LAKE ASSESSMENT PROGRAM

1992

Roberds Lake

MDNR ID Number 66-0018

MINNESOTA POLLUTION CONTROL AGENCY

Division of Water Quality

Nonpoint Source Section

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SUMMARY AND CONCLUSIONS

Roberds Lake was sampled during the summer of 1992 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 Roberds Lake is poorer than similar lakes in the North Central Hardwood Forest ecoregion of Minnesota. The mean summer concentrations of total phosphorus and chlorophyll were 150 and 64 µg/l, respectively, and the mean Secchi disk transparency was 3.6 feet. Based on these water quality values Roberds Lake would be considered eutrophic to hypereutrophic.

Phosphorus and chlorophyll data fit Carlson's model for trophic status indicators reasonably well (Carlson 1977). The Secchi disk transparency values were somewhat higher than expected based on the observed phosphorus and chlorophyll concentrations. Transparency readings can still provide good long-term estimates of phosphorus and chlorophyll and can be a useful tool for tracking future trends. An empirical computer lake model was used to predict 1992 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 Roberds Lake is poor relative to other lakes in this ecoregion; however, this is partially due to the fact that the lake is located in a more fertile portion of the ecoregion. Based on total phosphorus measurements made over the past 12 years, the lake would be classified as hypereutrophic (extremely productive). Further changes in land use 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 1992 assessment of Roberds Lake:

1. Participation in the Citizens Lake Monitoring Program should continue since it is an effective way to assess long-term and year-to-year variations in algal productivity (lake trophic status). Monitoring should be conducted over the site of maximum depth near MPCA site 101.
2. The Roberds Lake Association 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. A lake lot with a diverse community of native vegetation will also provide habitat for songbirds and other small animals. 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 Lake Association.
3. Any development in the immediate watershed should be completed so that the impacts to lake water quality are minimized. Setback provisions and natural 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 Roberds Lake watershed, such as wetland removal or major land use alterations that change the drainage or flow patterns, should be discouraged. Establishment and maintenance of effective buffers between

agricultural areas and ditches, streams, and the lake will help to minimize nutrient-rich runoff and provide wildlife habitat.

5. The members of the Roberds Lake Association 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 Roberds Lake. Those efforts which address shoreline management, and aquatic plant control will be of special interest to club members.
6. Although it can be difficult to assess how much impact individual watershed projects will have on the lake, the cumulative effect of several projects 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. The MDNR has constructed a map of the remaining natural areas and rare species in Rice County. These few remaining natural areas should be targeted for protection.
7. A few factors such as watershed size, lake depth and potential for nutrient recycling from the sediments may make Roberds Lake a good candidate for in-lake treatment options (i.e., alum addition, hypolimnetic aeration). Prior to implementing any in-lake treatments, a more detailed analysis of P loading to the lake should be conducted. In-lake treatments are most effective after watershed loadings are controlled to the maximum extent.

LAKE ASSESSMENT PROGRAM - 1992

Roberds Lake

(ID No. 66-0018)

Rice County, Minnesota

The Roberds Lake Association applied for inclusion in the Lake Assessment Program in 1992 and listed in their application the following water quality concerns for Roberds Lake.

1. An increase in the frequency of the toxic blue-green algae blooms in the last 10 years.
2. A dramatic increase in the growth of aquatic vegetation.
3. 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 the water quality problems. A report prepared by Rice County in 1986 stated that removing the threat of fecal contamination of Roberds Lake must be the priority for the future. The presence of fecal coliform bacteria indicates that the lake has been impacted by untreated animal and/or human waste.

The Lake Assessment Program (LAP) 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 the land-use and drainage patterns in the watershed. During the summer of 1992 staff of the Minnesota Pollution Control Agency (MPCA) and St. Olaf College collected baseline water quality data as a part of the LAP for Roberds Lake. Conclusions and recommendations based on water quality and watershed data are included in the report.

BACKGROUND

Roberds Lake was sampled five times during the summer of 1992 by Ed Weir of the MPCA Rochester regional office and Mark Vlasak and Al Akins of St. Olaf College. Roberds Lake Resort provided the boat and motor for the sampling crew. The Citizens Lake Monitoring Program volunteers were Lloyd Marik, Bob Cross and Jim Nelson.

Roberds Lake is two miles northwest of the city of Faribault in central Rice County (Fig. 1). Surface area of the lake is 654 acres and the shore length is 5 miles. It is one of seven lakes in Rice County larger than 600 acres. The maximum depth of the lake is 43 feet (13.1 meters) and the mean depth is 10.6 feet (3.2 meters). The littoral zone or that part of the bottom that supports rooted plants covers approximately 63% of the lake (Table 1).

Roberds Lake was formed by an ice-block in glacial till (Zumberge, 1952). When the ice melted a pit was left which collected water to become a lake. Lakes in the area that were formed in a similar manner include Cedar and Mazaska. Typically lakes of this type are steep-sided and the lake depth is determined by the maximum relief of the local topography. If the water and accumulated sediment were removed from the lake basin, the lake bed would occupy a natural position in the local topography.

Soils in the Roberds Lake watershed belong to the Lester-Heyden associations which are moderately steep loams that were formed in upland glacial till.

Permeability of the soil is moderate and the water table is below 10 feet. The soils are suited for use as septic tank drain fields except in areas of high slope. Runoff is moderate to rapid and potential for erosion can be severe. Native vegetation in this area was prairie grass and deciduous trees. Some areas remain as forest or wooded pasture but most soils are presently used for crops.

Because conditions in the surrounding watershed affect the water quality in a lake, it is helpful to divide the state into areas, called ecoregions, where climate, native vegetation and land characteristics are similar. Minnesota can be divided into seven ecoregions based on soils, land surface form, natural vegetation, and current land use (Fig. 1). Roberds 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 ecoregion is typically 22-50% cultivated, 11-25% pastured and open, 14-30% water or marsh, 6-25% forested and 2-9% developed. The land use in the 8025-acre Roberds 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). See Appendix for map of Roberds Lake watershed.

Water quality information was collected on May 13, June 10, July 7, August 3 and September 1, 1992 at two sites on Roberds Lake (Fig. 2). Site 101 in the south central portion of the lake was chosen because it is the location of maximum depth (43 feet, 13.1 meters). The second site, 102, was chosen to gain an understanding of the water quality variability within the lake. The depth at site 102 was approximately 13 feet (4 meters). Lake surface water samples were collected with an integrated sampler, which is a PVC tube 6.6 feet (2 meters) long with an inside diameter of 1.4 inches (3.5 centimeters). Samples from near the bottom were collected with a 2-liter Kemmerer sampler, a water trap that closes at a desired depth. Plankton samples were collected with a Wisconsin plankton net which was towed vertically from the bottom to the surface. A qualitative evaluation of the zooplankton 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 for pH, conductivity, Secchi disk transparency, and temperature and dissolved oxygen profiles were made in the field. Algal composition was determined by means of a rapid assessment method. Nearly two decades of Citizen Lake Monitoring Program transparency measurements along with water quality data collected in 1980, 1981, and 1989 are available for comparison (Tables 2, 3, 4). 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 1992

Temperature

Lakes in temperate climates tend to stratify or separate into three layers in the summer due to differences in density caused by differences in temperature. The metalimnion or thermocline is the middle zone where the water temperature drops rapidly with small increases in depth. This zone separates the epilimnion above from the hypolimnion below. The epilimnion contains warmer water of similar density. This layer is mixed by the wind and is where most algae growth occurs. The hypolimnion contains much colder water, that does not mix, and is the zone where dead plant material accumulates and decomposes.

The temperature profiles measured at the deepest site (101) show that the lake did not thermally stratify during the summer of 1992 (Figs. 3a-e). Surface water temperature ranged from 17.0° to 24.2° C (63° to 76° F) and bottom temperatures from 15.5° to 20.4° C (60° to 69° F) The greatest difference between the surface and bottom was 21.5° to 15.5° C (71° to 60° F) recorded on June 10. There are probably two major reasons that the lake did not thermally stratify. The summer of 1992 was relatively cool and atmospheric temperatures affect water temperatures. Also the lake has a maximum depth of only 43 feet and a relatively large surface area of 654 acres. That is, Roberds is rather shallow and has a large wind fetch, which means that the lake tends to mix quite easily. (Although Roberds Lake did not stratify, the terms epilimnion and hypolimnion will still be used to refer to surface and bottom waters, respectively.)

Dissolved Oxygen

Dissolved oxygen concentrations decreased rapidly with increasing water depth during the summer at site 101 (Figs. 3a-e). Concentrations in the surface water remained above 8 mg/l throughout the summer. Near the bottom oxygen concentrations were near 0 mg/l in June, July and August. Very low concentrations were common at depths below 7 meters (23 feet). The lack of oxygen in the bottom water is caused by high oxygen demand by decomposition in the sediments and incomplete mixing of the water column. Also, algal photosynthesis, which contributes oxygen to the water, is probably limited to the upper 5-6 feet due to poor transparency.

The oxygen levels in different areas of a lake will determine where fish and other organisms are found. Concentrations greater than 5 mg/l are considered necessary for long-term survival of game fish. Below 5 mg/l fish will occupy the warmer more oxygenated waters near the surface. Low oxygen can also affect the amounts of other chemicals present. For example, the amount of phosphorus in lower levels of a lake tends to increase as oxygen concentrations fall.

Total Phosphorus

Phosphorus is an important nutrient for plant growth, and in most lakes it is the nutrient that limits the amount of algae and weed growth. Total phosphorus (TP) in the epilimnion decreased between the May and June samplings and then increased until September (Fig. 4). The mean (average) TP concentration in the epilimnion was 150 µg/l and ranged from 46 to 248 µg/l. Wind mixing of the upper portion of the lake resulted in high levels of TP in the epilimnion in August (223 µg/l) and September (248 µg/l). TP concentrations in the epilimnion at sampling site 102 were similar to those at site 101 (Table 4). The mean TP value is much higher than concentrations in a set of minimally impacted (reference) lakes in the North Central Hardwood Forest ecoregion of Minnesota which ranged from 23 to 50 µg/l (Table 3); 81 % of the 436 assessed lakes in this ecoregion had phosphorus levels less than 150 µg/l. On all sampling dates TP concentrations in the hypolimnion were higher than in the epilimnion. Concentrations near the bottom of the lake ranged from 203 (June) to 432 µg/l (July) and the mean was 307 µg/l. There was a sharp increase between June and July and then a decline in August and September.

An increase in phosphorus in the bottom waters during the summer is characteristic of productive, stratified lakes and is largely the result of two processes. First, periods of low oxygen levels near the bottom will stimulate the release of phosphorus from the sediments into the lake. Second, algae in the upper waters take in phosphorus as they grow. When algae die, they settle out of the epilimnion and into the hypolimnion where the phosphorus is released into the water during decomposition. This often results in a decline in TP in the epilimnion from spring to fall. While phosphorus concentrations will likely increase in hypolimnetic waters under stratified conditions, much of the phosphorus will remain unavailable for the production of algae in the epilimnion. However, when stratification breaks down after the growing season, phosphorus is mixed throughout the lake and may be available for phytoplankton growth the next spring. Since Roberds Lake did not stratify, some mixing occurred throughout the summer. By September the lake was well mixed (Fig. 4).

In the North Central Hardwood Forest ecoregion, distinct differences exist between lakes which maintain a stable stratification (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 stratified throughout the summer.

TP concentrations in Roberds Lake were more characteristic of a well-mixed lake. The lake did not thermally stratify during the summer of 1992. Phosphorus levels in the epilimnion increased from June to September rather than declining as is typical in a stratified lake.

Total Nitrogen

Total nitrogen (TN) which is defined as the sum of the total Kjeldahl nitrogen and nitrate-nitrite nitrogen averaged 1.99 mg/l during the summer of 1992. This is higher than the typical TN value for the ecoregion reference lakes which ranges between 0.6 to 1.2 mg/l. The average total Kjeldahl nitrogen concentration measured in Roberds Lake (1.98) is higher than those measured in reference lakes in the region (Table 3). Nitrogen sources such as nitrogen fertilizer, septic system effluent, and animal waste may contribute to the somewhat high TN concentrations in Roberds Lake.

