LAKE ASSESSMENT PROGRAM
1987
ELBOW LAKE
(I.D. #69-0717)

C. Bruce Wilson
March, 1988
Minnesota Pollution Control Agency
Program Development Section
In cooperation with John Adams
Minnesota Department of Natural Resources
Waters Division
Grand Rapids, Minnesota

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

MPCA staff would like to thank Mr. and Mrs. John Mohr and Mr. John Peterson for their efforts in the sampling and analysis of Elbow Lake and its watershed. They spent many hours working with MPCA staff and other concerned citizens. This report would not have been possible without their efforts.

INTRODUCTION

Since the summer of 1985, the Minnesota Pollution Control Agency (MPCA) has received numerous citizen complaints concerning to the water quality of Elbow Creek (Snowden Creek) and Elbow Lake. As a result of this concern, there have been a lengthy series of meetings and interactions between local citizens (Elbow Lake Restoration Committee), Clinton Township, the City of Eveleth and the MPCA. Due to the lack of recent lake water quality information, it was proposed that the lake group work with MPCA staff in a cooperative program called the Lake Assessment Program (LAP) to obtain lake water quality data. The LAP program was designed to assist local lake management groups in the collection of baseline lake water quality data for the purpose of assessing the current trophic status of their lake. The general work plan for LAP includes cooperative lake sampling by MPCA and the lake association; participation in the Citizen Lake-Monitoring Program (CLMP); examination of land use and drainage patterns in the watershed; and an assessment of the data collected.

The City of Eveleth's wastewater treatment facility (WWTF) empties into Snowden Creek. Additionally, the City has a history of bypassing from its collection and treatment system. As a result, this report has included extensive data pertaining to the City's WWTF and its bypasses in order to more accurately estimate its impacts to the downstream receiving waters.

The degradation of lakes may be caused by many factors, but most often it is caused by the excessive export of nutrients and sediments from the land or watershed. The nutrient and sediment enrichment of water bodies is referred to as eutrophication. In an undisturbed watershed, eutrophication is a slow process occurring over a period of many hundreds or thousands of years where nutrients and sediments, generated by the lake's watershed, accumulate producing a gradual filling-in of the lake with silt and organic debris.

The rate of eutrophication is greatly accelerated if abundant nutrient and sediment sources are located in the watershed of the lake. And, when these nutrient sources own their origins to man's activities, a new term, cultural eutrophication or enrichment, is used to describe the potentially rapid enrichment which may take place. Human activities such as wastewater disposal, other waste disposal practices, urbanization and agricultural activities can make even large lakes eutrophic or over-supplied with nutrients in only a few years.

Eutrophic lakes may be characterized by a variety of water quality conditions, dependent upon the rate of nutrient supply or eutrophication. In many instances in Minnesota, eutrophic lakes may support excellent warm water fisheries. However, in advanced stages, the effects of lake eutrophication may cause serious resource degradation. These lakes may have blue-green algal blooms of such severity as to turn the water to "pea-soup," reduce the potential for support of sports fisheries, reduce riparian property values and in very severe cases, cause the development of toxic algal blooms capable of killing pets, livestock, waterfowl and other wildlife. Body contact activities in these lakes may be severely reduced due to aesthetically unpleasing conditions of taste and foul odors associated with the algal blooms. Blue-green algal blooms have also been associated with human respiratory, gastrointestinal and dermal disorders. In general, very eutrophic (hypereutrophic) lakes have a variety of nuisance conditions that detract from the resource's value.

Additionally, blue-green algae tend to become dominant in fertile lakes due to their rapid reproduction and their ability to float near the water surface, sometimes almost excluding the more desirable algae. In the summer months, these algae can dominate the lake and produce massive blooms. As the blooms die-off, they can produce foul odors and reduce the oxygen content of the lake causing fish kills or stress that allows other diseases to cause fish kills. Reduced oxygen content may also produce conditions favoring rough fish species which may have greater tolerance to the lower oxygen content of the waters. These consequences of eutrophication can seriously impair the lake's resource value now and for the generations to come, if not corrected.

In hypereutrophic lakes (or lakes which are very fertile), phosphorus may be present in excessive amounts which provide a potential for producing maximum amounts of algae in the water. This 'potential' may or may not be expressed because of other limitations such as bad weather, lack of light penetration into the water due to coloration or suspended matter, or nutritional deficiencies. Control of external phosphorus quantities reaching a lake is a necessary first step in restoring the water quality of hypereutrophic lakes.

In general, Elbow Lake's water quality problems are due to both point and nonpoint sources of pollution which have caused cultural (human caused) eutrophication of the lake. That is, the increased fertility of Elbow Lake downstream of Eveleth's WWTF is caused by excessive amounts of nutrients, and in particular, the amounts of phosphorus. These phosphorus quantities cause nuisance blooms of blue-green algae which can cause surface scums, odors and other problems. The bypassing of wastewater during high flow events (rainfall etc.) also causes citizen concerns due to fecal solids and bacterial contaminations. This report does not address issues relating to bacteria, solids, or dissolved oxygen depletions in the Elbow or Snowden Creek areas.

Nonpoint sources of pollution may also be sources of nutrients to the creek and lake. These include nutrient and sediment related runoff from parking lots, rooftops, lawns, roads, feedlots, leakage from septic tanks, and various other urban sources. Of these sources, it has been generally found that the greatest quantities of nutrients and sediments are released (or exported) from urban and agricultural areas. In comparison, forested and wetland areas release relatively small quantities of nutrients and sediments.

In general, the majority of the complaints received to date indicate that the occurrences of algal blooms have been the primary nuisance condition to lake resource users. Algal bloom potential is directly related to the amounts of nutrients (phosphorus) entering the lake from its watershed and to the recycling of nutrients within the lake.

BACKGROUND

Elbow Lake is located in St. Louis County in the St. Louis River watershed in northeastern Minnesota, approximately five miles southwest of Eveleth, Minnesota (Figure 1). The lake covers an area of about 169 acres.

Elbow Lake is comprised of two main basins: (1)the southwest basin (SW basin) which covers an area of about 74 acres and has a mean depth of about 13.5 feet; and (2) the northeast basin (NE basin) covering an area of about 95 acres with a mean depth of about 7.5 feet (Figure 2).

Since 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", as defined by soils, land surface forms, natural vegetation, and current land use. Elbow Lake is located in the Northern Lakes and Forests ecoregion (Figure 3). Its watershed is about 7.0 square miles (mi^2) (18.2 square kilometers (Km^2)) and land use is divided between forested, urban, mining, and water+wetland categories. The lake is about 4% of the total watershed area, or stated another way, the watershed to lake surface area ratio is about 27. Regionally, forested land use is, on average, about 75% of the total. The City of Eveleth along with the areas of West Eveleth and Leonidas comprise about 1000 acres (or 1.6 mi^2 or 4 km^2.) The area of the immediate watershed of Elbow Lake (or the watershed immediately around the lake) is about 1082 acres (or 1.7 mi^2 or 4.4 km^2).

RESULTS AND DISCUSSION

Water quality data were collected on three occasions from Elbow Lake and from the lake inlet over the summer of 1987 on July 10, August 13, and September 4, 1987. Lake samples were collected at two sites (Figure 1). All samples were submitted to the Minnesota Department of Health laboratory for analysis.

Lake samples were analyzed for color, pH, suspended solids, turbidity, chloride, conductivity, total Kjeldhahl nitrogen, nitrate+nitrite nitrogen, total phosphorus (TP), total alkalinity, and chlorophyll-a. Temperature and dissolved oxygen profiles and Secchi disk transparency measurements were also obtained. Data from the U.S. Environmental Protection Agency's (USEPA) survey of 1972 were also included for comparison. All data were entered into STORET, the USEPA's national water quality data bank.

The watershed area was determined from discussions with Mr. John Mohr and Mr. John Peterson, observation of the watershed by air from Mr. Mohr's plane, and from ground observations. Predominant land usages were determined by planimetering the surface areas from U.S. Geological Survey maps of the watershed.

Lake modeling was performed using software developed for the U.S. Army Corps of Engineers entitled Bathtub (Walker, 1985.) Additional modeling was also performed using Trophic (Vennie, 1986.)

The City of Eveleth prepared summaries of the quantities of wastewater diverted from its collection system which is summarized in Appendix H. Over a thirteen month period extending from June 7, 1986 through July 22, 1987, a total of 17.1 million gallons of wastewater were diverted into the Snowden Creek watershed. This translates into about 0.065 cubic hectares (HM3) or about 13,821 acre feet of water. The average monitored TP for this time period for the bypasses was about 0.667 milligram per liter (mg/l) (or 0.807 when including storm sewer samples). For the purposes of estimating the TP loading reaching Elbow Lake from the Eveleth WWTF, the average annual flow of 0.8 million gallons per day (MGD) was used with an average TP concentration of 0.500 mg/l. The monitored average TP value has been about 0.500 mg/l. The phosphorus concentration of 0.807 mg/l was used for the by-pass phosphorus loading calculations.

The following discussions assume that the reader is familiar with basic water quality terminology as used in the "Citizens Guide to Lake Protection." For further information and a glossary of terms, please refer to the Citizens Guide to Lake Protection.

INLAKE CONDITIONS

Temperature/Dissolved Oxygen

Physical processes occurring in lakes strongly influence water quality patterns and one of the most significant of these processes is the annual temperature and dissolved oxygen cycle. In the spring time after ice-out, lakes tend to have the same temperature from the surface waters to the lake bottom. A similar pattern for dissolved oxygen concentrations is usually observed with lakes having a uniform concentration of about 10 - 12 mg/l of oxygen. With the progression of spring, water temperatures increase and result in warming of the lake. As a result, the colder more dense water tends to remain at the lake bottom separated from the less dense warm waters by a transition zone, the thermocline.

The results of the temperature and dissolved oxygen monitoring are typically displayed in graphical form as shown in Figure 4. Here the temperature and dissolved oxygen profiles are graphed by depth where it is apparent that the warmer waters correspond to the lake's upper layers. In Figure 4, the temperature at Site 101, the SW Basin, on July 10, 1987 varied from 24 degrees Celcius (C) or 75°F at the surface to about 11.5 degrees (or 52°F) at a depth of 6 meters. Dissolved oxygen concentrations varied from about 13 mg/l at the surface to about 0.5 mg/l at a depth of 3 meters. On the same date at Site 102 (the NE Basin) a similar stratification of temperature and dissolved oxygen was observed with dissolved oxygen concentrations declining to about 0.5 mg/l at a depth of 2 meters (6.6 feet). It should be noted that the bottom waters in both basins had warmed from an expected spring low of 4 degrees C (32°F) to about 13 degrees C (or 56°F) which indicates that mixing of the entire lake had occurred. The thermocline, the lake depth where the water temperatures decline rapidly, was between 1 and 3 meters.

Similar dissolved oxygen and temperature profile patterns were monitored on August 13, 1987 except that the maximum dissolved oxygen concentration in the surface waters had decreased to a level of 5 - 6 mg/l. Dissolved oxygen declined to about 0 at the 3 m (about 10 feet) interval in both basins. This is particularly important to fishermen/women, since oxygen concentrations less than 5 mg/l limits the habitat available to sports fisheries and other aquatic life during periods of stratification and under ice cover.

Lake TP concentrations were very high on all sample dates averaging about 0.177 mg/l in the NE Basin and 0.426 mg/l in the SW Basin. Relative to a sample of 1,028 Minnesota lakes this phosphorus concentration would place Elbow Lake between the 94 th - 99 th percentiles (Heiskary, 1985.) In other words, its phosphorus concentration was higher than about 94-99 % of the lakes included in the 1985 report. Elbow Lake would be classified as hypereutrophic or highly productive based upon these TP concentrations.

