Eastern Marathon County Lakes Study

Pike 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 developed watersheds.

Eleven lakes in eastern Marathon County were selected for this study, which was aimed at obtaining a better understanding of the current conditions of the lakes' water quality, fisheries, habitats, and aquatic ecosystems. This information will help lake users and municipalities by identifying how to improve existing problems and make informed decisions to preserve and protect the lake from future issues. Data collected in studies completed between fall 2010 and fall 2012 focused on the fisheries, water quality, groundwater, algae, zooplankton, lake histories, shoreline habitats, watersheds, and residents' opinions. This report contains the results of these studies for Pike 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 PIKE 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. Pike Lake is located in the Townships of Reid and Elderon, east of County Highway Y, north of Bevent and south of Hatley. One public boat launch is located on its southeastern side. Pike Lake is a 206 acre drainage lake with an inflow stream, surface runoff and groundwater contributing most of its water. The maximum depth in Pike Lake is 31 feet; the lakebed has a moderate to steep slope, especially on the western side (Figure 1). Its bottom sediments are mostly muck, with sand along the northern and eastern shores and rock sampled throughout. Pike Lake has an estimated water residence time of approximately 8 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.

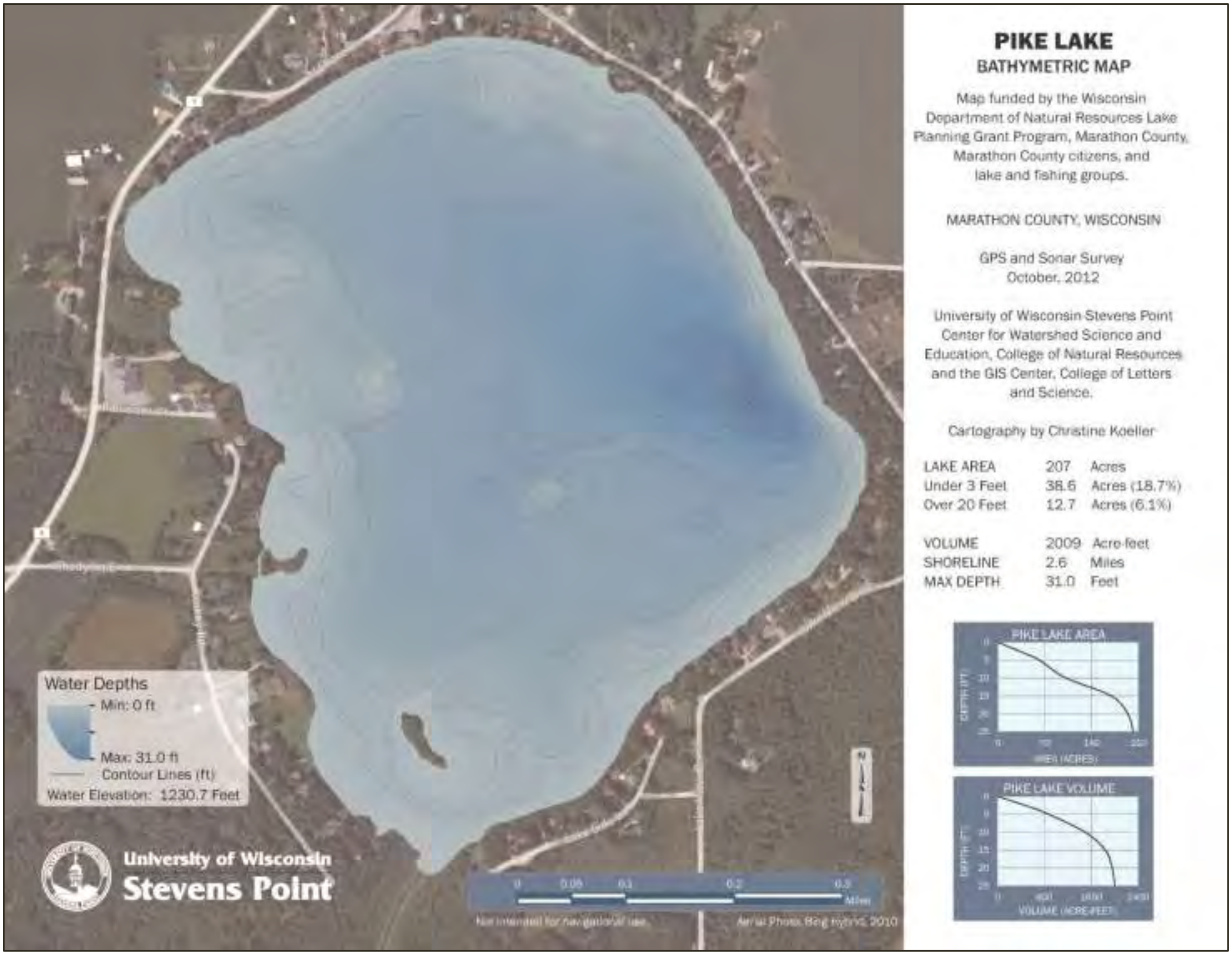


FIGURE 1. CONTOUR MAP OF THE PIKE LAKE LAKEBED.

The water quality in Pike 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 Pike 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 Pike Lake is called a surface watershed. Groundwater also feeds Pike Lake; its land area (groundwater watershed) is different from the surface watershed. Both the groundwater and surface watersheds are shown in Figure 2.

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 that 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 and cover 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 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 are used to 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 Pike Lake is approximately 3,766 acres (Figure 2). The dominant land uses in the watershed are forests (54%) and agriculture (24%). The lands closest to the lake often have the greatest impact on water quality and habitat; land uses near Bass Lake's shoreland include mostly residential development.

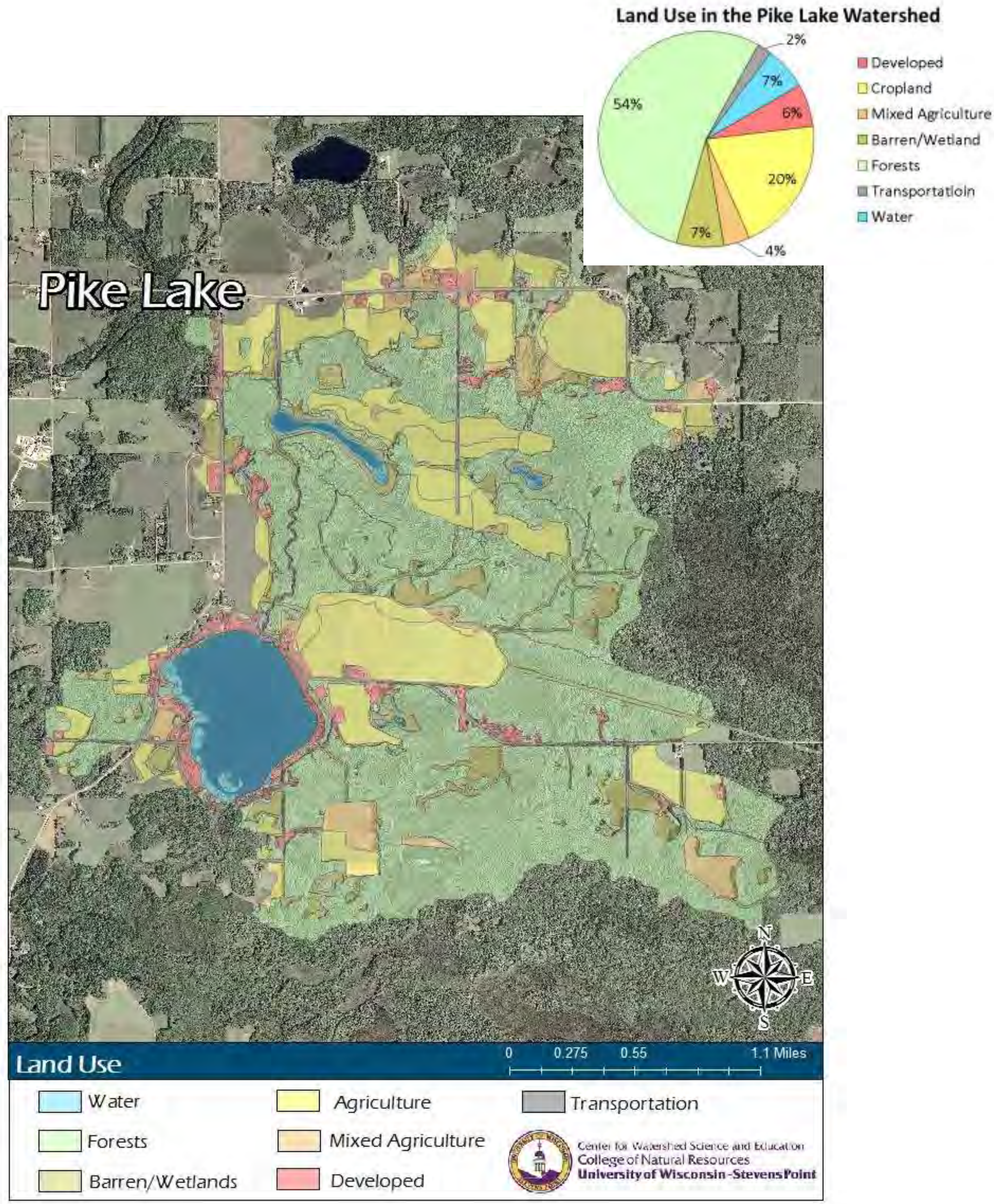
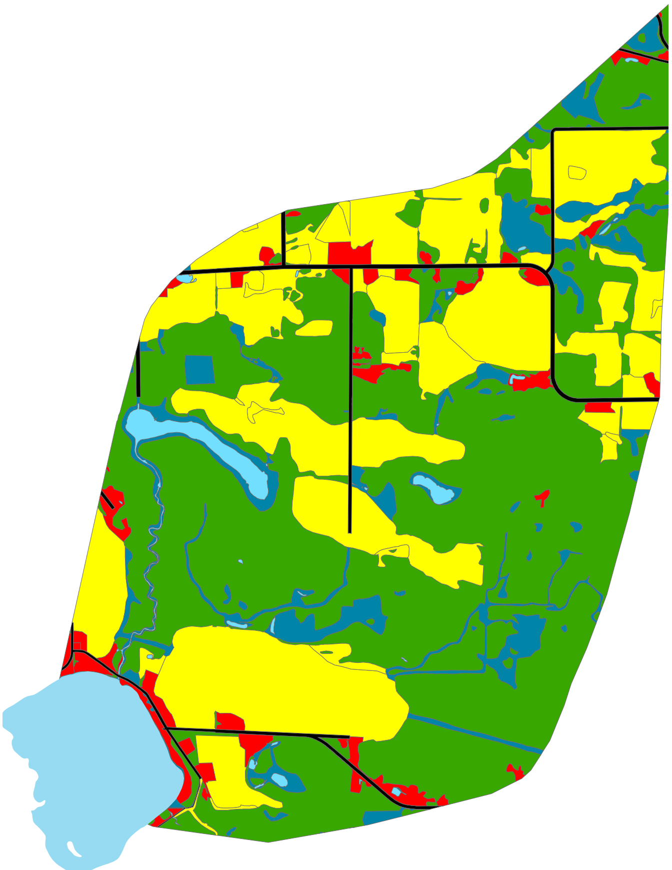


FIGURE 2. LAND USE IN THE PIKE LAKE SURFACE WATERSHED.

The groundwater watershed is the area where precipitation soaks into the ground and travels below ground towards the lake. Pike Lake's groundwater watershed is approximately 2,929 acres (Figure 3). The primary land uses in the Pike Lake groundwater watershed are forests and agriculture. In general, the land adjacent to the lake where most of the groundwater is entering has the greatest immediate impact on water quality. Residential development and agriculture are adjacent to Pike Lake where the groundwater enters.