Total Nitrogen to Total Phosphorus Ratio (TN:TP)

Phosphorus and nitrogen are required for growth of aquatic plants and algae. Although phosphorus is usually the nutrient limiting the productivity in most Minnesota lakes, nitrogen may be the limiting nutrient in some situations. The ratio of TN:TP can indicate which nutrient is limiting. For Roberds Lake the TN:TP ratio is 13:1. The TN:TP ratio measured in Roberds Lake is considerably lower than the typical ratios for the ecoregion which range from 25:1 to 35:1 (Table 3). The extremely high TP concentration is the primary reason for the low TN:TP in Roberds Lake. TN:TP ratios greater than about 17:1 suggest phosphorus limitation, while ratios less than 10:1 suggest nitrogen limitation. TN:TP ratios in Roberds Lake are intermediate and thus phosphorus or nitrogen may be limiting under certain conditions. However, TN:TP ratios are most meaningful at much lower phosphorus than those observed in Roberds Lake (e.g., less than about 50 µg/l phosphorus). This suggests that increases in the in-lake phosphorus concentration may increase the production of algae and large aquatic plants.

Chlorophyll-a

Chlorophyll concentrations provide a measure of the amount of algae in a lake. During the summer, lake chlorophyll concentrations ranged from 2.24 to 114 µg/l with a mean concentration of 54 µg.l (Table 3, Fig. 5). The high concentrations observed in August and September corresponded with the lowest Secchi disk transparency measurements. Based on surveys of CLMP volunteers, concentrations from 10 to 20 µg/l would be perceived as a mild algal bloom, and concentrations greater than 30 µg/l would be perceived as severe nuisance conditions (Heiskary and Walker, 1988). The chlorophyll values reported for Roberds Lake exceeded the nuisance conditions level in July, August and September and are higher than summer-mean concentrations in the set of reference lakes for the ecoregion which range between 5 and 22 μg/l (Table 3, Fig. 5).

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 (Table 3) measured during the lake assessment sampling was 3.6 feet (1.1 meters). The average transparency based on the values determined by volunteer measurements was equal to 4.4 feet (1.3 meters) for the entire summer and 2.4 feet (0.7 meters) for July and August (Fig. 6). The difference between the two averages is due to natural variability and the number of measurements. The transparency measured for Roberds Lake is slightly lower than typical values for the ecoregion reference lakes.

Other Physical and Chemical Parameters

Other water quality parameters measured for Roberds Lake in the summer of 1992 including color, pH, conductivity, total suspended solids, total suspended inorganic solids, alkalinity and turbidity were all higher than values typical for the ecoregion (Table 3). These values were more comparable to the Western Cornbelt Plains ecoregion. The alkalinity, pH and conductivity values are fairly typical for a productive hardwater lake.

Phytoplankton (Algae)

Phytoplankton samples taken in May, June and July from site number 101 were analyzed. Several species of green algae were abundant in the May and June samples. In addition, the blue-green alga *Aphanizomenon flos-aquae* was common.

Aphanizomenon grows in bunches which resemble small grass clippings. This species tends to increase in abundance in area lakes during the summer. In July *Aphanizomenon* accounted for 90% of the volume in the algae samples.

Zooplankton

Zooplankton (microscopic animals) was collected and analyzed at each sampling date. Many small-bodied forms were observed in May, but fewer animals were observed in June and July. In July about 25% of the entire plankton sample was zooplankton, approximately half of which were water fleas and half copepods. Few large-bodied zooplankton were observed in any of the samples. Large-bodied forms can be beneficial for lakes because they can consume large quantities of algae.

Aquatic Plants (Macrophytes)

The Roberds Lake Association expressed concern about the increased growth of pondweed along the lake shore of Roberds Lake. In a plant survey conducted in the summer of 1992, the most abundant species was the curly-leaf pondweed, *Potamogeton crispus*. This plant is an introduced, or exotic species, that out-competes and replaces more desirable native species.

Fish survey reports prepared by the Department of Natural Resources show that prior to the mid 1970's Roberds Lake had only sparce growth of large aquatic plants. A 1972 report stated , "aquatic plants almost totally lacking in the lake proper -- occasional pondweed fringe". Curly-leaf pondweed was probably introduced during the late 1960's and has been reported as abundant since 1980. This plant is of concern because it has gradually increased in density and areal extent. Only areas of lake bottom shallow enough to receive adequate light will support the growth of macrophytes. There is a direct relationship between Secchi disk transparency and the maximum depth of colonization (MDC) by aquatic plants (Canfield et al., 1985).

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

Over the monitoring period the average Secchi disk transparency was 3.6 feet (1.1 meters). Using this value, the maximum depth of colonization for Roberds Lake would be 6.2 feet. At 6 feet plant growth will be sparce and more plants will grow in progressively shallower water. About 23% of the lake is less than 5 feet deep. Most plant growth is in this area and forms a ring of weeds around the lake that may be a nuisance for boating or swimming.

A number of techniques may be used to control nuisance macrophytes in small areas. Manual or mechanical harvesting can be an effective, short-term control technique for small swimming areas or boat paths. This also has a small additional benefit of removing nutrients from the lake. 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 in small areas. See the Lake and Reservoir Restoration Guidance Manual (USEPA 1990) for more information. When deciding on an appropriate control technique, remember that many 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 this weed without a reestablishment of native perennial species may result in an increase in the severity and frequency of algal blooms.

Physical Condition and 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 below for 1992:

Month	Transparency (mean ft.)	Physical Condition (mean class)	Recreational Suitability (mean class)	Chl-a (mean µg/l)
May	10.3	2	2	2
June	6	2	2	5
July	2.5	4	4	37
August	2.4	5	5	114
September	2.3	4.5	4	113

These data show that transparency and the physical condition and recreational suitability perceptions of the observer usually agreed. Because transparency is an indication of water quality, one would expect that high transparency often corresponds to high physical condition and recreational suitability perceptions (low scale values). On only one date, June 21, was a low transparency recorded (2.5 feet) but relatively good physical conditions (2) and recreational suitability (2) were perceived. This was probably because the algae forming the bloom were greens rather than blue-greens. The changes in physical condition and recreational suitability rankings correspond to Secchi transparency and algal concentrations based on chlorophyll-a measurements (Table 2, Fig. 5). Algal type may also influence user perception, e.g., blue-green algae are often perceived as a nuisance.

In the summer of 1993 perceptions of Roberds Lake water quality were collected from people fishing the lake as part of MDNR creel surveys. The surveys were conducted from 19 June to 16 October. Ratings (daily average) of the lake's "physical condition" ranged from 1 (crystal clear water) to 4 (high algal levels with limited clarity and/or mild odor apparent). "Recreational suitability" ratings also ranged from 1 (beautiful, could not be better) to 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). See Appendix for complete survey results. The best water quality perceptions were from mid-September to mid-October.

Based on user perception data, Secchi transparencies of less than three feet and chlorophyll-a concentrations of greater than 30 µg/l are associated with "high algal green" and "no swimming". These conditions occurred much of the summer; therefore, the frequency of chlorophyll-a events of greater than 30 µg/l needs to be reduced.

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:

Total phosphorus TSI (TSIP) = 14.42 ln(TP) + 4.15

Chlorophyll TSI (TSIC) = 9.81 ln(Chl a) + 30.6

Secchi disk TSI (TSIS) = 60 - 14.41 ln(SD)

Note units: TP in µg/l, Chlorophyll in µg/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 (Fig. 7).

The TSI values of total phosphorus, chlorophyll, and Secchi disk transparency for Roberds Lake are between 59 and 76 with an average of 69 (Table 3). Based on these values the lake would be considered eutrophic to hypereutrophic or very nutrient rich. Usually the three TSI values are more similar than those determined for Roberds Lake. Part of the discrepancy may be due to the dominance of the blue-green algae *Aphanizomenon*. Under these conditions, Secchi disk transparencies tend to be higher than would be expected based on the TP and chlorophyll concentrations. However, Secchi disk monitoring of Roberds Lake can still provide a reliable indication of the algal and phosphorus trends in the lake.

Comparison of TSI values for Roberds 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 69 ranks in the 26th percentile for the ecoregion. In other words 74 percent of the lakes assessed in the region have TSI values less (are less eutrophic) than Roberds Lake (Table 3).

Another way to compare the trophic status variables is on scatterplots. Figure 8 illustrates the general relationships between total phosphorus, chlorophyll, and Secchi disk transparency and where the Roberds Lake data plot on the graphs. The three parameters generally are closely correlated since phosphorus is often the nutrient limiting algal production, and Secchi disk transparency is dependent upon the algal 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 Roberds Lake data plots on the upper ends of Figures 8a and 8c, fairly large reductions in total phosphorus or chlorophyll will be required for noticeable increase in transparency.

Trend Analysis/Historical Data

Historical data is available for Roberds Lake and other lakes in Rice County. National Biocentric completed a water quality evaluation of lakes and streams in the county in 1972. Secchi disk measurements taken by the CLMP volunteers are available from 1974 to the present (Fig. 9). Water quality data from county and state sampling efforts are available for 1980, 1981, 1989 and 1992. Although other water quality information is available, only years with two or more measurements for any parameter will be considered in this discussion. Mean summer total phosphorus, chlorophyll and Secchi disk measurements from previous years are shown below.

Year	TP (# of obs.) (μg/l)	Chl a (# of obs.) (μg/l)	Secchi (# of obs.) (feet)
1972	370 (3)		4.5 (2)
1974			3.6 (4)
1975			5.2 (5)
1977			3.1 (4)
1980	275 (4)		3.5 (4)
1981	219 (3)		5.8 (8)
1982			4.2 (5)
1984	205 (2)		2.5 (6)
1989	258 (9)	53.2 (5)	1.7 (5)
1990	330 (2)		
1992	150 (5)	64 (5)	5.38 (5)

It is difficult to assess historical trends in Roberds Lake water quality based on the data available. In measurements taken over the past 20 years total phosphorus concentrations varied widely, from 150 to 370 μg/l. However, based on all of the TP measurements taken during the past 12 years, the lake would be classed as hypereutrophic. Not enough chlorophyll-a data is available to establish a historical trend. The mean trophic status index (TSIP) for the years 1980 and 1992 was 83. This value categorizes the lake as hypereutrophic.

National Biocentrics assigned water quality indexes to nine lakes in Rice County in 1972. Each index was based on Secchi disk transparency, biochemical oxygen demand (BOD), available phosphate, ammonia, pH and total coliform bacteria. Direct comparison of the 1972 Biocentric data with the LAP data collected in 1992 is not meaningful, but the 1972 study does provide an indication of the relative water quality of lakes in Rice County at that time. Roberds was rated below Fox, Mazaska, French and Shields Lakes and above Cedar, Circle, Union and Cannon Lakes. In 1986 Rice County compiled a water quality evaluation of lakes and streams in the county which compared historical data and data the county collected in 1984. Agricultural runoff, lakeshore development and nutrient-rich sediment were considered to be the major sources of nutrient input.

Mean summer Secchi disk transparencies have been collected for Roberds Lake on an irregular basis since 1974. Secchi disk values vary considerably from year to year but there has been a general decrease in transparency since 1974. This is most notable in the readings for July and August (Fig. 9).

Nutrient Sources

There are five small inflow streams to Roberds Lake and one large outflow to the southeast (Fig. 2). The inflow streams carry water from subwatersheds of the entire watershed. The size and amount of agricultural activity in these subwatersheds differs. Nutrient inputs from the streams draining these areas varies because of these differences. Average total phosphorus concentration in samples taken from four of these streams in August of 1990 were northeast 600 µg/l, south 290 µg/l, southwest 640 µg/l and west 630 µg/l. Mean TP concentration in samples from the outflowing stream was 450 µg/l.

It is likely that nonpoint source pollution accounts for much of the nutrient input to Roberds Lake. Nonpoint source pollution includes: agricultural runoff from croplands and pastures, pesticide and fertilizer use, feedlot runoff, urban runoff from streets, yards and construction sites, leachate from septic systems, dredging and draining activities, and the impacts from the loss of wetlands. The TP concentrations of the input streams given above are very high. These values suggest that high phosphorus sources, such as direct feedlot drainage or direct wastewater inputs, are occurring in addition to nonpoint sources. These sources must be addressed along with the nonpoint sources. 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 for agriculture should be selected that meet water quality goals as well as the individual farm operation. Refer to the MPCA's Agriculture and Water Quality publication for more information on agricultural BMP's.

