in the 2012 survey. Similar-looking species were observed during the June survey, including variable-leaf pondweed (*Potamogeton gramineus*) and clasping-leaf pondweed (*Potamogeton richardsonii*). Mayflower Lake was again inventoried for non-native aquatic species during the full aquatic plant survey in August 2012; no aquatic invasive species were found during this survey.

Overall, the aquatic plant community in Mayflower Lake can be characterized as having good species diversity. 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 MAYFLOWER LAKE, 2012.

Common Name	Scientific Name	Coefficient of Conservatism Value (C Value)
Emergent Species		
common arrowhead	*Sagittaria latifolia*	3
softstem bulrush	*Schoenoplectus tabernaemontani*	4
broad leaved cattail	*Typha latifolia*	1
Floating Leaf Species		
watershield	*Brasenia schreberi*	6
spatterdock	*Nuphar variegata*	6
white water lily	*Nymphaea odorata*	6
Submergent Species		
coontail	*Ceratophyllum demersum*	3
muskgrass	*Chara*	7
slender waterweed	*Elodea nuttallii*	3
water star-grass	*Heteranthera dubia*	6
northern water-milfoil	*Myriophyllum sibiricum*	6
slender naiad	*Najas flexilis*	6
northern naiad	*Najas gramicillima*	7
Fries' pondweed	*Potamogeton friesii*	8
variable pondweed	*Potamogeton gramineus*	7
floating-leaf pondweed	*Potamogeton natans*	5
white-stem pondweed	*Potamogeton praelongus*	8
clasping-leaf pondweed	*Potamogeton richardsonii*	5
flat-stem pondweed	*Potamogeton zosteriformis*	6
Sago pondweed	*Stuckenia pectinata*	3
creeping bladderwort	*Utricularia gibba*	9
common bladderwort	*Utricularia vulgaris*	7

