2014

Waushara County Lakes Study
Pine Lake - Springwater

Final Report
to Waushara County and
Wisconsin Department of Natural Resources

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WAUSHARA COUNTY LAKES STUDY BACKGROUND

Lakes and rivers contribute to the way of life in Waushara County. Local residents and visitors alike enjoy fishing, swimming, boating, wildlife viewing, and the peaceful nature of the lakes. Healthy lakes add value to our communities. They provide places to relax and recreate, and they can stimulate tourism. Like other infrastructure in our communities, lakes require attention and good management practices to remain healthy in our developing watersheds.

Thirty-three lakes in Waushara County were selected for this study. The study focused on learning about the lakes' water quality, aquatic plant communities, shoreland habitats, watersheds and histories in order to help people make informed lake management decisions. This report summarizes data collected for Pine Lake between fall 2010 and fall 2012.

ABOUT PINE 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. Pine Lake is located in the township of Springwater, northeast of Wild Rose, east of Highway 22, and north of County Highway A. There is one public boat launch located on the western side. Pine Lake is a 137-acre seepage lake with surface runoff and groundwater contributing most of its water. The maximum depth in Pine Lake is 48 feet; the lakebed has a steep slope (Figure 1). Its bottom sediments are mostly sand with a small amount of muck.

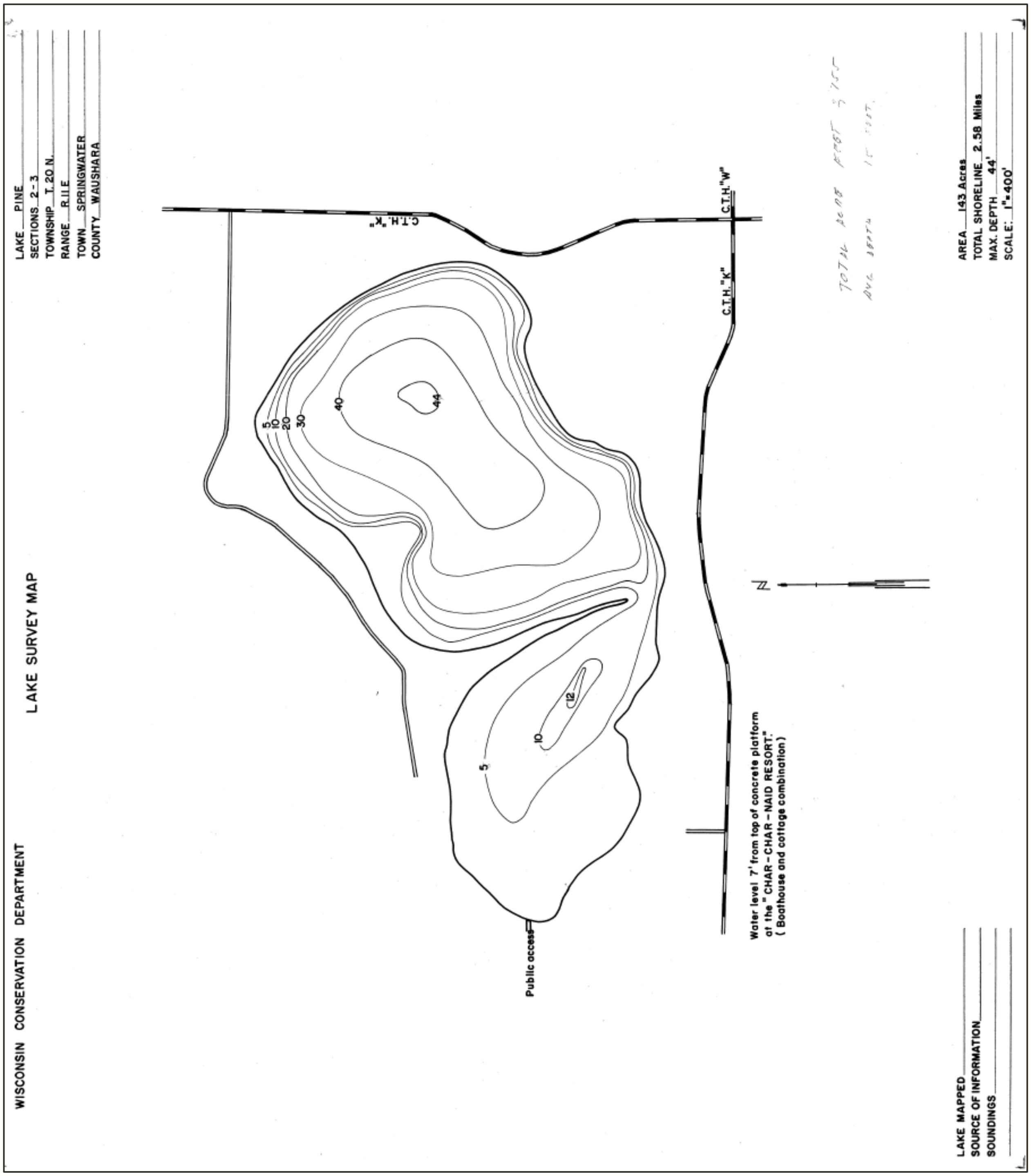


FIGURE 1. CONTOUR MAP OF THE PINE LAKE LAKEBED.

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

It is important to understand where Pine 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 Pine Lake is called a surface watershed. Groundwater also feeds Pine Lake; its land area may be slightly different than the surface watershed. The surface watershed is 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, 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 and 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. Soil also contains nutrients that increase the growth of algae and aquatic plants. Development on the land often results in changes to natural drainage patterns, alterations to 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 crops 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, rain barrels, and routing drainage from pavement and roofs away from the lake. Some practices are used to help reduce nutrients from 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. Waushara County staff and other professionals can work with landowners to determine which practices are best suited to a particular property.

The surface watershed for Pine Lake is approximately 2,679 acres (Figure 2). The dominant types of land use in the watershed are forests (67%). The land closest to the lake often has the greatest impact on water quality and habitat; Pine Lake's shoreland is surrounded primarily by wetlands and development.

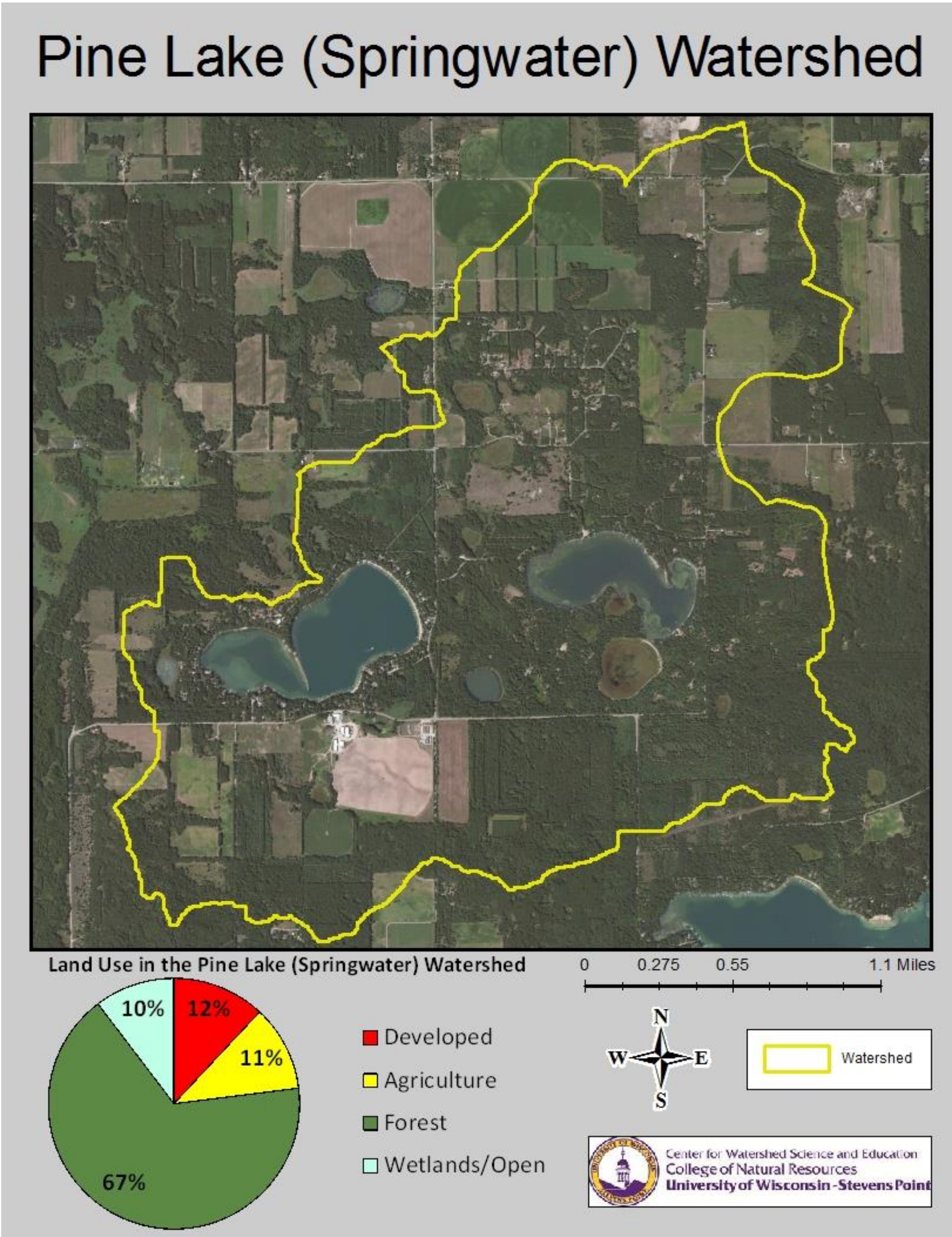


FIGURE 2. LAND USE IN THE PINE LAKE SURFACE WATERSHED.

The more the lake's water interacts with groundwater, the more influence the geology has on the lake. The length of time water remains below ground affects the temperature and chemistry of the groundwater. Groundwater temperature is near constant year round; during the summer, groundwater feeding Pine Lake will help keep the lake water cooler.

Groundwater flows below ground from higher to lower elevations, discharging into wetlands, streams, and lakes. The groundwater feeding the lakes in Waushara County originates nearby. The black arrows in Figure 3 indicate the general direction of groundwater flow. Much of the groundwater enters Pine Lake from the north.

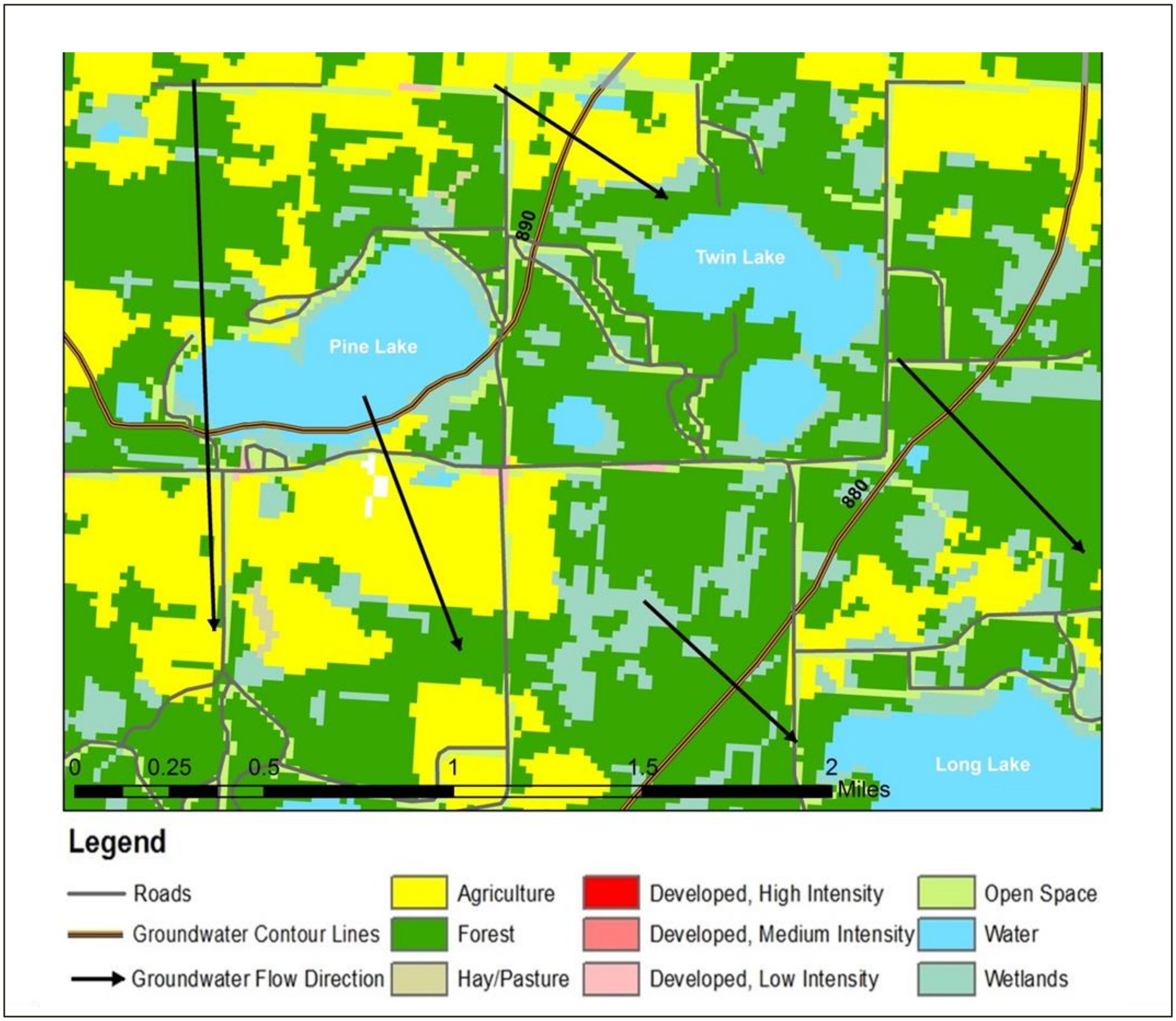
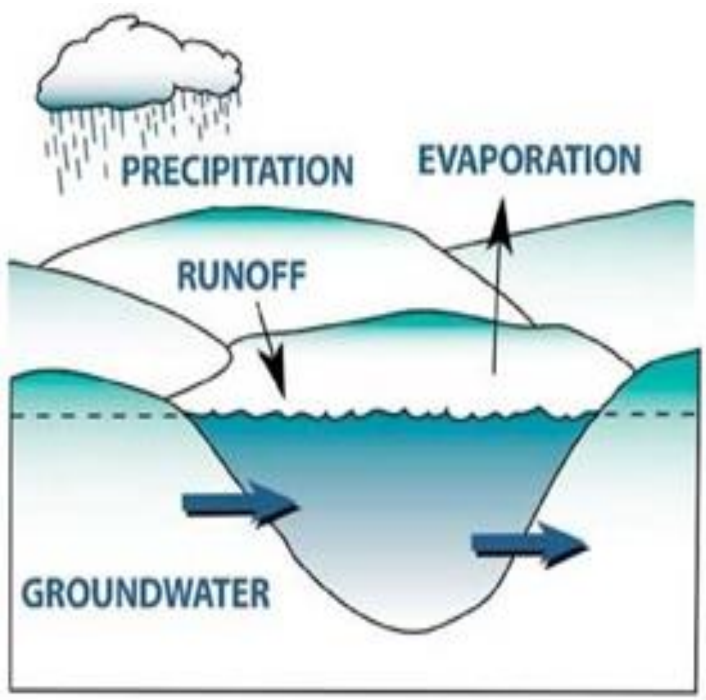


