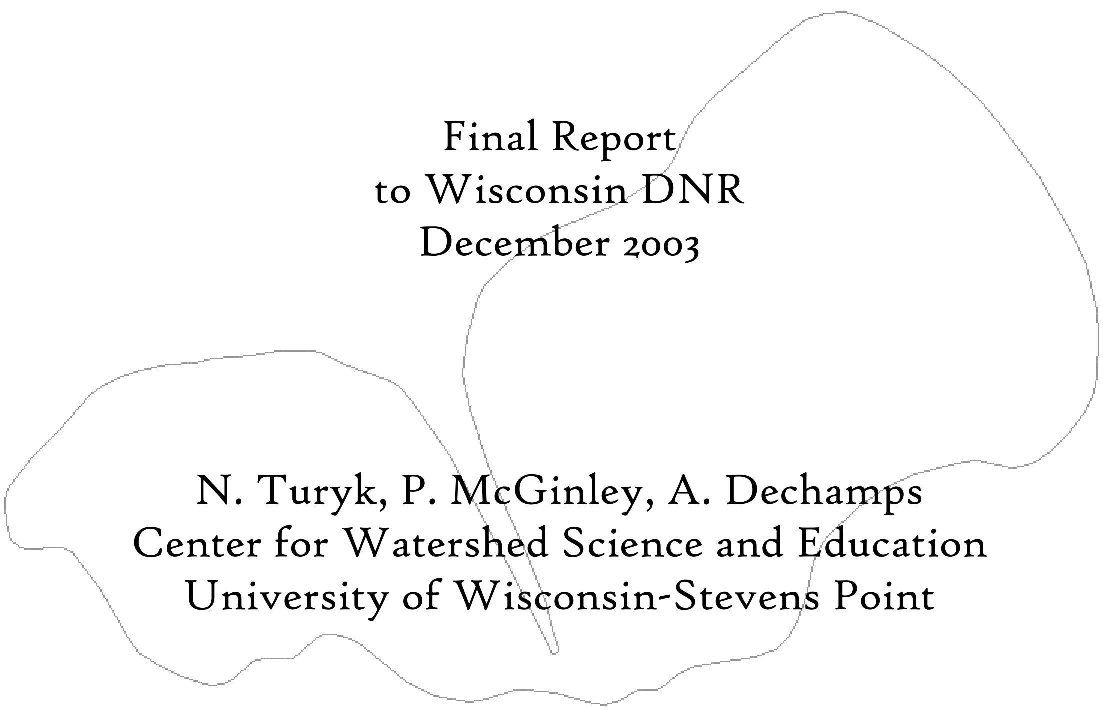
Water Quality Assessment of Pine Lake Waushara County, Wisconsin



Final Report
to Wisconsin DNR
December 2003

N. Turyk, P. McGinley, A. Dechamps
Center for Watershed Science and Education
University of Wisconsin-Stevens Point

College of Natural Resources

ACKNOWLEDGEMENTS

This research was completed with the help of many people from the University of Wisconsin-Stevens Point, the Pine Lake Property Owners Association, the Department of Natural Resources, and the We Really Kare Fish Club. I sincerely appreciate their time and patience given to me during this project. A special thanks goes out to those who have assisted with the development, implementation, and completion of this project. Specifically,

- Paul McGinley and Nancy Turyk for hours of planning, data review, and feedback
- Dick Stephens, Jim Licari, Kandace Waldmann, and Deb Sisk for coordinating the analysis of samples and their patience and insightful information
- Raquel Cramlet and Jeff Stelzer for field assistance
- Gene Tubbs and Kevin Lawton for excellent technical assistance
- Students of the Water and Environmental Analysis Lab who conducted the laboratory analyses on the samples and assisted with field work, especially Tracy Milkovich, Adam Freihoefer, Eric Frank, Josh Zvolenza, Rachel Kutschera, Jodie Bymers, Kristen Nowicki, and Kurt Rasmussen
- Judy and Jack Kusch, William Powell, Al Betz, Robert Ellis, and the property owners on Pine Lake for the use of resources and cooperation
- Mary Ganzberg from the WI Department of Natural Resources and Laura Felda of UW-Extension for carrying out the plant survey
- We Really Kare Fish Club.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Members of the Pine Lake Property Owners Association initiated this two-year study in 2001 in cooperation with UW-Stevens Point Center for Watershed Science and Education and Wisconsin Department of Natural Resources to obtain current information about the lake's water quality, aquatic plants, its relation with the watershed landscape and land use activities, and opinions of watershed residents. This document summarizes the activities conducted and results obtained by UWSP.

Pine Lake is a 143-acre lake located in northern Waushara County. It has a 1,526-acre surface watershed and an 887-acre groundwater shed. The shoreline has a high level of development with approximately 135 parcels around the lake including a large tract of land on the north side, which is owned and used by Pine Lake Lutheran Camp. Much of the shoreline is comprised of mowed vegetation. The lake experiences heavy recreational use throughout the summer.

Pine Lake is a seepage lake that receives its water from groundwater, surface runoff during rains and snowmelt, and precipitation on the lake. Water is retained in the lake for approximately 3 years and leaves the lake by evaporation and groundwater outflow. Pine Lake's water quality was assessed by Secchi depth measurements, chlorophyll *a* concentrations, temperature and dissolved oxygen profiles, and chemical analysis. Currently the lake is classified as an oligotrophic lake, which is characterized by good water quality and clarity. Chlorophyll *a* concentrations were low with an average of 2.14 ug/L and clarity averaged 12.1 feet in the west lobe and 15.1 feet in the east lobe. Average phosphorus concentrations were 18 ug/L in the west lobe and 12 ug/L in the east lobe. Pine Lake contains marl (calcium carbonate), which can help to reduce phosphorus that might otherwise be available for algae and aquatic plant growth. Oxygen remained mixed throughout the water column in the west lobe and stratification was observed during summer and winter in the east lobe. During times when stratification was prolonged, oxygen dropped below 2 mg/L below 30 feet of water.

Groundwater was assessed using existing water table maps, current private well water analyses, and by installing small wells in the lakebed every 200 feet around the lake perimeter. Regional groundwater flows into Pine Lake from the northwest. Forty–five percent of the small wells indicated groundwater inflow, with the area of greatest inflow to the lake on the north shore. Groundwater quality was examined by obtaining samples from the small wells. Overall, the water quality was found to be good. Some of the samples did indicate local impacts from septic systems and lawn fertilizers. Private well samples indicated some watershed-scale impacts from agricultural land use practices. Bacteria problems were exclusive to individual wells and associated with improper well installation, lack of vermin-proof caps, etc.

An opinion survey of residents was conducted. Eighty-three of 150 surveys were returned giving a 55% response. Seventy-one percent of the returned surveys were from part-time residents and the remaining 29% were full-time residents. Ninety-three percent of the respondents felt the water quality in Pine Lake was good to excellent, however, 55% felt the water quality had declined. Boating, development, septic seepage, fertilizer use, and soil erosion were identified to be the predominant sources of the perceived decline in water quality. The most problematic issues in Pine Lake were weeds and boating. Ninety-eight percent of the respondents use the lake for recreation including swimming, boating, aesthetic appreciation, and fishing. One-hundred ninety-seven watercrafts were owned by the survey respondents, using an estimated 3,200 gallons of gas per year on the lake.

It is recommended that a lake management plan be developed using these study results. The plan should be developed by Pine Lake watershed residents with the help of local agency personnel (UW-Extention, Waushara County Land Conservation Department, etc). In addition, management of Eurasian water milfoil and water quality monitoring for trends should be continued. To maintain the good water quality currently found in Pine Lake, efforts should be made to institute good land management practices which will limit the movement of nutrients into and within the lake including re-establishing unmowed buffers to state standards, allowing growth of near shore in-lake vegetation, elimination/reduction of lawn fertilizers, reduced disturbance of in-lake sediments, and increased set back of new/replacement septic systems.

INTRODUCTION

Pine Lake in northern Waushara County, Wisconsin had not previously been studied in detail. Recent discovery of the exotic aquatic plant species Eurasian Milfoil prompted interest in a study of the physical, chemical, and biological characteristics of the lake and the sources of its water and nutrients. This report describes the two-year study.

The first year of the study consisted of surface water sampling, groundwater mapping and sampling, watershed delineation, interstitial water, sediment, and plant analyses, assessment of land use practices in the watershed, aquatic plant survey, a resident survey, fish survey, and mapping of the shoreline vegetation. The second year of the study included continued water quality sampling of the surface water, groundwater assessment using private wells, the development of lake nutrient and water budgets, and recommendations. The Pine Lake Property Owners Association initiated this study in 2000 in cooperation with We Really Kare Fish Club, the Wisconsin Department of Natural Resources, and University of Wisconsin–Stevens Point.

STUDY AREA

Pine Lake is located in northern Waushara County, Town of Springwater, ten miles south of Waupaca. It is part of the Wolf River Basin of Wisconsin in the Pine/Willow Watershed. Pine Lake is a 144-acre natural lake partitioned by a sand peninsula; the west lobe of the lake has a maximum depth of 16 feet and the east lobe has a maximum depth of 48 feet. It is a seepage lake, meaning that only groundwater recharges the lake; there is no stream flowing into or from the lake.

The surface watershed (Figure 1) based on regional topography (land surface elevation) is approximately 1526 acres. The predominant land uses are forest (50%), grassland (23.4%), and agriculture (13.9%). The surface watershed includes rolling hills and lowlands, with several marshes in the watershed near Pine Lake. Although regionally this watershed is higher in elevation and could direct surface drainage to the lake, much of it appears to drain internally to the marshes and other low lying areas. A portion of the watershed is more likely to result in surface drainage to the lake. This direct drainage was estimated to have an area of 157 acres.

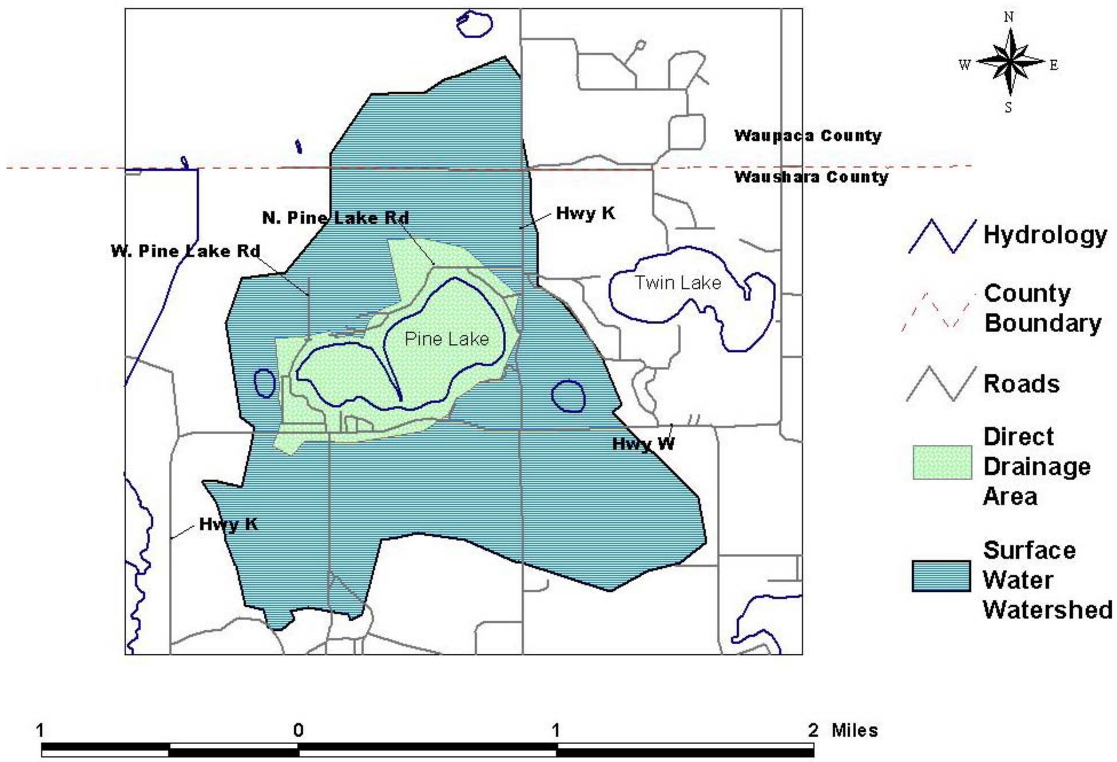


Figure 1. Direct Drainage Area and Surface Water Watershed for Pine Lake, Waushara County

The groundwater watershed is approximately 887 acres (Figure 2) and originates in Portage County. The regional groundwater flows from the northwest to the southeast in the watershed. Some of the groundwater discharges into the lake and some flows below the lake. Steep topography in local regions creates groundwater inflow from other regions of the lake. Land use in the groundwater watershed constitutes forest (35%), agriculture (27%), wetlands (19%), and grassland (18%).

There are 108 land parcels around the lake. Approximately 135 properties are located in the lake's immediate direct drainage area. The lake's development includes a large tract of land on the northern side, which is owned by Pine Lake Lutheran Camp. There is one public boat landing and no public beaches. Very little unmowed native vegetation exists around the lake.

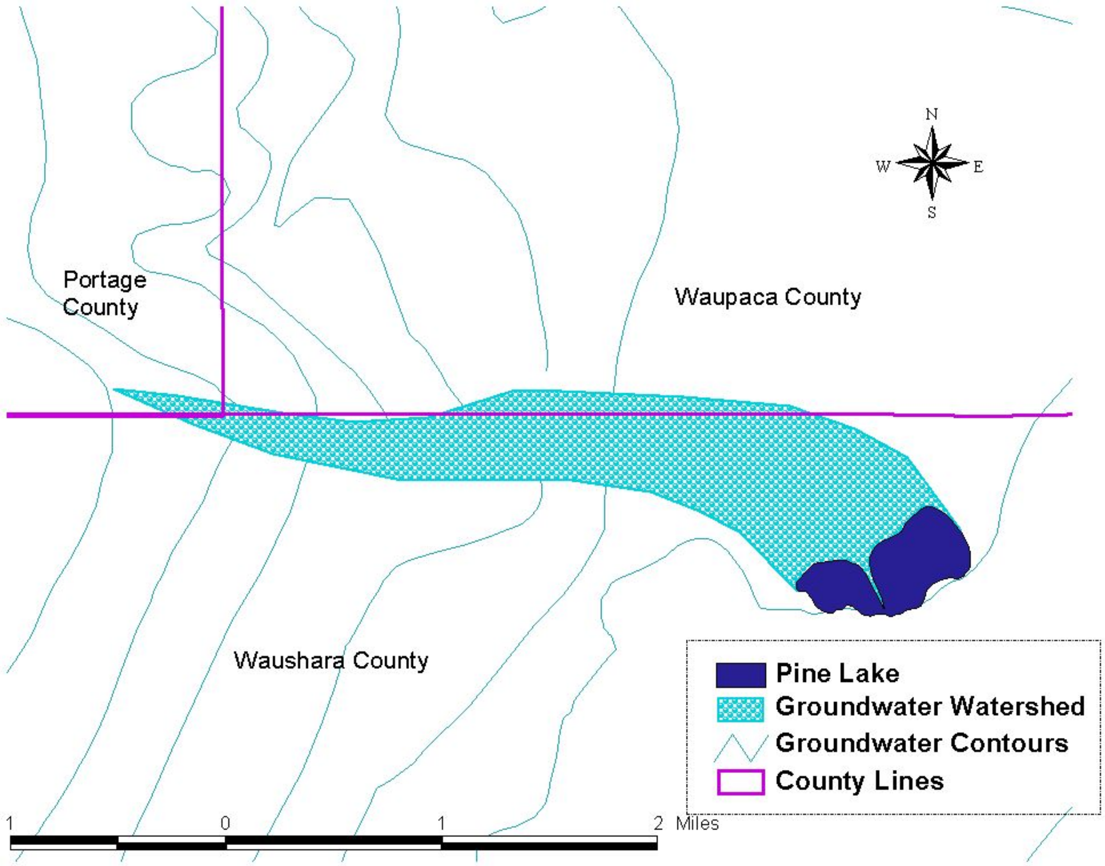


Figure 2. Location of Pine Lake's Groundwater Watershed in Waushara, Waupaca, and Portage Counties

METHODS

MID-LAKE CHEMISTRY

Mid-lake water samples were taken in each lobe of the lake. The deep holes were determined using a bathymetric map and an anchored measuring tape and marked with a Global Positioning System (GPS). Landmarks were used to return to the same location each sampling episode. Samples were collected from the deep holes once per month in May through October and also February of 2001 and 2002. The shallow west lobe of Pine Lake was sampled at the top and bottom strata of the water column. Three samples were taken in the east lobe at the top (epilimnion), middle (metalimnion), and bottom (hypolimnion) layers. Samples were also taken at mid-depth from each lobe during the spring and fall turnover (April and November). The last sample was collected in February 2003.

Each time a sample was collected, a temperature and dissolved oxygen profile was measured in the deep hole. This information was used to determine the three strata and the location of sample collection. Temperature and dissolved oxygen were measured using an YSI Model 50B dissolved oxygen meter (4500-06, APHA 1995). Readings were taken every two feet from the surface of the water to the lake bottom.

Samples were collected at different depths using an alpha bottle. Each sample was transferred to three high-density polypropylene bottles, a 500-ml bottle containing unpreserved and unfiltered sample, a 125-ml bottle with H_2SO_4-preserved unfiltered sample, and a 125-ml bottle filtered and H_2SO_4-preserved. Filtering was accomplished by drawing sample up with a 60-ml syringe and pushing it through a back-to-back 1-micron glass microfiber filter (934-AH) and a 0.45-micron cellulose micropore filter.

Clarity was measured in each lobe using a standard 8-inch diameter weighted Secchi disc. The disc was lowered over the downwind, shaded side of the canoe until it just disappeared from sight and then raised until it was just visible. The mean of these depths was recorded. Surface conductivity was field measured with a Mettler 126 conductivity meter.

Chlorophyll *a* samples were collected roughly one foot below the lake surface as grab samples and field filtered through a 1-micrometer glass fiber filter. The filter was folded in half (chlorophyll *a* on the inside) and wrapped in aluminum foil. Five chlorophyll *a* samples were collected May through August 2001, with two sampling events in June. Four chlorophyll *a* samples were collected in 2002, monthly from June through September.