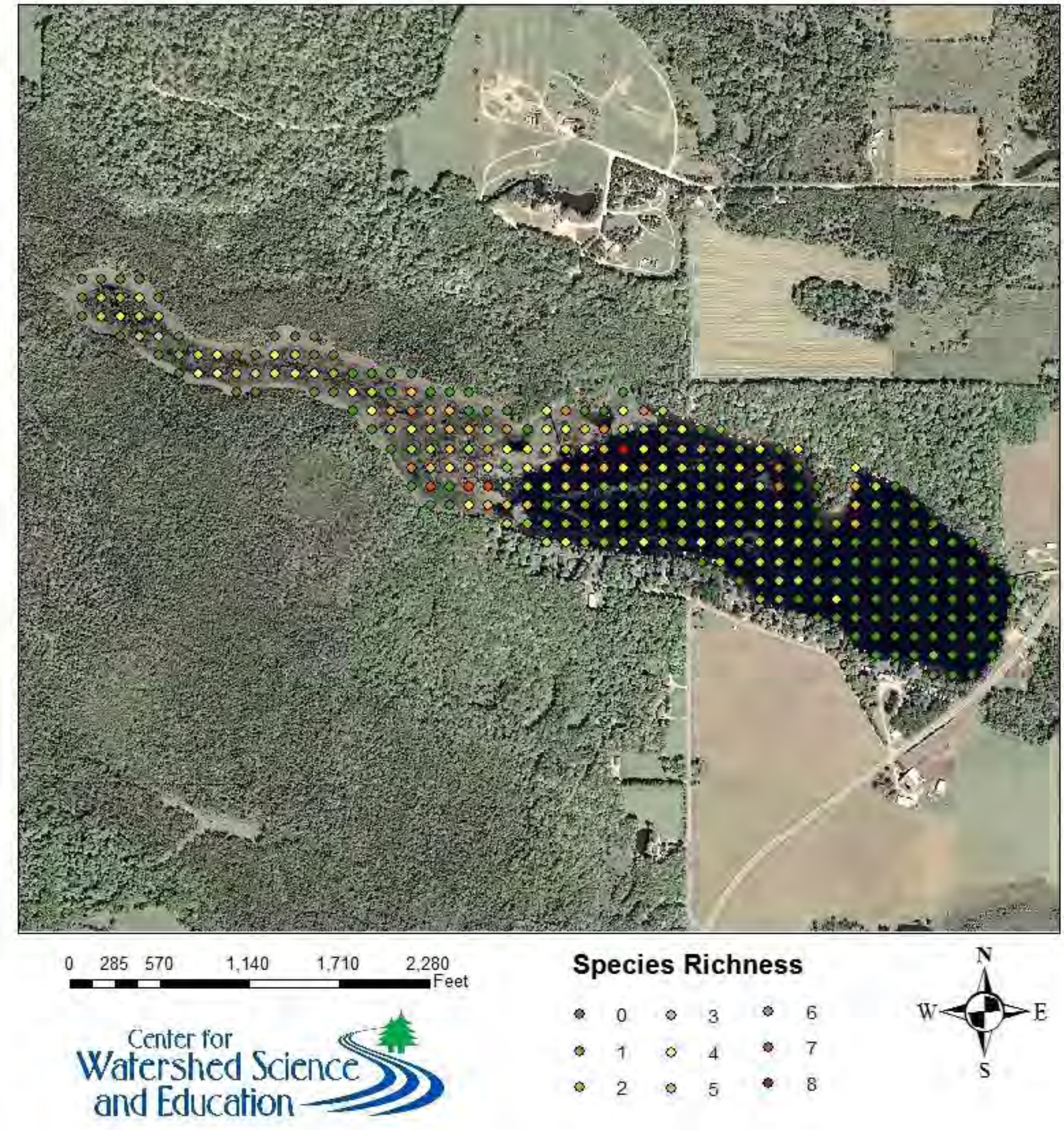


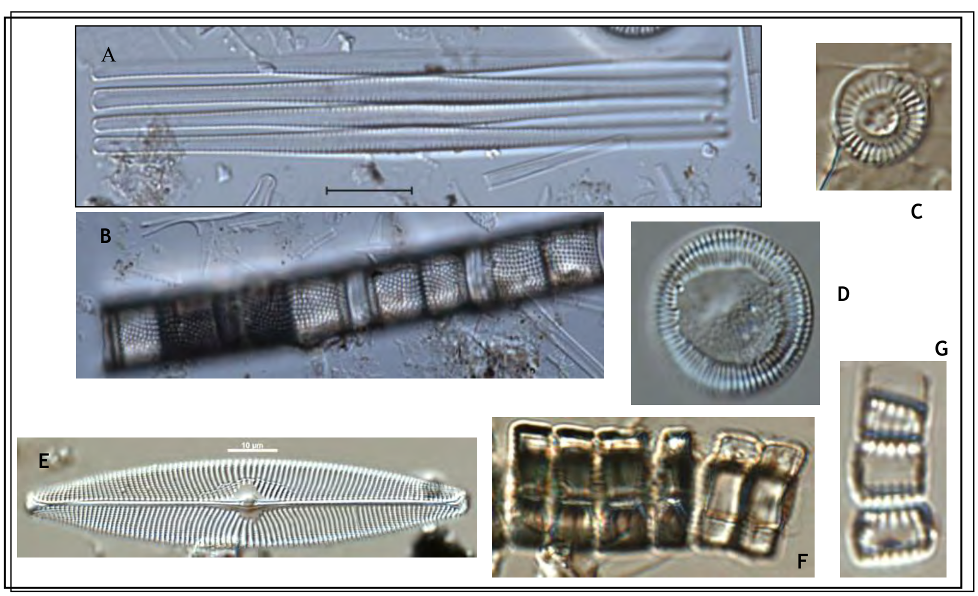
FIGURE 18. SPECIES RICHNESS AT SAMPLE SITES ON MAYFLOWER LAKE.

