LAKE ASSESSMENT PROGRAM

1993

BEAVER LAKE
(MDNR ID. # 74-0023)
Steele County, Minnesota

MINNESOTA POLLUTION CONTROL AGENCY
Division of Water Quality
Nonpoint Source Section
and
Southeast Regional Office
Lee Ganske
August 1993

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SUMMARY AND CONCLUSIONS

Beaver Lake was sampled during the spring and summer of 1993 as part of the Minnesota Pollution Control Agency's (MPCA) Lake Assessment Program (LAP). Data collected during the study showed that in terms of total phosphorus, chlorophyll-a and Secchi disk transparency, the water quality of Beaver Lake is better than most lakes in the Western Corn Belt Plains ecoregion. The mean summer concentrations of total phosphorus and chlorophyll-a were 47.5 and 26.8 ug/l (ug/l = micrograms per liter) respectively and the mean Secchi disk transparency was 1.8 meters (5.9 feet). Based on these values, and Carlson's Trophic Status Index (TSI) (Carlson, 1977), which ranges from 0 (very oligotrophic) to 100 (hypereutrophic), Beaver Lake would be considered eutrophic. The average TSI value for Beaver Lake is 59. Beaver Lake is considered by MPCA to be "minimally impacted" and is used as a reference lake for the ecoregion.

A primary reason for the reasonably good water quality exhibited by Beaver Lake may be the small size of its watershed. The Beaver Lake watershed is approximately 98 hectares (242 acres). The watershed area to lake area ratio is about 2:1. Many lakes in the Western Corn Belt Plains ecoregion have ratios of 10:1, 15:1 or greater. Larger watersheds in similar ecoregions generally deliver more water, soil, organic matter, and nutrients to lakes. In areas where land use activities (such as agriculture or land clearing for development) increase this delivery, the size of the watershed becomes more important.

In the fall of 1993, and through the spring of 1994, Beaver Lake experienced reddish pink colored water followed by burgundy scum in the spring. It appears that a "bloom" of Ocillatoria rubescens, a blue-green algae which contains a red pigment, caused this. The scum probably consisted of dead O. rubescens. By May of 1994, visible signs of O. rubescens had disappeared.

Two empirical computer lake models were used to predict 1992 water quality and the results were compared to observed conditions. The results of both models agreed well with observed conditions.

The small watershed of Beaver Lake provides opportunities for lake protection and improvement not available for many other lakes in this ecoregion. Because the watershed is small, the activities of relatively few people (the lakeshore community and a few larger land owners) can have a strong positive influence on water quality. The lakeshore community should not underestimate their potential to protect or improve water quality with upgraded wastewater treatment and better lawn and garden practices.

LAKE ASSESSMENT PROGRAM: 1993

Beaver Lake

(I.D. #74-0023)

Steele County, Minnesota

INTRODUCTION

The Beaver Lake "Eager Beavers" Association applied for inclusion in the MPCA Lake Assessment Program in 1993. Concerns expressed by the Association included a perceived deterioration in water quality and inadequate wastewater treatment for many homes on the lake. Steele County has been working with the lake association to improve wastewater treatment around the lake. At the annual lake association meeting in September of 1993, the membership voted to form a Beaver Lake sanitary district. As of June 1994, this formation has not occurred.

The Lake Assessment Program was designed to assist lake associations, counties, or municipalities in the collection and analysis of baseline water quality data for the purpose of assessing the current trophic (nutrient enrichment) status of their lake. The work plan for local participants in the Lake Assessment Program includes collection of lake transparency data through the Citizens Lake Monitoring Program (CLMP), compilation of a watershed history, and examination of land use and drainage patterns in the watershed. With assistance from lake association members, staff of the Minnesota Pollution Control Agency (MPCA) collect water quality data. Conclusions and recommendations based on this cooperative work arrangement are included in the report.

The report is written with the assumption that the reader is familiar with basic water quality terminology as used in the Citizens Guide to Lake Protection.

BACKGROUND

Beaver Lake was sampled five times during the summer of 1992 by Lee Ganske and Ed Weir of the MPCA Rochester regional office, Will Munson of the MPCA St. Paul office, and Deanna Asbell and Andy Johnson of Beaver Lake. The sampling days were used as opportunities to discuss lake protection issues and demonstrate sampling techniques to the association leaders. Deanna Asbell was the Citizen Lake Monitoring Program volunteer. A brief history of Beaver Lake was gathered at a meeting of "old-timers" organized by Deanna Asbell (see Appendix 3). Mike Carron gathered watershed information with the assistance of the Steele County Soil and Water Conservation District.

Beaver Lake is located approximately 20 miles south of the City of Owatonna in southern Steele County. The surface area of the lake is 40.3 hectares (99.6 acres), placing it in the top 25 percent in terms of area statewide (MDNR, 1968). Beaver Lake has a maximum depth of 8.25 meters (27 feet). This is shallower than 50 percent of lakes included in a fairly comprehensive statewide study of approximately 1000 lakes (Heiskary, 1985). The mean depth of the lake is approximately 4.4 meters (14.5 feet), and the littoral zone (the lake zone which can potentially support rooted vegetation) covers approximately 45 percent of the lake. According to Zumberge (1952), Beaver Lake was formed when an ice block which separated from the main mass of a glacier was buried in glacial till. The subsequent melting of the ice block formed the lake basin. The watershed of Beaver Lake covers approximately 98 hectares (242 acres).

Beaver Lake is one of the few lakes in the county that has not be drastically affected by artificial drainage. According to the Minnesota Department of Natural Resources (1968), nearly 90 percent of the lakes in Steele County are affected by artificial drainage and many are dry most of the time. Areas that were once lakes may not even be recognized as such anymore.

Beaver Lake has exhibited high and low water conditions over the years. A outlet structure for regulating water level is currently in place. In addition, a system was installed many years ago to allow for the diversion of water to Beaver Lake from a small stream about 1/4 mile to the south of the lake. A small gate exists in the side of the bridge culvert where this stream crosses highway

28. According to some residents, this gate has not been opened for years.

Soils in the Beaver Lake watershed belong to the Lester-Webster-LeSueur association. This association contains well-drained to poorly drained, nearly level to rolling, loamy soils. Management considerations for this association include controlling erosion and shallow depth to the water table.

The native vegetation of the Beaver Lake watershed was dominated by scattered trees and groves referred to as oak openings and barrens (Marschner, 1930). While over half of the watershed is now used for crops, remnants of these oak groves remain, particularly in the shoreland area.

Since the landscape affects water quality, it is helpful to divide the state into areas of similar landscape 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). Beaver Lake is located in the Western Corn Belt Plains (WCBP) Ecoregion. Land use composition in the watersheds of the WCBP ecoregion is typically 42-75% cultivated, 0-7% pastured and open, 3-26% water or marsh, 0-15% forested and 0-16% developed (Heiskary and Wilson, 1990). Land use in the Beaver Lake watershed is shown in Table 1.

