# LAKE ASSESSMENT PROGRAM

1991

CIRCLE LAKE
(MDNR ID. # 66-0027)
Rice County, Minnesota

MINNESOTA POLLUTION CONTROL AGENCY
Division of Water Quality
Nonpoint Source Section
and
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<u>TABLE OF CONTENTS</u>

## LIST OF TABLES



## LIST OF FIGURES



## APPENDIX



The following have been combined into a 'FTALA' folder:

-Lake septic system survey forms
-MDNR fish surveys, wildlife survey, lake level information, correspondence
-newspaper articles
-watershed maps

## SUMMARY AND CONCLUSIONS

Circle Lake was sampled during the summer of 1991 as part of the Minnesota Pollution Control Agency's (MPCA) Lake Assessment Program. Data collected during the study showed that in terms of total phosphorus, chlorophyll and Secchi disk transparency, the water quality of Circle Lake is poorer than similar lakes in the same ecoregion. The mean summer concentrations of total phosphorus and chlorophyll were 575 and 126 ug/l (ug/l = micrograms per liter) respectively and the mean Secchi disk transparency was 4.1 feet. Based on these values, and on Carlson's Trophic Status Index (TSI) (Carlson, 1977), which ranges from 0 (very oligotrophic) to 100 (hypereutrophic), Circle Lake would be considered hypereutrophic. The average TSI value for Circle Lake is 78.

The TSI value for secchi disk transparency (TSIS) suggests less eutrophic conditions (better transparency) than the values calculated for total phosphorus (TSIP) and chlorophyll (TSIC). This is often the case for lakes with very high total phosphorus concentrations. While the relatively low TSIS is encouraging, it is very unlikely that it would decrease further without very large total phosphorus reductions. Although the TSIS may "underestimate" productivity, secchi disk readings are still important, especially for looking at water quality trends.

An empirical computer lake model was used to predict 1991 water quality and the results were compared to observed conditions. The model predictions and observed conditions did not agree well. The model estimated total phosphorus concentrations which were much lower than those observed in the lake. The contribution of nutrients from the sediments during the summer may provide some explanation for this discrepancy.

The water quality of Circle Lake is poor relative to other lakes in the ecoregion; however, this is partially due to the fact that the lake is located in a more fertile portion of the ecoregion. The mean total phosphorus measured in 1991 was greater than for three other years (1980, 1981, and 1989) in which phosphorus was measured. This may indicate increasing phosphorus concentration in the lake over time. Further land use changes in the immediate watershed, such as increased development and draining or filling of wetlands, could result in a continual increase in phosphorus loading and a resulting decrease in water quality.

The following recommendations are based on the 1991 assessment of Circle Lake.

1. Participation in the Citizens Lake Monitoring Program (CLMP) should continue since it is an effective way to assess long-term and year-to-year variations in algal productivity (lake trophic status). At a minimum, monitoring should continue at the current

CLMP site (208 on Figure 2). Consideration should also be given to monitoring site 102.

2. The Forest Township Agri-Lakes Association (FTALA) should attempt to provide educational materials to homeowners with respect to lawn maintenance and shoreline protection. Protection of the existing vegetation along the shore will minimize erosion and preserve the aesthetic value of the lake. Lakeshore with a diverse community of native vegetation will also provide better habitat for songbirds and other small animals than large areas of lawn. The MPCA, MDNR, and county offices may be able to provide assistance in this area. The book Landscaping for Wildlife and the booklet A Citizens Guide to Lake Protection may also be a useful educational tool for the committee.

3. Any development in the immediate watershed should be completed in ways that the impacts to lake water quality are minimized. Provisions for setbacks and vegetative buffer strips should be strictly adhered to. Soil loss can be reduced by utilizing best management practices during construction or road building. Rice county's shoreland regulations will be important in this regard.

4. Activities in the Circle Lake watershed, such as wetland removal or major land use alterations that change the drainage or flow patterns, should be discouraged. Maintenance of effective buffers between agricultural areas and ditches, streams, and the lake will help to minimize nutrient rich runoff.

5. The members of FTALA should keep up to date on the progress of the French Lake Clean Water Project. Some of the projects

management techniques may be applicable at Circle Lake. Those efforts which address shoreline management, and aquatic plant control will be of special interest to anyone interested in Circle Lake.

6. Although it can be difficult to assess how much impact individual projects within the watershed will have on the lake, the cumulative effect can be significant. In addition to the positive effects on water quality, watershed projects such as restoration of wetlands, protection of natural areas, and creation of buffer strips will improve the wildlife habitat, plant diversity and aesthetics of the watershed.

# LAKE ASSESSMENT PROGRAM: 1991

Circle Lake

(I.D. #66-0027)

Rice County, Minnesota

## INTRODUCTION

The Forest Township Agri-Lakes Association (FTALA) applied for consideration in the Lake Assessment Program in 1991 and listed in their application the following water quality concerns in Circle Lake:

* An increase in the frequency of toxic blue-green algae blooms in the last 10 years.
* Aquatic vegetation growth has increased dramatically.
* The potential for increased pressure on the lake resource as demographics change.

The group attributed the water quality problems to nutrient rich agricultural runoff which reaches the lake through the extensive drainage system in the watershed. Improperly maintained septic systems, extensive use of lawn fertilizers and the removal of natural lake shore vegetation were also cited as contributors to water quality problems. Data gathered by Rice County in 1984 consistently showed fecal coliform bacteria contamination at two sites in the lake. The presence of fecal coliform bacteria indicates that the lake has been impacted by untreated animal and/or human waste.

The Lake Assessment Program was designed to assist lake associations or municipalities in the collection and analysis of baseline water quality data for the purpose of assessing the current trophic status of their lake. The work plan for participants in the Lake Assessment Program includes collection of lake transparency data through the Citizens Lake Monitoring Program (CLMP) and examination of land-use and drainage patterns in the watershed. During the summer of 1991 staff of the Minnesota Pollution Control Agency (MPCA) collected baseline water quality data as a part of the LAP for Circle Lake. Conclusions and recommendations based on watershed information and water quality data are included in the report.

## BACKGROUND

Circle Lake was sampled five times during the summer of 1990 by Ed Weir and Ellen Snyder of the MPCA Rochester regional office and Will Munson of the MPCA St. Paul office. Richard Nugent provided a boat and motor for the sampling crew. Ann Passe and Sam Sunderlin were the Citizens Lake Monitoring Program volunteers, and they gathered watershed information with the assistance of the Soil and Water Conservation District.

The sampling days were used as opportunities to discuss lake protection issues, and members of the lake association hosted elected officials, St. Olaf College students and staff, county officials, and other state agency staff. This format gave those involved in lake protection a first hand look at the concerns of the lakeshore residents and an opportunity for lake shore residents to meet those people who will be involved in various aspects of future lake protection issues.

Circle Lake is located ten miles north of the City of Faribault in central Rice County. The surface area of the lake is 976 acres, placing it in the top 5 percent in terms of area statewide (MDNR, 1968), and making it the second largest lake in Rice County. Circle Lake has a maximum depth of 16 feet, making it shallower than 75 percent of lakes included in a fairly comprehensive statewide study (Heiskary, 1985). Circle Lake is also shallower than most of the larger lakes in Rice County (Appendix C). The mean depth of the lake is 6.0 feet, and the littoral zone (the lake zone which supports rooted vegetation) covers approximately 100 percent of the lake. Circle Lake contains a 100 acre island. According to Zumberge (1952), Circle Lake was formed by the depression left by an ice block in glacial till.

Soils in the watershed belong to the Lester-Hayden-LeSueur (south portion) and Kilkenny-Shields-Lerdal (north portion) associations. These associations are nearly level to steep loams that formed in upland glacial till. Runoff is moderate to rapid and the potential for erosion can be severe. Permeability is moderate and the seasonal high water table ranges from 2 feet to greater than 10 feet. The soils of the Lester-Hayden-LeSueur association are moderately to well suited for use as septic tank drain fields for private homes except in areas where high slopes pose a problem. Soils of the Kilkenny-Shields-Lerdal association are not as well suited for drain fields due to slow permeability. Controlling erosion is a principal management concerns for both associations.

The native vegetation of the region was mixed deciduous trees and tall prairie grasses. Much of the watershed is now used for crops. While there are only small areas of native vegetation remaining in the watershed (including a band on the perimeter of the island), additional land is in forest, wooded pasture, wetland, or set-aside fields.

Since land use affects water quality, it is helpful to divide the state into areas of similar land use and water resources. These areas are termed ecoregions. Minnesota can be divided into seven ecoregions based on soils, land surface form, natural vegetation, and current land use (Figure 1). Circle Lake is located in the southern lobe of the North Central Hardwood Forest Ecoregion near the border of the Western Corn Belt Plains ecoregion. Land use composition in the watersheds of the North Central Hardwood Forest (NCHF) ecoregion is typically 22-50% cultivated, 11-25% pastured and open, 14-30% water or marsh, 6-25% forested and 2-9% developed (Heiskary and Wilson, 1990). Although it isn't always the case for watersheds at the margins of ecoregions, the Circle Lake watershed is more similar to the land use in the North Central Hardwood Forest Ecoregion than the typical land use in the Western Corn Belt Plain ecoregion (Table 1). In terms of depth, Circle Lake is more typical of lakes in the Western Corn Belt Plain ecoregion.

Water quality information was collected on May 20, June 11, July 9, August 6, and September 9, 1991 at two sites on the lake (Figure 2). Site 101 was located just east of the south end of the island in the deepest part of the lake. Site 102 was located in the shallower western arm of the lake. The two sites were selected to reflect water quality differences that might occur within the lake. Lake surface samples were collected with an integrated sampler, a PVC tube 6.6 feet (2 meters) in length with an inside diameter of 1.4 inches (3.5 cm). Near-bottom samples were collected with a 2-liter Kemmerer sampler, a "water trap" that closes at the depth a sample is desired. Zooplankton samples were collected from 5-meter tow using a Wisconsin plankton net. A qualitative evaluation of the zooplankton sample was made in the field.

Sampling procedures were followed as described in the MPCA Quality Control Manual and analyzed by the Minnesota Department of Health for total phosphorus, total kjeldahl nitrogen, nitrate-nitrite nitrogen, suspended solids, alkalinity, chloride, color, turbidity, and chlorophyll a. Field measurements of pH, conductivity, Secchi disk transparency, and temperature and dissolved oxygen profiles were taken by MPCA staff. Algal composition was determined from surface samples by means of a rapid assessment method. CLMP transparency measurements dating back to 1974 along with water quality data collected in 1980, 1981, 1986, 1989 are available for comparison. All data with the exception of algal composition was stored in STORET, the U.S. Environmental Protection Agency's national water quality data bank. The following discussion assumes that the reader is familiar with basic water quality terminology as used in the Citizens Guide to Lake Protection.

## RESULTS AND DISCUSSION

### In-lake Conditions, 1991

#### Temperature

In temperate climates, lakes deeper than Circle Lake tend to stratify into three layers during the summer as a result of temperature caused density differences. The metalimnion, or thermocline (layer of rapid temperature change) separates the epiliminion (warmer surface water) from the hypolimnion (cooler deeper water). In deeper lakes, this stratification usually remains stable through the summer. Shallower lakes, like Circle Lake, tend not to exhibit stable stratification because the water column is relatively easily mixed by wind. The greatest temperature difference between the surface and the bottom of the deepest part of the Circle Lake was 5°C, recorded on June 11. The lake could have mixed completely on the following day if wind conditions were right. Whether a lake stratifies or not, and how stable that stratification is, can greatly affect dissolved oxygen concentrations in a lake, and how a lake responds to nutrient loading. The temperature and dissolved oxygen profiles measured at site 101 are indicative of weak stratification (Figures 3a-e).

Dissolved Oxygen

Dissolved oxygen concentrations in the deeper water of site 101 fell below 5 mg/l on June 11, July 9, and August 5 (Figure 3). This was also the case for June 11 and July 9 at site 102. On July 9 and August 5 at site 101, and on July 9 at site 102, the low oxygen measurements were at all depths below 3 ft. Dissolved oxygen concentrations greater than 5 mg/l are considered necessary for long-term survival of game fish.

The presence or absence of oxygen at different depths in a lake will determine where fish and other organisms will be found. In the case of Circle Lake, game fish which cannot tolerate low oxygen level might have to stay in the top few feet of the water column at times in June and July. This could be a problem for fish adapted to a deeper habitat.

Although the deeper water of a polymictic (mixes frequently) lake like Circle Lake can be reoxygenated during a mixing event, dissolved oxygen is depleted from the deeper water during calm periods. Since one of the processes that consumes oxygen in plant decomposition, oxygen depletion can occur quite rapidly in a hypereutrophic lake like Circle Lake.

Total Phosphorus

Total phosphorus (TP) is an important nutrient for plant growth. In most lakes it is the nutrient which limits the amount of plant and algae growth. Total phosphorus concentrations in Circle Lake were lowest in May and tended to increase throughout the summer (Figure 4). The mean (average) TP concentration of the epilimnion between June 15 and September 15 of the 1991 sampling period was 575 ug/l. Concentrations ranged from 325 to 670 ug/l. The mean TP value is significantly higher than concentrations measured in a set of representative lakes in the North Central Hardwood Forest ecoregion of Minnesota The TP concentrations in these representative lakes tend to fall between 23 to 50 ug/l (Table 3). Based on total phosphorus concentrations measured in 436 lakes in the NCHF ecoregion, 98 percent of the lakes have TP concentrations less than 575 ug/l.