Questions often arise concerning how a lake's water quality has changed over time related to changes in land use in the watershed, the abundance and diversity of its aquatic plant communities, and the state of its shoreland vegetation. The analysis of a lake's sediment core is an effective means to reconstruct some of the changes that have occurred over time. Lakes act as sediment traps for particles that are either delivered to the lake from the surrounding landscape, the atmosphere, or occur in the lake itself. The chemical composition of the sediment can help decipher the composition of lake's past water quality. Lake sediment also contains the remains of diatom skeletons, algal species' cell walls, and partially preserved aquatic plants. By examining remains trapped in the sediment, changes in the lake's ecosystem can be inferred.

Five lakes in the Eastern Marathon County Lakes Study were chosen for sediment core analysis. A single sediment core approximately 35 inches in length was extracted for analysis from the deepest area of Mayflower Lake in 15 feet of water in November 2012. It was estimated that the bottom portion of this core was deposited at least 150 years ago.

BIOLOGICAL COMPONENTS IN THE SEDIMENT CORE

Aquatic organisms can be good indicators of water chemistry because they live in direct contact with the water and are strongly affected by the chemical composition of their surroundings. Most indicator groups grow rapidly and are short-lived, so the community composition responds to changing environmental conditions. Diatoms, a type of algae, are especially useful because they are usually abundant, are ecologically diverse and their ecological tolerances are understood. In addition, the cell walls of diatoms are made of silica, which enables them to be highly resistant to degradation and well-preserved in sediments (Figure 19).



THE FIRST FOUR DIATOMS, FRAGILARIA CROTONENSIS (A), AULACOSEIRA AMBIGUA (B), DISCOTELLA STELLIGERA (C), AND CYCLOTELLA MICHIGANIANA (D) TYPICALLY ARE FOUND IN OPEN WATER ENVIRONMENTS. STAUROSIRA CONSTRUENS (F) AND STAUROSIRA CONSTRUENS VAR. VENTER (G) ARE COMMONLY FOUND ATTACHED TO SUBSTRATES SUCH AS AQUATIC PLANTS, OTHER FILAMENTOUS ALGAE OR GROWING ON THE SEDIMENTS AND ARE OFTEN ASSOCIATED WITH HIGHER NUTRIENT CONCENTRATIONS. NAVICULA VULPINA (E) GROWS ON AQUATIC PLANTS AND IS USUALLY FOUND IN LOW NUTRIENT ENVIRONMENTS.

Figure 2. Photomicrographs of the common diatoms found in the sediment cores. The first four diatoms (A) *Fragilaria crotonensis*, (B) *Aulacoseira ambigua*, (C) *Discotella stelligera, and (D) Cyclotella michiganiana* typically are found in open water environments. *Staurosira construens* (F) and *Staurosira construens* var. *venter* (G) is commonly found attached to substrates such as aquatic plants, other filamentous algae or grow on the sediments and are often associated with higher nutrient concentrations. *Navicula vulpina* (E) grows on aquatic plants and is usually found in low nutrient environments.

FIGURE 19. PHOTOMICROGRAPHS OF THE COMMON DIATOMS FOUND IN THE MARATHON COUNTY LAKE SEDIMENT CORES.

The diatom community was analyzed in samples from the top and bottom of Mayflower Lake's sediment core. Both the bottom and the top of the core were dominated by benthic (bottom-feeding) species of diatoms (Figure 20). The dominant species in the bottom of the core was *Staurosirella pinnata,* which is commonly seen growing on sediments and is associated with filamentous algae. In contrast, this species was not common at the top of the core. Although benthic species were abundant, planktonic diatom species were common as well. The diatom species richness and diversity are greater at the top of the core, indicating that more aquatic plants are present now than in the past. The increase in phosphorus levels in recent years has not likely been substantial, as the top of the core was not dominated by diatom species typically found in nutrient-rich conditions.

