LAKE ASSESSMENT PROGRAM

CROOKNECK LAKE
1992
(ID Number 49-0133)

MORRISON COUNTY, MINNESOTA

Minnesota Pollution Control Agency

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ACKNOWLEDGMENTS

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Crookneck Lake Association - Mavonne Prokop and Jerry Gross for their monitoring and background assistance.

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SUMMARY

Crookneck Lake is located in Central Minnesota near the town of Motley, Minnesota in Morrison County. The lake is 168 acres with a maximum depth of 22 feet. The watershed consists of 477 acres with forested land as the primary land use. The lake occupies about 40 percent of the watershed.

Crookneck Lake was sampled during the summer of 1992 by the Minnesota Pollution Control Agency (MPCA) staff and members of the Crookneck Lake Association as a part of the Lake Assessment Program (LAP). Water quality data collected during this study indicate that Crookneck Lake is borderline mesotrophic to eutrophic with a mean total phosphorus concentration of 30 ug/l, a summer mean Secchi transparency of 6.6 ft and a mean chlorophyll a of 7.2 ug/l.

Computer models were used to estimate existing water quality conditions in Crookneck 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 Crookneck Lake is good. The lake has a mean phosphorus concentration within the range for minimally-impacted lakes within the North Central Hardwood 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 Crookneck Lake:

1. Crookneck Lake has a very small watershed and is thus very sensitive to minor 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 Crookneck 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 the deepest site (Site 201) in each lake.

b. The Crookneck 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.

c. Any future development in the watershed of Crookneck 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 Crookneck 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 Crookneck 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. For the Association to more accurately determine sources of excess nutrient loadings from the watershed, 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. 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 and inorganic nitrogen and hydrologic inputs and outputs.

3. The water quality Crookneck Lake is good, however, small increases in the in-lake total phosphorus can cause a measurable decline in the lake's transparency. For Crookneck 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.

Since an estimated 60 percent of the phosphorus entering Crookneck Lake is from the near shore area, proper management of lawn fertilization and septic systems is extremely important. Crookneck Lake Association should actively pursue options and educational programs to assist in the reduction of phosphorus from this area. Local resource protection agencies may be a source of assistance with these measures.

Additionally, the lake association should consider a comprehensive macrophyte (aquatic vegetation) management program, which include minimizing the use of herbicides. Crookneck Lake presently has an oxygen depletion period, in a non-stratified lake, caused by the decomposition of organic matter including aquatic vegetation. All aquatic vegetation controls should include the removal of the controlled vegetation from the lake. Any aquatic vegetation removal should be undertaken in a controlled manner to prevent major changes in the ecosystem. If the system is altered, without any decline in the amount of nutrients entering the lake; the resulting decrease in macrophytes could result in an increase in the amount algae and algal blooms.

Technical assistance on best management practices may be available through local resource management agencies (Morrison 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 Crookneck Lake, an application to the Clean Water Partnership Program, if undertaken, should stress the further identification of sources and correction of the problems from the near shore areas contributing to the nutrient loadings.

4. Future changes in the water quality of Crookneck 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 Crookneck Lake might be if the average summer transparency declined to below about 6 feet or if 40 percent of the annual summer readings were below 6 feet. This "trigger level" can be refined with a few more years of data collection.

   b. An inspection of the land use practices, as part of a comprehensive lake management program within the watershed of Crookneck 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 Crookneck Lake Association, as part of its comprehensive lake protection program, should work with the Minnesota Department of Natural Resources (MDNR), Division of Waters, to initiate a 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

Crookneck Lake
(ID Number 49-0133)

INTRODUCTION

Crookneck 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. 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 Crookneck Lake Association because of water quality concerns by the Association and potential development around the lake and in the watershed.

Crookneck 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 Jerry Gross of the Crookneck Lake Association. The Lake Association also collected the CLMP data, the historical data, and provided the watershed boundaries, soils, and land use data.

BACKGROUND

Crookneck Lake is located in central Minnesota near the City of Motley, Minnesota, in Morrison County, and is approximately 100 miles northwest of the Minneapolis - St Paul metropolitan area (Map 1). The lake is approximately 200 acres in size which places it in the upper 20 percentile of Minnesota's lakes in terms of surface area (MDNR, 1968) (Table 1). The lake has a mean depth of 8.9 feet and its maximum depth is 22 feet. The watershed land area to lake surface area ratio is 2.4:1.

Crookneck Lake Historical Summary

From information furnished by the lake association, the area around Crookneck Lake was the scene of early development pressure. The lake has also been known as Lake McDonald.

MAP 1

LOCATION OF CROOKNECK LAKE

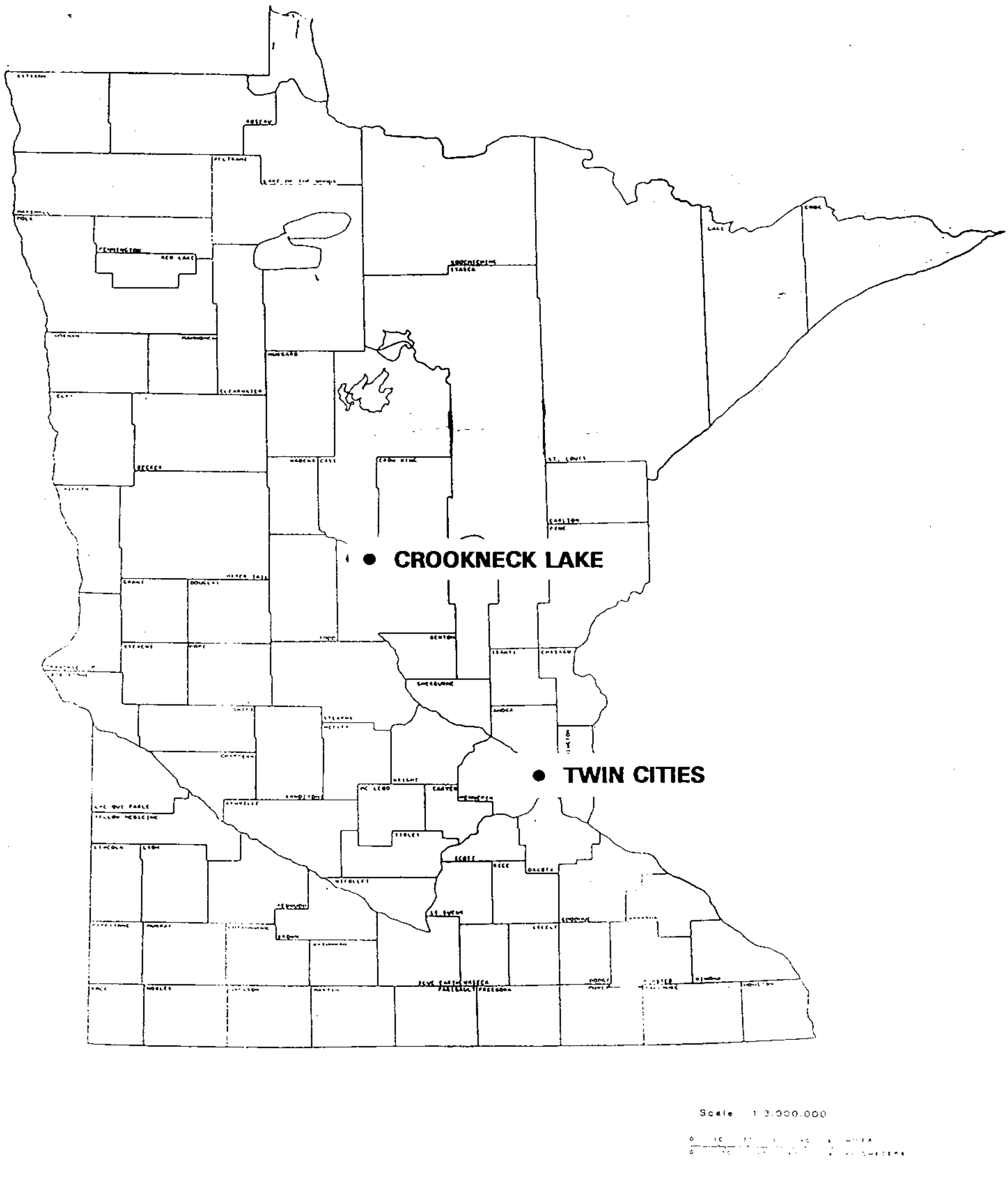


TABLE 1
LAKE MORPHOMETRIC, WATERSHED, AND FISHERY CHARACTERISTICS
CROOKNECK LAKE

STORET ID:	49-0133
MORPHOMETRIC DATA	
Area in Acres (ha):[1]	200 (81)
Mean Depth in ft. (m):	8.9 (2.7)
Max. Depth in ft. (m):[2]	22 (6.7)
Volume in acre feet (hm):[3]	1,516.4 (1.9)
WATERSHED CHARACTERISTICS	
Watershed Area in Acres (ha):[4]	477 (190.8)
Watershed Area to Lake Surface Area Ratio:	2.4:1
Estimated Mean Hydraulic Residence Time:	7 to 8 Years
FISHERIES DATA	
Lake Class[5]:	29
Species Management[6]:	Largemouth Bass
NUMBER OF PUBLIC ACCESSES	1
LAND USE DATA	
Shoreland Zoning:	Recreational Development
Development Trends[7] (Homes)	
1967 Survey	
Seasonal	62
Permanent	1
Total	63
1982 Survey	
Seasonal	117
Permanent	29
Total	146
1992 Survey[8]	
Seasonal	100
Permanent	15
Total	115
Land Use Percentages:	

	Forest	Open Water	Marsh	Pasture	Cultivated	Residential
Crookneck Lake	28.3	41.9	7.1	2.3	0	20.3
North Central Hardwood Forests	6-25	14-30		11-25	22-50	2-9

[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 Crookneck Lake (See Schupp, D. DNR Fisheries Investigational Report 417.)

[6] DNR Crookneck Lake Fisheries Management Plans.

[7] MDNR data

[8] Completed by the Crookneck Lake Association

1962

In 1962 there were two cabins built on the lake. Both properties were purchased from the Lampert Lumber Company of Little Falls. Each cabin, on a one acre site with well and septic system sold for $3,000.

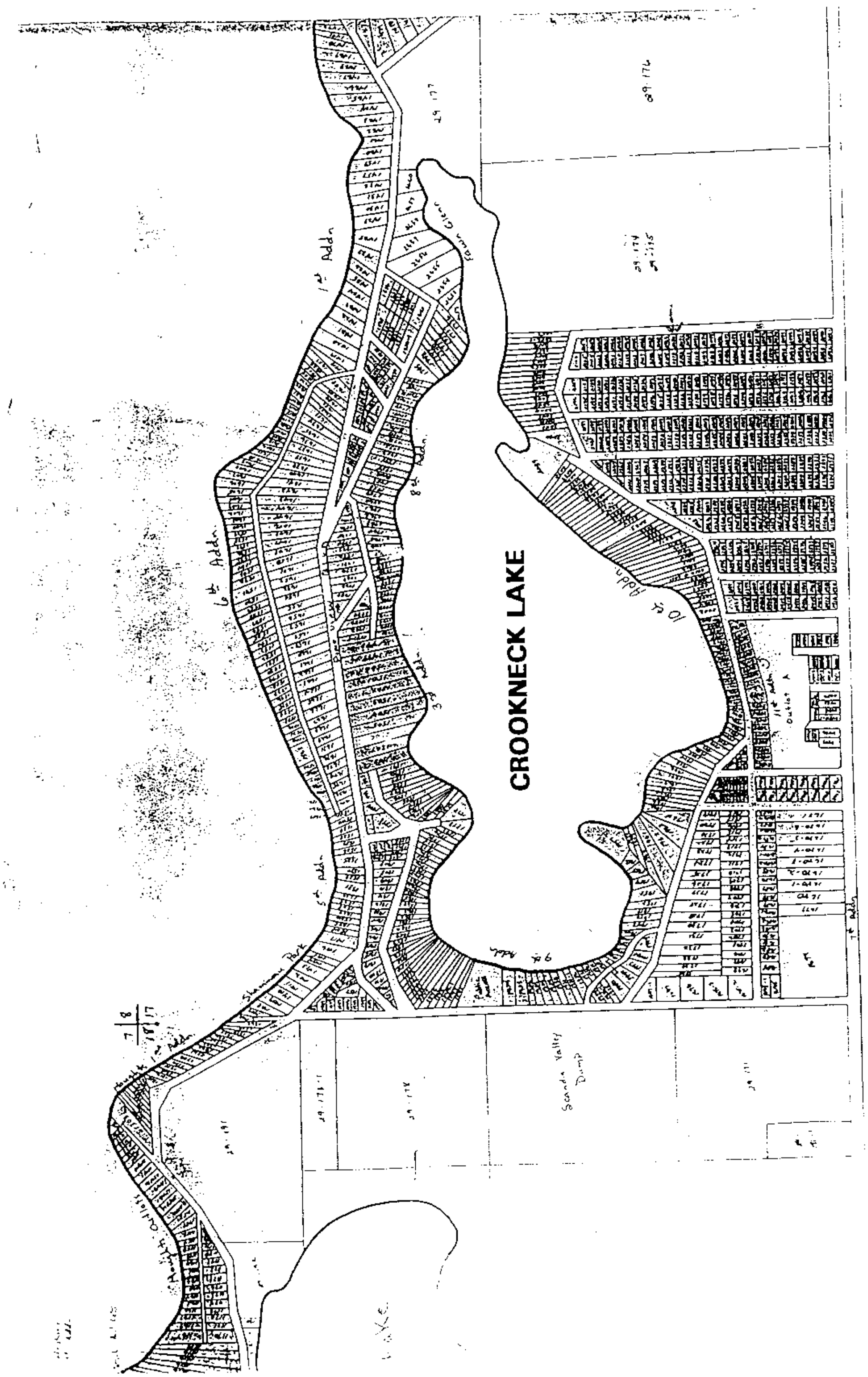
Early in the summer of 1962, a California developer named Don Eastvold, who was originally from Brainerd, Minnesota and his wife, Ginny Simms, who had been a singer with the then popular band of Kay Kyser from the 1940's era, replatted the area from 100 foot lots to 50 foot lots and started a vacation home concept (Map 2). This project was called the Scandia Valley Lake Estates. Each lot sold for $1,600 and those purchasing a lot on the first day of viewing it received a $400 rebate.

The A frame structure on the west bay was the Ginny Simms model. Ginny Simms also had a development on Lake Shamineau.

The building on the corner of Shamineau Road and County Road 203 was the sales office and later the clubhouse for the development. All forms of recreation were available for the first year or so, including ball fields, swimming pool, tennis courts, volleyball, and horseback riding. A boat access for members was also maintained.

MAP 2

HISTORICAL PLATTED AREA OF CROOKNECK LAKE



Almost all of the lots sold in the first summer, and the remaining few sold in the next one to two years. The last lot to sell was the one next to the model. The purchase of a lot also included a full year membership in the Scandia Valley Lake Estates.