FIGURE 1. LAKE LOCATION MAP

Minnesota's ecoregions noted

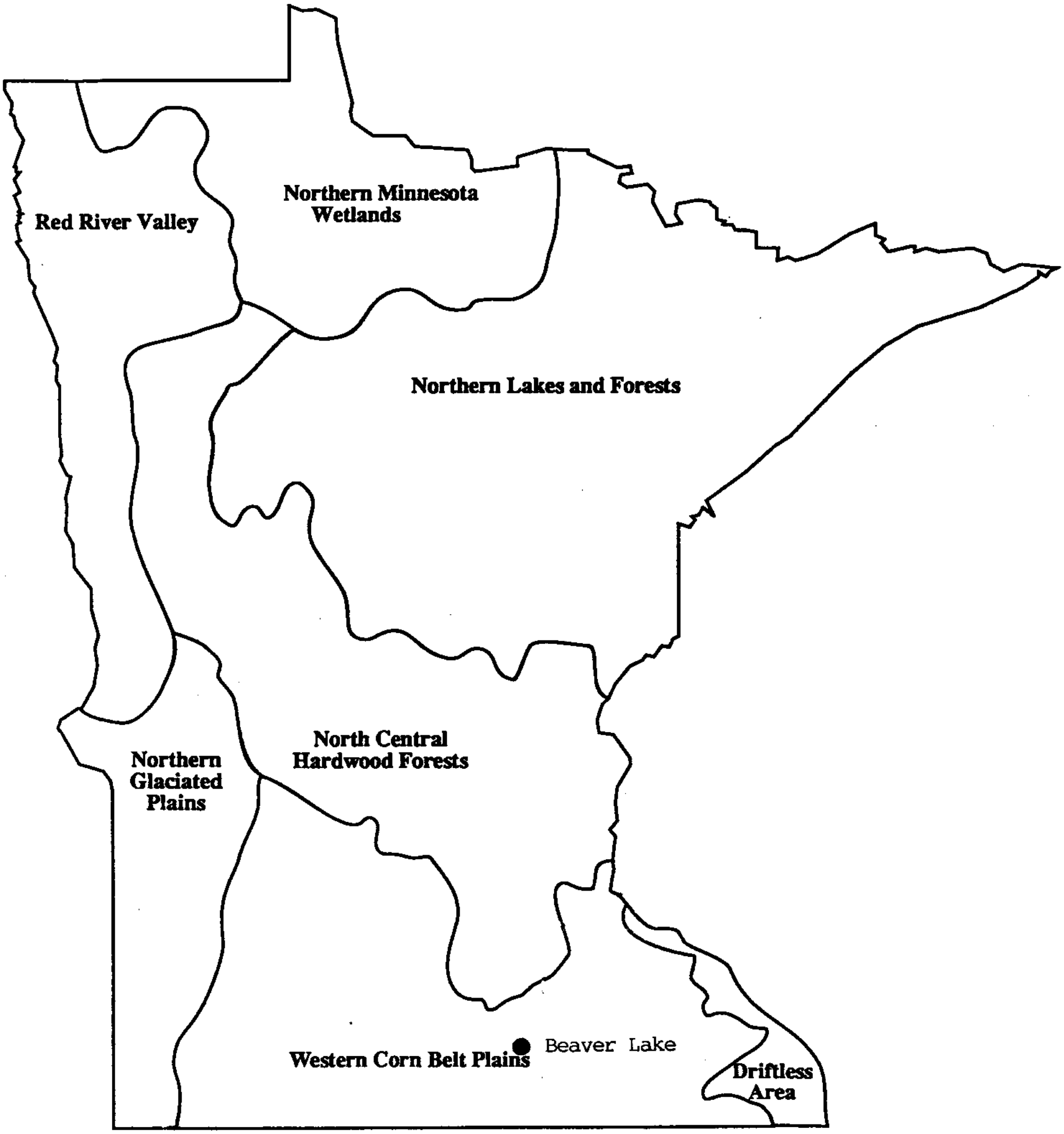


TABLE I: BEAVER LAKE MORPHOMETRIC, WATERSHED, AND FISHERY CHARACTERISTICS

MDNR I.D. # 74-0023

Area : 99.6 acres (40.3 ha)

Mean Depth: 14.5 feet (4.4 meters)

Maximum Depth: 27 feet (8.2 meters)

Volume: 1444 acre-ft

Littoral Area[2]: 45%

Shoreline Length[2]: 1.6 miles

Watershed Area[1]: 238 acres (96 ha)

Watershed Area: Lake Surface Area Ratio: 2.4 : 1

Estimated Average Water Residence Time[3]: 11.7 years

Ecological Classification[2]: Centrarchid

Management Classification[2]: Centrarchid

Land Use (percentage):

	Forests	Water/Marsh	Pasture/CRP	Cultivated	Urban
Beaver Lake[1]	27	10	14	133	59
Western Corn Belt Plains[4]	0-15	3-26	0-7	42-75	0-16

Public Access: 1 - southeast side of lake

Inlets/Outlets: inlets consist of an intermitent waterway on the north side and wetland areas on the northwest end, 1 Outlet

Shoreland Zoning: Recreational development

Development (Homes)

Year	Seasonal	Permanent	Total
1954[5]			34
1992[5]			91

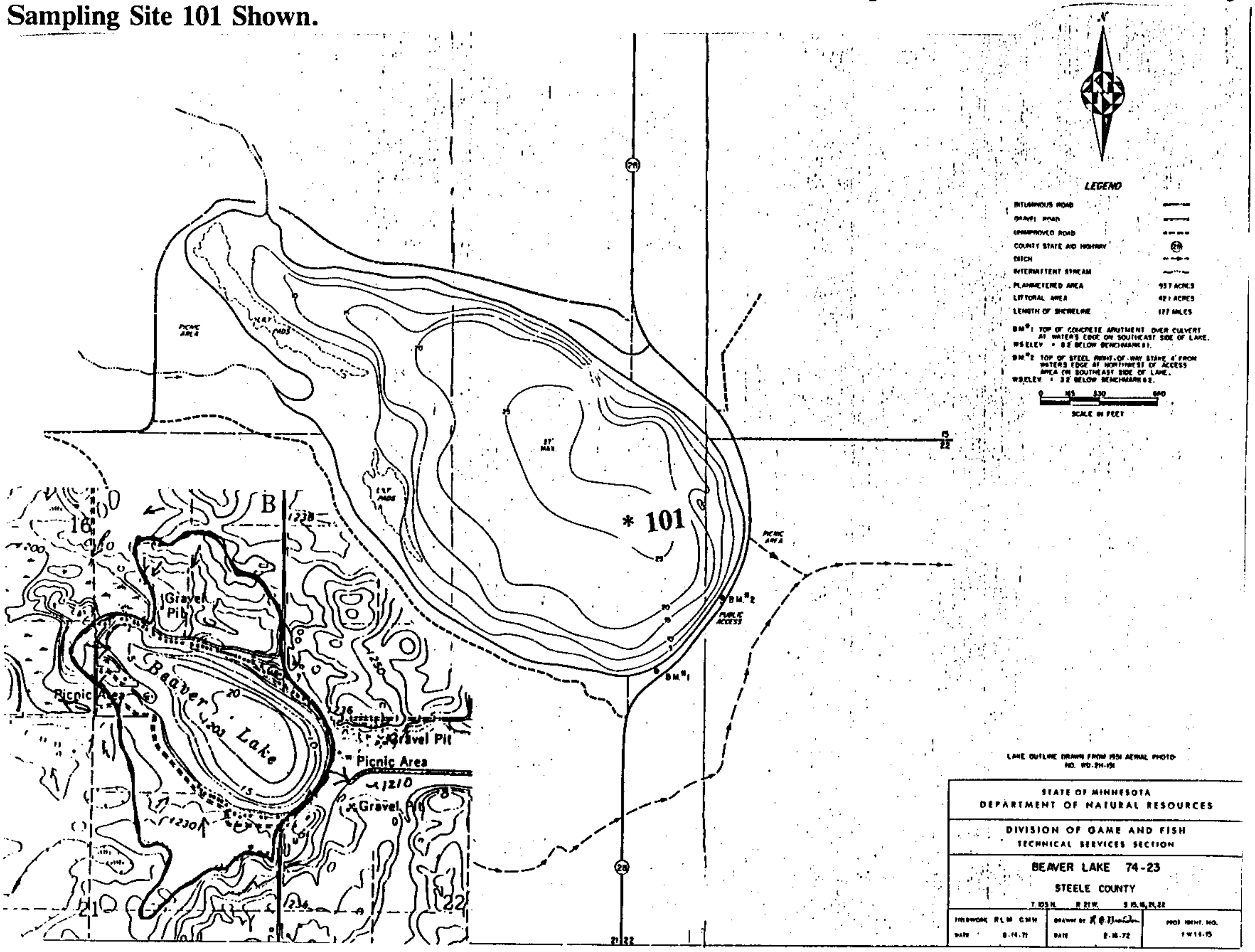
1 - Steele County SWCD
2 - State Planning Agency SWIM file
3 - estimated with MINLEAP
4 - 25-75th percentile for representative lakes in the ecoregion (Heiskary & Wilson, 1990)
5 - MDNR Fisheries files