In lakes that maintain stable stratification over the summer, epilimnetic phosphorus concentrations often decrease over the summer. Algae in the epilimnion assimilate phosphorus as they grow. When algae die, they settle into the hypolimnion where phosphorus is released into the water during decomposition. The decomposition also consumes oxygen. The settling, along with the release of phosphorus from the sediments under low oxygen conditions results in a decline in epilimnetic concentrations and a increase in hypolimnetic concentrations during the period of stratification (Figure 4). Epilimnetic TP concentrations did not decrease over the summer in Circle Lake, probably because of it's polymictic status. However, hypolimnetic TP concentrations were greater than epilimnetic concentrations on 2 of the 3 dates both layers were sampled. Even though the lake is polymictic, high oxygen demand in the sediments produces oxygen poor conditions conducive for phosphorus release.

On all sample dates, epilimnetic TP concentrations at site 102 were somewhat greater than at site 101 (Table 4). There are two possible reasons for this. First, even weak stratification at the deeper site 101 allowed some phosphorus to settle out, or be released from the sediments, then temporarily tied up in the epilimnion. The second possibility is that more phosphorus is entering the lake in the vicinity of site 102. It appears that approximately half of the watershed may drain into the lake near site 102.

Whenever phosphorus is tied up in the hypolimnion, it is unavailable for the production of algae in the epilimnion. Since stratification coincides with the main growing season, this can serve to limit algae growth. Since the stratification in Circle

Lake is quite weak, phosphorus is being stirred back into the epilimnion during the growing season. In the North Central Hardwood forest ecoregion, distinct differences exist between lakes which maintain a stable thermocline (referred to as dimictic lakes) and those which only stratify intermittently or do not stratify at all. In general, the phosphorus concentration of dimictic lakes tend to be two to three times lower than those lakes which do not remain stratifies throughout the summer.

Transparency (Secchi disk)

The Secchi disk transparency is an indirect measurement of the amount of algae and other suspended material in the lake. Transparency values can often be accurately correlated to the chlorophyll and the total phosphorus concentrations. The average transparency measured during the lake assessment sampling was 3.75 feet (1.1 meters). The average transparency including the values determined by volunteer measurements was equal to 3.7 feet (1.1 meters). The two averages agree very well.

Total Nitrogen

Total nitrogen (TN), which is defined as the sum of the total Kjeldahl nitrogen and nitrate-nitrite nitrogen, averaged 3.97 mg/l during the summer of 1991. This value (as well as both components) is higher than the typical TN value for the ecoregion, which ranges between 0.8 to 1.2 mg/l (Table 3). Kjeldahl nitrogen includes organic nitrogen and ammonium. The high nitrate-nitrite concentration, on the other hand, point to "fresh" sources such as animal feedlots or livestock in the lake. The presence of "fresh" sources is supported by a relatively high chloride concentration. This Values for both forms of nitrogen as high as those measured indicate that sources including fertilizer, septic system effluent, and animal waste are strongly influencing the nitrogen concentrations in Circle Lake.

TN:TP

Nitrogen is a nutrient required for growth of aquatic plants and algae. Although phosphorus is usually the nutrient limiting the productivity of a lake, nitrogen may be the limiting nutrient in some situations. The ratio of TN:TP can indicate which nutrient is limiting the growth of algae and aquatic plants in the lake. For Circle Lake the TN:TP ratio is 7:1. The value of this ratio suggests that at least at some times, nitrogen is limiting plant growth in Circle Lake. In theory, more algae could grow at these times if more nitrogen were available. At some point, however, algae growth may become dense enough that it limited by light availability. Nitrogen limitation points to the need for very large reductions in phosphorus entering the lake.

Chlorophyll a

Chlorophyll (a pigment produced by algae) concentrations provide an estimate of the amount of algae in the lake. During the summer, lake chlorophyll concentrations ranged from 30 to 425 ug/l with a mean concentration of 126 ug/l (Table 3). Concentrations from 10 to 20 ug/l would be perceived as a mild algal bloom, and concentrations greater than 30 ug/l would be perceived as severe nuisance conditions (Heiskary and Walker, 1988). The chlorophyll values reported for Circle Lake exceeded the nuisance conditions for all sampling dates except May (not included in above average), and are much higher than typical values determined for the North Central Hardwood Forest ecoregion which typically range between 5 and 22 ug/l. It is interesting to note that the chlorophyll concentrations are significantly less at site 101 than at site 102 on all sampling dates. Secchi transparency was also greater at site 101.

Phytoplankton

Phytoplankton samples from May, July and August were analyzed and found to contain an algal population of limited diversity. In July and August, the blue-green algae Aphanizomenon flos-aquae comprised 99 and 98 percent respectively by volume of the phytoplankton population.

## Zooplankton

Zooplankton (microscopic animals) were collected and analyzed qualitatively during each sampling event. Abundant small and medium varieties were observed during May and June. Few zooplankton were present during July and August. No significant populations of large bodied zooplankton were observed during any sampling event. Large bodied zooplankton can be beneficial for lakes because of their ability to consume large quantities of algae. This reduction in algae may have a noticeable affect on lake transparency. It should be noted, however, that even large bodied zooplankton may not feed on all algae varieties.

## Physical Condition/Recreational Suitability

Along with the CLMP transparency measurements, subjective measures of the lake's "physical appearance" and "recreational suitability" (Heiskary and Wilson, 1988) were made by the CLMP observer (Table 2). Physical appearance ratings range from "crystal clear" (class 1) to "dense algal bloom, odor, etc." (class 5), and recreational suitability ratings range from "beautiful, could not be nicer" (class 1) to "no recreation possible" (class 5). Transparency, physical appearance, and recreational suitability values from the CLMP records are summarized on the next page for 1991:

| Month | obs | Transparency (mean) | Physical Condition (mean class) | Recreational Suitability (mean class) |
|---|---|---|---|---|
| June | 7 | 5.6 feet | 3 | 3 |
| July | 9 | 3.9 feet | 2.5 | 2.5 |
| August | 6 | 3.7 feet | 2.5 | 2.5 |
| September | 3 | 2.8 feet | 3 | 3 |

These data show that transparency, physical condition, and recreational suitability do not always agree. Since transparency is an indication of water quality, one would expect high transparency to correspond to high physical condition and recreational suitability (low scale values). In June, the month with the highest transparency, the lake was given physical condition and recreational suitability ratings that were no better than any other month. This may be due to different types of algae blooms being experienced during the summer.

Other water quality parameters including color, total suspended solids, total suspended inorganic solids, pH, and turbidity were all higher than typical ecoregion values. Alkalinity and conductivity fell within the ranges typical for the ecoregion.

## TROPHIC STATUS

One means of evaluating the trophic status or productivity of a lake and interpreting the relationship between total phosphorus, chlorophyll, and Secchi disk transparency is Carlson's Trophic State Index (Carlson, 1977). This index was developed from the relationships of summer Secchi disk transparency and the surface water concentrations of total phosphorus and chlorophyll. Trophic state index (TSI) values are calculated as follows:

$$\text{Total phosphorus TSI (TSIP)} = 14.42 \ln(TP) + 4.15$$

$$\text{Chlorophyll TSI (TSIC)} = 9.81 \ln(\text{Chl } \underline{a}) + 30.6$$

$$\text{Secchi disk TSI (TSIS)} = 60 - 14.41 \ln(SD)$$

Note units: TP in ug/l, Chlorophyll in ug/l, Secchi disk transparency disk in meters.

Possible values for TSI range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). With this index, each increase of 10 units represents a doubling of algal biomass.

The TSI values of total phosphorus, chlorophyll, and Secchi disk transparency for Circle Lake are 96, 78, and 59 respectively, with an average of 78 (Table 3, Figure 6). Based on these values the lake would be considered hypereutrophic or very nutrient rich. Usually the three TSI values are more similar than those determined for Circle Lake. Part of the discrepancy may be due to the dominance of the blue-green algae Aphanizomina. This algae species grows in small bunches which resemble lawn clippings. Under these conditions, Secchi disk transparencies tend to be higher than would be expected based on the TP and chlorophyll concentrations. Provided this is taken into account, Secchi disk monitoring of Circle Lake can still provide a reliable indication of the algal and phosphorus trends in the lake.

Comparison of TSI values for Circle Lake to those of other lakes in the North Central Hardwood Forest ecoregion can provide a basis for evaluating the water quality of the lake. A TSI value of 78 ranks in the 6th percentile for the ecoregion. In other words, 94 percent of the lakes in the region have TSI values less (are less eutrophic) than Circle Lake.

Another way to compare the trophic status variables is on scatterplots. Figure 5 illustrates the general relationships between total phosphorus, chlorophyll, and Secchi disk transparency. At the very high phosphorus concentrations exhibited in Circle Lake, these relationships tend to break down. At lower levels, however, the three parameters are closely correlated since phosphorous is often the nutrient limiting algae production and Secchi disk transparency is dependent upon the algae levels in the lake. The plots show that increases in phosphorus will result in an increase in chlorophyll and a decrease in Secchi disk transparency depth. Alternately, a decrease in phosphorus will result in an increase in water quality as measured by chlorophyll concentrations and transparency readings. It is important to note that because Circle Lake data plots on the upper ends of Figures 5b and 5c, large reductions in total phosphorus or chlorophyll will be required for noticeable increase in transparency.

## TREND ANALYSIS/HISTORICAL DATA

A relatively large amount of historical data is available for Circle Lake and other lakes in Rice county. National Biocentric completed a water quality evaluation of Rice county in 1972. Secchi disk measurements for Circle Lake taken by the CLMP volunteers are available from 1974 to present. Water quality data from county and state sampling efforts are available for 1980, 1981, 1989, and 1991.

Mean summer total phosphorus, chlorophyll, and Secchi disk measurements from the four state and county sampling efforts are as follows:

| Year | TP (ug/l) | Chorophyll a (ug/l) | Secchi (feet) |
|---|---|---|---|
| 1980 | 288 (4) | | 1.1 (4) |
| 1981 | 200 (3) | | 2.2 (7) |
| 1989 | 419 (6) | 98.3 (5) | 3.5 (22) |
| 1991 | 575 (8) | 126.4 (8) | 4.1 (33) |

Based on the data above, it appears that TP has increased since 1980. Some of the difference may be attributed to natural factors (such as climate) which can influence phosphorus concentrations. It is interesting to note that Secchi disk readings seemed to increase along with phosphorus concentrations. This is the opposite of would be expected. One possible explanation is a shift in the algae community to forms which tend to clump, thereby producing a greater water clarity than there would be if the algae were uniformly distributed in the water.

In a study of nine lakes in Rice County conducted by National Biocentrics in 1972, Circle Lake was grouped with two others as having the poorest water quality. This ranking was determined through the use of a water quality indices based on transparency, biological oxygen demand, available phosphate, ammonia, pH, and total coliform. A direct comparison of data collected for the lake assessment and data collected in the 1972 study is probably not very meaningful. Nevertheless, the 1972 study is an interesting resource. Mazaska and Fox lakes were determined to have the best water quality, while Cannon and Union were the other two poor water quality lakes (National Biocentrics, 1972).

In 1986 Rice County staff compiled a water quality evaluation for the county which was a comparison of historical data and data collected by Rice county in 1984. The report stated that water quality has changed very little since 1972. While this statement was not based on a great deal of information, it does appear that Circle Lake has been hypereutrophic for some time. Fecal coliform was detected in four of eighteen samples during the sampling in 1984. The problem of sediment "choking" the northwest bay was stressed.

Secchi disk transparencies have been collected by volunteers for a number of years since 1974 (Figure 7). Although it seems that the total phosphorus concentrations have increased in the last decade, the Secchi disk values do not reflect this very well. With the exception of 1975 and 1976, summer mean transparency values have been greatest in the past few years. Possible reasons for the discrepancy between phosphorus and Secchi disk values include relatively few measurements of both parameters in the 1970's and early 1980's, or an algae community shift as discussed earlier.

## NUTRIENT SOURCES

### Watershed

Wolf Creek is the major stream inlet to Circle Lake (Appendix C). Wolf Creek originates in Lake Mazaska and continues through Fox Lake before entering Circle Lake. The majority of the Circle Lake watershed, however, is drained by a network of small streams and ditches which come together and drain into the lake on the south side of the northwest arm of the lake. There is a fairly extensive wetland area bordering this part of the lake.

Based on what is known for the region as well as what has been observed during this study, nonpoint source pollution is likely a major source of nutrients to Circle Lake. Nonpoint pollution sources include: agricultural runoff; pesticide and fertilizer use on agricultural land and lawn; feedlot runoff; urban runoff from streets, yards, and construction sites; leachate from septic systems; dredging and drainage activities; and the impacts from the loss of wetlands.

Although it is unrealistic to expect that all nonpoint pollution sources can be eliminated, the implementation of Best Management Practices (BMP's) and other land use changes can minimize human impacts on water quality.