The developer also attempted to cut a channel between Lake Crookneck and Lake Shamineau on the far east end. The Department of Natural Resources vetoed the idea because Lake Crookneck is at a higher level than Lake Shamineau.

1968

The Scandia Valley Dump was established on the west end of the lake. The dump has since closed and all solid waste is hauled out.

1980

The public access was developed in July of 1980. The Scandia Valley Lake Estates had funds of $4,500 but it was in disarray. It took 18 years for it to disband. The members had maintained the clubhouse the entire time, which included the swimming pool, riding horses and tennis courts.

The Lake Crookneck Improvement Association (LCIA) (a non-profit organization) was started in July of 1980. With the Scandia Valley Lake Estates folding, the members could either receive their money or vote to have it contributed to the LCIA. The LCIA had 35 members.

Other Historical Factors

The lake rose between 6 to 8 inches between 1962 and 1977. In July of 1972, there was one week of excessive flooding (referred to as the Randall flood by the local community). The lake was high for the first time and stayed that way for awhile but then gradually lowered.

There was a sandbar between the two points between the west bay and the main part of the lake. In 1962, the lake was shallow enough to permit walking across the two points. Some residents believe that a channel was then dredged out, but others do not recall the dredging.

The cutting of the aquatic vegetation in the bay by a commercial harvester started in 1981. Coontail used to be the predominant vegetation in the lake, which is 95% gone. The replacement is a broad leaf type of vegetation. The aquatic vegetation bed on the south side of the lake has narrow leaf vegetation. Cutting has continued on a schedule of at least once per year, and most of the time twice a year. A total of $26,000 has been spent on mechanical harvesting of the vegetation.

A small Hockney weed cutter was also purchased in 1981 for $5,000. The Hockney was used by lake residents to cut the vegetation 100 feet in to shore.

According to the lake association members, the vegetation growth is less noticeable in years of heavy snowfall. The west bay has always had a vegetation problem.

The water level has fluctuated over the years. Local speculation is that the springs that were feeding the lake dried up during the drought of the late 1980's.

It is believed that there was a complete freeze-out in the early spring (April) in the 1960's.

Septic System Survey

The septic system survey completed by the lake association as part of the Lake Assessment yielded the following information. In total 106 surveys were completed.

- Sealed septic tank with drainfield - 43 (40%)
- Open bottom cesspool - 4 (4%)
- Septic tank and drywell - 8 (8%)
- Privy - 14 (13%)
- Direct discharge into lake - 0 (0%)
- Direct discharge into ditch - 2 (2%)
- Holding tank - 19 (18%)
- Other - 3 (3%)
- Unable to determine - 13 (12%)

In addition, the surveys identified 15 residences as year round. The survey respondents did not indicate the maintenance level or the age of the on-site systems, which is a major factor in their effectiveness for pollution control.

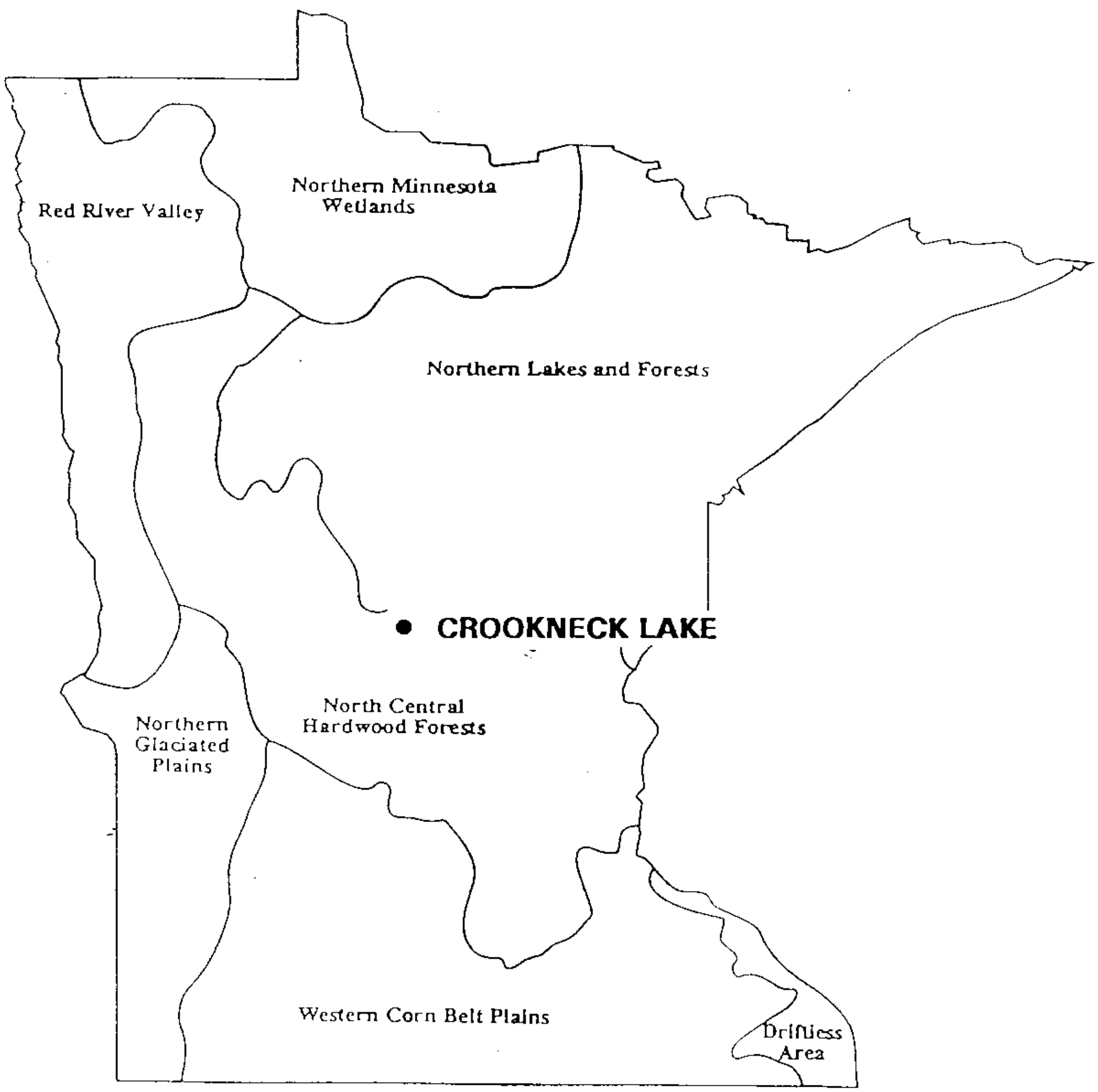
Crookneck Lake Soils, Land Use, and Watershed

Soils in the watershed are classified as Menahga loamy sand, with 15 to 25 percent slopes. It is associated with hilly or steep, excessively drained soil on ridges and convex side slopes on outwash plains and valley trains. The surface layer is typically a very dark gray loamy sand about 3 inches thick. The subsoil is brown sand about 17 inches thick. The subsoil is brown sand about 17 inches thick. The underlying material to a depth of about 60 inches is brown sand. Permeability is rapid and available water capacity is low. Surface runoff is rapid. The content of organic matter is low or moderately low. Most areas of this soil are in woodland. It is generally unsuited to cultivated crops, hay, or pasture because of droughtiness and steep slopes (Appendix B for descriptions and a map of Morrison County soils).

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. Crookneck Lake is located in the North Central Hardwood Forests ecoregion (Map 3).

MAP 3

MINNESOTA'S ECOREGIONS and CROOKNECK LAKE



In the Crookneck Lake Watershed (Map 4), open water and forested are the major land uses. Open water and marsh land use accounts for 49 percent followed by forested at 28.3 percent. The remaining land uses in the watershed are grouped together with urban or residential land uses of 20.3 percent and pasture or open land 2.3 percent. Agricultural land use consisting of cultivated land was not identified in the watershed. The percentage of residential land uses is higher than the typical range primarily because of the high nearshore development on the lake (Table 1).

The average annual precipitation in the Crookneck 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.

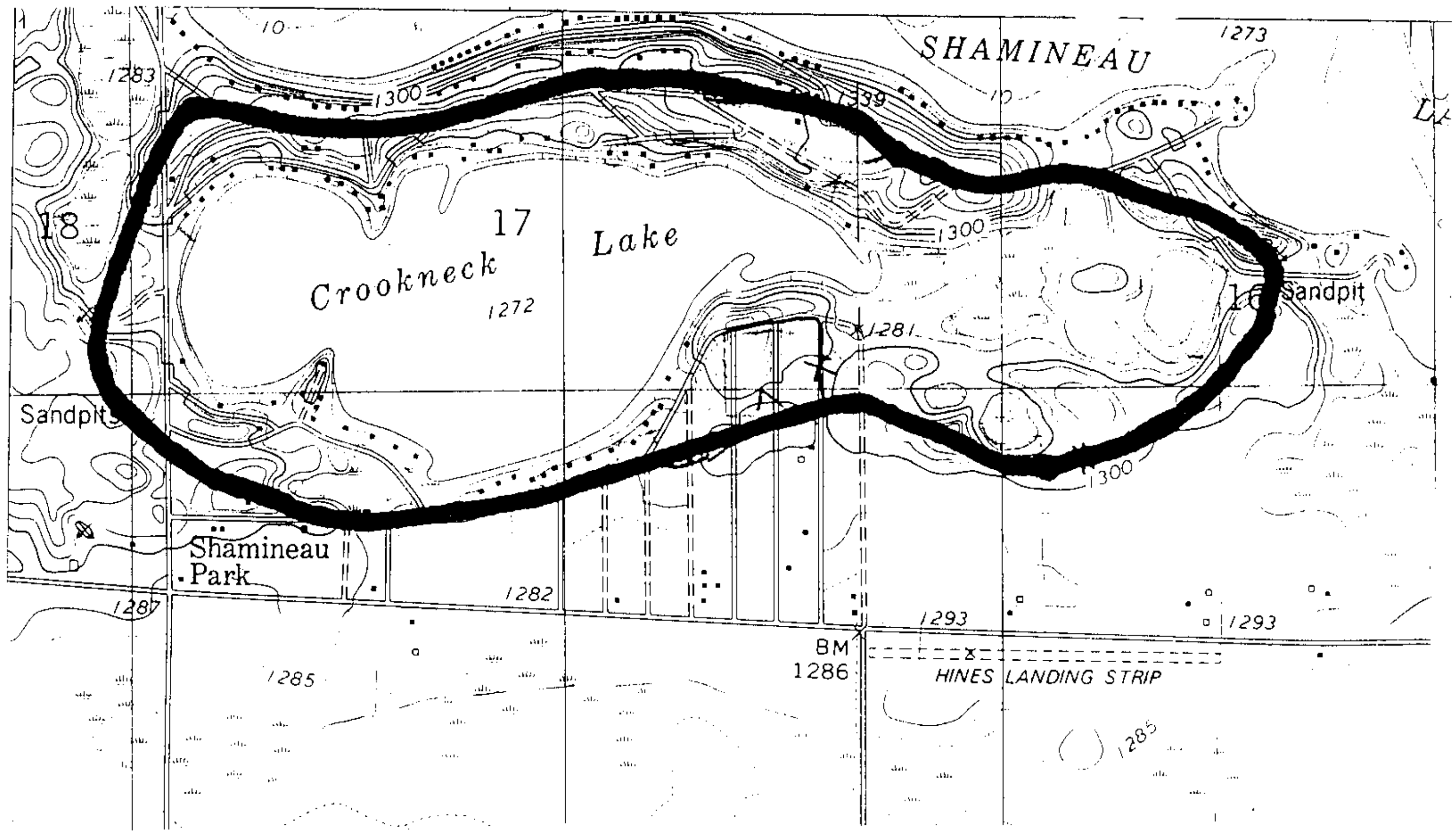
CROOKNECK LAKE FISHERY CHARACTERISTICS

1992 Fish Population Status

Minnesota's lakes have been classified using a number of physical and chemical parameters in order to make fish community comparisons and facilitate proper management. Crookneck Lake belongs to Lake Class 29 which is characterized by relatively small, shallow lakes with extensive littoral area. Secchi disk

MAP 4

CROOKNECK LAKE'S WATERSHED



transparencies and total alkalinities in the moderate range typify Lake Class 29 lakes.

The most recent fish survey on Crookneck Lake was conducted in June of 1991. Gamefish populations or northern pike, largemouth bass, walleye, black crappie, bluegill, rock bass and yellow perch were noted. Other species present included white sucker, brown bullhead and black bullhead.

Northern pike gillnet catches indicated a very high population for Lake Class 29. Fish collected ranged in length from 12 to 34 inches. Growth rates were normal and reproduction appears good as many year classes were represented.

The walleye sample consisted of only four fish ranging in length from 20 to 24 inches. These fish were the result of a stocking of yearling walleyes in 1987. Fingerling walleyes stocked in 1988 and 1989 did not show up in the survey. High northern pike populations are often correlated with low walleye populations because northern pike prey on small walleyes. Northern pike also prey heavily on yellow perch which are an important forage species for walleyes. Due to the low survival and return from fingerling stocking, Crookneck Lake will no longer be stocked with fingerling walleyes.

Populations of bluegill, rock bass, and pumpkinseed were high for Lake Class 29. Bluegill and black crappie growth rates were slow and the populations show evidence of stunting. No bluegills and only one crappie over seven inches in length were observed. Heavy weed growth provides extensive cover for small panfish to hide, which reduces their vulnerability to predators. Stunting of panfish is common in relatively clear, weedy lakes with high northern pike populations.

Largemouth bass were sampled in low numbers during the survey, however, this species is difficult to capture with netting gear. An electrofishing assessment will be performed in conjunction with the next netting survey in 1997 to aid in the evaluation of the bass population.

Yellow perch net catches were low for this lake class. High northern pike populations often depress perch numbers as they are a preferred forage fish. Low perch numbers also allow for increases reproduction of sunfish and crappie which adds to the stunting problem.

Fisheries Management

Past fisheries management on Crookneck Lake consisted of northern pike stocking in 1972 and 1980, and walleye stocking in 1987, 1988, 1989. As the northern pike numbers increased the high population was identified as a problem to proper management of the fish community. Northern pike were removed from the lake in 1987, 1988, and 1989 with no apparent effect as northern pike are still considered overabundant. Bullheads were also removed by commercial fisherman in 1990.

The fish community on Crookneck Lake will be monitored on a six year basis. Assessment netting and electrofishing surveys will be conducted every six years beginning in 1997 to determine changes in fish populations and provide information for management decisions. Current information indicates the lake is best suited for management of largemouth bass, panfish, and northern pike.

