An Evaluation of Past and Present Water Quality Conditions in Bear Lake, Waupaca County, Wisconsin

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Executive Summary

Water quality concerns regarding Bear Lake, Waupaca County, Wisconsin have prompted this study of the physical, chemical and biological characteristics of the lake, the groundwater feeding it, and its watershed. Some of the local residents have perceived an increase in aquatic plants over the years and the State of the Wolf Basin (DNR, 2001) has characterized Bear Lake as being sensitive to phosphorous loading and having poor water quality due to some algae blooms and somewhat excessive plant growth**.**

This study was conducted beginning in the spring of 2001 to evaluate current water quality conditions in Bear Lake. The study consisted of lake and stream water quality monitoring, a shallow groundwater assessment, an aquatic plant survey, delineation of groundwater and surface watersheds, and a survey of the residents living within the Bear Lake watershed. We met with the Bear Lake Association and watershed citizens before the study to discuss study design and again at the end to share the results.

In addition to a current "State of Bear Lake", the results of this study were compared to the results of a study conducted in the late 70's and early 80's to determine if noticeable changes are occurring within the lake and to guide lake management decisions. Depleted dissolved oxygen concentrations continue to be a concern. Much of the lake (below 20 feet deep) has dissolved oxygen concentrations that are below 1 mg/L during the summer growing season. These are conditions that are uninhabitable by most aquatic organisms. These oxygen conditions are related to nutrients (predominantly phosphorus) that entered the lake over time. The sources of the nutrients are from within the watershed as well as local shoreland practices and uses.

Results of the current study, when compared to the 1980s data, show several changes. Secchi disk readings, which measure water clarity, have improved since the late 1970's and early 1980's. Chlorophyll *a* (a measure of algae) has also shown a great improvement over the past twenty-five years. Nutrient concentrations appear to have remained fairly constant in the hypolimnion (bottom) of the lake. This continuity is not surprising, as once phosphorus enters a lake, it begins to cycle within the system and removal is difficult and takes a considerable amount of time.

Over time the reduction of new nutrient inputs to the lake should improve the lake's water quality. This nutrient reduction should take place on both a local and watershed scale. The citizen survey revealed that 95% of the respondents use lawn and/or garden fertilizer. Efforts to reduce/eliminate the use of fertilizers should be made. Other near-lake recommendations include recreating riparian buffers to reduce sediments and nutrient movement to the lake and provide habitat for the majority of lake species that require near-shore habitat as part of their life cycle.

Much of the shallow groundwater flowing into Bear Lake is impacted from local and/or wetland influences. Approximately 20% of the shallow groundwater sites that were sampled appear to be influenced by septic system impacts. Efforts should be made to site future systems as far from the lake as possible, particularly in areas identified as groundwater inflow in this study.

In the watershed the use of best management practices can help to reduce agricultural sources of nutrient inputs to Bear Lake. These practices include (but are not limited to) nutrient management, cover crops, crop rotations, fencing animals from streams, maintaining vegetative cover in pastures, controlling and properly land spreading animal waste, and utilizing buffers near wetlands, steam corridors, and the lake.

The diversity of aquatic plants in Bear Lake is about average for a developed lake in this part of Wisconsin. Most of the plants that are present are tolerant of disturbance and some can coexist well with light-limited conditions produced by algae blooms. Eurasian milfoil was identified in the aquatic plant survey. This exotic species was concentrated in a small area on the north end of the lake. Prompt action is necessary to control the spread of this exotic species.

It is important for individuals that live within the Bear Lake watershed to acknowledge their role in protecting the lake. Information about Bear Lake is available and should be utilized to develop a lake/watershed management plan. This plan should identify a vision for the lake, goals for the lake water and habitat quality, and identify options for obtaining these goals. Ideally the plan should be constructed using input from the Lake Association members, watershed citizens and businesses, county and university personnel, Department of Natural Resources, and others.

ACKNOWLEDGEMENTS

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The Bear Lake Association for their interest and desire to learn more about the lake.

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INTRODUCTION

Water quality concerns regarding Bear Lake, Waupaca County, Wisconsin have prompted further study of the physical, chemical and biological characteristics of the lake and the groundwater feeding it. Local residents have observed an increase in plants over the years. The Wolf Basin team has characterized Bear Lake as being sensitive to phosphorous loading and having poor water quality due to some algae blooms and somewhat excessive plant growth. This study was initiated to assess Bear Lake and its watershed and identify areas and practices that can reduce nutrient inputs to the lake.

Description of Study Area

Bear Lake is a 194-acre natural drainage lake with a maximum depth of 62 feet, and is located just outside the town of Manawa, and in the townships of Little Wolf and Royalton in Waupaca County, Wisconsin. It receives its water from groundwater inflow, runoff, precipitation, and three streams, which converge in a wetland area and flow into the southwest end of Bear Lake. Bear Lake drains into the Lower Little Wolf River and is within the Wolf River Basin. Both residents and area visitors use Bear Lake for recreation. The lake's development includes 85 houses and a public campground on the east side. It has one public boat landing and one public beach.

A lake management plan was produced for the Bear Lake Watershed in 1984 using water quality data collected in the late 1970's and early 1980's. The Bear Lake Homeowners Association was interested in collecting water quality and plant information to compare with the older data to determine if measurable changes are occurring in the lake and to update management strategies. The Lower Little Wolf River watershed was designated in 1998 as an USDA-EQIP watershed and henceforth, has had some non-point source issues addressed by the Waupaca County Land Conservation Department staff. Some of their efforts have resulted in conservation tillage practices on over 300 acres and the re-creation of wetlands within the Bear Lake Watershed .

The surface watershed (Figure 1) is approximately 2,725 acres and the groundwater watershed is approximately 3,569 acres (Figure 2). The regional (deeper) groundwater flow comes in from the southwest and flows out of the north-northeast end of the lake. Due to the steep topography of the area, there is local groundwater inflow all around the lake.

Objectives of this study were to:

- Determine the current quality of groundwater feeding Bear Lake, the surface water quality of Bear Lake, and long-term trends in surface water quality.

- Assess the land use practices within the surface and groundwater watersheds and how they are related to Bear Lake's water quality.

- Quantify principle nutrient and water budget components through groundwater flow estimates, water quality measurements, and land use. Relate to surface water quality through lake response models.

- Survey the aquatic macrophytes within the lake and determine if exotic species are present.

- Survey the landowners within the watershed to determine their uses of the lake, perceptions of water and fishing quality, and changes that may have occurred, as well as household and land use practices that may effect lake water quality.

- Provide recommendations to update the 1984 management plan that can initiate steps toward future lake management decisions to maintain or improve the health of the Bear Lake ecosystem.

Figure 1. Surface watershed of Bear Lake, Waupaca County, Wisconsin.

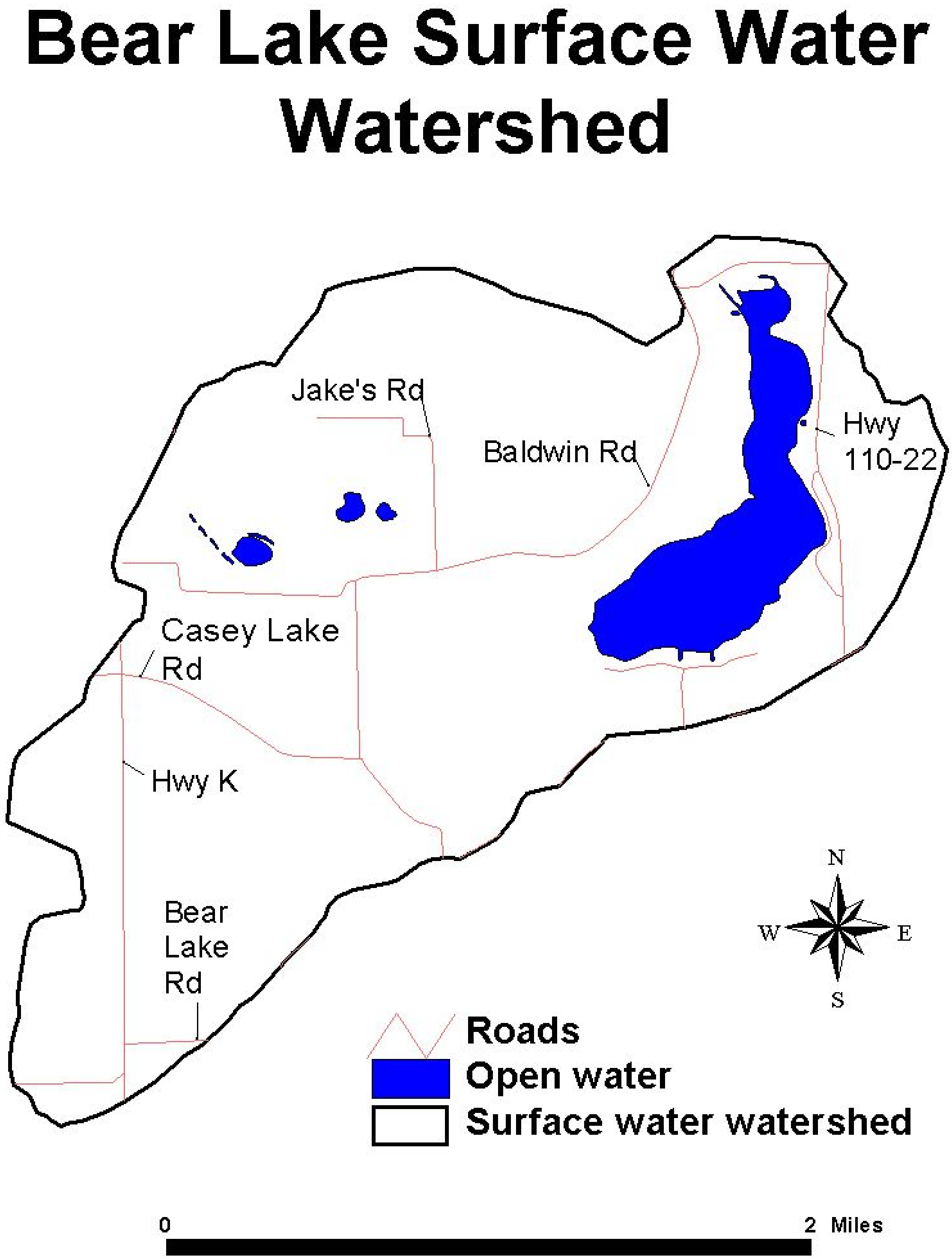
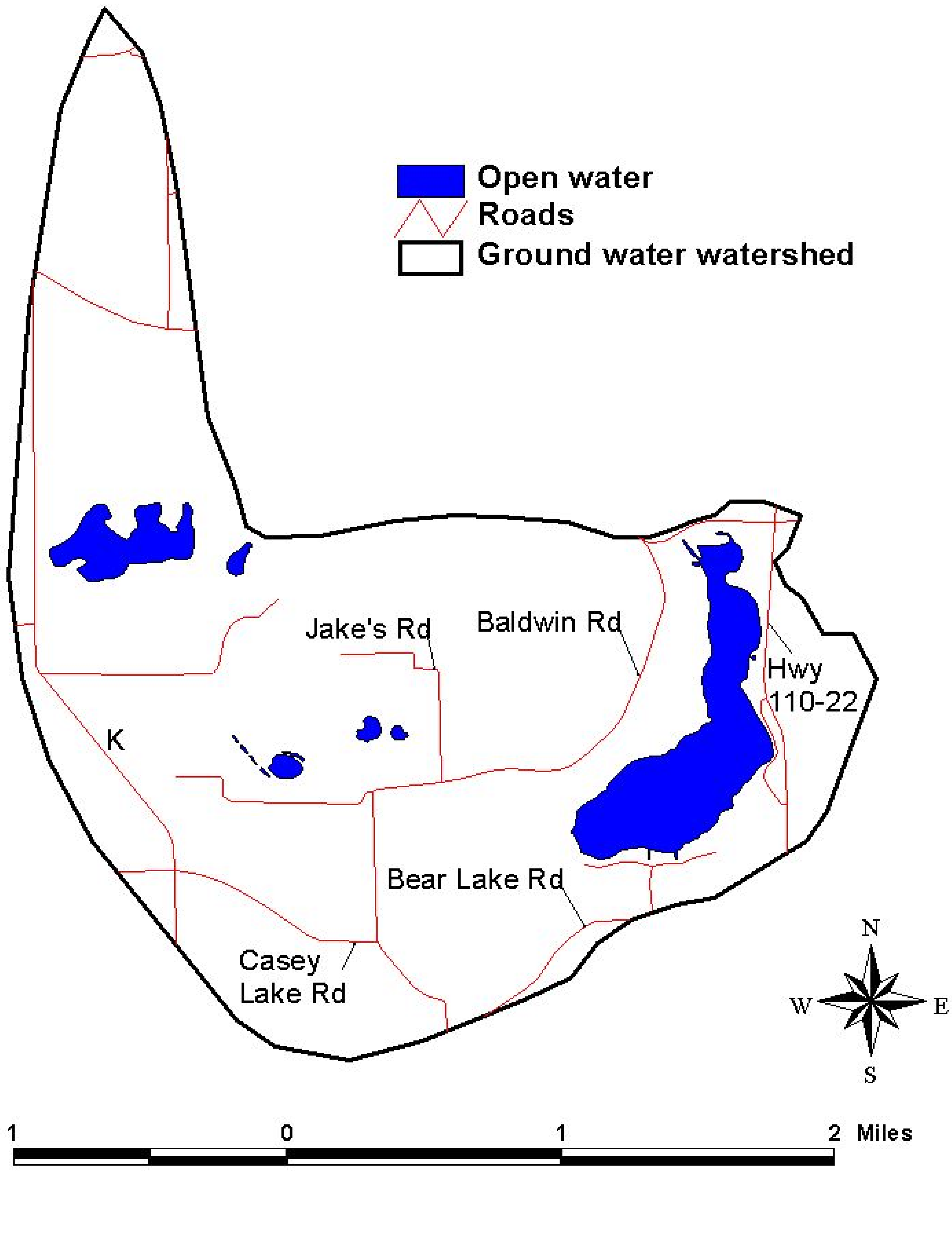


Figure 2. Groundwater watershed of Bear Lake, Waupaca County, Wisconsin.

Bear Lake
Groundwater Watershed

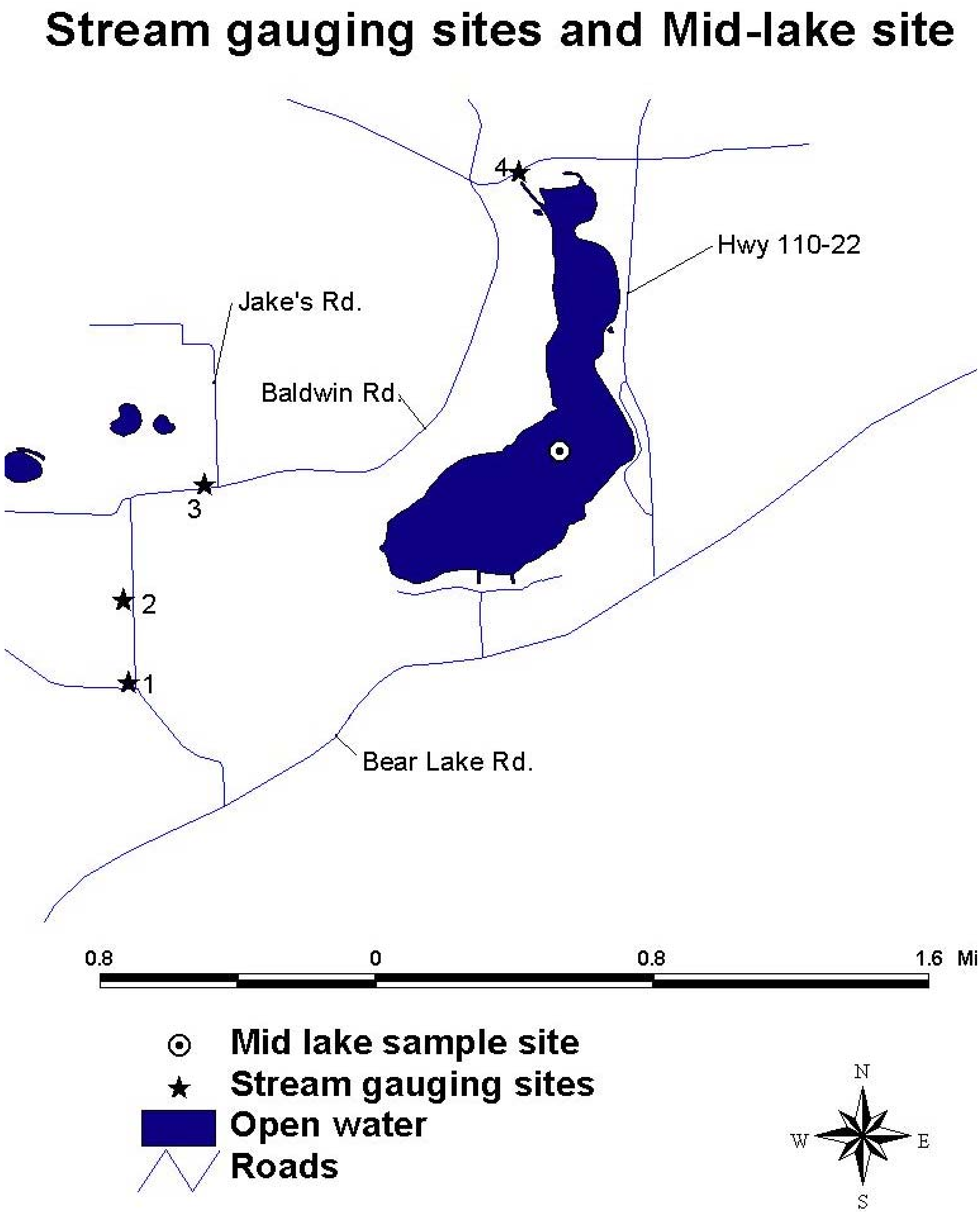


Methods

Stream Flow

Stream flow was measured at the Bear Lake inflows and outflow bi-monthly during June through September of 2001 with a Marsh McBirney Model 2000 portable flow meter, 100 ft. tape, and 2 chaining pins. The inflow consists of three streams, which converge in a wetland area, so the inflow was gauged at the three separate streams along Baldwin Road prior to convergence. A map displaying the locations of the stream gauging sites can be found in Figure 3. Inflow 1 is located on the southwest side of the intersection of Baldwin and Casey Lake Road. Inflow gauging site 2 is in a wooded corridor on the south side of Baldwin Rd. west of inflow 1. Inflow gauging site 3 is located where Spiegleberg Creek crosses Baldwin Rd., just south of the intersection of Jake's Rd. and Baldwin Rd. The outflow of Bear Lake was gauged on the south side of North Water Dr. (4).

Figure 3. Map of stream gauging sites and the mid-lake sample site.



Mid-Lake Chemistry

Temperature and dissolved oxygen profiles, Secchi disk readings, and surface conductivity readings were taken bi-monthly from June through September 2001, and monthly in May, October, November, and January, at the mid-lake site. The mid-lake site, the deepest area in the lake, is 62 feet deep, and was found by using an on-board depth recorder. The site was described by using landmarks around the lake, and marked with a Global Positioning System (GPS) (Figure 3).

Secchi disc readings were taken using a standard 8-inch diameter weighted disc. The disc was lowered over the downwind, shaded side of the boat until it just disappeared from sight and then raised until it was just visible. The mean of the two depths was recorded. Surface conductivity was measured with a Mettler 126 conductivity meter.

Dissolved oxygen and temperature readings were taken using an YSI Model 50B dissolved oxygen meter (Method 4500-06, APHA 1995). Readings were taken every two feet starting at the surface and terminating at the lake bottom. The readings were used to determine stratification and identify depths to take the water samples. Samples for epilimnion, metalimnion, and hypolimnion were collected monthly from May through November and once in February of 2002, using an alpha bottle. A preserved 125ml bottle was prepared in the lab with 0.35mls of 1+1 H_2SO_4 per 125mls of sample and filled in the field by transferring the sample from an unpreserved bottle to avoid loss of the H_2SO_4. All samples that needed to be filtered were field filtered through an 42.5 mm in-line filtering apparatus with a 60 ml syringe and 0.45 *u*m membrane filters. Analyses performed on the mid-lake samples include: nitrate and nitrite (NO_2+NO_3-(N)), ammonium (NH_4-(N)), Total Kjeldahl Nitrogen (TKN), Total phosphorus (TP), soluble reactive phosphorus, chloride, pH, conductivity, alkalinity, total hardness, and chlorophyll *a*.

Chlorophyll *a* samples were collected monthly from June through September. Samples were collected near the surface as grab samples and field filtered using a 42.5 mm in-line filtering apparatus with a hand pump through 0.45 *u*m membrane filters. The filter was folded in half (chlorophyll *a* on the inside) and wrapped in aluminum foil and transported back to the ETF lab on ice. One exception occurred on May 31st when the sample was transferred into a 1 liter polyethylene bottle and transported back to the lab for filtering.

All samples were collected and transported on ice to the state certified Environmental Task Force Lab (ETF) located at the University of Wisconsin-Stevens Point. All lab analyses were completed using the methods described in Table 1.

Groundwater Study

Mini-piezometers were inserted into the lake bottom approximately every 200-300 feet. Mini-piezometers were used to collect hydraulic head data at 69 sites around Bear Lake in August 2001, using the Hvorslev slug test (Hvorslev, 1951). Each site was thoroughly described and GPS readings were collected along with markings on a map with site identification (Figure 4). Groundwater inflow areas occurred where the head level in the mini-piezometer was above the lake surface and outflow areas occurred where the head level in the mini-piezometer was below the lake surface (Figure 5). Samples were collected from groundwater inflow (up-welling) areas.

Mini-piezometers were constructed from 5 foot length 4mm hollow polypropylene tubing. At one end there is 2-inch screen that was made by using a small diameter needle and sewing machine to allow the pore water to enter into the tubing, completely separate from lake water. The end below the holes was melted closed and a 1 mL plastic pipette tip was attached to the end of the well for ease of insertion. A steel rod was inserted into the mini-piezometer tube to make it rigid enough to be pushed into the sediment. A steel tile probe initiated the hole before the well was introduced into the ground. The tile probe was only used on sites where it became difficult to insert the well due to the hard, compact substrate.

The mini-piezometers were inserted approximately 2 ft. into the sediment in approximately 18 inches of water. Once the mini-piezometer was installed, a plastic syringe was used to determine the hydraulic head relative to the lake water surface and to extract a pore water sample from each site. Pore water was filtered through a 42.5 mm in-line filtering apparatus with a 60 ml syringe through 934/AH (0.45 micron) membrane filters and analyzed for $NO_2 + NO_3$ (N), ammonium, chloride, and reactive phosphorus.

Table 1. Analytical methods and corresponding detection limits for ETF Lab.

ANALYSES	*METHOD*	**METHOD DETECTION LIMIT**
Alkalinity	Titrimetric 2320 B	4 mg/L
Chloride	Automated Ferricyanide 4500 C1 E	0.2 mg/L
Chlorophyll *a*	Spectrometric 10200 H	0.1 mg/L
Color	Spectrometric 2120	5 cu
Conductivity	Conductivity Bridge 2510 B	0 umhos
Hardness, Calcium	Titrimetric 3500 Ca D	4 mg/L
Hardness, Total	Titrimetric 2340 C	4 mg/L
Nitrogen, Ammonia	Automated Salicylate 4500-NH_3 G	0.01 mg/L
Nitrogen, Nitrate + Nitrite	Automated Cadmium Reduction 4500 NO_3 F	0.021 mg/L
Nitrogen, Total Kjeldahl	Block Digester; Auto Salicylate 4500-NH3 G	0.08 mg/L
pH	Electrometric 4500 H B	0 mg/L
Phosphorus, 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	2/46 ug/L
Sulfur (SO4)	ICP 3120B	26 ug/L
Turbidity	Nephelometric 2130 B	0.5 mg/L

Figure 4. Location of mini-piezometer sampling sites around Bear Lake.