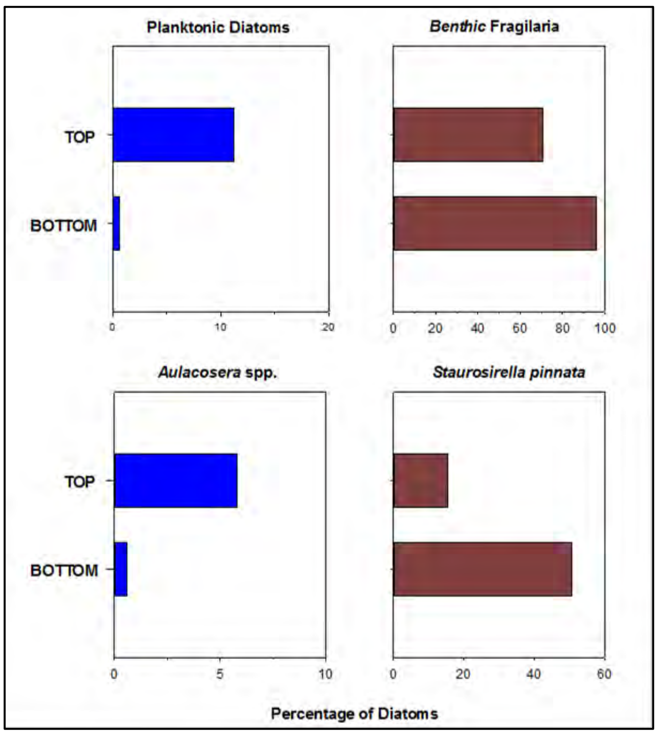


FIGURE 20. CHANGES IN ABUNDANCE OF IMPORTANT DIATOMS FOUND AT THE TOP AND BOTTOM OF THE SEDIMENT CORE FROM MAYFLOWER LAKE.

Relative dating techniques were used to provide chronological control of the sedimentary record of lake events. A spike in ragweed pollen (*Ambrosia* spp.) serves as a strong indicator of initial land clearance. When combined with historical maps, tax records and other documentation, an accurate date can be ascribed to the onset of these settlement activities, and thus the depth of the ragweed spike in the lake sediment.

In Mayflower Lake, ragweed pollen grains are fewer and the ragweed index is lower deeper in the core. Both begin to rise at the depth of 20-21 inches and then again at 16-17 inches (Figure 21). The initial increase in ragweed at 20-21 inches likely accompanied the onset of logging in the area. The second increase at 16-17 inches from the top of the core most likely occurred a decade or two later as agricultural fields replaced the logged area near Mayflower Lake.

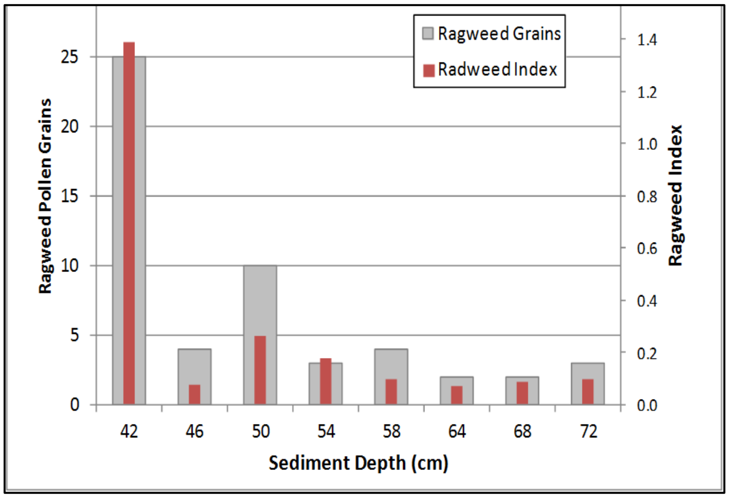
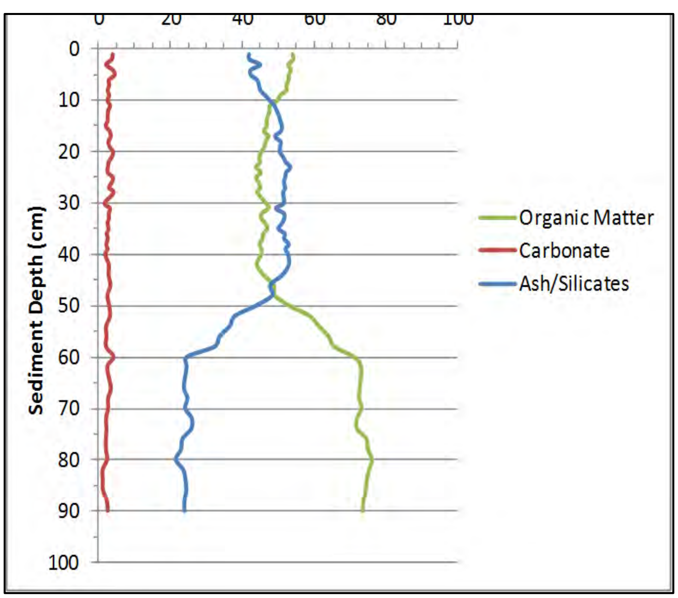