METHODS

Water quality information was collected on April 26, June 9, July 7, August 10, and September 9, 1993 at a single site on the lake (Figure 2). Site 101 is at the deepest part of the lake. Lake surface samples were collected with an integrated sampler, a PVC tube 2 meters (6.6 ft.) in length with an inside diameter of 3.5 centimeters (1.4 inches). 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 a 5-meter tow using a Wisconsin plankton net.

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 for by means of a rapid assessment method. A qualitative evaluation of the zooplankton sample was made in the field. CLMP transparency measurements taken during the summers of 1989-1993, along with water quality data collected in 1986 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.

Figure 2 - Beaver Lake Depth Contour and Watershed (lower left) Maps With Lake Assessment Project Sampling Site 101 Shown.



RESULTS AND DISCUSSION

In-lake Conditions, 1993

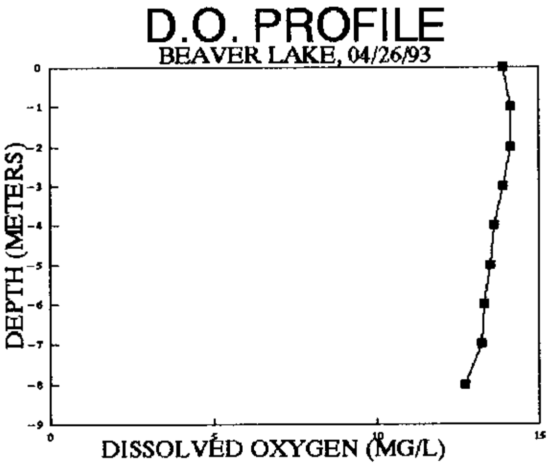
Temperature

In temperate climates, lakes as deep or deeper than Beaver Lake generally 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 epilimnion (warmer surface water) from the hypolimnion (cooler deeper water). This stratification usually remains stable through the summer. Shallower lakes, like most WCBP ecoregion lakes, tend not to exhibit stable stratification because the water column is relatively easily mixed by wind. Whether a lake stratifies or not, and how stable the stratification is, can greatly affect dissolved oxygen concentrations in a lake, and how a lake responds to nutrient loading. In stratified lakes, deep water is not reoxygenated during the summer. The temperature and dissolved oxygen profiles measured at site 101 are indicative of fairly stable stratification through June, July and August (Figures 3a-e). The greatest temperature difference between the surface and the bottom of the deepest part of the Beaver Lake was 7.3°C, recorded on August 10. By September, cooling of the surface water allows the lake to mix or "turn over."

FIGURES 3a–3e
DISSOLVED OXYGEN AND TEMPERATURE PROFILES FOR SITE 101, BEAVER LAKE, 1993.

FIGURE 3a.

DATE	SITE	DEPTH	D.O.	TEMP
04/26/93	101	0	13.9	8.3
		−1	14.1	8.2
		−2	14.1	8.3
		−3	13.9	8.2
		−4	13.6	8.1
		−5	13.5	8.1
		−6	13.3	8
		−7	13.2	8
		−8	12.7	7.9



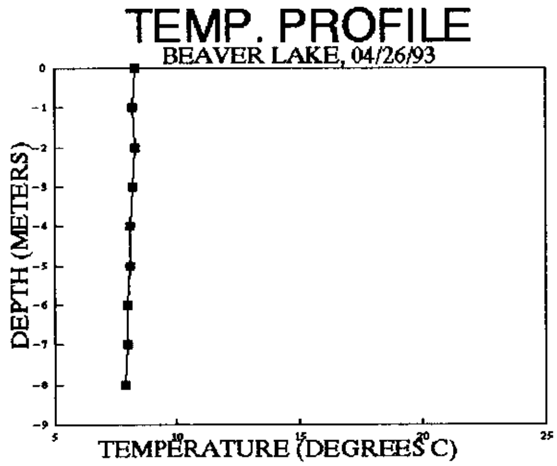
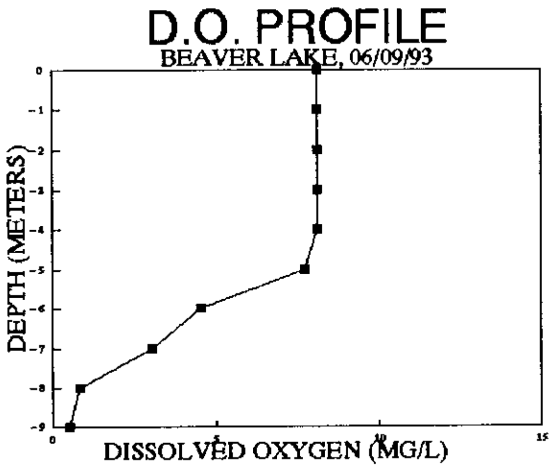


FIGURE 3b.

06/09/93	101	0	8.1	17
		−1	8.1	17
		−2	8.1	17
		−3	8.1	17
		−4	8.1	17
		−5	7.7	16.5
		−6	4.5	15
		−7	3	14
		−8	0.8	13.5
		−9	0.5	13



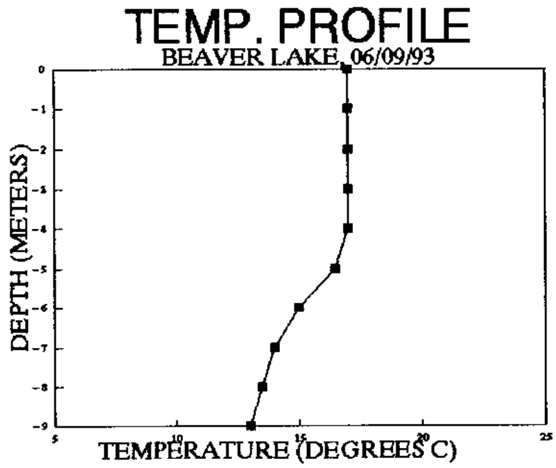
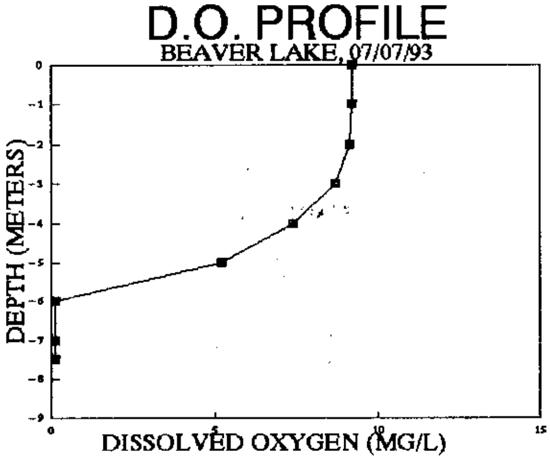


FIGURE 3c.