Land Use	Acres
Agriculture	936
Developed	111
Forested	1447
Roads	61
Water	147
Wetland	227

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

Locally, groundwater enters some parts of the Pike Lake lakebed (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 Pike Lake (Figure 4). Most of the groundwater entered the lake on the northern and northeastern sides of the lake (green markers). Areas with no connection between groundwater and the lake were observed on the western side of the lake and sporadically around the rest of the lake (white dots). Some additional groundwater may enter Pike Lake in areas that were deeper than the surveyed locations. 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 Pike Lake.

The more lake water interacts with groundwater (inflow), 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 remain constant year round, so groundwater feeding Pike Lake will help to keep the lake water cooler during the summer months.

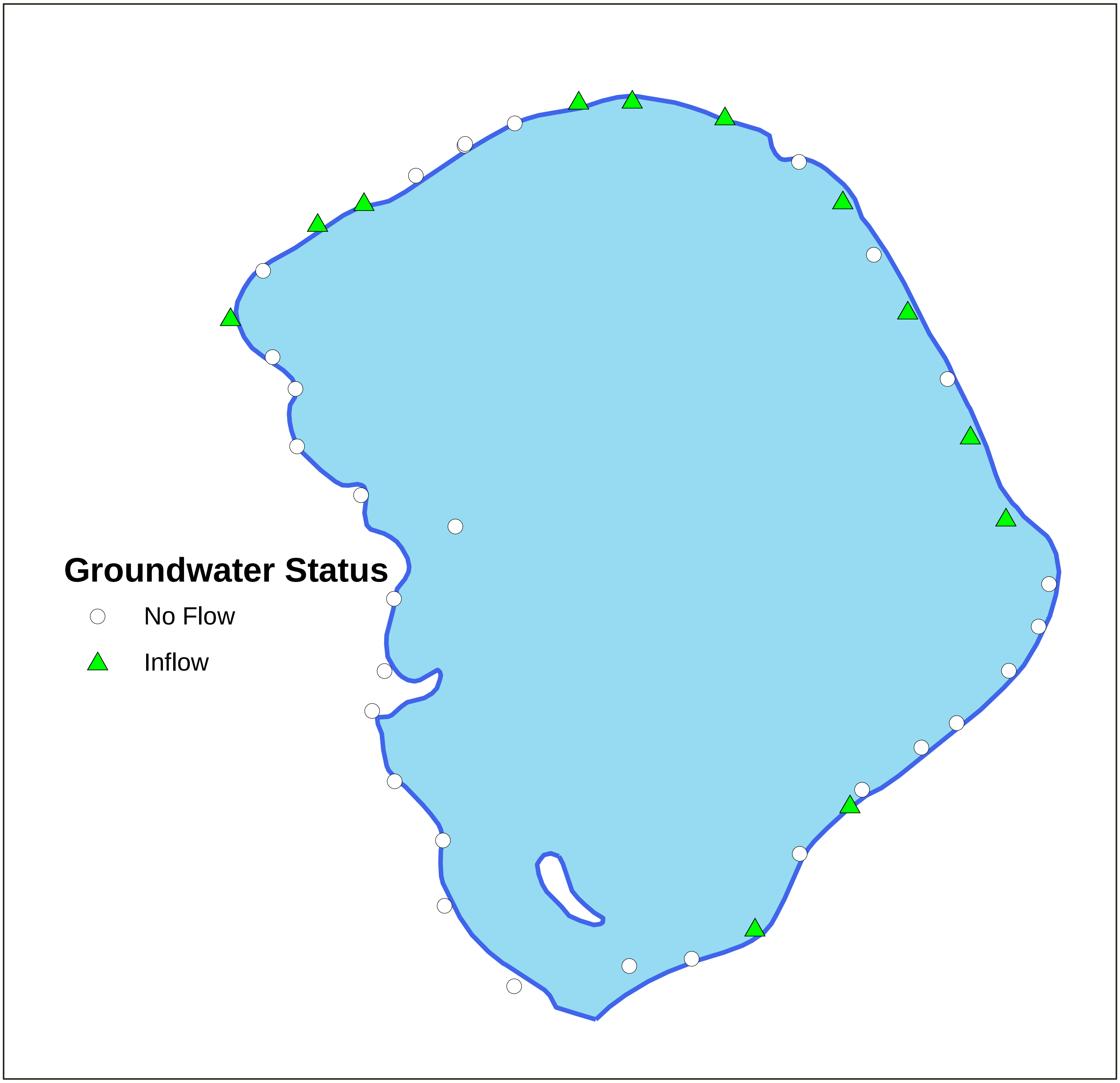


FIGURE 4. GROUNDWATER INFLOW TO PIKE LAKE, 2011.

WATER QUALITY

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 Pike 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 choosing management practices to preserve or influence that quality. Pike Lake is classified as a drainage lake. Water enters this lake primarily through a stream on the northern end of the lake that originates with Rice Lake and, to lesser extents, from groundwater, runoff, and precipitation (Figure 5). Water exits the lake primarily through its outflow stream at the southern end of the lake, ultimately draining to the Plover River. In general, drainage lakes receive water from a large area of land; therefore, more sediments and nutrients are deposited in it. Water exchange also takes place more rapidly than lakes without stream inlets.

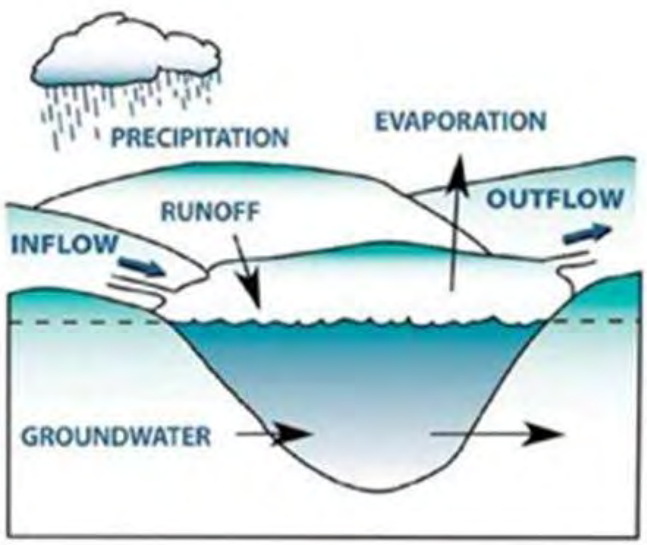


FIGURE 5. CARTOON SHOWING INFLOW AND OUTFLOW OF WATER IN A DRAINAGE LAKE.

The geologic composition that lies beneath a lake has the ability to influence the temperature, pH, minerals, and other properties of the lake. As groundwater moves through the soil, some substances are filtered out, but other materials dissolve into the groundwater (Wetzel, 2001). Minerals such as calcium and magnesium in the soil around Pike Lake dissolve, making the water hard. The average hardness for Pike Lake during the 2010-2012 sampling period was 152 mg/L, which is considered hard (Table 1). Hard water provides the calcium necessary for building bones and shells for animals in the lake. The average alkalinity was 136 mg/L; higher alkalinity in inland lakes can support higher species productivity. Hardness and alkalinity also play roles in the type of aquatic plants that are found in a lake (Shaw et al., 2000).

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

Pike Lake	Alkalinity (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mg/L as CaCO3)	Color SU	Turbidity (NTU)
Average	136	32.0	16.9	152	55.8	3.1

Chloride concentrations, and to lesser degrees sodium and potassium concentrations, are commonly used as indicators of impacts from human activity. The presence of such compounds at elevated levels in the lake indicates the movement of pollutants from the landscape to the lake.

Over the monitoring period, concentrations of potassium, chloride and sodium were elevated (Table 2). These concentrations are not harmful to aquatic organism, but indicate that pollutants are entering the lake. Sources of chloride and potassium include animal waste, septic systems, fertilizer, and road-salting chemicals. Atrazine (DACT), an herbicide commonly used on corn, was below the detection limit (<0.01 ug/L) in the samples that were analyzed from Pike Lake.

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

Pike Lake	Average Value (mg/L)			Reference Value (mg/L)		
	Low	Medium	High	Low	Medium	High
Potassium		1.4		<.75	0.75 - 1.5	>1.5
Chloride		8.7		<3	3.0 - 10.0	>10
Sodium		2.5		<2	2.0 - 4.0	>4

Dissolved oxygen is an important measure in aquatic ecosystems because a majority of organisms in the water depend on 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 aquatic plants and algae 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.

Water temperature in a lake 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 Pike Lake from top to bottom at the time of each sample collection in 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 and February 2012). Data collected in spring and fall indicated the lake had mixed, thereby replenishing oxygen in the lake bottom. Based on temperature, the lake was somewhat stratified during the growing season (May-September) as surface water warmed. Water temperatures near the bottom of the lake had an 8 degree range (reaching a high of 13°C or 55°F in summer), while surface temperatures ranged by nearly 30 degrees (Figure 6).

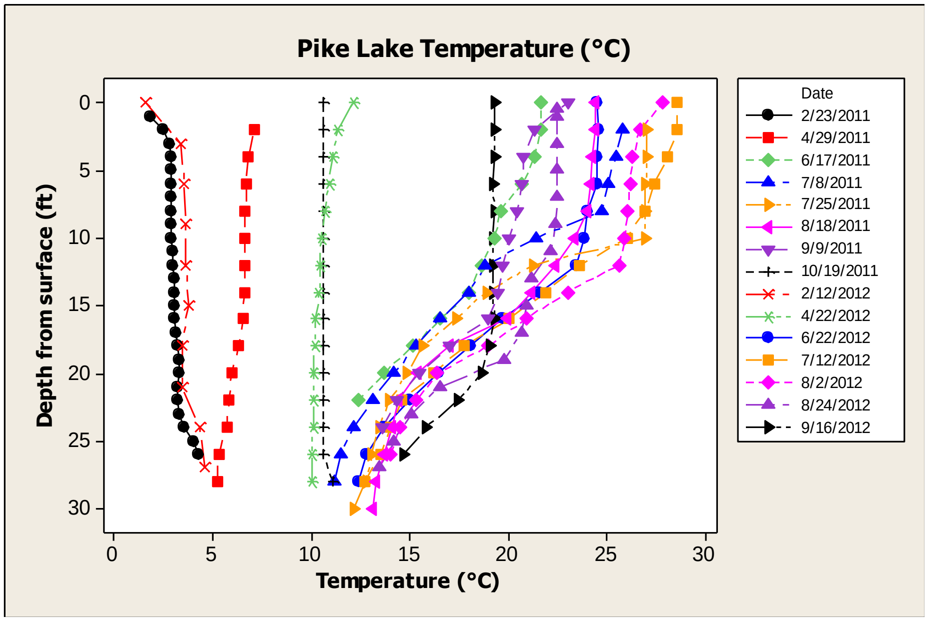


FIGURE 6. TEMPERATURE IN PIKE LAKE, 2010-2012.

Dissolved oxygen concentrations in Pike Lake ranged from plentiful to limited, depending upon depth and time of year. Like temperature, dissolved oxygen was mixed from top to bottom during spring and fall. In the winter of both years, dissolved oxygen fell below concentrations needed to support many fish species at the deep hole (Figure 7); however, the aeration system operated during the winter months in Pike Lake helped to insure that the fishery had sufficient oxygen for survival. Following spring overturn, dissolved oxygen concentrations began to drop sharply at depths of 6-10 feet as biological processes in the sediment consumed oxygen.