FIGURE 21. RAGWEED POLLEN IN MAYFLOWER LAKE SEDIMENT CORE.

PHYSICAL PROPERTIES OF SEDIMENT

Mayflower Lake's sediment is dark greenish-black to almost black in color throughout the core. The dark color is likely the result of high a mounts of organic matter or iron staining of the sediment. As microbes and other organisms decompose in the lake sediment, dissolved oxygen in the overlying water decreases and the sediment is altered by the production of iron compounds. Although this typically occurs seasonally in most lakes, it becomes more pronounced with increased nutrients, algae, and aquatic plants. The darkest colors in the core are seen from 7-23 inches.

In addition to the color changes in the sediment core, there were also textural changes. Coarse silt and sand were observed from the top of the core to depths of 23 inches. Sand is indicative of shoreland disturbance related to erosion from land clearing and large storm events.



A test to determine the composition of Mayflower Lake's sediment core was conducted. This test is called loss on ignition (LOI). Various components comprise the bulk of the lake's sediment core, including organic matter, marl (carbonate), and silica (sand, silt, and clay). During the LOI analysis, the components are burned off (Figure 22). The LOI data for Mayflower Lake indicated that organic matter was more abundant in the top 4 inches and again below 23 inches in the sediment core. Silica is abundant in the core from depths of 4-23 inches. The reduction of silica in the top 4 inches of the core suggests a reduction in shoreland disturbance in recent years.

FIGURE 22. LOSS ON IGNITION RESULTS FOR MAYFLOWER LAKE.

SEDIMENT CORE RESULTS SUMMARY

Analysis of the biological components and physical properties of Mayflower Lake's sediment core indicated an increase in erosion-induced processes such as land clearing, storm events, and shoreland disturbance since the time of land settlement around the lake. The analyses indicate these activities occurred more frequently in recent decades, but appear to have been minimized in recent years. Results suggest an increase in nutrient delivery, including phosphorus, to the lake over this time period. While the diatom communities and the physical properties of the sediment did not directly show this increase, they did indicate an increase in aquatic plants and algae in recent years near the top of the core. These analyses also suggest that Mayflower Lake has experienced a limited increase in phosphorus concentrations, but substantial changes in habitat during the last century. Overall, there was a slight decrease in organic matter in the lake. This, along with slightly lighter sediment colors at the top, suggests that erosion and aquatic plant growth may have stabilized and declined slightly in recent years.

CONCLUSIONS & RECOMMENDATIONS

A balanced fish community has a mix of predator and prey species, each of which has different needs in order to flourish, including sufficient food, habitat, appropriate nesting substrate, and water quality.

Mayflower Lake supports a warm water fish community. In a fishery survey conducted in 2012, nine fish species were sampled and identified out of the fourteen total species that have been recorded in surveys dating back to 1958 obtained from the Wisconsin Department of Natural Resources.