To control soil erosion, reduce the use of fertilizers and pesticides, and improve manure management, best management practices should be selected that meet water quality goals and fit individual farm operations. Refer to the MPCA's Agriculture and Water Quality publication for more information on agricultural BMP's.

Culverts which empty directly into the lake were identified in this study. These, and direct runoff from the immediate watershed can contribute a significant amount of nutrients to the lake. Three sources of nutrients were identified as potential problems in the immediate watershed of Circle Lake: livestock pastured along the lake shore, failing on-site sewage treatment systems, and lawn fertilizers which contain phosphorus.

### Livestock

Cattle allowed to wade in a lake tend to increase erosion along the shoreline and degrade water quality in the lake. Animal manure deposited directly to the lake contributes nutrients, organic material and bacteria. Maintaining an effective buffer of vegetation between permanent pasture and the lake would decrease the runoff of contaminants from the animal manure.

### On-site sewage treatment systems/lawn care

A survey form was sent out to about 30 property owners around Circle Lake by the Association. Thirty forms were returned, out of 30 homes on the lake. A copy of the form and a summary of the results is included in Appendix 2. The purpose of this survey is to provide the Association with some basic information regarding the type of on-site systems on the lake, age of the systems, type of dwelling, and frequency of pumping. This information should assist the Association and county in determining whether more education is needed with respect to design and maintenance of on-site systems and lake safe lawn care practices. The table below summarizes the responses. The majority of the on-site systems (73 percent) were 20 years old or less, while 27 percent were greater than 21 years of age or of unknown age. About 57 percent of the respondents pumped their systems at least once every two years. The remainder did not respond to the question, or indicated less frequent pumping. Minnesota Extension Service recommends pumping every one to three years for a 1,000 gallons tank serving a three bedroom house and four occupants (assumes year round use).

The survey also asked about lawn care practices. Lawn fertilizers can be a source of nitrogen and phosphorus, and therefore, are not recommended for use around lakes or in residential areas which are serviced by storm sewers that drain into lakes. In particular, those high in phosphorus should be used only in the quantities needed, as determined by present soil nutrient conditions. A buffer of unfertilized natural vegetation should be maintained along the shoreline to help control erosion as well as trap some of the nutrients that may run off the lawn and into the lake. Leaving grass clippings on a lawn can reduce the need for fertilizers; however, in areas where clippings and leaves could wash into the lake, removal to a compost site away from the lake is recommended.

# Septic System Survey Results

## Participation

About 30 surveys were sent to property owners around Circle Lake. Thirty surveys were returned. Of the 30 residents, 25 are year-round residents and 5 are seasonal residents.

## System Types

| | | |
|---|---|---|
| Septic tank - drainfield | 23 | (77%) |
| Septic tank - drywell | 4 | (13%) |
| Privy | 1 | (3%) |
| Other | 2 | (7%) |

## System Ages

| | | |
|---|---|---|
| 0-5 yr | 6 | (20%) |
| 6-10 yr | 9 | (30%) |
| 11-15 yr | 3 | (10%) |
| 16-20 yr | 4 | (13%) |
| 21-25 yr | 4 | (13%) |
| 26-30 yr | 2 | (7%) |
| 31+ yr | 0 | |
| unknown | 2 | (7%) |

## Type of Dwelling

| | | |
|---|---|---|
| Seasonal | 5 | (17%) |
| Year round | 25 | (83%) |

Distance from lake to closest point of system (in feet)

| | | |
|---|---|---|
| 0-50 | 2 | (7%) |
| 51-100 | 6 | (20%) |
| 101-150 | 10 | (33%) |
| 151-200 | 6 | (20%) |
| 201-250 | 3 | (10%) |
| 251+ | 2 | (7%) |
| no response | 1 | (3%) |

System Pumping

| | | |
|---|---|---|
| every year | 3 | (10%) |
| at least every 2 years | 14 | (47%) |
| not regularly (less than every 2 years) | 8 | (27%) |
| no response | 5 | (17%) |

Aware of county ordinances pertaining to on-site systems

| | |
|---|---|
| yes | 17 |
| no | 12 |
| no response | 1 |

Use of P containing fertilizers or commercial lawn service

| | | |
|---|---|---|
| yes | 9 | (all expressed willingness to change practice) |
| no | 20 | |
| no response | 1 | |

Summary

Most of the systems around the lake are the conventional septic tank - drainfield type. Most are less than 20 years old. The majority of system owners reported pumping at least every two years. A number of respondents, however, reported less frequent pumping, or did not respond to the question. Based on the results of the survey it appears that some work on septic tank maintenance (education and inspection) may be appropriate.

In-lake

Some portion of the nutrients which enter a lake from the watershed become bound to the lake sediments. These nutrients can be released under certain conditions. Phosphorus, for example, is released from sediments when the hypolimnion contains no oxygen. The contribution of phosphorus from the sediment can represent a significant part of the phosphorus load to the lake, and in some cases, may be the major source of phosphorus.

AQUATIC PLANTS (MACROPHYTES)

The Lake Association expressed concern about the increased growth of curly-leaf pondweed (*Potamogeton crispus*) along the shoreline of Circle Lake. Curly-leaf pondweed is an exotic species which tends to dominate the aquatic plant community at the expense of more desirable native species.

A 1951 waterfowl and muskrat habitat survey conducted by the Department of Conservation listed sago pondweed as common and a variety of other species present. This survey did not note the presence of Curly-leaf pondweed. Fish surveys conducted by MDNR staff also give aquatic plant abundances for Circle Lake. Neither a 1983 or 1988 survey indicated the presence of Curly-leaf pondweed. This may point to a relatively recent boom for the plant. Based on filed observations during LAP sampling, Curly-leaf beds have spread rapidly. Growth in the northwest bay is especially dense. Unfortunately, the depth of Circle Lake makes continued spreading likely. A direct relationship between Secchi disk transparency and the maximum depth of colonization (MDC) by macrophytes has been established to determine the areas of a lake which can support macrophyte growth (Canfield et al, 1985):

$$\log MDC = 0.79 \log SD(\text{meters}) + 0.25$$

Over the summer of 1991, the average Secchi transparency depth was approximately 3.7 feet. Using this value, the formula above yields a MDC of 6.4 feet. As least 50% of Circle Lake is shallower than 6.4 feet.

A number of techniques may be used to control nuisance macrophytes in small areas. Manual or mechanical harvesting can be an effective and control technique for small swimming areas or boat paths. This also has the added benefit of removing nutrients from the lake. All plants must be removed from the lake during any harvesting operation. In some cases permits from the DNR are required for weed control.

Sediment covers or surface shading are experimental techniques which may effectively control weed growth by controlling light. See the Lake and Reservoir Restoration Guidance Manual (USEPA 1990) for more information. Remember when deciding on an appropriate control techniques that some aquatic plants play an essential role in the health of the lake community. Although Curly-leaf pondweed is an exotic species, removal of large areas of weed without reestablishment of native perennials may result in a more algae dominated system.

## MODELING SUMMARY

Numerous models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in a lake. Alternately, they may be used for estimating changes in the quality of lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow or amount of water entering the lake. The "Minnesota Eutrophication Analysis Procedure" (MINLEAP) model and the Reckhow and Simpson (1980) model were used to assess the current water quality of Circle Lake. MINLEAP was developed by MPCA staff based on an analysis of data collected from a set of representative minimally impacted lakes for each ecoregion. Total phosphorus, chlorophyll, and transparency values calculated by MINLEAP should reflect the values found in a minimally impacted lake with the watershed size, lake morphometry, and geographic location of Circle Lake. It is intended to be used as a screening tool for estimating lake condition with minimal data input and is described in greater detail in Heiskary and Wilson (1990).

Published runoff coefficients, precipitation and evaporation data, and nutrient export coefficients were used in this modeling. Precipitation and evaporation data were derived from Gunnard (1985) and data from the State Climatology Office (1989). Inputs to the models are noted in Tables 5 and 6.

The TP and chlorophyll concentrations for Circle Lake predicted by MINLEAP were 70 and 33 ug/l respectively. These values are much lower than those determined in the 1991 sampling (Table 3). The predicted and observed Secchi disk depth agreed quite well. While the predicted Circle Lake TP value may seem unrealistically low, it is closer to the TP concentrations measured in 1980 and 1981. In addition, the model predicts concentrations for a minimally impacted lake. Circle Lake is highly impacted by nonpoint sources of pollution. It should also be noted that even the comparatively low predicted chlorophyll concentration of 33 ug/l is reflective of algae blooms. Blooms, however, would be much less frequent with a relatively unimpacted watershed than they currently are.

The MINLEAP model was run a second time using "Western Corn Belt Plain" as the ecoregion input. As previously noted, Circle Lake is similar to a typical Western Corn Belt Plain lake in certain ways. This resulted in predicted TP and chlorophyll concentrations of 178 ug/l and 127.65 ug/l respectively (Table 5A).

The second model used was Reckow and Simpson (1980) which predicts the impact of watershed characteristics and management on lake phosphorus concentrations. The uncertainty associated with this simplified assessment requires that the model output be expressed in a range of values with a "most likely" value specified.

The Reckow and Simpson model predicts in-lake total phosphorus concentrations for the present watershed ranging from a low value of 60 to a high of 112 ug/l with a most likely value of 75 ug/l (Table 6). The results were somewhat higher than those predicted by MINLEAP, reflecting land use in the watershed which has more agriculture than most watersheds in the ecoregion. They were, however, still well below observed concentrations. Typical phosphorus export values for the area were used in the model. Based on these estimates, agricultural land use (not including pasture) contributes approximately 83 percent of the watershed phosphorus load to the lake. A variety of other land uses make up the remaining 17 percent of the phosphorus load from the watershed.

A likely explanation for at least some of the difference between TP and chlorophyll values predicted by the models and those observed is internal loading of phosphorus from the sediments. In a relatively shallow lake like Circle, sediment phosphorus can be stirred into the water column physically, by wind, fish, or power boat action; or by diffusion, especially when oxygen concentrations near the sediment are low. Two of the three hypolimnetic TP yielded the highest concentrations found in the lake during the study.

## GOAL SETTING

In order to maintain the fisheries, aesthetics, and full recreation, phosphorus levels below 40 are desirable for most of the state. This is probably out of reach for Circle Lake. The MINLEAP model predicted TP concentration of 70 for the North Central Hardwood Forest Ecoregion and 178 for the Western Corn Belt Plain Ecoregion. Goals of modest water quality improvement (phosphorus concentrations somewhere between 70 and 178), having some forms of recreation some of the time, and having a fishery not completely dominated by a couple species might be more reasonable. In addition, even a lake that does not have great swimming and fishing can be a beautiful and important part of the landscape. Specifically, Circle Lake's island is ringed with one of the few relatively undisturbed areas of native vegetation remaining in Rice County. Circle Lake also appears to be used by a wide variety of waterfowl, shorebirds, and raptors.

Large reductions in TP loading will be required for even modest water quality improvement. Some reduction in the TP loading will be required to keep the water quality of the lake from deteriorating further. Loading from the watershed should be controlled before any in-lake treatments are attempted. If present conditions and inputs continue, a gradual worsening of the lake's condition and suitability for recreation will result.

The lake is a reflection of its watershed. The quality of the lake water is determined by not only the lake's morphometry and ecology, but also the activities that occur in the watershed. The results of this study suggest that excessive phosphorus is reaching the lake from the lake watershed and/or the lake sediments. Implementation of best management practices on cultivated land, feedlots, and in the immediate watershed should help to reduce the phosphorus loading. A more detailed study would be necessary to predict the lake's response to watershed and in-lake treatment methods.