All samples were transported on ice to the state-certified Water and Environmental Analysis Lab (WEAL) located at the University of Wisconsin-Stevens Point. Analyses followed standard procedures and quality assurance measures. Analyses performed on the mid-lake samples include: nitrate and nitrite (NO_2+NO_3-N), ammonium (NH_4-N), Total Kjeldahl Nitrogen (TKN), total phosphorus (TP), soluble reactive phosphorus (SRP), chloride, pH, conductivity, alkalinity, total hardness, and chlorophyll *a*. The four turnover samples were also analyzed for calcium hardness, color, turbidity, sulfate, sodium, and potassium. The analytical methods are shown in Table 1.

ANALYSES	METHOD	METHOD DETECTION LIMIT
Alkalinity	Titrimetric 2320 B	4 mg/L
Chloride	Automated Ferricyanide 4500 C1 E	0.2 mg/L
Chlorophyll *a*	Spectrometric 10200 H	0.1 mg/L
Color	Spectrometric 2120	5 cu
Conductivity	Conductivity Bridge 2510 B	1 umho
Hardness, Calcium	Titrimetric 3500 Ca D	4 mg/L
Hardness, Total	Titrimetric 2340 C	4 mg/L
Nitrogen, Ammonium	Automated Salicylate 4500-NH_3 G	0.01 mg/L
Nitrogen, Nitrate + Nitrite	Automated Cadmium Reduction 4500 NO_3 F	0.021 mg/L
Nitrogen, Total Kjeldahl	Block Digester; Auto Salicylate 4500-NH3 G	0.08 mg/L
pH	Electrometric 4500 H B	0.05 pH unit
Phosphorus, Soluble Reactive	Automated Colorimetric 4500 P F	0.003 mg/L
Phosphorus, Total	Block Digester, Automated 4500 P F	0.012 mg/L
Potassium	ICP 3120B	270 ug/L
Sodium	ICP 3120B	0.2 mg/L
Sulfur (SO4)	ICP 3120B	26 ug/L
Turbidity	Nephelometric 2130 B	0.5 mg/L

Table 1. Analytical methods and corresponding detection limits used in analysis of water samples at UWSP's Water and Environmental Analysis Lab

MINI-PIEZOMETERS

In late August 2001, hydraulic head measurements using mini-piezometers and the Hvorslev falling head test (Hvorslev, 1951) were conducted at 62 sites with approximatly 200-foot intervals around the perimeter of Pine Lake. Each site was recorded with a Global Positioning System, thoroughly described, and marked on a map (Figure 3). Samples for chemical analysis were also taken to determine lake water quality from the groundwater flowing into the lake at 32 sites: 1 outflow site, 3 static sites, and 28 inflow sites. Temperature and conductivity were measured in the field. Groundwater samples were collected, transported on ice, and analyzed for NO_2+NO_3-N, NH_4-N, Cl^-, and reactive P at the WEAL.

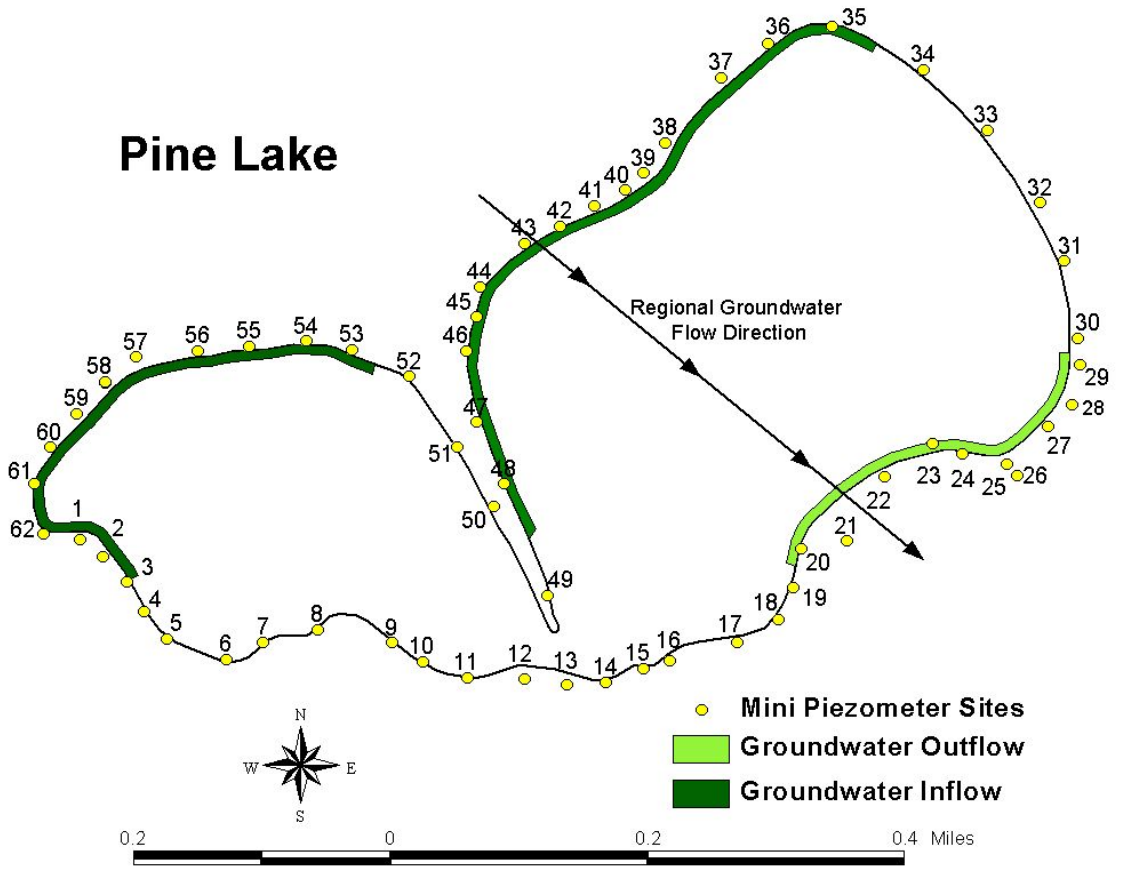


Figure 3. Location of Mini Piezometer Sites

The mini-piezometers were constructed of 5-foot polypropylene ¼ inch internal diameter tubing. One end of the tubing had a heat formed point and an inch of screen was made on the same end by driving a small diameter-sewing needle into the tubing. A 1mL pipet tip was attached to the end of the screen for easier installation into the sediment. In the field, a long metal rod was inserted into the mini-piezometer to make the tubing rigid. A steel tile probe initiated the hole before the mini-piezometer was inserted into the ground. Without the tile probe, wells were difficult to install due to compact substrate at some of the sites.

The mini-piezometers were inserted roughly two feet into the lake sediment in a depth of approximately 18 inches of water. At this depth, the mini-piezometer is below the interstitial root zone and into groundwater. Once the metal insertion rod was removed, a 60cc syringe was used to draw the groundwater into the mini-piezometer. If no water could be drawn, then the well had to be developed. Injecting two to three full syringes into the well and then drawing at least four out was usually enough to develop a well. The wells were purged by removing at least three full syringes of water or water until it was clear, indicating connection with the groundwater. Once there was clear water in the mini-piezometer, the static head was allowed to reach equilibrium.

Measurements were then recorded in inches for installation depth (depth of tubing below sediment), tube length above sediment, surface water level, static head (level of groundwater in tube compared to lake water height), slug height (length of tube above static head), Hvorslev position (Hvorslev, 1951), and time of falling head test (recorded in seconds). Following the measurements, each mini-piezometer was removed from the site.

The static head was used to determine the volume of groundwater by the use of the falling head test and also to determine whether or not the groundwater was entering or leaving the lake at that specific site. If the static head was above the surface of the lake water, then groundwater was discharging to the lake or inflow. If the static head was below the surface water, outflow was occurring, and lake water was actually recharging the groundwater. If neither inflow nor outflow occurred, the site was considered to be static.

Falling Head Test

To time the fall of the water for the falling head test, an o-ring was placed 37 percent of the slug height above the static head. The water was then drawn up to the top of the mini piezometer with the syringe, released, and timed the drop to the o-ring. Three trials were timed and averaged. The hydraulic conductivity was determined for each site by dividing the coefficient of hydraulic conductivity by the average falling head time (Hvorslev, 1951). Hydraulic conductivity refers to the amount of groundwater movement in an aquifer, which depends on the porosity, soil conditions, and fluid content of the aquifer. The hydraulic conductivity multiplied by the hydraulic gradient gives the velocity of the groundwater at that location.

SEDIMENT, AQUATIC PLANTS, INTERSTITIAL WATER

Sediment, aquatic plants, and interstitial water samples were collected at twelve sites around the lake (Figure 4). These sites correspond with the WDNR transects used in the June 2001 plant survey. A 1/8-meter sampling square constructed of ¾" diameter PVC tubing was randomly dropped in about three feet of water at each of the 12 sites to establish the sampling area. All aquatic macrophytes within the area were clipped above the roots, collected, bagged, and transported on ice to the WEAL for analysis. Samples were oven dried at 55°C to a constant weight. Analyses for aquatic macrophytes include total Kjeldahl nitrogen, total phosphorus, and percent biomass.

Interstitial water was collected in the same area. Interstitial water is that which is located in the top 6 inches of the sediment. Water diffuses between the soil and the surface water continuously. At this interface, there is also interaction with plant roots and microbes which affect the water chemistry. These data are useful in evaluating relationships between nutrient availability and aquatic plant species or biomass. Interstitial water was collected using a 6-inch length of polyethylene diffuser tubing (3/4 inch outside diameter) with a 1-inch Delrin tip. A ¼-inch threaded rod was screwed inside the diffuser tubing and a 1/8-inch outside diameter piece of Tygon tubing was attached. A six-inch metal disk with a ½ inch lip was attached to the diffuser tubing to prevent surface water infiltration into the sample (Figure 5). The device was inserted into the sediment adjacent to the disturbed area where aquatic macrophytes were collected using a rigid steel rod attached to the rod inside the diffuser tubing. Sample was drawn up through the piece of Tygon tubing with the aid of a hand pump. The hand pump was attached to a side-arm flask equipped with an in-line filter cassette containing a 0.45micron cellulose micropore filter and a 934 AH 47mm glass microfiber filter. The first 20mL of sample were used to rinse the device; then the analyzed sample was collected in a H_2SO_4-preserved bottle. The interstitial water was analyzed for NO2+NO3-N, ammonium, reactive phosphorus, and chloride.

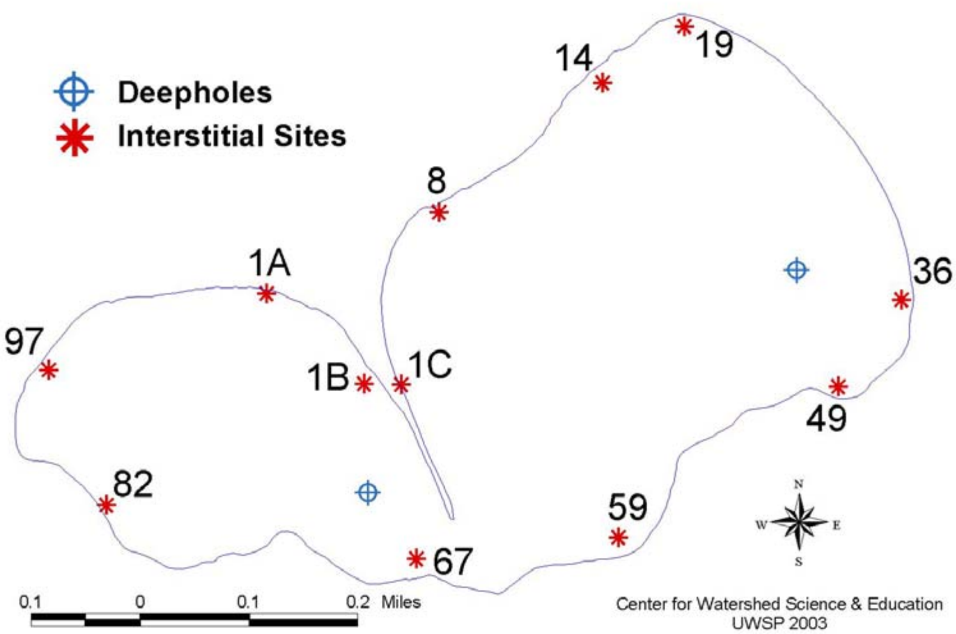


Figure 4. Approximate Location of Deep Hole and Interstitial/Sediment/Aquatic Macrophyte Sampling Sites

Sediment samples were collected from an undisturbed area adjacent to the aquatic macrophyte and interstitial water sample sites. A 3-inch diameter hollow PVC tube was inserted approximately 6" into the sediment and topped with a rubber stopper to create suction. The tube was lifted and the samples were deposited in whorl-pak bags. The sediment samples were analyzed for NO2+NO3-(N), NH4, potassium, sulfate, total percent solids, and percent organic matter.

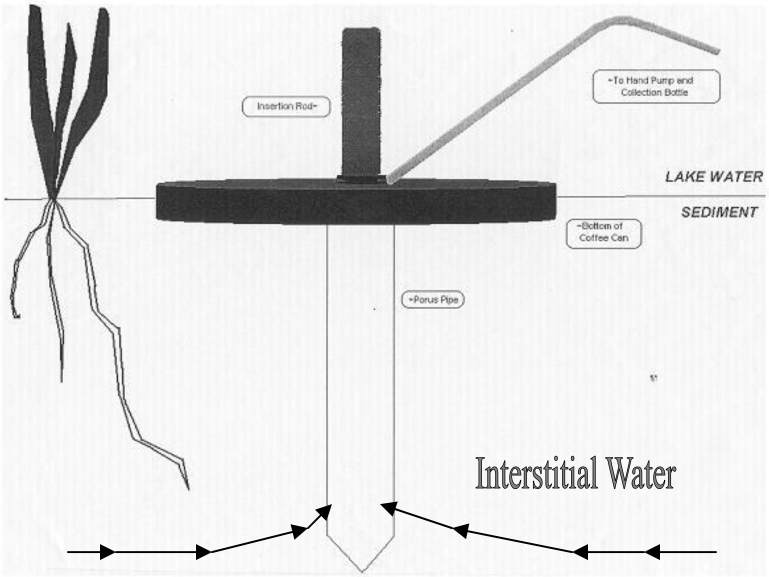


Figure 5. Diagram of Interstitial Water Sampling Device

HOMEOWNER SURVEY

A survey was distributed to the homeowners in the surface watershed in September of 2001. The WEAL Program developed a section of the survey to acquire information that was pertinent to this study. This survey was given to the Pine Lake Property Owners Association (PLPOA) who distributed this survey plus their own survey via mail to all the lake and watershed residents. The information in the surveys was compiled by the PLPOA into an excel spreadsheet. These data were assessed to help estimate uses of the lake, perceptions of water and fishing quality and changes that may have occurred, boat use, and household and land use practices that may affect lake water quality. The survey questions and responses can be found in the Appendix.

RESULTS AND DISCUSSION

SURFACE WATER

Water quality in Pine Lake was assessed throughout the years 2001 and 2002. A total of 18 sampling periods were monitored; seven samples were collected during 2001 growing season (May through September) and six samples during 2002 (May through September). Spring and fall over-turn samples were collected each year and winter samples were collected in February of 2002 and 2003. The following is a summary and discussion of the results and water quality characteristics of Pine Lake.

WATER QUALITY

Dissolved Oxygen and Temperature

A lake's water quality and ability to support fish are affected by internal mixing caused by seasonal changes in wind, water temperature, and water density. The depth, size, and shape of a lake are the most important factors influencing mixing, although climate, lakeshore topography, and vegetation also play a role (Shaw et al., 2000). In Wisconsin, most lakes cycle though periods of mixing (spring and fall) and stratification (summer and winter).

Stratification occurs during both the summer and winter months, while mixing occurs in spring and fall. In the summer, the epilimnion, or surface layer, is exposed to wind and constant mixing with the atmosphere. Dissolved oxygen levels in the water tend to stabilize with that of the atmosphere. As lake levels get deeper, there is less exposure to the atmosphere and sun. The temperature of the water decreases as the warm atmosphere does not penetrate, and dissolved oxygen (DO) levels also decrease because of less mixing with the atmosphere and the presence of fish and decaying organic matter, which consume oxygen. This layer is called the metalimnion, or the transition zone between the warm and cold water. The metalimnion is defined as the middle layer where temperatures decrease rapidly. The schematic in Figure 6 shows a temperature profile and corresponding strata. The hypolimnion is at the bottom of the lake where temperatures are the coolest. As the period of stratification continues, dissolved oxygen levels become depleted from decaying organic matter and lack of oxygen replenishment in this layer. During this condition, nutrient release from the sediments and can move into the water column. Nutrients are trapped in the hypolimnion, but can mix throughout the water column during spring and fall over-turn.