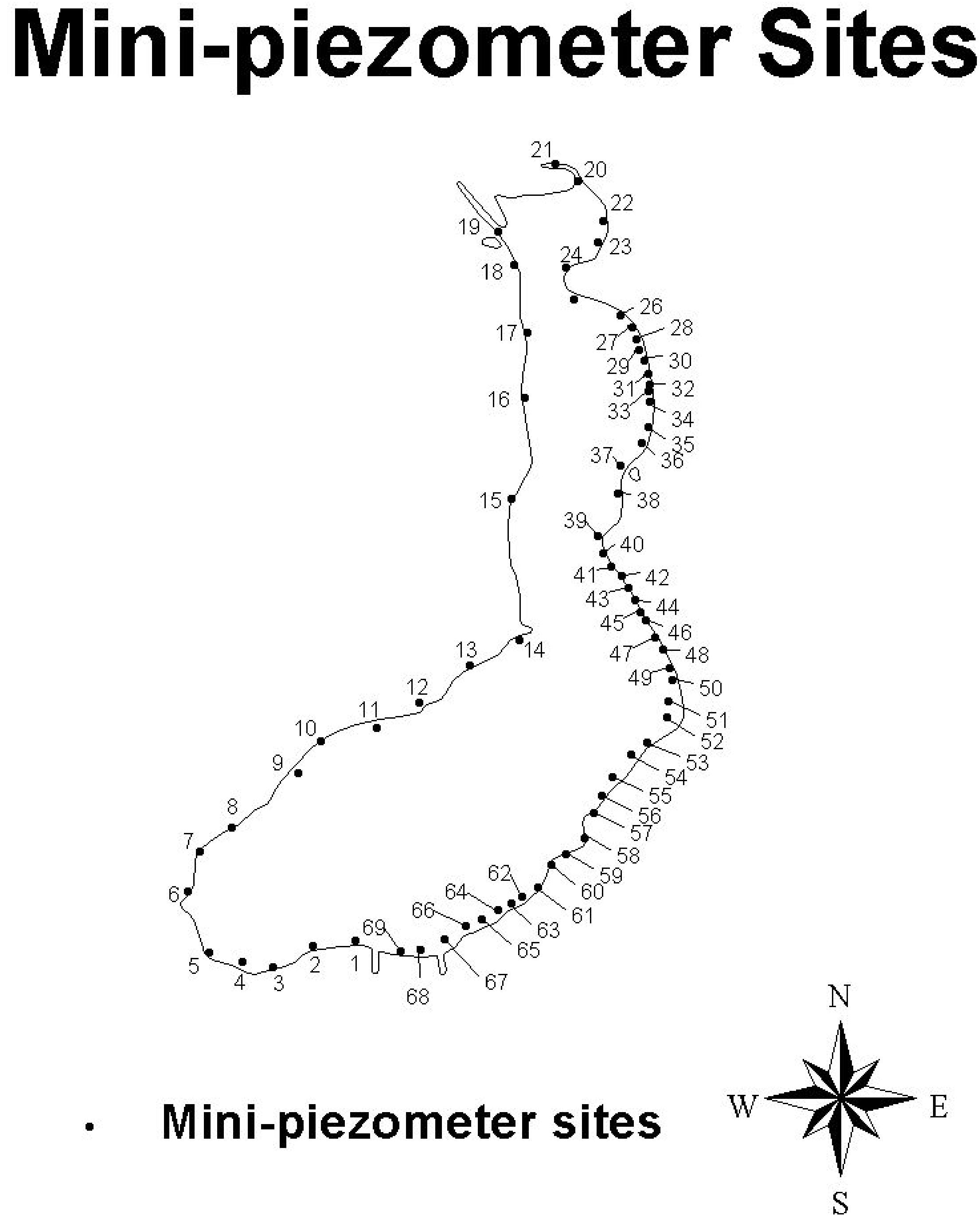
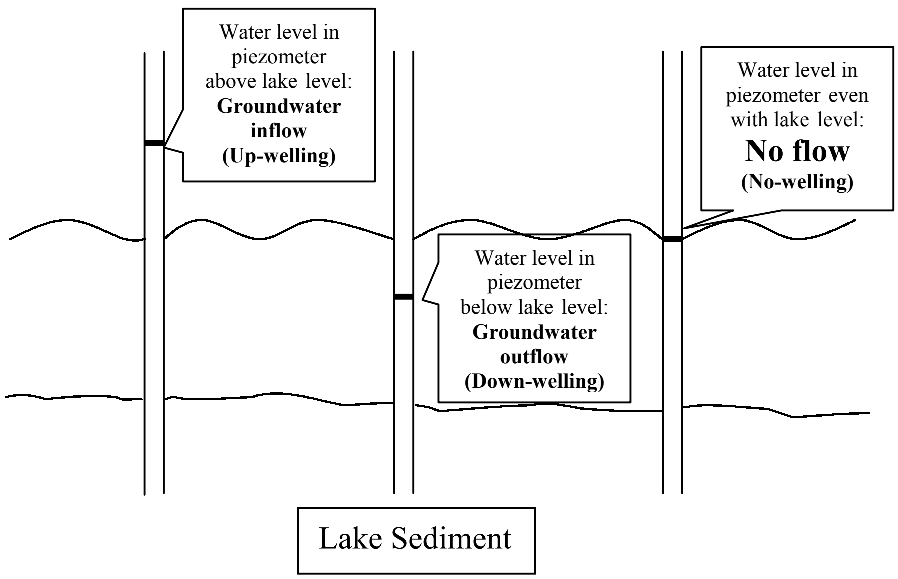


Figure 5. Diagram showing determination of groundwater up-welling, down-welling and no-welling using mini-piezometers.



Interstitial Water, Aquatic Macrophyte, and Sediment Study

Sediment, aquatic macrophyte, and interstitial water samples were taken at twelve sites around the lake (Figure 6), which site numbers corresponded with the aquatic plant survey conducted by the ETF lab. A 1/8 meter square constructed of ¾" diameter PVC tubing, was randomly dropped in about three feet of water at each of the 12 sites around the lake. Aquatic macrophytes rooted within the PVC area were collected and transported on ice to the ETF lab for analysis. Analyses for aquatic macrophytes include: TKN and TP.

Interstitial water samples were taken using a 6-inch length of polyethylene diffuser tubing (3/4 inch outside diameter) with a 1 inch Delrin tip. A ¼ inch threaded rod was placed inside the diffuser tubing and a 1/8-inch outside diameter piece of Tygon tubing was attached. The bottom of a 6"coffee can was also attached to the diffuser tubing to prevent surface water infiltration into the sample. Figure 7 shows a diagram of the interstitial water sampling device. The device was inserted into the sediment adjacent to the disturbed area where aquatic macrophytes were collected, using a rigid steel rod

Figure 6. Map of interstitial water, sediment, and aquatic macrophyte collection sites around Bear Lake, which also correspond with the aquatic plant survey sites.

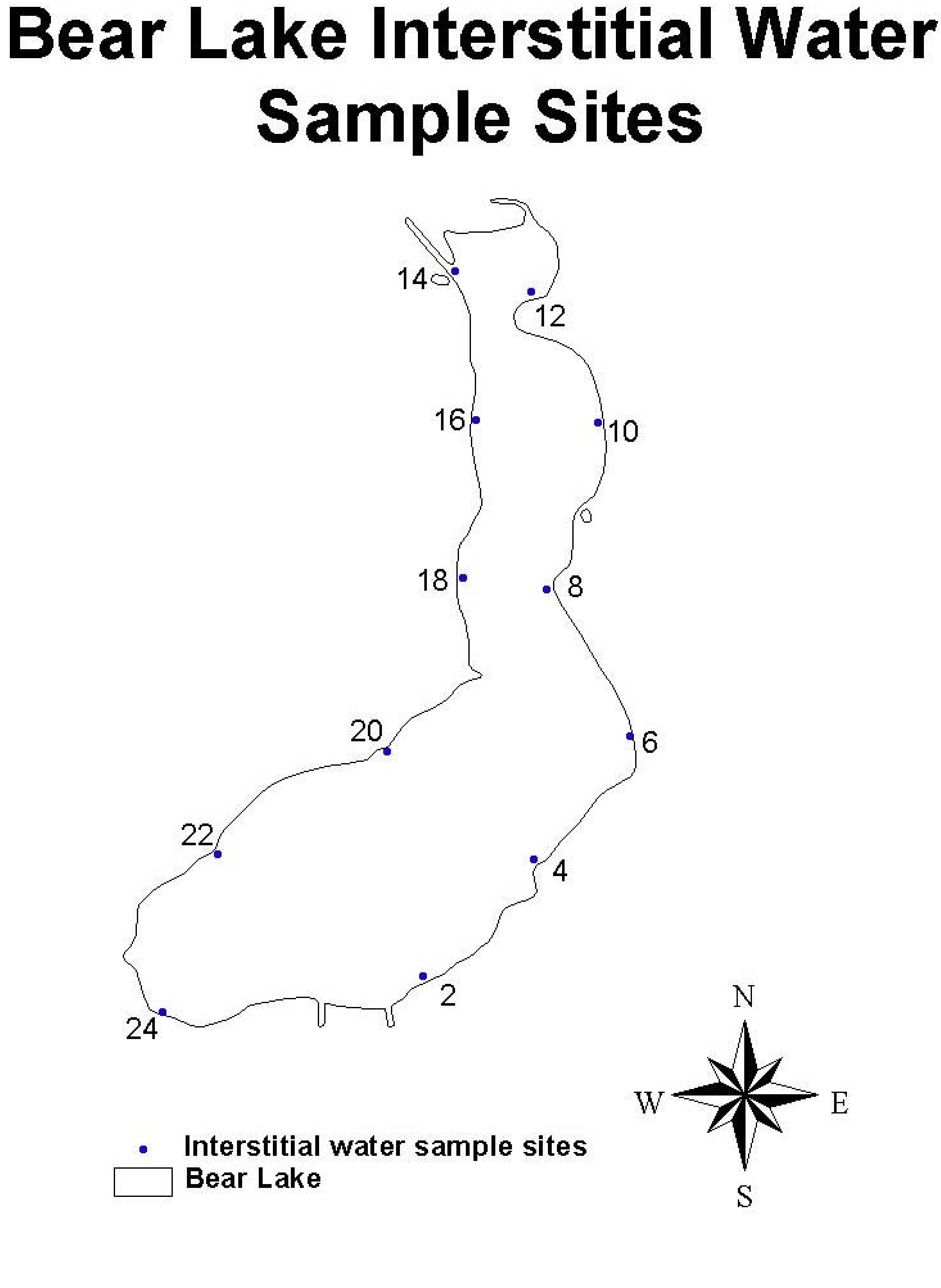
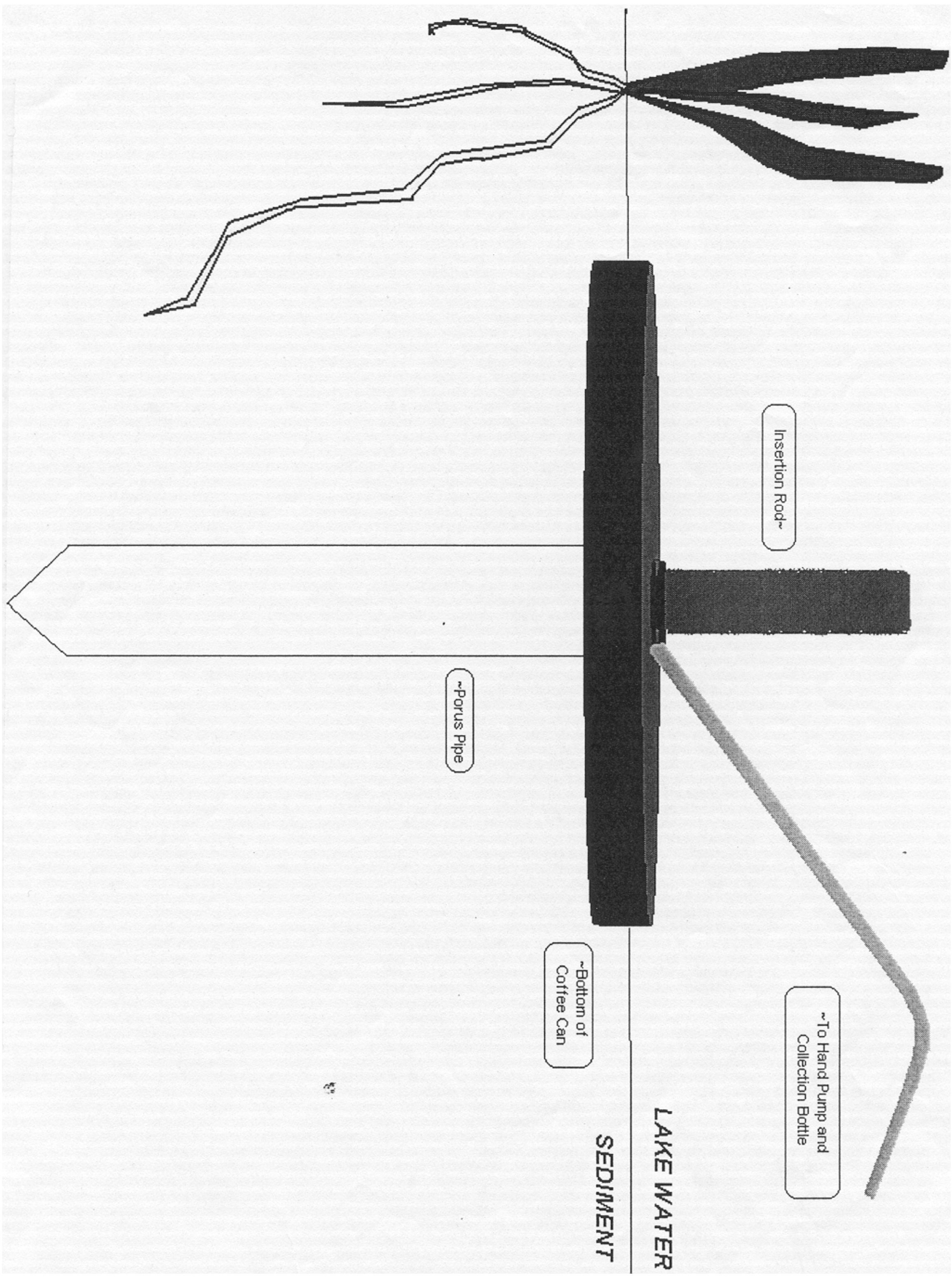


Figure 7. Diagram of interstitial water sampling device.



threaded to the rod inside the diffuser tubing. Sample was pulled up through the piece of Tygon tubing with the use of a hand pump. The hand pump was attached to a side-arm flask equipped with an in-line filter cassette containing a 0.45 micron and a 934 AH 47mm glass fiber filter. The first 20ml of sample was used to rinse the device, then the analyzed sample was collected in a H_2SO_4 preserved bottle.

Sediment samples were taken from an undisturbed adjacent area to the aquatic macrophyte and interstitial water samples. A hollow PVC pipe 2 inches in diameter, was inserted approximately 6" into the sediment and a rubber stopper was inserted in the top to create a suction to collect sediment from the lake bottom. The samples were collected in plastic food grade bags and transported on ice back to the ETF lab for analysis. The sediment samples were analyzed for NO_2+NO_3, ammonium, potassium, sulfate, reactive phosphorus, total percent solids, and percent organic matter.

PHYSICAL SETTING

Topography

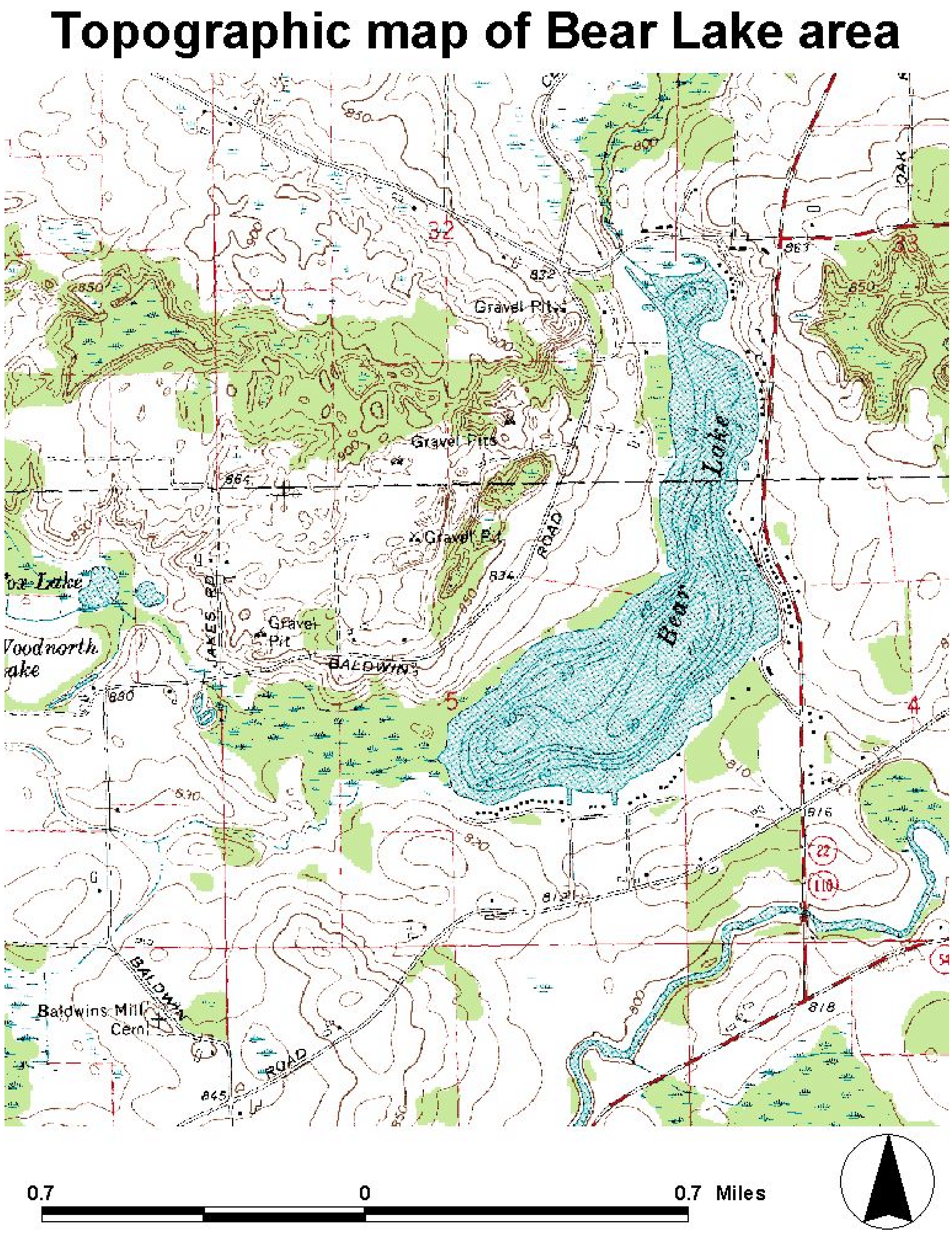
The topography of the Bear Lake watershed consists of rolling hills with gentle to steep slopes interspersed with flat poorly drained basins (Figure 8). Areas of high relief form the boundaries of the surface water watershed (Figure 1).

The topography of the northwestern and north-central portions of the watershed is quite complex and is frequently pitted with kettles (depressions left by large, melting ice blocks during the waning years of glaciation). Most of the kettles are filled with water to form small ponds and Woodnorth and Fox Lakes. The topography of this area has been further altered by sand and gravel mining operations.

Geology

The bedrock underlying the watershed consist of mostly Precambrian granites, which are the oldest types of bedrock found in Wisconsin. Much of the younger, overlying sandstone and limestone bedrock was eroded away in this area prior to the last glacier. Glaciers further eroded the crystalline granite bedrock and considerably altered the landscape. However, the major drainage valleys of the Wolf River remained (Berkstresser 1964; Weidman and Schultz 1915).

Figure 8. Topography map of the Bear Lake Area, Waupaca Co., WI.



The surface geology of Waupaca County was largely determined by the Cary and Valders stages of the Wisconsin Glacier. Massive ice movements and subsequent melting resulted in the formation of hills, drumlins, kettles, drainage basins and their surface deposits. The Bear Lake watershed is located near the border between Cary and Valders deposits. These glacial drift deposits are composed of silt, sand, gravel, cobbles and boulders that originally came from bedrock types to the north and east of Waupaca County (Bushweiler, B. and Rasman, T. 1984.).

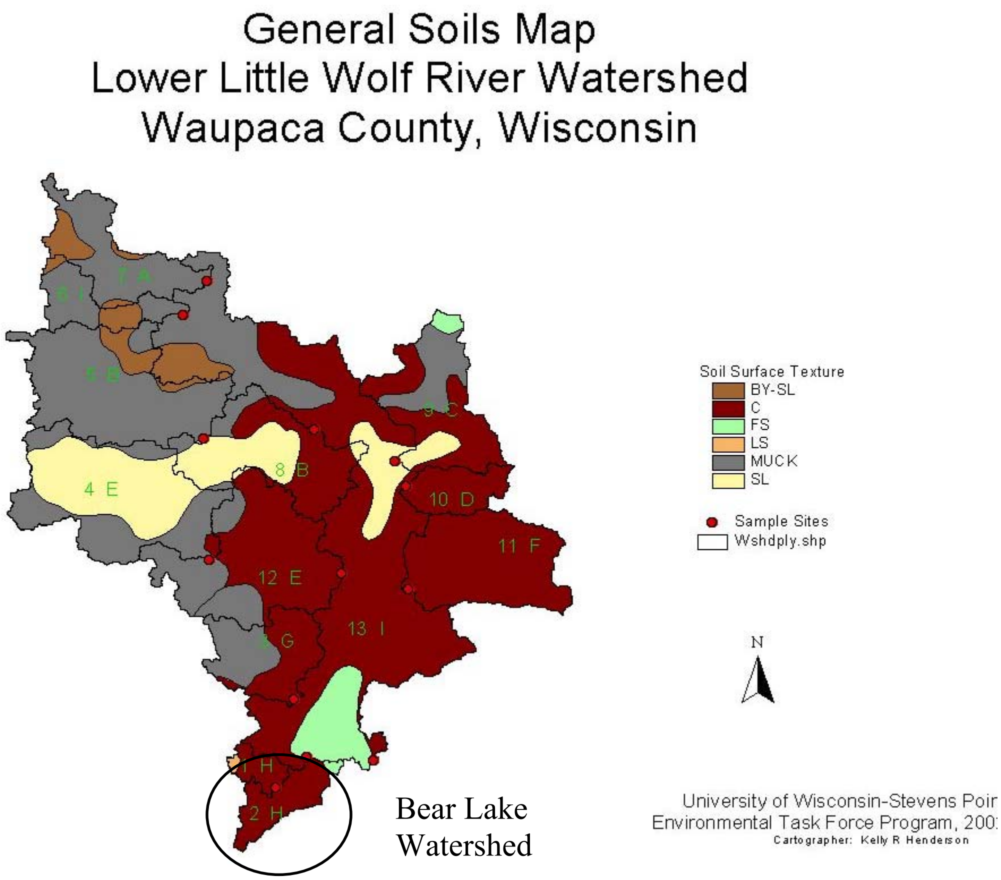
Soils

The soils found in Waupaca County have been derived primarily from the weathering and transport of glacial drift deposits. Types of soils are classified according to soil texture, structure, organic content, permeability and subsoils. The suitability of soils for various uses will be determined by these properties as well as by slope of the land and depth to bedrock or water table. Table 1 lists soil types, slopes, erosion potential and some of the limitations and suitable uses for soils in the Bear Lake watershed. A general soil map of the Waupaca County is presented in figure 9. Dominant soil types can be divided into three groups: (I) Sandy loam and Loam Soils; (II) Loamy Sand Soils; and (III) Organic muck soils.

<u>Sandy loam and loam soils</u> (Group I) have a yellow-brown to reddish-brown subsoil, where they are well drained, covered by dark gray-brown topsoil. Their natural fertility and good soil structure make these soils some of the best cropping soils in Waupaca County. However, good land management practices are necessary to prevent excess topsoil erosion particularly on slopes greater than 2%. Most of the Hortonville Loams on slopes greater than 6% have already been severely eroded. Loam soils in the watershed vary from excessively permeable, droughty soil to slowly permeable, wet soils depending upon the quantity of sand, silt, or clay in the soils and the depth to groundwater. Generally, sandy loam soils are found along drainage ways and in basins. Some of the Group I soils are not suitable for septic systems because they percolate too quickly or are too close to the water table.

Loamy sand soils (Group II) have a higher percentage of sand than loam soils. These soils are found along drainage ways and adjacent slopes. They are excessively permeable and tend to be droughty on upland slopes or too wet in low-lying areas. Crop production is slightly lower due to lower organic content and fertility. Erosion due to soil blowing is also a problem. For these reasons, loamy sands are better suited to woodland or

Figure 9. General Soils Map of the Lower Little Wolf Watershed, Waupaca County, Wisconsin.



pastureland than cropland. Good management practices are required on Group II soils to prevent soil erosion from both water and wind and to maintain soil fertility. Group II soils are also severely limited for proper septic system function because effluents drain too rapidly through the soil and may contaminate the groundwater before proper treatment can be achieved. Many homes along the south shore of Bear Lake are located on these soils (Bushweiler, B. and Rasman, T. 1984.)

Organic muck soils (Group III) can be found along drainage ways and in low lying depressions in the watershed. These soils were formed from deposits of herbaceous organic material under wet conditions and consist of black mucky peat and deep muck over sandy subsoils. Muck soils are poorly drained and have a high available water capacity. The water table is above or near the soil surface throughout much of the growing season. These areas generally support marsh and wooded wetland vegetation. They are considered to be unsuitable for most intensive land uses including cropland, residential development and septic systems (Bushweiler, B. and Rasman, T. 1984.).

Land Use

GIS Coverage Data:

ArcView GIS land coverage's of Wisconsin were obtained by the Wisconsin Initiative for Statewide Cooperation on landscape Analysis and Data (WDNR, WISCLAND). Land cover data was derived from Landsat Thematic Mapper (TM) satellite imagery acquired from fly-overs from 1991-1993. Specifically on the map, each pixel represents a 30 meter square, or 900 square meters on the ground.

Land use within the surface and ground water watershed plays an important role in the water quality of aquatic ecosystem. According to the 1993 Wisconsin land use cover map (WDNR, WISCLAND), nearly half (47%) of the surface water watershed, is covered by agriculture. Forested land was the next predominant land use, covering approximately 17% of the watershed. Wetland areas cover about 15% of the watershed, while forested wetland areas cover approximately 8%. Open water (7%), grasslands (5%) and barren land (3%) cover the remainder of the watershed. Figure 10 shows the land use map of the Bear Lake surface water watershed.

Land use within the groundwater watershed is quite similar to the land use within the surface water watershed. Agriculture covers nearly half of the groundwater watershed, while forested land and wetlands are the next predominant land uses covering approximately 15% each. Grasslands, forested wetlands, barren land and open water cover the other 20% of the groundwater watershed. Figure 11 shows the land use map of the Bear Lake groundwater watershed.

Figure 10. Land use map of the Bear Lake surface water watershed, Waupaca Co., WI.