FIGURE 3. GROUNDWATER FLOW DIRECTION NEAR PINE LAKE.

Lake water quality is a result of many factors including the underlying geology, the climate, and land management practices. Assessing lake water quality allows us to evaluate current lake health and changes from the past. We can then identify 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 Pine Lake was assessed by measuring different characteristics including temperature, dissolved oxygen, water clarity, water chemistry, and algae.



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. Pine Lake is classified as a seepage lake. Seepage lakes receive their water primarily through groundwater and, to a lesser extent, direct runoff and precipitation (Figure 4). Seepage lakes have higher concentrations of minerals such as calcium and magnesium, which are picked up by groundwater moving through soil and rock. Seepage lakes generally have 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. Seepage lakes are also more vulnerable to contamination moving towards the lake in the groundwater. Examples for Pine Lake may include septic systems, agriculture, and road salt.

FIGURE 4. CARTOON SHOWING INFLOW AND OUTFLOW 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 the lake. As groundwater moves, some substances are filtered out, while others dissolve into the groundwater. Minerals such as calcium and magnesium in the soil around Pine Lake are dissolved in the water. The average hardness for Pine Lake during the study was 122 mg/L, which is considered hard (Table 1). Hard water provides the calcium necessary for building the bones and shells of animals in the lake. The average alkalinity was 119 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 PINE LAKE, 2010-2012.

Pine Lake	Alkalinity (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mg/L as $CaCO_3$)	Color (SU)	Turbidity (NTU)
Average Value	119	26.6	15.9	122	9.2	1.7

Chloride concentrations, and to a lesser degree sodium and potassium concentrations, are commonly used as indicators of how a lake is being impacted by human activity. The presence of these compounds where they do not naturally occur indicates sources of water contaminants.

During the study, the average concentrations of chloride and potassium were low, but sodium concentrations were slightly elevated (Table 2). These concentrations were not harmful to aquatic organisms, but indicated that pollutants might be entering the lake. Chloride and sodium sources include animal waste, septic systems, fertilizer, and road-salting chemicals. Atrazine, an herbicide commonly used on corn, was detected (0.10 µg/L DACT) in the sample analyzed from Pine Lake. The presence of this chemical suggested that agricultural activities in the surrounding area were impacting water quality. Some toxicity studies have indicated that reproductive system abnormalities can occur in frogs at these levels (Hayes et al., 2001and Hayes et al., 2003).

Table 2. Pine Lake average water chemistry, 2010-2012.

Pine Lake	**Average Value**			**Reference Value**		
(Springwater)	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Potassium (mg/L)	0.6			<.75	0.75-1.5	>1.5
Chloride (mg/L)	1.8			<3	3.0-10.0	>10
Sodium (mg/L)		2.0		<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. Algae and aquatic plants also produce oxygen when sunlight enters the water, but the decomposition of dead plants and algae reduces oxygen in the lake. Some forms of iron and other metals carried by groundwater can also consume oxygen when the groundwater discharges to the lake.

In a lake, 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 the amount of available habitat for sensitive cold water species of fish and other aquatic organisms.

Water temperature and dissolved oxygen were measured in Pine Lake from the surface to the bottom at the time of sample collection during the 2010-2012 study. Temperature followed a classic pattern for deeper lakes in Wisconsin. The lake water was mixed during the spring and fall, and during the summer Pine Lake became stratified (Figure 5). Thermal stratification was well-developed by June in Pine Lake, with similar patterns observed during the two years (2011-2012). The summer data illustrated decreasing temperatures with depth, ranging as high as 28C (82°F) at the surface to 7C (45°F) near the bottom in mid-summer. The winter data illustrated a very typical late winter profile in February 2011 and 2012 with freezing temperatures at the surface and gradual warming with depth.

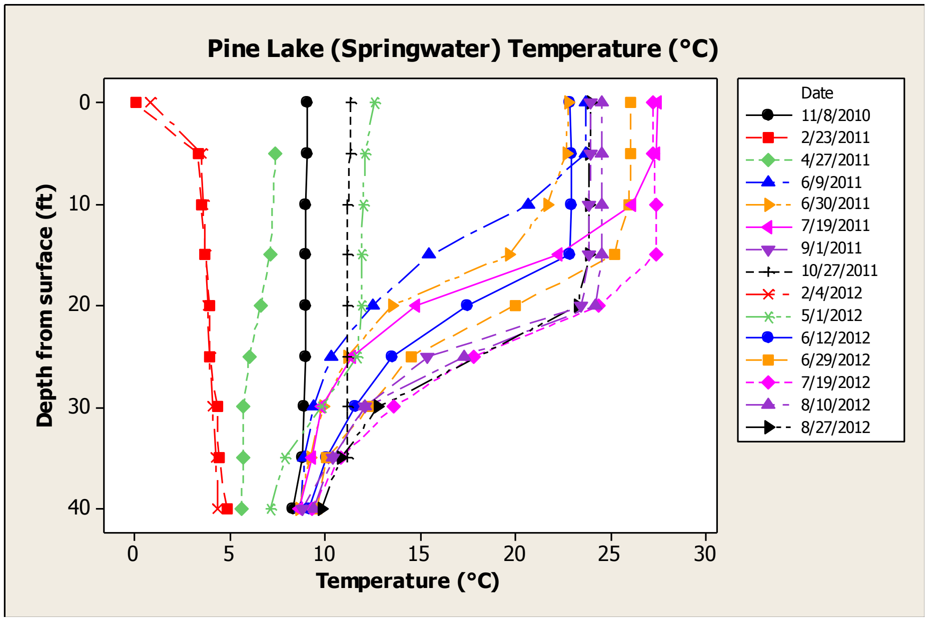


FIGURE 5. TEMPERATURE PROFILES IN PINE LAKE, 2010-2012.

Throughout the year, dissolved oxygen was plentiful in the upper 30 feet of water (Figure 6). Dissolved oxygen followed patterns similar to temperature, especially during the summer. Oxygen production by algal blooms was evident throughout the summer when dissolved oxygen increased with depths 8 to 22 feet below the surface.

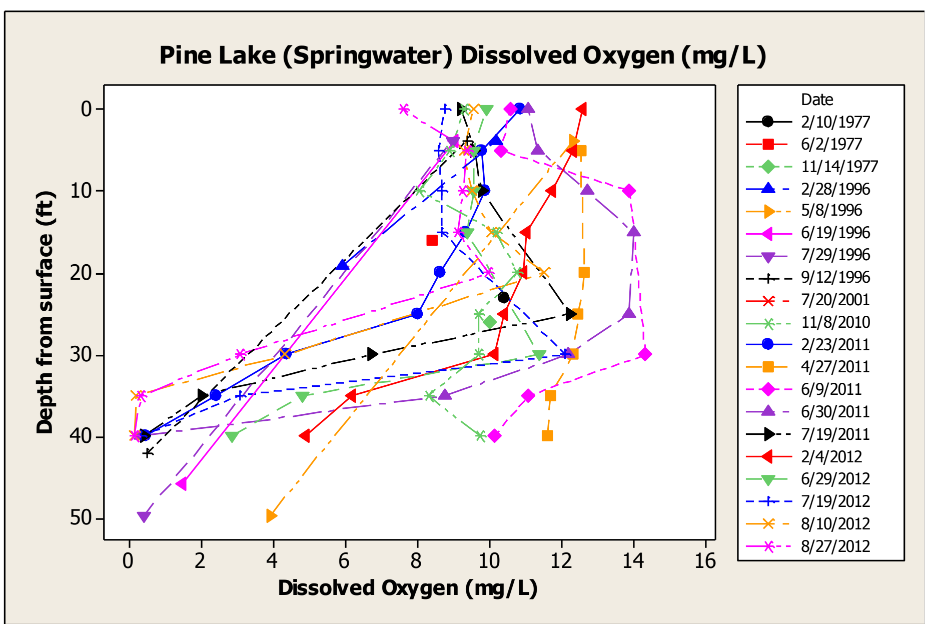
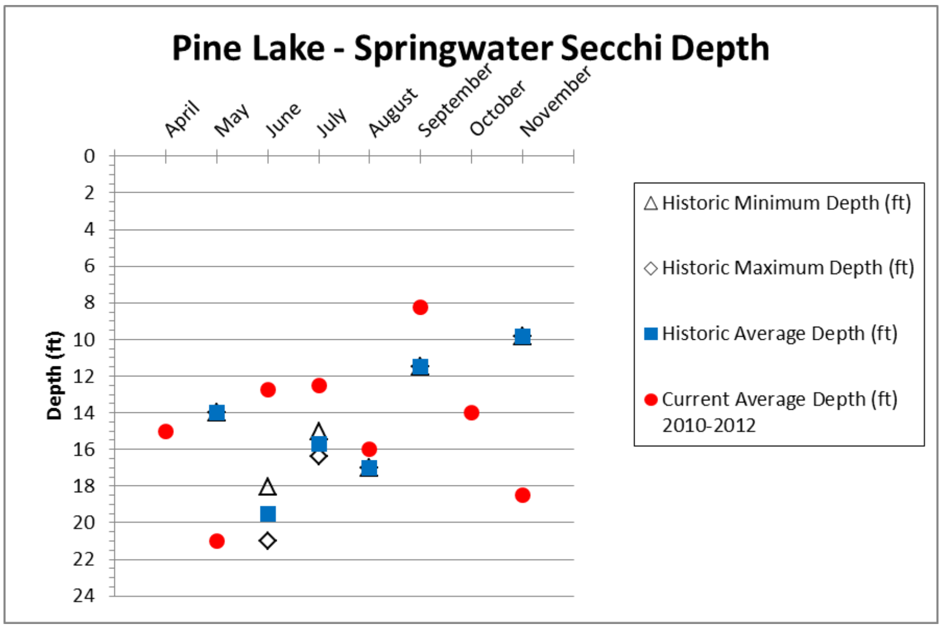


FIGURE 6. DISSOLVED OXYGEN PROFILES IN PINE LAKE, 2010-2012.

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 Pine Lake, color was relatively low (Table 1), so the variability in transparency throughout the year is primarily due to fluctuating algae concentrations and re-suspended sediment following storms and/or heavy boating activity. The water clarity measured in Pine Lake during the study was considered good: depending on the time of year, water clarity ranged from 8.2 feet to 21 feet (Figure 7). When compared with past data, the average water clarity measured during the study was better in May and November and poorer during the growing season months of June, July, August and September. Historic data extended back to 1977.



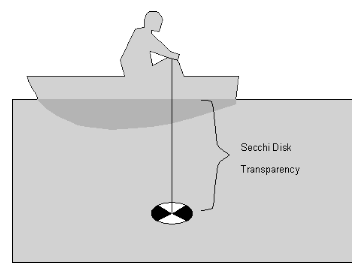


FIGURE 7. WATER CLARITY IN PINE LAKE, 2010-2012 AND HISTORIC.

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. Common sources from human activities include soil erosion, animal waste, fertilizers and septic systems.