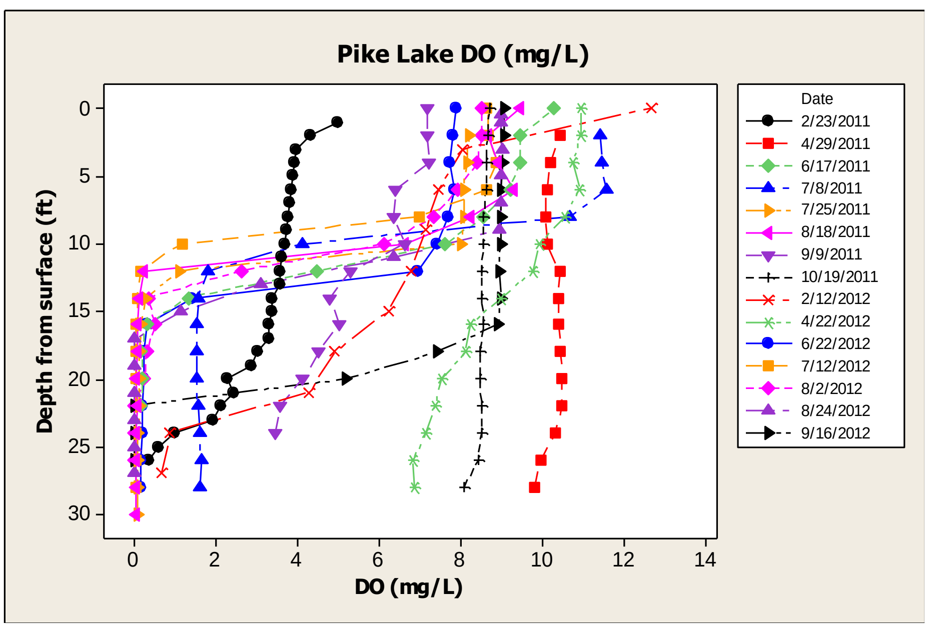
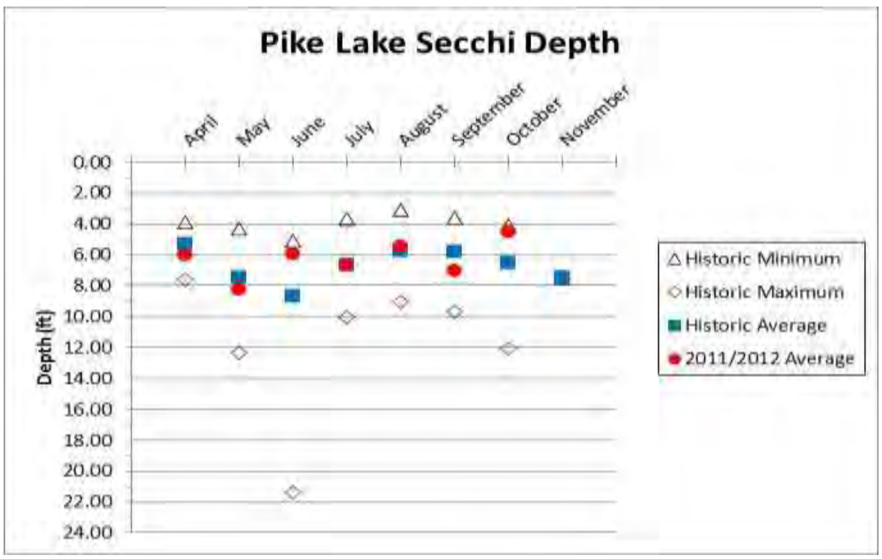


FIGURE 7. DISSOLVED OXYGEN (DO) IN PIKE LAKE, 2010-2012.

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 Pike Lake, the color was moderately stained (Table 1). Brown staining from tannins in the surrounding wetlands and forest are the natural source of the slightly elevated color index.

The variability in water clarity throughout the year in Pike Lake was primarily due to fluctuating algae concentrations and re-suspended sediment following storms or heavy boating activity. The water clarity in Pike Lake is considered fair. During the growing season, the average water clarity measurements collected from Pike Lake were poorest in August and best in July (Figure 8). A relatively complete dataset of water clarity measurements has been collected for Pike Lake since 1988. When compared with this historic data, the average water clarity measured during the study was slightly better in May and September and poorer in June and October.



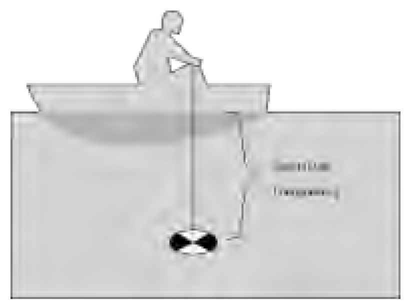


FIGURE 8. AVERAGE MONTHLY WATER CLARITY IN PIKE LAKE, 2010-2012 AND HISTORIC.

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 Pike Lake ranged from a high of 99 µg/L in April 2012 (following spring runoff) to a low of 19 µg/L in August 2012 (**Error! Reference source not found.**Table 3). The summer median total phosphorus concentrations were 31 µg/L and 26 µg/L in 2011 and 2012, respectively. These are very close to Wisconsin's phosphorus standard of 30 µg/L for deep drainage lakes.

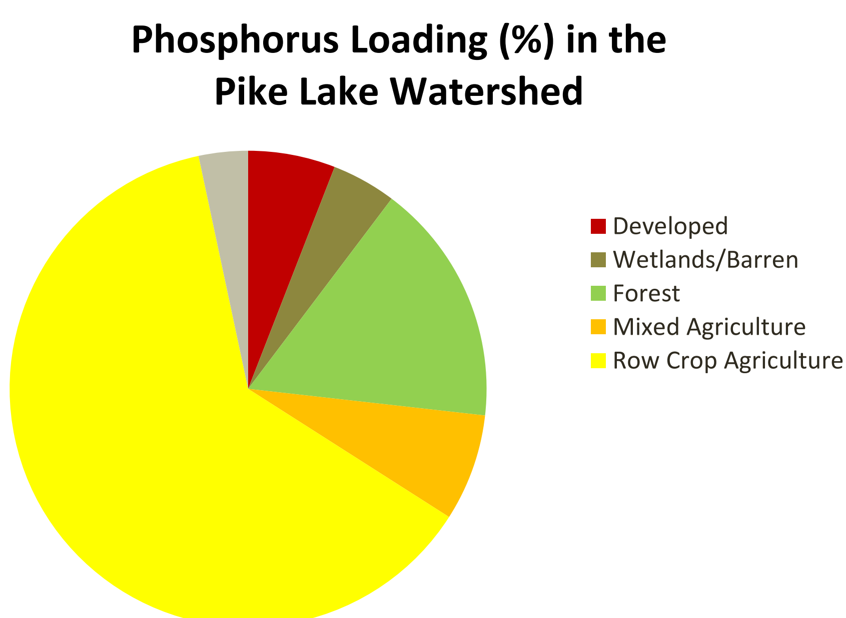
During the study, inorganic nitrogen concentrations in samples collected during the spring averaged 0.6 mg/L (Table 3). Concentrations above 0.3 mg/L are sufficient to enhance algal blooms throughout the summer (Shaw et al., 2000). Inorganic nitrogen typically moves to lakes with groundwater.

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

Pike 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	34	35	36	1	3	4	1.03	1.10	1.17	0.19	0.20	0.20	0.84	0.91	0.97
Spring	32	61	99	3	7	10	1.57	1.67	1.76	0.54	0.58	0.61	0.96	1.09	1.22
Summer	19	28	36												
Winter	20	24	27	3	10	17	1.45	1.68	1.91	0.65	0.88	1.11	0.80	0.80	0.80

Estimates of phosphorus from the landscape can help to understand the phosphorus sources to Pike 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 distance from the lake also affect the contributions to the lake from a parcel of land. Although forests comprise the greatest amount of land in the groundwater and surface watersheds, modeling results indicated that agriculture contributed the greatest percentage of phosphorus from the watershed to Pike Lake (Figure 9).

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



The phosphorus contributions by land use category, called phosphorus export coefficients, are shown in Table 4. The phosphorus export coefficients were obtained from studies throughout Wisconsin (Panuska and Lillie, 1995).

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

Pike Lake Land Use	Phosphorus Export Coefficient (lbs/acre-yr)	Land Use Area Within the Watershed		Phosphorus Load	
		Acres	Percent	Pounds	Percent
Water	0.10	246	**7**	18-55	**3**
Developed	0.13	244	**7**	33-65	**6**
Wetland/Barren	0.09	271	**7**	24-72	**5**
Forest	0.04	2043	**55**	91-164	**17**
Mixed Agriculture	0.27	150	**4**	40-107	**8**
Row Crop Agriculture	0.45	775	**21**	346-692	**65**
*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. Chlorophyll *a* concentrations in Pike Lake were generally quite high, ranging from a high of 26.7 µg/L in August 2011 to a low of 6 µg/L in July 2012. Concentrations during the summers of 2011 and 2012 averaged 20.4 µg/L and 8.8 µg/L, respectively.

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 evaluation of a lake's water quality because there are more varieties 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). Diatoms were the dominant algal group in Pike Lake during both 2011 and 2012 (42% and 41% average community composition respectively). While there was some variation in the seasonal pattern of the algal community, both years were clearly led by the diatoms as no other algal group was ever more dominant over the study period (Figure 10). The diatoms were represented by a rich species mixture, most of which are associated with eutrophic waters. These species are colonial and planktonic, grow quite densely, and likely contributed to the low Secchi disk (water clarity) values seen in 2011 and 2012.

All data (total phosphorus, Secchi disk depths, and algae) point to Pike Lake being a very enriched, eutrophic body of water.

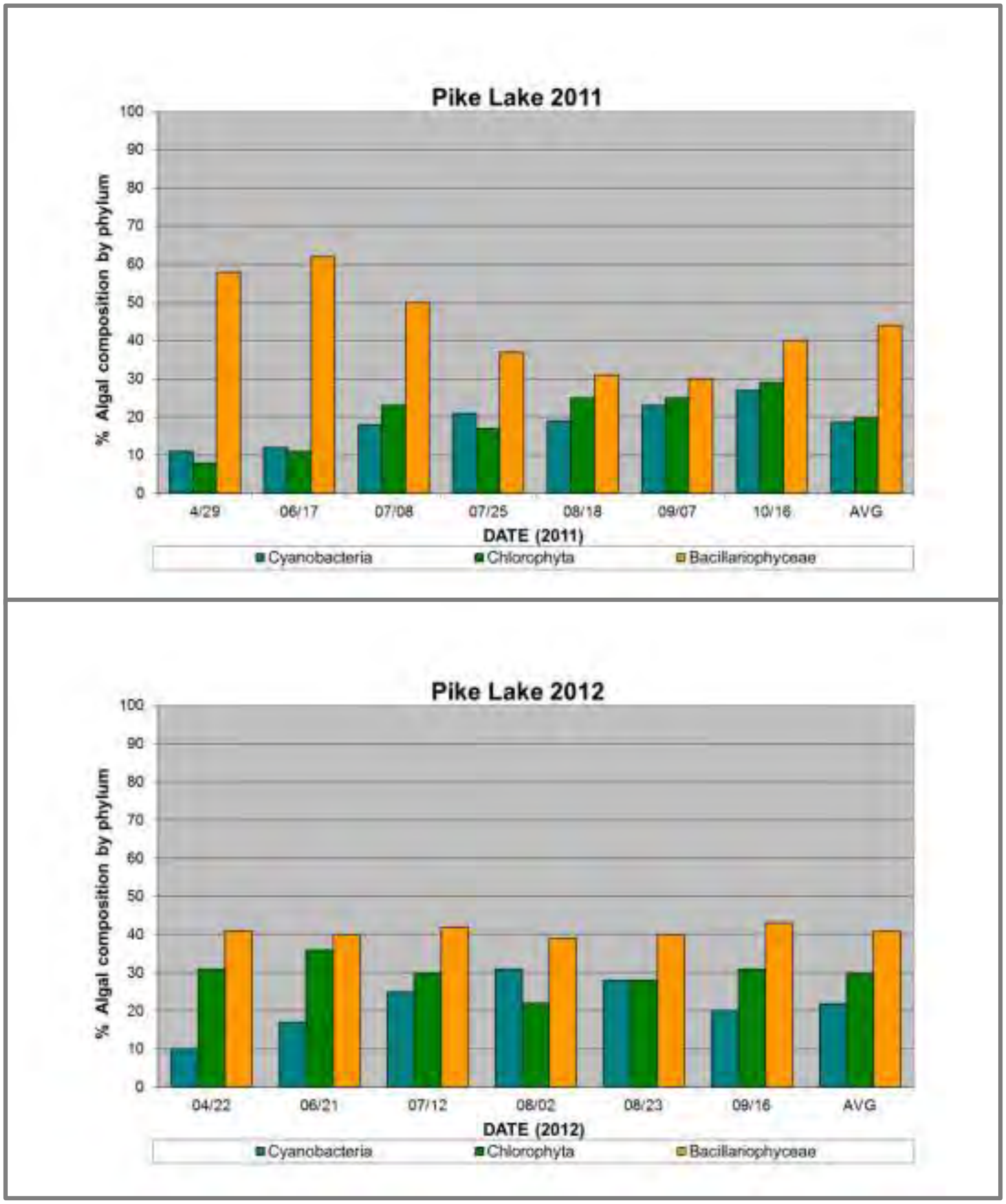


FIGURE 10. PERCENT ALGAL COMPOSITION OF PIKE LAKE, 2011 AND 2012.