- In 2012, although infrequently encountered, walleye and northern pike were the largest sampled fish in Mayflower Lake, with walleye reaching over 25 inches and pike exceeding 28 inches. Bluegill caught during the survey reached a maximum size of 7 inches and largemouth bass did not exceed 7.3 inches in the sample.
- The presence of young bass and abundant sunfish sampling indicated successful reproduction of these species. The absence of young northern pike and walleye may indicate poor natural reproduction; however, more intensive sampling efforts would be required to properly assess reproductive success of any individual fish species.
- Crayfish were not encountered during the sampling period in 2012.
- Due to several winter fishkill events resulting from low dissolved oxygen concentrations, dip netting permits were approved in 1972, 1975, and 1979. In response to these frequent winterkill events, an aeration system was installed on Mayflower Lake in 1979.
- During the 2010-2012 study, measurements of dissolved oxygen in Mayflower Lake indicated that concentrations ranged from plentiful to limited depending upon the depth and time of year. Dissolved oxygen was plentiful from the lake surface to the lake bottom during spring and fall. In winter of both years, at the deep hole, dissolved oxygen concentrations fell below 5 mg/L. During summer months, dissolved oxygen concentrations varied with depth as biological processes in the lake consumed or generated oxygen.
- Bottom substrate and woody habitat were examined from the shoreline lakeward for a distance of 90 feet. Substrate distribution in Mayflower Lake varied. In the western portion of the lake, sediments were generally soft, and muck dominated. In the southern and eastern portions of the lake, large areas of hard substrate were present, including boulder beds, cobble, and mixed substrates that are utilized by many fish for spawning habitat.
    - Gravel areas are utilized as spawning habitat by many sunfish (bluegill, pumpkinseed (Lepomis gibbosus), black bass), where males will construct nests and guard their young.
    - Northern pike, which do not offer parental care, utilize areas with emergent and floating-leaf vegetation in shallow or flooded areas for spawning. Bulrush was present along areas of the western shoreline in Mayflower Lake and randomly along the northern shoreline.
    - Black crappie (Pomoxis nigromaculatus) utilize bulrush habitat on gravel or sand substrates where they construct nests and guard young.
    - Yellow perch and walleye utilize near-shore cobble in oxygen-rich environments for spawning activity and offer no parental care.
    - Sand can be important habitat for reproduction of non-game minnow.
- Coarse woody habitat (CWH), including downed trees and logs, is utilized by young prey fish and other aquatic organisms for spawning, foraging, and protective cover.
    - CWH was abundant in portions of Mayflower Lake, but was lacking along most of the shoreland.

- The addition of near shore CWH cover in sparse areas of Mayflower Lake would benefit the fish community.

The interdependence of algae, zooplankton, and young fish as predators and prey form the primary food web in most lakes. Zooplanktons 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, helping 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 identified in Mayflower Lake during the sample periods were relatively common and none of those that reached numerical dominance in the sample counts were considered invasive or exotic.
- The stable, little-changing zooplankton community dominated by the nano-plankton rotifers and copepods suggested that Mayflower Lake is fairly mesotrophic.

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, green algae, and diatoms.
- The significant diatom populations in Mayflower Lake are a positive sign, the increasing blue-green populations are a potentially bad sign, and the lower green algae populations indicated heavy consumption by the fishery.
- Based on the heavy midsummer algal growth, the common species of the dominant groups, water clarity depths, and nutrient loads, Mayflower Lake appeared to be moderately mesotrophic. Current conditions do not support a prediction of Mayflower Lake sliding into a nutrient-rich (eutrophic) state.

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.

- Twenty-three species of aquatic plants were found in Mayflower Lake, with the greatest diversity located in the shallows of the western side of the lake.
- Three high quality aquatic plant species (with a C value of eight or greater) are in Mayflower Lake: creeping bladderwort, Fries' pondweed, and white-stem pondweed. The Floristic Quality Index for Mayflower Lake was slightly above-average compared with the other lakes in the Eastern Marathon County Lakes Study.