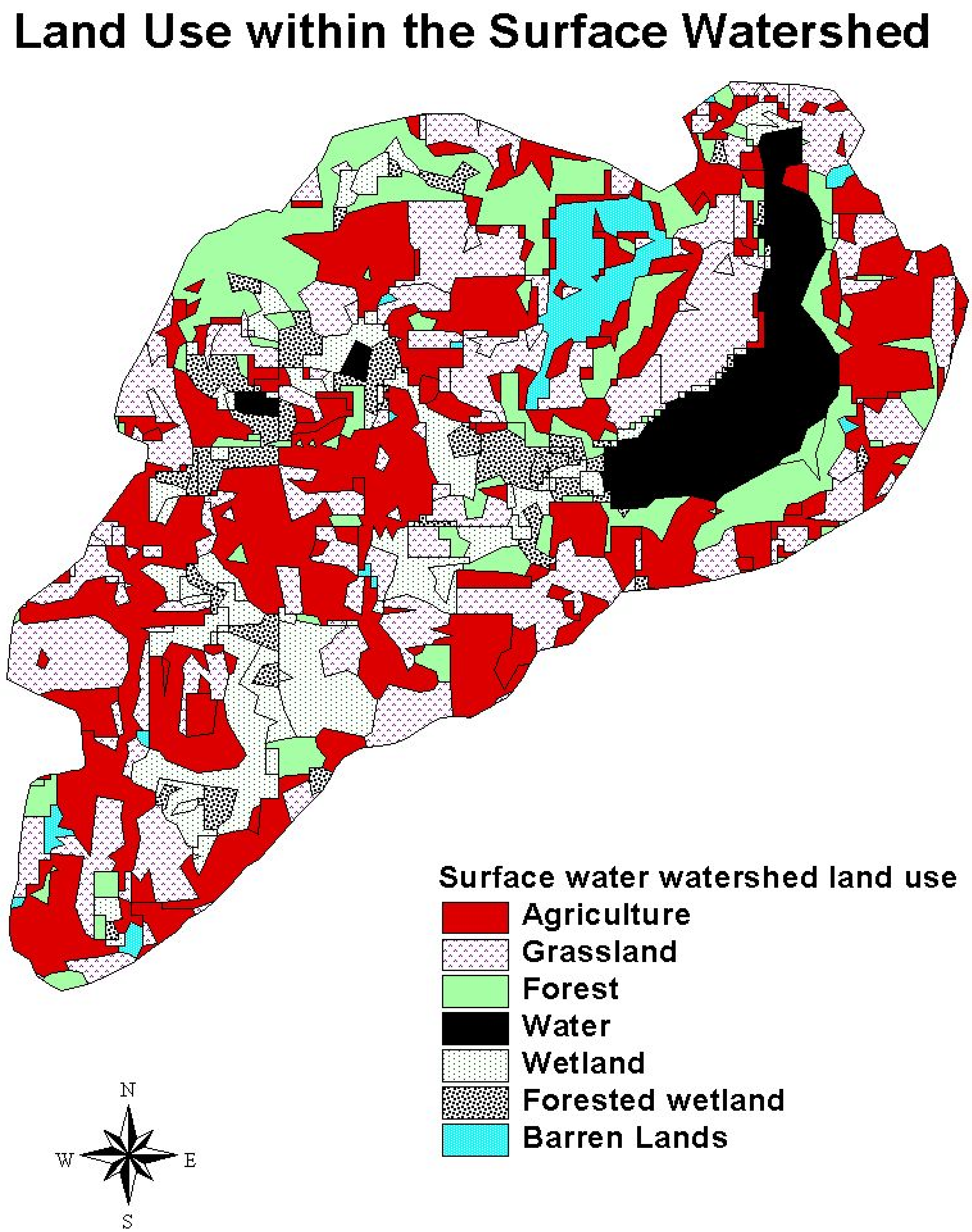
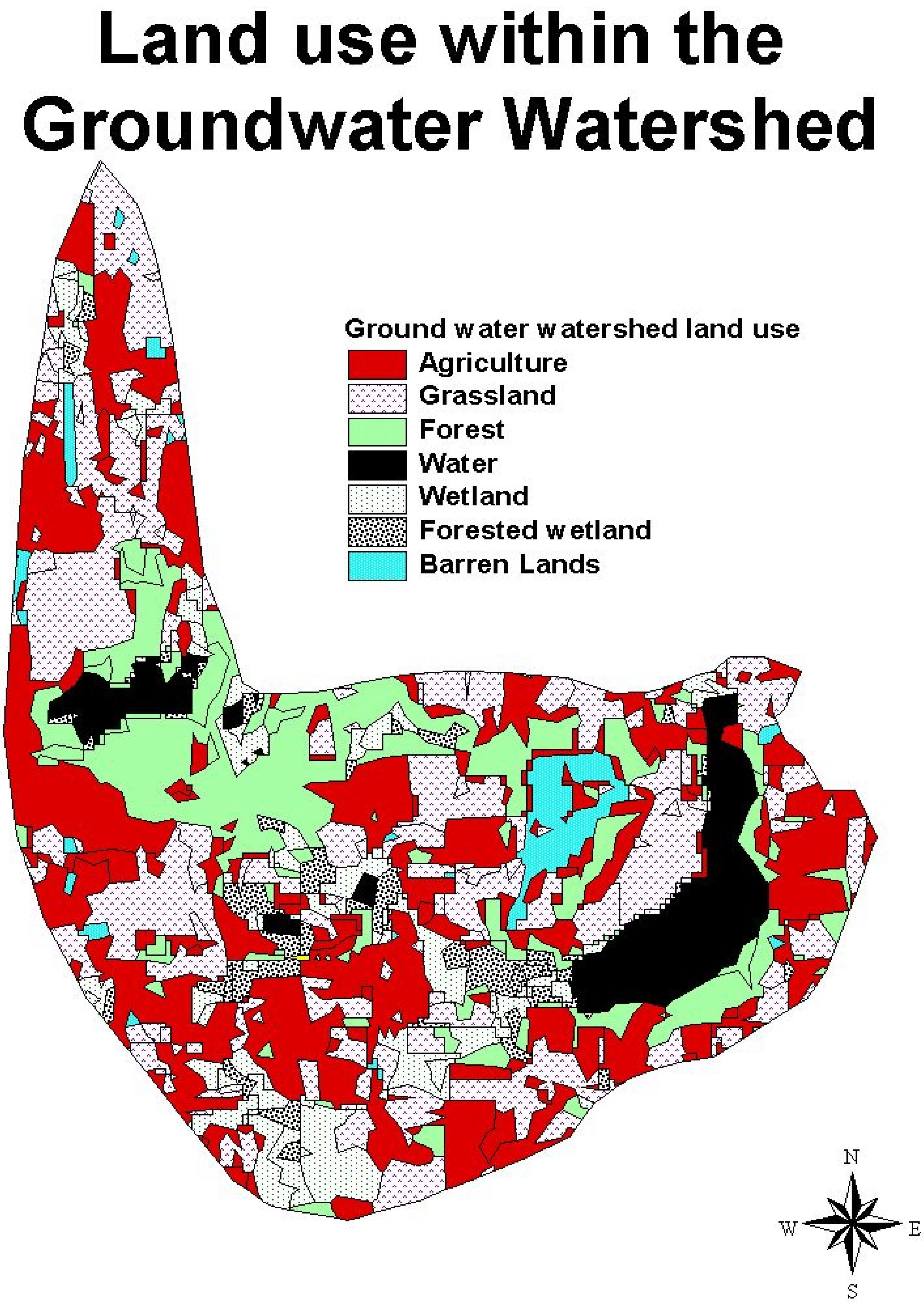


Figure 11. Land use within the Bear Lake ground water watershed, Waupaca Co., WI.



RESULTS AND DISCUSSION

Bear Lake Citizen Survey

In our assessment of Bear Lake, it was desirable to identify the lake water quality and recreational concerns of the people who use the lake. A survey questionnaire was used to determine recreational uses of the lake, potential use conflicts, public perception of water quality problems and the level of public interest in protecting the lake. In June of 2001, the questionnaires were mailed or hand delivered to 276 residents in the watershed, and 46 were returned; two of which were not completed but had comments written on them. This was a 17% response, and approximately a 20% response is considered to be average. A copy of the questionnaire and the hand written responses to the questions are contained in (Appendix A).

Most of the respondents (75%) were lakeshore property owners. About one third of the respondents who own or rent property on the lake, are year round residents. Range of time living in the Bear Lake watershed was 1 to greater than 100 years. Ninety-one percent of the respondents use the lake for some form of recreation. Recreational uses are shown in Figure 12 and include: boating, fishing, picnicking, ice skating, hunting, sail/wind surfing, snowmobiling, water-skiing, swimming, scenic view, hiking, cross country skiing, entertaining, tubing, watching wildlife, and peace and quiet. Fishing and swimming tied for the predominant uses, at 79%. Boating and aesthetics (enjoying the natural scenic beauty) were also very popular among the respondents, both at 69%. Other recreational uses, in declining order, include peace and quiet, entertaining, watch wildlife, water skiing, ice-skating, picnicking, sail/wind surfing, hiking or cross-country skiing, hunting and snowmobiling. Nearly 70% of the respondents owned a fishing boat, 38% owned a paddleboat, 33% owned a pontoon boat, 21% owned a ski boat, 21% owned a sail boat, and 7% owned a personal water craft (PWC) (Figure 13). The maximum amount of marine gas used was 144 gallons per year used by one household and the minimum was none. The average estimated amount of marine gas used per year was found to be 21.4 gallons. The estimated total amount of marine gas used annually by survey respondants on Bear Lake is 770 gallons.

Perception of water quality changes was mixed; over half of the respondents (55%) felt that the water quality of Bear Lake has stayed the same. Thirty-two percent felt that the water quality has declined, and 13% felt that the water quality has improved. Septic system seepage (25%), herbicide/pesticide use (23 %), soil erosion (20%) and fertilizer use (18%) were perceived by survey respondents to be the greatest contributors to water quality decline.

Figure 12. Percentage of survey respondents who use Bear Lake for recreational activities.

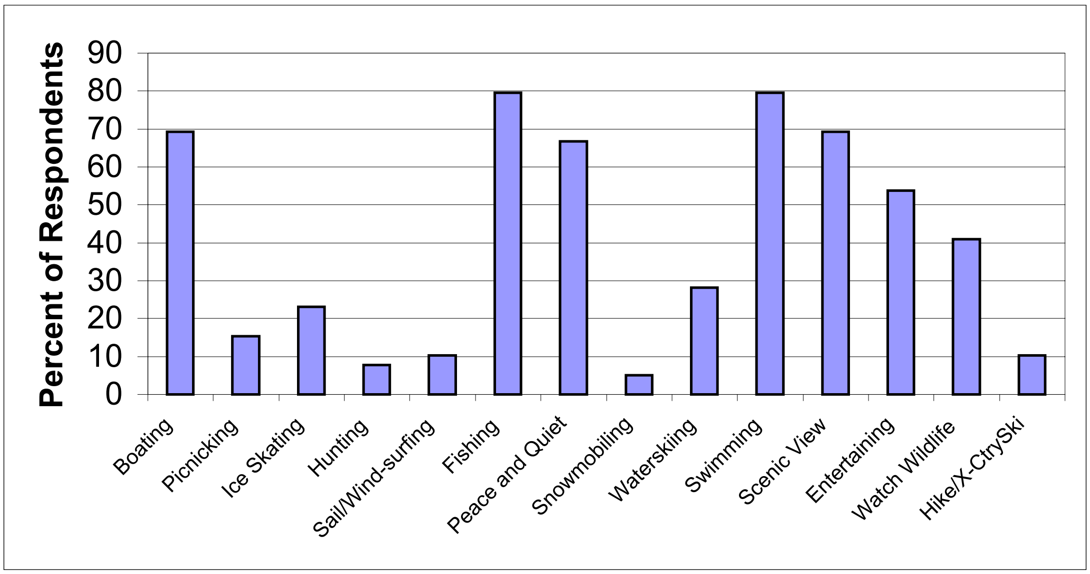
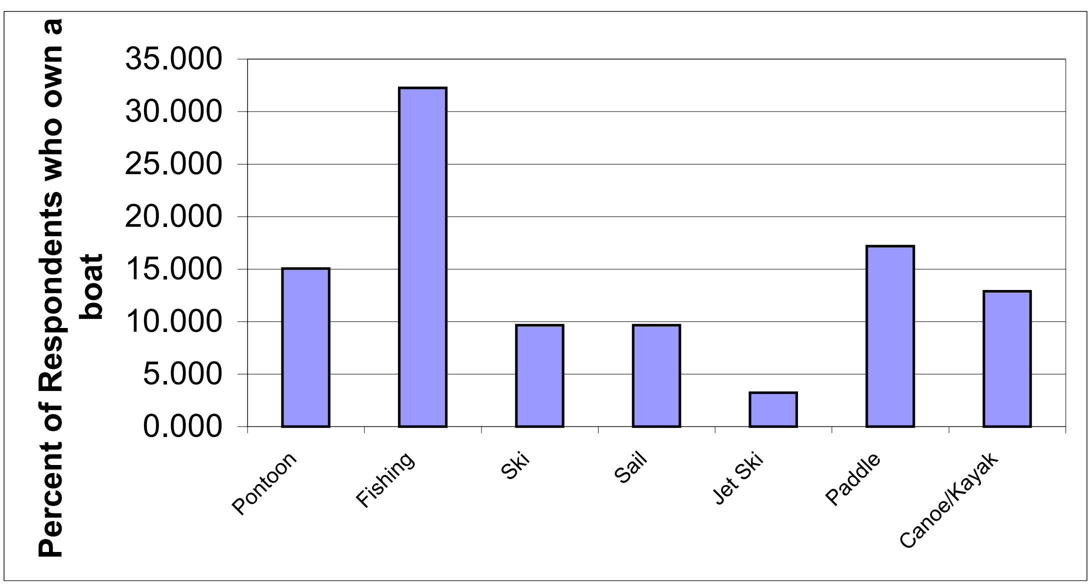


Figure 13. Percentage of survey respondents who own a boat.



The majority of the respondents (68%) felt that the fishing quality of Bear Lake has stayed the same since they have fished on Bear Lake. Thirty-two percent felt that the fishing quality has declined and there was not a single respondent who felt that the fishing quality had improved. Just over half of the respondents felt that the fishing quality of Bear Lake is good, while 21% feel that it is fair. Heavy recreational use (38%), soil erosion (15%), and pesticide/herbicide use (15%) were perceived by survey respondents to be the greatest contributors to fishing quality decline.

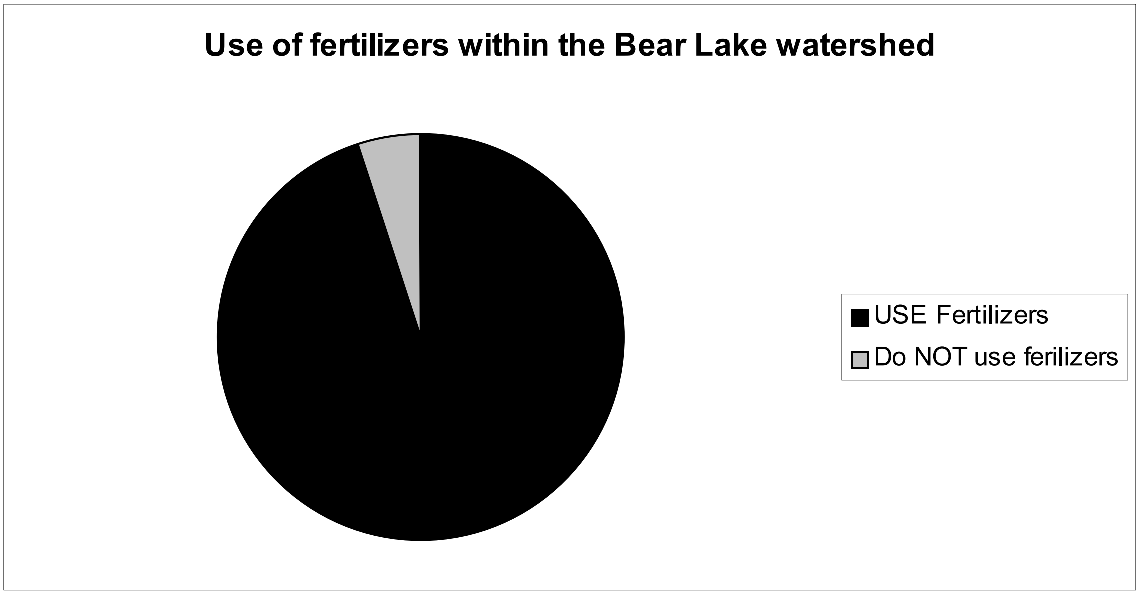
Nearly half of the respondents have a septic tank (45%), while 28% have a drainage field, and 17% have a holding tank. The type, age, and quality of condition of sewage disposal system, affects the nutrient loads entering the lake, however, even properly functioning septic systems will release nutrients to the groundwater.

Just over half of the respondents use an automatic clothes washer, 35 % use a dishwasher, and 12% of the respondents use a garbage disposal. Grounds up food from garbage disposals contribute nutrients to the waste stream. Dishwasher detergents contain phosphorus whereas other detergents purchased in Wisconsin do not. All of these contribute heavier usage to one's septic system, which may in turn contribute to the nutrient load entering the lake.

Of the respondents, 95% use fertilizer and 5% do not use any type of fertilizer (Figure 14). The majority of the respondents (75%) live on Bear Lake. Of these respondents who live on the lake, 41% use fertilizers. Of the respondents who live on the lake **and** use fertilizers, 86% use fertilizers on their lawn. This may affect the lake directly by contributing excess nutrient runoff, which may enter the lake through surface water runoff or via shallow groundwater flow. Efforts to reduce/eliminate the use of fertilizers should be made within the surface and groundwater watershed.

Of the respondents who live within the Bear Lake watershed, only one-third use fertilizers. This would have less impact to the lake due to a greater distance between the fertilized area and the lake, and usually the distance between the fertilized area and the water table is greater than those who live on the lake, however, it is still an input that should be reduced and eliminated whenever possible.

Figure 14. Use of fertilizers within the Bear Lake Watershed.



WATER QUALITY

Stream flow

Stream flow was measured 9 times throughout the study between June and November. This information was used for the modeling portion of the project. The inflow of Bear Lake consists of Spiegleberg Creek and two other intermittent streams, which converge in a wetland area and flow into the lake. Flow was at a peak in June in all of the streams, with the exception of inflow 3, which reached its peak flow in September, but it was also near peak flow in June due to heavy rainfall. Dry conditions reduced flow in inflows 1 and 2 to an immeasurable level in July. All stream flow data are located in Appendix B, and figure 3 displays a map with stream gauging sites and the mid-lake sample site.

Inflow 1 is located on the southwest corner of the intersection of Baldwin Rd. and Casey Lake Rd. Discharge reached its maximum in mid-June at 0.96 cubic feet per second due to heavy amounts rainfall in June. The average discharge between June and November measured at this inflow was 0.18 cubic feet per second, the mean temperature was 18.2^{o}C, and the average conductivity was 504 *u*mhos.

Inflow 2 is a wooded stream corridor, which passes under Baldwin Rd. This stream was gauged on the south side of Baldwin road. This intermittent stream only had flow in mid-June, with a discharge of 0.09 cubic feet per second. It was dried up completely in July and August, however, in September through November, there was water in the stream, but there was no flow registered by the stream gauge due to the presence of leaves and other debris. Between June and November, the average temperature was 17.4^{o}C, and the average conductivity was 632 *u*mhos.

Spiegleberg Creek (inflow 3) is located on Baldwin Rd. just south of Jake's Rd. and is the main stream flowing into Bear Lake. The stream was gauged on the west side of Baldwin Rd. This stream reached its peak discharge at 2.1 cubic feet per second in August. The average discharge between June and November was 0.74 cubic feet per second, the average temperature was 17.1^{o}C, and the average conductivity was 428.9 umhos.

The outflow of Bear Lake, a branch of the Lower Little Wolf River, was gauged on the south side of Northshore Dr. Peak discharge occurred in late June and again in early September, with a discharge of 3.6 and 3.3 cubic feet per second, respectively. The average discharge measured at the outflow of Bear Lake between June and November was 2.4 cubic feet per second; the conductivity ranged from 390 to 485 *u*mhos, with an average was 407 *u*mhos. The average temperature from August to November was 16^{o}C.

In January 2002, the outflow of Bear Lake was not completely frozen over near Northshore Dr. The temperature of the outflow was 1.1^{o}C and the conductivity was 396 *u*mhos.

Mid-lake Water Quality Data

All mid-lake water quality data from the summer of 2001 are presented in Appendix C. The following is a description of results for each major group of water quality characteristics. Figure 3 displays where the mid lake samples were collected.

<u>Dissolved Oxygen and Temperature</u>

Bear Lake is typical of many northern temperate lakes in that its yearly cycle includes two periods of stratification and two periods of water mixing. Stratification occurs during both the winter and summer months. During the summer, the epilimnion, or surface is 12-20 feet in Bear Lake and has a fairly constant temperature with dissolved oxygen readings ranging from 9.3 mg/L in late May to 8.3 mg/L in late August. The surface water temperature ranged from 16.3°C in May to 26.7°C in early August, and back down to 13.6 °C in October. The average temperature of the epilimnion from May through November was 19.8°C.

The epilimnion is followed by a strong temperature gradient, or thermocline, and finally the Hypolimnion (Figure 15). Figure 16 displays one temperature profile per month in Bear Lake, however, it should be noted that during the summer of 2001, profiles were collected twice per month. All data is displayed in Appendix C. The water temperature in the hypolimnion is warmer than the epilimnion in the winter months and cooler in the summer months. The water temperature difference between the epilimnion and hypolimnion creates a density difference between the two layers and in summer the colder hypolimnion becomes isolated from mixing and addition of oxygen. Bacteria that decompose plant residue and organic matter in the bottom sediments use up most of the available dissolved oxygen in the hypolimnion. This results in low hypolimnion dissolved oxygen concentrations, making this portion of the lake inhospitable to most life forms.

Figure 15. Diagram of Lake Stratification

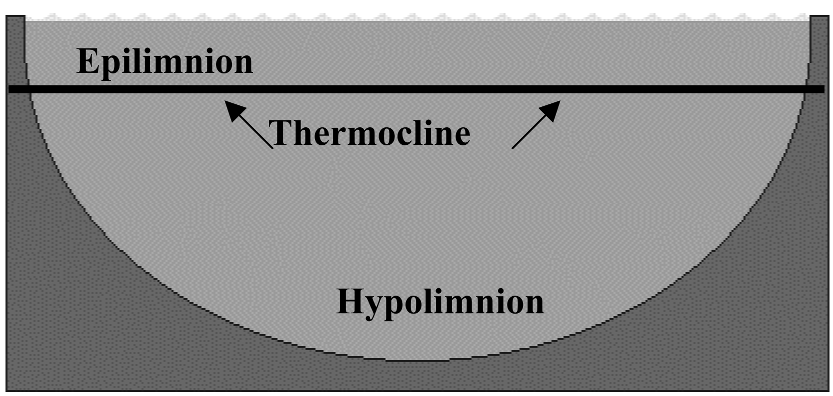
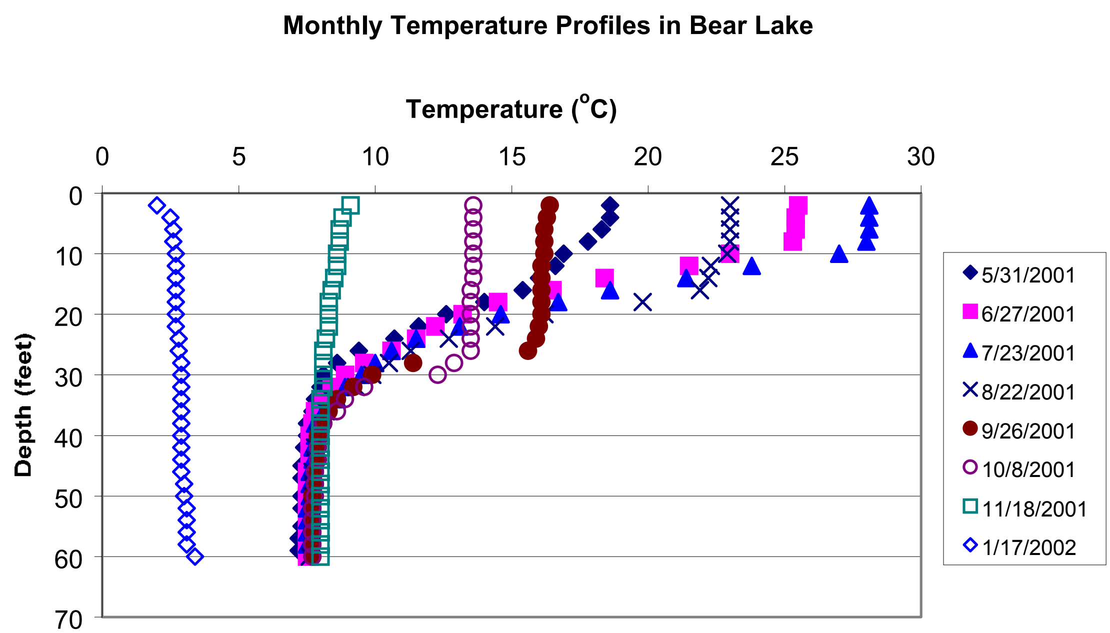


Figure 16. Temperature profile in Bear Lake during summer stratification and fall turnover.