Total nitrogen (TN) which consists of Total Kjeldahl nitrogen (TKN) plus Nitrate and Nitrite nitrogen (NO2+NO3-N) are other essential nutrients for plant growth. TN concentrations were quite high in 1987, averaging 1.900 mg/l in the NE Basin and 2.260 mg/l in the SW Basin. Nitrate and nitrite concentrations were at detection limits in July and August and slightly higher (0.020 mg/l) in September. Average inlake concentrations of NO2+NO3-N may typically be expected to be 0.030 mg/l or less in most Minnesota lakes.

The ratio of TN:TP can provide an indication as to which nutrient is limiting the production of algae in a lake. Ratios of TN:TP < 10 have been used to indicate nitrogen limitation while ratios in excess of 14-17 indicate phosphorus limitation. The average TN:TP ratio for Elbow Lake varied from 5.3 in the SW Basin to 10.7 in the NE Basin. This suggests that Elbow Lake may be periodically nitrogen limited. Reduction of the amounts of nitrogen reaching the lake is generally not feasible since the atmosphere is predominantly nitrogen. Reducing the amounts of phosphorus reaching the lake may result in beneficial effects such as shifting the predominant species of algae in the lake (e.g. shift from blue-green algae to green algal species). Given sufficient reduction of the phosphorus reaching the lake, reduction of the amounts of algae in the lake will occur.

Chlorophyll-a concentrations provide an estimate of the amount of algal production or quantities in a lake. In 1987, the average lake chlorophyll-a concentration was 80 micrograms per liter (ug/l) or parts per billion with a peak measured value of 235 ug/l which occurred on July 10, 1987. Values greater than 30 ug/l have been suggested bloom or nuisance conditions while concentrations greater than 40 ug/l are suggestive of severe nuisance conditions (Walmsley, 1984) such as surface scum and odor formation. Peak chlorophyll-a values are typically 2-3 times the average summer value which is consistent with the results of this monitoring program.

Field observations in 1987 indicated that the dominant algae species was Aphanizomenon flos-aquae, a blue-green algae species. This algae appears like "grass-clippings" in the water. Another blue-green algal species noted in August was Microcystis spp. which was observed forming gelatinous looking surface scum on the edges of the lake protected from the wind action. These species frequently dominate lakes with high nutrient concentrations. Photomicrographs taken of algae samples obtained from Elbow Lake on July 10, 1987 are shown in Figure 5. In this photo, the dominant phytoplankton is Aphanizomenon flos-aquae which appears as individual filaments rather than "clumps" of filaments.

Secchi disk transparency is generally a function of the amount of algae in the water. Suspended sediments (silt) and color due to dissolved organic matter may also reduce water transparency. In 1987, the average Secchi depth was about 3.8 feet or 1.1 m with a range of 0.6 to 2.4 m (2-7.9 feet). According to Mr. John Mohr, somewhat greater transparency was observed in the southwest basin than the northeast basin.

1974 U.S. Environmental Protection Agency Report

Lake sampling was conducted in 1972 by the U.S. Environmental Protection Agency (USEPA) as a part of the National Eutrophication Survey (NES), which examined 80 Minnesota lakes. The NES report concluded that Elbow Lake was eutrophic, with only three lakes at that time having greater phosphorus concentrations (of the Minnesota lakes). Of the external phosphorus loading sources, the City of Eveleth was estimated to contribute over 98% while the nonpoint sources contributed less than 2% of the phosphorus load. The average inlake TP was 1.320 mg/l, the majority of which was dissolved phosphorus. Total nitrogen averaged about 2.053 mg/l and the transparency was about 1.9 m (6.25 feet). The report detailed that blue-green algae dominated the lake's algae, however, the measured chlorophyll-a concentrations noted in 1972 were inaccurate due to laboratory errors.

The Eveleth WWTF has been upgraded and thereby reduced its phosphorus contribution to Snowden Creek from about 11,800 pounds per year to about 1224 - 1500 pounds per year currently being experienced. Thus Eveleth has eliminated nearly 87% of its previous WWTF loading rate to Snowden Creek. Concurrently monitored average whole lake TP has dropped from about 1.320 mg/l to about 0.300 mg/l. The NE Basin averaged 0.177 mg/l in 1987. The extent of the changes in algal blooms, chlorophyll-a or transparency cannot be made based upon the limited data.

Current Lake Trophic Status

One means of evaluating the trophic status of a lake is to interpret the relationship between total phosphorus, chlorophyll-a and Secchi depth using Carlson's Trophic Status Index (TSI, Carlson, 1977.) The index was developed from the interrelationships of summer Secchi depth and the concentrations of surface water chlorophyll-a and total phosphorus. TSI values are calculated as follows:

1. Total Phosphorus TSI (TSIP) = $14.42 \ln(TP) + 4.15$
2. Chlorophyll-a TSI (TSIC) = $9.81 \ln(Chl\text{-}a) + 30.6$
3. Secchi Depth TSI (TSIS) = $60 - 14.41 \ln(SD)$

with TP and chlorophyll-a in ug/l and Secchi depth in meters. Practically speaking, TSI values range in Minnesota from about 30 (oligotrophic) to 100 (hypereutrophic). In this index, each increase of 10 units represents a doubling of algal biomass. Average TSI values for 1987 are listed in Table 1. These values suggest that Elbow Lake would be considered eutrophic to hypereutrophic depending upon the parameter used. The TSIS suggests less eutrophic conditions than the TSIP. This is likely a function of the "artificially high" transparency due to the clumping of the algae, Aphanizomenon flos-aquae, which may give greater transparency than may be observed with a different type of algae. In contrast, the TSIP value suggests a hypereutrophic lake or that the lake could assume a much greater productivity than is currently being observed.

SUBWATERSHED AREAS AND RUNOFF VOLUMES

Water volumes reaching Elbow Lake were estimated for an average runoff year and an average runoff value of about 0.25-0.30 meters per year (m/year)(range 0.13-0.31 m/year). The annual precipitation was estimated using a value of 0.71 m/year with an annual evaporation of 0.66 m/year. The principal water source for the lake is Snowden Creek since it has a drainage area of about 12.6 km^2 (4.9 mi^2). This watershed probably contributes the majority of the water volumes reaching the lake which flow into and out of the NE lake Basin. Other sources of water include Unknown Lake which flows into the NE Basin. This water source is not a large contributor but it is likely water with very low nutrient concentrations since trout may be present in this lake. The immediate lake watershed, that is, the area of the lake's watershed that does not drain into permanent or ephemeral (intermittent) streams, consists of an area of about 3.4 km^2 (1.3 m^2).

On an average basis, the lake water residence time is about 0.4 years or about 150 days. There is a significant difference in the estimated water residence times for the two basins. Based upon average runoff values and planimetered watershed areas, the SW basin likely has a longer water residence time (in excess of 2.4 years) while the NE Basin likely has a short water residence time (on the order of 0.2 years). This is very important in that wind/turbulence generated mixing between the basins may not be significant due to the basin morphometry and predominant wind axes.

As may be seen in Table 2, the dominant land use (56%) in the watershed is in the 'Forested' category followed by 17% in 'Urban+residential' land use and 11% in 'Extractive' or mining land use. There is less land use in the 'Pasture + Open' categories and intensive agriculture categories. These percentages are substantially different than the regional values observed in the Northern Lakes and Forests ecoregion, especially for the percentages in urban and forest categories. It is significant that there are generally greater amounts of water, sediment and nutrients exported from urban and agricultural land uses than from forested, wetland and water land uses. Hence, the lake will likely receive relatively larger quantities of nutrients and sediments from the general urban runoff from the greater Eveleth area. Evidence of this was obtained when sampling of a storm sewer adjacent to the Eveleth WWTF and a ditch in West Eveleth on October 21, 1987 revealed TP concentrations of 1.650 mg/l and 0.209 mg/l, respectively. It was later learned that there was a commercial car wash facility that was discharging into the storm sewer and that these concentrations may not be indicative of general storm water.

Tributary Water Quality

Grab samples were collected from Snowden Creek at CSAH-19 above Elbow Lake to evaluate the concentrations of phosphorus and total Kjeldahl nitrogen. As may be seen in Table 3, the concentrations of TP varied from about 0.204 to 0.442 mg/l. A recent survey of stream data for the Northern Lakes and Forest ecoregion shows that 95% of the stream concentrations for the "least impacted" streams were less than 0.098 mg/l and the median concentration was 0.052 mg/l. Thus the values measured in Snowden Creek were considerably greater than would be expected for minimally impacted streams from this part of the state.

The stream water quality results represent only grab samples and are of limited value for assessing detailed phosphorus loading rates. They do suggest that there are sources of nutrients that are causing relatively high quantities of nutrients to reach the lake. Since there are no other permanent streams reaching the lake, this inlet is likely contributing the majority of the water and the phosphorus reaching the lake.

Quantifying Changes Needed for Lake Water Quality Improvements

As stated previously, eutrophication can be defined as the nutrient enrichment of water bodies leading to an excessive production of organic materials by algae and/or aquatic plants and filling-in of a lake basin by silt. Lake water quality degradation is not necessarily irreversible if the amounts of silt and nutrients reaching the lake are reduced and the lake's characteristics allow for assimilation of nutrients. In many instances, it has been shown that reducing the amounts of phosphorus supplied to a lake has resulted in improvement in lake water quality as estimated by water transparency and by chlorophyll-a concentrations. It has also been shown that there are lakes, typically shallow lakes or lakes that have extensive shallow shelves, that also have "internal" sources of nutrients.

Internal loading occurs in lakes that can temporarily stratify and thereby lose oxygen concentrations at the lake bottom sediment-water boundary. This allows the phosphorus that would be chemically bound to the sediments when oxygen is present to be released into the water layers above the sediments when there is no oxygen. This phosphorus can be mixed into the upper water layers by the passage of summer storms/cold fronts with sufficient wind mixing. In deeper lakes, there is usually sufficient 'strength' in the thermocline to prevent the mixing of the anoxic bottom waters with the surface waters except in the spring and in the fall. Typically, lakes with maximum depths less than 30 feet may be expected to have some degree of mixing from top to bottom and therefore have internal sources of phosphorus. Elbow Lake has a maximum depth of about 22 feet in the southwest basin and about 10+feet in the northeast basin and may be expected to be polymictic (or mix occasionally from top to bottom). Evidence for the occurrence of internal loading in Elbow Lake is the large fluctuation in surface water TP values (see Appendix). For example, the TP concentration in the southwest bay on July 10, 1987 was 0.098 mg/l and 0.915 mg/l on August 13, 1987. A similar but less pronounced increase was noted in the northeast bay. These large increases in inlake TP greatly exceed the concentrations monitored in the inlet and are likely a function of internal loading of nutrients rather than external sources of nutrients. This phenomenon will be significant for future lake management efforts.

Predicting Future Lake Water Quality

Judging the effects of various lake management alternatives upon the quality of Elbow Lake may accomplished by the use of computer models. Use of these models is necessary due to the complexity of the mathematical and statistical relationships that have been developed. The models typically require information relating to phosphorus loading, water flow-through the lake basins, and lake morphometry (such as mean depth and surface area). These models relate the effects of nutrient reduction practices upon inlake characteristics such as average TP, algal blooms and Secchi disk transparency ranges.

A Note On User Expectations

A questionnaire was developed to collect data from MPCA staff and the CLMP observers in 1987 relating lake measurements (phosphorus, chlorophyll-a, and transparency) to subjective classifications or nuisance ratings based upon physical appearance ("crystal clear" to "severe scums") and recreational suitability ("no problems" to "no swimming"). Analysis of data from 176 citizen volunteers reveal that there are regional patterns in public perception of lake condition. Lake users in the Northern Lakes and Forests (NLF) typically see lakes with average summer transparency of 2 - 4 m (7 - 13 feet). As a consequence, they may have higher expectations for lake water quality (i.e. greater transparencies and lower algae concentrations) than lake users in the Western Cornbelt Plains (southern Minnesota) in which lakes typically have transparencies less than 0.5 meters (1.6 feet). It is important to note, however, that there will be lakes that will have water quality less desirable than local expectations that may nonetheless provide valuable recreation and aesthetic opportunities. More productive lakes, for example, may provide excellent fisheries and waterfowl production and yet may not be perceived as "swimmable" by a percentage of lake resource users. As a result, the water quality of one lake may not satisfy all different lake resource users and lake water quality goals should reflect regional/area user preferences, as well as achievable water quality.

