An Evaluation of Water Quality Characteristics in Stratton Lake, Waupaca Co., WI

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2000

ABSTRACT

A water quality study was conducted in the summer of 1998 to evaluate current water quality conditions in Stratton Lake, Waupaca Co, WI. Concerns over increasing nitrate and triazine concentrations in the lake prompted the study.

Results from monthly samples taken from the epilimnion (surface) and hypolimnion (bottom) at the mid-lake, deepest area in both the north and south basin of the lake showed nitrogen and triazine concentrations at very high levels compared to other Wisconsin lakes. Much of the groundwater entering the lake, particularly in the north basin, had high concentrations of nitrate nitrogen and triazine. Over 30 percent of private wells sampled had nitrate nitrogen concentrations above the DNR health standard of 10 mg/l and many of these wells (again mainly in the north basin) also had elevated triazine concentrations. Significant irrigated agriculture within the groundwater watershed of the lake is believed to be the largest source of these contaminants. Several septic systems surveyed were found to be in violation of current WI Administrative Code and several were found to be possibly failing hydraulically. This is also believed to be a source of contamination to the lake. Aquatic plants were analyzed for triazine and a slight positive correlation was seen between increasing triazine concentration in the plant and increasing plant biomass. These results are similar to other studies that found an increase in plant biomass with low concentrations of triazine present. These and other findings are discussed further in this report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

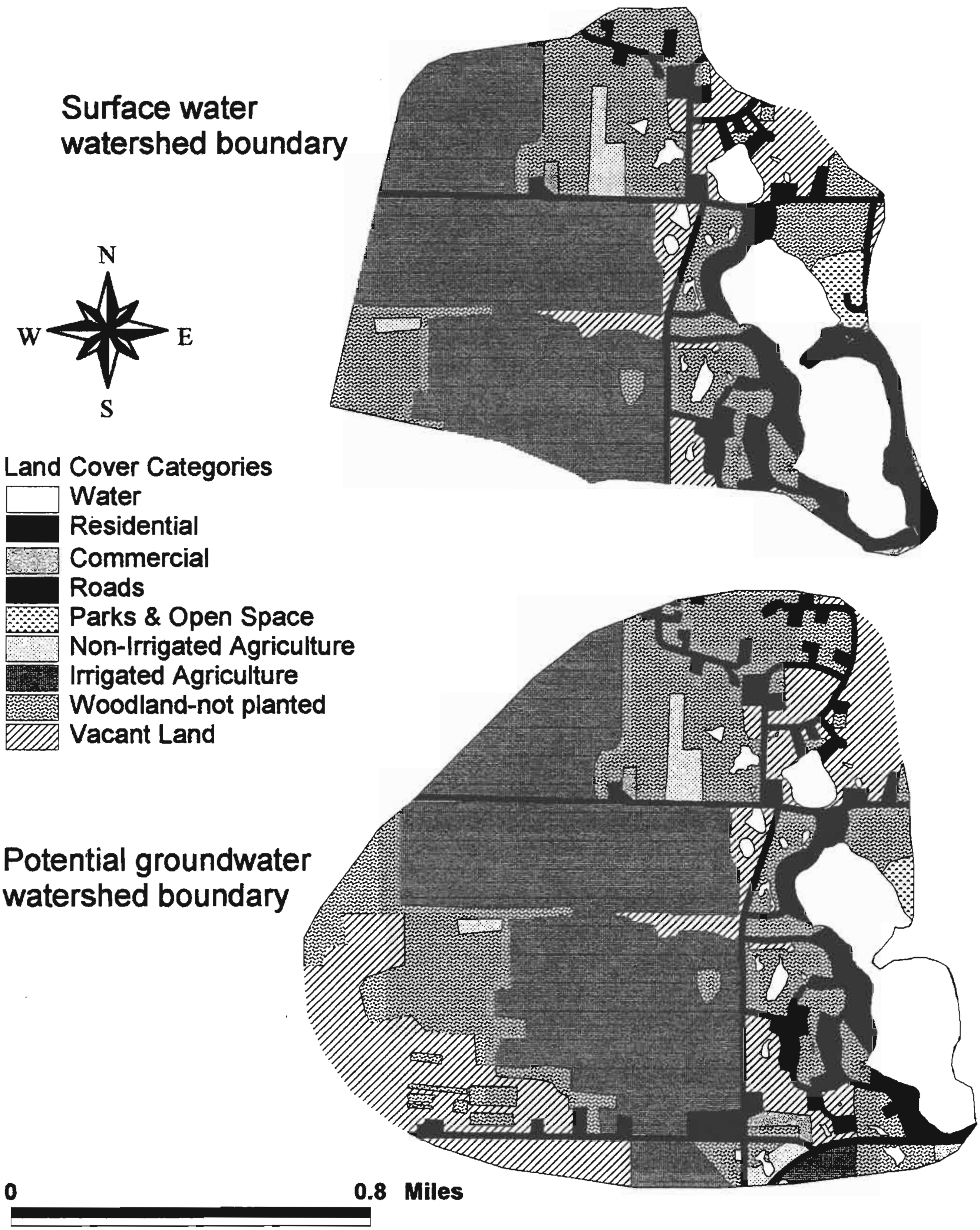
INTRODUCTION

Water quality concerns regarding Stratton Lake, Waupaca County, Wisconsin have prompted further study of the physical, chemical, and biological characteristics of the lake and the groundwater feeding it. Agriculture, including irrigated agriculture, occurs within much of the groundwater watershed of the lake. Previous sampling of the lake and well water in the vicinity of the lake revealed the presence of high concentrations of both nitrate and triazine herbicides. Nitrate is a form of nitrogen (N) commonly found in agricultural and lawn/garden fertilizer and in human/animal waste. Triazine is a family of pesticides, which includes atrazine, commonly used on field corn, and simazine, used on tree plantations (Draak, 98). Both nitrate and triazine readily leach from the soil into the groundwater. Because of the health and water quality concerns associated with these compounds, a study of their impacts on the quality of Stratton Lake was conducted. The study included monthly sampling of mid-lake general water chemistry, lake sediment thickness and chemistry, aquatic plant relationships to nutrient sources and to groundwater flow and chemistry, and sampling private wells for general chemistry and triazine. The following report summarizes the findings of this study.

DESCRIPTION OF STUDY AREA

Stratton Lake is an 87 acre groundwater drainage lake. The lake is situated in an area of glaciofluvial deposits that are generally well-sorted deposits of sand and gravel (Berkstresser, 1964). Groundwater flow is generally west to east. The lake receives significant groundwater inflow that is characterized by hard water derived from the weathering of calcium and magnesium carbonate minerals along groundwater flowpaths into the lake. The lake is separated into two basins connected by a narrow channel. The larger basin to the south has a maximum depth of 42 feet and the smaller basin to the north has a maximum depth of 29 feet. Water clarity tends to be better in the larger basin (ETF, 98). The western and northern shorelines rise steeply from the lake with a more moderate rise along the eastern shore. The surface water watershed of Stratton Lake is 0.66 square miles. Land use within the watershed is dominated by irrigated agriculture, which encompasses 0.33 mi^2 or 50% of the total land area. The next biggest land use is the lake itself (Figure 1). The potential groundwater watershed for the lake encompasses much of the same land area as the surface water watershed (Figure 1). The outflow

Figure 1. Potential groundwater watershed, surface water watershed, and landuse within each watershed of Stratton Lake, Waupaca Co., WI.



of Stratton lake is located in the southeast corner of the larger basin. The average summer 1998 discharge of the outflow was 3.45 cfs (ETF, 98). Both the stream outflow and groundwater outflow from the lake flow into Radley Creek to the south.

The lake receives heavy recreational use from the 65 seasonal and permanent residences along the shoreline, the public access point located in the southwest corner of the larger basin, and a summer camp for boys located on the eastern shoreline of the smaller basin. The 65 residences and the boy's camp all have their own on-site sewage disposal systems.

METHODS

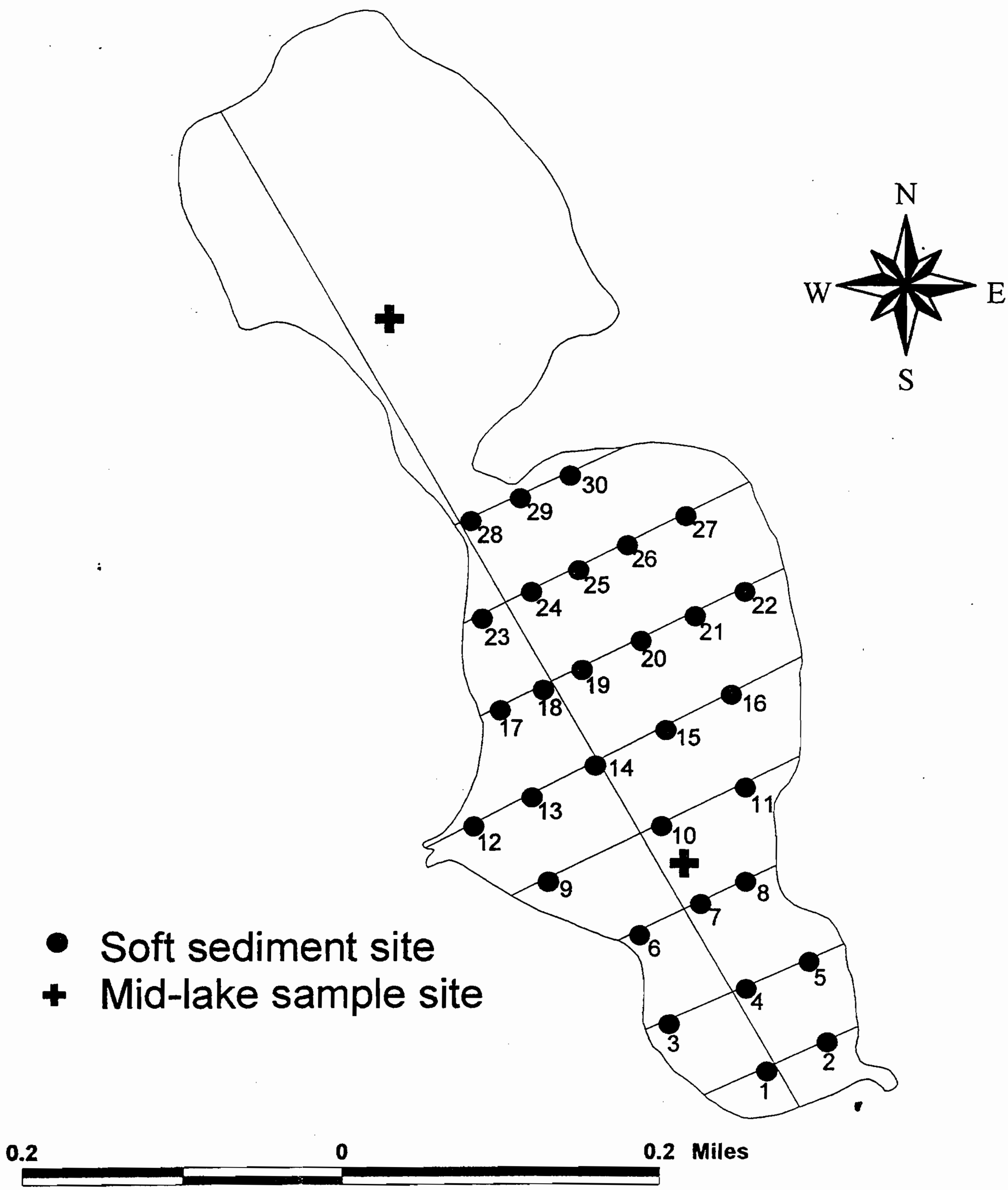
Streamflow

Stream discharge was measured at the Stratton Lake outflow once a week during June, July, and August of 1998 with a Marsh McBirney Model 2000 portable flowmeter, 100 ft. tape, and 2 chaining pins.

Mid-Lake Chemistry

Temperature/oxygen profiles were taken bi-monthly from June through August 1998 at the mid-lake, deepest area of both the big basin (South Stratton) and the little basin (North Stratton). The mid-lake, deepest area was found by using a bathymetric map and an anchor rope marked at one foot intervals. A thorough description of the site was described using landmarks around the lake so the site could be located each month (Figure 2). Dissolved oxygen and temperature readings were taken using a 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 at what depths to take the water samples. Samples near the bottom were collected using an alpha bottle. Epilimnion samples were taken as a grab sample over the side of the boat. An unpreserved 250ml polyethylene sample bottle and a plastic 50 ml centrifuge tube (for triazine analysis) were rinsed three times with sample before being filled. A preserved bottle was prepared in the lab with 0.7 mls1+1 H_2SO_4 per 250 mls of sample and filled in the field by transferring sample from the unpreserved bottle to avoid losing any of the H_2SO_4. None of the samples were field filtered. Analyses performed were NO_2+NO_3-N, NH_4, TKN, total phosphorus (TP), reactive phosphorus , chloride, pH, conductivity, alkalinity, total hardness, Ca^{2+} hardness, triazine, and chlorophyll-a.

Figure 2. Locations of soft sediment depth data collected in January of 1998 and mid-lake sample sites; Stratton Lake, Portage Co., WI.



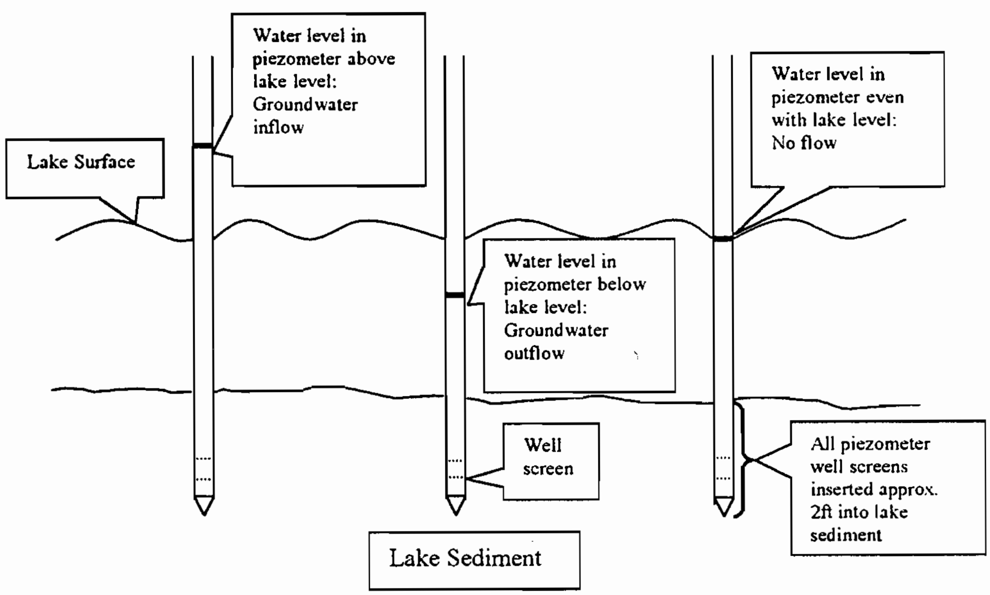
Chlorophyll-a samples were collected from water at the surface and transferred into a dark brown, one liter, polyethylene bottle. Secchi disk readings were taken monthly (Shaw et. al. 1996).

All samples collected were transported on ice to the state certified Environmental Task Force Lab at the University of Wisconsin-Stevens Point. Analysis for all samples followed the procedures outlined in Appendix A.