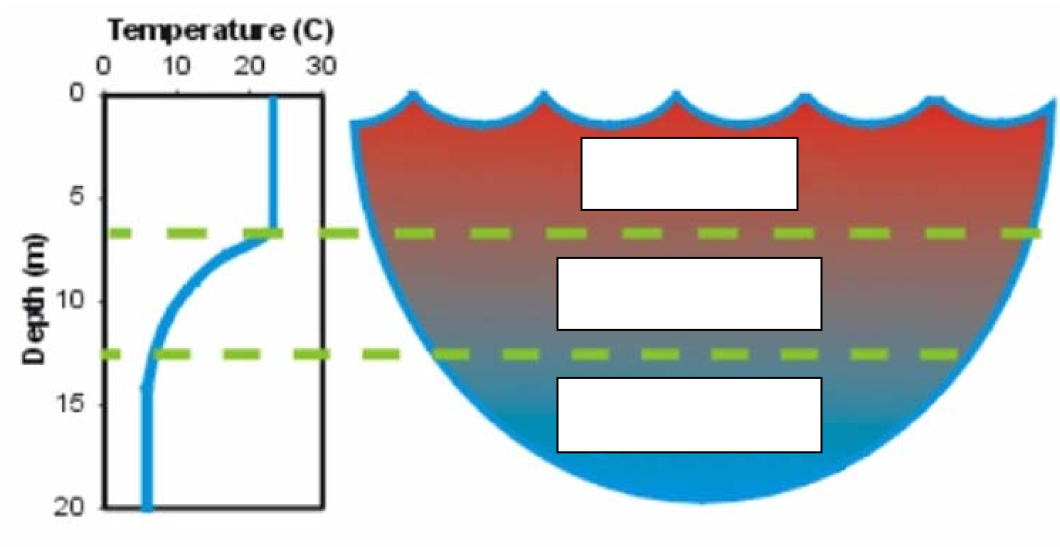


Figure 6. Cross Section of a Lake Showing a Temperature Profile and Corresponding Stratification Layers

Dissolved oxygen and temperature were measured twice per month in Pine Lake. Because of the difference in water depth, each lobe of Pine Lake has a distinct profile. The western lobe (Figures 7 and 8), with a maximum depth of 16 feet, does not stratify to the same extent as the eastern lobe (Figures 9 and 10). The water circulates throughout the water column in the west lobe and therefore, the temperature remains relatively constant. A distinct metalimnion (middle layer) does not form. The temperature in the west lobe on any specific date does not vary by more than 3.5 degrees (Figure 7). In spring 2001, the temperature of the water in the west lobe was approximately 16^{o}C and warmed to 27.8^{o}C at the end of July. The temperature of the lake for the remainder of the year cooled off, eventually reaching 2.8^{o}C at the surface in February 2002. The water was warmest at the surface where it was exposed to wind and sun, and cooled an average of 1.7 degrees as it reached the bottom of the lake. The reverse was observed in February when there was ice-cover cooling the surface water and on September 9. The later was during a storm, which cooled at the surface by precipitation (NOAA climatic records).

The temperature profile of the west lobe in 2002 was very similar to 2001 (Figure 8). The water warmed from spring until mid-July (26.7°C), and then cooled again. The greatest variation in the temperature profile was on June 27, 2002, with a difference of 7.4 degrees from top to bottom.

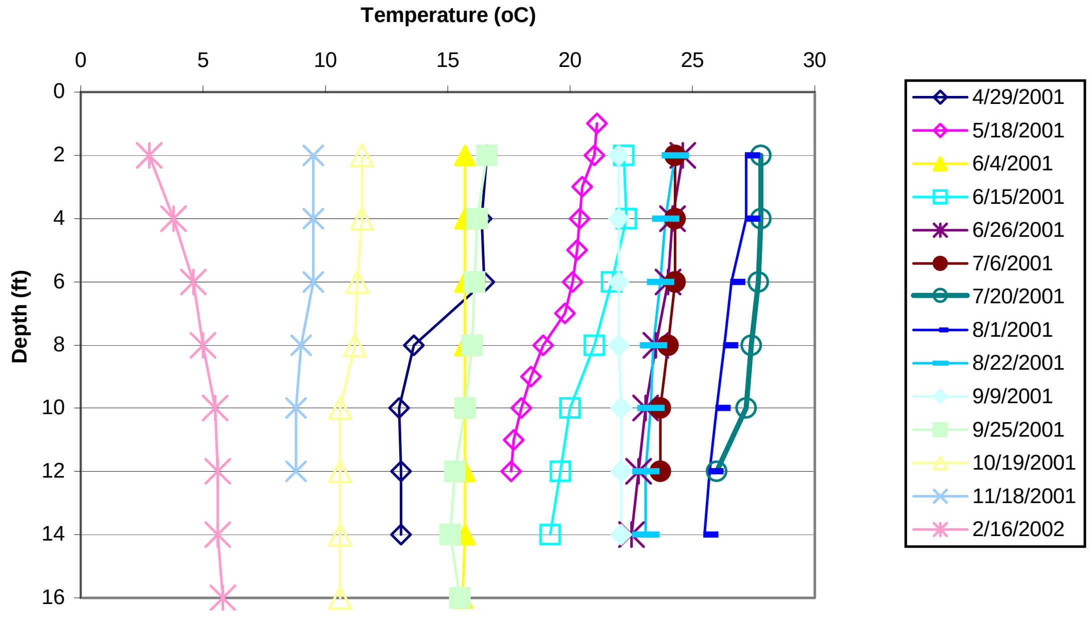


Figure 7. Temperature Profile in the West Lobe of Pine Lake, 2001

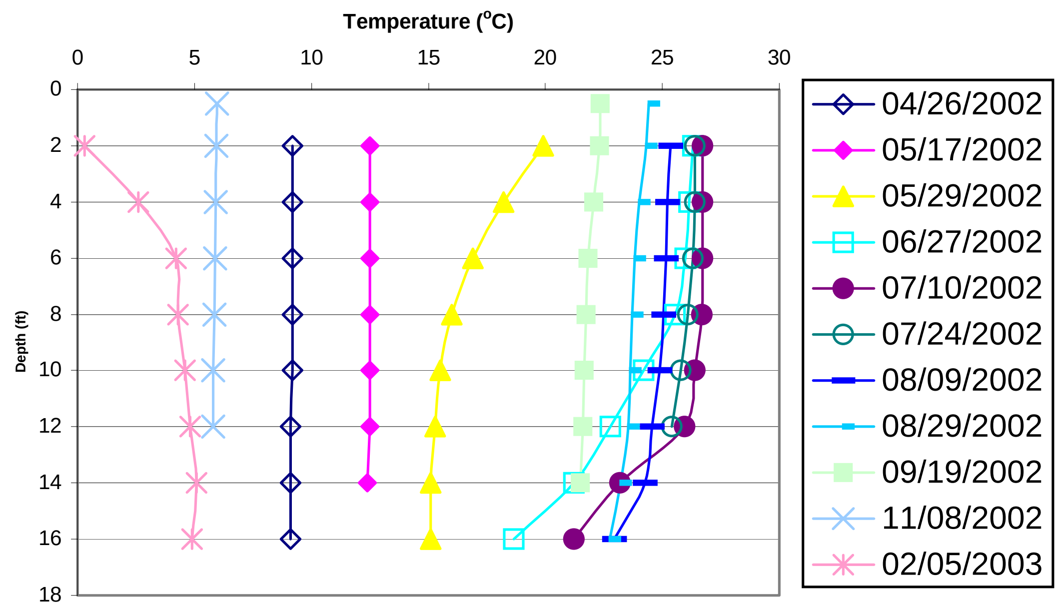


Figure 8. Temperature Profile in the West Lobe of Pine Lake, 2002

Dissolved oxygen is also affected by the mixing and warming pattern in a lake. During spring and fall over-turn (April and November sampling events), oxygen is replenished in the lake as the bottom water becomes exposed to the atmosphere during mixing. Dissolved oxygen concentrations predominantly ranged between 8 and 10 mg/L at the surface of the lake. As the summer progresses, bottom waters have minimal to no addition of oxygen and can therefore become depleted. Anoxic conditions are when dissolved oxygen drops below 2 mg/L. These conditions were recorded during two monitoring periods in 2001 (Figure 9) and five times in 2002 (Figure 10). This depletion of dissolved oxygen is likely due to the decomposition of organic matter that had settled to the bottom of the west lobe.

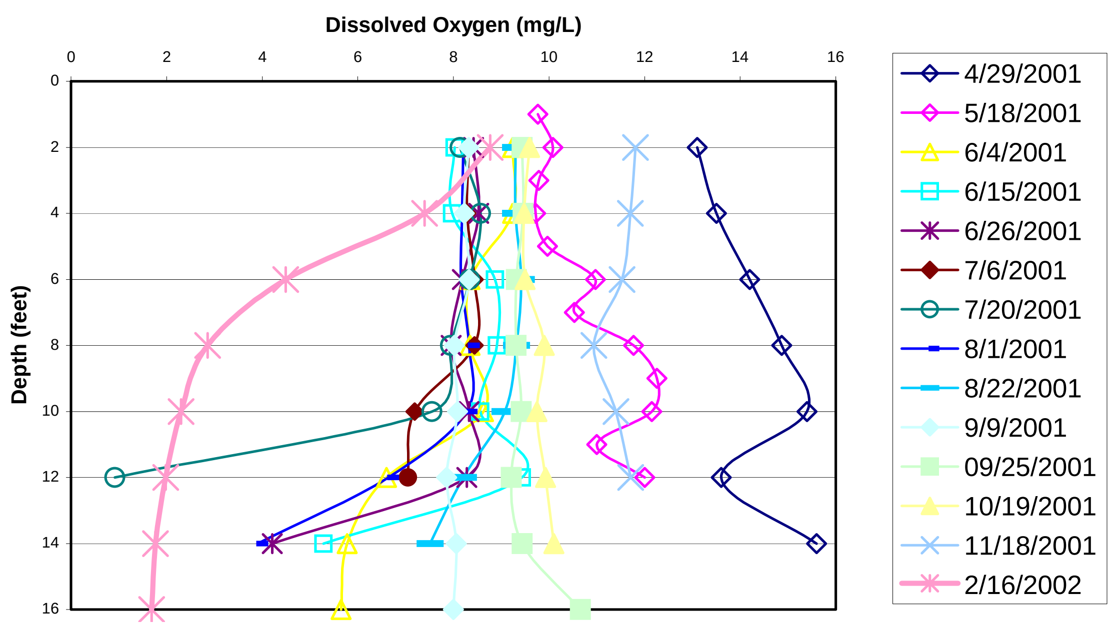


Figure 9. Profile of Dissolved Oxygen Concentrations in the West Lobe of Pine Lake, 2001

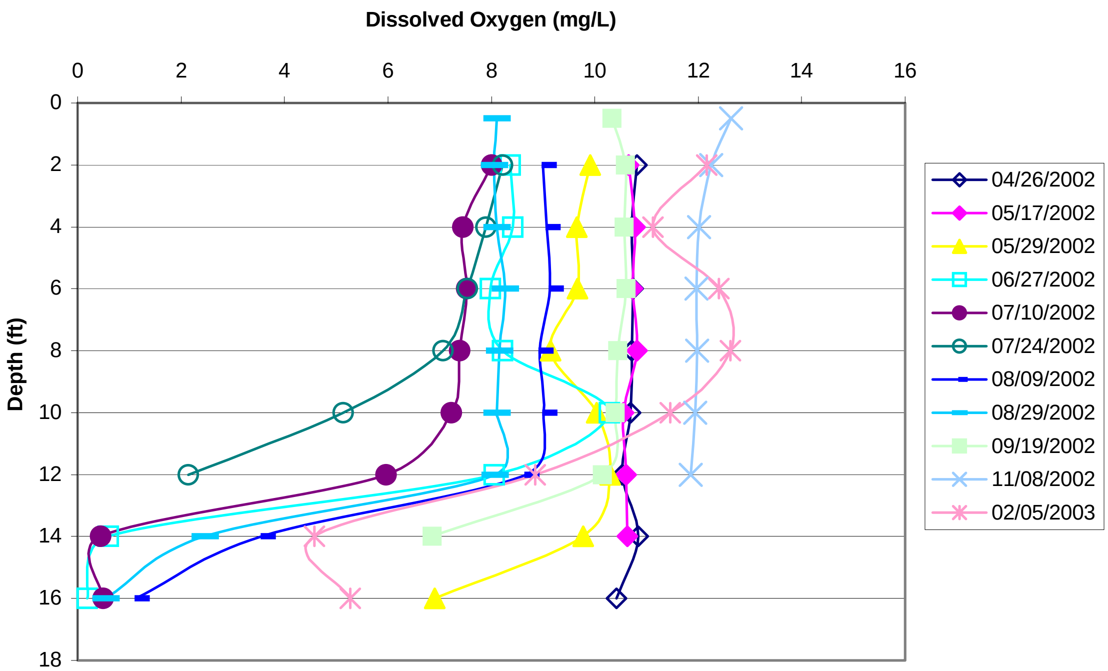


Figure 10. Profile of Dissolved Oxygen Concentrations in the West Lobe of Pine Lake, 2002

The temperature profile in the east lobe follows a more typical Wisconsin temperate lake pattern with a cyclical pattern of two periods of stratification and two periods of mixing (Figures 11 and 12). Spring over-turn (mixing) occurred prior to the first monitoring date on May 18, 2001. During the summer months, noticeable layers formed in the water column. The warm epilimnion existed from the surface to about 16 feet (the distance varies throughout the summer). The metalimnion layer ensued in the middle. The cooler waters of the hypolimnion began between 30 and 35 feet to the bottom of the lake. The second period of mixing occurred at fall over-turn around November 18, 2001. The same pattern of mixing and stratification occurred in the east lobe of Pine Lake during 2002 (Figure 12).

The dissolved oxygen profile in the east lobe is influenced by algae in the water column as well as by the seasonal mixing pattern. During the middle summer months, the dissolved oxygen in the east lobe increases with depth, likely due to algal photosynthesis (Figure 13 and 14). This pattern existed between June 4 and August 22, 2001, and was observed during six of the 2001 sampling dates. Below a depth of approximately 25 feet, the increase in dissolved oxygen ends. The water is anoxic (less than 2 mg/L DO) at a depth of 39 feet on June 15, and by September 25, below 29 feet.