No direct discharges to Roberds Lake from drain tiles or culverts were identified in the study. However, runoff from the immediate watershed contributes a significant amount of nutrients to the lake. Three sources of nutrients were identified as potential problems in the immediate watershed of Roberds Lake: livestock feedlots near the lake shore, failing on-site sewage treatment systems, and lawn fertilizers which contain phosphorus.

Livestock

Feedlots may contribute large amounts of nutrients to a lake. Animal manure contains not only nutrients but oxygen-demanding material and bacteria. Water samples of runoff from a feedlot near Roberds Lake taken in 1990 contained a mean TP concentration of 4.37 mg/l (4,370 µg/l) or nearly seven times the concentration in the highest inflow stream. Reductions from sources such as these are essential to reduce phosphorus concentrations in Roberds Lake. Agricultural BMP's include suggestions for the management of animal wastes.

In-Lake

A portion of the nutrients that enter a lake from the watershed become bound to the bottom sediment. These nutrients are released under certain conditions. Phosphorus, for example, is released from the sediment when the bottom contains no oxygen. This was the case at site 101 in Roberds Lake in 1992 on the June, July and August sampling dates. The contribution of phosphorus from the sediment can represent a significant part of the phosphorus load to a lake and, in some cases, may be the major source of phosphorus. If internal phosphorus is a major source, it is because of the history of excessive external loads. The only permanent solution is to reduce external loading.

On-Site Treatment Systems

A survey of property owners around Roberds Lake was conducted by the Lake Association in 1992. Survey forms were sent to 162 property owners. A copy of the questionnaire is included in the Appendix. The purpose of the survey was to provide the Association with basic information regarding the types of on-site septic systems on the lake, ages of the systems, types of dwellings, frequency of pumping and the use of lawn fertilizers. This information should assist the association and Rice County in determining whether more education is needed with respect to the design and maintenance of on-site septic systems and lake-safe lawn care practices.

The Association received responses from 65% of the lake property owners. The table below summarizes the responses. A majority of the respondents (53%) have systems 20 years old or less while 35% were greater than 25 years or unknown. Six percent of the respondents are served by the Misgen Bay Utility Company and four percent have no treatment system. Misgen Bay Utility is an association of 18 land owners that maintains a common well and septic system drain field. The drain field is located on a hill approximately 400 meters from the north shore of the lake. About 38% of the respondents pump their systems at least once every three years. Twenty percent responded that their systems had not been pumped since installation. The Minnesota Extension Service recommends pumping every one to three years for a 10,000 gallon tank serving a three bedroom house and four occupants, assuming year round use.

Septic System Survey Results (based on 105 respondents)

Type of Dwelling		
Seasonal	36	(34%)
Year round	69	(66%)
System Ages		
0-5 yr	19	(18%)
6-10 yr	15	(14%)
11-15 yr	12	(11%)
16-20 yr	10	(10%)
21-25 yr	2	(2%)
26-30 yr	7	(7%)
31+ yr	7	(7%)
Unknown	23	(22%)
Sewer provided by Misgen Bay Utility Co.	6	(6%)
No system	4	(4%)

System Pumping		
Last in '86	1	(1%)
Last in '87	1	(1%)
Last in '88	2	(2%)
Last in '89	8	(8.5%)
Last in '90	11	(12%)
Last in '91	4	(4%)
Last in '92	7	(7%)
Last in '93	14	(15%)
Never	20	(21%)
Unknown	27	(28.5%)
Use P-containing fertilizers or comm. lawn service		
Yes	30	(29%)
No	59	(56%)
No response	16	(15%)

Most of the on-site systems around the lake are the conventional septic tank-drainfield type. A majority of the systems of the respondents were less than 20 years old and seemed properly maintained. However, there are many septic systems over 25 years old and a large number have not been pumped regularly.

Based on the results of the survey, it appears that some education on septic system maintenance and lawn care is needed. County assistance and inspections may also be appropriate.

Lawn Maintenance

Lawn fertilizers can be a large source of nitrogen and phosphorus and are not recommended for use around lakes. Of those responding to the Roberds Lake survey, 29% said that they use phosphorus-containing fertilizer. Lawn fertilizers high in phosphorus should be used only in 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 and trap nutrients that may run off the lawn into the lake. Leaving grass clippings on a lawn can reduce the need for fertilizers. However, in areas where clippings and leaves can wash into a lake, removal to a compost site away from the lake is recommended.

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 a 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 Lake Eutrophication Analysis Procedure" (MINLEAP) model and the Reckhow and Simpson (1980) model were used to assess the current water quality of Roberds 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 Roberds Lake. It is intended to be used as a screening tool for estimating lake conditions 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 effort. 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 Roberds Lake predicted by MINLEAP were 48 and 19 µg/l respectively which is over three times lower than the values determined in the 1992 sampling (Table 5). The observed Secchi disk depth was slightly lower than the predicted value. The estimated phosphorus loading, corresponding to an in-lake phosphorus concentration of 48 µg/l, is 703 kg/yr. However, given the difference between the predicted versus observed in-lake phosphorus concentration, it is likely the actual phosphorus loading is much higher. MINLEAP estimated phosphorus retention at 71 percent and water residence time at approximately 2 years.

Roberds Lake was also modeled as if it were located in the Western Corn Belt Plains ecoregion. For the MINLEAP model, this means a higher inflow phosphorus concentration. This model run predicted an in-lake phosphorus concentration of 108 µg/l which is lower than the 150 µg/l measured in 1992. Thus, even with these changes, Roberds Lake's phosphorus concentration is higher than predicted based on its morphometry and watershed.

The second model used was Reckhow 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 as a range of values. The Reckhow-Simpson model (using the Canfield/Bachman equation) predicts an in-lake phosphorus concentration ranging from 92 to 143 μg/l for Roberds Lake. The "high" concentration value of 143 μg/l is most comparable to the 1992 summer mean (150 μg/l). At 143 μg/l the Reckhow-Simpson model estimates an inflow phosphorus concentration of 602 μg/l which is consistent with measurements taken from several inflow streams in August, 1990. Also, the phosphorus flux (load) corresponding to a concentration of 142 μg/l is 4303 kg/yr. Thus, the difference in phosphorus flux predicted by Reckhow-Simpson (using "average" export coefficients) versus MINLEAP (703 kg/yr) suggests that the phosphorus loading to Roberds Lake is approximately 6 times that expected based on Roberds Lake's morphometry, watershed size, and ecoregion. Neither model indicates how much of the "excess" nutrient loading is from the watershed and how much is recycled from lake sediments (internal loading). Internal loading may be important, but watershed sources are the most important overall and must be considered first.

Typical phosphorus export values for the area, based on "average" export coefficients, are used in the Reckhow-Simpson model. Based on these estimates, agricultural lands potentially contribute about 75 percent of the phosphorus from the watershed. Urban areas and septic tanks may contribute about 15 percent, while the remaining land uses contribute the remaining 10 percent. However, these are just estimates, and the actual contributions may vary significantly from the percentages above.

GOAL SETTING

The historical data and model predictions indicate that attaining an average epilimnion phosphorus concentration of 50 to 55 μg/l is an aggressive goal for

Roberds Lake. To maintain fisheries, aesthetics and full recreational usage, phosphorus levels below 40 µg/l are desirable for a majority of the lakes in Minnesota. This concentration may be difficult to attain for Roberds Lake. However, if levels are maintained at 50 to 55 µg/l, the lake would support fishing and swimming most of the time. Some algae would be present most of the summer but the periods of severe algal blooms (chlorophyll concentrations greater than 30 µg/l) would exist only about 30% of the summer. Presently, chlorophyll concentrations exceed 30 µg/l over 80% of the summer.

Reduction in the phosphorus loading will be required to reach the goals stated above. Loading from the watershed must be controlled before 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 shape 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 watershed and the lake sediments. Implementation of best management practices on cultivated land, feedlots, and the immediate watershed (lawns and septic systems) should help to reduce the phosphorus loading. Once watershed contributions are adequately controlled, some in-lake treatment which addresses the sediment contributions may be appropriate. 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. Roberds Lake morphometric, watershed and fishery characteristics.

MDNR I.D. 66-0018

Area: 654 acres (264.8 hectares)

Mean Depth: 10.6 feet (3.2 meters)

Maximum Depth: 43 feet (13.1 meters)

Volume: 6471.3 acre-feet (8 HM3)

Littoral Area: 63%

Shoreline Length: 5.0 miles

Watershed Area: 8025 acres (3249 hectares)

Watershed Area: Lake Surface Area Ratio: 14:1

Estimated Average Water Residence Time: 2 years

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

Land Use (percentage):

	Forests	Water/Marsh	Pasture/CRP	Cultivated	Urban
Roberds Lake	14	22	12	41	11
North Central Hardwood Forest	6-25	14-30	11-25	22-50	2-9

Public Access: 1 - west shore of the lake

Inlets/Outlets: 5 inlets (unnamed) 1 outlet (stream to Cannon River)

Shoreland Zoning: General Development

	Development (Homes)		
Year	Seasonal	Permanent	Total
1967	63	61	124
1982	94	66	160

Table 2. Citizen Lake Monitoring Program data for sampling site 201 on Roberds Lake in 1992.

MDNR I.D. 66-0018

Date	Secchi Disk (ft)	PHYS	REC
5/10	13.5	2	2
5/17	11.0	2	2
5/24	8.0	2	2
5/31	8.5	2	2
6/7	6.5	2	2
6/14	12.0	2	2
6/21	2.5	2	2
6/28	3.0	3	3
7/5	2.0	5	4
7/12	2.5	4	4
7/19	2.5	4	4
7/26	3.0	4	4
8/2	3.0	4	4
8/9	2.5	5	4
8/16	3.0	5	5
8/23	1.5	5	5
8/30	2.0	5	5
9/6	2.0	5	5
9/13	2.0	5	4
9/20	2.5	4	4
9/27	2.5	4	4
10/4	5.0	4	4

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 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. Roberds Lake average summer water quality characteristics and trophic status indicators (based on epilimnion 1992) compared with other lakes in the North Central Hardwood Forest ecoregion.

	Mean	Typical Range for Ecoregion[1]
Total Phosphorus (µg/l)	150	23-50
Chlorophyll-a (µg/l) mean	64	5-22
Chlorophyll-a (µg/l) maximum	140	7-32
Secchi disk (meters)	1.1	1.5-3.2
Secchi disk (feet)	3.6	4.9-10.5
Total Kjeldahl Nitrogen (mg/l)	2.0	0.6-1.2
Nitrite & Nitrate-N (mg/l)	0.01	< 0.01
Alkalinity (mg/l)	162.5	75-150
Color (Pt-Co Units)	22.5	10-20
pH (SU)	8.7	8.6-8.8
Chloride (mg/l)	13.3	4-10
Total Suspended Solids (mg/l)	14.3	2-6
Total Suspended Inorganic Solids (mg/l)	5.0	1-2
Turbidity (NTU)	6.1	1-2
Conductivity (µmhos/cm)	350	200-300
TN:TP ratio	13:1	25:1-35:1

Trophic Status Indicators: 1992

Carlson Trophic Status Index Values		Percentile[2]
TP TSIP	76	21
Chl-a TSIC	71	22
Secchi TSIS	59	39
Mean TSI	69	23

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

[2] - Relative to approximately 700 lakes in the NCHF ecoregion. One hundred percent level implies lowest TP and chlorophyll concentration or deepest Secchi disk measurement for that ecoregion.

Table 4. Roberds Lake water quality data collected by MPCA ecoregion monitoring program and 1992 Lake Assessment Program study.

