LAKE ASSESSMENT PROGRAM

SULLIVAN LAKE
1992
(ID Number 49-0016)

MORRISON COUNTY, MINNESOTA

Minnesota Pollution Control Agency

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ACKNOWLEDGMENTS

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Sullivan Lake Association - Elmer Wright and Darvin Dahlke for their monitoring and background assistance.

Minnesota Department of Natural Resources, Little Falls Area Fisheries Office - Brady Becker, author of the fisheries section.

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SUMMARY

Sullivan Lake is located in Central Minnesota near the town of Harding, Minnesota in Morrison County. The lake is 1,119 acres with a maximum depth of 56 feet. The watershed consists of 21,855 acres with forested land as the primary land use.

Sullivan Lake was sampled during the summer of 1992 by the Minnesota Pollution Control Agency (MPCA) staff and members of the Sullivan Lake Association as a part of the Lake Assessment Program (LAP). Water quality data collected during this study indicate that Sullivan Lake is mesotrophic with a mean total phosphorus concentration of 23.8 ug/l, a summer mean Secchi transparency of 8.1 feet and a mean chlorophyll a of 8.06 ug/l.

Based on the sampling information computer models were used to estimate existing water quality conditions in Sullivan Lake. These models are useful for predicting and diagnosing the water quality of the lake and estimating the impacts of land use in the watershed on the lake water quality. Additionally, the models can assist in identifying management options to improve the water quality of the lakes.

The water quality monitoring and computer modeling indicate that the overall quality of Sullivan Lake is good. The lake has a

mean phosphorus concentration within the range for minimally-impacted lakes within the Northern Lakes and Forest Ecoregion.

Based on the results of the 1992 LAP study, efforts should be taken to establish a nondegradation program to protect the water quality of the lake. As improvements in water quality are sought, i.e., a reduction in chlorophyll a concentration or improved transparency, the results of the models used in this study will be useful. In addition, if any changes are proposed in the watershed, model results can be used to determine the anticipated impacts on the lake. Since the majority of the phosphorus load to the lakes appears to be from within the watershed, efforts on improvement should be focused in that area. It should be noted however, that a more detailed study will be required to determine whether improved conditions can be achieved through the implementation of watershed controls or through in-lake measures.

The following recommendations are based on the 1992 LAP study of Sullivan Lake:

1. The Sullivan Lake watershed is sensitive to increases in nutrient loading rates from the watershed. The lake association, in conjunction with local units of government should make every effort to encourage and adopt a lake protection plan which includes land use and

zoning ordinances for the protection of lake water quality. The following statements should be included in the plan:

a. The Sullivan Lake Association should continue to participate in the Citizen Lake-Monitoring Program (CLMP). Data from this program provides an excellent basis for assessing long term and year-to-year variations in algal productivity, i.e., the trophic status of the lake. Measurements should be taken weekly between mid-June through mid-September at site 210 at a minimum in the lake. Sites 202 and 203 are useful to characterize spatial differences in the lake.

b. The Sullivan Lake Association should continue the evaluation of all on-site septic systems around the lakes. Any systems out of compliance with county/state codes (Minnesota Rules Chap. 7080) should be brought into compliance. This step may require the assistance of the Morrison County Planning and Zoning Department. The education of homeowners around the lake regarding septic systems, lawn maintenance, and shoreland protection may be beneficial. Staff from the MPCA and the Minnesota Department of Natural Resources (MDNR), along with county officials (Planning and Zoning Department, Agricultural Extension, and the Morrison County Soil and Water Conservation District) could provide assistance in this area. The booklet, A Citizens' Guide to Lake Protection may be a useful educational tool for the Association. Additionally, some parts of Sullivan Lake's watershed are in Crow Wing County. Future efforts should include representatives of Crow Wing County.

c. Any future development in the watershed of Sullivan Lake should occur in such a manner as to minimize the impacts on the water quality of the lakes. Setback provisions and septic tank regulations should be enforced. In addition, activities which directly alter the drainage patterns, such as wetland drainage or other land use changes, should be avoided unless appropriate measures are undertaken to mitigate the impacts. The Sullivan Lake Association should provide input or seek representation on boards or commissions that address land use or management decisions to ensure that land use impacts on water quality are minimized. The MPCA booklet, Protecting Minnesota's Waters: The Land-Use Connection should be of assistance in this area.

d. The Sullivan Lake Association should encourage cooperative and shared efforts for the best management of their lake. Such efforts should include Morrison County officials, local MPCA and MDNR staffs, extension agents, and sporting or citizen groups. These groups can share resources and expertise on issues which affect lake water quality.

e. If a more accurate assessment of sources of excess nutrient loadings from the watershed, is desired, a more detailed study would need to be undertaken. This study should examine nutrient sources from runoff over forested lands, fertilized lawns in the watershed, road construction, and poorly functioning on-site septic systems. Additionally, Platte Lake should be considered in such a study. The County and State offices mentioned above could be helpful in this regard.

   If this alternative is implemented, the Minnesota Pollution Control Agency's Clean Water Partnership program may be a source of funding assistance.

2. This Lake Assessment Report serves as a foundation for further studies and assessments. The water and nutrient

income-outgo summaries are estimated based on limited monitoring data and should be considered, at best, approximations. The next step for the lake association is to define nutrient sources in more detail to determine if further lake protection efforts are required. These detailed analyses should include an estimation of total phosphorus (and ortho-phosphorus), total nitrogen, inorganic nitrogen and hydrologic inputs and outputs.

3. The water quality Sullivan Lake is good, however, small increases in the in-lake total phosphorus can cause a measurable decline in the lake's transparency. For Sullivan Lake, changing land use practices in the watershed would be the most likely cause for changes in the amount of phosphorus entering the lake. The prevention of additional nutrients or the further reduction of the amount of nutrients that enter the lake will help maintain or result in improved transparency and a reduction in algal blooms. The implementation of best management practices (land management activities used to control nonpoint source pollution) in the watershed is one method of reducing the nutrient input to the lakes. Technical assistance on best management practices may be available through local resource management agencies (Morrison County, Crow Wing County,

MDNR, MPCA). The Minnesota Pollution Control Agency's Clean Water Partnership Program is also an option for further assessing the nonpoint sources of water pollution within the watershed. In view of the water quality of Sullivan Lake, an application to the Clean Water Partnership Program, if undertaken, should stress protection and identification of sources and correction of the problems contributing to the nutrient loadings.

4. Future changes in the water quality of Sullivan Lake should necessitate further action. Factors which may trigger further action include:

   a. A further decline in the water quality of the Lake. This could be determined by a significant decline in the summer average transparency. Continued participation in the Citizen's Lake Monitoring Program (CLMP) will provide this information. The actual "trigger level" for Sullivan Lake might be if the average summer transparency declined to below about five (≈1.5 meters) feet or if 40 percent of the annual summer readings were below 6.5 feet (≈2 meters). This "trigger level" can be refined with a few more consecutive years of data collection.

   b. An inspection of the land use practices, as part of a comprehensive lake management program within the watershed of Sullivan Lake, reveals the need for the implementation of best management practices (BMP's) to protect the lake from further impacts. These BMP's include activities addressed through local controls, ordinances or services of the local units of government as well as technical on-land correction measures implemented by the land owner.

5. Should the lake association decide to pursue a Clean Water Partnership project, it will be necessary for the Association to have a governmental sponsor, such as Morrison County. Sponsorship may be provided by a county, city, township, watershed district, watershed management organization, or through joint powers agreements with several local units of government.

6. The Sullivan Lake Association, as part of its comprehensive lake protection program, should work with the Minnesota Department of Natural Resources (MDNR), Division of Waters, to continue the volunteer lake level gauge reading program. This information would be required if a more in-depth study of the lakes is pursued.

LAKE ASSESSMENT PROGRAM 1992

Sullivan Lake
(ID Number 49-0016)

INTRODUCTION

Sullivan Lake was sampled by the Minnesota Pollution Control Agency (MPCA) staff during the summer of 1992 as a part of the Minnesota Pollution Control Agency's Lake Assessment Program (LAP) to determine the lake's water quality and determine possible sources of nutrient's inputs to the lakes.

As designed, the Lake Assessment Program assists local lake associations, local units of government, or other groups interested in protecting a local lake resource in collecting and analyzing water quality data. This data is then used to establish an information baseline and determine the current trophic status of the lake(s). The general work plan for a LAP includes cooperative lake sampling by the MPCA staff and the local sponsor or lake association, participation in the Citizen's Lake Monitoring Program (CLMP), examination of the land use and drainage patterns in the watershed of the lake's and an assessment of the data collected. The LAP was conducted by the MPCA at the request of the Sullivan Lake Association because of water quality concerns by the Association and the potential for increased development around the lake and in the watershed.

Sullivan Lake was sampled on five occasions during the spring and summer of 1992 by Jim Hodgson and Will Munson of the Minnesota Pollution Control Agency and Elmer Wright and Darvin Dahlke of the Sullivan Lake Association. The Lake Association also collected the CLMP data and the historical data.

BACKGROUND

Sullivan Lake is located in central Minnesota near the City of Harding, Minnesota, in Morrison County, and is approximately 100 miles northwest of the Minneapolis - St Paul metropolitan area (Map 1). The lake is approximately 1,119 acres in size which places it in the upper 5 percent of Minnesota's lakes in terms of surface area (MDNR, 1968) (Table 1). The lake has a mean depth of 17.6 feet and its maximum depth is 56 feet. The watershed land area to lake surface area ratio is 18:1.

Sullivan Lake Historical Summary

From information furnished by the lake association, the area around Sullivan Lake experienced early development pressure. A survey conducted around the lake in 1948 indicated the lake had four resorts and 90 cottages. By 1951, the lake had 95 cottages and four resorts. The Sullivan Lake Improvement Association was formed in 1952. A survey in 1956 reported three resorts and 115

MAP 1
LOCATION OF SULLIVAN LAKE

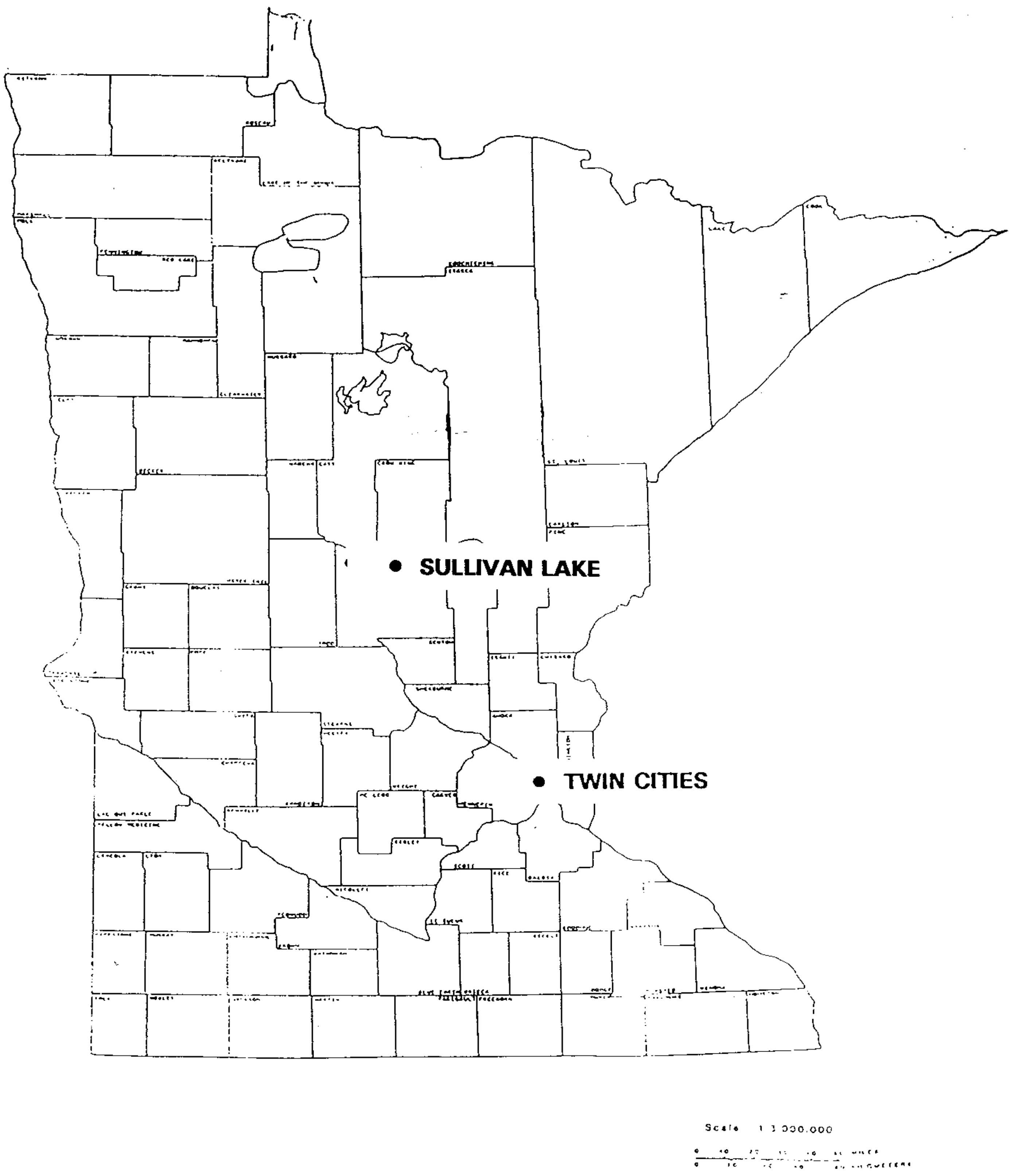


TABLE 1
LAKE MORPHOMETRIC, WATERSHED, AND FISHERY CHARACTERISTICS
SULLIVAN LAKE

STORET ID:	49-0016
MORPHOMETRIC DATA	
Area in Acres (ha):[1]	1199 (485.4)
Mean Depth in ft. (m):[2]	17.6 (5.4)
Max. Depth in ft. (m):[2]	56 (17.1)
Volume in acre feet (hm):[3]	21,956.6 (27.1)
WATERSHED CHARACTERISTICS	
Watershed Area in Acres (ha):[4]	21,855 (8,742)
Watershed Area to Lake Surface Area Ratio:	18:1
Estimated Mean Hydraulic Residence Time:	1 to 1.5 years
FISHERIES DATA	
Lake Class[5]:	27
NUMBER OF PUBLIC ACCESSES	2
LAND USE DATA	
Shoreland Zoning:	General Development
Development Trends[6] (Homes)	
1967 Survey	
Seasonal	171
Permanent	13
Total	184
1982 Survey	
Seasonal	202
Permanent	44
Total	246

Land Use Percentages:

	Forest	Open Water	Marsh	Pasture	Cultivated	Residential
Sullivan Lake	47.9	14.8	1.3	18.9	9.6	7.5
North Central Hardwood Forests	6-25	14-30		11-25	22-50	2-9
Northern Lakes Forests	50-80	15-30		0-6	<1	0-7

1 Taken from MDNR data

2 MDNR Fisheries data

3 Calculated by the MPCA

4 Calculated by the MPCA-Brainerd.

5 Lake Class has replaced the Ecological Classification - Centrarchid - for Sullivan Lake (See Schupp, D. DNR Fisheries Investigational Report 417.)

6 MDNR data

cottages. In 1958, the Shadow Wood project platted an additional 21 lots for sale in 1959. When the most recent survey was completed in 1982 the lake had a total of 243 cottages and year round homes.

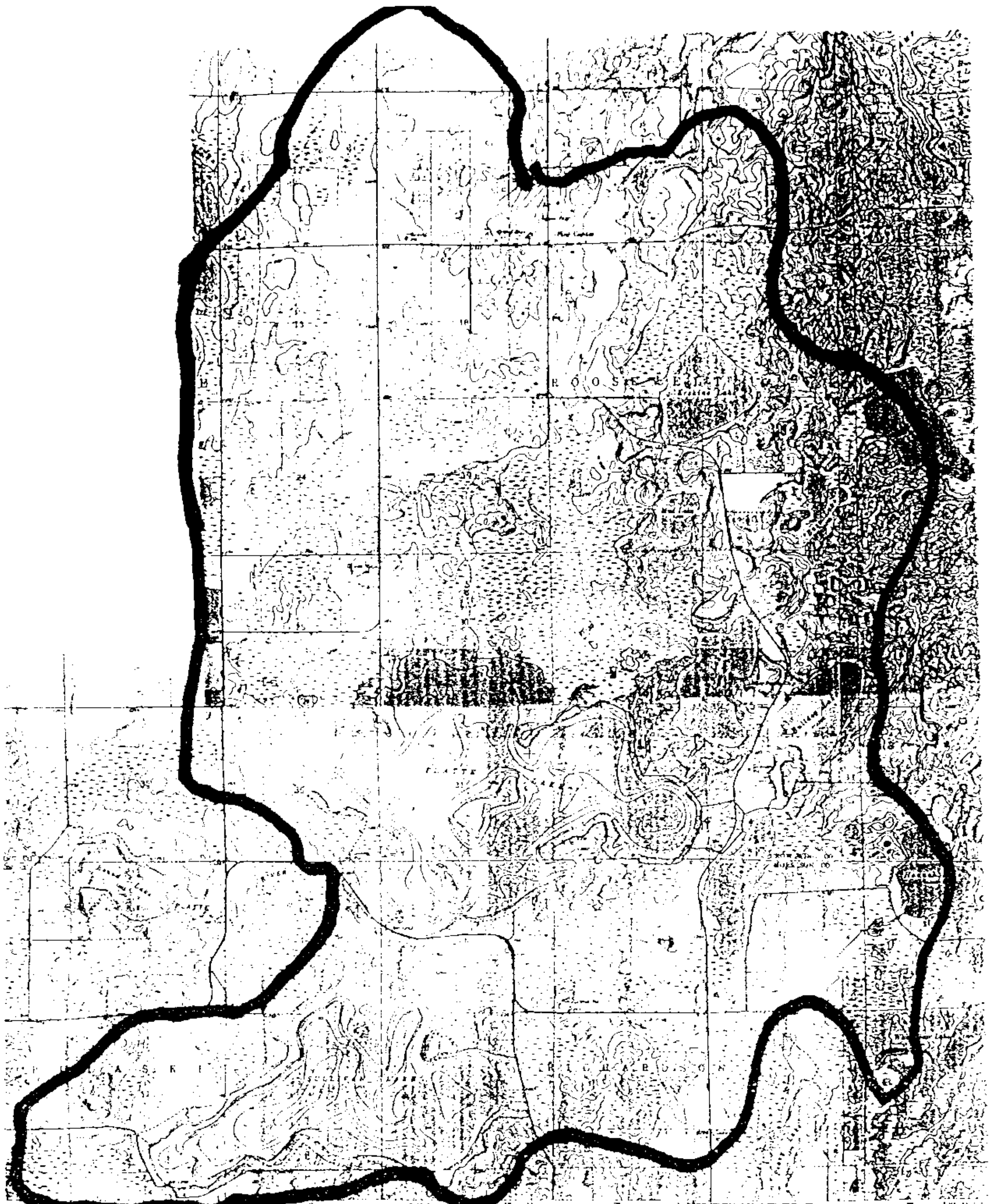
Lake Sullivan Property Owners / Septic System Survey

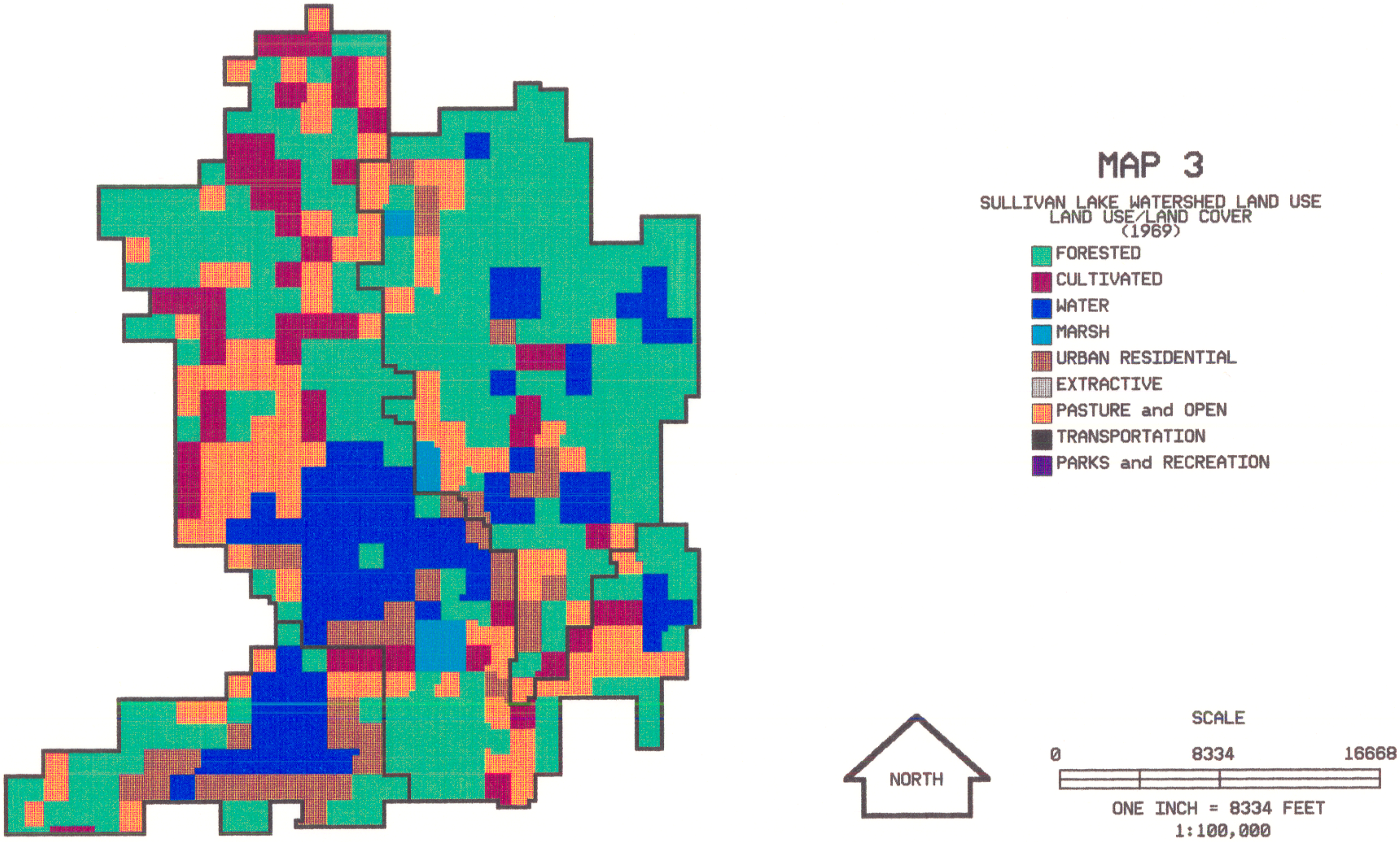
A survey conducted by the Sullivan Lake Property Owners Association in 1992 identified 50 percent of the 220 systems inspected were non-conforming. Site inspections also indicated that many of the residences tanks are in the ground water and the effluent would not be receiving adequate treatment. Additionally overflow or grey water pipes to adjacent wetlands were also identified.

Sullivan Lake Land Use and Watershed

In the Sullivan Lake Watershed (Map 2), forested and pasture/open land are the major land uses (Map 3). Forested land use accounts for 47.9 percent followed by pasture/open at 18.9 percent. The remaining land uses in the watershed are grouped together with urban or residential land uses of 7.5 percent and open water or marsh 16.1 percent. Agricultural land use consisting of cultivated land is 9.6 percent of the land use identified in the watershed.

MAP 2
SULLIVAN LAKE WATERSHED





SULLIVAN LAKE ASSESSMENT

A LAKE ASSESSMENT PROJECT
BETWEEN
THE MINNESOTA POLLUTION CONTROL AGENCY
AND
THE SULLIVAN LAKE ASSOCIATION

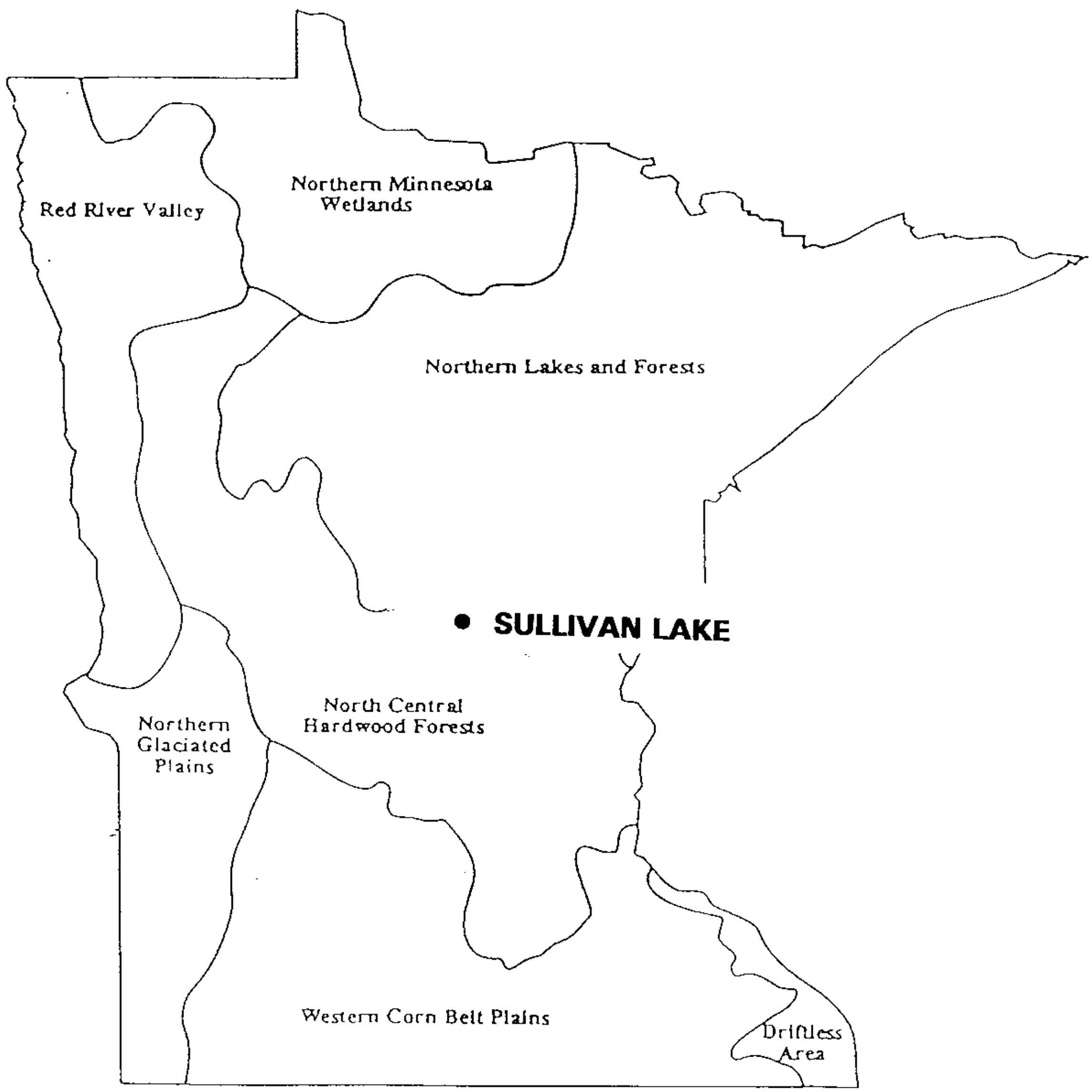
Since the land use affects water quality, it is useful to divide the state into regions where the land use and water resources are similar. For Minnesota, this results in seven regions, referred to as "ecoregions." Ecoregions are defined by the soils, land surface form, natural vegetation, and current land uses within the area. Representative minimally-impacted lakes have been sampled in each region. Data from these lakes serves as a reference for evaluataing the condition of other lakes in the ecoregion. Sullivan Lake is located in the Northern Lakes and Forest Ecoregion (Map 4) near the transition with the North Central Hardwoods Forest Ecoregion. This is reflected by that fact that the land use composition is somewhat intermediated between the "typical" composition for lakes in the North Central Hardwoods Forest ecoregion and the Northern Lakes and Forests ecoregion (Map 4).

The average annual precipitation in the Sullivan Lake Area Watershed ranges between 26 and 27 inches. The evaporation rate ranges between 34 to 36 inches (Gunard, 1985). The summer (May to September) precipitation averages about 17 inches.

Sullivan Lake Water Levels

The Minnesota Department of Natural Resources, Division of Waters has monitored Sullivan Lake levels in cooperation with volunteer readers since 1987. Also the DOW has historic levels from the

MAP 4
MINNESOTA'S ECOREGIONS and SULLIVAN LAKE



1940's, when the USGS actively monitored the lake. The water level has fluctuated 2.7 feet since 1938, from a high of 1256.24

Table 2
Sullivan Lake Recorded Water Levels
1938 - 1992

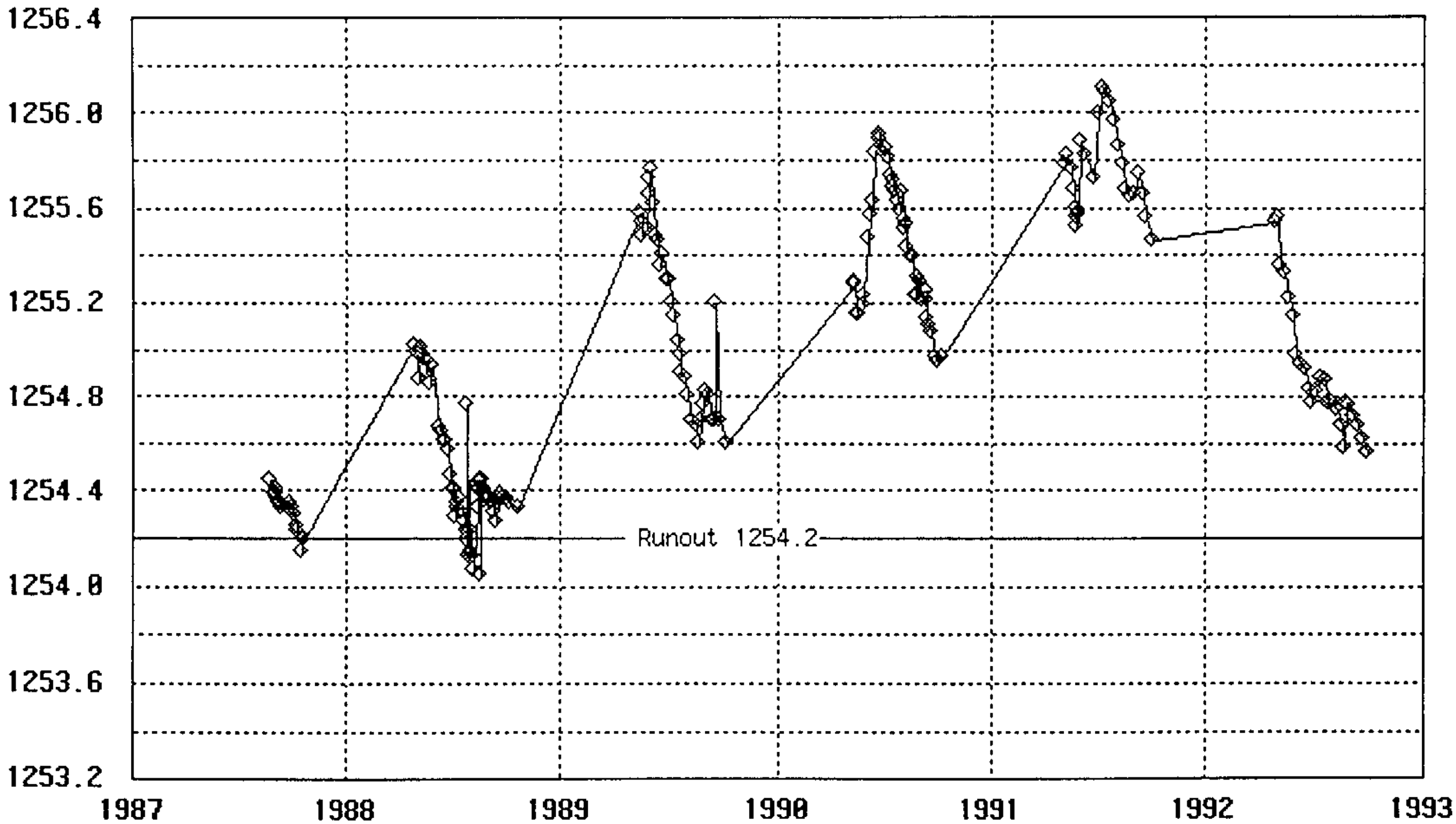
Year	Max.	(Date)	Min.	(Date)	Range	Mean
1992	1255.56	05/01/92	1254.56	09/30/92	1.00	1254.91
1991	1256.10	07/08/91	1255.46	10/02/91	0.64	1255.74
1990	1255.91	06/21/90	1254.95	09/28/90	0.96	1255.43
1989	1255.76	06/03/89	1254.60	10/09/89	1.16	1255.12
1988	1255.02	04/27/88	1254.05	08/19/88	0.97	1254.46
1987	1254.45	08/20/87	1254.15	10/14/87	0.30	1254.31
1985	1255.26	03/21/85	1255.10	01/17/85	0.16	1255.18
1983	1254.44	07/25/83	1254.44	07/25/83	0.00	1254.44
1982	1254.54	10/05/82	1254.45	09/22/82	0.09	1254.50
1981	1255.01	08/06/81	1255.01	08/06/81	0.00	1255.01
1979	1255.18	06/08/79	1255.18	06/08/79	0.00	1255.18
1972	1255.29	09/28/72	1254.64	12/14/72	0.65	1254.97
1971	1254.26	08/19/71	1254.21	09/21/71	0.05	1254.24
1970	1253.85	10/27/70	1253.82	08/14/70	0.03	1253.84
1969	1253.79	09/10/69	1253.79	09/10/69	0.00	1253.79
1967	1253.97	11/21/67	1253.97	11/21/67	0.00	1253.97
1961	1254.08	10/05/61	1254.08	10/05/61	0.00	1254.08
1955	1254.26	08/16/55	1254.20	07/15/55	0.06	1254.23
1954	1254.42	06/30/54	1254.42	06/30/54	0.00	1254.42
1950	1253.95	09/21/50	1253.95	09/21/50	0.00	1253.95
1949	1254.34	04/07/49	1253.80	10/25/49	0.54	1254.08
1946	1255.38	07/06/46	1253.73	05/18/46	1.65	1254.41
1945	1254.92	09/22/45	1253.96	06/02/45	0.96	1254.35
1944	1255.85	06/06/44	1253.56	04/07/44	2.29	1254.58
1943	1256.24	06/26/43	1253.76	12/28/43	2.48	1255.07
1942	1255.12	10/08/42	1253.84	04/23/42	1.28	1254.65
1941	1256.18	06/21/41	1254.72	11/28/41	1.46	1255.45
1940	1255.22	05/23/40	1254.13	10/28/40	1.09	1254.29
1939	1255.56	04/08/39	1254.22	11/14/39	1.42	1254.79
1938	1255.90	05/10/38	1254.22	02/12/38	1.68	1255.00

on June 26, 1943 to a low of 1253.56 on April 7, 1944. The lake outlets into the Platte River through a concrete dam at elevation 1254.2 (Table 2 and Figure 1). Data from the recent time period 1987 - 1992 indicates water has been flowing out of the lake with the execption of portions of 1987 and 1988, likely reflective of drought conditions during that time (Figure 1).

FIGURE 1

Sullivan Lake Morrison County

RECORDED WATER LEVELS



SULLIVAN LAKE FISHERY CHARACTERISTICS

Fish Population Status

Classification of Minnesota's lakes is based on a variety of physical and chemical parameters. Fish community comparisons and fish management decisions are facilitated by the classification system. Sullivan Lake belongs to Lake Class 27 which is characterized by medium sized lakes with extensive littoral area and maximum depths of 40 to 60 feet.

The most recent summer netting on Sullivan Lake was completed in July 1990. In addition, annual spring ice-out nettings have also been conducted since 1990. Gamefish populations consist of walleye, northern pike, largemouth bass, black crappie, bluegill, pumpkinseed, rock bass and yellow perch. Other species present include bowfin, northern cisco (tullibee), white sucker, yellow bullhead and brown bullhead.

Summer gillnet catches and ice-out surveys indicate northern pike are found in normal abundance for Lake Class 27, however, the abundance of larger pike (24+ inches) appears low. Individuals up to 35 inches long have been sampled recently indicating there is potential to provide large pike. Experimental regulations have been in place on Sullivan Lake since 1991 in an effort to increase the abundance of larger northern pike and stabilize the fish communities in both lakes.

Walleye numbers also appear normal for lakes of Sullivan's classification. Walleye fingerlings have been stocked on an annual basis since 1981, however, the walleye net catches have not changed. During ice-out surveys large numbers of walleyes were observed utilizing ice-out shoal areas for spawning. The success of walleye spawning and the contribution of natural reproduction is unknown. A fall electrofishing survey will be conducted in 1993 to evaluate the success of natural reproduction. Additional electrofishing surveys will be performed on a regular basis to monitor walleye recruitment.

Largemouth bass are difficult to capture during summer netting operations. Ice-out netting and fall electrofishing information will be used to better evaluate the largemouth bass population. Recent information suggests a healthy bass population resides in the lake.

Sullivan Lake is noted for producing bluegills and black crappies of quality size. Spring and summer netting surveys show that large bluegills (9 to 10 inches) and black crappies (12 to 13 inches) are present. The bluegill population is normal for Lake Class 27 in terms of abundance while the black crappie population is high.

Yellow perch and northern cisco are found in low numbers for Lake Class 27 but both species are still considered important forage species.

Fisheries Management

An experimental regulation was placed on Sullivan Lake in 1991 with the intent to increase the abundance of larger northern pike and decrease the numbers of small pike. The limit for northern pike was increased to six, however, fish between 24 and 30 inches could not be kept and only one fish over 30 inches could be kept. With fewer but larger northern pike, the abundance of forage species such as perch and tullibees may increase, additionally largemouth bass and walleye numbers could increase due to reduced competition from pike. A healthy and balanced fish community is the desired result.

Annual walleye fingerling stocking has not been successful in increasing walleye numbers. Natural reproduction will be monitored and future walleye stocking will be dependent upon evaluations of natural contributions. The use of stocking gaps may be employed to aid in the assessment of natural reproduction.

Habitat protection within the lake and along its shoreline is vitally important in maintaining healthy fish populations. Land use practices within the lake's watershed can also significantly impact water quality and fish populations. Habitat protection and watershed management have warranted increased emphasis by fisheries managers.

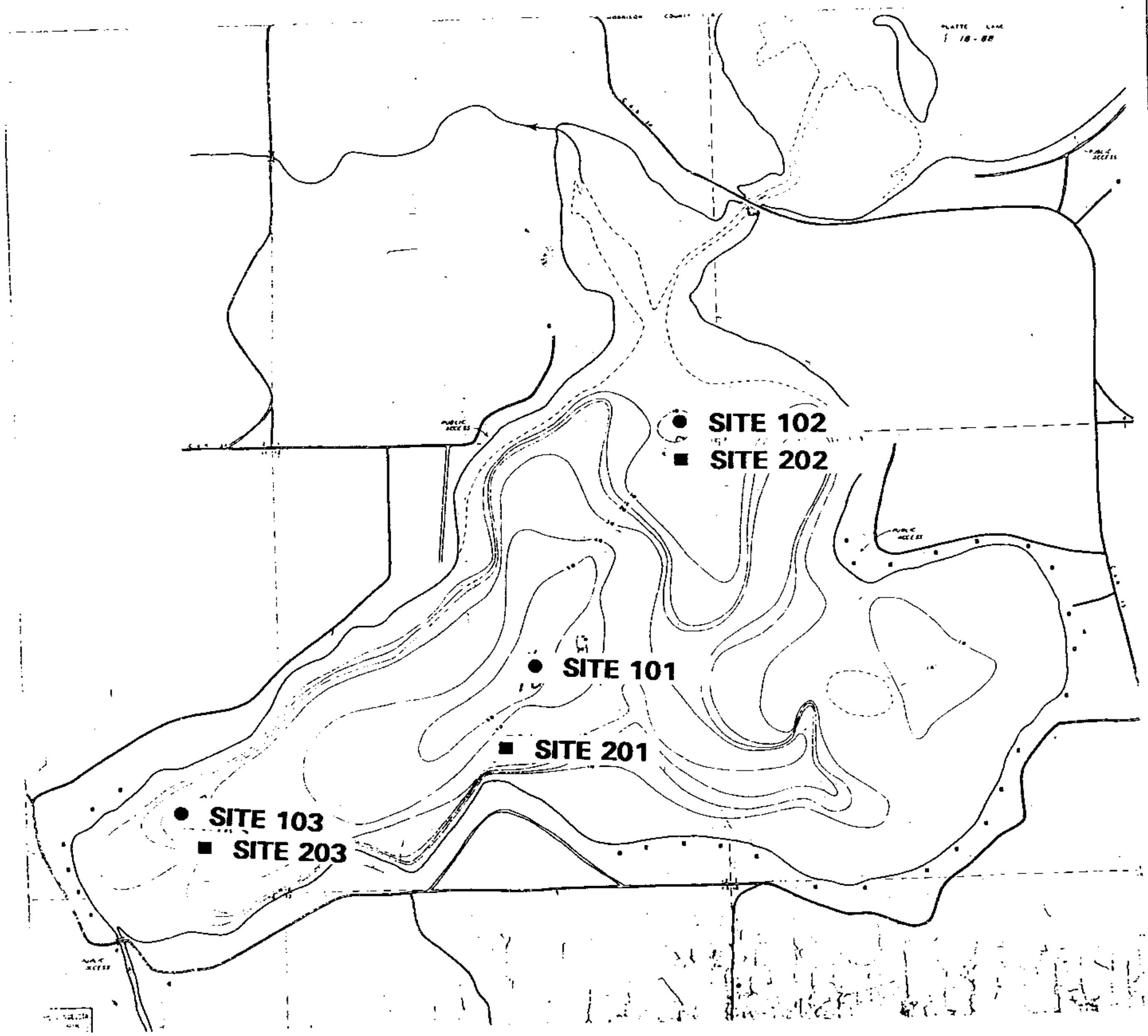
Summer assessment nettings and fall electrofishing surveys will be conducted in 1993 and on a four year basis thereafter. Spring ice-out nettings will be performed on an annual basis until the year 2000 at which time a decision will be made regarding the experimental northern pike regulations. The regulations could be given special regulation status (made permanent), changed, or eliminated.

WATER QUALITY RESULTS AND DISCUSSION

Water quality data was collected on May 20, June 16, July 20, August 19, and September 22, 1992 on Sullivan Lake, at three sites in the lake basin (Map 5). The lake water samples were collected using an integrated sampler, which is a 2 meter (6.5 feet) polyvinyl chloride (PVC) tube with an inside diameter of 1.25 inches. The near bottom water samples were collected using a two-liter Van Dorn sampler.

The samples were analyzed by the Minnesota Department of Health laboratories using U.S. Environmental Protection Agency (USEPA) procedures. All water sampling methods are described in the MPCA Quality Control Manual. Samples were analyzed for nutrients,

MAP 5
SULLIVAN LAKE'S SAMPLING SITES



color, solids, pH, conductivity, alkalinity, turbidity, and chlorophyll a (Appendix B). Temperature and dissolved oxygen profiles and Secchi disk transparency measurements were also taken.

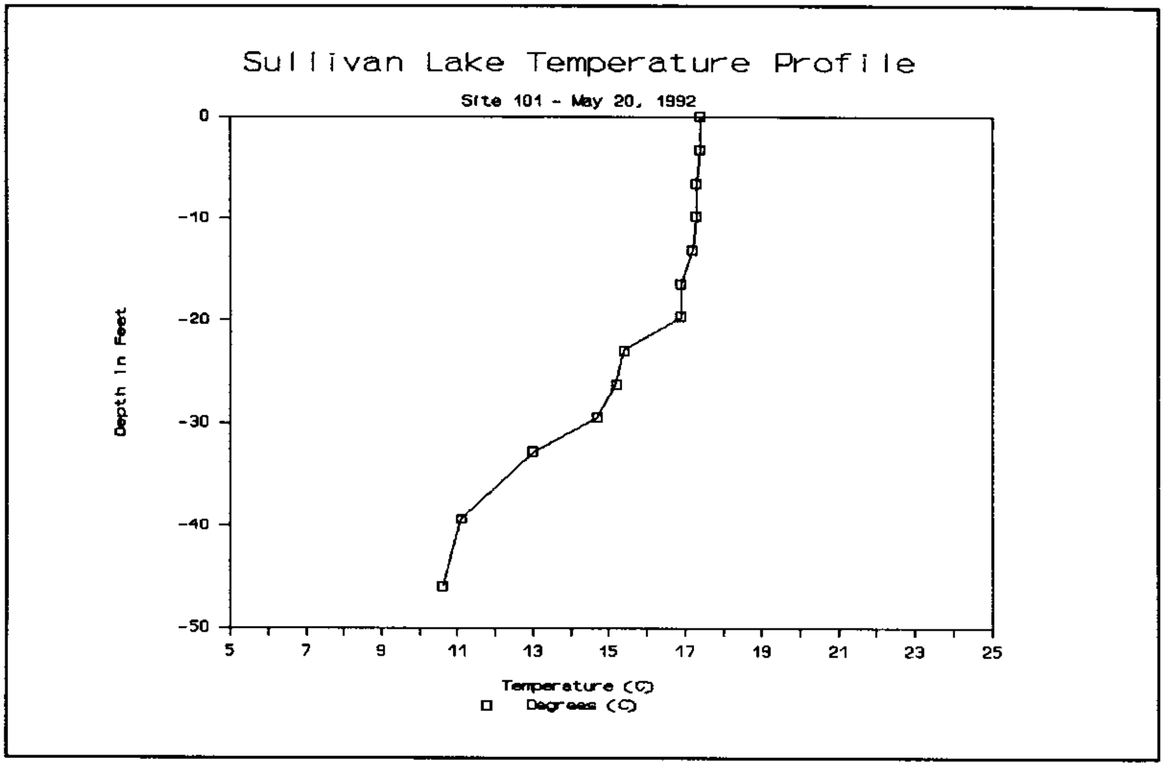
In addition, the Citizens Lake Monitoring Program (CLMP) Secchi disk measurements, when available, were used for comparison. All data was entered in STORET, the USEPA national water quality data bank. The water quality averages used are for the summer of 1992 (June - September).

1992 Lake Conditions

Dissolved oxygen and temperature profiles were taken at site 101, the site of maximum depth, in Sullivan Lake. The temperature profile for Sulllivan Lake showed the lake was stratified from May through early September (Figure 2). The thermocline (zone of greatest change in temperature over a small change in depth) formed at about twenty to twenty-two feet. By the September sample date the thermocline had disappreared indicating that fall turnover and mixing had occurred.

In Sullivan Lake the maximum epilimnitic temperature recorded was 21.5 degrees Celsius and was observed on the July 20, 1992 sample date. The minimum epilimenitic temperature was 15.0 degrees Celsius observed on September 22, 1992. The minimum hypolimnitic temperature was 12.0 degrees Celsius observed on August 19, 1992.

FIGURE 2
DISSOLVED OXYGEN AND TEMPERATURE PROFILES FOR SULLIVAN LAKE



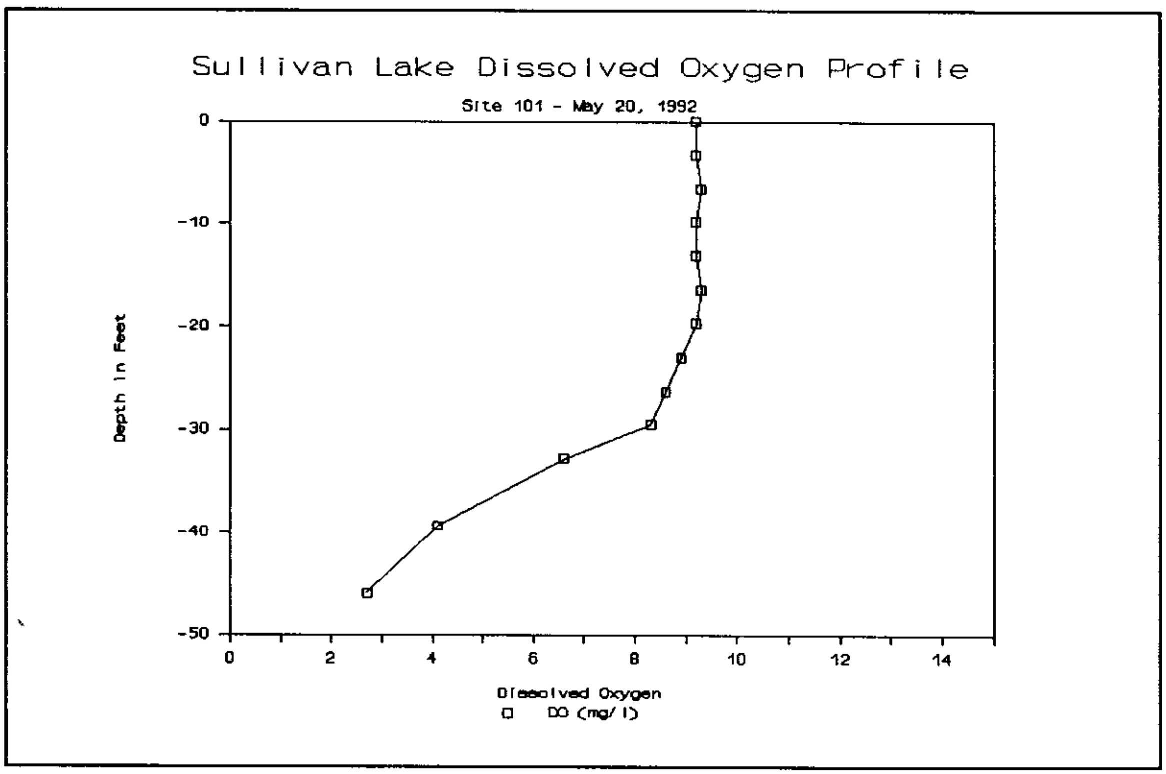
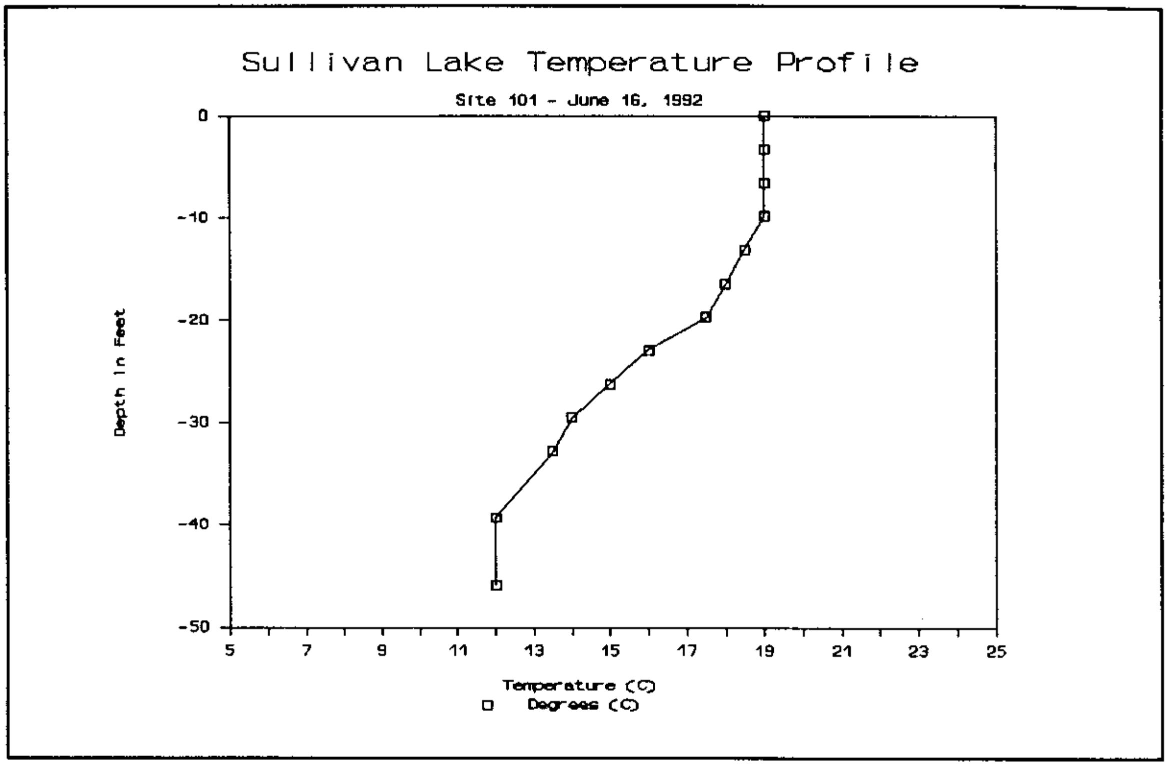
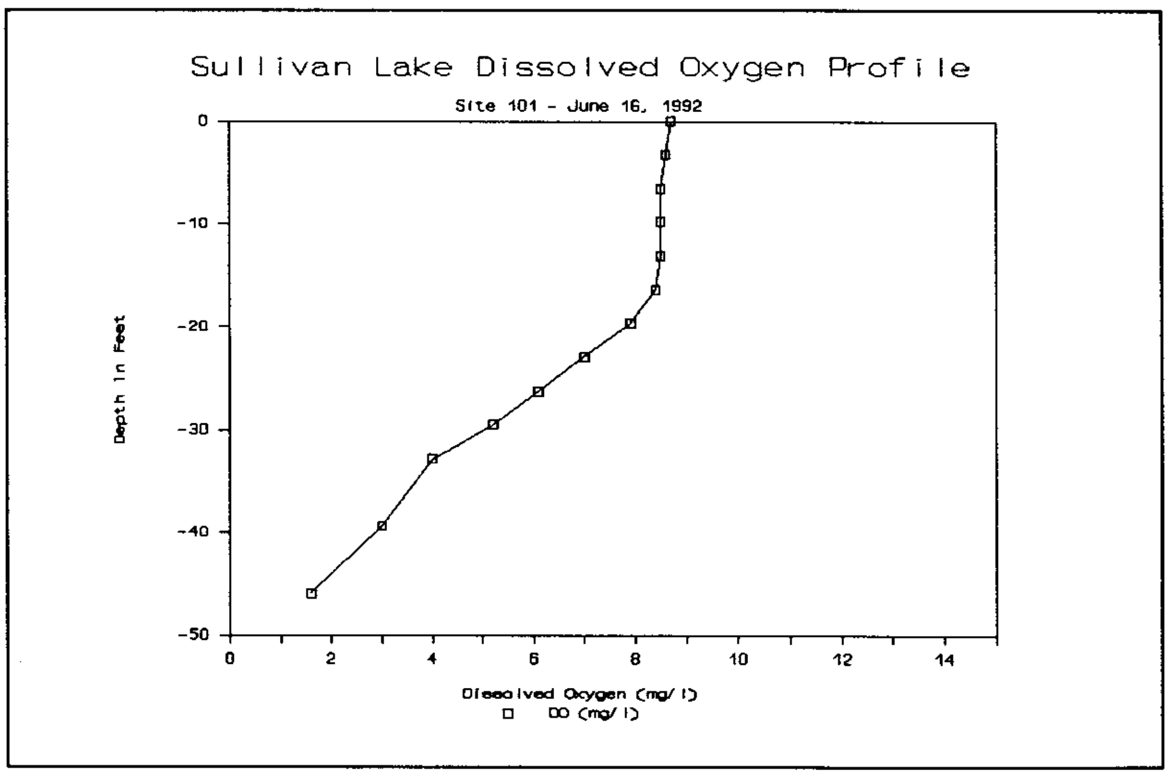


FIGURE 2 Continued





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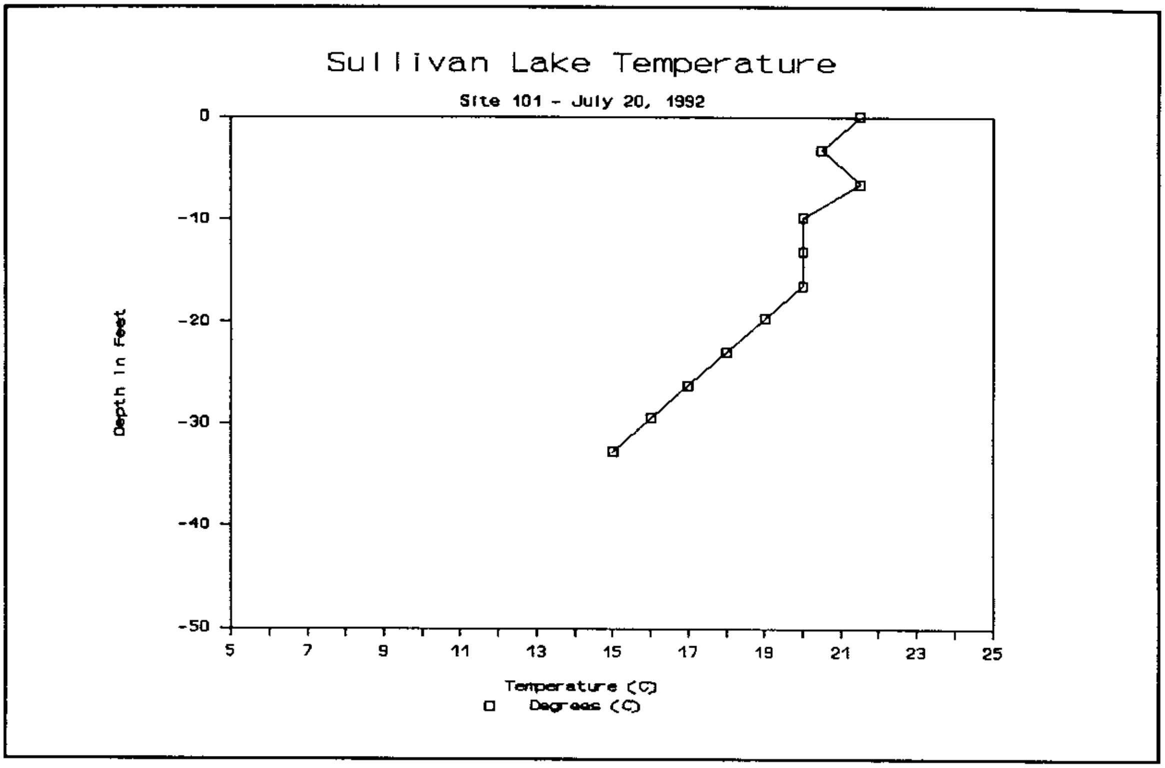

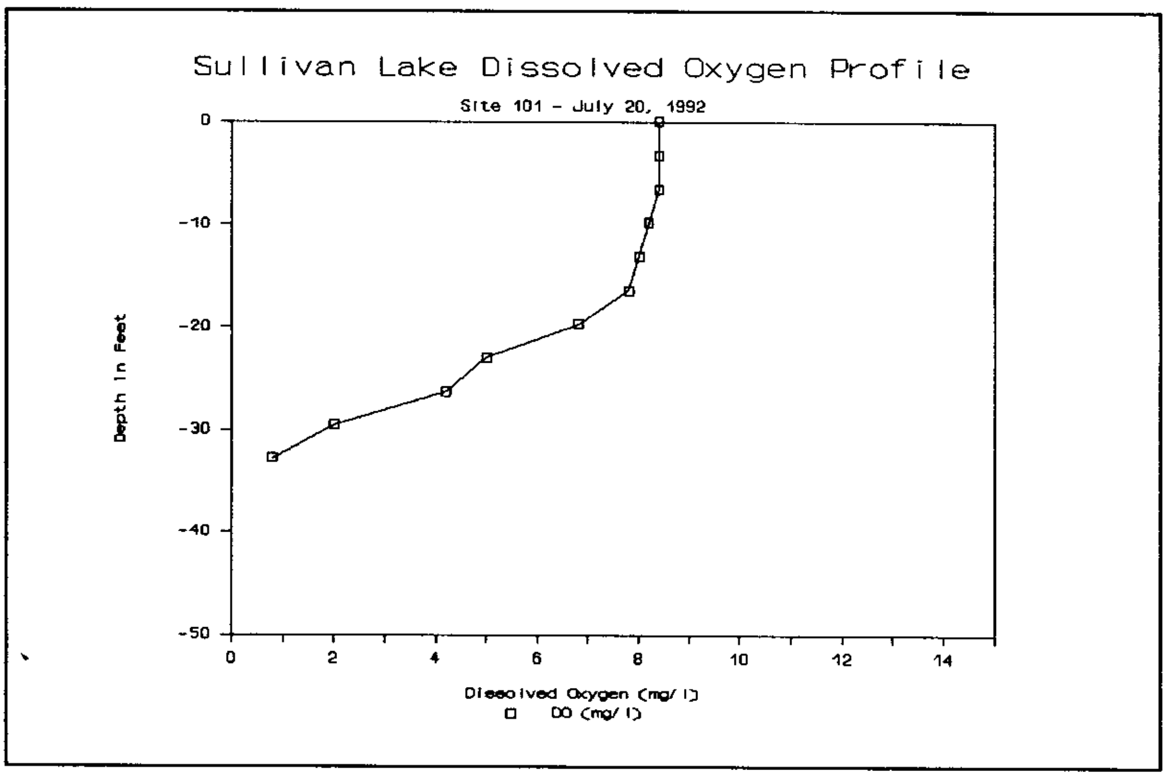

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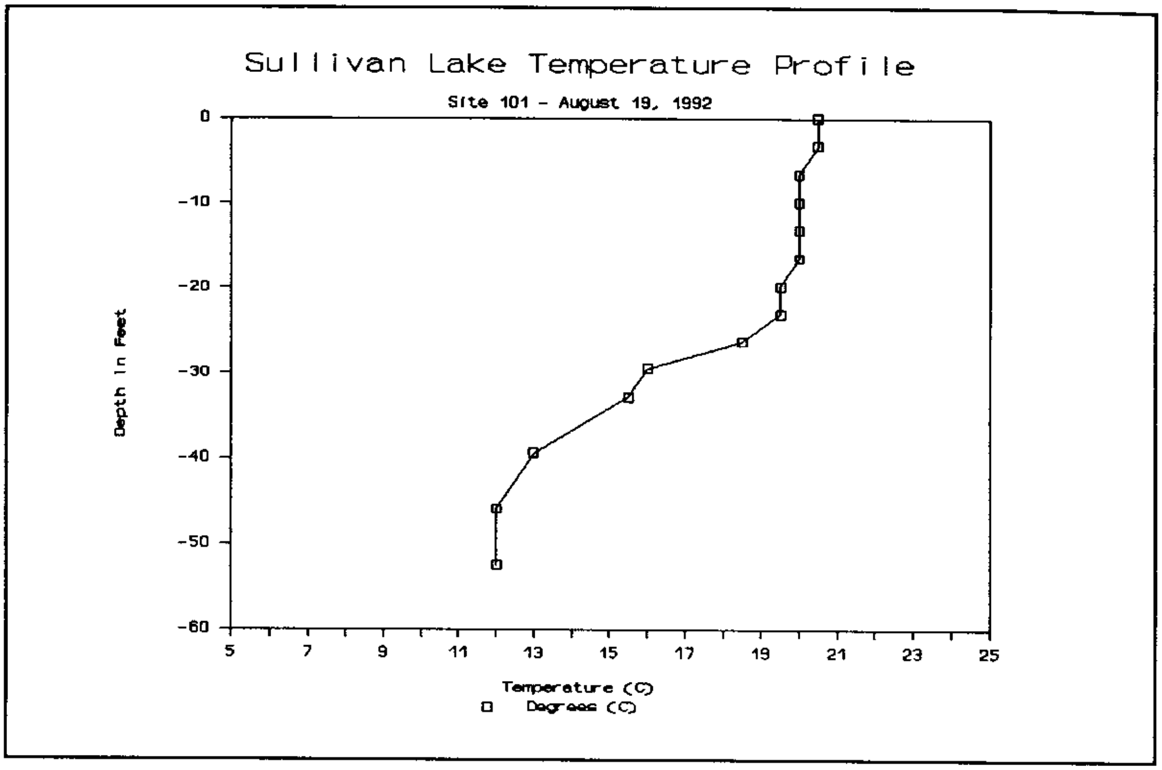

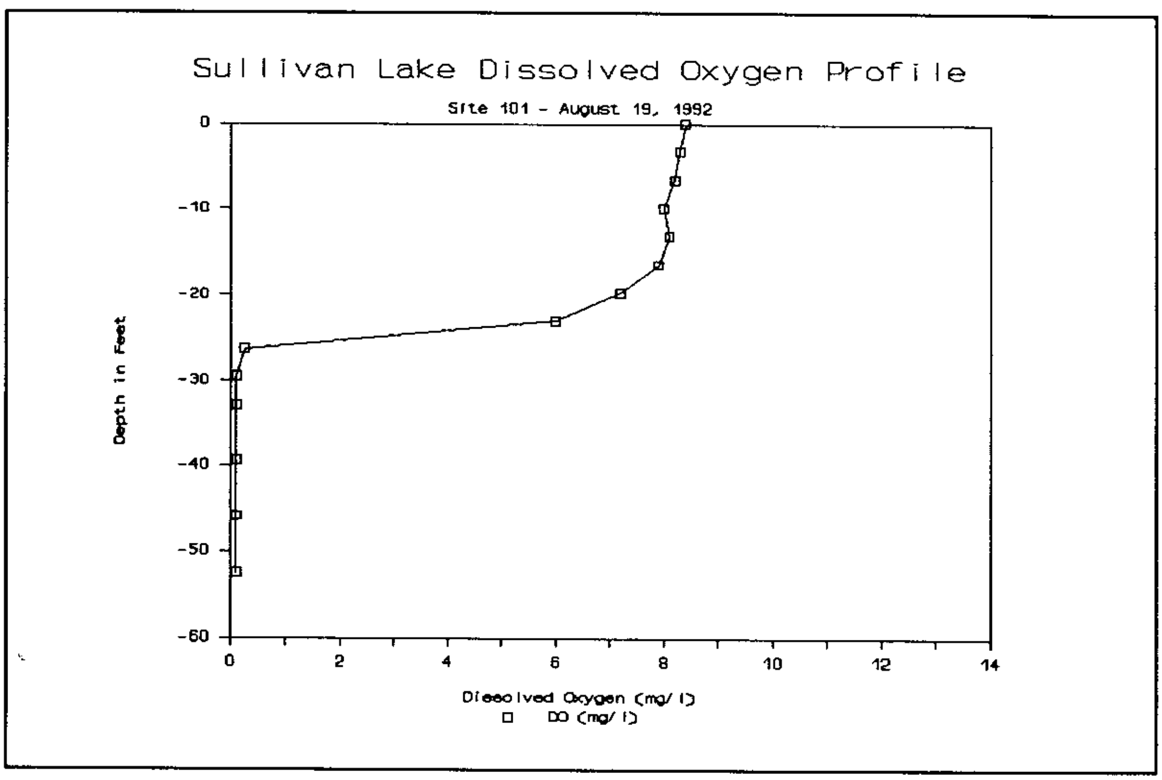

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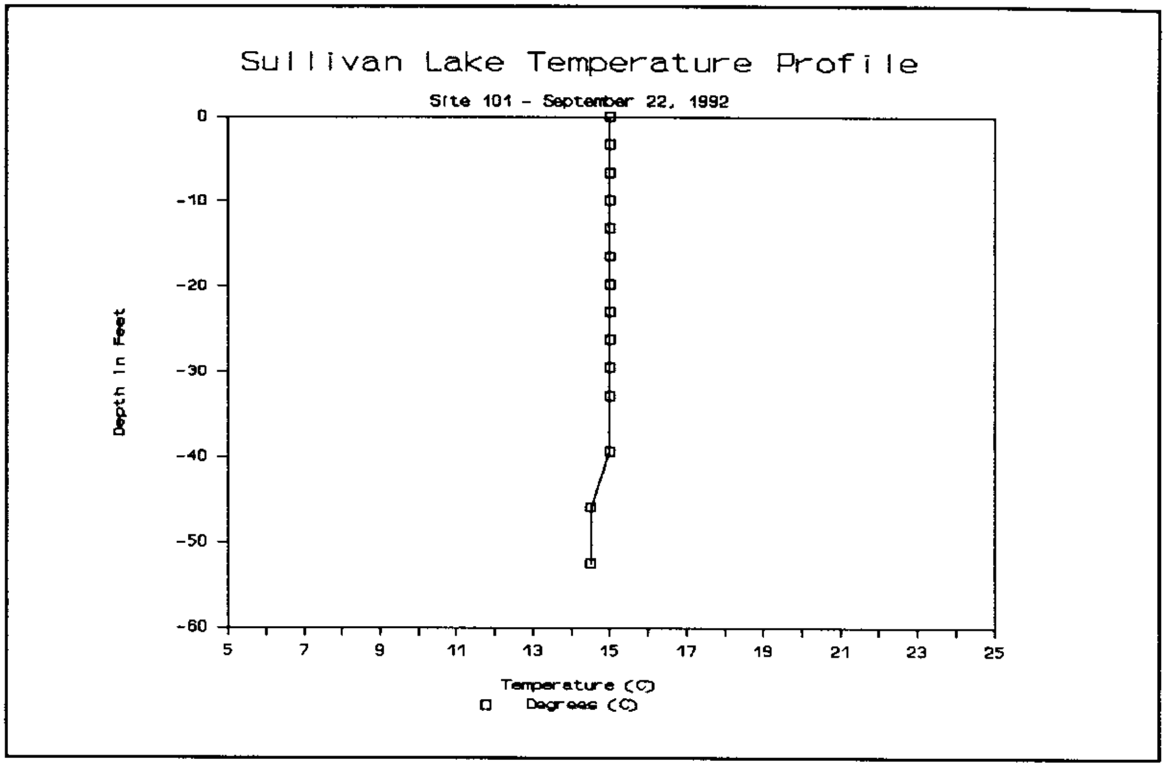

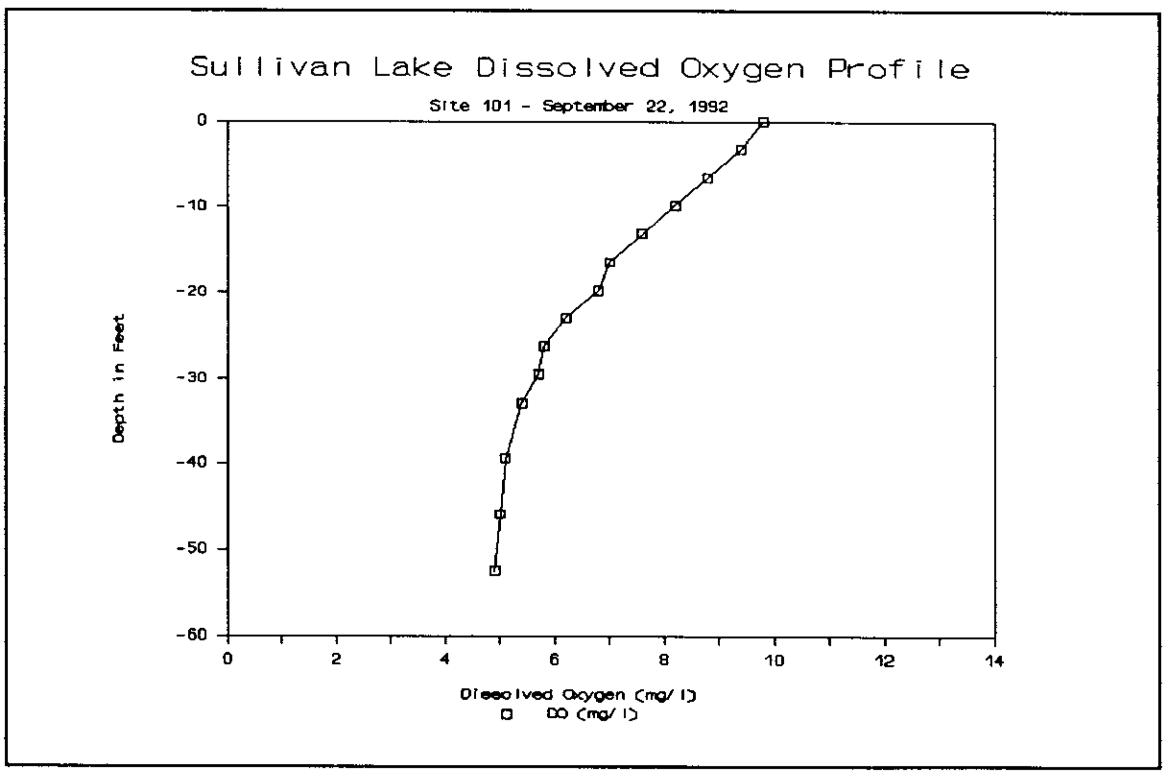

The dissolved oxygen concentrations in Sullivan Lake remained above 5 mg/l in the epilimnion (upper warmer layer) on all the sample dates. However, the dissolved oxygen dropped below 5 mg/l in the hypolimnion (lower, cooler layer) on all the sample dates and approached 0 mg/l on the July and August sample dates indicating the lake was nearing an anoxic condition (devoid of oxygen)(Figure 2). By the September sample date the lake had turned over and the oxygen level was greater than five throughout the water column. An oxygen concentration below 5 mg/l is to low to support game fish.

A reduction of oxygen in the hypolimnion indicates that the sediments of the lake are placing a demand on the dissolved oxygen in the water. The oxygen is depleted as it is used to decompose organic matter in the sediments. The effects are most pronounced during periods of stratification when there is little or no oxygen produced in the hypolimnion. This is a common occurrence in lakes which remain stratified throughout the summer.

The epilimnetic total phosphorus (TP) concentrations (an important nutrient for plant growth) in Sullivan Lake ranged from 16-38 ug/l (micrograms per liter or parts per billion) during the sampling season with a mean (average) concentration of 23.8 ug/l. The mean concentrations for Sullivan Lake is within the range observed in minimally impacted (reference) lakes in the Northern Lakes and Forest ecoregion (Table 3) which range from 14 to 27 ug/l.

Hypolimnetic phosphorus concentrations were measured in Sullivan Lake during the sampling season. If the hypolimnion becomes anoxic, phosphorus may be released into the water from the bottom sediments. While the lake is stratified, phosphorus released from the sediments generally remains in the hypolimnion. However, when the stratification break down (due to cooling of the water and wind mixing) the phosphorus will be mixed into the water column and available for plant use. The highest hypolimnetic phosphorus concentration measured in Sullivan Lake was 185 ug/L on August 19, 1992. Concentrations declined to 40 ug/L on the September sampling date which coincided with fall turnover.

The total nitrogen (TN) concentration, which consists of total Kjeldahl nitrogen plus nitrate-N, averaged 0.541 mg/l in Sullivan Lake over the summer of 1992. This concentration is comparable to the range typically observed in the ecoregion. The nitrite and nitrate-N concentrations averaged .011 mg/l in Sullivan Lake, which is fairly comparable to the range of concentrations for reference lakes in this ecoregion (Table 3).

TABLE 3
AVERAGE SUMMER WATER QUALITY INDICATORS
Based on epilimnetic data from 1992
Sullivan Lake

Parameter	Sullivan Lake	Typical Range for Ecoregion[7]
Total Phosphorus (ug/l)	23.8	14-27
Chlorophyll a (ug/l) mean	8.06	<10
Chlorophyll a (ug/l) maximum	16.7	<15
Secchi disk (feet)[8]	8.1	8-15
Total Kjeldahl Nitrogen (mg/l)	.530	<0.75
Nitrite + Nitrate-N (mg/l)	.011	<0.01
Alkalinity (mg/l)	83.0	40-140
Color (Pt-Co Units)	22.5	10-35
pH (SU)	8.2	7.2-8.3
Chloride (mg/l)	1.95	<2
Total Suspended Solids (mg/l)	2.85	<2
Total Suspended Inorganic Solids (mg/l)	0.90	<2
Turbidity	1.474	<2
Conductivity (umho/cm)	150.0	50-250
TN:TP Ratio	22.7:1	25:1-35:1

The ratio of total nitrogen (TN) to total phosphorus (TP) can give an indication to which nutrient is limiting the production of algae in a lake. The ratio for Sullivan Lake is 22.7:1. This number suggests that phosphorus is the least abundant nutrient in the lake and therefore will be the limiting factor for biological productivity (algae production) in the lake. The TN:TP ratio for the lake is slightly lower than the range found in minimally impacted lakes in the Northern Lakes and Forests Ecoregion.

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[7] 25 - 75th percentile of representative-minimally impacted (reference) lakes in the Northern Lakes and Forests Ecoregion (Heiskary and Wilson, 1988).

[8] Includes CLMP data.

Chlorophyll a concentrations provide an estimate of the amount of algal production in a lake. During the summer of 1992, chlorophyll a concentrations averaged 8.06 ug/l for Sullivan Lake (Figure 3). The maximum concentration for Sullivan Lake was 16.7 ug/l. Chlorophyll a concentrations from 10-20 ug/l would be perceived as a mild algal bloom. Concentrations greater than 30 ug/l would be perceived as a severe nuisance (Heiskary and Walker, 1988). In Sullivan Lake the concentrations of chlorophyll a generally increased over the summer (which is common in Minnesota lakes) from a mean of 5.44 ug/l for the three sample sites in June to a mean of 14.83 ug/l for the three sites in September. However, the concentration varied widely from one sample period to another. The average and peak concentrations of chlorophyll a for Sullivan Lake are within the range of chlorophyll a concentrations for minimally impacted lakes in the ecoregion.

The composition of the phytoplankton (algae) population of Sullivan Lake is presented in Figure 4. The information is presented in terms of algal type. Samples were collected at Site 101. The June 16, 1992 sample was comprised of Cyanophyta (blue-green) algae (35 percent) followed by Chlorophyta (greens)(25 percent) and Chrysophyta algae (Bacillariophycease)(25 percent). Pyrrhophyta (Ceratium) followed at 15 percent.

FIGURE 3

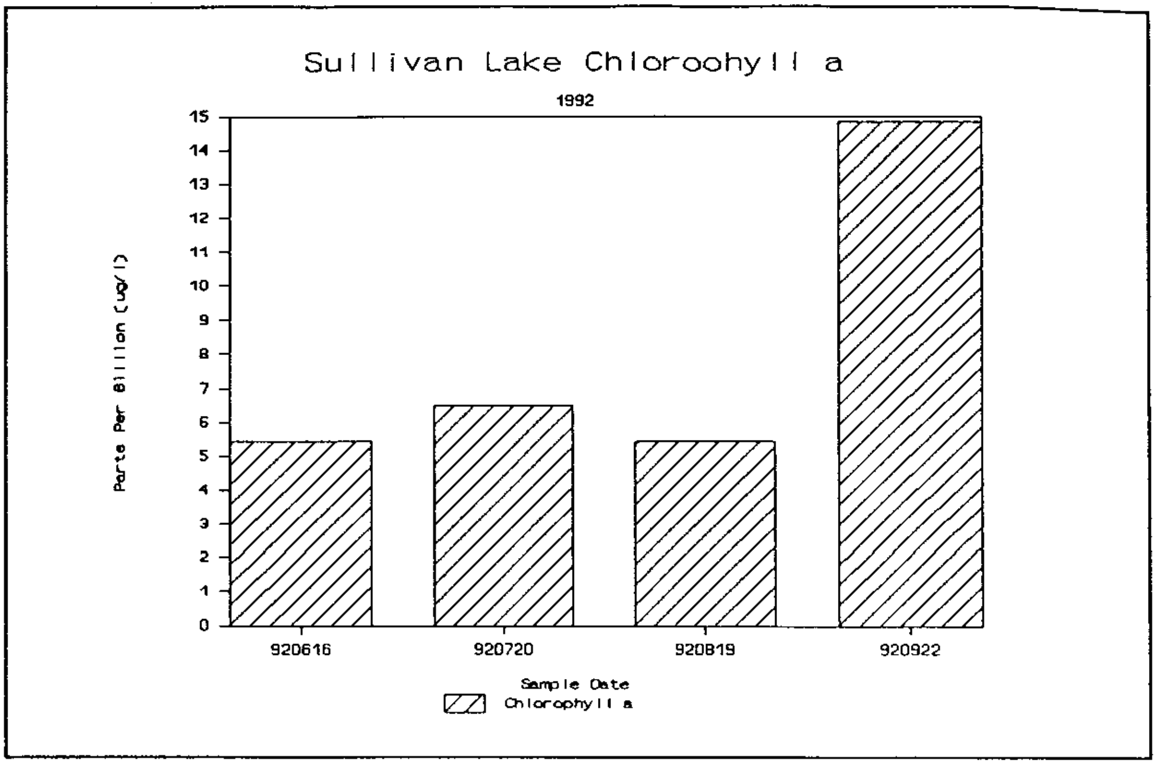
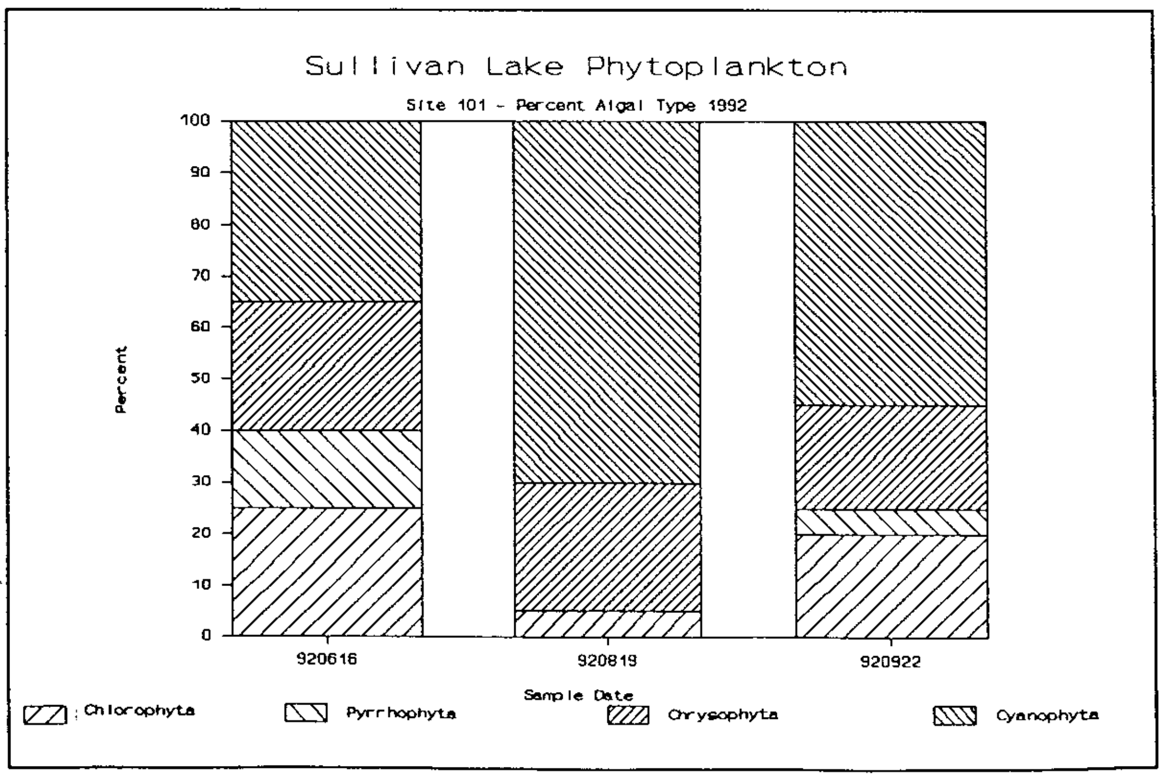


FIGURE 4



The August 19, 1992 sample, was dominated by Cyanophyta (blue-green) algae (70 percent) followed by Chrysophyta (25 percent). The remaining 5 percent consisted of Chlorophyta (green) algae.

Blue-greens remained dominant through the September sampling. However, green algae (20 percent) and diatoms (20 percent were also prominent. The high presence or dominance by blue-green algae in late summer is fairly common in Minnesota lakes.

Secchi disk transparency is generally a function of the amount of algae in the water. However, suspended sediments or color due to dissolved organics in the water may also reduce the transparency. For Sullivan Lake the color averaged 22.5 Platinum-Cobalt (Pt-Co) Units, which is fairly typical for the ecoregion and indicates moderately clear water, relatively free from sediments or bog staining. Readings greater than 20 Pt-Co units could be observed as a mild tea-color stain to the long term lake observer.

Total suspended solids (TSS) values averaged 2.85 mg/l for Sullivan Lake, which is in the range typically found in ecoregion lakes. At these levels, the total suspended solids should not appreciably limit the Secchi transparency of the lakes.

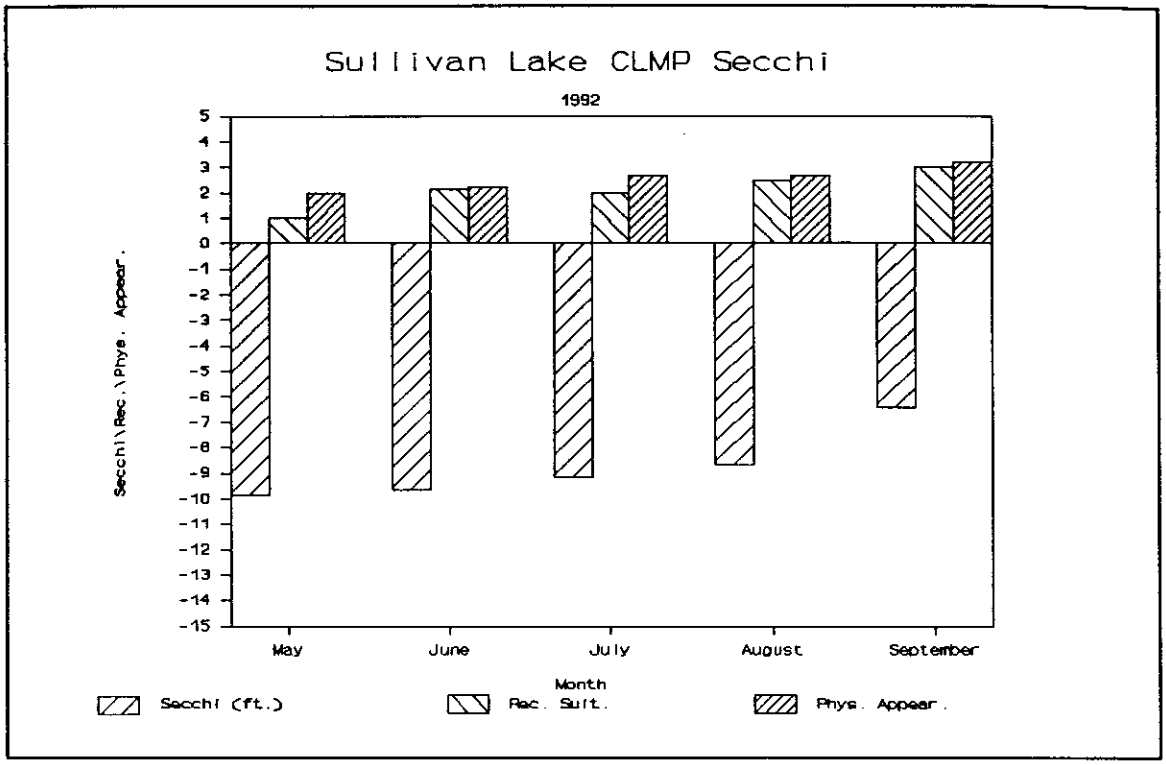
Secchi disk measurements were also taken during the summer of 1992 through the Minnesota Pollution Control Agency's Citizens Lake Monitoring Program. The summer mean Secchi transparency for Sullivan Lake was 8.7 feet (Table 4). Overall the transparency declined during the summer in Sullivan Lake (which is common in Minnesota's lakes). The Secchi transparency values are typical for minimally impacted lakes in the North Central Hardwood Forest Ecoregion.

TABLE 4
TRANSPARENCY, RECREATIONAL SUITABILITY, AND PHYSICAL APPEARANCE FOR SULLIVAN LAKE
(1992)

Site	Month	Secchi (Mean-feet)	Recreational Suitability (Mean Class)	Physical Appearance (Mean Class)
Site 201 and 203	May	9.9	1	2
	June	9.7	2	2
	July	9.2	2	3
	Aug.	8.7	3	3
	Sept.	6.4	3	3

Along with the CLMP transparency measurements, subjective measures of "physical appearance" and "recreational suitability" were made by the CLMP observer in 1992 (Appendix B). Physical appearance ratings range from "crystal clear" (Class 1) ... to "dense algal blooms, odors, etc." (Class 5) (Heiskary and Wilson, 1988). The recreation suitability ratings range from "beautiful" (Class 1) to "No recreational use possible" (Class 5). These subjective measurements provide a basis for evaluating lake conditions relative to Secchi transparency or chlorophyll a measurements. Transparency, physical appearance, and recreational suitability for Sullivan Lake in 1992 is summarized in Table 4 and Figure 5 from the CLMP records in Appendix B. The

FIGURE 5



Sullivan Lake CLMP Secchi
1992
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
Secchi\Rec.\Phys. Appear.
May
June
July
August
September
Month
Secchi (ft.)
Rec. Suit.
Phys. Appear.

data reveals that the seasonal declines in transparency for the Lake, were reflected in the user's perception of the physical condition and recreational suitability of the lake.

In Sullivan Lake the CLMP transparency averaged 8.5 feet from June through September. The recreational suitability ratings ranged from Class 1 (Beautiful) to Class 3 (swimming and aesthetic enjoyment slightly impaired) (Table 4 and Figure 5). Physical appearance ratings also ranged from Class 2 (some algae present) to Class 3 (Definite algal presence) during the summer (Table 4 and Figure 5).

The other water quality parameters such as turbidity and alkalinity, in Sullivan Lake are well within the typical range for lakes in the Northern Lakes and Forests Ecoregion (Table 3). The alkalinity measures indicate that Sullivan Lake is a well buffered hard-water lake and would not be considered sensitive to acid deposition.

<u>Trophic Status Index</u>

One method to evaluate the trophic status of a lake and to interpret the relationship between total phosphorus, chlorophyll <u>a</u>, and Secchi disk readings is Carlson's Trophic State Index (TSI), (Carlson 1977). This index was developed from the interrelationship of summer Secchi disk transparency and the concentrations of surface water chlorophyll a and total phosphorus. TSI values are calculated as follows:

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

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

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

TP and chlorophyll a are in ug/l and Secchi disk transparency is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of 10 units represents a doubling of algal biomass.

The average values for trophic variables in Sullivan Lake and the respective TSI's are presented in Table 5 and Figure 6 Based on these values, Sullivan Lake would be considered mesotrophic. The mean TSI of 48.8 for Sullivan Lake would rank the lake at the 75th percentile relative to 970 other lakes in the Northern Lakes and Forests Ecoregion. In other words, the lakes's TSI value is lower (less eutrophic) than 25 percent of the lakes evaluated in the region. The individual TSI measures, in general, agree quite well for the lake and suggest that the measurement of Secchi transparency can provide a good reflection of the trophic status of these lakes.

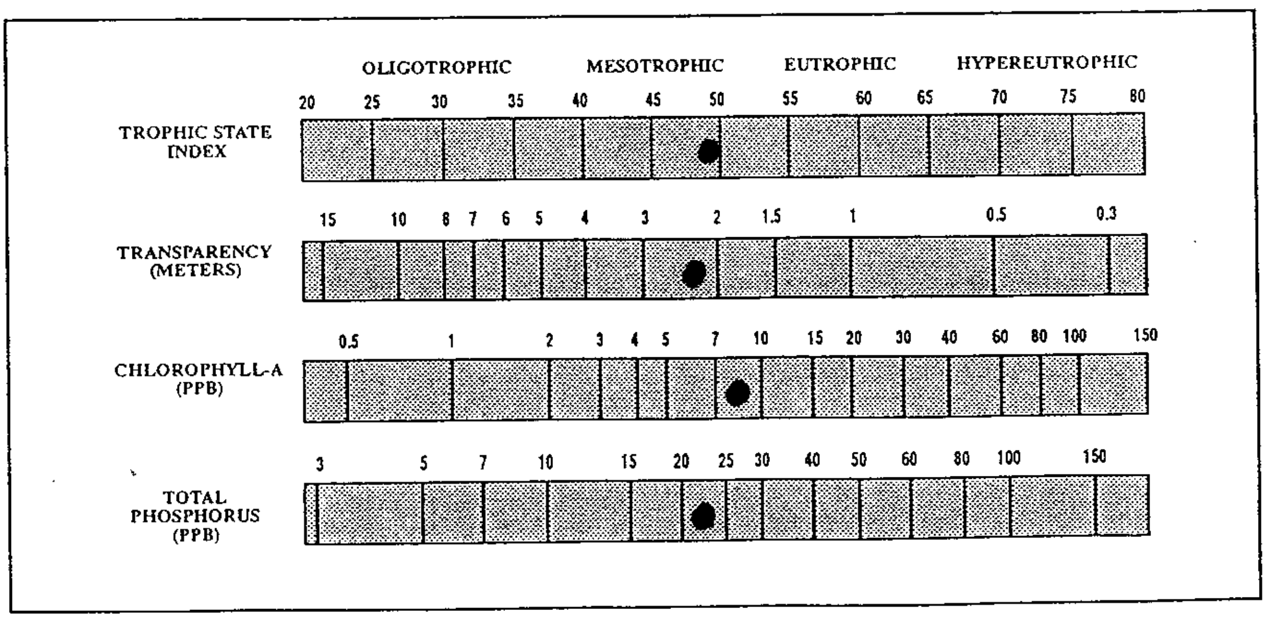
Another means for comparing these variables is graphically on scatterplots. Values for Sullivan Lake are noted in Figure 7.

FIGURE 6
SULLIVAN LAKE
CARLSON'S TROPHIC STATUS INDEX VALUES FOR SULLIVAN LAKE

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

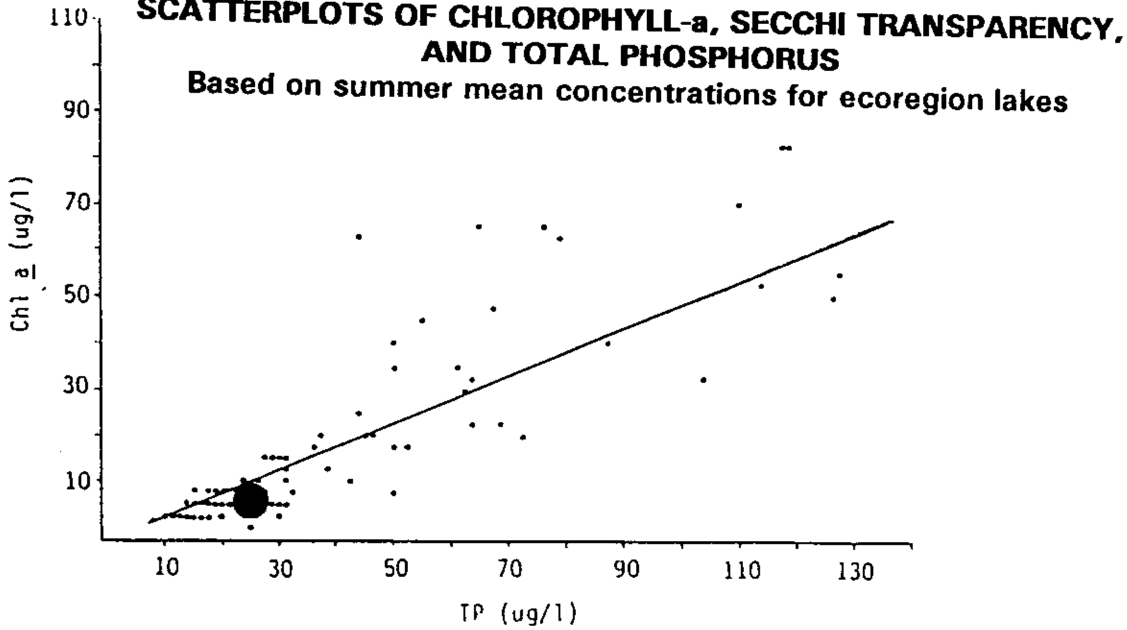
R.E. Carlson

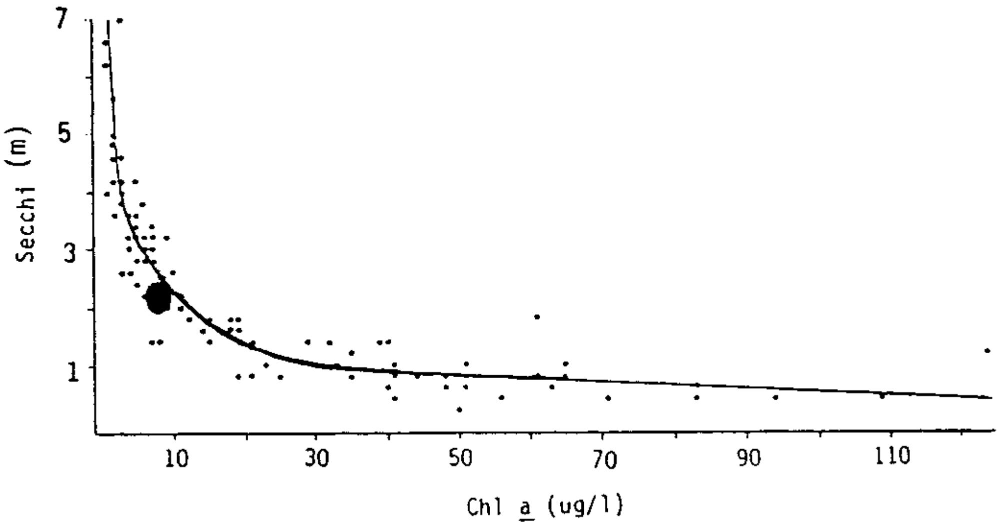
TSI < 30	Classical oligotrophy: Clear water, oxygen throughout the year in hypolimnion, salmonid fisheries in deep lakes.
TSI 30 - 40	Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.
TSI 40 - 50	Water moderately clear, 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.



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

FIGURE 7
SULLIVAN LAKE
SCATTERPLOTS OF CHLOROPHYLL-a, SECCHI TRANSPARENCY, AND TOTAL PHOSPHORUS
Based on summer mean concentrations for ecoregion lakes





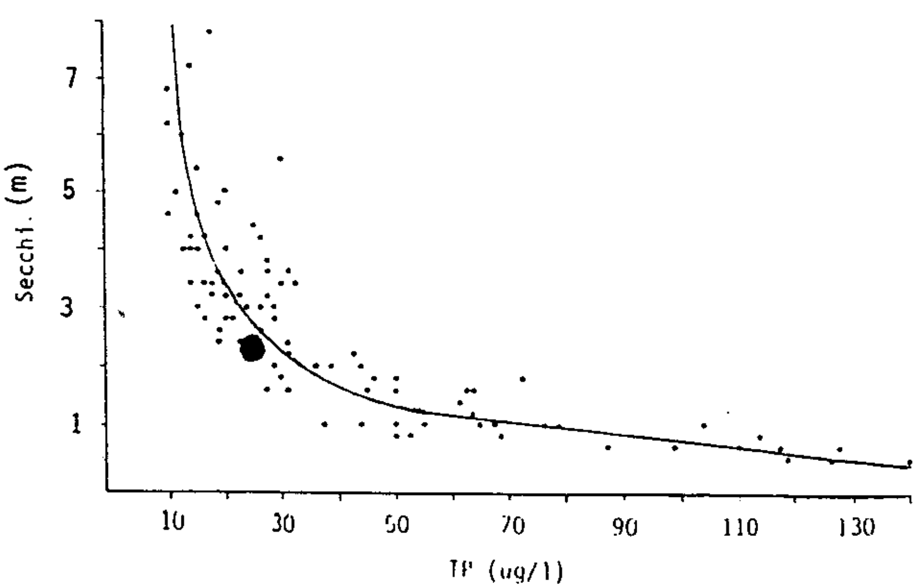


TABLE 5
TROPHIC STATUS INDICATORS
SULLIVAN LAKE

Carlson Trophic State Index Value	
TP TSIP	49.2
Chl-a TSIC	50.1
Secchi TSIS	47.2
Mean TSI	48.8
Percentile[9]	75th

In general, we note that the total phosphorus - chlorophyll a - Secchi transparency relationships for Sullivan Lake are typical of observations in other Minnesota lakes. Figure 7 also suggests that small increases in the in-lake phosphorus concentrations would result in measurable (and perceptible) changes in the transparency and the amount of algae in Sullivan Lake.

Water Quality Trends

The only "historical" data available for comparison consists of CLMP measurements collected by lake association members from the following six years - 1973, 1979, 1980, 1990, 1991, and 1992. These data do not represent a continuous record for Sullivan Lake, however they do provide some historical perspective and provide a basis for evaluating year-to-year variation in transparency (Table 6 and Figure 8). The summer - mean Secchi

[9] Relative to approximately 800 lakes in the Northern Lakes and Forests Ecoregion. A one hundred percent level implies the lowest TP concentrations or deepest Secchi disk measurement for that Ecoregion.

TABLE 6
SULLIVAN LAKE SUMMER MEAN SECCHI TRANSPARENCY
Based on CLMP Data

Secchi Transparency
(in Feet)

	1973	1979	1980	1990	1991	1992
	5.8	6.7	7.3	7.2	8.2	8.7
Number of Obs.	18	5	11	17	17	37

transparencies, from these six years, exhibit a significant (Kendall tau-b=0.93, p=0.01) increasing trend in transparency overtime. Because the data record is rather short (six years) and discontinuous it is difficult to determine if this trend is "real". However, the data suggest that the transparency of Sullivan Lake in recent years (x= 8.0 feet, 1990-1992) may be slightly better than measures from the earlier period (x=6.6 feet, 1973-1980).

Based on Secchi data from these six years it appears that transparency may vary from about 6 feet to 9 feet as a summer mean. Continued monitoring will provide a basis for assessing trends over time. Based on the six years of data the long-term mean transparency is about 7 feet. The "average" yearly variation from this value is about one foot (or about 13 percent of the mean). This is calculated by subtracting the summer-mean

FIGURE 8

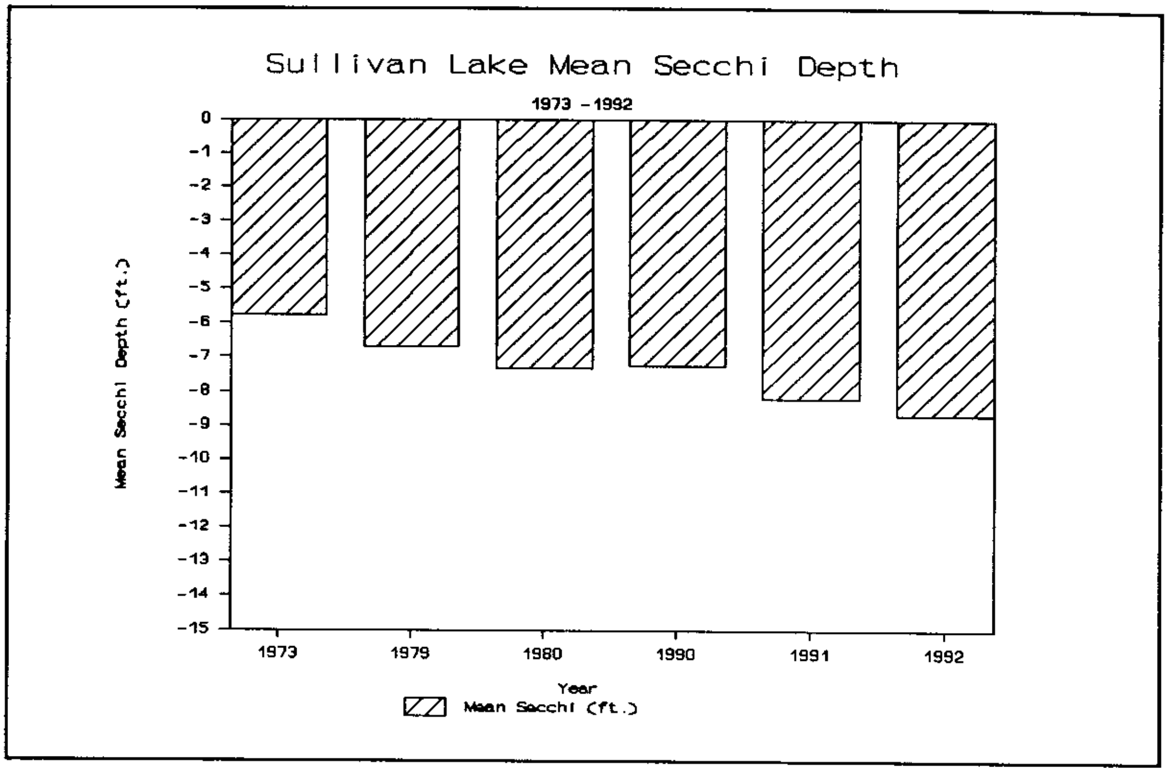
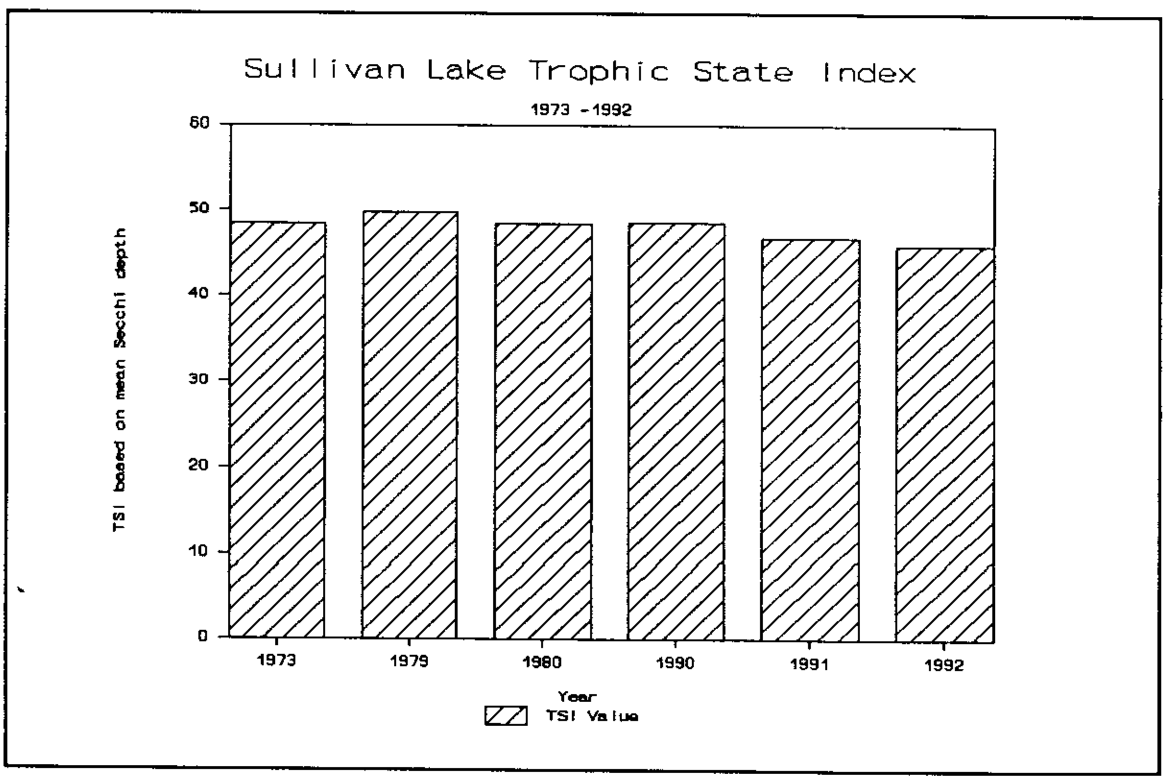


FIGURE 9



transparency for each year (residual) from the long term mean and averaging the "residuals" from each year.

While the year-to-year variation may seem large (e.g. 5.8 feet in 1973 to 8.7 feet in 1992 it is comparable to that observed in other lakes in the state (i.e. within about 10-20 percent of the long-term mean). This year-to-year variation should be kept in mind as monitoring continues in future years and the data are analyzed for trends.

TABLE 7
SULLIVAN LAKE SUMMER TROPHIC STATE INDEX
Based on CLMP Secchi Transparency Data

Secchi Transparency
(in Feet)

1973	1979	1980	1990	1991	1992
48.5	49.7	48.4	48.6	46.8	46.0

The Trophic State Index based on Secchi Transparency is relatively stable from season to season. The Secchi disk appears to give an excellent measure of the health and trophic status of the lake and should be continued (Table 7 and Figure 9).

Secchi disk monitoring will be valuable for characterizing the trends in the transparency of the lake over time. Since relatively good agreement exists between TP , chlorophyll a, and

Secchi (Figure 6) - it should provide an accurate estimate of changes in trophic condition over time.

Modeling Summary

Numerous mathematical 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 the lake. Alternatively, they may also be used for estimating changes in the quality of the lake as a result of altering the flow or amount of water that enters the lake. To analyze the 1992 quality of Sullivan Lake, the models Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) (Wilson and Walker 1989) and Reckhow and Simpson (1980) were used. Reckhow and Simpson's model is used extensively for assessing lake water quality.

The "Minnesota Lake Eutrophication Analysis Procedure," MINLEAP was developed by MPCA staff based on an analysis of data collected from a set of representative minimally impacted lakes for each ecoregion. MINLEAP is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1988).

No actual measure of water flow into or out of Sullvan Lake or measure of nutrient concentrations into or out of the lake were made. Rather, 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 preliminary data from the State Climatology Office (1992). Inputs to the model are noted in Appendix B.

For Sullivan Lake the Northern Lakes and Forest MINLEAP model predicted a similar phosphorus concentration (24.8 ug/l) compared to the observed concentration (23.8 ug/l) in 1992 (Table 8). The predicted chlorophyll a (7.2 ug/l) and Secchi transparancy (2.39 meters) is also comparable to the 1992 observed conditions of 8.06 ug/l of chlorophyll a and a secchi transparency of 2.5 meters.

Based on the Northern Lakes and Forest MINLEAP model the estimated the water residence time (average time it would take to replace the entire volume of the lake) for Sullivan Lake is on the order of 1 - 1.5 years. Sullivan Lake retains approximately 53 percent of the phosphorus that enters the lake.

One reason for the good water quality for Sullivan Lake is the close proximity of Platte Lake. Water from the northern portion of the watershed must first flow through Platte Lake. In similar cases the upper lakes in the watershed could be acting as a nutrient sink, thus improving the water quality for lakes further down the watershed. Any further study of Sullivan Lake must also address it's interaction with Platte Lake.

TABLE 8
SULLIVAN LAKE
NORTHERN LAKES AND FORESTS ECOREGION
MINLEAP MODELING AND OBSERVED CHARACTERISTICS COMPARISON
1992

	1992 Observed	MINLEAP
TP (ug/l)	23.8	24.7
Chlorophyll a	8.06	7.18
Secchi (meters)	2.5	2.4
Water Residence Time (yrs)	---	1 - 1.5 years
P retention coefficient	---	0.5332
Total Phosphorus Load	---	1118 kg/year

The Reckhow and Simpson model was also used to estimate the water quality for Sullivan Lake. This model estimates the total phosphorus concentration of a lake based on the lake's morphometry, watershed area, and land use in the watershed. The phosphorus export coefficients were selected from studies conducted in Minnesota (Walker, 1985 and Verry and Timmons, 1982). The Canfield and Bachmann (1981) model was used for the phosphorus load portion of the Rechhow and Simpson model. The precipitation and evaporation data were derived from Gunnard (1985) and preliminary data from the State Climatology Office. The land use data for the watershed was taken from topographic maps and 1969 land use data supplied by the State of Minnesota.

A quick field check by the MPCA Regional Office staff of the land use indicted no major identifible changes on a scale large enough to impact the modeling. Inputs and results of the model are noted in Appendix B.

The Reckhow and Simpson model predicts an in-lake phosphorus concentration of about 32 ug/l (Appendix B) using the "low" phosphorus export coefficient. The total P flux between low and average (1187 to 2144 kg/yr) is within the range identified by the MINLEAP estimate (1828 kg/yr).

The model also provides the opportunity to estimate the relative magnitude of phosphorus which might be exported from the various sources in the watershed during an average year. In general terms, watershed sources (including agriculture, urban, pasture, forests, and wetlands) contribute about 87 percent of the phosphorus load to the lake, with the remainder from precipitation on the lake surface (8%) and septic systems (5%) The septic system concentrations are based on a soil retention of 80%, which implies that the soils retain 80 percent of the P load from septic tanks. However if the soil retains less (e. g. only 60 or 70 percent) or if systems are pooorly maintained, the potential contribution could be much higher.

In terms of the watershed sources of phosphorus - the urban/residential loading may be the most significant (and potentially most controllable) contributing about 30 percent of the load to the lake. This should not diminish the importance of loading from agricultural land uses in the watershed. These sources may be particularly important if runoff from poorly managed lands (cultivated, feedlots, etc.) enters tributaries to the lake.

TABLE 9
SULLIVAN LAKE
RECKHOW AND SIMPSON MODEL PHOSPHORUS COMPARISON
1992

Land Use	Phosphorus Flux	Percent of Total
Forested	335	28.2
Agriculture	167	14.1
Urban	326	27.5
Wetland	9	0.7
Pasture or Open	198	16.7
Precipitation	97	8.2
Septic	55	4.6
Point Sources	0	0.0
Total P Flux	1187	100.0

The phosphorus loadings predicted by these models should be considered estimates only. The loadings estimated using the "low" phosphorus export coefficients agree fairly well with the MINLEAP modeling, which in turn predicts an in-lake phosphorus comparable to the observed. The Secchi and chlorophyll a, and total phosphorus measure are very similar, therefore the Secchi disk can provide an excellent measure of the lakes long term characteristics. The modeling results could provide a basis for estimating in-lake changes which could result from changes in land use in the watershed.

Goals and Objectives

The water quality observed in Sullivan Lake in 1992 was comparable to model predictions based on the lake's morphometry, watershed size, composition of land uses in the watershed, and comparable to or better than minimally impacted lakes in the ecoregion.

Based on the LAP monitoring results from 1992, CLMP data from 1989 - 1992, and MINLEAP model results, a total phosphorus goal on the order of 20 - 30 ug/l is appropriate for Sullivan Lake. A summer mean phosphorus concentration in this range should yield transparencies from 2.0 - 3.0 meters (6 - 10 feet) and a mean chlorophyll a from 7 - 12 ug/l. Over this range of phosphorus; chlorophyll a concentrations would exceed 10 ug/l ("scums evident) less than 21 percent of the summer.

Based on user perception responses from 1992 it appears that Secchi transparencies less than nine feet and chlorophyll a concentrations greater than 10 ug/L are associated with "impaired swimming" and "definite algal green coloration". In 1992 these conditions occurred about 25 percent of the summer. To avoid an increased occurance of "nuisance" algal blooms (chlorophyll a greater than 20 ug/L) the in-lake phosphorus should remain at or below 25 ug/L. An increase to 30 ug/L for example would yield a summer mean chlorophyll a of 9.5 ug/L; which would produce chlorophyll a concentrations greater than 10 ug/l about 40 percent of the summer, and a subsequent decline in Secchi transparancy. Further increases in phosphorus to 40 ug/L would lead to nuisance algal blooms (greater than 20 ug/L chlorophyll a) on the order of 20 percent of the summer. These conditions would be perceptibly different to the long term lake user than the conditions observed in 1992.

Secchi monitoring will help to better characterize fluctuations in the quality from year-to-year and could serve as a means for detecting degradation in the quality of the lake. For example, a summer average transparency less than about five (5) feet may be indicative of a significant change in the quality of the lake.

A further detailed study would be necessary to determine sources of excess nutrient loading to Sullivan Lake from its watershed. A study of this nature would involve the measurement of nutrient and water loading to the lakes from the various tributaries. This data would allow for the estimation of reasonably accurate total phosphorus, total nitrogen, water budgets, and definition of year-to-year variability for the lake. From this information, feasible alternatives for reducing the loading to the lakes may be identified. This study, however, does provide a good baseline for assessing future changes in the water quality of Sullivan Lake and for developing and implementing protection strategies to maintain the current (1992) quality of the lakes.

The Sullivan Lake Association should continue participation in the Minnesota Department of Natural Resources' lake level monitoring program. This information would be useful in developing the nutrient and water budgets for the lake and the impact from runoff.

Since an estimated 87 percent of the phosphorus entering the lake arises from forested, urban, and pasture or open land uses, activities or best management practices which minimize the impacts form these land use should be stressed, with a particular focus on urban and agricutural sources.

Additionally, even though septic tanks only contribute on the order of 5 to 7 percent of the total phosphorus to the lake, it is an amount that lake association (shoreland property owners) can effectively reduce. The lake association should conduct education and information programs to insure compliance with rules and regulations concerning the construction of septic systems. The Sullivan Lake Association should work closely with the Morrison County Planning and Zoning Department and other governmental agencies in efforts to promote Best Management

Practices (BMP's) and ensure that all septic systems are in compliance in the watershed.

Finally, The Sullivan Lake Association should contact the Morrison County Planning and Zoning Office, Minnesota Department of Natural Resources, and the Minnesota Pollution Control Agency for assistance in developing a long term plan to address the monitoring and protection activities required to protect the lake's water quality.

APPENDICES

APPENDIX A

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REFERENCES

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APPENDIX B

SULLIVAN LAKE
DATA SUMMARY

SULLIVAN LAKE WATER QUALITY DATA (LAKEID=49-0016). Taken from STORET.

DATE	SITE	D	TP	RTP	TKN	N2N3	RN2N3	TSS	TSIN	ALK	PHF	CL	CONF	TURB	COLOR	CHLA	PHEO	SDF	PHYS	REC
920520	101	0	.		0.32	0.01	K	1.6	0.6	74	8.1	2.2	145	1.0	30	3.36	0.96	5.7	2	1
920520	102	0	.		0.35	.		.	.	.	8.1	.	150	.	.	2.72	1.12	6.6	2	1
920520	103	0	.		0.75	.		.	.	.	8.1	.	150	.	.	4.16	1.28	6.6	2	1
920616	101	0	.020	Q	0.20	0.01		3.4	1.8	78	8.0	2.2	150	1.0	30	6.09	0.32	8.2	2	1
920616	102	0	.016	Q	0.13	.		.	.	.	8.1	.	150	.	.	5.13	0.32	9.8	2	1
920616	103	0	.018	Q	0.18	.		.	.	.	8.2	.	150	.	.	5.13	0.64	6.6	2	1
920720	101	0	.026	Q	0.58	0.01	K	2.2	0.6	78	8.6	1.8	150	1.6	20	6.41	1.28	8.2	2	1
920720	101	32	.030	Q	0.62	.		.	.	.	.	.	.	.	.	.	.	.		
920720	102	0	.024	Q	0.77	.		.	.	.	8.3	.	150	.	.	7.69	0.96	6.6	2	1
920720	103	0	.021	Q	0.60	.		.	.	.	8.3	.	149	.	.	5.45	0.64	8.2	2	1
920819	101	0	.020	Q	0.49	0.01	K	2.2	0.4	78	8.7	1.2	149	1.0	20	5.13	0.96	10.5	2	1
920819	101	50	.185	Q	1.38	.		.	.	.	.	.	.	.	.	.	.	.		
920819	102	0	.019	Q	0.62	.		.	.	.	8.5	.	149	.	.	5.45	1.28	8.2	2	1
920819	103	0	.017	Q	0.65	.		.	.	.	8.4	.	150	.	.	5.77	0.64	9.8	2	1
920922	101	0	.028		0.82	0.01	K	3.6	0.8	98	7.8	2.6	150	2.3	20	16.70	0.96	6.9	3	1
920922	101	52	.040		0.67	.		.	.	.	.	.	.	.	.	.	.	.		
920922	102	0	.038		0.64	0.02		.	.	.	8.0	.	150	.	.	13.40	0.32	6.9	3	1
920922	103	0	.038		0.68	0.01	K	.	.	.	8.0	.	150	.	.	14.40	0.64	6.9	3	1

Water Quality Data Abbreviations and Units

SITE= sampling site ID
DM= sample depth in meters (0=0-2 m integrated)
TP= total phosphorus in mg/l
OP= total ortho-phosphorus in mg/l
DP= dissolved phosphorus in mg/l
TKN= total Kjeldahl nitrogen in mg/l
N2N3= nitrite+nitrate N in mg/l
NH4= ammonia-N in mg/l
TNTP=TN:TP ratio
PH= pH in SU (F=field, L or =lab)
ALK= alkalinity in mg/l (lab)
TSS= total suspended solids in mg/l
TSV= total suspended volatile solids in mg/l
TSIN= total suspended inorganic solids in mg/l
TURB= turbidity in NTU (F=field)
CON= conductivity in umhos/cm (F=field, L=lab)
CL= chloride in mg/l
SI= total silica in mg/L
DO= dissolved oxygen in mg/l
TEMP= temperature in degrees centigrade
SD= Secchi disk in meters (SDF=feet)
CHLA= chlorophyll-a in ug/l
TSI= Carlson's TSI (P=TP, S=Secchi, C=Chla)
PHEO= pheophytin in ug/l
PHYS= physical appearance rating (classes=1 to 5)
REC= recreational suitability rating (classes=1 to 5)
RTP, RN2N3...= remark code; k=less than, Q=exceeded holding time

SULLIVAN LAKE (LAKEID=49-0016) DISSOLVED OXYGEN, TEMPERATURE, AND TOTAL PHOSPHORUS PROFILE DATA.

SITE	DATE	DM	NDM	DO	TEMP	TP
101	920520	0	0	9.2	17.4	.
101	920520	1	-1	9.2	17.4	.
101	920520	2	-2	9.3	17.3	.
101	920520	3	-3	9.2	17.3	.
101	920520	4	-4	9.2	17.2	.
101	920520	5	-5	9.3	16.9	.
101	920520	6	-6	9.2	16.9	.
101	920520	7	-7	8.9	15.4	.
101	920520	8	-8	8.6	15.2	.
101	920520	9	-9	8.3	14.7	.
101	920520	10	-10	6.6	13.0	.
101	920520	12	-12	4.1	11.1	.
101	920520	14	-14	2.7	10.6	.
101	920616	0	0	8.7	19.0	.020
101	920616	1	-1	8.6	19.0	.
101	920616	2	-2	8.5	19.0	.
101	920616	3	-3	8.5	19.0	.
101	920616	4	-4	8.5	18.5	.
101	920616	5	-5	8.4	18.0	.
101	920616	6	-6	7.9	17.5	.
101	920616	7	-7	7.0	16.0	.
101	920616	8	-8	6.1	15.0	.
101	920616	9	-9	5.2	14.0	.
101	920616	10	-10	4.0	13.5	.
101	920616	12	-12	3.0	12.0	.
101	920616	14	-14	1.6	12.0	.
101	920720	0	0	8.4	21.0	.026
101	920720	1	-1	8.4	20.5	.
101	920720	2	-2	8.4	21.5	.
101	920720	3	-3	8.2	20.0	.
101	920720	4	-4	8.0	20.0	.
101	920720	5	-5	7.8	20.0	.
101	920720	6	-6	6.8	19.0	.
101	920720	7	-7	5.0	18.0	.
101	920720	8	-8	4.2	17.0	.
101	920720	9	-9	2.0	16.0	.
101	920720	10	-10	0.8	15.0	.030
101	920819	0	0	8.4	20.5	.020
101	920819	1	-1	8.3	20.5	.
101	920819	2	-2	8.2	20.0	.
101	920819	3	-3	8.0	20.0	.
101	920819	4	-4	8.1	20.0	.
101	920819	5	-5	7.9	20.0	.
101	920819	6	-6	7.2	19.5	.
101	920819	7	-7	6.0	19.5	.
101	920819	8	-8	0.3	18.5	.
101	920819	9	-9	0.1	16.0	.
101	920819	10	-10	0.1	15.5	.
101	920819	12	-12	0.1	13.0	.
101	920819	14	-14	0.1	12.0	.
101	920819	16	-16	0.1	12.0	.
101	920922	0	0	9.8	15.0	.028
101	920922	1	-1	9.4	15.0	.
101	920922	2	-2	8.8	15.0	.

The SAS System

LAKEID=49-0016
(continued)

SITE	DATE	DM	NDM	DO	TEMP	TP
101	920922	3	-3	8.2	15.0	.
101	920922	4	-4	7.6	15.0	.
101	920922	5	-5	7.0	15.0	.
101	920922	6	-6	6.8	15.0	.
101	920922	7	-7	6.2	15.0	.
101	920922	8	-8	5.8	15.0	.
101	920922	9	-9	5.7	15.0	.
101	920922	10	-10	5.4	15.0	.
101	920922	12	-12	5.1	15.0	.
101	920922	14	-14	5.0	14.5	.
101	920922	16	-16	4.9	14.5	.040

SULLIVAN LAKE (LAKEID=49-0016) CLMP
SECCHI TRANSPARENCY DATA.