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## TABLE 1. CIRCLE LAKE MORPHOMETRIC, WATERSHED, AND FISHERY CHARACTERISTICS

MDNR I.D. #66-0027

Area[1] : 976 acres (395 ha)

Mean Depth: 6.0 feet (1.8 meters)

Maximum Depth: 16 feet (4.9 meters)

Volume: 5856 acre-ft

Littoral Area: 100%

Shoreline Length: 5.8 miles

Watershed Area: 9322 ha

Watershed Area/Lake Surface Area Ratio: 23.6:1

Estimated Average Water Residence Time: 0.6 years

Fisheries - Ecological Classification: Roughfish-Gamefish
Management Classification: Warmwater gamefish

Land Use (percentage):

| | Forests | Water/Marsh | Pasture/CRP | Cultivated | Urban |
|---|---|---|---|---|---|
| Circle Lake[3] | 8 | 21 | 14 | 52 | 1 |
| North Central Hardwood Forest[4] | 6-25 | 14-30 | 11-25 | 22-50 | 2-9 |

Public Access: 1 - north west shore of the lake

Inlets/Outlets: 2 inlets (Wolf Creek, unnamed) 1 outlet (Wolf Creek)

Shoreland Zoning: Recreational development

Development (Homes)

| Year | Seasonal | Permanent | Total |
|---|---|---|---|
| 1967[5] | | | 25 |
| 1991[6] | 5 | 25 | 30 |

[1] - Planimetered from MDNR morphometric map dated 1987
[2] - Determined by members of the Forest Township Agri-Lakes Assoc. from aerial photos and USGS 7.5 minute quadranges.
[3] - Calculated by members of the Forest Township Agri-Lakes Assoc.
[4] - 25-75th percentile for representative lakes in the ecoregion (Heiskary & Wilson, 1990)
[5] - Borchert et al., 1970
[6] - Information provided by FTALA

TABLE 2. 1991 CITIZEN LAKE MONITORING DATA FOR CIRCLE LAKE

LAKEID=66-0027

| SITE | DATE | SECCHI DISK (FT) | PHYS | REC |
|---|---|---|---|---|
| 208 | 910512 | 11.0 | 1 | 1 |
| 208 | 910519 | 5.5 | 2 | 2 |
| 208 | 910525 | 6.5 | 3 | 3 |
| 208 | 910602 | 9.5 | 2 | 2 |
| 208 | 910605 | 7.0 | 2 | 2 |
| 208 | 910608 | 7.0 | 2 | 2 |
| 208 | 910614 | 7.5 | 3 | 3 |
| 208 | 910623 | 3.0 | 4 | 4 |
| 208 | 910627 | 3.0 | 3 | 3 |
| 208 | 910629 | 2.5 | 4 | 4 |
| 208 | 910703 | 2.5 | 4 | 4 |
| 208 | 910707 | 2.5 | 3 | 3 |
| 208 | 910710 | 4.5 | 3 | 3 |
| 208 | 910714 | 5.0 | 2 | 2 |
| 208 | 910717 | 5.5 | 3 | 2 |
| 208 | 910720 | 4.0 | 2 | 2 |
| 208 | 910724 | 3.0 | 3 | 3 |
| 208 | 910728 | 3.0 | 2 | 2 |
| 208 | 910731 | 5.0 | 2 | 2 |
| 208 | 910804 | 4.0 | 2 | 2 |
| 208 | 910810 | 4.5 | 2 | 2 |
| 208 | 910814 | 4.0 | 2 | 2 |
| 208 | 910821 | 4.0 | 3 | 3 |
| 208 | 910824 | 3.0 | 3 | 3 |
| 208 | 910828 | 2.5 | 3 | 3 |
| 208 | 910902 | 2.0 | 3 | 3 |
| 208 | 910907 | 2.5 | 3 | 3 |
| 208 | 910914 | 4.0 | 3 | 3 |

**Physical Condition (PHYS)**
1. Crystal clear water
2. Not quite crystal clear - a little algae present/visible
3. Definite algal green, yellow, or brown color apparent
4. High algal levels with limited clarity and/or mild odor apparent
5. Severe high algae levels with one or more of the following:
   -massive floating scums on lake or washed up on shore
   -strong, foul odor
   -fish kill (please note the number and types of fish

**Suitability for Recreation (REC)**
1. Beautiful, could not be better
2. Very minor aesthetic problems; excellent for swimming, boating, etc.
3. Swimming and aesthetic enjoyment slightly impaired because of algae levels
4. Desire to swim and level of enjoyment of the lake substantially reduced because of algae levels (i.e. would not swim, but boating is okay)
5. Swimming and aesthetic enjoyment of the lake nearly impossible because of algae levels

TABLE 3. CIRCLE LAKE AVERAGE SUMMER WATER QUALITY AND TROPIC STATUS INDICATORS. Based on summer epilimnetic data from 1991.

| | Mean | Typical Range for NCHF Ecoregion[1] |
|---|---|---|
| Total Phosphorus (ug/l) | 575 | 23-50 |
| Chlorophyll-a (ug/l) mean | 126.3 | 5-22 |
| Chlorophyll-a (ug/l) maximum | 425 | 7-32 |
| Secchi disk (meters)[2] | 1.1 | 1.5-3.2 |
| Secchi disk (feet) | 4.07 | 4.9-10.5 |
| Total Kjeldahl Nitrogen (mg/l) | 3.8 | 0.8-1.2 |
| Nitrite & Nitrate-N (mg/l) | 0.14 | <0.01 |
| Alkalinity (mg/l) | 155 | 75-150 |
| Color (Pt-Co Units) | 42.5 | 10-20 |
| pH (SU) | 8.9 | 8.6-8.8 |
| Chloride (mg/L) | 13 | 4-10 |
| Total Suspended Solids (mg/l) | 10.6 | 2-6 |
| Total Suspended Inorganic Solids (mg/l) | 4.8 | 1-2 |
| Turbidity (NTU) | 11.6 | 1-2 |
| Conductivity (unhos/cm) | 400 | 200-300 |
| TN:TP ratio | 7:1 | 25:1-35:1 |

<u>Tropic Status Indicators: 1991</u>

| Carlson Trophic State Index Values | | Percentile[3] |
|---|---|---|
| TP TSIP | 96 | |
| Chl-a TSIC | 78 | |
| Secchi TSIS | 59 | |
| Mean (above 3 values) TSI | 78 | 6th |

1 - 25-75th percentile for representative - minimally impacted lakes in North Central Hardwood Forest Ecoregion (Heiskary & Wilson, 1990)

2 - Includes CLMP measurements

3 - Relative to approximately 40 lakes in the North Central Hardwood Forest ecoregion. One hundred percent level implies lowest TP and chlorophyll concentration or deepest Secchi disk measurement for that ecoregion.

TABLE 4. CIRCLE LAKE WATER QUALITY DATA COLLECTED AS PART OF 1991 LAP STUDY AND MPCA ECOREGION MONITORING

LAKE CHEMISTRY DATA FROM 1989 AND 1991

| DATE | SITE | DEPTH(ft) | TP (ug/l) | TKN (mg/l) | N2N3 (mg/l) | TSS (mg/l) | TVS (mg/l) | ALK | CL (mg/l) | COND (us/cm) | TURB (NTU) | COLOR (pcu) | CHLA A (ug/l) | pheoph-a (ug/l) | SD meters | SD feet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05/18/89 | 101 | 0 | 287 | 2.19 | 0.53 | 2.2 | 1.2 | 130 | 140 | 335 | 0.6 | 30 | | | | 9.2 |
| 06/27/89 | | | 223 | 3.2 | 0.01 | 11 | 2.4 | 150 | 14 | 310 | 6.3 | 30 | 81.7 | 8.01 | | 3.6 |
| 07/26/89 | | | 510 | 3.57 | 0.01 | 18 | 3 | 150 | 14 | 320 | 6.5 | 30 | 103 | 0.8 | | 2.6 |
| 08/29/89 | | | 500 | | | 24 | 6 | 160 | 15 | | 5.4 | 40 | 120 | 1.6 | | 2.3 |
| 05/20/91 | 101 | 0 | 180 | 2.72 | 0.75 | 2 | 0.5 | 140 | 15 | 340 | 1.5 | 40 | 2.24 | 2.56 | 3.25 | 10.7 |
| 06/11/91 | | | 325 | 2.56 | 0.49 | 4.2 | 0.8 | 140 | 14 | | 15 | 40 | 39.1 | 0.32 | | 6.5 |
| 07/09/91 | | | 592 | 3.34 | 0.02 | 5.2 | 1.4 | 150 | 13 | 350 | 3.5 | 50 | 30.4 | 1.6 | | 4.3 |
| 08/06/91 | | | 576 | 3.2 | 0.01 | 16 | 11 | 150 | 13 | 380 | 8 | 40 | 29.9 | 2.14 | | 4.9 |
| 09/09/91 | | | 606 | 1.51 | 0.01 | 17 | 6 | 180 | 14 | 390 | 20 | 40 | 154 | 1.6 | | 2.5 |
| 06/27/89 | 102 | 0 | 262 | 3 | | | | | | 310 | | | 24 | 28.8 | | 5.2 |
| 07/26/89 | 102 | 0 | 508 | 4.19 | | | | | | 310 | | | 162 | 2.4 | | 2 |
| 08/29/89 | 102 | 0 | 511 | 4.33 | | | | | | | | | 99.3 | 1.6 | | 2.6 |
| 05/20/91 | 102 | 0 | 198 | 2.42 | | | | | | | | | 4.49 | 3.84 | 2.2 | |
| 06/11/91 | 102 | 0 | 583 | 4.62 | 0.31 | | | | | | | | 87.3 | 70.5 | | 5 |
| 07/09/91 | 102 | 0 | 670 | 5.16 | 0.02 | | | | | 360 | | | 130 | 3.2 | | 2.3 |
| 08/06/91 | 102 | 0 | 620 | 3.8 | | | | | | 380 | | | 115 | 0.85 | | 3 |
| 09/09/91 | 102 | 0 | 628 | 6.44 | | | | | | 410 | | | 425 | 2.14 | | 1.5 |
| 06/11/91 | 101 | 16 | 309 | 2 | 0.61 | | | | | | | | | | | |
| 07/09/91 | 101 | 13 | 780 | 4.23 | 0.01 | | | | | | | | | | | |
| 08/06/91 | 101 | 13 | 695 | 4.1 | | | | | | | | | | | | |

TABLE 5. MINLEAP MODELING SUMMARY

MINNESOTA LAKE EUTROPHICATION ANALYSIS PROCEDURE

**INPUT VARIABLES**
LAKE NAME = CIRCLE LAKE
ECOREGION = NORTH CENTRAL HARDWOOD FOREST
WATERSHED AREA (HA) = 9322
LAKE SURFACE AREA (HA) = 395
LAKE MEAN DEPTH (M) = 1.8
OBSERVED MEAN LAKE TP (UG/L) = 575
OBSERVED MEAN CHL-A (UG/L) = 126.3
OBSERVED MEAN SECCHI (M) = 1.1

| | | | |
|---|---|---|---|
| LAKE = CIRCLE LAKE | | ECOREGION = CHF | |
| AVERAGE INFLOW TP = 155.7477 | UG/L | TOTAL P LOAD = 1912.053 | KG/YR |
| LAKE OUTFLOW = 12.2766 | HM3/YR | AREAL WATER LOAD = 3.108 | M/YR |
| RESIDENCE TIME = .5791506 | YRS | P RETENTION COEF = .5488183 | |

| VARIABLE | UNITS | OBSERVED | PREDICTED | STD ERROR | RESIDUAL | T-TEST |
|---|---|---|---|---|---|---|
| TOTAL P | (UG/L) | 575.00 | 70.27 | 20.35 | 0.91 | 6.31 |
| CHL-A | (UG/L) | 126.00 | 32.85 | 18.13 | 0.58 | 2.19 |
| SECCHI | (METERS) | 1.10 | 0.99 | 0.38 | 0.05 | 0.26 |

NOTE: RESIDUAL = LOG10(OBSERVED/PREDICTED)
T-TEST FOR SIGNIFICANT DIFFERENCE BETWEEN OBS. AND PREDICTED

CHLOROPHYLL-A INTERVAL FREQUENCIES (%)

| CHL-A PPB | OBSERVED | PREDICTED CASE A | PREDICTED CASE B | PREDICTED CASE C |
|---|---|---|---|---|
| 10 | 100.00 | 98.74 | 98.06 | 92.18 |
| 20 | 99.98 | 78.66 | 76.84 | 69.27 |
| 30 | 99.70 | 47.89 | 48.05 | 48.64 |
| 60 | 90.43 | 6.73 | 8.36 | 17.17 |

CASE A = WITHIN-YEAR VARIATION CONSIDERED
CASE B = WITHIN-YEAR + YEAR-TO-YEAR VARIATION CONSIDERED
CASE C = CASE B + MODEL ERROR CONSIDERED

TABLE 5A. MINLEAP MODELING SUMMARY

MINNESOTA LAKE EUTROPHICATION ANALYSIS PROCEDURE

**INPUT VARIABLES**
LAKE NAME = CIRCLE LAKE
ECOREGION = WESTERN CORN BELT PLAIN
WATERSHED AREA (HA) = 9322
LAKE SURFACE AREA (HA) = 395
LAKE MEAN DEPTH (M) = 1.8
OBSERVED MEAN LAKE TP (UG/L) = 575
OBSERVED MEAN CHL-A (UG/L) = 126.3
OBSERVED MEAN SECCHI (M) = 1.1

LAKE = CIRCLE
AVERAGE INFLOW TP = 568.6573 UG/L
LAKE OUTFLOW = 12.3556 HM3/YR
RESIDENCE TIME = .5754475 YRS

ECOREGION = WCP
TOTAL P LOAD = 7026.102 KG/YR
AREAL WATER LOAD = 3.128 M/YR
P RETENTION COEF = .6868748

| VARIABLE | UNITS | OBSERVED | PREDICTED | STD ERROR | RESIDUAL | T-TEST |
|---|---|---|---|---|---|---|
| TOTAL P | (UG/L) | 575.00 | 178.06 | 60.39 | 0.51 | 3.11 |
| CHL-A | (UG/L) | 126.30 | 127.65 | 77.77 | -0.00 | -0.02 |
| SECCHI | (METERS) | 1.10 | 0.44 | 0.18 | 0.39 | 2.10 |