LAKEID=66-0018

DATE	SITE	D	TP	RTP	TKN	N2N3	RN2N3	TSS	TSIN	ALK	PHF	CL	CONF	TURB	COLOR	CHLA	PHEO	SDF
800716	201	0	.278		3.41	.		.	.	.	.	.	.	.	50	.	.	2.5
800801	201	0	.296		2.09	.		.	.	.	.	.	.	.	40	.	.	5.0
800814	201	0	.320		1.90	.		.	.	.	.	.	.	.	35	.	.	2.5
800829	201	0	.204		1.77	.		.	.	.	.	.	.	.	20	.	.	4.0
810626	201	0	.051		1.22	.		.	.	.	.	.	.	.	5	.	.	5.5
810717	201	0	.200		2.65	.		.	.	.	.	.	.	.	20	.	.	3.5
810821	201	0	.260		2.63	.		.	.	.	.	.	.	.	40	.	.	2.5
810928	201	0	.196		2.74	.		.	.	.	.	.	.	.	30	.	.	4.0
890518	101	0	.094		1.56	0.01	K	8.2	4.8	100	.	14	260	2.2	30	21.40	2.10	2.0
890627	101	0	.106		2.62	0.01	K	18.0	6.0	110	.	14	260	11	20	47.30	0.80	2.3
890627	101	32	.363		4.65	.		.	.	.	.	.	.	.	.	.	.	.
890627	102	0	.128		2.72	.		.	.	.	.	.	.	.	.	46.50	13.6	2.0
890726	101	0	.190		2.42	0.01	K	26.0	8.0	120	.	14	250	17	20	57.70	0.80	2.0
890726	101	16	.197		1.85	.		.	.	.	.	.	.	.	.	.	.	.
890726	101	29	.376		2.80	.		.	.	.	.	.	.	.	.	.	.	.
890829	101	0	.250		2.93	0.01	K	31.0	8.0	120	.	15	255	22	20	92.90	1.60	1.3
890829	101	31	.620		2.90	.		.	.	.	.	.	.	.	.	.	.	.
920513	101	0	.091		1.40	0.01		2.4	0.4	170	8.0	13	370	1.0	20	2.24	0.64	13.1
920513	102	0	.112		1.33	.		.	.	.	8.3	.	370	.	.	2.24	0.32	10.5
920610	101	0	.046	Q	1.28	0.01	K	4.2	2.2	160	8.5	14	370	2.3	20	5.45	1.28	6.2
920610	101	34	.203		1.79	0.01	K	.	.	.	.	.	.	.	.	.	.	.
920610	102	0	.044	Q	1.24	0.01	K	.	.	.	8.6	.	360	.	.	6.41	0.32	8.2
920707	101	0	.105	Q	1.94	0.01	K	13.0	4.8	160	8.7	12	350	6.0	20	36.50	0.64	3.0
920707	101	36	.432		3.36	0.01	K	.	.	.	.	.	.	.	.	.	.	.
920707	102	0	.099	Q	1.92	0.01	K	.	.	.	9.0	.	350	.	.	28.80	0.64	2.8
920803	101	0	.223	Q	2.39	0.01	K	23.0	10.0	170	8.7	12	340	7.3	20	114.00	0.64	2.0
920803	101	29	.336	Q	3.03	0.01	K	.	.	.	.	.	.	.	.	.	.	.
920803	102	0	.171	Q	1.76	0.01	K	.	.	.	8.7	.	350	.	.	69.80	0.64	2.0
920901	101	0	.248		2.46	0.03		17.0	3.0	160	8.9	15	340	9.0	30	113.00	0.64	2.6
920901	101	41	.256		2.66	.		.	.	.	.	.	.	.	.	.	.	.
920901	102	0	.260		2.85	0.01	K	.	.	.	9.0	.	340	.	.	140.00	0.64	2.0

Table 5. MINLEAP modeling summary for Roberds Lake 1992.

```
Minnesota Lake Eutrophication Analysis Procedure

LAKE NAME   Roberds
ECOREGION NUMBER        2=CHF
WATERSHED AREA (HA)            3240
LAKE SURFACE AREA (HA)         265
LAKE MEAN DEPTH (M)            3.2
OBSERVED MEAN LAKE TP (UG/L)   150
OBSERVED MEAN CHL-A (UG/L)     64
OBSERVED MEAN SECCHI (M)       1.1

INPUT DATA:
LAKE NAME =Roberds                ECOREGION=CHF
LAKE AREA = 265  HA
WATERSHED AREA (EXCLUDING LAKE) = 3240  HA
MEAN DEPTH = 3.2  METERS
OBSERVED MEAN TP = 150  UG/L
OBSERVED MEAN CHL-A = 64  UG/L
OBSERVED MEAN SECCHI = 1.1  METERS

                    results

LAKE = Roberds                          ECOREGION = CHF
AVERAGE INFLOW TP = 162.7781  UG/L      TOTAL P LOAD       = 702.876  KG/YR
LAKE OUTFLOW      = 4.318  HM3/YR       AREAL WATER LOAD   = 1.629434 M/YR
RESIDENCE TIME    = 1.963872  YRS       P RETENTION COEF   = .7063994

VARIABLE  UNITS      OBSERVED PREDICTED STD ERROR  RESIDUAL   T-TEST
TOTAL P   (UG/L)       150.00     47.79     16.56      0.50     2.98
CHL-A     (UG/L)        64.00     18.71     11.56      0.53     1.83
SECCHI    (METERS)       1.10      1.38      0.57     -0.10    -0.52
NOTE: RESIDUAL = LOG10(OBSERVED/PREDICTED)
      T-TEST FOR SIGNIFICANT DIFFERENCE BETWEEN OBS. AND PREDICTED

CHLOROPHYLL-A INTERVAL FREQUENCIES (%)
CHL-A             PREDICTED PREDICTED PREDICTED
  PPB  OBSERVED    CASE A    CASE B    CASE C
  10     99.99      85.68     83.75     73.70
  20     98.55      35.19     36.27     41.03
  30     90.98      11.04     12.91     23.32
  60     45.73       0.38      0.69      5.64
CASE A = WITHIN-YEAR VARIATION CONSIDERED
CASE B = WITHIN-YEAR + YEAR-TO-YEAR VARIATION CONSIDERED
CASE C = CASE B + MODEL ERROR CONSIDERED
Ok
```

Table 6. Reckhow and Simpson modeling summary for Roberds Lake 1992.

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	Roberds							
Watershed Area (ha)	3249		7147826.5	=EST Q	7.15	=HM3	1.1	=Water Residence (year)
Lake Area (ha)	265		2.7	=EST qs				
Water Runoff (m)	0.22		NOTE: 1HM3 = 1,000,000 M3					
Precipitation(m)	0.9		0.15	=Observed TP (mg/l)				
Evaporation(m)	0.8	(mean)	0.08	=Observed TP StDev				
Volume (HM3)	8		10	=N				
County capitas/cabin	2.8		64	=Observed Chla (ug/l)				
Number Seasonal Cabins	94		1.1	=Observed Secchi (m)				
Number Perm. Cabins	66							

	Before	After	Delta
Forest Area (ha)	1642	455	0
Agric Area (ha)	0	1332	1332
Urban Area (ha)	0	357	357
Wetland Area (ha)	1072	715	357
Pasture/Open (ha)	552	390	162

Export Values		Low	Average	High	Before Low	Before Average	Before High			After Low (PK)	After Average	After High
Forest P Export		0.08	0.1	0.15	131	164	246	=Forested Flux	=	36	46	68
Agric P Export		1.3	1.9	2.5	0	0	0	=Ag flux	=	1732	2531	3330
Urban P Export		0.5	1	1.25	0	0	0	=Urban flux	=	179	357	446
Wetland P Export		0.08	0.1	0.1	86	107	107	=Wetland flux	=	57	72	72
Pasture/open Export		0.2	0.3	0.4	110	166	221	=Pasture/Open flux	=	78	117	156
Atmospheric Export		0.2	0.3	0.4	53	80	106	=Ppt flux	=	53	80	106
Soil Retention Coef		0.7	0.6	0.5								
Point Source Before	kg/yr	0	0	0								
Point Source After	kg/yr	0	0	0	75	100	125	=Septic flux	=	75	100	125
Delta Point Source kg/yr		0	0	0								
Capita Years		249.3	249.3	249.3	0	0	0	=Point Souce	=	0	0	0

**** P EXPORT REFERENCE ****

****

Prairie & Kalff (1986) \Wilson & Walker (1989)
"Effect of Catchment Size... \Development of Lake Assessment...

Use	Ha	P export	\Ecoreg.	Dominant Landuse	Net** P Export
Forest	1642	0.08	\NCHF	Cul+Mixed	0.19
Ag-mix	0	#NUM!	\NLF	For (75%)	0.12
Ag-row++	1864	0.23	\NGP	Cul (83%)	0.76
Ag-nonrow++	1864	0.56	\WCBP	Cul (84%)	0.74
Pasture	552	0.18	** Of all landuse values.		

Wat.Res.Bull 22:465-470 \ Lake Res.Man.5:11-22.
++Fill in this estimated landuse data

****

Before Low	Before Average	Before High			After Low (PK)	After Average	After High
455	617	805	=Total P Flux	=	2210	3303	4303
172	233	304	= P LOAD	=	834	1246	1624
64	86	113	= Inflow P ug/l	=	309	462	602
0.012	0.016	0.02	=PREDICTED TP	=	0.056	0.084	0.109
	-1.79588		=LOG Pml	=		-1.075721	
	0.005		= + MODEL ERROR	=		0.029	
	-0.004		= - MODEL ERROR	=		-0.021	
	0.002		= + LOADING ERROR	=		0.0125	
	0.002		= - LOADING ERROR	=		0.014	
	0.005		=TOTAL + UNCERTAINT	=		0.032	
	0.004		=TOTAL - UNCERTAIN	=		0.025	

		Before Low	Before Average	Before High		After Low	After Average	After High
RECKHOW/SIMPSON	ug P/l	12	16	21	55% CONFIDENCE LIMITS	59	84	116
RECKHOW/SIMPSON		8	16	26	90% CONFIDENCE LIMITS	34	84	148
CANFIELD/BACHMANN	ug P/l	30	37	45	CANFIELD/BACHMANN	92	121	143

Table 6. cont.

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

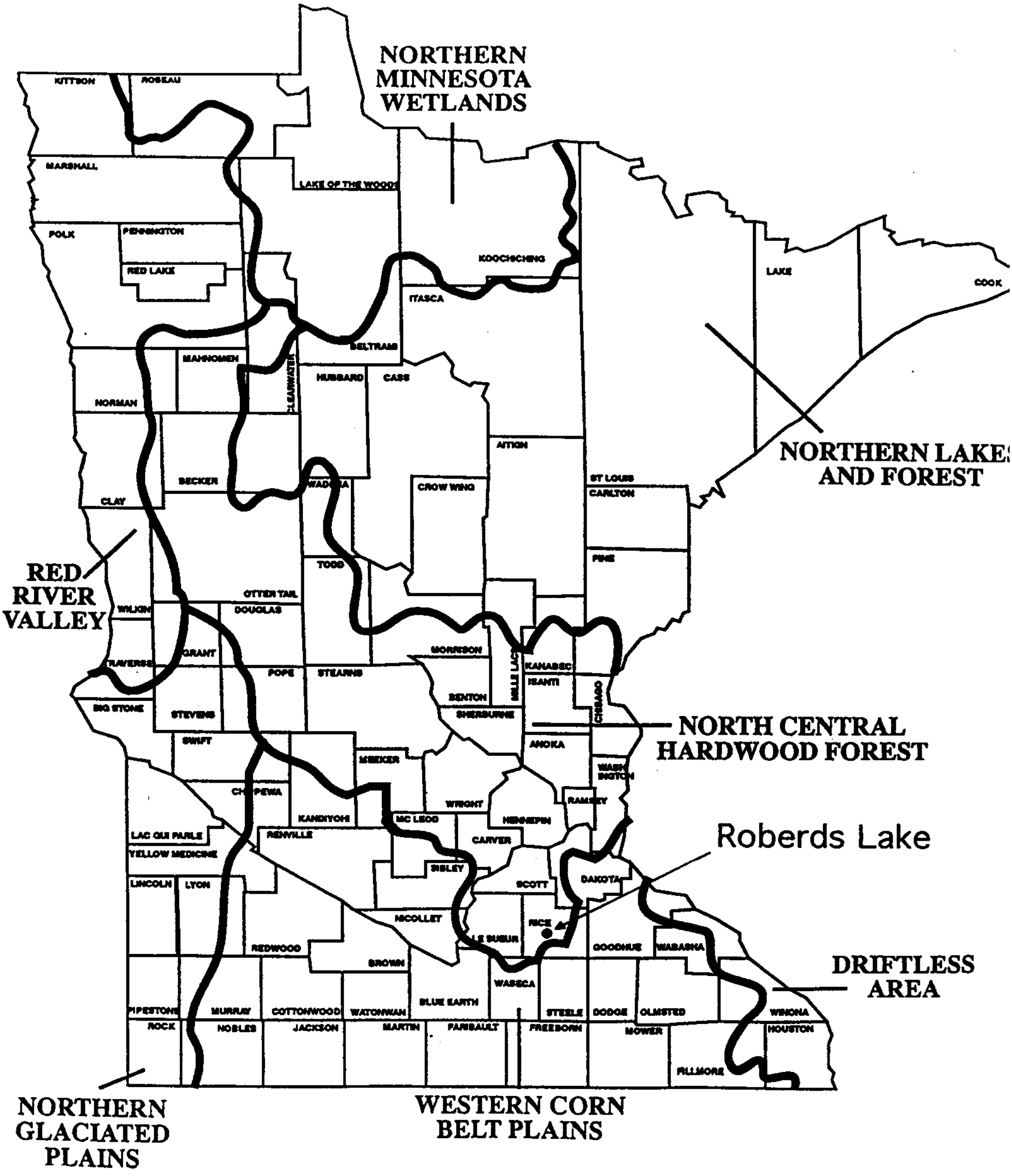
Former -	New +	Net TP			Pred Bounds			Projected TP Change	
				-	+			Incr/Decr	+/-
-0.002726	0.009078	0.006352	0.0118039	0.0087907	0.0158499			0.006352	0.0035412

	Lake Data Lake TP	StDev	St Error	Pred Error		Obs TP	Net Change		Predicted P		+/- Pred Error
III.	0.15	0.09	0.0183712	0.0187094		0.15	0.006352	=	0.156	+/-	0.0187094
								=	156	+/-	19

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	0.15	0.18	0.237	0.323
LAKE CHLA	ug/l	64	129.7	193.8	304.5
LAKE SECCHI	m	1.1	0.4	0.3	0.3
TSI TP		78.4	79	83	87.5
TSI CHLA		71.4	78.3	82.3	86.7
TSI SD		58.6	73.2	77.3	77.3

Figure 1. Location of Roberds Lake and Minnesota ecoregions.