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 phosphorous 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 natural shorelands in need of protection. In addition, this information will provide a baseline database from which to measure and monitor success.

PIKE 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 Pike Lake in Figure 12 depict the depth of vegetation along Pike 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.

Pike Lake has approximately 12,200 feet of shoreline, or 2.3 miles. The survey indicated that 10,550 linear feet (86%) of shoreline were classified as having a grasses/forbs buffer depth of less than 35 feet. Similar results were classified for the shrubs layer as well. The grasses, forbs, and shrubs vegetation buffers are required to be at least 35 feet, according to Wisconsin and Marathon County shoreland zoning ordinances. Trees represented the most abundant vegetative layer around the lake, with 7,633 linear feet classified as having a buffer width greater than 50 feet. Shoreland survey results are displayed in Figure 11. Although Pike Lake's shoreland has abundant development, efforts can be made to improve the shorelands. In order to minimize impacts from current and 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 Rice Lake.

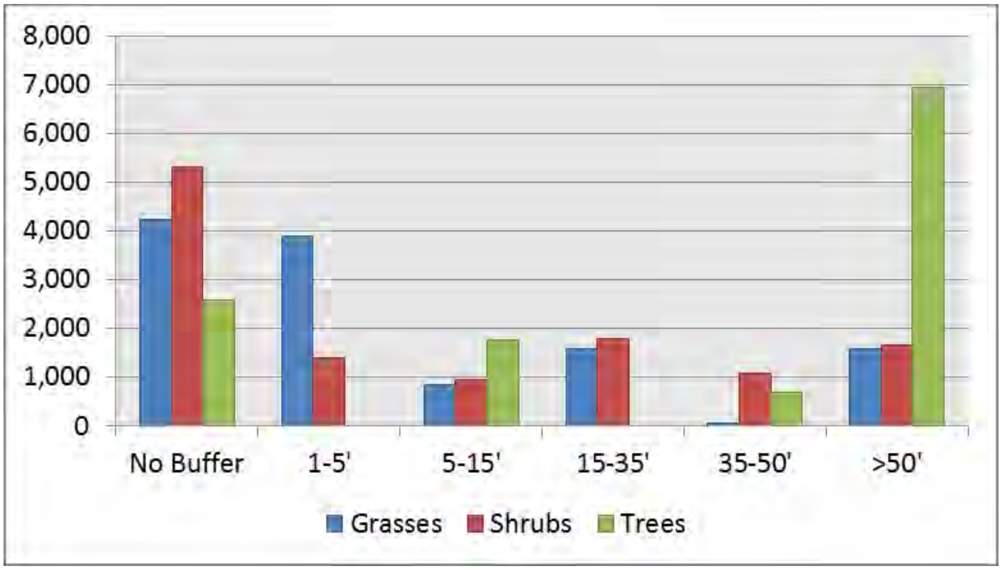


FIGURE 11. SHORELAND VEGETATION SURVEY RESULTS BY BUFFER DEPTH AROUND PIKE LAKE, 2011.

On the same day the shoreland vegetation survey was conducted, an assessment of manmade disturbances was conducted on Pike 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 documents the manmade disturbances found on Pike Lake, and Figure 13 shows the locations of the disturbances identified in the survey. Structures such as seawalls, rip-rap (rocked shoreline), and artificial beaches often result in habitat loss. Docks and artificial beaches can result in altered in-lake habitat, and denuded lakebeds provide opportunities for invasive species to become established and reduce habitat important to fish and other lake inhabitants. Erosion can contribute sediment to the lake, altering spawning habitat and carrying 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 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.

TABLE 5. DISTURBANCES AND STRUCTURES LOCATED ON PIKE LAKE, 2011 SURVEY.

	No. of Occurrences
Artificial Beach	0
Dock	91
Riprap	22
Seawall	0
Erosion	2
Structures w/in 35'	16
Structures 35-75'	53

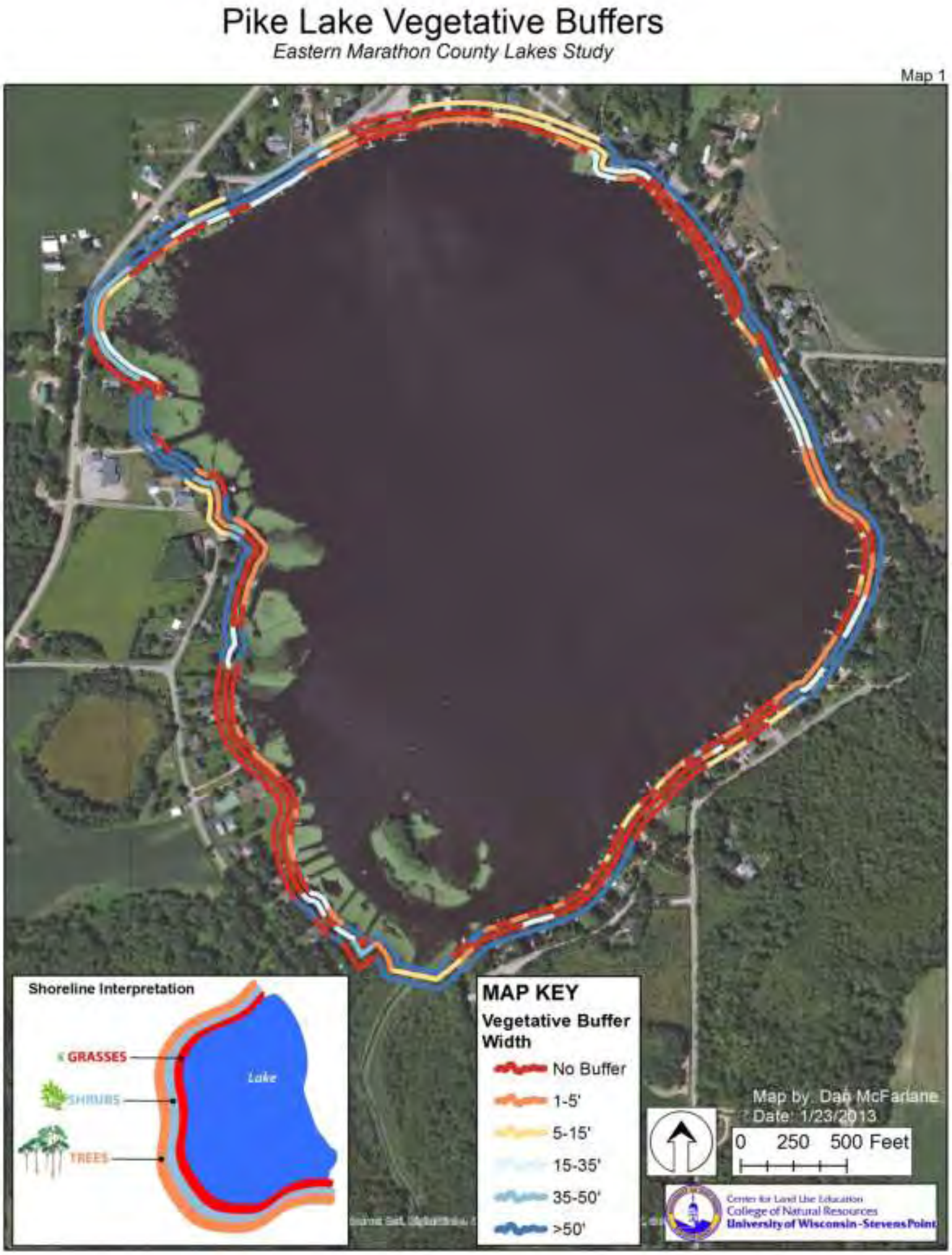


FIGURE 12. SHORELAND VEGETATION SURVEY OF PIKE LAKE, 2011.

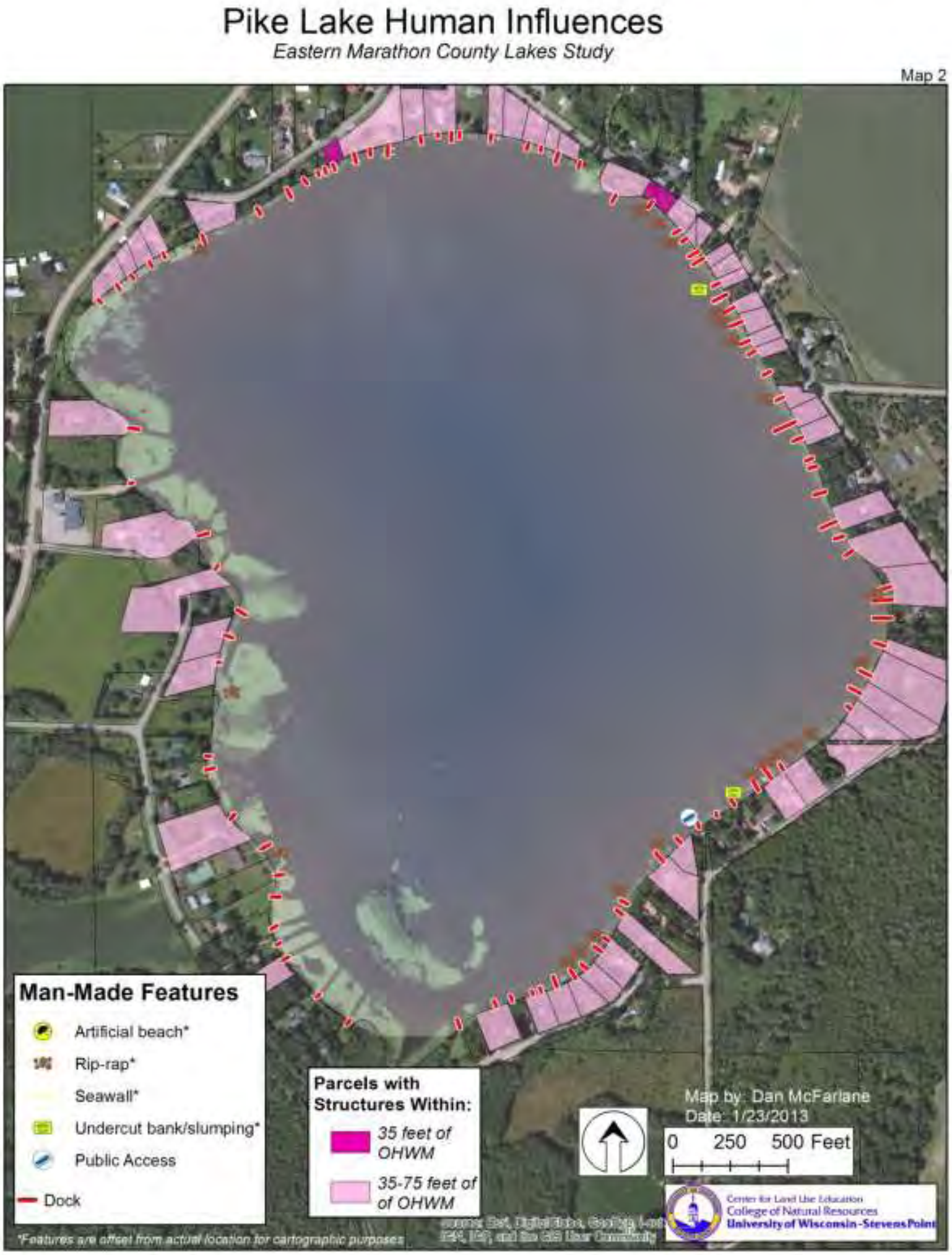


FIGURE 13. SHORELINE DISTURBANCE SURVEY OF PIKE LAKE, 2011.

