An Evaluation of Past and Present Water Quality Conditions in Rinehart Lake, Portage Co., WI

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ABSTRACT

A mid-lake water quality study was conducted to evaluate current water quality conditions in Rinehart Lake and compare them to water quality data acquired between 1972 and 1981. Although it is hard to compare one year of data to six because of changes in weather patterns between years, the study will give a general idea of what is going on chemically now compared to the 1970s.

Results from monthly samples taken from the epilimnion (surface) and hypolimnion (bottom) at the mid-lake, deepest area show several differences. Secchi disk readings were better in 1998-99 than 1972-81. Chlorophyll-a (measure of algae) showed a possible improvement, but there is not enough data available from 1972-81 to make a clear statement. Total P concentrations were on the average lower in both the epilimnion and hypolimnion in 1998-99. This should correlate to better secchi disk and chlorophyll-a measurements. However, Total N was slightly higher in both strata in 1998-99. Possible sources of these nutrients in the past could have been animal waste from livestock farming within the surface watershed boundaries. Current higher nitrogen levels could be attributed to contamination from a greater distance, showing up as nitrate in the groundwater flow. High nitrogen, phosphorus, and chlorophyll-a were detected during the winter of 1998-99. These high levels were not present in past years of data. These findings are discussed further in this report.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

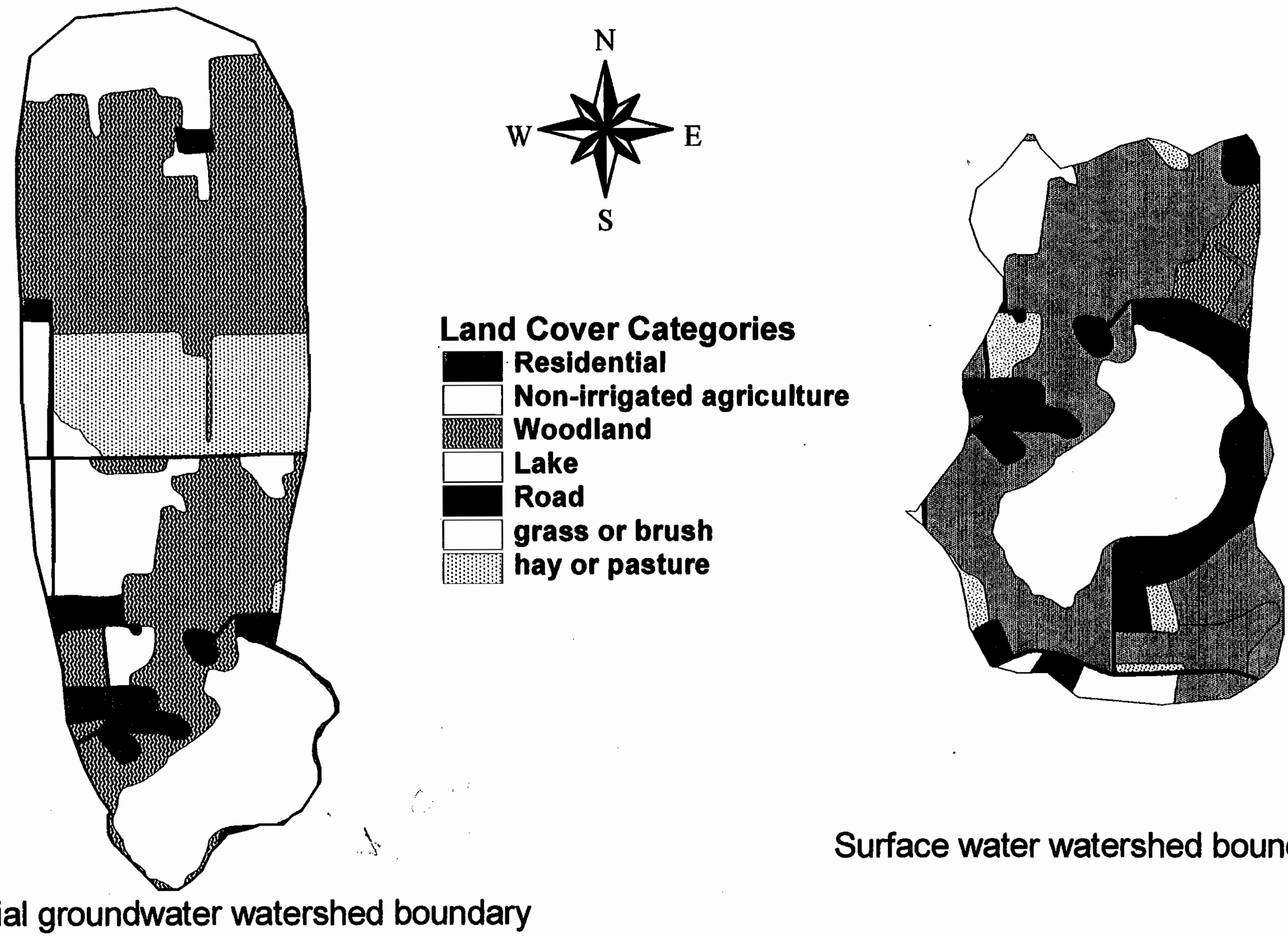
INTRODUCTION

The Environmental Task Force Program in the College of Natural Resources, UW-Stevens Point compiled monthly data on Rinehart, as well as other Portage County lakes in the late 1970s and early 1980s. Since then no data has been compiled on Rinehart Lake. The purpose of this research was to collect monthly samples at the mid-lake, deepest point, and to compare general lake chemistry as well as Secchi disk readings to the 1972-81 data. In addition, lake sediment thickness and chemistry, aquatic plant speciation, and relationship to nutrient source and to groundwater flow and chemistry were studied to evaluate the water quality dynamics affecting Rinehart Lake. This will be useful in determining if there are water quality problems, what may be causing them, and what can be done to improve or sustain Rinehart Lake's water quality for the future.

DESCRIPTION OF STUDY AREA

Rinehart Lake is a 42.5 acre, groundwater drainage lake located in the drift geological province of eastern Portage County. The area is characterized by thick deposits of sandy till, glacial fluvial deposits of sand, gravel, silt and clay, and alluvium and marsh deposits underlain by crystalline rock (Holt 1965). The lake has a marl bottom due to weathering of dolomite incorporated in the glacial deposits along the groundwater flowpath causing high amounts of calcium carbonate (Shaw et al. 1996). Groundwater flow is to the southeast, with the groundwater divide between the Tomorrow/Waupaca and the Little Wolf River watersheds just to the west. Land use within the groundwater watershed is predominantly non-irrigated agriculture, woodland, and some residential (Figure 1a). The surface area that drains directly to the lake, or surface water watershed, is very small. Land use within the surface water watershed is predominantly woodland and residential, with a small amount of grassland and non-irrigated agriculture (Figure 1a). Nace Creek is the outflow located at the northeast corner of the lake. Nace Creek had an average discharge of 0.31 cfs during the study (ETF 1998). There is a small wetland to the north of the lake that drains to the lake during runoff events. Currently

Figure 1a. Maps showing the potential groundwater watershed, surface water watershed, and landuse within each watershed of Rinehart Lake, Portage Co. WI.



there are 43 residences around the lake. Of these, 11 are year round homes. All of the residences have their own on-site sewage disposal systems (Schmidt 1998).

STUDY METHODS

Streamflow

Outflow at Nace Creek was measured 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 September and monthly from October 1998 until May 1999 at the mid-lake, deepest point. The mid-lake, deepest point was found by using a bathymetric map and an anchor rope marked at one ft intervals. A thorough description of the site was created using landmarks around the lake so the site could be located each month (Figure 10). Dissolved oxygen and temperature readings were taken using a YSI Model 50B dissolved oxygen meter (Method 4500-06, APHA 1995) except during February and April where a YSI Model 54A dissolved oxygen meter was used because Model 50B was unavailable. Readings were taken every two feet starting at the surface and terminating at 22 feet. The readings were used to determine stratification and the depths in which to take the water samples. Samples were taken from water near the bottom using an alpha bottle. Epilimnion samples were taken as grab samples over the side of the boat. An unpreserved 250ml polyethylene sample bottle was 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.. Neither sample was filtered. Analyses performed were NO_2+NO_3-N, NH_4, TKN, Total P, Reactive P, chloride, pH, conductivity, alkalinity, total hardness, Ca^{2+} hardness, silicon, and chlorophyll-a.

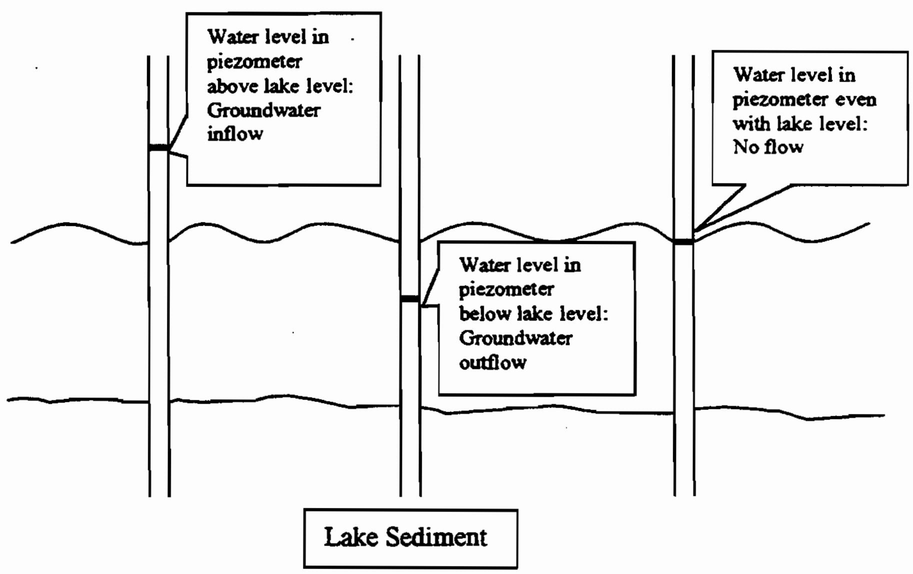
Chlorophyll-a samples were put in a dark brown, one liter, polyethylene bottle. Secchi disk readings were taken monthly (Shaw et al. 1996).

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

Mini-Piezometers

Hydraulic head data was collected approximately every 200 ft. along the shoreline 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 1b).

Figure 1b. Diagram depicting how groundwater inflow, outflow, and no flow areas were determined using mini-piezometers.



The mini-piezometers were constructed from a 5 ft length of 4 millimeter inside diameter polypropylene tubing. A plastic screw was inserted in one end and the well was given a 1 inch screen using a small diameter needle. 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 to push in the piezometer, 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 more course substrate was encountered. This often involved moving into water that was shallower than 18 inches. 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 groundwater inflow site for lab NO_2+NO_3-N and chloride analysis.

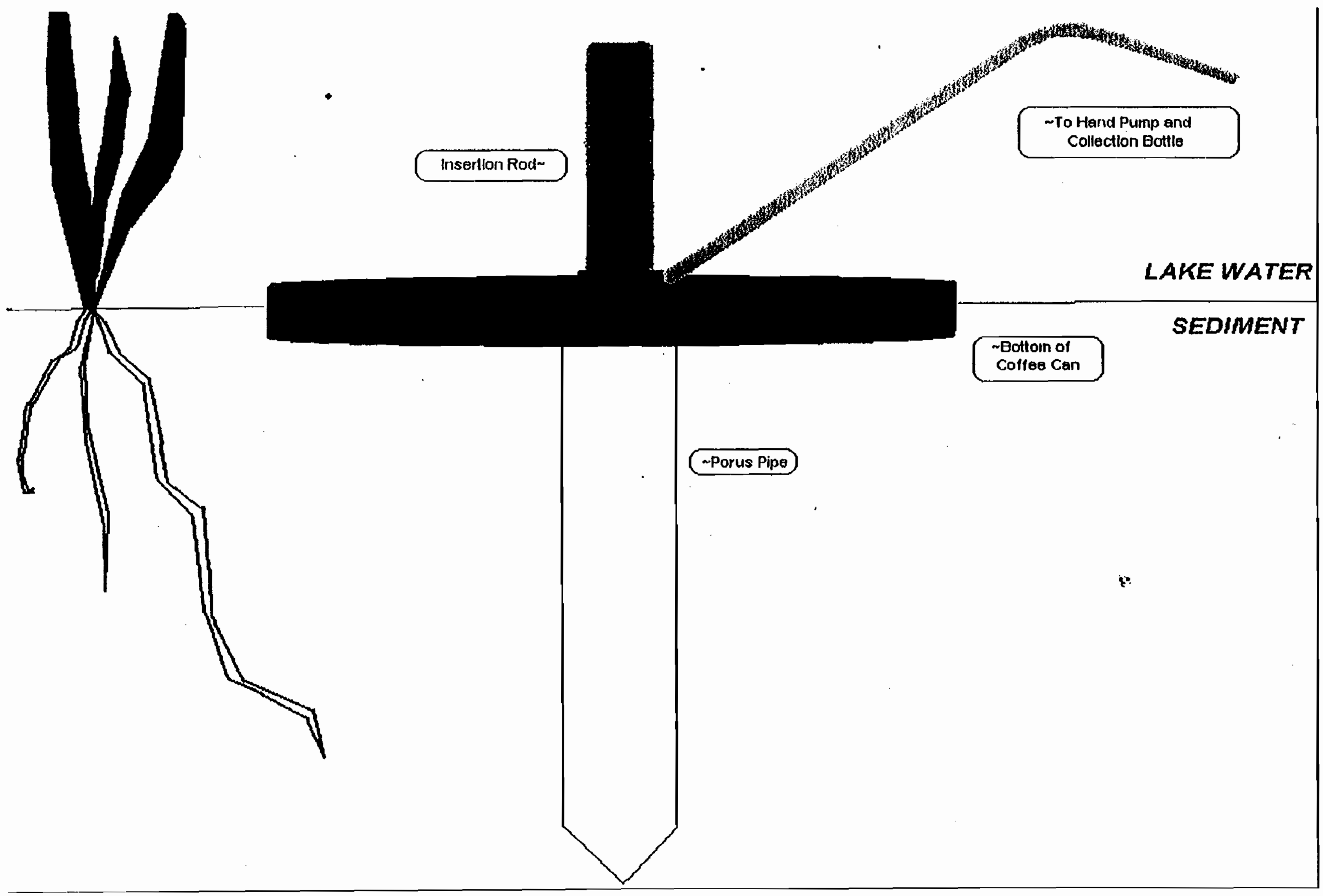
Seepage Meters

Eight seepage meters were installed at groundwater inflow areas of the lake that had been determined with mini-piezometers. The seepage meters were constructed according to Lee (1977), using the top or bottom 10 inches of a plastic 55 gallon drum. Medical supply Gent-L-Kare 1.5 liter enema bags were used to collect the seepage water before it mixed with lake water. Seepage water samples were filtered using a 1 micron glass fiber filter and preserved using 0.7 mls 1+1 H_2SO_4 per 250 mls of sample. The samples were analyzed for NO_2+NO_3-N, NH_4, TKN, Total P, Reactive P, total hardness, chloride, and silicon.

Sediment, Macrophyte, Interstitial Water

Sediment, aquatic macrophyte, and interstitial water samples were all taken within a 1/8 meter square piece of ¾ inch diameter PVC tubing at sites shown in Figure 10. The PVC square was randomly dropped over the side of the boat in about 18 inches of water at approximately the same sample sites where the mini-piezometers were installed. 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 1c). The device was inserted

Figure 1c. Interstitial water sampling device used to collect pore water from the plant rooting zone.



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 millipore and a 934 AH 47mm glass fiber filter. 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 side-arm flask into a sample bottle preserved with 0.7 mls1+1 H_2SO_4 per 250 mls of sample. Interstitial water samples were analyzed for NO_2+NO_3-N, NH_4, TKN, Total P, Reactive P, total hardness, chloride, and silicon.

Aquatic macrophytes were collected taking great care to remove the macrophytes that were not rooted within the square, but got trapped when the square was dropped. The macrophytes were cut at the sediment level, rinsed to remove as much non-organic material as possible, and measured for wet weight in the field to determine fresh plant biomass per square meter. Macrophyte samples were placed in Ziploc bags 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 analysis for Total N and Total P.

Sediment samples were taken using a 5 cm outside diameter, clear PVC tube with a beveled edge. 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 hard 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, extractable P, potassium, NO_2+NO_3-N, and NH_4. Samples were put in Ziploc bags and stored in a 4°C refrigerator immediately upon being received in the lab.

Aquatic Plant Survey

A modified version of a Deppe and Lathrop (1992) rake sampling technique was used to sample the aquatic macrophyte community along transects at depths of 1.5, 3, 5 & 8 feet of water. The ten sampling sites chosen were in approximately the same area as the sediment, macrophyte and interstitial water sites. Samples were taken from both sides of the boat, the bow, and the stern at each depth. Each sample was rinsed to remove sediment and the sample was placed in an onion bag to allow excess water to drain. The sample was weighed on an Ohaus Model C305 portable top loading balance. A spring scale was used for the final 4 sites because the top loader became too wet to be effective. Similar results were obtained with the spring scale. The fresh biomass values obtained from the rake sampling were merely qualitative to determine the relative biomass differences between sites.

Species present were determined from the samples at each depth and given a scaled value from 1 to 5 with 1 meaning the species was present on one of the rake throws, 2 meaning the species was present on 2 throws and so on. A value of 5 was given when a species was present in abundance with each of the 4 throws at each depth.

Homeowner Survey

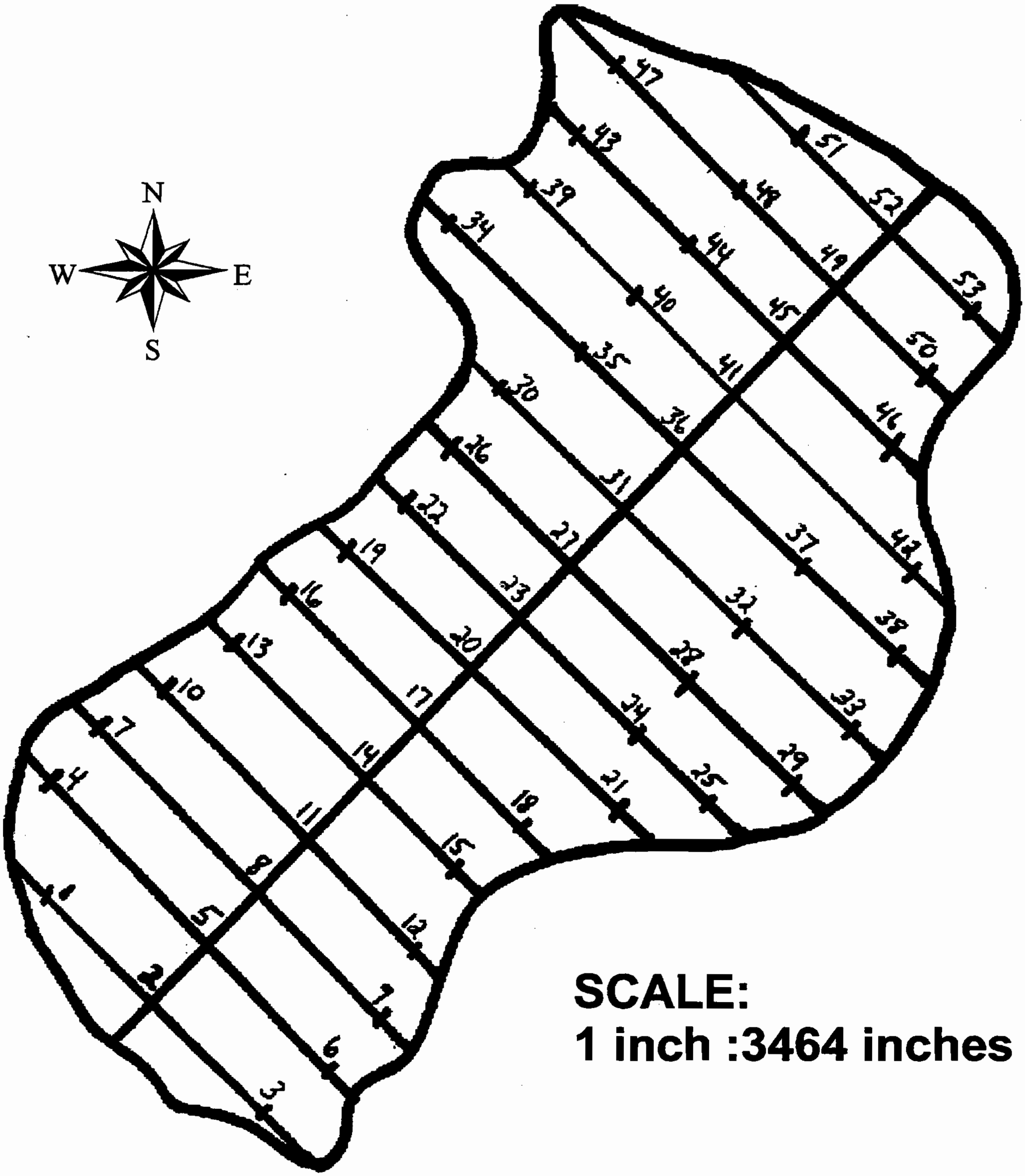
A door-to-door homeowner survey was conducted. A copy of the questions asked in the survey is displayed in Appendix . The purpose of the survey was to find out what homeowners around the lake felt about the quality of Rinehart Lake and to collect water samples of private wells. The water samples were 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 NO_2+NO_3-N, Reactive P and chloride, analysis.

The Portage County Zoning Department in 1996-97 conducted a survey of older septic systems around the lake. Approximate setbacks, type of system, and approximate elevation above the lake are displayed in Appendix F.

Soft sediment and lake 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 lines perpendicular to the main transect, and also 50 feet from shore (Figure 1d). At each of the 53 sites, a hole was drilled through the ice, depth to the top of the sediment was

Figure 1c. Map showing locations of soft sediment depth and lake depth data collection in January 1999, Rinehart Lake, Portage Co., WI.



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.

RESULTS AND DISCUSSION

STREAMFLOW

The average summer 1998 discharge measured at the Nace Creek outflow was 0.31 cfs. Flow was at a peak in early July (1.27 cfs). However, dry conditions reduced flow to an unmeasurable level at the end of July. By mid-August enough precipitation had occurred to increase flow to the summer average. Flow data is displayed in Table 2B of Appendix B.

RINEHART BATHYMETRIC AND SOFT SEDIMENT MAPS

The bathymetric map and approximate soft sediment depth created from data collected in January 1999 is displayed in Figures 2a & b respectively. Figure 2c uses the soft sediment data to create a theoretical bathymetric map of what Rinehart Lake may have looked like before it began filling in with marl deposits after the last Ice Age.

GROUNDWATER INTERACTIONS

The amount of groundwater entering Rinehart Lake was found to be surprisingly small for a hard water lake with significant marl deposition. This is, however, consistent with the small amounts of outflow leaving the lake during the study. Three sites in the northwest corner of the lake had the highest inflow. Another significant inflow point was found at the southern end of the lake in a depression thought to be the result of past marl dredging activities. Hydraulic head data was not collected at this site, but temperature probing revealed that the sediment temperature in the dredged area was 13°C, while the sediment both next to the dredged area and along most of the western shore of the lake averaged 18-20°C, suggesting minimal inflow. The sediment in the other high inflow areas averaged between 12 and 13°C. These data suggest that the old dredging

Figure 2a. 1999 bathymetric map of Rinehart Lake, Portage Co., WI.

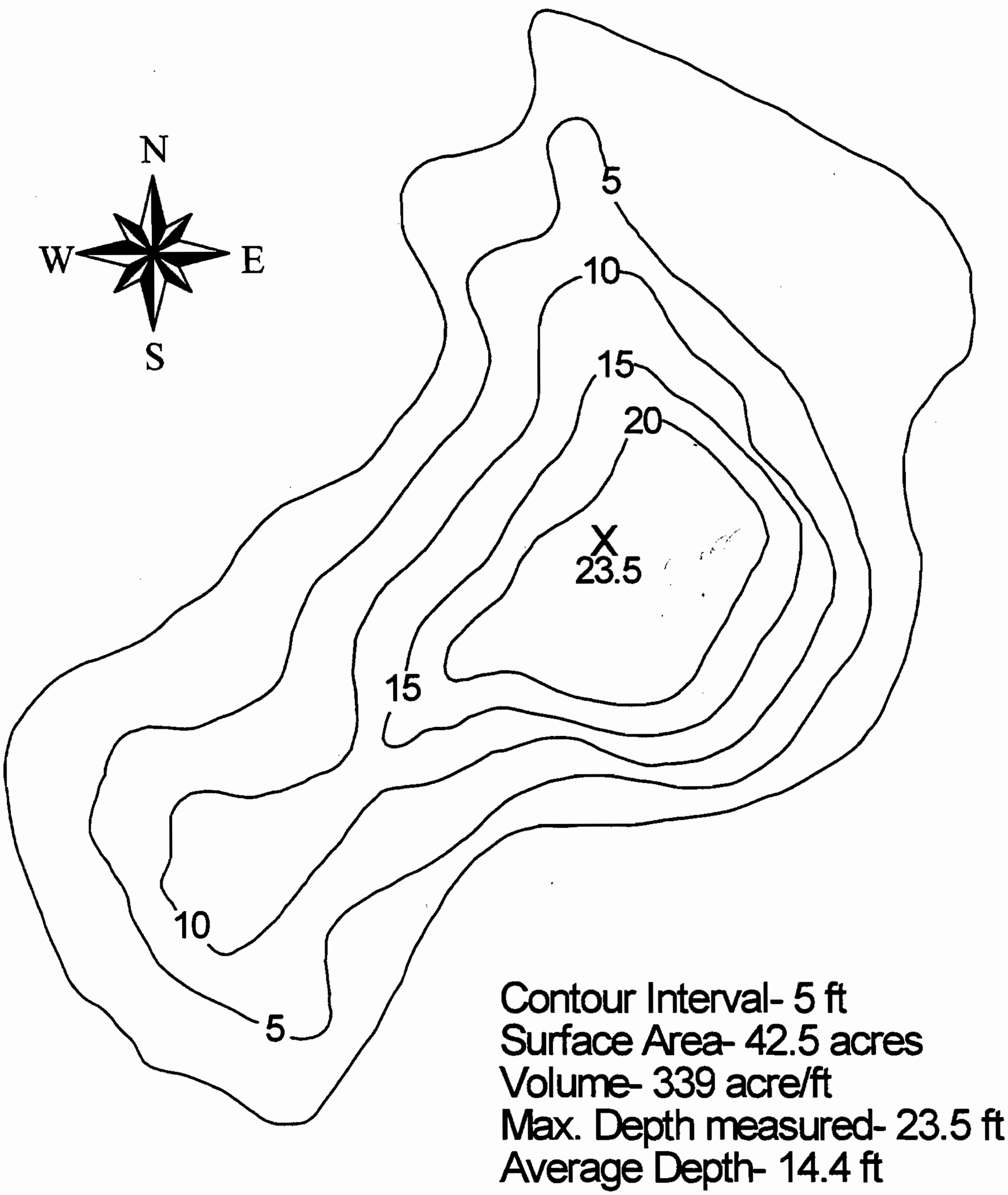


Figure 2b. Map showing approximate soft sediment depth of Rinehart Lake, Portage Co., WI.