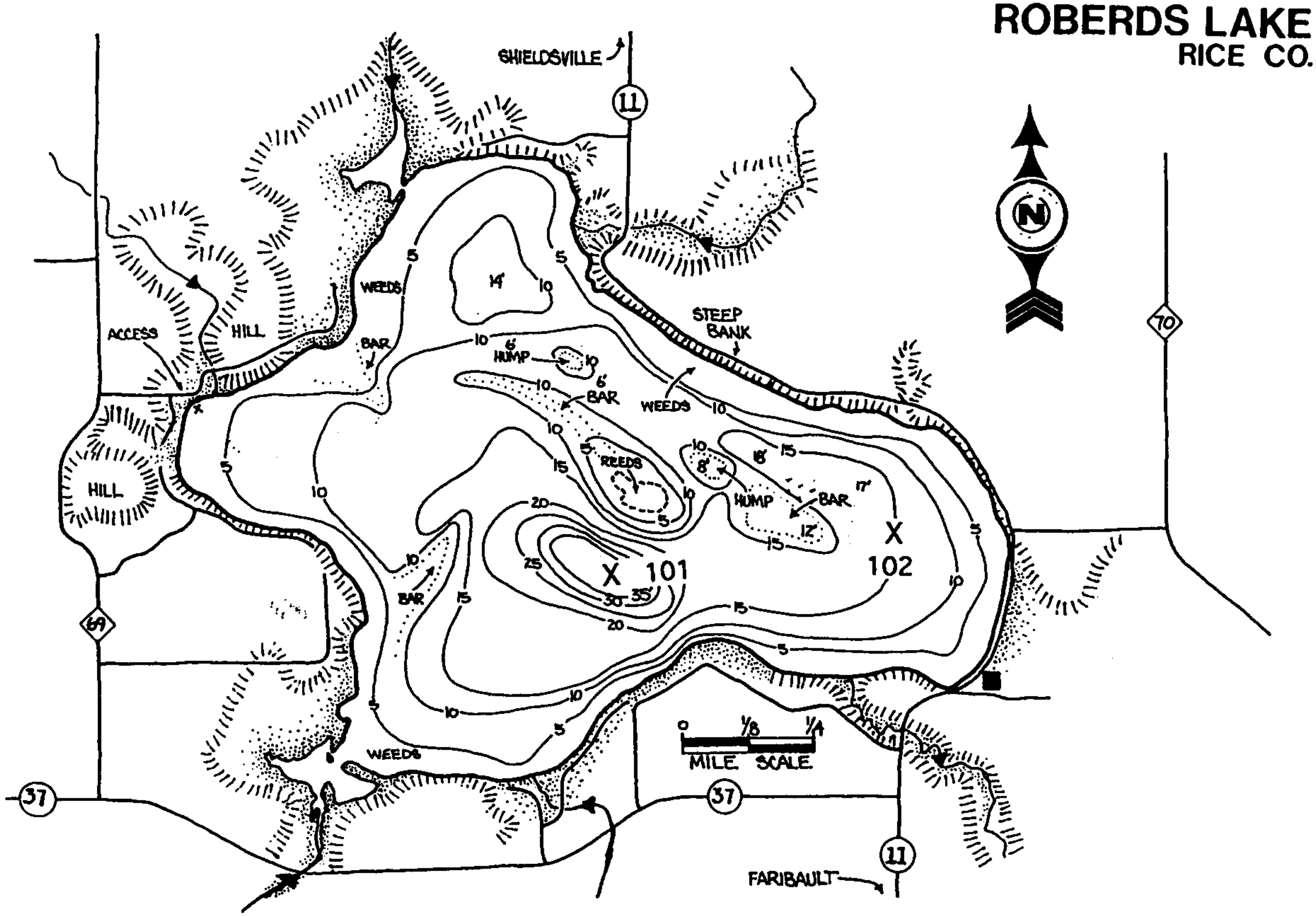


Figure 2. Roberds Lake sampling sites 101 and 102. (map by D. D. I.)

Figure 3a. Dissolved oxygen and temperature profiles for sampling site 101 on Roberds Lake - May 13, 1992.

SITE	DEPTH (m)	D.O. (mg/l)	TEMP (°C)
101	0	8.3	17
	1	8.3	16.9
	2	8.3	16.8
	3	8.3	16.8
	4	8.3	16.8
	5	8.2	16.7
	6	8.2	16.7
	7	8.2	16.7
	8	8.1	16.7
	9	8.1	16.7
	10	8	16.7
	11	8	16.7

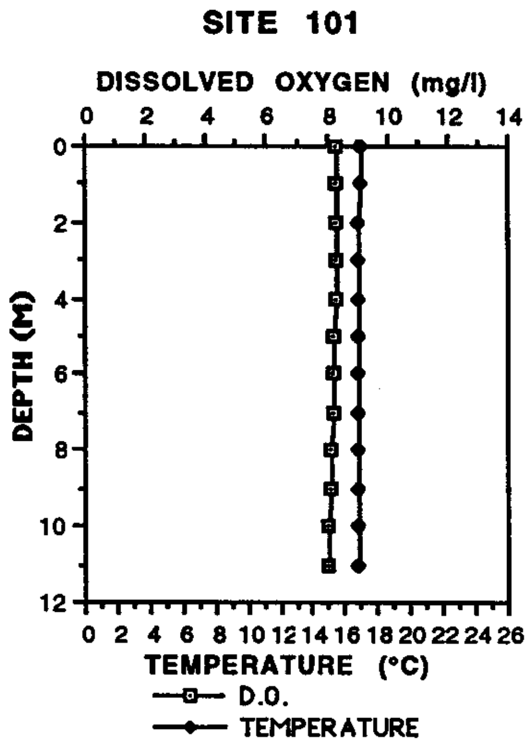
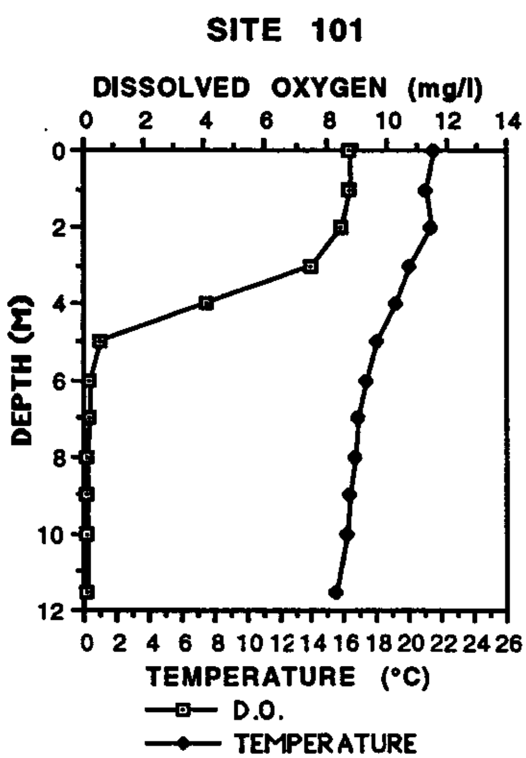


Figure 3b. Dissolved oxygen and temperature profiles for sampling sites 101 and 102 on Roberds Lake - June 10, 1992.

SITE	DEPTH (m)	D.O. (mg/l)	TEMP (°C)
101	0	8.8	21.5
	1	8.8	21
	2	8.5	21.3
	3	7.5	20
	4	4.05	19.2
	5	0.5	18
	6	0.2	17.2
	7	0.2	16.8
	8	0.1	16.6
	9	0.1	16.3
	10	0.1	16.1
	11.5	0.1	15.5
102	0	7.8	21.7
	1	7.8	21
	2	7.4	20.2
	3	7	19.8
	4	4.3	19.1



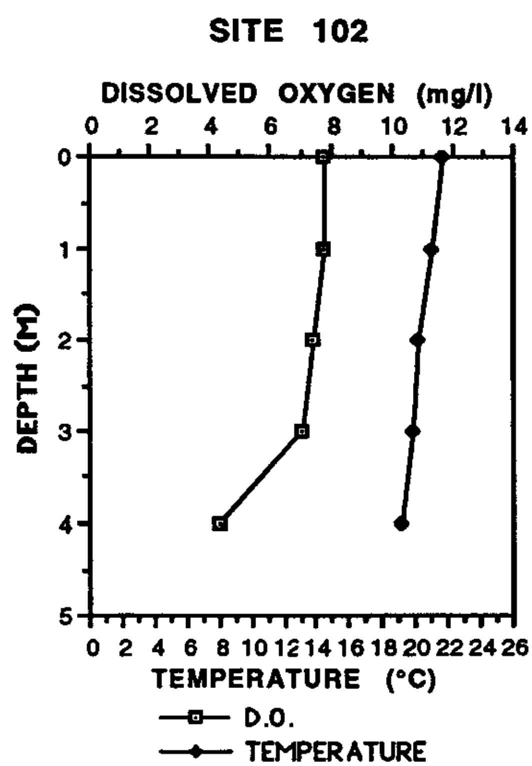
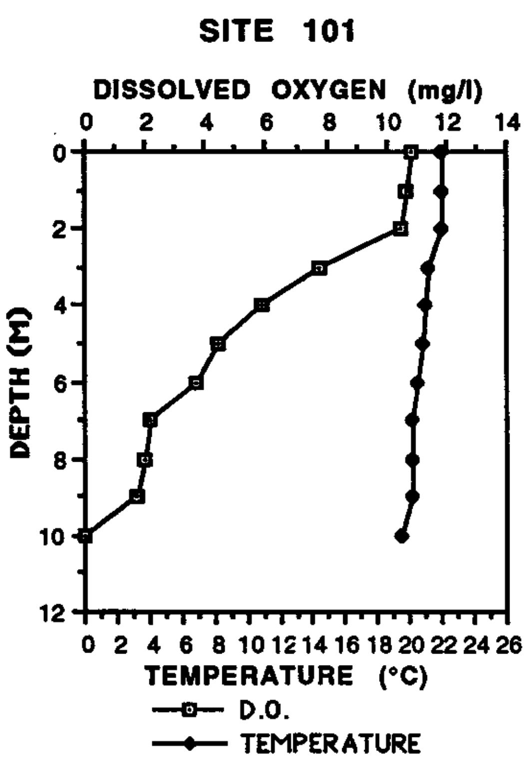


Figure 3c. Dissolved oxygen and temperature profiles for sampling sites 101 and 102 on Roberds Lake - July 7, 1992.