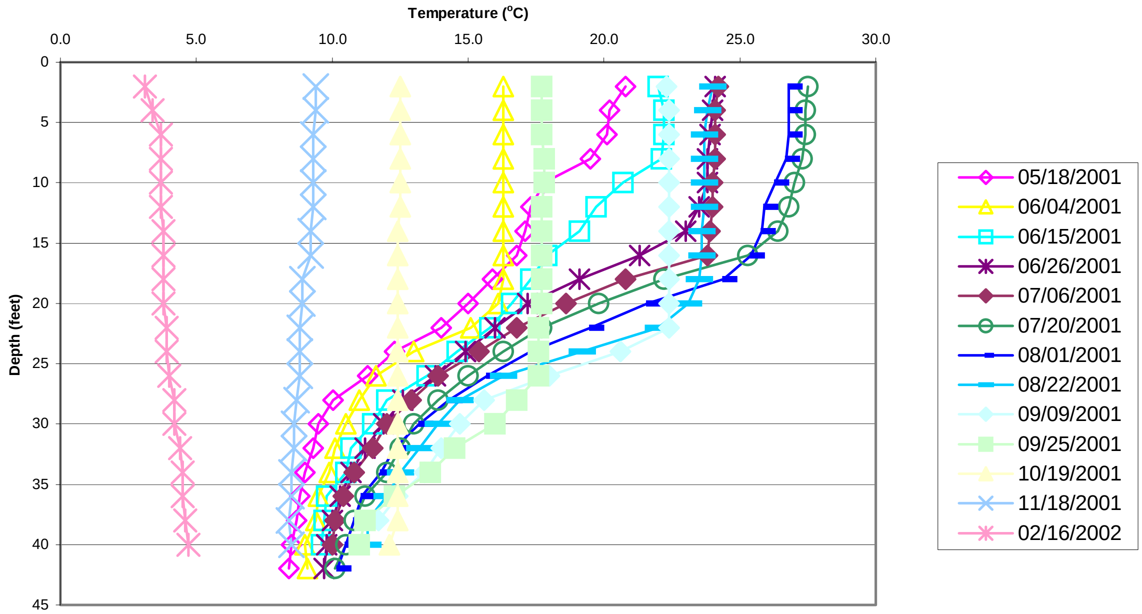


Figure 11. Temperature Profile in East Lobe of Pine Lake, 2001

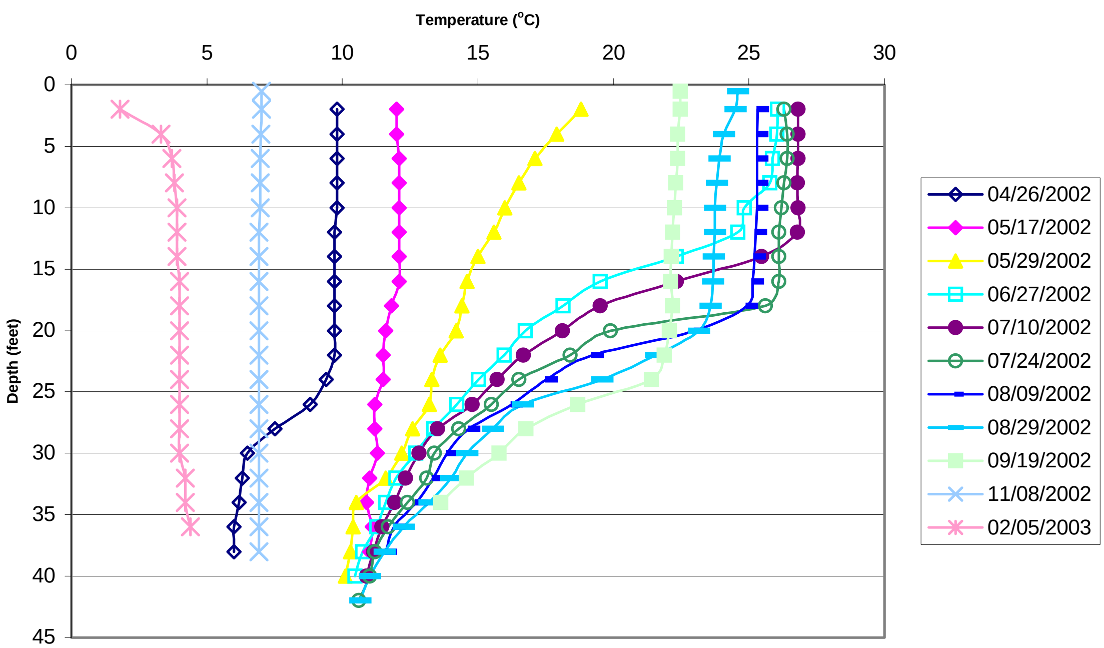


Figure 12. Temperature Profile in East Lobe of Pine Lake, 2002

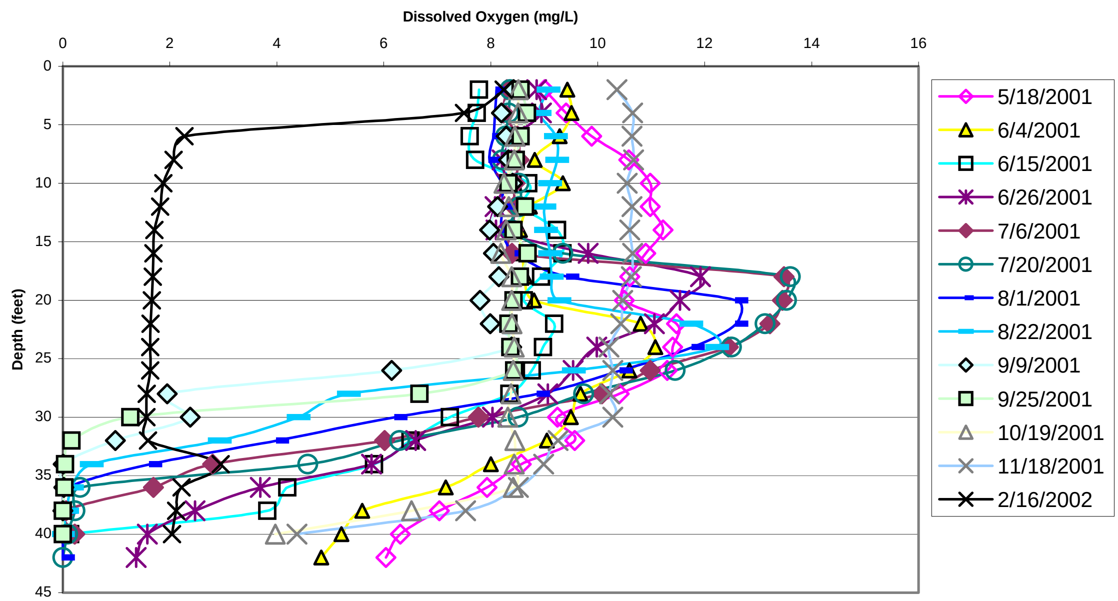


Figure 13. Dissolved Oxygen Profile in East Lobe of Pine Lake, 2001

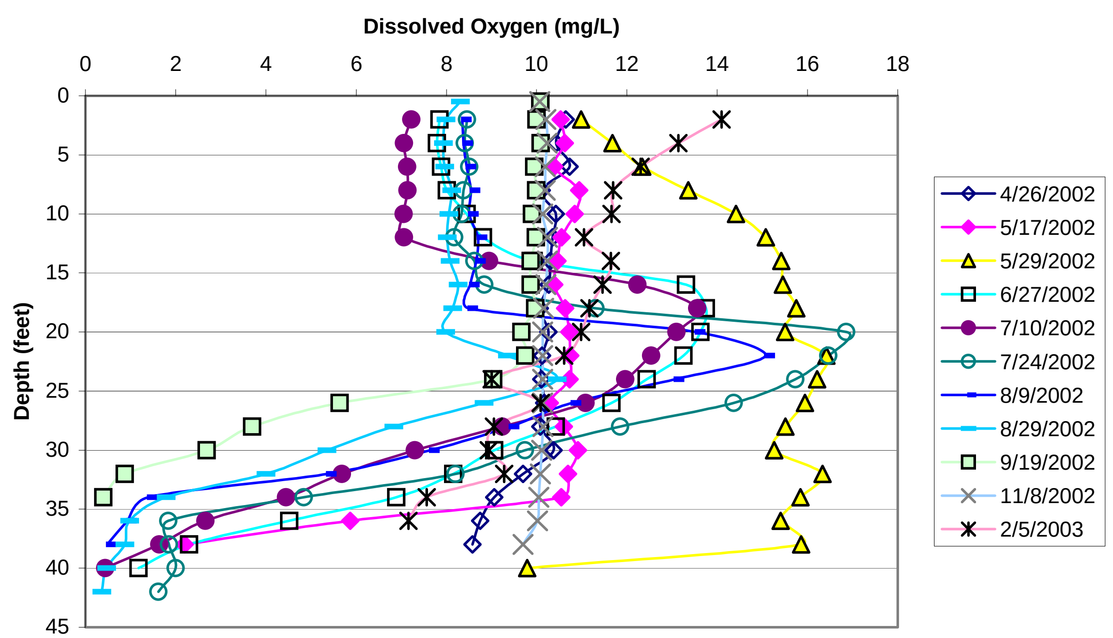


Figure 14. Dissolved Oxygen Profile in East Lobe of Pine Lake, 2002

Secchi Depth and Chlorophyll *a*

Light is essential for aquatic plants and algae to grow. The amount of light penetration through a water column can be quantified using a Secchi disk. Light penetration dictates the depth at which rooted aquatic macrophytes can exist. Algae and other suspended and dissolved solids in the water affect the transparency of the water and the depth at which light can be used, therefore, Secchi depth is a direct measure of the amount of turbidity (materials *suspended* in the water) and color (materials *dissolved* in the water).

Pine Lake's Secchi depth for both lobes ranked from good to very good in water clarity (Table 2). In 2001, the west lobe of Pine Lake had an average Secchi depth of 11.6 feet with a range of 7.6 to 14.8 feet. The east lobe had an average Secchi depth of 13.8 feet with a range of 8.4 to 27 feet. The Secchi depth in 2002 averaged 12.5 feet in the west lobe and 16.3 feet in the east lobe.

Water Clarity	Secchi depth (feet)
Very Poor	3
Poor	5
Fair	7
Good	10
Very Good	20
Excellent	32

Table 2. Water Clarity Interpretations as Related to Secchi Depth. From Shaw et al., 2000

Chlorophyll *a* is an indicator of the amount of photosynthesis taking place due to algae. Chlorophyll *a* samples were collected five times on Pine Lake in 2001 and four times in 2002. The chlorophyll *a* in the west lobe averaged 2.51 μg/L and ranged from 0.90 to 4.0. The chlorophyll *a* in the east lobe averaged 1.76 μg/L and ranged from 0.80 to 2.84. All of these concentrations indicate good water quality ranging from oligotrophic to mesotrophic.

pH and Conductivity

pH is an index of the lake water's acid levels. The higher the pH value, the less acidic the water is and the fewer hydrogen ions in the water. Distilled water has a pH of 7, which is considered neutral. At a pH of 3.0, water is toxic to all fish. Lethal effects are generally below pH 4.5 (acid conditions) and above pH 9.5 (basic conditions). The pH of Pine Lake is considered alkaline, with a surface average of 8.6 (see Table 3). Typical lakes in Wisconsin range from less than 5 for an acidic bog lake to more than 8 for a hard-water, marl lake (Shaw et al., 2000). The higher pH of Pine Lake is due to the natural composition of the groundwater discharging into the lake. Pine Lake sits in glacial outwash and dolomitic till (Summers, 1965). The groundwater dissolves the dolomite, increasing the hardness and alkalinity, and raising the pH.

The west lobe has a somewhat higher pH relative to the east lobe. The elevated pH is two fold. First, the west lobe has substantial groundwater inflow for its volume. Secondly, there is a large aquatic plant community in the west lobe due to the overall shallower depth of water. Plants consume carbon dioxide for photosynthesis, making the water more basic.

The difference in pH between the strata of the east lobe may be caused by decay of organic matter. When organic matter that has accumulated at the bottom of the lake breaks down, it consumes oxygen through respiration and gives off carbon dioxide, making the water more acidic. This process typically is why the hypolimnion of a lake will be more acidic than the epilimnion (Table 3).

Lakes with a high pH and alkalinity are said to have buffering capacity against acid rain (see discussion on alkalinity). Low pH values influence the movement of metals; hydrogen ions readily react with metals (aluminum, zinc, and mercury) if they are present in lake sediment or watershed soils and allow the metals to diffuse into the water column (Shaw et al., 2000). The high pH and buffering capacity of Pine Lake ensures that toxic metals will not immediately affect the biota in the lake by way of solution in the water.

Conductivity is a measure of the dissolved ions in the water that are able to conduct an electrical flow. Also referred to as specific conductance, conductivity is largely a result of the dissolved species from the local geology. The average conductivity in Pine Lake is 203 µmho in the west lobe and 209 µmho in the east lobe. According to Shaw et al., (2000) conductivity values are usually twice the total hardness unless contaminants are introduced into the system. Urbanization tends to increase the conductivity as dissolved ions are added from pollution sources (road salts, fertilizers, septic systems, pet wastes, etc.).

As debris that has settled to the bottom of the lake decomposes and ions are released from lake sediments, it is logical that the conductivity in the hypolimnion of both lobes is greater than that of the epilimnion (Table 3). In Pine Lake, calcium and magnesium carbonate is a major component of the ion make-up. Therefore, conductivity levels closely resemble alkalinity and hardness concentrations.

	West Epilimnion	**West Hypolimnion**	**East Epilimnion**	**East Metalimnion**	**East Hypolimnion**
pH	8.58	8.52	8.62	8.35	7.68
Conductivity (µmho)	194	200	196	206	219
Alkalinity (mg/L $CaCO_3$)	105	108	105	109	115
Total Hardness (mg/L $CaCO_3$)	107	111	105	108	116

Table 3. Average pH, Conductivity, Alkalinity, and Hardness in Pine Lake from Samples Collected during the Growing Seasons of 2001 and 2002

Alkalinity, Total Hardness, and Calcium Hardness

Alkalinity is related to hardness in that the calcium or magnesium (i.e. hardness) readily combines with the carbonates that make up alkalinity. Carbonates have a complex cycle that depends on the amount of carbon dioxide present. Carbon dioxide reacts with water to form carbonic acid (H_2CO_3). Carbonic acid dissociates rapidly and yields bicarbonate (HCO_3) plus a hydrogen atom (H^+). The bicarbonate also dissociates to form carbonate

(CO_3) and H^+. This process is heavily dependent on the pH of water and can also influence the pH as the carbonate systems attempts to reach equilibrium. In this way, alkalinity is an acid buffer or has acid neutralizing capacity. The higher levels of calcium carbonate or bicarbonate can react with hydrogen ions from acids to neutralize them. With an average alkalinity greater than 100 mg/L $CaCO_3$, Pine Lake is not sensitive to acid rain (Table 4).

Sensitivity to Acid Rain	**Alkalinity (mg/L $CaCO_3$)**
High	0 – 2 mg/L
Moderate	2 – 10 mg/L
Low	10 – 25 mg/L
Not Sensitive	> 25 mg/L

Table 4. Alkalinity Concentrations as Related to the Sensitivity of a Lake to Acid Rain from Shaw et al. 2000

Hardness is predominantly a measure of dissolved calcium and magnesium, which is related to the composition of soluble minerals in the watershed, primarily dolomite or limestone around Pine Lake, which are composed mostly of calcium and magnesium. These minerals are used by aquatic biota in the formation of shells and bones. Table 5 illustrates the different classifications of hardness for water. The average total hardness in Pine Lake ranges from 105 to 116 mg/L as $CaCO_3$, which is considered to be moderately hard (Table 3). Pine Lake has an average calcium hardness of 64 mg/L as $CaCO_3$ during over-turn, indicating that over half of the total hardness is attributed to

Hardness Description	**Total Hardness as mg/L $CaCO_3$**
Soft	0 – 60 mg/L
Moderately Hard	61 – 120 mg/L
Hard	121 – 180 mg/L
Very Hard	> 180 mg/L

Table 5. Interpretation of Total Hardness Concentrations from Shaw et al., 2000

calcium hardness. The occurrence of calcium carbonate may be an important factor of a reduced response in the lake to nutrient inputs. See “marl” section later in this document for a more detailed discussion.

Chloride

Chloride is an ion that is not normally abundant in Wisconsin’s freshwater lakes. Chloride is relatively un-reactive biologically (plants and algae do not utilize chloride) and, therefore, does not readily change in the environment. The presence of chloride is an indicator of impacts to water from human activities. Common sources of chloride include septic systems, lawn/garden fertilizers, animal waste, potash and agricultural fertilizers, and road salts. The average lake chloride concentration was 0.6 mg/L with a maximum of 2 mg/L. These concentrations are low, indicating that sources of impact are significantly less than the dilution potential.

Total Nitrogen to Total Phosphorus Ratio

The amount of plants and algae that can grow in a lake is dependent upon the amount and type of nutrients available. The major nutrients affecting aquatic plant growth are nitrogen and phosphorus. These nutrients are available in different aquatic systems in different proportions depending upon the geology, soil, climate, lake age, and land uses in the surface and groundwater sheds. Generally, one of the nutrients is abundant and in excess of aquatic plant requirements. The amount of the less abundant nutrient actually controls the amount of plant growth. This is termed the limiting nutrient. The total nitrogen (TN) to total phosphorus (TP) ratio evaluates whether nitrogen or phosphorus is the “limiting” nutrient for plant growth. When the TN:TP ratio is greater than 15:1, plant growth is generally restricted by the amount of phosphorus available for plants to utilize (Carlson, 1980). When the ratio is less than 10:1, this indicates nitrogen is the limiting nutrient. The average TN:TP ratio in Pine Lake from April 2001 to February 2003 was 60:1, indicating that phosphorus is the limiting nutrient. This was also true during over-turn and during the winter when the ratio was around 70:1. This ratio means that any addition of phosphorus, which is the nutrient that is most limited, can enhance the growth of aquatic plants or algae.

Phosphorus

Phosphorus is the number one limiting nutrient for 80 percent of the lakes in Wisconsin (Shaw et al., 2000). This is largely due to the minimal amount of phosphorus in the geology of Wisconsin. Sources of phosphorus from the watershed can include human and animal wastes, soil erosion, detergents, septic systems, and fertilizer runoff from agriculture and lawns and gardens.

Once phosphorus enters a seepage lake (like Pine), it is difficult for phosphorus to leave the system and will continue to be recycled by lake biota for many years. Because of this, additional inputs from human impacts could have significant affects on lake water quality. Phosphorus is present in several forms, but soluble reactive phosphorus (orthophosphate or PO_4^{3-}) and total phosphorus are the main complexes for which water samples are analyzed. Soluble reactive phosphorus (SRP) is dissolved phosphorus in the water column that is available in a form which can readily be utilized by plants and algae. Total phosphorus (TP) is a measure of the SRP *plus* organic and inorganic particulate phosphorus suspended in the water. Some of this phosphorus (SRP) is immediately available for plants to use while other forms may only become available to plants with significant changes in pH, temperature, and or oxygen.

Shaw et al., (2000) suggest that an ideal SRP concentration following spring over-turn should be 10 μg/L or less to prevent summer algae blooms. The west lobe of Pine Lake had a spring turnover SRP concentration of 6 μg/L, and the east lobe had an SRP concentration of 11 μg/L. SRP concentrations during the growing season ranged from 2 to 18 μg/L (average 7 μg/L) in the west lobe and from 2 to 15 μg/L (average 6 μg/L) in the east lobe.

Ideally upper or epilimnion TP should be less than 20 μg/L to avoid nuisance algal blooms (Shaw et al., 2000). Lower or hypolimnion TP can become elevated due to release from the anoxic sediments and decomposition of settling organic matter. During fall and spring over-turn, hypolimnion phosphorus can become mixed throughout the lake.

In addition, in shallow lakes, elevated phosphorus in the anoxic bottom waters may periodically mix with surface waters and encourage algae blooms. Table 6 displays minimum, average, and maximum phosphorus concentrations for each strata of the lake and Figure 15 shows the epilimnion TP concentrations for each sample date. TP concentrations in the upper portions of the lake ranged from <2 to 27 μg/L. TP concentrations in the east hypolimnion ranged from 2 to 78 μg/L with an average of 28 μg/L. On three sampling dates in the east lobe hypolimnion the TP concentration rose above 35 μg/L. Total phosphorus was highest in the east lobe hypolimnion during the latter part of summer when the dissolved oxygen was low. Seasonal variations occurred, and TP and SRP levels dipped in July and August as phosphorus was used by plants and/or settles into lower portions of the lake. In the shallow, west lobe, phosphorus concentrations increase later in the summer probably a result of mixing and plant die-back. That increase was particularly noticeable in 2001 suggesting this lobe may be vulnerable to excessive mixing and reentrainment of phosphorus into the water column. Such mixing is anticipated from the temperature profile for the west lobe, which showed little variation from top to bottom (Figures 7 and 8). Table 7 gives an index for water quality determined by total phosphorus concentrations. This table, used as a reference, shows average TP values in Wisconsin for natural and impounded lakes. Pine Lake falls under "good" water quality, which is average for most lakes in Wisconsin.

Stratum	Minimum SRP	Average SRP	Max SRP	Minimum TP	Average TP	Max TP
East Epilimnion	2	6	10	2	12	21
East Metalimnion	2	4	12	6	17	26
East Hypolimnion	2	7	15	2	28	78
West Epilimnion	2	7	16	12	18	27
West Hypolimnion	2	7	13	13	23	35

Table 6. Minimum, Average, and Maximum Soluble Reactive and Total Phosphorus Concentrations (μg/L) in Each Strata of Pine Lake during 2001 and 2002

SPRING AND FALL OVERTURN PARAMETERS

During spring and fall overturn, nutrient concentrations tend to be elevated because materials from the bottom of the lake are mixed throughout the water column. Sampling during these mixed conditions is an excellent way to measure the total nutrients in a system. In addition to nutrients, sulfate, sodium, potassium, turbidity, and color were also analyzed for the overturn samples. Following is a summary of concentrations found in Pine Lake during the spring and fall overturn of 2001 and 2002.

Phosphorus concentrations in the epilimnion of each lobe are shown in Figure 15. The overturn samples are illustrated with darker bars. Phosphorus concentrations are elevated at the beginning and end of each season. Phosphorus tends to adhere to particulate matter, albeit organic material or sediments. Because of the circulation of the lake water in spring and fall, the bottom sediments also get stirred-up, bringing some of the phosphorus back into the water column. Conductivity, total hardness, and alkalinity concentrations are also elevated during over-turn. Total nitrogen does not follow the same pattern because nitrogen is usually dissolved in the water and not attached to sediment particles.