Lake Management Options

The potential lake management options that have been identified that have been identified for Elbow Lake include the following:

1. No Action.
2. Elimination of the bypasses from the Eveleth collection system.

3. Reduction of the phosphorus quantities from Eveleth WWTF's by reducing the phosphorus limitation from the current limit of 1.000 mg/l.
4. Diversion of the Eveleth effluent from Elbow Lake.
5. Addition of minepit dewatering volumes to dilute the lake.

For these lake/watershed management alternatives can (1) existing lake water quality models adequately predict future conditions and (2) will there be observable lake water quality improvements?

For this study, two computer models were employed to reasonably estimate the quantities of water and phosphorus which go into and out of Elbow Lake during an average year. The first of the models employed was that of Reckhow and Simpson (1980) which was refined by Chapra and Reckhow (1986). This model does not have excessive data requirements and yet can give good general predictive information. It requires land-use data along with runoff information to generate probable ranges of phosphorus loading and inlake phosphorus concentrations. The model also includes a statistical error analysis calculation to more accurately convey the degree of certainty of predictions.

Chapra and Reckhow Model

This model estimates the amount of phosphorus reaching the lake from major land use categories such as the amount of phosphorus from urban sources, forest runoff, and the atmosphere. For the purposes of this exercise, estimates of phosphorus export were used to give a generally worst case loading resulting from the urban area of Eveleth, West Eveleth and Leonidas. The amount of phosphorus from the WWTF, including the bypassing varied from a high of 1000 to a 'most likely' value of 885 and a 'low' amount of 620 kg P/year (2205; 1951; or 1367 pounds per year, respectively, which correspond to average WWTF TP concentrations of 1.0, 0.75 and 0.50 mg/l). Added to that are estimates of phosphorus from nonpoint sources (runoff from forests, roads, etc.). Total phosphorus amounts reaching the lake varied from a 'high value' of 6636 pounds P/year to 'most likely value' of 4235 pounds P/year to a 'low value' of about 2590 pounds P/year. The results of this modeling are shown in Appendix G, where it may be seen that the likely predicted inlake TP concentrations were:

P(high) = 0.210 mg/l
P(most likely) = 0.134 mg/l
P(low) = 0.082 mg/l.

The average observed TP for Elbow Lake was 0.302 mg/l when averaging values monitored from both lake basins. The predicted value (above) is close to the observed TP concentrations for the NE Basin of the lake (0.177 mg/l) but not the SW Basin (0.426 mg/l). Therefore, it does not appear that this model adequately predicts current conditions for the lake.

A second model, Walker (1986), was employed to estimate the amounts of water, phosphorus and nitrogen that reach the lake on an average water year. This model requires significantly more data/information such as land use, stream flow or runoff values, subwatershed areas, and inlake data such as TP, chlorophyll-a, and Secchi depth. Lake basin measurements are also needed to run this model such as lengths, volumes and oxygen stratification patterns.

Based upon the values of loading of water and nutrients from all external sources, the lake was predicted to have an average value of about 0.105 mg P/l which is less than to the value predicted by the Chapra and Rechklow model and significantly less than the value measured in the lake. Rerunning the Walker model to incorporate lake basin morphometry (i.e. hypolimnetic depths) and to use observed lake data for calibration, it then predicted that SW Basin could have significant rates of internal loading of phosphorus from the sediments during the summer. From these analyses, the internal loading appears to be significant and may represent approximately 50+% of the loading from all of the external sources. The lake appears to retain a small percentage of the phosphorus from external sources in contrast to "average" lakes in this part of the state, which may be expected to retain the majority of the phosphorus inputs.

The relative magnitudes of phosphorus reaching the lake from external sources is summarized in Table 4, where it should be noted that the nonpoint sources of phosphorus are based upon export coefficients measured in similar watersheds and the point sources are based upon detailed monitoring conducted by the City of Eveleth. As such, these nonpoint source values are approximations of the magnitude of watershed phosphorus sources and should not be viewed as absolute values. Even so, the Eveleth WWTF contributes less than one-half (45%) of the phosphorus loading to the lake. Allowing that WWTF effluent generally contains phosphorus in forms more readily available to algal growth, the WWTF may contribute as much as 56% of the available phosphorus flux to the lake in the calculations prepared for this report.

Water Quality Management Options

1. No Action. It is likely that lake resource users may expect a continuation of conditions monitored and/or encountered over the past several years.

The growing season may have large fluctuations in blue-green algal concentrations with periodically and severe bloom conditions. It is likely that nuisance concentrations, that is, chlorophyll-a concentrations greater than 30-40 ug/l, will be encountered in excess of 80% of the summer season. Inlake TP concentrations will likely continue to fluctuate dramatically due to the magnitude of external and internal nutrient sources and concentrations between 75 - 1000 ug/l are probable. On the higher end of this range, it is possible that there will be some degree of potential for winterkill/ summerkill of fisheries due to the volumetric oxygen demand exerted by the decaying organic matter. This may especially true in the SW Basin.

2. Elimination of the Eveleth Bypasses. Elimination of the bypassing from the Eveleth collection system would not likely materially affect the inlake TP concentrations since the bypasses were calculated to be about 5% of the TP flux to the lake. Elimination of this nutrient source with other nutrient reduction could likely cause perceptible water quality changes, though.

3. Reduction of the Eveleth effluent TP. Wastewater effluent monitoring results supplied by the City of Eveleth to the MPCA for the time period June 1986 - July 1987 averaged 0.5 mg P/l (+/- 0.17 mg P/l) which is nearly twice as good as required by their NPDES permit (i.e. one-half of the City's effluent limitation of 1.0 mg P/l). Reducing this limitation to 0.5 mg P/l would not likely cause any difference from recently experienced conditions in Elbow Lake. Reduction of the effluent limitation to 0.3 mg/l (nearly "best available technology") may result in a reduction of about 500 pounds P/year (227 kg P/year) or about 10% of the TP loading to the lake estimated by this report. In light of the magnitude of the current

inlake conditions, this amount of reduction would not likely result in a significant (observable) response in Elbow Lake and the costs would likely be very high for construction and operation of the WWTF to meet a 0.3 mg/l effluent limitation for phosphorus.

4. Diversion of the WWTF effluent from Elbow Lake.* Using the model of Walker, prediction of the range of inlake water quality resulting from the diversion of the Eveleth WWTF was attempted. Subsequent to diversion of the effluent, the estimated TP loading rate to the lake would likely be on the order of 500 - 800 kg/year (1100-2200 lbs/year) from external sources, based upon the above nonpoint source export calculations (with a most likely value of about 700 kg/year).

   The largest of these external sources is the nonpoint source runoff from the urban areas of Eveleth, West Eveleth and Leonidas which enter the lake via the flows of Snowden Creek. If there was no internal phosphorus loading occurring, predicted inlake TP values would likely be less than 0.100 ug/l. However, monitoring data from 1987 clearly indicate that there is significant internal loading potential and therefore, prediction of inlake values resulting from diversion of the effluent is not possible with the current models.

   In general, it has been observed that subsequent to large changes in nutrient loading to lakes, a period of time is necessary for the lake to reach "steady state" or equilibrium. Estimation of this period of time for

* NOTE: Diversion means no WWTF effluent, but continuation of the Snowden Creek water flows.

Elbow Lake is complicated due to the twin basin configuration of the lake, with the predominant water flow occurring through the NE Basin rather than the SW Basin. The SW Basin may take a significantly longer time period to reach its new equilibrium (than the NE Basin), perhaps even on the order of 5 to 10 years (depending upon the extent of mixing between the two basins). At that time, average inlake TP and maximum chlorophyll-a values would likely be lower than currently being experienced. However, it is likely that bloom conditions (surface scums, etc.) may continue indefinitely (see Shagawa Lake readings in Appendix F).

It is not possible to categorically say that subsequent to diversion that there will be a reduction in the number of the algal blooms. This will be dependent upon additional factors such as the weather, the degree of mixing, and other factors. All other factors being equal, however, the maximum chlorophyll-a concentrations will tend to decrease with decreasing TP. Until it can be demonstrated that inlake TP concentrations can be decreased to about 0.050-0.070 mg/l, all affected parties should be aware of the uncertainties and dangers of making longterm assessments of algal bloom (chlorophyll-a) conditions. Above this range, inlake TP concentrations will be sufficient to generate nuisance algal blooms which may persist for short or long time periods (Allan, 1980; and Walker, 1983).

5. Addition of the Minepit Water Volumes to Snowden Creek.

   a. Current Conditions (No Diversion).

      In order to generalize as to the potential effects of the addition of the minepit volumes to the water quality of Elbow Lake, several assumptions were made including:

1) the volume would be about 4.97 HM3 or 4029 acre feet or 5.6 cfs;
2) the average flow weighted mean TP concentration, of 16 ug/l was chosen; and
3) the degree of short circuiting of the water flows, due to the proximity of the inlet to the outlet, will likely reduce the dilution effects to the SW Basin some degree.

The minepit water flows will, in effect, dilute the nutrient concentrations occurring in Snowden Creek. The modeling of these conditions suggests that there would be a reduction in the NE Basin TP values but the extent of the inlake reduction would be complicated by the internal loading occurring from the SW Basin. This loading would enter the NE Basin via advective ("flowing water") and wind mixing, etc. from the SW Basin. In general, it is expected that there would be a net export of phosphorus from the SW Basin and therefore, the longer that the minepit water is added, the greater the degree of nutrient dilution that may be expected to occur. Water residence times can be expected to decrease (e.g. more flushing) in the NE Basin, and this will tend to flush out algal accumulations. It is likely then, that there will be a reduction in the severity of the nuisance conditions caused by algal blooms, particularly in the NE Basin. Due to the magnitude of the internal loading, the changes in the SW Basin are difficult to predict but it is likely that the continuation of nuisance conditions will likely occur, especially during low flow conditions and during hot/dry periods occurring in the ice-free season. The above comments pertaining to "steady state" are also applicable in this situation.

b. Addition of Minepit Volumes (Dilution) after Diversion.

The difficulty in predicting future conditions resulting from diversion of the WWTF effluent has been discussed above. The principal difficulty has been prediction of the degree of the internal loading occurring from the SW Basin and the length of time necessary for reduction of this internal loading - given substantial reduction of the phosphorus loading to the lake. Application of Walker's model again indicates that inlake TP values, without internal loading, should be less than 0.100 mg/l. However, it may be that these values may not be realized in the lake even with diversion and dilution.

Considerable efforts have been expended by Clinton Township residents and by the City of Eveleht to find alternative discharge location(s) for the Eveleth WWTF. Over the course of several meetings and letters between Clinton Township, City of Eveleth, MPCA and MDNR representatives, several alternative discharge locations have been proposed and investigated. Options discussed have included discharge relocation to: (1) Evelth Taconite pit lakes with an eventual discharge to Stream #1; (2) Fayal Pond Creek and then to Mud, Horseshoe and Long Lakes; (3) the Pike River (over the Laurentian Divide) and Lake Vermillion; and (4) diversion of Snowden Creek around Elbow Lake. None of the options have been found feasible to this point, due to lack of technical feasibility, degradation of other lakes and/or streams, expense or potential for degradation of Elbow Lake (as in the preceding option #4, if all Snowden Creek water volumes are diverted from the lake).

Therefore, of the lake and watershed management options that have been proposed, it is recommended that the addition of the minepit water (dilution volumes) be implemented as soon as possible. The monitoring of transparency for both to NE and SW Basins should be continued by citizens over the course of the next two years, at a minimum. This data will be essential for understanding the effects of the dilution water upon the internal nutrient loading occurring in Elbow Lake and the resulting amounts of algae.