THE FISHERY

A sustainable fishery is one that is in balance with the lake's natural ability to support the fish community and is adaptable to reasonable fishing pressures without additional stocking or input. A healthy fish community has a balance between predator and prey species, and each species of fish has different needs in order to flourish, including food sources, habitat, nesting substrate, and water quality.

People are also an important part of a sustainable fishery, as the numbers and sizes of fish taken out of the lake can influence the fish community. Appropriate fishing regulations can help to balance the fishery with healthy prey and predatory species, and can be adjusted as needed. Each species has its preferred tolerance range for dissolved oxygen, pH, water clarity, temperature, and minerals. Predatory species, for example, need good water clarity to effectively hunt their prey. Even within a species, water quality tolerance ranges may vary for reproduction. Choosing the wrong fish species for a lake's conditions will result in an unsustainable fishery, requiring outside inputs such as aeration or additional stocking.

Pike Lake supports a warm water fish community. The Pike Lake fish species assemblage is more diverse than neighboring lakes in eastern Marathon County because it is a drainage lake and fish have opportunities to enter from upstream and downstream systems. In 2012, fourteen fish species were sampled and identified out of the eighteen total species that were recorded in surveys dating back to 1956 obtained from the Wisconsin Department of Natural Resources (WDNR) (Table 6). Four fish species were newly documented in 2012: bluegill x pumpkinseed (*Lepomis gibbosus*) hybrid, brown bullhead (*Ameiurus nebulosus*), bluntnose minnow (*Pimephales notatus*), and Iowa darter (*Etheostoma exile*). Four fish species were documented previously, but not observed during the 2012 survey: channel catfish (*Ictalurus punctatus*), rock bass (*Ambloplites rupestris*), slender madtom (*Noturus exilis*), and spotfin shiner (*Cyprinella spiloptera*). Bluegill (*Lepomis macrochirus*), yellow perch (*Perca flavescens*), and yellow bullhead (*Ameiurus natalis*) were abundant during the survey. Golden shiner (*Notemigonus crysoleucas*), brown bullhead (*Ameiurus nebulosus*), Iowa darter (*Etheostoma exile*), spottail shiner (*Notropis hudsonius*), common shiner (*Luxilus cornutus*), and white sucker (*Catostomus commersoni*) were infrequently encountered. Length information recorded during the 2012 sampling can be found in Table 7and Table 8. Two rusty crayfish (*Orconectes rusticus*) were captured during the sampling period.

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

Species	1956	1969	1973	1975	1976	1977	1990	1996	2002	2005	2008	2012
Black Bullhead		x		x			x	x	x			x
Black Crappie	x	x	x	x	x	x	x	x	x		x	x
Bluegill	x	x	x	x	x	x	x	x	x	x	x	x
Bluegill x Pumpkinseed hybrid												x
Brown Bullhead												x
Bluntnose Minnow												x
Channel Catfish								x				
Common Shiner										x		x
Golden Shiner	x	x					x	x	x			x
Iowa Darter												x
Johnny Darter					x							x
Largemouth bass	x	x	x	x	x	x	x	x	x	x	x	x
Northern pike	x	x	x	x	x	x	x	x	x	x	x	x
Pumpkinseed		x			x		x	x	x	x	x	x
Rock Bass									x			
Slender Madtom										x		
Spotfin Shiner									x			
Spottail shiner										x		x
Walleye		x	x	x		x	x	x	x		x	x
White sucker	x	x		x	x			x	x			x
Yellow bullhead									x			x
Yellow Perch	x	x	x	x	x	x	x	x	x	x	x	x

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

Species	Min Length (in)	Max Length (in)	Average Length (in)	Total Catch
Bluegill	0.8	10.9	3.8	177
Yellow Bullhead	7.8	13.2	9.7	138
Yellow Perch	3.2	8.1	4.8	107
Bluntnose Minnow	1.3	2.2	1.8	100
Black Crappie	4.9	15.3	9.6	37
Northern Pike	17.3	28.7	22.4	29
Pumpkinseed	4.5	7.2	5.9	17
Walleye	14.8	24.6	21.7	10
Johnny Darter	2.0	2.4	2.1	7
Largemouth Bass	11.0	15.6	13.8	5
Black Bullhead	7.0	12.6	9.8	2
Golden Shiner	1.7	7.2	4.4	2
Brown Bullhead	12.6	12.6	12.6	1
Iowa Darter	1.9	1.9	1.9	1
Spottail Shiner	2.6	2.6	2.6	1
White Sucker	7.2	7.2	7.2	1
Bluegill x Pumpkinseed hybrid	3.9	3.9	3.9	1

TABLE 8. TOTAL CATCH AND LENGTHS (MIN/MAX/AVERAGE) OF SPECIES IN PIKE LAKE DURING THE 2012 BOOM SHOCKING SURVEY.

Species	Min Length (in)	Max Length (in)	Average Length (in)	Total Catch
Bluegill	1.4	7.9	4.2	51
Pumpkinseed	2.2	7.3	4.7	38
Yellow Bullhead	7.6	10.8	9.6	14
Black Crappie	3.2	9	6.1	10
Black Bullhead	5.2	13	10.7	7
Yellow Perch	3.1	6.7	5.1	7
Largemouth Bass	4.5	17.9	12.2	6
Northern Pike	15.7	20.3	18.4	5
Common shiner	3	3.3	3.1	3
Bluntnose Minnow	1.7	2.7	2.6	2
White sucker	8.1	9.2	8.7	2
Brown Bullhead	11	11	11.0	1

WDNR records revealed extensive management efforts on Pike Lake related to fish and fish habitat dating back to the 1930s. Noteworthy habitat activities from 1940-1970 included lake treatment with sodium arsenite and copper compounds to control aquatic plants, manual cutting of aquatic plants, and spraying of shoreline vegetation with other approved herbicides. There were a number of reports of herbicide applications on the lake from 1940 until 1984 and after 1990. As part of more environmentally-friendly efforts to control aquatic plants, mechanical control methods began in 1984. In 1982, the WDNR listed a number of specific herbicides that were approved for control of aquatic plants in the lake. They specifically indicated that Silvex (2, 4, 5-T) was not allowed. Silvex was of concern because of contamination with 2, 3, 7, 8-TCDD (dioxin) and past use of this herbicide would likely result even today in unacceptable concentrations in lake sediment. There was no evidence of Silvex use in this lake based on WDNR records, although it was used in nearby lakes in Portage County.

In 1963, fish (unspecified numbers and species) were transferred to Pike Lake from the Eau Pleine Flowage where a winterkill from low dissolved oxygen concentrations was underway. Fish kills in Pike Lake of walleye (*Sander vitreus*), yellow perch and northern pike (*Esox lucius*) believed to be related to the occurrence of toxic algae were first noted in 1962. Mortality in bullhead species believed to be related to bacterial infections was reported up until the 1970s. In 1971, it was reported that eutrophication of Pike Lake was occurring more rapidly than expected because of algae blooms and occasional winterkills of fish due to low dissolved oxygen. The concern over eutrophication continues today as evidenced by continued sporadic reports of winterkills. Bullheads were reported to be the dominant fish species in terms of biomass at times from 1960-1970, which is another indication of winterkill as they are more tolerant of low dissolved oxygen than many other species. In order to reduce the bullhead population, considerable efforts were made to increase the walleye population through stocking and natural reproduction. With WDNR approval, a walleye spawning reef was installed by the Pike Lake Sportsmans Club in 1981 along the eastern shore; however, this did not improve the natural reproduction of walleye. After 2006, Walleyes for Tomorrow installed a second artificial walleye spawning reef adjacent to the southern inlet with better contouring and a larger surface area for the same purpose. In 2006, boy scouts installed three fish cribs constructed of wooden pallets anchored to the bottom.

Fish stocking records for Pike lake date back to 1938 in WDNR files (Table 9). Walleye have been prevalently stocked from 1938 through recent years. Stocking management has switched from primarily fry walleye to fingerling size, including more fry stocking in recent years. Although fish mortality rates are high for any stocking effort, fry are especially vulnerable. Yellow perch have also been stocked in recent years and an abundant population of perch was present during 2012 sampling. It is not possible to evaluate the effectiveness of these stocking efforts with the limited sampling conducted during this study.

TABLE 9. WISCONSIN DEPARTMENT OF NATURAL RESOURCES FISH STOCKING SUMMARY FOR PIKE LAKE, INCLUDING SPECIES, AGE CLASS, NUMBER STOCKED, AND AVERAGE LENGTH IN INCHES.

Year	Species	Age Class	Number Fish Stocked	Year	Species	Age Class	Number Fish Stocked	Avg Fish Length (in)
1938	Walleye	Fry	1,331,950	1972	Walleye	Fingerling	26,000	5
1939	Walleye	Fry	1,375,000	1975	Walleye	Fingerling	20,000	3
1940	Walleye	Fry	1,375,000	1976	Brook Trout	Yearling	2,100	
1941	Bluegill	Adult	1,000	1979	Walleye	Fingerling	20,000	4
1941	Bluegill	Fingerling	1,500	1980	Walleye	Fingerling	10,040	5
1941	Crappie	adult	560	1983	Walleye	Fingerling	20,000	3
1941	Northern Pike	Fry	45,000	1984	Walleye	Fingerling	16,200	3
1941	Walleye	Fry	1,000,000	1985	Walleye	Fingerling	20,400	3
1942	Northern Pike	Fry	45,000	1986	Walleye	Fingerling	20,000	3
1942	Walleye	Fry	480,000	1987	Walleye	Fingerling	120,480	3
1943	Northern Pike	Fry	35,000	1988	Walleye	Fingerling	9,860	5
1943	Walleye	Fry	412,000	1989	Walleye	Fingerling	12,062	4
1944	Northern Pike	Fry	30,000	1990	Walleye	Fingerling	2,040	8
1944	Smallmouth Bass	Fingerling	50	1991	Walleye	Fingerling	2,080	5
1944	Walleye	Fry	350,000	1992	Walleye	Fingerling	15,347	3
1945	Largemouth Bass	Fingerling	800	1994	Walleye	Fingerling	4,986	2
1946	Walleye	Fry	900,000	1994	Walleye	Fingerling	2,050	7
1947	Largemouth Bass	Fingerling	600	1995	Walleye	Fingerling	5,300	3
1948	Northern Pike	Fry	60,000	1997	Walleye	Small Fingerling	10,250	2
1949	Walleye	Fry	900,000	1999	Walleye	Small Fingerling	10,600	2
1950	Walleye	Fingerling	9,080	2000	Walleye	Small Fingerling	10,400	2
1951	Northern Pike	fry	47,355	2002	Walleye	Small Fingerling	10,400	2
1951	Northern Pike	Adult	180	2004	Walleye	Small Fingerling	10,400	1
1952	Walleye	Fingerling	2,239	2005	Yellow Perch	Large Fingerling	3,500	5
1953	Northern Pike	Adult	60	2006	Walleye	Small Fingerling	10,672	2
1955	Walleye	Fingerling	5,400	2006	Yellow Perch	Large Fingerling	4,200	5
1956	Northern Pike	Adult	265	2007	Walleye	Large Fingerling	1,500	7
1957	Northern Pike	Adult	1,149	2008	Walleye	Small Fingerling	7,036	2
1957	Walleye	Fry	15,000	2008	Walleye	Yearling	2,000	
1958	Walleye	Fry	10,800	2008	Yellow Perch	Large Fingerling	1,000	
1959	Walleye	Fry	45,000	2009	Walleye	Large Fingerling	1,990	8
1960	Walleye	Adult	6	2009	Yellow Perch	Adult	847	8
1960	Northern Pike	Adult	25	2010	Walleye	Small Fingerling	7,015	2
1960	Walleye	NA	NA	2010	Walleye	Adult	1,450	10
1963	Northern Pike	Adult	711	2010	Walleye	Fry	200,000	0
1965	Walleye	Fry	1,000,000	2010	Yellow Perch	Adult	1,000	10
1965	Walleye	Fingerling	45,000	2011	Walleye	Fry	2,000,000	1
1965	Northern Pike	Fry	296,898	2011	Walleye	Yearling	1,900	8
1967	Walleye	Fingerling	12,000	2011	Yellow Perch	Yearling	2,450	7
1970	Walleye	Fingerling	7,175	2012	Walleye	Fry	1,000,000	1