NOTE: RESIDUAL = LOG10(OBSERVED/PREDICTED)
T-TEST FOR SIGNIFICANT DIFFERENCE BETWEEN OBS. AND PREDICTED

CHLOROPHYLL-A INTERVAL FREQUENCIES (%)

| CHL-A PPB | OBSERVED | PREDICTED CASE A | PREDICTED CASE B | PREDICTED CASE C |
|---|---|---|---|---|
| 10 | 100.00 | 100.00 | 100.00 | 99.88 |
| 20 | 99.98 | 99.99 | 99.96 | 98.50 |
| 30 | 99.71 | 99.73 | 99.48 | 95.20 |
| 60 | 90.52 | 90.89 | 89.09 | 78.81 |

CASE A = WITHIN-YEAR VARIATION CONSIDERED
CASE B = WITHIN-YEAR + YEAR-TO-YEAR VARIATION CONSIDERED
CASE C = CASE B + MODEL ERROR CONSIDERED

TABLE 6. RECKOW AND SIMPSON (1980) MODEL SUMMARY

I. The first model is described in:
Reckhow,K.H. J.T. Simpson.1980. A Procedure using modeling and error analysis for the prediction of lake phosphorus concentration from land use information. Can.J.Fish.Aq.Sci.37(9):1439−1448.

| Name | Circle | | | | |
|---|---|---|---|---|---|
| Watershed Area (ha) | 9322 | 20508361 =EST Q | 20.51 | =HM3 | 0.4 =Water Residence (year) |
| Lake Area (ha) | 395 | 5.19 =EST qs | | | |
| Water Runoff (m) | 0.22 | NOTE: 1HM3 = 1,000,000 M3 | | | |
| Precipitation(m) | 0.8 | 0.575 =Observed TP (mg/l) | | | |
| Evaporation(m) | 0.9 (mean) | 0.037 =Observed TP StDev | | | |
| Volume (HM3) | 7.22 | 8 =N | | | |
| County capitas/cabin | 2.8 | 126.3 =Observed Chla (ug/l) | | | |
| Number Seasonal Cabins | 5 | 1.1 =Observed Secchi (m) | | | |
| Number Perm. Cabins | 25 | | | | |

| | Before | After | Delta |
|---|---|---|---|
| Forest Area (ha) | 746 | 746 | 0 |
| Agric Area (ha) | 4847 | 4847 | 0 |
| Urban Area (ha) | 93.2 | 93.2 | 0 |
| Wetland Area (ha) | 1958 | 1958 | 0 |
| Pasture/Open (ha) | 1305 | 1305 | 0 |

| | | | | | Before | | | | | After | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Export Values | | Low | Average | High | Low | Average | High | | | Low (PK) | Average | High |
| Forest P Export | | 0.08 | 0.1 | 0.15 | 60 | 75 | 112 | =Forested Flux | = | 60 | 75 | 112 |
| Agric P Export | | 0.64 | 0.9 | 1.4 | 3102 | 4362 | 6786 | =Ag flux | = | 3102 | 4362 | 6786 |
| Urban P Export | | 0.5 | 1 | 1.25 | 47 | 93 | 117 | =Urban flux | = | 47 | 93 | 117 |
| Wetland P Export | | 0.08 | 0.1 | 0.1 | 157 | 196 | 196 | =Wetland flux | = | 157 | 196 | 196 |
| Pasture/open Export | | 0.2 | 0.3 | 0.4 | 261 | 392 | 522 | =Pasture/Open flux | = | 261 | 392 | 522 |
| Atmospheric Export | | 0.2 | 0.3 | 0.4 | 79 | 119 | 158 | =Ppt flux | = | 79 | 119 | 158 |
| Soil Retention Coef | | 0.95 | 0.8 | 0.7 | | | | | | | | |
| Point Source Before | kg/yr | 0 | 0 | 0 | | | | | | | | |
| Point Source After | kg/yr | 0 | 0 | 0 | 4 | 14 | 21 | =Septic flux | = | 4 | 14 | 21 |
| Delta Point Source kg/yr | | 0 | 0 | 0 | | | | | | | | |
| Capita Years | | 71 | 71 | 71 | 0 | 0 | 0 | =Point Souce | = | 0 | 0 | 0 |
| | | | | | 3710 | 5251 | 7912 | =Total P Flux | = | 3710 | 5251 | 7912 |
| | | | | | 939 | 1329 | 2003 | = P LOAD | = | 939 | 1329 | 2003 |
| | | | | | 181 | 256 | 386 | = Inflow P ug/l | = | 181 | 256 | 386 |
| | | | | | 0.053 | 0.075 | 0.112 | =PREDICTED TP | = | 0.053 | 0.075 | 0.112 |
| | | | | | | −1.12494 | | =LOG Pml | = | | −1.12494 | |
| | | | | | | 0.026 | | = + MODEL ERROR | = | | 0.026 | |
| | | | | | | −0.019 | | = − MODEL ERROR | = | | −0.019 | |
| | | | | | | 0.0185 | | = + LOADING ERROR | = | | 0.0185 | |
| | | | | | | 0.011 | | = − LOADING ERROR | = | | 0.011 | |
| | | | | | | 0.032 | | =TOTAL + UNCERTAIN | = | | 0.032 | |
| | | | | | | 0.022 | | =TOTAL − UNCERTAIN | = | | 0.022 | |
| RECKHOW/SIMPSON ug P/l | | | | | 53 | 75 | 107 | 55% CONFIDENCE LIMITS | | 53 | 75 | 107 |
| RECKHOW/SIMPSON | | | | | 31 | 75 | 139 | 90% CONFIDENCE LIMITS | | 31 | 75 | 139 |
| CANFIELD/BACHMANN ug P/l | | | | | 88 | 114 | 154 | CANFIELD/BACHMANN | | 88 | 114 | 154 |

**** P EXPORT REFERENCE ****

Prairie & Kalff (1986) "Effect of Catchment Size...

\Wilson & Walker (1989) \Development of Lake Assessment...

| Use | Ha | P export | \Ecoreg. | Dominant Landuse | Net** P Export |
|---|---|---|---|---|---|
| Forest | 746 | 0.08 | \NCHF | Cul+Mixed | 0.19 |
| Ag−mix | 4847 | 0.59 | \NLF | For (75%) | 0.12 |
| Ag−row++ | 4120 | 0.16 | \NGP | Cul (83%) | 0.76 |
| Ag−nonrow++ | 727 | 0.62 | \WCBP | Cul (84%) | 0.74 |
| Pasture | 1305 | 0.13 | ** Of all landuse values. | | |

Wat.Res.Bull 22:465−470 \ Lake Res.Man.5:11−22.

++Fill in this estimated landuse data

TABLE 6. (CONTINUED)

II. The second model is described in:
Reckhow, 1983 "A Method for Reduction of Lake Model Prediction Error"

| Former − | New + | Net TP | | Pred Bound − | Pred Bound + | Projected TP Change Incr/Decr | Projected TP Change +/− |
|---|---|---|---|---|---|---|---|
| −0.00278 | 0 | −0.00278 | 0.00278 | 0.002071 | 0.003733 | −0.00278 | 0.000834 |

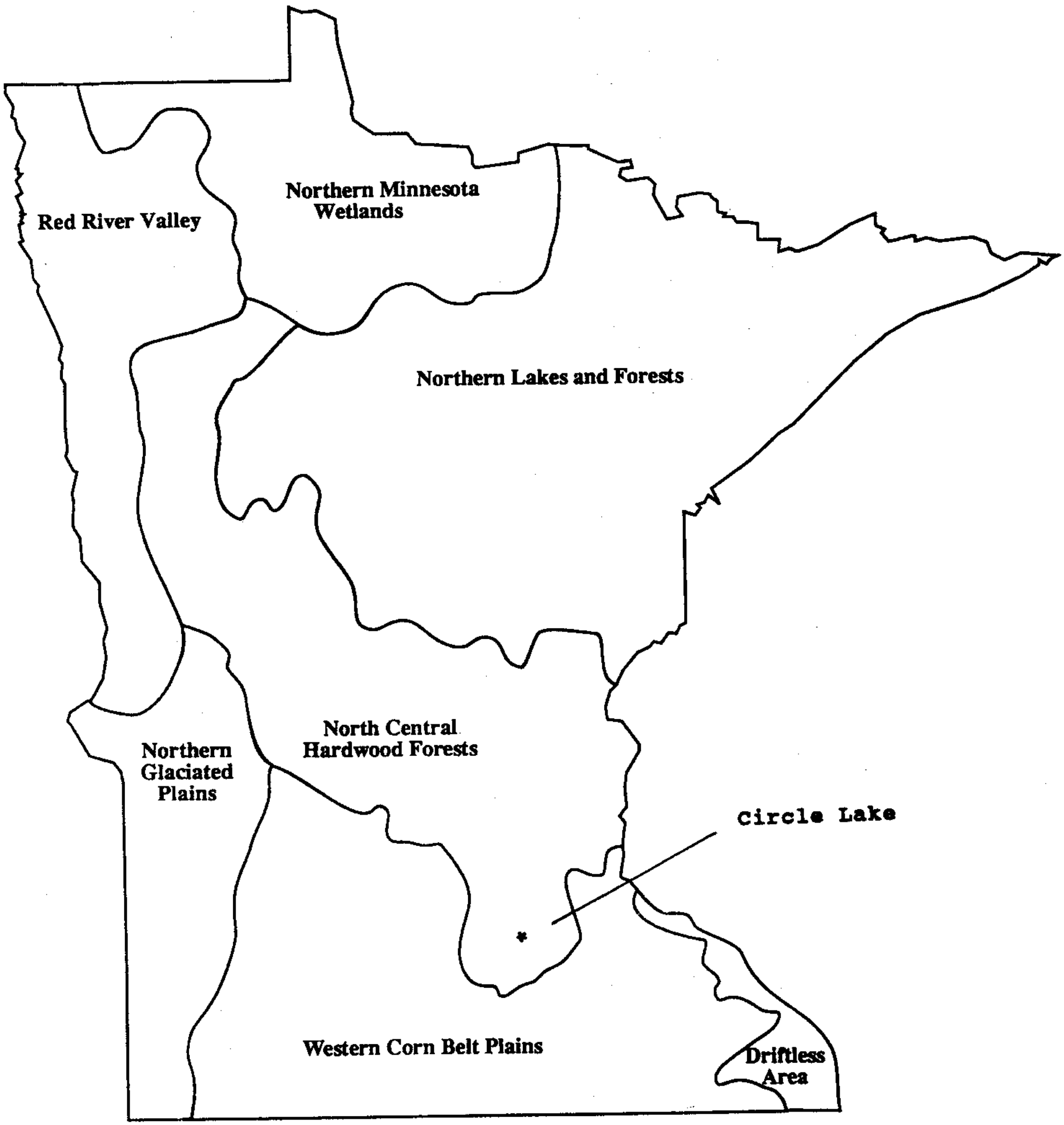
| | Lake Data Lake TP | StDev | St Error | Pred Error | Obs TP | Net Change | | Predicted P | | +/− Pred Error |
|---|---|---|---|---|---|---|---|---|---|---|
| III. | 0.575 | 0.345 | 0.070423 | 0.070428 | 0.575 | −0.00278 | = | 0.572 | +/− | 0.070428 |
| | | | | | | | = | 572 | +/− | 70 |

Predicted changes in Secchi, Chlorophyll and Trophic Status

| | | CURRENT Observed | "BEFORE" (low) Predicted | (average) | "AFTER" (high) Predicted |
|---|---|---|---|---|---|
| | | | Fill−in from above (Canfield/Bachmann) or insert other values. | | |
| LAKE TP | mg/l | 0.575 | 0.088 | 0.115 | 0.154 |
| LAKE CHLA | ug/l | 126.3 | 45.6 | 67.4 | 103.3 |
| LAKE SECCHI | m | 1.1 | 0.8 | 0.6 | 0.5 |
| TSI TP | | 95.8 | 68.7 | 72.6 | 76.8 |
| TSI CHLA | | 78.1 | 68.1 | 71.9 | 76.1 |
| TSI SD | | 58.6 | 63.2 | 67.4 | 70 |