Nonpoint Loading

As previously stated, the urban areas of Eveleth, West Eveleth and Leonidas likely contribute a relatively large percentage of the total phosphorus load (42%) to the lake. Urban runoff sources usually have greater percentages of impervious surfaces in roads, parking lots and rooftops. As such, runoff after rain and snow melt may be rapid, thus scouring the impervious surfaces of their dirt, fertilizer, etc. Other factors that tend to increase the magnitude of this runoff is the watershed configuration (narrow and long) and the sharp drop in elevation occurring from Mud Lake to Elbow Lake (approximately 42 feet per mile). These characteristics tend to increase the volume of the runoff which in turn carries increased amounts of nutrients and sediments from the urban areas. It is possible to reduce the quantities of urban nonpoint source phosphorus. For example, properly constructed sediment basins may retain significant quantities of phosphorus and sediment. The city has also begun a program of eliminating improper sewer connections (see Appendix J), which will also decrease the nonpoint urban phosphorus loading.

Conclusions and Recommendations

1. Reduction of the inlake TP will tend to reduce the severity of the blue-green algae and the nuisance conditions generated by blue-green algal blooms. For this purpose, the addition of the minepit water to Elbow Creek and to Elbow Lake should be implemented as soon as possible. This will dilute the inlake concentrations of nutrients.

2. Internal loading of phosphorus to the lake appears to be significant. In 1987, the observed area weighted mean inlake TP was about 0.300 mg/l or 300 ug/l and greatly exceeded the values predicted by computer models by about a factor of about 2. The net difference appeared to be due to the extent of the internal loading occurring in the lake, particularly in the SW Basin. Internal loading may potentially represent a significant percentage of the current external TP loading rate from all external sources (e.g. rain, point sources, urban runoff and bypasses).

3. It was therefore not possible to predict attainable water quality resulting from implementation of several lake management options. Based upon the analyses completed to date, it is important to note that Elbow Lake will likely never achieve lake water quality comparable to many other area lakes due to the nature of the internal loading and the nature of the nonpoint runoff from the urban areas.

4. At this time, it is recommended that the City of Eveleth maintain its current phosphorus effluent limitation of 1.0 mg/l with a total annual TP mass not to exceed 2400 pounds per year.

5. Efforts to reduce the nonpoint sources of phosphorus from the urban areas should continue. For this purpose, various best management practices (BMP's) may be employed, including sediment basins, elimination of sewer connections to storm sewers and other measures.

TABLE 1. ELBOW LAKE: 1987 TROPHIC STATUS INDEX VALUES.

	SW BAY	NE BAY	AREA-WEIGHTED MEAN
TSIP	91.5	78.8	85.7
TSIC	75.4	71.2	73.3
TSIS	58.6	54.2	56.0

TABLE 2. ELBOW LAKE: MORPHOMETRIC, WATERSHED AND FISHERY CHARACTERISTICS.

MDNR I.D. # 69-0717

STORET # 69-0717 Watershed: St. Louis River

Total lake surface area, Ao, (Note 1) : 168.6 acres
Southwest Bay : 73.9 acres
Northeast Bay : 94.7 acres

	Volume	Mean Depth
Total Lake Volume (Note 1)	1756 acre feet	11.3 feet
Southwest Bay	1046 acre feet	13.5 feet
Northeast Bay	710 acre feet	7.5 feet

Maximum Lake Surface Distances

	Fetch	Width
Southwest Bay	823 m	366 m
Northeast Bay	1250 m	305 m

Hydraulic Loading Coefficients
Average Runoff: 0.25 m
Low Runoff : 0.13 m
High Runoff : 0.31 m

Mean Hydraulic Retention Time : 0.4 years
Southwest Bay : 2.5 years
Northeast Bay : 0.2 years

Maximum Depth : 22 feet

Littoral Area : 78.7 % (103 acres)

Fisheries Management:
Shoreland Zoning : Natural Environment

Public Access : 1
Subwatersheds : 3
Inlets/Outlets:
1 Outlet
2 Stream Inlets

Watershed Area to Lake Area : 31.3

Estimated Land Use Summary versus Regional Average Values by Percents. (Note 2):

	Elbow Lake* %	Elbow Lake* ha	Regional Average %
Forested	56%	1196	75.2%
Water+Wetland	11%	235	10.1%
Urban+Residential	17%	363	1.9%
Pasture+Open	5%	107	7.3%
Cultivated	-		4.6%
Mining	11%	235	0.4%

* Note 2: Values for Elbow Lake were determined by planimetering dominant land use surface areas from USGS topographic maps of the area.

Development (homes): 4 permanent homes total

Note 1 : Surface areas planimetered from MDNR map dated 10-28-68.

TABLE 3. SNOWDEN CREEK NUTRIENT CONCENTRATIONS (mg/l)*.

Date	TKN	TP
May 11, 1987	0.640	0.204
July 10, 1987	0.600	0.442
September 4, 1987	0.700	0.324

[* in mg/l. Multiply by 1,000 for ug/l]

TABLE 4. ESTIMATED EXTERNAL PHOSPHORUS CONTRIBUTIONS BY SOURCE.

Source	Percent of Income to the Lake. Total I %*	Adjusted for Available I. %
Eveleth WWTF	45	56
Bypasses	4	5
Snowden Creek	42	33
Unknown Lake	1	1
Immediate Watersheds	6	3
Precipitation	2	2

* Note: Values are the best approximations from limited data. Detailed studies are required to provide further resolution.

TABLE 5. AVERAGE SUMMER WATER QUALITY AND TROPHIC STATUS INDICATORS.

Water Quality Characteristics: Average Summer Epilimnetic (Surface Water) Values.

Parameter	1987 Mean	Range of Values
Secchi Disk (Feet)	3.8 (1.17 m)	2.0 - 7.9 (0.6 - 2.4 m)
Chlorophyll-a (ug/l)	80	26 - 235
Total Phosphorus (mg/l)	0.302	0.095 - 0.915
Total Kjeldahl Nitrogen (mg/l)	2.07	1.24 - 3.36
Nitrite + Nitrate Nitrogen (mg/l)	0.01	0.01 - 0.02
Alkalinity (mg/l)	111	88 - 190
Color (Pt-Co Units)	48	40 - 50
Chloride (mg/l)	16	15 - 18

Total Nitrogen (mg/l)	SW Basin	= 2.25	
	NE Basin	= 1.89	
	All	= 2.07	
Total Phosphorus (mg/l)	SW Basin	= 0.426	
	NE Basin	= 0.177	
	All	= 0.302	Area Weighted Mean = 0.286
Chlorophyll-a (ug/l)	SW Basin	= 96	(Range 26-235)
	NE Basin	= 63	(Range 27-130)
	All	= 80	

TABLE 6. WATERSHED NONPOINT AREAS, EXPORT COEFFICIENTS AND RUNOFF VALUES.

CASE: elcurcor2

INPUT GROUP 11 - NON-POINT WATERSHED AREAS (KM2)

ID	SEG	NAME	Urban	Forest	Water	Pasture	Wetland	Mining
1	2	Snowden Creek	3.650	4.640	.202	.000	2.140	2.008
2	2	Unknown Lake	.000	.496	.122	.000	.615	.000
3	1	Immediate SWBay	.000	1.213	.000	.214	.551	.000
4	2	Immediate NWBay	.000	1.245	.000	.000	1.215	.000

<H>

CASE: elcurcor2

INPUT GROUP 12 - NON-POINT EXPORT COEFFICIENTS

OPT=1 AREAL EXPORT (KG/KM2-YR), OPT=2 CONC (PPB)

IU	OPT	LAND USE		RUNOFF M/YR	CONSERV	TOTAL P	TOTAL N	ORTHO P	INORG N
1	1	Urban		.35	.0	100.0	1000.0	10.0	500.0
			CV:	.20	.00	.25	.25	.25	.25
2	1	Forest		.25	.0	20.0	500.0	5.0	250.0
			CV:	.20	.00	.10	.25	.25	.25
3	1	Water		.10	.0	10.0	100.0	2.0	50.0
			CV:	.25	.00	.25	.25	.25	.25
4	1	Pasture		.25	.0	20.0	500.0	5.0	250.0
			CV:	.25	.00	.25	.25	.25	.25
5	1	Wetland		.25	.0	10.0	150.0	2.0	50.0
			CV:	.25	.00	.25	.25	.25	.25
6	1	Mining		.25	.0	16.0	1000.0	5.0	850.0
			CV:	.25	.00	.25	.25	.25	.25

<H>

CASE: elcurcor2

REFERENCES

Borchert, J.R., G.W. Orning, J. Stinchfield, and L. Make. 1970. Minnesota's lakeshore: resources development, policy needs. Summary of the Minnesota Lakeshore Development Study, University of Minnesota, Department of Geography and C.U.R.A., Minneapolis, Minnesota.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography 22:361-369.

Chapra, S.C. and K.H. Reckhow. 1983. Engineering Approaches for Lake Management. Volume 2. Mechanistic Modeling. Butterworth Publishers, Woburn, MA. 492 pp.

Chapra, S.C. and K.H. Reckhow. 1986. Lake Modeling. A course presented at Duke University in November, 1986.

Citizens' Guide to Lake Protection. 1985. Minnesota Pollution Control Agency. St. Paul, MN. Freshwater Society, Navarre, MN. 6 pp.

Heiskary, S.A., C.B. Wilson, P. Larson. 1986. Analysis of Regional Lake Water Quality Patterns: Implications for Lake Resource Management in Minnesota. Minnesota Pollution Control Agency, St. Paul. 22 pp.

Heiskary, S.A. 1985. Minnesota Pollution Control Agency. Trophic Status of Minnesota Lakes. St. Paul, MN. 39 pp.

Minnesota Department of Natural Resources. 1968. An Inventory of Minnesota Lakes: Bulletin 25. MDNR. St. Paul, MN. 492 pp.

Omernik, J.M. 1977. Nonpoint Source - Stream Nutrient Level Relationships: A Nationwide Study. EPA-600/3-77-105. 152 pp.

PIC. 1986. Planning Information Center. State Planning Office. St. Paul, MN.

Reckhow, K.H. and J.J. Simpson. 1980. A procedure using modeling and error analysis for the prediction of lake phosphorus concentration from land use information. Can. J. Fish. Agent. Sci. 37:1439-1448.