SITE	DEPTH (m)	D.O. (mg/l)	TEMP (°C)
101	0	10.8	22
	1	10.7	22
	2	10.5	22
	3	7.8	21.2
	4	5.9	21
	5	4.4	20.8
	6	3.7	20.4
	7	2.2	20.2
	8	2	20.2
	9	1.7	20.2
	10	0.01	19.5
102	0	10.5	22
	1	10.2	22
	2	9.7	22
	3	5.3	21
	4	4.5	20.6
	5	3	20.5



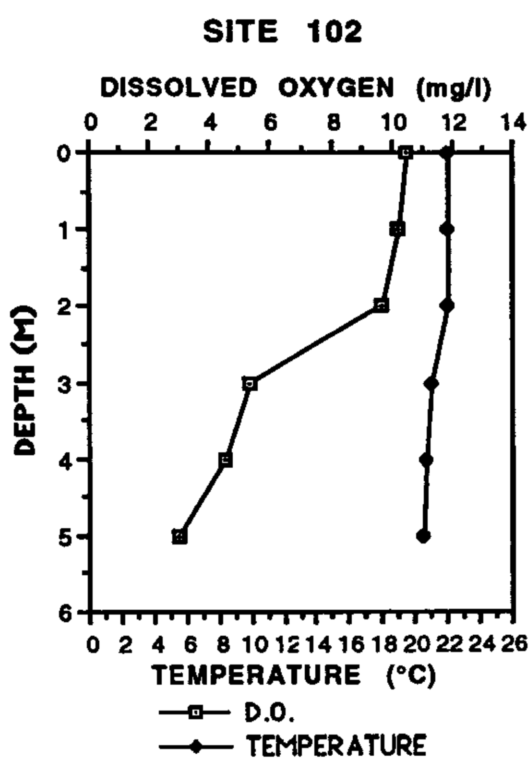


Figure 3d. Dissolved oxygen and temperature profiles for sampling site 101 on Roberds Lake - August 3, 1992.

SITE	DEPTH (m)	D.O. (mg/l)	TEMP (°C)
101	0	10.3	24.2
	1	10.3	24.2
	2	9.4	23.9
	3	9.1	23.8
	4	9.1	23.7
	5	4	23.4
	6	1.35	22.6
	7	0.2	21.9
	8	0.15	21.4
	9	0.15	20.8
	10	0.12	20.4

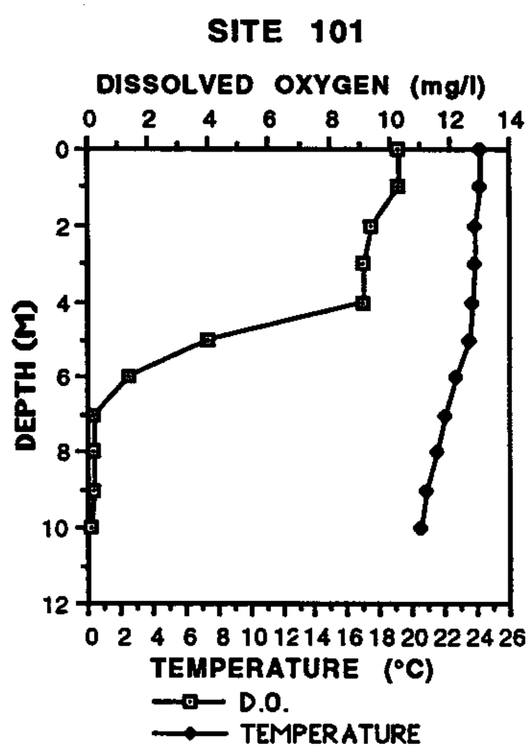
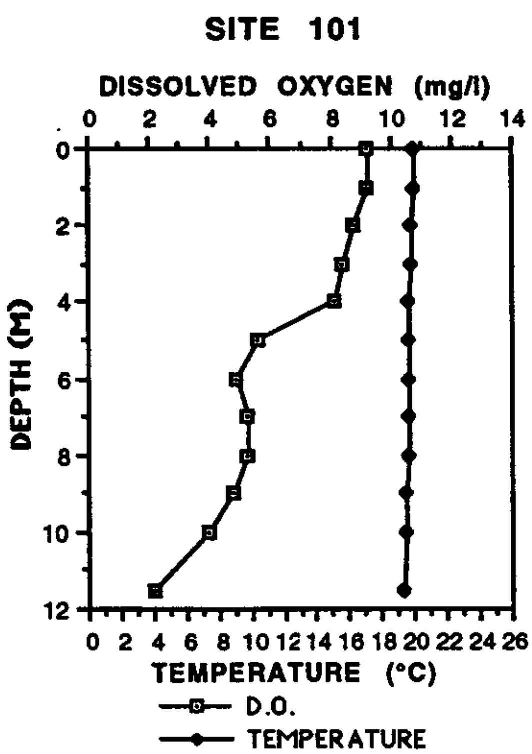


Figure 3e. Dissolved oxygen and temperature profiles for sampling sites 101 and 102 on Roberds Lake - September 1, 1992.

SITE	DEPTH (m)	D.O. (mg/l)	TEMP (°C)
101	0	9.2	19.9
	1	9.2	19.9
	2	8.8	19.8
	3	8.4	19.8
	4	8.1	19.7
	5	5.6	19.7
	6	4.9	19.6
	7	5.2	19.6
	8	5.2	19.6
	9	4.8	19.5
	10	4	19.5
	11.5	2.2	19.3
102	0	10.3	20
	1	10.2	20
	2	10	20
	3	10	20
	4	9.3	20



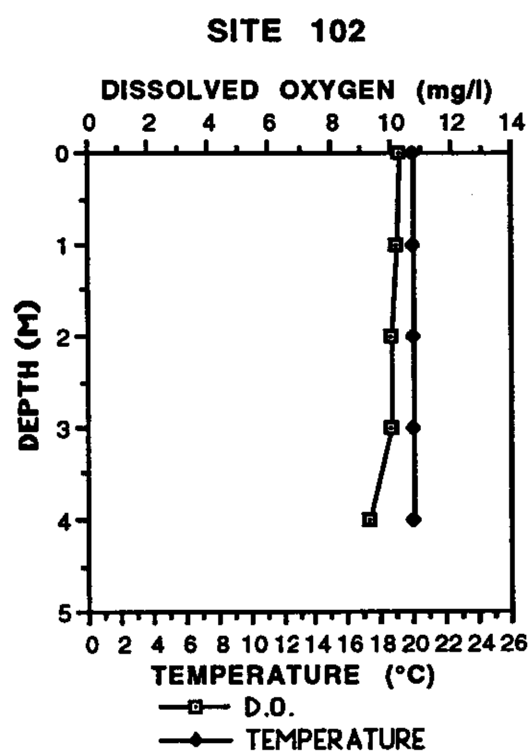


Figure 4. Surface (epilimnion) and bottom (hypolimnion) water total phophorus (TP) concentrations at sampling site 101 on Roberds Lake in 1992.

Date	Depth (ft)	TP (µg/l)
05/13/92	0	91
06/10/92	0	46
07/07/92	0	105
08/03/92	0	223
09/01/92	0	248
06/10/92	34	203
07/07/92	36	432
08/03/92	29	336
09/01/92	41	256

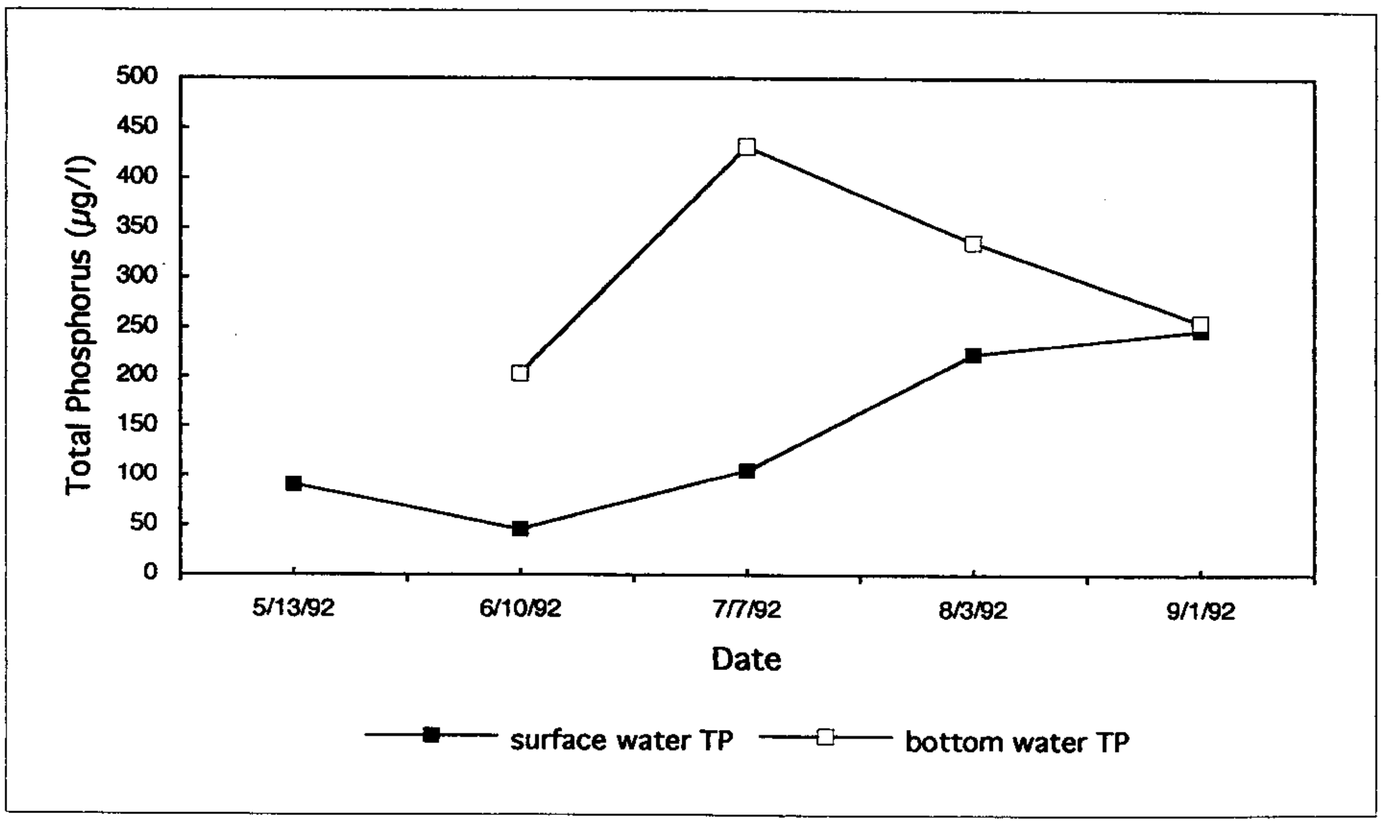


Figure 5. Chlorophyll-a concentrations in surface (epilimnion) water at sampling site 101 on Roberds Lake in 1992.

Date	Chl-a (µg/l)
05/13/92	2.24
06/10/92	5.45
07/07/92	36.5
08/03/92	114
09/01/92	113

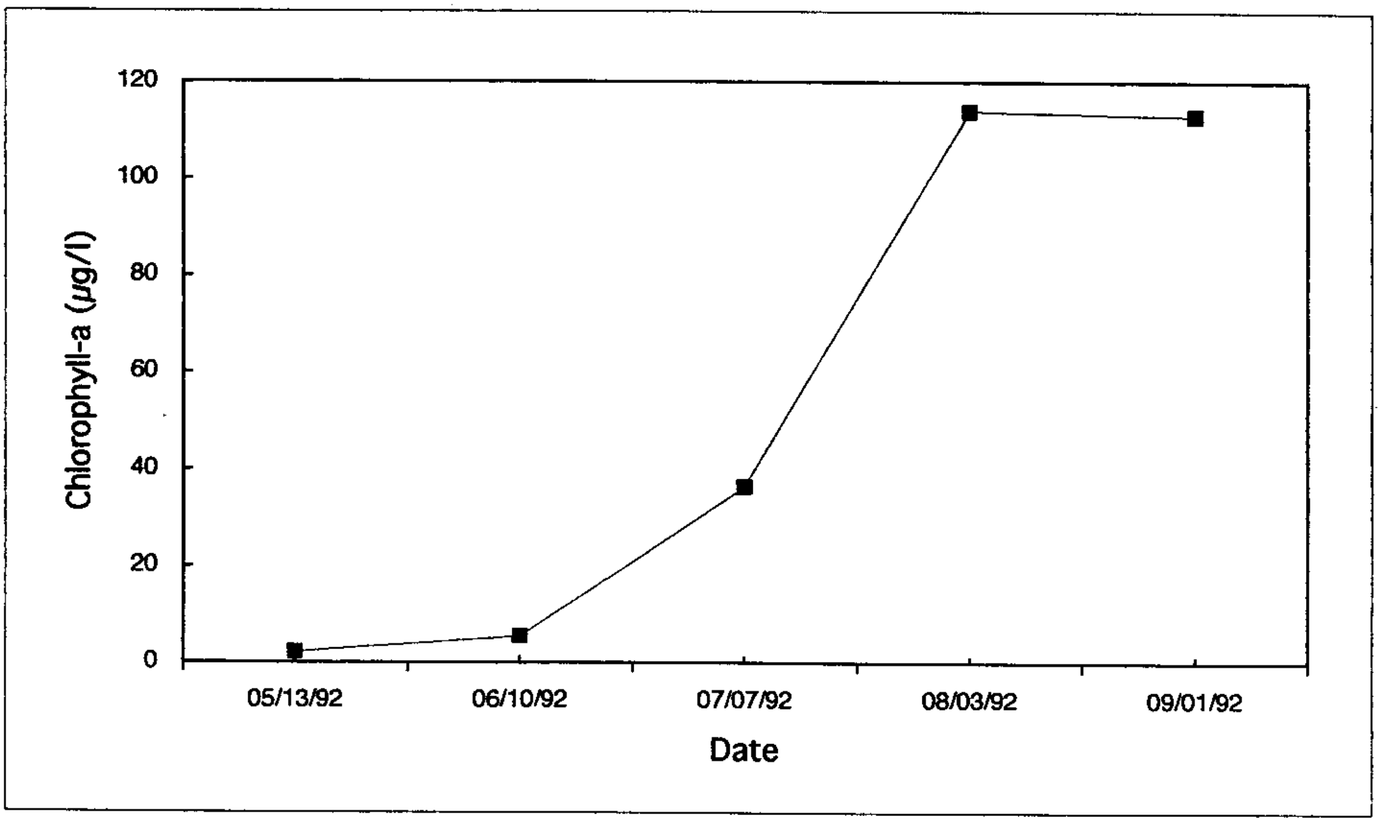


Figure 6. Secchi disk transparencies for Roberds Lake in 1992, from measurements by the Citizen Lake Monitoring Program and the Lake Assessment Program.

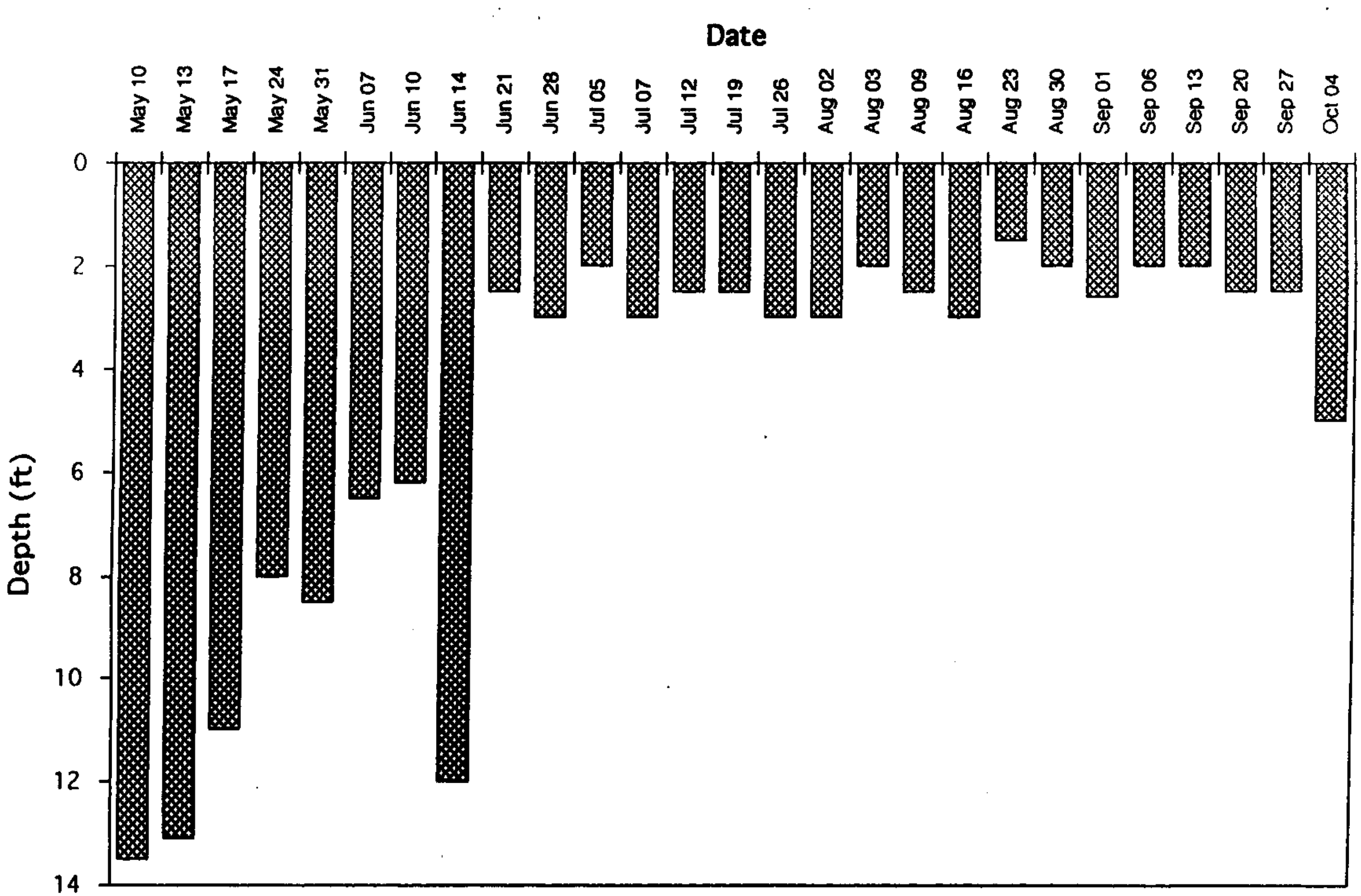


Figure 7. Carlson Trophic Status Index values (TSI) and relationships to Roberds Lake data for 1992.

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..

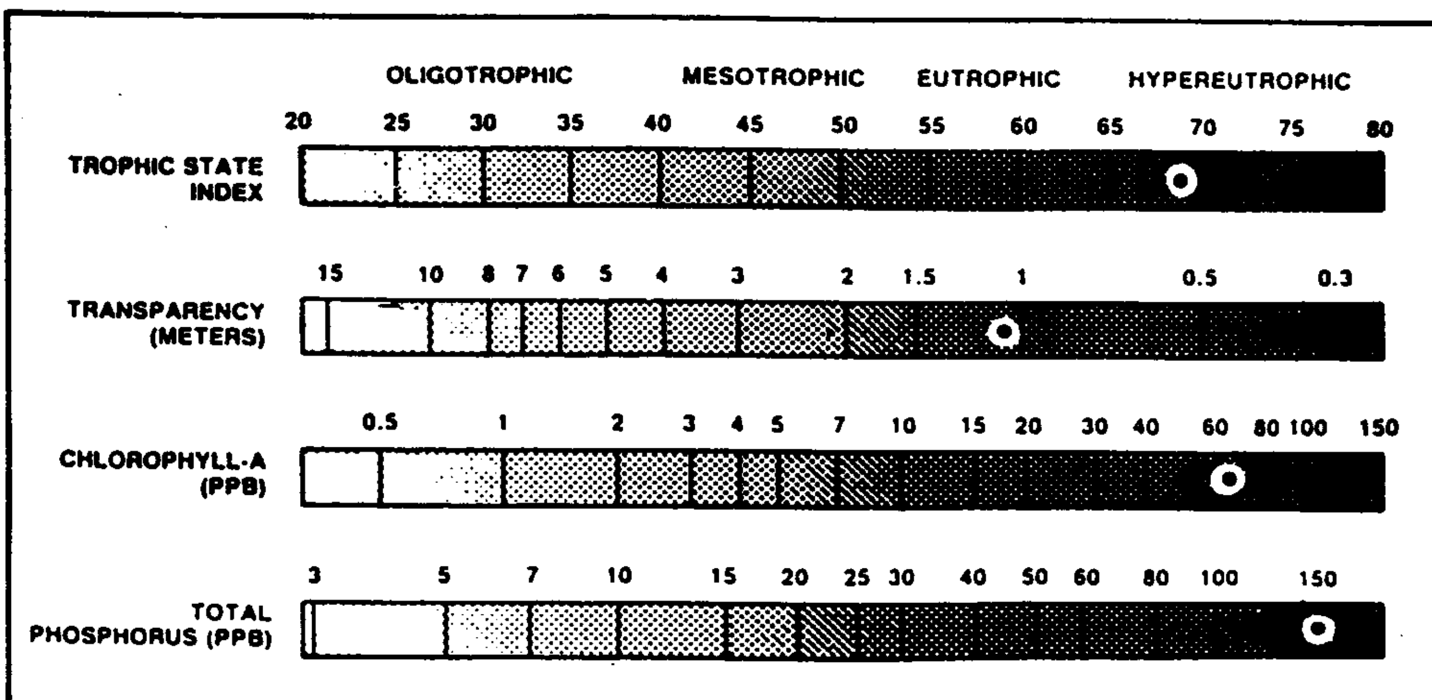
TSI 50 - 60 Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.

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.

• = Roberds Lake values



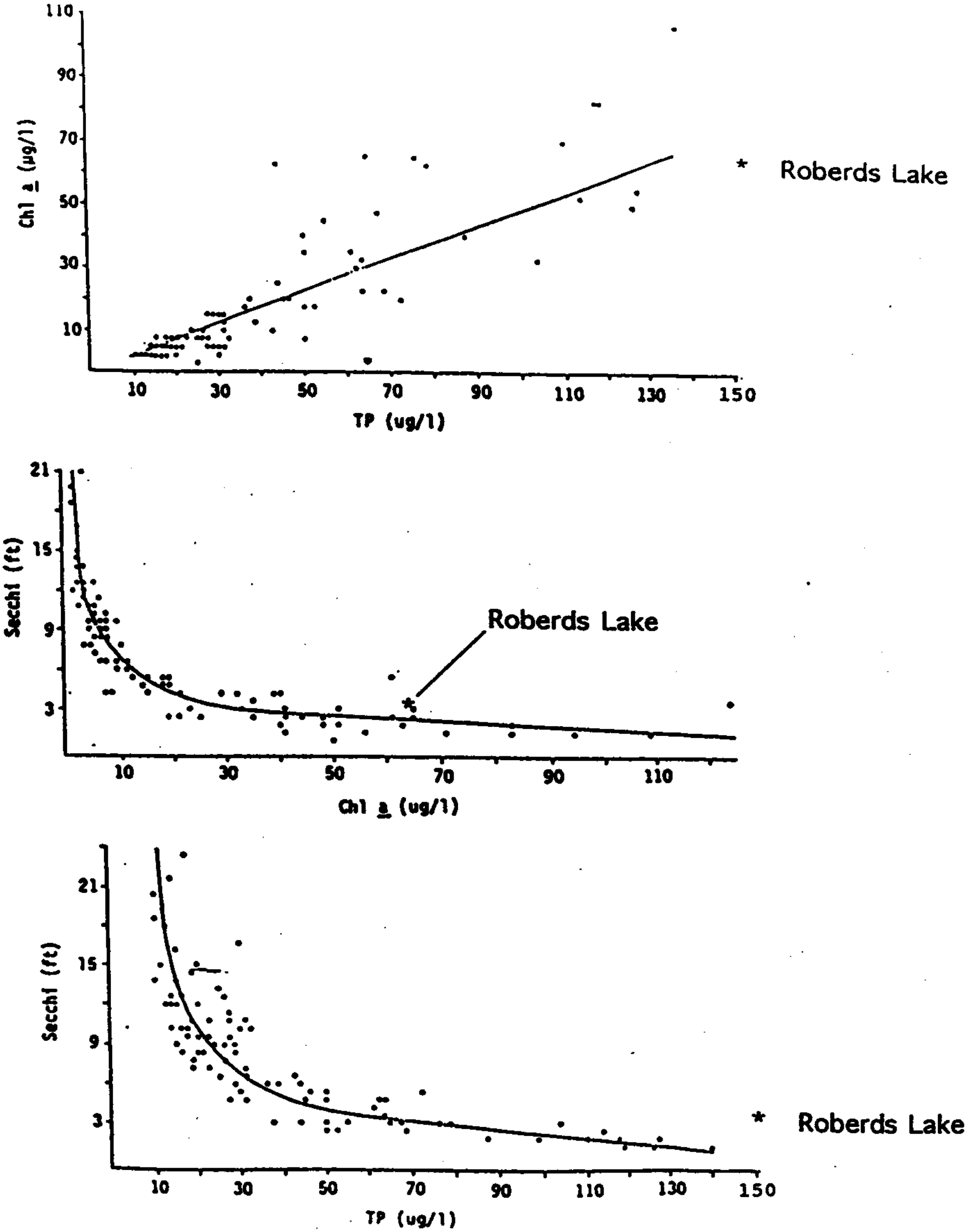
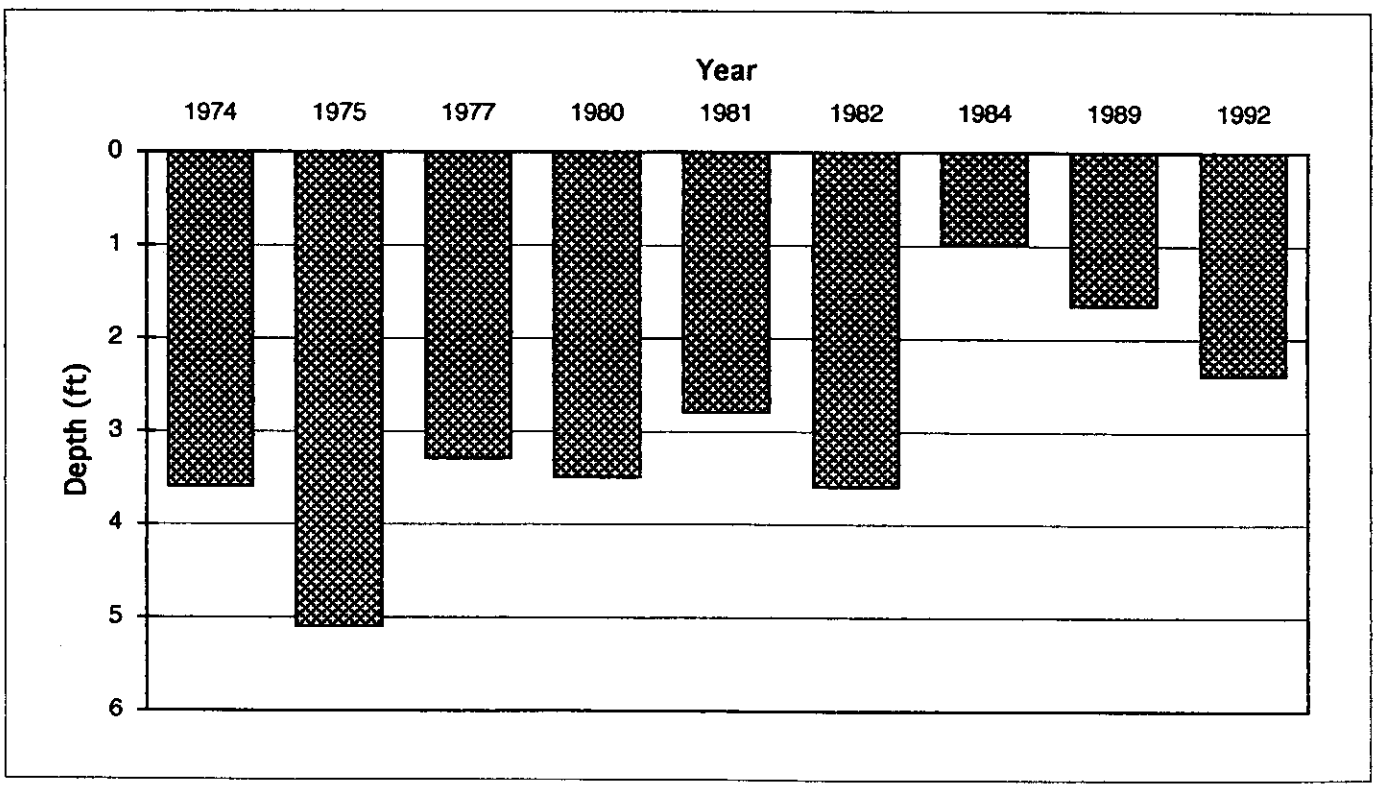


Figure 8. Scatterplots of chlorophyll-a, total phosphorus and Secchi disk transparencies based on summer data from a set of representative lakes from four ecoregions in Minnesota with values for Roberds Lake in 1992.

Figure 9. Mean Secchi disk transparencies in July and August for Roberds Lake since 1974.

CLMP data for Roberds Lake

Date	Feet	# of obs
1974	3.6	4
1975	5.1	4
1977	3.3	3
1980	3.5	4
1981	2.8	3
1982	3.6	4
1984	1	3
1989	1.65	2
1992	2.4	49



APPENDIX

Summary of responses to lake water quality questions collected during 1993 creel surveys on Roberds Lake.

Date	n	Physical Condition	Recreational Suitability
6-19	1	3	2
6-22	2	4	3
6-26	4	3	2.5
6-27	7	2.5	3
7-2	1	2	2
7-28	3	2	3
7-31	2	4	4
8-1	2	3.5	3.5
8-5	2	3.5	3
8-6	1	3	3
8-12	1	3	1
8-27	3	3	3
9-3	2	2.5	2.5
9-4	5	3	3
9-13	1	3	3
10-1	1	2	1
10-2	1	4	4
10-12	2	1.5	1
10-13	1	3	3
10-16	1	1	1

Physical Condition
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. Sever 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

Suitability for Recreation
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

Water Clarity and Aquatic Plants

Of 43 responses:

-11 (26%) prefer turbid water and few aquatic plants

-32 (74%) prefer clear water and many aquatic plants

Roberds Lake septic system, well, solid waste disposal and lawn care survey.

Survey Date____________

Name________________________________ Lake Address__________________________

Home Address____

Years lived at Lake Address_________ Age of House__________ Age of Septic System_____

# of Bedrooms__________ # of Baths____________

Type of Occupancy: Year Round_______ or Seasonal Use_______ or Weekends Only_______

Number of Residents____________ Septic Tank Size__________________

Last Pumped_______________________

Type of Drainfield: 1) Bed________ 2) Trenches_______ 3) Dry Well or Seepage Pit_______

4) Holding Tank_______ 5) Other______________ 6) Don't Know_______

Approximate Square Footage of Drainfield____________________

Has any part of the septic system ever discharged to the surface?______________

Any outside odors?__________ Has the septic system ever backed up into the house?______

Have any repairs/corrections been made recently to the system?__________

Have you ever had to minimize water use so that the system would work?__________

Please identify those types of water use appliances that you use:

Appliances	Present?	Into Septic System?	Or into other? (Comments)
Clothes Washer			
Dish Washer			
Water Softener			
Garbage Disposal Unit			
Basement Floor Drain			
Hot Tub/Jaccuzzi			
Other (Describe)			

Basement present?__________ If so, Water Problems?_________ Sump Pump Present?_________

Basement Footing Drains?__________ If so, separate outlet from Septic?__________

If necessary to dye-test your septic system, when would you be available?

Please circle your choices: 1) weekdays 2) weekends 3) weekend nights

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WELL INFORMATION

Age of Well____________ On-lot well_____ or shared?_____ Total Well Depth__________

Type of Well: Drilled_______ Bored_______ Dug_______ Driven (sandpoint)_______

Well Distance _______feet to house _______feet to septic tank

_______feet to lake _______feet to sewage disposal area

Would you like a Water Test Kit (Cost: $26) for you to sample your well water?_______

Previously Tested?_________ Results:__________________________________

Are there any underground or above ground storage tanks on this property?__________

If yes, how many and size in gallons:________________________________

Additional Comments:____

MISCELLANEOUS

Solid Waste: Do you have rural garbage pick-up from a commercial hauler?__________

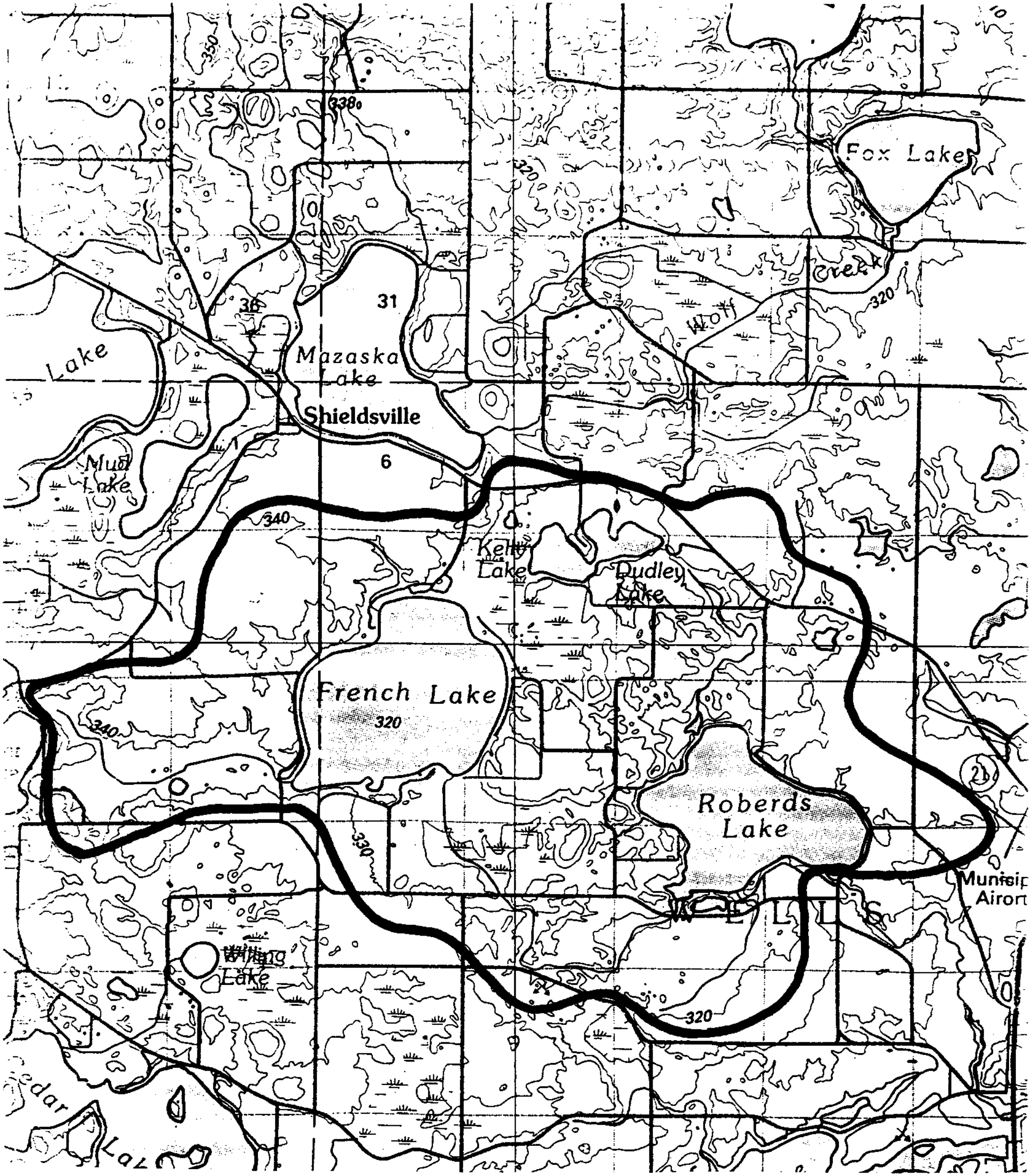
If not, how is garbage disposed of?____________________________________

Would you want individual household pick-up for recyclables if available___

OR would you want a drop-off site for recyclables?____________________

Is fertilizer used for lawn or garden?______________ Kind used__________________

Would you be willing to use non-phosphorus fertilizer if an outlet is provided for its purchase?______________



Approximate watershed area of Roberds Lake.