# FIGURE 1. LAKE LOCATION MAP

**Minnesota's ecoregions noted**



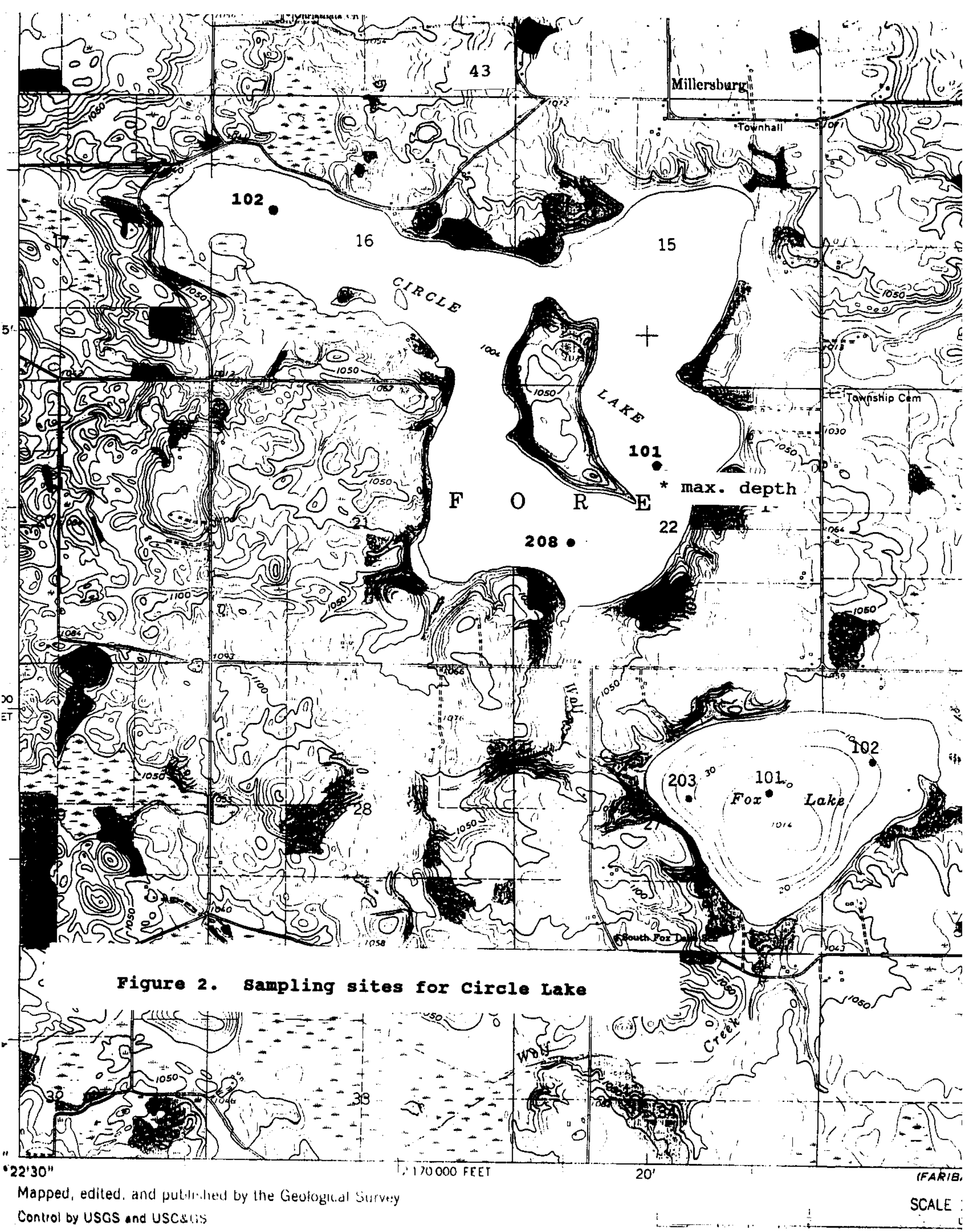
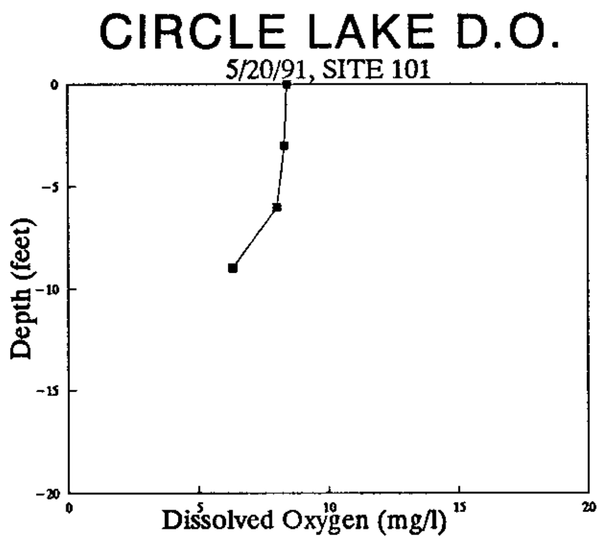



Figure 2. Sampling sites for Circle Lake

FIGURES 3a–e. DISSOLVED OXYGEN AND TEMPERATURE PROFILES FOR SITE 101, CIRCLE LAKE 1991.

FIGURE 3a.

| DATE | SITE | DEPTH | D.O. | TEMP |
|---|---|---|---|---|
| 05/20/91 | 101 | 0 | 8.4 | 15.4 |
| | | −3 | 8.3 | 15.4 |
| | | −6 | 8 | 15.3 |
| | | −9 | 6.3 | 15.2 |



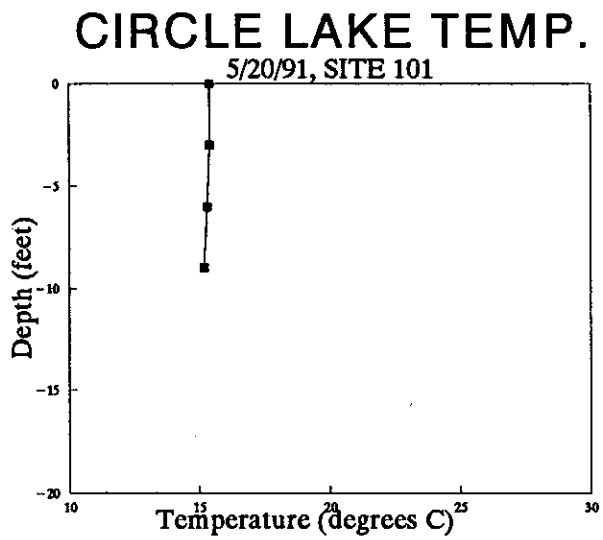
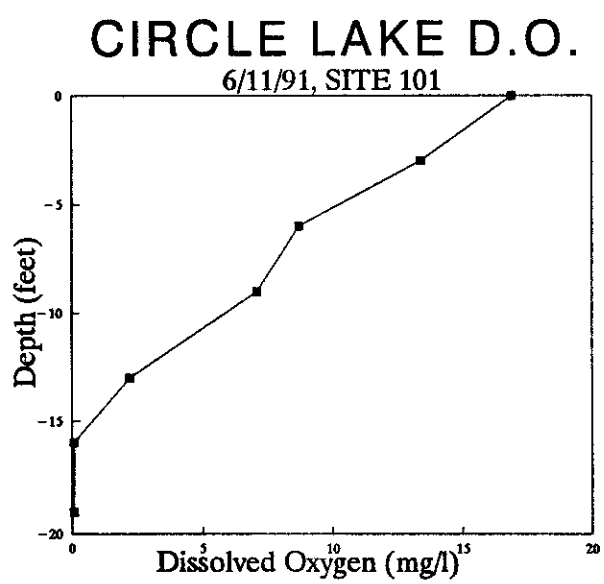




FIGURE 3b.

| | | | | |
|---|---|---|---|---|
| 06/11/91 | 101 | 0 | 16.9 | 27 |
| | | −3 | 13.4 | 24.6 |
| | | −6 | 8.7 | 23.8 |
| | | −9 | 7.1 | 23.1 |
| | | −13 | 2.2 | 22.3 |
| | | −16 | 0.05 | 22.1 |
| | | −19 | 0.05 | 22.1 |



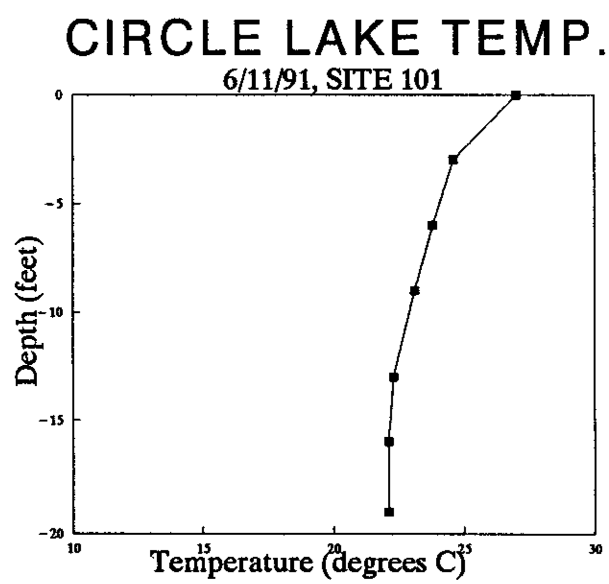
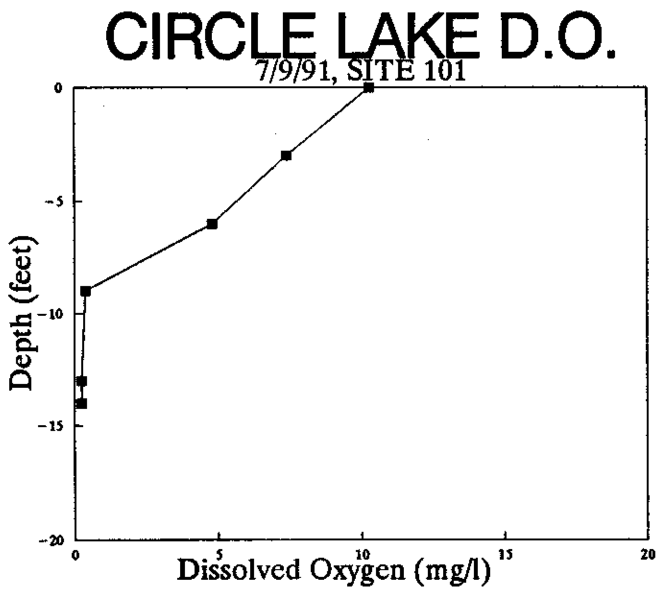



FIGURE 3c.

| | | | | |
|---|---|---|---|---|
| 07/09/91 | 101 | 0 | 10.3 | 27 |
| | | −3 | 7.4 | 25.3 |
| | | −6 | 4.8 | 24.8 |
| | | −9 | 0.4 | 24.8 |
| | | −13 | 0.25 | 24.7 |
| | | −14 | 0.25 | 24.5 |



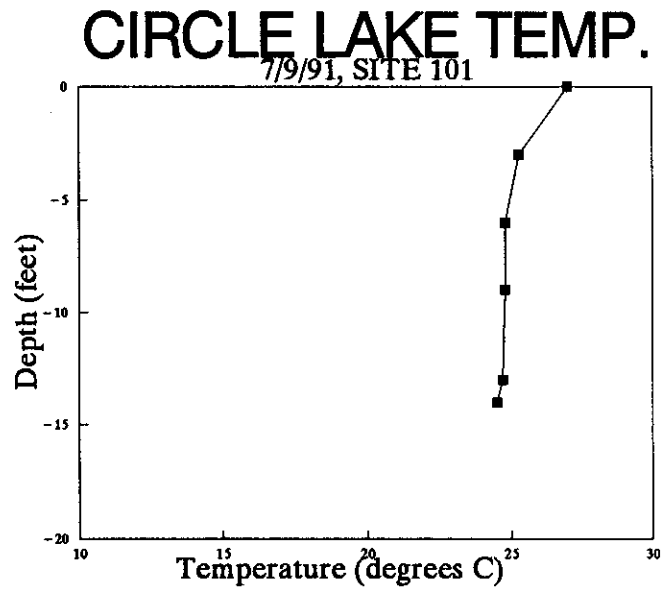
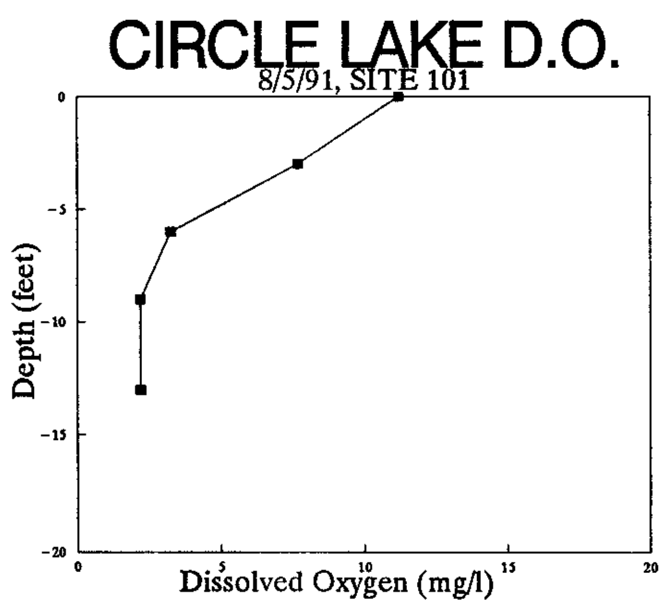




FIGURE 3d.

| | | | | |
|---|---|---|---|---|
| 08/05/91 | 101 | 0 | 11.2 | 24.8 |
| | | −3 | 7.7 | 23.5 |
| | | −6 | 3.25 | 23 |
| | | −9 | 2.2 | 23 |
| | | −13 | 2.2 | 23 |