It is most common for phosphorus to move from the land to the water 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 and animal tissue, and sediment. The phosphorus continues to cycle within the lake for many years.

Total phosphorus concentrations for Pine Lake ranged from a high of 24 ug/L in November 2010 to a low of 3 ug/L in August 2012 (Table 3). The summer median total phosphorus concentrations were 10 ug/L and 8 ug/L in 2011 and 2012, respectively. This is below Wisconsin's phosphorus standard of 20 ug/L for deep seepage lakes. During the study, inorganic nitrogen concentrations in samples collected during the spring averaged 0.22 mg/L. 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, and this was observed during a groundwater survey of Pine Lake in an earlier study (Turyk et al., 2003).

Chlorophyll *a* is a measurement of algae in the water. Chlorophyll *a* concentrations in Pine Lake varied slightly throughout the monitoring period, ranging between 0.5 ug/L and 6 ug/L. The average for the monitoring period was 2.2 ug/L.

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

Pine Lake - Springwater	Inorganic Nitrogen (mg/L)			Organic Nitrogen (mg/L)			Total Nitrogen (mg/L)			Soluble Reactive Phosphorus (ug/L)			Total Phosphorus (ug/L)		
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
Fall	0.13	0.15	0.18	0.59	0.59	0.59	0.77	0.77	0.77	9	9	9	9	16.5	24
Spring	0.14	0.22	0.30	0.54	0.54	0.54	0.84	0.84	0.84	1	3	5	10	11	11
Summer													3	9	12
Winter	0.17	0.24	0.32	0.48	0.48	0.48	0.80	0.80	0.80	3	5	6	4	9	14

Estimates of phosphorus from the landscape can help to understand the phosphorus sources to Pine 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. Forests comprised the greatest percent land use in the watershed. Based on water quality modeling results, agriculture and forests had the greatest contributions of phosphorus from the watershed to Pine Lake (Figure 8). 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).

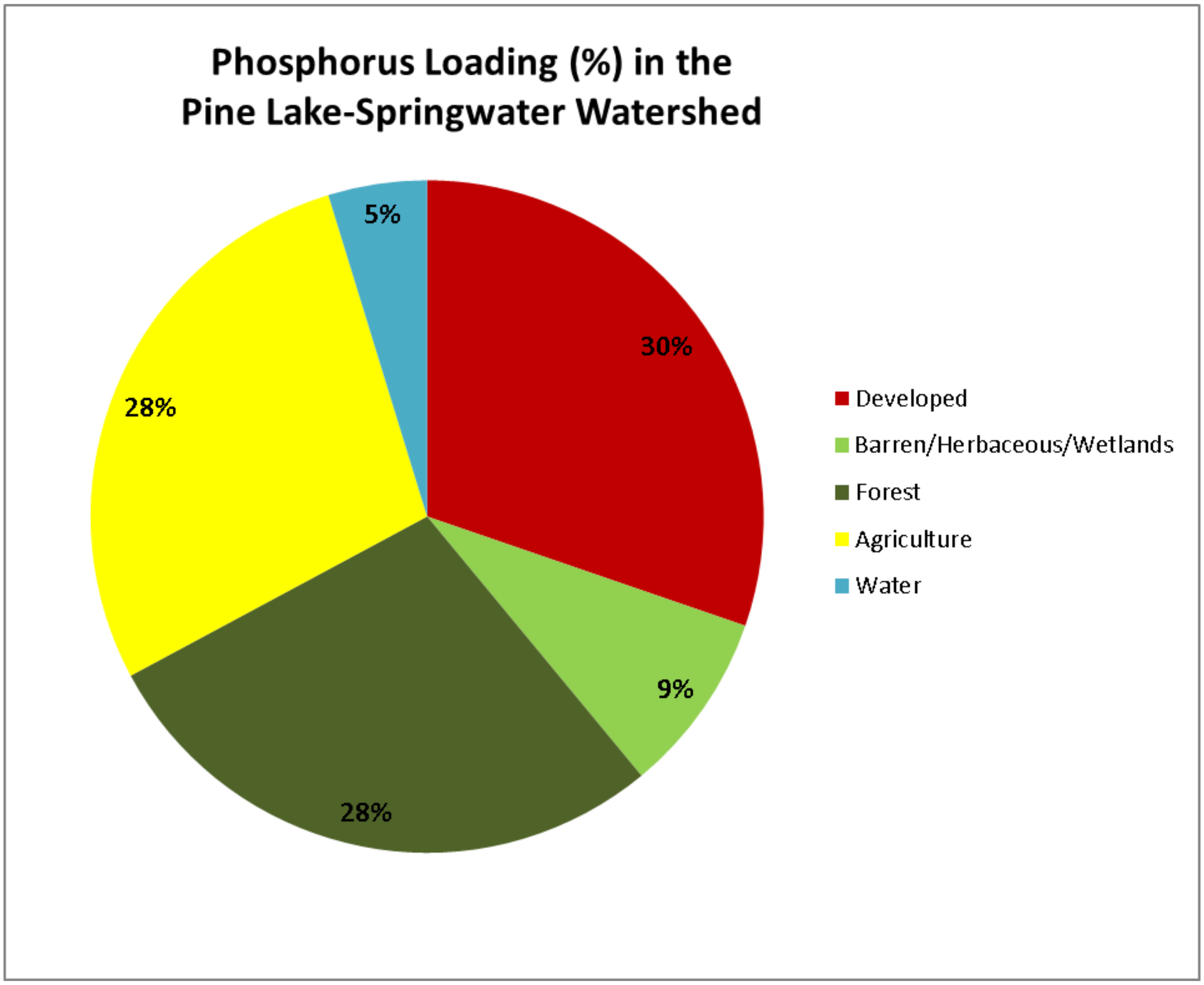


FIGURE 8. ESTIMATED PHOSPHORUS LOADS FROM LAND USES IN THE PINE LAKE WATERSHED.

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

Pine Lake-Springwater Land Use	Phosphorus Export Coefficient (lbs/acre-yr)	Land Use Area within the Watershed		Estimated Phosphorus Load	
		Acres	Percent	Pounds	Percent
Water	0.1	242	**9**	12-37	**5**
Developed	0.27	291	**11**	78-157	**30**
Barren/Herbaceous/Wetland	0.09	252	**9**	22-68	**9**
Forest	0.04	1624	**61**	72-130	**28**
Cultivated Agriculture	0.45	270	**10**	72-194	**28**

*Values are not exact due to rounding and conversion.