07/07/93	101	0	9.2	22
		−1	9.2	22
		−2	9.1	22
		−3	8.7	22
		−4	7.4	21.5
		−5	5.2	21
		−6	0.1	19
		−7	0.1	16
		−7.5	0.1	15



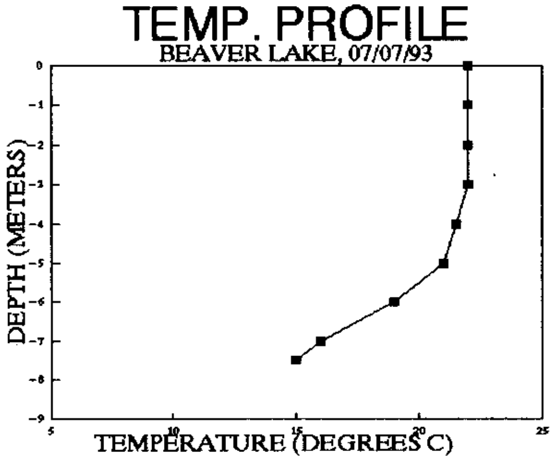
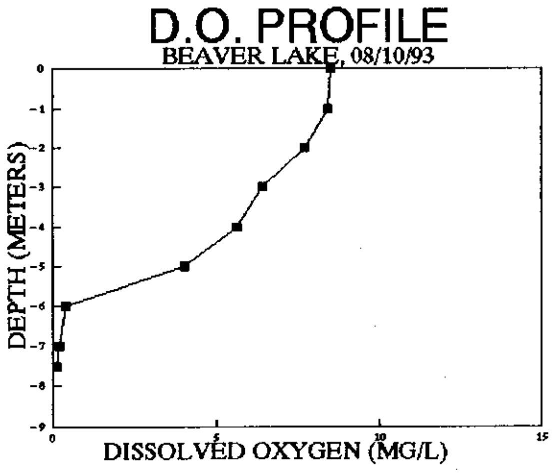


FIGURE 3d.

08/10/93	101	0	8.5	24
		−1	8.4	23
		−2	7.7	23
		−3	6.4	22.5
		−4	5.6	22.2
		−5	4	22
		−6	0.4	21
		−7	0.2	18.1
		−7.5	0.1	16.7



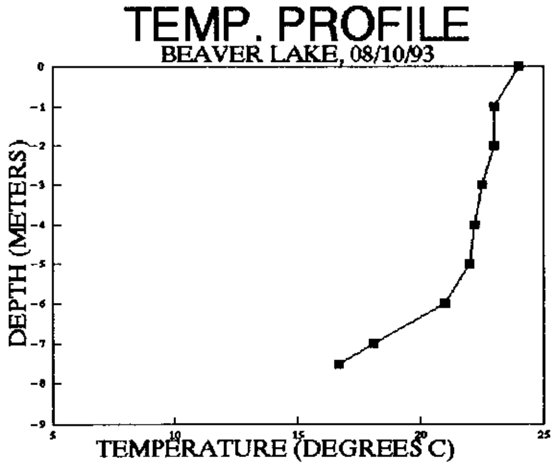
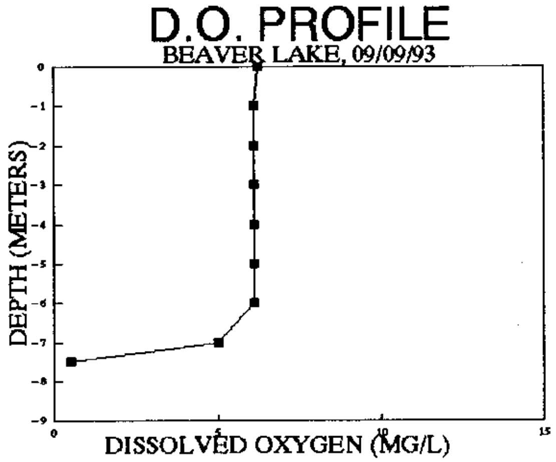
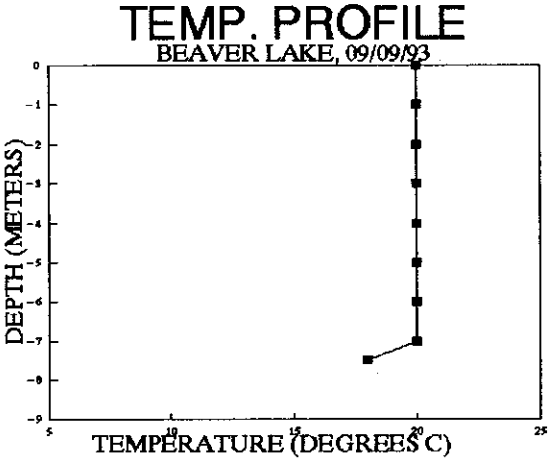


FIGURE 3e.

09/09/93	101	0	6.2	20
		−1	6.1	20
		−2	6.1	20
		−3	6.1	20
		−4	6.1	20
		−5	6.1	20
		−6	6.1	20
		−7	5	20
		−7.5	0.5	18





Dissolved Oxygen

The amount of dissolved oxygen at different depths and areas of a lake will determine where, and if, fish and other organisms are found. Dissolved oxygen concentrations of greater than 5 mg/l are considered necessary for long-term survival of game fish.

Low dissolved oxygen at the sediment-water interface can allow for the release of phosphorus from the sediments into the water column. As oxygen concentrations approach zero, iron compounds in the sediments lose their ability to bind phosphorus. Stratification, however, keeps much of this phosphorus rich water locked up in the hypolimnion until fall turnover.

Dissolved oxygen concentrations in the deeper water of site 101 fell below 5 mg/l starting in June and lasting until September. Game fish which cannot tolerate low oxygen levels would need to move into the upper portion of the water column during this time. With the exception of April 26, dissolved oxygen concentrations just above the sediments were near zero for the entire sampling period.

Total Phosphorus (TP)

Phosphorus is an important nutrient for plant growth. In most lakes it is the nutrient which limits the amount of plant and algae growth. The mean (average) TP concentration of the epilimnion between June and September of the 1993 sampling period was 47.5 ug/l. Concentrations ranged from 40 to 56 ug/l. The mean TP value is towards the low end of the range of concentrations measured in a set of 16 representative, minimally impacted reference lakes in the Western Corn Belt Plains ecoregion of Minnesota. The TP concentrations in the reference lakes tend to fall between 65 and 150 ug/l (Table 2). Based on total phosphorus concentrations measured in 60 lakes in the WCBP ecoregion, only about 5 percent of the lakes have mean TP concentrations less than 47.5 ug/l.

Total phosphorus concentration in the epilimnion (surface water) of Beaver Lake was greatest in April 23 (77 ug/l) and remained fairly constant over the rest of the summer. 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. This settling, along with the release of phosphorus from the sediments under low oxygen conditions often results in a decline in epilimnetic concentrations and an increase in hypolimnetic concentrations during the period of stratification. Epilimnetic TP concentrations did not appear to decrease over the summer in Beaver Lake. However, the hypolimnetic TP concentration on August 10 was 346 ug/l.

TABLE 2. BEAVER LAKE AVERAGE SUMMER WATER QUALITY AND TROPHIC STATUS INDICATORS. Based on summer epilimnetic data from 1993.