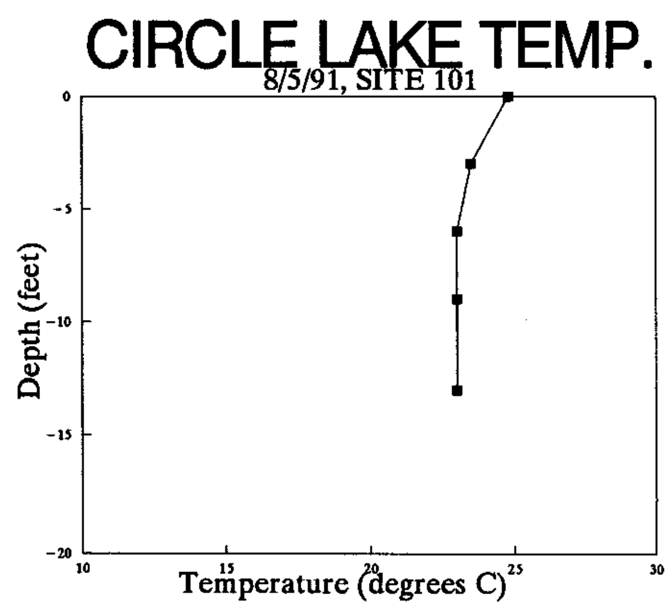
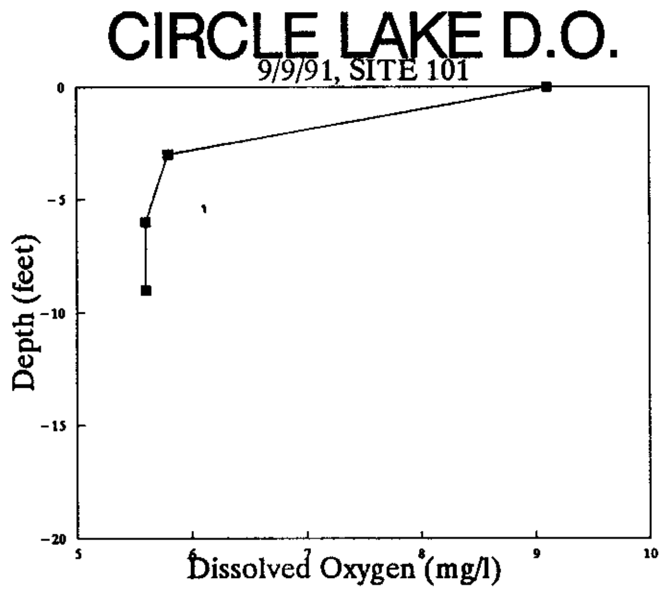



FIGURE 3e.

| | | | | |
|---|---|---|---|---|
| 09/09/91 | 101 | 0 | 9.1 | 23 |
| | | -3 | 5.8 | 22.5 |
| | | -6 | 5.6 | 22.5 |
| | | -9 | 5.6 | 22.5 |



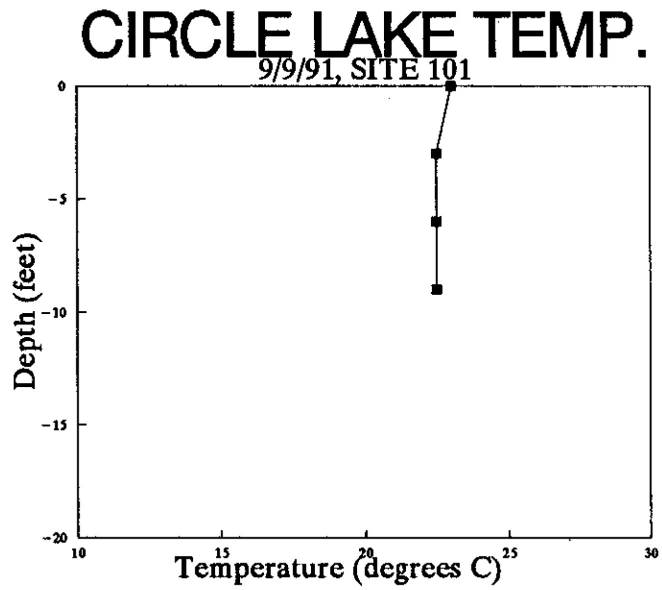



FIGURE 4. 1991 EPILMINETIC AND HYPOLIMNETIC PHOSPHORUS CONCENTRATIONS

| DATE | SITE | DEPTH | TP (UG/L) |
|---|---|---|---|
| 05/20/91 | 101 | 0 | 180 |
| 06/11/91 | 101 | 0 | 325 |
| 07/09/91 | 101 | 0 | 592 |
| 08/06/91 | 101 | 0 | 576 |
| 09/09/91 | 101 | 0 | 606 |
| 06/11/91 | 101 | 16 | 309 |
| 07/09/91 | 101 | 13 | 780 |
| 08/06/91 | 101 | 13 | 695 |

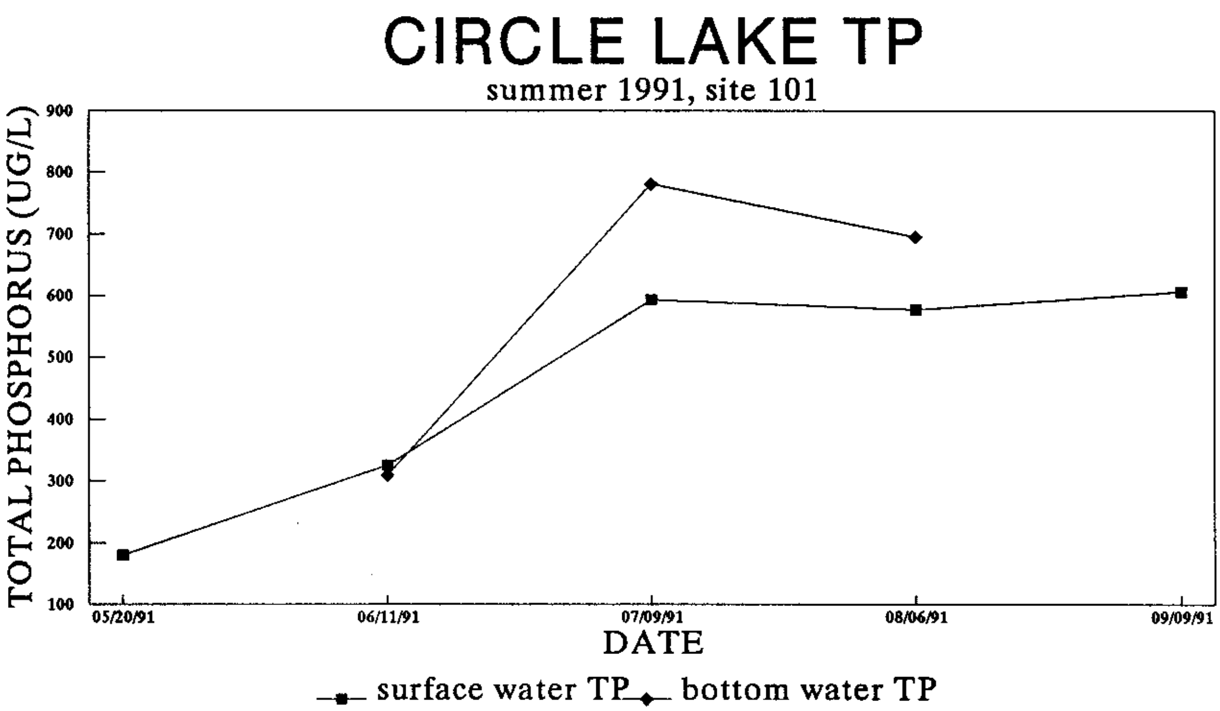
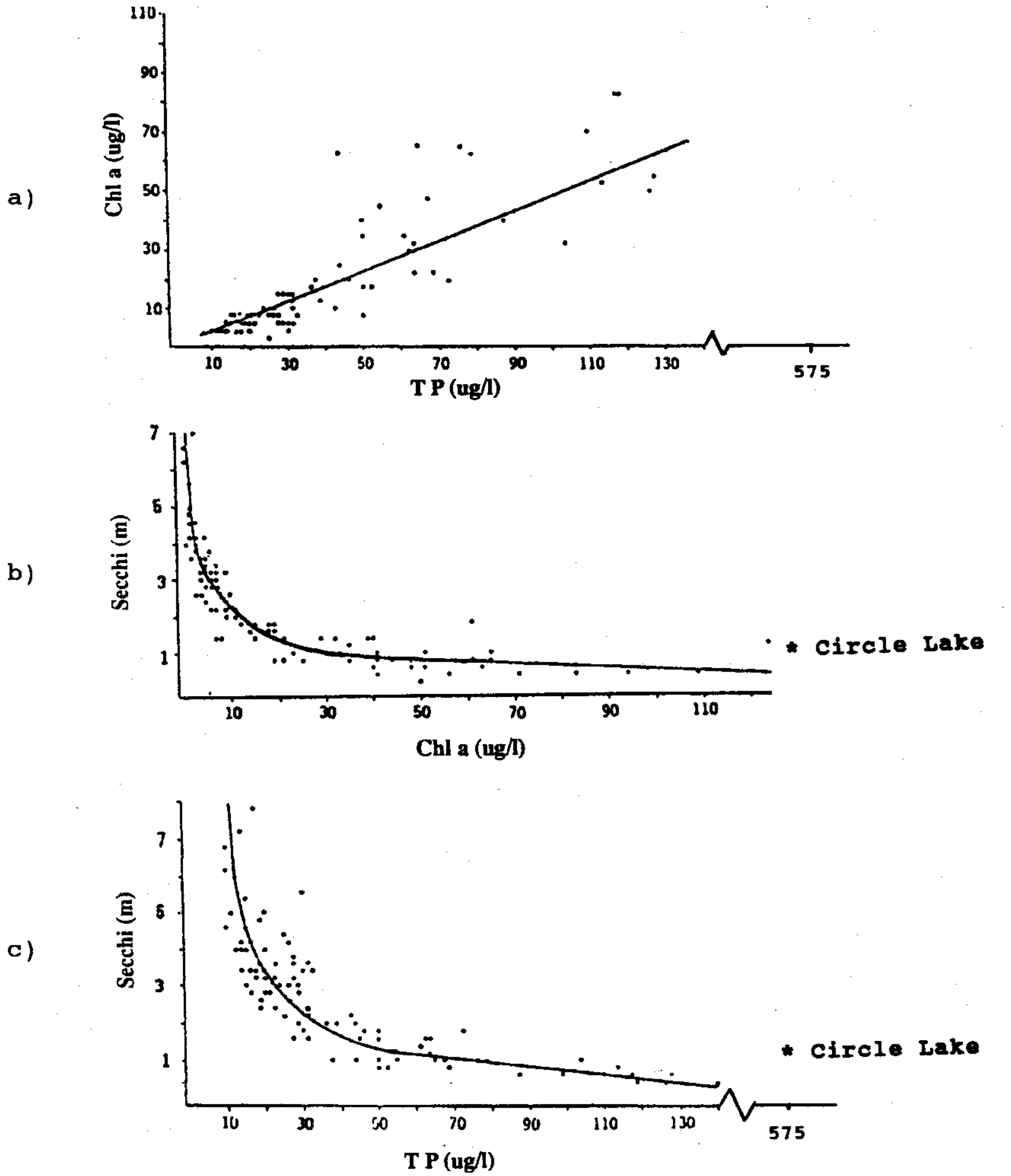


Figure 5. SCATTERPLOTS OF CHLOROPHYL-a, TOTAL PHOSPHORUS AND SECCHI TRANSPARENCY. Based on summer data from a set of representative lakes from four ecoregions in Minnesota. Values for Circle Lake noted:

* Circle Lake



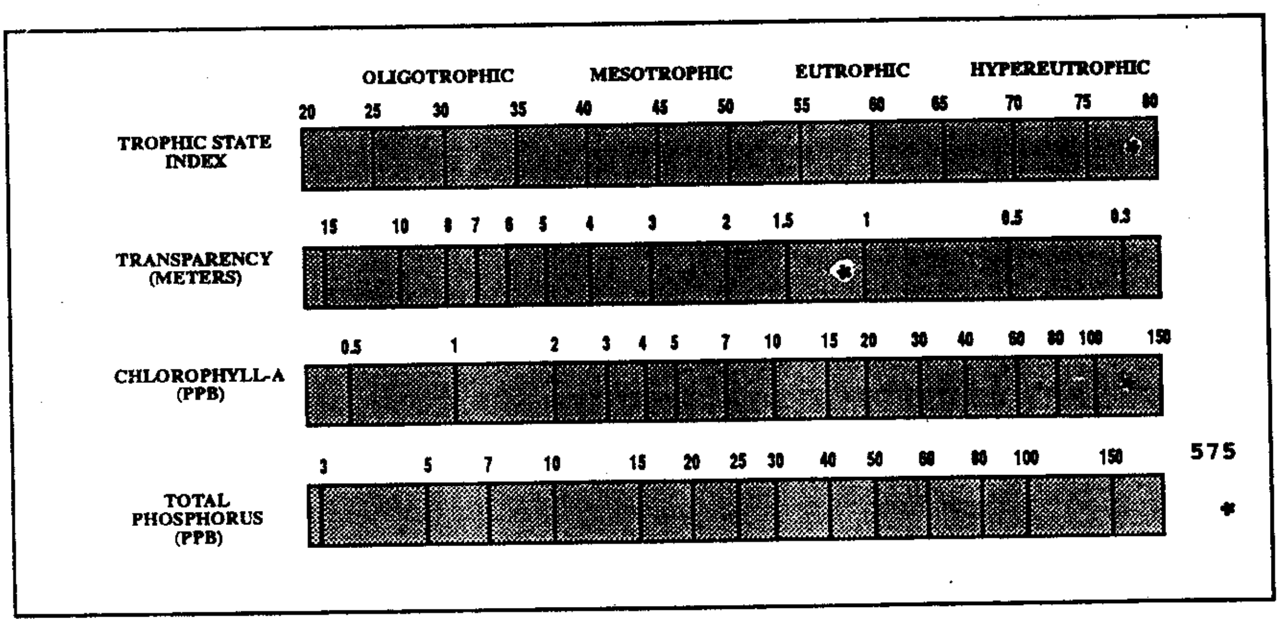
## Figure 6. CARLSON'S TROPHIC STATE INDEX VALUES
### TSI Relationships based on mean summer data for 1991.