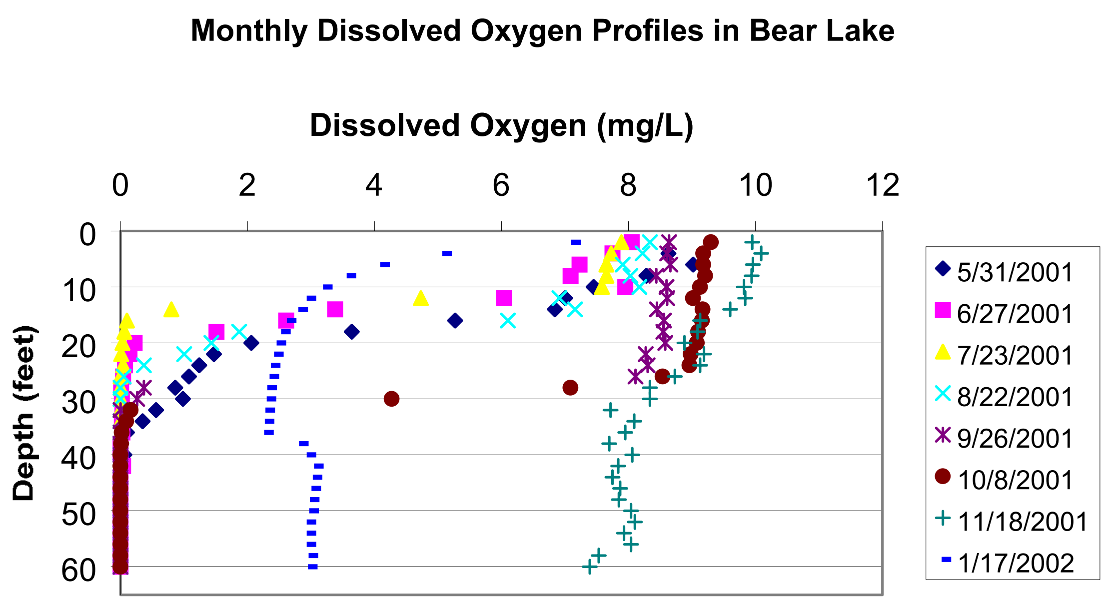
During the summer months of 2001, the hypolimnion had no measurable dissolved oxygen. Warmer water temperature and an increase in biological activity can create an anoxic hypolimnion during the summer months. The dissolved oxygen levels in Bear Lake were below 1 mg/L at a depth of 14 feet in late July, and at a depth of 32 feet in October. Bear Lake has a maximum depth of 62 feet deep, so during the summer months of 2001, there was 44-50 feet of water with a low dissolved oxygen concentration, in which aquatic life may be stressed to breathe. Figure 17 displays monthly dissolved oxygen profiles in Bear Lake, however, it should be noted that profiles were collected twice per month during the summer months of the 2001. All data are displayed in the Appendix C.

Water mixing or turnover occurs in spring and fall, usually evident in April and October or November. During fall turnover when the anoxic hypolimnion water began to mix with the rest of the water column, dissolved oxygen concentrations at the bottom of the lake increased from less than 1 in October, to 7.4 mg/L in mid-November. Lower water temperatures, less biological activity, and the introduction of oxygenated water, lead to an increase in dissolved oxygen in late fall.

Fall turnover and ice-free conditions lasted longer than normal in 2001 due to unseasonably warm temperatures through December and January. Winter dissolved oxygen levels ranged from 7.1 mg/L at the surface, to 2.9 mg/L at the lake bottom in January. Temperature in January ranged from 1.5°C at the surface, to 3.5°C at the lake bottom.

Dissolved oxygen data from the previous study shows that Bear Lake exhibited anoxic conditions during the summer months at approximately the same depth as in 2001.

Figure 17. Monthly dissolved oxygen profile in Bear Lake during summer stratification and during fall turnover.

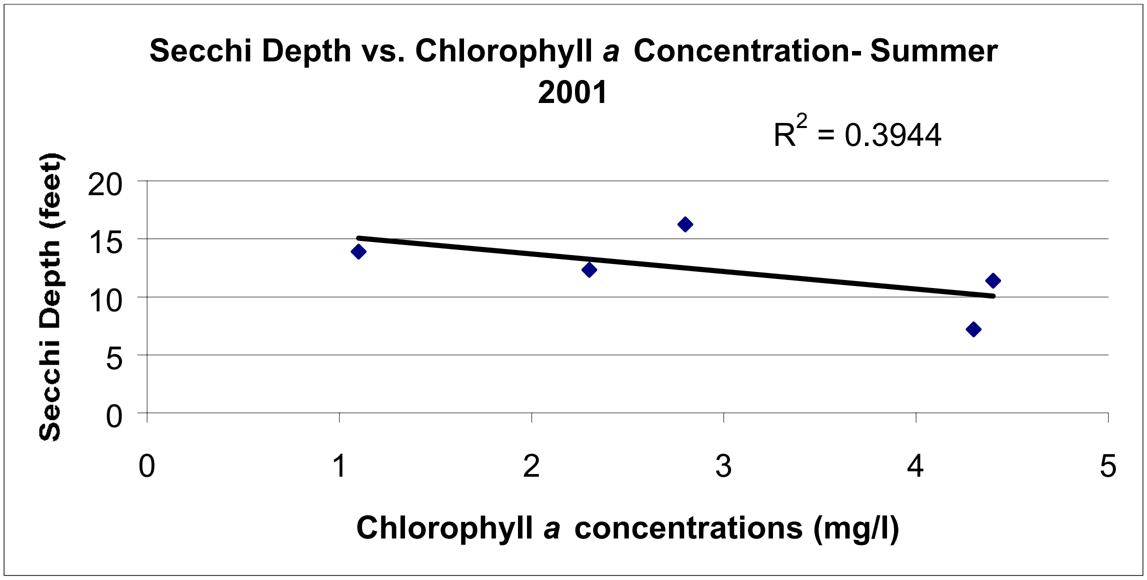


Secchi Depth and Chlorophyll *a*

Secchi depth is a measure of water clarity which includes small particulates and, and it can often be directly compared to chlorophyll *a*, a measure of algae growth. Chlorophyll *a* can also be an indicator of phosphorus levels (Shaw et. al. 1996). If chlorophyll a is the source of suspended particles, higher chlorophyll *a* should correlate to a shallower Secchi depth reading; however, many variables such as time of day and wind can affect Secchi depth readings. Throughout the year, Secchi depth ranged from 6.8 to 16.3 feet with an average of 11 feet. Secchi depth reached its minimum from the end of July through the end of August 2001. Chlorophyll *a* concentrations reached a maximum in August and September (4.3 and 4.4 *u*g/L, respectively). Secchi readings did inversely correlate somewhat with the chlorophyll *a* concentration; generally as chlorophyll *a* concentrations decrease, Secchi depth increases (Figure 18). The data from 1982 displayed a strong correlation between the epilimnion TP concentration and chlorophyll *a* concentration however, few data points existed to show much variability throughout the growing season (Figure 19).

Based on relationships described in Shaw et al, 2000, Secchi depth in Bear Lake ranked water clarity from fair to good (Table 2) in 2001. The Secchi data from 1980-82 ranked the water clarity in Bear Lake from poor to fair. Comparison of recent data with data from about twenty years ago reveals that the chlorophyll *a* concentration has decreased considerably while Secchi depth has increased.

Figure 18. Graphs show relationship between Secchi depth, chlorophyll *a* concentrations, and TP concentrations of the epilimnion of Bear Lake during the summer of 2001.



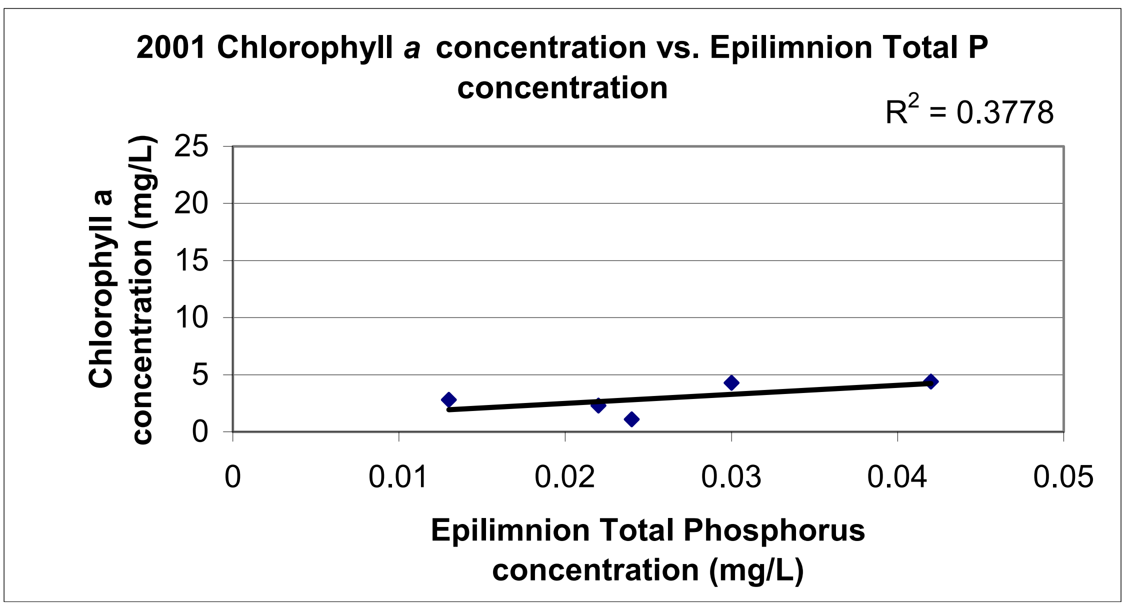


Figure 19. Graphs show the relationship between epilimnion total phosphorus and chlorophyll *a* concentrations in Bear Lake, Waupaca Co., WI, from 1980-1982.

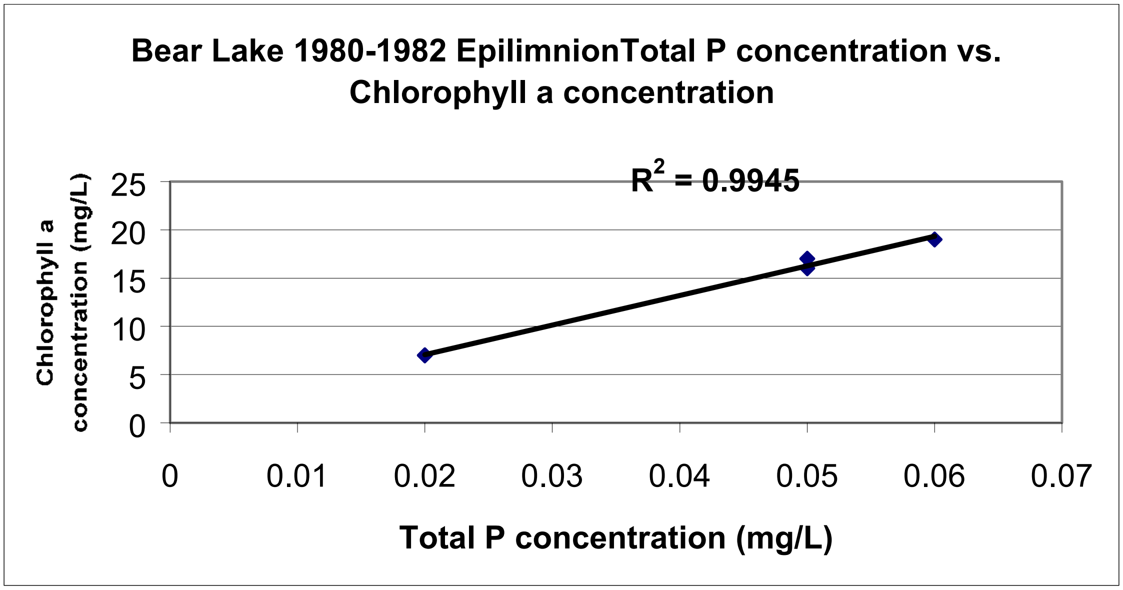


Table 1. Water Clarity Index based on Secchi depth measurements

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

1980-82
2001

*Adapted from Shaw et al., 2000.

Conductivity, Alkalinity, Total Hardness, pH

Conductivity, or what is sometimes called specific conductance is the measure of the ability of a solution to conduct electrical flow. Conductivity increases with increasing ion content, so the purer the water, the greater its resistance to electrical flow (Wetzel, 2001). Values are commonly two times the water hardness unless the water is receiving high concentrations of contaminants introduced by humans (Shaw et al, 2000). The average conductivity in Bear Lake in 2001 and 2002 was 393 *u*mhos. Both the epilimnion and hypolimnion average conductivity are approximately twice the water hardness. Conductivity data was not collected in the 1975 and 1980-82 study.

According to Shaw et al., 2000, a lake's hardness and alkalinity are affected by the type of minerals in the soil and bedrock in the watershed, and by how much the lake water comes into contact with these minerals. If a lake receives its groundwater from an aquifer containing limestone minerals such as calcite ($CaCO_3$) and dolomite ($CaMgCO_3$), hardness and alkalinity will be high, as is the case with Bear Lake. High levels of hardness (greater than 150 mg/L) and alkalinity can cause marl ($CaCO_3$) to precipitate out of the water. This bi-product is harmless and can actually result in more fish production and aquatic plants than soft water lakes (Shaw et al., 2000). It can also act as a balancing mechanism, however, phosphorus precipitates with marl, thereby controlling algae blooms.

The average alkalinity in 1975 was 176 mg/L, and from 1980-82 it was 195 mg/L. The 2001-02 average alkalinity was 190mg/L. The average total hardness in 2001-02 was 206 mg/L. Total hardness data was not collected in the previous study. Bear Lake has very hard water as shown in Table 2. Table 3 shows that Bear Lake is not very sensitive to acid rain due to the carbonate buffering in the lake. Comparison of data from 1980-82 shows that the average alkalinity in Bear Lake has remained fairly constant over the past twenty years.

Table 2. Categorization of Hardness by mg/L of Calcium Carbonate ($CaCO_3$)

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

**Adapted from Shaw et al., 2000.*

Table 3. Sensitivity of Lakes to Acid Rain

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

**Adapted from Shaw et al., 2000.*

An index of lake water's acid level, pH is and important component of the carbonate system. A pH of 7 is neutral and water with a pH of above 7 is considered to be basic. This means that water with a higher pH will have less hydrogen ions than that of acidic waters (lower pH). In Wisconsin, pH ranges from 4.5 in some acid bog lakes to 8.4 in hard water, marl lakes (Shaw et al., 2000). The average pH in Bear Lake in 2001 was 7.9, and since Bear Lake is a hard water, marl lake, it would be expected that the pH would be around 8. The average pH of the epilimnion in the summer of 2001 was slightly higher than 8.0, at a pH of 8.5, probably driven by plant growth. If the pH increases above 9, it would force phosphorus to become soluble. The average pH of the hypolimnion was slightly lower than 8.0, at a pH of 7.6. The January pH level was 8.1 in the epilimnion and 8.2 in the hypolimnion. Due to the carbonate buffering in the lake, the pH in Bear Lake has remained fairly constant over the past twenty-five years, at a slightly basic pH of 8.

Total Phosphorus (TP)

In more than 80% of Wisconsin's lakes, phosphorus is the limiting nutrient affecting the amount of weed and algae growth (Shaw et. al. 2000). Phosphorus enters the lake through surface runoff, overland flow, groundwater inflow, and the inflowing streams. The presence of wetlands where the inflowing streams converge may absorb much of the phosphorus coming from within the watershed through these streams. In the past, there were more barnyards and animals around the lake and within the watershed, which contributed phosphorus to the lake. Local residents indicated that the algae blooms were once more significant than they currently are. Also, agriculture practices within the watershed have been focused on controlling sediment and nutrients, so it is reasonable to believe that phosphorus in the lake will reduce over time if riparian inputs are reduced as well.

In a marl lake such as Bear Lake, carbonate (marl/$CaCO_3$) precipitates out of the water as pH increases and carbon dioxide (CO_2) is lost from plant uptake, increasing water temperature and causing a decrease in carbon dioxide solubility and mixing. Contact with the atmosphere allows the excess carbon dioxide to escape. Plants speed up marl deposition by using carbon dioxide (CO_2), which raises the pH and converts most alkalinity to the carbonate. Phosphorus has been shown to co precipitate with carbonate precipitation (marl) (Otsuki and Wetzel, 1972). Marl helps control algae growth in lakes, by precipitating phosphorus, which is then unavailable for biological uptake. Concentrations above 0.02 mg/L can initiate algae blooms.

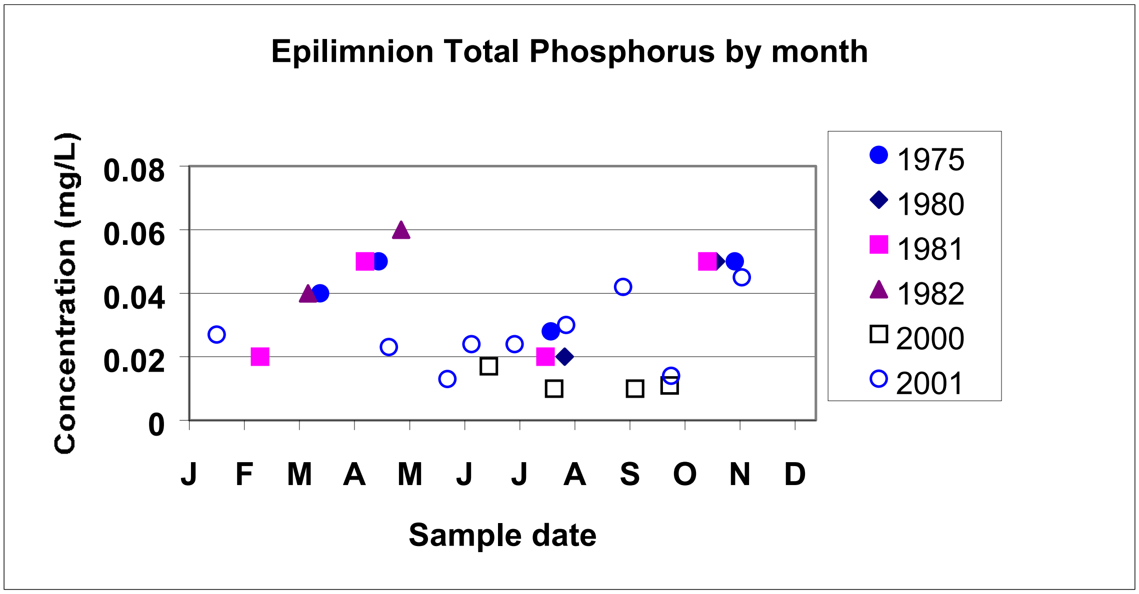
According to Shaw et al., 2000, local sources of phosphorus are largely related to human activities including soil erosion, non-Wisconsin purchased detergents, septic systems, runoff from lawns or gardens, and agricultural fields or barnyards. Dishwasher detergents contain phosphorus, whereas laundry detergents purchase in Wisconsin do not. Regional sources may include animal wastes along with runoff from farmlands.

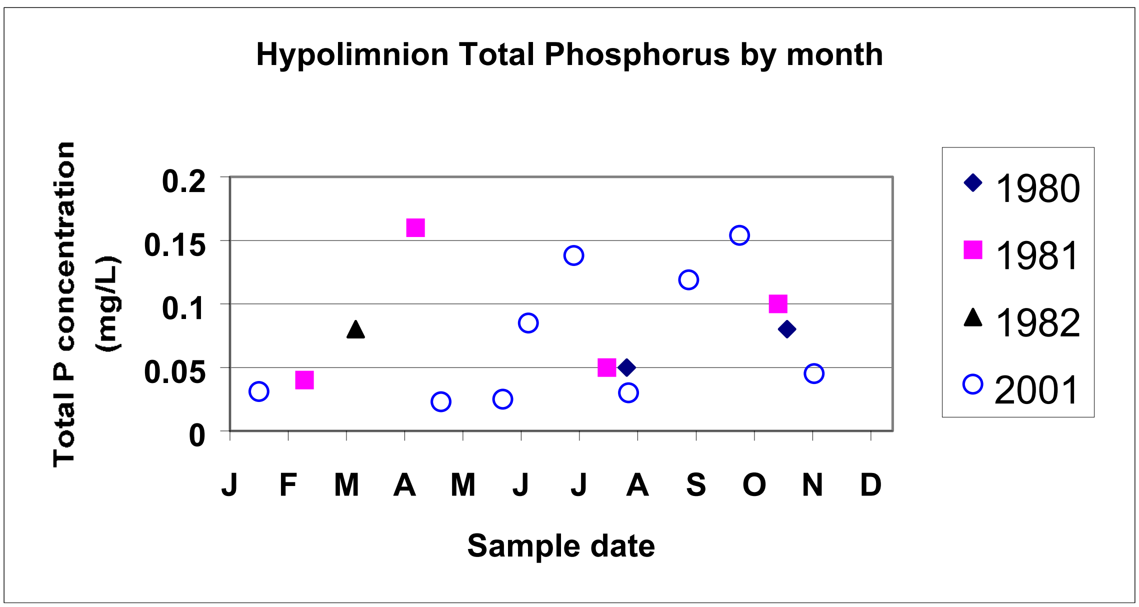
Dissolved reactive phosphorus is the form of phosphorus that is available for plant and algae uptake, however, total phosphorus (TP) was used in these comparisons rather than reactive phosphorus because its levels remain more constant and are not affected by rapid cycling due to aquatic organisms (Shaw et al., 2000).

The average epilimnion TP concentration in 2001-02 ranged from 0.013 to 0.045 mg/L with an average of 0.027 mg/L. This average concentration is great enough to spur algae blooms and aquatic plant growth. Since the TP concentrations fluctuate throughout the growing season, and the previous study took quarterly samples, the data was compared by month (Figure 20). The TP concentration in 1975 ranged from 0.028 to 0.050 mg/L with an average of 0.040 mg/L. The 1980-82 epilimnion TP concentration ranged from 0.02 to 0.06 mg/L, with an average of 0.04 mg/L. TP concentrations in the epilimnion of Bear Lake fluctuate throughout the 2001 study, but overall have slightly decreased over time. As variation of TP concentrations can occur on an annual basis, with rainfall or climatic variation, efforts should be made to collect samples for TP analysis on an ongoing basis.

The hypolimnion TP concentration in 1980-1982 ranged from 0.04 to 0.16 mg/L with an average of 0.08 mg/L, whereas, the hypolimnion TP concentration in 2001-02 ranged from 0.023 to 0.154 mg/L with an average of 0.072 mg/L. This shows that the concentration of TP in the hypolimnion also fluctuates throughout the year and has remained fairly constant over the past twenty years. Higher levels of phosphorus in the hypolimnion during the summer months can be attributed to anoxic conditions causing a release of phosphorus from the bottom sediments. Due to stratification, the hypolimnion does not mix with epilimnion water until turnover. When the water does mix, phosphorus levels in the epilimnion can increase (Voss et al., 1992), as observed in the November sample at Bear Lake. The increased phosphorus concentration in the epilimnion can lead to fall algal blooms, which occurred in the fall and early winter in Bear Lake during 2001. Once these nutrients are in the lake, they are very difficult to remove because they get recycled. Bear Lake can loose some of its phosphorus load to the stream flowing out of the lake, which flows into the Lower Little Wolf River.

Figure 20. Graph of the epilimnion and hypolimnion total phosphorus concentrations in Bear Lake, Waupaca Co., WI, by month for each sample year.





Nitrogen

Nitrate-N and ammonium-N are two forms of nitrogen that are readily available to plants and can rapidly move to groundwater and surface water. Nitrogen is second only to phosphorus as an important nutrient for plant and algae growth (Shaw et al., 2000). It also represents a threat to human health, especially in the form of nitrate because of its association with methemoglobinemia (Blue Baby Syndrome) in infants (VanRyswyk, 1996). In Wisconsin, nitrogen does not occur naturally in most soil minerals, but is a major component of organic matter (Shaw et al., 2000). According to Shaw et al. (2000), nitrogen compounds often exceed 0.5 mg/L in rainfall, so that precipitation may be the primary nitrogen source for pristine seepage and some drainage lakes. The amount of nitrogen in lake water usually is strongly related to local land use such as septic systems or lawn and garden fertilizer used on lakeshore property. Nitrogen may also come from sources within the watershed that include fertilizer and animal wastes on agricultural lands. This nitrogen can then enter the lake through surface runoff or groundwater inflow.