	Mean	Typical Range for Ecoregion[1]
Total Phosphorus (ug/l)	47.5	65-150
Chlorophyll-a (ug/l) mean	27	30-80
Chlorophyll-a (ug/l) maximum	42	60-140
Secchi disk (feet)	4.25	1.6-3.3
Total Kjeldahl Nitrogen (mg/l)	1.4	1.3-2.7
Nitrite & Nitrate-N (mg/l)	0.045	.01-.02
Alkalinity (mg/l)	140	125-165
Color (Pt-Co Units)	10	15-25
pH (SU)	8.4	8.2-9.0
Chloride (mg/L)	15.5	13-22
Total Suspended Solids (mg/l)	7.3	7-18
Total Suspended Inorganic Solids (mg/l)	2.6	3-9
Turbidity (NTU)	3.9	3-17
Conductivity (umhos/cm)	318	300-650
TN:TP ratio	18:1	17:1-27:1

Trophic Status Indicators: 1992

Carlson Trophic State Index Values		Percentile[2]
TP TSIP	60	
Chl-a TSIC	60	
Secchi TSIS	57	
Mean TSI	59	95

1. 25-75th percentile for 16 representative - minimally impacted lakes in the Western Corn Belt Plains Ecoregion (Heiskary & Wilson, 1990)

2. Relative to approximately 40 lakes in the Western Cornbelt Plains ecoregion. One hundred percent level implies lowest TP and chlorophyll concentration or deepest Secchi disk measurement for that ecoregion.

In thermally stratified lakes phosphorus released from the sediments generally remains in the hypolimnion and is unavailable for use by algae. Upon fall turnover, however, this phosphorus is available for algae growth. Fall turnover started in Beaver Lake in early September.

A single total phosphorus sample was collected from the stream south of the lake on June 11, 1993. The total phosphorus concentration of this sample was 126 ug/l. While a single sample with no associated flow cannot be used to characterize the water quality of this stream, this concentration was greater than any of the epilimnetic lake samples. Consequently, diversion of water from this stream to Beaver Lake could degrade water quality by increasing phosphorus loading.

Total Nitrogen

Total nitrogen (TN), which is defined as the sum of the total Kjeldahl nitrogen and nitrate-nitrite nitrogen, averaged 1.4 mg/l during the summer of 1992. This value is on the low end of the range for minimally impacted lakes in the WCPB ecoregion. The nitrate/nitrite-N is in the range of concentrations found in the reference lakes (Table 2). This suggests an absence of "fresh" sources of nitrogen such as animal feedlots or livestock in the lake.

TN:TP

Nitrogen and phosphorus are 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 Beaver Lake the mean TN:TP ratio is 30:1. Given that the lowest ratio for the summer of 1993 was 22:1, phosphorus is considered the limiting nutrient for algal growth in Beaver Lake.

Chlorophyll-a

Chlorophyll-a (a pigment produced by algae) concentrations provide an estimate of the amount of algae in the lake. During the summer, lake chlorophyll-a concentrations ranged from 6 to 42 ug/l with a mean concentration of 27 ug/l (Table 2). 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-a values reported for Beaver Lake exceeded the nuisance threshold in May, August, and September. The chlorophyll values, however, fall at the low end of the range for the ecoregion reference lakes, which typically range between 30 and 80 ug/l.

Phytoplankton

Phytoplankton (algae) samples showed a fair amount of diversity and, with one exception, reflect typical community dynamics. Diatoms dominated the May sample. Green algae dominated the June sample. The August and September samples were dominated by blue-greens.

The exception referred to above was apparent in the September sample, when 70% of the algae was the blue-green genus Ocillatoria. Later in the fall and through the winter and spring of 1994, Beaver Lake turned a reddish color. A sample taken in March of 1994 revealed a significant bloom of Ocillatoria rubescens, which contains a reddish pigment. Beaver Lake still had a red scum on it's surface in early May of 1994. The scum dissipated by late May however.

Zooplankton

Zooplankton (microscopic animals) were collected and analyzed qualitatively during each sampling event. With the exception of May 26, noticeable quantities of zooplankton were present through the summer. June 9 was the only date where the qualitative analysis showed "abundant large-bodied daphnia." 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. Zooplankton feed preferentially on small algal forms.

Fecal Coliform Bacteria

Fecal coliform bacteria is found in the waste products of warm blooded animals, including humans. While not a disease causing bacteria itself, fecal coliform is an indicator of human or animal waste which may contain other disease causing bacteria. Fecal coliform sampling is generally not a part of LAP projects. Steele County, however, collected a number of samples in 1993. Samples were collected from the lake surface at the beach area and from the small stream that flows under highway 28 approximately 1/4 mile south of the lake. This stream does not enter the lake unless a gate is opened. Results of 5 lake surface samples and 4 stream samples showed only 1 exceedance of the 200 organisms per 100 ml state water quality standard. A sample taken from the stream on August 10, 1993 showed 570 organisms per 100 ml. This is not a particularly high count for a stream which flows through a livestock pasture.

Transparency (Secchi disk)

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-a and the total phosphorus concentrations. The average transparency measured during the lake assessment sampling was 1.3 meters (4.25 feet). The average transparency values determined by the CLMP volunteer measurements was 4.1 feet (1.26 meters). The two averages agree quite well.

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 both by the CLMP volunteer and during LAP sampling. 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). The 1993 CLMP record is summarized in Table 3.

Table 3 - Transparency, physical condition, and recreational suitability values from 1993 CLMP record.

Month	obs	Transparency (mean)	Physical Condition (mean class)	Recreational Suitability (mean class)
June	2	4.7 feet	2	2
July	3	4.5 feet	2	2
August	3	3.8 feet	3	2
September	1	3.0 feet	3	2

With a decrease in transparency in August and September, the physical conditions ratings increase, reflecting more algae. According to the CLMP volunteer, however, recreational suitability was still good.

Other water quality parameters including color, total suspended solids, total suspended inorganic solids, pH, turbidity, alkalinity, chloride, and conductivity were within or at the low end of the range of values for the minimally impacted lakes in the ecoregion. The relatively low total suspended solids is consistent with a small watershed, particularly in a extremely wet year like 1993, when one might expect excess sediment to enter water bodies.

Historical and 1993 water quality data for individual sampling dates in contained Appendix 1.

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-a. 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 ug/l, Chlorophyll-a 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 Beaver Lake are 60, 60, and 57 respectively, with an average of 59 (Table 2, Figure 4). Based on these values the lake would be considered eutrophic or moderately nutrient rich. The relatively good agreement between index values points to the

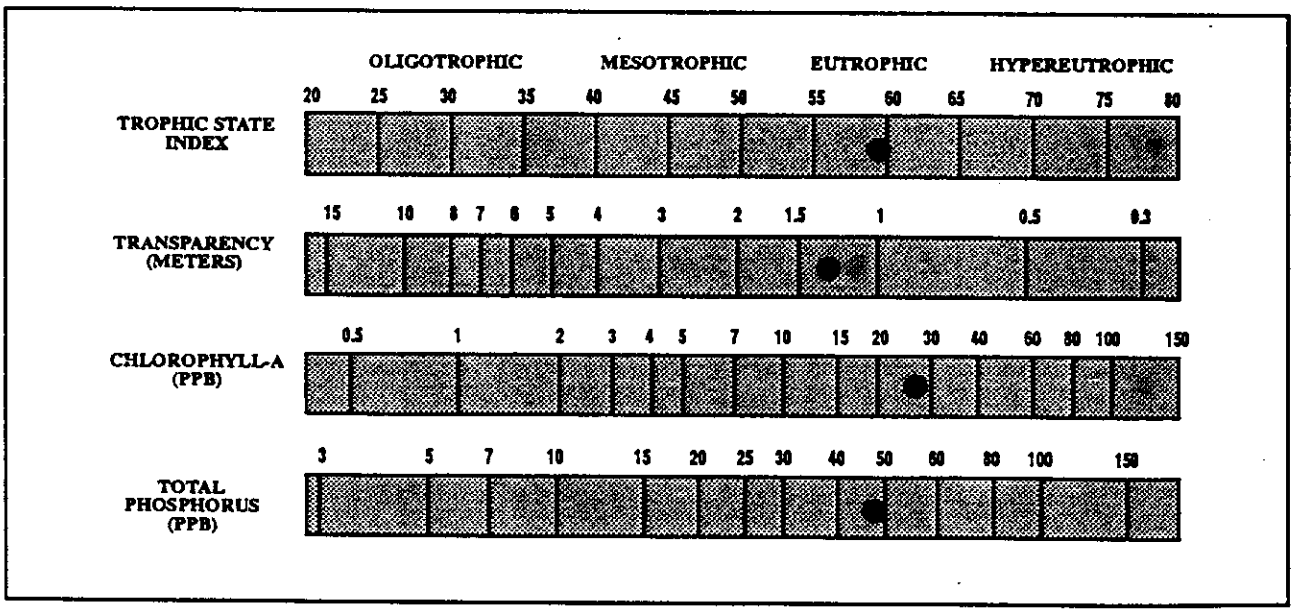
Figure 4. CARLSON'S TROPHIC STATE INDEX VALUES
TSI Relationships based on mean summer data for 1993.