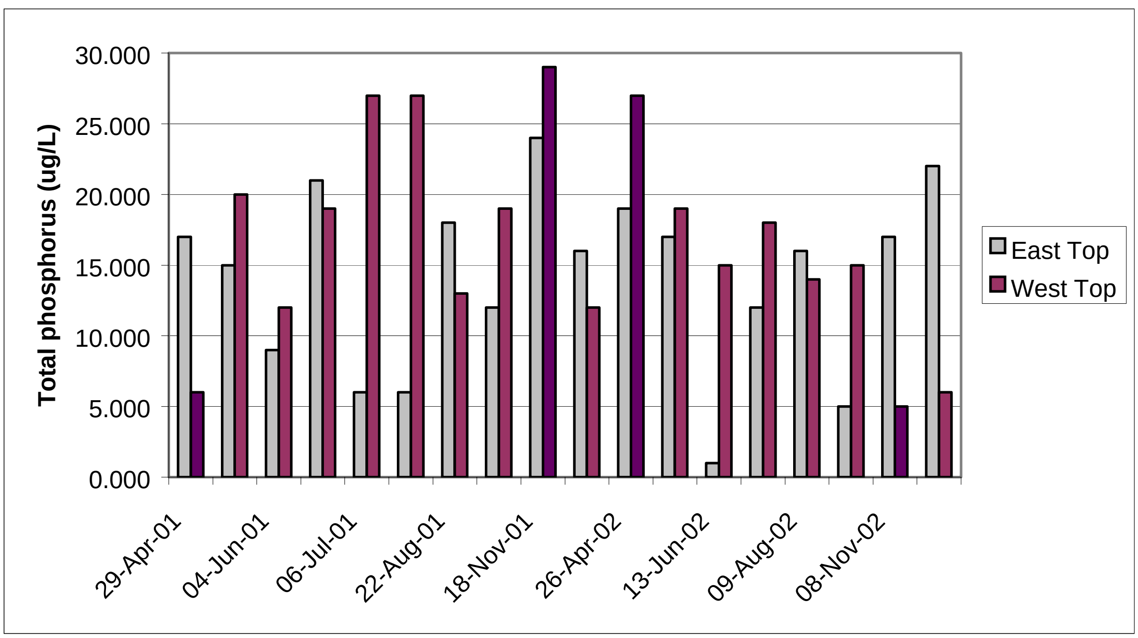


Figure 15. Total Phosphorus Concentrations in Pine Lake's Epilimnion over the Two-Year Sampling Period

Water Quality Index	Total Phosphorus (µg/L)	Wisconsin Lakes
Very Poor	150	
Poor	140	
	130	
	120	
	110	
	100	
	90	
	80	
	70	<-- Average for impoundments
	60	
Fair	50	
	40	
Good	30	<--Average for natural lakes
	20	**<--Pine Lake**
Very Good	10	
Excellent	1	

Table 7. Water Quality Index Based on Total Phosphorus Concentrations
(Adapted from Lillie and Mason, 1983)

Marl

Moderate- to hard-water, marl lakes may have a natural buffer system against nuisance blooms. Under conditions of high pH, calcium carbonate or marl forms in a lake(Wetzel, 1972). Marl usually forms with high levels of hardness (greater than 150 mg/L) and alkalinity. The water becomes supersaturated with respect to carbonate around aquatic macrophytes and algae as the organism utilizes carbon dioxide, raising the pH in the vicinity of the plant. Carbonate combines with the calcium in the water and a solid results. For this reason, marl is often seen encrusted on the leaves and stem of macrophytes. Marl can act as a balancing mechanism because phosphorus precipitates with marl, thereby controlling algae blooms.

Nitrogen

Nitrogen is the second most important macro-nutrient for plant and algae growth. In Wisconsin, nitrogen does not normally exist in soil minerals, but is a major constituent of organic matter (Shaw et al., 2000). Nitrogen can be in a variety of forms, depending upon source and surrounding conditions. Sources of nitrogen include precipitation falling directly on the lake's surface (up to 0.5 mg/L), lawn and garden fertilizer used on lakeshore property, agricultural fertilizer, septic systems, and animal wastes. This nitrogen can enter the lake through surface runoff and groundwater flowing into the lake. In-lake sources of nitrogen include decaying plant and animal tissue, sediments, and release from wetlands. Some species of aquatic plants (i.e. blue green algae) can obtain nitrogen directly from the atmosphere.

Nitrogen has a complex cycle, which includes bacteria and microorganisms that transform the element. The forms of nitrogen most important to aquatic systems include NH_4^+ (ammonium), NO_2^- + NO_3^- (nitrite and nitrate), and organically bound nitrogen. Aquatic plants and algae can use all inorganic forms of nitrogen (NH_4^+, NO_2^-, and NO_3^-). If these inorganic forms of nitrogen exceed 0.3 mg/L (as N) in spring, there is sufficient nitrogen to support summer algae blooms (Shaw et al., 2000). Ammonium is the most available form of nitrogen to aquatic plants, but does not move as readily through soil as nitrate. When oxygen is present, the ammonium form (NH_4) of nitrogen can oxidize to nitrate (NO_3) in a process known as nitrification. This form of nitrogen is virtually unrestricted in its mobility in soil and groundwater. Organic nitrogen tends to occur in higher levels in hard water lakes as a result of relatively high inputs in calcareous regions and low amounts of biological uptake because of low productivity (Wetzel, 1983).

Nitrogen in Pine Lake occurred at relatively low levels. Table 8 gives an average of the nitrogen values for both 2001 and 2002. The average nitrite-nitrate concentration for Pine Lake was 0.09 mg/L. It is believed that most groundwater enters Pine Lake at shallow depths. Because nitrate tends to travel with groundwater, we see higher concentrations of NO_2+NO_3 in the west lobe; however, these concentrations are still low for a lake found in an agricultural, sandy region of the state. Nitrate concentrations were highest in the epilimnion of the east lobe. The atmosphere and precipitation are also sources of nitrogen, contributing to the epilimnetic nitrate concentration. As plants utilize nitrogen for growth, the nitrate concentration decreases with depth.

Ammonium levels were also quite low, ranging from <0.01 to 0.34 mg/L. The lake average of ammonium was 0.08 mg/L. Ammonium levels are expected to be the highest where there is no oxygen, like that of the east hypolimnion where ammonium was 0.13 mg/L. TKN measures organic-nitrogen plus ammonium. Organic nitrogen is the largest component of nitrogen on Pine Lake; and again, levels are highest within the hypolimnion as the organic matter accumulates. Lake levels of TKN ranged from 0.48 to 1.38 mg/L.

Stratum	NH_4	NO_2+NO_3-N	Organic N	TN
East Epilimnion	0.06	0.09	0.62	0.77
East Metalimnion	0.07	0.07	0.59	0.73
East Hypolimnion	0.13	0.07	0.68	0.88
West Epilimnion	0.06	0.15	0.60	0.81
West Hypolimnion	0.07	0.16	0.73	0.96

Table 8. Average Nitrogen Concentrations (mg/L) in Each Stratum of Pine Lake from Samples Collected between April 29, 2001, and February 5, 2003

Trophic Status Index

The trophic status is another gauge of water quality. Lakes can be placed into one of three categories based on their trophic level – oligotrophic, mesotrophic, and eutrophic. The status reflects a lake’s nutrient and clarity levels. Determining a trophic status is valuable in assessing changes in water quality over time for a given lake, as well as comparing lakes. The succession of lakes begins in the oligotrophic state. Oligotrophic lakes are characterized as having low amounts of aquatic macrophytes, having clear water, and low productivity (low nutrients). As a lake ages, it reaches the mesotrophic state. Mesotrophic lakes have increased production and begin to accumulate organic matter. As more plant matter accumulates and depletes the oxygen during decomposition, the lake reaches an eutrophic state. Eutrophic lakes are high in nutrients and support a large biomass. They are typically weedy and/or subject to frequent algae blooms. Increasing the inputs of nitrogen and phosphorus can accelerate the aging process of lakes and result in culturally eutrophic lakes.

Common measurements of trophic status include Secchi depth, TP concentration, and chlorophyll *a* concentration (measure of algae). Although many factors influence these relationships, the Trophic State Index (TSI) relies on the assumption that the amount of chlorophyll *a* present is primarily related to the phosphorus concentration, and water clarity is primarily dependent on the chlorophyll *a* concentration (Lillie, 1983). Normally, as TP increases, so do chlorophyll *a* concentrations, therefore reducing the transparency measurement and Secchi depth.

There have been several TSIs developed in an attempt to translate several of the measurable water chemistry variables into an assessment of lake water quality. Lillie, Graham, and Rasmussen (1993) produced a representative set of equations based on a random survey data set from 1979 by the Bureau of Research (utilizing both lakes and impoundments that were greater than 5 feet deep and at least 25 acres in size.) The index uses existing Wisconsin databases to derive area-specific formulas. The calculations were based on monthly sampling periods during the summer months defined as May through September.

The results from the Pine Lake calculations are presented in Table 9. In general, the lower the Wisconsin Trophic Status Index (WTSI) equivalent value, the better the water quality. The TP concentrations indicate a mesotrophic lake. However, when examining chlorophyll *a* and Secchi depth, the values presented are characteristic of an oligotrophic lake, and the WTSI values are very good.

<u>Sulfate</u>

All living organisms utilize sulfur, however, usually in small amounts. The average content of sulfur (dry weight basis) in bacteria is 0.2 percent (Wetzel, 1983). The importance of sulfur in a lake is not, therefore, the amount present, but its influence on the cycling of other nutrients in the lake ecosystem. Sulfate in Wisconsin lake water is primarily from the geology of the watershed and acid deposition/rain. Effluents from paper-producing industries are another source of sulfate for receiving waters. Sulfate levels in Waushara County generally range from <10 mg/L to 20 mg/L (Shaw et al., 2000). Sulfate concentrations in Pine Lake were found to be between 3.6 and 4 mg/L.

	Interpretation	**Secchi Depth (m)**	**Chlorophyll *a* (µg/L)**	**Total P (µg/L)**
Pine Lake Average	Average Value	4.1	2.14	13
	WTSI	39.7	40.6	48.0
	Shaw et al.	Oligotrophic	Oligotrophic	Oligo -Meso
	Carlson	Very Good	Very Good	Good
West Lobe Average	Average Value	3.7	2.51	18
	WTSI	41.2	41.8	50.5
	Shaw et al.	Oligotrophic	Oligotrophic	Mesotrophic
	Carlson	Very Good	Very Good	Good
East Lobe Average	Average Value	4.5	1.76	12
	WTSI	38.3	39.1	47.4
	Shaw et al.	Oligotrophic	Oligotrophic	Oligo - Meso
	Carlson	Very Good	Very Good	Good

Table 9. 2001 and 2002 Average Values, Corresponding Classification, and Wisconsin Trophic Status Index values for Pine Lake. *Interpretations adapted from Shaw et al. (2000) and Carlson (1977)*

Sodium and Potassium

According to Shaw et al. (2000), natural levels of sodium and potassium ions in Wisconsin's soil and water are very low, and their presence may indicate impacts from human activities. Sodium is often associated with chloride while potassium is a component of potash fertilizers and animal waste. Pine Lake has minimal concentrations of both sodium (1.8 mg/L) and potassium (0.5 mg/L) indicating no significant impacts to the lake.

Color and Turbidity

The color of lake water reflects the type and amount of dissolved organic chemicals in it. Decomposing plant material and a release from algae prior to decomposition are common sources of color. Color can affect water clarity and hence, the Secchi reading. The average color in Pine Lake was 11 units with a range of 4 to 31. This is classified as low color.

Turbidity is a measure of particles in the water rather than dissolved matter. Turbidity and color not only affect the depth at which light can penetrate, but also the aesthetics of the lake water. Turbidity in Pine Lake during turnover averaged 1.2 NTU.

GROUNDWATER

Groundwater was examined around the perimeter of the lake at 62 sites, and samples were collected from 32 sites; one outflow site, three static sites, and 28 inflow sites. This groundwater generally originates fairly close to the lake and is indicative of the relationship between the lake water quality and the local land use. It can also indicate the susceptibility of the lake to impacts from current local land use practices. As groundwater samples were collected every 200 feet, this survey was intended to acquire general water quality trends around the lake and not site-specific information. The combination of analyzed parameters at elevated concentrations can signify pollution or unnatural levels of nutrients coming from different sources.

The flow direction was determined at each site around the lake to establish whether it was a source of groundwater inflow to the lake, outflow from the lake, or was not connected with the groundwater. Forty-five percent of the sites sampled represented groundwater flowing into the lake. Flow velocities were measured at each site and groundwater samples were collected for analysis at the lab. This information was used in the preparation of the water and nutrient budgets. The pattern of the welling sites indicates the direction of regional groundwater flow, which is from the northwest of the groundwater watershed to the southeast (Figure 3).

Nitrate

Nitrate is a form of nitrogen found when oxygen is present. It is found in fertilizers, animal waste and septic effluent. Nitrate can readily leach through Pine Lake's sandy soil and into the groundwater and discharge to a local or regional waterbody. The nitrate concentrations in the groundwater in this study were low, with a maximum value of 2.5 mg/L (Figure 16).

The nitrate concentrations of the mini piezometer samples ranged from less than 0.02 to 2.46 mg/L. Eleven of the 28 sites (39%) had nitrate concentrations less than 0.02 mg/L. The average nitrate concentration of all sites was 0.18 mg/L. Of the seven sites with relatively high nitrate values, all occurred on the northern edge of the lake. This was to be expected as nitrate travels with groundwater, and the northern shore is the location of the greatest groundwater inflow.

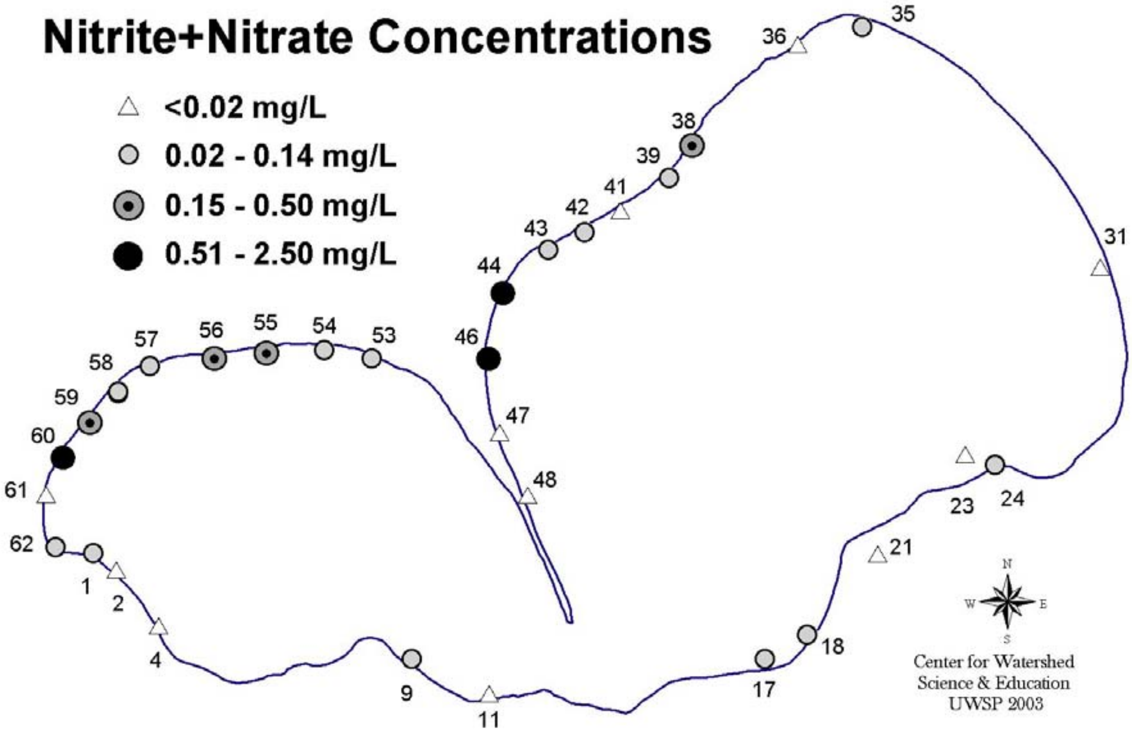


Figure 16. Nitrate Concentrations in Shallow Groundwater Samples Collected Around Pine Lake

<u>Ammonium</u>

Ammonium is a form of nitrogen (NH_4) that exists when oxygen is not present in the system. This condition is common when decomposition of organic matter occurs or when metals (i.e. iron, manganese) are elevated in the soil or groundwater. Its sources are similar to nitrate, however some natural sources such as wetlands and organic material also exist. Some aquatic biota are susceptible to the harmful effects of too much ammonia. The EPA concluded in its 1984 *Ambient Water Quality Criteria for Ammonia* that there is not a toxic effect of ammonia build up to humans.

Figure 17 shows the ammonium concentrations in the samples collected. Ammonium concentrations ranged from less than 0.01 mg/L to 1.82 mg/L in the shallow groundwater and were present in inflow, outflow, and static sites. Elevated concentrations occurred around the southern border of the lake in small bays where organic matter accumulates. Slightly elevated concentrations of ammonium also occurred at the tip of the east lobe where groundwater flows through a wetland. Sample sites on the east side of the sand spit were in an area of natural vegetation with downed trees and organic matter accumulation.