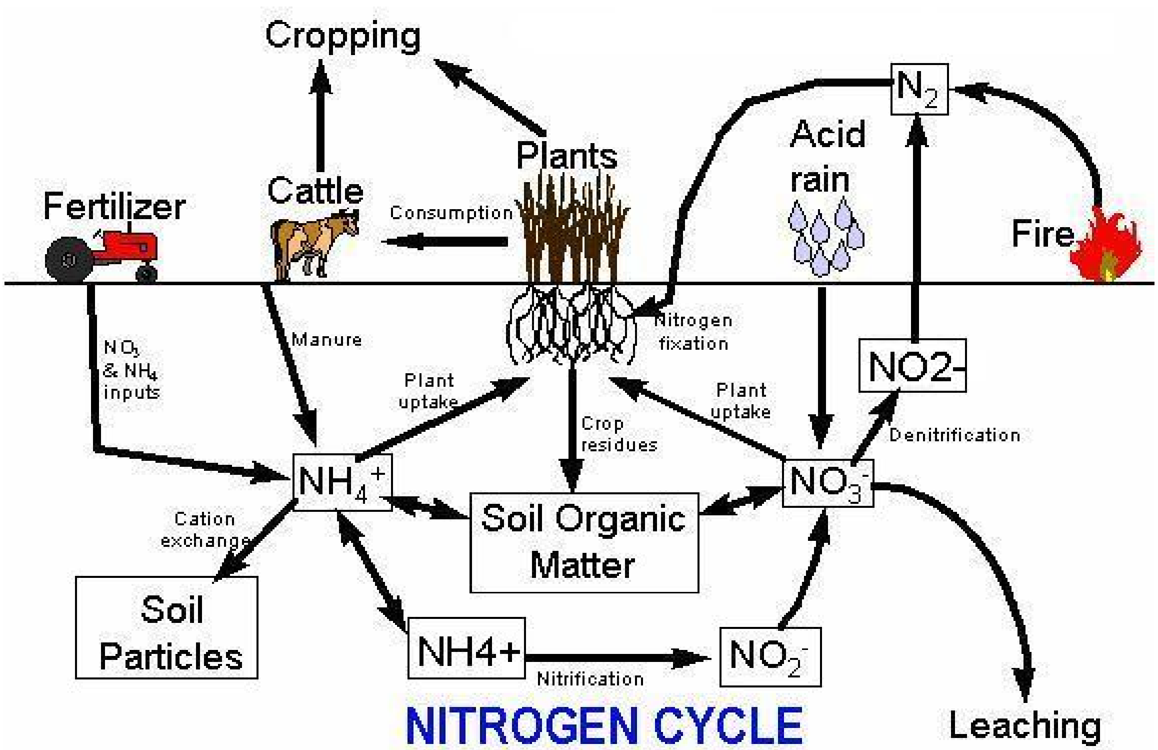
The forms of nitrogen that were analyzed include NH_4^+ (ammonium), NO_2^- + NO_3^- (nitrite + nitrate), and Total Kjeldahl Nitrogen (TKN), which is organic nitrogen plus ammonium. TKN tends to occur in higher levels in hard water lakes as a result of relatively high inputs in calcareous regions and low amounts of biological uptake because of low productivity (Wetzel, 1983). TKN includes both inorganic forms of nitrogen (NO_3+NO_2 and NH_4^+) and organic N. Both forms of inorganic nitrogen (NO_3+NO_2 and NH_4^+) are used by aquatic plants and algae and are very soluble, which means they are readily leached to groundwater. These forms can be transformed to organic N, and from organic N back to the inorganic forms through the nitrogen cycle (Figure 21)(Shaw et al., 2000).

The epilimnion concentration of ammonium in 1975 ranged from 0.05 to 0.51 with an average of 0.23 mg/L and in 1980-82, it ranged from 0.02 to 0.81 mg/L with an average of 0.47 mg/L. The epilimnion ammonium concentration in 2001-02 ranged from 0.01 to 0.58 mg/L. The ammonium concentration in the hypolimnion in 2001-02 range from 0.41 to 1.4 mg/L with an average of 0.476 mg/L. Figure 22 shows ammonium concentrations in Bear Lake by month. Elevated levels of all analyzed forms of nitrogen were found in the anoxic hypolimnion throughout the summer and in early October. The ammonium concentrations fluctuate throughout the growing season and have remained relatively constant since 1975.

The greatest concentrations of NO_2 + NO_3 in 2001 were found within the thermocline or middle layer of the lake, at 1.29 mg/L in late April. This is likely due to sediment release of nitrogen during turnover. The epilimnion concentration of NO_2 +

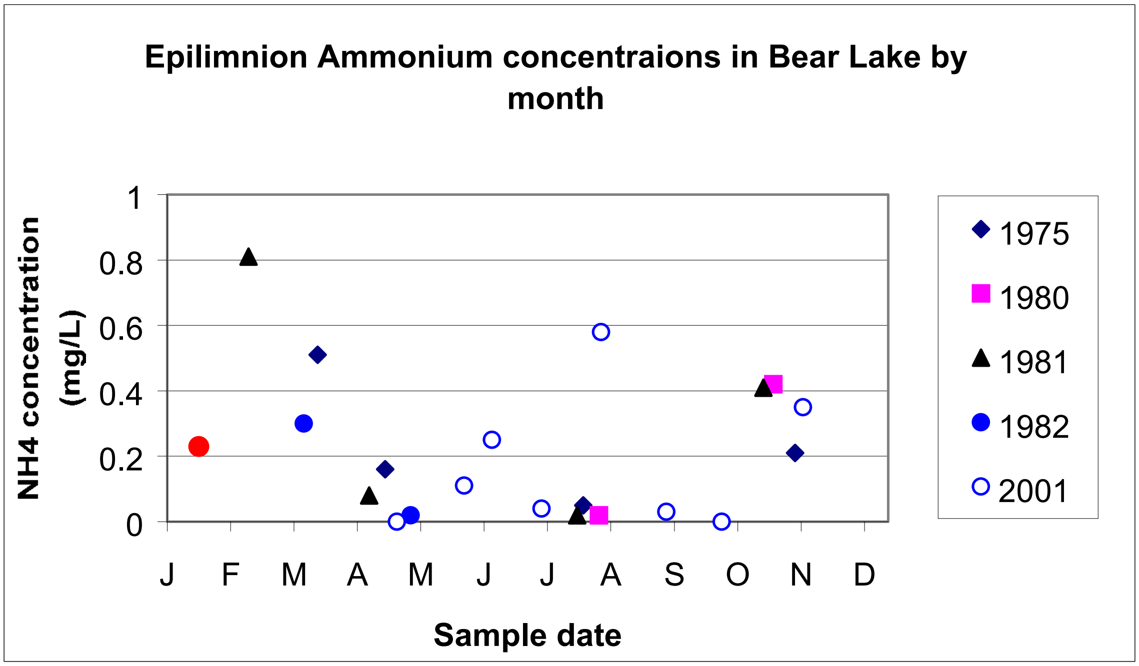
NO_3 in 2001-02 ranged from 0.02 to 1.29 mg/L with an average of 0.22 mg/L. The concentration of $NO_2 + NO_3$ in 1975 ranged from 0.01 to 0.51 mg/L, and in 1980-82 the epilimnion concentration ranged from 0.02 to 1.1 mg/L. The epilimnion or surface concentration of $NO_2 + NO_3$ has remained fairly constant since the late 70's and early 80's and is relatively low.

Figure 21. Schematic showing various forms of nitrogen and its movement in the environment. (University of Minnesota. 2002)



The $NO_2 + NO_3$ concentrations in the hypolimnion in 2001-02 ranged from 0.002 to 1.290 mg/L with an average of 0.206 mg/L. The $NO_2 + NO_3$ concentration in the hypolimnion in 1980-82 ranged from 0.02 to 0.37 mg/L with an average of 0.08 mg/L. Figure 23 shows the $NO_2 + NO_3$ concentrations by month in order to compare the data from the previous study. The $NO_2 + NO_3$ concentrations fluctuate throughout the growing season and with precipitation, however, it should be noted that the greatest concentrations are available during spring overturn which likely stimulates early algae and macrophyte growth.

Figure 22. Epilimnion and hypolimnion ammonium concentrations in Bear Lake by month.



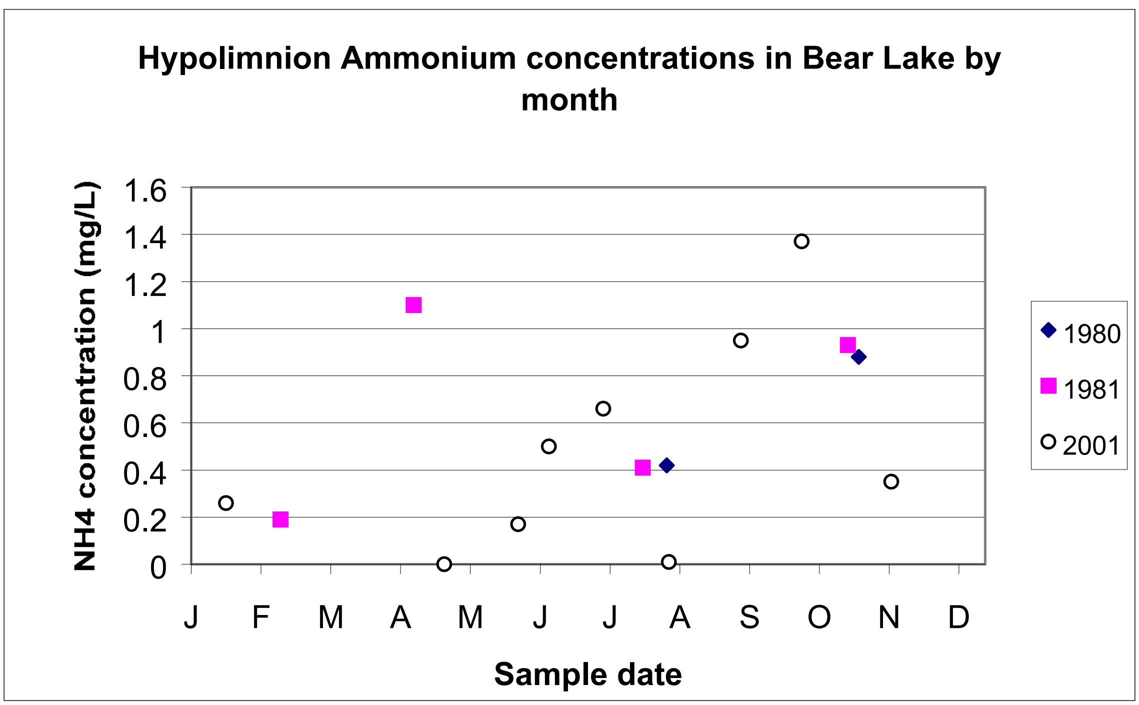
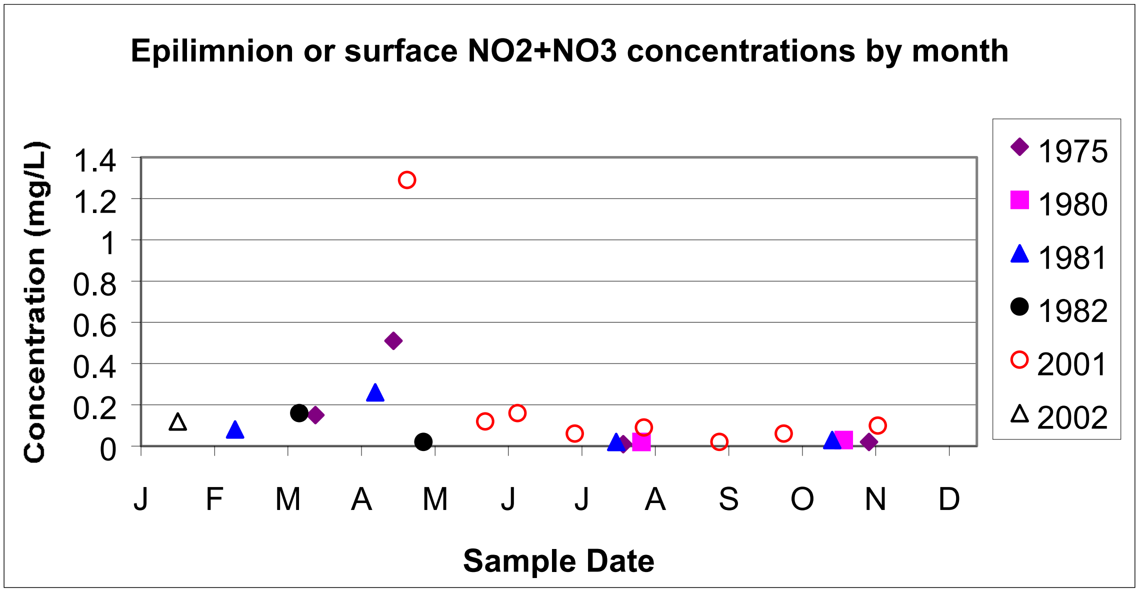


Figure 23. $NO_2 + NO_3$ concentrations by month in Bear Lake, Waupaca Co., WI.



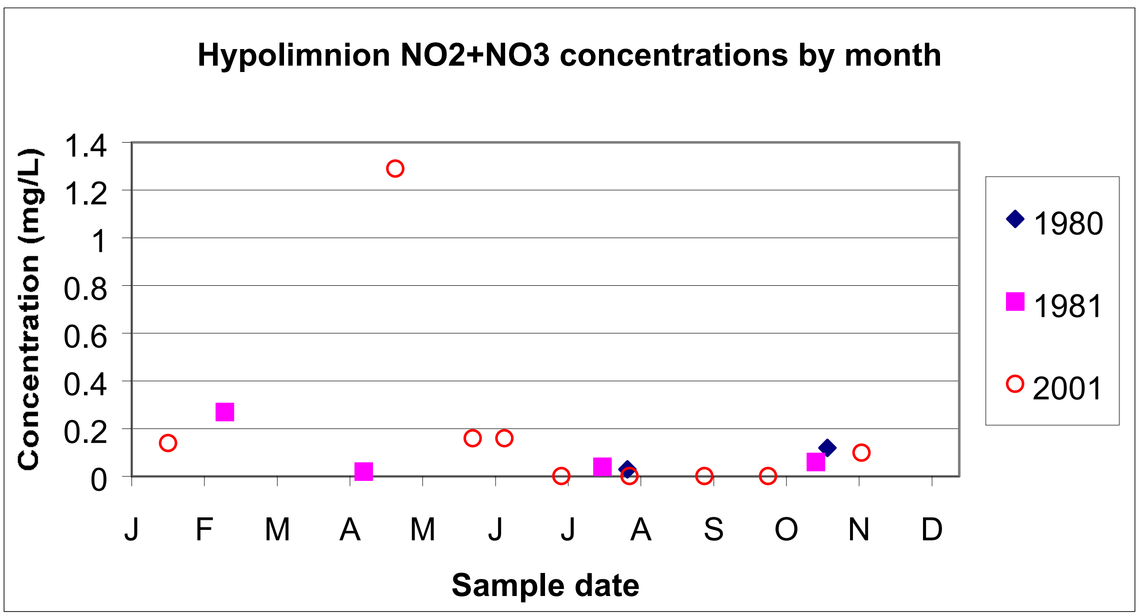
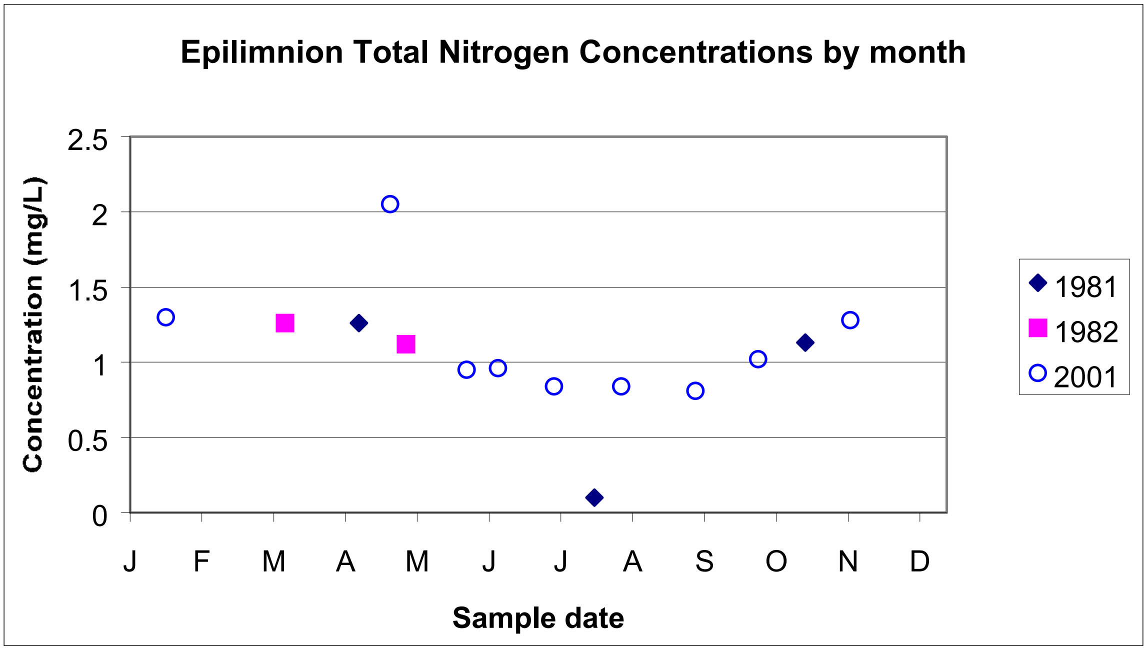
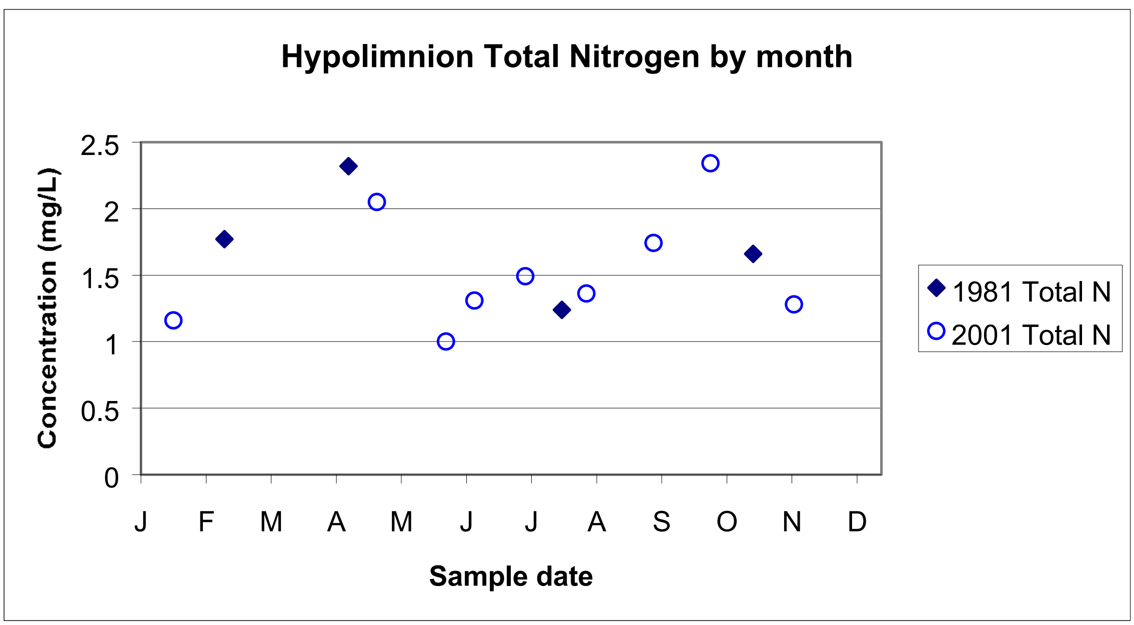


Figure 24 shows the concentration of Total Nitrogen in the epilimnion fluctuates within the growing season and with rainfall. Total Nitrogen was calculated by adding the NO_2+NO_3 concentration to the TKN concentration.

Figure 24. Total Nitrogen concentrations by month in Bear Lake, Waupaca Co., WI.

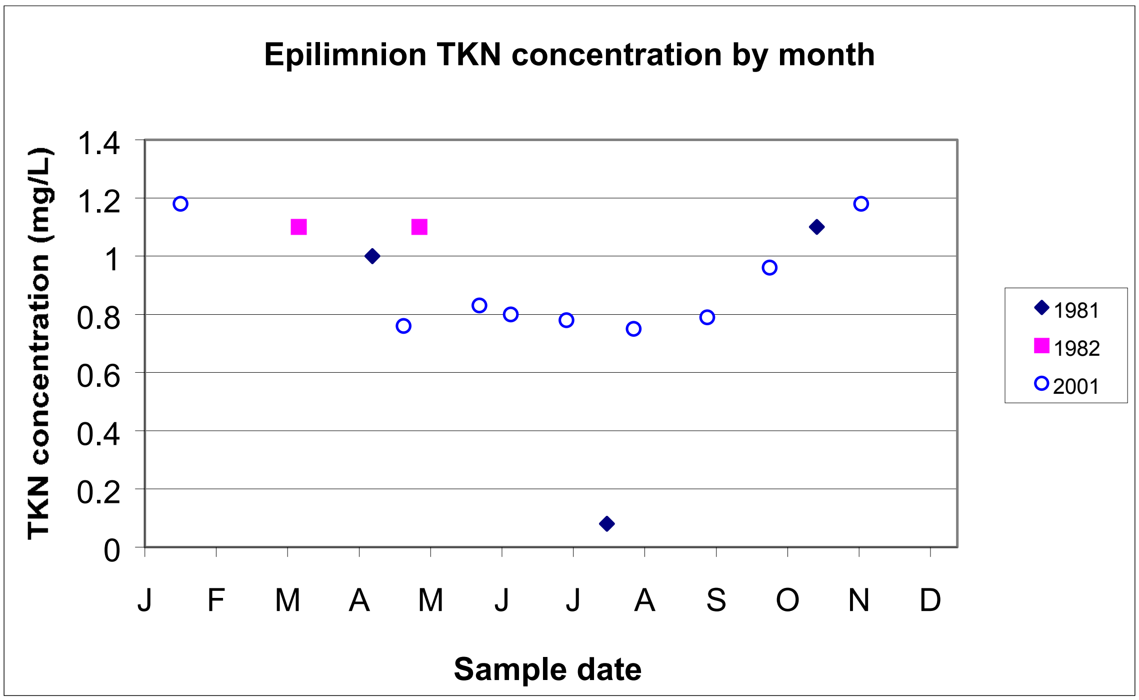


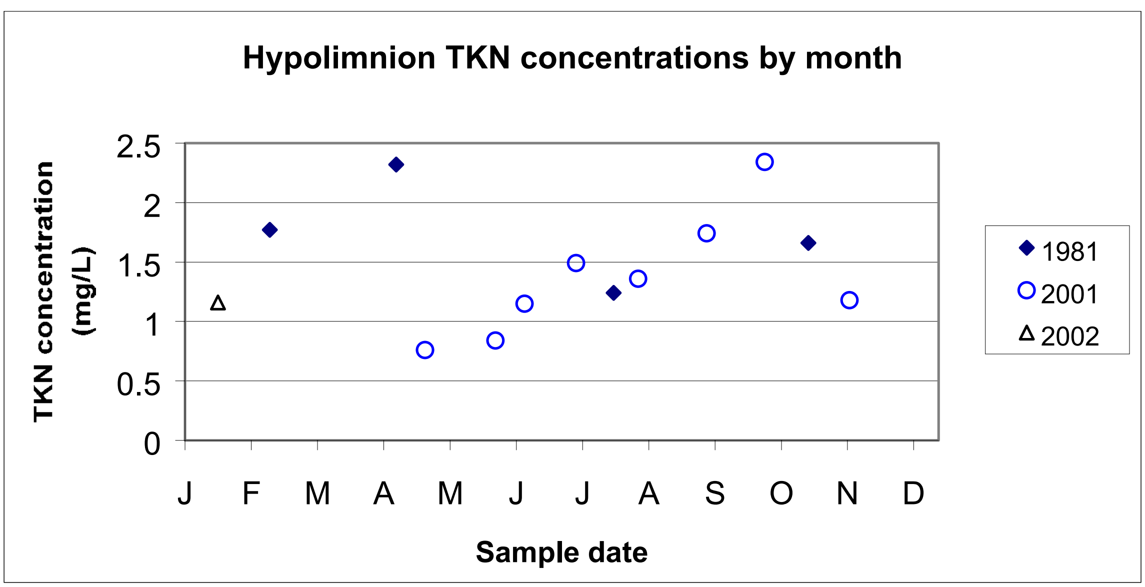


The epilimnion TKN concentration in 2001-02 ranged from 0.75 to 1.18 mg/L with an average of 0.89 mg/L. The epilimnion TKN concentrations in 1980-82 ranged from 0.08 to 1.1 mg/L with an average of 0.876 mg/L. This shows that the epilimnion TKN concentrations have remained fairly constant (Figure 25).

The hypolimnion TKN concentrations in 1980-82 ranged from 1.5 to 2.3 mg/L with an average of 1.65 mg/L. The 2001-02 hypolimnion concentrations ranged from 0.76 to 2.34 mg/L with an average of 1.32 mg/L. Nitrogen levels in the hypolimnion have remained fairly constant over the past twenty to twenty-five years.

Figure 25. Epilimnion TKN concentrations by month in Bear Lake, Waupaca Co., WI.





During fall turnover, the concentrations of all analyzed forms of nitrogen were greater than the average epilimnion concentrations from May through October 2001. The average concentrations of these forms of nitrogen in the hypolimnion during the same time period were greater than the concentrations in the fall turnover sample, showing that the higher concentrations of hypolimnion nitrogen was mixed with the lower concentrations of the epilimnion resulting in an overall concentration somewhere in between the epilimnion and hypolimnion averages after fall turnover.

Sediment, Macrophyte, and Interstitial Water Study

Interstitial water is the pore water in the upper 6-12" of sediment. This water can be nutrient rich and undergoes a significant amount of biological activity. It is the water in contact with the roots of aquatic macrophytes. Interstitial water also serves as a source of nitrogen and other essential nutrients (Wetzel, 1983). Absorption of nutrients from the water column does occur, but it is dependent on the concentration of the nutrient in the water. Algae more readily accomplishes nutrient uptake from the water column. When algae die and decompose in bottom sediments, nitrogen, phosphorus and other nutrients become available in the interstitial water due to the anaerobic, reducing environment provided by the sediment. These elements are less soluble in aerobic sediments or in aerobic lake water (Hudson, M., Shaw, B.H., and Reas, L., 1998-99).

While it has been fairly well accepted that submerged aquatic plants receive the bulk of their nutrient supply from sediment pore water, it is poorly understood what factors are responsible for aquatic plant growth and distribution (Welch, 1992). Certainly sediment type, organic matter content, groundwater inflow or outflow areas, slope, and nutrient and light availability will all contribute to the suitability of a site for colonization by a certain species or many species of aquatic plants.

In attempt to draw relationships between interstitial water, plant growth, and sediments, a study was conducted to determine whether the data correlated to the distribution and biomass of aquatic plants. However, since there were only 12 sites sampled, attempts to draw significant correlations become difficult due to different physical, chemical, and human impacts at each site. Therefore each site or group of sites with similar characteristics will be discussed separately. The interstitial water, plant, and sediments sites are displayed in Figure 6 and the data are displayed in Appendix D.

Interstitial sites 2, 4 and 6 are located on the East side of the lake, north of the boat landing. Site 2 is in an area that has moderate shoreline development and a sandy bottom with little or no aquatic vegetation. Site 2 had elevated levels of ammonium and chloride in the interstitial water and elevated levels of potassium (K) and sulfate (SO_4) in the sediments. Site 4 was located just south of the Bear Lake campground beach near a wetland area. This site had a sandy bottom and did not have any elevated nutrient concentrations or aquatic plants. Site 6 had elevated levels of ammonium in the interstitial water and did not have many aquatic plants.

Site 8 had elevated levels of reactive phosphorus and ammonium in the interstitial water, however, had the lowest concentrations of TKN, TP and percent biomass in the plant tissues collected. The sediments at this site contained the greatest total percent solids of all the sample sites on the lake.

Site 10 is located near the east side of the lake in an area with shoreline development most of which is not used full time year round. The interstitial water data shows that this site had the greatest concentration of nitrate and nitrite at 0.04 mg/L. The plant tissues at this site had slightly elevated TKN and TP concentrations. The sediments at this site contained high levels of nutrients, but had a low percent organic matter.

Site 12 is located in a wetland area, on the north end of the lake. This site had the highest concentrations of all analyzed nutrients in the sediments. These concentrations were at least double the concentration of any other site on the lake, in all of the nutrients in the sediments. This site may still be seeing impacts from an old barnyard up the hill from this wetland area, which is no longer in agricultural use. Chara and pond lily were the dominant plant species at this site. The plant tissues from this site had the second highest concentrations of TKN and TP. However, the interstitial water had no elevated levels of nutrients.

Site 14 is located on the northwest end of the lake and has moderate shoreline development. Site 14 had the greatest concentration of reactive P in the interstitial water on the lake, however there was no aquatic plant growth. The sediments at this site had the lowest nutrient concentrations in the lake, and contained the most percent organic matter. This site also had the lowest total percent solids in the sediments. At this site, the samples were collected from the boat due to lack of solid ground to stand on. Aquatic plant growth at this site may have been hindered due to disturbance by human activity.

Sites 16 through 22 are located on the west side of Bear Lake which does not have any shoreline development; this may explain some differences between the east and west sides of the lake. Thick aquatic vegetation predominantly chara and pond lily line the west side of the lake, which also has a thick buffer of natural woody and wetland vegetation, which provides critical fish and wildlife habitat.

Sites 24, 16 and 18 had the highest percent biomass possibly due to the fact that these areas have not been developed and do not receive as much disturbance as areas on the east side of the lake. The greatest concentration of ammonium in the interstitial water was found at site 16. This may be due to the high concentrations of ammonium flowing into the lake via shallow groundwater near this site, which was determined by the mini-piezometer study. Site 18 had elevated levels of reactive phosphorus and chlorides in the interstitial water. Analysis of the sediment reveals that elevated levels of NO_2+NO_3 were found at sites 16 and 18. Site 20 had no elevated levels of nutrients in the sediments or interstitial water, and no aquatic plants were located at this site. Site 22 had the greatest concentration of chloride in the lake, but did not have elevated levels of nutrients in the interstitial water. The aquatic plant tissues collected at this site had elevated levels of TKN and TP. Chara was the predominant plant species present at this site.

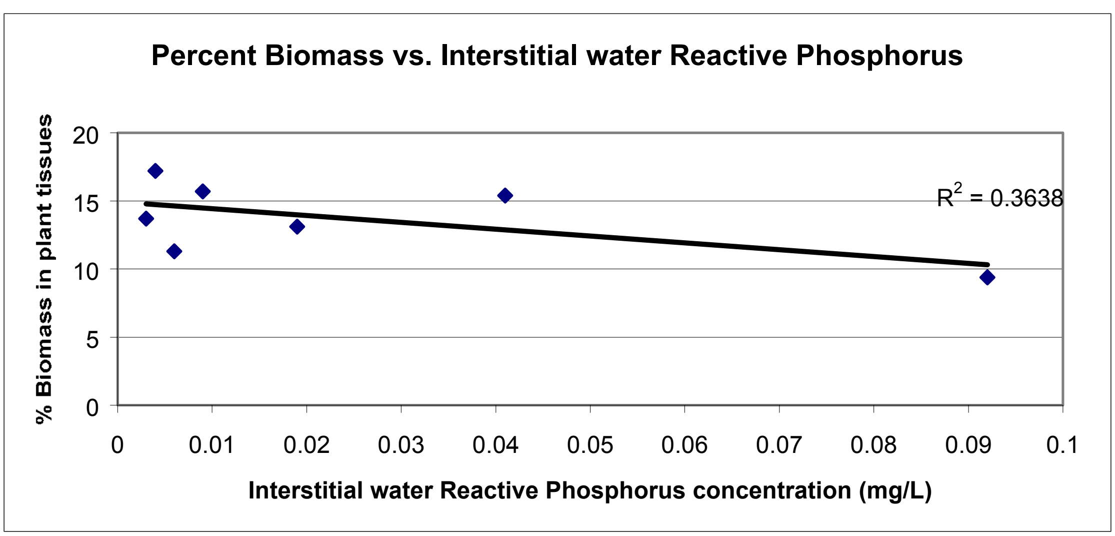
Site 24 is located on the southwest end of the lake by a large wetland area. This wetland area is made up of three converging streams, which flow into Bear Lake. These streams carry nutrients and sediments from within the watershed, however, the wetland area may be retaining some of these nutrients from entering the lake. Site 24 had elevated ammonium concentrations in the interstitial water and had the greatest concentration of TKN in the plant tissues. This site also had the highest percent biomass on the lake, possibly due to lack of human disturbance.

Analysis of plant tissues from each site revealed that the greatest concentrations of TKN in plants were at sites 24, 12 and 22, which are located in wetland areas with thick aquatic vegetation. The greatest concentrations of TP in the plant tissues were found at sites 22, 12, 10 and 24, respectively. The interstitial water reactive phosphorus concentration had a moderate correlation with the percent biomass in the plant tissues collected (Figure 26). Generally, as the interstitial water reactive phosphorus concentration decreases, the percent biomass in the plant tissues increases. Percent biomass also had a fairly strong correlation with nutrient levels in the sediment, with the exception of site 12. Generally, as TKN and TP concentrations in the plant tissue increases, reactive P, ammonium and nitrate levels of the interstitial water decrease, showing that the plants are using the available nutrients in the interstitial water.

Site 12 had the highest levels of all of the nutrients analyzed in the sediments, however, did not have the greatest percent biomass. The high nutrient concentrations in the sediments at this site are likely due to impacts from an old abandoned barnyard that was located up the hill from this area. The dominant plant species at site 12 was chara and pond lily.

Noticeably elevated concentrations of chloride were found at sites 22, 2, and 18 with concentrations of 26.6, 23.0 and 22.0 mg/L respectively. The average concentration of chloride in the interstitial water was 14.5 mg/L. Site 2 is located on the southeast side of the lake where there is heavy shoreline development and the area has been influenced by local impacts. Sites 18 and 22 have no shoreline development and are in undisturbed areas with an abundance of aquatic vegetation.

Figure 26. Shows that as the interstitial water reactive P concentration increases, the percent biomass in the plant tissues increases.



Groundwater Study

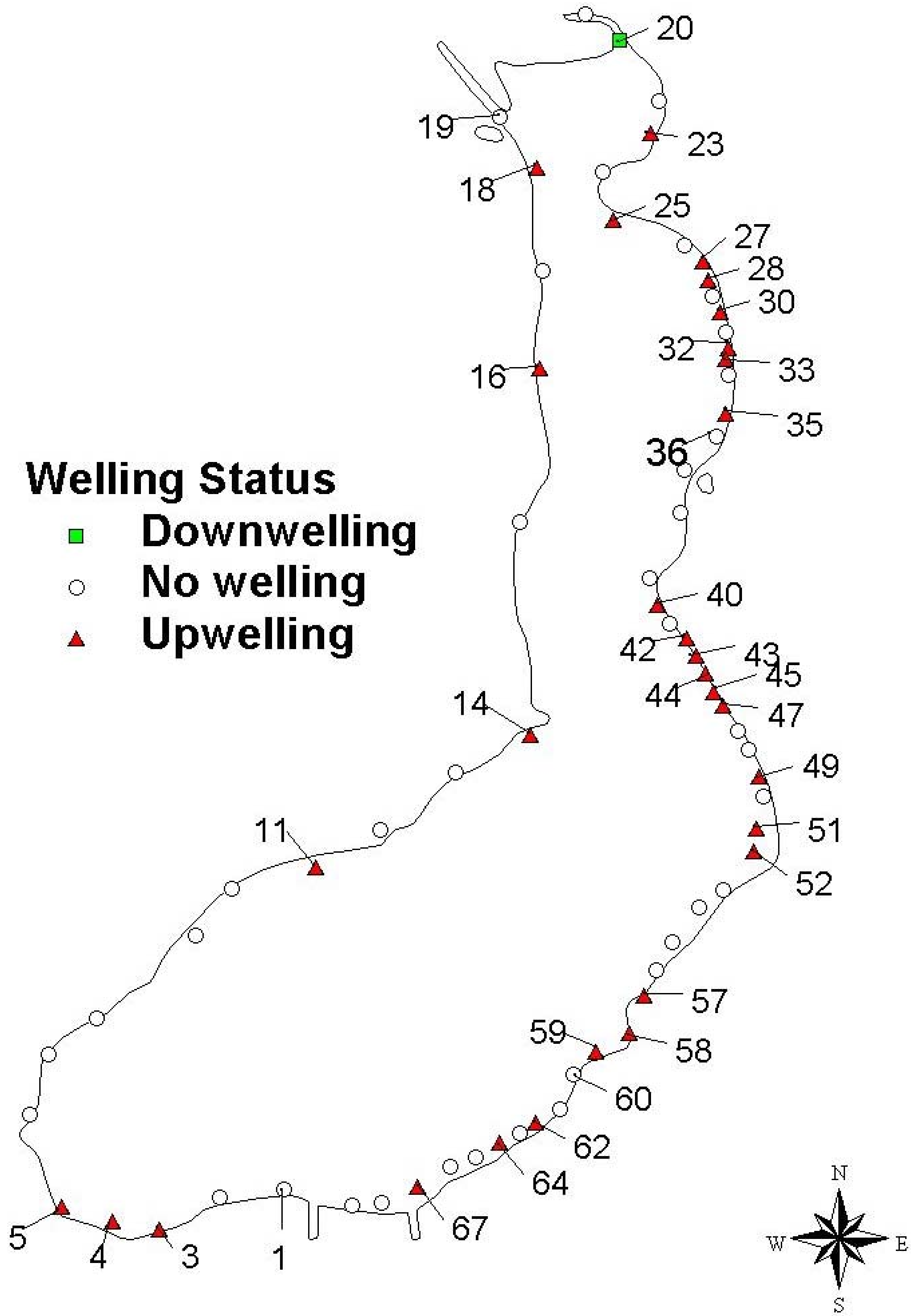
Mini-piezometers were inserted approximately every 200-300 feet in the lake bottom, and used to collect shallow groundwater samples for chemical analysis along with general information regarding groundwater inflow or outflow around the lake. A map of mini-piezometer sites can be found in Figure 4, and all mini-piezometer data can be found in Appendix E. Hydraulic head data were collected at sixty-nine sites around the lake using mini-piezometers and the Hvorslev slug test (Hvorslev, 1951) in August of 2001. This information was used to estimate water and nutrient budgets for the lake.

Samples were collected at all up-welling or ground water inflow sites, along with a couple samples from no-welling sites, where the groundwater is not flowing in or out of the lake. Down-welling or groundwater outflow sites will have concentrations similar to lake water, since the lake water is feeding the groundwater. The regional groundwater flow is from the southwest to the northeast end of the lake. The shallow groundwater inflow and outflow around Bear Lake determined by this study was sporadic. Figure 27 shows the shallow groundwater flow direction around Bear Lake. Approximately 44% (30 sites) of the sites were up-welling sites, 55% (38 sites) were no-welling sites and only 1% (1 site) on the northeast end of the lake was a down-welling site. The greatest velocity of groundwater is entering the lake at sites 47 and 45.

Temperature and conductivity were measured in the field and the samples were transported on ice to the Environmental Task Force Lab and analyzed for $NO_2 + NO_3$, chloride, ammonium, and reactive phosphorus. This information provides a general overview of the relationship between local land uses and shallow groundwater quality. As samples were taken every 200-300 feet, this information should not be used to determine fertilizer and septic inputs on a specific property. Data will be interpreted using site impact classifications which include *locally impacted, wetland impacted, wetland/locally impacted and non-impacted.*

The presence of chloride, where it does not occur naturally indicates possible water pollution (Shaw et al., 2000). In fact, septic systems do not effectively remove chloride due to its anionic form and conservative or non-reactive nature and as a result are often an indication of contamination from man-made sources. Chloride is a common constituent in animal and human wastes, potash fertilizer (potassium chloride), and often

Figure 27. Shallow groundwater inflow/outflow determined by mini-piezometers around Bear Lake.



a component of road deicing agents. Chloride concentrations above 2 mg/L indicate an impact on water quality. Over 80% of the sites had chloride concentrations greater than 2 mg/L. One-third of the mini-piezometer sites had chloride concentrations greater than 10 mg/L. Figure 28 shows the mini-piezometer chloride concentrations around Bear Lake.

Locally impacted sites may include impacts from septic systems, road salts, abandoned barnyards or lawn and garden fertilizers. Septic, abandoned barnyard, and lawn and garden fertilizer influenced sites will usually have elevated chloride and nitrate values, while having isolated amounts of reactive phosphorus or ammonium. Sites affected by road salts will strictly have elevated chlorides. Sites grouped under locally impacted sites, may include a combination of these factors. Approximately 37% of the sampled mini-piezometer sites fall into this category. Chloride concentrations at locally impacted sites range from 3.0 to 81.0 mg/L with an average of 19.0 mg/L. NO_2+NO_3 concentrations at locally impacted sites range from 0.02 to 5.8 mg/L with an average of 0.70 mg/L. Sites 42-47 are located in an area that is close to Highway 22-110 and appear to be influenced by several local impacts. Sites 57-59 also appear to be influenced by local impacts.

Wetland impacted sites were identified by elevated levels of reactive phosphorus and ammonium. Concentrations of nitrate and chloride were minor or non-existent. Sources of ammonium and reactive phosphorus from wetlands are from decomposition and release of nutrients from organic matter. Figure 29 shows the mini-piezometer ammonium concentrations around Bear Lake. Approximately 12% of the mini-piezometer sites appeared to be wetland impacted sites. Sites 4, 5, 33, and 36 were identified as wetland impacted sites. Concentrations of reactive phosphorus ranged from 0.003 to 0.095 mg/L with an average of 0.031 mg/L. Figure 30 shows reactive phosphorus concentrations around Bear Lake.

Ammonium concentrations at wetland impacted sites ranged from 0.34 to 1.90 mg/L with an average of 1.01 mg/L. Chloride concentrations at wetland impacted sites ranged from 0.5 mg/L to 5.0 mg/L with an average of 1.9 mg/L.

Wetland/locally impacted sites demonstrate at least some concentration of all the examined nutrients along with detectable chloride levels. There is likely a combination of sources for these sites, as indicated by the complex water chemistry. Abandoned barnyards around Bear Lake may also be contributing nutrients to the lake via groundwater. Nearly 40% of the sampled mini-piezometer sites appeared to be wetland/locally impacted. Chloride concentrations at wetland/locally impacted sites ranged from 1.0 to 39.0 mg/L with an average of 8.3 mg/L. Reactive phosphorus concentrations ranged from 0.003 to 1.900 mg/L with an average of 0.530 mg/L.

Areas of high nutrient groundwater inflow possibly from septic systems, is contributing to the excessive aquatic plant growth found in many parts of the lake. An elevated concentration of chloride is an excellent indicator of septic or fertilizer contamination when accompanied by elevated reactive phosphorus, and ammonium or nitrate. Approximately 20% of the mini-piezometer sites appear to be impacted by septic systems. Sites 1, 32, 35, 45, 47, and 67 had elevated concentrations of NO_2+NO_3 and chloride in the shallow groundwater flowing into Bear Lake. Sites 67, 45, and 47 had the three greatest concentrations of NO_2+NO_3 at concentrations of 20.50, 5.80 and 2.89 mg/L, respectively, and three of the four greatest chloride concentrations. Figure 31 shows mini-piezometer NO_2+NO_3 concentrations around Bear Lake. The groundwater at sites 47 and 45 is flowing into Bear Lake with the greatest velocity of any of the sites sampled on the lake. Therefore, these sites are contributing nutrients to the lake at a greater rate than anywhere else on the lake.

Non-impacted sites are sites that demonstrated little or no concentrations of all aspects measured. The chemistry at these sites will best represent unaffected shallow groundwater flow to Bear Lake. Sites 14, 51, 52, 62, and 64 were classified as non-impacted sites. Non-impacted sites comprised about 14% (5 sites) of the sampled mini-piezometer sites. Chloride concentrations at non-impacted sites range from 1.5 to 10.0 mg/L with an average of 5.3 mg/L. Concentrations of all other nutrients were low at these sites.

Sites 6-13, with the exception of site 11, are located on the southwest edge of the lake, and yielded no water due to the fine marl sediments sealing up the holes in the mini-piezometer screen. The water that was pulled up through the mini-piezometer in this area and at site 25 was of a white milky consistency due to the marl sediments, however, enough water could not be drawn through the mini-piezometer in order to make sure that a representative groundwater sample could be taken. Since the shallow groundwater flow associated with these sites has little to no contact with the lake water, these sites were classified as no-welling sites.

Figure 28. Map of mini-piezometer chloride concentrations around Bear Lake.

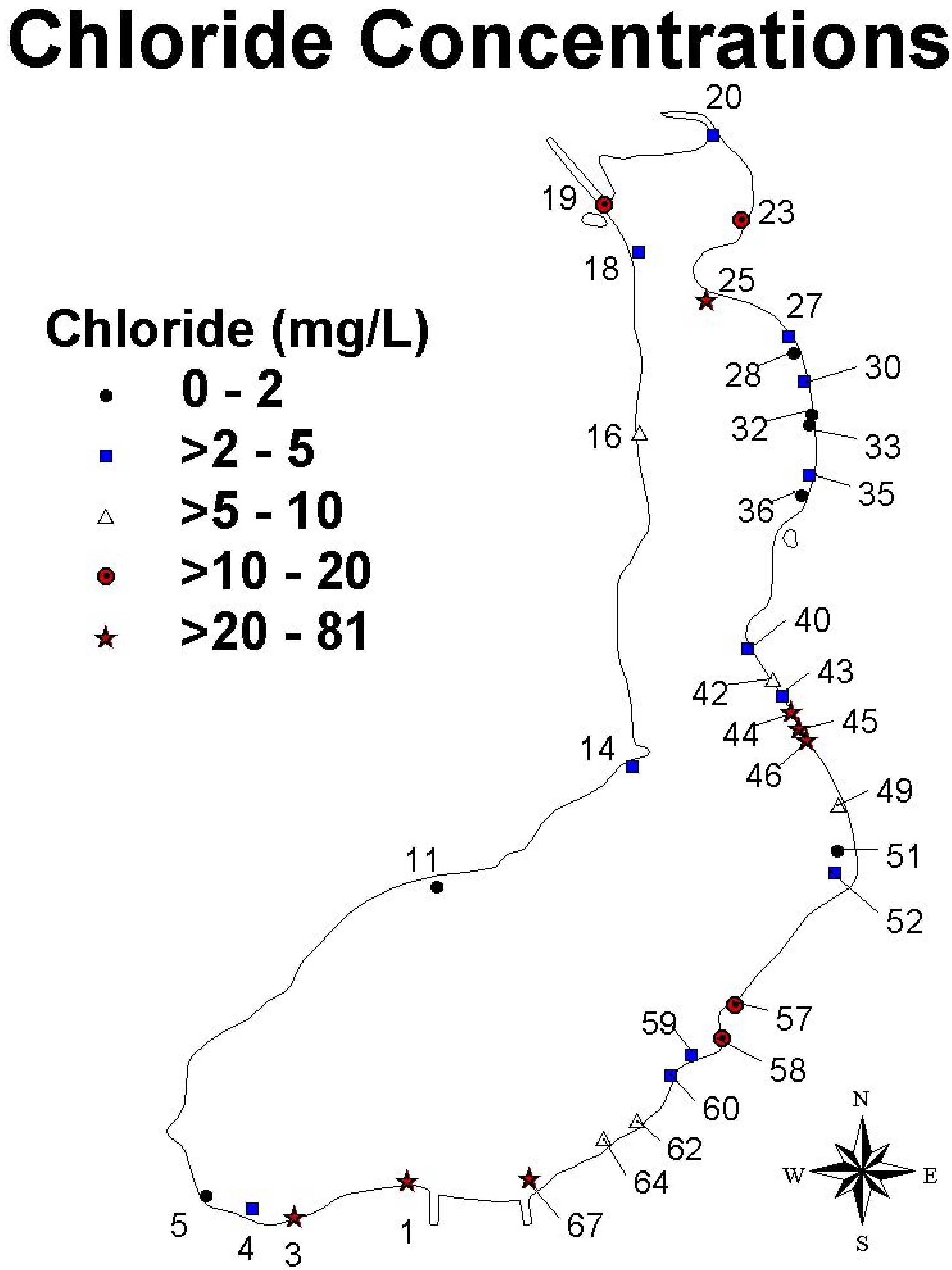


Figure 29. Mini-piezometer ammonium concentrations around Bear Lake.

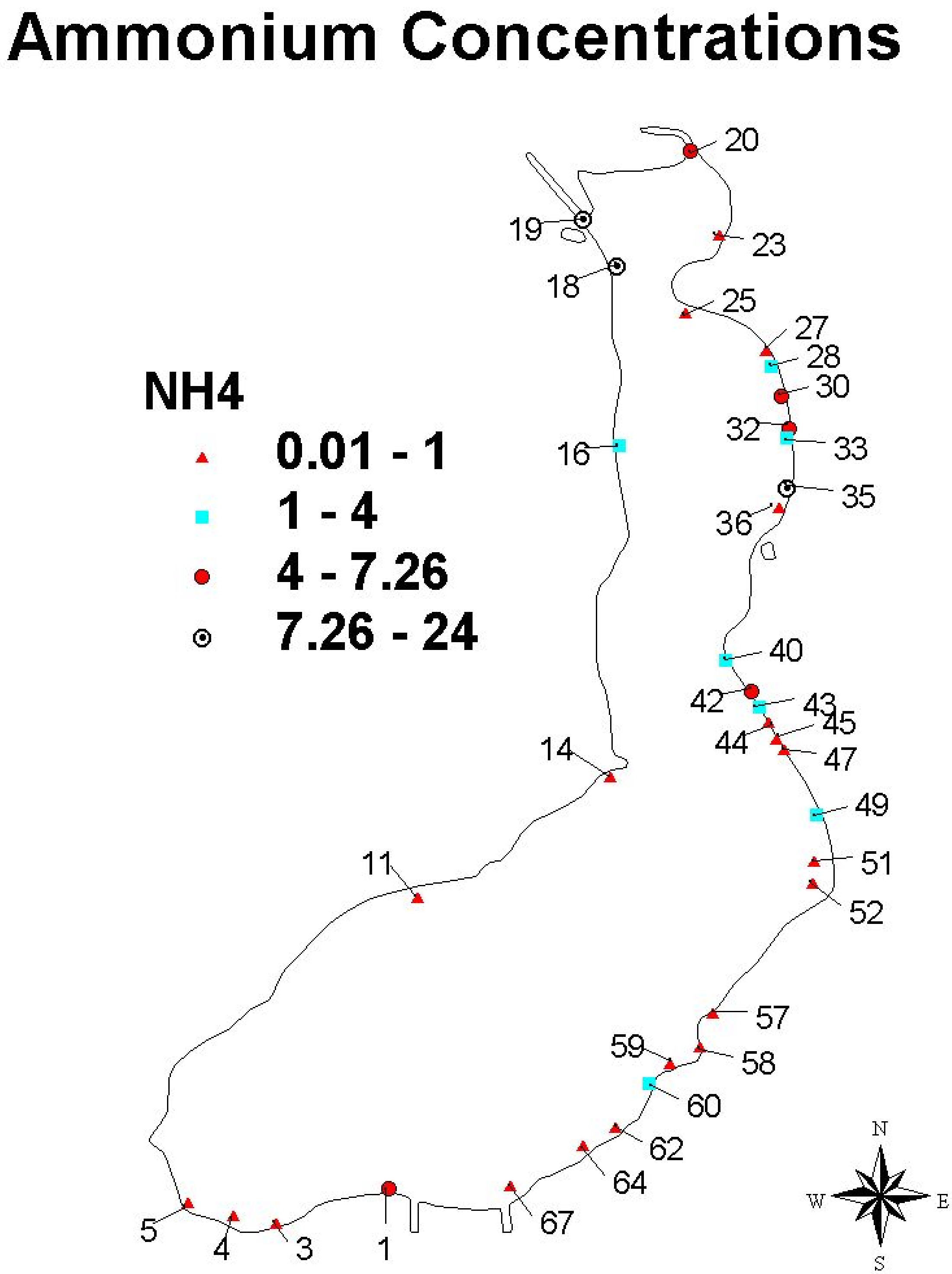


Figure 30. Map of mini-piezometer reactive phosphorus concentrations around Bear Lake.

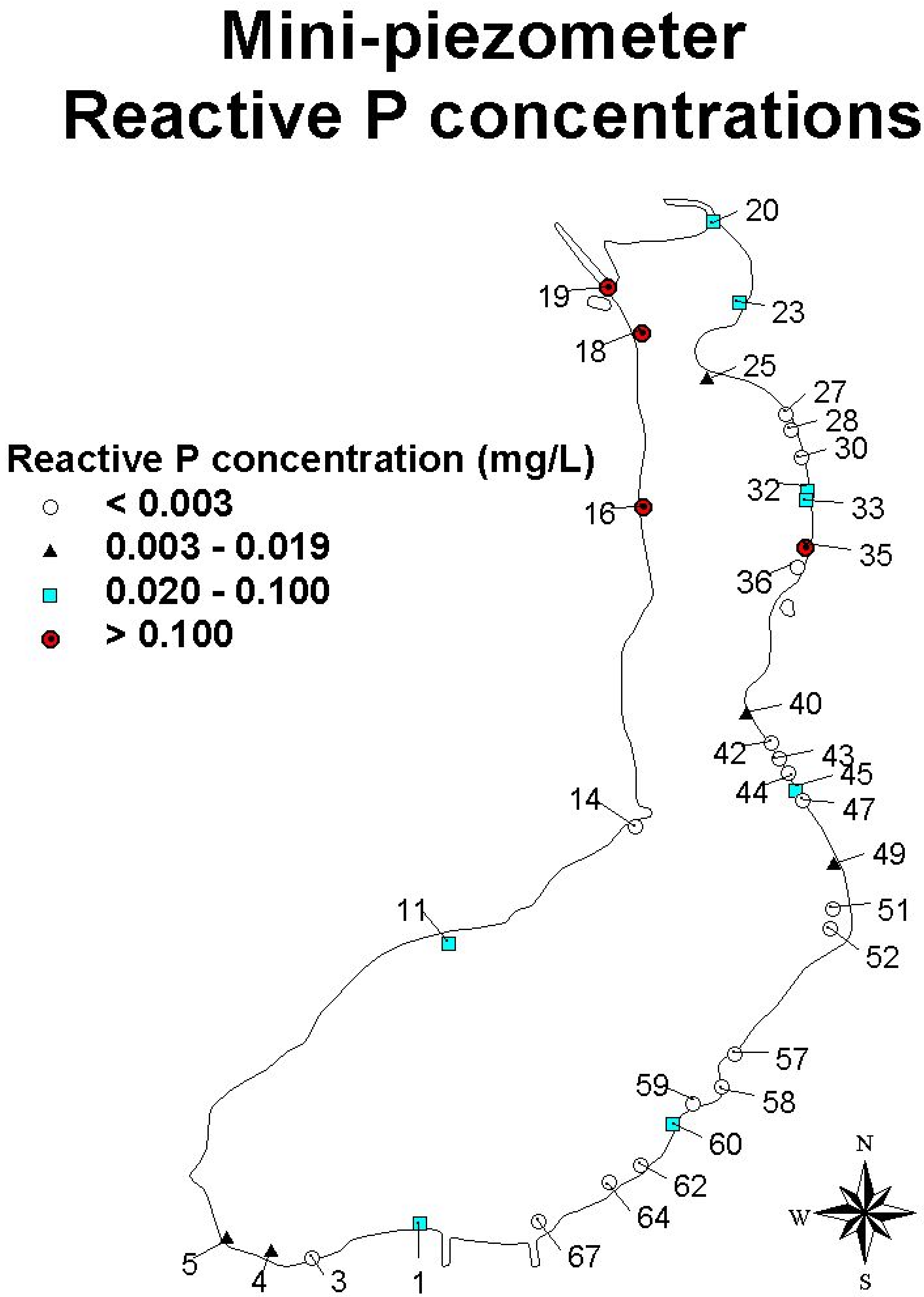
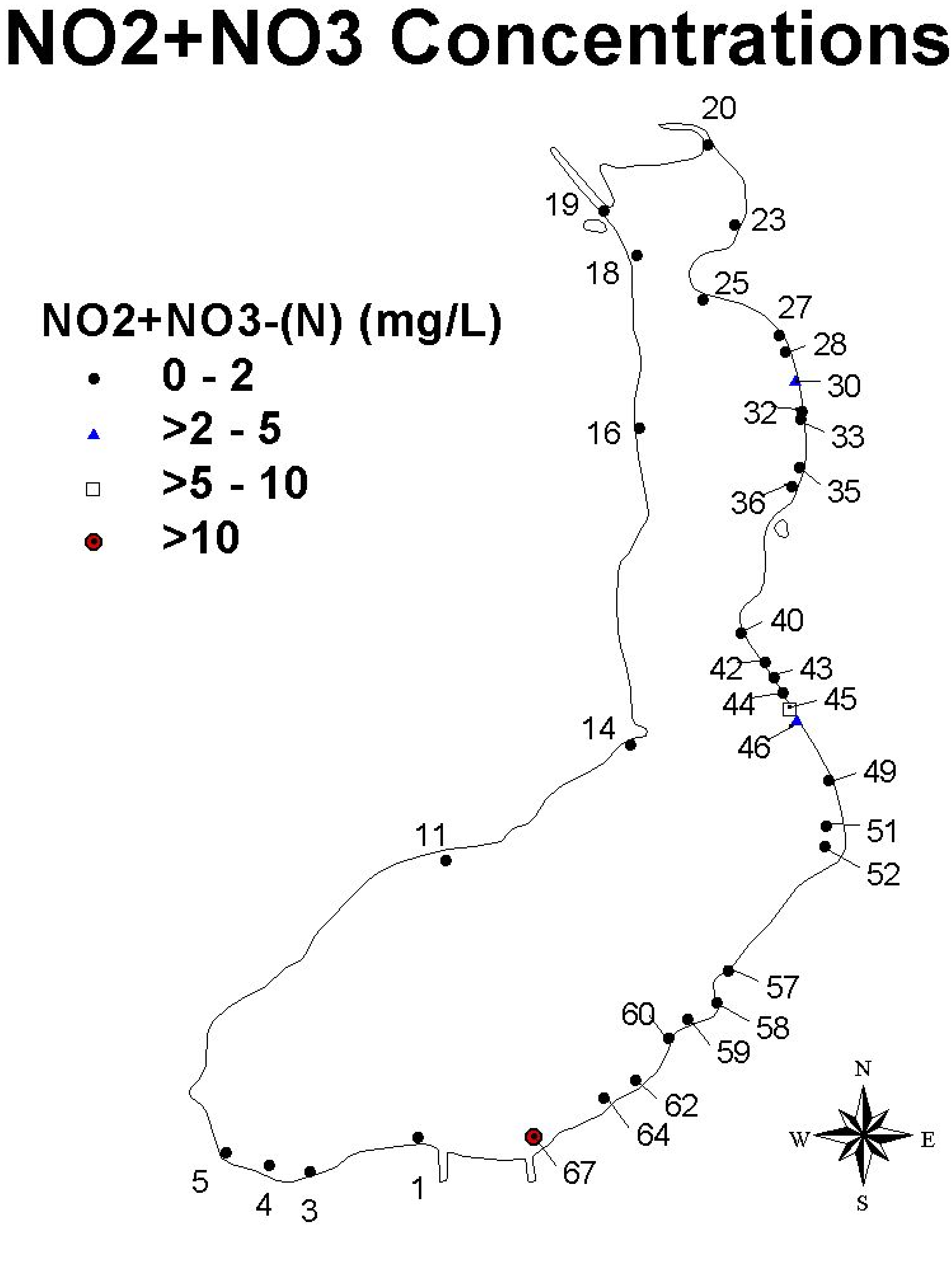


Figure 31. Map of mini-piezometer NO_2+NO_3 concentrations around Bear Lake.



Trophic Status Index

The trophic status is another way to characterize water quality. Lakes are classified into one of three stages based on trophic state – oligotrophic, mesotrophic, and eutrophic (Shaw et al., 2000). The status reflects a lake's nutrient and clarity levels. These categories are related to the natural aging of a lake, however, this aging process can be accelerated by changing the riparian zone and land uses within a lake's watershed.

According to Shaw et al., oligotrophic lakes are generally clear, deep and free of weeds or large algae blooms. They are low in nutrients and do not support large fish populations, but can support a fishery of large game fish. Oligotrophic lakes are often limited by phosphorus and contain nitrogen in quantities in excess of demand from growth supported by available phosphorus (Wetzel, 2001). Oligotrophic lakes are "young" lakes. As the lake becomes more productive, the primary effecting agent is increased loading of phosphorus.

Eutrophic lakes are high in nutrients and support a large biomass (all plants and animals living in the lake). They are usually either weedy or subject to frequent algae blooms, or both. Eutrophic lakes often support large fish populations, but are also susceptible to oxygen depletion. Small, shallow, eutrophic lakes are especially vulnerable to winter kill which can reduce the number and variety of fish.

Mesotrophic lakes lie between the oligotrophic and eutrophic stages. They are void of oxygen in late summer, and the hypolimnion limits cold-water fish and cause phosphorus cycling from sediments.

Common measures of trophic status include Secchi depth (water clarity), total phosphorus (TP) concentration, and chlorophyll *a* concentration (measure of algae). Although many factors influence these relationships, the major assumptions that bring the Trophic State Indices (TSI) together are that 1) the amount of chlorophyll *a* present is primarily related to the phosphorus concentration, and 2) water clarity is primarily dependent on the chlorophyll *a* concentration (Lillie, 1983). Usually, as total phosphorus values increase, the chlorophyll *a* levels also elevates while the Secchi depth decreases due to algal communities in the lake profile.

There have been several Trophic State Indices developed in an attempt to translate several of the measurable water chemistry variables into an assessment of lake water quality. The indices are valuable in comparing both water quality changes over time in a given lake, as well as quantitative comparisons to other lakes. The most representative set of equations was taken from Lillie and Graham (1993), which are based on the Bureau of Research's 1979 random survey data set (combined lakes and impoundments) that were greater than 5 feet deep and at least 25 acres in size. It uses existing Wisconsin databases to derive area specific formulas. The calculations were based on monthly sampling periods during the summer months defined as May through September. Average summer secchi depth and chlorophyll *a* values were calculated using data from the summer of 2001. The average summer TP was calculated using a weighted TP value. The equations used to determine WTSI values are listed below:

$$\text{WTSI (SD)} = 60 - 14.4 \ln(\text{SD})$$

where SD is the average summer (May-September) secchi depth in meters.

$$\text{WTSI (CHL)} = 34.8 + (7.56 \ln(\text{CHL}))$$

where CHL is the average summer (May-September) chlorophyll *a* concentration in (*u*g/L).

$$\text{WTSI (TP)} = 28.2 + (7.73 \ln(\text{TP}))$$

where (TP) is the average weighted summer (May-September) Total phosphorus concentration in (ug/L).

The weighted TP value was determined by weighting each layer concentration proportionally to its volume of the water column. In order to compare the data from the 1980-82 study, the TP concentrations were also weighted proportionally to its volume in the water column.

Since there is no chlorophyll *a* data from 1975, the trophic state index could not be applied to that data. Since the data from 1980-82 contains secchi depth, chlorophyll *a* and TP concentrations may be applied to the trophic state index, however, there was only one sample taken in each summer, and quarterly samples were collected, so all the samples dates were averaged to determine a 1980-82 average. Table 4 presents the summer averages and the WTSI data from 1980-82 and 2001.

Table 4. 1980-82 and 2001 average summer Secchi depth, chlorophyll *a* concentrations, weighted TP values with calculated WTSI equivalent values.

	Secchi Depth (feet)	Secchi Depth (meters)	WTSI(SD)	Chlorophyll a (ug/L)	WTSI(CHL)	TP concentration (ug/L)	WTSI(TP)
1980-82	5	1.5	54.2	11	52.9	70*	61.0
2001-02	10.5	3.4	42.5	3.7	44.7	75.1*	59.4

*Total Phosphorus values were calculated using layer concentrations weighted by volume of the water column.

In general, the lower the WTSI equivalent value, the better the water quality is. Using the Lillie and Mason Water Quality Index (Table 5), the 1980-82 data rate Bear Lake's apparent water quality as fair to poor. Using the Lillie and Mason Trophic Classification (Table 6), the 1980-82 data classified Bear Lake as a eutrophic lake.

Chlorophyll *a* content was measured monthly from May through September 2001, and ranged from 1.1 to 4.4 *u*g/L, with an average of 2.98 *u*g/L. Secchi depth ranged from 2.0 to 5.0 meters in the summer of 2001, with an average of 3.4 meters. Using the Lillie and Mason Water Quality Index (Table 5), Bear Lake has very good water quality when examining Secchi depth, and chlorophyll *a* content. However, TP levels rank the lake's apparent water quality as poor. Using the Lillie and Mason Trophic Classification (Table 6), the average summer chlorophyll *a* concentration and Secchi depth, Bear Lake presented characteristics of an oligotrophic lake. This shows a decrease in chlorophyll *a* and TP concentrations and an increase in Secchi depth over the past twenty years.

TP values may be elevated in the lake because of a chemical reaction that produces marl. TP is a measure of all the phosphorus in the sample and is not the phosphorus available for plant uptake. If the amount of carbonate (CO_3) is high enough, it will react with calcium in the water to form $CaCO_3$ (marl). Marl precipitates out leaving a white substance in the sediment and can often be observed as white residue on plant leaves. The marl precipitate bonds with phosphorus, thereby eliminating its availability to the plant community and reducing algae growth.

Also, the plant community can only take up phosphorus that is not rendered unavailable to plants through marl precipitation. TP values may actually be much higher in Bear Lake due to macrophyte growth, since plants contain and utilize phosphorus for growth.

Improvements of all parameters of the trophic status index present an improvement in apparent water quality and a slight improvement in the trophic state since the late 1970's and early 1980's. Overall, the TSI determines Bear Lake's current water quality conditions as mesotrophic to eutrophic. Bear Lake does exhibit characteristics of a eutrophic lake such as: oxygen depletion, algal blooms, abundance of aquatic macrophytes and elevated nutrient concentrations, while exhibiting characteristics of an oligotrophic lake such as good water clarity. With the carbonate buffering in the lake, and reduction of inputs of phosphorus via groundwater and surface runoff, Bear Lake may continue to see improved water clarity.

Table 5. Apparent water quality categories for Wisconsin lakes based on chlorophyll a content, water clarity, and Total P concentrations.*

Water Quality Index	Approximate Chlorophyll a Equivalent (ug/L)	Approximate Secchi Depth Equivalent (m)	Approximate Total P Equivalent (ug/L)	Approximate TSI** Equivalent
Excellent	<1	>6.0	<1	<34
Very Good	1 to 5	3.0-6.0	1 to10	34-44
Good	5 to 10	2.0-3.0	10 to 30	44-50
Fair	10 to 15	1.5-2.0	30 to 50	50-54
Poor	15 to 30	1.0-1.5	50 to 150	54-60
Very Poor	>30	<1.0	>150	>60

*From Lillie and Mason (1983)
**From Carlson (1977)

Table 6. Trophic classification of Wisconsin lakes based on chlorophyll a, water clarity measurements, and total phosphorus values. (Adapted from Lillie and Mason, 1983.)

Trophic class	Total Phosphorus (*u*g/L)	Chlorophyll a (*u*g/L)	Secchi disc feet
Oligotrophic	3	2	12
	10	5	8
Mesotrophic	18	8	6
	27	10	6
Eutrophic	30	11	5
	50	15	4
Bear Lake-2001	**56.3**	**2.98**	**11.1**

*Adapted from Shaw et al., 1996.

<u>Aquatic Macrophyte Survey</u> (contributed by Stacey Allen)

Aquatic macrophytes (larger sized plants) have apparently been abundant in Bear Lake for some time. A 1954 survey indicated that aquatic macrophytes approached nuicance levels in some parts of the lake. Pondweeds were most common, with big leaf pondweed predominating. No water milfoil was observed at that time. In 1959, big leaf pondweed was again the most widely distributed species and an influx of water milfoil was documented. In some eutrophic lakes water milfoil becomes quite abundant by out-competing other aquatic plants. In October 1973, big leaf pondweed was described as excessive in certain areas of the lake and American lotus (<u>Nelumbo</u> <u>lutea</u>) was documented. American lotus is becoming rare and is a protected species in Wisconsin. A survey in the summer of 1975 again indicated that aquatic vegetation, particularly pondweeds was abundant in Bear Lake. Water milfoil was now described as excessive. Some musk grass, wild celery, and bushy pondweed were also noted (Bushweiler, B. and Rasman, T. 1984.).

The survey of aquatic vegetation conducted during the summers of 1980-81 revealed that *Lemna spp., Nymphaea spp., Nuphar spp., Ceratophyllum demersum, Myriophyllum exalbescens, Chara spp.,* and *Potamogeton praelongus* were abundant aquatic plants in Bear Lake. The 2001 aquatic plant survey did not identify *Myriophyllum exalbescens* and *Potamogeton praelongus* within Bear Lake.

The survey of aquatic vegetation conducted during the summers of 1980-81 revealed that *Heteranthera dubia,* and *Potamogeton natans*, were aquatic plants common in Bear Lake, however, they were not identified in the 2001 aquatic plant survey. Since there were only 25 transects, it is possible that this survey did not locate these species, or they could have been eliminated from the lake ecosystem.

The latest survey of aquatic vegetation was conducted during the summer of 2001. The three species with the greatest total occurrence in Bear Lake were *Chara sp., Najas flexilis* and *Potomageton zosteriformis*. The two species with the least total occurrence were *Myriophyllum spicatum* and *Spirodela polyrhiza*. In depth zones one, two, and three *Chara sp*. had the highest total occurrence. In depth zone four, *Ceratophyllum demersum* had the highest total occurrence.

The 2001 aquatic plant survey revealed the presence of the exotic species of Eurasian milfoil on the north end of the lake. Eurasian water milfoil (*Myriophyllum spicatum*) is a submersed aquatic plant native to Europe, Asia and northern Africa. It is one of eight milfoil species found in Wisconsin and the only one non-native to the state. Generally, the plant goes unnoticed until it has established itself in a lake and become a nuisance. Eurasian water milfoil first showed up in Wisconsin's counties in the 1960's. In the past three decades, this exotic species has significantly expanded its range, especially over the last five years from 1994 to 2001. Boats or boat trailers that have aquatic plants from another body of water usually transport Eurasian milfoil. Since the boat landing is on the south end of the lake, boats that were not launched from the boat landing may have introduced this exotic species into Bear Lake. Since the exotic species is only found in a small area of the lake, the spread of this species should try to be controlled.

Because of its potential for explosive growth and its incredible ability to regenerate, Eurasian water milfoil can successfully out compete most native aquatic plants, especially in disturbed areas. In a number of Wisconsin lakes, Eurasian water milfoil has formed huge monoculture stands with vast mats of surface foliage that shade-out native aquatic plants and diminish the aesthetic beauty. Recreational activities like swimming, boating and sport fishing are also diminished on lakes infested with Eurasian water milfoil. A variety of techniques have emerged for controlling Eurasian water milfoil populations on Wisconsin's lakes. These techniques include mechanical cutting and harvesting in open areas, limited use of herbicide treatments and more recently the introduction of weevils as a biological control agent.

2001 Bear Lake Aquatic Plant Survey

Methodology

Sampling methods were based on the rake-sampling method developed by Jessen and Lound (1962) and currently used by the Wisconsin DNR. Site location was accomplished by measuring the shoreline of Bear lake using a cartometer and then dividing the shoreline into 25 equal segments. A transect, perpendicular to the shoreline, was randomly placed within each segment.

Sampling sites were randomly located within depth zones of 0-2 ft., 2-5 ft., 5-10 ft and 10-20 ft along each transect. Locations of each site were recorded on a map. Four rake samples were taken at each sampling site using a long-handled, steel-thatching rake. The four samples were collected from each quarter of a 6-foot diameter quadrant. Aquatic plant species collected on each rake sample were hand identified and each species were given a density rating (0-5) based on the number of rake samples on which it was present at each sampling site. A rating of 1 indicates that a species was present on one rake sample, a rating of 4 indicates that it was present on all four rake samples and a rating of 5 indicates that it was abundantly present on all rake samples at that sampling site.

Visual inspection and periodic samples were taken between transect lines in order to record the presence of any species that did not occur at the sampling sites.

The sediment type at each sampling site and the type of shoreline cover at the beginning of each transect were recorded. A section of shoreline, 50 feet on either side of the transect intercept with the shore and 30 feet back from the shore, was evaluated. The percentage of each cover type within this 100’ x 30’ rectangle was visually estimated and verified by a second researcher.

An Excel file provided by Deb Konkel, DNR Eau Claire, was used to enter and analyze the data.

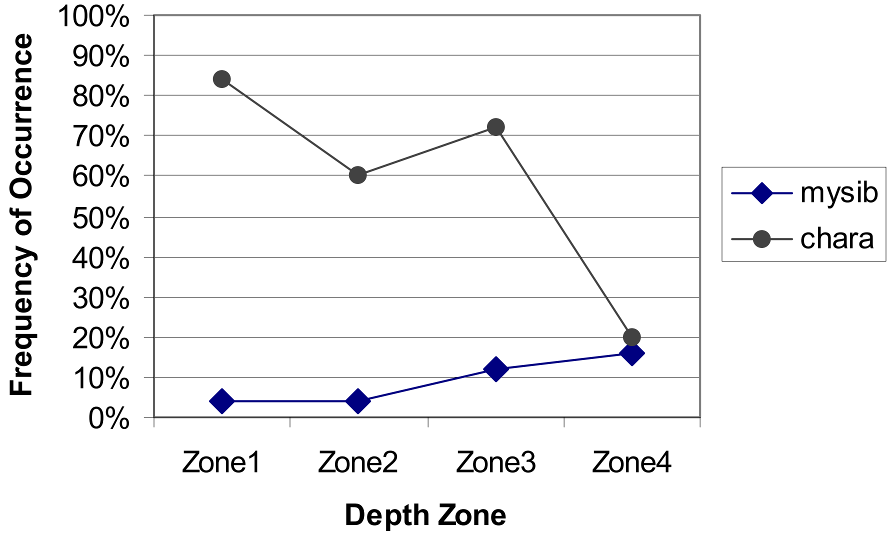
Bear lake Aquatic Plant Species

Of the 20 species found in Bear Lake three were emergent species, four were floating leaf species and 13 were submergent species. *Chara sp*. was the most frequent species found (59%). While *Najas flexilis, Potamogeton zosteriformis and Ceratophyllum demersum* were also abundant (32%, 25%, 19%). Figure 32 lists the aquatic plant species that were found in Bear Lake during the 2001 aquatic plant survey. Table 7 displays the percent frequency of two species found in Bear Lake.

Figure 32. Aquatic plant species present in Bear Lake.

Scientific Name		**Common Name**	**I.D. Code**
Emergent Species			
1)	*Scirpus validus*	soft stem bulrush	scval
2)	*Typha latifolia*	cattail	typha
3)	*Pontederia cordata*	pickerel weed	pocor
Floating leaf Species			
4)	*Lemna minor*	small duckweed	lemin
5)	*Nymphaea odorata*	white water lily	nyord
6)	*Nuphar advena*	yellow pond lily	nuadv
7)	*Spirodela polyrhiza*(L.)Schleiden.	great duckweed	sppol
Submergent Species			
8)	*Caltha palustris*	marsh marigold	capal
9)	*Ceratophyllum demersum*	coontail	cedem
10)	*Chara* sp.	muskgrass	chara
11)	*Elodea canadensis* Michx.	common waterweed	elcan
12)	*Myriophyllum sibiricum* Komarov.	common water milfoil	mysib
13)	*Myriophyllum spicatum* L.	Eurasian water milfoil	myspi
14)	*Najas flexilis* (Willd.) Rostkov & Schmidt.	Slender naiad	nafle
15)	*Potamogeton illinoensis*	Illinois pondweed	popec
16)	*Potamogeton pectinatus* L.	Sago pondweed	popec
17)	*Potamogeton richardsonii*	clasping leaf pondweed	poric
18)	*Potamogeton zosteriformis* Fern.	flat-stem pondweed	pozos
19)	*Utiricularia vulgaris*	bladderwort	utvul
20)	*Vallisaneria americana*	water celery	vaame

Table 7. Frequency of Occurrence of aquatic plant species in each depth zone.



Coefficient of Conservatism

The Coefficient of Conservatism is the probability that a species will occur in a relatively undisturbed habitat. Each species is assigned a value from 0-10 (ref). The average Coefficient of Conservatism is the mean of the Coefficients of Conservatism for each species found in a lake. The Coefficient of Conservatism has a range from a low of 2.0, the most disturbances, to a high of 9.5, the least disturbed. Bear Lake has an average coefficient of conservatism of 5.1. This places Bear Lake in the lowest quartile of lakes in Wisconsin, among the group of lakes in Wisconsin most disturbance tolerant. The Floristic Quality Index is 22.25, which is below the mean for Wisconsin lakes. This indicates that plants in Bear Lake are exhibiting the effects of disturbance. Table 8 displays the coefficient of conservatism for species found in Bear Lake.

Table 8. Table of Coefficient Conservatism for species found in Bear Lake.