BOTTOM SUBSTRATE AND COARSE WOODY HABITAT

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 which 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 and woody habitat were examined from the shoreline lakeward to a distance of 30 meters. Substrate distribution in Pike Lake is approximately one-half soft bottom (55.6% muck) and one-half hard bottom (26.4% sand, 15% sand/gravel/cobble, <1% cobble or boulder) (Figure 14). Harder surfaces are present mainly along the eastern shoreline. Gravel areas are used by many fish for spawning habitat, including sunfish (bluegill, pumpkinseed, 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*) also use bulrush habitat on gravel or sand substrates where they construct nests and guard their young. Yellow perch and walleye seek near-shore cobble in oxygen-rich environments for spawning activity; no parental care is offered. Bulrush is present along areas of the western shoreline in Pike Lake. Sand can be important habitat for reproduction of non-game minnow.

The presence of young bass and abundant sunfish sampling indicate successful reproduction is occurring in Pike Lake. The absence of young northern pike in 2012 may be an indicator of poor reproduction, although more intense population sampling efforts over several seasons would be required to determine the reproductive success for individual fish species. Walleye reproduction has been variable in Pike Lake, and no young walleyes were observed during the sampling period.

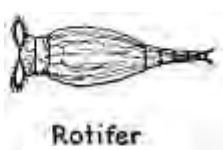
Coarse woody habitat (CWH), including downed trees and logs, are sparse in Pike Lake (Figure 14). Woody habitat is an important component of the lake ecosystem, as it is used by fish and other aquatic organisms for spawning, foraging, and protective cover. The addition of CWH cover into Pike Lake would benefit the fish community.

FIGURE 14. DISTRIBUTION OF SUBSTRATE AND COARSE WOODY HABITAT IN PIKE LAKE, 2012. SUBSTRATE ABUNDANCE WAS ESTIMATED USING A LOWRANCE HDS5 WITH SIDE-SCAN SONAR WITHIN 30M OF SHORE.

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 types 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.



www.revistadel

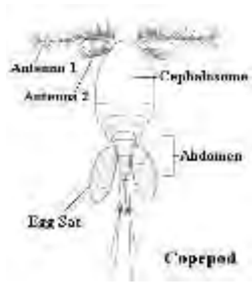
Rotifers are small invertebrate animals with simple body designs. They are usually not found uniformly throughout lakes, but congregate in areas of high food abundance (bacteria, algae, and other rotifers). Generally, a lake's trophic status influences, or can be predicted by, the abundance and diversity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


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 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 a response to avoid heavy fish predation and can result in lower than expected cladoceran numbers during daytime collections.



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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 Pike Lake was moderately diverse during the 2011-2012 sampling (Table 10, Table 11). Zooplanktons were classified based on two general size categories: nano-plankton (80 *u*m or less) or net plankton (210 *u*m or less).

The dominant group of nano-plankton was composed of rotifers, with rotifers and copepods as subdominants.

- There were 3,900 individuals counted during this period
    - 3,459 rotifers, 167 cladocerans, 275 copepods

The dominant groups of net plankton were composed of rotifers and copepods, with cladocerans as subdominants.

- There were 634 individuals counted during this period
    - 194 rotifers, 237 cladocerans, 203 copepods

Rotifers were the dominant taxa in three of four sample periods during the 2011-12 sampling. These taxa dominated from early summer though late fall before falling into subdominant positions in winter. Copepods were dominant in winter in both nano-plankton and net plankton samples. The cladocerans occupied the most abundant slot in early spring and were subdominant for all other seasons.

The zooplankton community presented the picture of a lake transitioning to eutrophic when considered relative to the algal, phosphorus, and nitrogen values for Pike Lake. The 5 genera of rotifers, 5 genera of cladocerans, and 6 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. Rotifers dominated the zooplankton community in both nano and net plankton.

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

Date	Primary dominant	Species	Secondary dominant	Species	Tertiary dominant	Species
April 29	Rotifer	*Polyarthra vulgaris*	Rotifer	*Filinia terminalis*	Rotifer	*Kertella cochlearis*
June 17	Rotifer	*Kertella longispina*	Rotifer	*Polyarthra dolichoptera*	Cladoceran	*Bosmina longirostris*
October 19	Rotifer	*Kertella cochlearis*	Rotifer	*Polyarthra dolichoptera*	Copepod	*Diacyclops nanus*
March 4	Copepod	*Diacyclops nanus*	Copepod	Nauplii	*Cladoceran*	*Bosmina longirostris*

TABLE 11. MOST COMMON (NET) ZOOPLANKTON BY DATE IN PIKE LAKE FROM APRIL 2011 TO MARCH 2012.

Date	Primary dominant	Species	Secondary dominant	Species	Tertiary dominant	Species
April 29	Cladoceran	*Bosmina longirostris*	Rotifer	*Filinia terminalis*		
June 17	Rotifer	*Asplanchna* spp.	Cladoceran	*Daphnia retrocurva*	Copepod	*Acanthocyclops vernalis*
October 19	Rotifer	*Asplanchna* spp.	Copepod	*Diacyclops nanus*	Cladoceran	*Daphnia retrocurva*
March 4	Copepod	*Diacyclops nanus*	Cladoceran	*Bosmina longirostris*	Copepod	*Acanthocyclops vernalis*

Aquatic plants are the forested landscape within a lake. They provide food and habitat for a wide range of species including fish, waterfowl, turtles, 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 Pike Lake, thirty-seven percent (126 of 345) of sites sampled had vegetative growth. Of the sampled sites within Pike Lake, the average depth was 6 feet, with a maximum depth of 25 feet. Twenty-one species of aquatic plants were found in Pike Lake (Table 12), with the greatest diversity located in west and southwest sides of the lake.

TABLE 12. AQUATIC PLANTS IDENTIFIED IN THE AQUATIC PLANT SURVEY OF PIKE LAKE, 2012.

Common Name	Scientific Name	Coefficient of Conservatism Value (C Value)
Emergent Species		
common arrowhead	*Sagittaria latifolia*	3
pickerelweed	*Pontederia cordata*	8
Broad-leaved cattail	*Typha latifolia*	1
Floating Leaf Species		
watershield	*Brasenia schreberi*	6
small duckweed	*Lemna minor*	4
forked duckweed	*Lemna trisulca*	6
spatterdock	*Nuphar variegata*	6
white water lily	*Nymphaea odorata*	6
Submergent Species		
coontail	*Ceratophyllum demersum*	3
muskgrass	*Chara* spp.	7
common waterweed	*Elodea canadensis*	3
water star-grass	*Heteranthera dubia*	6
northern water-milfoil	*Myriophyllum sibiricum*	6
slender naiad	*Najas flexilis*	6
nitella	*Nitella* spp.	7
Illinois pondweed	*Potamogeton illinoensis*	6
white-stem pondweed	*Potamogeton praelongus*	8
clasping-leaf pondweed	*Potamogeton richardsonii*	5
flat-stem pondweed	*Potamogeton zosteriformis*	6
sago pondweed	*Stuckenia pectinata*	3
wild celery	*Vallisneria americana*	6

Figure 15 shows the number of species that were identified at each sampling site. The dominant plant species during the survey was flat-stem pondweed (*Potamogeton zosteriformis*), followed by coontail (*Ceratophyllum demersum*) and muskgrass (*Chara* spp.). Flat-stem pondweed provides a food source for waterfowl. This native and widespread aquatic plant also provides cover and grazing opportunities for fish. Coontail offers an important food source to a wide range of waterfowl species. A number of invertebrates and fish use the bushy stems and stiff whorls of coontail leaves as habitat, especially in the winter when other aquatic plants have died back. Muskgrass is a favorite food source for a wide variety of waterfowl. Beds of muskgrass offer cover and food for fish, especially 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 more intolerant of disturbance. The FQI for Pike Lake was 24.8. This value was slightly below average compared to the other lakes in the Eastern Marathon County Lakes Study.

Two of the species in Pike Lake were considered high quality with a C value of 8 (Table 12). No species of special concern in Wisconsin were found in Pike 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 amounts of biodiversity. Pike Lake had a SDI value of 0.88. This represents above average biodiversity when compared to all of the other lakes in the Eastern Marathon County Lakes Study.

Pike Lake has been home to the non-native species curly-leaf pondweed (*Potamogeton crispus*) since 1989, according to WDNR records. A special survey of Pike Lake was conducted in June 2012 to inventory populations of this species. During the survey, curly-leaf pondweed was found along the entire length of the lake’s western shore. This non-native species grows under the ice during late winter and early spring and typically begins to die back in late June and early July. This die-back releases nutrients into the water just as other species of aquatic plants and algae are beginning to grow. The input of nutrients fuels algal blooms and excessive plant growth.

Attempts have been made since the 1940s to control aquatic plants and algae in Pike Lake through harvesting and the application of a variety of chemical compounds. In addition to the most recent plant survey, aquatic plant surveys were conducted in Pike Lake in 1999, 2002, and 2006. When data was reviewed, it was observed that both the FQI and SDI values had decreased over time. The overall number and species composition had shifted as well. Not only were aquatic plant management efforts damaging native plants, they were unsuccessful in achieving desired conditions. As a result, a plan for aquatic plant management in Pike Lake was developed.

The aquatic plant management plan was a collaborative effort between citizens living around and near Pike Lake, the Pike Lake Sportsman Club, the towns of Reid and Elderon, and the Marathon County Land Conservation Department. Guidance was provided by professionals from the WDNR and the UW-Stevens Point Center for Watershed Science and Education. The plan addressed non-native aquatic plant species control with the harvesting of curly-leaf pondweed and access lanes between docks and open water developed in balance with the protection of critical habitat areas and the conservancy area around the island at the south end of Pike Lake. Through these actions, citizens will be able to enjoy the lake while the fishery and wildlife in and around the lake benefit.

Overall, the aquatic plant community in Pike Lake can be characterized as having good species diversity. The habitat, food source, and water quality benefits of this diverse plant community should be the focal points in decision-making concerning future lake management strategies.

