An Evaluation of McGinnis Lake, Adams County, Wisconsin

Surface and Ground Water Quality, Aquatic Plant Assessment, and Phytoplankton Survey

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EXECUTIVE SUMMARY

McGinnis Lake is a 33 acre, hard-water lake in Adams County, Wisconsin that was the focus of this study to investigate surface water quality, groundwater flow, aquatic plants and algae in the lake. This study was designed to help better understand and manage lake water quality in the future.

McGinnis Lake exhibited symptoms of nutrient enrichment. The lake could be classified as moderately eutrophic, and increasing levels of nutrients were measured in the water during the growing season. This increase appears to be linked to the die-back of the dominant aquatic plan, curly-leaf pondweed (*Potamogeton crispus*) during the summer.

The north and the south lobe of the lake are different. The south lobe remained mixed or was partially stratified for short time periods, while the north lobe stratified with a pronounced thermocline and cooler hypolimnion (bottom). Dissolved oxygen (DO) in the north lobe increased in the metalimnion in the beginning of the season likely in response to algae in the water column. In the deeper depths of the north lobe, DO concentrations decreased and were very low at the bottom.

McGinnis is a phosphorus-limited lake, meaning that contributions of phosphorus to the system may increase algae or plant growth. The surface total phosphorus concentration (TP) in the north lobe averaged 23 μg/L and was much higher in the oxygen-depleted hypolimnion. The average TP in the south lobe was 29 μg/L and the outflow averaged 37 μg/L TP. Soluble reactive phosphorus (SRP) was quite low in the upper layers of the lake (north and south) with average concentrations were between 5 to 7 μg/L. The hypolimnion of the north lobe had an average SRP concentration of 128 μg/L.

Clarity was low in the lake. The north lobe had an average Secchi depth measurement of 3.6 feet and the south lobe had an average of 5.2 feet. The south lobe water clarity declined substantially by late July, most likely corresponding to the increase in algae growth stimulated by the release of nutrients from the curly-leaf pondweed. Chlorophyll *a* was also higher during late July.

The groundwater entering McGinnis Lake is a source of calcium and carbonate to the lake. McGinnis is considered a hardwater lake with an average total hardness concentration of 125 mg/L as $CaCO_3$ in the epilimnion. Solid calcium carbonate (marl) forms in the lake. This is evident from the reduction in calcium and carbonate concentrations during the growing season in the north lobe. Settling calcium carbonate may also dissolve in the deeper portions of the lake, based on the increased total hardness and alkalinity concentrations in the north hypolimnion were 231 and 242 mg/L as $CaCO_3$, respectively. The composite total hardness and alkalinity average concentrations in the south lobe were 112 and 111 mg/L as $CaCO_3$, respectively.

Generally, water in marl-forming lakes is expected to be low in phosphorus due to binding with calcium carbonate. In the case of McGinnis Lake, this binding may not be sufficient to prevent eutrophic conditions because much of the marl formation occurs in the north lobe and phosphorus release from the curly-leaf pondweed occurs in the south lobe. In June, curly-leaf pondweed comprised the major plant type in the south lobe and channel and was also found in the littoral zone of the north lobe. Curly-leaf pondweed has a unique life cycle that allows it to out-compete native vegetation because it is tolerant of cold-water conditions and is usually the first plant species in the spring. A survey of the curly-leaf pondweed was conducted in June, just prior to its die-back. The estimated total biomass was 1,800 kg (3,970 pounds) of which approximately 4 kg (8.8 pounds) is estimated to be phosphorus. The nitrogen in the plant tissue was estimated to be 40 kg (88 pounds).

Phosphorus and the algal community increased in the south lobe following the die back of the curly-leaf pondweed. Chlorophyll *a* increased in the south lobe with a maximum on the July 10 sampling date. Water clarity was also lower in July than in June. The dissolved oxygen (DO) in the south lobe also decreased following the die back, likely reflecting organic matter decomposition.

Shallow groundwater was sampled to determine the areas of groundwater inflow and outflow as well as the quality of the groundwater discharging to McGinnis Lake. Generally, nitrate was entering at the strongest inflow sites in the northwest corner of the north lobe. Much of this groundwater likely originated further out into the watershed. Ammonium was present sporadically in groundwater around the lake, but had highest

concentrations along the southern edge of the south lobe. SRP was also high along the southern edge as well as other areas of the lake. Eighteen of the 28 (64%) samples sites had elevated SRP concentrations.

Groundwater from two locations of strong inflow in the north lobe was analyzed at various depths. SRP concentrations ranged from 5 to 13 μg/L, nitrate ranged from 0.40 to 1.82 mg/L, ammonium was less than 0.01 mg/L in all sites, alkalinity ranged from 130 to 175 mg/L as $CaCO_3$, total hardness ranged from 140 to 180 mg/L as $CaCO_3$, and chloride ranged from 0.5 to 2.5 mg/L. Variations in the deep groundwater quality indicate some human influence from land use practices in the groundwater watershed.

This study was conducted as a cooperative effort between the Center for Watershed Science and Education and the Department of Biology at UW-Stevens Point, the Army Corp of Engineers Eau Galle Aquatic Ecology Lab, Wisconsin Department of Natural Resources, McGinnis Lake Association, the Town of Chester, and Adams County Land Conservation Department.

INTRODUCTION

McGinnis Lake is located at the headwaters of the Neenah Creek Watershed in Adams County, Wisconsin. Little is known about McGinnis Lake and previous studies did not examine the lake in detail. For example, the Neenah Creek Priority Watershed Basin report (1994) classified McGinnis Lake as having "excessive plant growth and algae blooms limiting fishing and recreation potential…Winterkills have taken place on McGinnis Lake and an aeration system has been installed to help alleviate the low-oxygen winter situations." To help lake residents and lake managers better understand McGinnis Lake, this study on the surface water and groundwater, chemistry, aquatic plants and algae of McGinnis Lake was initiated.

This study was conducted as a cooperative effort between the Center for Watershed Science and Education and the Department of Biology at UW-Stevens Point, the Army Corp of Engineers Eau Galle Aquatic Ecology Lab, Wisconsin Department of Natural Resources, McGinnis Lake Association, Town of New Chester and Adams County Land Conservation Department.

STUDY AREA

McGinnis Lake is a groundwater drainage lake in New Chester Township in southeastern Adams County. The current McGinnis Lake was developed in 1965 by damming the 10-acre wetland at the stream outlet. The lake is now 33 acres in size with the two lobes connected by a channel. The Wisconsin Department of Natural Resources' bathymetric map shows the north lobe with a maximum depth of 29 feet and the south lobe with a maximum depth of 10 feet. McGinnis Lake is a headwater Lake in the Fox/Wolf Watershed as shown in Figure 1. Neenah Creek leaves the south lobe of the lake through an outlet that is nine feet below the water surface

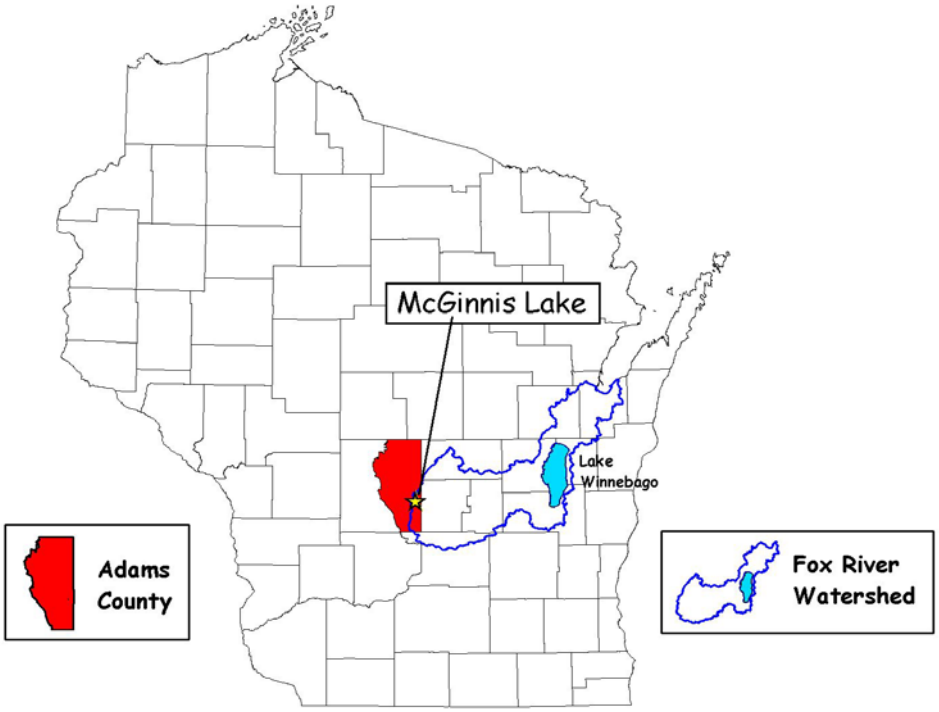

Figure 1. Location of McGinnis Lake, Adams County, Wisconsin

The topographic (surface) watershed is the area of land that precipitation could flow over land to McGinnis Lake. The 200 acre surface watershed of McGinnis Lake is shown in Figure 2. The management of the land within the surface watershed can affect the lake water quality because surface water can carry soil particles and nutrients from the land to the lake. The predominant land uses within the surface watershed are forest (49.9%), grassland (24.9%), open water (16.5%), agriculture (6.0%), and shrubland (2.7%).

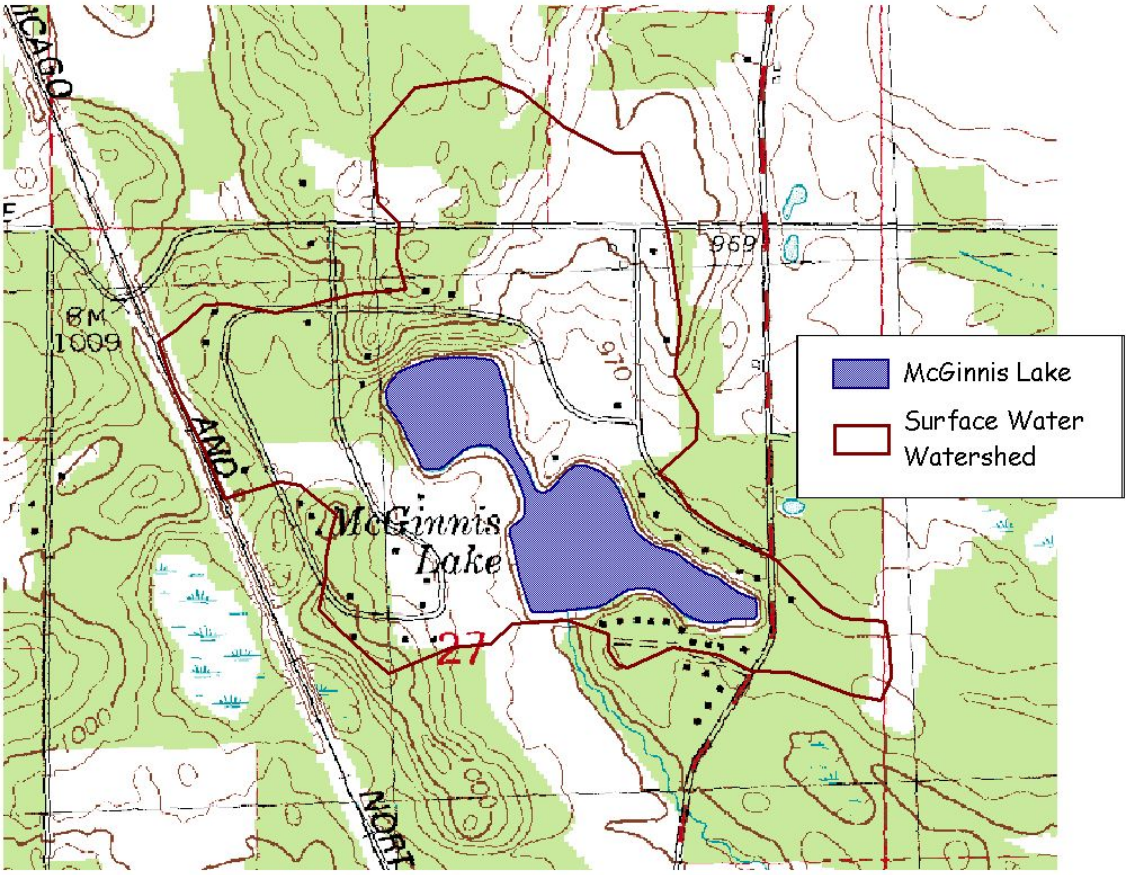

Figure 2. Surface Watershed for McGinnis Lake in Adams County, Wisconsin

McGinnis Lake has a groundwater watershed as well as a surface watershed. The groundwater watershed is based on the slope of the water-table. Figure 1 shows the approximate groundwater contributing area to McGinnis Lake. Unlike most of Adams County, the water in this area flows to the southeast and into the Fox-Wolf River Basin. The groundwater watershed is approximately 1,070 acres and originates just south of Grand Marsh (see Figure 3). Much of the groundwater originating in this groundwater watershed discharges into McGinnis Lake. This groundwater can be observed in the springs discharging to the lake along the northwestern shoreline. The predominant land uses in the groundwater watershed are forest (57.0%), agriculture (20.2%), grassland (19.36%), water (2.9%), and shrubland (0.5%).

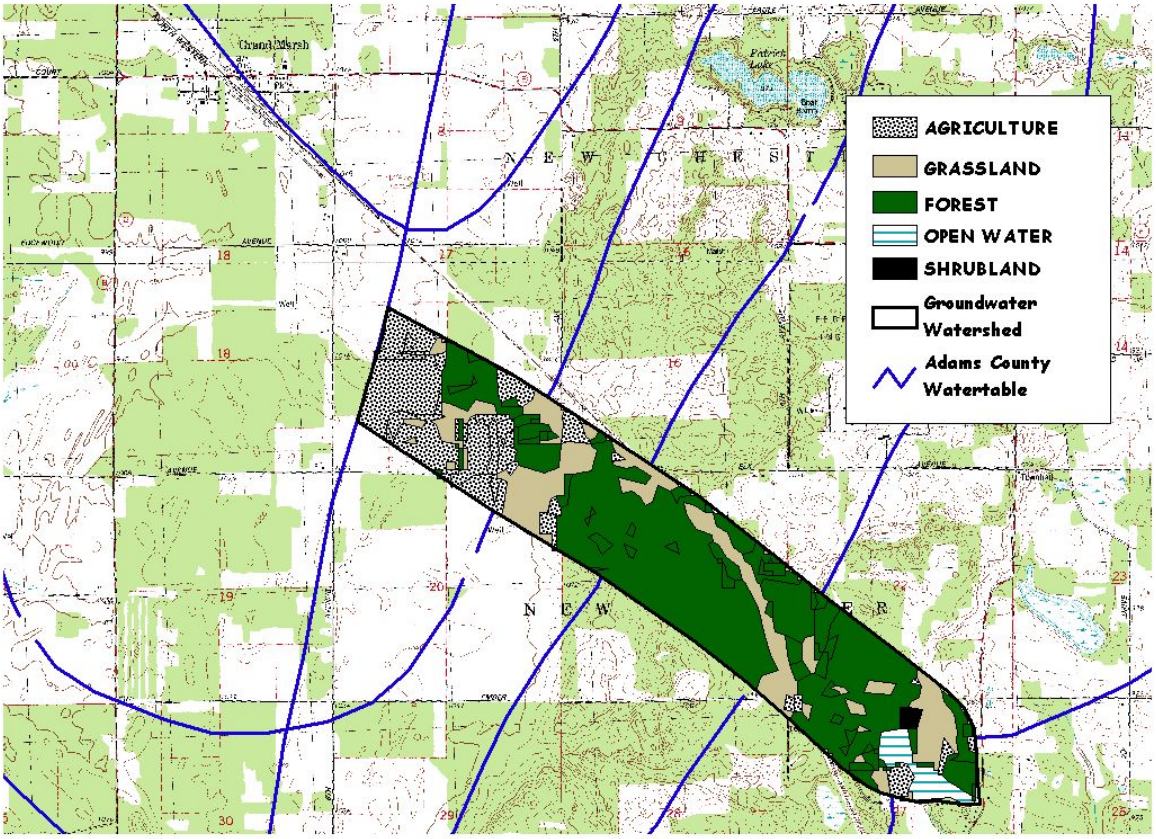

Figure 3. Approximate Groundwater Watershed for McGinnis Lake in Adams County, Wisconsin

GEOLOGY AND SOIL

Many glaciers have moved across Wisconsin and influenced the topography and geology of Adams County. Precambrian granite in the McGinnis Lake watershed is more than two billion years old. It was covered by thick Cambrian sandstone, formed by the accumulation of sediment particles when Wisconsin was under water 500 million years ago. Periods of uplift and erosion, combined with glaciation have removed the rocks deposited above these layers. Glaciers of the Wisconsin Glaciation (ending 10,000 years ago) eroded rocks and deposited the unconsolidated materials above the bedrock. McGinnis Lake sits within the glacial end moraines, the farthest reach of the glaciers, in the uneven terrain composed of sandy calcareous till and pitted outwash (Weidman et al., 1915).

Lakes in the relatively coarse glacial deposits of central Wisconsin are usually in close connection with the groundwater. McGinnis Lake is strongly influenced by groundwater. This groundwater originates from precipitation that moves through the calcareous till, outwash and sandstone. As groundwater moves through these materials, some of the minerals in the rock dissolve, move with the water, and are eventually conveyed to the lake. Calcium and magnesium that is dissolved in the groundwater aquifer lead to McGinnis Lake being a hard-water lake. The calcium can precipitate in the lake as calcium carbonate or "marl". This marl accumulates over time. Some of the marl was removed many years ago (Klick et. al 1966). The 1924 Soil Survey of Adams County indicates that marl deposits were dredged in McGinnis Lake as well as several other lakes for agricultural lime.

General Soil

The Soil Conservation Service of Adams County describes the soil in the McGinnis Lake region as Coloma-Wyocena-Okee soil. Coloma-Wyocena-Okee soil is gently sloping to steep, well-drained and somewhat excessively drained soils that have a sandy and loamy subsoil underlain by sandy outwash deposits or sandy glacial till.

Soil types immediately surrounding McGinnis Lake include Okee loamy sand, Delton sand, Plainfield sand, Richford loamy sand, and Wyeville loamy sand. The slope surrounding the lake ranges from 0 to 35 percent slope. These soils have moderate to severe limitations for agriculture, recreation, and some urban uses because of their sloping relief and sandy nature. Soil along Neenah Creek is deep, well-drained to poorly drained sands over silty clay and silty clay loam subsoils over lake-laid sand, silt, and clay. The three dominate soil types are described below.

Okee Loamy Sand (12% to 25% slope) Okee loamy sand is a steep, well-drained soil on convex ridge tops and side slopes of moraines. Water and air move through the sandy mantle of the soil at a moderately rapid rate and throughout the upper part of the subsoil at a moderate rate, making the groundwater below somewhat susceptible to

contamination. Natural fertility is low and the organic matter content is moderately low. There is severe erosion potential for cultivation of this soil type.

Delton Sand (2% to 6% slope) Delton sand is gently sloping and well-drained on convex side slopes on outwash plains and glacial lake palins. Water and air move through the soil at a moderately rapid rate in the upper part and at a slow or very slow rate in the lower part because of silty clays in the lower profile, about 30 inches from the surface. Natural fertility and organic matter content of the surface layer are low. This soil is suitable for cultivation, pasture land, trees, and building development.

Plainfield Sand (6% to 12% slope) Plainfield sands are sloping, excessively drained soil on ridges of ground moraines. Water and air move through the soil at a rapid rate, making the groundwater below susceptible to contamination. Subsoils are very strongly acid to medium acid. The available water capacity and natural fertility are low as is the organic matter content. The soil is unsuited to cultivated crops and too steep for irrigation. The erosion hazard is moderate.

METHODS

MID-LAKE WATER QUALITY CHEMISTRY

Mid-lake samples were collected in the deeper portions of each lobe of the lake that are shown as the Surface Water Sites in Figure 4. The locations 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 in 2002 at the deep holes twice per month from May through September. The south lobe of McGinnis Lake, the shallow lobe, was sampled using a 7-foot long PVC column integrator. The sampler collects a vertical sample of the lake water, giving a composite or integrated sample. Four sample depths were used in the north lobe: the surface or epilimnion, a composite in the metalimnion using the column integrator, the top of the hypolimnion, and the bottom of the hypolimnion. Samples were also taken at mid-depth in each lobe during the spring and fall turnover (April and November). Discrete location samples were collected using an alpha bottle.

Each time a sample was collected, a temperature and dissolved oxygen profile was first measured in the vertical plane at the deep hole. This information was used to identify the three strata and the depth at which the samples would be collected. Temperature and dissolved oxygen were measured using either an YSI Model 50B dissolved oxygen meter (4500-06, APHA 1995) or a Hydrolab Quanta. Readings were taken every two feet from the surface of the water to the lake bottom.

Samples for analysis were transferred to three different 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 pre-filter (934-AH) and a 0.45-micron cellulose micropore filter. All samples were transported on ice to UWSP's state-certified Water and Environmental Analysis Lab (WEAL).

Chlorophyll *a* samples were collected in 1-L polypropylene bottles from water at roughly one foot below the surface as grab samples. The samples were transported to the WEAL on ice where they were then filtered through a 1-micrometer glass fiber filter. The filters were frozen until analysis. Five chlorophyll *a* samples were collected May through August, with two sampling events in June.

Secchi disc readings were taken in each lobe to measure water transparency using a standard 8-inch diameter weighted 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 or the Hydrolab Quanta.

Grab samples for water quality analysis were collected at the stream outflow where Neenah Creek flows under Highway G. All samples were transported on ice to the University of Wisconsin-Stevens Point. Analyses followed standard procedures and quality assurance measures. Analyses performed on the mid-lake and outflow 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), total suspended solids, alkalinity, total hardness, and chlorophyll *a*. Four turnover samples were analyzed for the same parameters plus calcium hardness, chloride, sulfate, sodium, and potassium. The methods and detection limits to complete these analyses are outlined in Table 1.

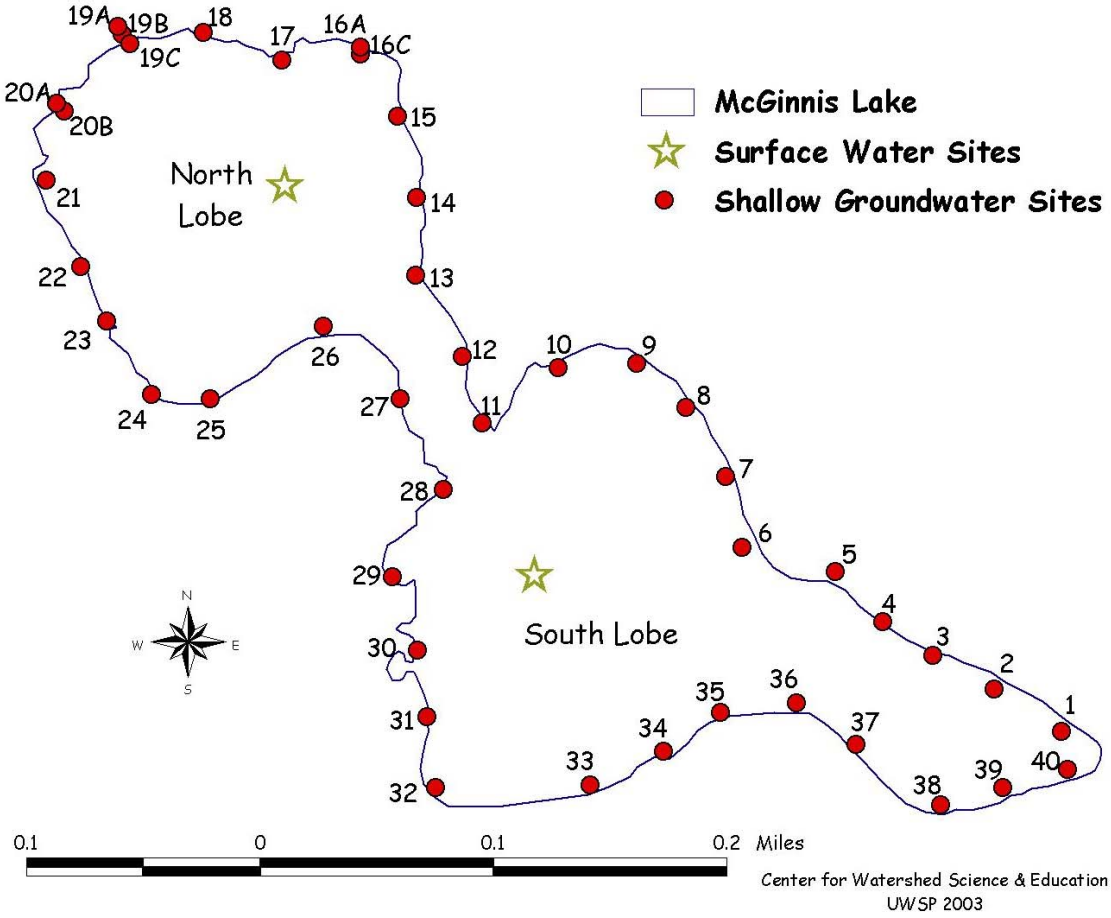

Figure 4. Location of Surface Water Sampling Sites and Mini-Piezometer Sites Around McGinnis Lake, Wisconsin

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
Conductivity (in lab)	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
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
Total Suspended Solids	Glass Fiber 103-105C 2540D	1 mg/L

Table 1. Analytical Methods Used at WEAL for the McGinnis Lake Water Quality Samples and Corresponding Detection Limits

GROUNDWATER

The principal source of water entering McGinnis Lake is groundwater. Groundwater originates throughout the McGinnis Lake groundwater watershed as the difference between precipitation and evapotranspiration. Weeks and Stangland (1971) estimated that between 7 and 18 inches of water per year entered the groundwater for different locations in the central Wisconsin sand plain. The groundwater flow to the lake is evident in the amount of water that is leaving the McGinnis Lake outlet. The link between the groundwater and McGinnis Lake is also evident in the lake water quality. Hardness from calcium and magnesium, nutrients such as phosphorus and nitrogen from fertilizers, animal wastes, and septic systems, and pesticides from residential and agricultural use can all move to the lake through groundwater.

In August, shallow groundwater samples, hydraulic head measurements, and Hvorslev falling head test measurements (Hvorslev, 1951) were taken using mini-piezometers (small wells) installed approximately every 200 feet around the perimeter of McGinnis Lake. Forty sites were monitored. Each site was marked with a Global Positioning System, thoroughly described, and marked on a map (Figure 4). Samples for chemical analysis were evaluated at 28 sites: two outflow sites, one static site, and 25 inflow sites. Temperature and conductivity of the groundwater were measured in the field using either the Hydrolab Quanta or a digital electrical thermometer and Mettler 126 conductivity meter. Groundwater samples were transported on ice and analyzed for NO_2+NO_3-N, NH_4-N, Cl, reactive P, alkalinity, and total hardness at the WEAL.

The mini-piezometers were constructed from 5-foot polypropylene tubing with ¼-inch internal diameter. 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 1-mL pipet tip was attached to the end of the screen for easier installation into the sediment. In the field, a stainless steel 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 substrate.

The mini-piezometers were inserted two feet into the lake sediment in a depth of approximately 18 inches of water. At this depth, the mini-piezometer is located below the interstitial water/root zone and is collecting shallow groundwater. The metal insertion rod was then removed, and a 60-ml syringe was used to draw the groundwater through the mini-piezometer. To purge the well, the water from three full syringes was removed from the mini-piezometer and discarded. If no water could be drawn, then the well had to be developed. Injecting two to three full syringes of lake water into the well was usually enough to develop a well. The amount of water injected into the mini-piezometer was then drawn out and discarded plus three more full syringes of water to purge the well. Once there was clear water in the mini-piezometer (indicating connection with the groundwater), the static head was allowed to reach equilibrium. Measurements recorded included the 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 and collection of the samples, each mini-piezometer was removed.

The static head was used to determine whether or not the groundwater was entering or leaving the lake at that location. If the static head was above the surface of the lake water, groundwater was entering the lake (inflow). If the static head was below the surface of the lake, ouflow was occurring and lake water was recharging the groundwater. If neither inflow nor outflow occurred, the site was considered static or no flow.

Transects were established at three of the sites where groundwater was strongly inflowing. The purpose was to determine how deep into the lake the groundwater was entering. Mini piezometers were inserted at depths of 18 inches of water, two feet of water, and four feet of water. The insertion methods, measurements, and sampling procedures were the same as above.

Falling Head Test

The volume of groundwater entering and leaving the lake was quantified using the Hvorslev falling head test. To time the fall of the water for the falling head test, a black 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 a stopwatch was used to time how long it took to fall to the black o-ring. The theory behind the falling head test is that the amount of time that it takes for water to drop in the mini-piezometer depends on the hydraulic conductivity of the sediments at that site. The hydraulic conductivity and the hydraulic gradient can be used to estimate the groundwater velocity. Hydraulic conductivity reflects the ease with which water moves through an aquifer, and it depends on the soil particle size distribution and porosity. Three trials of the falling head were timed and averaged. The hydraulic conductivity was then multiplied by the hydraulic gradient (static head measurement minus the surface water level divided by the installation depth), to estimate the velocity or seepage rate of the groundwater.

The amount of groundwater flowing into McGinnis Lake was estimated using the velocity of the groundwater movement multiplied by a representative area. The representative area was assumed to be half the distance between two sampling sites and from the lakeshore to a depth of three feet of water. This area was identified in ArcView GIS. The product was then summed to determine the annual rate of groundwater inflow. Groundwater flow can vary through the year and may be more variable across the inflow areas that were used. This calculation is a best estimate and could be improved with additional sampling. The number is used as an approximate estimate for annual inflow and for a comparison of sites around the lake.

INTERSTITIAL WATER

Lakes are home to a very active ecosystem. Not only are the birds, mammals, amphibians, fish, insects, aquatic plants, and algae important to the ecosystem, but also the bacteria and microbes which live in the water column and in the sediments just below the lake water. This zone of water that exists where the lake water contacts the sediment

at the interface with the sediments and into the sediments is called the interstitial water. Besides hosting the active microorganisms, the interstitial water is also a zone of nutrient retention and release. As organic matter from decaying plants settles to the bottom of the lake, the microbes in the interstitial water help to break down the tissue, and nutrients are released.

Most aquatic plants obtain their nutrients from the lake sediments and interstitial water with which their roots are in contact. The location and amount of aquatic plant growth depends on the conditions within a lake. The factors affecting aquatic plant establishment include nutrient availability in the water and sediment, 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 human impacts at the sites. Aquatic plant growth is important in the cycling of nutrients in a lake and can act as a source or sink of nutrients.

Interstitial water samples were collected at eight sites around McGinnis Lake (Figure 5). The water chemistry in the top six inches of the sediment can be quite different from both the groundwater and lake water chemistry. Water diffuses between the soil and the surface water continuously, influenced by plant roots and microbes. Interstitial water data is useful in evaluating relationships that may exist between nutrient availability and aquatic plant species or biomass.

We sampled the interstitial water at groundwater inflow sites at a depth of three feet of lake water. We used 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. The bottom of a 6-inch can with a 1 inch lip was attached to the diffuser tubing to prevent surface water infiltration from the top into the sample (Figure 6). The device was inserted into the sediment adjacent to the mini-piezometer site using a rigid steel rod attached to the rod inside the diffuser tubing. Sample was drawn up through the piece of Tygon tubing with a 60-mL syringe. The sample was drawn up slowly with the syringe

so as not to create a cone of depression, which would result in the collection of lake water. The sample was then transferred into two bottles. The first sub-sample was unpreserved and unfiltered. The second sub-sample was filtered with an in-line filtering cassette containing a 934 AH 47mm glass fiber pre-filter and a 0.45micron filter into an H_2SO_4-preserved polypropylene bottle. The interstitial water was analyzed for NO2+NO3-N, ammonium, reactive phosphorus, alkalinity, total hardness, and chloride.

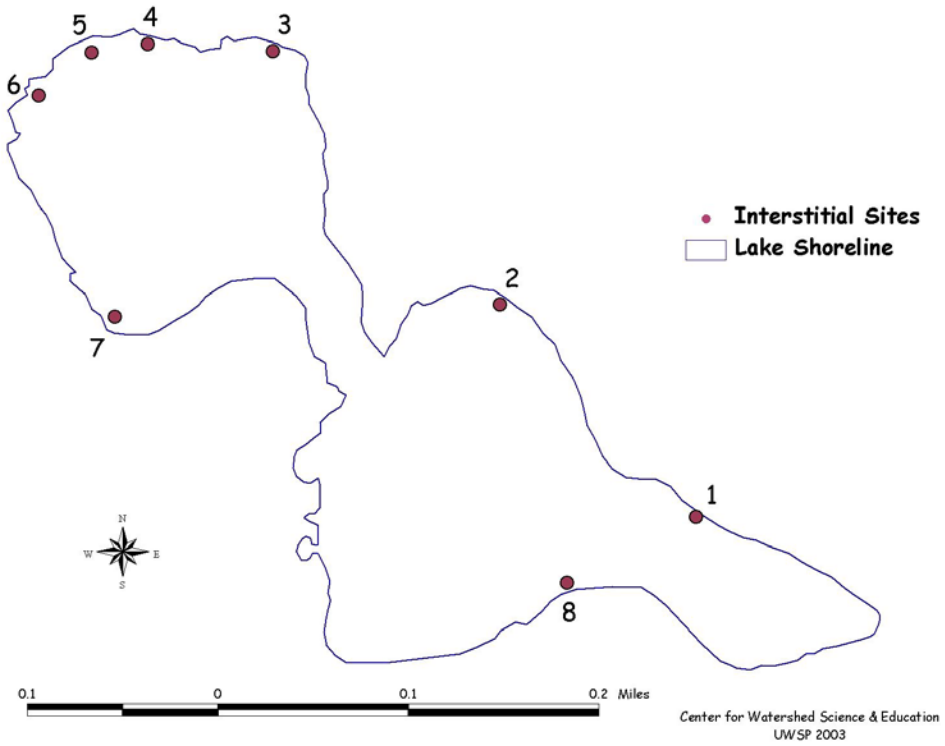

Figure 5. Location of Interstitial Sites Sampled Around McGinnis Lake, Wisconsin

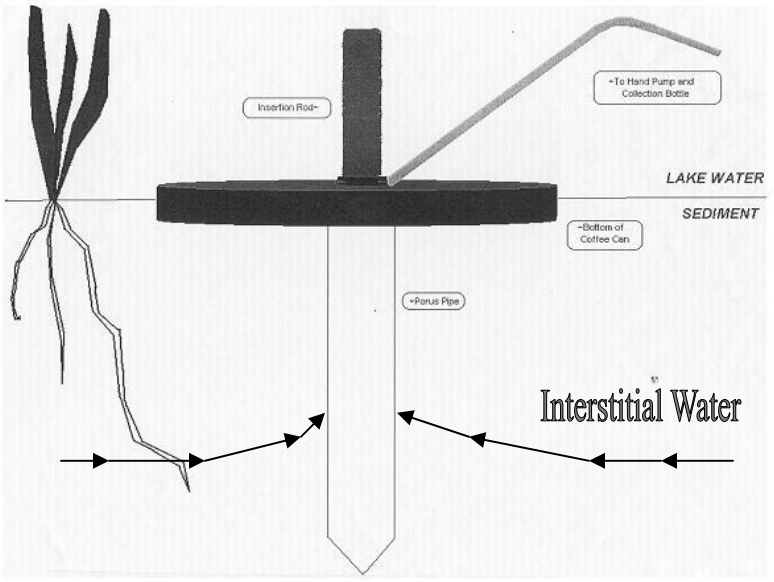

Figure 6. Diagram of Interstitial Water Sampling Device

DEEP GROUNDWATER

Deep groundwater was sampled on November 16, 2002, at two locations on the western bank of the north lobe. These two locations were selected because they have springs and a lot of groundwater entering the lake, where deep groundwater would likely be entering the lake. A total of eight samples were collected.

A piezometer well constructed of 1-inch PVC with a 1-foot screen was inserted into the shoreline at each site to a depth of 7 feet. The piezometer was inserted manually the first two to three feet. A fence post driver was used to assist installation. After the wells were installed, they were purged for several minutes using a peristaltic pump. A sample was then drawn into the cup of the Hydrolab Quanta so temperature and conductivity of the sample could be measured. An in-line filtering cassette containing a 934 AH 47 mm glass fiber pre-filter and a 0.45-micron filter was attached to the tubing of the pump, and a filtered sample of groundwater was collected in a H_2SO_4-preserved polypropylene bottle. The filter was removed, and an unfiltered, unpreserved sample was collected. The well was raised one foot, again purged for several minutes, and a sample collected. Samples were collected at 4-foot, 5-foot, 6-foot, and 7-foot depths at each location. The

samples were transported on ice to the WEAL and tested for soluble reactive phosphorus, nitrite+nitrate-N, ammonium, alkalinity, and total hardness.

AQUATIC MACROPHYTES

The curly-leaf pondweed (*Potamogeton crispus*) survey was conducted from June 11 to June 13, 2002. Nine randomly selected transects were identified in McGinnis Lake (three in the north lobe, six in the south lobe) by William James, Army Corp of Engineers (ACOE). Each transect was demarcated with a rope perpendicular from the shoreline. The horizontal transect extended from the shoreline to a depth of six feet of water. This distance was multiplied by three random numbers to determine the sampling locations for the macrophyte survey. The first sample site was located between 0- and 3-foot water depth. The length of the 3-foot transect was multiplied by a random number, and a sampling site was set up at this calculated location. The total distance of the 6-foot transect less the 3-foot distance was multiplied by two random numbers to determine the locations of the two sampling sites in the deeper water.

After the sites were established, marked with a buoy, and located with a GPS unit, an ACOE quadrat sampler was lowered over the site. The quadrat sampler was a rectangular "cage" with dimensions of 0.5 m x 0.5 m x 2 m. It was made of aluminum to be lightweight yet sturdy enough to rake plants from the site.

The plant samples were raked and cut from within the quadrat sampler, and the roots were removed. Each site along a transect was sampled in triplicate and treated as a separate sample. Only the curly-leaf pondweed was collected from the half-meter squared sample area. The samples were placed in a mesh bag along with a sample number and location and stored on ice in a cooler. At mid-day, the samples were taken to shore, separated to only include curly-leaf pondweed, rinsed with lake water, spun 40 times in the mesh bag to remove excess water, and weighed. Seventy-two samples were collected and brought back to the WEAL.

At the WEAL, fifteen percent of the samples (randomly selected) were acid washed to remove the marl that had deposited on the aquatic plants. The bag and wet plants were first weighed to the nearest hundredth of a gram. The plants were then rinsed in a dilute solution of 1M hydrochloric acid until the reaction ceased. The plants were rinsed three additional times in deionized water to remove any acid residue. The plants were then returned to the bag, dewatered by spinning the bag 40 revolutions, and reweighed. The plant samples were then placed in a paper bag and air-dried at 55^{o}C to a constant weight. The plants were chopped in a Wyle mill, and stored in a whirl pack bag for further chemical analysis. Plant tissue was analyzed for total Kjeldahl nitrogen and total phosphorus.

PHYTOPLANKTON

Algae samples were collected in the deep hole of each lobe during each sampling episode. In the south lobe, a column integrator was used to collect a composite sample of algae. In the north lobe, a grab sample from the epilimnion was collected approximately 1 foot below the surface of the water. A composite sample was also collected in the north lobe from the metalimnion with the column integrator. The samples were transferred to 250-mL high-density polypropylene brown bottles and transported to UWSP on ice. The samples were delivered to Dr. Robert Bell, Department of Biology, for algal analyses.

Algal samples were fractionated into fresh and iodine-preserved aliquots. Initial evaluations revealed general homogeneity between lobes and consequently all composite samples were pooled for analysis. Fresh samples were surveyed immediately to provide the most accurate genus list. Preserved samples were stored cold until counted.
For analysis, 1-mL aliquots of preserved material were placed into a Sedgewick-Rafter counting cell and allowed to settle for one hour. Random fields were counted at 400X under an Olympus ZH20 Inverted Microscope with long working distance lenses. Colonial and filamentous organisms were counted as a single unit if intact. Counts were conducted until the sample total reached 300 per date. Generic identification was from standard freshwater reference texts including (but not limited to) “Freshwater Algae of

the United States (G.M. Smith) or Freshwater Algae of the Western Great Lakes Area (G. Prescott).

METADAT

The surface watershed was delineated using USGS 1:24,000-scale topographic maps and classified according to land use. Land use cover data was obtained from WISCLAND using data derived from Landsat Thematic Mapper satellite imagery acquired from flights in 1991-1993. The groundwater watershed was delineated using a groundwater contour map developed by the Wisconsin Geological and Natural History Survey in 1981.

RESULTS AND DISCUSSION

SURFACE WATER

Mid-lake water quality data were collected April through September of 2002. The following is a summary and discussion of the results and water quality characteristics. It is important to note that lake water quality can vary significantly with precipitation, temperature, date of ice off, and other climatic factors. Sampling should be accomplished routinely over a number of years to obtain the most accurate representation of a lake's water quality.

WATER CHEMISTRY AND FIELD MEASUREMENTS

Dissolved Oxygen and Temperature

A lake's water quality and ability to support fish are affected by the internal mixing cycle caused by seasonal changes in wind, water temperature, and 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 deeper lakes cycle though periods of mixing (spring and fall) and stratification (summer and winter).

Each lobe of McGinnis Lake has a distinct dissolved oxygen and temperature profile which appear related to the differences in water depth and surrounding topography. The southern lobe, with a maximum depth of 10 feet, showed only modest stratification at certain times and otherwise was well-mixed (Figure 7). The water circulates throughout the water column, constantly mixing because of the shallow depth, flow-through current, and wind action. A difference of 6.7 degrees between the top and bottom of the south lobe was present on June 27, 2002, as the top water warmed faster than the circulation of the column. The water warmed from 9.7 C at spring overturn (April) to 27.4 C in the beginning of July. Following July, the water continually cooled.

The dissolved oxygen levels in the south lobe were likely affected by the presence of the aquatic macrophytes (plants) and mixing. The dissolved oxygen was nearly uniform at

spring turnover (Figure 8). In the month of May, dissolved oxygen concentrations increased with depth as the plants released oxygen during photosynthesis. The dissolved oxygen levels decreased with depth in the south lobe in June and July likely because dissolved oxygen was being consumed by microbial decomposition of the plants. Although the dissolved oxygen profile does show a difference in concentration throughout the water column, the dissolved oxygen in the south lobe only fell below 2 mg/L (anoxic conditions) during one sampling event (June 27, 2002).

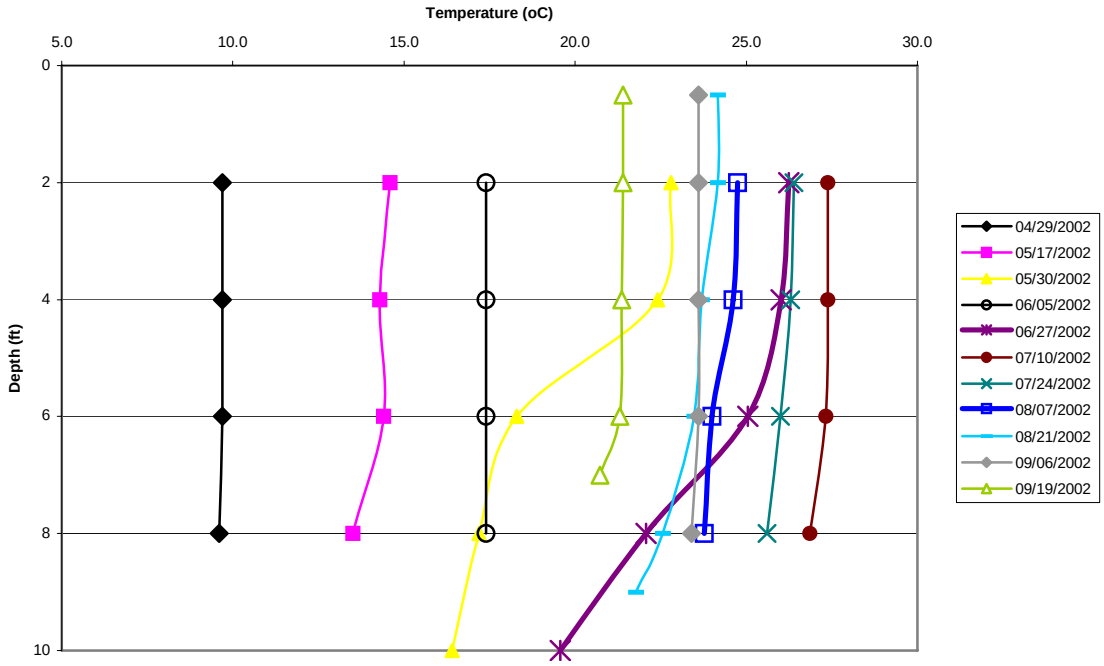

Figure 7. Temperature Profile in the South Lobe of McGinnis Lake, Wisconsin (2002)

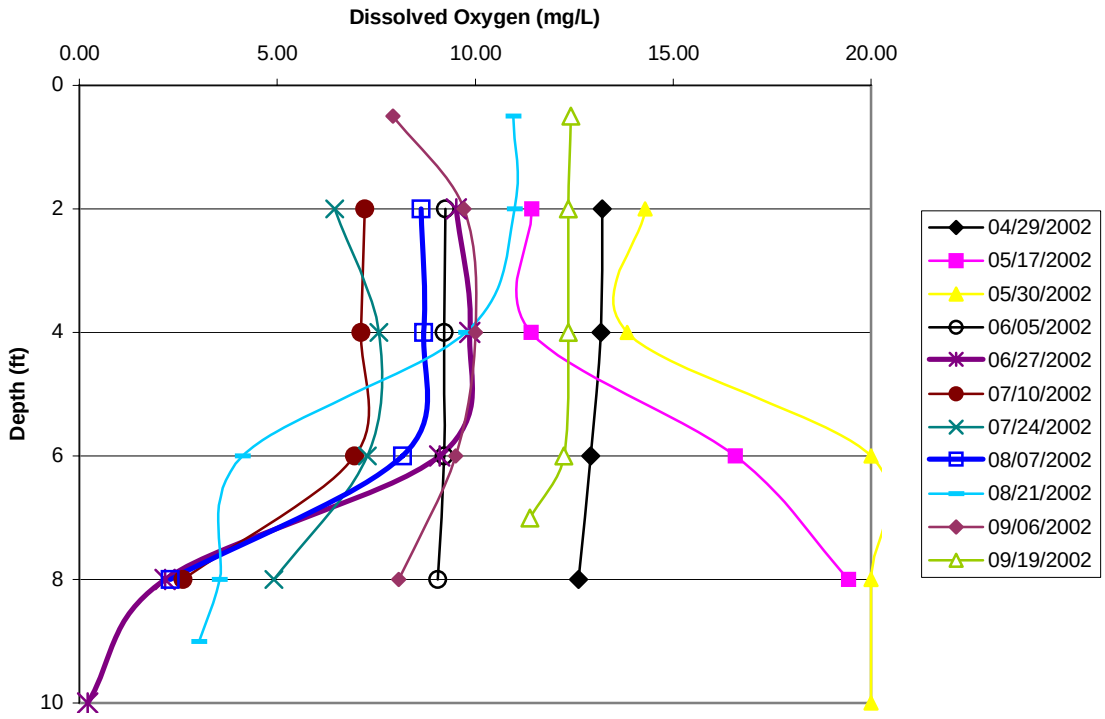

Figure 8. Dissolved Oxygen Profile in the South Lobe of McGinnis Lake, Wisconsin (2002)

Figure 9 shows the temperature profile of the north lobe throughout the summer season. The north lobe of the lake, with a maximum depth of 29 feet, does develop a distinct thermal stratification or layering. The lake stratification was used to identify an epilimnion, metalimnion, and hypolimnion during the winter and summer months. The epilimnion, or warm surface layer, is exposed to wind, sun, and constant mixing with the atmosphere. Deeper in the lake, decreased atmospheric effects and inputs of cooler groundwater both result in a lower water temperature. The transition zone between the warm and cold water is called the metalimnion. At the bottom of the lake where the sunlight does not reach, the temperature was quite constant between 6.8 and 9.3 C. This cold layer at the lake bottom is called the hypolimnion.

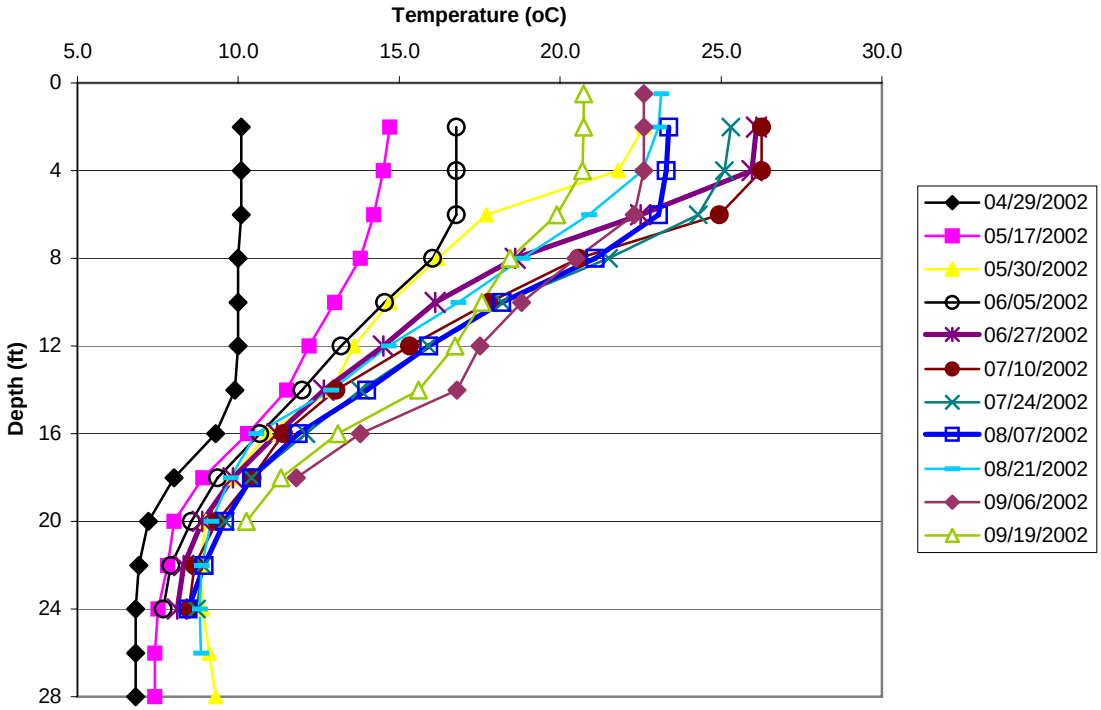

Figure 9. Temperature Profile of the North Lobe of McGinnis Lake, Wisconsin (2002)

After the lake stratifies, dissolved oxygen levels can become depleted from the lack of oxygen replenishment and the microbial decay of organic matter. When oxygen levels become very low, nutrients can be released from the sediments and move into the water column. These nutrients can become trapped in the hypolimnion because of the low water mixing, but they can be redistributed throughout the water column during spring and fall overturn.

Algae plays a significant role in the oxygen levels in the north lobe. The increase in dissolved oxygen in the metalimnion suggests algal blooms that release oxygen. The dissolved oxygen profile in Figure 10 shows the hypolimnion of the north lobe becomes and remains anoxic for most of the summer.

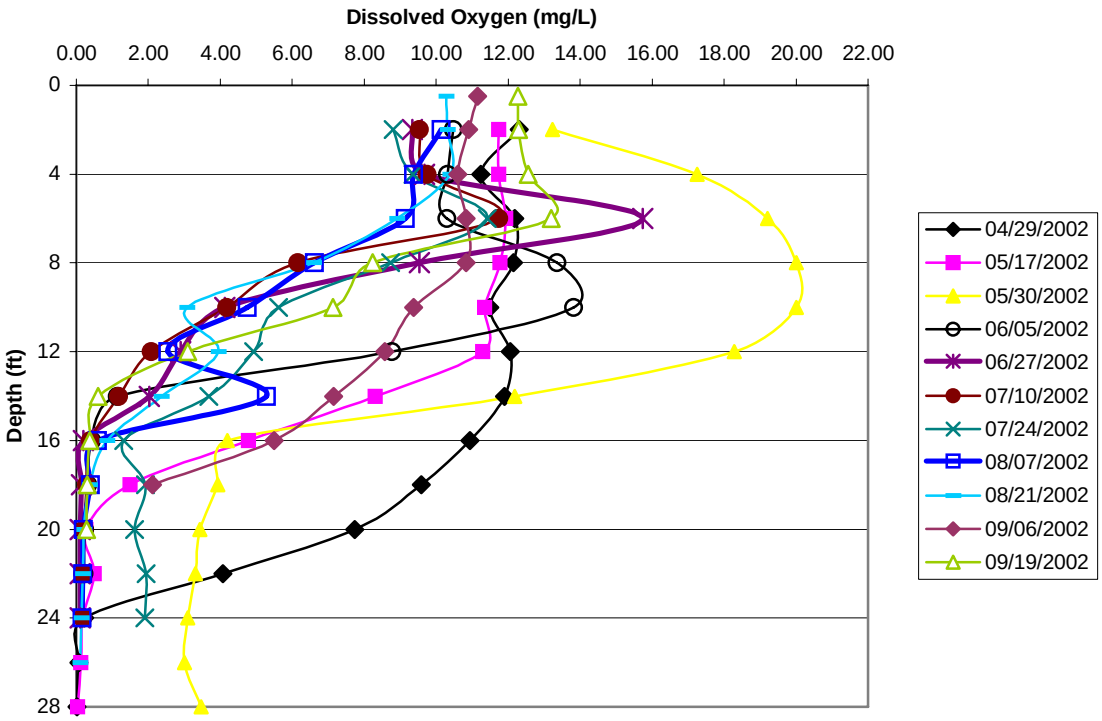

Figure 10. Dissolved Oxygen Profile of North Lobe of McGinnis Lake, Wisconsin (2002)

Total Suspended Solids

Total suspended solids (TSS) are a measure of solids in the water that cannot pass a 0.45µ filter. TSS includes a wide variety of materials, such as algae, soil, plant and animal matter. In hard water lakes, the precipitation of marl may also contribute to TSS concentration. In biologically productive lakes, TSS concentrations could increase with algal density. Wind mixing in shallow lakes can also increase TSS concentrations as previously settled materials mix in the water.

High concentrations of suspended solids can cause many problems for aquatic life by blocking light. As the amount of light passing through the water is reduced, photosynthesis slows down, thereby reducing the addition of oxygen to the water. Materials suspended in the water column may affect the ability of fish to see and catch food, clog fish gills, decrease resistance to disease, prevent egg and larval development, and decrease habitat. When suspended solids settle to the bottom of a water body, they

can smother the eggs of fish and aquatic insects, as well as suffocate newly hatched insect larvae and alter desirable fish habitat. High TSS can also cause an increase in surface water temperature because the suspended particles absorb heat from sunlight.

TSS levels in the south lobe were relatively low, with a high value of 7 mg/L on September 6, 2002 (Figure 11). TSS levels in the north lobe were higher, increasing with depth. The north epilimnion had an average TSS concentration of 3 mg/L, the north metalimnion 6 mg/L, the top of the hypolimnion 9 mg/L, and the bottom of the water column was 12 mg/L. The top and bottom of the hypolimnion had the highest TSS levels of 21 and 19 mg/L, respectively, at the end of July.

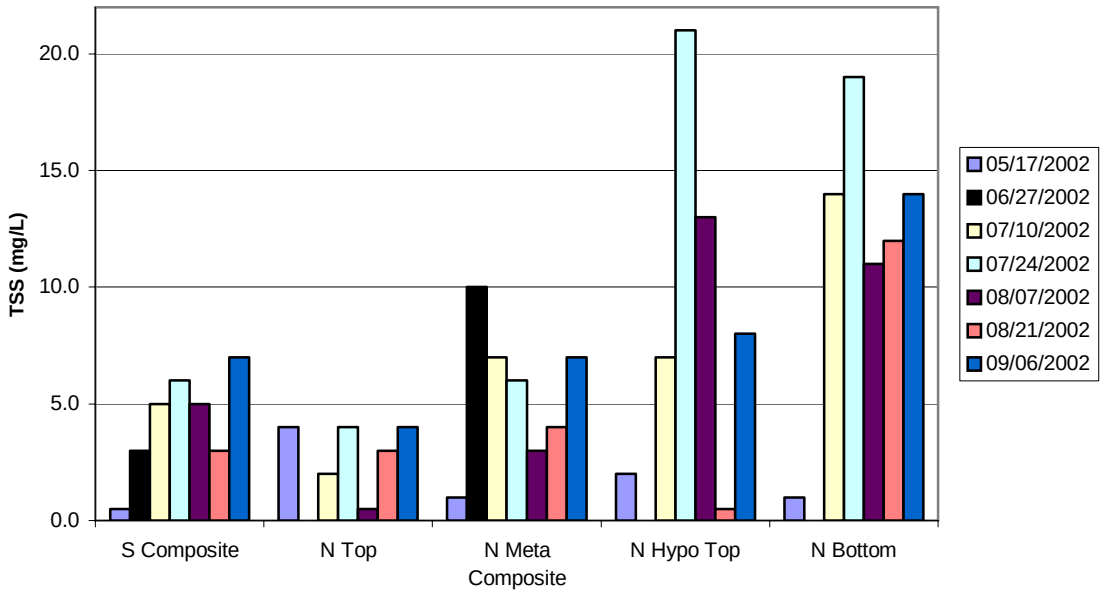

Figure 11. Total Suspended Solids Concentrations in McGinnis Lake, Wisconsin

TSS corresponds inversely with Secchi depth because higher TSS reduces water clarity. Total suspended solid values correlated with total phosphorus concentrations (correlation coefficient = .72), TKN (R=0.64), total hardness (R=.68), and alkalinity (R=.68) in McGinnis Lake, indicating that the total suspended solids are due both to algae and organic particulates in the lake and the calcium carbonate precipitates.

Secchi Depth and Chlorophyll *a*

Secchi depth is a measure of light transparency in the water column. Algae, suspended solids and some dissolved compounds can absorb or scatter light and will affect the depth at which the Secchi disc can be seen. In this way, Secchi depth is a direct measure of the amount of turbidity (materials *suspended* in the water) and color (materials *dissolved* in the water). The Secchi depth also dictates the depth at which rooted aquatic macrophytes can exist.

The Secchi depth in McGinnis Lake ranged from 2 to 4.5 feet in the north lobe and between 2.5 and 8.5 feet in the south lobe during the growing season (Figure 12). During fall overturn (November 8), the Secchi depth increased to 6.5 feet in the north lobe and 8.5 feet in the south lobe. The average growing season Secchi depth for the year in the north and south lobe was 3.6 and 5.2 feet, respectively. According to Shaw et al. (2000), this is an indication of very poor to poor water clarity.

The water clarity in the south lobe had a dramatic change in the middle of the summer. The Secchi depth decreased from the previous reading by over 4 feet on July 24, 2002. The dissolved oxygen profile in the south lobe indicates the presence of algae on this same date. Chlorophyll *a* concentrations and TSS values were also elevated on July 24, 2002, in the south lobe. Marl formation on this date is unlikely because alkalinity and total hardness were similar to samples collected during the previous sampling.

An indicator of the amount of algae biomass in the water column is chlorophyll *a*. Chlorophyll *a* is necessary for photosynthesis to take place and is easily measured in the laboratory. Chlorophyll *a* levels are frequently inversely correlated with Secchi depth because the higher chlorophyll *a* suggests greater algae, which reduces clarity. Chlorophyll *a* was sampled on seven dates in McGinnis Lake at two locations. The chlorophyll *a* in the north lobe averaged 4.6 μg/L (range less than 0.01 to 9.73 μg/L). The chlorophyll *a* in the south lobe averaged 10.9 μg/L (range less than 0.01 to 38.9 μg/L). Chlorophyll *a* was highest in the south lobe on July 10, following the

senescence (die off) of curly-leaf pondweed (Figure 13). Chlorophyll *a* in the north lobe increased steadily over the growing season.

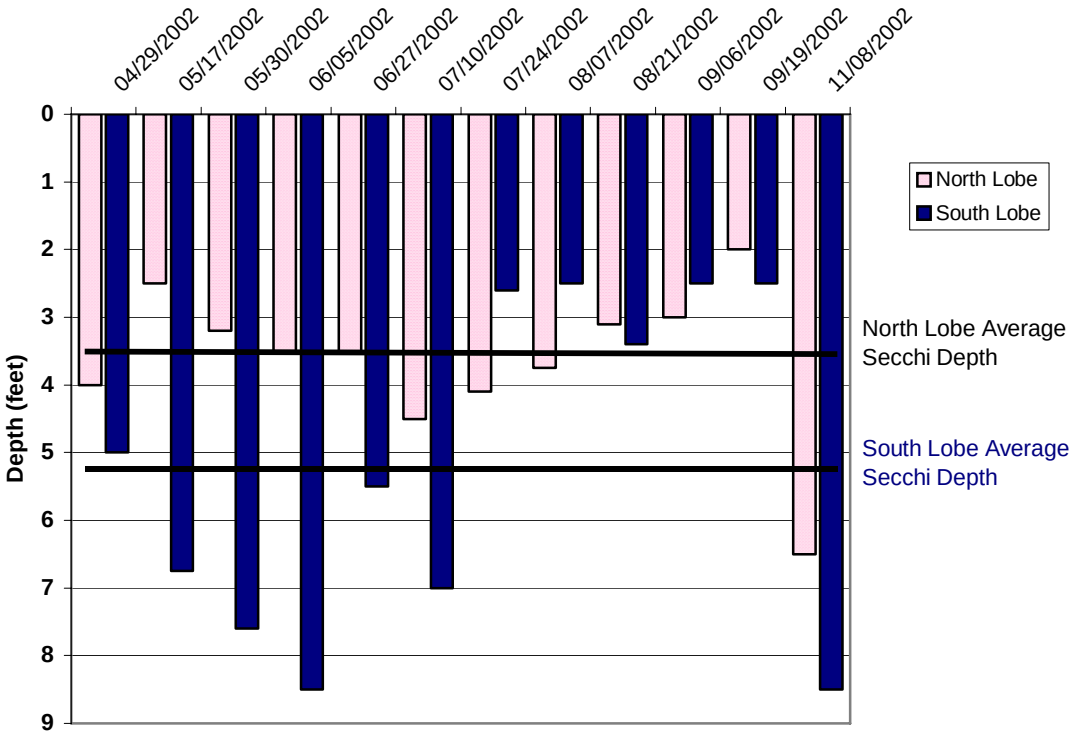

Figure 12. Secchi Depths in McGinnis Lake During the Growing Season of 2002

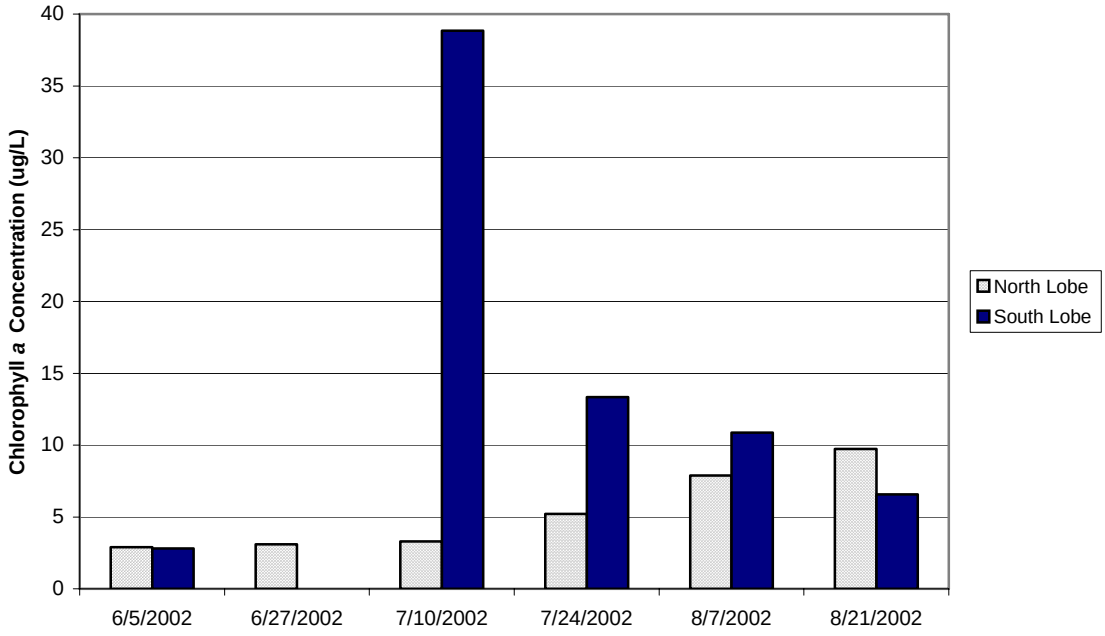

Figure 13. Chlorophyll *a* Concentrations in McGinnis Lake, Wisconsin

pH, Alkalinity, Total Hardness, and Calcium Hardness

pH is an index of the lake water acid levels. A lower pH indicates the lake water is more acidic, and conversely, a higher pH value indicates the water is more basic. At and below a pH of 3.0, water is toxic to all fish. Lethal effects begin near pH 4.5 (in acid conditions) and pH 9.5 (in basic conditions). McGinnis Lake is considered to be basic, with an average pH of 7.9 (range 6.6 to 9.3) in the north lobe and 8.8 in the south lobe (range 6.6 to 10.1). pH changes throughout the day in the water column due to plant uptake of carbon dioxide and respiration. During active photosynthesis, when plants are taking up carbon dioxide, the pH should be higher. When decomposition is the dominant process, such as at night, carbon dioxide can be released during microbial respiration and the pH can be lower.

Low pH water can lead to the release of metals such as aluminum and zinc from the lake sediment (Shaw et al., 2000). The high pH and buffering capacity of McGinnis Lake suggests that this will not occur. The basic nature (pH above 7.0) of McGinnis Lake

results from the geology of the McGinnis Lake groundwater watershed. The McGinnis Lake watershed is located within glacial deposits that contain dolomitic limestone (Klick et al., 1966). Groundwater flowing through the carbonate, calcium and magnesium-rich deposits acquires alkalinity and hardness and moves it into the lake. These materials neutralize the groundwater and move the pH towards basic conditions. The alkalinity of the water, which is largely the bicarbonate and carbonate in the water, was an average of 180 mg/L as $CaCO_3$ in the north lobe and 111 mg/L as $CaCO_3$ in the south lobe. The outflow had an average alkalinity concentration of 116 mg/L as $CaCO_3$. Table 2 summarizes the average alkalinity and total hardness concentrations in McGinnis Lake by layer.

Total hardness is a measure of the dissolved multivalent cations (positively charged ions with a charge of 2 or greater) in the water. In McGinnis Lake watershed, this is the sum of calcium and magnesium concentrations. The total hardness of McGinnis Lake at spring turnover was 168 mg/L as $CaCO_3$ in the north lobe and 120 m/l as $CaCO_3$ in the south lobe. McGinnis Lake is a hard-water lake (Table 3). Hardness concentrations were still higher in the north lobe in the May 17th sample, but in June and July hardness concentrations were similar in both lobes. Alkalinity is related to hardness in that the calcium or magnesium (i.e. hardness) and alkalinity are all largely derived from dolomitic carbonates in the glacial deposits. The calcium hardness was measured in spring and fall overturn samples. The concentrations in the north lobe were 84 and 89 mg/L as $CaCO_3$, respectively, and in the south lobe were 40 and 61 mg/L as $CaCO_3$, respectively.

Site	Alkalinity (mg/L as $CaCO_3$)	Total Hardness (mg/L of $CaCO_3$)
South Composite	111	112
Outflow	116	118
North Epilimnion	125	125
North Metalimnion	153	151
North Hypo Top	190	192
North Bottom	242	231

Table 2. Average Alkalinity and Total Hardness Concentrations in McGinnis Lake, Wisconsin From Samples Collected May 17 to September 6, 2002

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

Table 3. Interpretation of Total Hardness Concentrations from Shaw et al., 2000

NUTRIENTS

Total Nitrogen to Total Phosphorus Ratio

The amount of plants and algae that can grow in a lake depends on the amount of nutrients that are available. The major nutrients of concern for surface waters in Wisconsin are phosphorus and nitrogen. In a given body of water, a plant community's requirement for phosphorus is usually different than for nitrogen. The total nitrogen (TN) to total phosphorus (TP) ratio indicates whether nitrogen or phosphorus is the limiting nutrient for plant growth. When the TN:TP ratio is greater than approximately 15:1, plant growth is generally restricted by the amount of phosphorus available (Carlson, 1980). When the ratio is less than 10:1, this indicates nitrogen could be the limiting nutrient. The average TN:TP ratio in McGinnis Lake from May 2002 to September 2002 was 25:1, which indicates that phosphorus is the limiting nutrient. This information is

important to lake managers because it indicates that controlling phosphorus inputs from the watershed is important to controlling eutrophication.

Phosphorus

Phosphorus is the primary limiting nutrient for McGinnis Lake as it is for most Wisconsin lakes (Shaw et al., 2000). Phosphorus is present in several forms, but the two general categories of soluble reactive phosphorus and total phosphorus are the most commonly measured. Soluble reactive phosphorus (SRP) is dissolved phosphorus in the water column that is readily available to plants and algae. Because it is taken up easily, SRP is usually present in low concentrations (about 5% of organic phosphorus, Wetzel, 1983). Total phosphorus (TP) is a measure of the dissolved phosphorus *plus* organic and inorganic particulate phosphorus in the water. TP is often used as a measure of lake phosphorus because it is less variable than SRP. Although the SRP represents the most readily available phosphorus, phosphorus in organic and inorganic particulate forms can also become available for use by aquatic plants and algae.

Phosphorus participates in many biological and chemical reactions in the lake and watershed. Phosphorus reactivity can differ under aerobic (oxygenated) versus anaerobic (no oxygen) conditions, varying temperatures, and at different pH levels. Phosphorus will form insoluble precipitates with calcium, iron, and aluminum under appropriate conditions. In a lake, phosphorus that becomes incorporated into biological and inorganic solids, can settle to the lake bottom but then be released when it enters low oxygen or low pH environments within the hypolimnion or the sediment. Phosphorus also adsorbs to soil particles and travels with solids. Although this lead to phosphorus retention within the groundwater, if the soil's capacity to hold phosphorus is exceeded, phosphorus movement in groundwater can increase. In addition to the naturally occurring phosphorus in soils and plants, other sources of phosphorus from the watershed include human and animal wastes, soil erosion, and detergents.

Soluble Reactive Phosphorus

Shaw, et al. (2000) suggests that the SRP concentrations following spring overturn should be 10 μg/L or less to prevent summer algae blooms. The north lobe of McGinnis Lake

had a spring overturn SRP concentration of 6 μg/L, and the south lobe had an overturn SRP concentration of 7 μg/L. These relatively low concentrations may reflect the early season macrophyte population (primarily *P. crispus)* incorporating available SRP in its tissue and accumulation of the phosphate into precipitating calcium carbonate. Throughout the growing season, SRP concentrations in the north lobe remained low, averaging 5 μg/L (ranging between 3 and 9 μg/L) in the top layers. Deeper, bottom water in the north lobe had a much higher reactive phosphorus concentration (averaging 128 μg/L, range from 4 to 243 μg/L.). The higher SRP concentrations in the hypolimnion of the north lobe were mostly likely due to the release of phosphorus from decaying plant material and dissolving calcium carbonate. The average SRP concentration in the south composite samples was 7 μg/L (range 4 to 12 μg/L), and the outflow SRP was 12 μg/L (range 7 to 18 μg/L).

Site	Average SRP (μg/L)	Average TP (μg/L)	SRP:TP Percent
South Composite	7	29	24
Outflow	12	37	32
North Epilimnion	5	23	22
North Metalimnion	7	26	27
North Hypolimnion Top	6	73	8
North Bottom	128	220	58

Table 4. 2002 Average Growing Season Phosphorus Concentrations in McGinnis Lake, Wisconsin

Total Phosphorus

The TP concentrations in McGinnis Lake varied from lobe to lobe and from layer to layer. The surface layer in the north lobe had an average TP concentration of 23 μg/L with a range of 18 to 32 μg/L. In the south lobe composite sample, the average TP concentration was 29 μg/L with a range of 19 μg/L to 37 μg/L. The average TP concentration in the outflow of McGinnis Lake was 37 μg/L with a range of 26 to 46 μg/L. The highest concentrations of TP were found in the deeper waters of the north lobe during the middle of the season when algae growth was at a maximum, aquatic plants were decaying, and a strong, anoxic hypolimnion had formed. The TP concentrations in

the north lobe increased with increasing depth. The north metalimnion (middle layer) had an average TP concentration of 26 μg/L (range of 15 to 32 μg/L). The top of the hypolimnion had an average TP concentration of 73 μg/L (range of 15 to 228 μg/L). The bottom of the hypolimnion averaged 220 μg/L of TP (range 59 to 377 μg/L). Higher phosphorus concentrations at the lake bottom are likely the result of phosphorus release from particles settling out of the water column and the re-release of phosphorus from the sediments under anoxic conditions.

Table 5 gives an index for water quality of Wisconsin lakes and impoundments as developed by Lillie and Mason (1983). McGinnis Lake has the same water quality as the average natural lake in Wisconsin. The volume-weighted average TP concentration was 28 μg/L and falls under "good " water quality. The Environmental Protection Agency also determined regional background water quality information on lakes and impoundments. In Ecoregion VII, the regional background TP concentrations averages 14 μg/L.

Water Quality Index	Total Phosphorus (ug/L)	Wisconsin Lakes
Very Poor	150	
Poor	140	
	130	
	120	
	110	
	100	
	90	
	80	
	70	
	60	← Average for impoundments
Fair	50	
	40	
Good	30	← Average for natural lakes ← **McGinnis Lake**
	20	
Very Good	10	←Average of EPA Ecoregion VII
Excellent	1	

Table 5. Water Quality Index Based on Total Phosphorus Concentrations
(Adapted from Lillie and Mason, 1983)

The TP concentrations also vary throughout the growing season (Figures 14 and 15). The phosphorus concentrations in McGinnis Lake increased until the middle of the summer and then decreased. The date of the maximum concentration varied in each lobe. In the north lobe of McGinnis Lake (Figure 14), the epilimnion (top) climbed to 32 μg/L on August 7 and then decreased. The metalimnion sample also had a high concentration of 32 μg/L, which was measured on July 10 and August 7. The top portion of the hypolimnion peaked on July 24 with a TP concentration of 228 μg/L. The concentration of total phosphorus at the bottom of the north lobe was highest on June 27 at 311 μg/L, decreased on July 10, and again increased on July 24 to 377 μg/L. This increase in the upper and lower parts of the hypolimnion may reflect both internal loading of phosphorus and the settling of particles from the upper portions of the lake.

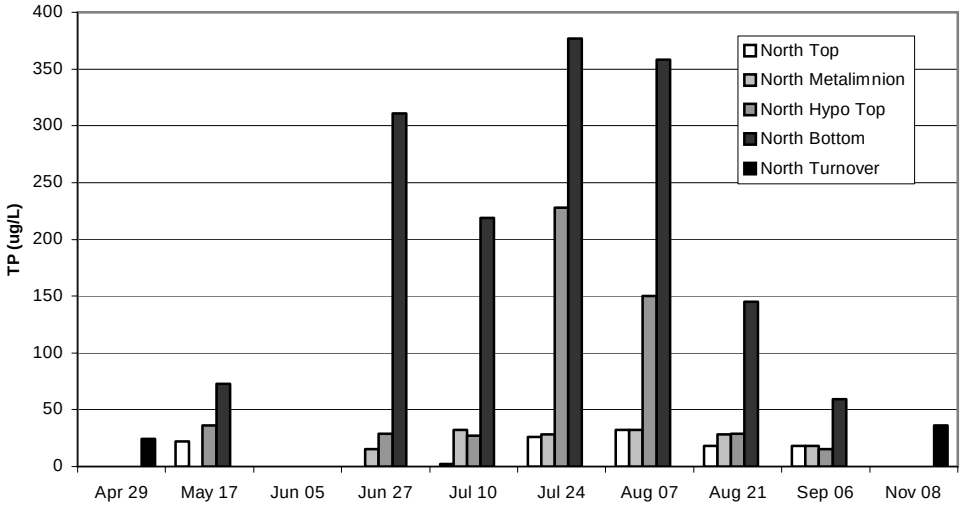

Figure 14. Total Phosphorus Concentrations in the North Lobe Over the Growing Season 2002.

In the south lobe (Figure 15), TP increased steadily from May 17 until it peaked at 29 μg/L on July 10 following the senescence of curly-leaf pondweed. The outflow had an average TP concentration of 37 μg/L and reached its maximum for the season on June 27.

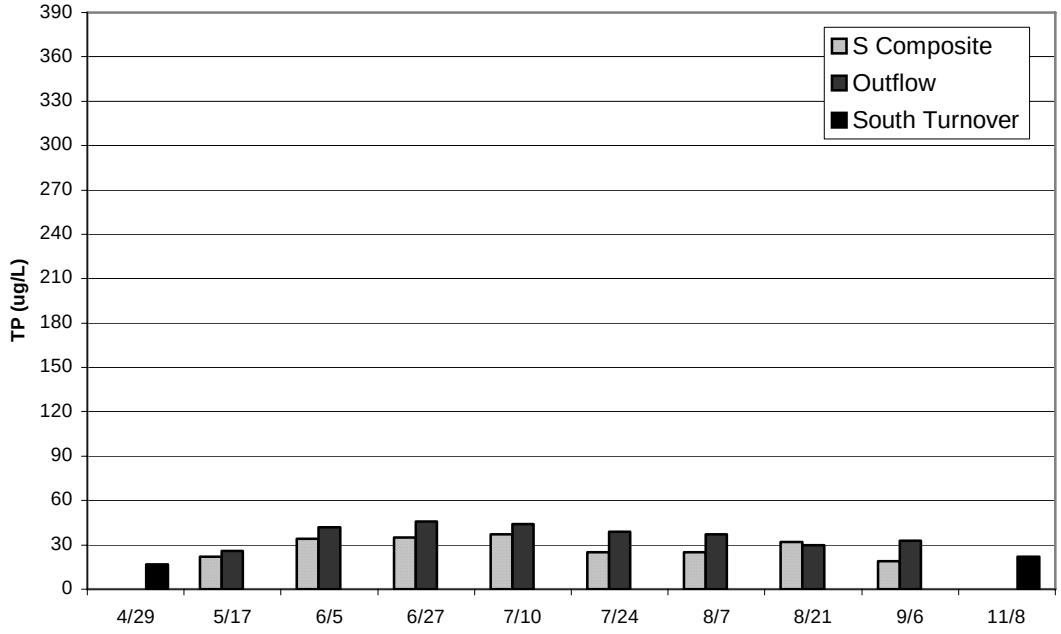

Figure 15. Total Phosphorus Concentrations in the South Lobe During the Growing Season 2002, McGinnis Lake, Wisconsin

Marl

The TP in McGinnis Lake can be influenced by the precipitation of calcium carbonate because the calcium carbonate can react with phosphorus and provide a buffer system against excess phosphorus and algae nuisance blooms (Otsuki and Wetzel, 1972, Brunskill, 1969, Murphy et al., 1983). Calcium under conditions of high pH and high alkalinity forms solid a calcium carbonate solid, called marl, which drops from the water column to the sediments. Phosphorus can be incorporated into this solid and then become unavailable for use by aquatic plants. Marl usually forms with high levels of hardness (greater than 150 mg/L) and alkalinity. Microclimates develop around aquatic macrophytes as the plant utilizes the carbon dioxide, raising the pH above 10 in the vicinity of the plant (Wetzel, 1983). For this reason, marl is often encrusted on the leaves and stems of aquatic plants. Marl also forms where groundwater enters surface water. Groundwater tends to have relatively high concentrations of carbon dioxide. Carbon dioxide dissipates to the atmosphere as the groundwater stabilizes with the lake water. This raises the pH and can precipitate calcium carbonate.

In the case of McGinnis Lake, the relationship between marl formation and phosphorus removal may vary by lobe. The south lobe of McGinnis Lake has organic sediments and a mid-season senescence of curly-leaf pondweed. Wetlands have sediments that are high in organic matter and nutrients. As lake water or incoming groundwater passes through these soils, the nutrients can be carried with the water. In addition, organic matter (from both wetland soils and plant material in the lake) will bind with the calcium carbonate exchange sites in the marl, and reduce the amount of phosphorus which can be removed (Wetzel, 1983, Kleiner, 1990, House, 1990). As the calcium carbonate exchange sites become full, the phosphorus is left in suspension in the water column, available to plants and algae. The role of the mid-season plant senescence may also be important. This die-back introduces organic matter and nutrients into the lake. Because this occurs after much of the marl may have already formed during the spring, and it occurs in locations which are likely to have less marl production because of their location in this flow through lake, these nutrients may be more available to algae in the lake.

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 exists in a variety of forms, depending upon source and surrounding conditions and 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. External 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 waste.

Nitrogen has a complex cycle, which involves bacteria and microorganisms that transform the element from one form to another. The forms of nitrogen most important for aquatic growth in systems include NH_4^+ (ammonium), NO_2^- + NO_3^--N

(nitrite plus nitrate), and total Kjeldahl nitrogen (TKN), which is organic nitrogen plus ammonium. Aquatic plants and algae can use all inorganic forms of nitrogen (NH_4^+, NO_2^-, and NO_3^-), but require organic material to first be broken down by microorganisms. If these inorganic forms of nitrogen in lake water exceed 0.3 mg/L (as N) in spring, there is sufficient nitrogen to support summer algae blooms (Shaw et al., 2000). McGinnis Lake had a spring overturn inorganic nitrogen concentration of 0.27 mg/L. Table 6 summarizes the nitrogen concentrations in McGinnis Lake.

Ammonium Nitrogen

Ammonium is the most available form of nitrogen to aquatic plants. Ammonium (NH_4) and ammonia (NH_3) concentrations are dependent on the pH and temperature of the water solution. The relative proportions of each form will change instantly with changes in the solution. The hardness of the water will also play a role in regulating the ammonium and ammonia concentrations. As hardness, pH, and temperature increase, NH_4 converts to toxic NH_3. 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.

Ammonium levels in McGinnis Lake were low except in the hypolimnion (bottom) of the north lobe where organic matter accumulates and is decomposed. Bacteria utilize the dissolved oxygen in the water through decomposition and convert nitrate (NO_3) to ammonium (NH_4) (see Table 6). Ammonium levels throughout the season in the upper layers of both lobes of the lake ranged from below lab detection limits (<0.01 mg/L) to 1.11 mg/L, with an average concentration of 0.09 mg/L. Ammonium concentrations in the hypolimnion of the north lobe averaged 3.16 mg/L, ranging from 0.49 to 4.80 mg/L.

Site	Average NH_4 (mg/L)	Average $NO_2 + NO_3$ (mg/L)	Average Organic Nitrogen (mg/L)	Average TN (mg/L)
Spring Overturn (N & S Ave)	0.03	0.27	0.50	0.79
North Epilimnion	0.04	0.29	0.50	0.83
North Metalimnion	0.02	0.06	0.51	0.59
North Hypolimnion Top	0.23	0.11	0.91	1.22
North Hypolimnion	3.16	0.04	1.42	4.16
South Composite	0.02	1.52	0.62	2.16
Outflow	0.04	0.09	0.58	0.71
Fall Overturn (N & S Ave)	0.03	0.20	0.53	0.76

Table 6. 2002 Average Nitrogen Concentrations in McGinnis Lake, Wisconsin

Organic Nitrogen

Total Kjeldahl Nitrogen (TKN) measures organic-nitrogen plus ammonium. By subtracting ammonium concentrations from TKN, one can obtain the amount of organic nitrogen in the lake water. Organic nitrogen is a large component of nitrogen in McGinnis Lake, comprising most of the nitrogen in the lake. Lake concentrations of organic nitrogen ranged from 0.38 to 2.22 mg/L. The average concentration of organic nitrogen within each layer is displayed in Table 6. The upper layers of the north lobe averaged 0.5 mg/L, increased to 0.91 mg/L in the upper portion of the hypolimnion, and increased to a season average of 1.42 mg/L in the bottom of the hypolimnion. The south lobe composite sample had an organic nitrogen concentration of 0.62 mg/L and the outflow had an average concentration of 0.58 mg/L. Concentrations of organic nitrogen are highest within the hypolimnion where organic matter accumulates. However, nitrogen in the form of ammonium was also highest in the hypolimnion. The accumulation and decomposition of organic matter and anoxic conditions are responsible for the elevated nitrogen concentrations in the hypolimnion.

Nitrite-Nitrate Nitrogen

Nitrate-nitrogen in McGinnis Lake occurred at relatively low levels. The average lake concentration of nitrite+nitrate-N was 0.38 mg/L. Nitrate concentrations were highest in the epilimnion and south composite samples averaging 0.29 mg/L and 1.52 mg/L, respectively. The average nitrate concentration in the south lobe was affected by the May 17 sampling date when the nitrate concentration was 11.8 mg/L. All other concentrations were 0.20 mg/L or less in the south lobe. Atmospheric contributions and precipitation are

sources of nitrogen, and as plants utilize the nitrogen for growth, nitrate concentrations decrease with depth. Nitrate concentrations in the bottom of the hypolimnion averaged 0.04 mg/L and the outflow averaged 0.09 mg/L. Lake nitrate concentrations ranged from 0.01 to 11.8 mg/L throughout the growing season.

GROUNDWATER SAMPLING

The groundwater measured in this study originated from within the groundwater watershed. Groundwater is recharged as precipitation infiltrates the land. This water comes in contact with chemicals and nutrients on the land, and can carry them to the groundwater. The use and management of land will have an impact on the groundwater and lake water quality. For example, nutrients from lawn and garden fertilizers, animal wastes, and septic systems can all reach the lake through the shallow groundwater.

Shallow groundwater was evaluated at 40 sites during the mini-piezometer study. Water samples were collected from 28 of these: 2 outflow sites, 1 static site, and 25 inflow sites. Shallow groundwater generally originates from land close to the lake and illustrates the relationship between local land use and lake water quality. As groundwater samples were collected every 200 feet around the periphery of the lake, this survey was intended to acquire general trends of the shallow groundwater entering the lake and not site-specific information. However, a combination of analyzed parameters at elevated concentrations can signify pollution or unnatural levels of nutrients in an area coming from a variety of sources. The results of the groundwater investigation performed on August 6 - 8, 2002 are described here.

Direction of Flow

The direction of groundwater flow was established at each site by comparing the head (water level) in the mini piezometer to the lake level. Flow was either into the lake (inflow), leaving the lake (outflow), or was at equilibrium with or not connected to groundwater (static). The pattern of inflow and outflow is illustrated in Figure 16. Eighty-nine percent of the sites had groundwater flowing into the lake. Groundwater entered around the entire perimeter of the north lobe of lake. The west side of the south

lobe and channel was static with a balance of groundwater entering at the same rate it is leaving the lake. The north, east, and south side of the south lobe were also mostly inflow with the exception of two outflow sites and three static sites. Sites 33 and 36 were outflow, where water is leaving the lake and entering the groundwater.

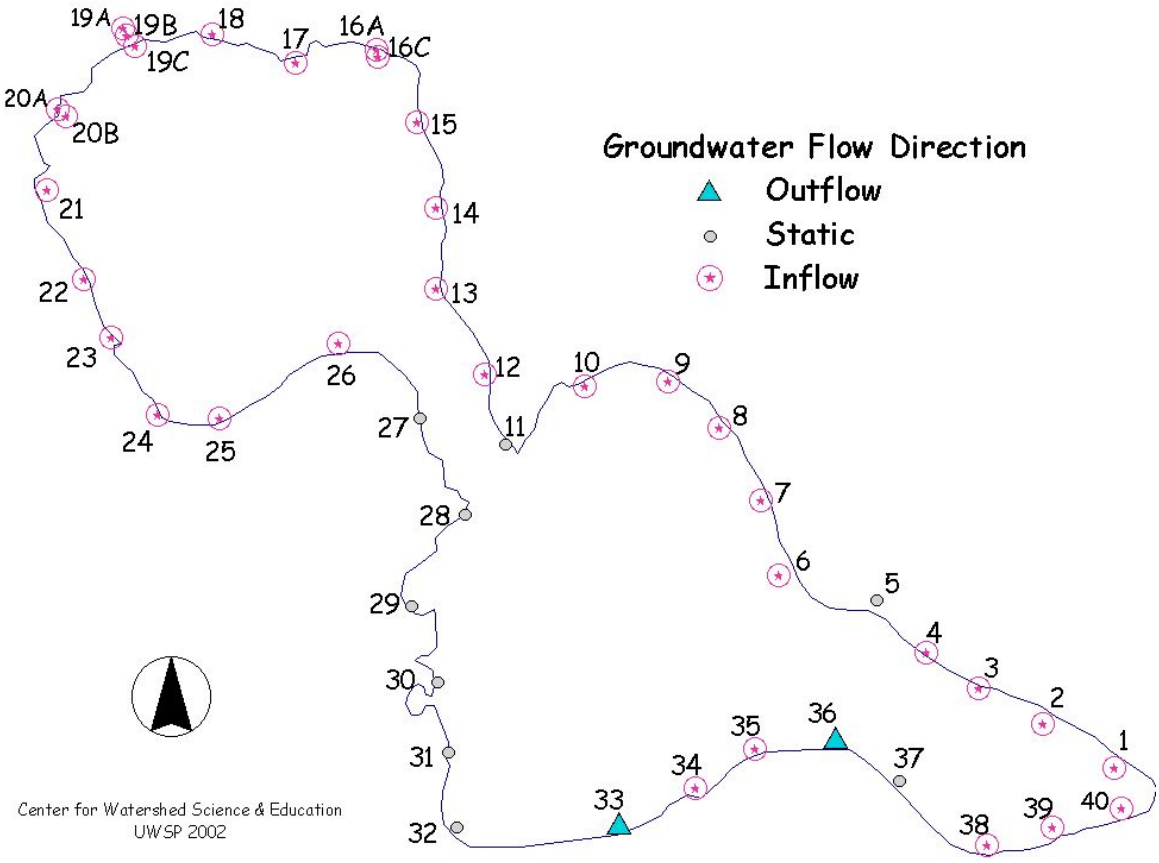

Figure 16. Groundwater Inflow/Ouflow Measured at Mini Piezometer Sites Around McGinnis Lake, Wisconsin

Temperature and Conductivity

The groundwater temperature and conductivity were measured in the field at each site where a sample was collected. Temperature gives an indication of the distance traveled by the water coming into the lake. Water traveling from further away will have been in the ground longer and subject to the temperature of the aquifer and no sunlight. This water will be colder than water traveling a shorter distance. Using this knowledge, we can extrapolate the flow patterns of McGinnis Lake. Colder groundwater from a greater distance was entering the lake at the northwest corner (temperatures 15.2 – 21.4^{o}C) (Figure 17). At the southeast end of the lake and also in the channel, shallow

groundwater temperature was about equal to the temperature of the lake water (24.0 – 26.8 C). This warmer water means that the groundwater is coming from a very short distance or that lake water may actually enter at these sites. Areas that were not in the main groundwater flowpath (the south bay in the north lobe, the north and east bays in the south lobe) had an intermediate temperature between 21.6 and 22.6 C. This groundwater originated from an intermediate distance or was a mixture of deep and shallow groundwater.

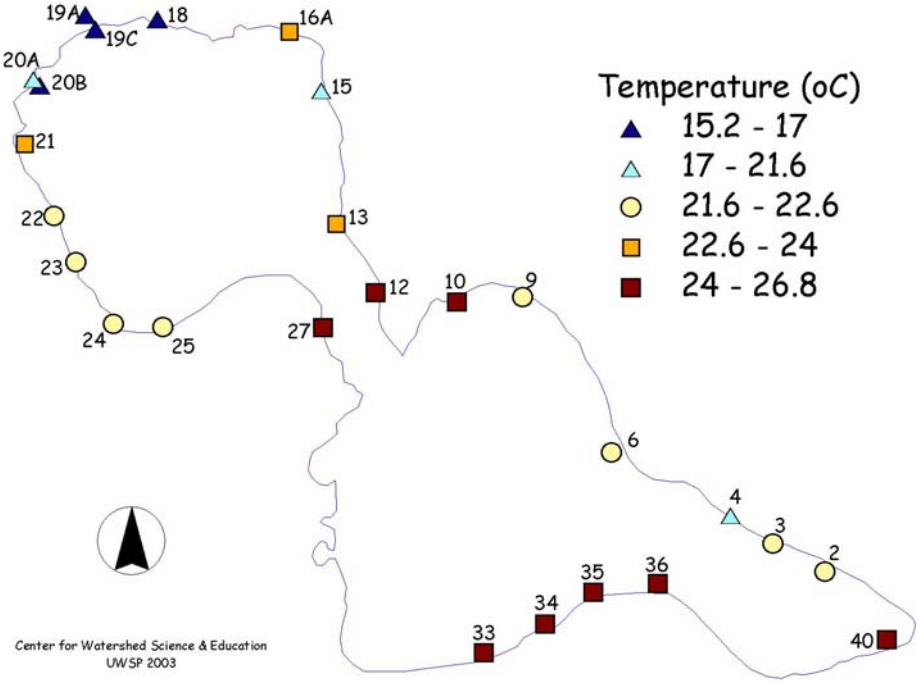

Figure 17. Temperature of Shallow Groundwater in McGinnis Lake, Wisconsin

Conductivity is a measure of the dissolved ions in the water that are able to conduct an electrical current. Also referred to as specific conductance, conductivity is largely a result of the dissolved species from the local geology. Local influences such as decomposing material and dissolved salts could also be a source of conductivity. Conductivity values ranged from 131 to 600 μmho in the shallow groundwater, with an average conductivity of 332 μmho (Figure 18). The average conductivity for the groundwater is higher than the average conductivity for the surface water in both the north lobe and the south lobe. The north lobe had an average conductivity of 320 μmho and the south of 217 μmho.

According to Shaw et al., (2000) conductivity in surface water is usually twice the total hardness unless contaminants are introduced into the system (total hardness is discussed later in this section). Urbanization and agriculture tends to increase the conductivity as dissolved ions are added from additional sources (road salts, fertilizers, septic systems, animal wastes, etc.). Conductivity tended to be highest in the north lobe. The southern edge of the south lobe also had high conductivity values, meaning there were a lot of dissolved ions in the shallow groundwater at those sites.

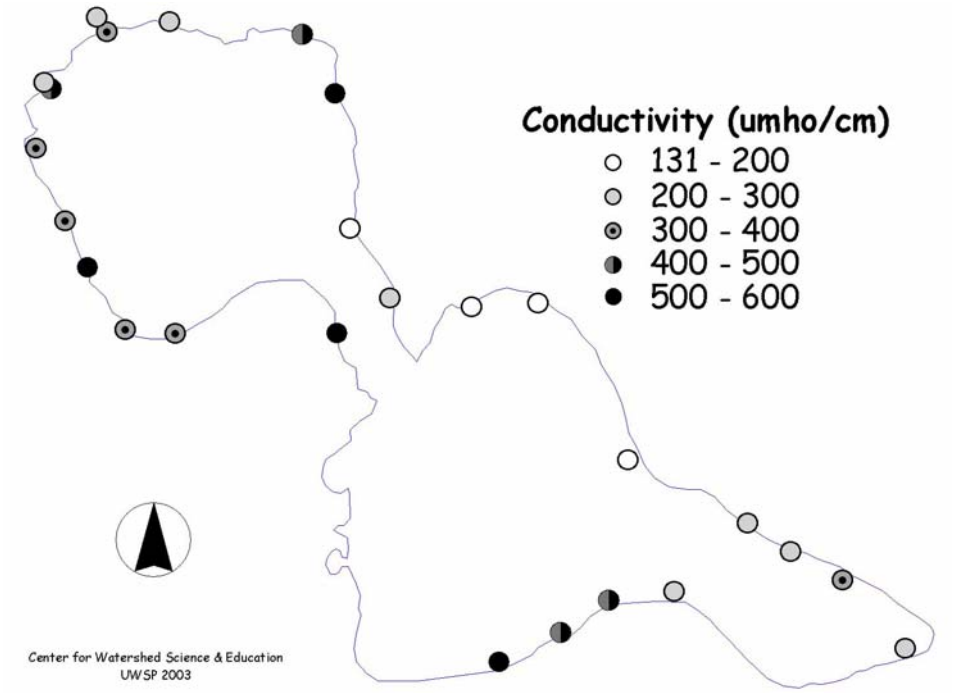

Figure 18. Conductivity in Shallow Groundwater Samples, McGinnis Lake, Wisconsin

Nitrite + Nitrate Nitrogen

Nitrite+nitrate-N concentrations were low in the mini-piezometer samples, with a maximum concentration of 1.71 mg/L. The highest concentrations of nitrite+nitrate-N were found at the strong inflow areas of the lake (northwest corner). This was to be expected because nitrite-nitrate is very soluble and travels with groundwater. Sources of nitrate to groundwater include agricultural fertilizers, lawn and garden fertilizers, and septic drain fields. These sources can be found in the McGinnis Lake groundwater shed. The nitrite+nitrate-N concentrations for all mini-piezometer samples are illustrated in Figure 19.

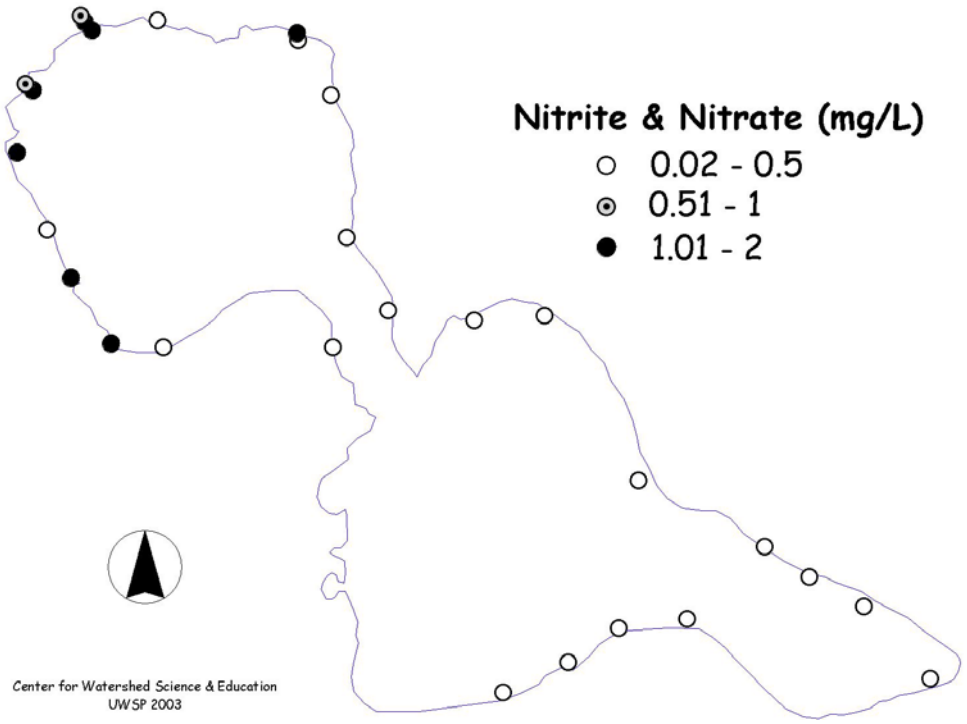

Figure 19. Nitrite-Nitrate Concentrations in Shallow Groundwater Samples, McGinnis Lake, Wisconsin

Ammonium Nitrogen

Ammonium concentrations ranged from less than 0.01 to 5.67 mg/L in the groundwater. Ammonium is a form of nitrogen (NH_4) that exists when oxygen is not present in the system. This is common when there is a lot of decomposition of organic matter or when readily oxidized metals (i.e. iron and manganese) are in significant concentrations in the groundwater. Ammonium is also present in septic system effluent and fertilizers. Figure 20 is a visual representation of the ammonium concentrations in the samples collected. Of the 28 sites, 12 samples were below the detection limit for ammonium. Ammonium in the groundwater was highest in the south lobe between the outflow sites. Ammonium was also slightly elevated in wetland-type areas where organic matter has accumulated. Ammonium concentrations above 1.0 mg/L only occurred from sites 33 through 40 (south end of south lobe). Nitrate is usually associated with the presence of oxygen, and ammonium is found in areas of oxygen depletion. Because of this cycling, ammonium is not typically found in combination with nitrate (Figures 19 and 20).

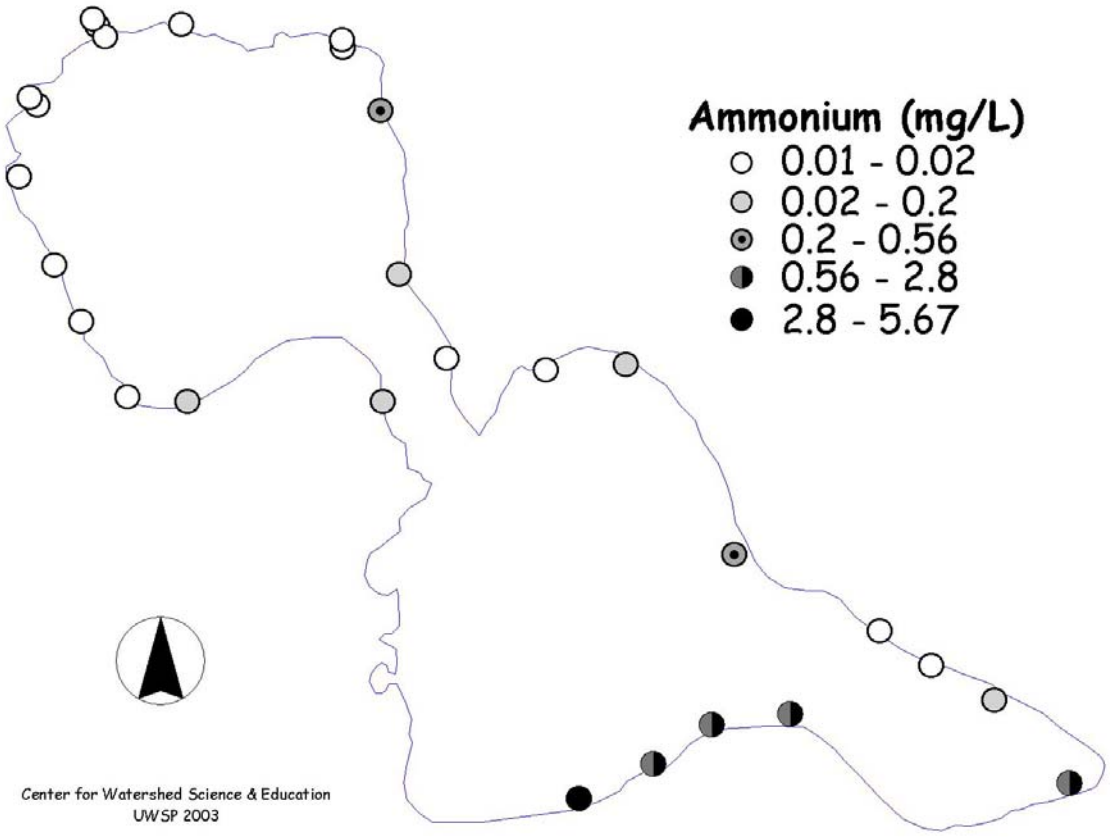

Figure 20. Ammonium Concentrations in Shallow Groundwater Samples, McGinnis Lake, Adams County, Wisconsin

Soluble Reactive Phosphorus

Soluble reactive phosphorus (SRP) concentrations in shallow groundwater samples ranged from 9 to 1450 μg/L. Groundwater normally contains relatively low concentrations of SRP and septic systems, fertilizers, decomposing organic matter in sediments and wetlands are sources of increased reactive phosphorus. Figure 21 illustrates the reactive phosphorus concentrations around the lake. Concentrations are quite variable, indicating local conditions significantly influence the SRP. The southern edge of the south lobe had the sites highest in reactive phosphorus. Two of these were outflow sites. Typically, outflow sites have nutrient concentrations resembling the lake water quality, but the SRP concentration in the south lobe on August 7, 2002, was 6 μg/L. Because ammonium concentrations were also high in the groundwater collected at these sites in the south lobe, and iron was confirmed to be high in one of the samples, this is an indication of anoxic, reduced conditions where phosphorus would be released from the

sediments. Since the two are outflow sites, this water is moving away from the lake and therefore should not impact the lake water quality. The lowest temperature groundwater collected in the areas of upwelling on the north side of the lake had relatively low SRP concentrations.

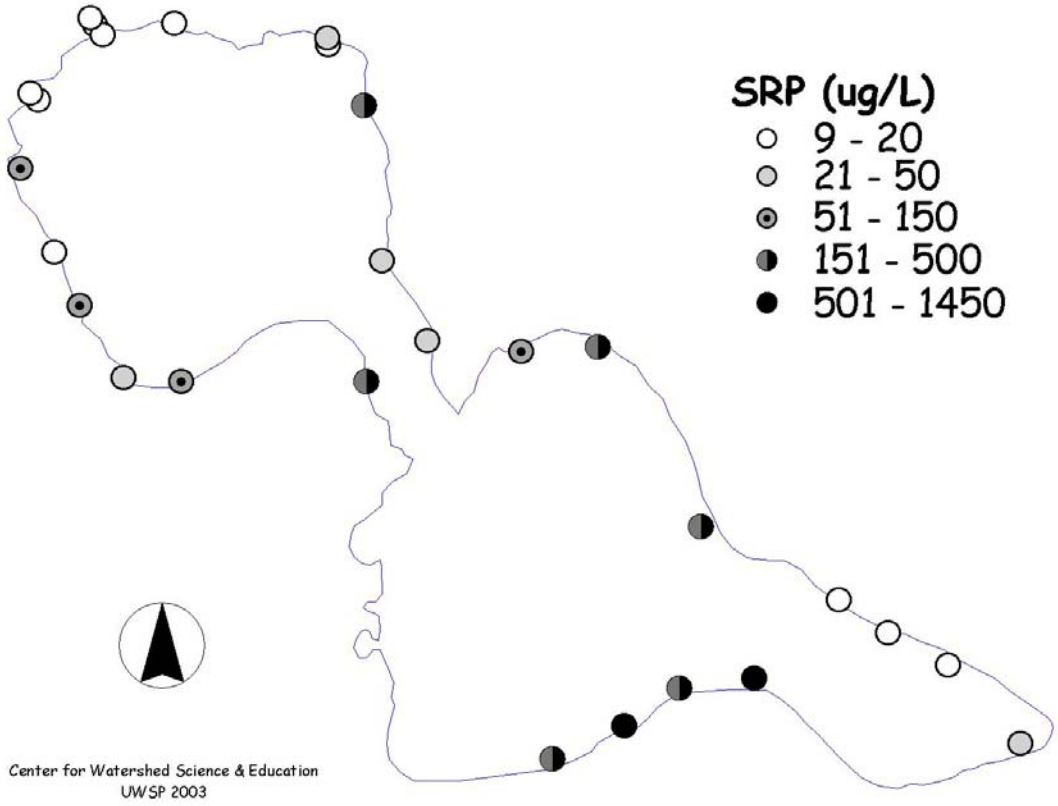

Figure 21. Soluble Reactive Phosphorus Concentrations in Shallow Groundwater Samples, McGinnis Lake, Adams County,Wisconsin

Chloride

Chloride is a biologically unreactive element. Groundwater in Adams County that has not been impacted by human uses usually has chloride concentrations that are less than 2 mg/L. Therefore, the presence of chloride is an indication of human impacts to groundwater. Common sources of chloride include septic systems, lawn/garden fertilizers, animal waste, agricultural fertilizers, and road salt. The highest value of chloride in McGinnis Lake groundwater was 48 mg/L (Figure 22). This occurred in the south bay at the boat landing. Three of the surrounding sites high in chloride were not high in nutrients, indicating road salt is the most likely source. The other areas with

higher chloride concentrations are the north side of the lake in the north lobe, the channel, and the south lobe with concentrations ranging between 3.5 and 12.5 mg/L. High chloride concentrations coupled with elevated SRP and nitrate or ammonium could indicate influence from fertilizers or septic systems.

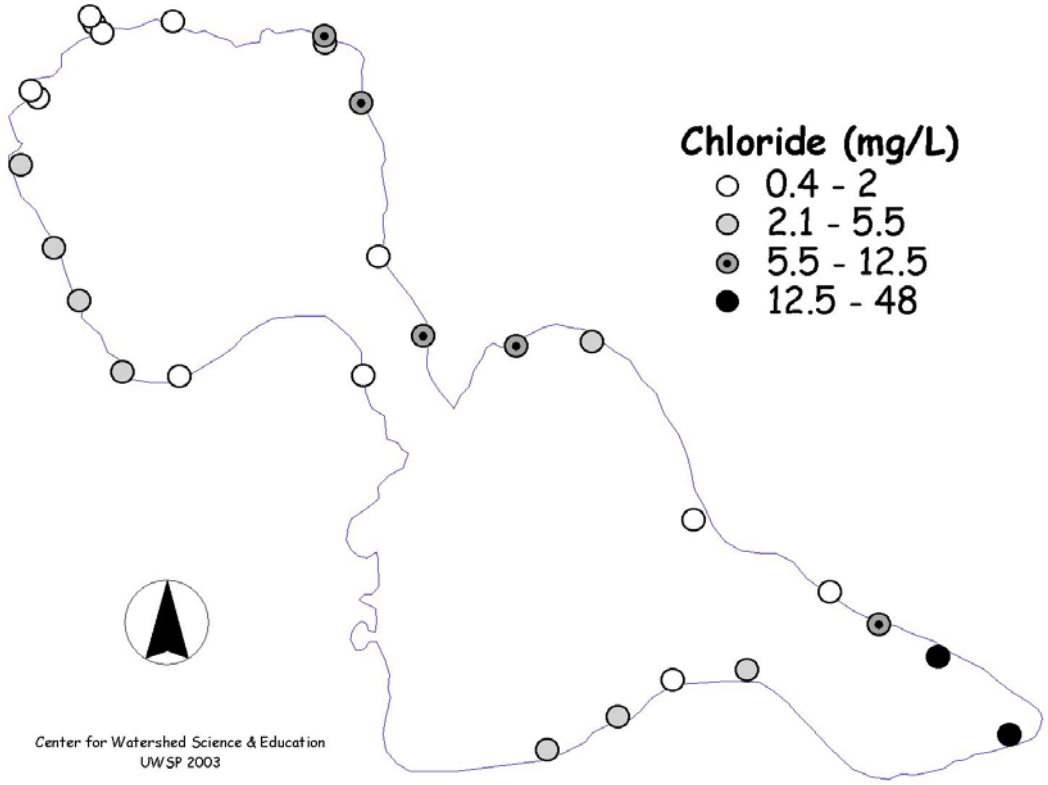

Figure 22. Chloride Concentrations in Shallow Groundwater Samples, McGinnis Lake, Adams County, Wisconsin

Alkalinity and Total Hardness

As groundwater flows through the calcareous till in the McGinnis Lake groundwater watershed, calcium, magnesium, and carbonate are dissolved and move with the water. The carbonate component makes up the alkalinity. Together, calcium and magnesium account for total hardness in the water. Alkalinity and total hardness often occur in a 1:1 ratio from the dissolution of calcium and magnesium carbonates. This is true for all areas of the lake except in the south bay near the boat landing where chloride and sulfate concentrations are high. Figure 23 and 24 show the alkalinity and total hardness concentrations around the lake.

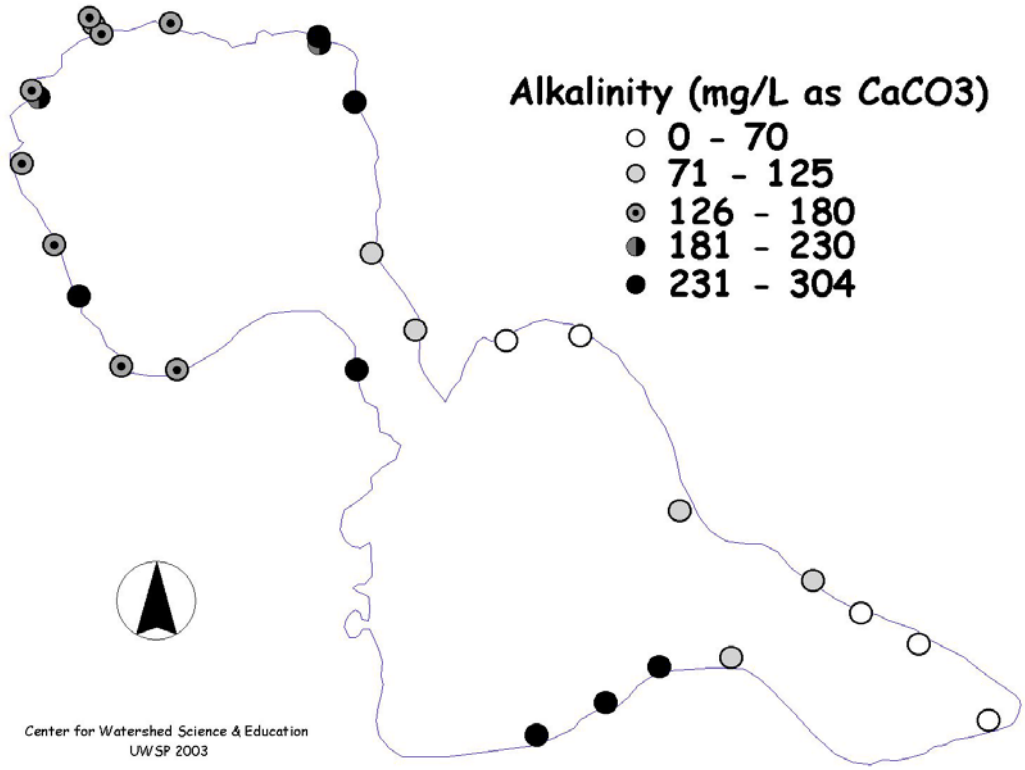

Figure 23. Alkalinity Concentrations in Shallow Groundwater Samples, McGinnis Lake, Adams County, Wisconsin

Overall, the average alkalinity and total hardness of the groundwater flowing into the lake was 164 mg/L as $CaCO_3$ and 170 mg/L as $CaCO_3$, respectively. Increased concentrations occurred near the discharge area (outflow), static sites, and the south side of the channel. The north side of the south lobe shows reduced concentrations of carbonate and total hardness with respect to deep groundwater concentrations. This might reflect groundwater that has less contact time with minerals in the aquifer. The pattern of high and low alkalinity and total hardness concentrations around the lake matches the pattern of conductivity (Figure 18) around the lake.

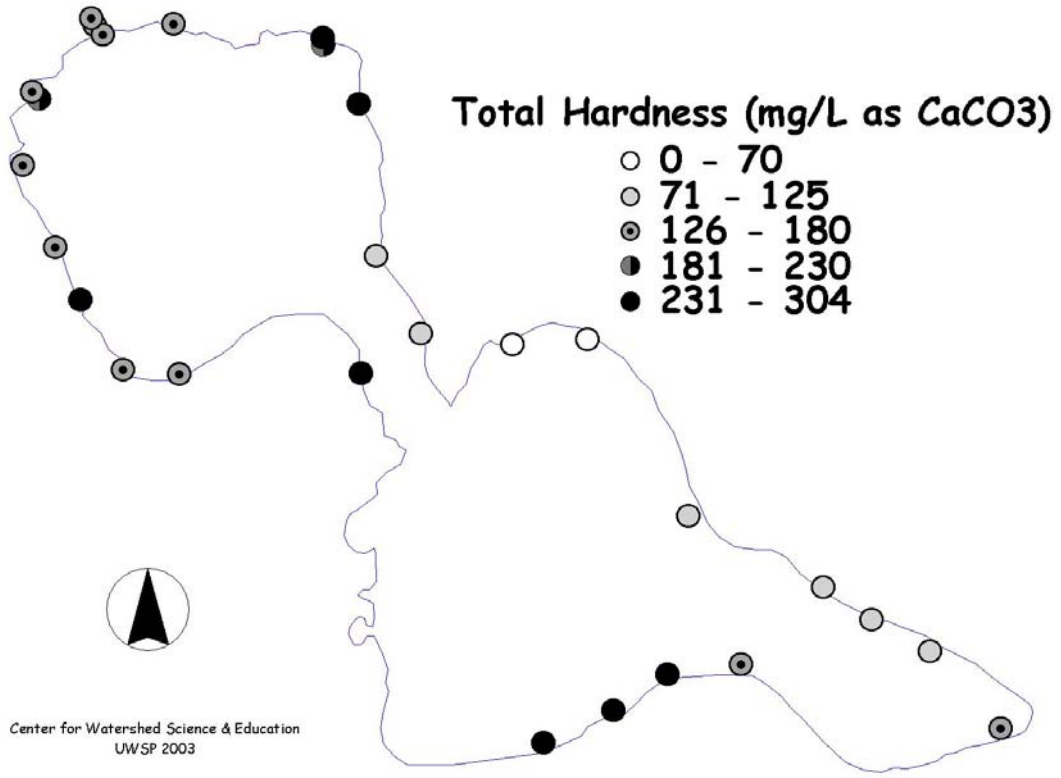

Figure 24. Total Hardness Concentrations in Shallow Groundwater Samples, McGinnis Lake, Adams County, Wisconsin

Groundwater Transects

In addition to shallow groundwater sampled around the lake, groundwater was also sampled at different depths along a line perpendicular to the shore at several locations. These groundwater transects were set up at sites 16, 19, and 20 (areas of high inflow) to determine how groundwater inflow varies with distance into the lake. Figure 25 shows the location of these transects, and Table 7 shows the concentrations for the samples collected from each transect.

At the Site 16 location, three depths were sampled (1.5, 2, and 4 feet of water). The shallow depth, Site 16A (in 1.5 feet of water), was at the same depth as the other sites around the lake. Site 16B (in 2 feet of water) had an impermeable layer that did not allow water to flow through it, and a sample was not collected. Site 16C was sampled at a depth of 4 feet.

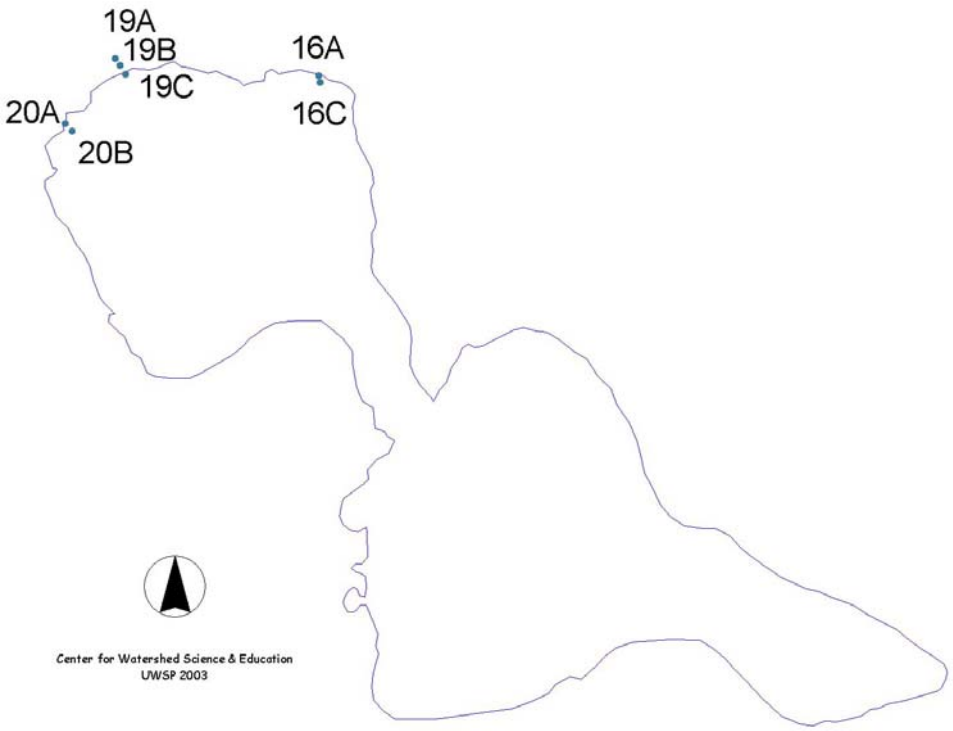

Figure 25. Location of Shallow Groundwater Transects in McGinnis Lake, Wisconsin

Site	Temp (^oC)	Cond (µmho/cm)	Alkalinity (mg/L as $CaCO_3$)	T Hardness (mg/L as $CaCO_3$)	Cl (mg/L)	NO_2 + NO_3 (mg/L)	NH_4 (mg/L)	SRP (mg/L)
16A	23.7	497	283	304	7.5	1.15	0.02	36
16C			182	200	5.5	0.32	<0.01	18
19A	16.9	287	155	160	<0.5	0.98	<0.01	13
19B			156	164	<0.5	1.17	<0.01	19
19C	16.3	330	158	160	0.5	1.14	<0.01	15
20A	21.4	245	144	144	<0.5	0.82	<0.01	16
20B	15.2	460	208	220	<0.5	1.71	<0.01	13

Table 7. Sample Concentrations from the Shallow Groundwater Transect Sites in McGinnis Lake, Wisconsin

Similar results were found at location 19 and 20. Site 19 was located at the discharge of a spring in the northwest corner of the lake. Site 19A was sampled at the spring, 19B was sampled in 1.5 feet of water and 19C was sampled in 3 feet of water. There was little variation in water quality between the Site 19 samples. Groundwater was entering at both Site 20A (1.5 feet) and 20B (3 feet). There were some variations in chemical characteristics of the water along the different transects.

DEEP GROUNDWATER SAMPLING

The deeper groundwater entering McGinnis Lake was sampled to provide information about total hardness and alkalinity as well as the primary nutrient concentrations flowing into the lake from deep groundwater. Based on the groundwater flow map and results of the shallow groundwater monitoring, samples were taken from two inflow locations in the north lobe at four depths in the fall of 2002. The northwest site (NW) is located at shallow groundwater site 19 where a spring discharges into the lake (Figure 26). The west site (W) is located between shallow groundwater sites 20 and 21. Analytical results from the deep groundwater samples are displayed in Table 8.

The groundwater differed between the NW and W sites. The NW site had higher hardness and alkalinity and lower nitrate than the W site. There were some differences with depth at each site. The concentrations of alkalinity to total hardness were in a 1:1 ratio throughout the column consistent with the calcareous source. The difference in water quality patterns between the two sites may be due to the origin of the groundwater (how far the water traveled in the watershed to get to this discharge point), soils and geology, and the land use practices in the area that discharges water to these locations.

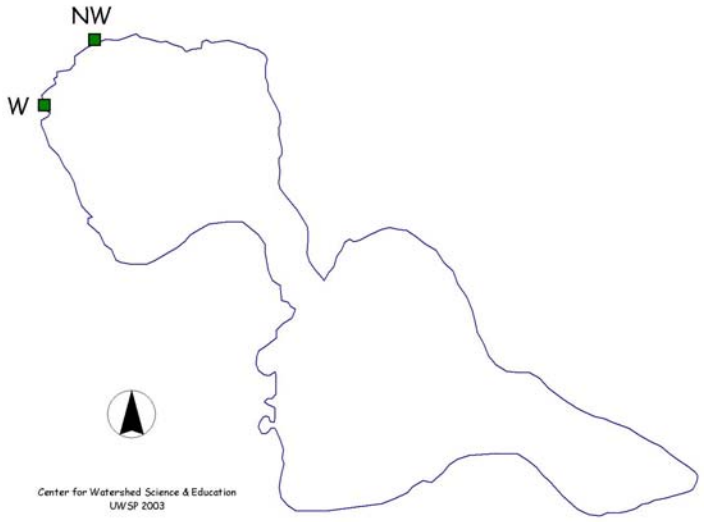

Figure 26. Location of Deep Groundwater Sites in McGinnis Lake, Wisconsin

Site – Depth (ft)	SRP (μg/L)	NO_2+NO_3 (mg/L)	Cl (mg/L)	NH_4 (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Total Hardness (mg/L as $CaCO_3$)
NW- 4	5	0.46	0.5	<.01	175	180
NW- 5	8	0.40	2.5	<.01	172	180
NW- 6	10	0.46	0.5	<.01	171	172
NW- 7	13	0.62	0.5	<.01	164	168
W- 4	8	1.82	2.0	<.01	130	140
W- 5	6	1.76	2.0	<.01	134	144
W- 6	6	1.70	2.0	<.01	133	144
W- 7	8	1.66	2.0	<.01	136	148

Table 8. Analytical Results of Deep Groundwater Samples Flowing into McGinnis Lake, Wisconsin

INTERSTITIAL WATER

The location, type and amount of aquatic plant growth depends on the conditions within a lake. The factors affecting establishment of aquatic plants include nutrient availability in the sediment and water, pH, alkalinity, the plant's nutrient requirements, substrate type and texture, shoreline slope, depth of water and light penetration, groundwater inflow and outflow areas, organic matter content, and human impacts at the sites. Aquatic plant growth is important in the cycling of nutrients in a lake and as food and habitat for waterfowl, invertebrates and fish.

Most aquatic plants obtain the needed nutrients from the sediments and interstitial water with which their roots are in contact. For those that do not have a developed root system such as *Chara*, water column nutrients play a greater role in meeting their requirements. Plant uptake is also a function of the relative availability of the nutrient, depending on the form in which it is present. We would expect to find more nutrients in the plant tissue under conditions when more nutrients are available in the interstitial water and sediments.

Minitab Statistical Software 13.1 program was used to analyze these data and make correlations with water chemistry, aquatic macrophyte biomass, and plant tissue concentrations. For most analyses, strong correlations between plant biomass and chemical parameters did not exist, however, the key relationships are highlighted.

SRP was high at all sites, from 26 to 152 μg/L. Ammonium was also higher in the interstitial samples than in groundwater with concentrations ranging from 0.03 to 1.95 mg/L. Nitrate was slightly elevated at interstitial water sites 19 and 20 (high inflow) and low at the other sites. Chloride varied at all sites and was greatest at Site 16B. Alkalinity was similar to total hardness at all sites.

Shallow GW Site	Interstitial Site ID	Alkalinity (mg/L as $CaCO_3$)	Total Hardness (mg/L as $CaCO_3$)	Cl (mg/L)	NO_2+NO_3 (mg/L)	NH_4 (mg/L)	SRP (μg/L)
4	1	147	140	1.5	0.04	0.39	32
9	2	204	204	4.5	0.07	1.95	152
16B	3	207	216	6.5	0.05	0.42	39
18	4	156	152	0.5	0.16	0.22	35
19	5	135	144	<0.5	0.82	0.03	28
20	6	188	192	1.5	1.26	0.03	26
24	7	183	176	2.5	0.05	0.68	101
35	8	223	204	1.0	0.11	3.1	63

Table 9. Concentrations of Interstitial Water Chemistry in McGinnis Lake, Wisconsin

AQUATIC MACROPHYTES (AQUATIC PLANTS)

Aquatic macrophytes have root systems that acquire their nutrients from the lake sediments. Lake sediments are an important source of phosphorus for plant (Carpenter, 1980). Normally, lake sediments are considered a sink for nutrients, locking them into a form that is not biologically available, but plants can acquire phosphorus from the sediments and interstitial water by their roots.

Curly-leaf pondweed (*Potamogeton crispus*) dominates the McGinnis Lake aquatic plant community in spring and early summer. This non-native, invasive plant was surveyed in McGinnis Lake because of its dominance in the plant community and its possible influence on nutrient concentrations in the lake. Curly-leaf pondweed is able to tolerate cold-water temperatures and can begin growth under ice cover. When it is near its maximum growth in the spring, it can shade native plants. In early summer when water temperatures rise, curly-leaf pondweed undergoes senescence and dies. As the plant

decomposes, some of the nutrients leach out of the plant tissue and into the water column. The nutrients can then be available for other aquatic plants and algae.

The goals of the macrophyte survey conducted in McGinnis Lake in the summer of 2002 were to determine the biomass of the curly-leaf pondweed in McGinnis Lake, measure the amount of phosphorus in the tissue of the plants, and extrapolate those numbers to the entire lake to estimate the amount phosphorus that can be released when the curly-leaf pondweed dies back. The lake was divided into separate sections to conduct the plant survey. Nine transects were identified for sampling. Figure 27 shows the location of each transect in the lake and the approximate areas of abundant plant growth. The density of *Potamogetan crispus* varied throughout the lake. Some areas were choked with plants, while others barely had any growth. It was estimated that *Potamogetan crispus* covers most of the south lobe, the channel between the lobes, and portions of the north lobe littoral zone. These areas were determined by visual observations and sample transects and measured in ArcView GIS. In the south lobe and channel, curly-leaf pondweed covered the entire 85,680 square meters (21.2 acres). In the north lobe, curly-leaf pondweed was found in a depth of water to 6-feet. Using the tools available, the surface area was calculated from the shoreline of the north lobe to the 5-foot bathymetric contour and an additional region in the southeast corner of the north lobe where curly-leaf pondweed had been more abundant. This area comprised approximately 15,650 square meters (3.8 acres) in the north lobe. The north lobe was further divided into two sections because differences were found in the density of the plant growth. The north section of the north lobe was found to be 4,570 square meters (1.1 acres), and the south section of the north lobe was determined to be 11,090 square meters (2.7 acres).

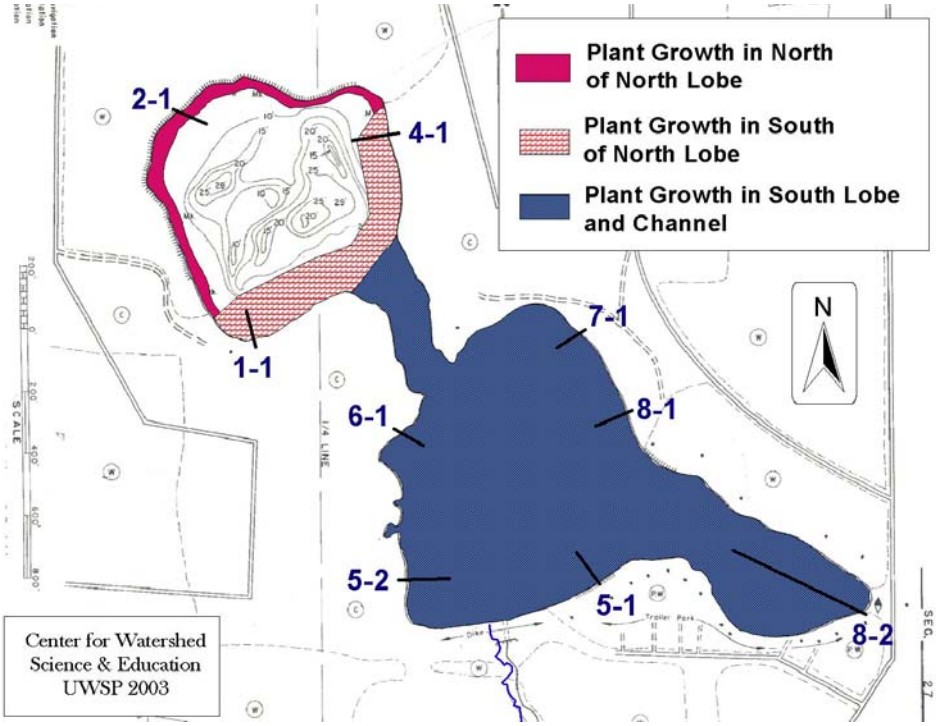

Figure 27. Aquatic Plant Survey Transects and Estimated Areas with *Potamogetan crispus* in McGinnis Lake, Wisconsin, June 2002

Table 10 summarizes the average plant density found at each transect and the average TP and TKN of the plant tissue for each transect. The area of the section affected by plant growth was multiplied by the average density of biomass found in that area, which gave the total mass of the plants. This mass was multiplied by the nutrients in the plant tissue from that section, giving the total phosphorus and nitrogen content. Table 11 summarizes the biomass, TP, and TKN by section. The raw data from the aquatic macrophyte survey can be found in the appendix.

Transect	Average Plant Biomass (g/m^2)	Plant Tissue Average TP (g/kg)	Plant Tissue Average TKN (g/kg)
1-1 North Lobe	4.6	2.6	24.8
2-1 North Lobe	0.9	1.6	17.5
4-1 North Lobe	14.7	1.8	19.2
5-1 South Lobe	21.5	2.0	20.7
5-2 South Lobe	44.9	1.7	21.4
6-1 South Lobe	10.1	2.1	25.3
7-1 South Lobe	27.8	2.0	26.3
8-1 South Lobe	10.2	1.6	17.0
8-2 South Lobe	19.5	2.3	27.4

Table 10. Summary by Transect of Nutrients in Curly-leaf Pondweed During the 2002 Aquatic Macrophyte Survey, McGinnis Lake, Wisconsin

Section	Area (m^2)	Plant Biomass (kg)	Plant Phosphorus (kg)	Plant Nitrogen (kg)
North Part of North Lobe	4,570	4	.007	.07
South Part of North Lobe	11,090	106	.21	2.2
South Lobe and Channel	85,680	1,700	3.4	39.8
Total	**101,300**	**1,810**	**3.6**	**42.1**

Table 11. Summary Plant Biomass and Tissue Nutrients in Curly-leaf Pondweed Collected During June 2002 Survey McGinnis Lake, Wisconsin

In the north part of the north lobe, the average total biomass of curly-leaf pondweed was estimated to be 4 kg (based on 4 sample sites). The plant density was approximately 0.9 g/m^2. The average TP in the plant tissue was 1.6 g/kg (n=2). The average TKN in the plant tissue was 16.4 g/kg (n=2). The mean total mass of TP of the north part of the north lobe was 6.7 g. The mean total mass of TKN was 68 g.

The south part of the north lobe had a greater biomass of curly-leaf pondweed at 9.5 g/m^2. The estimated average total biomass was 106 kg (n=6). The average TP in the tissue of the curly-leaf pondweed was 2.0 g/kg (n=4), and the average TKN was 20.6 g/kg (n=4).

The average total mass of TP in the south part of the north lobe was 209 g, and the average total mass of TKN was 2,175 g.

In the south lobe, the density and total biomass of curly-leaf pondweed was much greater than that measured in the north lobe. The average density, based on 50 samples, was 20.0 g/m^2. The average biomass estimate within the lobe was 1,700 kg of pondweed. The plant tissue average TP was 2.0 g/kg (n=23) and average TKN was 23.2 g/kg (n=23). The average total mass of TP was estimated at 3,377 g and average TKN was 39,800 g.

The total dry weight of curly-leaf pondweed in McGinnis Lake was estimated to be 1,810 kg. These plants are getting their nutrients from the lake sediments, interstitial water, and the water column and these nutrients can be released into the water during senescence. In late June, approximately 3.6 kg of total phosphorus and 42.1 kg of TKN could be released into McGinnis Lake.

PHYTOPLANKTON (ALGAE)

The algal community of Lake McGinnis is fairly typical of a shallow, nutrient-enriched, temperate-zone impoundment. The community had representatives from 6 algal phyla encompassing 82 total genera (Appendix). The green algae (Chlorophyta) were the most common phylum with 35 genera present during the course of the study. The green algae were followed by the ochrophytes (Ochrophyta, including diatoms), comprising 19 genera (15 diatom genera), the blue-green bacteria (Cyanobacteria) with 13 genera present, and the euglenoids (Euglenophyta) with 9 identified taxa. Representatives from the dinoflagellates (Dinophyta, 4 taxa) and the cryptophytes (Cryptophyta, 2 taxa) were also found during the study period.

The ten most common algal genera counted during the sample period are listed in Table 12. The mucilaginous, spherical, colonial cyanobacterium – *Coelosphaerium*, was the most commonly seen taxon. It was present in all ten samples (as were 6 of the other top 10) and represented nearly 6% of all cell counted. This organism is not a preferred food

item because of the large and unpalatable polysaccharide sheath. A host of euglenoids followed in frequency of occurrence, 2 species each of the genera *Euglena* and *Phacus*, separated by a dinoflagellates taxa – *Peridinium*. Each of these five taxa contributed an average of 4-5% to the algal community over the year. The last of the top ten most frequently encountered taxa include the cyanobacterial genera *Microcystis* and *Aphanizomenon*, the green alga *Ankistrodesmus*, and the dinoflagellate *Ceratium*. Together the ten most common taxa averaged 40% of the total cells counted. Although there were plenty of diatom taxa present (15) there were no diatom taxa in the group of ten most common, this is a bit unusual.

Phylum	Class	Genus	Total Counts[a]	Total % [b]	Cumulative %[c]	Total Occurrences[d]
Cyanobacteria	Cyanophyceae	*Coelosphaerium*	169	5.6	5.6	10
Euglenophyta	Euglenophyceae	*Euglena 3*	162	5.4	11.0	7
Euglenophyta	Euglenophyceae	*Euglena 2*	134	4.5	15.5	10
Dinophyta	Dinophyceae	*Peridinium*	122	4.1	19.6	10
Euglenophyta	Euglenophyceae	*Phacus 1*	115	3.8	23.4	10
Euglenophyta	Euglenophyceae	*Phacus 2*	112	3.7	27.1	10
Cyanobacteria	Cyanophyceae	*Microcystis*	111	3.7	31.2	10
Chlorophyta	Chlorophyceae	*Ankistrodesmus*	105	3.5	34.7	10
Dinophyta	Dinophyceae	*Ceratium 2*	100	3.3	38.0	9
Cyanobacteria	Cyanophyceae	*Aphanizomenon*	81	2.7	40.7	7

[a] Total Counts equals sum of taxon counted during 10 sampling periods.
[b] Total Percent (%) equals taxon counts/total cells counted (n=3000).
[c] Cumulative Percent (%) equals sum of taxon and all taxa above it.
[d] Total Occurrences equals number of samples a taxon was found in (of 10 possible)

Table 12. Ten Most Common Algal Genera in McGinnis Lake, Wisconsin, 2002

The community percent composition from each phylum varied substantially over the study period as growth rates varied, herbivory removed preferred food species, and environmental conditions shifted competitive interactions among algal taxa (Figure 28).

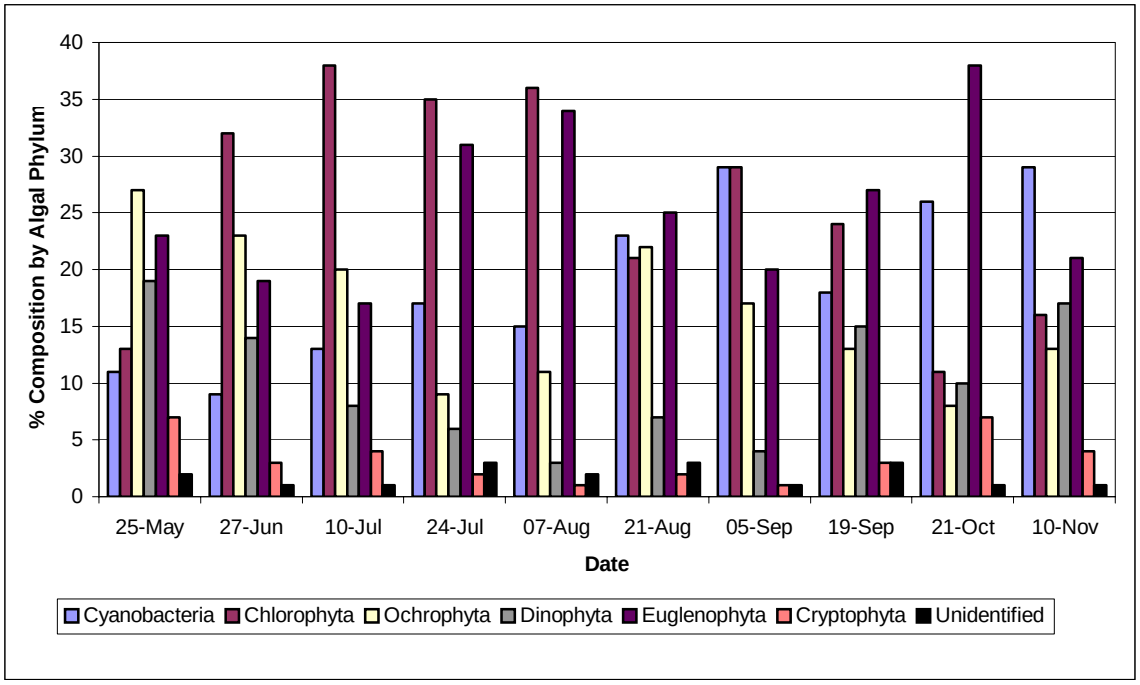

Figure 28. 2002 Phytoplankton Percent Composition by Sample Date in McGinnis Lake, Wisconsin.

The green and euglenoid algae were the most common groups across the sampling period (each phylum represented an average of 25.5% of cells counted). The green algae ranged from a minimum community component value of 11% to a maximum of 38%. The green algal contribution to the community rose steadily from the early season on, reaching a maximum in early August and declining steadily to the end of the season. The motile euglenoids were present at fairly similar levels throughout the entire sampling period. These facultative heterotrophs ranged from a low of 17% community composition to a high of 38% and showed less inter-sample variation than the green algae that fluctuated much more between sample periods.

The other phyla also showed individual seasonal patterns. The Cyanobacterial numbers started slowly in the spring, building in late August and staying relative level and high (18 to 29%) for the rest of the season. The ochrophytes provided an average of 16% of community composition, ranging from a low of 8% to a high of 27%. This group started fast and dropped almost every period, except for late August. The ochrophytes are composed of two different subgroups, the motile golden algae (*Dinobryon*, *Synura*,

Mallomonas) and the siliceous diatoms. The first group accounted for most of the early season numbers and were consistently present across the sampling period. The second group, the diatoms, started slow, built until August, accounted for the late August bump up, and then declined in importance to the end of the season, likely due to silica depletion. The final two algal groups, the dinoflagellates (3 to 19%) and the cryptophytes (1 to 7%), showed similar patterns. They started and ended the season with their highest contributions to the algal community and they both waned to their seasonal minima during the hottest part of mid-summer.

One of the green algal taxa that can be problematic is the genus *Mougeotia*. This filamentous organism is described as forming "metaphytic clouds". This means that macroscopic aggregations of filaments with a near neutral buoyancy form foggy, subsurface clouds that reduce clarity for submerged macrophytes and also reduces recreational and aesthetic values of the water. This organism is clearly a problem in McGinnis Lake. Based on a crude surface area survey conducted during the 2002 sampling season the percentage of the lake surface area subtended by an identifiable *Mougeotia* cloud is shown in Figure 29. Percent cover ranged from 0% at season start to a maximum of 60% in early August, declining slowly for the rest of the season. A dying and fragmented cloud was still present over 10% of the lake into November. From late August on to the end of the season the cloud began to fragment and discolor as the green algae became photo-oxidized and began to decay.

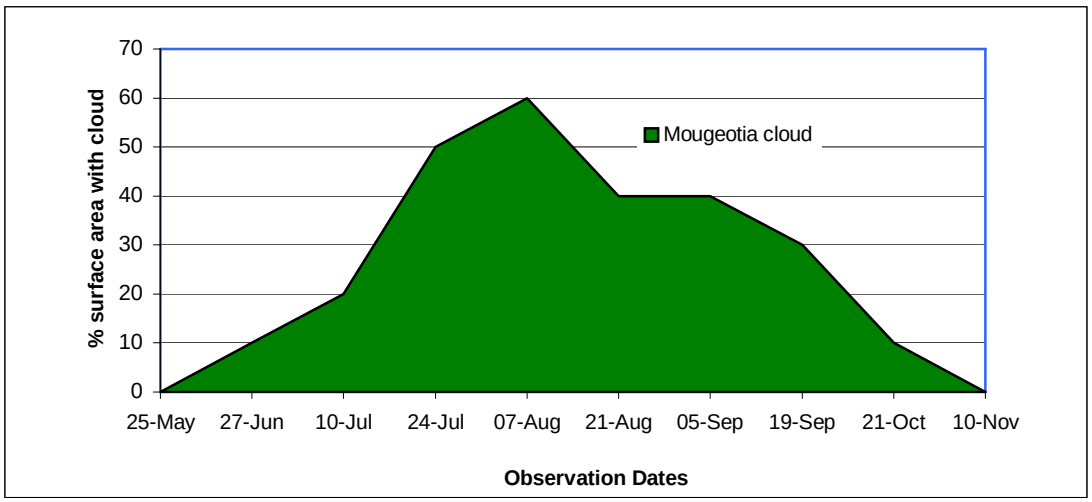

Figure 29. Mougeotia "cloud" in McGinnis Lake, Wisconsin, 2002

SUMMARY

This study of McGinnis Lake has found the lake to be exhibiting symptoms of nutrient enrichment. The lake could be classified as moderately eutrophic, but more significantly, the variations in water quality during the growing season lead to problematic levels of nutrients in the water column during the later growing season. These changes appear to be linked to the dynamic plant community changes, the hydrology of the lake system, and the physical configuration of the lake basins.

Differences between the north and the south lobes of the lake relate to their differing depths, variations in groundwater inputs, and differences in topography and development. The water in the south lobe remained mixed for the season while the north lobe became stratified with a thermocline and cooler hypolimnion. Dissolved oxygen (DO) in the north lobe increased in the metalimnion at the beginning of the season likely in response to algae in the water column. In the deeper depths of the north lobe, DO concentrations decreased and became very low at the bottom. The aquatic plants in the south lobe also impacted the DO concentrations. In the beginning of the season, DO actually increased at lower depths probably as a result of plant release of oxygen during photosynthesis. Following June 27, 2002, and the dieback of the curly-leaf pondweed (*Potamogetan crispus*), DO concentrations decreased. This was likely the result of oxygen consumption during decomposition of the plant material.

Water clarity was relatively low in the lake. The north lobe had an average Secchi depth measurement of 3.6 feet and the south lobe had an average of 5.2 feet. The south lobe water clarity had a major decline near July 24, most likely corresponding to the increase in algae growth stimulated by the release of nutrients from the curly-leaf pondweed dieback. The chlorophyll *a* concentration was also high in late July.

The groundwater entering McGinnis Lake delivers calcium, magnesium and carbonate to the lake from rocks and soils in the watershed. The relatively high concentrations of calcium and magnesium make McGinnis Lake a hardwater lake. The high concentrations of calcium and carbonate lead to the formation of solid calcium carbonate (marl). Some

of the marl settles to the bottom of the lake. Testing showed higher overturn total hardness and alkalinity concentrations in the north lobe than in the south lobe. Lower and relatively similar concentrations in the two lobes during the summer suggest more marl precipitation occurs early in the year.

McGinnis is a phosphorus-limited lake, meaning that increases in phosphorus to the system may increase algae or plant growth. SRP was quite low in the upper layers of the lake (north and south) with average concentrations between 5 to 7 μg/L. The hypolimnion (bottom) of the north lobe had an average SRP concentration of 128 μg/L. North surface total phosphorus averaged 23 μg/L, increasing to 220 μg/L at the north bottom. The south composite had an average TP of 29 μg/L and the outflow averaged 37 μg/L TP.

Marl-forming lakes are expected to be low in TP because calcium carbonate binds with phosphorus. In the case of McGinnis Lake, the higher concentrations of TP may not be ameliorated by the marl formation because the phosphorus is released from the decomposing curly-leaf pondweed after much of the marl formation has already occurred. In addition, much of the groundwater appears to enter the north lobe and marl formation there is separated spatially from the bulk of the phosphorus estimated as available for release from the curly-leaf pondweed.

The groundwater study was used to determine the areas of groundwater inflow and outflow as well as the quality of the groundwater discharging to McGinnis Lake. The coldest groundwater was entering the north-west corner of the north lobe. These were areas of relatively strong groundwater inflow. Nitrate concentrations were elevated at some of the strongest inflow sites. This groundwater may originate further out into the watershed and increased nitrate may reflect agricultural influences. Ammonium was present sporadically around the lake, but had highest concentrations along the southern edge of the south lobe and seemed to correspond to areas of organic matter decomposition where soluble reactive phosphorus was also elevated. The colder and deeper groundwater generally had low reactive phosphorus concentrations. Chloride was

highest in the shallow groundwater near the boat landing. Chloride concentrations were also elevated in the channel, northeast corner of the north lobe, the west edge of the north lobe, and the south edge of the south lobe. Chloride is a biologically unreactive compound and its presence at elevated levels suggests human impacts. Higher chloride concentrations in some of the shallow and deep groundwater samples may reflect the influence of septic systems, fertilizers and road salts.

Alkalinity and total hardness concentrations in the shallow groundwater were highest where groundwater inflow was greatest and in areas where calcium carbonate was likely to be deposited (where water was exiting to groundwater). Alkalinity and total hardness generally occurred at the same concentration consistent with a geologic source. The south edge of the south lobe had higher concentrations, and all sites in the north lobe had concentration greater than 126 mg/L as $CaCO_3$.

In June, curly-leaf pondweed (*Potamogeton crispus*) comprised the major plant type in the entire south lobe and channel and was also found in the littoral zone of the north lobe of McGinnis Lake. This pondweed is tolerant of cold-water conditions and begins growing very early in spring. Relatively large quantities of phosphorus are held in the plant tissue. When the water warms, and the curly-leaf pond weed dies back, some of the phosphorus from the plant tissue is released into the water column, becoming available to other aquatic macrophytes and algae. The survey of *Potamogeton crispus* was conducted in June, just prior to senescence. Nine transects were set up in the lake, and the plants were removed from a known area, weighed, and analyzed to estimate the mass and nutrient concentrations. The estimated total biomass of *Potamogeton crispus* in McGinnis Lake was 1,800 kg (3,970 pounds). Approximately 4 kg (8.8 pounds) of TP was estimated from the *P. crispus* plant tissue while at its maximum growth in June. The TKN mass in the plant tissue was estimated to be 40 kg (88 pounds).

Phosphorus in the water column of the south lobe peaked near the time of senescence of the curly-leaf pondweed. The algal community also responded to this increase in nutrients. Chlorophyll *a* increased in the south lobe with a maximum on the July 10

sampling date. Water clarity fluctuated throughout the growing season, with the best water clarity measurements in June and in November. The dissolved oxygen (DO) in the south lobe decreased following the curly-leaf pondweed die back.

CONCLUSIONS/RECOMMENDATIONS

- Water quality in McGinnis Lake can be affected by both groundwater inflow and in-lake nutrient loading. Sources of in-lake nutrients include the elevated concentrations found in the hypolimnion of the north lobe and the decomposition of the curly-leaf pondweed. Human impacts to groundwater are suggested by the high concentrations of chloride and nutrients in some locations. Although interpreting sources of these impacts to groundwater quality is complicated by variations in travel times and flow paths, future land use planning in the groundwater shed should consider the groundwater connection between the land and McGinnis Lake.

- McGinnis Lake benefits from low quantities of surface runoff entering the lake. Relatively permeable soils result in most runoff infiltrating into the ground. This reduces the quantity of nutrients entering the lake by filtering particles and allowing for reaction and recycling on the land. Future land management should encourage infiltration and reduce runoff from residential and transportation activities near the lake. Establishing and maintaining high quality riparian buffers, minimizing runoff generation and designing to promote infiltration in the watershed will help water quality in the lake.

- Curly-leaf pondweed is dominating the aquatic macrophyte community in spring and is out-competing native species. Its June die-off is adding phosphorus to the lake system when algae are present and can use it. Intervention of this cycle may improve water quality. The shape and sediment composition in the south lobe of the lake will encourage macrophyte growth, and those plants likely stabilize the sediment and encourage settling of nutrients, but the establishment of other species may help water quality by altering the timing of the dieback. Mechanical harvesting and removing curly-leaf pondweed may help reduce phosphorus in the system.

- McGinnis Lake is a hard water, groundwater dominated lake which is subject to marl formation. Although marl formation has been suggested as a control to limit phosphorus levels, much of the marl appears to form in the lake in early spring, and the areas of significant groundwater inflow are on the northwest side of the north lobe. This time of substantial marl formation does not coincide with periods of high phosphorus concentration. While the precipitating marl may help reduce those levels, the timing and location of the mid-summer nutrient loading which appears linked to the curly-leaf pondweed die-back is at a time of low marl formation and located in the portion of the lake with lower marl formation potential. Consequently, the benefits of marl formation on phosphorus levels may not be offering significant relief for summer nutrient enrichment.

- Although this study was a detailed evaluation of McGinnis Lake water quality, it is based on a relatively short study. Continued water quality monitoring over time is important to confirming the trends observed during this study.

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APPENDICES

A – Water quality data

B – Lake turnover data

C – Interstitial chemistry

D – Mini piezometer data
Transect info with welling status

E – Macrophyte data

F – Algal data

MCGINNIS LAKE - 2002 ALGAL COMMUNITY COMPOSITION

PHYLUM GENUS TOTAL CELLS COUNTED & PERCENTAGE OF TOTAL, N=300

	05/25		06/27		07/10		07/24		08/07		08/21		09/05		09/19		10/21		11/10	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Cyanobacteria																				
Anabaena		0.0	2.0	0.7		0.0	3.0	1.0	1.0	0.3		0.0	3.0	1.0	2.0	0.7		0.0	3.0	1.0
Aphanizomenon		0.0		0.0	3.0	1.0	6.0	2.0	9.0	3.0	22.0	7.3	32.0	10.7	7.0	2.3	2.0	0.7		0.0
Chroococcus	3.0	1.0		0.0	1.0	0.3		0.0		0.0		0.0		0.0	1.0	0.3	2.0	0.7		0.0
Coelosphaerium	10.0	3.3	8.0	2.7	11.0	3.7	18.0	6.0	13.0	4.3	19.0	6.3	20.0	6.7	28.0	9.3	21.0	7.0	21.0	7.0
Gloeotrichia		0.0		0.0		0.0		0.0		0.0		0.0		0.0	2.0	0.7	4.0	1.3	3.0	1.0
Merismopedia	2.0	0.7		0.0	2.0	0.7		0.0		0.0		0.0		0.0		0.0	5.0	1.7		0.0
Microcystis	8.0	2.7	9.0	3.0	5.0	1.7	8.0	2.7	11.0	3.7	12.0	4.0	18.0	6.0	10.0	3.3	13.0	4.3	18.0	6.0
Nostoc		0.0		0.0		0.0		0.0		0.0		0.0	3.0	1.0		0.0	2.0	0.7	5.0	1.7
Oscillatoria	2.0	0.7		0.0	6.0	2.0	1.0	0.3		0.0	4.0	1.3	2.0	0.7	1.0	0.3	8.0	2.7	13.0	4.3
Phormidium		0.0		0.0	2.0	0.7		0.0		0.0		0.0	1.0	0.3		0.0		0.0	5.0	1.7
Scytonema		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	9.0	3.0	7.0	2.3
Snowella	7.0	2.3	5.0	1.7	9.0	3.0	11.0	3.7	9.0	3.0	11.0	3.7	7.0	2.3	2.0	0.7	7.0	2.3	6.0	2.0
Spirulina	1.0	0.3	3.0	1.0		0.0	4.0	1.3	2.0	0.7	1.0	0.3	1.0	0.3	1.0	0.3	5.0	1.7	6.0	2.0
		11.0		**9.0**		**13.0**		**17.0**		**15.0**		**23.0**		**29.0**		**18.0**		**26.0**		**29.0**
Dinophyta																				
Amphidinium	6.0	2.0		0.0	13.0	4.3	2.0	0.7		0.0	3.0	1.0	1.0	0.3	6.0	2.0	2.0	0.7		0.0
Ceratium 1	13.0	4.3		0.0		0.0		0.0		0.0		0.0		0.0	8.0	2.7	12.0	4.0	21.0	7.0
Ceratium 2	21.0	7.0	19.0	6.3	9.0	3.0	13.0	4.3	6.0	2.0	8.0	2.7	6.0	2.0	13.0	4.3	5.0	1.7		0.0
Peridinium	17.0	5.7	23.0	7.7	2.0	0.7	3.0	1.0	3.0	1.0	10.0	3.3	5.0	1.7	18.0	6.0	11.0	3.7	30.0	10.0
		19.0		**14.0**		**8.0**		**6.0**		**3.0**		**7.0**		**4.0**		**15.0**		**10.0**		**17.0**
Chlorophyta																				
Ankistrodesmus	5.0	1.7	13.0	4.3	19.0	6.3	18.0	6.0	11.0	3.7	7.0	2.3	13.0	4.3	9.0	3.0	4.0	1.3	6.0	2.0
Botryococcus		0.0		0.0	2.0	0.7	1.0	0.3	5.0	1.7	7.0	2.3	6.0	2.0	4.0	1.3	1.0	0.3	3.0	1.0
Bulbochaete		0.0		0.0		0.0		0.0	1.0	0.3		0.0	1.0	0.3	1.0	0.3		0.0		0.0

Chlamydomonas	2.0	0.7	5.0	1.7	2.0	0.7		0.0		0.0		0.0		0.0		0.0		0.0		0.0
Chlorella		0.0		0.0	6.0	2.0	4.0	1.3		0.0		0.0		0.0		0.0		0.0		0.0
Cladophora		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	1.0	0.3
Closterium	2.0	0.7	9.0	3.0	12.0	4.0	12.0	4.0	7.0	2.3	3.0	1.0	10.0	3.3	4.0	1.3	6.0	2.0	2.0	0.7
Coelastrum	4.0	1.3	7.0	2.3	11.0	3.7	8.0	2.7	6.0	2.0	4.0	1.3	7.0	2.3	4.0	1.3	2.0	0.7	2.0	0.7
Coleochaete		0.0		0.0		0.0		0.0		0.0	1.0	0.3		0.0		0.0		0.0	1.0	0.3
Cosmarium	1.0	0.3	3.0	1.0	5.0	1.7	8.0	2.7	6.0	2.0	3.0	1.0	9.0	3.0	4.0	1.3	2.0	0.7	4.0	1.3
Desmidium		0.0		0.0		0.0	1.0	0.3	2.0	0.7		0.0	1.0	0.3		0.0		0.0		0.0
Dictyosphaerium		0.0	2.0	0.7	5.0	1.7		0.0	4.0	1.3		0.0	3.0	1.0	1.0	0.3		0.0		0.0
Euastrum		0.0		0.0		0.0		0.0	1.0	0.3	1.0	0.3	1.0	0.3	3.0	1.0		0.0		0.0
Gonium	1.0	0.3		0.0	1.0	0.3		0.0		0.0		0.0		0.0		0.0		0.0		0.0
Haematococcus		0.0		0.0		0.0		0.0		0.0		0.0	3.0	1.0	1.0	0.3		0.0		0.0
Hydrodictyon		0.0		0.0		0.0		0.0	1.0	0.3		0.0	1.0	0.3	1.0	0.3		0.0		0.0
Mesotaenium		0.0		0.0	3.0	1.0	1.0	0.3	3.0	1.0		0.0	6.0	2.0		0.0		0.0		0.0
Micrasterias		0.0		0.0	2.0	0.7	5.0	1.7	4.0	1.3	1.0	0.3	5.0	1.7	2.0	0.7		0.0	1.0	0.3
Microspora		0.0		0.0		0.0		0.0		0.0		0.0	5.0	1.7		0.0		0.0		0.0
Mougeotia		0.0	5.0	1.7	8.0	2.7	13.0	4.3	20.0	6.7	11.0	3.7	6.0	2.0	5.0	1.7	7.0	2.3	1.0	0.3
Oedogonium		0.0	3.0	1.0	5.0	1.7	3.0	1.0	1.0	0.3		0.0		0.0	1.0	0.3		0.0	4.0	1.3
Oocystis	6.0	2.0	9.0	3.0	9.0	3.0	6.0	2.0	5.0	1.7	2.0	0.7	4.0	1.3	4.0	1.3		0.0	3.0	1.0
Pandorina	2.0	0.7	4.0	1.3		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0
Pediastrum		0.0	5.0	1.7	3.0	1.0	6.0	2.0	6.0	2.0	1.0	0.3		0.0		0.0		0.0	3.0	1.0
Pyramimonas	2.0	0.7	5.0	1.7	1.0	0.3		0.0		0.0		0.0		0.0		0.0		0.0		0.0
Quadrigula		0.0		0.0		0.0	1.0	0.3	3.0	1.0		0.0		0.0	2.0	0.7		0.0		0.0
Rhizoclonium		0.0		0.0		0.0		0.0	1.0	0.3		0.0		0.0		0.0		0.0		0.0
Scenedesmus	3.0	1.0	3.0	1.0	5.0	1.7	9.0	3.0	8.0	2.7	11.0	3.7	2.0	0.7	7.0	2.3		0.0	8.0	2.7
Selenastrum	4.0	1.3	13.0	4.3		0.0	5.0	1.7	8.0	2.7	6.0	2.0	2.0	0.7	10.0	3.3		0.0	4.0	1.3
Spirogyra		0.0		0.0		0.0		0.0	1.0	0.3		0.0		0.0	1.0	0.3		0.0	2.0	0.7
Staurastrum	1.0	0.3	5.0	1.7	9.0	3.0	2.0	0.7		0.0	2.0	0.7		0.0	6.0	2.0	3.0	1.0		0.0
Tetraedron		0.0		0.0		0.0		0.0	2.0	0.7		0.0		0.0		0.0		0.0		0.0
Tetraselmis	3.0	1.0	2.0	0.7		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0
Ulothrix		0.0	2.0	0.7	4.0	1.3		0.0		0.0		0.0		0.0	1.0	0.3	4.0	1.3		0.0
Zygnema		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	2.0	0.7	1.0	0.3
		12.0		**31.7**		**37.3**		**34.3**		**35.3**		**20.0**		**28.3**		**23.7**		**10.3**		**15.3**

Ochrophyta																				
Asterionella	3.0	1.0	5.0	1.7	3.0	1.0	2.0	0.7	3.0	1.0	6.0	2.0	2.0	0.7	4.0	1.3	1.0	0.3	1.0	0.3
Cyclotella	2.0	0.7	6.0	2.0	5.0	1.7	4.0	1.3		0.0		0.0		0.0		0.0		0.0		0.0
Cymbella	4.0	1.3	1.0	0.3	2.0	0.7		0.0	2.0	0.7	2.0	0.7	1.0	0.3	2.0	0.7		0.0		0.0
Diatoma		0.0	1.0	0.3		0.0		0.0	1.0	0.3	5.0	1.7	6.0	2.0	4.0	1.3		0.0	1.0	0.3
Dinobryon	16.0	5.3	12.0	4.0	7.0	2.3	2.0	0.7	1.0	0.3	6.0	2.0	8.0	2.7	11.0	3.7	4.0	1.3	7.0	2.3
Fragilaria 1	5.0	1.7	5.0	1.7	6.0	2.0	5.0	1.7	4.0	1.3	6.0	2.0	3.0	1.0	1.0	0.3		0.0		0.0
Fragilaria 2		0.0	6.0	2.0	3.0	1.0	1.0	0.3		0.0	8.0	2.7	4.0	1.3	3.0	1.0	5.0	1.7	2.0	0.7
Gomphonema	3.0	1.0	2.0	0.7		0.0	3.0	1.0	5.0	1.7	6.0	2.0	2.0	0.7	1.0	0.3	1.0	0.3	2.0	0.7
Mallomonas	8.0	2.7	5.0	1.7	2.0	0.7	1.0	0.3		0.0	1.0	0.3	3.0	1.0	6.0	2.0	3.0	1.0	4.0	1.3
Melosira		0.0		0.0	2.0	0.7	1.0	0.3	5.0	1.7	6.0	2.0	2.0	0.7	2.0	0.7	1.0	0.3	4.0	1.3
Navicula 1	5.0	1.7	1.0	0.3	3.0	1.0	3.0	1.0	3.0	1.0	5.0	1.7	1.0	0.3	1.0	0.3		0.0	2.0	0.7
Navicula 2	3.0	1.0	3.0	1.0		0.0		0.0		0.0		0.0		0.0		0.0	3.0	1.0	2.0	0.7
Navicula 3		0.0		0.0	1.0	0.3		0.0	1.0	0.3	5.0	1.7	1.0	0.3		0.0		0.0		0.0
Ochromonas	13.0	4.3	8.0	2.7	14.0	4.7	1.0	0.3	2.0	0.7	2.0	0.7	3.0	1.0	1.0	0.3	3.0	1.0	5.0	1.7
Stephanodiscus	1.0	0.3		0.0		0.0		0.0		0.0		0.0	1.0	0.3		0.0		0.0		0.0
Synedra 1	5.0	1.7	4.0	1.3	4.0	1.3	4.0	1.3	4.0	1.3	3.0	1.0	9.0	3.0	2.0	0.7	2.0	0.7	1.0	0.3
Synedra 2	2.0	0.7	1.0	0.3		0.0		0.0	2.0	0.7	3.0	1.0	4.0	1.3	1.0	0.3		0.0	2.0	0.7
Synura	11.0	3.7	9.0	3.0	8.0	2.7	0.0	0.0		0.0	2.0	0.7	1.0	0.3		0.0	1.0	0.3	4.0	1.3
Tabellaria		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	2.0	0.7
		27.0		**23.0**		**20.0**		**9.0**		**11.0**		**22.0**		**17.0**		**13.0**		**8.0**		**13.0**
Euglenophyta																				
Astasia	11.0	3.7	5.0	1.7	1.0	0.3	13.0	4.3	7.0	2.3	2.0	0.7	0.0	0.0	2.0	0.7	9.0	3.0	0.0	0.0
Colacium		0.0		0.0		0.0		0.0		0.0		0.0		0.0	1.0	0.3	5.0	1.7	3.0	1.0
Euglena 1	22.0	7.3	17.0	5.7	4.0	1.3		0.0	2.0	0.7	3.0	1.0		0.0	3.0	1.0	4.0	1.3	6.0	2.0
Euglena 2	5.0	1.7	3.0	1.0	13.0	4.3	22.0	7.3	31.0	10.3	20.0	6.7	14.0	4.7	11.0	3.7	12.0	4.0	3.0	1.0
Euglena 3		0.0		0.0		0.0	17.0	5.7	25.0	8.3	19.0	6.3	20.0	6.7	33.0	11.0	40.0	13.3	8.0	2.7
Phacus 1	17.0	5.7	21.0	7.0	17.0	5.7	10.0	3.3	6.0	2.0	7.0	2.3	15.0	5.0	7.0	2.3	13.0	4.3	2.0	0.7
Phacus 2	2.0	0.7	8.0	2.7	9.0	3.0	22.0	7.3	18.0	6.0	9.0	3.0	1.0	0.3	16.0	5.3	10.0	3.3	17.0	5.7
Phacus 3		0.0		0.0		0.0	5.0	1.7	13.0	4.3	14.0	4.7	8.0	2.7	4.0	1.3	7.0	2.3	3.0	1.0
Trachelomonas	12.0	4.0	3.0	1.0	7.0	2.3	4.0	1.3		0.0	1.0	0.3	2.0	0.7	4.0	1.3	14.0	4.7	21.0	7.0
		23.0		**19.0**		**17.0**		**31.0**		**34.0**		**25.0**		**20.0**		**27.0**		**38.0**		**21.0**
Cryptophyta																				

	Chilomonas	6.0	2.0	2.0	0.7	5.0	1.7	1.0	0.3		0.0		0.0		0.0	1.0	0.3	5.0	1.7	2.0	0.7
	Cryptomonas	15.0	5.0	7.0	2.3	7.0	2.3	5.0	1.7	3.0	1.0	6.0	2.0	3.0	1.0	8.0	2.7	16.0	5.3	10.0	3.3
			7.0		**3.0**		**4.0**		**2.0**		**1.0**		**2.0**		**1.0**		**3.0**		**7.0**		**4.0**
Unidentifiable																					
		3.0	**1.0**	1.0	**0.3**	2.0	**0.7**	2.0	**0.7**	2.0	**0.7**	3.0	**1.0**	2.0	**0.7**	1.0	**0.3**	2.0	**0.7**	2.0	**0.7**
			100.0		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**