Mini-Piezometers

Hydraulic head data were collected approximately every 150 ft. along the shoreline in groundwater inflow areas (34 sites) and every 300 ft. in groundwater outflow or no flow areas (10 sites) using mini-piezometers and the Hvorslev slug test (Hvorslev, 1951). 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 was below the lake surface. Several sites exhibited "no-flow" characteristics where the head level was even with the lake level (Figure 3).

Figure 3. Diagram depicting how groundwater inflow, outflow, and no flow was determined using mini-piezometers.

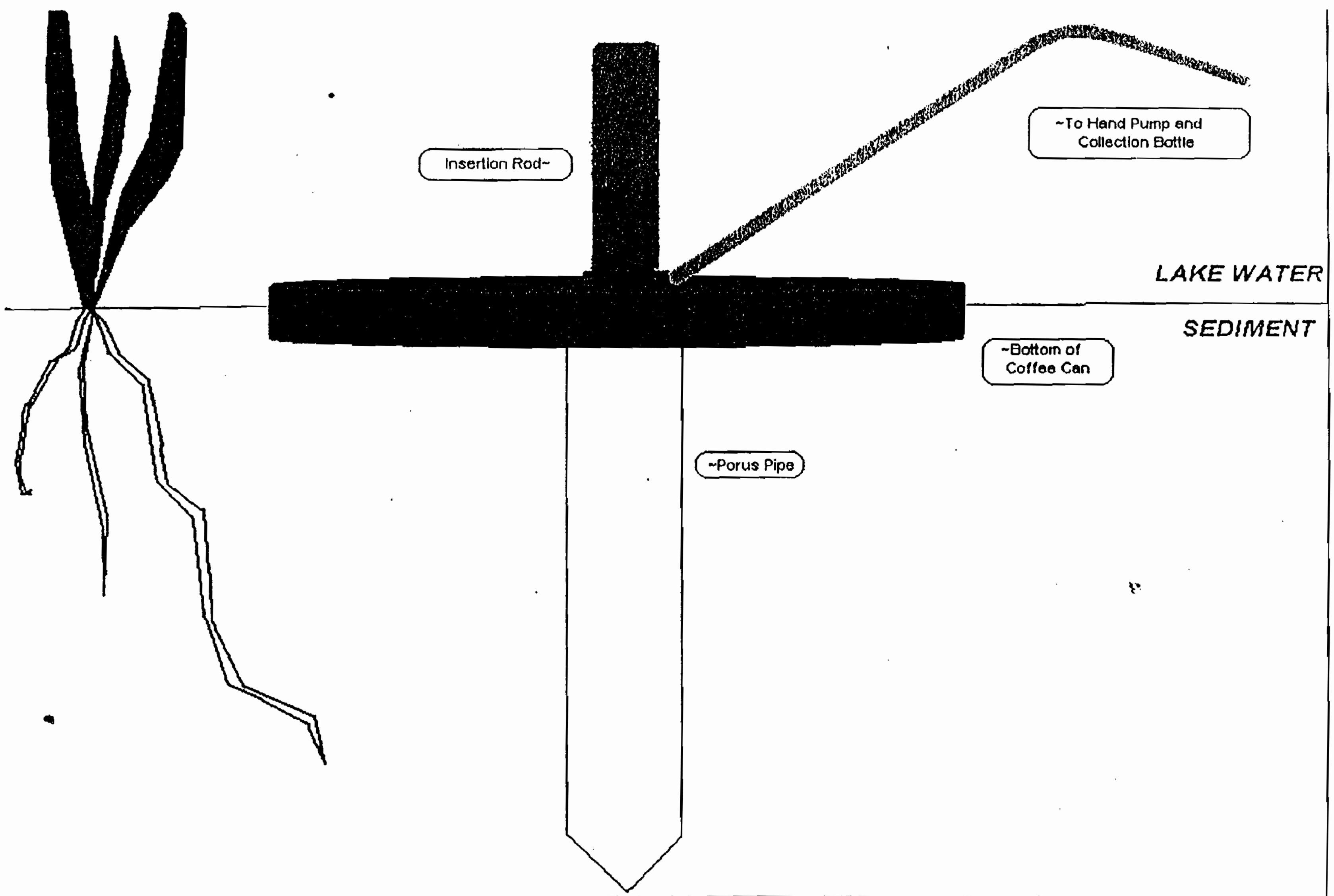


The mini-piezometers were constructed from a 5 foot length of 4 millimeter inside diameter polypropylene tubing. A plastic screw was inserted in one end and the well was given 1 inch perforations using a small diameter needle and sewing machine. A pipette tip was attached to the end to act as a well point. A steel rod was put into the piezometer to make it rigid enough to be pushed into the sediment. In cases where the substrate was too coarse, a rigid steel rod was used to create a guide-hole for the piezometer. The mini-piezometers were inserted approximately 2 ft. into the lake sediment in approximately 18 inches of water. Exceptions to this were made when the lake sediment was too soft at 18 inches to be able to draw water through the well. In these cases the mini-piezometer was pushed into the sediment until a course substrate was encountered. Occasionally this required inserting the mini-piezometer in water shallower than 18 inches. Only groundwater inflow sites were sampled because the outflow and no flow sites were assumed to have the same chemical properties as the lake water. A 60 cc syringe was used to develop the well. Water was drawn from each well until it was clear. At least three 60 cc volumes were drawn before taking a sample. A filtered (0.45 micron micropore filter and 1 micron glass fiber filter back-to-back) and preserved (0.7 mls 1+1 H_2SO_4 per 250 mls of sample) sample was collected at each site for NO_2+NO_3-N, NH_4, TKN, TP, reactive P, chloride, pH, conductivity, alkalinity, total hardness, and triazine.

Sediment, Aquatic Macrophyte, Interstitial Water

Sediment, aquatic macrophyte, and interstitial water samples were all taken within a 1/8 meter square constructed of ¾ inch diameter PVC tubing. The PVC square was randomly dropped over the side of the boat in about 18 inches of water at each of 45 sites chosen where a change in plant species or significant change in plant biomass was observed. Interstitial water samples were taken first using a 6 inch length of polyethylene diffuser tubing (¾ 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 coffee can was also attached to the diffuser tubing to prevent surface water infiltration into the sample (Figure 4). The device was inserted into the sediment using a rigid steel rod 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 a filter cassette containing a 0.45 micron and a 934 AH 47mm glass fiber filter. The first 20 mls of sample were used to rinse the device and the sample bottle. No more than 150 ml of sample was drawn into the side-arm flask because this was assumed to be the limit of interstitial pore water that could be drawn before surface water was drawn into the sample. The sample was transferred from the

Figure 4. Interstitial water sampling device used to collect pore water from the plant rooting zone.



side-arm flask into a sample bottle preserved with 0.7 mls 1+1 H_2SO_4 per 250 mls of sample. Analysis included NO_2+NO_3-N, NH_4-N, and reactive P.

When the square was dropped, great care was taken to remove those macrophytes that were trapped in the square, but not rooted within it. The macrophytes were cut at the sediment level, rinsed to remove as much non-organic material as possible, squeezed to remove excess water, weighed in the field to determine fresh plant biomass per square meter, and identified. Macrophyte samples were placed in Ziploc bags, transported on ice, and stored in a 4°C refrigerator. Samples were oven dried at 60°C to a constant mass. The dried weight was used to calculate actual plant biomass. The dried tissue was ground in a Wiley mill and stored in Whirl-Pack bags until they were analyzed for Total N and Total P. Samples to be analyzed for triazine were not dried.

Sediment samples were taken using a 5 cm outside diameter, clear PVC tube with a beveled edge. A depth of approximately 10 cm of sediment was taken because it was assumed to be close to the maximum plant rooting depth. When more or less than 10 cm was taken, it was noted. Some approximation did occur due to the nature of the soft sediments making it difficult to get exactly 10 cm. More than one core was taken at each site to assure enough sample would be available to determine texture, % organic matter, pH, TP, Total N, potassium, NO_2+NO_3-N, NH_4-N. Samples were put in Ziploc bags and stored in a 4°C refrigerator immediately upon being received in the lab.

Homeowner Survey

A door-to-door survey of homeowners was conducted to determine what the residents believed about the quality of Stratton Lake. Private well samples were collected and a survey of each on-site sewage disposal system was conducted with the resident's permission. The on-site sewage disposal system survey included: taking measurements to determine the location of systems relative to their well and the lake, using a laser level to determine system elevation above the lake, and sending a well popper down the system vent pipe to check for standing water (indication of a failing system).

Private well samples were taken from an unsoftened tap. The water was allowed to run for at least two minutes in order to ensure that fresh groundwater was being collected. The water samples were collected in 250 ml polyethylene bottles. An unpreserved bottle was filled for pH, conductivity, alkalinity, and total hardness measurements. A preserved bottle (0.7 mls 1+1

H_2SO_4 per 250 mls of sample) was filled for chloride, NO_2+NO_3-N, TKN, TP, and reactive P analysis. A plastic 50 ml centrifuge tube was used to collect a sample for triazine analysis. Two of the private wells were sampled a second time for broad-spectrum pesticide analysis.

Soft Sediment Depth

Soft sediment depth was determined during winter through holes in the ice. A main transect was marked spanning the longest stretch of the lake running from southwest to northeast. The sediment was probed every 200 feet along transects perpendicular to the main transect, and also 50 feet from shore (Figure 2). At each of the 30 sites, a hole was drilled through the ice, depth to the top of the sediment was measured with a Secchi disk, and soft sediment depth was determined by pushing an aluminum rod threaded into 10 ft sections and marked at 1 ft intervals into the sediment until pushing became difficult. This required the judgement of the persons performing the test.

Soft sediment depth was not determined for North Stratton due to thin ice making it too dangerous to attempt the survey.

RESULTS AND DISCUSSION

MINI-PIEZOMETER SURVEY

The area of greatest groundwater inflow occurred along the northern and northeastern shoreline of North Stratton Lake. Inflow areas with less energy were found along the eastern shoreline of North Stratton and along the entire western shore of the lake. Sites exhibiting outflow or no flow characteristics were found along the eastern shore of South Stratton Lake (Figure 5). The data collected are in agreement with the regional groundwater flow map for Waupaca County. Only groundwater inflow sites were sampled for water chemistry. Mini-piezometer water chemistry data is displayed in Appendix F.

Nitrate

Nitrate will readily leach through the soil profile and into the groundwater. The sandy soils around Stratton Lake allow for little attenuation of nitrate or other substances such as atrazine and chloride. Since nitrate is found in fertilizers, excess amounts applied to farm fields or lawns that is not used by plants and organisms in the rooting zone will leach into the groundwater.

Figure 5. Groundwater inflow and outflow areas of Stratton Lake, Waupaca Co., WI. Site numbers are labeled. Sites 31-40 were not sampled because they were not areas of groundwater inflow.

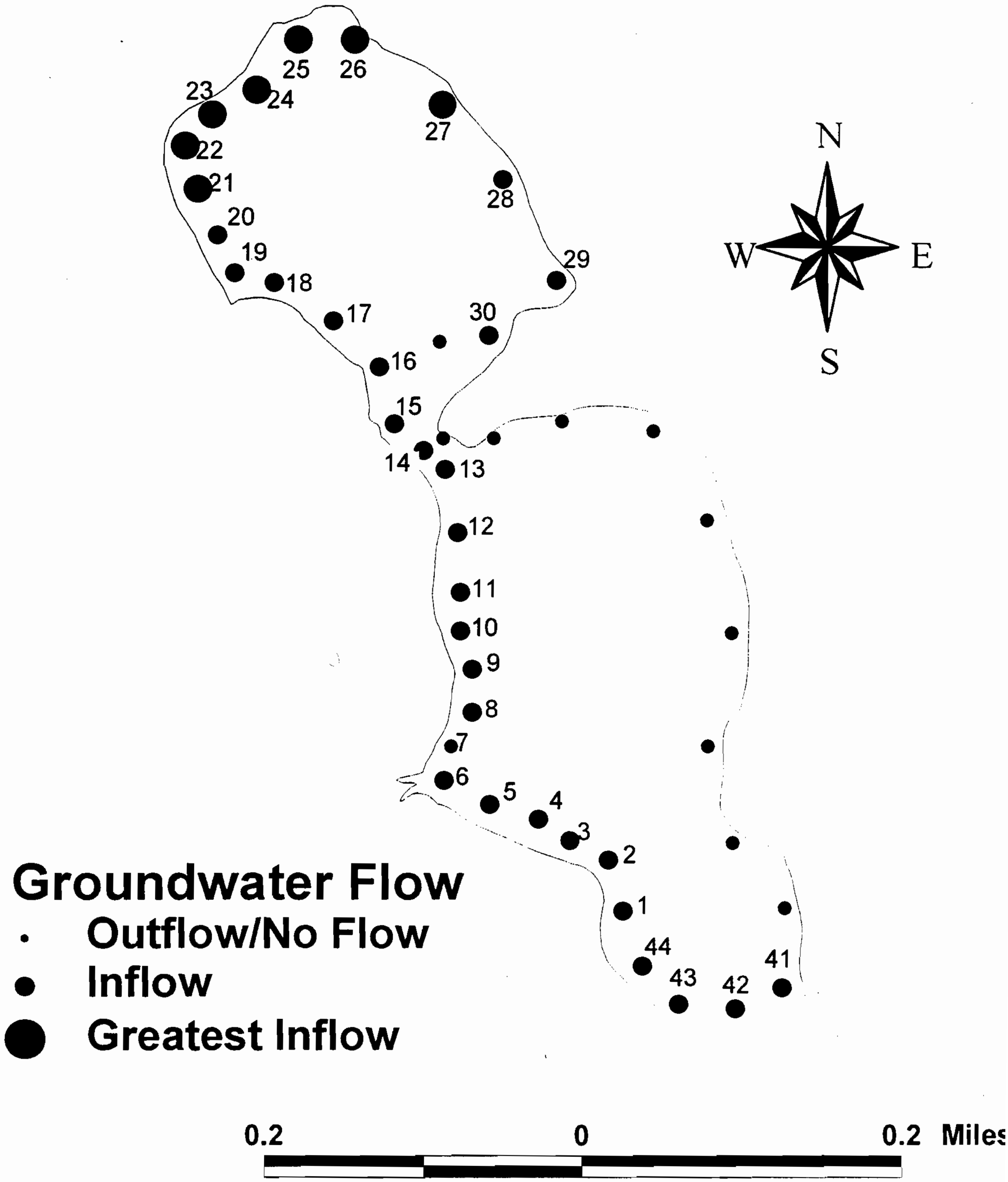
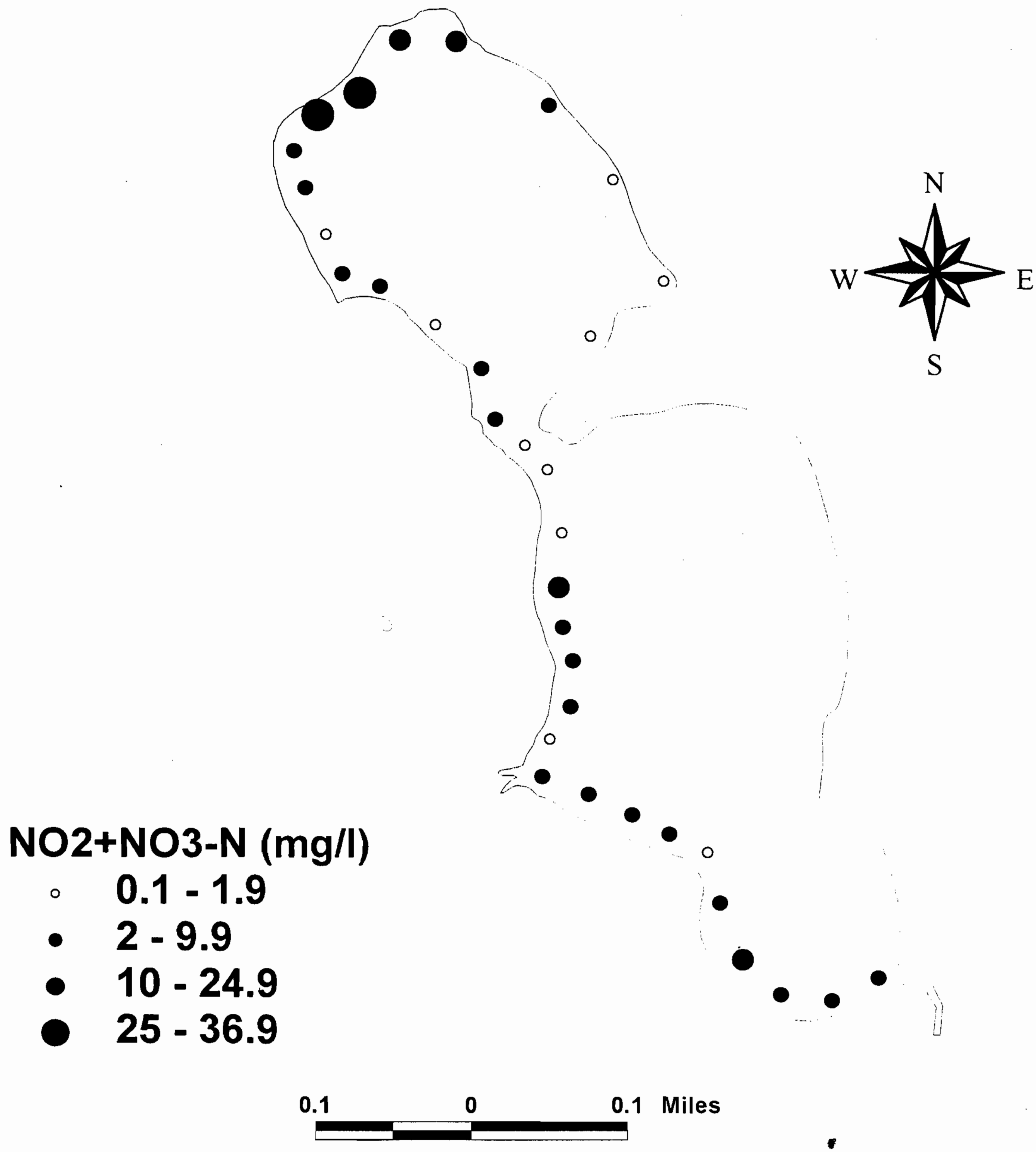


Figure 6. Nitrate concentrations found in Mini-piezometer samples from Stratton Lake, Waupaca Co., WI.



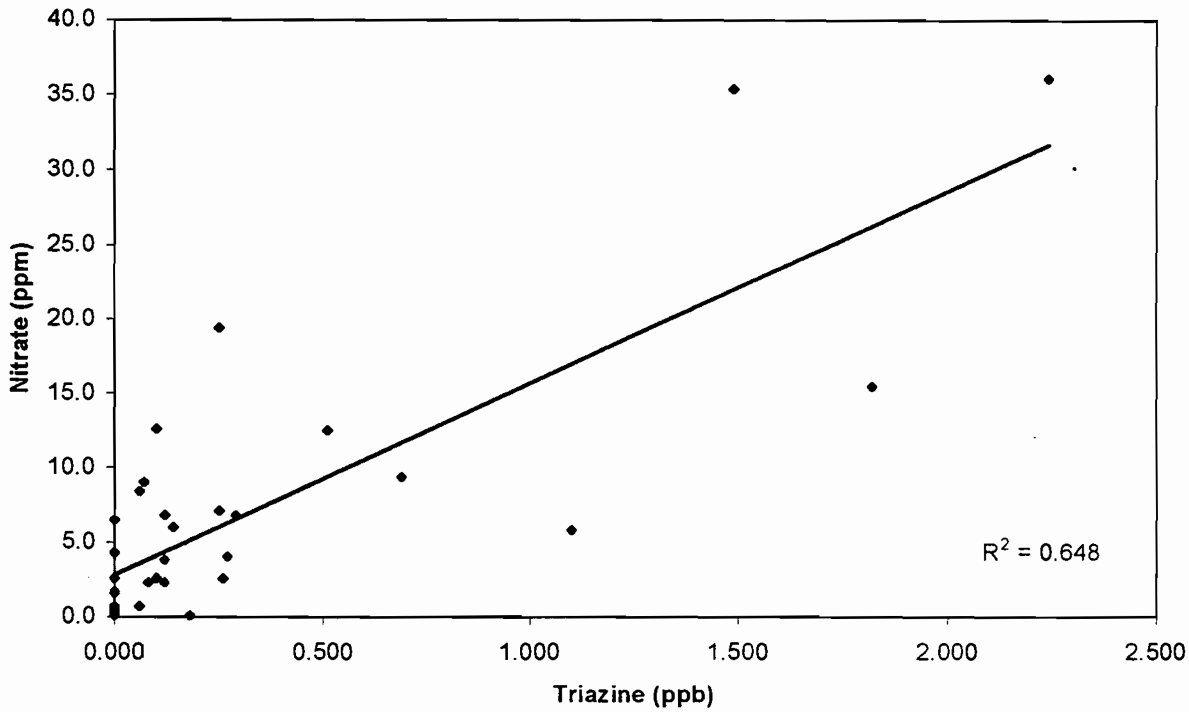
Nitrate concentrations of 36.1 mg/l and 35.4 mg/l were found at sites 23 and 24 respectively (Figure 6). Concentrations between 9.4 and 15.5 mg/l were found at sites 25 through 27. All five of these sites were along the northern shoreline of North Stratton, and were also the sites with the highest rates of groundwater inflow. Irrigated agriculture located within the groundwater watershed of the lake and up-gradient from these five sites is a likely source for the elevated nitrate concentratons. A few other isolated sites (11,41,44) in inflow areas had nitrate concentrations above 9.0 mg/l. Similar land use occurs upgradient of the entire groundwater inflow area of the lake. Reasons for higher concentrations in the north basin may be from past fertilizer use as the fields in the area have been in intensive agriculture for a number of years. Best management practices being used by local farmers will hopefully reduce the concentrations.

Triazine

Triazines are a family of herbicides that are heavily used in the United States for weed control in crops such as corn and sorghum, and in tree plantations. The mechanism of action of s-triazine herbicides, such as the commonly used herbicide atrazine, is to block the process of photosynthesis in target weeds by blocking electron transport in the light reaction of photosynthesis (Moreland, 1980). Atrazine in particular, will enter aquatic environments in run-off from agricultural fields and through leaching to groundwater, and is commonly detected in aquatic habitats (Kadoum and Mock, 1978; Frank et al. 1979; Wu et al., 1980; Glotfelty et al., 1984). Atrazine has a surface soil half-life of up to a year, but its three metabolites, de-ethyl atrazine, de-isopropyl atrazine, and di-amino atrazine can persist in groundwater for up to 50 years (Proost, 1998). Atrazine has been shown to increase algal biomass when present in low levels, and decrease biomass at higher concentrations (Pratt, 1997). Atrazine may not be toxic to aquatic fauna, but can indirectly affect organisms if macrophyte cover is reduced by exposure to the chemical (Kettle et al., 1987).

Triazine results from the mini-piezometers correlated well (0.81 Pearson correlation, $R^2 = 0.65$) with the nitrate results (Figure 7). The sites along the northern shoreline of North Stratton that exhibited the highest groundwater flow and nitrate concentrations also had the highest triazine concentrations. The combination of nitrate and triazine in relatively high concentration at these sites clearly illustrate that agriculture is having an impact on the chemistry of groundwater entering Stratton Lake. Several other groundwater inflow sites along the western shore of the lake had triazine detected, but in much lower concentrations than along the northern shoreline (Figure 8).

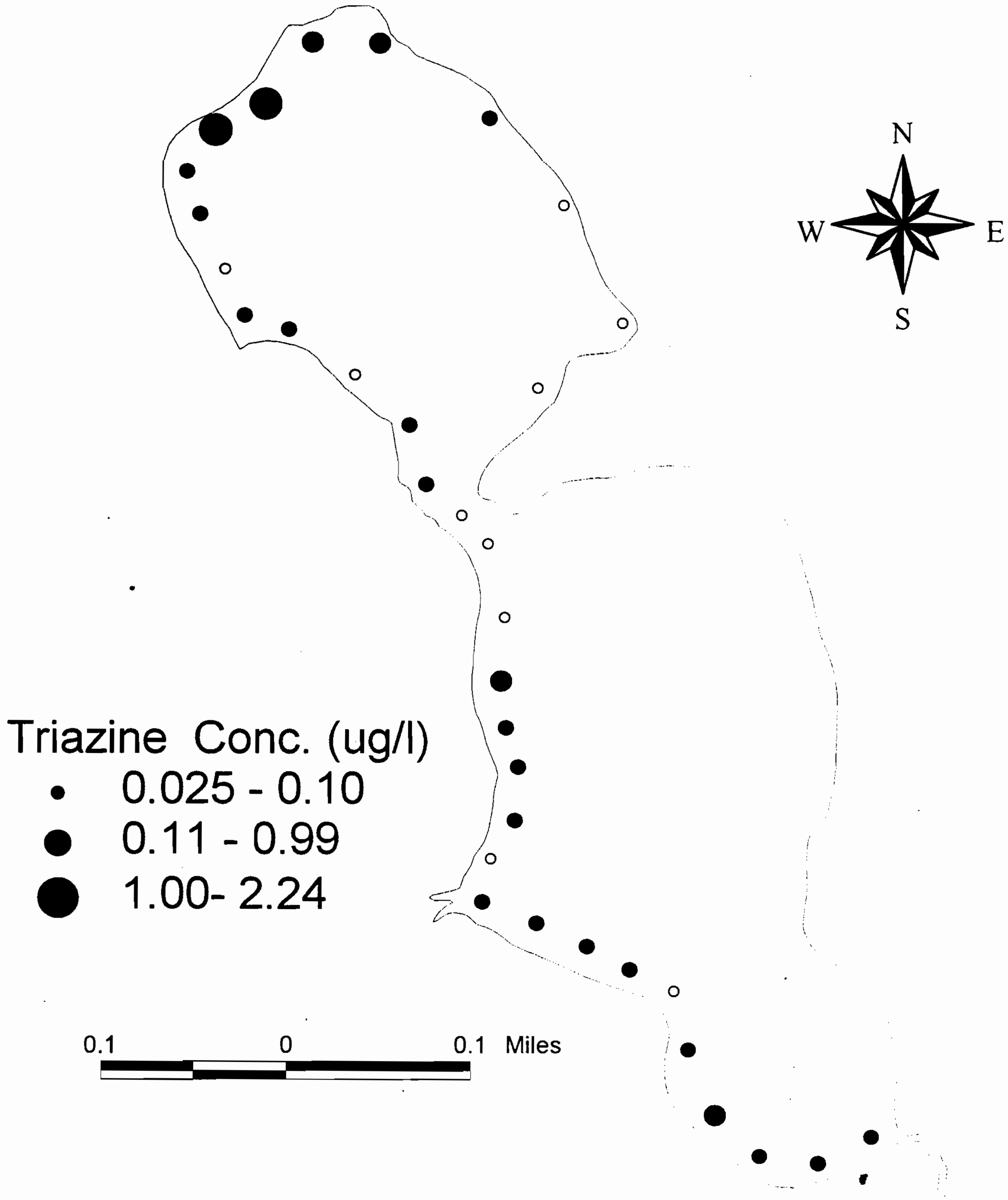
Figure 7. Graph of mini-piezometer nitrate and triazine concentrations, Stratton Lake, Waupaca Co., WI.



Chloride and Nitrate

Chloride and nitrate often occur from agricultural sources, but can also be indicators of groundwater contamination resulting from septic systems. Chloride behaves much like nitrate and is readily leached through the soil and into the groundwater. There were several sites (3,11,41,44) that showed high chloride and nitrate, but not high triazine. This suggests that sources such as septic systems, lawn fertilizer or fertilizer use without triazine herbicides may be impacting water quality at these sites. Sites 3,11,41, and 44, which displayed higher nitrate and chloride than adjacent sites, were all down gradient of septic systems that receive use 365 days/year, and 3 out of the 4 were over 24 years old. The age of the 4th system was not known by the owner, but even new systems can quickly contaminate groundwater with nitrate and chloride. While confirmation of the existence of contamination plumes from septic systems would require more study, it appears likely that with the sandy soils around Stratton Lake and

Figure 8. Map showing triazine concentrations found in mini-piezometer samples in Stratton Lake, Waupaca Co., WI.



the year-round use, these septic systems are impacting water quality. Chloride concentrations showed a good correlation with both nitrate and triazine (0.67 and 0.47 Pearson correlation respectively), but not with reactive phosphorus (-0.15 Pearson), another indicator of septic system failure that may take 15-20 years of full-time use at the site to saturate the soil and move to the groundwater.

Reactive Phosphorus and Ammonium

Reactive P is often associated with septic system effluent plumes. Phosphorus tends to adsorb to soil particles and be held in the soil rather than leach to the groundwater. However, if the soil's capacity to hold P is exceeded, which is often the case with older septic systems, P will also leach to the groundwater. None of the mini-piezometer sites that exhibited high reactive P concentrations correlated to the possible effluent sites mentioned in the previous section. It is possible that the more mobile contaminants (nitrate & chloride) may be showing up first, while the soil is not yet completely saturated with the less mobile P.

Ammonium (NH_4) and reactive P were found in highest concentration at sample sites 13 and 14, which were located in the channel connecting the two basins (Figure 9). The pH of the samples from these sites was also lower than most of the other sites. It is likely that the sediments in the channel are devoid of oxygen, which would allow for ammonium and phosphorus to be released into the water column rather than stay adsorbed to soil particles. The sediments throughout most of the channel were high in organic matter from a small wetland area at the end of the peninsula along the eastern shore of the channel. Anoxic sediments are very common with wetlands and areas high in organic matter where a lot of decomposition is taking place. They are isolated enough that they don't present a water quality problem to Stratton Lake.

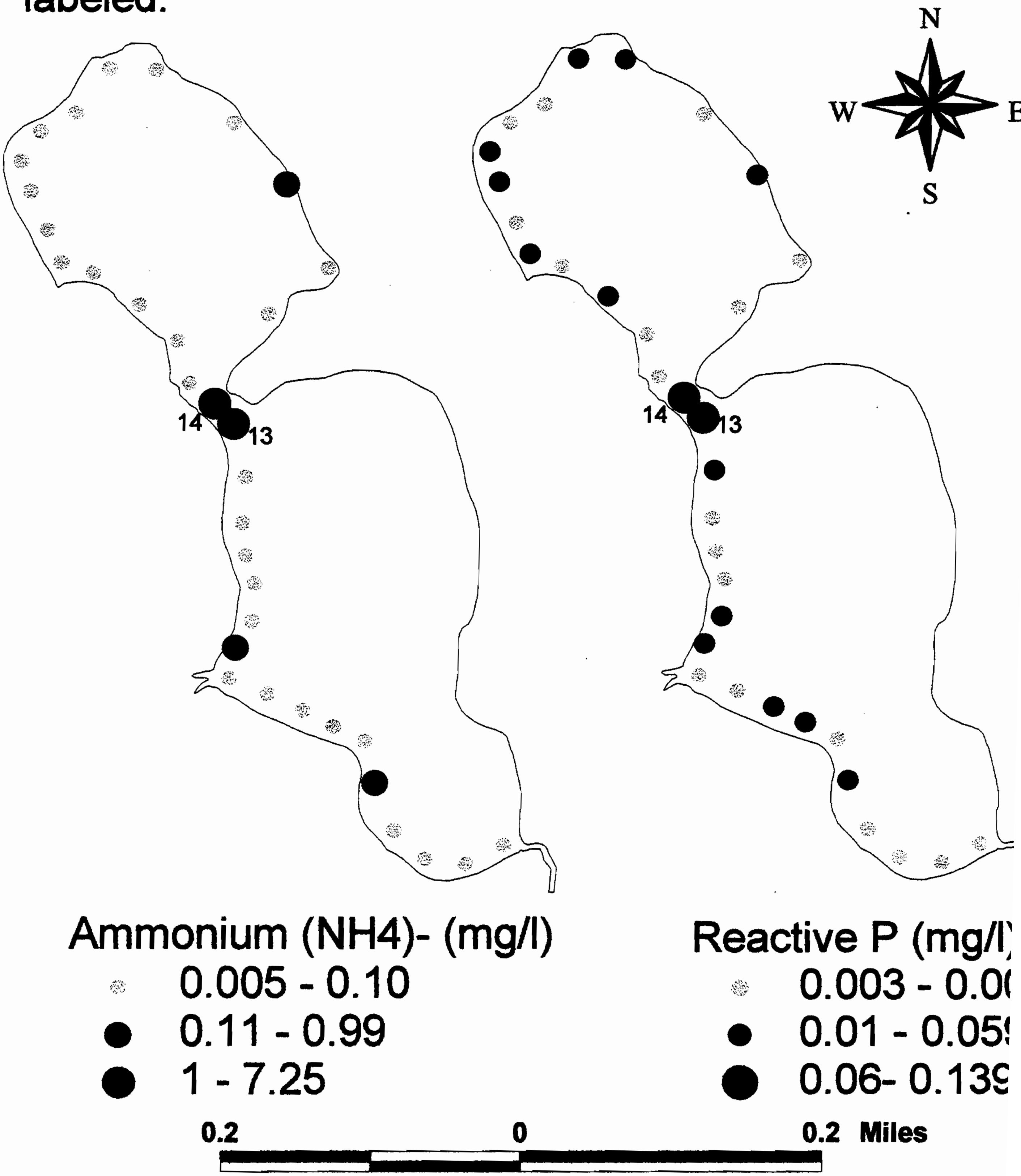
MID-LAKE WATER QUALITY

All mid-lake water quality data from the summer of 1998 are presented in Appendix B. The following is a description of results for each major group of water quality characteristics.

Dissolved Oxygen and Temperature

Stratton Lake is typical of many northern temperate lakes in that it becomes thermally stratified during the summer months. The epilimnion, or surface 12 feet (4 meters) in Stratton

Figure 9. Map showing Reactive P and Ammonium concentrations found in mini-piezometer samples from Stratton Lake, Waupaca Co., WI. The sites with the highest concentration of each chemistry (13&14) are labeled.



Lake, has a fairly constant temperature, and dissolved oxygen readings range from 10.5 mg/l in early summer to 9.2 mg/l in late August when warmer water temperatures lead to a decrease in dissolved oxygen solubility. A strong temperature gradient, or thermocline follows the epilimnion. The thermocline began at greater depths as the summer progressed due to constant warming of surface water and wind mixing leading to an increase in the thickness of the epilimnion. A dissolved oxygen increase that coincided with the top of the thermocline was seen through June and July in both basins of Stratton Lake. The increase was most likely due to both the colder water in the thermocline being able to hold more dissolved oxygen and the probability of algal blooms occurring at these depths that would contribute oxygen through photosynthesis. The hypolimnion, or bottom water, is below the thermocline. The water temperature in the hypolimnion is much cooler than the epilimnion during summer. 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. Bacteria that decompose plant residue and organic matter in bottom sediments use up most of the available dissolved oxygen in the hypolimnion. Dissolved oxygen concentrations below 1.0 mg/l occur in the lower 6.5 feet (2 meters) of South Stratton Lake. This was evident during all three months of sampling during the summer of 1998. North Stratton Lake exhibited dissolved oxygen concentrations below 1.0 mg/l only at the sediment/water interface. Dissolved oxygen concentrations below 5.0 mg/l were seen in the lower 5 to 6.5 feet (1.5 to 2 meters) of North Stratton Lake throughout much of the summer. These somewhat higher values may be due to oxygen contained in the groundwater entering North Stratton.

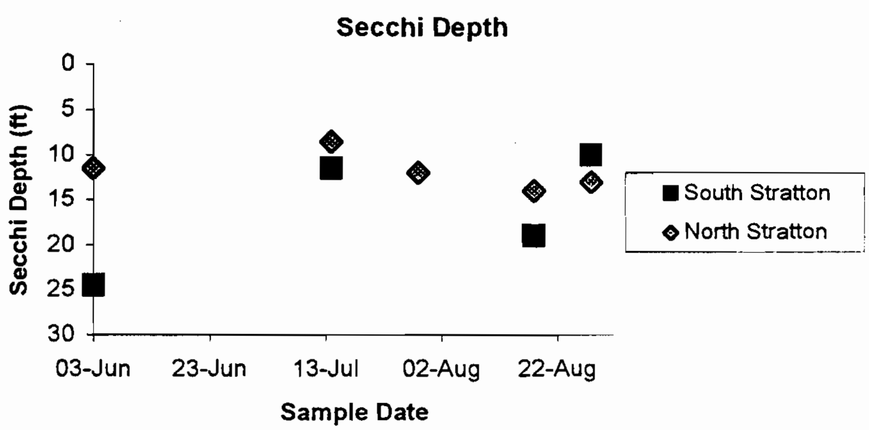
Secchi Depth and Chlorophyll-*a*

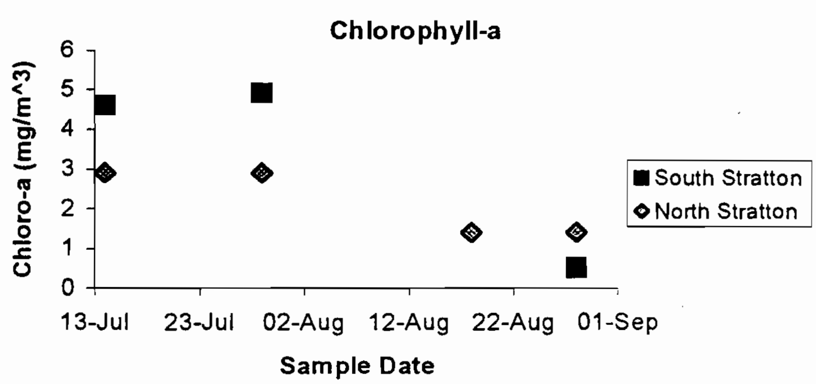
Secchi depth is a measure of water clarity, and it can often be directly compared to chlorophyll-*a*, a measure of algae growth. Chlorophyll-a can also be an indicator of phosphorus levels (Shaw et. al. 1996). Higher chlorophyll-*a* should correlate to a shallower Secchi depth reading; however, many variables such as time of day and wind can affect the Secchi depth accuracy. Secchi depth was generally greater in South Stratton Lake, but the chlorophyll-*a* data available were generally better in North Stratton (Figure 10). North Stratton Lake is shallower, meaning wind and boat traffic will stir up more sediments and account for reduced Secchi readings; even with lower amounts of chlorophyll-*a* present.

Total Phosphorus (Total P)

In more than 80% of Wisconsin's lakes, phosphorus is the limiting nutrient affecting the amount of weed and algae growth (Shaw et. al. 1996). In a marl lake such as Stratton, marl/$CaCO_3$ precipitates out of the water as pH increases due to carbon dioxide loss from plant uptake, increase in water temperature causing a decrease in carbon dioxide solubility, and mixing and contact with the

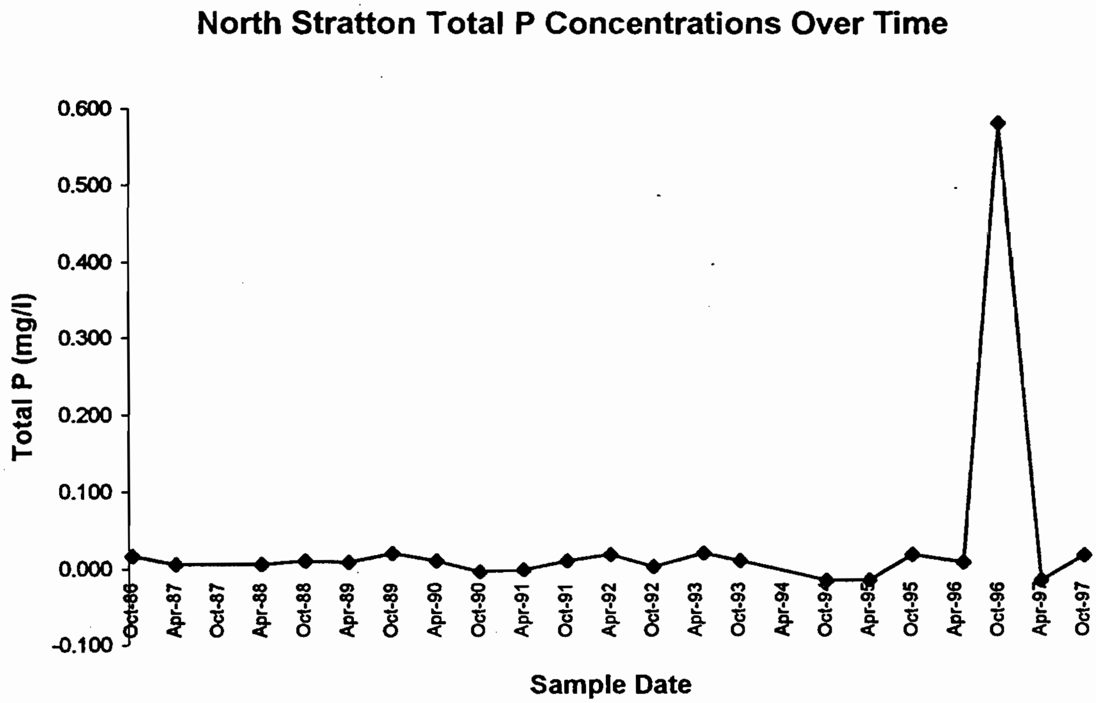
Figure 10. Secchi depth and chlorophyll-a concentrations from Stratton Lake, Waupaca Co., WI; Summer 1998.

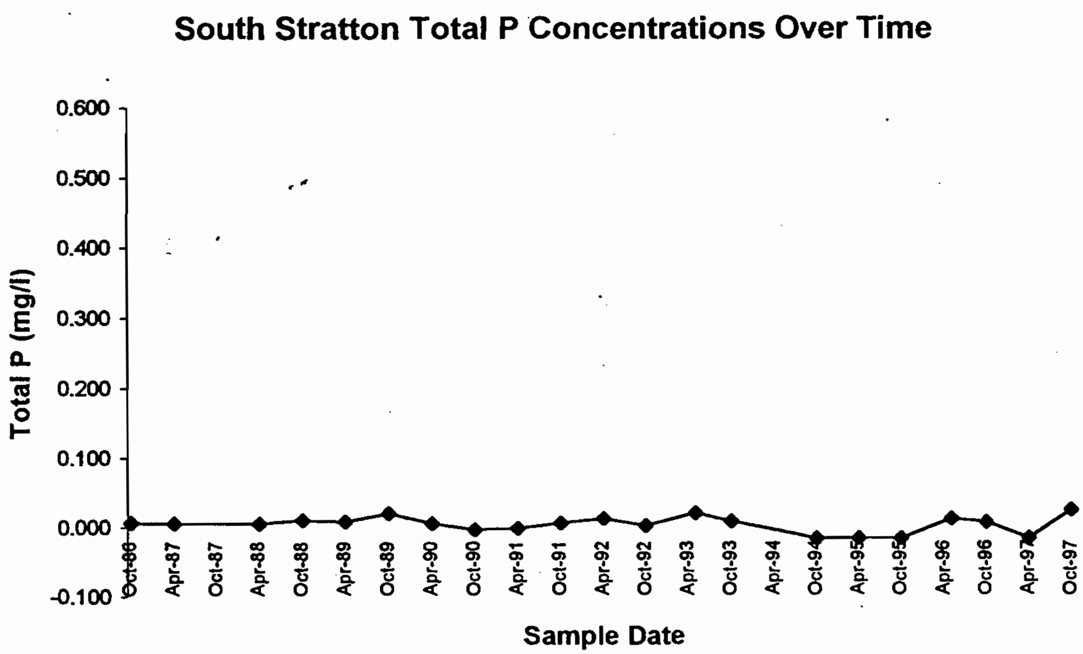




atmosphere which allows excess carbon dioxide to escape. Phosphorus has been shown to co-precipitate with marl precipitation (Otsuki et. al., 1973). Thus it will be removed from the water and be unavailable for algal uptake. If the system is working, a high input of phosphorus will not cause an algal bloom (Browne 1998). Total P was used in comparison rather than Reactive P

Figure 11. Total P concentrations for both basins from Stratton Lake, Waupaca Co.,WI between 1987-97.





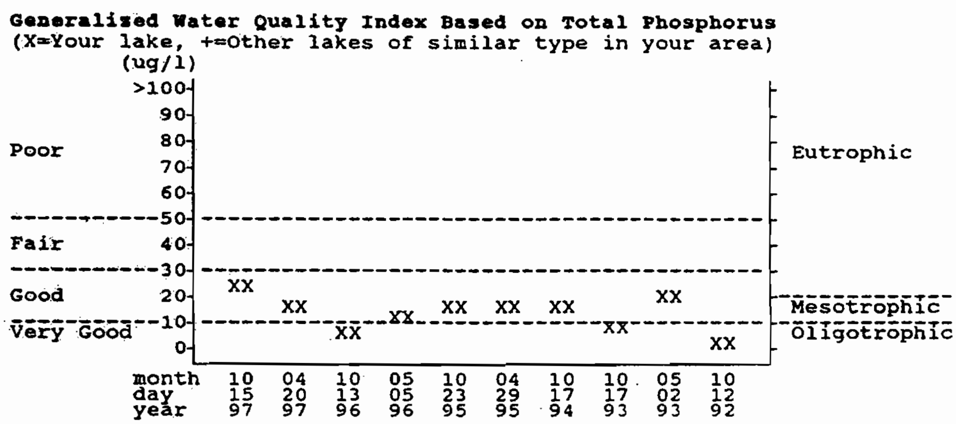
because throughout a day and from day to day Total P is not influenced as much as Reactive P by plant uptake and release (Shaw et. al. 1996).

Total P concentrations for both basins were almost identical throughout the summer of 1998. Both basins had a spike in Total P on the August 18th sample date. It is possible that strong winds caused some mixing of phosphorus-rich hypolimnion water with the rest of the water column resulting in a higher phosphorus concentration on this sampling date.

Overall, except for the August 18th samples, Total P concentrations were generally fairly low in both basins (average: 0.007 mg/l in North Stratton and 0.006 mg/l in South Stratton), which is typical for marl lakes. This results in low chlorophyll-a concentrations and good water clarity.

Long term data for Stratton Lake shows relatively constant levels of Total P since 1987 (Figure 11). All long term data from Stratton Lake is displayed in Appendix H. Using a generalized water quality index based on Total P, both North and South Stratton have good to very good water quality which gives the lake an upper mesotrophic/oligotrophic classification (Figure 12). Again, this is typical of marl lakes.

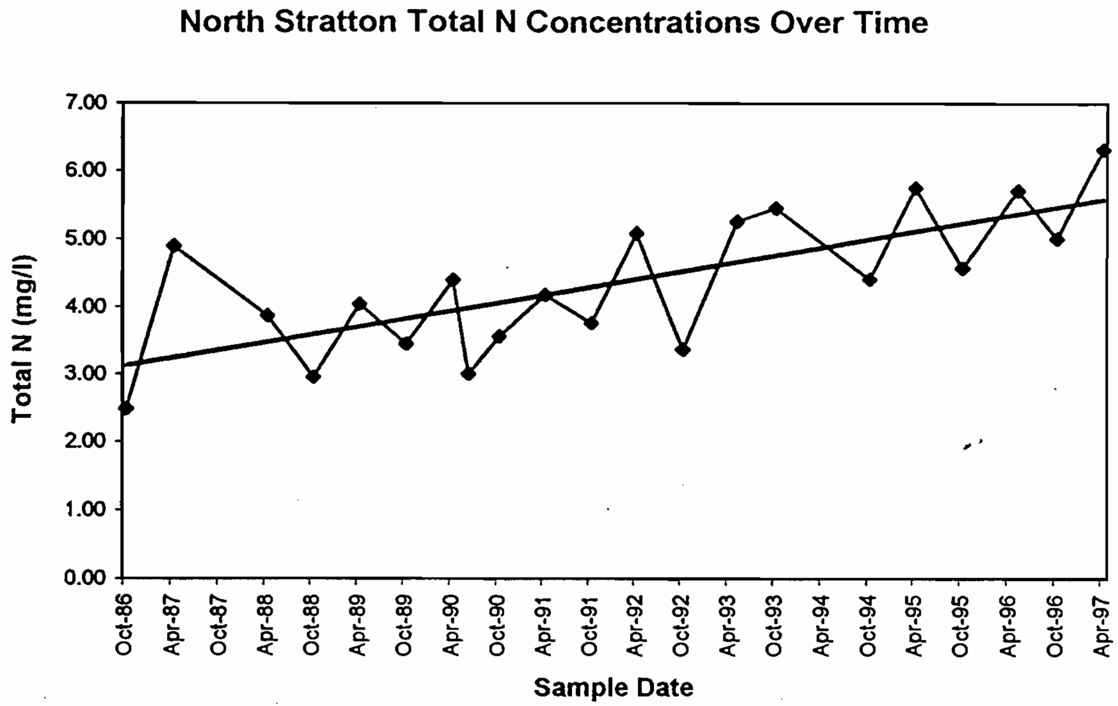
Figure 12. Stratton Lake generalized water quality using an index based on total phosphorus concentrations (mg/l). (From Understanding Lake Data: Shaw, et al, 1996)

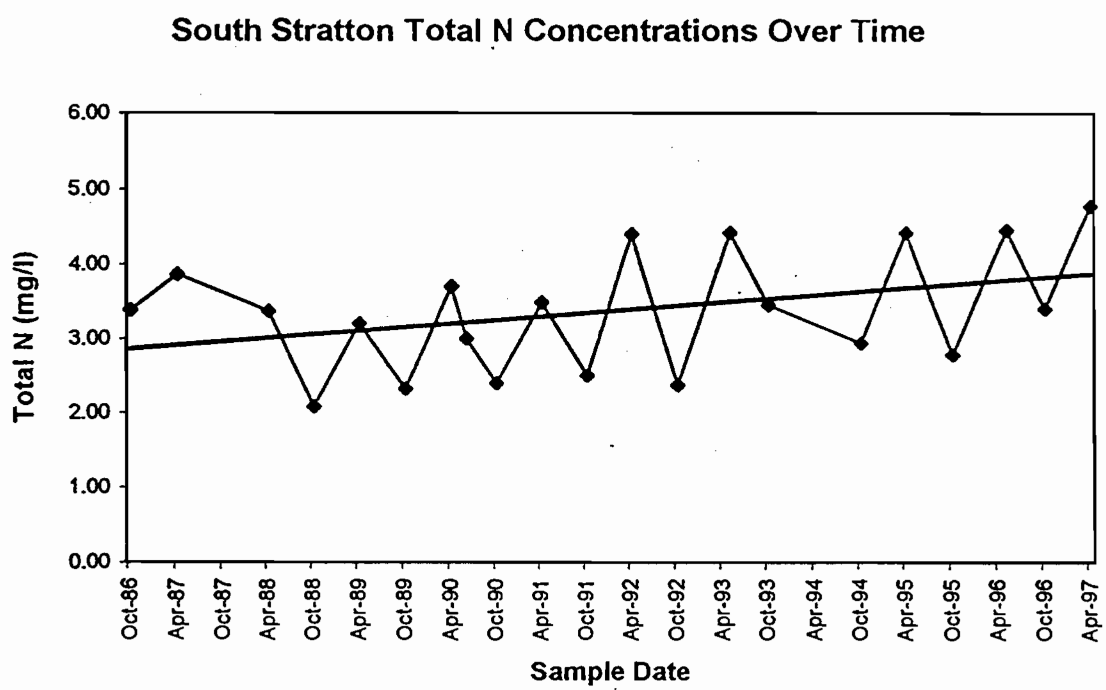


Total Nitrogen

Total N 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). Total nitrogen is calculated by adding total Kjeldahl nitrogen to nitrate + nitrite

Figure 13. Total N concentrations for both basins from Stratton Lake, Waupaca Co.,WI between 1987-97.





nitrogen (NO_3+NO_2-N). Total Kjeldahl nitrogen includes both ammonium (NH_4^+) and organic nitrogen. Both inorganic forms of nitrogen (NO_3+NO_2-N and NH_4^+) are used by aquatic plants and algae. These forms can also be transformed to organic nitrogen, and organic nitrogen back to the inorganic forms through the nitrogen cycle (Shaw et al. 1996).

Total N was relatively high in Stratton Lake, but is primarily impacted by nitrate levels. Epilimnion nitrate-N concentrations averaged 3.8 mg/l in North Stratton and 2.9 mg/l in South Stratton. The summer total N average for North Stratton was 4.3 mg/l and 3.6 mg/l for South Stratton. Even though Stratton Lake is unique because it is a marl lake, these total N concentrations are well above the mean total N concentration of 0.82 mg/l for natural lakes in Wisconsin, and even higher above the mean total N concentration of 0.74 mg/l for thermally stratified lakes in Wisconsin (Lillie & Mason, 1983). The impacts from agriculture on water quality are apparent due to this fact and also to the fact that total N concentrations were higher in North Stratton where the greatest groundwater input of nitrate was occurring.

Long-term graphs of Stratton Lake total nitrogen show significant increases in both basins (especially North Stratton) since 1987 (Figure 13).

Total Nitrogen: Total Phosphorus Ratio

When the total N:total P ratio is greater than 15:1, plant growth is generally limited to the amount of available P (Carlson, 1980). The mean TN:TP ratio for North Stratton during the summer of 1998 was 582:1 and in South Stratton it was 521:1. These data clearly show that phosphorus is the limiting nutrient in Stratton Lake. This is to be expected because co-precipitation of P with carbonate precipitation removes much of the available phosphorus. Also, the increased groundwater inputs of N into Stratton Lake have lead to excess N, which further indicates that P is the limiting nutrient in Stratton Lake.

Triazine

Triazine concentrations in mid-lake water samples were high, especially in North Stratton where the primary triazine loading from groundwater was occurring. The 1998 mid-lake summer average triazine concentration in North Stratton was 0.52 ug/l. The highest concentration occurred on the July 14 sampling date (1.44 ug/l). The 1998 mid-lake summer average triazine concentration in South Stratton was 0.19 ug/l. Triazine sampling has not been done on many other Wisconsin lakes, making comparisons difficult. The average concentrations, especially in North Stratton, are a concern and should be monitored to see whether levels are increasing or decreasing.

pH, Conductivity, Alkalinity, Total Hardness

Stratton Lake is a moderately hard water, moderate alkalinity lake with average total hardness of 134 mg/l and an average alkalinity of 108 mg/l during the summer of 1998. The moderately hard water is a result of groundwater weathering glacial deposits high in calcium and magnesium carbonate within the watershed and is good for aquatic productivity and also provides a good buffer from the effects of acid rain. Figure 14 is an acid rain index which shows that both North and South Stratton Lake are non-sensitive to acid rain effects based on alkalinity.

Figure 14. Stratton Lake sensitivity to acid rain using an index based on alkalinity. (UWSP Environmental Task Force Lab, Unpublished data.)

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Sensitivity to Acid Rain Index Based on Alkalinity
(X=Your lake, +=Other lakes of similar type in your area)
  (mg/l as CaCO3)
High____________0-|--------------------------------------
Moderate        5-|
---------------10-|--------------------------------------
               15-|
Low            20-|
---------------25-|--------------------------------------
               30-|
Non Sensitive  35-|
              >40-|  XX   XX   XX   XX   XX   XX   XX   XX   XX   XX
                  ------------------------------------------------------
            month    10   04   10   05   10   04   10   10   05   10
            day      15   20   13   05   23   29   17   17   02   12
            year     97   97   96   96   95   95   94   93   93   92
```

SEDIMENT, MACROPHYTE, INTERSTITIAL WATER

It has been fairly well documented that most rooted, submersed angiosperms obtain most of their phosphorus and nitrogen from interstitial pore water in the sediments rather than the sediments themselves (Bristow and Whitcombe, 1971; Schults and Malueg, 1971; DeMarte and Hartman, 1974; Bole and Allan, 1978; Welsh and Denny, 1979; Barko and Smart, 1980; Carignan and Kalff, 1980). Contradictory evidence does exist in the work of Seadler and Alldridge (1977) and Swanepoel and Vermaak (1977). 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 accomplish 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 (Wetzel, 1983). These elements are less soluble in aerobic sediments or in aerobic lake water. Peltier and Welch (1969) were able to show reduced growth of *Potamogeton pectinatus* in sand sealed from overlying water, illustrating the importance of sediments and interstitial water in nutrient supply.

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). It is likely that individual factors at any sampling site will determine species type and characteristics rather than processes uniform to an entire lake. 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.

An attempt to draw relationships between interstitial water, sediments, and plant growth, was done to show whether these data correlated to the distribution and biomass of aquatic plants. An attempt was also made to determine whether the elevated nitrate and triazine concentrations entering the lake were affecting aquatic plant growth.

The dominant plant species found growing at many sites was various species of the genus *Chara*. While most sites had *Chara* present, the sites that were most dominated by *Chara* also tended to have the highest overall biomass (Figure 15). It is possible that marl encrustation on the *Chara* plant tissue could have impacted biomass results, but it also appears conditions at these sites are most optimal for the growth of *Chara* over that of other rooted aquatic plants. There are several things about the genus *Chara* that make it a unique group. First of all, *Chara* is a macroalgae and not a typical rooted angiosperm. However, *Chara* does have rhizoidal structures, which have been shown to absorb phosphorus equally as well as the foliage (Littlefield and Forsberg, 1965). This differs from most rooted macrophytes, which use the roots as the primary source of nutrient absorption (Denny, 1972). *Chara* predominantly inhabits hard-water mesotrophic lakes with low phosphorus concentrations (Forsberg, 1965; Crawford, 1977). Kufel and Omizek (1994) found that *Chara* may act as a phosphorus sink in lakes because of its high storage capacity for phosphorus. The capacity of *Chara* to take up available phosphorus from interstitial water and the water column gives it a competitive advantage over rooted aquatic macrophytes as well as phytoplankton. Also, *Chara* has a slow decomposition rate and can grow during winter (Kufel and Omizek, 1994), which further limits the amount of available phosphorus that will be present in the sediments and interstitial water for use by rooted aquatic angiosperms. All of these factors suggest that *Chara* is a very important factor in controlling phosphorus turnover in Stratton Lake. The combination of high *Chara* biomass and the marl forming system certainly are controlling factors on the growth of other aquatic plants in Stratton Lake.

Another factor that could affect aquatic plant growth in Stratton Lake is the fact that the flocculent marl bottom is not a good anchoring substrate for plant roots. This could be another reason why *Chara* does so well in marl lakes since it does not have true roots. Wave action and heavy boat activity will also make it difficult for rooted aquatic plants to become established in soft, flocculent sediment. Dry weight biomass values tended to be higher at sites in North Stratton (Figure 16). This could be related to the higher concentrations of nitrogen being present in North Stratton from groundwater inputs. Table 1 lists the aquatic plant species that were

Table 1. Aquatic plant species found in Stratton Lake, Waupaca, Co., WI, summer 1998.

Emergent Species

Scirpus sp. (bulrush)

Floating-Leaf Species

Lemna sp. (duckweed)
Nymphaea tubersa (white water lily)

Submergent Species

Ceratophyllum demersum (coontail)
Chara sp. (muskgrass)
Elodea canadensis (common waterweed)
Filamentous algae
Myriophyllum sibiricum (water milfoil)
Najas flexilis (slender naiad)
Potamogeton gramineus (variable pondweed)
Potamogeton illinoensis (illinois pondweed)
Potamogeton natans (floating-leaf pondweed)
Potamogeton pectinatus (sago pondweed)
Potamogeton pusillus (pondweed)
Ranunculus sp. (water-crowfoot)
Vallisenaria americana (wild celery)
Zosterella dubia

Figure 15. Dominant plant species at each plant, sediment, interstitial water site in order of increasing dry weight biomass.

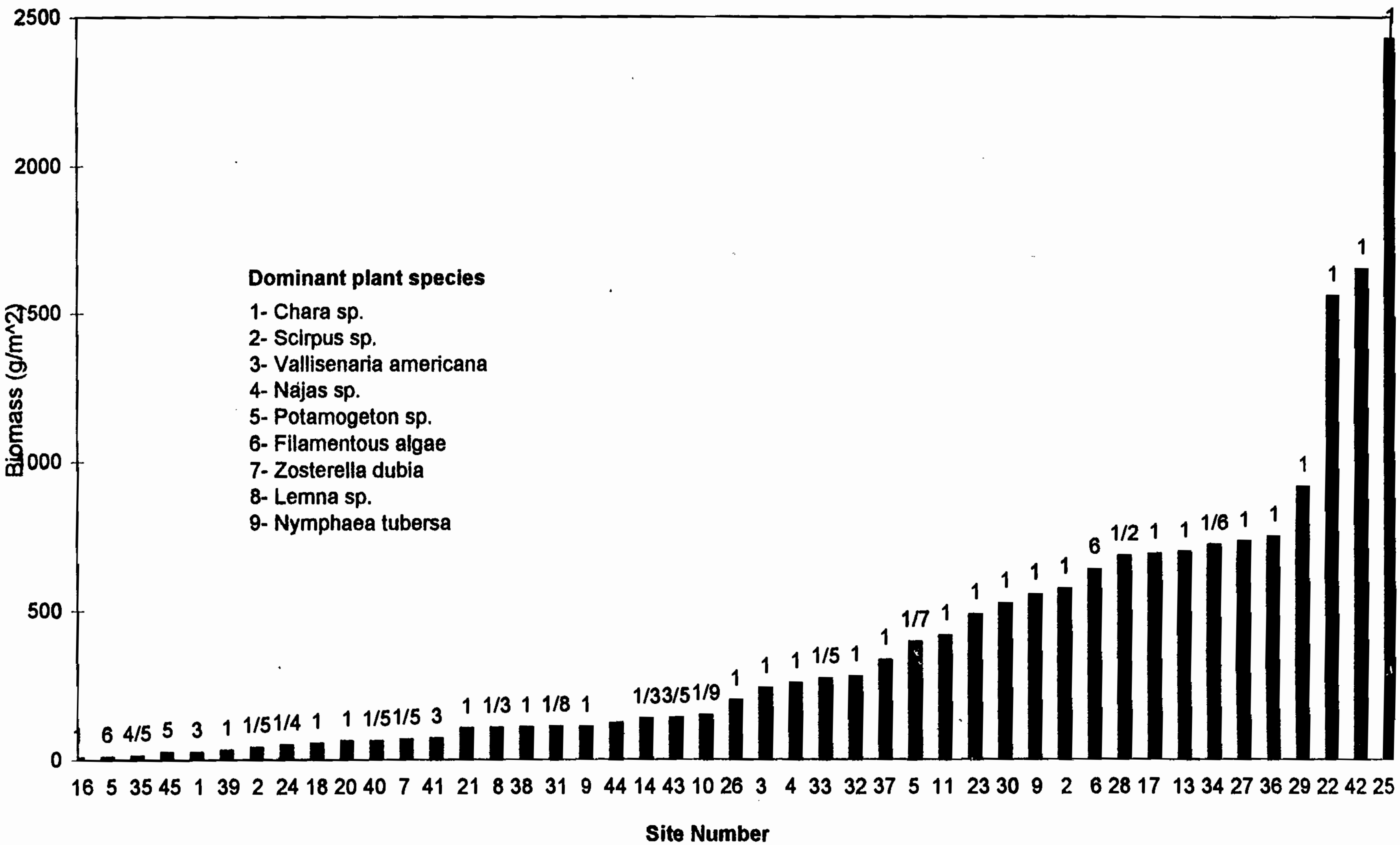
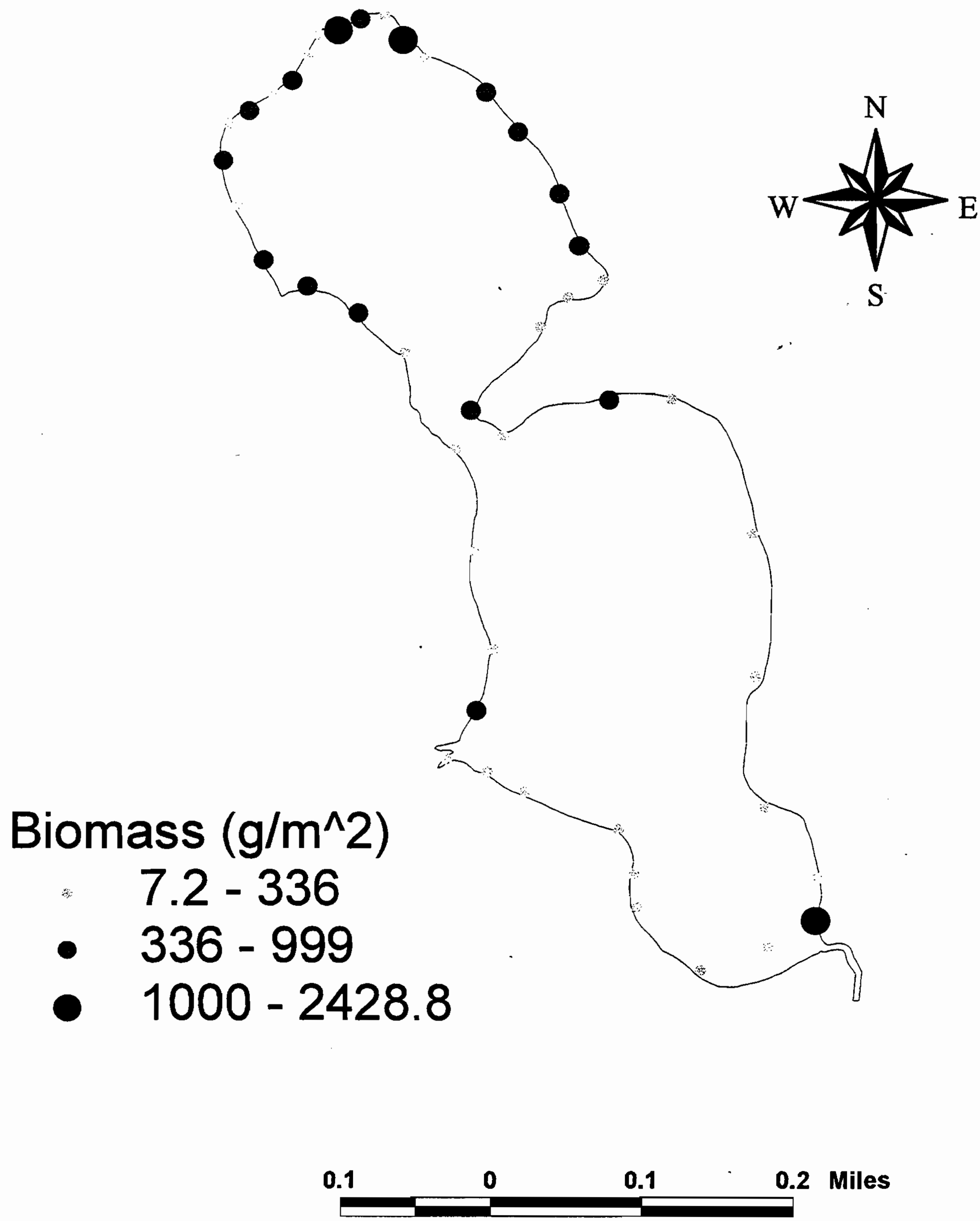


Figure 16. Dry weight biomass values from Stratton Lake, Waupaca Co., WI.

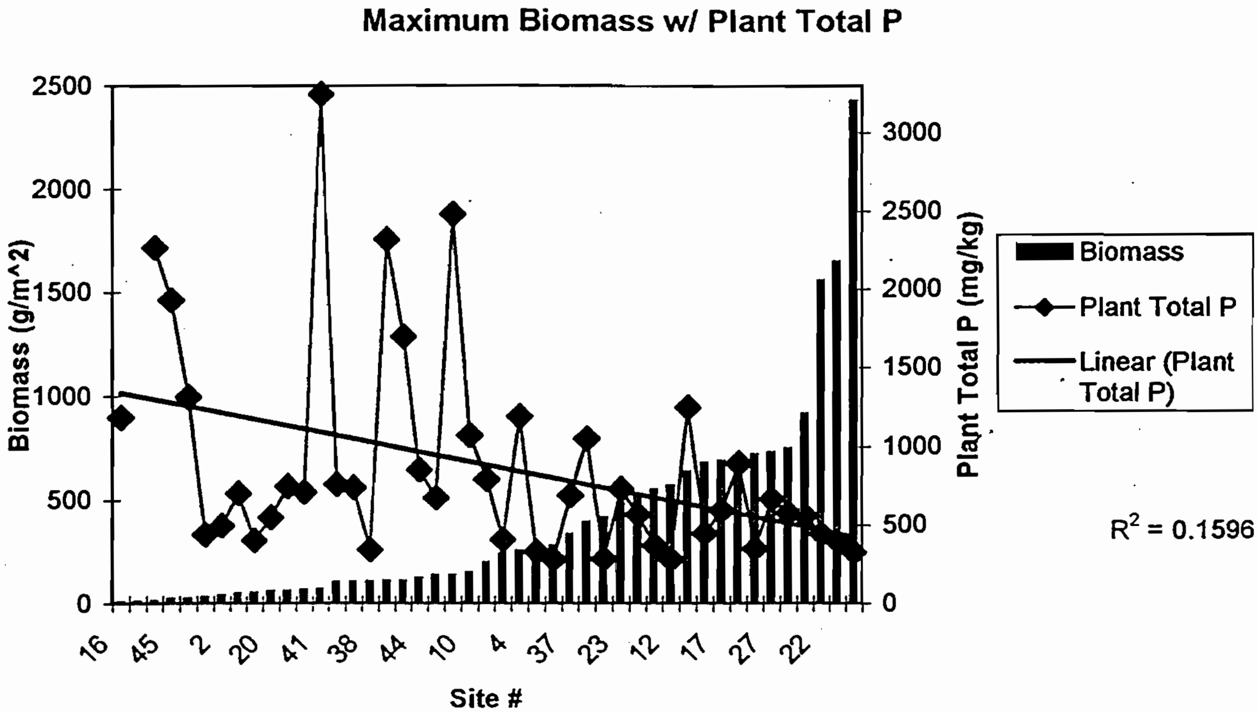


found during the plant, sediment, and interstitial water survey. The list is probably not a complete list of species present in Stratton Lake since the study did not include a full aquatic plant survey.

Another factor looked at that showed the possibility of having an effect on aquatic plant growth was the fact that as the amount of phosphorus and TKN increased in both the sediment and the plants, the amount of biomass tended to slightly decrease (Figure 17,18). While the relationship was not very strong, it was consistent between both the plant and sediment nutrient concentrations. Normally as the amount of available phosphorus and also available nitrogen increases, so should aquatic plant growth. It is likely that marl encrusted on particularly the *Chara* samples contributed weight to the biomass values but did not contribute nitrogen or phosphorus. Since most of the high biomass sites were dominated by *Chara*, the slight decreasing trend seen between plant and sediment nitrogen and phosphorus and biomass could be a result of marl encrustation impacting biomass results. The marl was not removed from the plant samples before they were dried and weighed. This process is very difficult because the marl is tightly attached to the plant material. It is also possible that the growth of aquatic plants, especially *Chara*, is limited to other site specific limitations than sediment phosphorus or nitrogen concentrations.

Triazine concentrations from the mini-piezometer samples were shown to have a slight positive correlation (0.41 Pearson) with dry weight plant biomass. Not all of the mini-piezometer and plant, sediment, interstitial water sites matched. Figure 19 shows which of these sites were taken in the same location. The data from these sites were used to determine the Pearson correlation between mini-piezometer triazine and plant biomass. Triazine was also analyzed in plant tissue collected at each plant, sediment, interstitial site. These data revealed an even stronger positive correlation (0.62 Pearson) with dry weight plant biomass. Both of these Pearson correlations show that current triazine levels in the lake and groundwater entering the lake may actually be enhancing biomass growth. These data support the findings of Pratt (1997). While low levels of triazines may be enhancing plant growth at this point, if concentrations increase, there is the possibility of negative impacts on the plant community in Stratton Lake. No studies were done to determine the effect of triazines on algal growth.

Figure 17. Total P in plant and extractable P in sediment plotted against increasing biomass; Stratton Lake, Waupaca Co., WI.



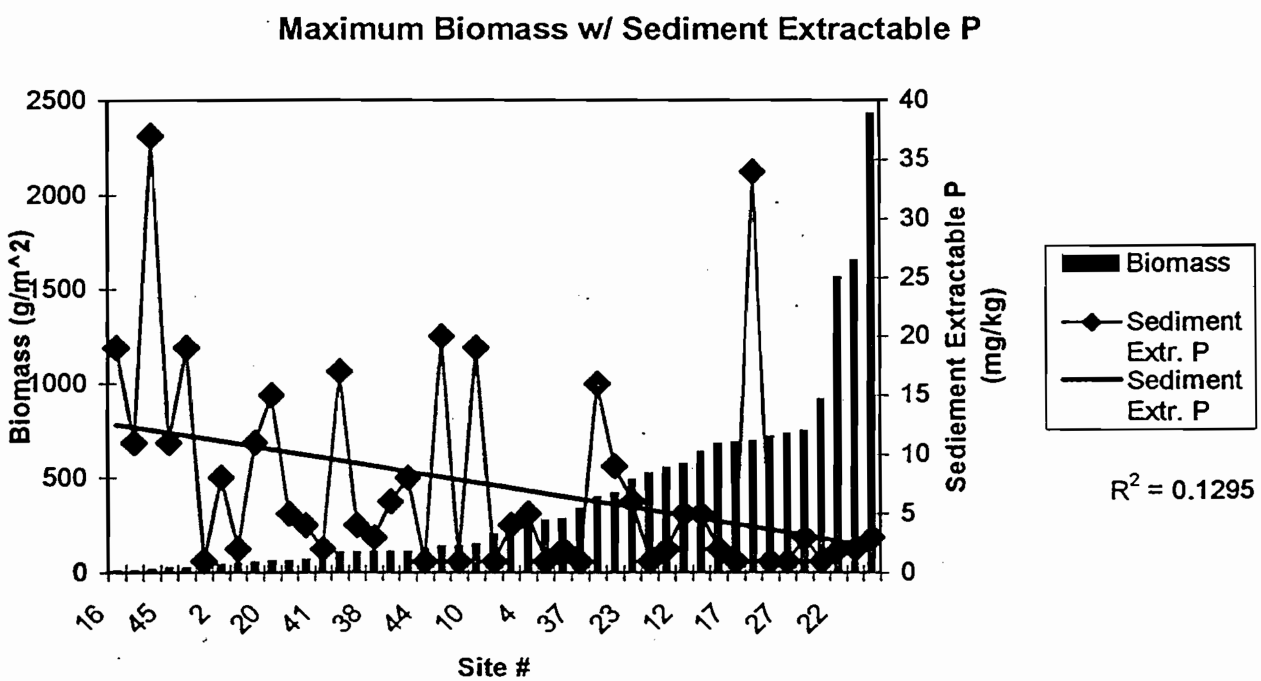
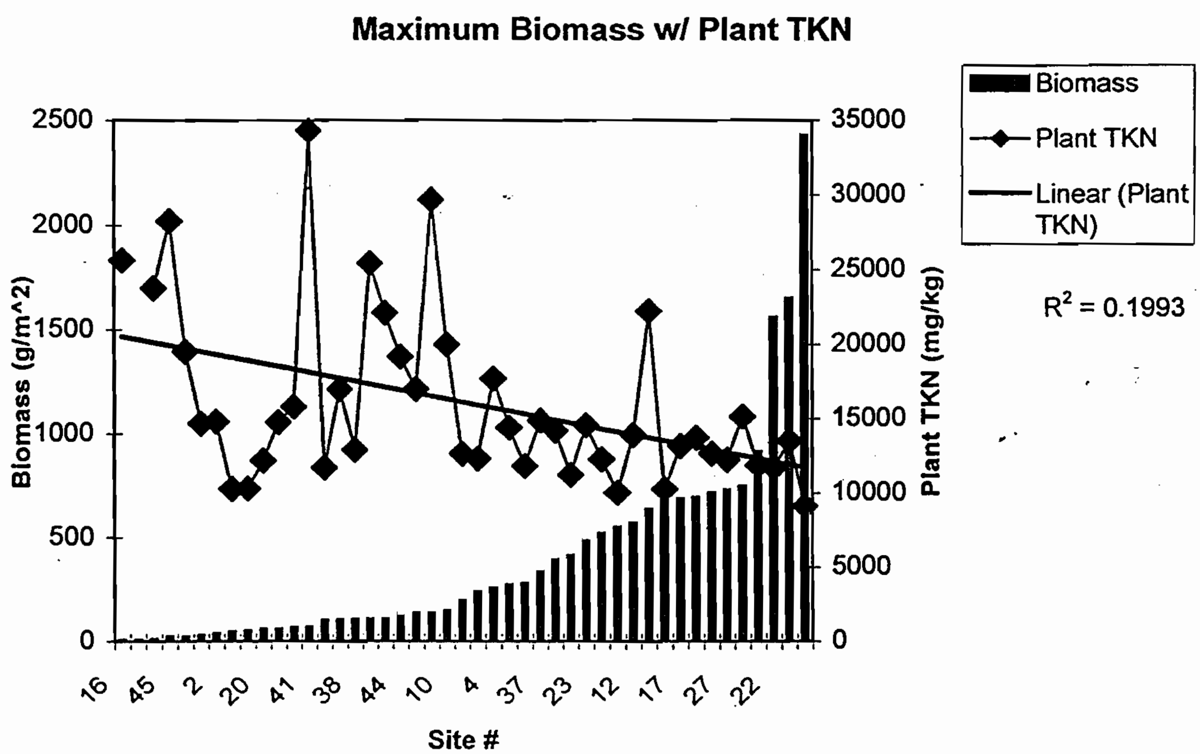


Figure 18. TKN in plant and in sediment plotted against increasing biomass; Stratton Lake, Waupaca Co., WI.



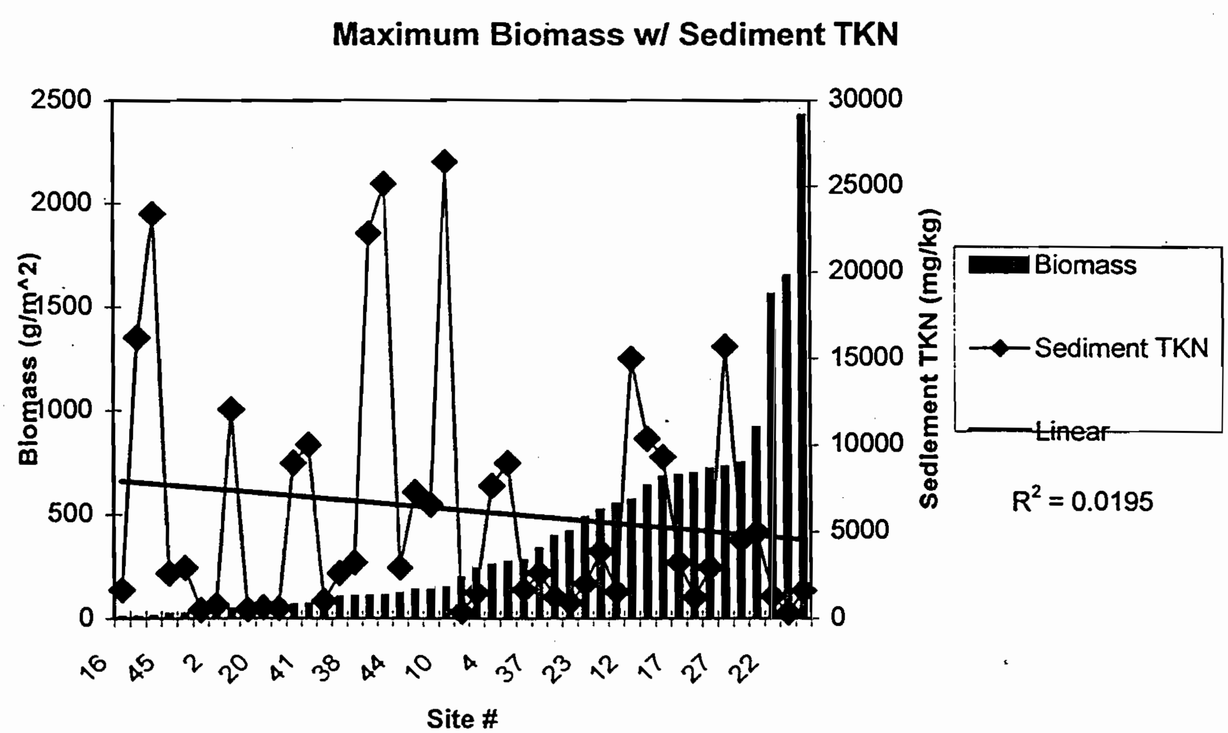
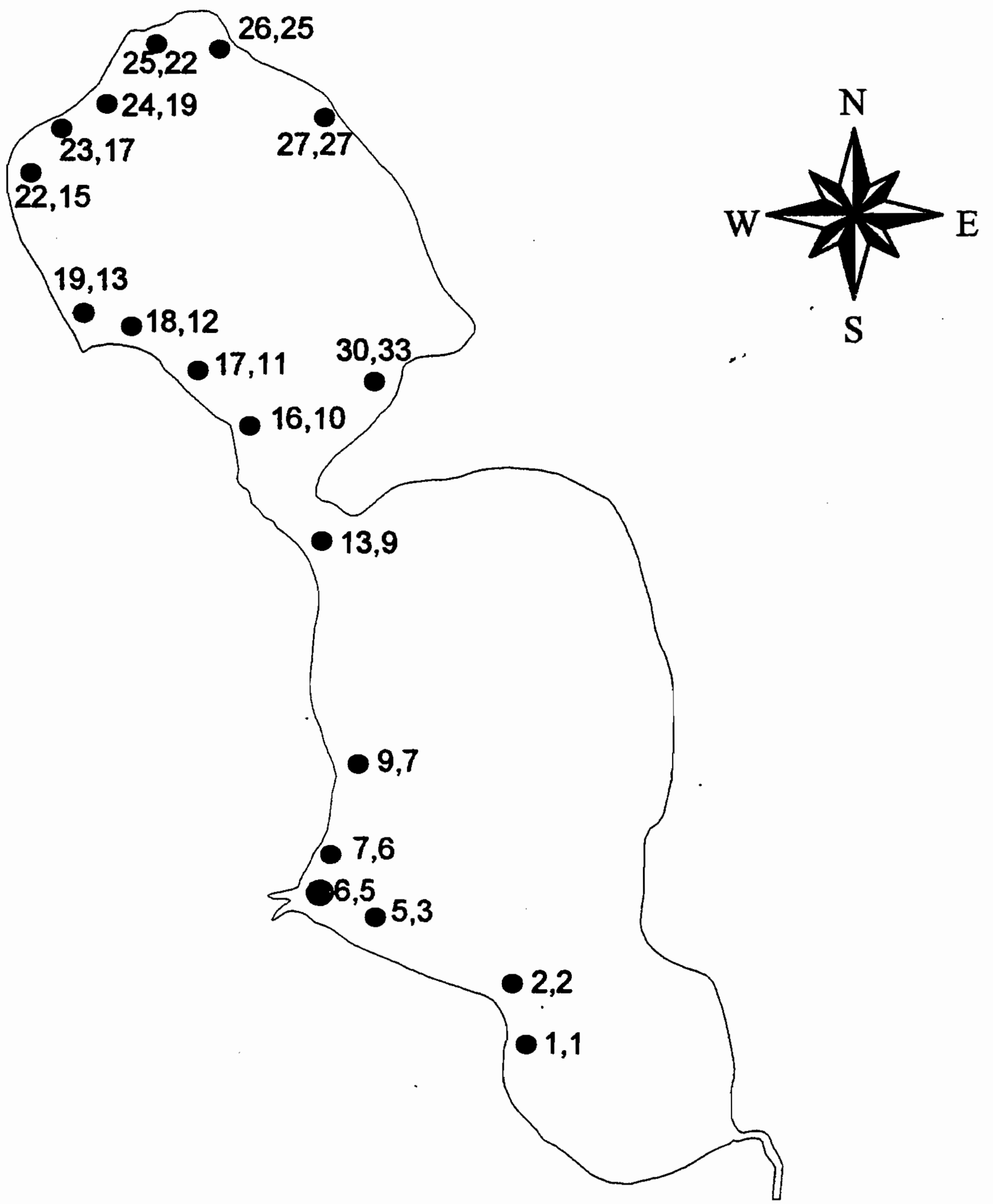


Figure 19. Mini-piezometer (first number), interstitial water, plant, and sediment sample sites (second number) that were in the same location; Stratton Lake, Waupaca Co., WI.



Nitrate concentrations entering the lake through groundwater (mini-piezometers) and interstitial water were shown to have slightly positive correlations to dry weight plant biomass, but they weren't significant at the 95% confidence level (0.33 and 0.31 Pearson correlation respectively).

HOMEOWNER AND SEPTIC SYSTEM SURVEY

Septic System Survey

The homeowner and septic system survey was conducted at 29 out of the 65 residences on Stratton Lake (Figure 20). The remaining homeowners were not present during survey attempts. Violations of Wisconsin Administrative Code that were found are listed in Table 2.

Table 2. Septic system code violations found during survey of 29 systems on Stratton Lake.

Violation	Number of Systems
Absorption system 50 feet or less from lake	1
Absorption system 25 feet or less from occupied building	3
Absorption system 50 feet or less from well	8
Absorption system 5 feet or less from lot line	3
Ponding over absorption system	0
6 inches or more standing water in vent pipe	7*
Septic tank 5 feet or less from occupied building	1
Septic tank 25 feet or less from well	5
Septic tank 5 feet or less from lot line	3
Septic systems unable to locate	7°

* Two of these systems were dry wells

° Were all located at site 24 (See Appendix D)

Only one absorption system was found to be closer than 50 feet to the lake, however, only 45% of the homes were surveyed. Therefore, there may be more systems that violate this part of the code. It is also likely that these systems are older and would not be in violation due to grandfather clauses. Even if these systems are not in violation of current code, any septic system that is in close proximity to surface or groundwater has the potential to impact water quality. As the distance of the system from surface or groundwater increases, the length of time for the possibility of attenuating contaminants also increases. It should also be noted that even well designed, functioning septic systems will eventually saturate the soil's capacity to remove phosphorus and other contaminants.

One objective of the survey was to determine the number of systems that were failing hydraulically. A failing system, according to Wisconsin Administrative Code, is any private sewage disposal system which causes or results in any of the following conditions: (1) the discharge of sewage into surface or groundwater; (2) the introduction of sewage into zones of saturation which adversely affects the operation of a private sewage system; (3) the discharge of sewage to a drain tile or into zones of bedrock; (4) the discharge of sewage to the surface of the ground; (5) the failure to accept sewage discharges and back up of sewage into the structure served by the private sewage system.

A good indication of whether or not a system is failing hydraulically is standing water present in the vent pipe. Standing water present means that the water is not infiltrating the soil beneath the drain field as fast as it is entering from the home. This can lead to sewage backing up into the house or ponding on the surface of the drain field. A system failing in this manner can actually prevent or slow groundwater contamination because the effluent is not infiltrating the soil very rapidly. However, effluent ponding on the surface has the potential to be carried into surface water during a runoff event. In addition to the seven sites that had more than 6 inches of water present in the vent pipe, there were seven systems at site 24 and one other system without a vent pipe. The condition of the other 55% of systems that were not surveyed is also not known. It is possible some of these sites could be saturated as well.

The amount of use a septic system receives and whether or not appliances such as garbage disposals, automatic clothes washers, and dishwashers are present will have an impact on the amount and type of effluent being introduced into the system and the soil. Forty one percent of the homes surveyed receive use 365 days/year. Five out of the 7 systems that had 6 or more inches of standing water present in the vent pipe occurred in homes that receive use 365 days/year. None of these systems were installed after 1976. Use in the remaining homes ranged from 24 to 270 days/year. Garbage disposals can increase the amount of solids into a septic tank and thus increase the frequency the tank will need to be pumped as well as increase the contaminant load in the wastewater. Only one home surveyed had a garbage disposal. While the phosphorus content in detergents used in automatic clothes washers has been regulated, phosphorus in dishwasher and other soap will contribute significant phosphorus to a septic system and potentially to the lake. Sixty one percent of the homes surveyed had an automatic clothes washer and 25% had a dishwasher.

Data collected on the 29 septic systems is listed in Appendix D.

Homeowner Survey

The questions asked during the survey were to ascertain what residents around the lake perceive about the water and fishing quality of Stratton Lake and what could be done to improve or maintain the lake for the future. Forty-eight percent of the people surveyed felt Stratton Lake does have a water quality problem, while 37% did not. Fifteen percent said "maybe". Sixty-three percent felt that the water quality in Stratton Lake was either excellent or very good. Twenty-six percent felt the water quality was good and 11% thought it was fair. No one gave the water quality a poor rating. Of those that fish, 80% rated the fishing on Stratton Lake average, fair or poor. The remaining 20% rated the fishing very good or excellent.

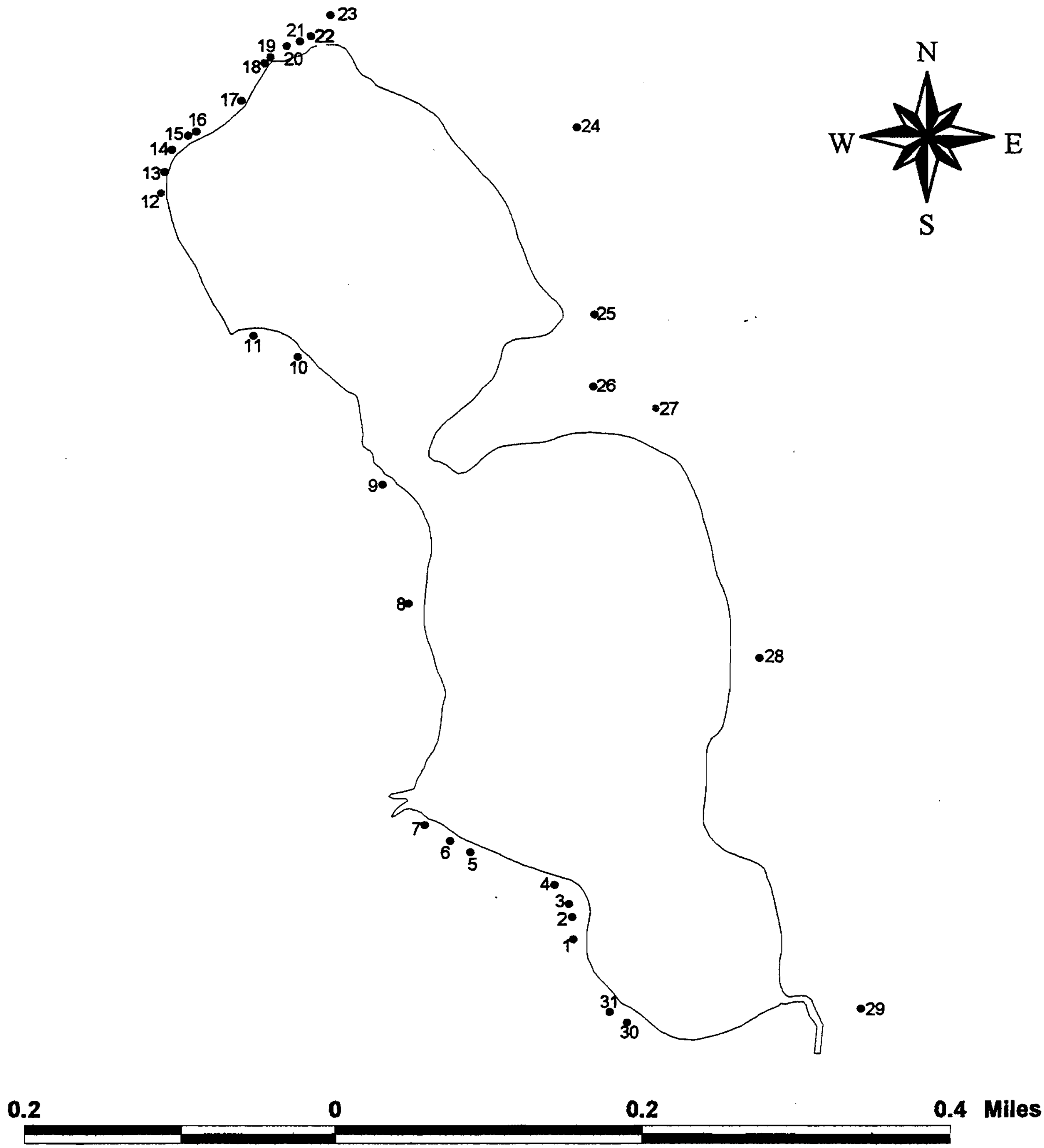
The major water quality problems perceived by people were: algae/scum (38%), weeds (21%), water clarity (17%), pesticides/nutrients (14%), septic system impacts (7%), and boating (3%). Of those that felt there has been a decline in water and/or fishing quality, the main reasons given were: herbicides/pesticides (16 people), fertilizer (15), heavy recreational use (12), septic seepage (11), development pressures (6), soil erosion (1), and air pollution (1). People were allowed to respond to more than one reason for a water and/or fishing quality decline.

Complete results from the homeowner survey are listed in Appendix G.

Private Wells

Private well samples were taken at 31 residences around the lake to evaluate the quality of the deep groundwater entering the lake (Figure 20). Thirty-two percent of the wells sampled had nitrate concentrations over the health standard of 10 mg/l, with 4 of these wells having concentrations over 25 mg/l. Eighty-one percent, or 25 out of the 31 wells had nitrate concentrations above the preventative action limit (PAL) of 2 mg/l (Figure 21). In addition to the high nitrate levels 11 (35%) of the wells had triazine concentrations above the PAL set at 0.3 ug/l with the highest concentration measured at 2.08 ug/l (Figure 21). While none of the wells exceeded the enforcement standard of 3.0 ug/l for triazines, the presence of triazines in so many wells and in the mini-piezometer samples clearly shows that much of the groundwater that is feeding Stratton Lake contains these potentially harmful compounds. The presence of high nitrate and triazine in so many wells presents a health concern to residents. Nitrate poses a health concern to infants younger than six months because its consumption in high enough levels can cause methemoglobinemia or "blue

Figure 20. Private well sampling and septic system survey locations from Stratton Lake, Waupaca, Co.,WI. Sites with a gray dot had well samples taken but no septic system survey (12 & 27).



baby syndrome" which is a condition in which hemoglobin is oxidized to a form unable to carry oxygen to body tissues. Consumption of high levels of nitrate can also be detrimental to a developing fetus. Consumption by adults has not been linked to any serious health problems, but is not recommended for long periods of time. The health concern associated with triazine compounds is that the EPA lists them as potential carcinogens.

Again, the highest concentrations of nitrate and triazine were found in wells along the northern shore of North Stratton. The triazine data supports the groundwater results obtained from the mini-piezometer survey and the nitrate data supports the groundwater results obtained from the mini-piezometer survey and the interstitial water samples (Figures 22,23).

Soft Sediment Depth

Soft sediment data was only collected for South Stratton because the ice thickness was questionable on North Stratton during probing attempts. Figure 24 shows approximate soft sediment thickness for South Stratton Lake.

Figure 21. Nitrate and triazine concentrations from private well samples on Stratton Lake, Waupaca Co., WI.

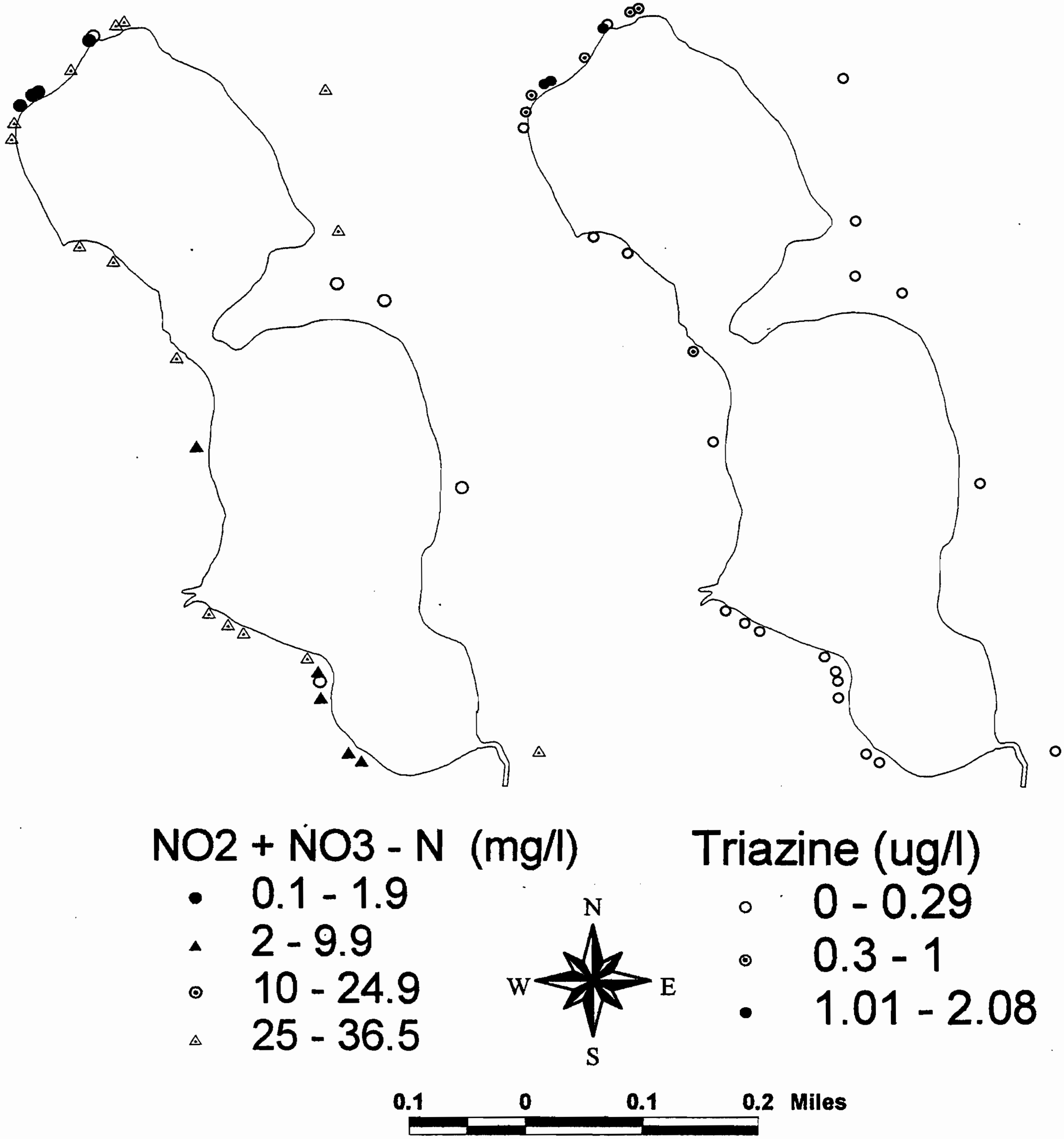
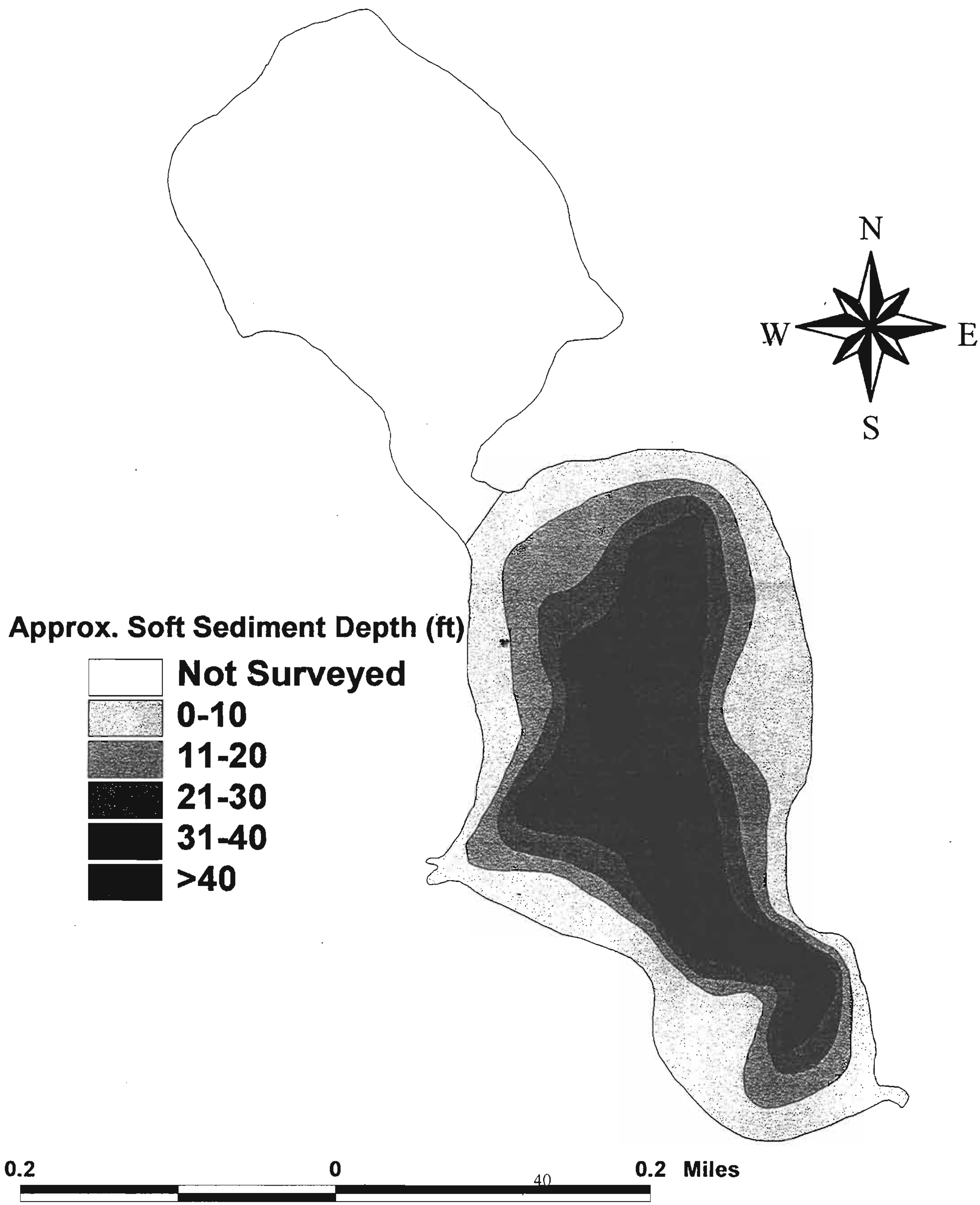


Figure 24. Approximate soft sediment thickness in the south basin of Stratton Lake, Waupaca Co., WI



CONCLUSIONS

1. Watershed analysis and mapping

a. By use of topographic and groundwater contour maps the topographic (surface water) watershed for the lake was determined to be fairly small and confined to the land area adjacent to the lake which slopes toward the lake. The groundwater watershed for the lake is somewhat larger and extends west and northwest for about a mile and includes some forest and significant areas of irrigated agricultural lands.

b. Landuses within the watershed are major concerns for the lake and include septic system and shoreline landuse practices by lake residents and agricultural practices in the groundwater recharge area.

2. Water supply to the lake

a. The source of water for Stratton Lake is predominantly from groundwater inflow and direct precipitation onto the lake surface. Exact amounts from each source will vary from year to year and would require a more detailed study to determine precise percentages.

b. Most groundwater was found to be entering the lake along the north and west sides of the lake with little or no groundwater inflow or outflow along the east side of the lake. The only significant groundwater inflow was occurring near the outlet stream.

3. Lake water quality

a. Water quality is generally very good and is better in the South Stratton than in the North Stratton.

b. Water quality remains good in spite of high inputs of nitrate and fairly high development on the lake. This is largely because of the marl deposits that coprecipitate most phosphorus out of the lake water and control the amount of algae growth possible. Water clarity is generally better in South Stratton. We believe this is due to higher nutrient input in North Stratton.

c. Nitrate levels in the lake continue to increase with concentrations being very high for lakes in Wisconsin. Concentrations are higher in the spring than in the fall largely due to aquatic plant use during the summer months. During winter, groundwater inflow with minimal plant growth results in increased nitrate concentrations by spring.

d. Nitrate concentrations are higher in North Stratton than South Stratton. This is due to the greatest volume of groundwater entering in North Stratton and the fact that this water has higher concentrations of nitrate than the groundwater entering South Stratton.

4. Groundwater and mini-piezometer sample results

a. Private wells and mini-piezometers installed into the lake bottom were used to evaluate the quality of groundwater entering the lake.

b. Water sampled by these two methods correlated well which showed that groundwater sampled by these methods gave similar results.

c. There was a high degree of variability in groundwater quality around the lake. The highest concentrations of nitrate and triazine residues were found in the north end of the lake with some high concentrations found along the west side of the lake. These were also areas of high volume of groundwater inflow.

d. Most of the high concentrations of contaminants are believed to be from agricultural landuse north and west of the lake.

e. Triazine results correlated to nitrate concentrations in most samples.

f. Groundwater sampling in multi-level wells installed upgradient of the lake showed high concentrations of nitrate and pesticide occurrence in the upper 30 feet of the aquifer with very low concentrations of contaminants in wells deeper than 45 feet.

g. Concentrations of nitrate in the multi-level wells appear to be decreasing recently. These results are encouraging, however, we are uncertain if this is a long-term trend.

h. Over 30 percent of the private wells exceeded the health standard of 10 mg/l nitrate-N, with 4 wells exceeding 25 mg/l.

i. The high concentrations of contaminants pose a health risk for residents but do not appear to be causing any severe problems in the lake at present. There may be some impacts to groups of organisms we did not sample in this project and there is some data that suggests some aquatic plants may be impacted.

5. Aquatic plants

a. Aquatic plant species distribution and abundance was found to be quite variable with a healthy population present in most areas.

b. No exotic/problematic species were found.

c. The fewest number of species were found in shallow marl deposits while the greatest number of species and biomass were found in areas sheltered from wind action and boat traffic. These areas also tended to have more organic matter present in the sediment.

d. Triazine levels in plants were analyzed and the data suggested that at this point triazines may actually be slightly enhancing plant growth. Further study would need to be done to determine the cause for this relationship and at what concentration the triazines would begin to have negative effects on the aquatic plant community.

e. No strong correlation could be found between groundwater quality and the abundance of aquatic plants.

RECOMMENDATIONS

1. Continue to work with the Waupaca County Land Conservation Dept. and local farmers to assure that best management practices are being used on agricultural lands in the Stratton Lake watershed.

2. Continue education efforts with lake property owners to communicate the need to minimize use of fertilizers on lake shore property; especially phosphorus fertilizers.

3. Encourage lake shore property owners to maintain a natural vegetation buffer along the lake shore to reduce runoff of sediments and nutrients and enhance aesthetics as well as natural populations of plants, birds, and wildlife.

4. Continue the spring and fall turnover monitoring of the lake to observe and document any changes that are occurring in water quality.

5. Work with the county to encourage continued monitoring of the multi-level wells upgradient of the lake to determine if the apparent downward trend of nitrate concentrations in groundwater continues.

6. Encourage residents with shallow wells and high nitrates to install wells at least 50 feed deep to avoid the groundwater high in nitrate and atrazine residues, or encourage use of bottled water until groundwater improves. This may be many years, if ever.

7. Continue the periodic monitoring of private wells either through the lake district or by individuals to determine long term trends and to document any changes.

8. Encourage frequent septic system pumping and maintenance and encourage or require that any new or replacement systems be installed as far from the lake as possible, especially if they are on the north or west side of the lake where groundwater flows toward the lake.

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