### Changes in the Biological Condition of Lakes With Changes in Trophic State

**R.E. Carlson**

| | |
|---|---|
| **TSI < 30** | Classical oligotrophy: Clear water, oxygen throughout the year in hypolimnion, salmonid fisheries in deep lakes. |
| **TSI 30 - 40** | Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer. |
| **TSI 40 - 50** | Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.. |
| **TSI 50 - 60** | Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only. |
| **TSI 60 - 70** | Dominance of blue-green algae, algal scums probable, extensive macrophyte problems. |
| **TSI 70 - 80** | Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypertrophic.. |
| **TSI > 80** | Algal scums, summerfish kills, few macrophytes, dominance of rough fish. |

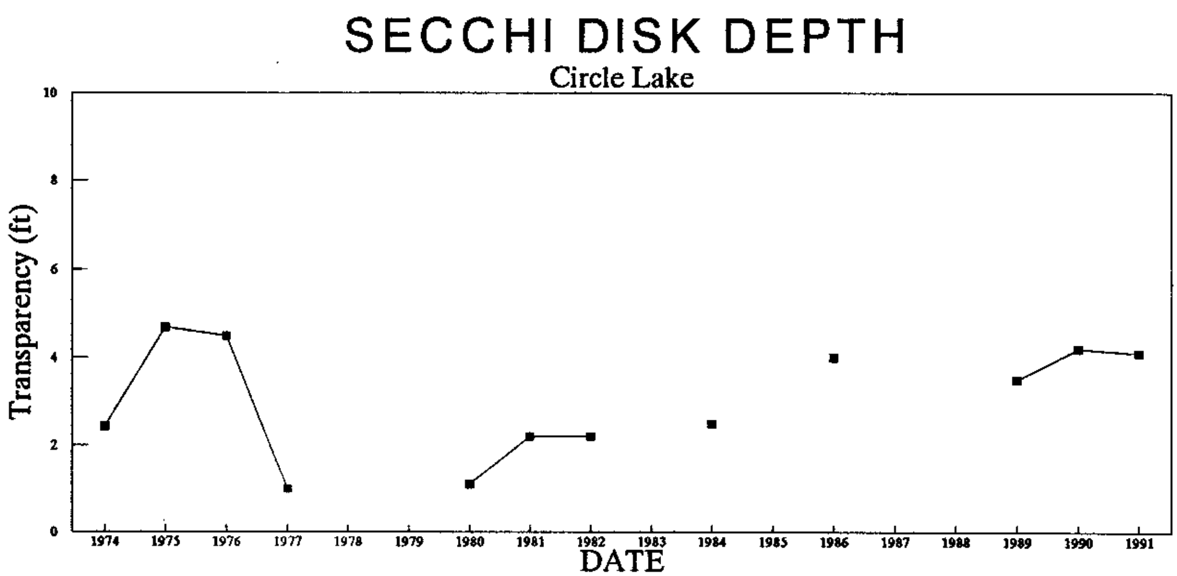
* = values for Circle Lake




After Moore, l. and K. Thornton, [Ed.] 1988. Lake and Reservoir Restoration Guidance Manual. USEPA> EPA 440/5-88-002..

FIGURE 7. CLMP DATA FOR CIRCLE LAKE

| DATE | FEET | # of obs |
|---|---|---|
| 1974 | 2.43 | 4 |
| 1975 | 4.7 | 20 |
| 1976 | 4.5 | 1 |
| 1977 | 1 | 4 |
| 1978 | | |
| 1979 | | |
| 1980 | 1.1 | 4 |
| 1981 | 2.2 | 7 |
| 1982 | 2.2 | 5 |
| 1983 | | |
| 1984 | 2.5 | 6 |
| 1985 | | |
| 1986 | 4 | 11 |
| 1987 | | |
| 1988 | | |
| 1989 | 3.5 | 22 |
| 1990 | 4.2 | 12 |
| 1991 | 4.1 | 33 |



APPENDIX A. Example Survey Form

# LAKE ASSESSMENT PROGRAM
# SEPTIC SYSTEM SURVEY

Fox and Circle Lakes have been selected for study this year by the Minnesota Pollution Control Agency(MPCA). The Lake Assessment Program(LAP) is a joint effort between the MPCA and lakeshore property owners to establish a baseline for any future programs aimed at improving water quality. The MPCA selects about ten lakes each year for participation in the Lake Assessment Program.

As part of the LAP, Forest Township Agri-Lakes Association(FTALA) is working with the MPCA to collect data on septic systems around the two lakes. This data will be used to write a report later this year outlining the problems and potential solutions to water quality problems facing Fox and Circle Lakes.

The information requested below is completely voluntary, and will be used only by the MPCA in assessing the relative impact that septic systems have on water quality. This information will not be used by any government agencies for determining compliance to current or future septic system requirements.

Please answer the questions below to the best of your ability. If you are not comfortable with any of the questions, or if they do not apply, feel free to leave them blank.

## QUESTIONNAIRE

1) Name ______________________________

2) Lake Address ______________________________

______________________________

3) Home or Winter Address ______________________________

______________________________

4) What year was your septic system installed? __________

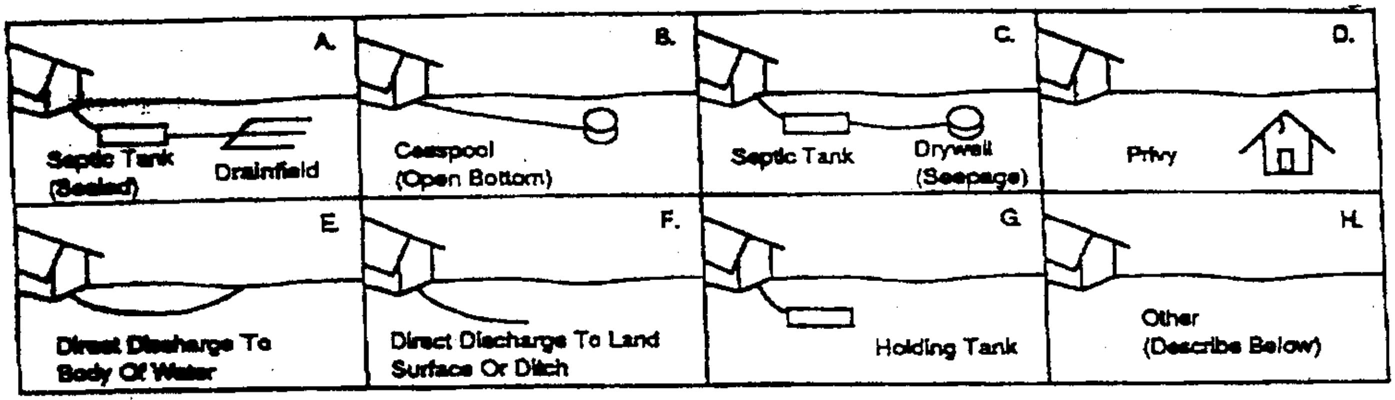
5) How many bedrooms in your home? __________

6) How many bathrooms in your home? __________

7) How many months a year is your cabin or lake home occupied? ______

8) How many people live in your cabin or lake home? __________

9) If you reside on the lake only during the summer, do you have any future plans to live here year round? __________




10) Which of the pictures above best represents the septic system for your cabin or lake home? ______________

11) What is the approximate distance from your drainfield to the lake? __________________ feet

12) What is the approximate distance from your drainfield to your well? __________________ feet

13) Approximately how high is the bottom of your drainfield above the water table? __________ feet

14) Do you have your septic system pumped regularly(at least once every two years)? ________

15) Are you aware of the new county ordinances regarding septic systems in shoreland areas? ______________

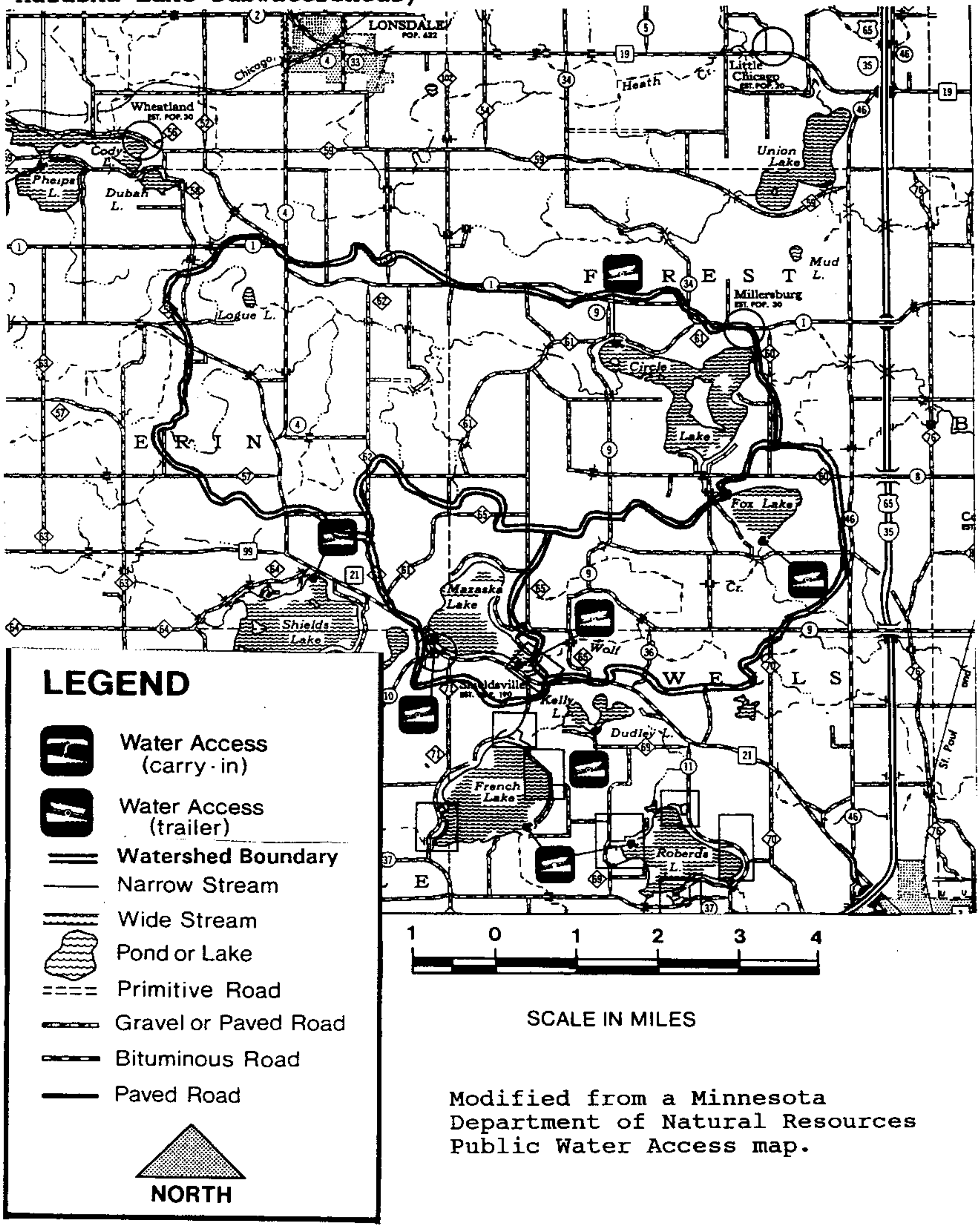
16) Would you be interested in a community septic system for lakeshore owners if partial funding were available to offset costs? ________

17) Do you use phosphorous containing fertilizers on your lawn? ______
If yes, approximately how many pounds per year? _______ lbs
Would you be willing to use low(or zero) phosphorous fertilizer instead? ______ Do you use a lawn service? ________

18) Would you like to receive a copy of the LAP report when it is completed? ________ Would you be interested in attending a public meeting this winter or spring to discuss the results of the Lake Assessment Program? ______

If you have any questions regarding the Lake Assessment Program or need assistance answering these questions, please feel free to call Rick Schwartz (334-2617), Craig Waterston (334-2863), Ann Passe(645-4996), or Sam Sunderland(663-1948). We will make the report available to anyone interested as soon as it is finished.

Appendix B. Watershed of Circle Lake (includes Fox Lake and Mazaska Lake subwatersheds)




Modified from a Minnesota Department of Natural Resources Public Water Access map.

Appendix C. Map of Circle Lake showing depth contours and stream inlets and outlets.