- In lakes, one of the measures of biodiversity is based on the number of species per site. The aquatic plant community in Mayflower Lake had above-average biodiversity when compared with other lakes in the Eastern Marathon County Lakes Study.
- Overall, the aquatic plant community in Mayflower Lake can be characterized as having good species diversity. The habitat, food source, and water quality benefits of this diverse plant community should be focal points in future lake management strategies.
- The presence of the non-native and potentially invasive plant, curly-leaf pondweed (CLP), was confirmed in Mayflower Lake by biologists from the Wisconsin Department of Natural Resources prior to the 2012 aquatic plant survey; however, it has not been observed in recent surveys of Mayflower Lake.
- No aquatic invasive plant species (AIS) have been identified in Mayflower Lake in recent years.
- The amount of disturbed lakebed from raking or pulling of plants should be minimized since these open spaces are ideal for AIS to become established.
- Boats and trailers that have visited other lakes can be a primary vector for the transport of AIS. Volunteer boat inspectors at the boat landing, trained through the Clean Boats Clean Waters (CBCW) program, can help prevent new AIS introductions.
- 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.

The analysis of a lake's sediment core is an effective means to reconstruct some of the changes that have occurred over time. Lakes act as sediment traps for particles that are either delivered to the lake from the surrounding landscape, the atmosphere, or occur in the lake itself. By examining remains trapped in the sediment, changes in the lake ecosystem can be inferred.

- Analysis of biological components and physical properties of Mayflower Lake's sediment core indicated an increase in erosion-induced processes such as land clearing, storm events, and shoreland disturbance since the time of land settlement around the lake. The analyses indicated these activities occurred more frequently in recent decades, but appear to have been minimized in recent years.
- Results suggested an increase in nutrient delivery, including phosphorus, to the lake over this time period. While the diatom communities and the physical properties of the sediment did not directly show this increase, they indicated an increase in aquatic plants and algae in recent years toward the top of the core.
- These analyses also suggested that Mayflower Lake has experienced limited increase in phosphorus concentrations, but large changes in habitat during the last century.
- Overall, there was a slight decrease in organic matter in the lake. This, along with slightly lighter sediment colors at the top, suggested that erosion and aquatic plant growth may have stabilized and declined slightly in recent years.

In general, Mayflower Lake had good water quality; however, a few water quality measurements, such as chloride and potassium, indicated that land use management practices in the watershed were influencing water quality in the lake.

- Concentrations of chloride and potassium were slightly elevated. While these concentrations were not harmful to aquatic organisms, they indicated that pollutants are entering the lake. Common sources of chloride and potassium include animal waste, septic systems, and fertilizer. Atrazine

(DACT), an herbicide commonly used on corn, was below the detection limit (<0.01 ug/L) in the samples that were analyzed from Mayflower Lake.

- Mayflower Lake had elevated nitrate (NO_2+NO_3-N) concentrations. Sources of nitrate include fertilizers, septic systems, and animal waste. The nitrate was likely moving to the lake in groundwater.
    - Water users around and upgradient of Mayflower Lake should have the water from their private wells tested to identify if they exceed the health standards for drinking water.
    - In a lake, nitrate can be readily used by aquatic plants and can increase the growth of aquatic plants and some types of algae.
- The water clarity in Mayflower Lake was considered fair. The variability in water clarity throughout the year in Mayflower Lake was primarily due to fluctuating algal concentrations and re-suspended sediment following strong winds.
- In Mayflower Lake, a relationship exists between water clarity and total phosphorus; as concentrations of total phosphorus increased, water clarity decreased.
- During the study, total phosphorus concentrations ranged from 10-34 μg/L. Growing season median concentrations of total phosphorus were 22.5 μg/L and 18 ug/L in 2011 and 2012, respectively. This is below Wisconsin's phosphorus standard of 40 ug/L for shallow seepage lakes.

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.