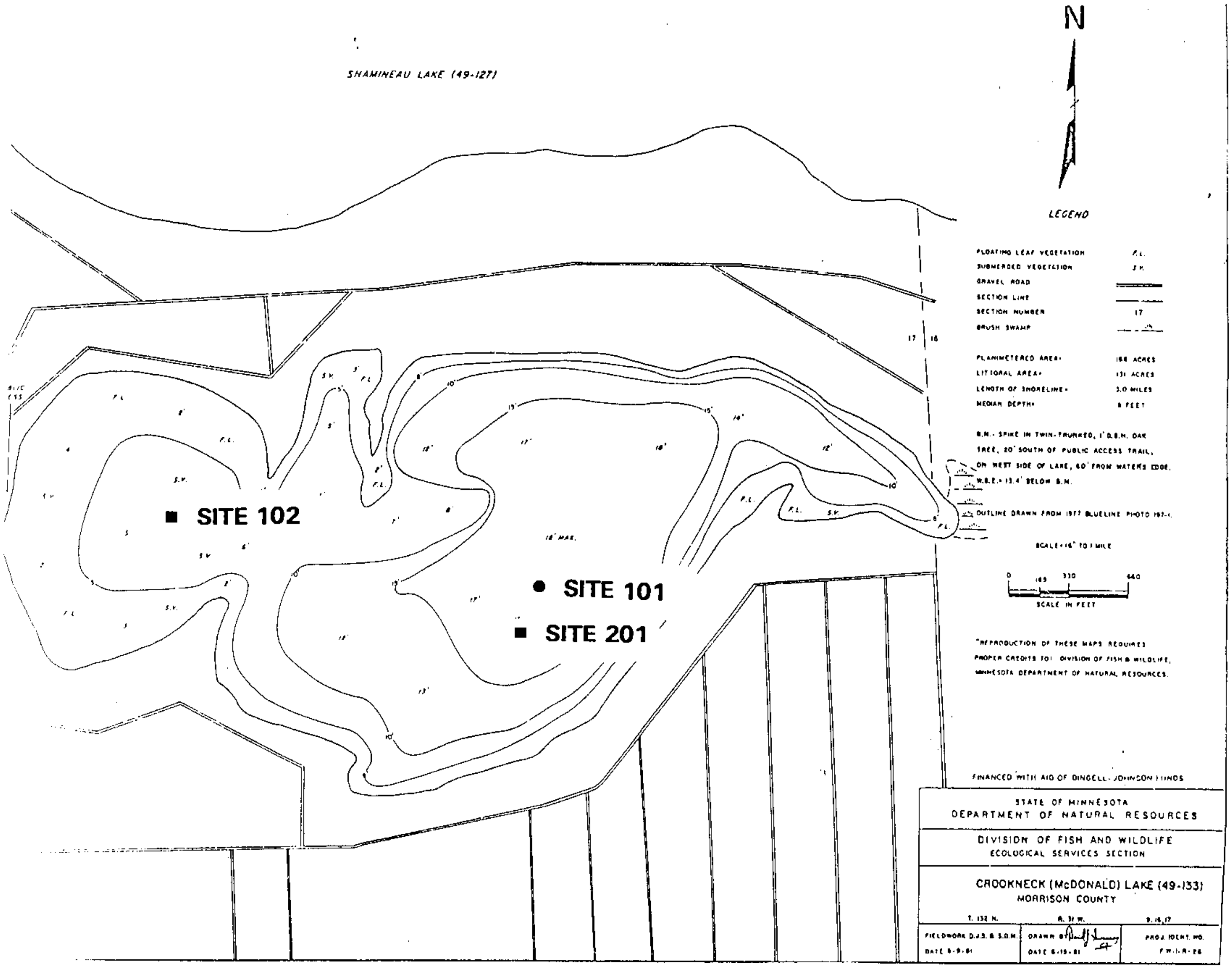
Protection of habitat within the lake and along its shoreline is critical in maintaining a healthy fish community. Land use practices within the lake's watershed can also have significant impacts on water quality and fish populations. Habitat protection and watershed management have warranted increased emphasis by fisheries managers.

WATER QUALITY RESULTS AND DISCUSSION

Water quality data was collected on May 20, June 18, July 20, August 19, and September 21, 1992 on Crookneck Lake, at site 101 in the lake basin (Map 5). Additionally, samples were taken at

MAP 5

CROOKNECK LAKE'S SAMPLING SITES



site 102 in the bay on three occasions, at the request of the lake association, for comparison with the rest of the lake. 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, color, solids, pH, conductivity, alkalinity, turbidity, and chlorophyll a (Appendix B). Temperature and dissolved oxygen profile 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 Crookneck Lake. No thermal (temperature) stratification was evident during the summer of 1992 (i.e. no distinct layers formed) (Figure 1).

In Crookneck Lake the maximum epilimnitic[9] (upper waters) temperature recorded was 21.5 degrees Celsius and was observed on the August 19, 1992 sample date. The minimum epilimenitic temperature was 15.5 degrees Celsius observed on September 21, 1992. The minimum hypolimnitic (bottom waters) temperature was 19.5 degree Celsius observed on August 19, 1992. The differences between the epilimnion and hypolimnion temperature was very slight if non-existent on most dates.

The dissolved oxygen concentrations in Crookneck Lake remained above 5 mg/l throughout the water column during May and June 1992. On the July and August sample date the dissolved oxygen remained above 5 mg/l in the epilimnion (upper waters) however, the dissolved oxygen dropped below 5 mg/l in the hypolimnion (lower waters) (Figure 1). An oxygen concentration below 5 mg/l is to low to support game fish. On the August sample date the dissolved oxygen approached 0 mg/l indicating the lake was nearing an anoxic condition (devoid of oxygen)near the bottom of the lake. An oxygen concentration below 5 mg/l is to low to support game fish.

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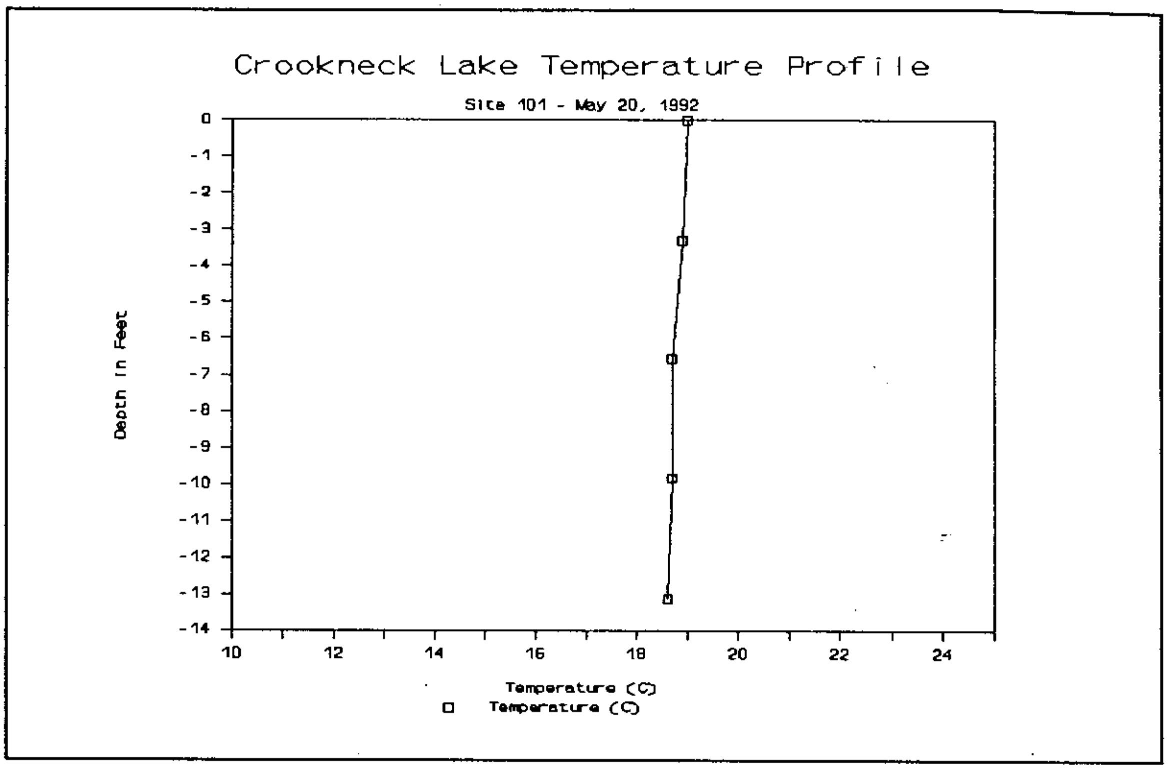
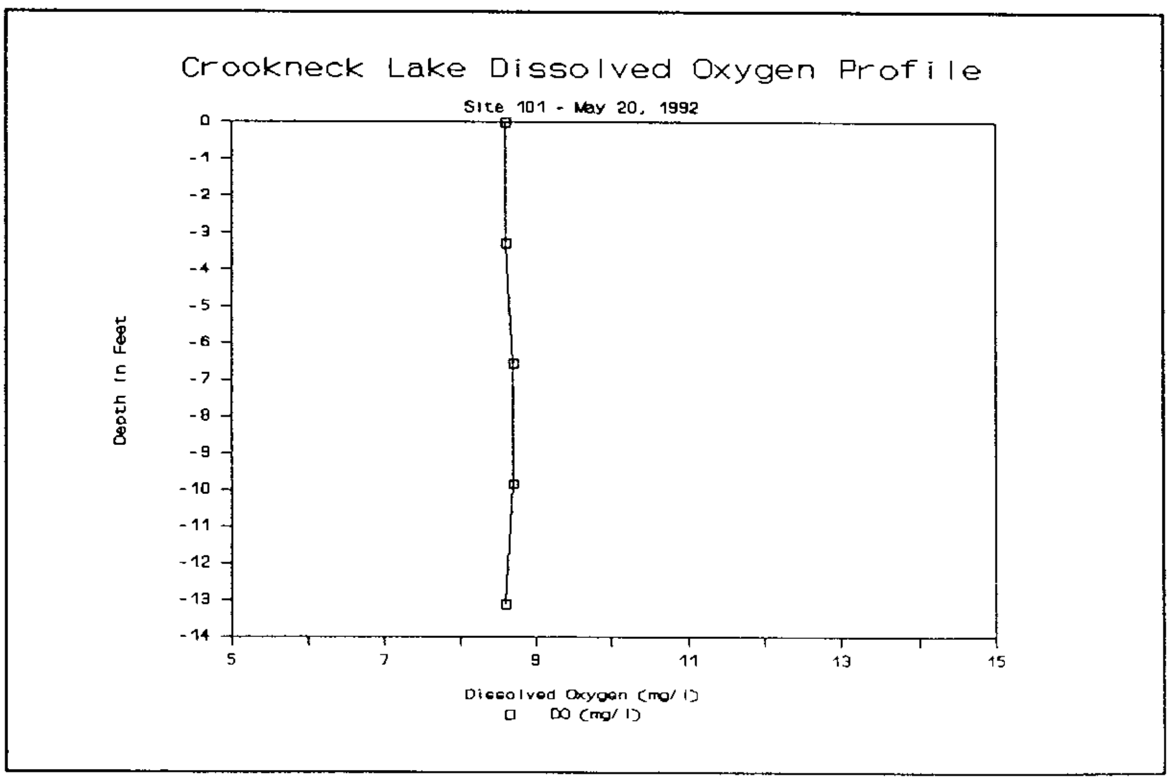
[9] For purposes of this report, the terms epilimnion and hypolimnion are used to define the upper and lower layers of the water column. Since no thermal stratification was present in Crookneck Lake, the technical definition of epilimnion and hypolimnion would not be present.

FIGURE 1

DISSOLVED OXYGEN AND TEMPERATURE PROFILES FOR CROOKNECK LAKE





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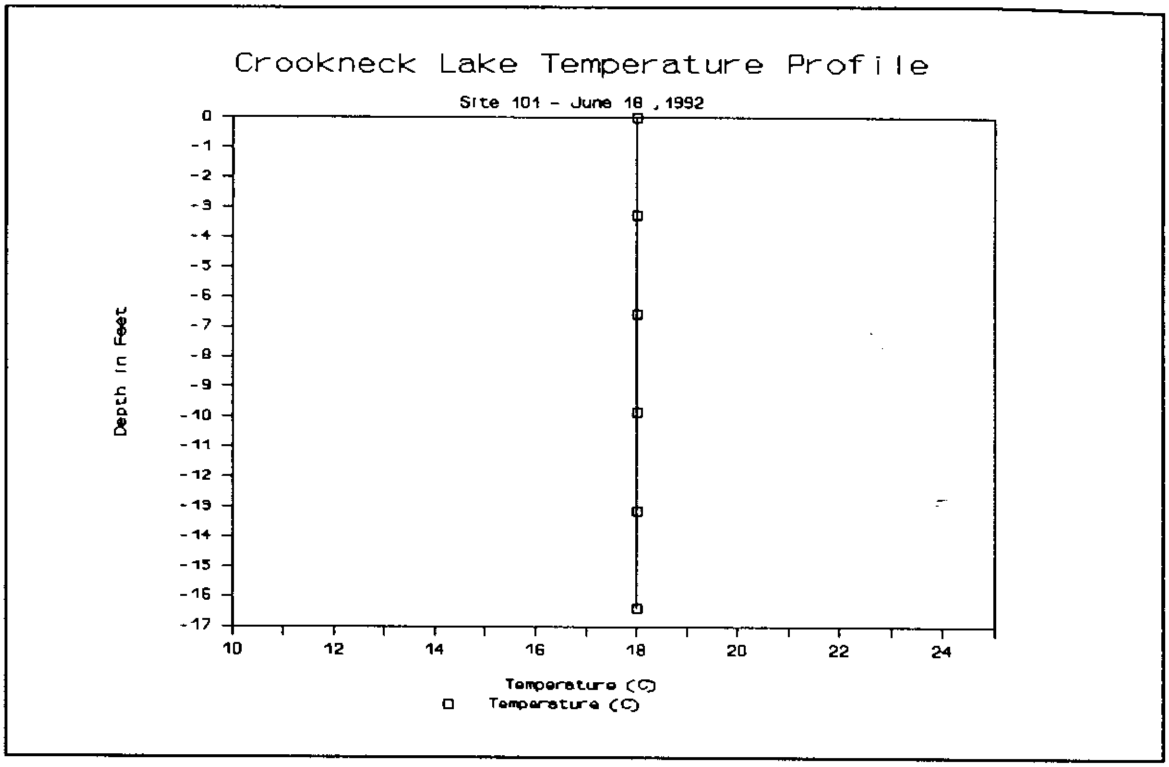