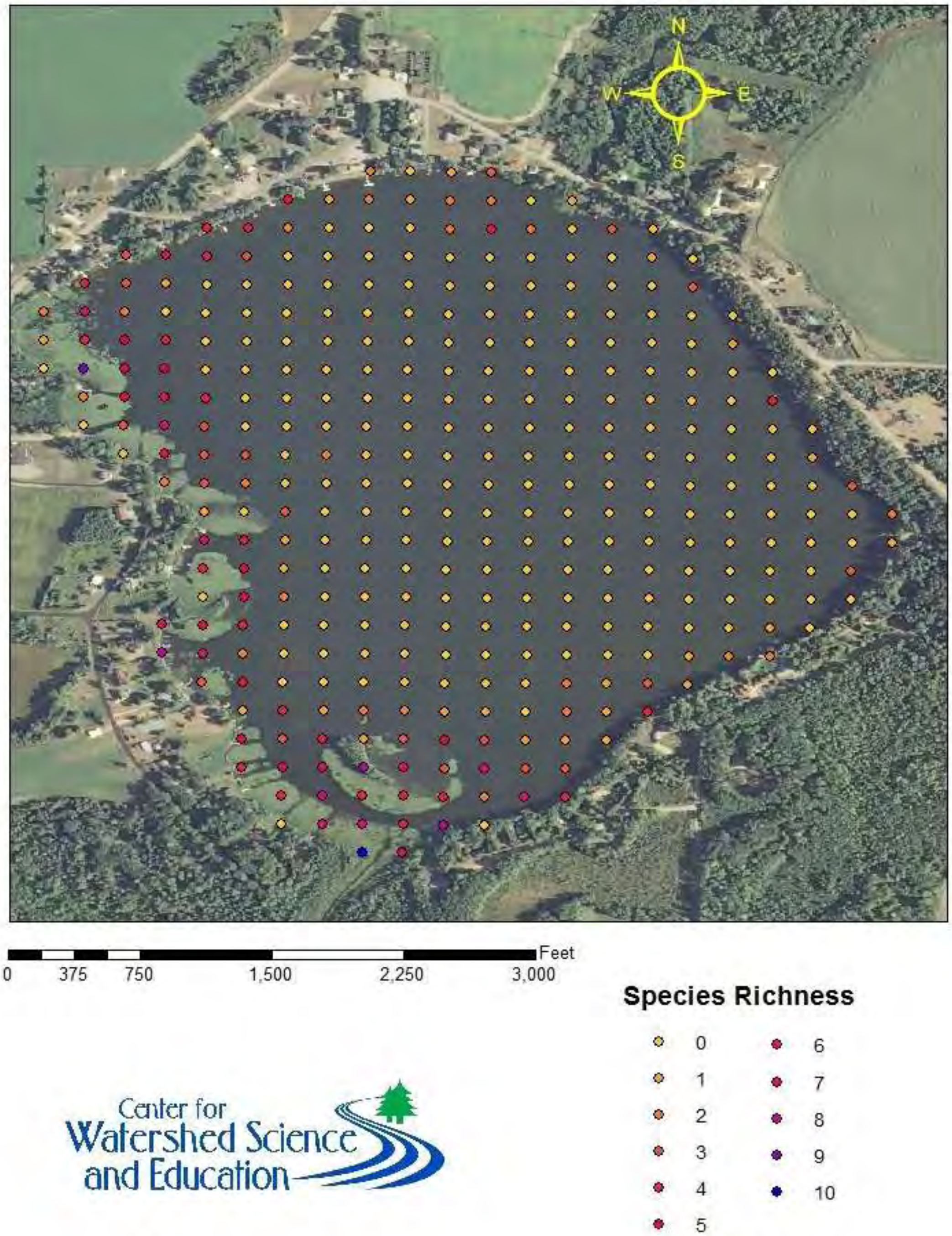

FIGURE 15. SPECIES RICHNESS AT SAMPLE SITES ON PIKE LAKE, 2012.

SEDIMENT CORES

Questions often arise concerning how a lake has changed over time related to changes in land use in the watershed, the abundance and diversity of its aquatic plant communities, and the condition of its shorelands. 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 and the atmosphere, or occur in the lake itself. The chemical composition of the sediment can help decipher the composition of the 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 selected for sediment core analysis. A single sediment core approximately 36 inches in length was collected for analysis from Pike Lake's deepest region in 28 feet of water in November 2012. It is 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. Good indicator organisms grow rapidly and are short-lived, so the community composition responds rapidly 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 well known. In addition, the cell walls of diatoms are made of silica, which enables them to be highly resistant to degradation and are well-preserved in sediments (Figure 16).

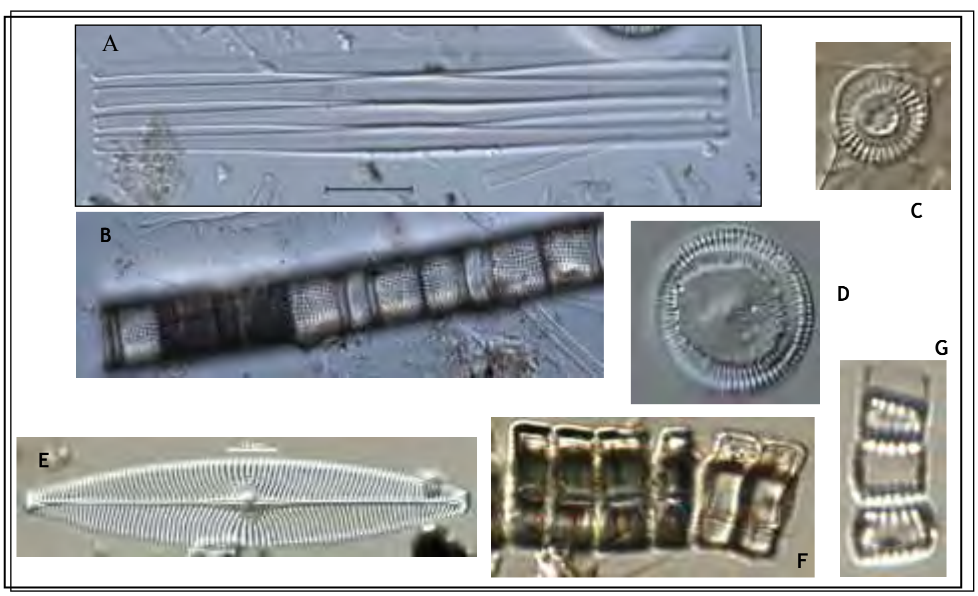

FIGURE 16. PHOTOMICROGRAPHS OF THE COMMON DIATOMS FOUND IN MARATHON COUNTY LAKE SEDIMENT CORES.

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.

ated with higher nutrient concentrations. *Navicula vulpina* (E) grows on aquatic plants and is usually found in low nutrient environments.

The diatom community was analyzed in samples from the top and middle of Pike Lake's sediment core. The middle of the core was dominated by *S. pinnata* and *S. construens,* which are both benthic (bottom feeding) species associated with higher nutrient sediment, submerged aquatic plants, and filamentous algae (Figure 17). In contrast, the top of the core was dominated by planktonic species of diatoms such as *A. ambigua* and *A. granulate*. These are most commonly found floating on top of open water and are associated with higher nutrient levels. As nutrients increase, water clarity decreases and less light reaches the bottom of the lake where benthic diatoms grow. Species richness and diversity were not much different between the top and the middle of the core. This suggests that the composition of the diatom community of Pike Lake has remained largely unchanged.

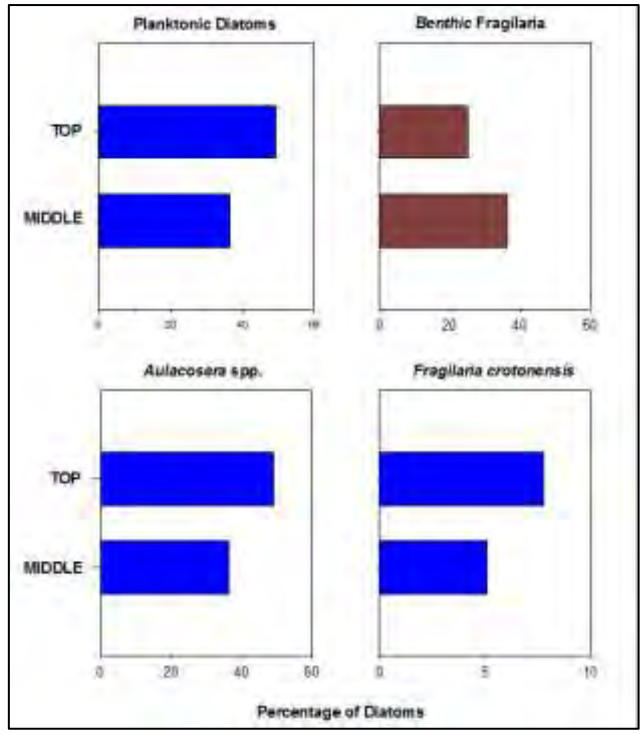

FIGURE 17. CHANGES IN ABUNDANCE OF IMPORTANT DIATOMS FOUND AT THE TOP AND MIDDLE OF THE SEDIMENT CORE IN PIKE LAKE.

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 sediment core.

Ragweed typically increases with increased logging and land clearing. Its pollen peaks when the remaining undergrowth is later cleared or burned for agricultural use. In Pike Lake, ragweed pollen is considered high throughout the core but is remarkably high between 10 and 11 inches, which indicates an increase in agricultural expansion of the land around Pike Lake during the early 20th century (Figure 18). The high ragweed level at 15 inches suggests earlier disturbance, such as land clearing by Native Americans.

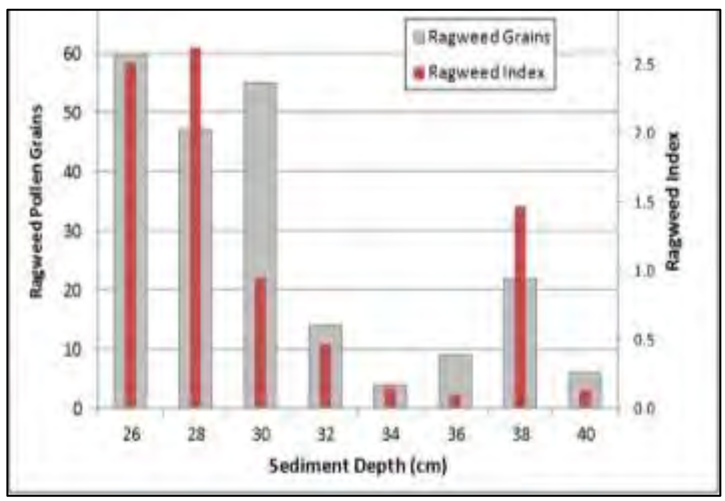

FIGURE 18. RAGWEED POLLEN IN PIKE LAKE SEDIMENT CORE.

PHYSICAL PROPERTIES OF SEDIMENT

Pike Lake's sediment was black at the top and green at the bottom of the core. The dark color at the top of the core is likely the result of high amounts of organic matter or iron staining the sediment. As microbes and other organisms decompose in a lake, dissolved oxygen in the overlying water decreases and the sediment is altered by the production of iron compounds. Although this typically occurs seasonally, it becomes more pronounced with an increase in nutrients, algae, and aquatic plants. The green color at the bottom of the core is a result of the presence of marl and mud.

There were few textural changes in comparison to color changes in the Pike Lake sediment core. The sediment was fine-grained and smooth and contained varying amounts of sand throughout. Increased sand is indicative of shoreland disturbance related to erosion from land clearing and storm events.

To determine the composition of Pike Lake's sediment core, a loss on ignition (LOI) test was conducted. Various components that make up the lake's sediment core, such as organic matter, marl (carbonate), and silica (sand, silt, and clay) are burned away during this analysis to provide more specifics about the core's composition in addition to color and textural analysis (Figure 19). There was a major change in the composition of Pike Lake's sediment between 30.7 and 32.3 inches based on the LOI results. Organic matter and carbonates essentially disappeared, while silica was in high abundance. This indicates a large disturbance event related to land clearing or a major storm event. Organic matter increased further up in the core but carbonates never recovered, so it is possible that this event permanently changed the marl forming processes in Pike Lake. Organic matter and silica were highly variable at the top of the core, which may be the result of aquatic plant and fish management efforts that have been implemented over the last century.