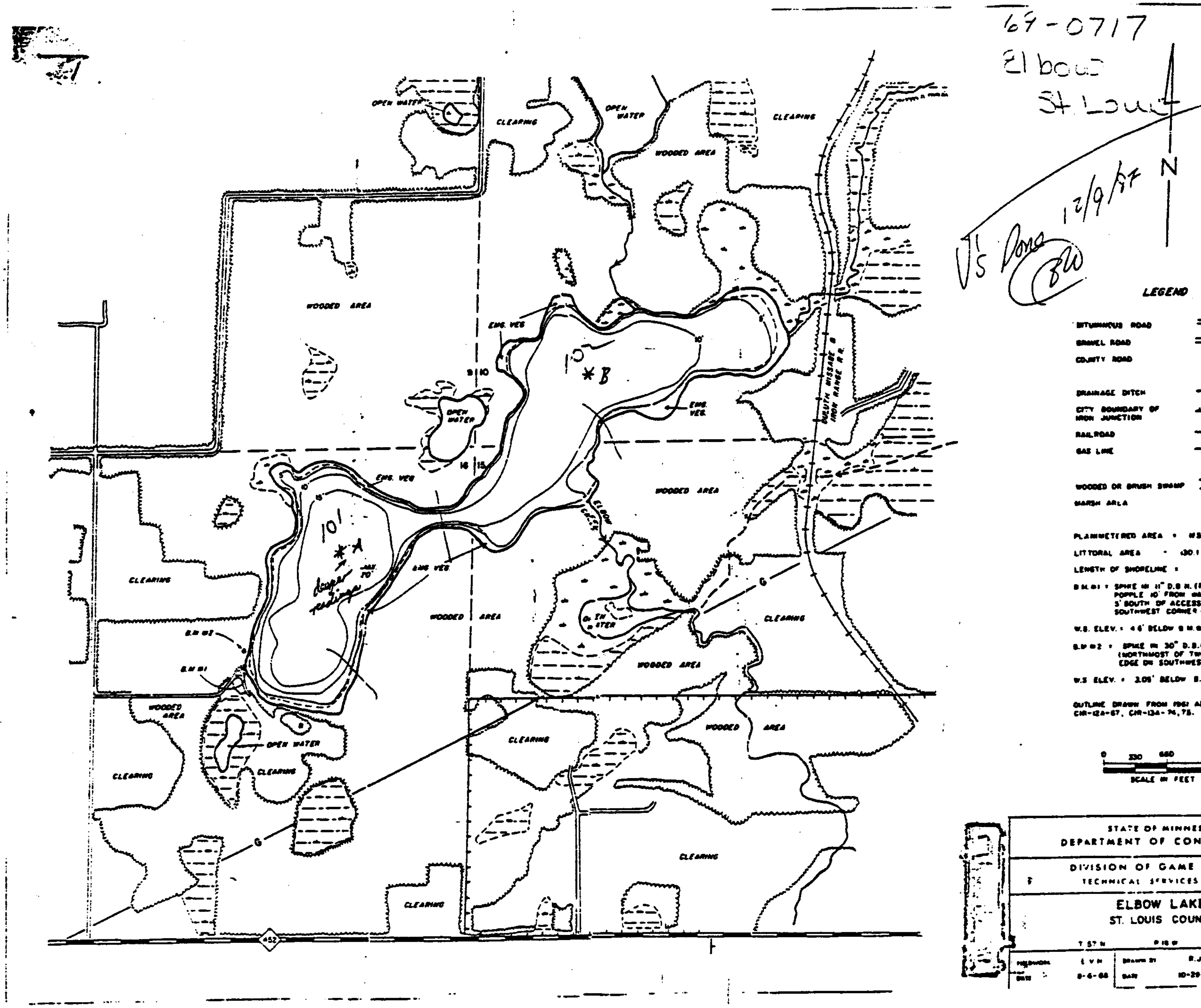
U.S. Environmental Protection Agency. 1974. Report on Elbow Lake, St. Louis County, MN. Working Paper No. 97 of the National Eutrophication Survey. 21 pp.

Watson, Bruce F. 1975. Minnesota and Environs. Weather Almanac 1975. 232 pp.

Walker, W.W. 1985. Empirical methods for Predicting Eutrophication in Impoundments, Report 4: Applications Manual. Prepared for Office, Chief of Engineers, U.S. Army, Administered by Environmental Laboratory, USACE Waterways Experimental Station, Vicksburg, Mississippi. Technical Report E-81-9.

Wisconsin Department of Natural Resources. 1986. Trophic Computer Model. WDNR. Madision, Wisconsin. James Vinnie.

Figure 1. Elbow Lake and Tributaries



LEGEND

BITUMINOUS ROAD
GRAVEL ROAD
COUNTY ROAD
DRAINAGE DITCH
CITY BOUNDARY OF IRON JUNCTION
RAILROAD
GAS LINE
WOODED OR BRUSH SWAMP
MARSH AREA

PLANIMETERED AREA = [illegible] ACRES.
LITTORAL AREA = 130.1 ACRES.
LENGTH OF SHORELINE = 3.7 MILES.

B.M. #1 = SPIKE IN 11" D.B.H. (PINE TOOTH) POPPLE 10' FROM WATER'S EDGE & 5' SOUTH OF ACCESS ROAD AT SOUTHWEST CORNER OF LAKE.

W.S. ELEV. = 4.6' BELOW B.M. #1.

B.M. #2 = SPIKE IN 30" D.B.H. WILLOW (NORTHMOST OF TWO) AT WATER'S EDGE ON SOUTHWEST SIDE OF LAKE.

W.S. ELEV. = 3.05' BELOW B.M. #2.

OUTLINE DRAWN FROM 1961 AERIAL PHOTOS, CIR-12A-67, CIR-13A-74, 75.

0 330 660 1320
SCALE IN FEET

STATE OF MINNESOTA
DEPARTMENT OF CONSERVATION
DIVISION OF GAME AND FISH
TECHNICAL SERVICES SECTION

ELBOW LAKE 69-717
ST. LOUIS COUNTY

T 57 N R 18 W S 10, 15, 16.

FIELDWORK	E V H	DRAWN BY	R.J.M.	PROJ. IDENT. NO.
DATE	8-6-68	DATE	10-29-68	7W18-43

Figure 2. Elbow Lake Watershed Area

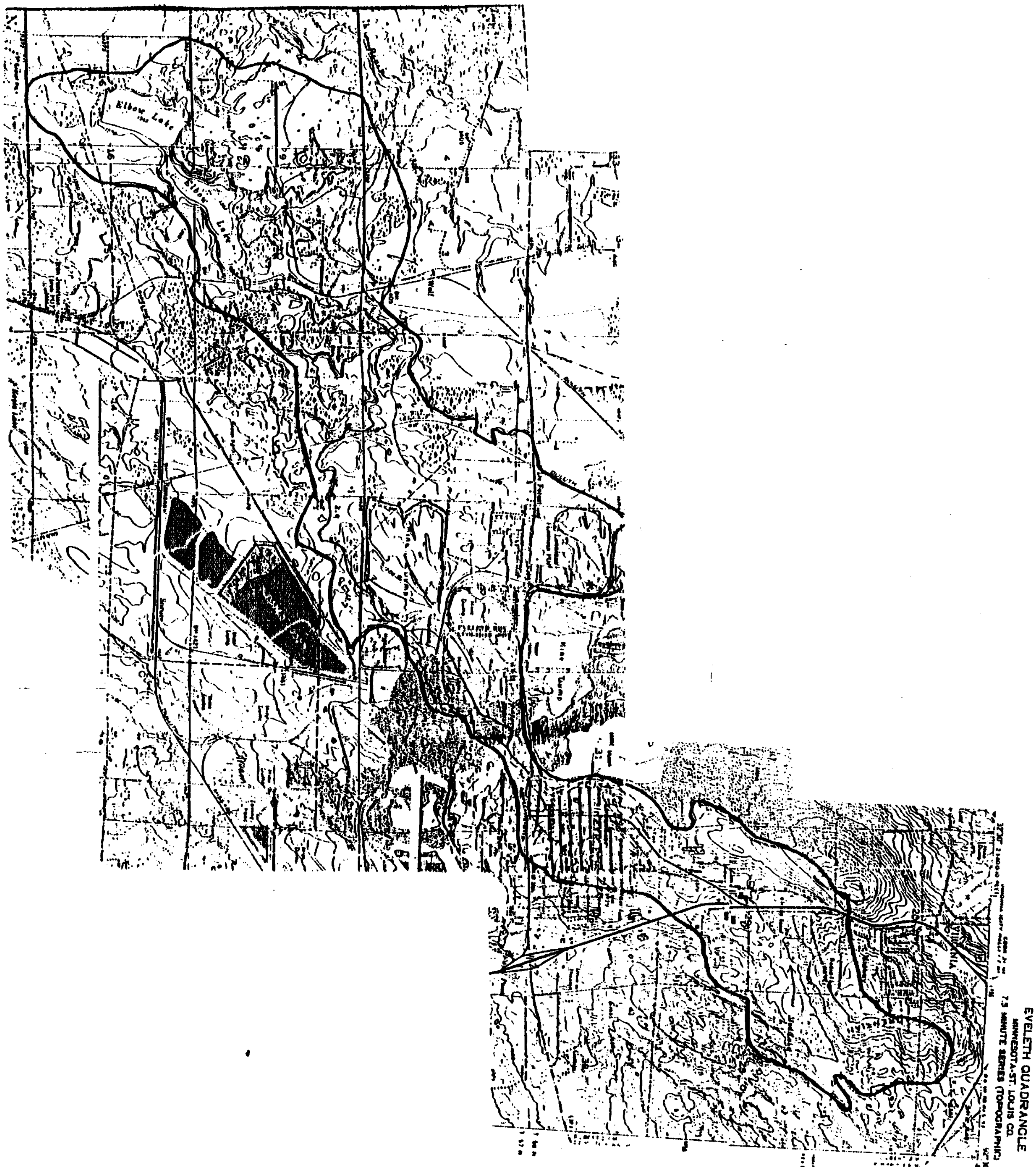

EVELETH QUADRANGLE
MINNESOTA-ST. LOUIS CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
Elbow Lake

Figure 3. Minnesota Ecoregions

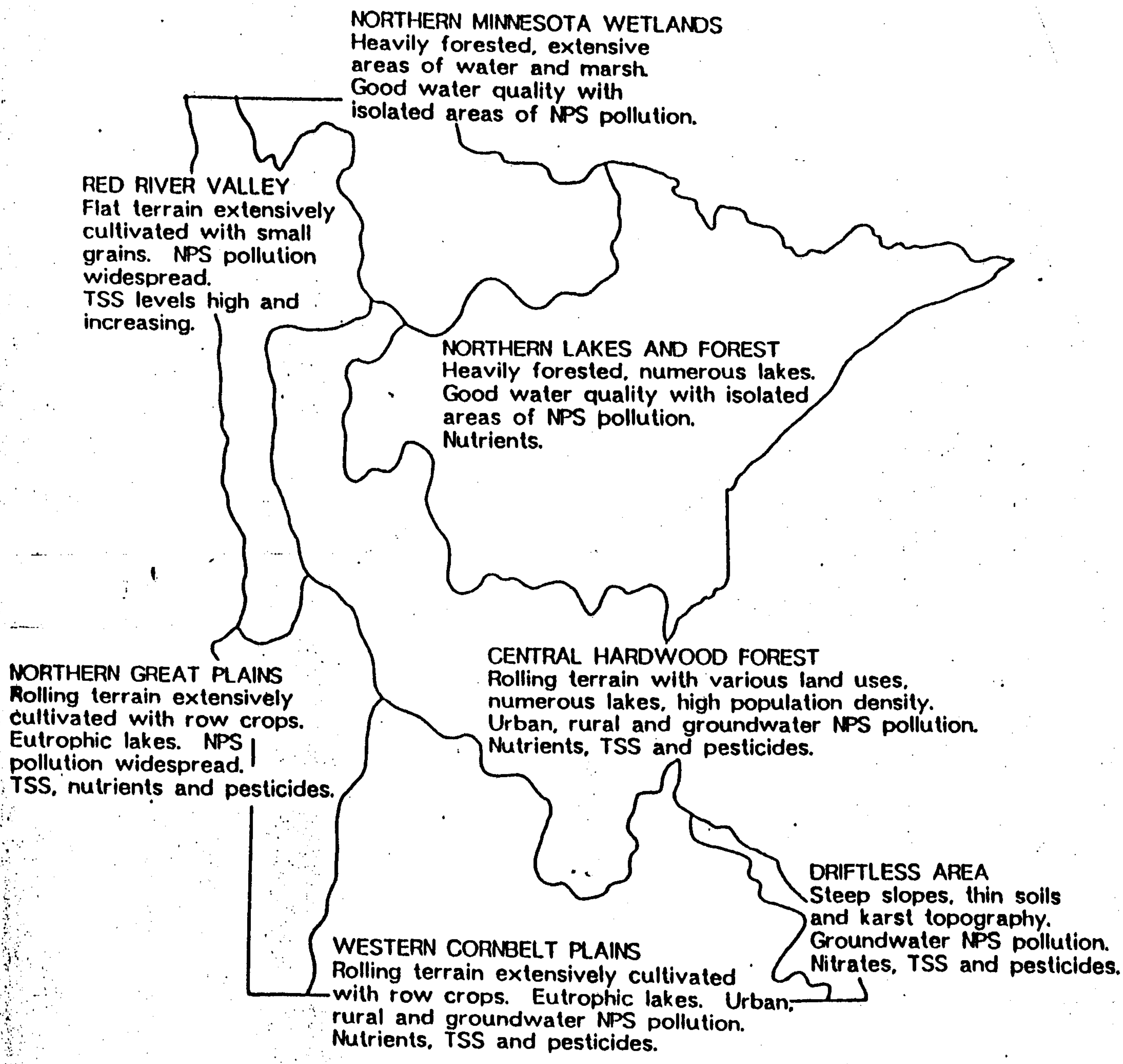
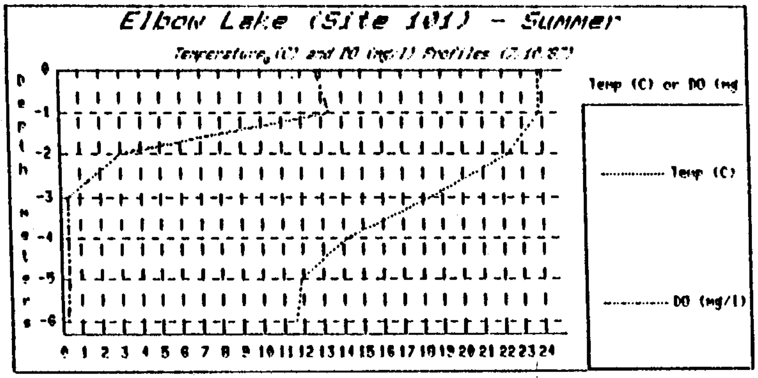
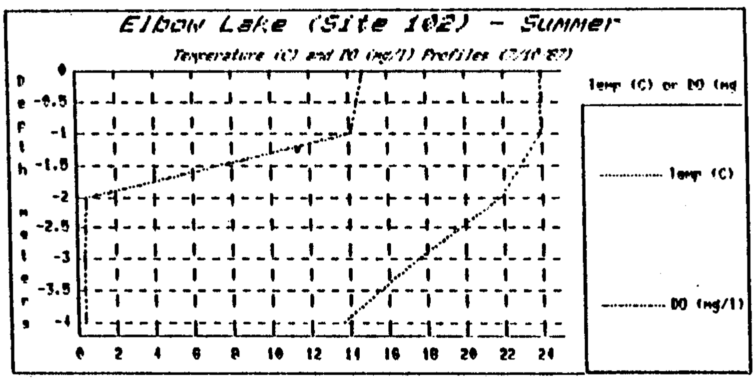
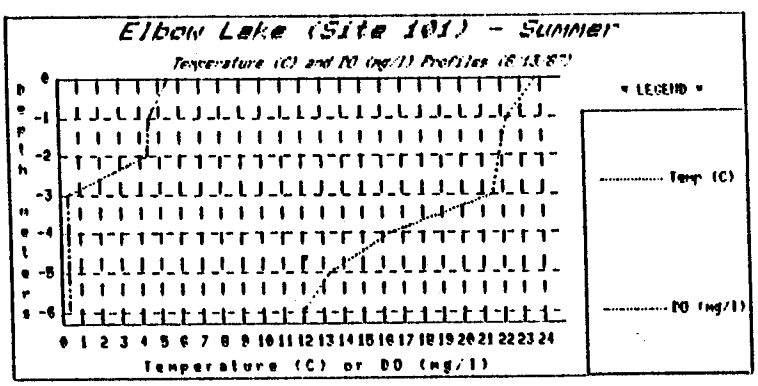
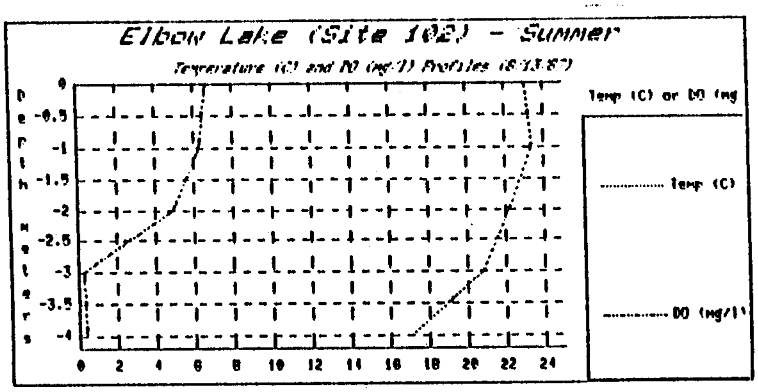

NORTHERN MINNESOTA WETLANDS
Heavily forested, extensive areas of water and marsh. Good water quality with isolated areas of NPS pollution.
RED RIVER VALLEY
Flat terrain extensively cultivated with small grains. NPS pollution widespread. TSS levels high and increasing.
NORTHERN LAKES AND FOREST
Heavily forested, numerous lakes. Good water quality with isolated areas of NPS pollution. Nutrients.
NORTHERN GREAT PLAINS
Rolling terrain extensively cultivated with row crops. Eutrophic lakes. NPS pollution widespread. TSS, nutrients and pesticides.
CENTRAL HARDWOOD FOREST
Rolling terrain with various land uses, numerous lakes, high population density. Urban, rural and groundwater NPS pollution. Nutrients, TSS and pesticides.
DRIFTLESS AREA
Steep slopes, thin soils and karst topography. Groundwater NPS pollution. Nitrates, TSS and pesticides.
WESTERN CORNBELT PLAINS
Rolling terrain extensively cultivated with row crops. Eutrophic lakes. Urban, rural and groundwater NPS pollution. Nutrients, TSS and pesticides.

Figure 4. Temperature and Dissolved Oxygen Profiles


Elbow Lake (Site 101) - Summer
Temperature (C) and DO (mg/l) Profiles (7/10/87)
Depth meters
Temp (C) or DO (mg
Temp (C)
DO (mg/l)


Elbow Lake (Site 102) - Summer
Temperature (C) and DO (mg/l) Profiles (7/10/87)
Depth meters
Temp (C) or DO (mg
Temp (C)
DO (mg/l)


Elbow Lake (Site 101) - Summer
Temperature (C) and DO (mg/l) Profiles (8/13/87)
Depth meters
Temperature (C) or DO (mg/l)
* LEGEND *
Temp (C)
DO (mg/l)


Elbow Lake (Site 102) - Summer
Temperature (C) and DO (mg/l) Profiles (8/13/87)
Depth meters
Temp (C) or DO (mg
Temp (C)
DO (mg/l)

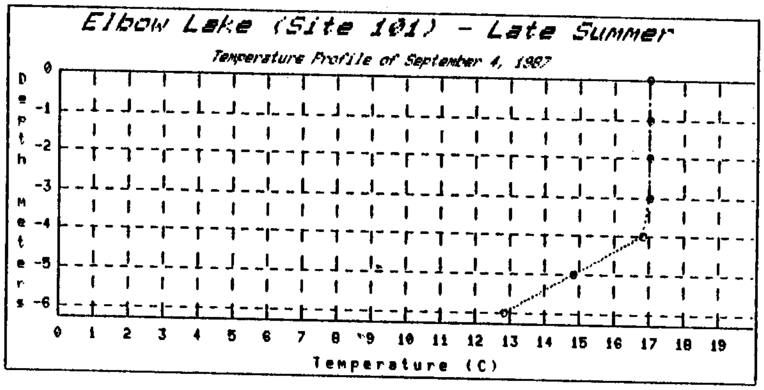
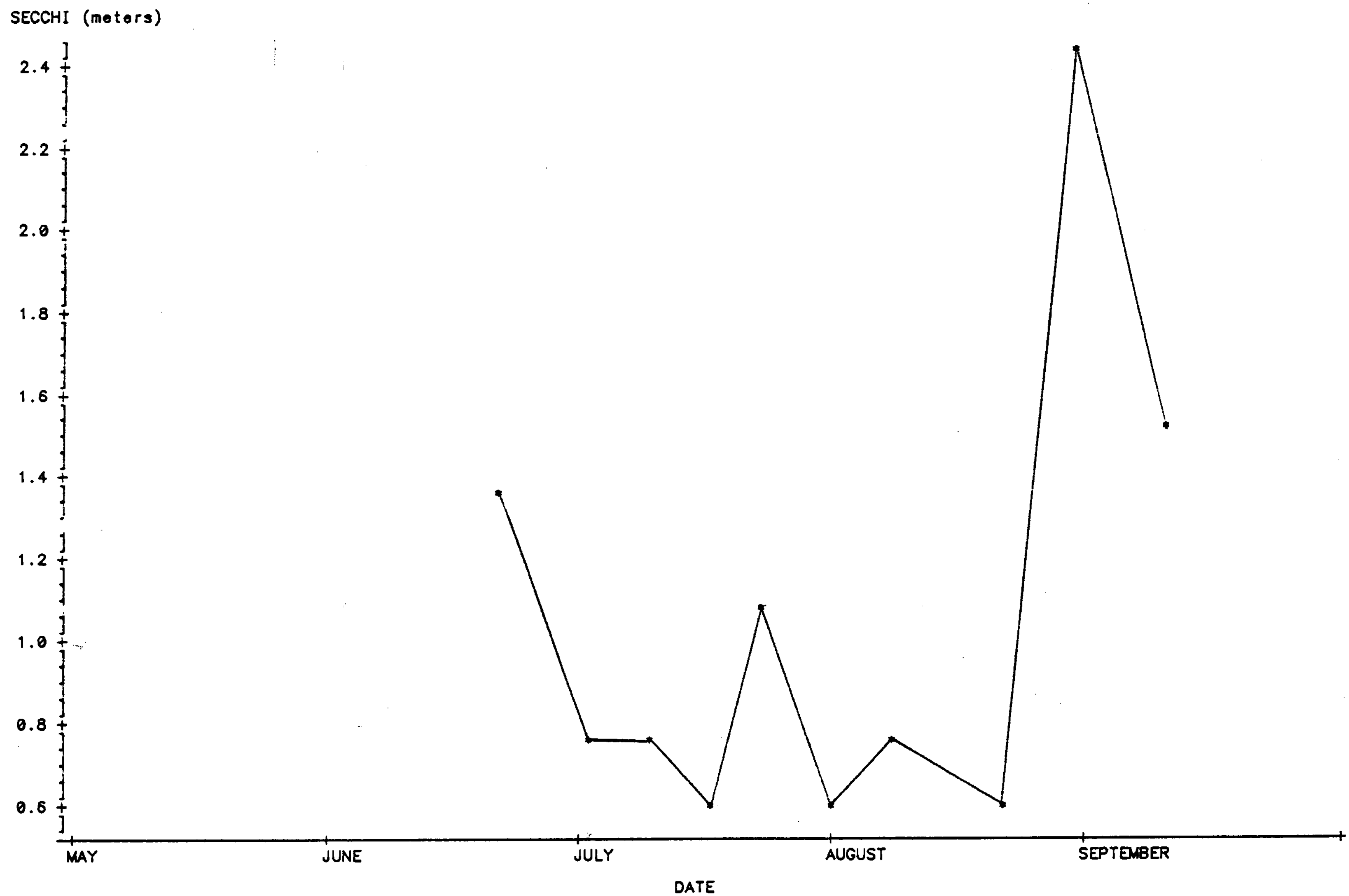

Elbow Lake (Site 101) - Late Summer
Temperature Profile of September 4, 1987
Depth Meters
0
-1
-2
-3
-4
-5
-6
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Temperature (C)

Figure 5. Photomicrograph of Aphanizomenon (Algae)

Figure 6. Summer Transparency Measurments (Secchi Depth in Meters)


SECCHI (meters)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
MAY
JUNE
JULY
AUGUST
SEPTEMBER
DATE

Appendix A

MDNR Fisheries Summary (6/22/82)

** LAKE SELECTION MENU **

ENTER	FUNCTION
(lake number)	to choose a lake
LIST	to list all lakes from this county
LAKE	to list specific lakes from this county
B	to go back one menu
Q	to leave this data base

Enter lake number or MENU: 717

SWIM-LAKE SUMMARY DATA FILE

Lake name: ELBOW   DNR Division of Waters lake number 69- 717
Primary county: ST. LOUIS   Secondary county: ST. LOUIS
Lake ELBOW   is in 1 county
Location: Township 57   Range 18
Watershed ST. LOUIS RIVER

ENTER	REPORT
PHY	for physical characteristics
DEV	for development characteristics
FIS	for the fish report
PER	for permit characteristics
ALL	for all four reports
B	to go back one menu (lake choice)
C	to go back two menus (county choice)
Q	to leave this data base

Enter the report or MENU: all

PHYSICAL CHARACTERISTICS FOR LAKE: ELBOW

Lake type: MARGINAL LAKE
Dominant forest/soil type: NOT AVAILABLE
Size of lake: 171 Acres   Shorelength: 3.1 Miles.
Maximum depth: 18.0   Median depth: 0.0

Secchi disk reading (water clarity): .NA
Lake contour map number: C1896 (available at cost from Documents Division)
(phone: 612-297-3000)

DEVELOPMENT CHARACTERISTICS FOR LAKE: ELBOW

Shoreland zoning classification: NATURAL ENVIRONMENT
Public accesses in 1983: 0

Development	Seasonal Homes	Permanent Homes	Total Homes
1967	0	3	3
1982	0	4	4

*** PUSH RETURN TO CONTINUE ***

DNR SECTION OF FISHERIES INFORMATION FOR LAKE ELBOW

WATER CHEMISTRY SURVEY DATE: 6/22/1982

Secchi disk: 1.5
Water color: Wtr Clear % Littoral: 79
Cause of water color: Hvy alg. blm cvrng entire lk.