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 Beaver Lake



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

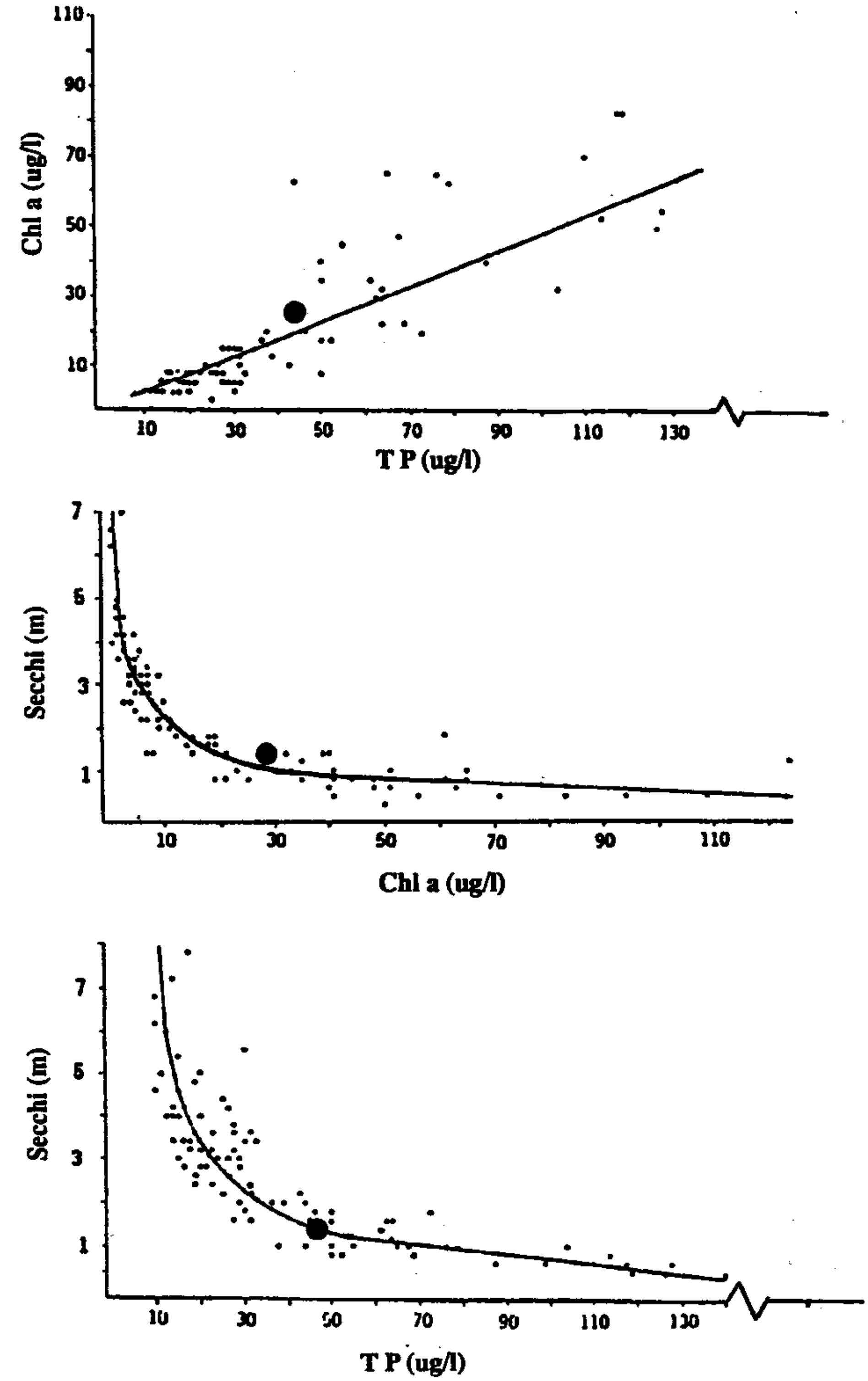
importance of continued Secchi disk monitoring of Beaver Lake to provide a reliable indication of the algal and phosphorus trends.

Comparison of TSI values for Beaver Lake to those of other lakes in the Western Corn Belt Plains ecoregion can provide a basis for evaluating the water quality of the lake. A TSI value of 59 ranks in the 92th percentile for the ecoregion. In other words, only 8 percent of the lakes in the ecoregion have TSI values less (are less eutrophic) than Beaver Lake.

Another way to compare the trophic status variables is on scatterplots. Figure 5 illustrates the general relationships between total phosphorus, chlorophyll-a, and Secchi disk transparency. The three parameters are closely correlated since phosphorus 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.

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 Beaver Lake **noted:**



TREND ANALYSIS/HISTORICAL DATA

A relatively small amount of historical data is available for Beaver Lake. CLMP data exists for the years 1989-1993. Water chemistry data from a 1986 state sampling effort is also available. The mean summer CLMP secchi disk measurements are listed below.

Table 4 - Historical CLMP Record

Year	Secchi Depth (feet)	Number of Readings
1986	4.6	3
1989	2.7	5
1990	2.8	11
1991	3.5	14
1992	3.3	6
1993	4.1	9

The above Secchi values show no discernable trend from 1986 to 1993. The 1986 data shows a mean total phosphorus concentration of 31 ug/l and a mean chlorophyll-a concentration of 15.4 ug/l. Both of these means are based on 4 samples.

AQUATIC PLANTS (MACROPHYTES)

A macrophyte survey of Beaver Lake was not done as part of the LAP. A few observations were made, however, and some historical information was obtained through the MDNR. Floating-leaved (e.g. lily pads) and emergent (rushes, cattails) aquatic plants were present along the west shore of the lake, particularly in the shallow northwest bay. Residents describe thick growth of a submergent (probably the exotic curled pondweed - potomogetan crispis) also in the northwest bay. Minnesota Department of Natural Resources fisheries information documents curled pondweed in 1947, the earliest documentation in the seven-county Waterville fisheries area. Curled leaf pondweed is very aggressive and can dominate the macrophyte community of a lake. Curled leaf can present problems for navigation on a lake, as well as create a nuisance during in die-off in late July or early August. It should probably be taken as a good sign that Beaver is not completely dominated by curled leaf.