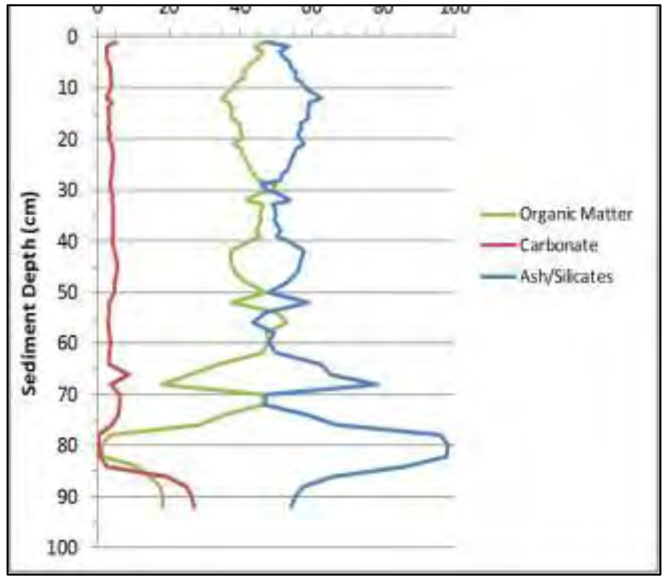

FIGURE 19. LOSS ON IGNITION RESULTS FOR MISSION LAKE.

SEDIMENT CORE RESULTS SUMMARY

Analysis of the biological and physical properties of Pike 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. There appeared to be an increase in nutrient delivery, including phosphorus, as well as an increase in color to the lake over the period of analysis (approx. 150 years). Diatom communities reflected only a modest increase in nutrients, but also indicated increases in the aquatic plant community and filamentous algae in the top of the core. These analyses suggest that Pike Lake has experienced limited increase in phosphorus concentrations, but large changes in habitat during the last century.

CONCLUSIONS AND RECOMMENDATIONS

A sustainable fishery is one that is in balance with the lake's natural ability to support the fish community, and is adaptable to reasonable fishing pressures without additional stocking or input. A healthy fish community has a balance between predator and prey species, and each species of fish has different needs in order to flourish, including sufficient food, habitat, appropriate nesting substrate, and water quality.

The Pike Lake fish species assemblage was more diverse than surrounding lakes in eastern Marathon County. Because it is a drainage lake, fish have an opportunity to enter from upstream and downstream systems.

- Four new species were documented in the 2012 survey: bluegill x pumpkinseed hybrid, brown bullhead, bluntnose minnow, and Iowa darter.
- Species documented previously, but not detected during the 2012 survey included channel catfish, rock bass, slender madtom, and spotfin shiner.
- Bluegill, yellow perch, and yellow bullhead were abundant during the survey. Golden shiner, brown bullhead, Iowa darter, spottail shiner, common shiner, and white sucker were infrequently encountered. The non-native rusty crayfish was identified during the survey.
- The presence of young bass and abundant sunfish sampling indicates successful reproduction is occurring in Pike Lake. The absence of young northern pike in 2012 may be an indicator of poor reproduction, although more intense population sampling efforts over several seasons would be required to determine the reproductive success for individual fish species.
- Walleye reproduction has been variable in Pike Lake, and no young walleyes were observed during the sampling period.
- In 1971, it was reported that eutrophication of Pike Lake was occurring more rapidly than expected because of the occurrence of algae blooms and occasional winter kills of fish from low dissolved oxygen. The concern over eutrophication continues today as evidenced by continued sporadic reports of winter kills. Bullheads were reported to be the dominant fish species in terms of biomass at times from 1960-1970, which is an indication of winterkill as they are more tolerant of low dissolved oxygen than many other species.
- Fish stocking has occurred in Pike Lake since 1938. Walleye have been prevalently stocked from 1938 through recent years. Stocking management has switched from primarily fry walleye to fingerling size, with recent years including more fry stocking. Although fish mortality rates are high for any stocking effort, fry are especially vulnerable.
- Yellow perch have also been stocked in recent years, and an abundant population of perch was present during 2012 sampling.
- The bottom substrate in Pike Lake was comprised nearly equally of soft bottom/muck and hard bottom (26.4% sand, 15% sand/gravel/cobble, <1% cobble or boulder). Harder surfaces are present mainly along the eastern shoreline. Bulrush was present along stretches of the western shoreline.
  - Sand can be important habitat for reproduction of non-game fish species.
  - Gravel areas are used by many fish for spawning habitat, including sunfish (bluegill, pumpkinseed, black bass), where males construct nests and guard their young.
  - Northern pike use areas with emergent and floating leaf vegetation in shallow or flooded areas for spawning.

    - Black crappie use bulrush habitat on gravel or sand substrates where they construct nests and guard young.
    - Yellow perch and walleye use near-shore cobble in oxygen-rich environments for spawning activity.
- Coarse woody habitat (CWH), including downed trees and logs, are sparse in Pike Lake. Woody habitat is an important component of the lake ecosystem. used by fish and other aquatic organisms for spawning, foraging, and protective cover. The addition of CWH into Pike 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. 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 types of zooplankton in Pike Lake identified during the sample periods were relatively common and the majority of those are not classified as invasive or exotic. Some of the non-native and invasive zooplankton are much larger in size than native zooplankton; therefore, non-native zooplankton can disturb the fishery in a lake because they are often too large to fit in the mouth of young fish.
- The zooplankton community when considered relative to the algal, phosphorus, and nitrogen values for Pike Lake, presents a picture of a lake transitioning to eutrophic (nutrient enriched).

In Marathon County lakes, there are three dominant groups of algae: blue-green algae, green algae, and diatoms.

- Diatoms were the dominant algal group in Pike Lake during both 2011 and 2012. The diatoms were represented by a rich species mixture and most are associated with eutrophic waters. These species are colonial and planktonic, grow quite densely, and likely contributed to the low Secchi disk (water clarity) values seen in 2011 and 2012.
- The remaining components of the algal community, green algae and blue-green algae, were minor constituents, and are also typical of eutrophic lakes.
- The high total phosphorus value, the low Secchi disk values, and the dense and dominating diatom community found in Pike Lake are typical of a eutrophic but stable lake.

Overall, the aquatic plant community in Pike Lake can be characterized as having good species diversity. The habitat, food source, and water quality benefits of this diverse plant community should be the focal points in decision-making concerning future lake management strategies.

- Twenty-one species of aquatic plants were found in Pike Lake, with the greatest diversity located in the western and southwestern sides of the lake.
- Two of the species in Pike Lake were considered high quality with a C value of 8 (white-stem pondweed and pickerelweed).

- Curly leaf pondweed (CLP) was identified in Pike Lake in1989. CLP can act as a part of the aquatic plant community, but can also become aggressive and invasive. This non-native species grows under the ice during late winter and early spring and typically begins to die back in late June and early July. This die back releases nutrients into the water just as other species of aquatic plants and algae begin to grow. The input of nutrients fuels algal blooms and excessive plant growth.
    - CLP is the focus of aquatic plant management in Pike Lake.
    - CLP is also present in Rice Lake. If populations are reduced in Pike Lake, it may be beneficial to reduce the spread in both Rice Lake and its downstream neighbor, Pike Lake.
- The amount of disturbed lake bed from raking or pulling of plants should be minimized since these open spaces are ideal for aquatic invasive plants to become established.
- Boats and trailers that have visited other lakes can be a primary vector for the transport of aquatic invasive species (AIS). Volunteer boat inspectors at the boat landing, trained through the Clean Boats Clean Waters (CBCW) program, can help prevent new AIS introductions.

Many water quality indicators suggest that Pike Lake is a nutrient-rich lake. Nutrient rich lakes exhibit algal blooms and insufficient oxygen to support some aquatic organisms, including some species of fish. These indicators included water analyses, physical measures of the lake, and the composition of the algal and zooplankton communities. The sediment analysis conducted in Pike Lake suggested that the lake was not always this nutrient-rich.

- In the winters of 2011 and 2012, dissolved oxygen at the deep hole fell below concentrations needed to support many fish species; however, the aeration system which operates during the winter in Pike Lake helped to insure that the fishery had sufficient oxygen for survival.
- In Pike Lake, the summer median total phosphorus concentrations were 31 μg/L and 26 μg/L in 2011 and 2012, respectively. These are close to Wisconsin's phosphorus standard of 30 μg/L for deep drainage lakes.
- During the study, inorganic nitrogen concentrations averaged 0.6 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, so owners of private wells should have their well water tested to determine if well water nitrate concentrations are safe for consumption.
- Monitoring should be conducted in Pike Lake for water clarity, phosphorus, chlorophyll *a*, and inorganic nitrogen to evaluate changes over time. The monitoring strategy should be developed to include summer samples and spring/fall overturn samples. Dissolved oxygen should be monitored during periods of ice cover.
- Efforts should be made to reduce the nutrient concentrations in Pike Lake. Indicators suggested that the lake is currently in a stable state, but may be approaching a potential state of flux. The best way to reduce nutrients in the lake is to look to the landscape where most of the lake's phosphorus originates. Changes in land management practices both near shore and throughout the watershed could have very positive effects in the lake.

Analysis of the biological and physical properties of Pike Lake's sediment core collected from the lake's deep region 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 appeared to have been minimized in recent years.
- There appeared to be an increase in nutrient delivery, including phosphorus, as well as an increase in color to the lake over the period of analysis (approx. 150 years).
- Diatom communities reflected only a modest increase in nutrients, but also indicated increases in the aquatic plant community and filamentous algae in the top of the core. These analyses suggest that Pike Lake experienced a limited increase in phosphorous concentrations, but large changes in habitat during the last century.

In general, each type of land use contributes different amounts of phosphorus and nitrogen 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.

- Identifying and taking steps to improve water quality in Pike Lake will depend upon understanding the sources of nutrients to the lake and identifying those that are manageable. Although forests comprise the greatest amount of land in the groundwater and surface watersheds, modeling results indicated that agricultural lands contribute the greatest percentage of phosphorus from the watershed to Pike Lake.
- The shoreland vegetation survey for Pike Lake indicated that 10,550 feet (86%) of shoreline were classified as having a grasses/forbs buffer depth of less than 35 feet. Similar results were classified for the shrubs layer as well.
    - The grasses, forbs, and shrubs vegetation buffers are required to be greater than 35 feet, according to Wisconsin and Marathon County shoreland zoning ordinances.
    - Trees represented the most abundant vegetative layer around the lake with 7,633 linear feet classified as having a buffer width greater than 50 feet.
- 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 often result in habitat loss. Twenty-two sites had rip-rap along Pike Lake's shore.
    - Erosion can contribute sediment to the lake, which can alter spawning habitat and carry nutrients into the lake. Two sites of erosion were identified in Pike Lake's shorelands.
    - Unmanaged runoff from rooftops of structures located near shore can also contribute more sediment to the lake. There were 69 structures within 75 feet of Pike 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 91 docks around Pike Lake. Impacts from docks can be reduced by properly managing the access to and around the docks, both on the land and in the water.
- Although Pike Lake's shoreland has abundant development, efforts can be made to improve the shorelands around Pike Lake. Minimizing impacts to Pike Lake from current and future development should include planning to ensure that existing landowners and prospective developers have the right information to make good decisions and that zoning is in place to achieve habitat, water quality, and aesthetic goals.
- The Marathon County Conservation Department and Natural Resources Conservation Service (NRCS) have professional staff available to assist landowners in learning how they can improve water quality through adjustments in land management practices.

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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 (N_2) 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 ($CaCO_3$), 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."