(Based on contributions from Golden Sands Resource Conservation & Development Council, Inc., 2014)

Aquatic plants play important roles in a lake's ecosystem. They provide habitat for the fishery and other aquatic organisms, stabilize the sediment, reduce erosion, buffer temperature changes and waves, and infuse oxygen into the water. Aquatic plants near shore provide food, shelter and nesting material for shoreland mammals, shorebirds and waterfowl. It is not unusual for otters, beavers, muskrats and deer to be seen along a shoreline in their search for food or nesting material. The aquatic plants that attract the animals to these areas contribute to the beauty of the shoreland and lake.

The rapid and dominant growth of aquatic invasive plants, such as Eurasian watermilfoil (EWM), can reduce the recreational value of a lake. Aquatic invasive plants may also outcompete and cause a decline in native vegetation, which degrades habitat diversity and can alter the aquatic ecosystem.

An aquatic plant survey was conducted on Pine Lake - Springwater in August 2013 by staff from Golden Sands Resource Conservation & Development Council, Inc. The diversity of an aquatic plant community is defined by the type and number of species present throughout the lake. Twenty-three species of aquatic plants were found in Pine Lake, with one additional species observed visually (Table 5). The twenty-four species observed within Pine Lake ranked it above average compared with the other lakes in the Waushara County Lakes Study. Seventy-nine percent (324 of 407) of the sites visited had vegetative growth. The greatest depth at which aquatic plant growth was found was 36 feet. The greatest diversity of aquatic plants occurred in parts of the western lobe (Figure 9).

The dominant plant species found in Pine Lake was muskgrass (*Chara* spp.), followed by stonewort (*Nitella* spp.) and variable pondweed (*Potamogeton gramineus*). *Chara* spp. is a favorite waterfowl food and also offers cover for fish. The algae and invertebrates living on the surfaces of *Nitella* spp. plants provide food for waterfowl, and provide food and cover for fish. Variable pondweed is eaten by muskrat, beaver and deer (Borman et al., 2001).

The Floristic Quality Index (FQI) evaluates how close a plant community is to undisturbed conditions. Each plant is assigned a coefficient of conservatism value (C value) that reflects its sensitivity to disturbance, and these numbers are used to calculate the FQI. C values range from 0 to 10. The lower the number, the more tolerant the plant is of disturbance. Having more plants with low C values than high C values is an indicator of disturbance, as the lower C value plants better tolerate stresses caused by disturbance. A C value of 0 is assigned to exotic species. The FQI for Pine Lake was 24.8, which is average for the lakes in the Waushara County Lakes Study.

In Pine Lake - Springwater, C values ranged from 0 to 8 (Table 5). Four of the species found in Pine Lake had a C value of 8, indicating good health in the aquatic plant community. These species included Fries' pondweed (*Potamogeton friesii*), southern naiad (*Najas guadalupensis*), stiff pondweed (*Potamogeton strictifolius*), and white-stem pondweed (*Potamogeton praelongus*). The average C value for Pine Lake - Springwater is above the statewide average for lakes. One invasive plant species was sampled, Eurasian watermilfoil (EWM), which had a C value of 0.

EWM was found in low abundance in scattered populations in Pine Lake. EWM can create dense beds that can damage boat motors, make areas non-navigable, stunt or alter the fishery, create problems with dissolved oxygen, and prevent activities like fishing and swimming. This plant can produce a viable seed; however, its primary mode of reproduction and spread is fragmentation of the plant. A one-inch fragment is enough to start a new plant, making EWM very successful at reproducing. Steps to control EWM have been taken by the lake association and should be continued.

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 from 0 to 1. Values closer to one represent higher amounts of biodiversity. The SDI of Pine Lake - Springwater for the 2013 survey was 0.82. This represents an average biodiversity when compared with the other lakes in the Waushara County Lakes Study.

Aquatic plants play another critical role in the lake's ecosystem by using nutrients that would otherwise be available to algae. Any management activities should be planned to minimize the disturbance of native species in the water and on shore in order to maintain the balance between aquatic plants and algae. In addition, care should be taken to minimize raking the lake bed and pulling plants, since disturbing these valuable open spaces may allow invasive plants such as EWM to establish.

TABLE 5. LIST OF AQUATIC PLANTS IDENTIFIED IN THE 2013 AQUATIC PLANT SURVEY OF PINE LAKE.

Common name	Scientific name	Sampled	Visuals	C value
bearded stonewort	*Lychnothamnus barbatus*	x		-
common waterweed	*Elodea canadensis*	x	x	3
coontail	*Ceratophyllum demersum*	x	x	3
Eurasian watermilfoil	*Myriophyllum spicatum*	x	x	0
flat-stem pondweed	*Potamogeton zosteriformis*	x	x	6
floating-leaf pondweed	*Potamogeton natans*	x	x	5
Fries' pondweed	*Potamogeton friesii*	x	x	8
large-leaf pondweed	*Potamogeton amplifolius*	x	x	7
leafy pondweed	*Potamogeton foliosus*	x	x	6
muskgrass	*Chara* spp.	x	x	7
northern watermilfoil	*Myriophyllum sibiricum*	x		6
sago pondweed	*Stuckenia pectinata*	x	x	3
slender naiad	*Najas flexilis*	x	x	6
small pondweed	*Potamogeton pusillus*	x	x	7
small stonewort	*Nitella tenuissima*	x	x	-
southern naiad	*Najas guadalupensis*	x	x	8
stiff pondweed	*Potamogeton strictifolius*	x		8
stoneworts	*Nitella* spp.	x		7
three-square bulrush	*Schoenoplectus pungens*		x	5
variable pondweed	*Potamogeton gramineus*	x	x	7
water celery	*Vallisneria americana*	x	x	6
water stargrass	*Heteranthera dubia*	x	x	6
white water lily	*Nymphaea odorata*	x	x	6
white-stem pondweed	*Potamogeton praelongus*	x	x	8
freshwater sponges		x	x	-

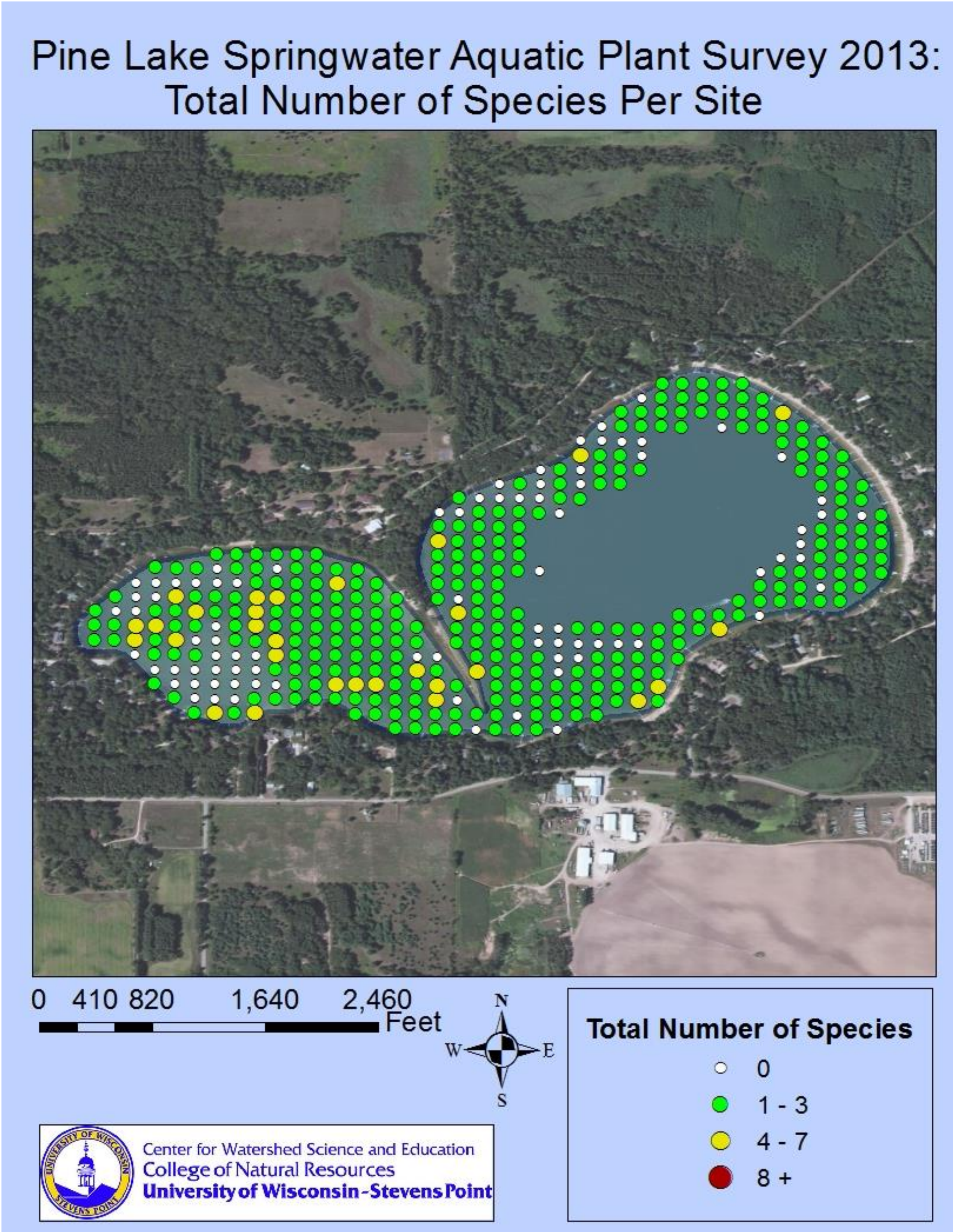


FIGURE 9. NUMBER OF AQUATIC PLANT SPECIES OBSERVED AT EACH SAMPLE SITE IN PINE LAKE- SPRINGWATER, 2013.

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 the lake. Healthy shoreland vegetation includes a mix of tall grasses/flowers, shrubs and trees which extend at least 35 feet landward from the water's edge.

To better understand the health of the Waushara County lakes, shorelands were evaluated by the Center for Land Use Education and Waushara County as a part of the Waushara County Lakes Study. The survey inventoried the type and extent of shoreland vegetation. Areas with erosion, rip-rap, barren ground, sea walls, structures and docks were also inventoried.

A scoring system was developed for the collected data to provide a more holistic assessment. Areas that are healthy will need strategies to keep them healthy, and areas with potential problem areas and where management and conservation may be warranted may need a different set of strategies for improvement. The scoring system is based on the presence/absence and abundance of shoreline features, as well as their proximity to the water's edge. Values were tallied for each shoreline category and then summed to produce an overall score. Larger scores denote a healthier shoreline with good land management practices. These are areas where protection and/or conservation should be targeted. On the other hand, lower scores signify an ecologically unhealthy shoreline. These are areas where management and/or mitigation practices may be desirable for improving water quality.

The summary of scores for shorelands around Pine Lake - Springwater is displayed in Figure 10. The shorelands were color-coded to show their overall health based on natural and physical characteristics. Blue shorelands identify healthy shorelands with sufficient vegetation and few human disturbances. Red shorelands indicate locations where changes in management or mitigation may be warranted. Many stretches of Pine Lake's shorelands are in good to moderately-good shape, but several long portions on the western and northern sides have challenges that should be addressed. Some of these stretches of Pine Lake - Springwater ranked as poor. A summary of shoreland disturbances is displayed in Table 6. For a more complete understanding of the ranking, an interactive map showing results of the shoreland surveys can be found on the County's webpage at http://gis.co.waushara.wi.us/ShorelineViewer/.

TABLE 6. DISTURBANCES WITHIN 15 FEET OF SHORE AROUND PINE LAKE, 2011.

Disturbance	**Length of Shore**	
	Feet	**Percent**
Artificial beach	11488	88
Barren, bare dirt	0	0
Boat landing	97	1
Dock/pier at water	11839	90
Gully erosion	0	0
Undercut banks erosion	0	0
Mowed lawn	3327	25
Rip-rap	6504	50
Seawall	6217	47