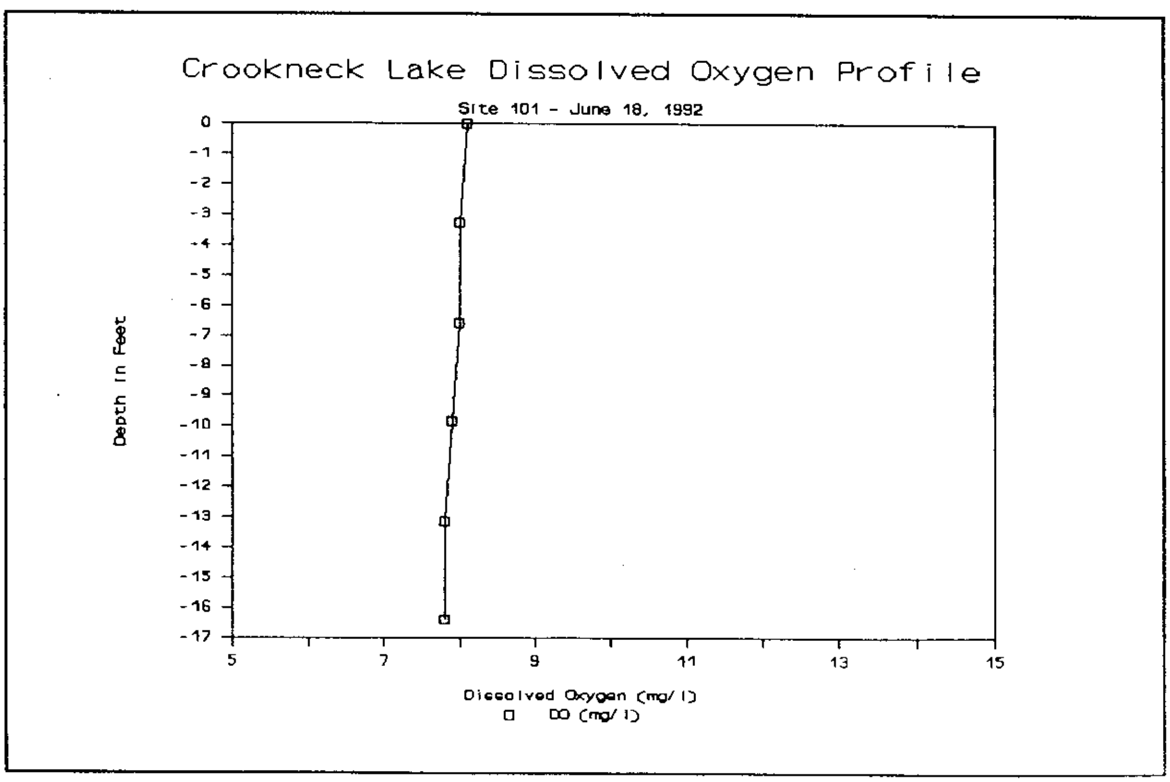

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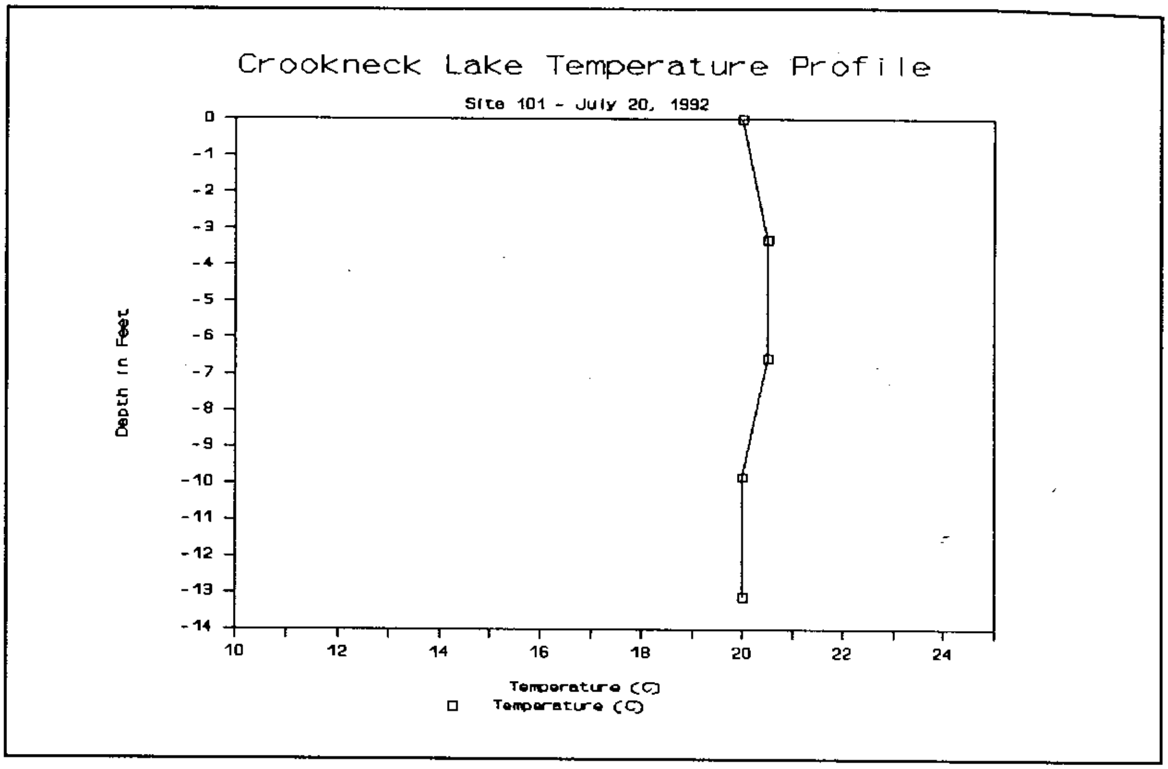

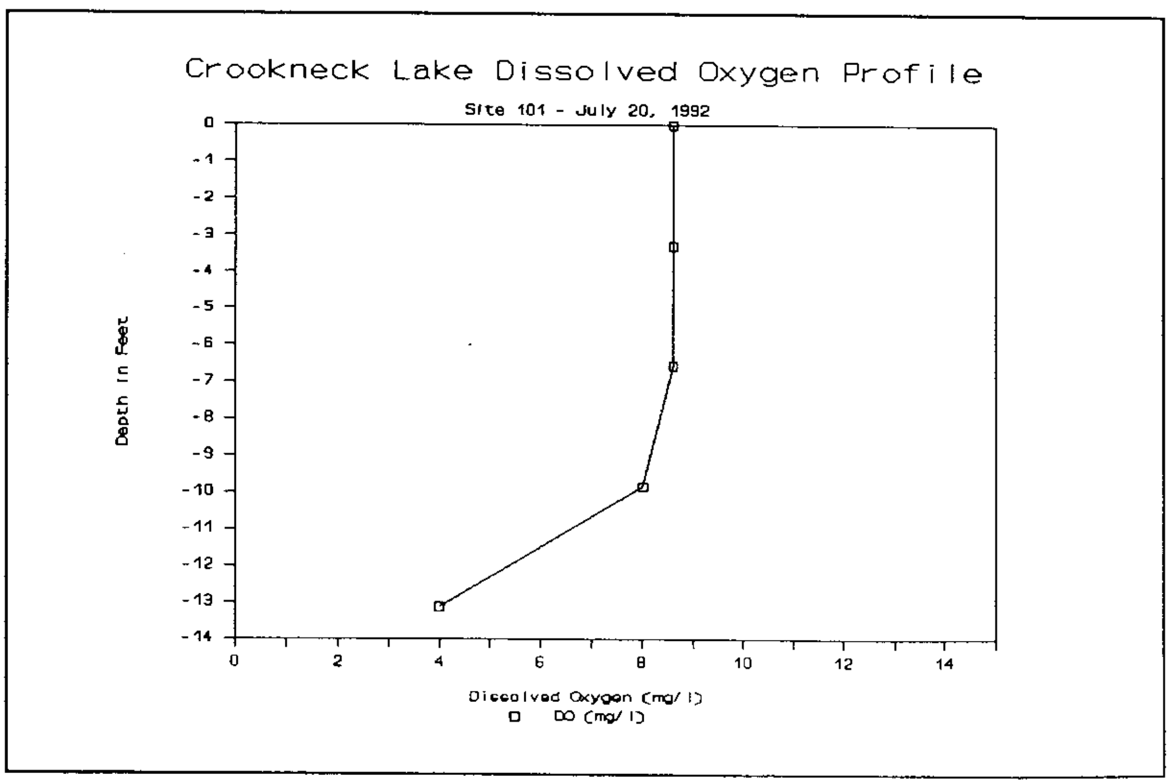

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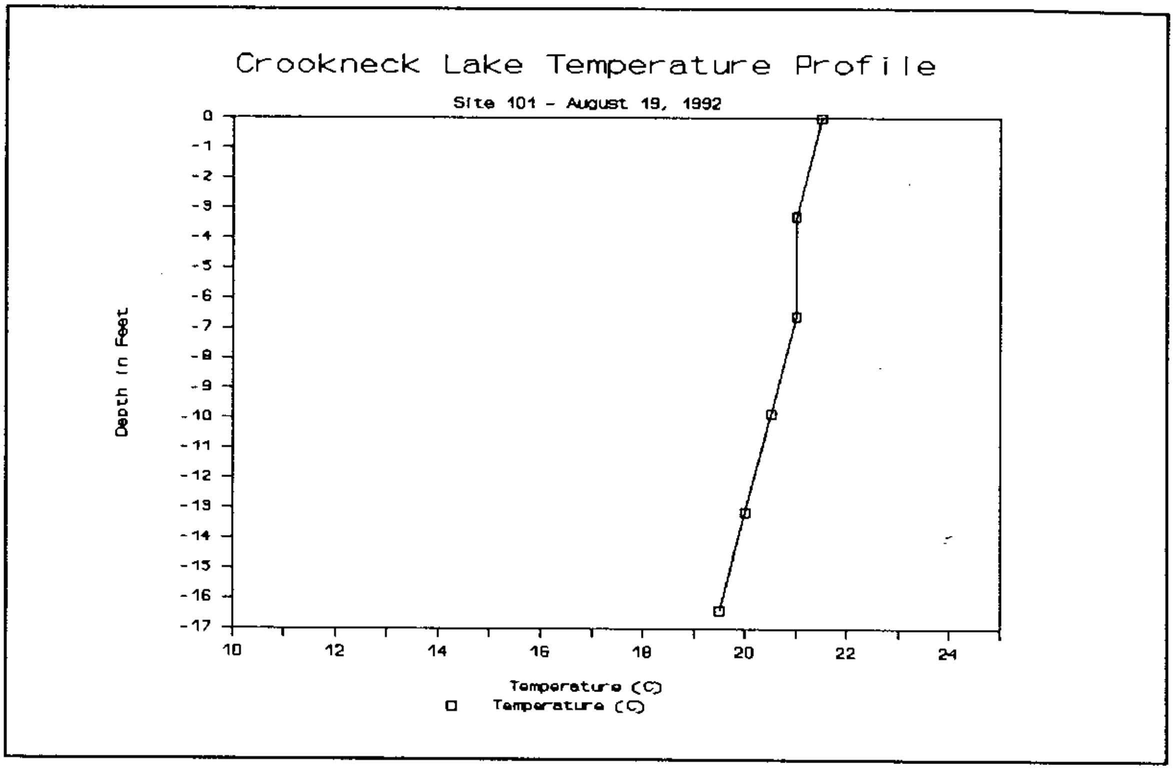