LAKE DESCRIPTION

Surface water area: 165
Management class: CENTRARCHID
Ecological type: CENTRARCHID

Accessibility: State boat landing is 1/4 mile down Co. Rd 552.

Area fisheries supervisor: MARK HEYWOOD (218) 365-3230
STAR ROUTE 2 ELY 55731

*** PUSH RETURN FOR CATCH DATA ***

NET CATCH DATA

GILL NETS No. of sets: 4 Gill net survey date: 6/22/1982

species	# fish	# per set	total pounds	pounds per set
White Sucker	39	9.8	75.00	18.75
Black Bullhead	18	4.5	7.00	1.75
Northern Pike	12	3.0	36.50	9.13
Yellow Perch	81	20.3	17.50	4.38
Black Crappie	49	12.3	15.00	3.75

TRAP NETS No. of sets: 5 Trap survey date: 6/22/1982

species	# fish	# per set	total pounds	pounds per set
White Sucker	9	1.8	26.50	5.30
Black Bullhead	1170	234.0	285.00	57.00
Northern Pike	4	0.8	14.50	2.90
Largemouth Bass	2	0.4	4.00	0.80
Pumpkinseed Sunfish	2	0.4	0.50	0.10
Black Crappie	107	21.4	31.00	6.20

*** FISH STOCKING DATA IS NOT AVAILABLE

```
Enter the report or MENU:
 REPORT CODES ARE CHARACTER STRINGS

Enter the report or MENU: q

WATERS (user 10) logged out Wednesday, 08 Apr 87 09:14:36.
Time used: 00h 04m connect, 00m 06s CPU, 00m 38s I/O.
  Regular : $1.69/hr          $322.54/hr    $7.91/hr
      cost: $0.11              $0.54        $0.08        Total:   $.73

4sQJ
NO CARRIER
```

Appendix B

MPCA Lake Data Summary

ELBOW LAKE WATER QUALITY DATA: 1987

DATE	SITE	D	TP	TKN	N2N3	PH	TSS	TSV	TURB	COLOR	CL	COND	ALK	CHLA	SD	PHYS	REC
870710	101	0	0.098	1.87	0.01	9.37	12.0	.	5.0	50	17	300	92	235.0	0.8	4	4
870710	101	16	0.801	2.32	.	.	.	.	.	.	.	.	.	.	.	.	.
870710	102	0	0.145	2.69	0.01	9.56	14.0	.	10.0	50	18	310	96	130.0	0.7	4	4
870710	102	11	0.531	2.10	.	.	.	.	.	.	.	.	.	.	.	.	.
870813	101	0	0.915	3.36	0.01	8.72	4.9	3.3	3.5	50	16	270	88	26.0	1.3	4	4
870813	101	16	0.121	1.29	.	.	.	.	.	.	.	.	.	.	.	.	.
870813	102	0	0.095	1.24	0.01	9.12	4.2	2.6	3.5	50	15	270	88	30.8	1.0	4	4
870813	102	9	0.091	1.18	.	.	.	.	.	.	.	.	.	.	.	.	.
870904	101	0	0.266	1.52	.	.	.	.	.	.	.	.	.	27.9	2.4	4	3
870904	101	16	1.620	6.18	.	.	.	.	.	.	.	.	.	.	.	.	.
870904	102	0	0.290	1.74	0.02	.	9.2	3.2	1.2	40	16	300	190	27.2	2.1	4	3

Abbreviations and Units

SITE= sampling site ID
DM= sample depth in meters(0=0-2 m integrated)
D= sample depth in feet
TP= total phosphorus in mg/l
TKN= total Kjeldahl nitrogen in mg/l
N2N3= nitrite+nitrate N in mg/l
PH= pH in SU (field)
ALK= alkalinity in mg/l (lab)
TSS= total suspended solids in mg/l
TSV= total suspended volatile solids in mg/l
TURB= turbidity in NTU
COND= conductivity in umhos/cm
CL= chloride in mg/l
SD= secchi disk in meters
CHLA= chlorophyll-a in ug/l
PHYS= physical appearance rating
REC= recreational suitability rating

Appendix C

Summary of Lake and Stream Survey Results

LS139 ELBO-9.4
47 26 50.0 092 36 06.0 2
ELBOW CK AT CSAH-19 3 MI SW OF EVELETH
27137 MINNESOTA ST LOUIS
MAJ BASIN: LAKE SUPERIO 222306
MIN BASIN: ST. LOUIS
21MINN 870221 04010201031 OFF
0000 FEET DEPTH

/TYPA/AMBNT/STREAM

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	00028 ANALYZE AGENCY CODE	00116 INTNSVE SURVEY IDENT	00625 TOT KJEL N MG/L	00665 PHOS-TOT MG/L P
87/05/11	1715	WATER			872710	.64	.204
87/07/10	1400	WATER			872710	.60	.442
87/09/04	0900	WATER			872710	.70	.324

Abbreviations and Units

SITE= sampling site ID
DM= sample depth in meters(0=0-2 m integrated)
D= sample depth in feet
TP= total phosphorus in mg/l
TKN= total Kjeldahl nitrogen in mg/l
N2N3= nitrite+nitrate N in mg/l
PH= pH in SU (field)
ALK= alkalinity in mg/l (lab)
TSS= total suspended solids in mg/l
TSV= total suspended volatile solids in mg/l
TURB= turbidity in NTU
COND= conductivity in umhos/cm
CL= chloride in mg/l
SD= secchi disk in meters
CHLA= chlorophyll-a in ug/l
PHYS= physical appearance rating
REC= recreational suitability rating

ELBOW LAKE CLMP SECCHI TRANSPARENCY DATA.

DATE	SITE	SD	PHYS	REC
870621	201	1.4	3	4
870702	201	0.8	3	4
870710	201	0.8	3	4
870717	201	0.6	4	4
870723	201	1.1	4	4
870801	201	0.6	4	4
870808	201	0.8	4	4
870822	201	0.6	4	4
870831	201	2.4	2	3
870911	201	1.5	3	4

Abbreviations and Units

SITE= sampling site ID
DM= sample depth in meters(0=0-2 m integrated)
D= sample depth in feet
TP= total phosphorus in mg/l
TKN= total Kjeldahl nitrogen in mg/l
N2N3= nitrite+nitrate N in mg/l
PH= pH in SU (field)
ALK= alkalinity in mg/l (lab)
TSS= total suspended solids in mg/l
TSV= total suspended volatile solids in mg/l
TURB= turbidity in NTU
COND= conductivity in umhos/cm
CL= chloride in mg/l
SD= secchi disk in meters
CHLA= chlorophyll-a in ug/l
PHYS= physical appearance rating
REC= recreational suitability rating

Appendix D

Summary of Temperature and Dissolved Oxygen Data

ELBOW LAKE DISSOLVED OXYGEN AND TEMPERATURE PROFILES.

DATE	SITE	D	DO	TEMP
870710	101	0	12.70	23.8
870710	101	3	13.40	23.8
870710	101	6	3.00	22.3
870710	101	9	0.40	18.4
870710	101	13	0.40	14.2
870710	101	16	0.40	11.9
870710	101	19	0.30	11.6
870710	102	0	14.80	23.9
870710	102	3	14.10	23.9
870710	102	6	0.50	21.8
870710	102	9	0.40	17.6
870710	102	13	0.40	13.6
870813	101	0	5.50	23.8
870813	101	3	4.50	22.3
870813	101	6	4.40	21.9
870813	101	9	0.40	21.5
870813	101	13	0.40	16.4
870813	101	16	0.40	13.3
870813	101	19	0.40	12.0
870813	102	0	6.70	23.1
870813	102	3	6.30	23.4
870813	102	6	4.90	22.2
870813	102	9	0.30	20.8
870813	102	13	0.35	17.1
870904	101	0	.	17.0
870904	101	3	.	17.0
870904	101	6	.	17.0
870904	101	9	.	17.0
870904	101	13	.	16.8
870904	101	16	.	14.8
870904	101	19	.	12.8
870904	102	0	.	17.3
870904	102	3	.	17.2
870904	102	6	.	17.2
870904	102	9	.	17.0

Abbreviations and Units

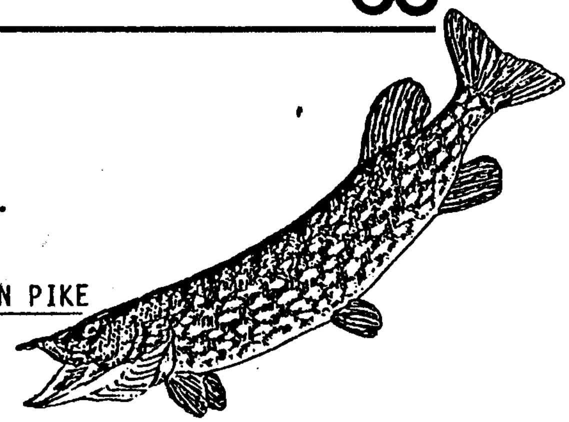
SITE= sampling site ID
DM= sample depth in meters(0=0-2 m integrated)
D= sample depth in feet
TP= total phosphorus in mg/l
TKN= total Kjeldahl nitrogen in mg/l
N2N3= nitrite+nitrate N in mg/l
PH= pH in SU (field)
ALK= alkalinity in mg/l (lab)
TSS= total suspended solids in mg/l
TSV= total suspended volatile solids in mg/l
TURB= turbidity in NTU
COND= conductivity in umhos/cm
CL= chloride in mg/l
SD= secchi disk in meters
CHLA= chlorophyll-a in ug/l
PHYS= physical appearance rating
REC= recreational suitability rating

Appendix E

MDNR/MPCA Lymphosarcoma in Northern Pike Summary

Minnesota Department of Natural Resources

Minnesota Pollution Control Agency



Answers to some commonly asked questions about....

LYMPHOSARCOMA IN NORTHERN PIKE

What is lymphosarcoma?

Lymphosarcoma is a cancerous tumor sometimes found on fish. It will usually look like a reddish sore or swelling near the tail of an affected fish.

What causes it?

The tumor is caused by a virus that is specific to northern pike and muskies. It is not contagious to humans or other fish species.

The disease spreads from infected fish to other northern pike through body contact during spawning.

Why do I seem to see more fish with tumors when the weather turns cold?

Cold water provides the best growth conditions for the virus. Lesions are generally seen on the fish when lake water cools off in late fall and early winter.

Is this virus something new?

No. Lymphosarcoma was first diagnosed in 1898, but many researchers feel that the disease may have been around for hundreds of years.

It has been observed in fish from lakes in several midwestern states, Canadian provinces and European countries.

Is the disease on the increase in Minnesota?

No. Staff from the Minnesota Department of Natural Resources (DNR) have studied lymphosarcoma for about 30 years now. During that time, they have not noticed any appreciable change in the number of lakes that are affected with the fish tumor.

Typically, less than 5 percent of the adult northern pike in affected lakes have contracted this disease.

(over)

Do all affected lakes have wastewater treatment discharges?

No. Some of the affected lakes have wastewater treatment discharges, but others do not. There does not seem to be a relationship between a discharge and the incidence of this tumor.

Is it safe to eat fish with lymphosarcoma?

While this disease is not known to infect people, the DNR and Minnesota Pollution Control Agency (MPCA) do not recommend eating fish with tumors.

If I catch an infected fish, should I throw it back in the lake?

You can help scientists learn more about lymphosarcoma by freezing any infected fish you catch in plastic or aluminum foil and submitting them to the nearest DNR fisheries office or the DNR pathology lab (612/296-3043).

Include the date and location where you caught the fish. Also indicate any other abnormalities or unusual circumstances that you noticed.

If you have further questions about lymphosarcoma in Minnesota lakes, contact:

Dan Helwig, MPCA, 520 Lafayette Road, St. Paul, Minnesota 55155
(612) 296-7250, outside the metro area: toll-free 1-800-652-9747,

or

Phil Economon, MDNR, 500 Lafayette Road, St. Paul, Minnesota 55155
(612) 296-3043.

This fact sheet was prepared on recycled paper.

Appendix F

Suggested Additional Readings

Suggested Additional Reading

1. A Citizens' Guide to Lake Protection 1985. Minnesota Pollution Control Agency, St. Paul, Minnesota. Freshwater Society, Navarre, MN. 16 pp.

2. Summer Internal Phosphorus Supplies in Shagawa Lake, Minnesota. Larsen, D.P., D.W. Schults and K.W. Malveg. 1981. Limnology and Oceanography 26(4): 740-753.

3. A Six-Year Water, Phosphorus, and Nitrogen Budget for Shagawa Lake, Minnesota. Malveg, K.W., D.P. Larsen, D.W. Schults and H.T. Mercier. 1975. Journal of Environmental Quality 4(2): 236-242.

4. Analysis of Regional Patterns in Lake Water Quality: Using Ecoregions for Lake Management in Minnesota. Heiskary, S.A., C.B. Wilson and D.P. Larsen. 1987. Lake and Reservoir Management 3: 337-344.

5. Sinden, C.L. 1987. Review of Effluent Limitations for Wastewater Treatment Facility at Eveleth, Minnesota. Minnesota Pollution Control Agency. St. Paul, Minnesota. 20 pp.

Appendix G

Reckhow/Simpson Model Summary

RESULTS

USER: Wilson LAKE: Elbow
LOCATION: Iron Minnesota CURRENT DATE/TIME: 1/25/88
REPORT TITLE: Elbow Lake LAP Report

THE AREAL WATER LOADING = 7.86947 m/yr

TOTAL PHOSPHORUS MASS LOADING:
1. W(high) = 3009.227 kg/yr 6636 lbs/year
2. W(ml) = 1920.726 kg/yr 4235 lbs/year
3. W(low) = 1174.48 kg/yr 2590 lbs/year

ANNUAL AREAL PHOSPHORUS LOADING:
1. L(high) = 4.408536 g/m^2-yr.
2. L(ml) = 2.813875 g/m^2-yr.
3. L(low) = 1.720621 g/m^2-yr.

LAKE PHOSPHORUS CONCENTRATION
1. P(high) = .2094976 mg/l
2. P(ml) = .1337179 mg/l
3. P(low) = 8.176549E-02 mg/l

STRIKE ANY KEY TO CONTINUE

RESULTS CONTINUED

USER: Wilson LAKE: Elbow
LOCATION: Iron Minnesota CURRENT DATE/TIME: 1/25/88
Elbow Lake LAP Report

PREDICTION UNCERTAINTY RESULTS
1. positive model error = 4.583381E-02 mg/l
2. negative model error = 3.413391E-02 mg/l
3. positive loading error = 3.788987E-02 mg/l
4. negative loading error = 2.597621E-02 mg/l
5. total positive uncertainty = 5.946747E-02 mg/l
6. total negative uncertainty = .0428939 mg/l

CONFIDENCE LIMITS RESULTS

PROB[3.935132E-02 mg/l <= P <= .2645463 mg/l] >= .9081726

STRIKE ANY KEY TO RETURN TO THE MAIN MENU

Appendix H

Summary of Eveleth Bypass Events (6/7/86-7/18/87)

Summary of Eveleth Bypassing Events

Date	Location	Amount(MG)	P(mg/l)
6/7/86	Sand Filters	1.0	
6/10/86		1.3	
6/22/86		1.2	
6/25/86		1.3	
7/3-4/86	Retention Tank	0.25	
	Adams LS	0.2	
	W. Ev. LS	0.1	
7/12/86	Retention Tank	0.5	
8/14/86	Retention Tank	0.02	
9/3-4/86	Retention Tank	0.53	
	W. Ev. LS	0.2	
	Adams LS	0.1	
9/11/86	Sand Filters	Unknown Amounts	0.3 mg/l
	Retention Tank		
9/17/86	Adams LS	0.1	
	W. Ev. LS	0.05	
11/6/86	Sand Filters	1.4	
1987			
3/6-8/87	Sand Filters	3.87	
3/23/87	Sand Filters	2.28	
5/16/87	Adams LS	0.05	
	Retention Tank	0.15	
5/17/87	Retention Tank	1.0	1.400 mg/l
	W. Ev. LS	0.2	
6/1/87	Retention Tank	1.0	0.700 mg/l
	Adams LS	0.25	
7/18-22/87			
	Adams LS	0.31	0.500 mg/l
	W. Ev. LS	0.1	0.500 mg/l
	Retention Tank	2.01	0.600 mg/l

19.5 mg = 0.074 HM3

55.4 kg P/year to Snowden Creek and then to Elbow Lake.

Appendix I

Centigrade Conversion Chart

The temperature, either Centigrade or Fahrenheit, which it is desired to convert to the other scale, is indicated below in bold face type. Equivalent temperature in degrees Centigrade is shown in column to the left; and approximate equivalent temperature in degrees Fahrenheit is shown in column to the right.

Cent.°		Fahr.°
−95.5	**−140**	−220
−90.0	**−130**	−202
−84.4	**−120**	−184
−78.9	**−110**	−166
−73.3	**−100**	−148
−67.6	**− 90**	−130
−62.2	**− 80**	−112
−56.6	**− 70**	− 94
−51.1	**− 60**	− 76
−45.5	**− 50**	− 58
−40.0	**− 40**	− 40
−34.4	**− 30**	− 22
−28.9	**− 20**	− 4
−23.3	**− 10**	14
−17.8	**0**	32
−17.2	**1**	33.8
−16.7	**2**	35.6
−16.1	**3**	37.4
−15.6	**4**	39.2
−15.0	**5**	41.0
−14.4	**6**	42.8
−13.9	**7**	44.6
−13.3	**8**	46.4
−12.8	**9**	48.2
−12.2	**10**	50.0
−11.7	**11**	51.8
−11.1	**12**	53.6
−10.6	**13**	55.4
−10.0	**14**	57.2
− 9.4	**15**	59.0
− 8.9	**16**	60.8
− 8.3	**17**	62.6
− 7.8	**18**	64.4
− 7.2	**19**	66.2
− 6.7	**20**	68.0

Cent.°		Fahr.°
−6.1	**21**	69.8
−5.6	**22**	71.6
−5.0	**23**	73.4
−4.4	**24**	75.2
−3.9	**25**	77.0
−3.3	**26**	78.8
−2.8	**27**	80.6
−2.2	**28**	82.4
−1.7	**29**	84.2
−1.1	**30**	86.0
− .6	**31**	87.8
0	**32**	89.6
0.6	**33**	91.4
1.1	**34**	93.2
1.7	**35**	95.0
2.2	**36**	96.8
2.8	**37**	98.6
3.3	**38**	100.4
3.9	**39**	102.2
4.4	**40**	104.0
5.0	**41**	105.8
5.6	**42**	107.6
6.1	**43**	109.4
6.7	**44**	111.2
7.2	**45**	113.0
7.8	**46**	114.8
8.3	**47**	116.6
8.9	**48**	118.4
9.4	**49**	120.2
10.0	**50**	122.0
10.6	**51**	123.8
11.1	**52**	125.6
11.7	**53**	127.4
12.2	**54**	129.2
12.8	**55**	131.0

Cent.°		Fahr.°
13.3	**56**	132.8
13.9	**57**	134.6
14.4	**58**	136.4
15.0	**59**	138.2
15.6	**60**	140.0
16.1	**61**	141.8
16.7	**62**	143.6
17.2	**63**	145.4
17.8	**64**	147.2
18.3	**65**	149.0
18.9	**66**	150.8
19.4	**67**	152.6
20.0	**68**	154.4
20.6	**69**	156.2
21.1	**70**	158.0
21.7	**71**	159.8
22.2	**72**	161.6
22.8	**73**	163.4
23.3	**74**	165.2
23.9	**75**	167.0
24.4	**76**	168.8
25.0	**77**	170.6
25.6	**78**	172.4
26.1	**79**	174.2
26.7	**80**	176.0
27.2	**81**	177.8
27.8	**82**	179.6
28.3	**83**	181.4
28.9	**84**	183.2
29.4	**85**	185.0
30.0	**86**	186.8
30.6	**87**	188.6
31.1	**88**	190.4
31.7	**89**	192.2
32.2	**90**	194.0

Cent.°		Fahr.°
32.8	**91**	195.8
33.3	**92**	197.6
33.9	**93**	199.4
34.4	**94**	201.2
35.0	**95**	203.0
35.6	**96**	204.8
36.1	**97**	206.6
36.7	**98**	208.4
37.2	**99**	210.2
37.8	**100**	212.0
43	**110**	230
49	**120**	248
54	**130**	266
60	**140**	284
66	**150**	302
71	**160**	320
77	**170**	338
82	**180**	356
88	**190**	374
93	**200**	392
99	**210**	410
100	**212**	414
104	**220**	428
110	**230**	446
116	**240**	464
121	**250**	482
127	**260**	500
132	**270**	518
138	**280**	536
143	**290**	554
149	**300**	572
154	**310**	590
160	**320**	608
166	**330**	626
171	**340**	644

Cent.°		Fahr.°
177	**350**	662
182	**360**	680
188	**370**	698
193	**380**	716
199	**390**	734
204	**400**	752
210	**410**	770
216	**420**	788
221	**430**	806
227	**440**	824
232	**450**	842
238	**460**	860
243	**470**	878
249	**480**	896
254	**490**	914
260	**500**	932
266	**510**	950
271	**520**	968
277	**530**	986
282	**540**	1004
288	**550**	1022
293	**560**	1040
299	**570**	1058
304	**580**	1076
310	**590**	1094
316	**600**	1112
321	**610**	1130
327	**620**	1148
332	**630**	1166
338	**640**	1184
343	**650**	1202
349	**660**	1220
354	**670**	1238
360	**680**	1256
366	**690**	1274

Cent.°		Fahr.°
371	**700**	1292
377	**710**	1310
382	**720**	1328
388	**730**	1346
393	**740**	1364
399	**750**	1382
404	**760**	1400
410	**770**	1418
416	**780**	1436
421	**790**	1454
427	**800**	1472
432	**810**	1490
438	**820**	1508
443	**830**	1526
449	**840**	1544
454	**850**	1562
460	**860**	1580
466	**870**	1598
471	**880**	1616
477	**890**	1634
482	**900**	1652
488	**910**	1670
493	**920**	1688
499	**930**	1706
504	**940**	1724
510	**950**	1742
516	**960**	1760
521	**970**	1778
527	**980**	1796
532	**990**	1814
538	**1000**	1832
543	**1010**	1850
549	**1020**	1868
554	**1030**	1886
560	**1040**	1904