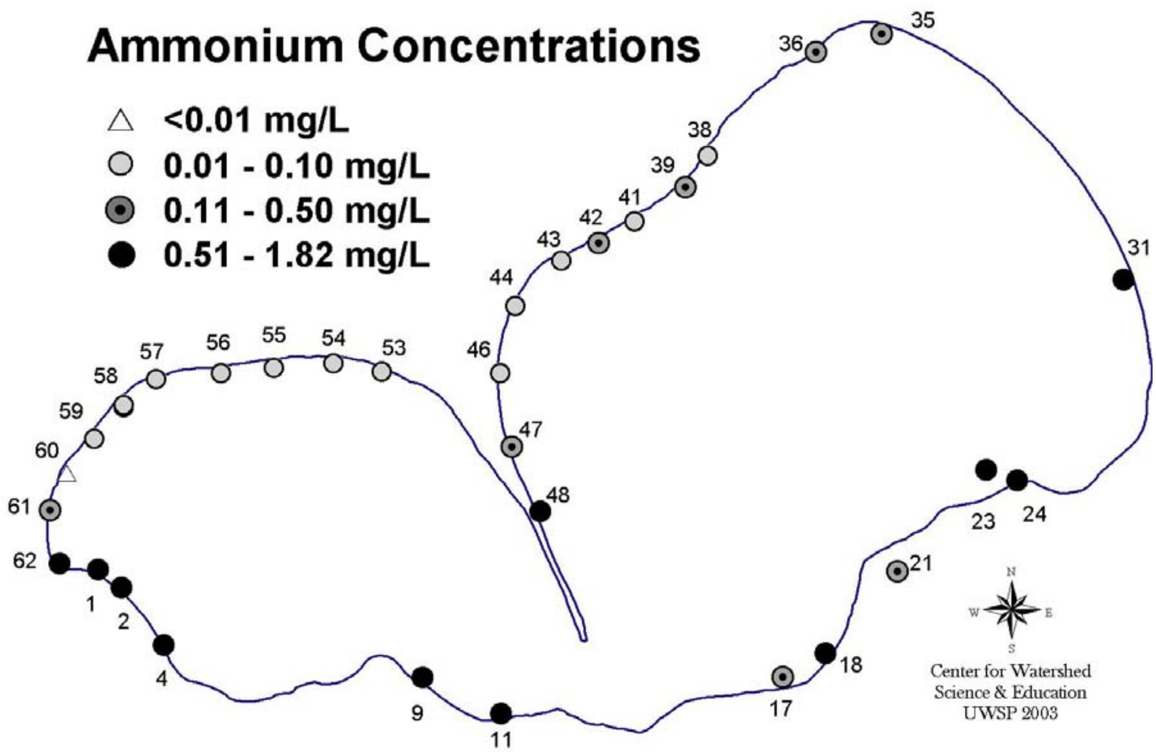


Figure 17. Ammonium Concentrations in Shallow Groundwater Samples Collected Around Pine Lake

Soluble Reactive Phosphorus (SRP)

Phosphorus sources include fertilizers, animal waste, septic systems, and as with ammonium, organic matter and wetlands are a major contributor of reactive phosphorus to Pine Lake groundwater. The range of SRP in samples collected was from 3 to 72 μg/L. Concentrations were quite variable, indicating the influence of sediments and local land use practices on the groundwater quality. Figure 18 illustrates the SRP concentrations around the lake. Many sites along the southern border of the lake with high SRP can be attributed to wetlands when they have a corresponding high level of ammonium and minimal chloride concentrations.

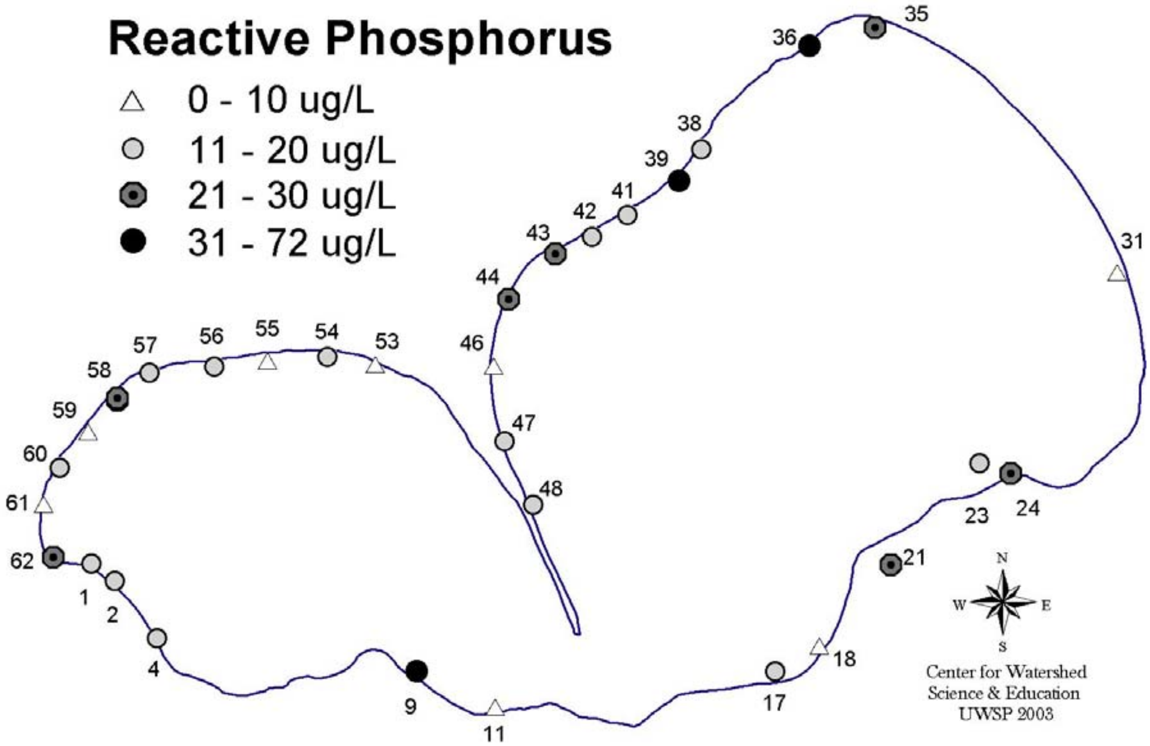


Figure 18. Reactive Phosphorus Concentrations in Shallow Groundwater Samples Collected Around Pine Lake

<u>Chloride</u>

Chloride is not used by plants and is, therefore, a good indicator of human activities on water quality. Chloride concentrations ranged from 0.3 mg/L to 22.0 mg/L. Chloride coupled with nitrate is an indicator of septic influence; however, in this study none of the sites high in chloride had high nitrate levels. Chloride combined with elevated SRP, nitrate, and ammonium levels could indicate excess fertilizers. Four sites exhibited this combination. Of the two sites highest in chloride concentrations, one is located near the boat landing. This site does not have exceptionally high nutrient levels, but is most likely affected by road salt. Figure 19 illustrates the chloride concentrations found around Pine Lake.

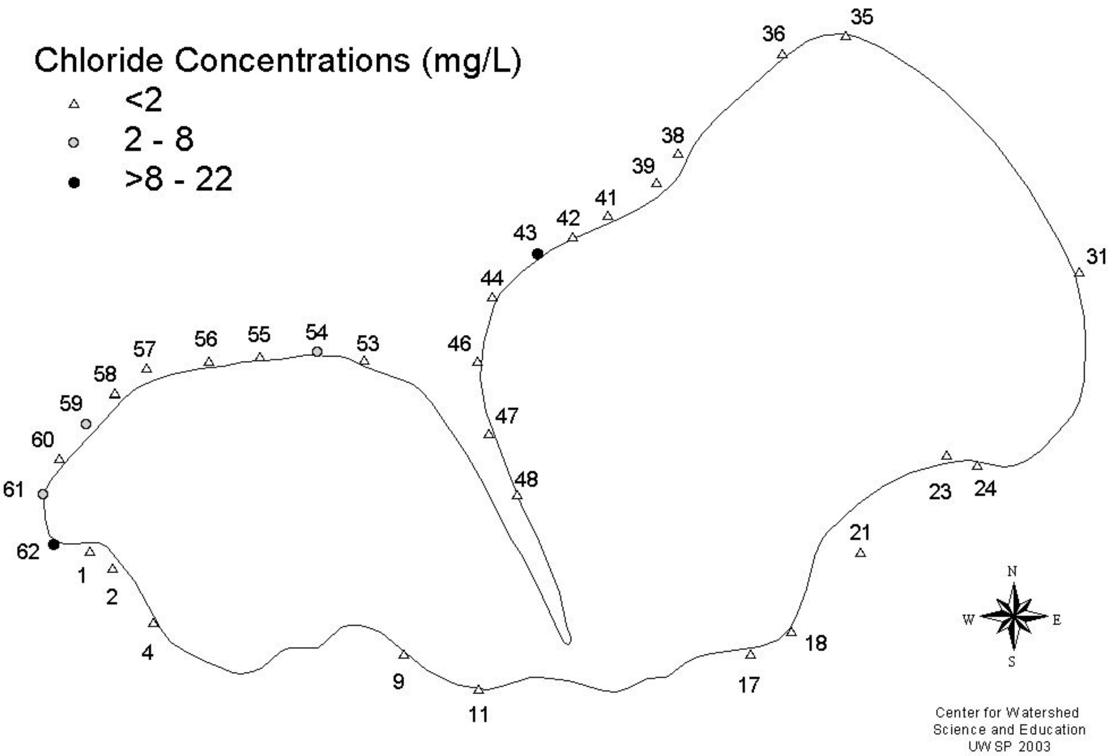


Figure 19. Chloride Concentrations in Shallow Groundwater Samples Collected Around Pine Lake

<u>Summary of Mini Piezometer Groundwater Survey</u>

Potential sources of nutrient enhancement or pollution to Pine Lake include organic sediments (wetland influence), agriculture and lawn/garden fertilizers, septic systems, and road salts. Elevated concentrations of reactive phosphorus, ammonium, and chloride distinguish sites influenced by organic sediments. Sites 43, 61, and 62 exhibited these characteristics. Road salts used in the winter will show up in the groundwater several months later having high chloride levels. Sites 54 and 59 had elevated chloride without presence of elevated nutrients.

PRIVATE WELL GROUNDWATER STUDY

In July of 2002, 59 water samples were taken by residents from their private wells in the Pine Lake watershed. These samples are generally indicative of the regional groundwater that moves through the aquifer and discharges to Pine Lake. The samples were analyzed at the WEAL for bacteria, nitrate, chloride, total hardness, alkalinity, conductivity, and pH. Private wells should be sampled at least annually and during different seasons as groundwater quality can change over time. Well owners with questions or results that indicated a potential problem were directed to contact the WEAL or Central Wisconsin Groundwater Center for recommendations.

Total hardness is a measure of dissolved calcium and magnesium, primarily the result of dissolving limestone or dolomite from soil and aquifer materials. Total hardness concentrations ranged from 100 to 320 mg/L, indicating relatively hard water. Five of the homeowners used water softeners, recognizable by the absence of hardness in the water. pH ranged from 7.22 to 8.29, which is considered neutral. Six samples had elevated levels of nitrate (>2 mg/L), three of these samples were above the EPA drinking standard of 10 mg/L. They also had elevated chloride concentrations, which indicates that there may be some impacts associated with septic systems, fertilizers, and/or road salts either on a local or watershed-level. Most of these samples were located near the western end of the lake. This is an area on the lake with relatively dense development. Overall, 14 samples had chloride concentrations over 3 mg/L. Although there are not health standards for chloride, its presence indicates the ability for other contaminants to move to the groundwater. Ten percent of the wells tested indicated the presence of total coliform bacteria, one tested positive for E. coli. The presence of bacteria is most likely exclusive to these wells and related to the type of well construction and/or lack of vermin-proof caps.

INTERSTITIAL WATER, SEDIMENTS, AND PLANT BIOMASS

Aquatic plant growth is important in the cycling of nutrients in a lake, throughout their growth they act as a sink for nutrients and are imperative for fish food and habitat. While it has been fairly well accepted that submerged aquatic plants receive the bulk of their nutrient supply from sediment pore water, it is poorly understood which factors are most responsible for aquatic plant growth and distribution. The establishment of aquatic plants depends on nutrient availability in the area, the plant's nutrient requirements, hospitable substrate (type and texture), shoreline slope, depth of water and light penetration, groundwater inflow and outflow areas, organic matter content, and site specific human impacts. A plant survey was conducted to investigate relationships between the plant biomass, sediment and interstitial water chemistry.

Most aquatic plants obtain needed nutrients from the sediments and interstitial water with which their roots are in contact. For plants that do not have a developed root system such as the algae *Chara*, water column nutrients play a greater role in meeting their requirements. Nutrient uptake is also a function of the relative availability of the nutrient, meaning both the form in which it is present and its concentration. More nutrients are generally present in the tissue of plants when more nutrients are available in the interstitial water and sediments.

For most analyses, we did not see strong correlations between plant biomass and chemical parameters in the environment. This may be because most areas around the shoreline of Pine Lake are developed and affected by boating activities, which affects the ability of plants to root. Funds limited the number of samples obtained for this portion of the study, however, Minitab Statistical Software 13.1 program was used to analyze the data and conduct correlations with welling status, water and sediment chemistry, sediment type, aquatic macrophyte biomass, and plant tissue concentrations.

<u>Aquatic Macrophytes</u>

According to Nichols and Shaw (2002), oligotrophic seepage lakes are most likely to see influences of groundwater inputs on plant abundance or distribution. In infertile sediments like sand, groundwater may provide a source of nutrients for macrophytes, therefore influencing their distribution and biomass. Most aquatic plants were found where groundwater inflow occurred; eight samples of plants were collected, and five of these occurred in inflow areas. The three sites with the highest plant biomass occurred in inflow areas. Inflow areas had a strong correlation with plant TKN, interstitial water nitrate and SRP, however, not with plant biomass. Plant TP somewhat correlated with welling, but the non-rooted dominate species, *Chara*, skewed the results. *Chara,* the dominate plant species found in Pine Lake, is known to uptake excessive amounts of P when it is available (Wetzel, 1983). Therefore, plant TP concentrations may be higher than the groundwater inflow concentration.

Chara was present at every site where plants were obtained in the survey. Plant biomass was not strongly correlated with TKN and TP concentrations in plant tissue. Biomass calculations were skewed with the presence of Chara because of the calcium carbonate (marl) that affixes to the exterior of the plant. Phosphorus frequently binds with the marl, affecting the measured concentrations of TP and relative amounts of TKN.

Sediment Chemistry

Nutrient availability from the sediments in Pine Lake are affected by a number of variables. Major factors include anaerobic release of ammonium and phosphorus from highly organic matter sediments, old septic plumes or anoxic release from sediments, and constant cycling of nutrients from lake to sediment to groundwater as lake and groundwater levels fluctuate.

Substrate types found in Pine Lake included mucky organic sediment, fine sand, sand, and sand and gravel. The type of substrate had a strong correlation with the amount of TKN and TP in the plant tissue. Generally, sand and gravel in the substrate yielded lower concentrations of nutrients in the plant tissue. The substrate type also correlated with the chloride and nitrate concentrations in the interstitial water as well as groundwater inflow.

Organic material and the minerals found in the watershed are the primary source of sulfates and potassium, which weather and travel with groundwater. Potassium concentrations in the sediment correlated to sediment nitrate, total nitrogen, reactive phosphorus, percent organic matter, and sulfate, indicating that potassium is traveling in the groundwater. Potassium also correlated with plant tissue TKN. Sulfates found in the sediment also correlated with the same parameters.

Interstitial Water

Correlations between the amount of ions and nutrients in the water and plant biomass are not strong. Biomass is weakly correlated with TKN and TP. The data show that local land uses are impacting the interstitial water. Surface water runoff carries fertilizers and excess nutrients from the land into the lake. The presence of chloride in the interstitial water is strongly correlated with nitrate, reactive phosphorus, and potassium in both interstitial water and sediments.

THE BIG PICTURE - WATER AND PHOSPHORUS BUDGETS

Hydrologic (water) and phosphorus budgets for Pine Lake were developed using data collected during 2001 and 200. Developing these types of budgets involves accounting for water and phosphorus inputs to Pine Lake and outputs from Pine Lake. These budgets are useful for understanding the origins of Pine Lake's water and significant/relative contributions of phosphorus. Having knowledge of this can assist in lake management and developing lake management plans.

The hydrologic and phosphorus budgets were developed using data collected over a relatively short time frame and projected to develop budgets applicable over a longer time period. Obviously, variations in conditions can impact these budgets, for example, climatic variability results in year-to- year variations in flow and phosphorus loading. As new information is collected or additional studies are performed, these budgets can be improved. The following discussion details the assumptions used in creating these intitial hydrologic and phosphorus budgets.

The concentration of phosphorus in the lake is the result of both external and internal (in-lake) sources. The available phosphorus influences the level of biological productivity, which ultimately impacts water clarity, plant and animal communities, and oxygen levels. The Wisconsin Department of Natural Resources' model, developed by John Panuska and Jeff Kreider (2001), was utilized to estimate phosphorus loading into Pine Lake by assessing contributions from external sources. Wisconsin Lake Modeling Suite (WiLMS) uses coefficients for each land use in the watershed to estimate the amount of phosphorus delivered to the lake. When pH and oxygen conditions are suitable, phosphorus contained in the sediments of the lake may leave the solid phase and assimilate into the water column, becoming available to plants and algae (in-lake loading). WiLMS can predict in-lake loading, however, the parameters needed to do so were not collected in this study.

Hydrology

The supply of water to Pine Lake comes from precipitation falling directly on the lake, surface water draining from areas of high elevation around the lake, and the groundwater that flows into the lake. Water leaving the lake includes groundwater and water that evaporates from the lake's surface. Obtaining a direct measure of evaporation is difficult and dependent on many variables. We approximated evaporation based on annual averages and subtracted it from the annual average precipitation estimate. The amount of precipitation falling directly onto Pine Lake minus evaporation was estimated by the WiLMS default of 3.2 inches in Waushara County. This value is similar to that used by Novitzki (1982), who used 3.0 inches in his hydrologic study in Waushara County. Surface runoff that drains to the lake from areas of higher elevation is difficult to estimate for lakes dominated by groundwater seepage. To provide a general estimate, we assumed two inches of runoff from the surface watershed enters the lake through surface flow paths.

Direct field measurements were used to estimate groundwater inflow and outflow volumes. Calculations were made using mini piezometer field measurements and Hvorslev's (1951) falling head test to compute velocity. The velocity of each inflow site was then multiplied by the area of influence assigned to that site. Previous studies of groundwater seepage into lakes by McBride and Pfannkuchen (1975) and Winter et al., (1998) suggest that groundwater inflow is greatest near the shoreline. Field-testing showed that a 40-foot distance from the shoreline into the lake was the area where most of the inflow occurs. This 40-foot distance, multiplied by half of the distance between a site's two adjacent sites, is the area of influence for each sample location. The area of influence, calculated using our GIS system (ArcView GIS 3.2a), was multiplied by the velocity of each site and then summed to determine the groundwater flux.

The estimated average flow into Pine Lake from the different components of the hydrologic budget totaled 1.3 cubic feet per second (cfs). This is similar to the estimated groundwater recharge which enters the 887 acre groundwater shed of 1.0 to 1.1 cfs for 10 and 11 inches of recharge annually. Estimates of flow out of the lake and into groundwater at the five outflow mini piezometer locations was approximately 0.5 cfs. The estimates of inflow and outflow both generally agree with that estimated for groundwater recharge. Even given the uncertainty in assigning groundwater flow to the near shore areas, the results suggest a substantial groundwater flow (e.g. 1 cfs) into the lake. Using the above values for the hydrologic budget and a bathymetric map obtained from the Wisconsin Department of Natural Resources to estimate lake volume and surface area, the amount of time water spends in Pine Lake (water residence time) is approximately 3 years. This is consistent with the WiLMS water residence time estimate of 3.3 years. The water residence time is calculated by dividing the lake volume by the annual inflow. This is essentially the amount of time that it would take to replace the water in Pine Lake with new water from the watershed.

External Phosphorus Loading

Phosphorus enters Pine Lake from both external sources and internal cycling. The Wisconsin Department of Natural Resources' WiLMS model (WDNR, 2001) was used to estimate phosphorus loading from external sources. These include surface water runoff from the drainage area, septic systems in the watershed, and atmospheric deposition. Phosphorus contribution from groundwater was measured directly in the field.

Pine Lake's watershed and direct runoff area (surface water into the lake) was delineated using USGS 1:24,000-scale topographic maps and classified according to land use. Land cover data was derived using Landsat Thematic Mapper satellite imagery obtained from WISCLAND. WiLMS manipulated the acreage by a standard coefficient (based on literature reviews and WiLMS defaults) to determine the phosphorus contribution by land use type. Table 10 summarizes the phosphorus loading to Pine Lake from these external sources and further by specific land uses. These results are displayed in Figure 20.

Category		**Area**	**Flow**	**P Load (kg/yr)**		**% P Loading**	
				Low	**Most-likely**		
Groundwater		887 acres	1102980 m^3/yr 1.2 cfs	20		**34.3**	
Net Atmospheric Deposition (Lake Surface Area) Rainfall minus Evaporation		144 acres	0.05 cfs	6	16	**27.1**	
Septic Tank (100 capita-years)				6	15	**25.8**	
Direct Drainage Area (157 acres)	Rural Residence	77 acres	0.04 cfs	2	3	5.4	**12.8**
	Forest	60 acres		1	3	4.6	
	Grass/Pasture	10 acres		0	1	2.1	
	Wetlands	10 acres		0	0	0.7	
Total			**1.3 cfs**	**35**	**58**	**100**	

Table 10. Phosphorus Loading Estimates to Pine Lake from External Sources

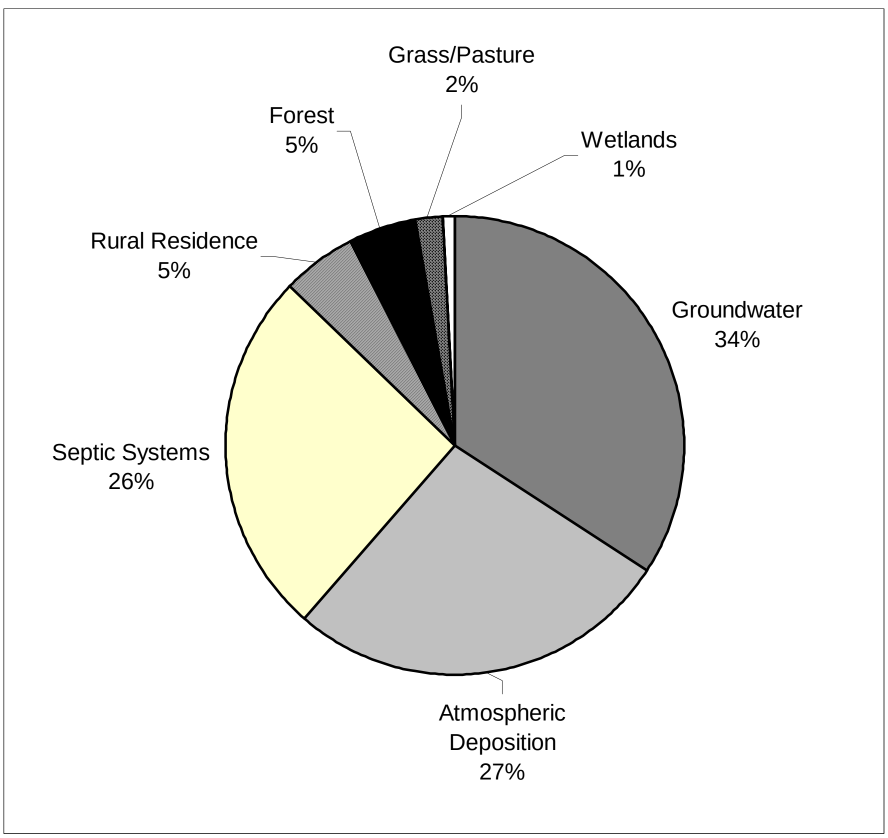


Figure 20. Percent of Phosphorus Loading to Pine Lake from External Sources

The phosphorus loading estimate suggests all four categories of phosphorus loading are important. Phosphorus present in the local groundwater was estimated to be the largest contributor of external phosphorus with 34% of the loading. We estimate phosphorus loading from groundwater to be 20 kg/yr. This was determined by multiplying the volume of groundwater inflow by the average phosphorus concentration of the inflow sites. Atmospheric deposition of phosphorus was the second largest source, contributing 27% of the total. The estimated deposition rate was 0.89 lb/acre/year (16 kg/yr) (estimated by WiLMS).

Septic loading is the third largest contributor of phosphorus to Pine Lake at 26% (15 kg/yr). Septic loading was based on an occupancy of 100 capita-years and retention in the soil based on texture. One capita-year is equal to one person occupying a dwelling for a period of one year. One hundred fifty-three parcels surround the lake. Taking into account seasonal versus permanent occupancy and the number of visitors/people per household, we assumed 100 for the capita-year. Phosphorus retention rates of 80, 70, and 60 percent were applied for the septic efficiency and soil type surrounding Pine Lake.

The total phosphorus loading from the watershed is estimated to be 58 kg per year (with a range of 25 kg per year as a low estimate to 145 kg as the high loading estimate).

<u>Water Column Phosphorus Concentration Modeling</u>

Prediction of lake water column phosphorus was done using equations developed by others to relate phosphorus loading to concentration (WiLMS' Prediction and Uncertainty module). The observed growing season (May-September) mean total phosphorus concentrations were predicted. The observed water column phosphorus concentration in Pine Lake was similar to the phosphorus prediction models, which ranged from 7 to 20 μg/L (12 average) as the most likely growing season mean phosphorus. Using the upper and lower range of phosphorus loading resulted in predicted phosphorus concentrations of 3 to 11 μg/L as the low, and 18 to 50 μg/L as the high estimate. Pine Lake's observed average total phosphorus concentration was 12.8 μg/L. This agreement suggests the phosphorus loading estimate is reasonable (Table 11).

External P Loading	58 kg/yr	
TP observed in epilimnion	12.8 μg/L	
TP predicted in WiLMS *(growing season mean)*	20 ug/l	Walker, 1987 Reservoir
	7 ug/l	Rechow, 1979 General
	11 ug/l	Rechow, 1977 water load <50m/yr

Table 11. Calculated and Predicted Phosphorus Values

<u>Uncertainty</u>

As with any modeling and fieldwork, there are uncertainties in the estimates of the hydrologic and phosphorus budgets. Limited amounts of data, variation throughout the year, and spatial variation contribute to the uncertainty. Although the estimates developed provide a relative assessment of the importance of these different phosphorus inputs, they should be viewed as preliminary estimates.

Water quality data was collected monthly, upon which phosphorus concentrations were determined for the lake. Plant cycles during the year will yield different amounts of nutrient uptake and release, changing the phosphorus concentrations. More surface water samples would better reflect in-lake concentrations.

Groundwater flow in Pine Lake is quite variable spatially, affecting both flux calculations and phosphorus loading. Mini piezometers were installed in 18 inches of water around the shoreline and at several sites transects were made perpendicular to shore until inflow was no longer observed. The measured velocities may not be representative of the entire influence area assigned to each site, but are a good estimate. Besides spatial variation in the lake, there are also seasonal fluctuations. Intense periods of groundwater upwelling can occur when lake levels are low, such as in August. During different stages of the hydrologic cycle, groundwater transport of P can have a more distinct impact on water quality.

As Pine Lake receives all water input from groundwater, precipitation, and surface runoff, there is ample uncertainty in the water budget as well as the phosphorus loading. Surface runoff and precipitation were not measured directly. Mini piezometers give an indication of the velocity and quality of the groundwater for one point in time. These data are used with care as it only suggests the general regime.

RESIDENT SURVEY

It is important to understand how a population perceives and uses a lake to identify education needs in a community and to guide the development of a lake management plan. A survey questionnaire was used to identify public perceptions of lake water quality and the recreational concerns of the people who use Pine Lake. A 55% response was received with 150 surveys distributed and 83 returned to the PLPOA. The PLPOA compiled the results into an Excel spreadsheet and forwarded it to UWSP for summary. Not all questions were answered on each survey therefore the results are displayed in percentages of the total number of responses for each question, unless multiple responses could be given.

On Pine Lake, 29% (24 of 82) of the respondents were full time residents and 71% were part time residents. Of the part time residents, 45% (27 of 60) used the lake for weekends and vacations, 30% used the lake seasonally for 6 months, 15% used the lake seasonally for 8 months, and 10% used the lake just during the summer months (Figure 21). The lake is used on average 155 days of the year (of 78 responses) with an average of 3.5 people visits per property when it is occupied (of 82 responses).

Of the 82 respondents, 41% rate the water quality of Pine Lake as very good. Twenty-eight percent rate the water quality as good, 24% rate it as excellent, and 6% rate it as fair (Figure 22). 55% (44 of 80) believe the water quality has declined. The decline is the result of (in order of most believed influence) boating (33), development pressures (18), septic seepage (18), fertilizer use (14), soil erosion (14), air pollution (2), weeds brought in from other lakes (2), milfoil (1), jet boating (1), lack of swimming area (1), sand being dumped on the beach (1), soap (1), and low water levels (1) (illustrated in Figure 23). Pine Lake is also believed to be facing issues of (in order of most problematic) weeds (56), boating (40), water clarity (18), algae/scum (17), litter (13), odors (5), and nothing (3).

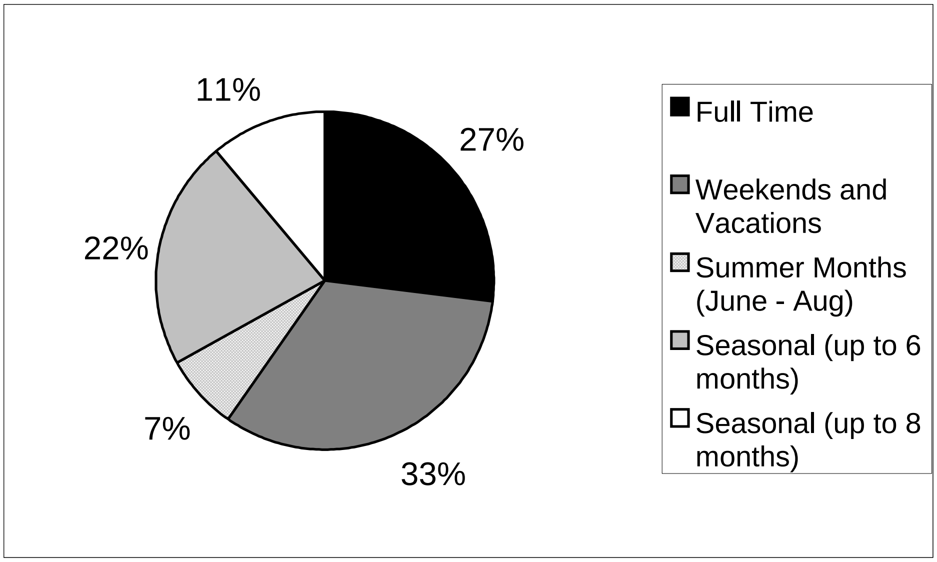


Figure 21. Approximate amount of Time Survey Respondents Spend at Pine Lake over a Year

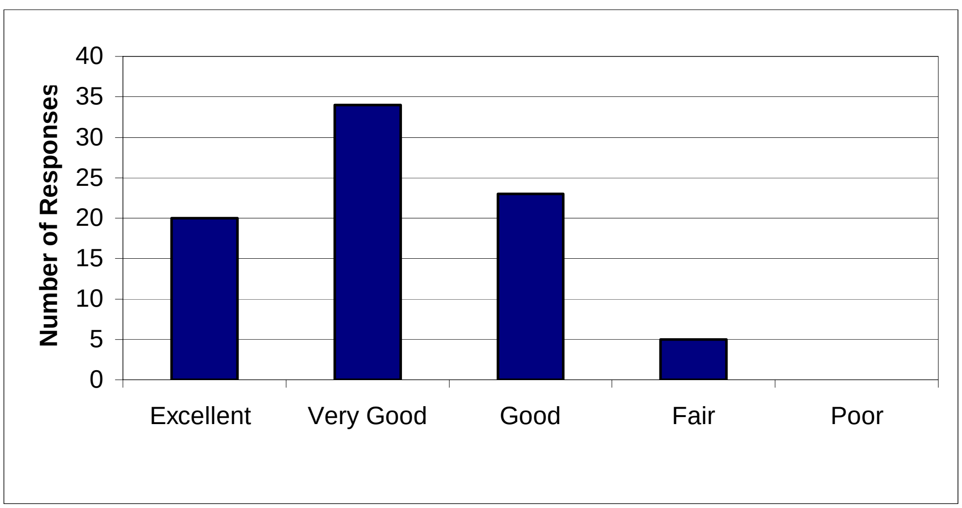


Figure 22. Perception of Pine Lake Water Quality

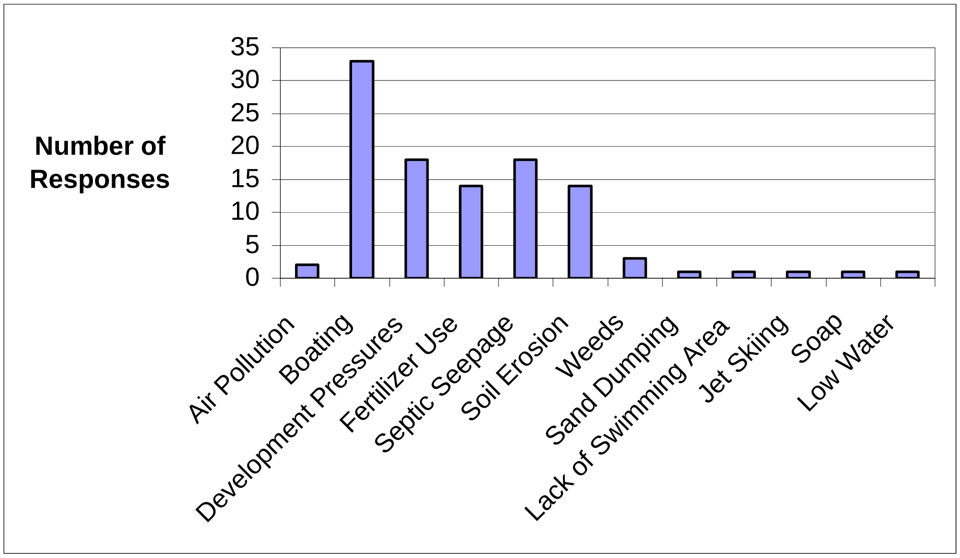


Figure 23. Perceived Influences of Decline of Water Quality in Pine Lake

Ninety-eight percent of the respondents (80 of 82) use the lake for recreation, including swimming (78), boating (72), aesthetic appreciation (62), fishing (59), water skiing (4), canoeing (2), and volleyball (1) (Figure 24). Of those who engage in boating activities,

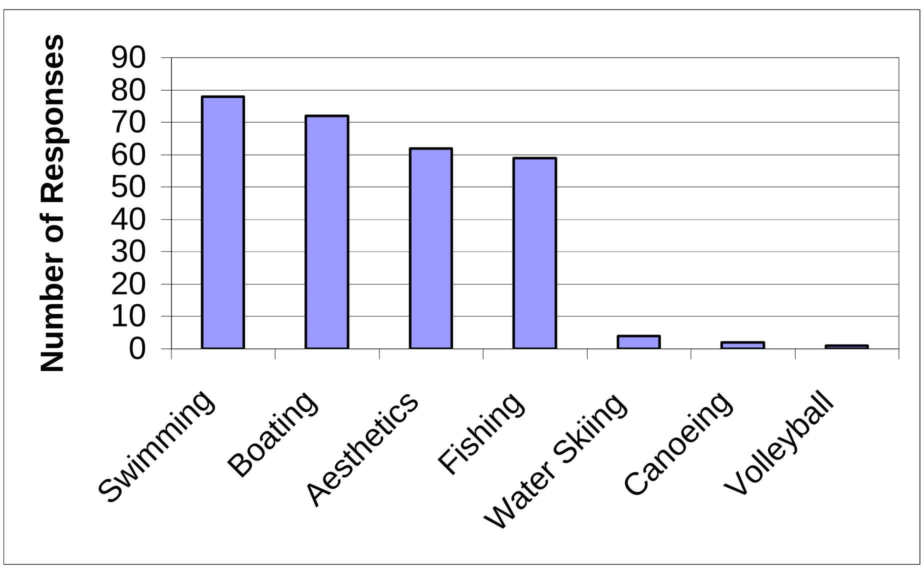


Figure 24. Recreational Uses of Pine Lake

47 own a fishing boat, 34 own a canoe, 33 own a ski boat, 33 own a paddle boat, 19 own a pontoon boat, 17 own a sailboat, 4 own a personal water craft (jet ski), 2 own a row

boat, and 2 own a kayak, for a total of 197 water crafts on Pine Lake from the respondents. It is estimated that the survey respondents used 3,200 gallons of gas last year on Pine Lake. Engine sizes on the boats range from 2 to 270 horsepower.

Forty four percent of the respondents (35 of 80) fish Pine Lake regularly. Seventy percent (39 of 56) of those surveyed feel fishing has declined in Pine Lake. Factors perceived to affect the fishing in Pine Lake include boating (25), development (11), soil erosion (5), over fishing (4), septic seepage (4), fertilizer use (2), air pollution (2), poor DNR management (1), weeds (1), lack of cover (1), and jet skiing (1) (Figure 25).

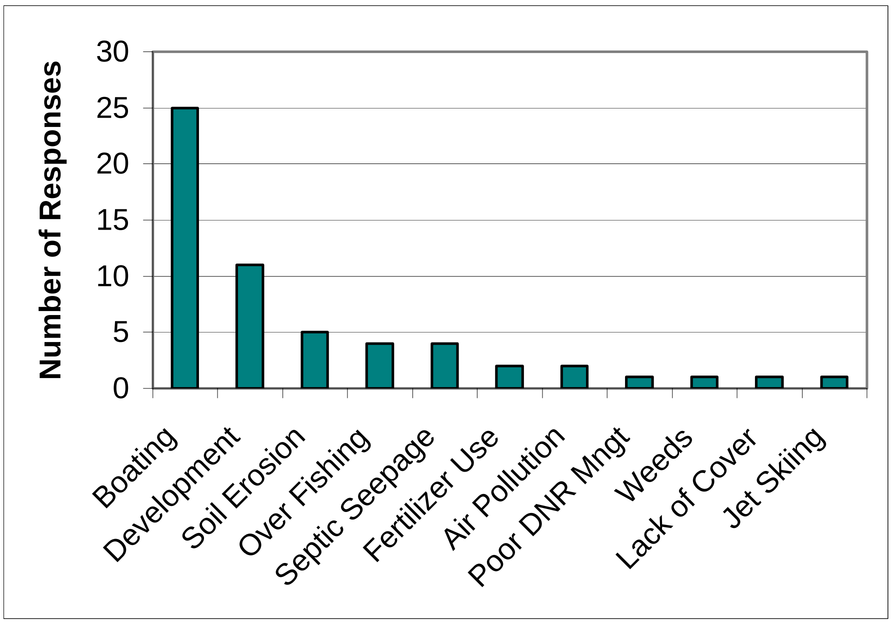


Figure 25. Reasons for Decline in Fishing Identified by Respondents

Many near shore land use practices can impact the water quality in Pine Lake, therefore questions to identify existing activities and use of products. Of 73 respondents, 89% (65) have their well located within 300 feet of the current shoreline. Of this subclass, the average distance of the well to shoreline is 100 feet. Of these shoreline residents, 52% (33 of 64) have an automatic clothes washer, and 35% (23 of 65) have an automatic dishwasher. Most dishwasher detergents contain phosphorus, whereas laundry detergents purchased in Wisconsin do not. All detergent usage may contribute to the nutrient load entering the lake because of the heavier use of one’s septic system through machine washing.

Lawn fertilizers were used by 21% (13 of 63) of the shoreline residents, who fertilize an average of 2000 square feet 1.33 times per year. Of these, 8% (5 of 61) also use pesticides. An average of 34% (n=61) of the lots are mowed lawn. Figure 26 depicts the percentage of mowed lawns around Pine Lake.

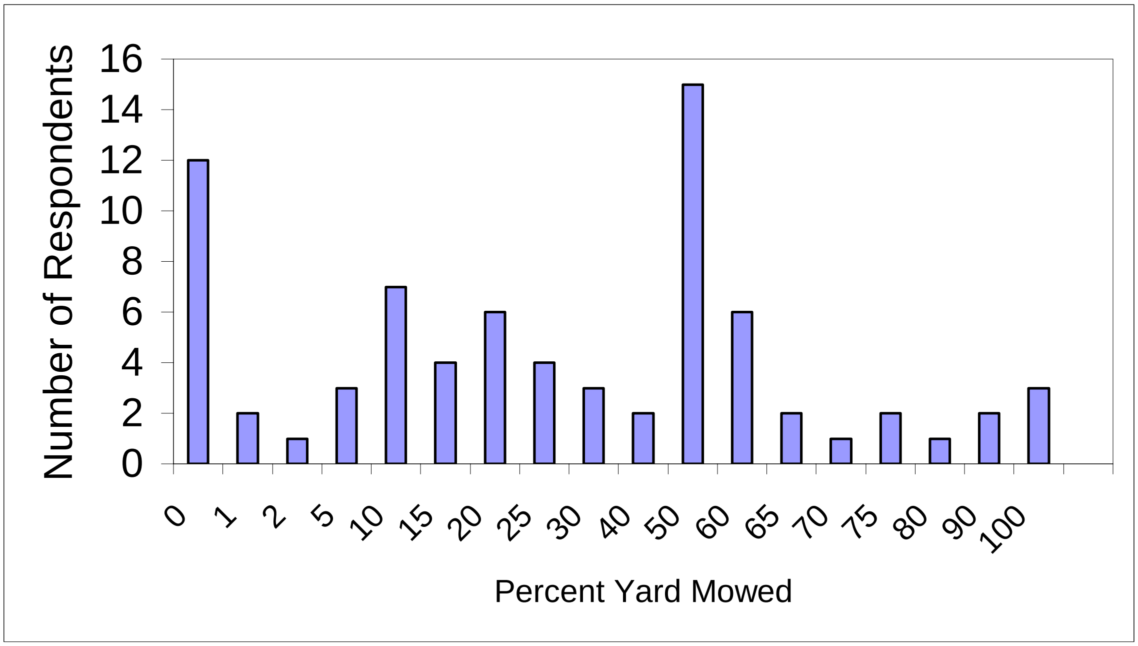


Figure 26. Percent of Mowed Lawn by Survey Respondents

Buffer strips, or filter strips, are an important part of a lake's ecosystem. Buffer strips not only trap sediment and debris from entering the lake water and prevent erosion, but the roots of the vegetation utilize some nutrients that would otherwise enter the lake. In addition, areas with native vegetation provide habitat to a variety of lake residents including terrestrial and aquatic organisms. In the State of Wisconsin, 35 feet is the minimum distance from the lake for a riparian buffer. (See s. NR115.05(3)(c), Wis. Admin. Code for more information on shoreland management and also the Department of Natural Resources' web page). Clear-cutting of trees and shrubs is not allowed in the strip of land from the ordinary high water mark to 35 feet inland. The exception is for a 30-foot wide path, for every 100 feet of shoreline, down to the water to allow for access. In hilly areas it is best that these paths to the lake meander rather than take a direct route, as this will reduce the sediment (and hence, nutrient) movement to the lake during periods of surface runoff. Eighty-three percent of shoreline residents (44 of 53) stated they have some sort of buffer strip between their lawn and the lake.

SUMMARY AND CONCLUSIONS

SURFACE WATER

1. Pine Lake is classified by the Wisconsin Trophic Status Index (WTSI) as an oligotrophic lake with very good water quality.
2. Pine Lake has very good water clarity. The Secchi depth in the west lobe averaged 12.1 feet over the two-year study and the east lobe averaged 15.1 feet.
3. Chlorophyll *a* concentrations were low with an average of 2.14 µg/L.
4. Nitrogen concentrations in Pine Lake are low. The average nitrate concentration was 0.1 mg/L and average ammonium concentration was 0.08 mg/L.
5. Seepage lakes are highly sensitive to human inputs of phosphorus. It is difficult for phosphorus to leave a seepage lake because there is no outlet other than through groundwater, so once phosphorus is in the system it will continue to be recycled. The two-year average soluble reactive phosphorus concentration in the west lobe was 7 µg/L and 6 µg/L in the east lobe. The average total phosphorus concentration in the west lobe was 18 µg/L and 12 µg/L in the east lobe. These concentrations are quite low, but efforts should be made to minimize phosphorus inputs to the lake.
6. Marl lakes like Pine Lake naturally protect against excess phosphorus and nuisance algae blooms, however, this protection has limits. Marl precipitation occurs because of the presence of calcium (hardness) and carbonates (alkalinity). Pine Lake is classified as a moderately hard lake based on its total hardness concentrations (range 105 to 166 mg/L as $CaCO_3$).
7. Pine Lake is not sensitive to acid rain as the average alkalinity concentration was greater than 100 mg/L as $CaCO_3$.
8. Due to differences in depth, the east lobe of Pine Lake thermally stratifies while the west lobe remains mixed throughout most of the season. The east lobe develops a hypolimnion below 30 feet depth where dissolved oxygen concentrations regularly drop below 2 mg/L.

INTERSTITIAL WATER/SEDIMENTS/PLANT BIOMASS

9. Strong correlations were not seen between plant biomass and nutrients in sediments and interstitial water. However, plant biomass was most likely affected by boating activity in the lake, skewing the results of the survey.

MODELING AND PHOSPHORUS LOADING

10. Estimated flow into and out of Pine Lake was between 0.5 and 1.3 cubic foot per second (cfs). The estimated residence time of the lake water is approximately 3 years.
11. Total phosphorus loading to the lake is predicted at 58 kg/year from all sources.

GROUNDWATER

12. Regional groundwater flow to Pine Lake is from the northwest to the southeast. The strongest groundwater inflow was measured along the north shore of the lake.
13. Nitrate concentrations in the shallow groundwater corresponded to groundwater inflow. Nitrate concentrations ranged from less than 0.02 mg/L to 2.5 mg/L in the groundwater obtained just below the lake bed.
14. Phosphorus in this groundwater ranged from 3 to 72 μg/L. Sources could include organic sediments, wetlands, fertilizer runoff, or septic systems.
15. Groundwater near the boat landing appears to be impacted by road salts.
16. Generally the quality of groundwater flowing into Pine Lake during the study was good.

PRIVATE WELL WATER

17. Total hardness concentrations in un-softened private well samples ranged from 100 to 320 mg/L, indicating relatively hard water.
18. Nitrate concentrations exceeded the drinking water standard (10 mg/L) in 3 of 59 samples.
19. Ten percent of the wells tested indicated the presence of total coliform bacteria, one tested positive for E. coli. The presence of bacteria is most likely exclusive to these wells and related to the type of well construction and/or lack of vermin-proof caps.

RESIDENT SURVEY

20. The perceived water quality of Pine Lake is very good (41%), good (28%), excellent (24%), and fair (6%).
21. The top three perceived reasons for decline of water quality on Pine Lake are boating, development pressures, and septic seepage.
22. According to the majority of the responses, the major water quality issue Pine Lake is facing is boating. Survey responses indicate that 197 watercrafts are owned on Pine Lake by the 83 survey respondents.

RECOMMENDATIONS

Water moves to Pine Lake via surface runoff, groundwater, and direct precipitation. Pollutants and other contaminants can enter the lake directly through these processes. Areas immediately surrounding the lake generally have the largest impact on lake water quality. However, much of the groundwater originates further out in the groundwater shed, so the land uses in the watershed can also affect Pine Lake's water quality. Efforts to reduce sediment and nutrient inputs to the lake should be made by both shoreland residents and landowners within the watershed.

Developed areas in the watershed are currently not very extensive. However, there may be local impacts due to increased runoff from impervious surfaces (roofs and driveways) and mowed vegetation. Best management practices for developed areas include measures that prevent/reduce runoff from transporting excess sediment, nutrients, or other pollutants to the lake. Rain gardens help alleviate concentrated flow from roofs and driveways by retaining water on the property. The water will slowly infiltrate the soil, which filters out sediments, nutrients, and other pollutants. Septic drainfields should be sited as far from the lake as possible, particularly in the areas around the lake where groundwater inflow has been identified. A few of the residences around the lake have lawns mowed to the water's edge. Twenty-one percent of the landowners responding to the survey indicate they use lawn fertilizer. Use of lawn and garden fertilizers should be minimized if used at all. Soil tests should be conducted routinely to determine if the use of fertilizers is warranted.

Much of the developed part of the lake lacks sufficient shoreline vegetative buffers to remove sediments, nutrients, and pollutants from runoff and to provide habitat for aquatic wildlife. Thirty-five feet from the water is the state standard for a functional buffer. Buffers should be re-established in these areas, and should include grasses, forbs, shrubs, and trees. Existing native shoreline vegetation around the lake should be protected and efforts should be made to establish more natural vegetation in shoreline riparian areas. This vegetation provides many benefits to the lake ecosystem. The grasses and shrubs filter out sediments, which flow from adjacent areas. The vegetation also uses nutrients that would otherwise flow to the water, taking up some phosphorus and nitrogen.

In-lake vegetation creates a microenvironment suitable for marl formation, which can further limit available phosphorus. It also provides habitat and food for fish, aquatic insects, reptiles, amphibians, waterfowl, and other birds. Aquatic plants in shallow water help to buffer the impact of waves on the shoreline, thus, reducing erosion and the need for rip-rap. The re-establishment of natural vegetation may also reduce the likelihood of Eurasian milfoil to invade other areas.

Motorized watercraft use (boats and personal water crafts) should be conducted in a way to allow the establishment of shoreline vegetation and reduce mixing of sediments into the water column. Turbulence and wakes produced by boating activity disrupt the rooting of the plants. No wake zones should be implemented through the narrow passing between the east and west lobe and within 200 feet of the shoreline in accordance with Wisconsin state law. Motorized boating restrictions would also allow for a balance of other recreational activities on the lake. Many survey respondents indicated they enjoyed canoeing, swimming, aesthetic appreciation, paddleboats, and volleyball as in-lake activities.

Water conservation in the home can reduce problems of septic system overloading which can reduce the level of waste treatement. Common sense measures like turning the water off while brushing your teeth reduces the amount of water going into the septic system. Over time, septic systems become less effective and contribute to the nutrient loading to Pine Lake. Proper operation and maintenance is vital toward the prevention of septic system failures. Septic tanks are designed to be pumped periodically (every 2-3 years on average). Pumping removes sludge from the tank that may otherwise overflow and clog the soil absorption field. A clogged field cannot properly treat effluent and may result in ponding or system back-ups. Surface runoff should be diverted away from the soil absorption field to prevent soil erosion, ponding, and saturation of the soil. Grassy cover should also be maintained to reduce absorption field erosion. Heavy structures, such as cars and boats, should be kept off of the absorption field to prevent soil compaction and reduced permeability. Proper care and operation of a septic system can prolong its service life and thereby save the property owner expensive repair or replacement costs. New septic drainfields should be sited as far from the lake as possible.

A management plan should be developed for Pine Lake and should include a vision and goals for the lake. It should identify ways to achieve goals and should be incorporated into the Town and County plans where appropriate. Many people should be involved in this process and inclusion of local and state professionals is strongly encouraged. Technical support is available from the UW-Extension, Natural Resources Conservation Service, County Land Conservation Department, consultants, Department of Natural Resources, websites, books, and nurseries.

Routine water quality monitoring is also recommended to assess the status of the lake over time and during various climatic conditions. Water chemistry will change over time in response to land use activities. At a minimum, annual sampling during over-turn would be useful. In addition, summer Secchi measurements and temperature and dissolved oxygen profiles are useful.

LITERATURE CITED

Born, S.M., S.A. Smith, and D.A. Stephenson, The hydrogeologic regime of glacial-terrain lakes, with management and planning applications, Inland Lake Renewal and Management Demonstrations Project, 73 pp., Univ. of Wisc., Madison, 1974.

Carlson, R.E., A trophic state index for lakes, *Limnol. And Oceanogr*. 22(2), 361-369, 1977.

Carlson, R.E., Using trophic state indices to examine the dynamics of eutrophication, International symposium on inland waters and lake restoration, EPA 440/5-81-010, 218-221, 1980.

Environmental Protection Agency, Ambient Water Quality Criteria for Ammonia, 1984. EPA#: 440/5-85-001 http://www.epa.gov/ost/pc/ambientwqc/ammonia1984.pdf

Department of Natural Resources, State of the Wolf River Basin Report, 220 pp., PUBL WT 664 2001, 2001. http://www.dnr.state.wi.us/org/gmu/wolf/wolf_final_801.pdf

Hennings, R.G., The hydrogeology of a sand plain seepage lake, Portage County, Wisconsin, M.S. thesis, University of Wisconsin – Madison, 1978.

Hvorslev, M.J, Time-lag and soil permeability in ground water observations, *U.S. Army Eng. Waterways Exp. Sta., Vicksburg, MS.*, Bull. 36, 50 pp.,1951.

Kehew, A. E., Applied Chemical Hydrogeology, Prentice Hall, Inc., 2001.

Lillie, R., and J. Mason, Limnological characteristics of Wisconsin Lakes, Wisconsin Dept. of Natural Resources, Technical Bulletin No. 138, 1983.

Lillie, R.A., S. Graham, and P. Rasmussen, *Trophic State Index Equations and Regional Predictive Equations For Wisconsin Lakes,* Research Management Finding, Bureau of Research, Wisconsin Dept. of Natural Resources, Number 35, May 1993.

McBride, M.S., and H. Pfannkuch, The distribution of seepage within lakebeds, *J. Res. U.S. Geol. Surv.*, 3, 505-512, 1975.

Nichols, S.A., B. Shaw, The influence of groundwater flow on the distribution and abundance of aquatic plants in some Wisconsin Lakes, *J. of Freshwater Ecology* 17(2), 283-295, 2002.

Novitzki, R.P., Hydrology of Wisconsin wetlands, United States Department of the Interior, Geological Survey and University of Wisconsin—Extension. *Wis. Geological and Natural History Survey*, 1982.

Otsuki, A., and R.G. Wetzel, Coprecipitation of phosphate with carbonates in a marl lake. *Limnology and Oceanography*, 17; 763-767, 1972.

Reckhow, K. H., Phosphorus models for lake management, Ph.D. dissertation, Harvard University, Cambridge, Massachusetts, Catalog No. 7731778, University Microfilms International, Ann Arbor, Michigan, 1977.

Reckhow, K. H., Uncertainty applied to Vollenweider's phosphorus criterion, J. Water Poll. Cont. Fed. 51: 2123-2128, 1979.

Shaw, B., C. Mechenich, and L. Klessig, Understanding lake data, University of Wisconsin - Stevens Point, 20 pp. University of Wis. Extension, 2000.

Summers, W.K., Geology and ground-water resources of Waushara County, Wisconsin, *Wis. Geological and Natural History Survey*. Geological Survey Water-Supply Paper 1809-B, 1965.

Walker, W W, Jr., Some analytical methods applied to lake water quality problems, Ph.D. dissertation, Harvard University, 1977.

Wetzel, R.G., Limnology, Second Edition, Saunders College Publishing, 1983.

Winter, T.C., J. Harvey, O. Franke, and W. Alley, Ground water and surface water, a single resource, *U.S. Geol. Surv*,. Circular 1139, Denver, CO, 1998.

Wisconsin Department of Natural Resources Shoreland Management Program http://www.dnr.state.wi.us/org/water/wm/dsfm/shore/title.htm

Wisconsin Lake Management Suite (WiLMS), Panuska, J. and J. Kreider, Department of Natural Resources, Version 3.3.5, 2001.

APPENDICES