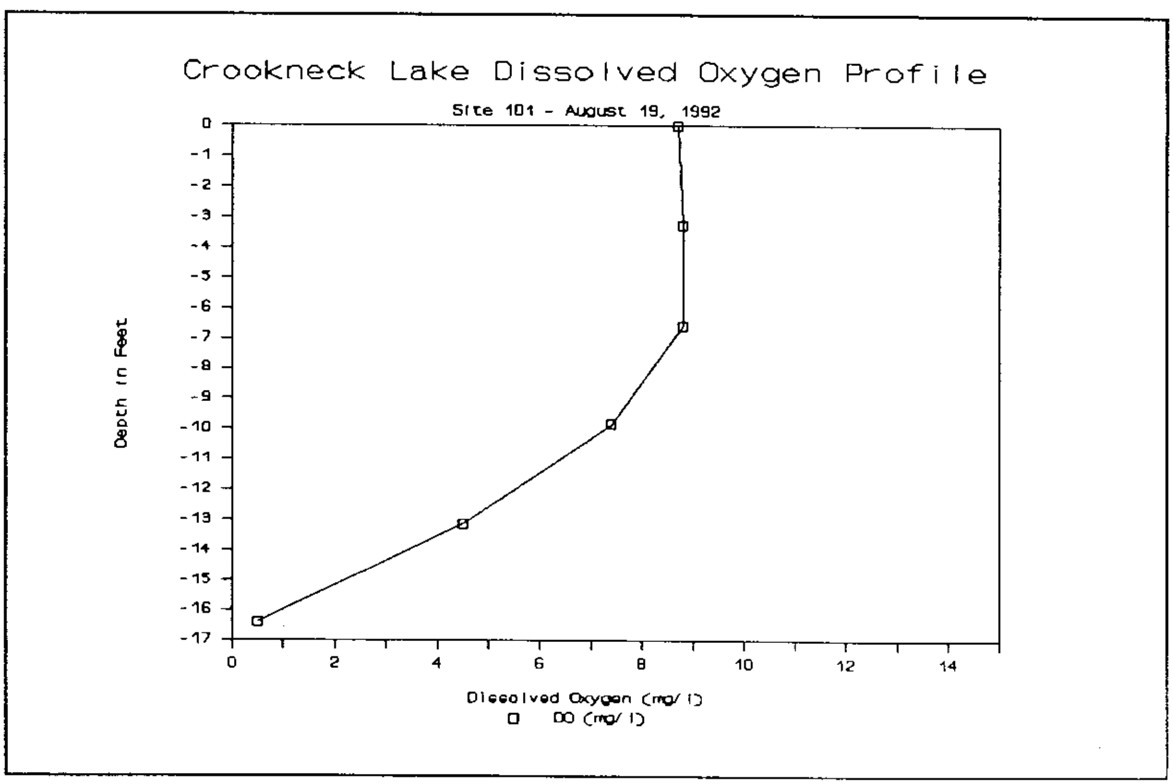

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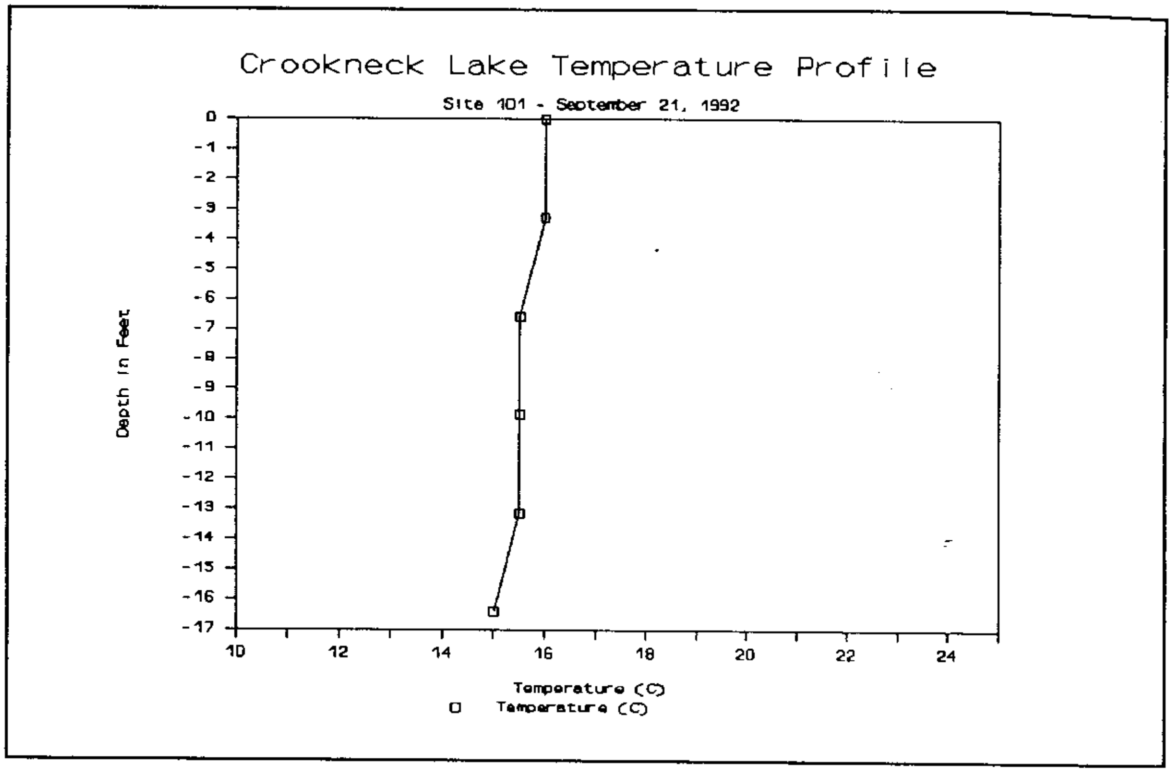
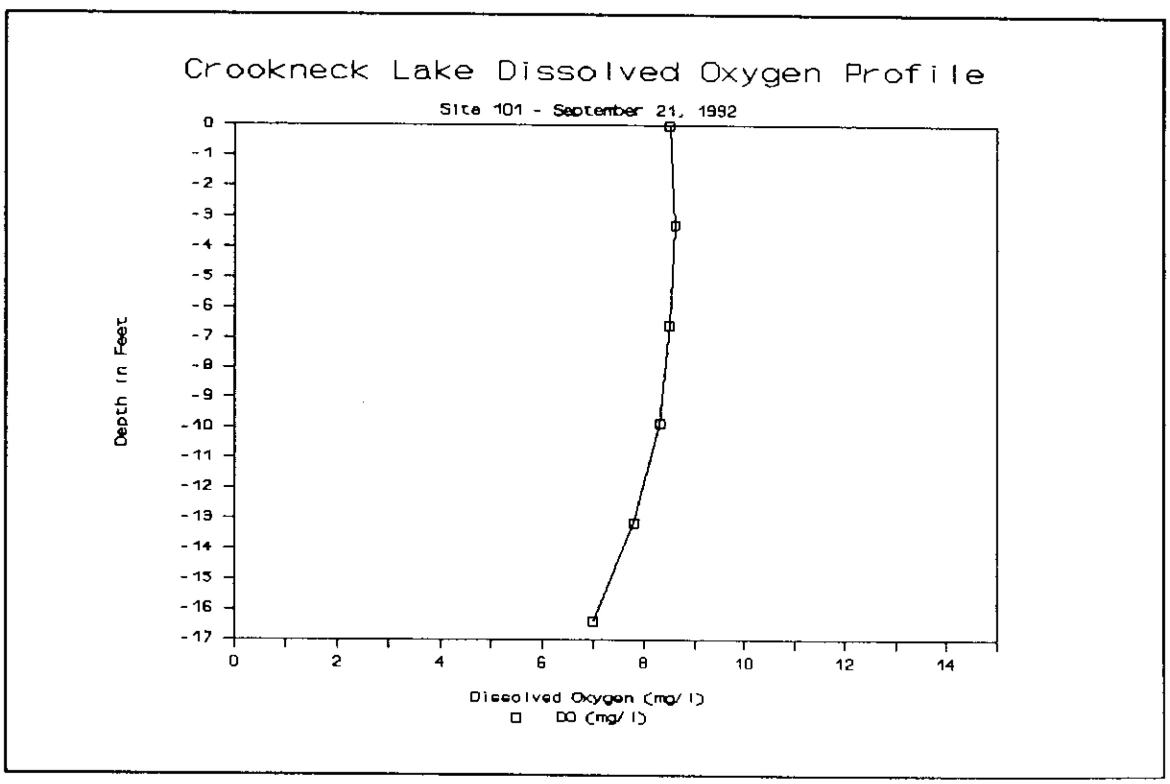




A reduction of oxygen in the hypolimnion (lower layer) indicates that the sediments of the lake are placing a demand on the dissolved oxygen in the water. The oxygen is depleted as it is used to decompose organic matter in the sediments. The effects are most pronounced during periods of stratification when there is little or no oxygen produced in the hypolimnion. This is a common occurrence in lakes which stratify throughout the summer. In the case of a shallow lake like Crookneck, which did not stratify, low oxygen concentrations in the bottom waters may coincide with very calm periods (i.e. no wind mixing) with warm temperature in the bottom waters (i.e. July and August), and low transparency.

In unstratified lakes, when the hypolimnion (lower layer) becomes anoxic, phosphorus is released into the water layer just above the sediments and become available for aquatic plant and algae use. In stratfied lakes, once the stratification layer breaks down, the phosphorus enters the water column during the fall turnover and become available for use.

The epilimnetic total phosphorus (TP) concentration (an important nutrient for plant growth) in Crookneck Lake ranged from 20-40 ug/l (micrograms per liter or parts per billion) during the sampling season with a mean (average) concentration of 30 ug/l. The mean value for Crookneck Lake is within the range of values in minimally impacted lakes in the North Central Hardwood Forest ecoregion (Table 2) which range from 23 to 50 ug/l.

At the request of the lake association samples were also taken in the western bay (Site 102) on three occasions. Those samples were very similar to the main lake indicating that there is

TABLE 2
AVERAGE SUMMER WATER QUALITY INDICATORS
Based on epilimnetic data from 1992
Crookneck Lake

Parameter	Crookneck Lake	Typical Range for Ecoregion[10]
Total Phosphorus (ug/l)	30.2	23-50
Chlorophyll *a* (ug/l) mean	7.22	5-22
Chlorophyll *a* (ug/l) maximum	15.00	7-37
Secchi disk (feet)[11]	6.6	4.9-10.5
Total Kjeldahl Nitrogen (mg/l)	.782	<0.60-1.2
Nitrite + Nitrate-N (mg/l)	.010	<0.01
Alkalinity (mg/l)	80.0	75-150
Color (Pt-Co Units)	11.25	10-20
pH (SU)	8.8	8.6-8.8
Chloride (mg/l)	1.77	4-10
Total Suspended Solids (mg/l)	2.57	2-6
Total Suspended Inorganic Solids (mg/l)	0.675	1-2
Turbidity	1.949	1-2
Conductivity (umho/cm)	146.6	300-400
TN:TP Ratio	26.2:1	25:1-35:1

interaction between the water bodies, and neither body acts significantly independent of the other (Table 3). The problems with aquatic vegetation growth and algae blooms are probably more of a function of the shallow depth in the bay.

[10] 25 - 75th percentile of representative-minimally impacted lakes in the North Central Hardwood Forests Ecoregion (Heiskary and Wilson, 1988).

[11] Includes CLMP data.

Hypolimnetic (lower layer) phosphorus concentrations were measured in Crookneck Lake during the sampling season. The

TABLE 3
TOTAL PHOSPHORUS CONCENTRATIONS IN 1992
(ug/l)
Sites 101 and 102
Crookneck Lake

Sample Date	Site 101 (ug/l)	Site 102 (ug/l)
July 20, 1992	35.0	29.0
August 19, 1992	20.0	23.0
September 21, 1992	38.0	40.0

highest hypolimnetic phosphorus concentration measured in Crookneck Lake was 56 ug/l on September 21, 1992. The mean hypolimnetic phosphorus was 38 ug/l which is slightly higher than the epilimnetic phosphorus. The slightly higher readings could be the result of the sediments releasing phosphorus back into the water column and particles (algae and sediment) settling in the bottom waters.

The total nitrogen (TN) concentration, which consists of total Kjeldahl nitrogen plus nitrate-N, averaged 0.792 mg/l in Crookneck Lake over the summer of 1992. This concentration is within the range typically observed in the ecoregion. The mean nitrite + nitrate-N concentration was less than .0100 mg/l in Crookneck Lake, which is typical for lakes in this region (Table 2).

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 Crookneck Lake is 26.2:1. 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 within the range found in minimally impacted lakes in the North Central Hardwood Forests Ecoregion.

Chlorophyll a concentrations provide an estimate of the amount of algal production in a lake. During the summer of 1992, chlorophyll a concentrations averaged 7.22 ug/l for Crookneck Lake (Figure 2). The maximum concentration for Crookneck Lake was 15.0 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 Crookneck Lake the concentrations of chlorophyll a generally increased over the summer (which is common in Minnesota lakes) from 2.24 ug/l to 15.00 ug/l. However, the concentration varied widely from one sample period to another. The average and peak concentrations of chlorophyll a for Crookneck Lake are within the range of chlorophyll a concentrations for minimally impacted lakes in the Ecoregion.

The composition of the phytoplankton (algae) population of Crookneck Lake as collected at Site 101 is presented in Figure 3. The information is presented in terms of algal type. The June 18, 1992 sample was dominated by Chrysophyta (diatoms) algae (35 percent) followed by Pyrrhophyta (Ceratium) (30 percent) and Cyanophyta (blue-green) algae (20 percent). Chlorophyta (green) followed with 15 percent.

In the August 19, 1992 sample, was dominated by the Cyanophyta (blue-green) (Anabaena, Nostoc, Oscillatoria/Lyngbya) algae at 95 percent. The remaining 5 percent consisted of Chlorophyta (green) algae.

By the September 21, 1992 sample in Crookneck Lake, Cyanophyta (blue-green) algae were present at 40 percent. However, the Chlorophyta (green) algae dominated the sample at 50 percent. Chrysophyta (diatoms) algae consisted of 10 percent. 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 Crookneck Lake the color averaged 11.25 Platinum-Cobalt (Pt-Co) Units which indicates relatively clear water free from sediments or bog staining.

FIGURE 2

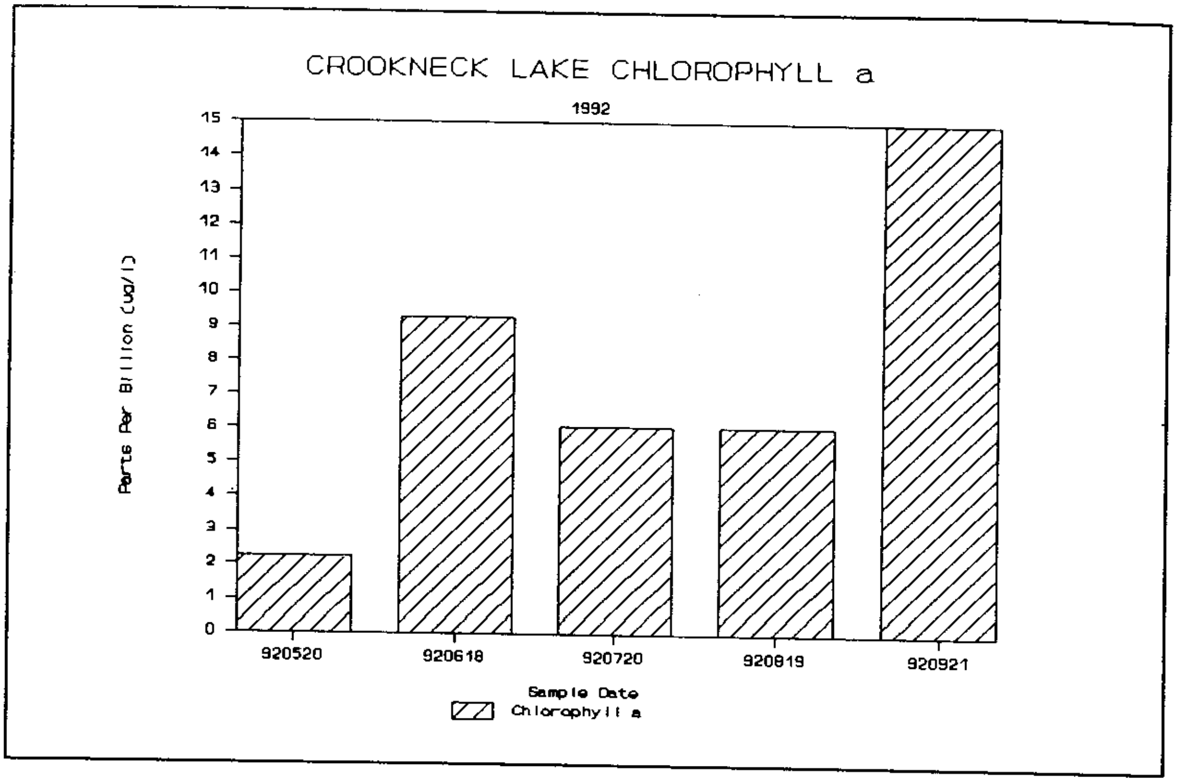
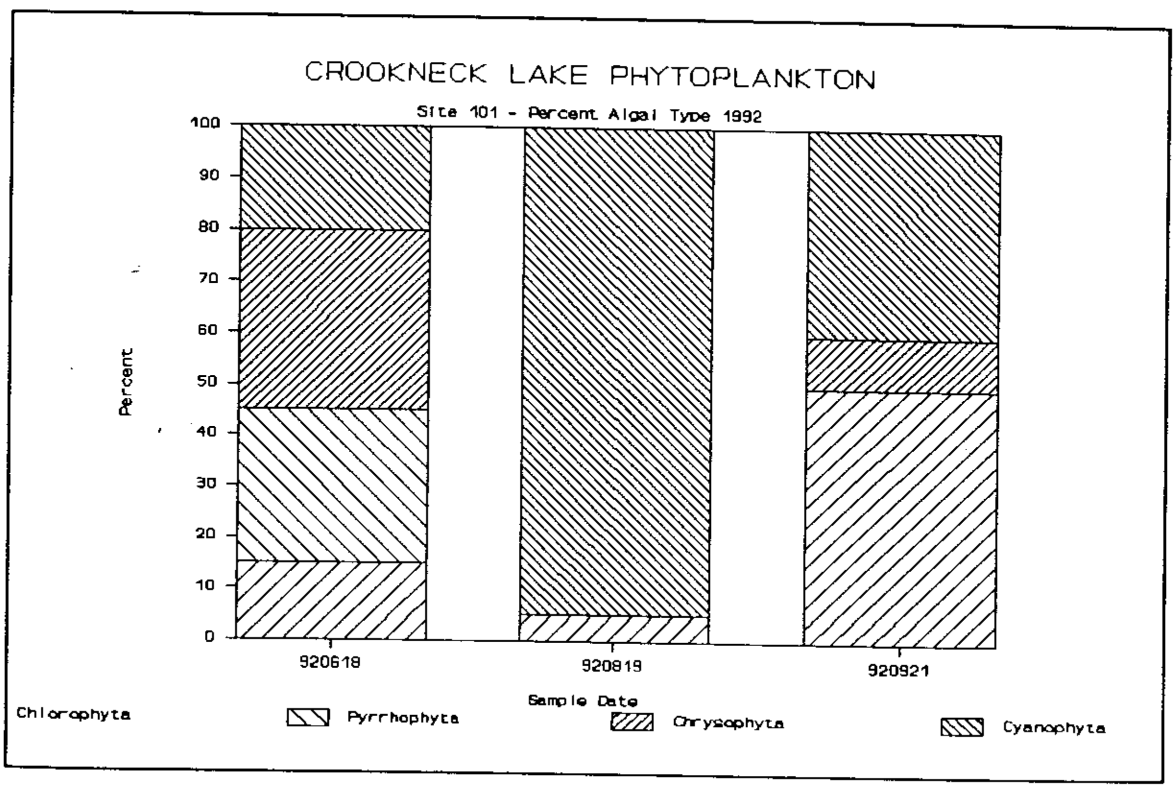


FIGURE 3



Total suspended solids (TSS) values averaged 2.6 mg/l for Crookneck Lake, which is in the range typically found in ecoregion lakes. At these levels, the lake water color or total suspended solids should not appreciably limit the Secchi transparency of the lakes.