Macrophytes, even curled leaf pondweed, can provide multiple benefits in lakes. Macrophytes may provide cover for zooplankton. The zooplankton, in turn, can reduce algae concentrations in a lake low through grazing. Macrophytes provide spawning and nursery areas for fish. Macrophytes may encourage the sedimentation of soil and soil-attached nutrients that enter the lake. Finally, macrophytes can also be important for holding bottom sediment in place and stabilizing shoreline. This helps water clarity and minimizes nutrient resuspension. Attempts have, and are being made to plant desirable macrophytes in southern Minnesota Lakes. These attempts have shown limited success. Because seed stock exists in the sediment of lakes, improving water clarity and allowing natural fluctuations in water level are two ways desirable macrophyte communities may become reestablished.

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. Sediment covers or surface shading are experimental techniques which may effectively control weed growth by controlling light. The Lake and Reservoir Restoration Guidance Manual (USEPA 1990) contains information on this topic. Although the benefit would be small, harvesting removes small amounts of nutrients from a lake. If low oxygen is a problem, the removal plant material that depletes oxygen as it decays may be a more important benefit. All plants must be removed from the lake during any harvesting operation. In many cases permits from the DNR are required for aquatic weed control.

NUTRIENT SOURCES

Watershed

Beaver Lake has a ditch inlet on the north side, as well as approximately 11 drain tile inlets. Some of these tiles are suspected of being connected to the wastewater systems of lakeshore homes/cottages. Although the Beaver Lake watershed is small, nonpoint source pollution is likely the major source of nutrients to Beaver Lake. Nonpoint pollution sources include: agricultural runoff; pesticide and fertilizer use on agricultural land and lawn; feedlot runoff; runoff from streets, yards, and construction sites;

seepage 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 on agricultural land, BMP's 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. Best management practices are also available for construction activities and for lakeshore property owners.

Livestock

Livestock waste contains nutrients, organic material, and bacteria that can enter streams and lakes if not managed properly. Proper management includes containing manure on any open lots as well as land application at rates that can be used by crops. There is one relatively small dairy operation in the Beaver Lake watershed. No direct runoff to the lake from open lots was evident or has been reported.

On-site sewage treatment systems

The Beaver Lake Association opted not to complete the usual LAP on-site wastewater treatment system survey for this project. Lake association members indicated that a detailed field survey would be completed with assistance from Steele County upon formation of a Sanitary District. While the association has approved the formation of a district, paper work on this has not been completed. Prompt action on this is needed. Lake projects that ignore failing on-site systems have the potential to lose credibility in other areas.

Even functioning on-site systems need to be properly maintained. 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). Water conservation practices and care in regard to the types of products placed in a system can also be very important for good operation and system longevity.

Lawn Care

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. Leaves should not be burned, particularly where ash may wash into the lake.

In-lake

A portion of the nutrients which enter a lake from the watershed become bound to the lake sediments. For Beaver Lake it is estimated these nutrients can be released under certain conditions. Phosphorus, for example, is released from sediments when the layer of water near the sediment contains no oxygen. 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. Because Beaver Lake is thermally stratified during the summer, much of the phosphorus that is release remains in the hypolimnion and is not available for algae growth. It is important to note that a lake with severe internal phosphorus loading has or had excessive external phosphorus loading.

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 Beaver 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 (TP), chlorophyll-a, 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 Beaver 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). The uncertainty associated with the predictions is substantial. Inputs to, and results from the model are shown in Appendix 2.

The TP concentration for Beaver Lake predicted by MINLEAP was 46.11 ug/l. The predicted chlorophyll-a concentration was 17.8 ug/l.

The predicted Secchi disk depth was 1.42 meters. All three agree fairly well with observed values of 47.5 ug/l, 26.8 ug/l and 1.29 meters, respectively. This implies that the quality of Beaver Lake is close to that expected for a minimally impacted lake based on its size, size of watershed, and the ecoregion it is located in.

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 (although more detailed than the MINLEAP) assessment requires that the model output be expressed as a range of values (low, average, and high). 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). Phosphorus export coefficients used are comparable to previous LAP studies. Inputs to, and results from the model are shown in Appendix 2.

The Reckow and Simpson model predicts in-lake TP concentrations ranging from 39 to 67 ug/l with an average value of 55 ug/l. The model predicts chlorophyll-a ranging from 13.9 to 30.6 ug/l with an average of 23 ug/l. Predicted Secchi disk transparency ranged from 1.6 to 1 meter with an average of 1.2 meters.

The summer mean TP concentration in 1993 is intermediate between the low and average values in the Reckhow and Simpson model, suggesting a range in phosphorus loading to the lake of 70-125 kg TP/year. Considering the good agreement between the observed (47.5 ug/l) and predicted (46.1 ug/l) TP concentrations in MINLEAP, a TP loading in this range (MINLEAP loading = 85 kg/yr) is likely a reasonable estimate. The majority of the TP loading most likely arises from runoff from the watershed and leaching from septic systems. In fact, the results suggest that septic systems have the potential to contribute more TP to Beaver Lake than runoff from the watershed. This is a result of the lake's rather small watershed and the relatively large number of homes around the lake.

GOAL SETTING

In order to maintain fisheries, aesthetics, and full recreation, phosphorus levels below 40 ug/l are desirable for many lakes in the state. This may be a reasonable TP goal for Beaver Lake. Among other things, moving from an average total phosphorus level of 47.5 ug/l to 40 ug/l could reduce the occurrence of severe algae blooms from 35% of the summer to about 15% of the summer. Average summer water clarity could also be increased 20-25%. Phosphorus loading to the lake must be reduced to achieve a TP concentration of 40 ug/l. The needed reduction may be on the order of 20%.

RECOMMENDATIONS FOR MAINTAINING AND IMPROVING WATER QUALITY

The following recommendations are based on the 1993 assessment of Beaver Lake. Because of its small watershed, the Beaver Lake Association can be particularly effective in protecting and improving the quality of the lake.

1. The Beaver Lake Association and Steele County should move ahead with plans to improve inadequate wastewater treatment. All systems should be up to code and properly maintained.
2. The Beaver Lake Association should develop a working relationship with the agricultural land owners in the watershed. If changes on agricultural land should be needed to protect or improve water quality, they are most likely to be accomplished in a cooperative manner. In addition, small pieces of agricultural land may be needed for lakeshore wastewater treatment.
3. The Beaver Lake Association should work closely with the Minnesota Department of Natural Resources (MDNR) Division of Fisheries to maintain a healthy fish community. A healthy fish community can benefit water quality, and visa versa.
4. 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).

5. The Beaver Lake Association should provide educational materials to lakeshore owners on shoreline and shoreland protection. Protection of the existing vegetation along the shore will minimize erosion and preserve the aesthetic value of the lake. In addition to providing water quality and fishery benefits, lakeshore with a diverse community of native vegetation will 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 are good guides.

6. 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. Steele county's shoreland regulations will be important in this regard.

7. Activities in the Beaver 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.

8. 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.

9. Any decisions on diverting water to Beaver Lake from the stream to the south should be carefully considered. Diverting water in this way effectively increases the size of the watershed and will generally result in more pollutants being carried to the lake.

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Appendix 1

BEAVER LAKE WATER QUALITY DATA (HISTORICAL, AND COLLECTED DURING LAP PROJECT OF 1993).

LAKE CHEMISTRY DATA

DATE	SITE	DEPTH (ft)	TP (ug/l)	TKN (ug/l)	N2N3 (mg/l)	TSS (mg/l)	TVS (mg/l)	ALK	PH (field)	CL (mg/l)	COND (us/cm)	TURB (NTU)	COLOR (pcu)	CHL A (ug/l)	PHEO. (ug/l)	SD meters	SD feet
04/23/86	101	0	98	2	0.18	11		140		16		5.4	20	55.4		0.79	2.6
04/23/86	101	22	95	1.9													
06/09/86	101	0	34	1.16	0.01	3.9		140		16		1.5	20	14		1.40	4.6
06/09/86	101	16	64	1.98													
06/09/86	101	22	191	5.42													
06/09/86	102	0	39	1.24										12.4			
07/22/86	101	0	24	1.09	0.01	4.6		120		18		2.1	10	10.2		1.49	4.9
07/22/86	101	19	62	1.79													
07/22/86	101	26	80	1.85													
08/18/86	101	0	27	1.18	0.01	3		130		17		1.5	10	25		1.31	4.3
08/18/86	101	19	38	2													
08/18/86	101	26	460	8.45													
04/26/93	101	0	77	1.14	0.6	13	6.6	150	8.1	17	350	3	20	80.1	17.9	0.91	3
06/09/93	101	0	56	1.15	0.11	6.4	3.6	150	8.4	16	360	3.3	10	5.77	2.14	1.80	5.9
06/09/93	101	26	101	1.68	0.04												
07/07/93	101	0	40	1	0.01	7.6	3.6	140	8.6	16	300	3.7	10	20.5	0.96	1.40	4.6
07/07/93	101	22	50	1.12	0.01												
08/10/93	101	0	40	1.78	0.01	8.1	1.7	120	8.5	15	310	5	10	38.8	0.32	1.22	4
08/10/93	101	24	346	3.72	0.01												
09/09/93	101	0	54	1.49	0.05	7.2	1.6	150	8.4	15	300	3.5	10	42.3	0.43	0.76	2.5
09/09/93	101	22	178	2.83	0.05												

Appendix 2 - Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) and Reckhow-Simpson Modeling Summary

INPUT DATA:
LAKE NAME =Beaver ECOREGION=WCP
LAKE AREA = 40.3 HA
WATERSHED AREA (EXCLUDING LAKE) = 98.29999 HA
MEAN DEPTH = 4.4 METERS
OBSERVED MEAN TP = 47.5 UG/L
OBSERVED MEAN CHL-A = 26.8 UG/L
OBSERVED MEAN SECCHI = 1.29 METERS

LAKE = Beaver
AVERAGE INFLOW TP = 558.8623 UG/L
LAKE OUTFLOW = .15197 HM3/YR
RESIDENCE TIME = 11.66809 YRS

ECOREGION = WCP
TOTAL P LOAD = 84.9303 KG/YR
AREAL WATER LOAD = .3770968 M/YR
P RETENTION COEF = .91749

VARIABLE	UNITS	OBSERVED	PREDICTED	STD ERROR	RESIDUAL	T-TEST
TOTAL P	(UG/L)	47.50	46.11	19.84	0.01	0.06
CHL-A	(UG/L)	26.80	17.76	12.81	0.18	0.54
SECCHI	(METERS)	1.29	1.42	0.67	-0.04	-0.20

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	96.52	83.08	81.16	69.75
20	64.47	31.24	32.58	39.56
30	31.70	9.12	10.92	23.57
60	2.75	0.27	0.52	6.69

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

I N P U T   S E C T I O N

****

	Beaver		
Watershed Area (ha)	98.3	0.0475	=Observed TP (mg/l)
Lake Area (ha)	40.3	0.009	=Observed TP StDev
Water Runoff (m)	0.25	4	=N
Precipitation (m)	0.8	26.8	=Observed Chla (ug/l)
Mean Evaporation (m)	0.95	1.29	=Observed Secchi (m)
Mean Depth (m)	4.4	1.7732	=Calc. Volume (Hm3)
County capitas/cabin	2.8		
No. Seasonal Cabins	61		
No. Permanent Res.	30		

****Fill in Est. Number Animal Units at a102****

	Before	After	Delta	%Total
Forest Area (ha)	10.9	0	0	11%
Agric Area (ha)	53.8	0	0	55%
Urban Area (ha)	23.9	0	0	24%
Wetland Area (ha)	4	0	0	4%
Pasture/Open (ha)	5.7	0	0	6%
	98.3			

Export Values		Low	Average	High
Forest P Export		0.1	0.125	0.15
Agric P Export		0.2	0.4	0.6
Urban P Export		0.5	1	1.25
Wetland P Export		0.1	0.1	0.1
Pasture/open Export		0.2	0.3	0.4
Atmospheric Export		0.3	0.3	0.3
Soil Retention Coef		0.75	0.5	0.25
Point Source Before	kg/yr	0	0	0
Point Source After	kg/yr	0	0	0
Delta Point Source kg/yr		0	0	0
Capita Years		127.3	127.3	127.3

||

O U T P U T   S E C T I O N   # 1

Reckhow-Simpson Modeling Summary

Low	KG P/YEAR Average	High	kg P/year
1	1	2	Forested Flux
11	22	32	Ag flux
12	24	30	Urban flux
0	0	0	Wetland flux
1	2	2	Pasture/Open flux
12	12	12	Ppt flux
32	64	95	Septic flux
0	0	0	Point Souce
69	125	173	Total P Flux
171	310	429	P LOAD (kg)
276	500	692	Inflow P ug/l
39	55	67	CANFIELD/BACHMANN

========================== ug/L =============

OUTPUT SECTION 2 WATERSHED CONTRIBUTIONS

-------------------- P load contribution--------------------

	Low flux	%	Avg flux	%	High flux	%
Wshed	25	36%	49	39%	66	38%
Septic	32	46%	64	51%	95	55%
Ppt	12	17%	12	10%	12	7%
Point	0	0%	0	0%	0	0%
Sum kg/yr	69		125		173	

OUTPUT SECTION 3. Reckhow-Simpson and MINLEAP Modeling Summary
Predicted changes in Secchi, Chlorophyll and Trophic Status

	Observed	Low Predicted	Average Predicted	High Predicted	MINLEAP Predicted
		Predicted inlake P conc.			84.93 kg/yr
		or insert other values.			
LAKE TP mg/l	0.048	0.039	0.055	0.067	0.046
LAKE CHLA ug/l	26.8	13.9	23	30.6	17.8
LAKE SECCHIm	1.29	1.6	1.2	1	1.42
TSI TP	60	57	62	65	59
TSI CHLA	63	56	61	64	59
TSI SD	56	53	57	60	55

Hydrologic Summary Information

Est Flow= 245744 0.25 =HM3
Est Qs = 0.61
NOTE: 1HM3 = 1,000,000 M3; HM3=A-F/811; Ha=Ac/2.47; Km2=2.59*Mi2
7.10 =Water Residence (year)

Appendix 3

Beaver Lake Historical Summary

This brief summary was prepared by Lee Ganske following a meeting with the following long-time residents of the Beaver Lake community: Tom Ahern, Noreen Jensen, Carl Oslund, Harold Dever, and Helen Burnes. Only a fraction of the information shared by these people is included here.

The first cottages were established on Beaver Lake in the 1920's and 1930's. At that time, a bit more of the Beaver Lake watershed was actively cropped or pastured and there were fewer trees along the shoreline. Most of the cottages presently on the lake were built after the mid-1940's. The south side of the lake was developed before the north side. Major physical alterations include the creation of channel and a pond on the north end of the lake.

The long-time residents do not perceive water quality as markedly declining or improving over the years. Periodic severe algae blooms have occurred as long as some residents can remember, including at least 2 blooms of the red pigmented algae Ocillatoria rubescens. There was general agreement, however, that their are fewer large water plants (particularly "lily pads") in the lake.

Some long-term residents feel that there are fewer large panfish, northern pike, turtles, and ducks in the lake. They see this as at least partially related to the decrease in aquatic plants. Winter fish kills of varying magnitude were reported to occur in intervals of roughly 6-8 years.

Water level in the lake has been a major ongoing concern of residents for many years. It has created some conflict. A control structure at the outlet can be used to regulate water levels. In addition, a system was installed that allows water to be diverted to the lake from a creek to the south.