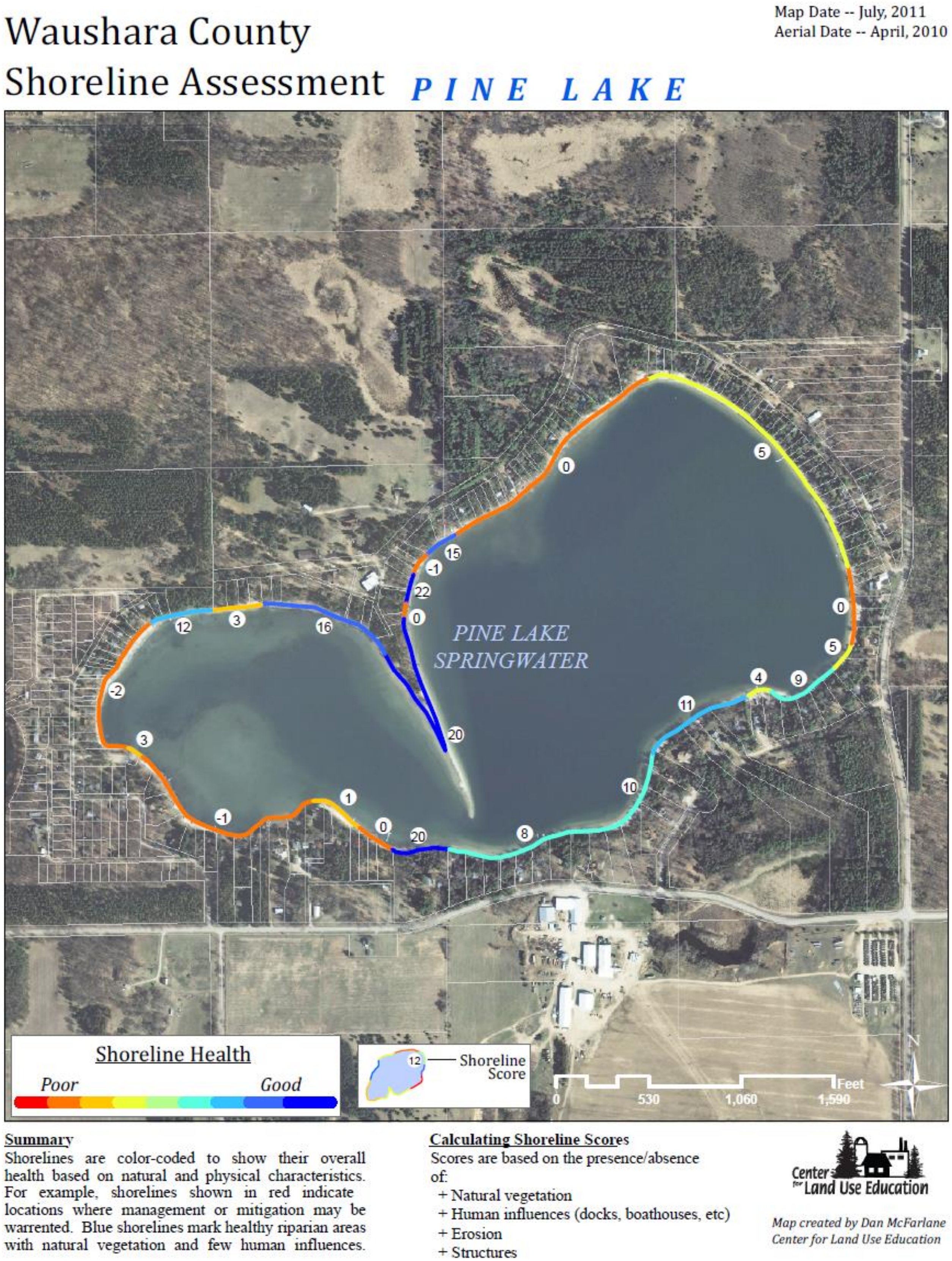


FIGURE 10. OVERALL SHORELAND HEALTH AROUND PINE LAKE - SPRINGWATER, 2011.

CONCLUSIONS & RECOMMENDATIONS

In general, the water quality in Pine Lake was good. The concentrations of pollutant indicators such as chloride, potassium, and sodium were low. Water clarity was good, but during the summer the water was not as clear as past measures. Water quality was affected by natural factors, as well as land management near shore and in the watershed. 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.

- The summer median total phosphorus concentrations were 10 ug/L and 8 ug/L in 2011 and 2012, respectively. This is well below Wisconsin's phosphorus standard of 20 ug/L for deep seepage lakes.
- The hard water in Pine Lake helps to keep the phosphorus concentrations low, but because capacity can be exceeded, efforts should be made to limit phosphorus additions to the lake.
- Identifying and taking steps to maintain or improve water quality in Pine Lake depends upon understanding the sources of nutrients and pollutants to the lake and identifying those that are manageable. Forests comprised the greatest percent land use in the watershed. Based on water quality modeling results, agriculture and forests had the greatest contributions of phosphorus from the watershed to Pine Lake.
- During the study, inorganic nitrogen concentrations in samples collected in the spring averaged 0.22 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. This was observed during a groundwater survey of Pine Lake in 2001.
- Atrazine, an herbicide commonly used on corn, was detected in the sample that was analyzed from Pine Lake. Some toxicity studies have indicated that reproductive system abnormalities can occur in frogs at these levels. The presence of this chemical indicated that agricultural activities were influencing the water quality in Pine 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. Pine Lake's shoreland was assessed for the extent of vegetation and disturbances. Shoreland vegetation provides habitat for many aquatic and terrestrial animals, including birds, frogs, turtles, and many small and large mammals. Vegetation 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 extending at least 35 feet inland from the water's edge. Alone, each manmade disturbance may not pose a problem for a lake, but on developed lakes, the collective impact of these disturbances can be a problem for lake habitat and water quality.

- Many stretches of Pine Lake's shorelands are in good to moderately-good shape, but several long portions on the western and northern sides have challenges that should be addressed. Some of these stretches of Pine Lake ranked as poor.
    - Structures such as seawalls, rip-rap (rocked shoreline), and artificial beach can result in habitat loss.

- 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.
- Mowed lawns do not provide habitat for animals using the shorelands. Lawns do not properly filter runoff traveling to the lake, so they can contribute to a reduced quality of lake water.

- 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 the disturbances, 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.
- The Waushara County Land Conservation Department and Natural Resources Conservation Service (NRCS) have professional staff available to assist landowners interested in learning how they can improve water quality through changes in land management practices.

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 that creates the diversity needed to make the aquatic plant community more resilient and help prevent the establishment of non-native aquatic species.

- The diversity of an aquatic plant community is defined by the type and number of species present throughout the lake. The twenty-four species observed within Pine Lake ranked it above average compared with the other lakes in the Waushara County Lakes Study.
- The dominant plant species found in Pine Lake was muskgrass, followed by stonewort and variable pondweed. Muskgrass is a favorite waterfowl food and also offers cover for fish. The algae and invertebrates living on the surfaces of stonewort plants provide food for waterfowl, and provide food and cover for fish. Variable pondweed is eaten by muskrat, beaver and deer.
- Four of the species found in Pine Lake were considered high quality plants (with a C value of 8), indicating good health in the aquatic plant community. These species were Fries' pondweed, southern naiad, stiff pondweed, and white-stem pondweed.
- The amount of disturbed lakebed from raking or pulling plants should be minimized, since these open spaces are “open real estate” for aquatic invasive plants to establish.
- Eurasian watermilfoil (EWM), an aquatic invasive species, is established in Pine Lake.
- Efforts to control EWM should be continued.
- Early detection of additional aquatic invasive species (AIS) can help to prevent their establishment should they be introduced into the lake. Boats and trailers that have visited other lakes can be a primary vector for the transport of AIS.
- Programs are available to help volunteers learn to monitor for AIS and to educate lake users at the boat launch about how they can prevent the spread of AIS.

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GLOSSARY OF TERMS

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

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

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

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

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

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

Clarity: See "Secchi disk."

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

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

Cyanobacteria: See "Blue-Green Algae."

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

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

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

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

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

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

Hardness: The quantity of multivalent cations (cations with more than one +), primarily calcium (Ca++) and magnesium (Mg++) in the water expressed as milligrams per liter of 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."