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

Site	Month	Secchi (Mean-feet)	Recreational Suitability (Mean Class)	Physical Appearance (Mean Class)
Site 201	May	12.5	2	3
	June	11.3	2	3
	July	6.5	3	3
	Aug.	6.5	4	4
	Sept.	7.3	4	4

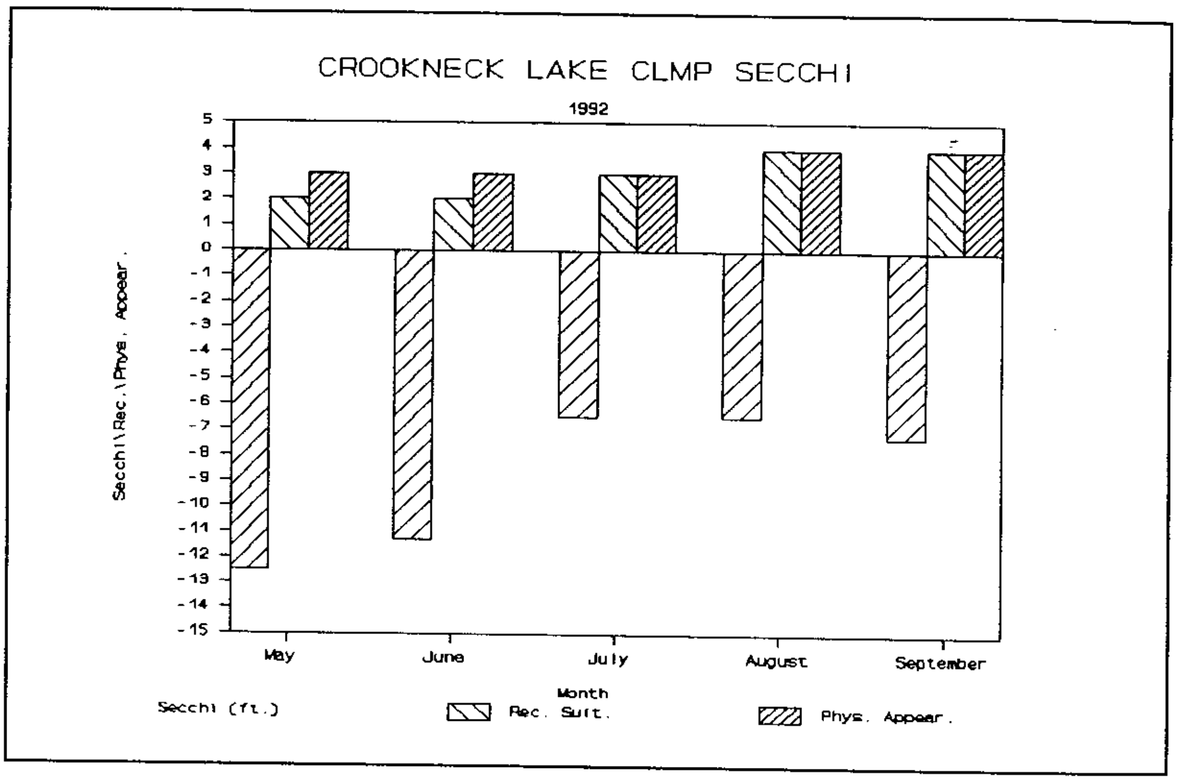
Secchi disk measurements were also taken during the summer of 1992 through the Minnesota Pollution Control Agency's Citizens Lake Monitoring Program. The summer mean Secchi transparency for Crookneck Lake was 7.9 feet at site 201 (Table 4). This value is typical for minimally impacted lakes in the North Central Hardwood Forest Ecoregion (Table 2).

Along with the CLMP transparency measurements, subjective measures of "physical appearance" and "recreational suitability" were made by the CLMP observer in 1991 (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 Crookneck Lake in 1992 are summarized in Table 4 and Figure 4 from the CLMP records in Appendix B. The 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 Crookneck Lake the CLMP transparency averaged 7.1 feet from June through September. The recreational suitability ratings ranged from Class 3 (swimming and aesthetic enjoyment slightly impaired) to Class 4 (swimming and aesthetic enjoyment substantially impaired)(Table 4). Physical appearance ratings also ranged from Class 3 (Definite algal presence) to Class 4 (High algae present) during the summer (Table 4). Class 4 ratings were generally associated with transparencies of 7 feet or less and chlorophyll a concentrations greater than about 5 ug/l.

The other water quality parameters such as conductivity, turbidity, and alkalinity, in Crookneck Lake are well within the typical range for lakes in the North Central Hardwood Forest

FIGURE 4



CROOKNECK 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.

Ecoregion (Table 2). The alkalinity and conductivity indicate that Crookneck Lake is a well buffered hard-water lake and would not be considered sensitive to acid deposition.

Trophic Status Index

One method to evaluate the trophic status of a lake and to interpret the relationship between total phosphorus, chlorophyll a, 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 Crookneck Lake and the respective TSI's are presented in Table 5 and Figure 5. Based on these values, Crookneck Lake would be considered borderline mesotrophic to eutrophic. The mean TSI of 50.5 for Crookneck Lake would rank the lake at the 74th percentile relative to 600 other lakes in the North Central Hardwood Forest Ecoregion. In other words, the lakes's TSI value is lower (less eutrophic) than 74 percent of the lakes evaluated in the region.

TABLE 5
TROPHIC STATUS INDICATORS
CROOKNECK LAKE

Carlson Trophic State Index Value	
TP TSIP	52.9
Chl-a TSIC	48.9
Secchi TSIS	49.9
Mean TSI	50.5
Percentile[12]	74th

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 Crookneck Lake are noted in Figure 6. In general, we note that the total phosphorus - chlorophyll a - Secchi transparency relationships for Crookneck Lake is typical of observations in other Minnesota lakes. Figure 6 also suggests

[12] Relative to approximately 600 lakes in the North Central Hardwood Forest Ecoregion. A one hundred percent level implies the lowest TP concentrations or deepest Secchi disk measurement for that Ecoregion.

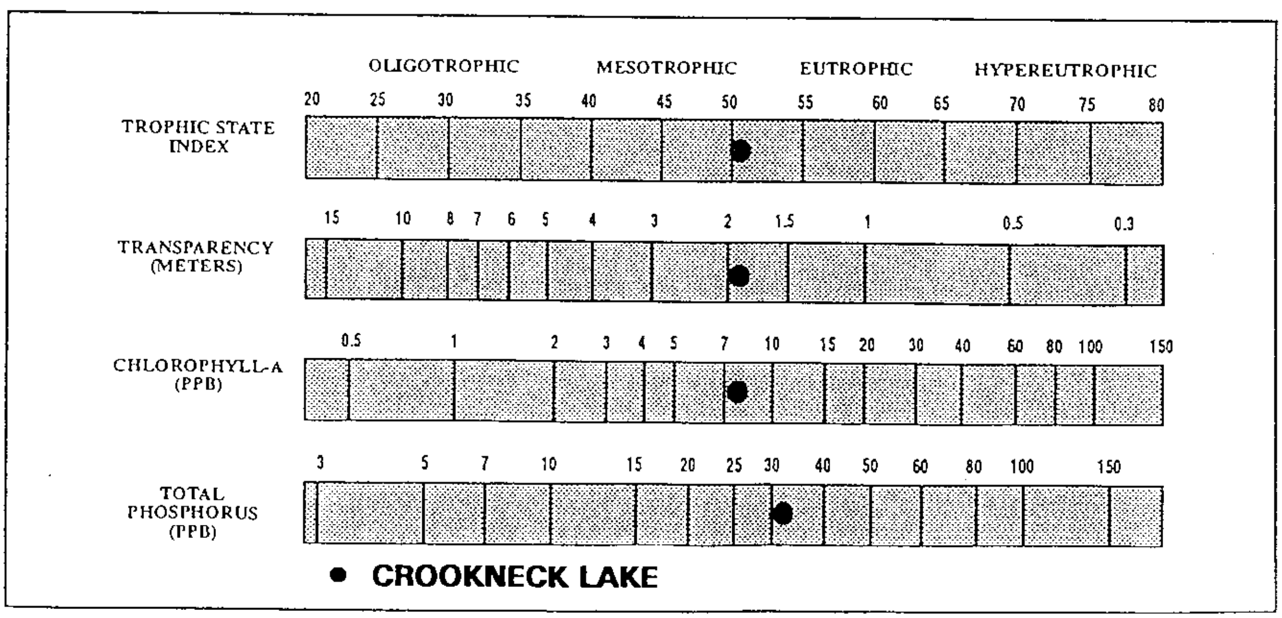
FIGURE 5

CARLSON'S TROPHIC STATUS INDEX VALUES FOR CROOKNECK LAKE

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

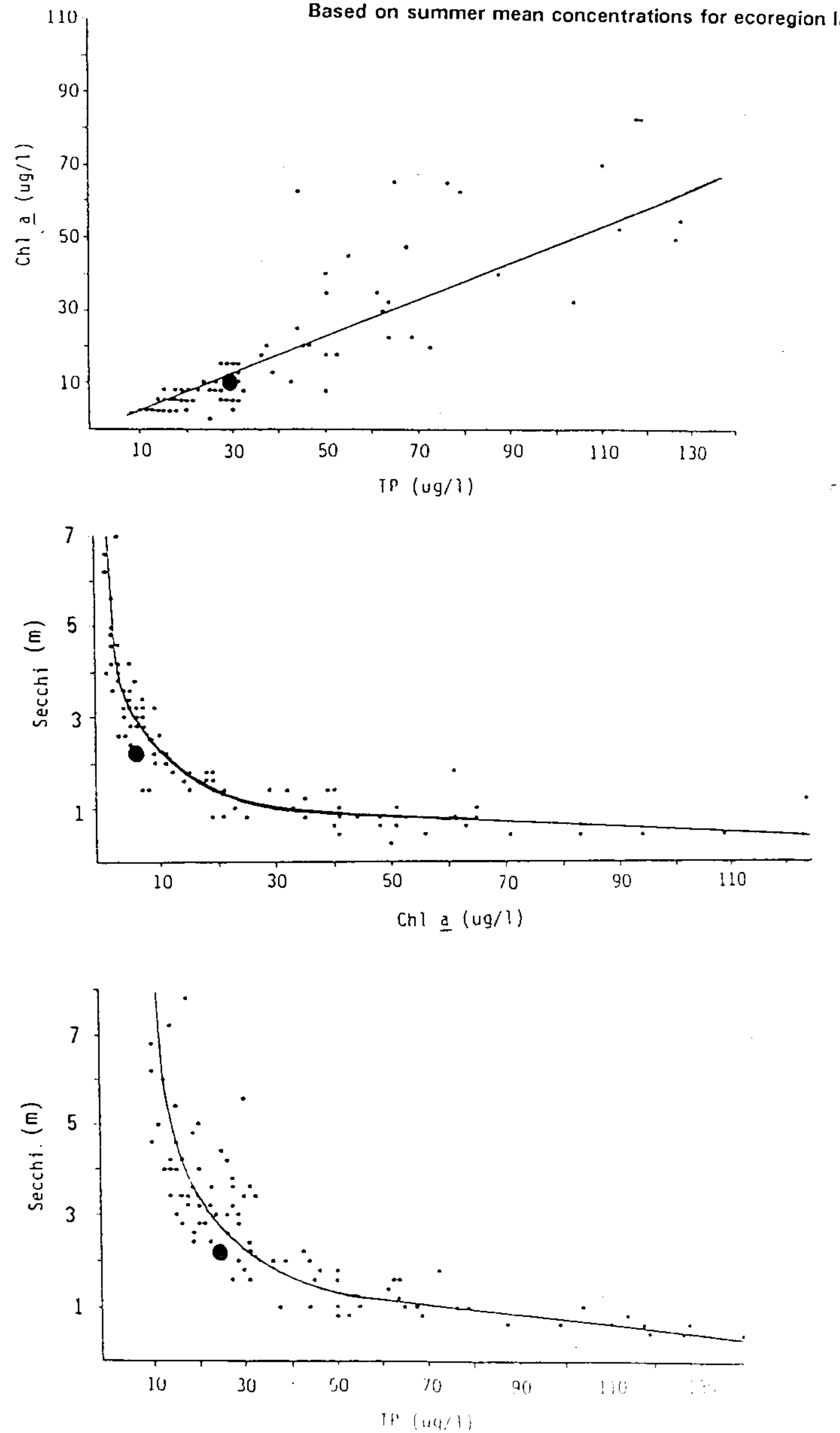
R.E. Carlson

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.



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

FIGURE 6
SCATTERPLOTS OF CHLOROPHYLL-a, SECCHI TRANSPARENCY, AND TOTAL PHOSPHORUS
Based on summer mean concentrations for ecoregion lakes



• CROOKNECK LAKE

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 Crookneck Lake.

Water Quality Trends

For Crookneck Lake little data is available for assessing the seasonal or long-term trends in the water quality. In terms of 1992 seasonal trends, total phosphorus concentrations fluctuated in the lake during the sampling season. The total phosphorus ranged from 48 ug/l in May, 27 ug/l in June, 20 ug/l in August, and finally 38 ug/l in September. The variability in total phosphorus during the spring to summer may be related to the uptake and cycling of phosphorus by algae and rooted plants within the lake, phosphorus loading from the watershed and possibly periodic reintroduction of phosphorus from the sediments.

The only "historical" data available for comparison consists of CLMP measurements collected by lake association members from 1989 through 1992. The Secchi disk data from 1989 through 1992 provides a basis for evaluating year-to-year variation in transparency (Table 6 and Figure 7).