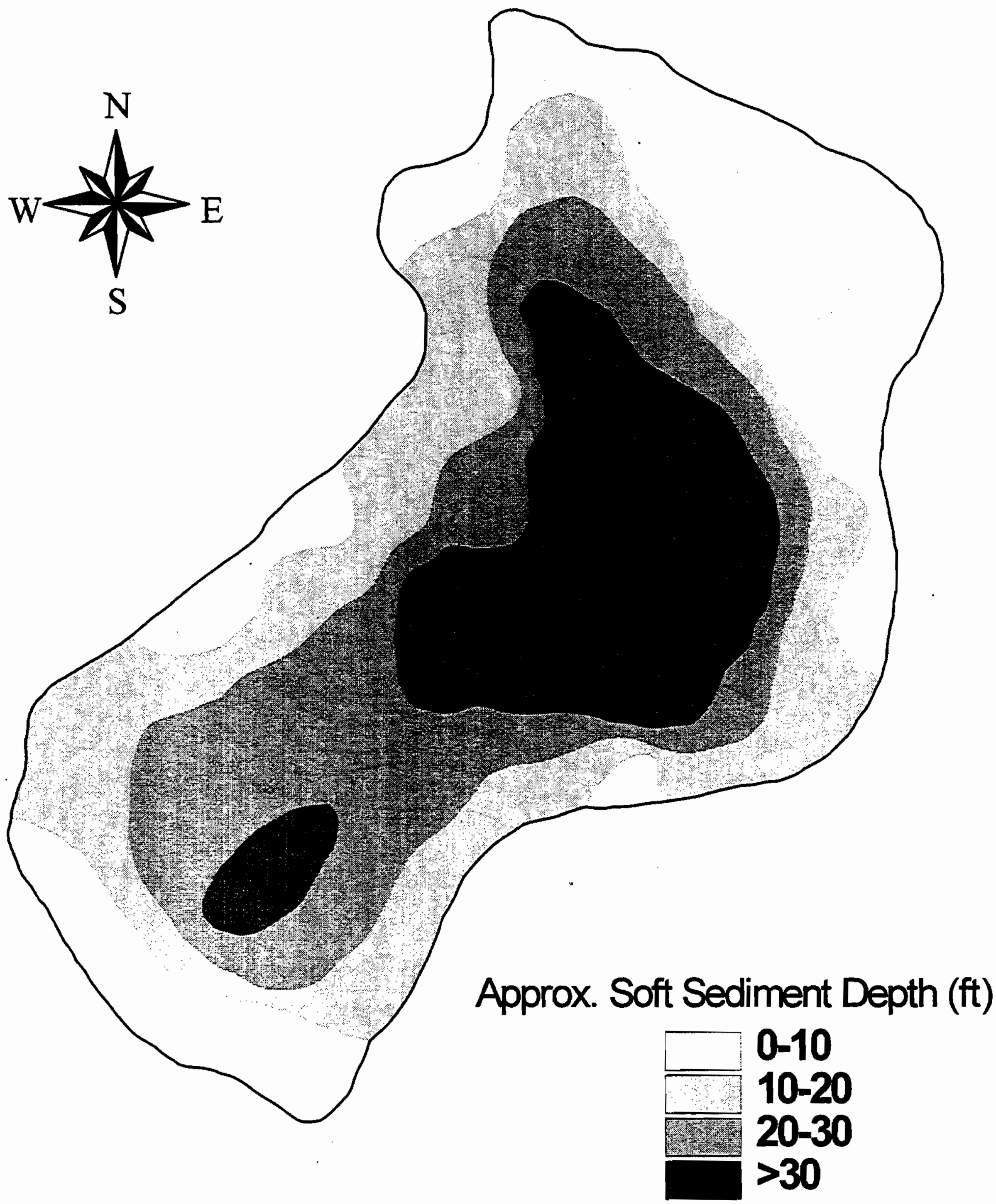
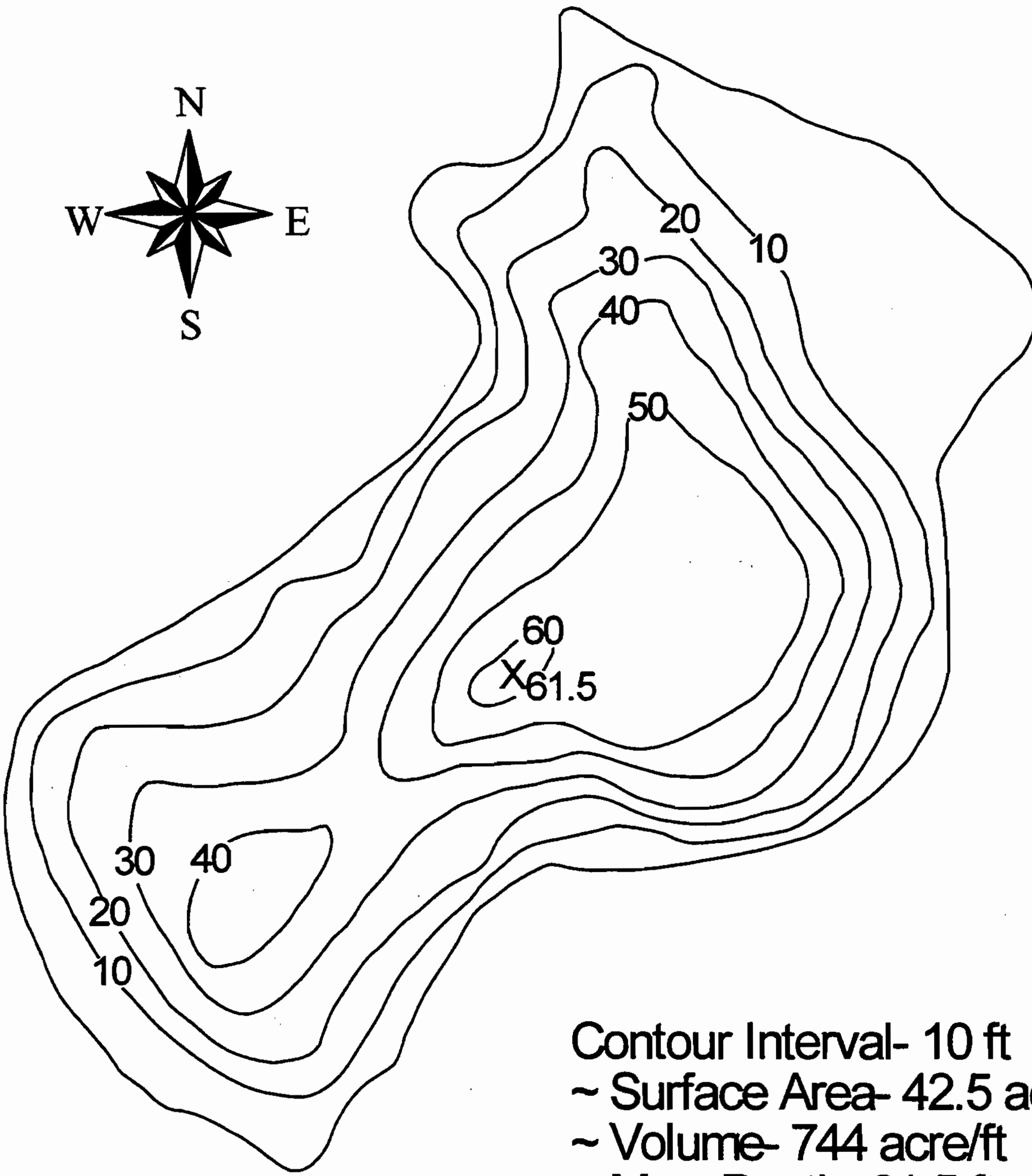


Figure 2c. Theoretical bathymetric map of Rinehart Lake, Portage Co., WI before it began filling in with marl deposits following the last Ice Age.



Contour Interval- 10 ft
~ Surface Area- 42.5 acres
~ Volume- 744 acre/ft
~ Max. Depth- 61.5 ft
~ Avg. Depth- 17.5 ft

depression is most likely an area of significant inflow.

As mentioned above, the sample sites along the western shoreline of the lake showed minimal inflow. Since the groundwater flow map for Portage County suggests the western shore of the lake should be an area of inflow, it is possible that significant marl deposits have virtually sealed the lake bottom from groundwater flow at these points. Qualitative results from the mini-piezometer survey are displayed in Figure 3. Hydraulic head data and groundwater flow estimation is presented in Table 1B of Appendix B.

AQUATIC MACROPHYTES

Rinehart Lake exhibits a typical characteristic of marl lakes in the Upper Great Lakes region because of its generally low diversity of aquatic macrophytes (Rich et al. 1971). Vegetation was sparse in water shallower than 3 feet, especially on the northern and western shoreline where the lake exhibits a characteristic marl bench, which is usually almost devoid of macrophytes. The characteristic steep drop-off is then populated by more dense and diverse macrophyte growth (Wetzel, 1972). Wet weight biomass (rake survey) increased with depth at each sampling point except in the northwest corner and one site in the southern end (Figure 4). These areas correlate to the areas of groundwater inflow into the lake (Figure 3). The northwest corner is an area of relatively high nutrient input from both groundwater and surface runoff from a ditch that intermittently flows from a small riparian wetland. The pocket of diverse plant growth in the south end of the lake occurs in a depression thought to be the result of past marl dredging in the lake. It is speculated that the dredging may have increased the groundwater inflow at that point, making more nutrient rich water available for macrophyte growth. Evidence to support this hypothesis comes from temperature probing the sediment both in the dredged area and around it (see *Groundwater Interactions* sec.). Although a sample of the groundwater entering at this point was not gathered, nitrate concentrations from nearby homeowner wells were elevated, suggesting the possibility that nutrient rich water is entering the lake at the dredged area and is supporting increased macrophyte growth. This is also an area that previously received nutrient inputs from a nearby livestock farm that is no longer in production.

Figure 3. Map showing groundwater inflow and outflow areas of Rinehart Lake, Portage Co., WI.

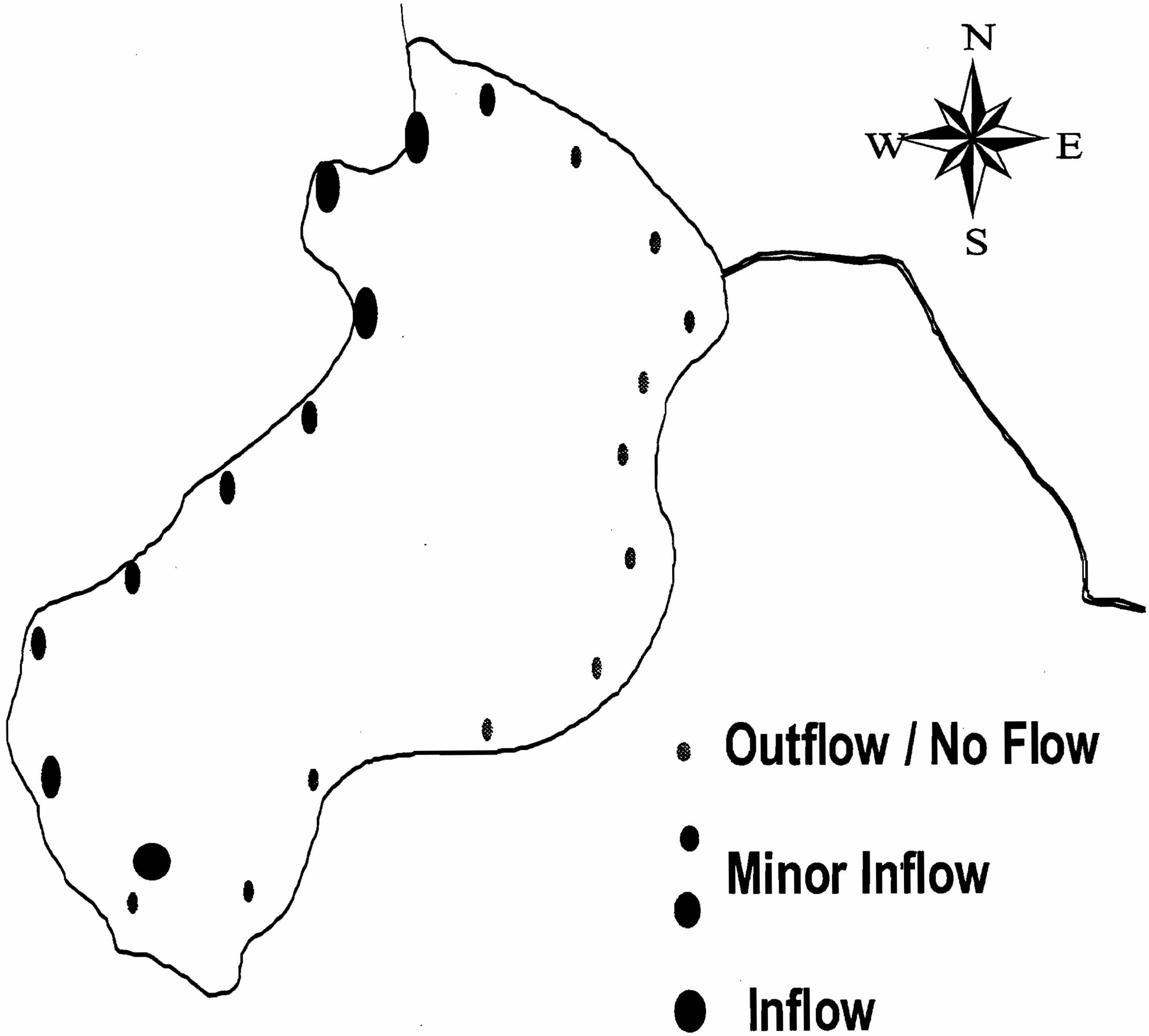
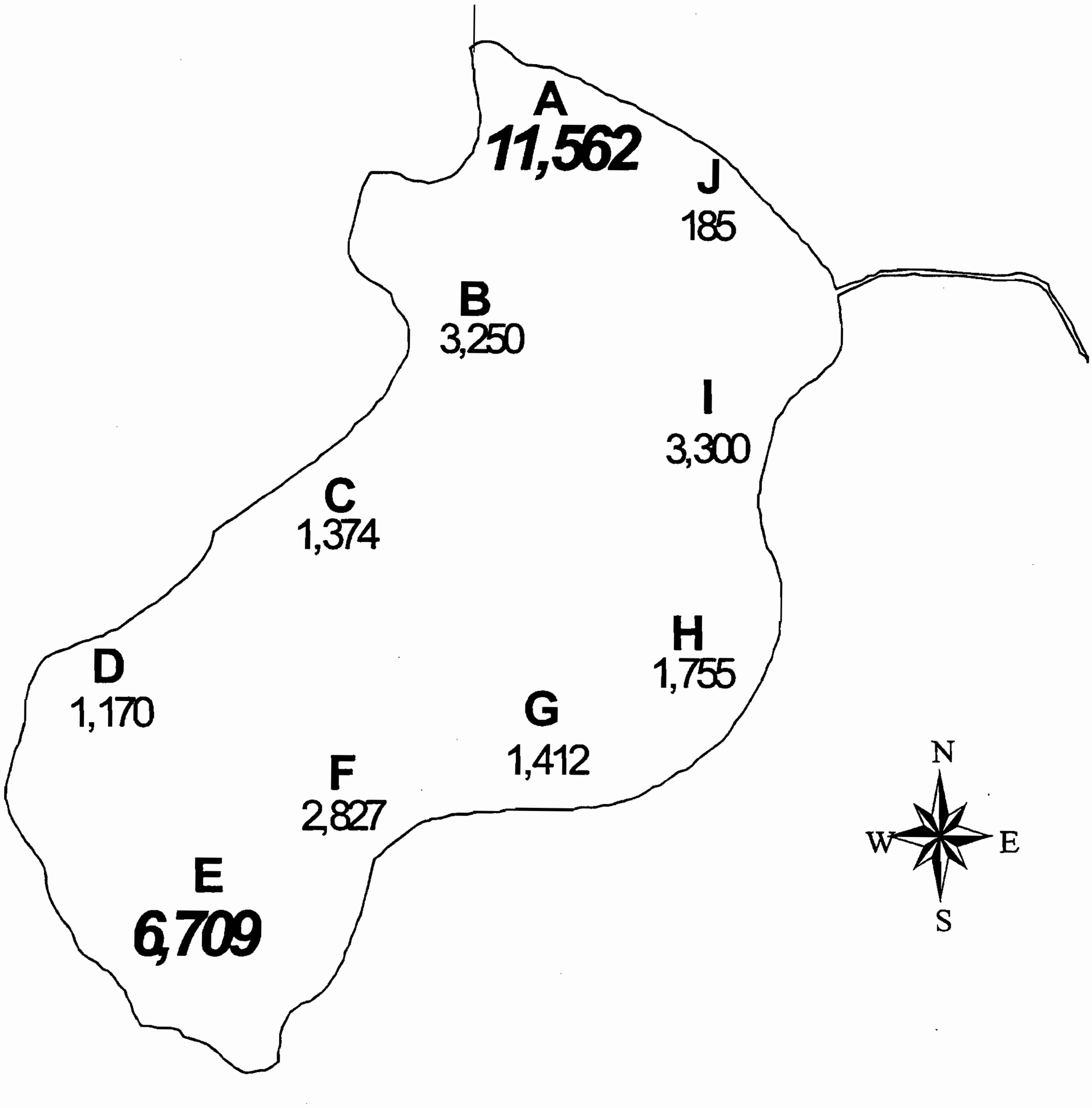


Figure 4. Map showing wet weight biomass (in grams) obtained during qualitative rake survey of Rinehart Lake.



The generally low diversity of macrophytes is typical of marl lakes because the highly buffered system leads to low availability of essential nutrients including free CO_2, phosphorus, iron, manganese, and easily decomposable dissolved organic substrates (Rich et al., 1971). These nutrients are effectively removed from the system by adsorption to precipitating calcium carbonate (Wetzel, 1983). Only certain well-adapted macrophytes are able to develop strongly. The most dominant species present in Rinehart Lake relative to both biomass and abundance were various species of Characeae (*Chara* spp.). *Chara* spp. biomass was found to be greatest along the steep slopes. It was found at depths as great as 20ft. The dominant species in the shallow water (to about 3ft) were *Scirpus* spp. and *Potamogeton natans*. The only other common species was *Potamogeton illioensis*. The rest of the macrophytes found in the lake generally occurred in the northwest and south ends of the lake as discussed earlier. Table 1 lists the aquatic plant species found in Rinehart Lake during the summer of 1998 and the species found during 1972. It is important to note that the aquatic plant list from 1972 was created from samples taken during November. Personal communication with Richard Stephens (the person who created the 1972 list) revealed that the samples taken that late in the year were partially decomposed and difficult to identify. Thus, the 1972 list may not include all the aquatic plant species present in Rinehart Lake at that time, and those identified may have been identified incorrectly. The 1998 list is more reliable because samples were taken and identified during summer.

Table 2 displays the scaled values obtained for species abundance at each rake sampling site.

Table 1. Aquatic plant species list; Rinehart Lake November 1972 and summer 1998.

1972 Aquatic Plant Species	**1998 Aquatic Plant Species**
Emergent Species	**Emergent Species**
Sagittaria latifolia (common arrowhead)	Equisetum sp. (horsetail)
Scirpus acutus (hard-stem bulrush)	Polygonum sp. (smartweed)
Typha latafolia (broad-leaf cat-tail)	Saggitaria sp. (arrowhead)
	Scirpus sp. (bulrush)
Floating-Leaf Species	**Floating-Leaf Species**
Nuphar sp. (yellow pond lily)	Lemna sp. (duckweed)
Nymphaea tubersa (white water lily)	Nuphar sp. (yellow pond lily)

Nymphaea tubersa (white water lily)

Submergent Species

Bidens beckii (water marigold)
Elodea canadensis (common waterweed)
Chara sp. (muskgrass)
Iris versicolor (blue flag)
Myriophyllum exalbescens (northern water milfoil)
Najas sp. (naiad)
Potamogeton amplifalius (large-leaf pondweed)
Potamogeton pectinatus (sago pondweed)
Potamogeton natans (floating-leaf pondweed)
Utricularia purpurea (purple bladderwort)

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 zosteriformis (flatstem pondweed)
Ranunculus sp. (water-crowfoot)
Utricularia vulgaris (great bladderwort)

Table 2. Relative abundance of aquatic plants found along transects in Rinehart Lake, the value given denotes the number of throws out of 4 that a species was present. A value of 5 means the species was very abundant on all 4 throws. X denotes the species was not present at that depth.

Site	Depth			
A	1.5ft	3ft	5ft	8ft
chara spp.	2	5	5	5
Ceratophyllum demersum (coontail)	5	1	X	X
Duckweed	4	3	X	X
Elodea canadensis	2	X	X	X
Myriophyllum sibiricum (water milfoil)	1	X	1	2
Potamogeton pectinatus	X	4	1	X
Najas flexilis	X	X	2	X
Filamentous algae	X	3	2	X
yellow water lily	X	X	1	X
Potamogeton zosteriformis	X	X	2	X
Potamogeton gramineus	X	X	2	X
Utricularia vulgaris (bladderwort)	X	X	X	2
	X	X	X	X
B				
chara spp.	4	4	4	4

Site	Depth					
B cont.	1.5ft	3ft	5ft	8ft		
Scirpus spp.	1	X	X	X		
Potamogeton gramineus	1	X	X	X		
white water lily	1	2	X	X		
Potamogeton natans (fl. leaf pondweed)	X	1	2	X		
Potamogeton pectinatus	X	X	X	1		
C						
chara spp.	4	4	4	4		
Scirpus spp.	2	X	X	X		
Potamogeton natans (fl. leaf pondweed)	X	1	X	X		
Potamogeton illinoensis	X	1	2	1		
D						
chara spp.	3	4	4	X		
Scirpus spp.	X	3	X	X		
white water lily	5	1	1	X		
Potamogeton natans (fl. leaf pondweed)	X	1	X	X		
Potamogeton illinoensis	X	X	1	X		
E					Second 3'	Second 5'
chara spp.	5	5	5	5	4	4
Scirpus spp.	X	X	X	X	2	X
white water lily	5	3	X	X	2	1
Potamogeton natans (fl. leaf pondweed)	X	X	X	X	3	2
Potamogeton pectinatus	2	1	3	X	X	X
Utricularia vulgaris (bladderwort)	X	1	X	X	1	X
Myriophyllum sibiricum (water milfoil)	1	X	X	X	X	X
Najas flexilis	X	1	1	X	X	X
Potamogeton zosteriformis	1	2	2	X	X	X
Ceratophyllum demersum (coontail)	X	3	2	X	1	X
arrowhead	X	X	2	X	X	X
F						
chara spp.	4	4	4	5		
Scirpus spp.	3	2	X	X		
white water lily	1	1	X	X		
Potamogeton natans (fl. leaf pondweed)	X	5	2	X		
Potamogeton illinoensis	1	X	X	X		
Myriophyllum sibiricum (water milfoil)	X	X	1	X		
Potamogeton zosteriformis	X	X	1	2		
Najas flexilis	X	X	2	X		

Site	Depth			
G	1.5ft	3ft	5ft	8ft
chara spp.	5	4	2	2
Scirpus spp.	2	X	X	X
Potamogeton natans (fl. leaf pondweed)	1	X	X	X
Potamogeton illinoensis	X	X	2	3
Potamogeton gramineus	X	X	1	X
H				
chara spp.	5	5	5	5
Potamogeton illinoensis	1	X	1	3
Najas flexilis	1	X	X	X
chara spp.	5	5	5	5
Potamogeton illinoensis	1	X	X	1
Najas flexilis	1	X	X	X
Scirpus spp.	3	3	1	X
J				
chara spp.	X	X	1	4
Potamogeton illinoensis	X	X	1	4
Scirpus spp.	X	X	2	X

AQUATIC MACROPHYTE COMMUNITY INDEX

A proposed biotic index for Wisconsin lakes using plant communities called the Aquatic Macrophyte Community Index (AMCI) (Nichols et al. 2000, In Press) was applied to the plant community of Rinehart Lake for use in determination of Rinehart Lake quality as compared to other Wisconsin lakes. The index considers several parameters to determine the overall condition of a macrophyte community in a given lake. The parameters used for the AMCI include: maximum depth of plant growth, the percentage of littoral area vegetated, Simpson's diversity index, the relative frequency of submersed species, the relative frequency of sensitive species, number of taxa, and the relative frequency of exotic species. Each parameter is given a 1 to 10 scale value with 10 being the most ideal condition. The AMCI value was then calculated by adding the seven scaled parameters. The highest possible value is 70 and the lowest possible is 7. Appendix C displays the scaled values used in the AMCI calculation. Rinehart Lake received an AMCI value of 62 (Table 3). Appendix C displays the scaled values used in the AMCI calculation.

Table 3. Scaled values for the Rinehart Lake plant community, 1998.

Parameter	Max. depth plant growth (m)	Littoral area veget. (%)	Simp-son's diversity	Sub. species (rel. %)	Sens. species (rel %)	Taxa number	Exotic species (rel %)	AMCI
Rinehart value	5.4	92.9	85.8	88.9	20.6	17	0	-
Scaled value	10	10	7	9	8	8	10	62

The median value for lakes falling in the North Central Hardwoods region of Wisconsin (where Rinehart is located) was 53 (Nichols et al. 2000. In Press). However, because Rinehart Lake is a marl lake, its chemical composition is different than many lakes that were sampled for use with the AMCI. Therefore, it would be most logical to compare the AMCI from Rinehart Lake to other marl lakes. However, no data from a marl lake similar to Rinehart was available. Other marl lakes included in the Nichols et al. (2000. In Press) paper were either in an urban setting, were much larger than Rinehart Lake, or had an invasion by exotic species, which can have a major impact on the aquatic plant community of a lake. Insufficient data was available for comparison to conditions in Rinehart Lake in the 1970s.

Although the high AMCI value for Rinehart Lake suggests a healthy aquatic plant community, a couple of the parameters are slightly misleading. The most noticeable is the fact the number of species was 17, but there were only 3 species that dominated the overall biomass. The other 14 species occurred primarily in the isolated areas of high nutrient input in the northwest and southern ends of the lake. Also, maximum depth of plant growth will be higher in Rinehart Lake because the marl forming system prevents significant phytoplankton growth that would normally limit availability of light to deeper water.

MID-LAKE WATER QUALITY RESULTS

All mid-lake water quality data from 1998-99 and 1972-81 is presented in Appendix C. The following is a description of results for each major group of water quality characteristics.

DISSOLVED OXYGEN AND TEMPERATURE

Rinehart 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. The epilimnion, or surface 14-18 feet (4.3-5.5 meters) in Rinehart Lake, has a fairly constant temperature and dissolved oxygen readings range from 14.8 mg/l in early summer to 7.9 mg/l in early fall when plant use of dissolved oxygen is at a peak and low oxygen hypolimnion water begins to mix with surface water. The epilimnion is followed by a strong temperature gradient, or thermocline, and finally the hypolimnion, or bottom water. The water temperature in the hypolimnion is warmer than the epilimnion during winter and cooler 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 the bottom sediments use up most of the available dissolved oxygen in the hypolimnion. This results in dissolved oxygen concentrations below 1.0 mg/l in the lower 3 ft (1 meter) of Rinehart Lake by mid-June and continues into early fall. Rinehart Lake is just deep enough to have a noticeable thermocline and hypolimnion.

Water mixing or turnover occurs in spring and fall, usually evident in April and late September to early October. Following turnover, water temperatures and dissolved oxygen become uniform throughout the water column. During fall turnover, dissolved oxygen concentrations increased from 7.3mg/l in late September when the low oxygen hypolimnion water began to mix with rest of the water column, to 13.2 mg/l in early December. Lower water temperatures and less biological use lead to an increase in dissolved oxygen in late fall. Fall turnover and ice-free conditions lasted longer than normal in 1998 due to unseasonably warm temperatures through early December. Winter dissolved oxygen concentrations ranged from 14.6mg/l in January to 7.6 mg/l in March in the upper 15 feet (4.6 meters) of the lake. These concentrations should be adequate to support the Rinehart Lake fish population throughout the winter months. Again, decomposition of aquatic plants and organic matter in bottom sediments caused a reduction in dissolved oxygen in the hypolimnion during winter, although not as pronounced as during the summer months.

Overall, the 1998-99 year average surface lake temperature was 13.3°C, which was 2.9°C warmer than the 1972-81 annual surface average of 10.4°C.

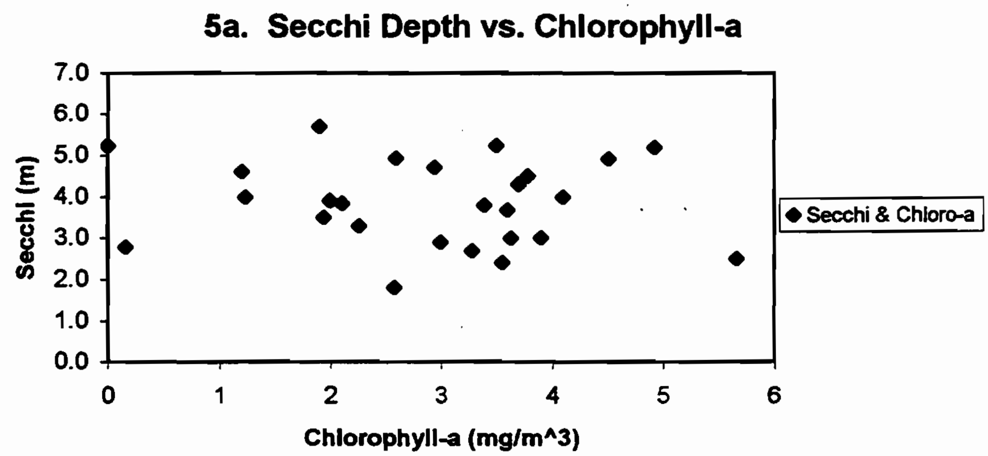
SECCHI DEPTH AND CHLOROPHYLL-A

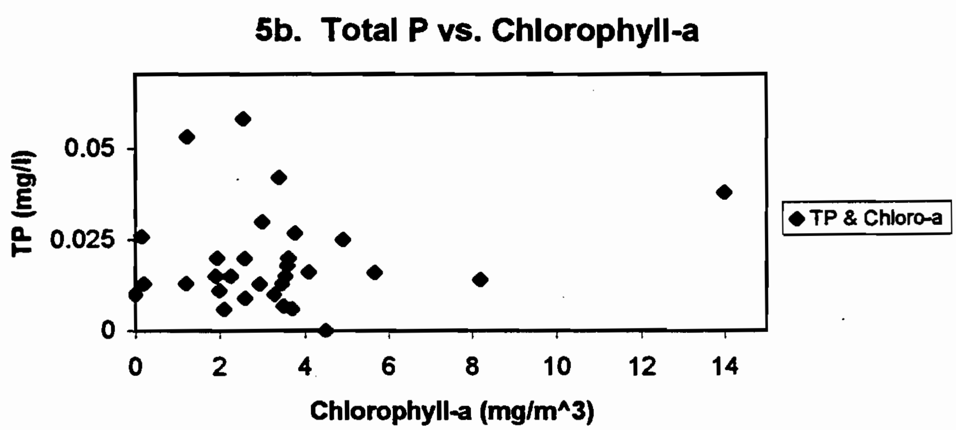
Secchi depth is a measure of water clarity. It can be directly compared to chlorophyll-a, a measure of algae growth. Chlorophyll-a can also be an indicator of phosphorus levels (Shaw et al. 1996). Higher chlorophyll-a should correlate to a smaller Secchi depth; however, many variables such as time of day and wind can affect the Secchi depth accuracy. There are no chlorophyll-a data available for the year's 1972-74 and 1981. There are several months of chlorophyll-a data missing from 1975-80, but that which exists does not clearly show the expected direct linear relationship between Secchi depth and chlorophyll-a (Figure 5a). In general, Secchi readings were better in 1998-99. Secchi depth data are not available for 1972-74. The mean Secchi for 1975-1981 was 11.2 feet (3.4 meters) with a standard deviation of 2.67 feet (0.82 meters), compared to 15.2 feet (4.67 meters) in 1998-99 with a standard deviation of 4.19 feet (1.29 meters). The mean chlorophyll-a from 1975-80 was 3.01 mg/m^3 with a standard deviation of 1.27 mg/m^3, compared to 2.91mg/m^3 in 1998-99 with a standard deviation of 2.51 mg/m^3. Despite some missing data, these values suggest an increase in water clarity and a decrease in algal growth between 1975-81 and 1998.

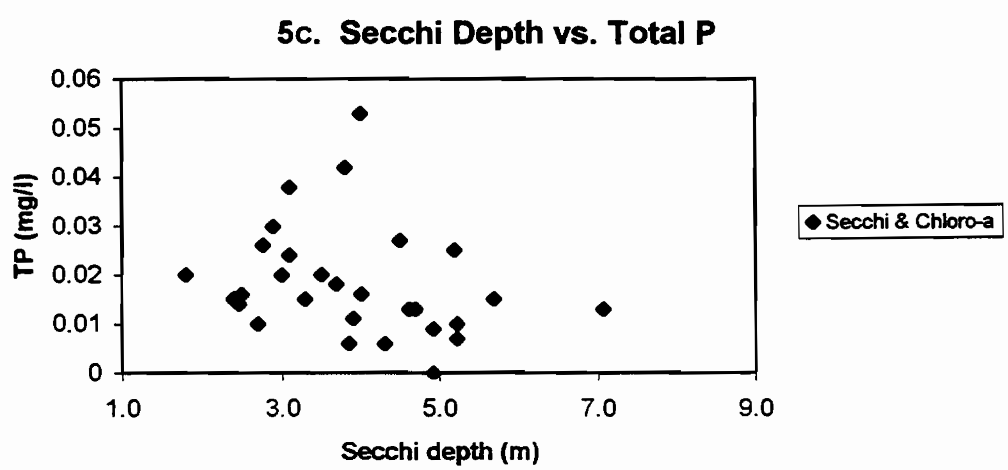
TOTAL P

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 Rinehart, carbonate (marl/$CaCO_3$) precipitates out of the water as pH increases and CO_2 is lost when groundwater enters the lake. Phosphorus has been shown to coprecipitate with carbonate precipitation (marl) (Otsuki and Wetzel, 1972). Thus it will be removed

Figure 5. Graphs showing relationships between secchi depth, chlorophyll-a, and Total P; Rinehart Lake, Portage Co., WI. Data is from all sampling years.



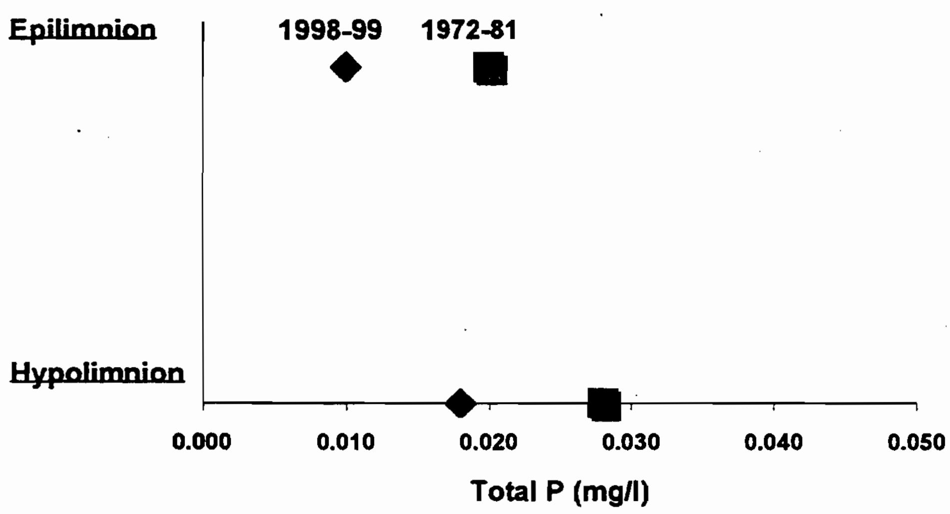




from the system and be unavailable for biological uptake. If the system is working, a high input of phosphorus will not cause an algal bloom (Browne 1998). Total P was used in comparison rather than Reactive P because its levels remain more constant and are not affected by rapid cycling due to aquatic organisms (Shaw et al. 1996).

Between 1972-81 the epilimnion water had a mean Total P concentration of 0.023 mg/l, with a standard deviation of 0.024 mg/l. The 1998-99 mean concentration was 0.012 mg/l with a standard deviation of .009 mg/l. This shows a decrease in Total P. Concentrations were higher in the hypolimnion in both groups of data, but again, 1998-99 showed a decrease from the 1972-81 mean of 0.028 mg/l (std.dev.- 0.023 mg/l) to 0.019 mg/l (st.dev. 0.011) in 1998-99 (Figure 6a).

Figure 6a. Comparisons of average mid-lake Total P concentrations between 1972-81 and 1998-99 in Rinehart Lake, Portage Co., WI.



Higher levels of phosphorus in the hypolimnion during the summer months can be attributed to anoxic water causing a release of phosphorus from the bottom sediments. Because of stratification, this phosphorus does not mix with epilimnion water until turnover, when phosphorus levels in the epilimnion can increase (Voss et al. 1992). This can lead to fall algal blooms, which occurred in late fall and early winter in Rinehart Lake during 1998.

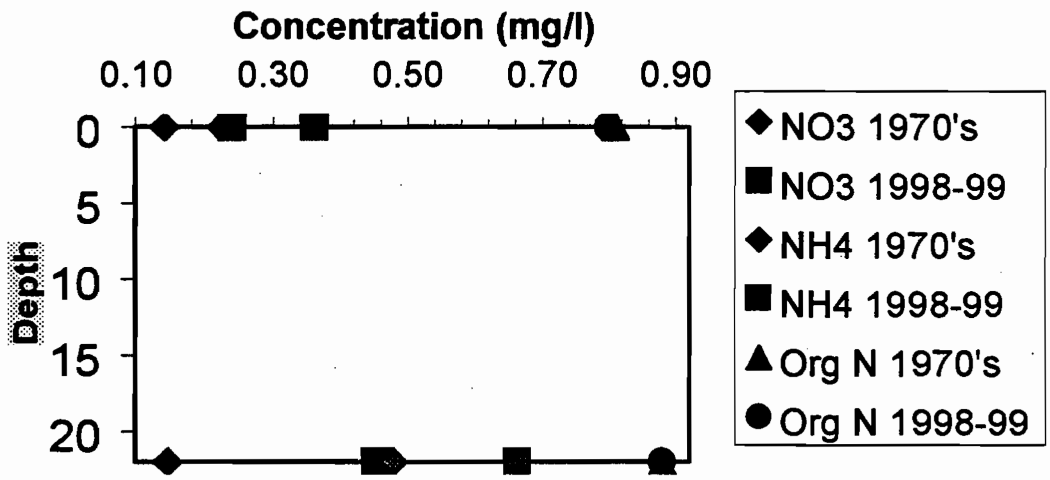
Total P was compared to chlorophyll-a concentrations from all sample years (Figure 5b). Because Total P, Secchi depth, and chlorophyll-a are often related, an increase in both Total P and chlorophyll-a should result in a direct linear relationship. Likewise, an increase in Total P should lead to a decrease in Secchi depth (Figure 5c). These relationships were not clearly revealed by the data. A lack of relationships between Total P, Secchi depth, and chlorophyll-a could be due to the fact that a lag time often exists between phosphorus release and algal growth (Shaw, 99). Sampling only once a month would not account for this lag time. Also, wind induced sediment turbidity could affect Secchi depth rather than algal growth alone.

TOTAL N

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 N is calculated by adding total Kjeldahl nitrogen (TKN) to nitrate + nitrite nitrogen (NO_3+NO_2-N). TKN includes both ammonium (NH_4^+) and organic N. 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 N, and organic N back to the inorganic forms through the nitrogen cycle (Shaw et al. 1996).

Total N trends between 1972-81 and 1998-99 were opposite those of Total P. The mean epilimnion concentration from 1972-81 was 1.12 mg/l with a standard deviation of 0.34 mg/l. The 1998-99 mean was 1.40 mg/l with a standard deviation of 0.32 mg/l. The hypolimnion mean for 1972-81 was 1.48 mg/l with a standard deviation of 0.89 mg/l. The 1998-99 mean was 1.86 mg/l with a standard deviation of 0.90 mg/l. Even though the concentrations from 1998-99 are higher than 1972-81, the 1998-99 concentrations show more fluctuation, and in August are well below the 1972-81 values. Figure 6b displays NO_3+NO_2-N, NH_4^+, and organic N average concentrations from both 1972-1981 and 1998-99. Figure 6b shows how inorganic N (NO_3+NO_2-N and NH_4^+) concentrations have increased since the 1970s while organic N concentrations have remained relatively constant. This suggests that there was excess inorganic N available in the water column in

Figure 6b. Graph comparing 1970s and 1998-99 inorganic N (NO_3+NO_2-N & NH_4) and organic N concentrations from top and bottom water in Rinehart Lake, Portage Co., WI.



1998-99 that wasn't being incorporated into algal biomass most likely because phosphorus is the limiting nutrient affecting algal growth in Rinehart Lake (*see Total N:Total P Ratio sec.*). It is possible that macrophytes may be using this excess inorganic N, but we have no data to support this. Possible sources for the excess inorganic N in 1998-99 include NO_3+NO_2-N in groundwater from farm runoff, release of nitrogen from lake sediments, septic system runoff, and runoff from lawn fertilizers. Wetzel (1972) also notes that organic and inorganic N levels usually occur at high levels and accumulate in the basins of hard-water marl lakes which have high inflow of groundwater that is often higher in nitrate than runoff or rainfall.

TOTAL N:TOTAL P RATIO

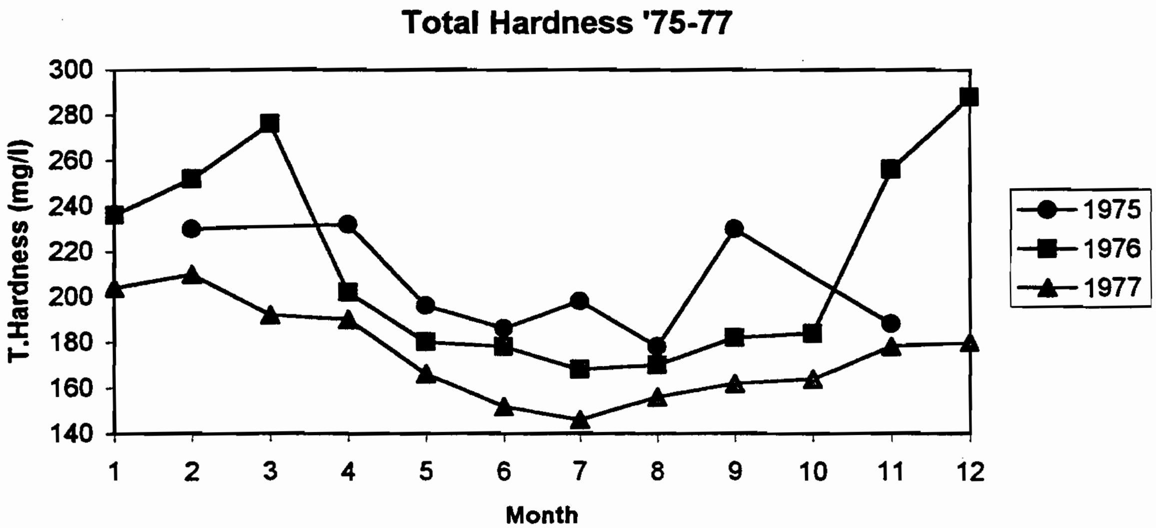
When the Total N : Total P ratio is greater than 15:1, plant growth is generally limited to the amount of available phosphorus (Carlson, 1980). The average summer (May-September) TN:TP ratio from 1972-81 was 127:1, and the 1998-99 average was 130:1. These data clearly show that phosphorus is the limiting nutrient in Rinehart Lake. This is to be expected because coprecipitation of phosphorus with carbonate precipitation removes much of the available phosphorus.

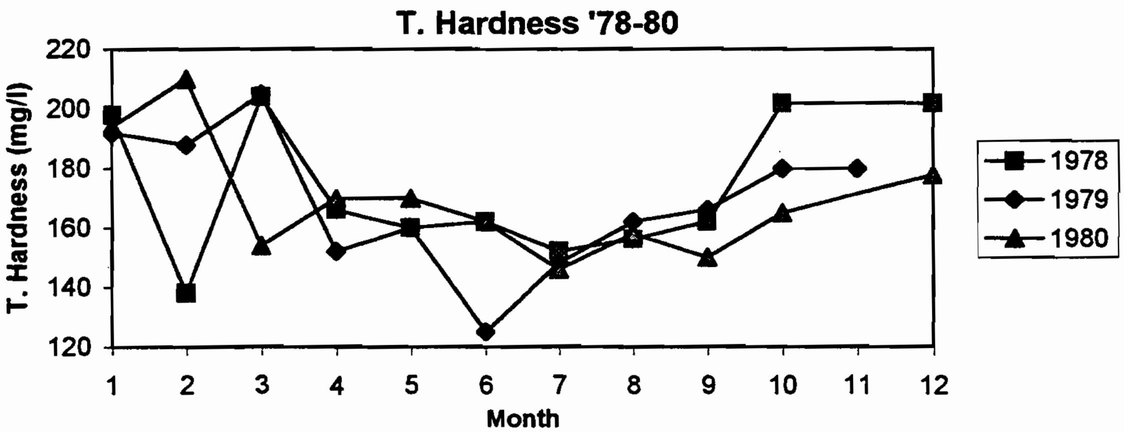
ALKALINITY, TOTAL HARDNESS, CALCIUM HARDNESS, pH, & CONDUCTIVITY

Rinehart Lake is a high alkalinity lake and thus has very hard water due primarily to dolomite-rich ($CaMgCO_3$) glacial till that exists along groundwater flowpaths into the lake. Calcium and magnesium ions become dissolved in the groundwater and enter the lake via groundwater inflow. Some of the ions recombine to form marl precipitates. The lake is well buffered, and with an epilimnion pH ranging from 8.0 to 8.85, bicarbonate is the dominant ion in the carbonate equilibrium (Wetzel, 1972). A summer decline in alkalinity, total hardness, and calcium hardness, as well as an increase in pH was observed during both periods of study. The summer (May-September) mean total hardness was 173 mg/l, alkalinity was 174 mg/l, calcium hardness was 88 mg/l, and mean pH was 8.56 during 1998. The remainder of the study year (October-April) had a mean total hardness of 198 mg/l, alkalinity of 191 mg/l, calcium hardness of 120 mg/l, and a mean pH of 8.31. The seasonal variation also occurred during the 1972-81 study years where the average summer total hardness was 181 mg/l, alkalinity was 157 mg/l, calcium hardness was 88 mg/l, and mean pH was 8.56. The remainder of the year averaged a total hardness of 199 mg/l, alkalinity of 181 mg/l, calcium hardness of 112 mg/l, and a pH of 8.10. Figures 7a, b, & c display data showing the seasonal cycle in each of these chemistries.

The seasonal decline in alkalinity, total hardness, and calcium hardness can be attributed both to a summer decrease in calcium carbonate solubility and CO_2 loss due to higher water temperatures and phytoplankton and macrophyte production causing an increase in pH. These factors all lead to an increase in precipitation of calcium carbonate as marl. McConnaughey et al. (1994) showed summer reduction in alkalinity and calcium inventories by 15% and 25%, respectively, due to plant calcification. Otsuki and Wetzel (1972) demonstrated that significant carbonate precipitation occurs above pH 9. While the overall pH of Rinehart Lake water was never at 9, it has been shown (Gessner 1939; Hutchinson 1957) that the pH of microenvironments around algal cells and macrophyte surfaces is raised well above 9. This relationship can help explain the reduction in calcium ions (seen as a reduction in total hardness) which precipitate out of

Figure 7a. Graphs of 1975-80 and 1998-99 total hardness values (epilimnion) plotted by month; Rinehart Lake, Portage Co., WI.





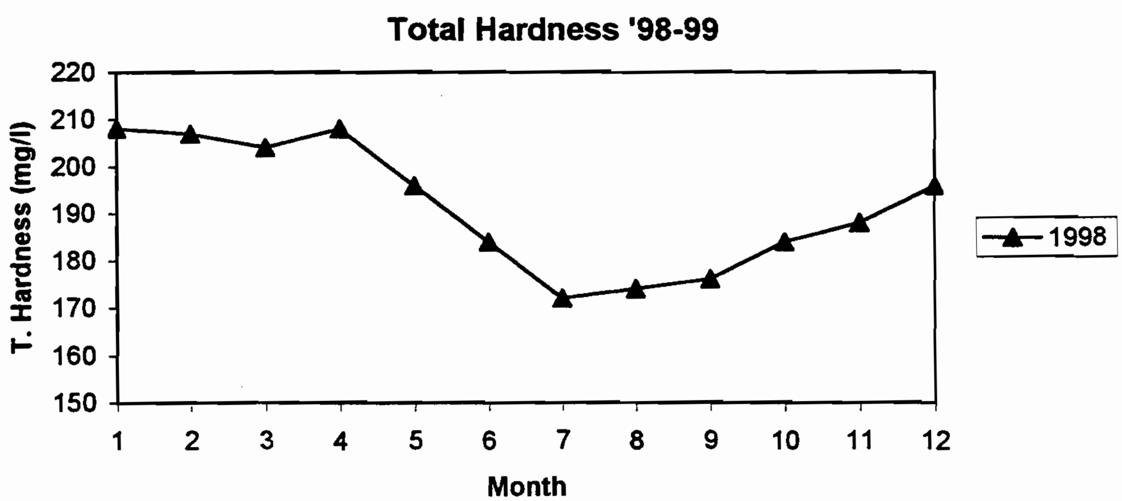
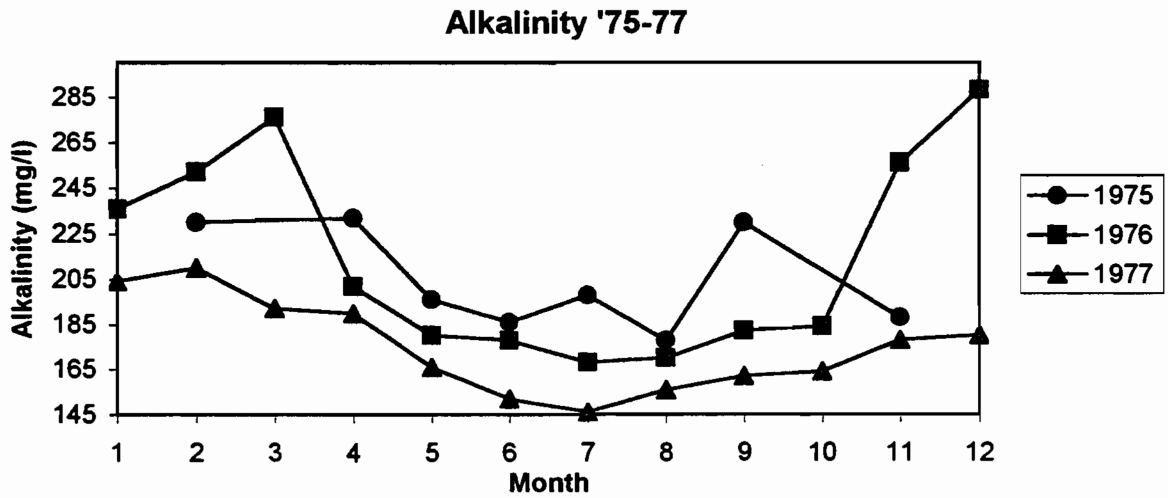
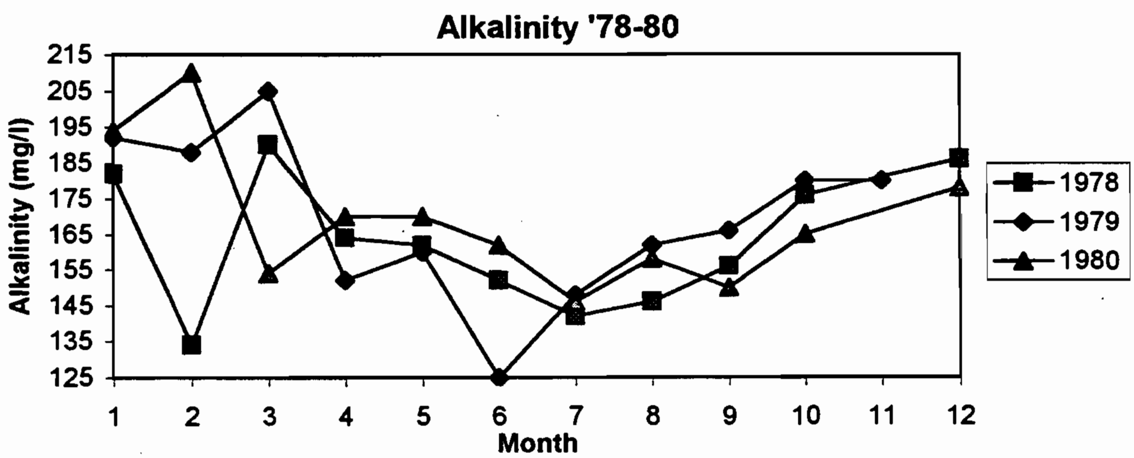


Figure 7b. Graphs depicting 1975-80 and 1998-99 alkalinity values (epilimnion) plotted by month; Rinehart Lake, Portage Co., WI.





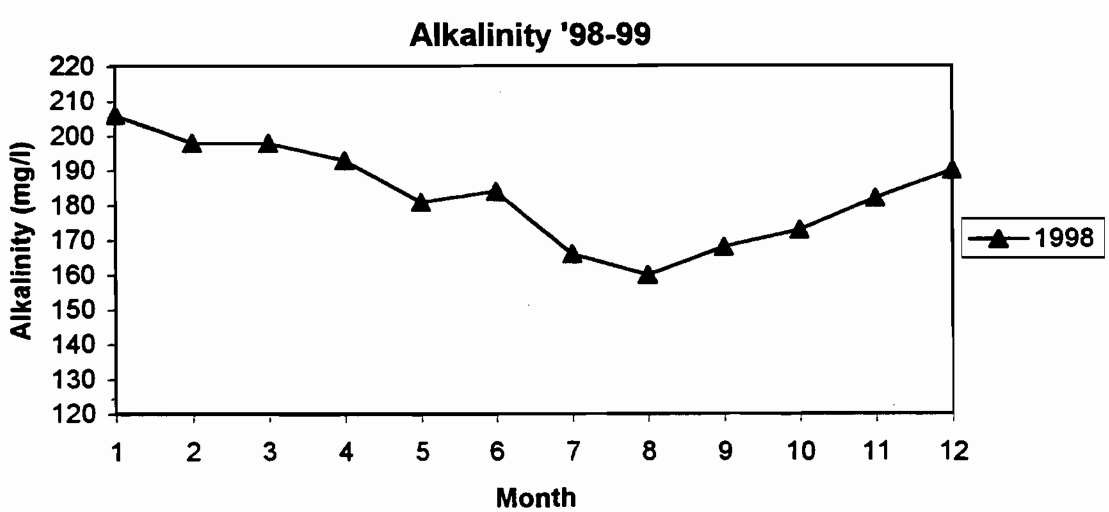
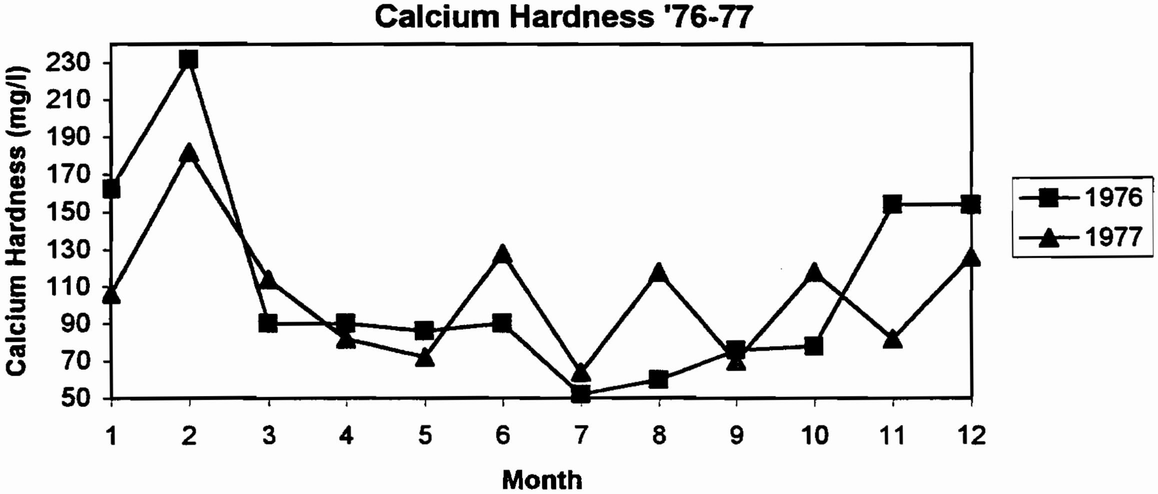
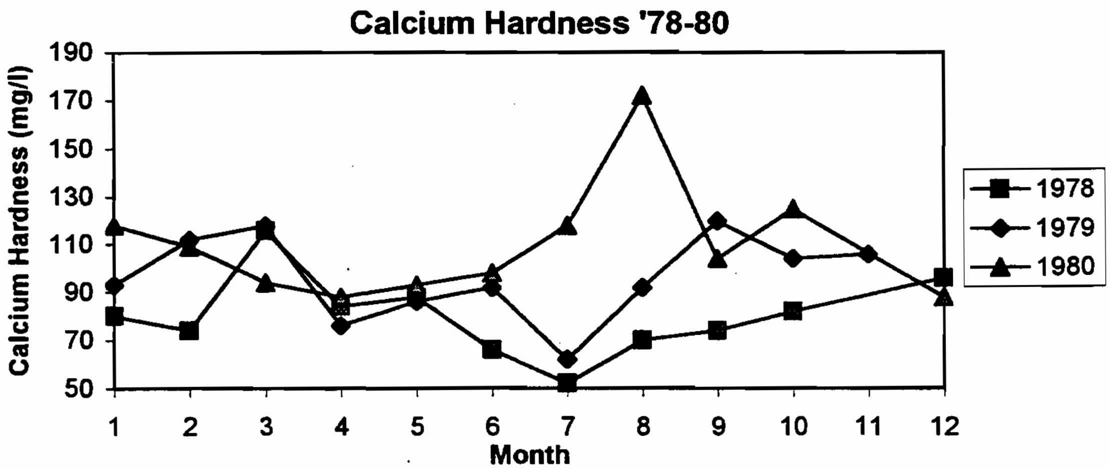
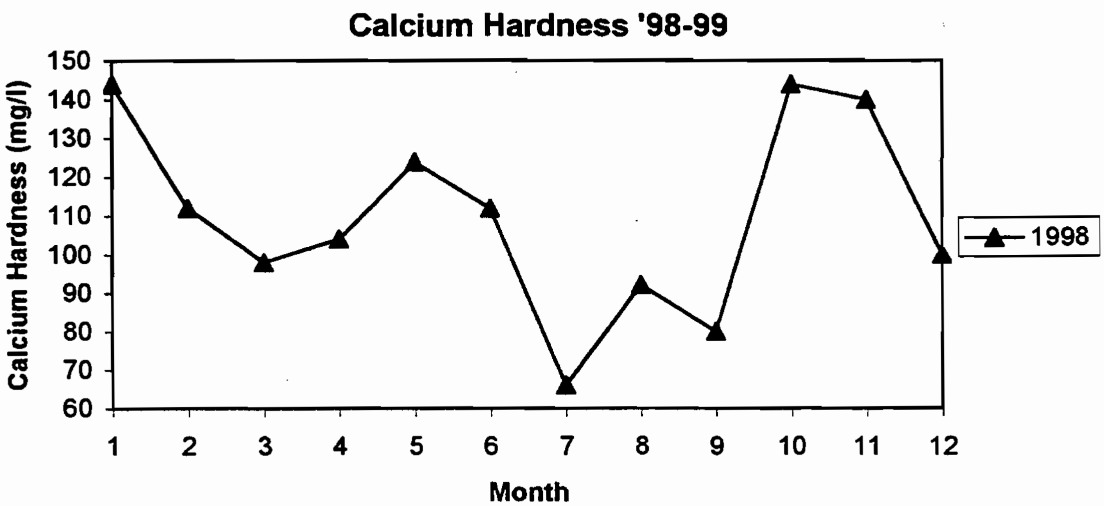


Figure 7c. Graphs of 1975-80 and 1998-99 calcium hardness values (epilimnion) plotted by month; Rinehart Lake, Portage Co., WI.







solution as marl, coupled with a raise in pH during the summer months where production is at its peak.

WINTER MID-LAKE WATER QUALITY

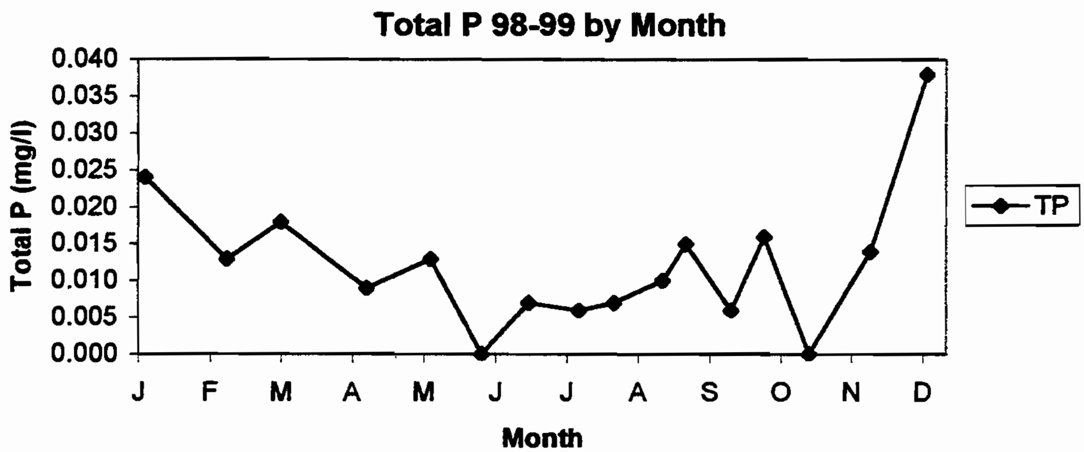
Mid-lake concentrations of Total P, Total N, and chlorophyll-a all showed an increase during the winter of 1998-99 (Figure 8). This increase is most likely a result of continued mixing and sediment release of phosphorus and nitrogen into late fall and early winter as a result of extended ice-free conditions in 1998. During winter, colder water temperatures and the presence of ice will prevent the loss of CO_2 to the atmosphere as new groundwater enters the lake. This will result in increased total hardness values and marl staying in solution. Without as much marl formation, more phosphorus will also be available in solution for use by algae. An increase in ammonium can occur because nitrifying bacteria can't function as well in cold water, even if there is oxygen present (Shaw, 99). Thus there is less conversion of ammonium to nitrate and therefore more ammonium present in the water column during the winter.

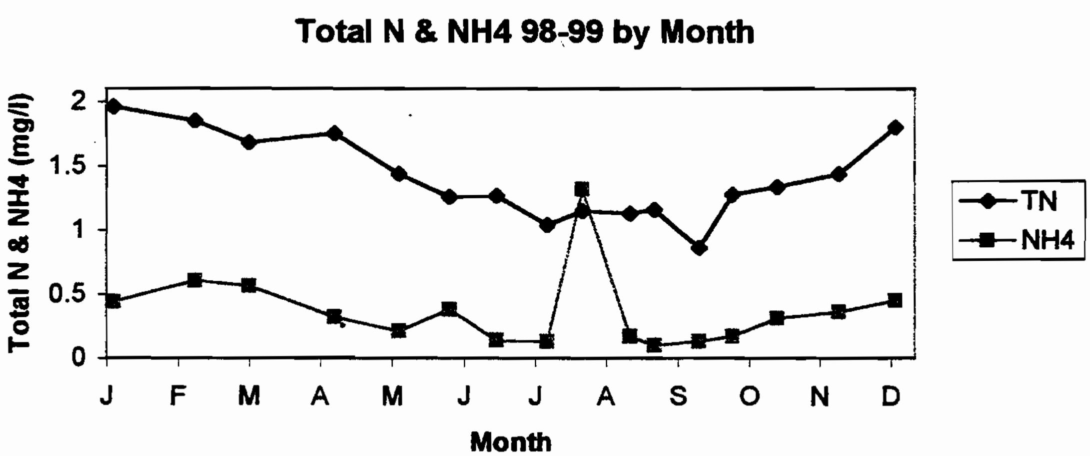
The February 1999 data showed a dramatic improvement in water quality data, even though there was no snowpack present to inhibit light penetration. It is possible the February sample was collected after many of the algae had died off as part of their cycle. March data returned to higher nutrient content and decreased Secchi depth. The trend of higher Total P in winter did not show up in the 1976-80 data (Figure 9a), but there was a slight increase in winter Total N and ammonium that occurred most noticeably in 1978, 79,& 80 (Figure 9b). This could again be due to nitrifying bacteria not being able to function in cold water temperatures and nitrogen being slowly released from the lake sediment and decaying algae.

TROPHIC STATUS INDEX

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. Because of Rinehart Lake's unique hard water (marl) characteristics, it becomes difficult to compare it to

Figure 8. Graphs depicting 1998-99 seasonal change in Total P, Total N, and chlorophyll-a in Rinehart Lake, Portage Co., WI. Months are labeled as one letter with the winter months on the far right and left of each graph.





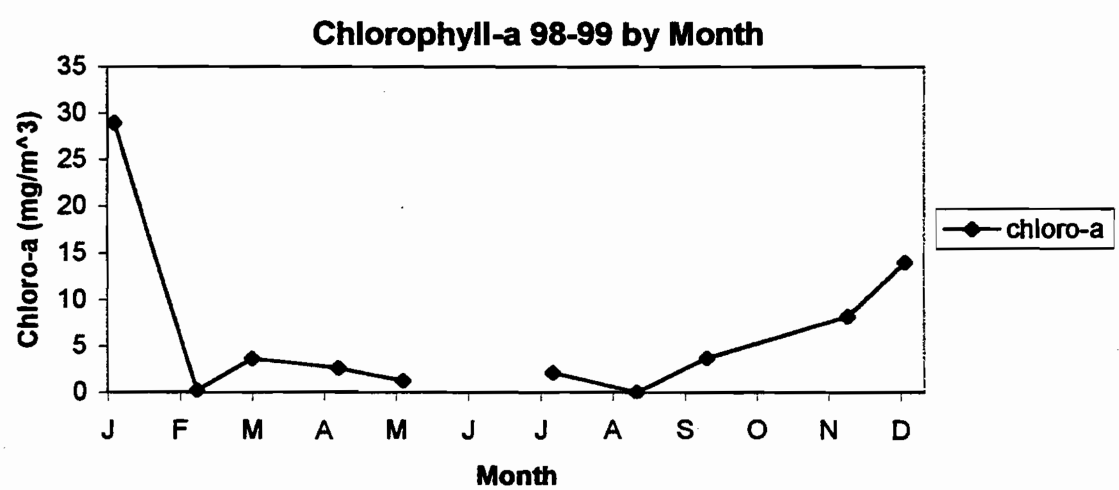
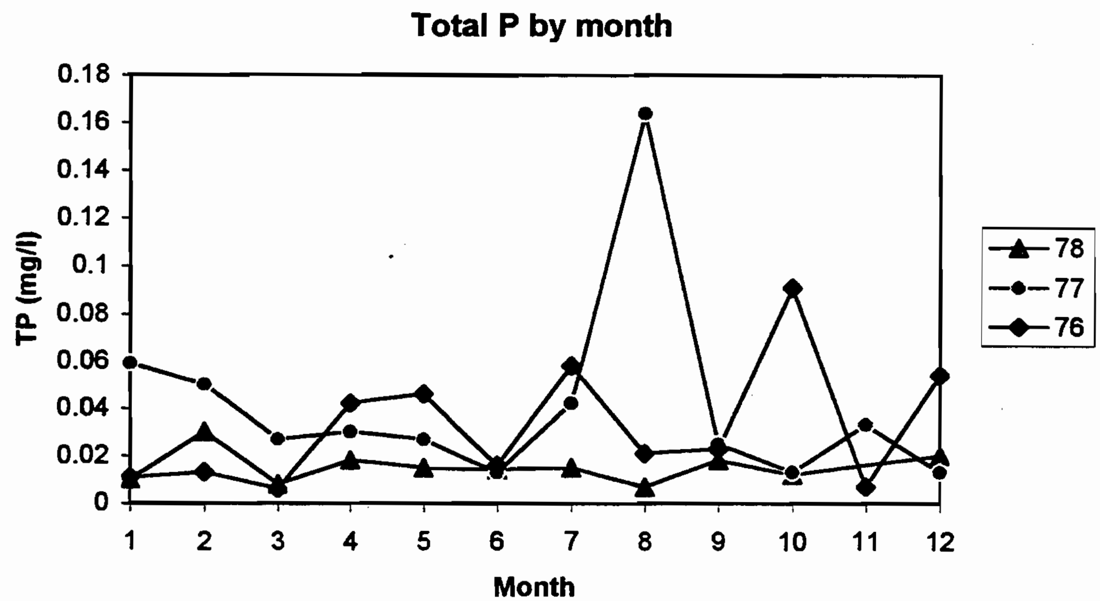


Figure 9a. Graphs of 1976-1980 Total P concentrations by month; Rinehart Lake; Portage Co., WI.



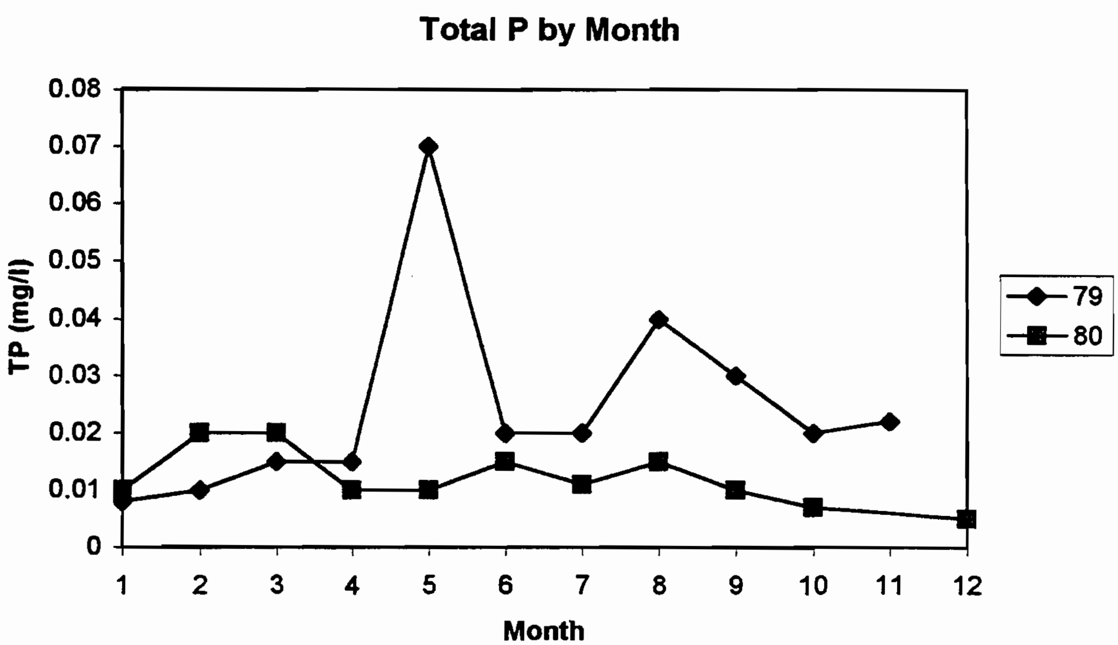
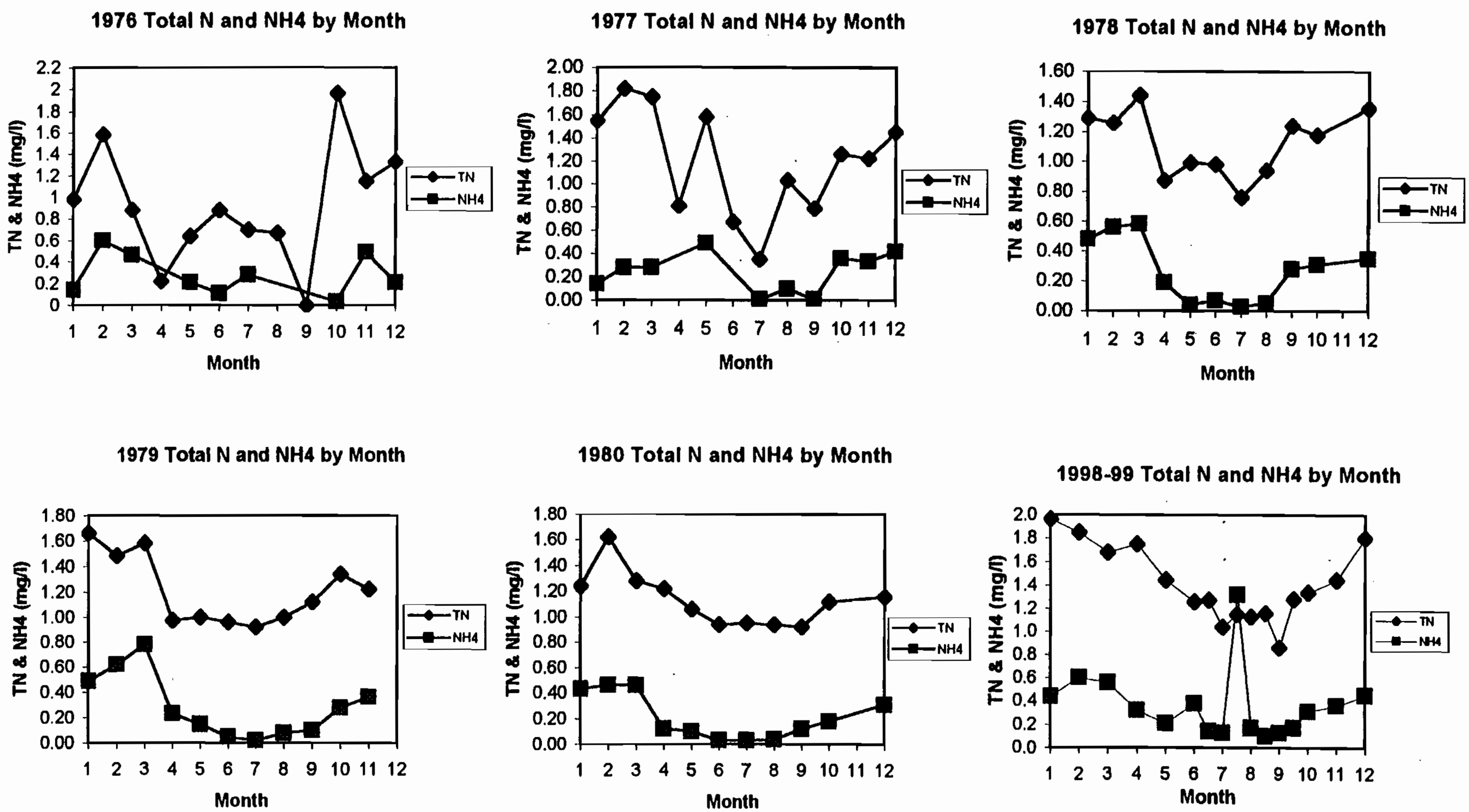


Figure 9b. Graphs of 1976-80 & 1998 Total N and ammonium (NH4) concentrations by month; Rinehart Lake, Portage Co, WI.



other lakes. The comparison is more valuable when looking at past data and how the Rinehart Lake indices have changed over time.

Common measures of trophic status include Secchi depth (water clarity), Total P concentration and chlorophyll-a concentration (measure of algae). These measures were chosen for Rinehart Lake. Although many factors influence the relationships between these measures, the major assumptions that bring the Trophic State Indices together are that the amount of chlorophyll-a present is primarily related to the phosphorus concentration, and water clarity is primarily dependent on the chlorophyll-a concentration (Lillie, 1983). The equations for the Trophic State Indices chosen for Rinehart Lake were taken from Voss et al. (1992), which are based on those of Martin (1983), and Carlson (1977). The calculations from 1998 were based on 2 sampling periods during each month of the summer, while the 1975-80 calculations were based on only one sampling period per month. There was not sufficient data from 1972-74 to use for the trophic status calculations. The equations used were:

$$TSI(P) = 10[6-(\ln(40.5/P)/\ln 2],$$

where P is the epilimnion summer (June-August) mean Total P concentration in ug/l.

$$TSI(CHL) = 10[6-(1.83-0.521 \ln(CHL)/\ln 2)],$$

where CHL is the epilimnion summer mean chlorophyll-a concentration in ug/l.

$$TSI(SD) = 10[6-\ln(SD)/\ln 2)],$$

where SD is the summer mean Secchi depth in meters.

In general, the lower the TSI equivalent value, the better the water quality. Table 4 presents all of the Rinehart Lake TSI data. The 1998 summer mean TSI (P) equivalent value was 37.5 with a standard deviation of 5.3, the mean TSI (CHL) equivalent value was 48.4 with a standard deviation of 2.5, and the mean TSI (SD) equivalent value was 36.5 with a standard deviation of 2.3. The mean TSI (P) and TSI (SD) equivalent values for 1998 were lower than the mean TSI (P) and TSI (SD) equivalent values for any summer between 1975 and 1980. The mean TSI (CHL) equivalent values for 1975 and 1979 were lower than the mean TSI (CHL) equivalent value for 1998, but the 1976 and 1977 TSI (CHL) equivalent values were higher than 1998. There are several months of chlorophyll-a data missing from the years 1975-80 as well as June 3 and 23, 1998. Therefore, the TSI (CHL) mean equivalent values from all years with missing data may not be entirely indicative of conditions in the lake during those time periods. When compared to average TSI equivalent values for all data from 1975-80, all three values for the summer of 1998 are lower (Table 4).

Table 4. Summer TP, Chloro-a, & Secchi data with TSI calculations.

	TP (ug/l)	Chloro-a (ug/l)	Secchi (m)	TSI (P)	TSI (CLR-A)	TSI (Secchi)
06/24/1975	26	0.16	2.6	53.6	27.7	46.4
07/21/1975	52		3.5	63.6		41.8
08/18/1975	53	1.23	4	63.9	43.3	40.0
avg.75	**44**	**0.70**	**3.4**	**61.1**	**38.9**	**42.5**
06/14/1976	16	5.66	2.5	46.6	55.0	46.8
07/12/1976	58	2.55		65.9	48.9	
08/10/1976	21		3.5	50.5		41.9
avg.76	**32**	**4.11**	**3.0**	**56.5**	**52.5**	**44.2**
06/20/1977	13	2.94	4.7	43.6	50.0	37.7
07/18/1977	42	3.39	3.8	60.5	51.0	40.7
08/17/1977	164	3.90	3	80.9	52.1	44.2
avg.77	**73**	**3.41**	**3.8**	**68.5**	**51.1**	**40.6**
06/20/1978	14		4.5	44.7		38.3
07/17/1978	15		3.7	45.7		41.1
08/15/1978	7		3.3	34.7		42.8
avg.78	**12**		**3.8**	**42.5**		**40.6**
06/25/1979	20	1.94	3.5	49.8	46.8	41.9
07/23/1979	20	2.58	1.8	49.8	49.0	51.5
08/20/1979	40		3.3	59.8		42.8
avg.79	**27**	**2.26**	**2.9**	**54.0**	**47.9**	**44.8**
06/09/1980	15	2.26	3.3	45.7	48.0	42.8
07/21/1980	11	1.99	3.9	41.2	47.0	40.4
08/25/1980	15	3.55	2.4	45.7	51.0	47.4
avg.'80	**14**	**2.60**	**3.2**	**44.3**	**49.0**	**43.2**
06/23/1998	7		5.7	34.7		34.9
07/14/1998	6	2.1	3.8	32.5	47.4	40.6
07/29/1998	7	3.5	5.2	34.7	51.3	36.1
08/18/1998	10	<0.1	5.2	39.8		36.1
08/28/1998	15	1.9	5.7	45.7	46.6	34.9
avg '75-80	**34**	**2.7**	**3.37**	**53.4**	**47.5**	**42.8**
avg '98	**9**	**2.5**	**5.14**	**37.5**	**48.4**	**36.5**
std. Dev '75-80				10.7	6.5	3.9
std. Dev '98				5.3	2.5	2.3

This comparison not only suggests an improvement in water quality since the late 1970s, but also the fact that both the mean TSI (P) and TSI (SD) equivalent values for 1998 are lower than any summer from 1975-80 shows that yearly fluctuations due to temperature and precipitation could not alone explain the apparent improvement in the water quality of Rinehart Lake based on the TSI values.

Although many other characteristics can define good water quality, the variables used in the TSI calculations give a good representation of what has occurred in Rinehart Lake over time.

Table 5 lists the apparent water quality index for Wisconsin lakes based on Secchi depth, Total P, and chlorophyll-a. Using this index, Rinehart Lake has good to very good apparent water quality based on its summer 1998 average TSI (P) equivalent value of 37.5 (very good), TSI (SD) equivalent value of 36.5 (very good), and TSI (CHL) equivalent value of 48.4 (good).

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 Disk Equivalent (m)	Approximate Total P Equivalent (ug/L)	Approximate TSI ** Equivalent
Excellent	<1	>6.0	<1	<34
Very Good	1-5	3.0-6.0	1-10	34-44
Good	5-10	2.0-3.0	10-30	44-50
Fair	10-15	1.5-2.0	30-50	50-54
Poor	15-30	1.0-1.5	50-150	54-60
Very Poor	>30	<1.0	>150	>60

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

SEEPAGE METERS

Seepage meters were installed in areas of groundwater inflow pre-determined by the use of mini-piezometers (Figure 10). The meters at sites 7 and 8 yielded no water, which gives further evidence to the idea that the marl bottom may have sealed part of the western shore of the lake from significant groundwater inflow. The greatest inflow of seepage water occurred at site 5 (11.5 cm/day), which corresponded with the site of the greatest hydraulic conductivity measured with the mini-piezometers. The mean inflow for the remaining sites was 0.064 cm/day with a standard deviation of 0.075. The nitrate concentration at site 5 was 23.7 mg/l (Figure 11a). The mini-piezometer nitrate

Figure 10. Map showing sample sites for interstitial water, sediment, aquatic plant, seepage meter, and mid-lake chemistry from Rinehart Lake, Portage Co., WI.

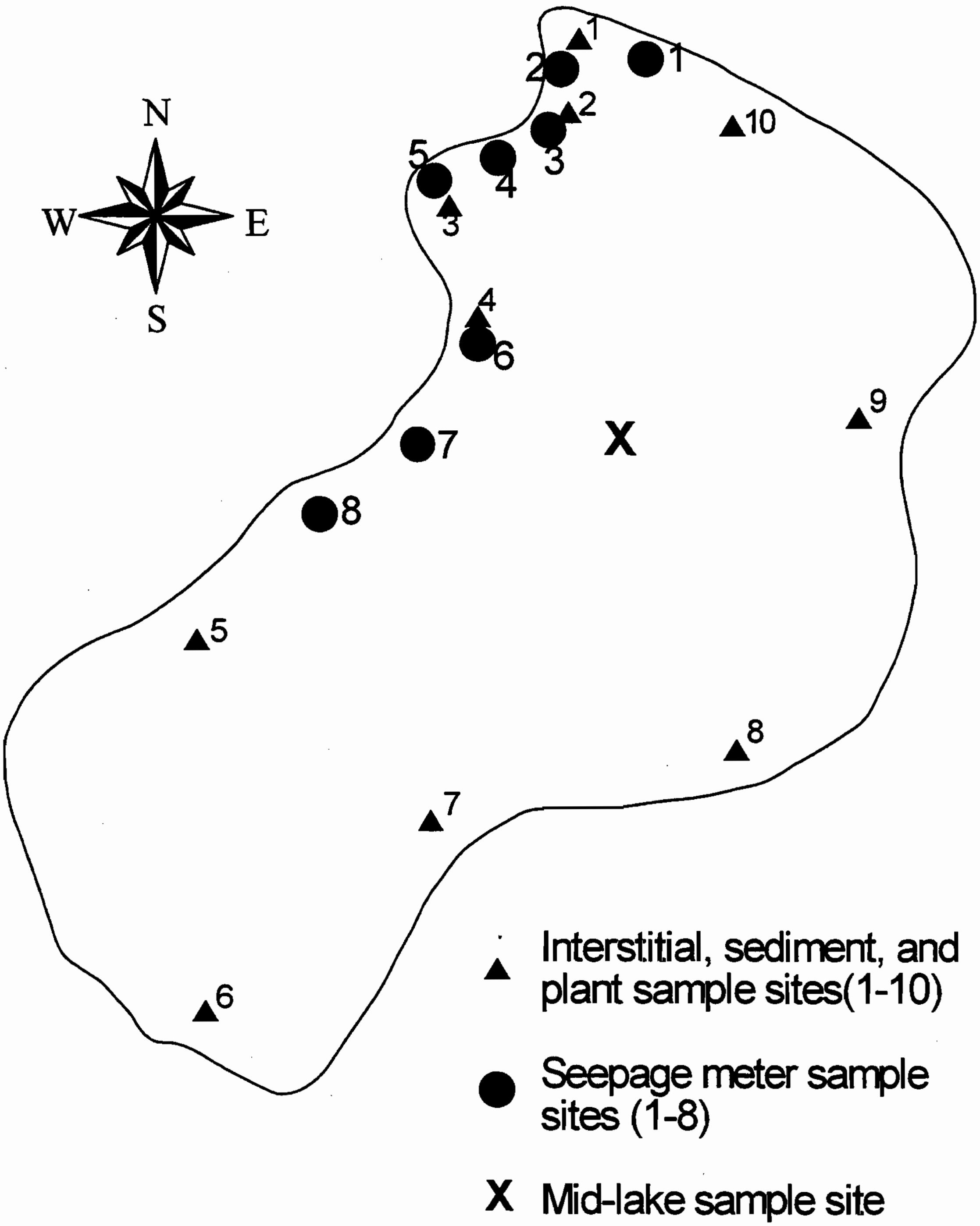
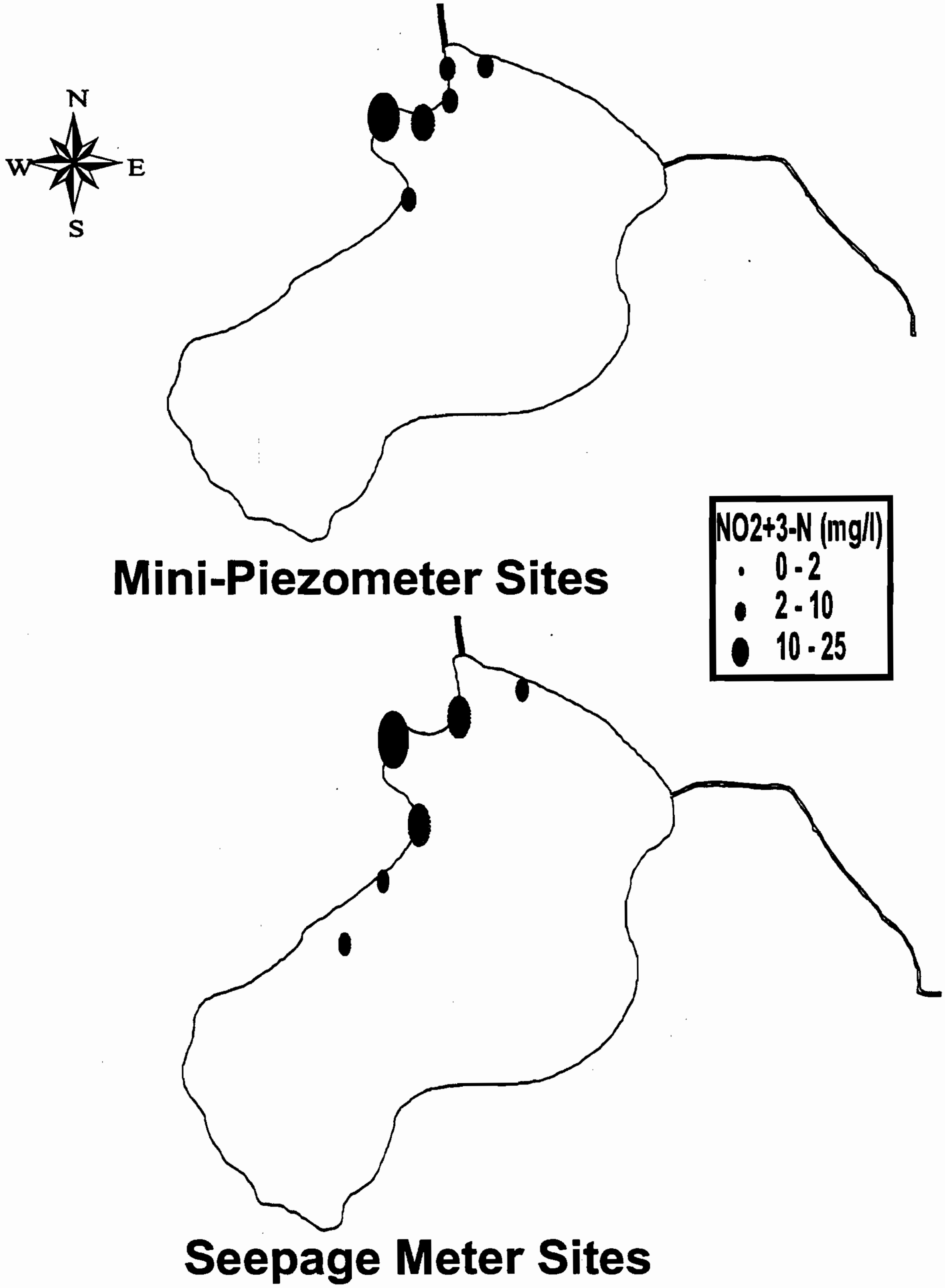


Figure 11a. Maps showingnitrate concentrations in seepage meters and mini-piezometers from Rinehart Lake, Portage Co., WI.



concentration at this site was 13.9 mg/l, and a private well about 200 ft. up-gradient from the site had a nitrate concentration of 15.3 mg/l. These data suggest the possibility of agricultural fertilizer or animal waste within the groundwater watershed of the lake impacting water quality at this point. Other data that suggests agricultural impacts at this site comes from a triazine scan that was performed on seepage water from site 5. Triazines are a family of pesticides, which include atrazine, commonly used on field corn, and simazine, used on tree plantations (Draak, 98). A triazine concentration of 1.05 ug/l was found at site 5. The WI DNR drinking water standard for triazines is set at 3.0 ug/l. While the concentration at site 5 was not above this standard, it was relatively high and suggests groundwater entering the lake at this point, and perhaps other points that were

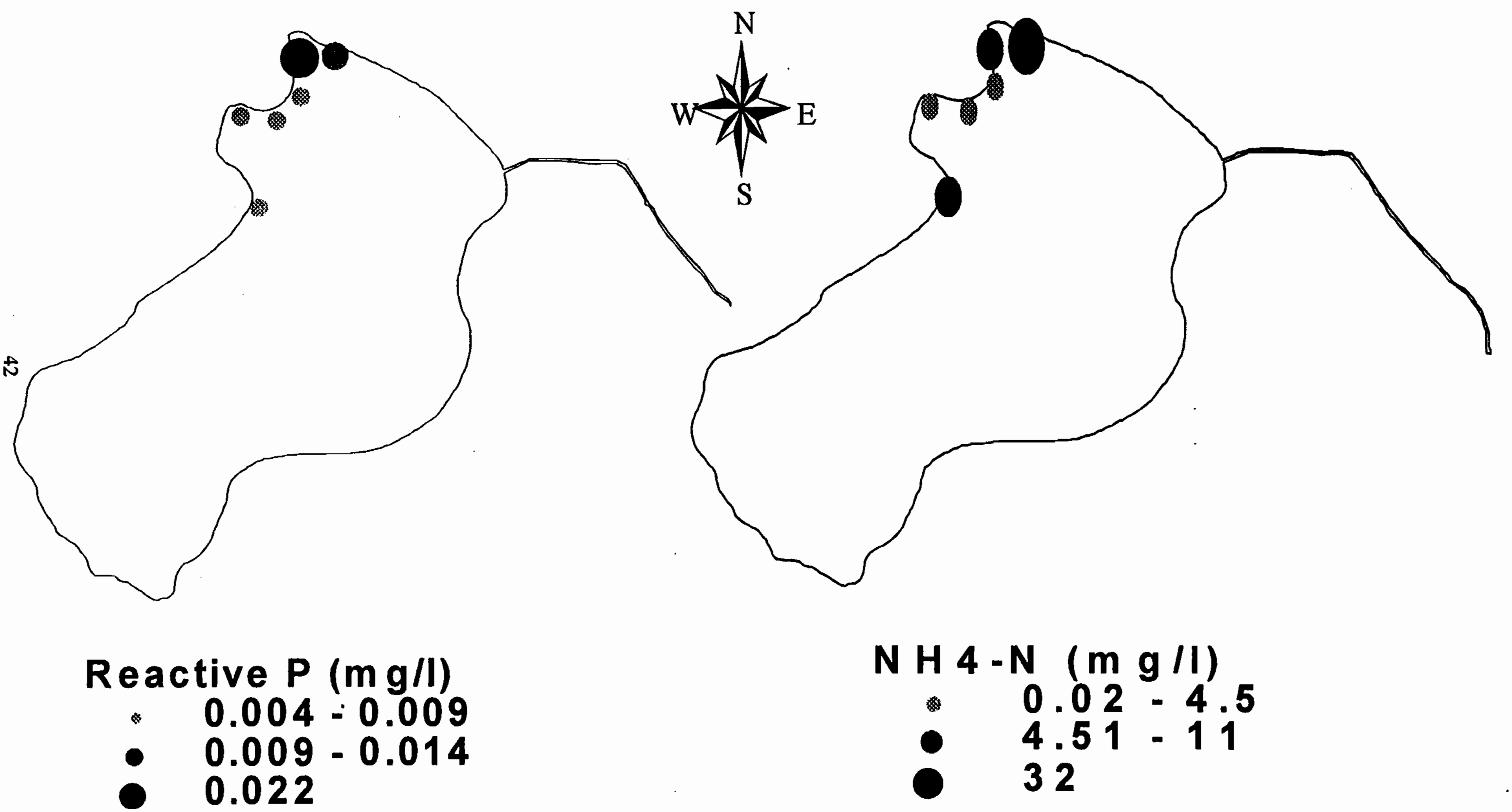
not sampled, are being impacted by agricultural practices. Further investigation would have to be done to determine if the triazines entering the lake are in high enough concentration to affect the health of the lake ecosystem.

Sites 1 and 2 were high in both ammonium and phosphorus (Figure 11b), suggesting anaerobic conditions. Both of these sites were located near the outflow of the intermittent ditch. The ditch drains a small riparian wetland. Outflows from the ditch tend to be high in organic carbon and phosphorus. This leads to a high organic matter content and anaerobic conditions that allow for the release of ammonium and phosphorus into the seepage water. Seepage meter data is displayed in Table 1D of Appendix D.

SEDIMENT, PLANT, & INTERSTITIAL WATER INTERACTIONS

It has been fairly well documented that most rooted, submersed angiosperms obtain most of their phosphorus and nitrogen from interstitial 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). Interstitial water also serves as a source for nitrogen and other essential nutrients (Wetzel, 1983). Absorption of nutrients from the water column does occur, but it is dependent on

Figure 11b. Map showing seepage meter Reactive P and ammonium concentrations in Rinehart Lake, Portage Co. WI.



the concentration of the nutrient in the water. The sediment, however, often provides an anaerobic, reducing environment that leads to the availability for plant uptake of such nutrients as phosphorus, ammonium, iron, and manganese in the interstitial water. These elements are less soluble in aerobic sediments or in aerobic lake water.

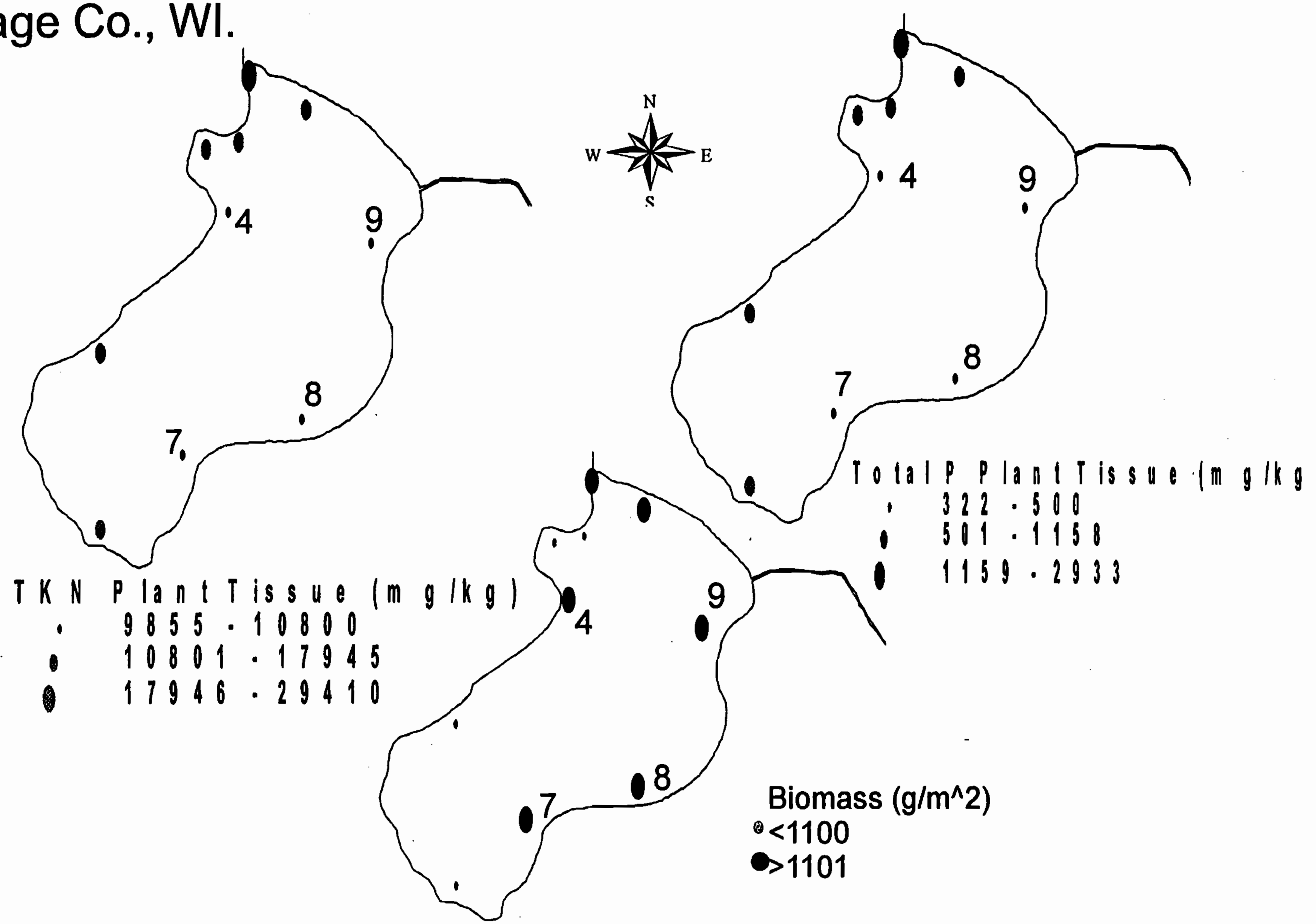
An attempt to draw relationships between interstitial water, plant growth, and sediments was done to show whether these data correlated to the distribution and biomass of aquatic plants. Since there were only 10 sites sampled, attempts to draw significant correlations become difficult due to different physical, chemical, and human impacts at each site. Therefore, each site or group of sites with similar characteristics will be discussed separately and then whether any general assumptions about the whole lake can be made from all sites. The interstitial, plant, and sediment sites are displayed in Figure 10, and the data is displayed in Appendix E.

Site 1 was unique because it was taken in an area of high nutrient input from the intermittent inlet. Interstitial water, plants, and sediment all had much higher nutrient concentrations at this site. The relationship to note here is the luxury uptake that is evident in the plant tissue due to excess nutrient availability. The presence of *Lemna* spp. (duckweed) signified an area of high nutrient input and shaded out the growth of rooted plants typical of a nutrient rich area. Also, the dominant species at this site was coontail (*Ceratophyllum demersum*), which is a non-rooted plant that receives most of its nutrients from the water column. The relative lack of *Chara* sp. to remove phosphorus from the water column may be one reason for the growth of coontail at this site.

Site 3 was also an area of high nutrient input, but had low biomass because of human removal of many of the plants. This was significant when using biomass to draw correlations with other parameters.

The dominant plant species found at many sites was *Chara* sp. What is interesting is that the most heavily *Chara* dominated sites (4,7,8,9) had the lowest plant nutrient content, but had some of the highest biomass (Figure 12). 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.

Figure 12. Map showing biomass and Total N and Total P in plant tissue for 4 sample sites dominated by *Chara* sp. in Rinehart Lake, Portage Co., WI.

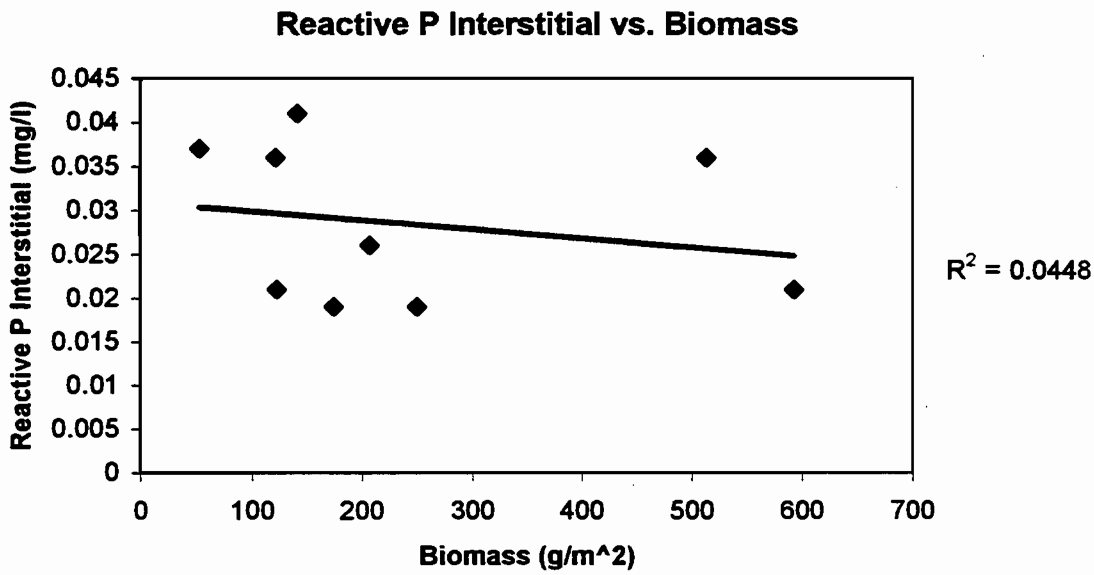


However, *Chara* does have rhizoidal structures, which have been shown to absorb phosphorus equally as well as the foliage (Littlefield and Forsberg, 1965). This differs from most rooted macrophytes, which use the roots as the primary source of nutrient absorption (Denny, 1972). *Chara* predominantly 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 both in marl encrusted on the plant tissue and in the plant tissue itself. 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 Rinehart Lake. The combination of high *Chara* biomass and the marl forming system certainly are controlling factors on the growth of other aquatic plants in Rinehart Lake.

The expected relationship between interstitial water nutrients and biomass throughout the lake was not clearly shown (Figure 13). A slight positive correlation is seen when relating TKN in plant tissue and NO_3 + NH_4 in interstitial water to biomass (Figure 14). The slight positive correlation is also seen between Total P in plant tissue and Reactive P in interstitial water (Figure 14). These correlations are not enough to make a clear conclusion, but they suggest the expected relationship between interstitial water and plant growth may exist, but is being affected by more complex processes not revealed in a simple data plot.

No clear relationships were seen between sediment chemistry and plant tissue nutrients (Figure 15). Sediment extractable phosphorus data was not used because of questionable results. Total P and TKN in the plants showed a slight negative correlation with biomass (Figure 16). Possible explanations may include that plants in the more nutrient rich areas of the lake may take up luxury amounts of these nutrients, but not increase overall biomass both because nutrient levels for maximum growth have been exceeded and because of other variables such as the presence of *Chara*.

Figure 13. Interstitial water reactive phosphorus and inorganic nitrogen concentrations compared to biomass of aquatic plants in Rinehart Lake Portage Co., WI.