Species	Coefficient Conservatism
Caltha palustris	
Ceratophyllum demersum	3.00
Chara sp.	7.00
Elodea canadensis	3.00
Lemna minor	5.00
Myriophyllum sibiricum	7.00
Myriophyllum spicatum	
Najas flexilis	6.00
Nuphar advena	8.00
Nymphaea odorata	6.00
Pontederia cordata	9.00
Potamogeton illinoensis	6.00
Potamogeton pectinatus	3.00
Potamogeton richardsonii	5.00
Potamogeton zosteriformis	6.00
Scirpus validus	4.00

Total Occurrence

Total occurrence was determined by adding each occurrence of the species throughout the depth zones. The three species with the greatest total occurrence in Bear Lake were *Chara sp.*, *Najas flexilis,* and *Potomageton zosteriformis*. The two species with the least total occurrence were *Myriophyllum spicatum, Pontederia cordata* and *Spirodela polyrhiza*. *Chara sp.* had the highest total occurrence in depth zones one, two, and three. In depth zone four *Ceratophyllum demersum* had the highest total occurrence. Table 9 lists the total occurrence for species found in Bear Lake.

Table 9. Table of Total occurrence for species found in Bear Lake.

Species	Total Occur.
Caltha palustris	8.00
Ceratophyllum demersum	19.00
Chara sp.	59.00
Elodea canadensis	5.00
Lemna minor	2.00
Myriophyllum sibiricum	9.00
Myriophyllum spicatum	1.00
Najas flexilis	32.00
Nuphar advena	13.00
Nymphaea ordonata	9.00
Pontederia cordata	1.00
Potamogeton illinoensis	14.00
Potamogeton pectinatus	6.00
Potamogeton richardsonii	6.00
Potamogeton zosteriformis	25.00
Scirpus validus	8.00
Spirodela polyrhiza	1.00
Typha latifolia	5.00
Utricularia vulgaris	2.00
Vallisaneria americana	31.00

Percent Frequency

The percent frequency of each species was determined by taking the number of sampling sites at which each occurred divided by the total number of sampling sites. The species in Bear Lake with the highest percent frequency were *Chara sp*., *Najas flexilis*, and *Vallisaneria americana*. The species with the least percent frequency were *Myriophyllum spicatum, Pontederia cordata* and *Spirodela polyrhiza.* Table 10 lists the percent frequency for species of aquatic plants in Bear Lake.

Table 10. Table of percent frequency for species of aquatic plants in Bear Lake.

Species	%Freq.
Caltha palustris	8.00%
Ceratophyllum demersum	19.00%
Chara sp.	59.00%
Elodea canadensis	5.00%
Lemna minor	2.00%
Myriophyllum sibiricum	9.00%
Myriophyllum spicatum	1.00%
Najas flexilis	32.00%
Nuphar advena	13.00%
Nymphaea ordonata	9.00%
Pontederia cordata	1.00%
Potamogeton illinoensis	14.00%
Potamogeton pectinatus	6.00%
Potamogeton richardsonii	6.00%
Potamogeton zosteriformis	25.00%
Scirpus validus	8.00%

Simpson's Diversity

The Simpson's Diversity Index for Bear Lake was 0.89. This number indicates a very good diversity. A rating of 1.0 would mean that each plant in the lake would be a different species.

Total Density

Total density, was determined by adding the total of times each species was found on a rake sample. The species with the overall highest total density in Bear Lake were *Chara* sp., *Najas flexilis*, and *Vallisaneria americana*. The species with the least total density were *Typha latifolia, Pontederia cordata* and *Lemna minor*. The species with the greatest density in depth zone one were *Chara sp.*, *Nymphaea ordonata*, and *Vallisaneria americana*. The species with the greatest density in depth zone two were *Chara sp*. and *Scirpus validus*. In depth zone three *Chara sp*. and *Najas flexilis* had the greatest density. It depth zone four *Ceratophyllum demersum* had the greatest density. Table 11 shows the total density of aquatic plant species found in Bear Lake.

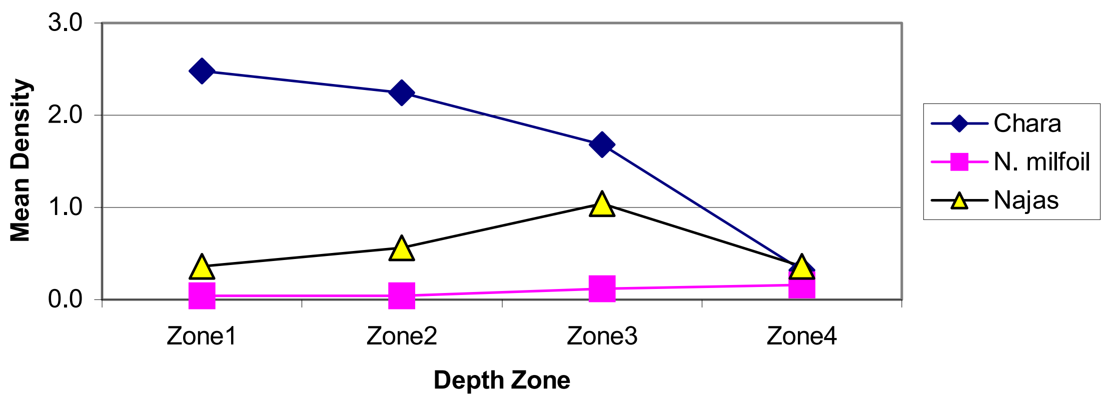
Table 11. Table of total density of aquatic plant species found in Bear Lake.

Species	Total Density
Caltha palustris	35.00
Ceratophyllum demersum	53.00
Chara sp.	168.00
Elodea canadensis	9.00
Lemna minor	2.00
Myriophyllum sibiricum	9.00
Myriophyllum spicatum	3.00
Najas flexilis	58.00
Nuphar	31.00
Nymphaea ordonata	30.00
Pontederia cordata	2.00
Potamogeton illinoensis	29.00
Potamogeton pectinatus	13.00
Potamogeton richardsonii	13.00

Mean Density

The mean density of species varied with the depth. *Chara sp*. was the species with the greatest mean density for depth zones one through three. As would be anticipated, *Najas flexilis* was most dense in zone three and decreased in zone four. The density of *Myriophyllum sibiricum* increased slightly in depth zone four, but showed vary little variation in depth zones one through three. Figure 33 shows the mean density of three species of aquatic plants in each depth zone of Bear Lake.

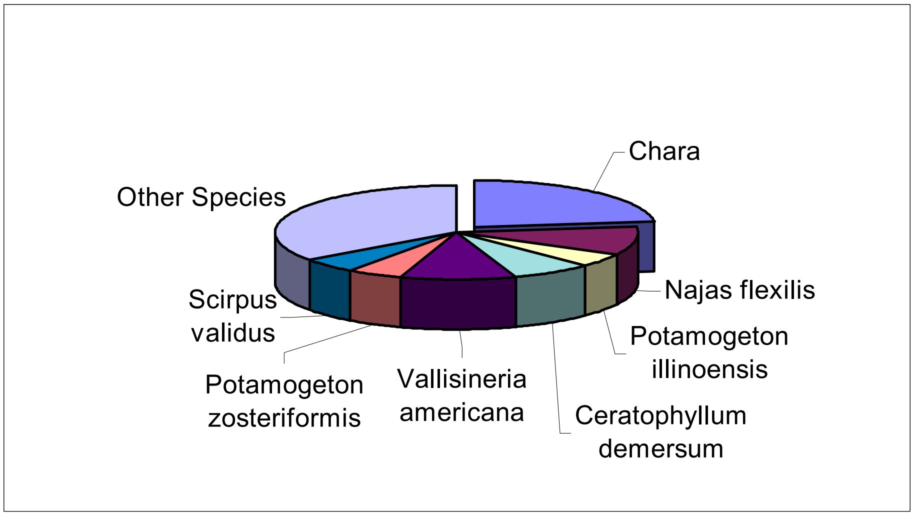
Figure 33. Diagram of the mean density of three species of aquatic plants in each depth zone of Bear Lake.



Dominance Value

Dominance value was calculated by adding the relative frequency and relative density. The species with the greatest dominance value in Bear Lake were *Chara sp*., *Vallisineria Americana, Najas flexilis and Ceratophyllum demersum*. The species with the least dominance value were *Lemna minor, Myriophyllum spicatum* and *Utricularia vulgaris.* Figure 34 shows dominance values for aquatic plant species found in Bear Lake.

Figure 34. Diagram of dominance values for aquatic plant species found in Bear Lake.



Discussion (S. Nichols, WGNHS and S. Allen)

The aquatic plant community is average quality, but has potential to get worse with increased nutrient or turbidity inputs and has the potential for milfoil to spread rapidly. For example if turbidity were to change the pondweeds (*Potamogeton* spp.), which are somewhat turbidity tolerant would be replaced with coontail (*Ceratophyllum demersum*), sago pondweed (*Potamogeton pectinatus*), and *Myriophyllum spicatum* will become a more dominant part of the vegetaion.

The floristic quality of the lake is below the median on both a regional and statewide level, which isn't a concern at this point. The reason for the low floristic quality is the average conservatism value. It is in the lower quartile of lakes on both a statewide and regional level. This means that the species in the lake are very tolerant to disturbance. The two predominant species are Chara and Najas. These are two pioneering species that usually invade open areas but they are not good competitors. Usually these species are replaced by others if there is no disturbance which may allow Myriophyllum spicatum to spread rapidly in open areas.

Wisconsin Lakes Modeling Suite (WiLMS) (Amy Dechamps and Paul McGinley)

Background

Hydrologic and phosphorus budgets for Bear Lake were developed using data collected during the 2001 study and other sources of information. The budgets are useful for understanding the most significant contributors of phosphorus to the lake and can thereby assist in lake management. The concentration of phosphorus in the lake is the result of both external and internal sources of phosphorus. The available phosphorus determines the level of biological productivity. The biological productivity ultimately impacts water clarity, plant and animal communities, and oxygen levels.

The hydrologic and phosphorus budgets of this study were developed using data which were collected over a relatively short time frame and projected to budgets which are applicable of a longer time period. Year to year variations in flow and phosphorus loading are expected. This discussion details the assumptions used in making the hydrologic and phosphorus budgets. As new information is collected or additional studies are performed, these budgets can be improved.

Hydrology

The sources of water to Bear Lake are surface streams which flow intermittently into the west side of the lake, precipitation falling directly on the lake, surface water which runs into the lake from the direct drainage area surrounding the lake, and the groundwater that discharges into the lake.

Surface water entering the lake includes flow from the streams and runoff from the direct drainage area surrounding the lake. Historical precipitation and evapotranspiration from land is approximately 30 inches and 20 inches per year, respectively, for Waupaca County (Olcott, 1968). The difference, approximately 10 inches per year, is the runoff to streams in the form of surface and groundwater. As groundwater was directly measured (discussed in a following paragraph), we subtracted its estimated flow contribution. In the direct drainage area, two inches per year was used as the total unit runoff largely due to major storm events or snow melt on frozen ground because of the relatively permeable soils in Waupaca County. The portion of precipitation that falls on the lake and is not evaporated was assumed to be 3.8 inches in Waupaca County (WiLMS, 2001).

Bear Lake has three streams that flow intermittently and converge to one inlet, which drains into the west end of the lake. Each intermittent stream was measured for discharge between March and November 2001. Based on discharge measurements in the study, the composite mean flow of the three streams was 1.0 cubic feet per second (cfs). The range of inflow when sampled was 0 to 2.1 cfs; higher flows are likely during storm events. The streams account for surface drainage of approximately 77 percent of the watershed, and they may also drain a portion of the groundwater recharge area. The area of the Bear Lake watershed, including stream catchments, is 2720 acres. The area of the watershed draining directly into the lake is 632 acres.

Groundwater flow to the lake was assayed using mini-piezometers at 69 sites during the week of August 8 – 14, 2001. The velocity (calculated by Hvorslev's method, 1951) of all upwelling sites was multiplied by the "upwelling area" assigned to each site to determine the volume of groundwater inflow into the lake. The upwelling area is the product of a 35-foot upwelling buffer into the lake [based on work by McBride and Pfannkuch (1975) and field-testing] and the distance halfway between each upwelling site and its adjacent sites. This area was calculated in Arc View GIS 3.2a. The volume of groundwater inflow from each site was then summed for a total groundwater contribution. The total inflow was entered into WiLMS as a point source for phosphorus. The calculated groundwater inflow was 1.8 cfs, which constitutes 60 percent of the water budget.

The estimated flow into Bear Lake from the different components of the hydrologic budget totals 3.0 cfs. Although the flow is based on several assumptions, it is similar to the discharge at the stream outlet, which was a median of 1.7 cfs (average 2.2 cfs and ranged from 0.3 to 7.2 cfs). There was one down-welling site on Bear Lake located at the stream outlet, and the volume of flow leaving through groundwater was 0.1 cfs. Using these values for the hydrologic budget, the water residence time of Bear Lake is approximately 4 years.

Phosphorus

The phosphorus in Bear Lake is the result of phosphorus entering the lake from external sources and internal cycling of phosphorus. External sources include phosphorus from stream flow, direct drainage, groundwater, and atmospheric deposition. The Wisconsin Department of Natural Resources' WiLMS model (WDNR, 2001) was used to estimate phosphorus loading into Bear Lake for external sources which were not directly measured. WiLMS (Wisconsin Lake Modeling Suite) uses coefficients for land uses based on previous research to estimate the amount of delivered phosphorus to a lake.

The intermittent stream inflow to the lake was treated as a point source. Based on the composite average inflow of 1.0 cubic feet per second and a median stream phosphorus concentration of 0.07 μg/l, the mass of phosphorus coming into the lake through this source is 63 kg/yr.

The phosphorus transport from the portion of the watershed that does not drain by way of the streams was estimated by WiLMS. The watershed was delineated using USGS 1:24,000-scale topographic maps. The direct drainage area (surface runoff into the lake) was also delineated and classified according to land use. Land use cover data was derived using Landsat Thematic Mapper satellite imagery from 1991-1993 and classified into land use categories (WDNR, WISCLAND). WiLMS manipulated the acreage by a standard export coefficient for the land use type (based on literature reviews and WiLMS defaults) to estimate the P loading into the lake. The phosphorus loading from the direct drainage area is summarized in Table 12, contributing approximately 150 kg/yr of phosphorus.

The groundwater phosphorus contribution was estimated by assuming a "background concentration" from all sites but three around the lake. These three sites exhibited significant levels of P almost certainly due to internal phosphorus loading (sites had high phosphorus, low chloride, and high ammonium, signs of organic matter decomposition). Groundwater sample reactive phosphorus concentrations are shown in Figure 30. The most-likely estimate of P loading from groundwater was determined by multiplying the inflow volume of each upwelling site by the phosphorus concentration of that site. The total phosphorus loading from sites considered to have background levels of phosphorus was 12 kg/yr. Phosphorus loading in groundwater from septic drain fields was calculated separately using WiLMS. The septic contribution was estimated assuming that 85 persons spend 365 days at the lake. This was projected from a survey conducted of Bear Lake residents. Average phosphorus loadings of 0.3 to 0.5 kg per person/year and phosphorus retention rates of 60 and 50 percent resulted in phosphorus loading from septic drain fields of 10 to 21 kg annually (low estimate and most-likely, respectively). Atmospheric deposition of phosphorus to the lake was assumed to be 0.24 lb/acre/yr (21 kg/yr) taken from WiLMS.

Table 12 summarizes the hydrologic and phosphorus contributions estimated for Bear Lake. The total phosphorus loading to the lake is estimated to be 175 kg/year (385 lb/year) for a low estimate or 268 kg/year (590 lb/year) as the most likely estimate. This is the estimated external loading. The phosphorus which leaves the lake was estimated by measuring the concentration and flow in the stream at the lake outlet. Based on the median flow of 1.7 cfs and a median concentration of 0.07 mg/L, it is estimated that 107 kg/year (235 lb/year) are leaving the lake through the stream. Mini-piezometer sampling revealed 2.9 kg/year are leaving through groundwater.

Because a portion of the phosphorus that enters the lake is expected to be retained by settling in the lake, we anticipate the phosphorus leaving the lake would be less than that which enters. Although internal sources of phosphorus (e.g., mixing of surface waters with phosphorus enriched deeper waters during the summer) could increase the phosphorus leaving the lake, it is likely the phosphorus loading to Bear Lake is underestimated. One of the more significant sources of uncertainty is the estimate of groundwater phosphorus contribution to the lake. There was evidence from the mini-piezometer investigation that some areas of the lake have higher concentrations of phosphorus.

In-Lake Phosphorus Concentration Modeling

Lake studies since the 1970's have prompted the development of tools to predict in-lake P concentrations based on estimates of external loads of phosphorus and physical characteristics of the lake. The WiLMS model utilizes several of these prediction tools. The predictions of in-lake phosphorus employing the hydrologic and phosphorus budgets were compared to calculations of actual data to ensure the models' usefulness. The external phosphorus load to Bear Lake was estimated to be approximately 590 lb (268 kg) per year with a range of 385 to 1400 lb (175 to 635 kg). Based on a lake surface area of 194 acres, this is an aerial loading of 3 lb/acre-yr (0.3 g/m^2/yr). Using several of the prediction models in WiLMS, the average predicted in-lake phosphorus is 12 to 30 mg/m^3 (Table 13). During the sampling period for this study, Bear Lake had a growing season average of 24.5 mg/m^3 P and a spring overturn concentration of 23.0 mg/L based on mid-lake samples collected between April 27 and October 18, 2001, at the deep hole on the lake described previously.

Phosphorus concentration in the lake water may increase by phosphorus transfer from sediments in the lake. This can occur do to some degree everywhere on the lake, but is most pronounced under conditions of high pH or low oxygen. In Bear Lake, the low oxygen conditions in the deeper portion of the lake appear to result in high phosphorus concentrations as evident in high P concentrations in the hypolimnion. This may reflect the release of phosphorus deposited in the past, and this phosphorus is only slowly released and removed from the lake. This phosphorus can transfer into the upper portions of the lake during overturn, thereby becoming available to the plants and algae.

Table 12. Hydrologic and Phosphorus Load Summary

<table>
<tr><th colspan="2" rowspan="2">Category</th><th rowspan="2">Area</th><th rowspan="2">Flow</th><th colspan="2">P Load (kg/yr)</th><th rowspan="2">% P Loading</th></tr>
<tr><th>Low</th><th>Most-likely</th></tr>
<tr><td colspan="2">Groundwater</td><td></td><td>1,607,580 m^3/yr
1.8 cfs</td><td colspan="2">12</td><td>4.5</td></tr>
<tr><td colspan="2">Stream Inflow</td><td></td><td>893,100 m^3/yr
1.0 cfs</td><td colspan="2">63</td><td>23.3</td></tr>
<tr><td colspan="2">Septic Tank (85 capita years)</td><td></td><td></td><td>10</td><td>21</td><td>7.9</td></tr>
<tr><td rowspan="6">Direct Drainage Area</td><td>Agriculture</td><td>240 acres</td><td rowspan="6">.15 cfs</td><td>48</td><td>97</td><td>36.2</td></tr>
<tr><td>Mixed Ag</td><td>75 acres</td><td>24</td><td>30</td><td>11.3</td></tr>
<tr><td>Grass/Pasture</td><td>129 acres</td><td>5</td><td>16</td><td>5.9</td></tr>
<tr><td>Rural Residence</td><td>43 acres</td><td>1</td><td>2</td><td>.6</td></tr>
<tr><td>Wetlands</td><td>44 acres</td><td>2</td><td>2</td><td>.7</td></tr>
<tr><td>Forest</td><td>101 acres</td><td>2</td><td>4</td><td>1.7</td></tr>
<tr><td colspan="2">Lake Surface/Atmospheric Deposition (Lake Surface Area)</td><td>194 acres</td><td>.08 cfs</td><td>8</td><td>21</td><td>7.9</td></tr>
<tr><td colspan="2">Total</td><td></td><td>3.0 cfs</td><td>175 kg/yr</td><td>268 kg/yr</td><td>100%</td></tr>
</table>

Table 13. Calculated and Predicted Values

Hydraulic Residence Time	**4 years (volume/outflow)**	
P Loading	**175 – 268 kg/yr**	
TP observed	**24.5 μg/L**	
TP predicted in WiLMS	**16-30 mg/m^3**	Walker, 1987 Reservoir
	12-22 mg/m^3	Rechow, 1979 General
	16-30 mg/m^3	Rechow, 1977 water load <50m/yr

Uncertainty

As with any modeling and fieldwork, there are uncertainties in the estimates of the phosphorus loading. The streamflow estimates are based on measurements taken with the Marsh McBirney flow meter about every month. Sampling dates do not correspond for each site. The quantity of water as well as the quality has limited sampling data. Water quality samples of the stream inflow are based on an average of four samples taken during the spring months. Mini piezometers give an indication of the velocity and quality of the groundwater for one point in time. This data is also used with caution as it may vary with season and over longer time periods as groundwater levels rise and fall. In 2001, the groundwater levels were lower than the long-term average for this area (USGS, 2002) and would decrease the groundwater flow into the lake.

The soil types in Waupaca County are generally sandy, and water infiltrates readily. For this reason, the default coefficients used to estimate loading for agriculture may be high. Phosphorus travels in the sediments carried by surface water and may not reach the lake if retained by the soils. As a result, the lower phosphorus loading values were considered a more accurate estimate of the phosphorus content in the lake.

Lastly, the spring overturn during the year of 2001 is not believed to have completely mixed. Therefore, the water quality estimate may not reflect the in-lake phosphorus.

Conclusions/Recommendations

1. Water moves to Bear Lake via streamflow, direct precipitation, surface runoff, and groundwater. Pollutants and other contaminants can enter the lake directly through these processes.

2. At depths below 20 feet, the dissolved oxygen in the water drops below 1 mg/L during much of the growing season, making much of the water inhospitable for most organisms. These anoxic conditions also allow complex reduction reactions to occur in the hypolimnion.

3. Sources of nutrient inputs (nitrogen and phosphorus) to Bear Lake come from within the watershed and from localized land use practices, therefore, efforts to reduce nutrient inputs to the lake should be made by both shoreland residents and landowners within the watershed.

4. Several times during the year total phosphorus concentrations exceeded 0.030 mg/L. Above this concentration stimulation of algae blooms and aquatic plant growth occurs. Average total phosphorus concentrations in Bear Lake are greater than the average for natural lakes in Wisconsin, however, much of this phosphorus likely entered the lake years ago and continues to cycle within the system. In the past, several barnyards around Bear Lake and within its watershed contributed large quantities of nitrogen and phosphorus to the lake. Once in a lake, phosphorus is slow to leave the system so it will some time before significant improvement in water quality can be observed.

5. In 2000-01, chlorophyll *a* concentrations were lower than concentrations in samples acquired in 1980-82. The same is true for most of the total phosphorus samples acquired in 2000-01. Continued water quality monitoring is recommended to determine if this is a trend or year-to-year variation.

6. The WiLMs model suggests that about 40% of the phosphorus inputs to the lake are from agricultural sources. Best management practices should continue to be implemented to further reduce these inputs.

7. Shallow groundwater samples contained nutrients and chloride, likely from local land use practices. These nutrients should be reduced or eliminated whenever possible. New septic drainfields should be sited as far from the lake as possible.

8. Ninety-five percent of the landowners responding to the survey indicate they use lawn fertilizer. Efforts should be made to eliminate/reduce the use of these fertilizers. Soil sampling should be conducted routinely to determine if any fertilizer application is warranted. Use of native plants eliminates the need for fertilizer application.

9. Existing buffered riparian areas around the lake should be protected. Much of the developed part of the lake lacks sufficient buffers to remove sediments and nutrients from runoff and to provide habitat for plants and animals. Buffers should be re-established in these areas, and should include grasses, forbs, shrubs, and trees. Current Waupaca County Shoreland Protection laws state that the vegetation protection area is within 50 feet of the ordinary high water mark. Land disturbing activities and vegetation removal are prohibited in this area, however, some exceptions exist including a 30 foot view corridor. Details regarding these exceptions can be found in Appendix G.

10. Many of the residences around the lake have lawns mowed to the water's edge. Implementing shoreland buffers will reduce nutrients that enter the lake via surface runoff. This practice would also be consistent with the Waupaca County Shoreland Zoning Ordinance.

11. Areas of minimal/no development should be protected when possible. These areas are providing spawning habitat for fish, frogs, turtles, and other lake/near-lake inhabitants. Many local, state, and federal programs are available to assist.

12. The aquatic plant survey revealed the presence of Eurasian water milfoil, an aggressive exotic plant. Currently it is localized so, aggressive action should be taken to eliminate this plant. This plant spreads rapidly; once it spreads it is very costly to manage and cannot be eliminated.

13. The diversity of aquatic plants in Bear Lake is about average for this area of Wisconsin. Most of the plants that are present are tolerant of disturbance and some are quite tolerant of light-limited conditions (i.e. algae blooms). These plants may become a nuisance if frequency of algae blooms increases.

14. Aquatic plants in shallow water provide habitat for aquatic organisms and help to buffer the impact of waves on the shoreline, thus reducing erosion and the need for rip-rap. Efforts should be made to minimize removal of near shore aquatic plants.

15. Many of the conclusions and recommendations from this study are similar to those recommended from the 1980's study on Bear Lake, therefore, the recommendations from the previous study are included in Appendix F. Though many advancements have been made, these management recommendations and conservation ideas should continue to be implemented and followed.

16. A management plan should be developed and should include a vision and goals for the lake. It should identify ways to achieve these goals and should be incorporated into the Town plans where appropriate. Many people should be involved in this process and inclusion of local and state professionals is encouraged.

APPENDICES