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

Secchi Transparency
(in Feet)

1989	Std. Error	1990	Std. Error	1991	Std. Error	1992	Std. Error
7.3	± .15	9.3	± .58	8.6	± .36	8.0	± .49

Based on Secchi data from these four years it appears that transparency may vary from about 7 feet to 9.5 feet as a summer mean. Continued monitoring will be necessary to establish a long term mean and fully characterize year-to-year variation. This will provide a basis for assessing trends overtime. Based on the four years of data the average transparency is about 8 feet. The "average" yearly variation from this value is about one foot (or about 12 percent of the mean). This is calculated by subtracting the summer mean 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. 7.3 feet in 1989 to 9.4 feet in 1990 it is comparable to that observed in other lakes in the state (i.e. within about 10-20 percent of the long term mean).

Likewise, 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 7).

FIGURE 7

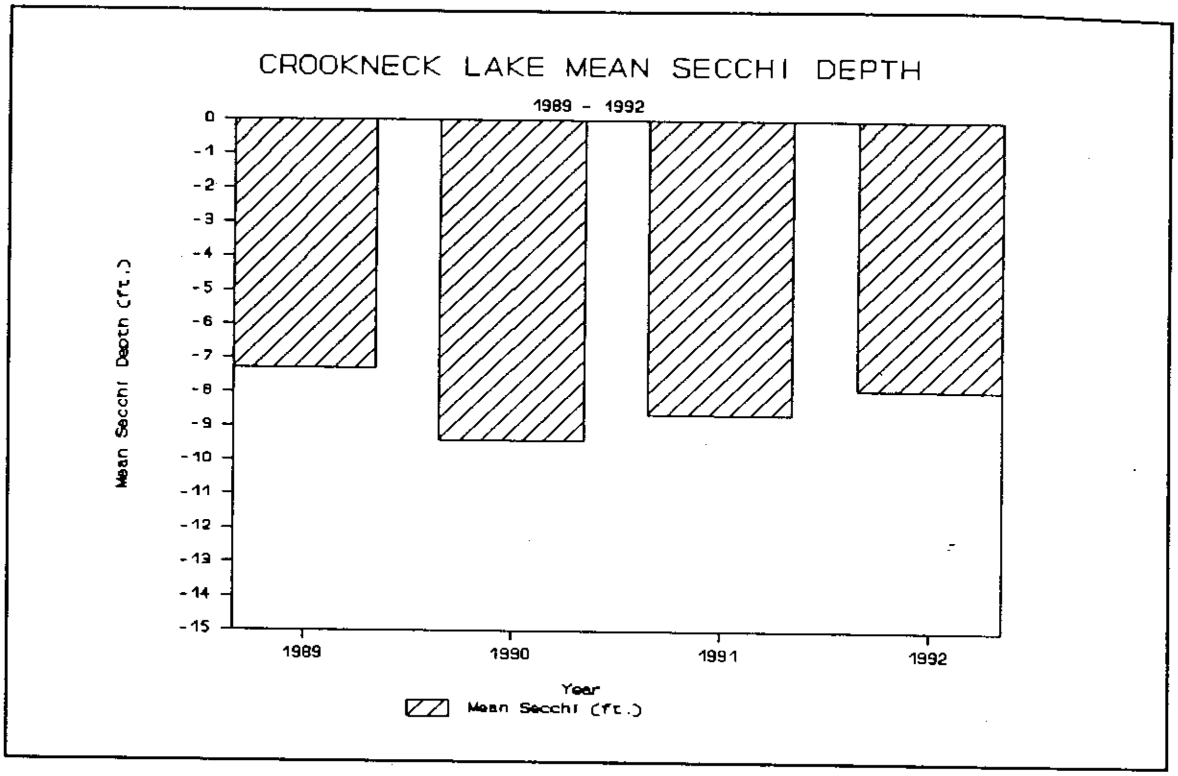
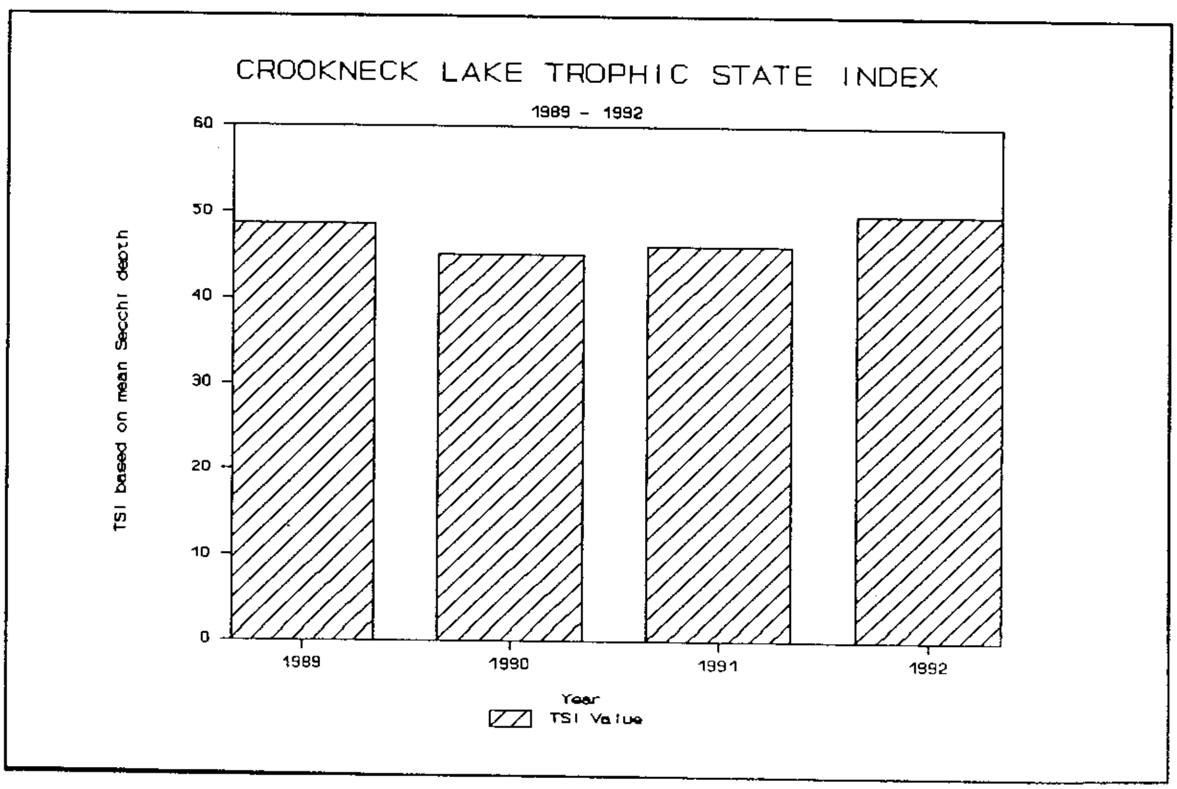


FIGURE 8



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 - it should provide an accurate estimate of changes in trophic condition over time.

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

Trophic State Index

1989	1990	1991	1992
48.7	45.2	46.2	49.9

It should be noted that the Summer mean Secchi transparency for a lake may vary 1 to 2 feet from year-to-year. This should be kept in mind when attempting to differentiate long term trends from normal year-to-year variation.

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 Crookneck 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 Crookneck 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 (1991). Inputs to the model are noted in Appendix B.

For Crookneck Lake the MINLEAP model predicted a very comparable phosphorus concentration (32 ug/l) compared to the observed concentration (30 ug/l) in 1992 (Table 11). The predicted Chlorophyll a of 10.41 ug/l is slightly higher than the observed 7.22 ug/l in 1992. Based on the MINLEAP model the estimated the water residence time (average time it would take to replace the entire volume of the lake) for Crookneck Lake is on the order of 7 - 8 years. Crookneck Lake retains approximately 85 percent of the phosphorus that enters the lake.

TABLE 8
CROOKNECK LAKE
MINLEAP MODELING AND OBSERVED CHARACTERISTICS COMPARISON
1992

	1992 Observed	Estimated MINLEAP
TP (ug/l)	30	32
Chlorophyll a	7.22	10.41
Secchi (meters)	2.01	1.95
Water Residence Time (yrs)	---	7.8 years
P retention coefficient	---	0.8529
Total Phosphorus Load	---	61 kg/year

The Reckhow and Simpson model was also used to estimate the water quality for Crookneck 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) and from the literature. The Canfield and Bachman (1981) model was used for the phosphorus load portion of the Reckhow 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 supplied by the Crookneck Lake Association and field checked by the MPCA Regional Office staff. Inputs and results of the model are noted in Appendix B.

The Reckhow and Simpson model predicts an in-lake phosphorus concentration of about 33 ug/l (Table 9) (Appendix B) using the "low" phosphorus export coefficient and the Canfield-Bachman lake

TABLE 9
CROOKNECK LAKE
RECKHOW AND SIMPSON MODEL PHOSPHORUS COMPARISON
1992

Total Phosphorus Concentration: 33 ug/l
Total P Flux: 58 ug/l

Land Use	Phosphorus Flux	Percent of Total
Forested	4	6.8
Agriculture	0	0.0
Urban	19	31.0
Wetland	1	1.7
Pasture or Open	1	1.7
Precipitation	16	27.5
Septic	17	29.3
Point Sources	0	0.0

model. The total P flux (58 kg/yr) using the low coefficients is comparable to the MINLEAP estimate (61 kg/yr).

The model also provides the opportunity to estimate the relative magnitude of phosphorus which might be exported from the variousland uses in the watershed during an average year. For Crookneck Lake, the Reckhow and Simpson model estimated that precipitation contributed about 27 percent of the phosphorus loading to the lake (Table 9). This relatively high contribution from precipitation is the result of the small watershed (lake occupies about 40 percent of the watershed). The largest amount was urban uses or residential uses, include lawn fertilization practices which accounted for 31.0 percent. Forested land uses contributed 6.8 percent of the phosphorus. Wetlands and open lands were responsible for 1.7 percent each.

Septic systems are estimated to contribute on the order of 29 percent of the phosphorus loading. This is based on a very conservative soil retention coefficient of 0.90, which implies that the soils retain 90 percent of the P load from septic tanks. However if the soil retains less (e.g. only 70 or 80 %) or if systems are poorly maintained the potential contribution could rise to approximately 46 percent of the P load to the lake.

The phosphorus loadings predicted by these models should be considered estimates only. The two models suggest differences in the amount of phosphorus expected to enter the lake. However, the two models have provided fairly comparable estimates of the in-lake conditions for the Crookneck Lake. Additionally, 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 Reckhow-Simpson model could provide a basis for estimating in-lake changes which could result for changes in land use in the watershed.

Goals and Objectives

The water quality observed in Crookneck 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 North Central Hardwood Forest 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 30 - 35 ug/l is appropriate for Crookneck Lake. A summer mean phosphorus concentration in this range should yield transparencies from 1.5 - 2.5 meters (4 - 7 feet) and a mean chlorophyll a from 7 - 15 ug/l. Over this range of phosphorus; chlorophyll a concentrations would exceed 10 ug/l ("scums evident) less than 44 percent of the summer.

In contrast, if the summer average TP increased to 40 ug/l the corresponding transparency would be on the order of 1.2 meters (4 feet) and chlorophyll a in the 15 to 20 ug/l range. Chlorophyll a values greater than 10 ug/l would likely occur on the order of 65 to 70 percent of the summer. These conditions would be perceptibly different than the conditions measured 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 6 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 Crookneck 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 and water budgets for the lakes and definition of year-to-year variability in water and nutrient budgets and other variations in the in-lake conditions. 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 Crookneck Lake and for developing and implementing protection strategies to maintain the current (1992) quality of the lakes.

The Crookneck 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 60 percent of the phosphorus entering the lake arises from urban land uses and septic tanks education and actions to insure compliance with rules and regulations concerning the construction of septic systems and the use of best management practices such as lawn fertilization are extremely important. The Crookneck Lake Association should work closely with the Morrison County Planning and Zoning Department in efforts to promote Best Management Practices (BMP's) in the watershed.

Finally, The Crookneck Lake Association should contact the Morrison County Planning and Zoning Office 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

CROOKNECK LAKE
DATA SUMMARY

CROOKNECK LAKE WATER QUALITY DATA IN STORET (LAKEID=49-0133)

DATE	SITE	D	TP	RTP	TKN	N2N3	RN2N3	TSS	TSIN	ALK	PHF	CL	CONF	TURB	COLOR	CHLA	PHEO	SDF
920520	101	0	.048		0.52	0.01	K	1.6	0.4	100	7.9	2.0	175	1.0	10	2.24	0.96	8.2
920618	101	0	.027	Q	0.15	0.01		1.5	0.7	86	8.3	1.9	170	1.7	20	9.29	2.24	6.9
920720	101	0	.035	Q	0.69	0.01		3.0	0.8	86	8.8	1.4	145	2.4	5	6.09	0.32	6.6
920720	101	14	.030	Q	0.53	.		.	.	.	.	.	.	.	.	.	.	.
920720	102	0	.029	Q	0.70	0.01	K	.	.	.	9.1	.	129	.	.	3.20	0.32	6.2
920819	101	0	.020	Q	0.82	0.01	K	2.4	0.2	78	9.0	1.4	140	1.8	10	6.09	0.32	7.9
920819	101	14	.027	Q	0.72	.		.	.	.	.	.	.	.	.	.	.	.
920819	102	0	.023	Q	0.71	0.01	K	.	.	.	9.3	.	130	.	.	4.81	0.32	5.9
920921	101	0	.038		1.30	0.01	K	3.4	1.0	70	8.9	2.4	140	1.9	10	15.00	0.32	6.9
920921	101	14	.056		1.35	.		.	.	.	.	.	.	.	.	.	.	.
920921	102	0	.040		1.11	0.01	K	.	.	.	8.8	.	140	.	.	6.09	0.32	5.9

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

CROOKNECK LAKE WATER QUALITY DATA IN STORET (LAKEID=49-0133)

DATE	SITE	D	TP	RTP	TKN	N2N3	RN2N3	TSS	TSIN	ALK	PHF	CL	CONF	TURB	COLOR	CHLA	PHEO	SDF
920520	101	0	.048		0.52	0.01	K	1.6	0.4	100	7.9	2.0	175	1.0	10	2.24	0.96	8.2
920618	101	0	.027	Q	0.15	0.01		1.5	0.7	86	8.3	1.9	170	1.7	20	9.29	2.24	6.9
920720	101	0	.035	Q	0.69	0.01		3.0	0.8	86	8.8	1.4	145	2.4	5	6.09	0.32	6.6
920720	101	14	.030	Q	0.53	.		.	.	.	.	.	.	.	.	.	.	.
920720	102	0	.029	Q	0.70	0.01	K	.	.	.	9.1	.	129	.	.	3.20	0.32	6.2
920819	101	0	.020	Q	0.82	0.01	K	2.4	0.2	78	9.0	1.4	140	1.8	10	6.09	0.32	7.9
920819	101	14	.027	Q	0.72	.		.	.	.	.	.	.	.	.	.	.	.
920819	102	0	.023	Q	0.71	0.01	K	.	.	.	9.3	.	130	.	.	4.81	0.32	5.9
920921	101	0	.038		1.30	0.01	K	3.4	1.0	70	8.9	2.4	140	1.9	10	15.00	0.32	6.9
920921	101	14	.056		1.35	.		.	.	.	.	.	.	.	.	.	.	.
920921	102	0	.040		1.11	0.01	K	.	.	.	8.8	.	140	.	.	6.09	0.32	5.9

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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

LAKEID=49-0133 SITE=101

OBS	DATE	DM	NDM	DO	TEMP	TP
66	920520	0	0	8.6	19.0	0.048
67	920520	1	-1	8.6	18.9	.
68	920520	2	-2	8.7	18.7	.
69	920520	3	-3	8.7	18.7	.
70	920520	4	-4	8.6	18.6	.
71	920618	0	0	8.1	18.0	0.027
72	920618	1	-1	8.0	18.0	.
73	920618	2	-2	8.0	18.0	.
74	920618	3	-3	7.9	18.0	.
75	920618	4	-4	7.8	18.0	.
76	920618	5	-5	7.8	18.0	.
77	920720	0	0	8.6	20.0	0.035
78	920720	1	-1	8.6	20.5	.
79	920720	2	-2	8.6	20.5	.
80	920720	3	-3	8.0	20.0	.
81	920720	4	-4	4.0	20.0	.
82	920819	0	0	8.7	21.5	0.020
83	920819	1	-1	8.8	21.0	.
84	920819	2	-2	8.8	21.0	.
85	920819	3	-3	7.4	20.5	.
86	920819	4	-4	4.5	20.0	.
87	920819	5	-5	0.5	19.5	.
88	920921	0	0	8.5	16.0	0.038
89	920921	1	-1	8.6	16.0	.
90	920921	2	-2	8.5	15.5	.
91	920921	3	-3	8.3	15.5	.
92	920921	4	-4	7.8	15.5	.
93	920921	5	-5	7.0	15.0	.