SITE	DATE	SDF	PHYS	REC
201	920610	11.5	2	2
201	920624	8.0	2	2
201	920626	10.0	2	2
201	920714	10.0	2	2
201	920722	10.0	2	2
201	920801	10.0	2	2
201	920807	8.5	2	2
203	920507	10.0	2	1
203	920515	10.0	2	1
203	920522	9.5	2	1
203	920528	10.0	2	1
203	920604	10.0	2	2
203	920611	10.0	2	2
203	920618	9.5	2	2
203	920625	9.5	3	2
203	920630	9.0	3	3
203	920708	8.5	3	2
203	920714	9.0	3	2
203	920722	9.0	3	2
203	920728	8.5	3	2
203	920804	9.0	3	2
203	920811	9.0	3	3
203	920819	8.5	3	3
203	920826	7.0	3	3
203	920901	7.0	3	2
203	920909	7.0	3	3
203	920915	6.5	4	4
203	920923	6.0	3	3
203	920930	5.5	3	3

Minnesota Pollution Control Agency
Citizen Lake-Monitoring Program
March 2, 1993

LAKEID: 49-0016

LAT.LON.: 460730 935730

LOCATION: 3 MI E OF HARDING
COUNTY: MORRISON
AREA: 1221 acres
MAXDEPTH: 57 feet

DATE	TIME	D	00029 SITE	*00078 SECCHI FEET	84141 PHYSCON 1-5	84142 RECSUIT 1-5
790722	0800	0	201	6.50	-	-
790807	1300	0	"	6.50	-	-
790814	1300	0	"	6.50	-	-
790822	1300	0	"	7.00	-	-
790912	1700	0	"	7.00	-	-

Minnesota Pollution Control Agency
Citizen Lake-Monitoring Program
March 2, 1993

LAKEID: 49-0016

LAT.LON.: 460730 935730

LOCATION: 3 MI E OF HARDING
COUNTY: MORRISON
AREA: 1221 acres
MAXDEPTH: 57 feet

DATE	TIME	D	00029 SITE	*00078 SECCHI FEET	84141 PHYSCON 1-5	84142 RECSUIT 1-5
800613	1000	0	201	9.00	-	-
800621	1600	0	"	9.50	-	-
800628	1400	0	"	6.50	-	-
800705	1600	0	"	11.00	-	-
800712	0930	0	"	9.00	-	-
800719	1000	0	"	7.00	-	-
800808	1400	0	"	5.50	-	-
800823	1600	0	"	5.50	-	-
800830	1800	0	"	6.00	-	-
800912	1600	0	"	6.00	-	-
800923	1400	0	"	5.50	-	-

Minnesota Pollution Control Agency
Citizen Lake-Monitoring Program
March 2, 1993

LAKEID: 49-0016

LAT.LON.: 460730 935730

LOCATION: 3 MI E OF HARDING
COUNTY: MORRISON
AREA: 1221 acres
MAXDEPTH: 57 feet

DATE	TIME	D	00029 SITE	*00078 SECCHI FEET	84141 PHYSCON 1-5	84142 RECSUIT 1-5
900701	1600	0	201	7.50	2	2
900713	1900	0	"	7.50	2	2
900720	1930	0	"	7.50	2	2
900723	1730	0	"	8.50	2	2
900802	1705	0	"	8.50	2	2
900806	1635	0	"	8.00	2	2
900815	1500	0	"	5.50	2	2
900828	1800	0	"	6.00	2	2
900910	1500	0	"	7.00	2	2
901007	1600	0	"	5.50	2	2
900806	1030	0	203	9.00	3	2
900814	1000	0	"	8.00	3	2
900821	1100	0	"	6.50	3	2
900827	1500	0	"	6.00	3	3
900904	1400	0	"	6.50	3	3
900909	1100	0	"	6.50	3	3
900920	1000	0	"	7.00	3	2
900926	1100	0	"	7.50	2	2

Minnesota Pollution Control Agency
Citizen Lake-Monitoring Program
March 2, 1993

LAKEID: 49-0016

LAT.LON.: 460730 935730

LOCATION: 3 MI E OF HARDING
COUNTY: MORRISON
AREA: 1221 acres
MAXDEPTH: 57 feet

DATE	TIME	D	00029 SITE	*00078 SECCHI FEET	84141 PHYSCON 1-5	84142 RECSUIT 1-5
910512	1445	0	203	10.00	2	2
910519	1400	0	"	10.00	2	2
910526	1345	0	"	9.50	2	2
910602	1430	0	"	9.50	3	2
910610	1000	0	"	10.00	2	2
910617	1000	0	"	10.00	2	2
910624	1400	0	"	9.00	3	2
910702	1300	0	"	9.00	2	2
910708	1445	0	"	8.50	2	2
910715	1100	0	"	8.50	2	2
910722	1300	0	"	8.00	3	3
910730	1400	0	"	7.50	3	2
910806	1100	0	"	7.50	3	2
910812	1400	0	"	8.00	2	2
910820	1100	0	"	8.00	2	2
910827	1400	0	"	7.50	4	3
910904	1100	0	"	7.00	3	3
910909	1030	0	"	7.50	3	3
910917	1100	0	"	7.50	3	2
910924	1130	0	"	6.50	3	3
911002	1400	0	"	6.50	3	3

Minnesota Pollution Control Agency
Citizen Lake-Monitoring Program
March 2, 1993

LAKEID: 49-0016

LAT.LON.: 460730 935730

LOCATION: 3 MI E OF HARDING
COUNTY: MORRISON
AREA: 1221 acres
MAXDEPTH: 57 feet

DATE	TIME	D	00029 SITE	*00078 SECCHI FEET	84141 PHYSCON 1-5	84142 RECSUIT 1-5
920610	1600	0	201	11.50	2	2
920624	1900	0	"	8.00	2	2
920626	1600	0	"	10.00	2	2
920714	1500	0	"	10.00	2	2
920722	1500	0	"	10.00	2	2
920801	1500	0	"	10.00	2	2
920807	1900	0	"	8.50	2	2
920507	1100	0	203	10.00	2	1
920515	1230	0	"	10.00	2	1
920522	1030	0	"	9.50	2	1
920528	1100	0	"	10.00	2	1
920604	1030	0	"	10.00	2	2
920611	1230	0	"	10.00	2	2
920618	1100	0	"	9.50	2	2
920625	1030	0	"	9.50	3	2
920630	1000	0	"	9.00	3	3
920708	1330	0	"	8.50	3	2
920714	1215	0	"	9.00	3	2
920722	1330	0	"	9.00	3	2
920728	1045	0	"	8.50	3	2
920804	1130	0	"	9.00	3	2
920811	1100	0	"	9.00	3	3
920819	1330	0	"	8.50	3	3
920826	1230	0	"	7.00	3	3
920901	1000	0	"	7.00	3	2
920909	1300	0	"	7.00	3	3
920915	1330	0	"	6.50	4	4
920923	1300	0	"	6.00	3	3
920930	1100	0	"	5.50	3	3

Minnesota Algal Rapid Assessment -- Assessment Form v. 2.0 e.b.s. 12/14/92

Lake Name: Sullivan	Depth: 0-2 m	Bull 25#: 49-0016	Site Id: 101
Sample date: 920616		Assessment date: 930223	Assessor's name: H. Markus

Algal Group		Taxon	% Abundance*	notes
Chlorophyta (greens)		Ankistrodesmus		
		Chlorella		
		Closterium		
		Coelastrum		
		Dictyosphaerium		
		Gloeocystis		
		Mougeotia		
	—	Oocystis	15	
		Pediastrum		
		Scenedesmus		
		Selanastrum		
		Staurastrum		
	—	Ulothrix	10	
		other-		
Euglenophyta		Trachelomonas		
		other-		
Pyrrhophyta	—	Ceratium	15	
		Peridinium		
		other-		
Chrysophyta (Xanthophyceae)		Tribonema		
		other-		
Chrysophyta (Chrysophyceae)	—	Dinobryon		
		Mallomonas		
		Synura		
		other-		
Chrysophyta (Bacillariophyceae)	-	Asterionella	5	
		Centric-1		
		Centric-2		
		Fragilaria		
	—	Melosira	20	
	—	Pennate-1		
		Pennate-2		
		Tabellaria		
		other-		
Cyanophyta (bluegreens)	-	Anabaena	10	
	-	Anacystis	5	
	—	Aphanizomenon	15	
		Chroococcus		
		Coelosphaerium		
		Gloeotrichia		
		Merismopedia		
	-	Microcystis		
		Nostoc		
	—	Oscillatoria/Lyngbya	5	
		other-		
		other-		
		other-		

*% abundance should be assessed by volume, not by numerical quantity alone.

Minnesota Algal Rapid Assessment -- Assessment Form v. 2.0 e.b.s. 12/14/92

Lake Name: Sullivan	Depth: 0-2	Bull 25#: 49-0016	Site Id: 101
Sample date: 920819		Assessment date: 930223	Assessor's name: H. Markus

Algal Group	Taxon	% Abundance*	notes
Chlorophyta (greens)	Ankistrodesmus		
	Chlorella		
	Closterium		
	Coelastrum		
	Dictyosphaerium		
	Gloeocystis		
	Mougeotia		
	Oocystis		
	Pediastrum		
	Scenedesmus		
	Selanastrum		
	– Staurastrum		
	– Ulothrix	5	
	other-		
Euglenophyta	Trachelomonas		
	other-		
Pyrrhophyta	– Ceratium		
	Peridinium		
	other-		
Chrysophyta (Xanthophyceae)	Tribonema		
	other-		
Chrysophyta (Chrysophyceae)	Dinobryon		
	– Mallomonas	5	
	Synura		
	other-		
Chrysophyta (Bacillariophyceae)	Asterionella		
	Centric-1		
	Centric-2		
	– Fragilaria	10	
	– Melosira		
	Pennate-1		
	Pennate-2		
	– Tabellaria	10	
	other-		
Cyanophyta (bluegreens)	– Anabaena	10	
	– Anacystis	10	
	– Aphanizomenon	10	
	– Chroococcus	10	
	– Coelosphaerium	10	
	Gloeotrichia		
	Merismopedia		
	– Microcystis	10	
	– Nostoc	5	
	– Oscillatoria/Lyngbya	5	
	other-		
	other-		
	other-		

*% abundance should be assessed by volume, not by numerical quantity alone.

Minnesota Algal Rapid Assessment -- **Assessment Form v. 2.0 e.b.s. 12/14/92**

Lake Name: Sullivan	Depth:	Bull 25#: 49-0016	Site Id: 101
Sample date: 920922		Assessment date: 930223	Assessor's name: H. Markus

Algal Group	Taxon	% Abundance*	notes
Chlorophyta (greens)	Ankistrodesmus		
	Chlorella		
	Closterium		
	Coelastrum		
	Dictyosphaerium		
	Gloeocystis		
	Mougeotia		
	– Oocystis	5	
	– Pediastrum		
	Scenedesmus		
	Selanastrum		
	– Staurastrum	5	
	– Ulothrix	10	
	other-		
Euglenophyta	Trachelomonas		
	other-		
Pyrrhophyta	– Ceratium	5	
	Peridinium		
	other-		
Chrysophyta (Xanthophyceae)	Tribonema		
	other-		
Chrysophyta (Chrysophyceae)	– Dinobryon	5	
	– Mallomonas		
	Synura		
	other-		
Chrysophyta (Bacillariophyceae)	– Asterionella	5	
	Centric-1		
	Centric-2		
	– Fragilaria	5	
	Melosira		
	– Pennate-1		
	Pennate-2		
	– Tabellaria	5	
	other-		
Cyanophyta (bluegreens)	– Anabaena	15	
	Anacystis		
	– Aphanizomenon	5	
	– Chroococcus	10	
	– Coelosphaerium	5	
	Gloeotrichia		
	Merismopedia		
	– Microcystis	10	
	– Nostoc	5	akinetes
	– Oscillatoria/Lyngbya	5	
	other-		
	other-		
	other-		

*% abundance should be assessed by volume, not by numerical quantity alone.

```
Minnesota Lake Eutrophication Analysis Procedure
ENTER INPUT VARIABLES
LAKE NAME ? Sullivan
ECOREGION NUMBER 1=NLF,2=CHF,3=WCP,4=NGP ? 1
WATERSHED AREA (HA)            ? 8257
LAKE SURFACE AREA (HA)         ? 485.4
LAKE MEAN DEPTH (M)            ? 5.4
OBSERVED MEAN LAKE TP (UG/L) ? 23.8
OBSERVED MEAN CHL-A (UG/L)     ? 8.06
OBSERVED MEAN SECCHI (M)       ? 2.5

INPUT DATA:
LAKE NAME =Sullivan                ECOREGION=NLF
LAKE AREA = 485.4  HA
WATERSHED AREA (EXCLUDING LAKE) = 8257  HA
MEAN DEPTH = 5.4  METERS
OBSERVED MEAN TP = 23.8  UG/L
OBSERVED MEAN CHL-A = 8.060001  UG/L
OBSERVED MEAN SECCHI = 2.5  METERS

<press ENTER to view results>
```

```
LAKE = Sullivan                                 ECOREGION = NLF
AVERAGE INFLOW TP = 54.03836  UG/L      TOTAL P LOAD        = 1060.347  KG/YR
LAKE OUTFLOW      = 19.62212  HM3/YR    AREAL WATER LOAD    = 4.042464 M/YR
RESIDENCE TIME    = 1.335819  YRS       P RETENTION COEF    = .5409218
```

VARIABLE	UNITS	OBSERVED	PREDICTED	STD ERROR	RESIDUAL	T-TEST
TOTAL P	(UG/L)	23.80	24.81	7.12	-0.02	-0.13
CHL-A	(UG/L)	8.06	7.18	3.94	0.05	0.19
SECCHI	(METERS)	2.50	2.42	0.92	0.01	0.08

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	24.50	17.61	19.52	27.72
20	1.64	0.88	1.42	6.59
30	0.15	0.06	0.15	2.05
60	0.00	0.00	0.00	0.15

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

RECKHOW AND SIMPSON MODEL RESULTS

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	Sullivan Lake				
Watershed Area (ha)	8257	12385403 =EST Q	12.39 =HM3	2.2 =Water Residence (year)	
Lake Area (ha)	485.4	2.55 =EST qs			
Water Runoff (m)	0.15	NOTE: 1HM3 = 1,000,000 M3			
Precipitation(m)	0.66	23.8 =Observed TP (mg/l)			
Evaporation(m)	0.86 (mean)	0.0075 =Observed TP StDev			
Volume (HM3)	27.1	12 =N			
County capitas/cabin	2.8	8.06 =Observed Chla (ug/l)			
Number Seasonal Cabi	202	2.5 =Observed Secchi (m)			
Number Perm. Cabins	44				

	Before	After	Delta
Forest Area (ha)	4188	4188	0
Agric Area (ha)	836	836	0
Urban Area (ha)	652	652	0
Wetland Area (ha)	115	115	0
Pasture/Open (ha)	1654	1654	0

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	335	419	628	=Forested Flux =	335	419	628
Agric P Export	0.2	0.6	0.66	167	502	552	=Ag flux =	167	502	552
Urban P Export	0.5	1	1.25	326	652	815	=Urban flux =	326	652	815
Wetland P Export	0.08	0.1	0.1	9	12	12	=Wetland flux =	9	12	12
Pasture/open Export	0.12	0.2	0.3	198	331	496	=Pasture/Open flux=	198	331	496
Atmospheric Export	0.2	0.3	0.4	97	146	194	=Ppt flux =	97	146	194
Soil Retention Coef	0.8	0.7	0.6							
Point Source Before kg/yr	0	0	0							
Point Source After kg/yr	0	0	0	55	82	109	=Septic flux =	55	82	109
Delta Point Source kg/yr	0	0	0							
Capita Years	273.1	273.1	273.1	0	0	0	=Point Souce =	0	0	0
				1187	2144	2806	=Total P Flux =	1187	2144	2806
				245	442	578	= P LOAD =	245	442	578
				96	173	226	= Inflow P ug/l	96	173	226
				0.017	0.03	0.039	=PREDICTED TP =	0.017	0.03	0.039

**** P EXPORT R E F E R E N C E ****
****
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	4188	0.08	\NCHF	Cul+Mixed	0.19
Ag-mix	836	0.66	\NLF	For (75%)	0.12
Ag-row++	836	0.32	\NGP	Cul (83%)	0.76
Ag-nonrow++	836	0.61	\WCBP	Cul (84%)	0.74
Pasture	1654	0.12	** Of all landuse values.		

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

	Before	After
=LOG Pml =	-1.52288	-1.52288
= + MODEL ERROR =	0.01	0.01
= - MODEL ERROR =	-0.008	-0.008
= + LOADING ERROR =	0.0045	0.0045
= - LOADING ERROR =	0.0065	0.0065
=TOTAL + UNCERTAIN =	0.011	0.011
=TOTAL - UNCERTAIN =	0.01	0.01

	Before Low	Before Average	Before High		After Low	After Average	After High
RECKHOW/SIMPSON ug P/l	20	30	41	55% CONFIDENCE LIMITS	20	30	41
RECKHOW/SIMPSON	10	30	52	90% CONFIDENCE LIMITS	10	30	52
CANFIELD/BACHMANN ug P/l	32	48	57	CANFIELD/BACHMANN	32	48	57

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

Former -	New +	Net TP	Pred Boun -	Pred Boun +		Projected TP Change Incr/Decr	+/-
-0.00016	0	-0.00016	0.000162	0.00012	0.000217	-0.00016	0.000048

	Lake Data Lake TP	StDev	St Error	Pred Error	Obs TP	Net Change		Predicted P	+/- Pred Error
III.	23.8	14.28	2.914893	2.914893	23.8	-0.00016	=	23.8	+/- 2.914893
							=	23800	+/- 2915

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	23.8	0.031	0.047	0.056
LAKE CHLA	ug/l	8.06	9.9	18.3	23.6
LAKE SECCHI	m	2.5	2	1.4	1.2
TSI TP		49.9	53.7	59.7	62.2
TSI CHLA		51.1	53.1	59.1	61.6