- Identifying and taking steps to maintain or improve water quality in Mayflower Lake depends upon understanding the sources of nutrients to the lake and identifying those that are manageable. Agriculture comprises the greatest amount of land in the watershed and, based on modeling results, had the greatest percentage of phosphorus and likely nitrogen contributions from the watershed to Mayflower 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.
- Shoreland health is critical to a healthy lake's ecosystem. Shoreland vegetation 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 the lake. Healthy shoreland vegetation includes a mix of tall grasses/flowers, shrubs and trees which should extend at least 35 feet landward from the water's edge. Mayflower Lake has 2.8 miles of shoreline. Mayflower Lake's shoreland was assessed for the extent of vegetation and disturbances.
    - The western shoreline vegetation remains primarily in a natural state with adequate shoreland vegetation.
    - Parts of Mayflower Lake's shoreland vegetation has been significantly altered due to development, especially along the southern and eastern shoreline. Most of the native grasses, forbs, and shrubs have been removed from or altered in these portions of the lake, leaving very little vegetation for stormwater infiltration, erosion protection, and wildlife habitat.
    - The overall findings show that 3,872 linear feet of shoreline were classified as having a grass/forb buffer depth of <u>less than</u> 35 feet inland from the water's edge. Similar results

exist for the shrubs layer. However, the grasses, forbs, and shrubs vegetation buffer depth was greater than 35 feet, the minimum depth required by Wisconsin and Marathon County shoreland zoning ordinances.
    - The tree layer was found to be abundant, but 5,709 linear feet were classified as having a buffer depth of only 5-15 feet inland from the water's edge.
- Alone, each manmade feature may not pose a problem for a lake, but on developed lakes, the collective impact of manmade disturbances can be a problem for lake habitat and water quality.
    - Structures such as seawalls, rip-rap (rocked shoreline), and artificial beach result in habitat loss. There were eight sites with rip-rap and seven with seawalls.
    - Unmanaged runoff from rooftops of structures located near shore can also contribute more sediment to the lake. Four structures were located within 35 feet of the lake and twenty-six were located between 35 and 75 feet of Mayflower Lake.
    - Docks and artificial beaches can result in altered in-lake habitat. Denuded lakebeds provide opportunities for invasive species to become established and reduce habitat that is important to fish and other lake inhabitants. There were 73 docks on Mayflower Lake.
    - Erosion can contribute sediment to the lake, which can alter spawning habitat and carry nutrients into the lake. No significant erosion was identified around the shores of Mayflower Lake.
- Strategies should be developed to ensure that healthy shorelands remain intact and efforts should be made to improve shorelands that have disturbance. Depending upon the source of disturbance, erosion should be controlled, vegetation should be restored, and/or excess runoff should be minimized.
- Dissemination of relevant information to property owners is the recommended first step towards maintaining healthy shorelands.

REFERENCES

Borman, Susan, Robert Korth, Jo Temte, 2001. *Through the looking glass, a field guide to aquatic plants.* Reindl Printing, Inc. Merrill, Wisconsin.

Hayes, T., K. Haston, M. Tsui, A. Hoang, C. Haeffele and A. Vonk. 2003. *Atrazine-Induced Hermaphroditism at 0.1 PPB in American Leopard Frogs (Rana pipiens): Laboratory and Field Evidence.* Environmental Health Perspectives 111: 568-575.

Hayes, T.K. A. Collins, M, L,, Magdelena Mendoza, N. Noriega, A. A. Stuart, and A. Vonk. 2001. *Hermaphroditic, demasculinized frogs after exposure to the herbicide atrazine at low ecologically relevant doses.* National Academy of Sciences vol. 99 no. 8, 5476–5480.

Panuska and Lillie, 1995. *Phosphorus Loadings from Wisconsin Watershed: Recommended Phosphorus Export Coefficients for Agricultural and Forested Watersheds.* Bulletin Number 38, Bureau of Research, Wisconsin Department of Natural Resources.

Shaw, B., C. Mechenich, and L. Klessig. 2000. *Understanding Lake Data.* University of Wisconsin-Extension, Stevens Point. 20 pp.

Wetzel, R.G. 2001. *Limnology, Lake and River Ecosystems, Third Edition.* Academic Press. San Diego, California.

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 CaCO3. 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 (CaCO3) 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 (NO3-): 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 (NO3-N) plus ammonium-nitrogen (NH4-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."