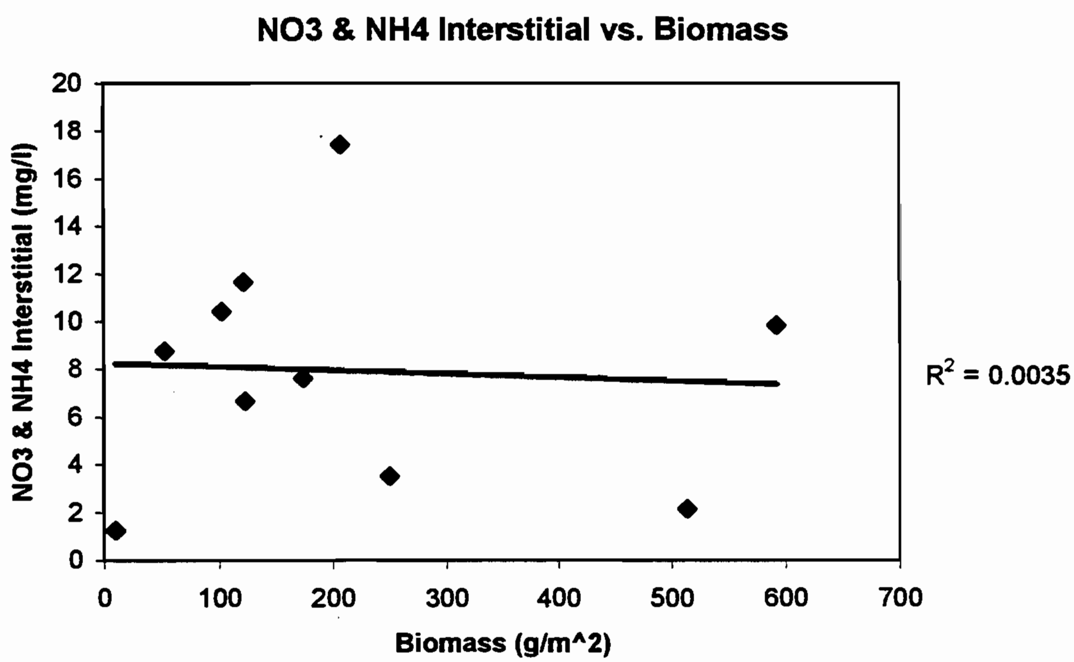
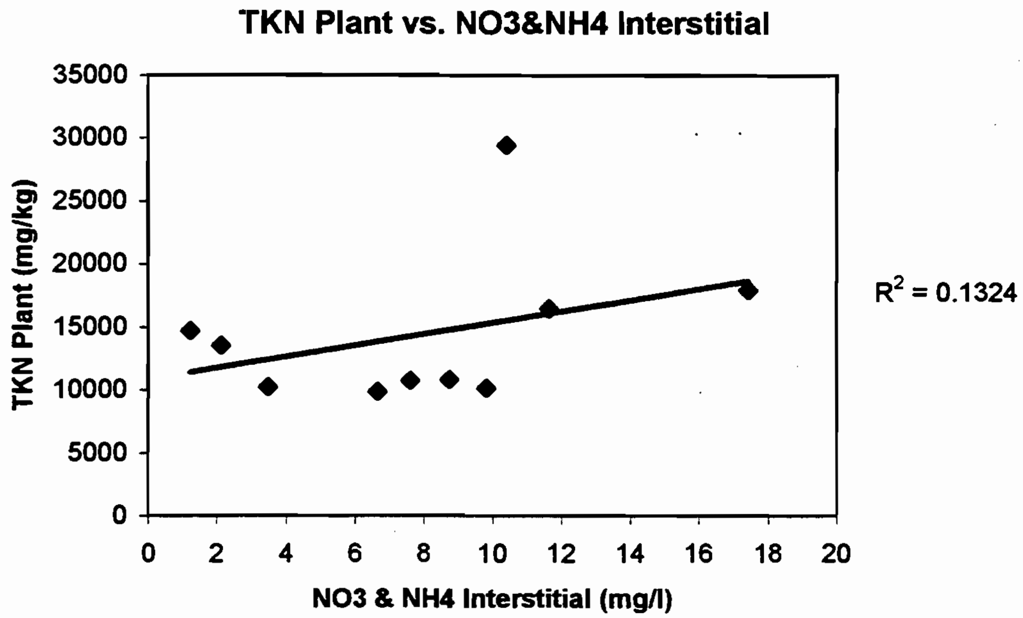


Figure 14. Graphs of TKN in plant tissue vs. inorganic nitrogen in interstitial water and total phosphorus in plant tissue vs. reactive phosphorus in interstitial water; Rinehart Lake, Portage Co., WI.



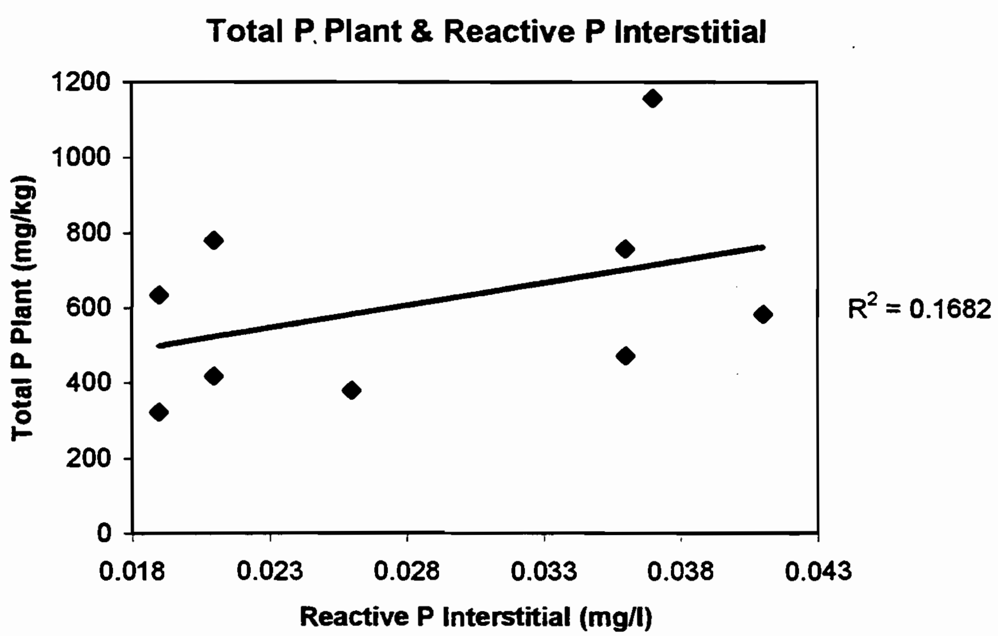
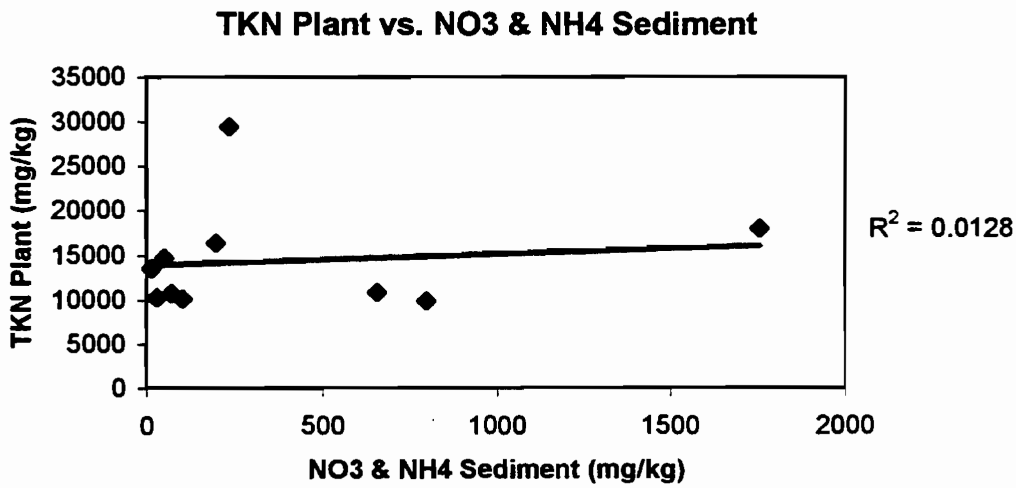
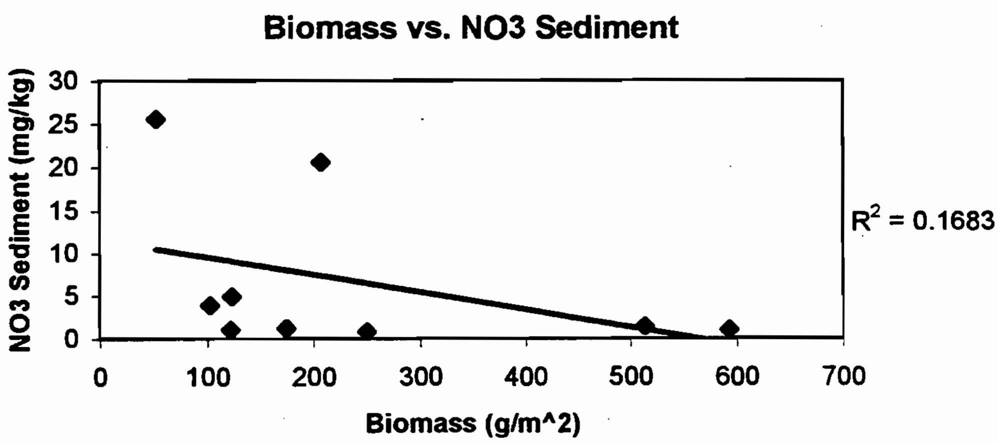


Figure 15. Graphs showing aquatic plant and sediment nutrient relationships for Rinehart Lake, Portage Co., WI.





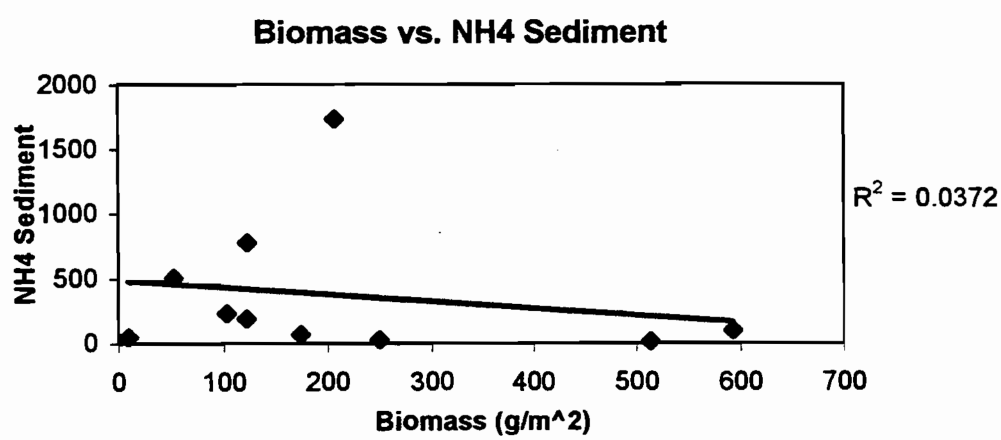
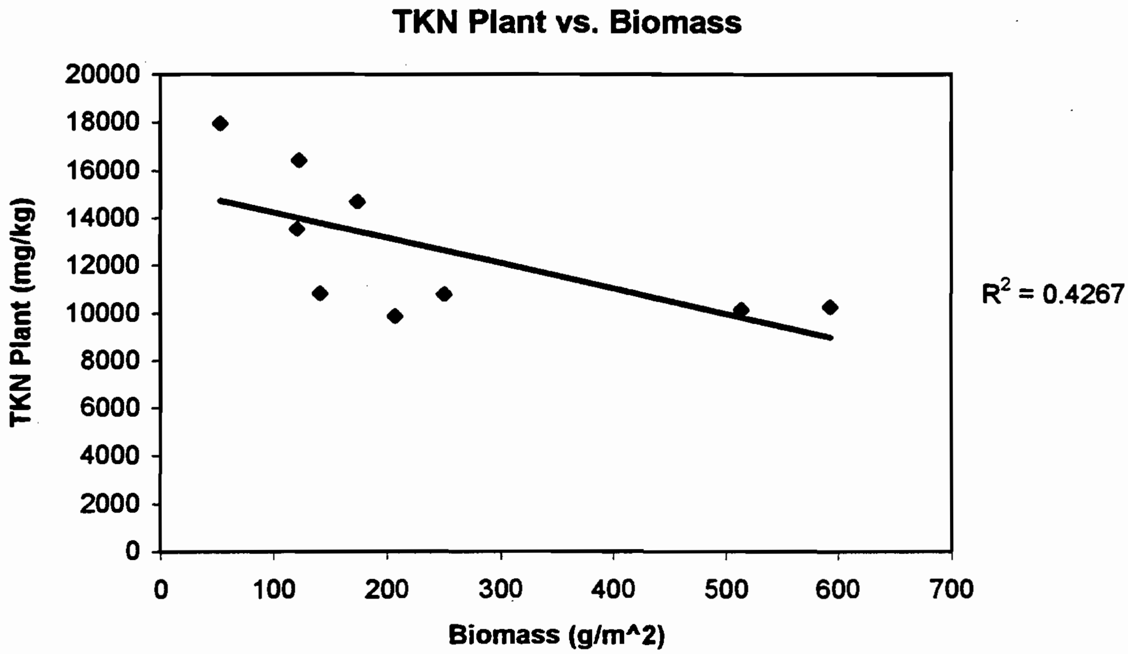
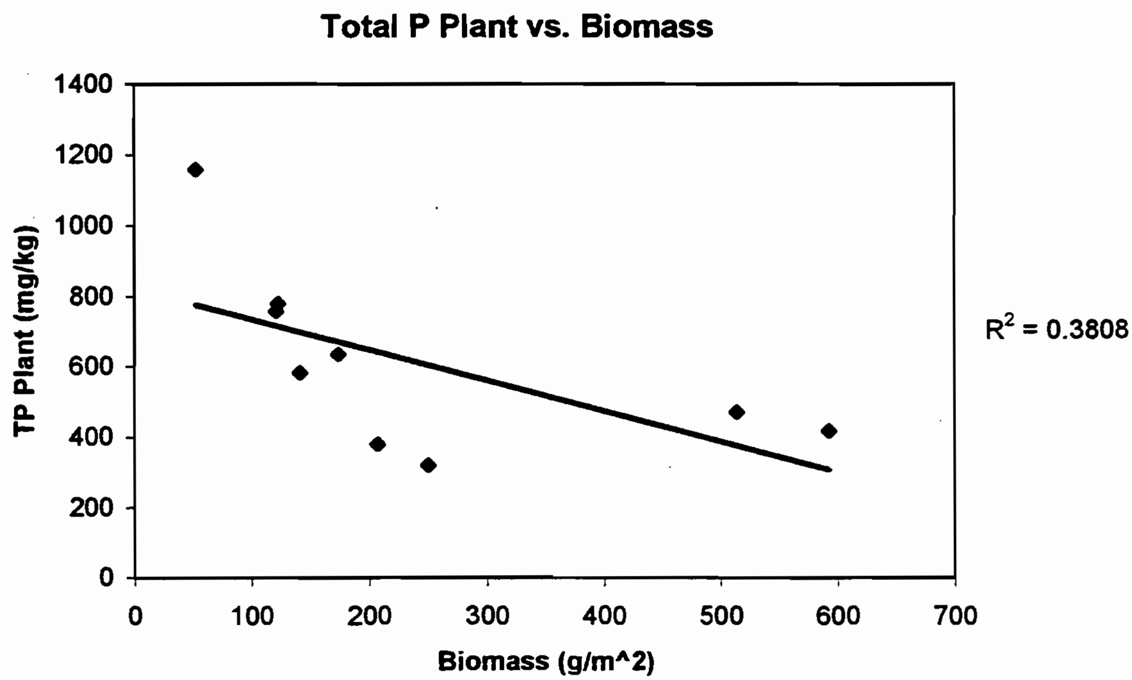


Figure 16. Graphs of TKN and total phosphorus in aquatic plants compared to biomass of aquatic plants in Rinehart Lake, Portage Co., WI.





Overall, the plant, sediment, and interstitial water data collected from this study provide little concrete data for drawing definite conclusions, which serves to show how complex and just how many variables are affecting plant growth in Rinehart Lake. However, the aquatic plant population and diversity is healthy and normal for marl lakes and helps prevent excessive growth of algae.

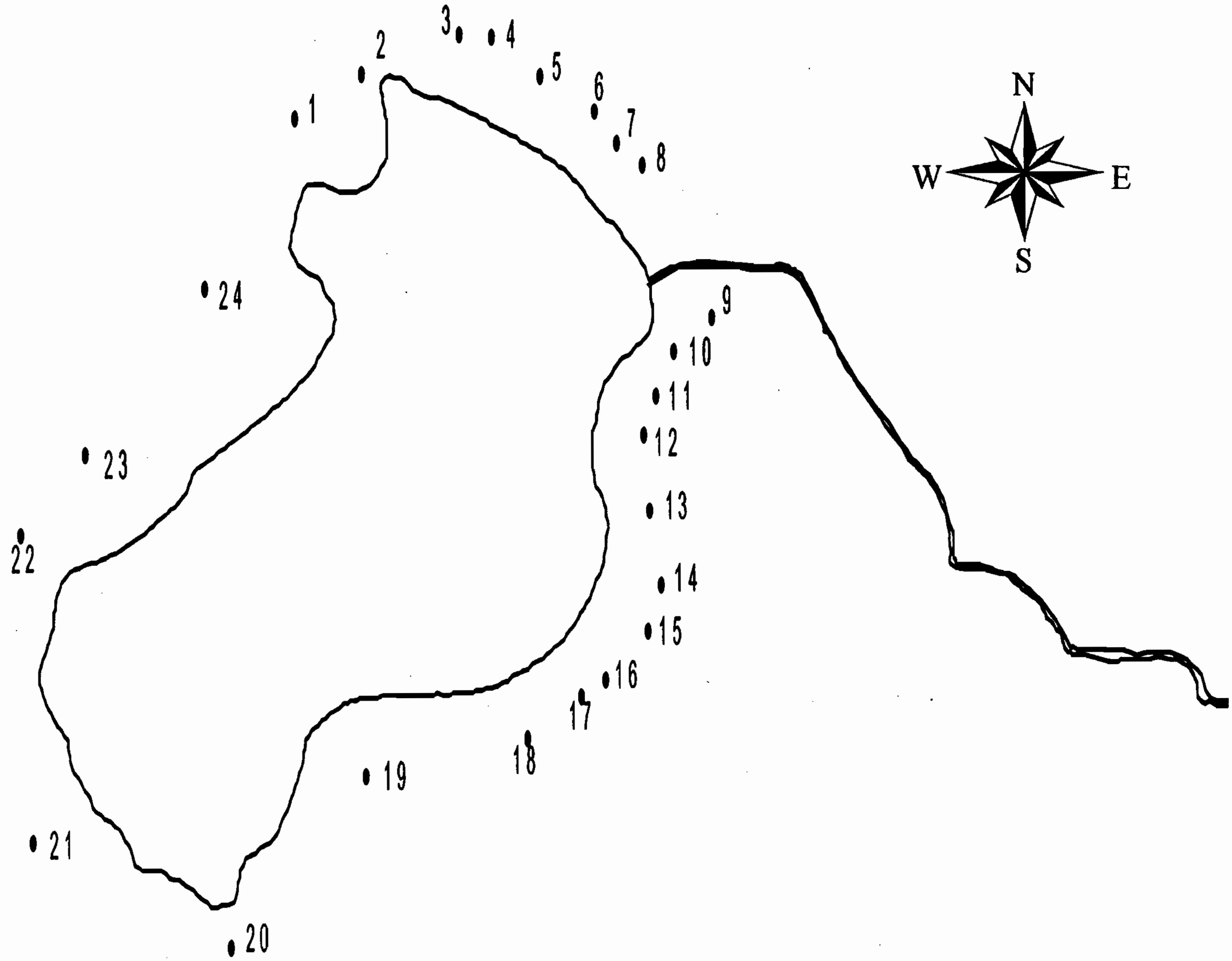
PRIVATE WELLS

Private well water was generally low in nutrients. The highest nitrate concentration was 15.3 mg/l. This well was located just up-gradient from the highest measured groundwater nitrate levels entering the lake. The nutrient-rich groundwater in this flowpath is likely the result of agriculture within the groundwater watershed. Other wells located in the northwest corner of the lake showed slightly elevated nitrate concentrations relative to the majority of the other wells. One well in the south end of the lake had a nitrate concentration of 6.3 mg/l. This particular homeowner said they had previously had nitrate levels in their well above the federal health standard of 10 mg/l. The highest Reactive P concentration (0.039 mg/l) was found along the eastern shoreline. The location of this well did not correlate with a groundwater inflow area and could be due to groundwater showing up in the well having passed through sediment high in phosphorus. The next highest Reactive P concentration was 0.016 mg/l. Overall the quality of well water around the lake was very good. Private well data is displayed in Table 2D of Appendix D. Figure 17 displays the location of the 24 wells that were sampled.

HOMEOWNER SURVEY

A total of 24 out of the current 40 homeowners on the lake, including one who was in the process of selling their home to another landowner, were able to be surveyed. The remaining 16 properties were unable to be surveyed mainly because they are used as vacation homes only and the owner was never present during survey attempts. Fifty eight percent of those surveyed felt that Rinehart Lake does not have a water quality problem, while 38% did. The other 4% were undecided. While nobody rated the perceived water quality of the lake as excellent, 79% rated it either very good or good and only 21% rated

Figure 17. Map showing homeowner well sampling locations from Rinehart Lake, Portage Co, WI. The numbers correspond to data in Table 2D of Appendix D. Well locations are not to scale.



it either fair or poor. The major water quality problems perceived by people were: algae and scum (46%), weeds (33%), smells and odors (25%), water clarity (12.5%), swimmer's
itch (12.5%), and litter (8%). Of those that felt there has been a decline in lake quality, the main reason given was septic seepage (5 people). Other reasons included fertilizer use (2), herbicide/pesticide use (2), development pressure (2), and heavy recreational use (1). People were allowed to respond to more than one reason for a water quality decline.

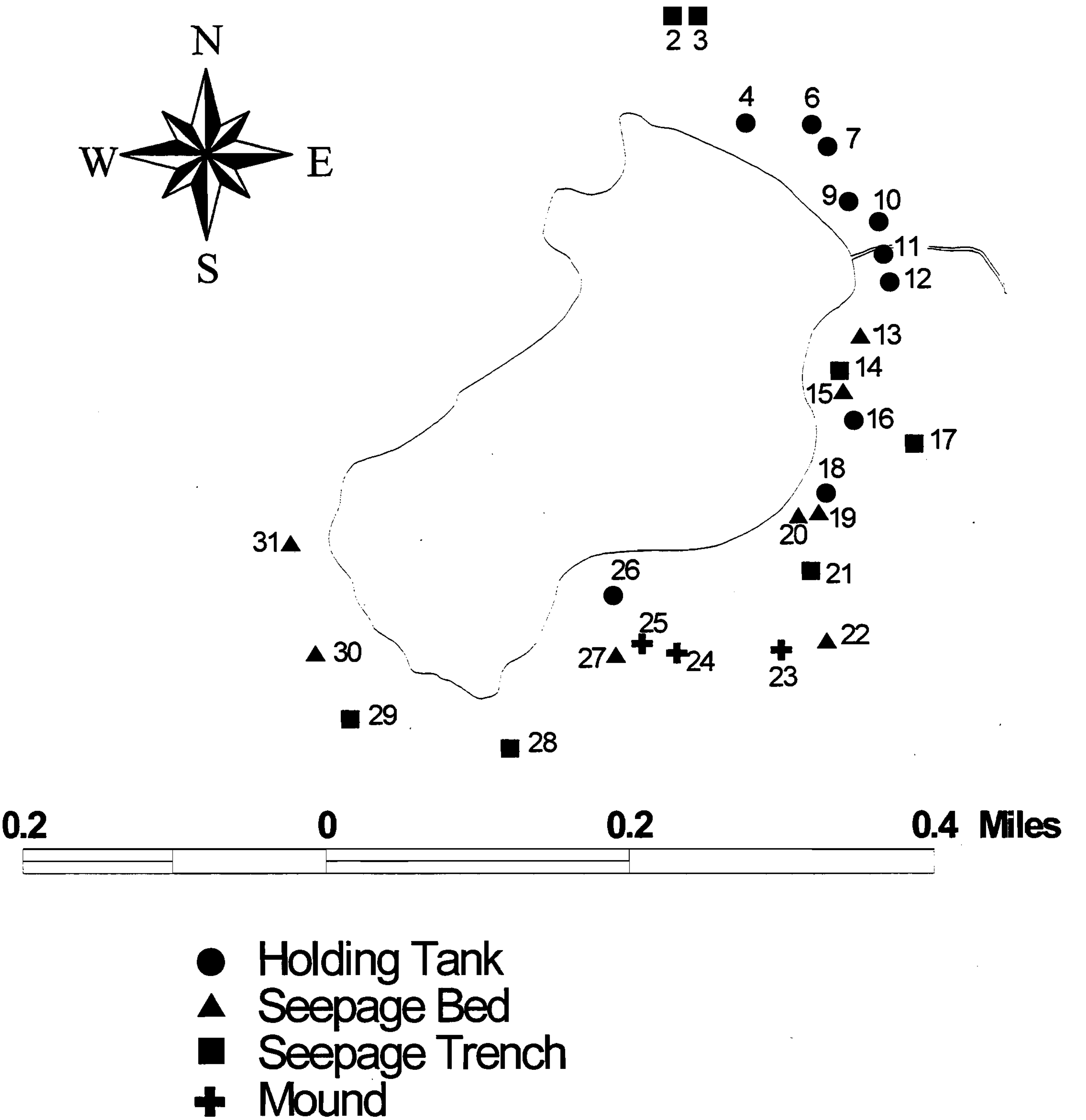
SEPTIC SYSTEM SURVEY

The Portage County Zoning Department conducted a survey of all of the current on-site sewage disposal (septic) systems around Rinehart Lake during 1996-97. Of the 43 residences on the lake, septic system data were available for 31. The majority of the homes along the northern and northeast shoreline were required in 1996-97 to replace their existing systems with holding tanks because of unsuitable amounts of soil present to support a septic system drainfield. Many of the homes along the eastern and southeastern shoreline were also required to bring their septic systems up to current code specifications. Approximate setbacks, type of system, and approximate elevation above the lake are displayed in Figure 18. Data are displayed in Appendix F.

CONCLUSIONS

Through personal communication with a resident (Donald Geneske) who has lived on Rinehart Lake for 35 years, it was learned that livestock, as well as crops were raised on the ridge at the south end of the lake during the 1970s. During the 1980s and early 1990s, the area was not farmed, but recently non-irrigated agriculture without livestock is being practiced (Figure 1a). This area of non-irrigated agriculture is within the surface watershed and possibly in the groundwater watershed of the lake (Figure 1a). A main reason for improved Total P concentrations in Rinehart Lake since the 1970s could be that livestock are no longer being raised within the surface watershed. Animal waste is often a major source of phosphorus and nitrogen loading into lakes by surface runoff. Phosphorus is normally adsorbed by soils and carried in surface rather than subsurface runoff (Neely 1989). Another reason for the improvement could be that two-

Figure 18. Map showing approximate septic system setback (to scale) and type of system of homes on Rinehart Lake, Portage Co., WI. Site numbers correspond to data in Appendix F.



thirds of the residents on the lake were required within the last five years to replace their existing septic systems with holding tanks. Failing and even well functioning, older septic systems are also a potential source for phosphorus loading to a lake (Shaw et. al.1996).

Over the time period from the 1970s to 1998-99, Total N levels have slightly increased. If runoff from the farmland, particularly the livestock, had caused high phosphorus levels in the past, nitrogen levels also should have been higher. One source of nitrogen that could explain this increase is nitrate + nitrite nitrogen (NO_3+NO_2-N) from groundwater. Nitrate + nitrite nitrogen (will be referred to as nitrate) is not held in the soil and readily leaches into the groundwater, showing up as groundwater flow to lakes and streams (Neely 1989). The nitrate mean for 1972-81 in the epilimnion was 0.14 mg/l and 0.15 mg/l in the hypolimnion. In 1998-99 the epilimnion concentration was 0.24 mg/l and the hypolimnion 0.45 mg/l. This shows an increase from 1972-81 to 1998-99, meaning nitrate originating some distance from the surface watershed could be showing up in the lake as groundwater flow. Increased fertilization over the years on nearby agricultural land could have caused this change (Alexander 1990), as well as contributions from septic systems and lawn fertilizers. Still, the mean 1998-99 nitrate concentration is skewed by high values from January through March. In the remaining months, nitrate contribution to Total N was small compared to organic N and ammonium (NH_4^+). However, plant uptake during summer will convert nitrate to organic N, which is later released as ammonium when plants decay (Shaw et. al. 1996). Higher winter nitrate concentrations during 1998-99 could be explained because there is little plant growth during the winter months to use the available nitrate entering the lake with groundwater.

The Trophic State Indices show an improvement in Rinehart Lake water quality based on chlorophyll-a levels, phosphorus levels, and Secchi depth in 1998-99 from the 1975-'80 study years.

The AMCI index suggests Rinehart Lake is of good quality based on its aquatic plant community. No exotic species were found.

The complex chemical and physical interactions occurring in the lake are manifested by the fact that no clear correlation could be drawn between aquatic plants and nutrient levels present in the sediment and interstitial water. These findings do not mean a correlation does not exist, but a more in-depth analysis of other variables such as sediment bulk density as related to plant rooting ability, and more research on the effects of *Chara* on the growth of other aquatic plants needs to be done. Also, more sites would need to be sampled in order to create a larger database to look at statistically valid data correlations.

Overall, water quality is very good and efforts should be made to maintain the current state of the lake. It should be noted that even well designed, functioning septic systems will eventually saturate the soil's capacity to remove phosphorus. The systems with the greatest setbacks and depth to groundwater will have a much longer time period for effective phosphorus removal than systems that are located near the lake with shallow depth to groundwater.

It should also be noted that there appears to be an excess nutrient supply available during the winter months. Higher Total P levels and very high chlorophyll-a were detected in the winter of 1998-99. This problem was not detected in previous years of data collection. No data exists that clearly indicates why winter nutrient levels were so high in 1998-99. Summer chlorophyll-a and Total P were actually better in 1998-99 than in previous study years. Continuing to monitor winter nutrient levels is recommended to show whether the 1998-99 winter was abnormal, and if a potential nutrient problem really does exist. No oxygen problems were seen during the winter of 1998-99, but with the nutrient supply that is available during winter coupled with a deep snowfall and subsequent algal die-off, dissolved oxygen depletion could become a greater problem. This could be detrimental to the Rinehart Lake fish population. It is not foreseen that oxygen depletion will be a problem, but the potential for it does exist.

It is recommended that the lake participates in the DNR Secchi disk monitoring program and the UWSP spring and fall turnover monitoring program to maintain a long-term database on lake water quality. These programs are at a low cost and enable the lake residents to document any changes that may occur.

Several concerns had been expressed about how to deal with the intermittent ditch in the northwest corner of the lake that flows from a small riparian wetland. An option to prevent flow of this water into the lake would be to divert the ditch to the outflow of the lake (Nace Creek). However, although the water that flows from the ditch to the lake is relatively high in nutrients, it is not seen as having a serious impact on the lake. The flow is minimal, and it has been present for many years. A diversion process would be destructive and expensive with little foreseeable gain in lake quality. A larger problem with nutrient loading is occurring with groundwater inflow. Efforts to work with local farmers on reducing fertilizer applications would be beneficial to the lake in the long run. Homeowners should also be encouraged to minimize the use of lawn and garden fertilizers and maintain as much natural vegetation near the lake as possible.

This study, although useful, has many limitations primarily due to only one year of recent data on Rinehart Lake. To get a better comparison, several more years of data would need to be taken to account for the changes in weather patterns that exist from year to year. These changes can have a profound effect on water quality (Shaw et al. 1996). Methods of analyzing samples and equipment used have also changed, as well as the people using them. This no doubt has some impact on results. Despite its limitations, the study provides beginning insight into the current water quality of Rinehart Lake and what can be done to maintain it into the future.

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APPENDIX C

Table 1C. Epilimnion data, 1972-81 & 1998-99 (includes mean '72-'81 & mean '98-99) All data mg/l unless noted.

	D.O.	Temp. Deg.C	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	NO2 + NO3(N)	TKN	TN	TP	React. P	Secchi (m)	chloro-a (mg/m^3)	Cl-	Ca^{2+}	NH4
08/18/1972	8.8	24.5	8.9	243	120	115	0.35	N/A	1.05	0.01	0.007	N/A	N/A	0.0	51	N/A
09/24/1972	8.0	18.0	8.6	288	141	142	0.22	N/A	2.21	0.001	0.001	N/A	N/A	5.3	78	N/A
10/26/1972	10.8	6.5	8.3	226	152	153	0.20	N/A	N/A	0.025	0.001	N/A	N/A	5.1	77	N/A
01/18/1973	9.8	0.0	7.6	384	159	157	0.08	N/A	1.29	0.005	0.003	N/A	N/A	1.8	97	0.03
02/15/1973	6.0	0.5	7.7	375	189	182	0.14	N/A	1.89	0.038	N/A	N/A	N/A	N/A	112	0.24
03/21/1973	7.9	4.0	7.6	107	62.5	48	0.28	N/A	0.84	N/A	0.005	N/A	N/A	1.0	44	0.32
04/18/1973	11.9	9.2	8.25	350	188	192	0.21	N/A	0.80	0.021	0.008	N/A	N/A	4.0	190	0.18
05/15/1973	10.0	13.0	8.2	330	168	256	0.32	N/A	1.05	0.009	0.004	N/A	N/A	3.0	116	0.21
06/05/1973	9.0	21.0	8.3	341	170	176	0.24	N/A	0.52	0.014	0.002	N/A	N/A	5.0	N/A	0.14
06/19/1973	8.4	22.7	8.4	333	152	168	1.02	N/A	N/A	N/A	<0.001	N/A	N/A	N/A	N/A	0.00
07/02/1973	10.1	23.3	8.5	338	160	164	<0.01	N/A	0.91	0.031	0.008	N/A	N/A	N/A	86	0.04
07/16/1973	8.4	23.5	8.45	308	154	158	0.07	N/A	3.96	0.004	0.001	N/A	N/A	N/A	82	0.28
07/31/1973	8.4	22.0	8.23	310	157	163	0.39	N/A	1.01	0.033	0.008	N/A	N/A	N/A	82	0.18
09/07/1973	6.9	21.3	8.25	327	184	180	0.07	N/A	1.26	0.003	0.002	N/A	N/A	1.5	136	0.14
10/31/1973	9.1	10.6	8.31	346	190	182	0.25	N/A	1.05	0.026	0.004	N/A	N/A	N/A	124	0.32
02/28/1974	6.2	1.5	7.7	460	244	242	0.49	N/A	1.82	0.01	0.001	N/A	N/A	2.0	194	0.56
05/22/1974	9.6	19.6	7.72	335	180	200	0.11	N/A	0.60	0.016	0.006	N/A	N/A	2.0	99	0.04
06/06/1974	9.8	20.5	7.96	342	180	190	0.14	N/A	0.81	0.013	0.006	N/A	N/A	2.5	94	0.14
06/19/1974	11.3	21.0	8.08	337	172	182	<0.01	N/A	0.98	0.014	0.005	N/A	N/A	3.0	86	0.06
07/09/1974	9.0	26.6	8.6	300	158	165	<0.01	N/A	0.70	0.015	0.011	N/A	N/A	3.8	72	0.04
07/30/1974	8.9	22.1	8.62	290	145	156	<0.01	N/A	0.56	0.009	0.001	N/A	N/A	N/A	74	0.00
02/17/1975	5.9	3.5	7.9	409	208	230	0.04	N/A	0.63	0.02	0.008	N/A	N/A	N/A	118	0.07
04/02/1975	1.2	2.0	7.7	410	214	232	0.35	N/A	0.98	0.011	<0.001	3.7	N/A	N/A	118	0.25
05/13/1975	12.5	17.0	7.6	360	172	196	<0.01	N/A	0.84	0.008	0.008	3.1	N/A	N/A	124	N/A
06/24/1975	9.3	27.0	7.2	310	158	186	0.04	0.8	0.84	0.026	0.005	2.8	0.16	N/A	N/A	N/A
07/21/1975	9.0	27.0	8.8	297	142	198	0.14	0.81	0.95	0.052	0.022	3.5	N/A	N/A	N/A	N/A
08/18/1975	8.7	23.0	8.7	296	148	178	0.21	0.73	0.94	0.053	0.024	4.0	1.23	N/A	N/A	N/A
09/30/1975	8.1	14.0	7.89	339	164	230	0.11	0.63	0.74	0.027	0.005	4.5	3.78	N/A	N/A	N/A
11/11/1975	9.3	7.0	8.4	373	176	188	<0.01	N/A	1.02	0.056	0.001	N/A	N/A	N/A	82	N/A

Table 1C. Continued

	D.O.	Temp. Deg.C	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	NO2 + NO3(N)	TKN	TN	TP	React. P	Secchi (m)	chloro-a (mg/m^3)	Cl-	Ca^{2+}	NH4
01/14/1976	11.0		8.20	435	196	236	0.03	0.95	0.98	0.011	0.002	N/A	N/A	N/A	162	0.14
02/10/1976	9.5	0.0	7.72	440	190	252	0.14	1.44	1.58	0.013	0.009	N/A	N/A	N/A	232	0.60
03/09/1976	5.1		7.84	410	200	276	0.14	0.74	0.88	0.006	0.006	N/A	N/A	N/A	90	0.46
04/20/1976	10.1	15.0	8.40	350	176	202	0.04	0.18	0.22	0.042	0.007	N/A	N/A	N/A	90	N/A
05/18/1976	9.6	15.5	8.15	338	170	180	0.11	0.53	0.64	0.046	0.007	3.3	N/A	N/A	86	0.21
06/14/1976	9.4	25.0	8.77	314	158	178	0.21	0.67	0.88	0.016	0.003	2.5	5.66	N/A	90	0.11
07/12/1976	8.5	25.5	8.91	302	152	168	<0.01	0.70	0.70	0.058	0.056	N/A	2.55	N/A	52	0.28
08/10/1976	7.9	24.0	8.42	318	152	170	<0.01	0.67	0.67	0.021	0.008	3.5	N/A	N/A	60	N/A
09/07/1976	8.1	22.0	8.08	390	160	182	<0.01	N/A	N/A	0.023	0.017	N/A	N/A	N/A	76	N/A
10/11/1976	9.0	12.0	8.33	361	176	184	0.11	1.86	1.97	0.091	0.008	4.0	N/A	N/A	78	0.04
11/17/1976	13.0	3.0	8.42	396	176	256	0.24	0.91	1.15	0.007	0.007	N/A	N/A	N/A	154	0.49
12/13/1976	13.9	1.8	8.45	280	198	288	0.21	1.12	1.33	0.054	0.003	N/A	N/A	N/A	154	0.21
01/10/1977	12.1	0.5	8.35	450	204	236	0.18	1.37	1.55	0.059	0.009	N/A	N/A	N/A	106	0.14
02/07/1977	8.7	0.1	8.00	375	210	232	0.21	1.61	1.82	0.050	0.032	N/A	N/A	N/A	182	0.28
03/08/1977	7.6	2.0	8.08	375	192	212	0.21	1.54	1.75	0.027	0.011	N/A	N/A	N/A	114	0.28
04/19/1977	10.8	17.0	8.44	340	190	186	<0.01	0.81	0.81	0.030	0.023	2.7	N/A	N/A	82	N/A
05/24/1977	9.2	23.1	8.71	350	166	182	0.46	1.12	1.58	0.027	<0.002	3.8	N/A	N/A	72	0.49
06/20/1977	9.9	22.3	8.90	288	152	170	<0.01	0.67	0.67	0.013	0.003	4.7	2.94	N/A	128	N/A
07/18/1977	9.0	28.0	9.10	288	146	162	<0.01	0.35	0.35	0.042	0.003	3.8	3.39	N/A	64	0.01
08/17/1977	7.5	21.8	8.80	305	156	168	0.01	1.02	1.03	0.164	0.003	3.0	3.9	N/A	118	0.10
09/12/1977	7.2	19.7	8.60	329	162	182	<0.01	0.79	0.79	0.025	0.005	5.2	4.92	N/A	70	0.01
10/12/1977	9.2		8.40	339	164	180	0.03	1.23	1.26	0.013	0.007	N/A	3.47	N/A	118	0.36
11/08/1977	9.3	10.2	8.30	342	178	180	0.04	1.18	1.22	0.033	0.010	4.0	N/A	N/A	82	0.33
12/13/1977	11.2	1.8	8.25	344	180	190	0.01	1.44	1.45	0.013	0.005	N/A	N/A	N/A	126	0.42
01/18/1978	10.3	0.3	8.15	371	182	198	0.05	1.24	1.29	0.010	<0.002	N/A	N/A	N/A	80	0.48
02/13/1978	7.4	0.0	7.90	281	134	138	0.16	1.10	1.26	0.030	0.010	N/A	N/A	N/A	74	0.56
03/14/1978	6.61	0.8	7.88	393	190	204	0.04	1.40	1.44	0.008	0.003	N/A	N/A	N/A	116	0.58
04/25/1978	11.7	8.0	8.58	344	164	166	0.02	0.85	0.87	0.018	<0.002	N/A	N/A	N/A	84	0.19
05/22/1978	10.0	20.1	8.71	318	162	160	0.01	0.98	0.99	0.015	0.010	3.0	N/A	N/A	88	0.04
06/20/1978	9.89	21.7	8.90	287	152	162	<0.01	0.98	0.98	0.014	0.014	4.5	N/A	N/A	66	0.07
07/17/1978	9.88	25.0	9.11	315	142	152	<0.01	0.76	0.76	0.015	0.015	3.7	N/A	N/A	52	0.03
08/15/1978	8.32	26.4	8.88	288	146	156	<0.01	0.94	0.94	0.007	<0.002	3.3	N/A	N/A	70	0.05
09/18/1978	5.4	18.8	8.06	355	156	162	<0.01	1.24	1.24	0.018	0.009	3.5	N/A	6.8	74	0.28
10/30/1978	10.1	10.1	8.30	255	176	202	<0.01	1.18	1.18	0.012	<0.002	2.9	N/A	8.8	82	0.31
12/11/1978	11.6	1.1	8.30	335	186	202	0.02	1.34	1.36	0.020	0.005	N/A	N/A	7.8	96	0.35

Table 1C. Continued

	D.O.	Temp. Deg.C	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	NO2 + NO3(N)	TKN	TN	TP	React. P	Secchi (m)	chloro-a (mg/m^3)	Cl-	Ca^{2+}	NH4
01/16/1979	8.2	0.8	7.83	380	192	206	<0.01	1.66	1.66	0.008	0.007	N/A	N/A	5.4	93	0.49
02/12/1979	6.5	1.5	7.75	300	188	204	0.02	1.46	1.48	0.010	0.007	N/A	N/A	5.6	112	0.62
03/12/1979	1.7	3.5	7.68	380	205	212	<0.01	1.58	1.58	0.015	0.010	N/A	N/A	7.3	118	0.78
04/23/1979	9.3	11.6	7.99	265	152	157	0.05	0.92	0.97	0.015	0.000	3.9	N/A	4.0	76	0.23
05/29/1979	9.6	18.6	8.47	305	160	172	0.10	0.90	1.00	0.070	0.034	4.1	N/A	4.7	86	0.15
06/25/1979	11.0	22.8	7.45	340	125	164	0.02	0.94	0.96	0.020	0.008	3.5	1.94	18.3	92	0.05
07/23/1979	9.7	27.2	8.88	295	148	154	<0.01	0.92	0.92	0.020	0.004	1.8	2.58	9.9	62	0.02
08/20/1979	8.2	21.4	8.50	275	162	166	<0.01	1.00	1.00	0.040	0.014	3.3	N/A	5.1	92	0.08
09/17/1979	8.3	18.7	8.30	335	166	176	0.10	1.02	1.12	0.030	<0.002	2.9	3	5.3	120	0.10
10/15/1979	8.94	9.5	8.21	300	180	186	0.02	1.32	1.34	0.020	<.005	3.0	3.63	4.9	104	0.28
11/26/1979	11.4	3.2	8.25	318	180	200	0.04	1.18	1.22	0.022	0.005	N/A	N/A	4.9	106	0.36
01/08/1980	12.6	1.2	8.26	380	194	202	0.08	1.16	1.24	0.010	<0.002	N/A	N/A	5.48	116	0.43
02/18/1980	10.9	1.0	8.06	420	210	214	0.08	1.54	1.62	0.020	0.005	N/A	N/A	4.42	109	0.46
03/24/1980	10.3	1.0	7.60	330	154	178	0.22	1.06	1.28	0.020	0.002	N/A	N/A	2.76	94	0.46
04/21/1980	11.6	13.7	8.31	360	170	174	0.12	1.10	1.22	0.010	0.002	2.5	N/A	3.2	88	0.12
05/19/1980	11.0	18.7	8.53	341	170	176	0.04	1.02	1.06	0.010	0.005	2.1	N/A	4.46	93	0.10
06/09/1980	8.57	20.5	8.47	329	162	174	0.02	0.92	0.94	0.015	0.002	3.3	2.26	4.41	98	0.03
07/21/1980	8.4	27.7	8.77	260	146	182	0.01	0.94	0.95	0.011	0.005	3.9	1.99	5.1	118	0.03
08/25/1980	8.1	23.0	8.60	245	158	162	0.02	0.92	0.94	0.015	0.005	2.4	3.55	4.6	172	0.04
09/22/1980	7.1	17.0	7.92	318	150	168	0.02	0.90	0.92	0.010	0.005	2.7	3.28	8.3	104	0.12
10/27/1980	10.2	6.0	8.31	328	165	194	0.06	1.06	1.12	0.007	0.002	6.0	N/A	4.7	125	0.18
12/15/1980	12.6	1.7	8.29	362	178	188	0.12	1.04	1.16	0.005	0.002	1.8	N/A	3.1	88	0.31
01/26/1981	11.4	1.5	6.03	379	192	207	0.14	1.16	1.30	0.015	0.005	3.6	N/A	2.9	122	0.37
03/02/1981	10.2	2.5	7.91	335	174	182	0.02	0.94	0.96	0.005	0.002	4.0	N/A	4.1	152	0.03
04/13/1981	10.8	11.8	8.38	350	174	182	0.13	0.82	0.95	0.020	0.002	3.0	N/A	3.9	98	0.17
05/18/1981	10.3	17.5	8.57	348	180	180	0.07	0.92	0.99	0.012	0.002	3.3	N/A	3.0	82	0.03
06/15/1981	9.1	24.2	8.79	290	156	165	<0.01	1.28	1.28	0.010	0.002	3.9	N/A	4.4	80	N/A
07/27/1981	8.4	22.0	8.99	212	142	154	<0.01	0.82	0.82	0.017	0.002	3.6	N/A	4.4	58	N/A
08/24/1981	8.36	24.0	8.98	270	140	164	<0.01	0.78	0.78	0.015	<0.002	3.0	N/A	4.5	72	0.10

Table 1C. Continued

	D.O.	Temp. Deg.C	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	NO2 + NO3(N)	TKN	TN	TP	React. P	Secchi (m)	chloro-a (mg/m^3)	Cl-	Ca^{2+}	NH4
06/03/1998	9.9	19.2	7.98	375	199	204	0.29	0.97	1.28	0.000	0.004	6.8	N/A	6.2	96	0.38
06/23/1998	11.26	26.9	8.72	337	184	184	0.23	1.04	1.27	0.007	0.002	5.7	N/A	7.1	112	0.14
07/14/1998	10.56	26.9	8.80	330	166	172	0.12	0.92	1.04	0.006	0.004	3.8	2.1	5.6	66	0.13
07/29/1998	9.57	24.7	8.84	341	160	172	0.12	1.03	1.15	0.007	0.003	5.2	3.5	6.4	0.06	1.32
08/18/1998	9.34	24.4	8.61	323	160	174	0.09	1.04	1.13	0.010	0.005	5.2	<0.1	6.0	92	0.17
08/28/1998	9.82	25.5	8.73	323	163	168	0.09	1.07	1.16	0.015	0.005	5.7	1.9	6.3	72	0.10
09/16/1998	8.63	22.0	8.57	354	168	176	0.03	0.83	0.86	0.006	0.007	4.3	3.7	6.1	80	0.13
09/30/1998	8.38	18.8	8.41	366	183	180	0.09	1.19	1.28	0.016	0.009	4.0	4.1	9.0	N/A	0.17
10/19/1998	9.98	12.5	8.37	346	173	184	0.14	1.20	1.34	0.000	0.007	4.9	4.5	7.0	144	0.31
11/14/1998	12.59	4.5	8.35	355	182	188	0.22	1.22	1.44	0.014	0.005	2.5	8.2	6.6	140	0.36
12/08/1998	13.2	5.0	8.31	355	190	196	0.30	1.50	1.80	0.038	0.024	3.1	14	8.4	100	0.45
01/13/1999	14.63	0.7	8.21	422	206	208	0.34	1.62	1.96	0.024	0.019	3.1	29	16.1	144	0.44
02/16/1999	12.0	0.0	8.22	443	198	207	0.42	1.43	1.85	0.013	0.009	7.1	0.2	7.0	112	0.60
03/11/1999	11.91	0.9	8.36	399	198	204	0.41	1.27	1.68	0.018	0.009	3.7	3.6	9.7	98	0.56
04/16/1999	10.8	10.2	8.33	408	193	208	0.59	1.16	1.75	0.009	0.004	4.9	2.6	3.8	104	0.32
05/13/1999	10.8	15.4	8.42	358	181	196	0.36	1.08	1.44	0.013	0.007	4.6	1.2	6.8	124	0.21
Mean '72-81	**9.2**	**13.9**	**8.29**	**331**	**169**	**185**	**0.14**	**1.03**	**1.12**	**0.023**	**0.007**	**3.4**	**3.01**	**4.7**	**100**	**0.22**
Mean '98-99	**10.8**	**14.9**	**8.45**	**365**	**182**	**189**	**0.24**	**1.16**	**1.40**	**0.012**	**0.008**	**4.7**	**6.05**	**7.4**	**99**	**0.36**
ST. Dev.'72-81	**2.0**	**9.8**	**0.39**	**48**	**20**	**29**	**0.09**	**0.31**	**0.34**	**0.024**	**0.009**	**0.9**	**1.02**	**2.9**	**33**	**0.19**
ST. Dev.'98-99	**1.7**	**10.1**	**0.24**	**36**	**15**	**14**	**0.16**	**0.21**	**0.32**	**0.009**	**0.006**	**1.3**	**2.70**	**2.7**	**37**	**0.30**

Table 2C. Hypolimnion Data, 1972-'81 & 1998-'99 (includes mean '72-'81 & mean '98-'99) All data mg/l unless noted.

	D.O.	Temp. Deg.C	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	NO2 + NO3(N)	TKN	TN	TP	React. P	Cl-	Ca2+	NH4
08/18/1972	0.0	13.5	7.3	440	239	180	0.26	N/A	3.68	0.025	0.012	N/A	33	N/A
09/24/1972	0.0	15.0	7.3	510	258	232	0.25	N/A	7.92	0.018	0.018	6.0	154	N/A
10/26/1972	10.8	6.5	8.3	275	150	153	0.17	N/A	N/A	0.009	0.008	5.25	73	N/A
01/18/1973	0.7	4.0	7.1	442	218	209	0.48	N/A	1.01	0.013	0.002	2.0	119	0.53
02/15/1973	0.4	3.5	7.4	387	201	196	0.46	N/A	1.26	0.019	N/A	N/A	194	0.52
03/21/1973	1.2	4.5	7.4	415	224	212	0.28	N/A	1.4	N/A	0.004	5.0	186	0.63
04/18/1973	12.1	8.0	8.35	345	188	172	0.38	N/A	1.16	0.011	0.002	4.0	126	0.14
05/15/1973	5.4	9.2	7.9	335	184	268	0.32	N/A	1.78	0.009	0.007	3.0	188	0.74
06/05/1973	0.2	11.0	7.7	365	200	168	0.04	N/A	0.6	0.025	0.002	3.0	N/A	0.52
06/19/1973	1.2	12.0	7.7	377	180	188	0.25	N/A	N/A	N/A	0.003	N/A	N/A	0.74
07/02/1973	0.01	12.0	7.4	404	202	198	0.04	N/A	1.78	0.044	0.019	2.0	64	1.05
07/16/1973	0.0	12.3	7.35	405	206	214	0.10	N/A	3.57	0.070	0.011	1.5	66	1.26
07/31/1973	0.2	13.0	7.41	395	207	208	0.035	N/A	2.31	0.051	0.012	2.5	152	0.32
09/07/1973	0.0	14.0	7.3	422	236	222	0.25	N/A	3.47	0.033	0.014	2.0	142	2.24
10/31/1973	8.7	10.5	8.34	349	190	186	0.25	N/A	1.12	0.020	0.005	N/A	124	0.32
02/28/1974	0.9	3.5	7.63	540	258	262	0.56	N/A	1.37	0.012	0.007	3.5	194	0.7
05/22/1974	4.85	10.7	7.81	370	198	210	0.14	N/A	0.98	0.026	0.006	2.5	118	0.18
06/06/1974	0.6	9.5	7.76	388	198	208	0.14	N/A	1.12	0.015	0.007	2.4	94	0.42
06/19/1974	0.6	10.3	7.55	383	206	211	<0.01	N/A	1.33	0.038	0.004	3.0	132	0.35
07/09/1974	0.1	11.0	7.5	408	220	222	<0.01	N/A	0.32	0.037	0.013	4.5	69	0.56
07/30/1974	0.1	11.6	7.8	423	196	220	<0.01	N/A	1.09	0.024	0.010	N/A	104	0
02/17/1975	0.1	4.5	7.35	445	232	266	0.37	N/A	0.80	0.024	0.010	N/A	150	0.35
04/02/1975	0.0	5.0	7.5	500	248	266	N/A	N/A	1.61	0.021	0.005	N/A	152	0.64
05/13/1975	0.7	9.0	7.5	433	220	260	N/A	N/A	1.53	0.047	0.007	N/A	220	0.28
06/24/1975	2.6	13.5	7.20	414	216	245	0.11	1.05	1.16	0.026	0.008	N/A	144	0.35
07/21/1975	2.3	14.0	7.60	425	226	248	0.11	1.79	1.90	0.052	0.007	N/A	146	2.8
08/18/1975	1.6	15.0	7.40	254	226	268	0.98	1.57	2.55	0.032	0.014	N/A	126	0.49
09/30/1975	6.6	14.0	7.34	341	164	230	0.04	0.63	0.67	0.030	0.004	N/A	80	0.11
11/11/1975	9.3	6.0	8.46	363	176	200	N/A	N/A	1.02	0.020	0.001	N/A	94	0.02

Table 2C. Continued

	D.O.	Temp. Deg.C	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	NO2 + NO3(N)	TKN	TN	TP	React. P	Cl-	Ca2+	NH4
01/14/1976	11.0		7.78	450	202	258	N/A	1.16	1.16	0.023	0.003	N/A	168	0.35
02/10/1976	9.5	4.0	7.56	460	212	280	0.11	1.54	1.65	0.018	0.003	N/A	210	0.77
03/09/1976	5.1		7.67	442	230	282	N/A	0.91	0.91	0.013	0.009	N/A	94	0.74
04/20/1976	10.1	9.0	7.69	400	30	240	0.04	0.70	0.74	0.038	0.003	N/A	116	0.35
05/18/1976	8.2	12.0	8.01	350	174	188	0.21	0.70	0.91	0.046	0.007	N/A	92	0.14
06/14/1976	8.2	12.0	8.01	350	174	188	0.21	0.70	0.91	0.046	0.007	N/A	94	0.21
07/12/1976	7.0	20.0	8.58	319	160	180	0.25	0.77	1.02	0.016	0.003	N/A	90	0.24
08/10/1976	0.8	16.5	7.62	398	194	200	<0.01	0.88	0.88	0.116	0.105	N/A	74	0.81
09/07/1976	0.3	17.5	7.68	407	210	220	<0.01	2.10	2.10	0.050	0.018	N/A	64	N/A
10/11/1976	8.5	12.0	8.29	371	170	190	0.14	1.96	2.10	0.038	0.015	N/A	78	N/A
11/17/1976	11.2	4.0	8.32	420	198	262	0.10	1.08	1.18	0.008	0.007	N/A	174	0.21
12/13/1976	6.9	4.0	8.19	365	208	292	0.25	1.05	1.30	0.096	0.001	N/A	184	0.32
01/10/1977	5.7	3.0	8.14	465	216	238	0.10	1.61	1.71	0.029	0.009	N/A	100	0.32
02/07/1977	1.0	3.0	7.8	440	228	248	0.04	1.54	1.58	0.053	0.026	N/A	174	0.49
03/08/1977	1.0	5.0	7.94	420	224	244	0.04	1.68	1.72	0.027	0.018	N/A	136	0.42
04/19/1977	10.8	11.5	8.25	360	180	210	0.04	1.99	2.03	0.035	0.025	N/A	88	0.21
05/24/1977	4.3	13.0	7.75	405	198	206	0.56	1.58	2.14	0.030	0.005	N/A	100	0.39
06/20/1977	8.0	19.0	8.40	327	168	184	<0.01	0.95	0.95	0.024	0.006	N/A	94	0.04
07/18/1977	9.1	26.0	9.05	297	152	168	<0.01	0.28	0.28	0.026	0.001	N/A	64	0.03
08/17/1977	4.0	20.0	8.29	335	168	180	0.03	1.16	1.19	0.136	0.002	N/A	102	0.17
09/12/1977	5.4	19.0	8.40	332	164	164	0.04	1.05	1.09	0.011	0.005	N/A	64	0.07
10/12/1977	9.0	9.0	8.30	338	170	192	0.02	1.05	1.07	0.011	0.011	N/A	152	0.32
11/08/1977	8.6	10.0	8.25	341	174	188	0.03	1.17	1.20	0.031	0.006	N/A	82	0.34
12/13/1977	4.9	3.2	7.90	367	184	196	0.01	1.70	1.71	0.010	0.003	N/A	110	0.69
01/18/1978	2.4	5.0	7.75	380	194	212	0.02	1.28	1.3	0.020	<.001	N/A	94	0.82
02/13/1978	5.7	2.5	7.85	280	132	144	0.16	1.06	1.22	0.020	0.006	N/A	74	0.63
03/14/1978	0.7	4.0	7.73	411	200	212	0.02	1.40	1.42	0.010	0.002	N/A	120	0.64
04/25/1978	12.0	7.2	8.51	340	166	170	0.01	0.91	0.92	0.054	0.016	N/A	82	0.23
05/22/1978	9.4	14.0	8.61	321	162	160	0.01	1.00	1.01	0.015	0.013	N/A	84	0.03
06/20/1978	4.12	6.4	8.02	315	170	180	<0.01	1.05	1.05	0.096	0.020	N/A	78	0.22
07/17/1978	0.1	17.0	7.69	310	184	172	<0.01	1.10	1.10	0.022	0.022	N/A	94	0.38
08/15/1978	0.94	22.8	7.79	360	182	192	<0.01	1.14	1.14	0.006	<0.002	N/A	92	0.33
09/18/1978	4.8	18.3	7.98	356	162	166	<0.01	1.24	1.24	0.014	<0.002	5.6	80	0.28
10/30/1978	10.1	9.8	8.3	260	170	192	<0.01	1.14	1.14	0.016	0.016	8.3	84	0.32
12/11/1978	5.9	1.1	7.8	355	186	202	0.02	1.60	1.62	0.022	0.006	7.8	98	0.76

Table 2C. Continued

	D.O.	Temp. Deg.C	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	NO2 + NO3(N)	TKN	TN	TP	React. P	Cl-	Ca2+	NH4
01/16/1979	0.3	2.2	7.48	490	204	214	N/A	1.96	1.96	0.010	0.009	5.1	108	0.72
02/12/1979	0.0	4.0	7.41	350	152	218	N/A	1.94	1.94	0.010	0.007	5.4	126	0.66
03/12/1979	0.0	5.0	7.62	410	216	224	N/A	1.86	1.86	0.015	0.009	7.3	114	0.88
04/23/1979	0.8	6.7	7.6	365	206	212	N/A	1.44	1.44	0.020	0.004	5.2	110	0.33
05/29/1979	0.7	9.3	7.76	400	208	230	0.05	1.84	1.89	0.082	0.082	4.7	118	0.67
06/25/1979	4.8	14.8	7.85	399	179	200	0.02	1.54	1.56	0.030	0.006	6.13	112	0.52
07/23/1979	4.2	17.7	7.63	400	210	212	<0.01	1.48	1.48	0.020	0.003	10.5	126	0.56
08/20/1979	0.0	16.3	7.59	390	222	224	<0.01	1.50	1.50	0.045	0.010	6.3	126	0.64
09/17/1979	4.1	17.3	7.78	360	182	186	<0.01	1.28	1.28	0.025	<0.002	5.4	148	0.32
10/15/1979	8.79	9.2	8.17	306	180	186	0.04	1.30	1.34	0.015	<.005	4.9	98	0.32
11/26/1979	11.2	3.2	8.19	322	180	204	0.04	1.20	1.24	0.024	0.005	5.7	132	0.36
01/08/1980	10.8	2.0	8.01	400	200	208	0.11	1.44	1.55	0.03	<0.002	4.42	114	0.52
02/18/1980	2.3	4.0	7.61	440	220	226	0.06	1.60	1.66	0.02	0.002	2.76	116	0.64
03/24/1980	0.83	4.6	7.50	460	240	250	0.12	1.46	1.58	0.02	<0.002	3.2	144	0.72
04/21/1980	11.2	9.5	8.02	410	196	198	0.10	1.32	1.42	0.010	0.002	4.48	136	0.26
05/19/1980	7.7	11.0	7.84	415	212	210	0.04	1.46	1.5	0.010	0.005	4.41	112	0.46
06/09/1980	8.82	11.0	8.07	348	180	196	0.03	1.28	1.31	0.020	0.002	4.03	96	0.16
07/21/1980	0.4	18.0	7.47	240	220	268	0.01	1.41	1.42	0.009	0.005	6.9	188	0.65
08/25/1980	0.4	19.0	7.38	335	230	232	0.02	1.62	1.64	0.020	0.005	4.8	122	0.8
09/22/1980	4.7	16.5	7.91	290	156	178	0.01	1.08	1.09	0.010	0.002	7.6	116	0.22
10/27/1980	10.2	6.2	8.21	323	163	194	0.06	1.04	1.10	0.007	0.002	5.6	140	0.2
12/15/1980	10.6	3.8	8.11	370	181	192	0.12	1.16	1.28	0.012	0.002	5.4	108	0.34
01/26/1981	3.1	4.0	7.63	395	210	220	0.11	1.38	1.49	0.005	0.002	2.5	126	0.58
03/02/1981	1.4	4.5	7.57	420	224	234	0.18	1.30	1.48	0.005	<0.002	4.7	174	0.62
04/13/1981	10.2	9.5	8.27	370	176	184	0.11	0.88	0.99	0.018	<0.002	4.0	90	0.11
05/18/1981	6.67	12.2	7.91	368	182	180	0.09	1.04	1.13	0.018	<0.002	3.5	78	0.21
06/15/1981	2.2	15.8	7.75	350	188	193	0.01	1.60	1.61	0.026	0.002	4.2	108	0.34
07/27/1981	1.6	18.5	7.66	280	194	204	<0.01	0.74	0.74	0.008	<0.002	5.2	108	0.28
08/24/1981	0.91	20.5	7.71	370	194	216	<0.01	1.00	1.00	0.012	<0.002	4.2	112	0.24

Table 2C. Continued

	D.O.	Temp. Deg.C	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	NO2 + NO3(N)	TKN	TN	TP	React. P	Cl-	Ca2+	NH4
06/03/1998	9.04	15.1	7.98	397	216	208	0.29	N/A	0.29	<0.002	<0.002	6.2	108	0.54
06/23/1998	0.23	17.2	7.88	381	213	236	0.11	1.35	1.46	0.013	0.004	6.2	108	0.54
07/14/1998	0.11	17.9	7.86	398	202	206	0.12	1.68	1.80	0.017	0.007	<0.5	94	0.57
07/29/1998	0.18	19.2	7.57	431	213	206	<0.02	2.44	2.44	0.033	0.006	5.6	188	0.94
08/18/1998	0.13	20.3	7.89	343	174	172	0.09	0.98	1.07	0.004	0.004	6.3	100	0.10
08/28/1998	0.23	20.5	7.40	382	198	196	0.04	3.60	3.64	0.053	0.010	6.8	92	1.42
09/16/1998	0.23	20.5	8.38	364	168	176	0.12	1.06	1.18	0.015	0.005	N/A	84	0.29
09/30/1998	0.86	18.4	8.49	361	171	176	0.10	1.26	1.36	0.022	0.006	6.0	N/A	0.19
10/19/1998	9.84	12.4	8.37	355	175	186	0.12	1.12	1.24	0.009	0.008	6.0	130	0.32
11/14/1998	12.55	4.4	8.36	353	187	188	0.23	1.27	1.50	0.014	0.005	6.6	144	0.36
12/08/1998	13.1	5.0	8.43	362	186	196	0.30	1.42	1.72	0.021	0.014	6.3	100	0.30
01/13/1999	7.21	4.3	7.91	480	219	236	0.99	1.50	2.49	0.016	0.018	11.2	148	0.99
02/16/1999	2.40	N/A	7.77	526	235	250	1.52	1.64	3.16	0.015	0.007	8.6	124	1.52
03/11/1999	2.60	5.3	7.73	500	239	260	1.81	1.41	3.22	0.021	0.008	16.3	N/A	1.81
04/16/1999	6.10	7.0	8.33	411	190	200	0.56	1.23	1.79	0.017	0.003	3.9	140	0.34
05/13/1999	16.3	11.2	8.57	370	187	204	0.38	1.09	1.47	0.019	0.015	8.6	104	0.38
Mean '72-'81	**4.46**	**10.4**	**7.83**	**378**	**194**	**211**	**0.15**	**1.29**	**1.48**	**0.028**	**0.010**	**4.6**	**117**	**0.48**
Mean '98-'99	**5.07**	**13.2**	**8.06**	**401**	**198**	**206**	**0.45**	**1.54**	**1.86**	**0.019**	**0.008**	**7.5**	**119**	**0.66**
St.Dev.'72-81	**4.04**	**5.7**	**0.37**	**57**	**31**	**32**	**0.17**	**0.38**	**0.89**	**0.023**	**0.015**	**1.8**	**37**	**0.40**
St.Dev.'98-99	**5.57**	**6.5**	**0.36**	**56**	**22**	**27**	**0.55**	**0.67**	**0.90**	**0.011**	**0.004**	**3.1**	**29**	**0.52**

Table 3C. 1998-99 Rinehart Mid-Lake water quality data including samples taken from the middle (metalimnion).

03-Jun	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	Cl-	$NO_2 + NO_3(N)$	NH_4+	TKN	TP	React. P	Ca	Si	Chloro-a (mg/m^3)
Surface	7.98	375	199	204	6.2	0.29	0.38	0.97	<.005	0.004	96	3.0	N/A
Middle	8.01	380	194	202	6.0	0.26	0.37	0.93	<.005	0.002	92	2.4	
Bottom	7.98	397	216	208	6.2	0.29	0.54	N/A	<.005	<.002	108	2.6	
23-Jun													
Surface	8.72	337	184	184	7.1	0.23	0.14	1.04	0.007	0.002	112	2.5	N/A
Middle	8.52	352	191	188	7.0	0.23	0.27	1.14	0.019	0.005	108	2.4	
Bottom	7.88	381	213	236	7.9	0.11	0.61	1.35	0.013	0.004	100	3.9	
14-Jul													
Surface	8.8	330	166	172	5.6	0.12	0.13	0.92	0.006	0.004	66	3.5	2.1
Middle	8.79	328	164	180	5.5	0.15	0.14	0.92	0.009	0.004	68	3.3	
Bottom	7.86	398	202	206	<0.5	5.94	0.57	1.68	0.017	0.007	94	4.8	
29-Jul													
Surface	8.84	341	160.4	172	6.4	0.12	0.06	1.03	0.007	0.003	132	4.7	3.5
Middle	8.77	344	164.8	156	6.0	0.11	0.06	1.12	0.008	0.004	88	4.8	
Bottom	7.57	431	212.8	206	5.6	<.02	0.94	2.44	0.033	0.006	188	7.8	
18-Aug													
Surface	8.61	323	160	174	6.0	0.09	0.17	*1.04	*0.01	0.005	92	5.6	<.1
Middle	8.61	315	161	166	6.0	0.10	0.11	1.03	0.004	0.004	100	5.6	
Bottom	7.89	343	174	172	6.3	0.09	0.1	0.98	0.004	0.004	100	6.4	
28-Aug													
Surface	8.73	323	163	168	6.3	0.09	0.1	*1.07	*0.015	0.005	72	6.0	1.9
Middle	8.65	324	164	172	5.7	0.10	0.08	1.13	0.015	0.004	72	6.4	
Bottom	7.4	382	198	196	6.8	0.04	1.42	3.60	0.053	0.010	92	9.0	

Table 3C. Continued

16-Sep	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	Cl-	$NO_2 + NO_3$(N)	NH_4+	TKN	TP	React. P	Ca	Si	Chloro-a (mg/m^3)
Surface	8.57	354	168	176	6.1	0.03	0.13	0.83	0.006	0.007	80	6.9	3.7
Middle	8.57	357	169	176	6.4	0.09	0.13	1.03	0.010	0.005	72	7.0	
Bottom	8.38	364	168	176	116.0	0.12	0.29	1.06	0.015	0.005	84	7.0	
30-Sep													
Surface	8.41	366	183	180	9.0	0.09	0.17	1.19	0.016	0.009	N/A	7.2	4.1
Middle	8.48	364	172	180	8.0	0.09	0.19	1.22	0.014	0.006	N/A	6.8	
Bottom	8.49	361	171	176	6.0	0.10	0.19	1.26	0.022	0.006	N/A	7.0	
20-Oct													
Surface	8.37	346	173	184	7.0	0.14	0.31	1.20	0.006	0.007	144	7.6	4.5
Middle	8.36	353	177	184	6.0	0.13	0.30	1.14	0.010	0.008	120	7.4	
Bottom	8.37	355	175	186	6.0	0.12	0.32	1.12	0.009	0.008	130	7.4	
14-Nov													
Surface	8.35	355	182	188	6.6	0.22	0.36	1.22	0.014	0.005	140	7.5	8.2
Middle	8.31	354	187	188	6.0	0.21	0.38	1.26	0.012	0.005	158	7.3	
Bottom	8.36	353	187	188	6.6	0.23	0.36	1.27	0.014	0.005	144	7.3	
08-Dec													
Surface	8.31	355	190	196	8.4	0.3	0.45	1.50	0.038	0.024	100	N/A	14
Middle	8.39	364	186	200	6.1	0.3	0.40	1.40	0.014	0.013	96	N/A	
Bottom	8.43	362	186	196	6.3	0.3	0.39	1.42	0.021	0.014	100	N/A	
13-Jan													
Surface	8.21	422	206	208	16.1	0.34	0.44	1.62	0.024	0.019	144	6.9	29
Middle	8.29	427	200	212	9.8	0.35	0.42	1.27	N/A	0.012	144	6.62	
Bottom	7.91	480	219	236	11.2	0.99	0.64	1.50	0.016	0.018	148	7.2	

Table 3C. Continued

16-Feb	pH (s.u.)	conductivity (umhos)	alkalinity	total hard.	Cl-	$NO_2 + NO_3(N)$	NH_4+	TKN	TP	React. P	Ca	Si	Chloro-a (mg/m^3)
Surface	8.22	443	198	207	7.0	0.42	0.60	1.43	0.013	0.009	112	6.78	0.2
Middle	8.19	450	204	215	7.0	0.44	0.64	1.45	0.016	0.006	92	7.24	
Bottom	7.77	526	235	250	8.6	1.52	0.97	1.64	0.015	0.007	124	7.23	
11-Mar													
Surface	8.36	399	198	204	9.7	0.41	0.56	1.27	0.018	0.009	98	6.15	3.6
Middle	8.17	418	215	224	10.2	0.42	0.67	1.34	0.024	0.01	100	6.58	
Bottom	7.73	500	239	260	16.3	1.81	0.91	1.41	0.021	0.008	N/A	6.76	
16-Apr													
Surface	8.33	408	193	208	3.8	0.59	0.32	1.16	0.009	0.004	104	4.1	2.6
Middle	8.38	407	194	196	5.9	0.82	0.43	1.17	0.015	0.013	124	4.1	
Bottom	8.33	411	190	200	3.9	0.56	0.34	1.23	0.017	0.003	140	4.2	
13-May													
Surface	8.42	358	181	196	6.8	0.36	0.21	1.08	0.013	0.007	124	2.0	1.2
Middle	8.45	366	182	196	7.9	0.39	0.17	1.22	0.017	0.013	96	2.1	
Bottom	8.57	370	187	204	8.6	0.38	0.15	1.09	0.019	0.015	104	2.6	

APPENDIX D

Table 1D. Seepage meter chemistry and flow data from Rinehart Lake.

Site	T.Hard.	TP	Reac.P	TKN	NO2+3-N	Cl-	NH4+	Si	Flow (cm/day)
1	836	0.028	0.014	35.50	<0.02	38.0	32.00	23.5	0.028
2	356	0.033	0.022	4.73	<0.02	5.0	4.67	15.2	0.025
3	348	0.004	0.007	1.16	<0.02	0.8	0.66	12.3	0.065
4	254	0.003	0.006	0.30	8.3	14.0	0.09	10.7	0.194
5	424	0.007	0.004	0.41	23.7	22.0	0.02	6.2	11.520
6	376	0.010	0.009	11.50	<0.02	11.0	10.90	19.2	0.009

Table 2D. Rinehart Lake private well chemistry data. See Figure 16 for location of site numbers.

Site #	pH	Cond.	T.Hard.	Alk.	Cl-	NO3	Reac.P
1	7.24	686	324	240	16	15.3	0.007
2	7.16	582	340	285	8	4.1	0.011
3	7.41	623	290	284	6	6.2	0.005
4	7.38	618	298	291	4	4.4	0.006
5	7.56	553	292	266	2	0.9	0.002
6	7.66	553	276	268	4	0.9	0.002
7	7.52	585	282	282	3	2.1	0.002
8	7.50	585	280	274	4	4.8	0.004
9	7.23	587	288	289	4	<0.02	0.011
10	7.79	544	292	262	6	4.4	0.006
11	7.81	593	6	274	4	2.1	0.010
12	7.61	361	178	177	3	<0.02	0.004
13	7.34	457	226	220	<1.0	<0.02	0.000
14	7.46	397	202	192	4	<0.02	0.007
15	7.46	442	236	249	4	<0.02	0.039
16	7.26	500	260	260	3	<0.02	0.012
17	7.63	432	224	224	<1.0	<0.02	0.009
18	7.10	529	<4.0	212	<1.0	<0.02	0.004
19	7.73	347	230	203	<1.0	0.3	0.009
20	7.62	548	258	241	3	6.3	0.004
21	7.73	405	208	197	<1.0	1.6	0.002
22	7.51	353	181	188	<1.0	<0.02	0.016
23	7.65	378	198	191	1	<0.02	0.003
24	7.93	512	<4.0	231	<1.0	<0.02	0.005

APPENDIX E

Table depicting aquatic plant, sediment, and interstitial water data from Rinehart Lake.

Plant Site	TKN	TP	N:P	Biomass (g/m^2)						
1	29410	2933	10.0	1550.4						
2	10835	583	18.6	853.6						
3	17945	1158	15.5	444.8*						
4	9855	380	25.9	1125.6						
5	16430	779	21.1	572.8						
6	13550	758	17.9	825.6						
7	10155	473	21.5	2020.8						
8	10240	418	24.5	3072.0						
9	10775	322	33.5	1317.6						
10	14690	635	23.1	1136.0						
Sediment	NO3	NH4	per. solids	per. OM	pH	K	Extr. P			
1	3.9	228	7.5	30.0	7.93	75	5			
2	150.0	507	2.6	9.5	7.77	45	1			
3	25.6	1731	1.9	33.2	7.92	63	1			
4	20.6	777	2.0	7.8	7.79	34	1			
5	4.9	190	8.9	26.9	7.79	70	2			
6	1.0	15	41.0	6.3	7.79	20	3			
7	1.4	100	27.3	9.4	7.73	26	2			
8	1.0	29	47.6	5.4	6.97	22	2			
9	0.8	69	45.7	4.3	6.89	20	2			
10	1.2	48	33.1	7.7	7.04	25	2			
Interstitial	NO3	NH4	TKN	TN	TP	N:P	React.P	T.Hard.	Cl	Si
1	0.12	10.30	11.20	11.32	1.070	10.6	1.050	404	7.1	25.9
2	8.60	0.14	0.59	9.19	0.062	148.2	0.041	328	11.8	9.2
3	0.22	17.20	18.70	18.92	0.135	140.1	0.037	444	11.6	28.6
4	0.06	6.60	7.40	7.46	0.095	78.5	0.026	308	7.5	17.9
5	0.05	11.60	12.30	12.35	0.048	257.3	0.021	280	7.5	22.7
6	0.06	2.07	2.91	2.97	0.072	41.3	0.036	228	8.2	15.4
7	0.05	9.80	12.50	12.55	0.111	113.1	0.036	372	10.9	26.1
8	0.07	3.42	4.06	4.13	0.037	111.6	0.021	256	8.1	16.9
9	0.06	7.55	8.05	8.11	0.037	219.2	0.019		9.1	19.1
10	0.06	1.19	2.24	2.30	0.038	60.5	0.019	164	9.2	11.8

* - Site 3 biomass was significantly impacted by homeowner removal of aquatic plants.

APPENDIX F

Table of on-site sewage disposal system data.

Site #	~Setback from Lake (ft)	~Elevation Above Lake (ft)	Type of System
1	N/A	<5	Septic Tank
2	375	<5	Seepage Trench
3	375	<5	Seepage Trench
4	90	<5	Holding Tank
5	N/A	<5	Holding Tank
6	100	<5	Holding Tank
7	100	<5	Holding Tank
8	N/A	<5	Holding Tank
9	90	<5	Holding Tank
10	100	2	Holding Tank
11	120	<5	Holding Tank
12	125	2	Holding Tank
13	200	5	Seepage Bed
14	100	<5	Seepage Trench
15	120	<5	Seepage Bed
16	150	2	Holding Tank
17	300	9	Seepage Trench
18	100	<5	N/A
19	100	4	Seepage Bed
20	60	3	Seepage Bed
21	250	6	Seepage Trench
22	500	4	Seepage Bed
23	400	8	Mound
24	360	9	Mound
25	360	7	Mound
26	120	7	Holding Tank
27	300	5-10	Seepage Bed
28	200	5	Seepage Bed
29	300	>20	Seepage Trench
30	250	>20	Seepage Bed
31	140	7	Seepage Bed