LAKEID=49-0133

OBS	SITE	DATE	SDM	SDF	PHYS	REC
30	201	920528	3.8	12.5	2	3
31	201	920603	3.8	12.5	2	3
32	201	920610	3.7	12.0	2	3
33	201	920617	3.4	11.0	2	3
34	201	920625	2.9	9.5	2	3
35	201	920702	2.9	9.5	3	3
36	201	920709	2.7	9.0	3	3
37	201	920715	2.4	8.0	3	3
38	201	920722	2.3	7.5	4	3
39	201	920729	2.1	7.0	4	3
40	201	920803	2.1	7.0	4	4
41	201	920810	2.0	6.5	4	4
42	201	920817	2.0	6.5	4	4
43	201	920825	1.8	6.0	4	4
44	201	920901	1.8	6.0	4	4
45	201	920909	2.0	6.5	4	4
46	201	920915	2.0	6.5	4	4
47	201	920922	2.0	6.5	4	4
48	201	920929	2.1	7.0	4	4
49	201	921007	2.1	7.0	4	4
50	201	921015	2.3	7.5	4	4
51	201	921020	2.3	7.5	4	4

LAKEID=49-0133 SITE=101

OBS	DATE	DM	NDM	DO	TEMP	TP
66	920520	0	0	8.6	19.0	0.048
67	920520	1	-1	8.6	18.9	.
68	920520	2	-2	8.7	18.7	.
69	920520	3	-3	8.7	18.7	.
70	920520	4	-4	8.6	18.6	.
71	920618	0	0	8.1	18.0	0.027
72	920618	1	-1	8.0	18.0	.
73	920618	2	-2	8.0	18.0	.
74	920618	3	-3	7.9	18.0	.
75	920618	4	-4	7.8	18.0	.
76	920618	5	-5	7.8	18.0	.
77	920720	0	0	8.6	20.0	0.035
78	920720	1	-1	8.6	20.5	.
79	920720	2	-2	8.6	20.5	.
80	920720	3	-3	8.0	20.0	.
81	920720	4	-4	4.0	20.0	.
82	920819	0	0	8.7	21.5	0.020
83	920819	1	-1	8.8	21.0	.
84	920819	2	-2	8.8	21.0	.
85	920819	3	-3	7.4	20.5	.
86	920819	4	-4	4.5	20.0	.
87	920819	5	-5	0.5	19.5	.
88	920921	0	0	8.5	16.0	0.038
89	920921	1	-1	8.6	16.0	.
90	920921	2	-2	8.5	15.5	.
91	920921	3	-3	8.3	15.5	.
92	920921	4	-4	7.8	15.5	.
93	920921	5	-5	7.0	15.0	.

LAKEID=49-0133

OBS	SITE	DATE	SDM	SDF	PHYS	REC
30	201	920528	3.8	12.5	2	3
31	201	920603	3.8	12.5	2	3
32	201	920610	3.7	12.0	2	3
33	201	920617	3.4	11.0	2	3
34	201	920625	2.9	9.5	2	3
35	201	920702	2.9	9.5	3	3
36	201	920709	2.7	9.0	3	3
37	201	920715	2.4	8.0	3	3
38	201	920722	2.3	7.5	4	3
39	201	920729	2.1	7.0	4	3
40	201	920803	2.1	7.0	4	4
41	201	920810	2.0	6.5	4	4
42	201	920817	2.0	6.5	4	4
43	201	920825	1.8	6.0	4	4
44	201	920901	1.8	6.0	4	4
45	201	920909	2.0	6.5	4	4
46	201	920915	2.0	6.5	4	4
47	201	920922	2.0	6.5	4	4
48	201	920929	2.1	7.0	4	4
49	201	921007	2.1	7.0	4	4
50	201	921015	2.3	7.5	4	4
51	201	921020	2.3	7.5	4	4

```
Minnesota Lake Eutrophication Analysis Procedure
ENTER INPUT VARIABLES
LAKE NAME ? Crookneck Lake
ECOREGION NUMBER 1=NLF,2=CHF,3=WCP,4=NGP ? 1
WATERSHED AREA (HA)            ? 190.8
LAKE SURFACE AREA (HA)         ? 81
LAKE MEAN DEPTH (M)            ? 2.7
OBSERVED MEAN LAKE TP (UG/L) ? 30.2
OBSERVED MEAN CHL-A (UG/L)     ? 7.22
OBSERVED MEAN SECCHI (M)       ? 2.01

INPUT DATA:
LAKE NAME =Crookneck Lake      ECOREGION=NLF
LAKE AREA = 81   HA
WATERSHED AREA (EXCLUDING LAKE) = 190.8  HA
MEAN DEPTH = 2.7  METERS
OBSERVED MEAN TP = 30.2  UG/L
OBSERVED MEAN CHL-A = 7.22  UG/L
OBSERVED MEAN SECCHI = 2.01  METERS

<press ENTER to view results>
```

```
LAKE = Crookneck Lake                      ECOREGION = NLF
AVERAGE INFLOW TP = 64.26597  UG/L         TOTAL P LOAD         = 34.96968  KG/YR
LAKE OUTFLOW      = .54414  HM3/YR         AREAL WATER LOAD     = .6717778 M/YR
RESIDENCE TIME    = 4.019187  YRS          P RETENTION COEF     = .698565
```

VARIABLE	UNITS	OBSERVED	PREDICTED	STD ERROR	RESIDUAL	T-TEST
TOTAL P	(UG/L)	30.20	19.37	6.66	0.19	1.17
CHL-A	(UG/L)	7.22	5.01	3.08	0.16	0.55
SECCHI	(METERS)	2.01	3.00	1.24	-0.17	-0.92

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	17.89	4.63	6.02	15.78
20	0.91	0.09	0.20	3.11
30	0.07	0.00	0.01	0.90
60	0.00	0.00	0.00	0.06

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

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	Crookneck Lake				
Watershed Area (ha)	190.8		286180.6 =EST Q	0.29 =HM3	6.6 =Water Residence (year)
Lake Area (ha)	81		0.35 =EST qs		
Water Runoff (m)	0.15	NOTE: 1HM3 = 1,000,000 M3			
Precipitation(m)	0.62		0.0302 =Observed TP (mg/l)		
Evaporation(m)	0.86 (mean)		0.0076 =Observed TP StDev		
Volume (HM3)	1.9		7 =N		
County capitas/cabin	2.8		7.22 =Observed Chla (ug/l)		
Number Seasonal Cabi	117		2.01 =Observed Secchi (m)		
Number Perm. Cabins	29				

	Before	After	Delta
Forest Area (ha)	54	54	0
Agric Area (ha)	0	0	0
Urban Area (ha)	38	38	0
Wetland Area (ha)	13.6	13.6	0
Pasture/Open (ha)	4.4	4.4	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	4	5	8	=Forested Flux =	4	5	8
Agric P Export		0.2	0.55	0.59	0	0	0	=Ag flux =	0	0	0
Urban P Export		0.5	1	1.25	19	38	48	=Urban flux =	19	38	48
Wetland P Export		0.08	0.1	0.1	1	1	1	=Wetland flux =	1	1	1
Pasture/open Export		0.2	0.3	0.4	1	1	2	=Pasture/Open flux=	1	1	2
Atmospheric Export		0.2	0.3	0.4	16	24	32	=Ppt flux =	16	24	32
Soil Retention Coef		0.9	0.8	0.7							
Point Source Before	kg/yr	0	0	0							
Point Source After	kg/yr	0	0	0	17	34	50	=Septic flux =	17	34	50
Delta Point Source	kg/yr	0	0	0							
Capita Years		167.6	167.6	167.6	0	0	0	=Point Souce =	0	0	0
					58	103	141	=Total P Flux =	58	103	141
					72	127	174	= P LOAD =	72	127	174
					200	355	486	= Inflow P ug/l	200	355	486
					0.006	0.011	0.014	=PREDICTED TP =	0.006	0.011	0.014
						-1.95861		=LOG Pml =		-1.95861	
						0.004		= + MODEL ERROR =		0.004	
						-0.003		= - MODEL ERROR =		-0.003	
						0.0015		= + LOADING ERROR =		0.0015	
						0.0025		= - LOADING ERROR =		0.0025	
						0.004		=TOTAL + UNCERTAIN =		0.004	
						0.004		=TOTAL - UNCERTAIN =		0.004	
RECKHOW/SIMPSON ug P/l					7	11	15	55% CONFIDENCE LIMITS	7	11	15
RECKHOW/SIMPSON					3	11	19	90% CONFIDENCE LIMITS	3	11	19
CANFIELD/BACHMANN ug P/l					33	47	56	CANFIELD/BACHMANN	33	47	56

**** 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	54	0.08	\NCHF	Cul+Mixed	0.19
Ag-mix	0	ERR	\NLF	For (75%)	0.12
Ag-row++	0	ERR	\NGP	Cul (83%)	0.76
Ag-nonrow++	0	ERR	\WCBP	Cul (84%)	0.74
Pasture	4.4	1.32	** Of all landuse values.		

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

NA-01570-01

LAKE MANAGEMENT PLAN

Region	Area	D.O.W Number	County	D.O.W. Lake Name	Acreage
III	Little Falls	49-133	Morrison	CROOKNECK	168

Long Range Goal:

To decrease northern pike population to 5 or less per gillnet (average weight 2.5 lbs.). To establish baseline population parameters for largemouth bass so that specific long range goals can be identified.

Operational Plan:

1. Aerial fish house counts twice each winter.
2. Conduct investigation of largemouth bass population by electrofishing by 1993.
3. Discontinue stocking of walleye fry or fingerlings, except after severe winterkill.
4. Evaluate with a population assessment in 1996 and resurvey in 2001.
5. Continue bullhead removal under Class "B" permit at least once every five years.
6. conduct dissolved oxygen checks during severe winters.

Mid-Range Objective:

To evaluate alternatives such as special regulations to reduce northern pike abundance to 5 or less per gillnet. Complete an electrofishing survey directed at largemouth bass to develop population indices. Evaluate impact of management objectives on bluegill and black crappie populations. Resolve need for aeration.

Potential Plan:

Investigate quality regulations for northern pike with a plan to be submitted by 2002.	$1,000.00
Determine feasibility of installation of a pump and baffle aeration system.	$25,000.00
TOTAL	$26.000.00

NARRATIVE: (Historical perspectives - various surveys; past management; social considerations; present limiting factors; survey needs; land acquisition; habitat development and protection; commercial fishery; stocking plans; other management tools; and evaluation plans)

(see reverse side)

Lake Classification: 29
Lake Priority: 6

Primary Species Management:	Secondary Species Management:
Largemouth Bass	Northern Pike

Area Supervisor's Signature:	Date
James D. Lilienthal	5-18-92
Regional Manager's Signature:	**Date**
Edwin L. [illegible]	5/26/92

FOR CENTRAL OFFICE USE ONLY

Entry Date:	Year Resurvey:
Stock Species -Size- Number per Acre	
Schedule:	Year Beginning
Population Manipulation ______YES ______NO Year______	
Development ______YES ______NO Year______	
Creel or Use Survey ______YES ______NO Year______	
Other: Year______	

LAKE MANAGEMENT PLAN

Region	Area	D.O.W Number	County	D.O.W. Lake Name	Acreage	Date
III	LITTLE FALLS	49-133	Morrison	CROOKNECK	168	5/18/92

NARRATIVE:

Various Surveys include: Lake Surveys in 1991 and 1981; Wildlife Survey in 1965; Population Assessment in 1986; and Natural Reproduction Check in 1969; Aerial fish house counts twice each winter beginning in 1981. A Winterkill investigation was conducted in April 1986. The lake was mapped in 1981.

Past Management consisted of annual stocking of walleye fingerlings and yearlings between 1987-1989. Northern pike fingerlings and yearlings were stocked in 1971 and 1980. High numbers of northern pike were sampled in 1986 population assessment and removal of 540 adult northern pike was done between 1987-1989 with little perceived impact. Approximately 800 adult bluegills were removed during 1989.

Social considerations: Crookneck Lake has a moderate amount of shoreline development (33 cabins/mile) with light to moderate angling pressure directed primarily toward northern pike and largemouth bass. The lake Crookneck Improvement Association (LCIA) has maintained interest in Area Fisheries activities.

Present Limiting Factors: Crookneck Lake experiences periodic winterkill conditions which favors higher populations of black and brown bullhead and northern pike. The shallow west bay has a heavy growth of submerged vegetation which limits boating and fishing opportunities. Bluegill numbers are too high and average size is small.

Survey Needs: Surveys will be conducted as indicated in Operational Plan.

Land Acquisition: No acquisition is planned at the present time.

Habitat Development and Protection: Critical review of A.P.M. and D.O.W. permits will continue along with support of the local water plan.

Commercial Fishery - Netting of bullheads will be scheduled under Class "B" permit at least once every five years.

Stocking Plans - No stocking is planned for Crookneck Lake, except after a very severe winterkill with walleye fry (200,000).

Evaluation Plans - See Operational Plan.

Add additional pages if needed

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY