LAKE ASSESSMENT PROGRAM

1991

FOX LAKE
(MDNR ID. # 66-0029)
Rice County, Minnesota

MINNESOTA POLLUTION CONTROL AGENCY
Division of Water Quality
Nonpoint Source Section
and
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- -watershed maps

SUMMARY AND CONCLUSIONS

Fox Lake was sampled during the summer of 1991 as part of the Minnesota Pollution Control Agency's (MPCA) Lake Assessment Program. Data collected during the study showed that in terms of total phosphorus, chlorophyll and Secchi disk transparency, the water quality of Fox Lake is poorer than similar lakes in the ecoregion. The mean summer concentrations of total phosphorus and chlorophyll were 102 and 104 ug/l respectively and the mean Secchi disk transparency was 3.85 feet. Based on these water quality values Fox Lake would be considered eutrophic to hypereutrophic.

Phosphorus and chlorophyll data fit Carlson's model for trophic status indicators reasonably well (Carlson 1977). The Secchi disk transparency values were somewhat higher than expected based on the observed phosphorus and chlorophyll concentrations. Transparency readings can still provide good long term estimates of phosphorus and chlorophyll and can be a useful tool for tracking future trends. An empirical computer lake model was used to predict 1991 water quality and the results were compared to observed conditions. The model predictions and observed conditions did not agree well. The model estimated total phosphorus concentrations which were much lower than those observed in the lake. The contribution of nutrients from the sediments during the summer may provide some explanation for this discrepancy.

The water quality of Fox Lake is poor relative to other lakes in the ecoregion; however, this is partially due to the fact that the lake is located in a more fertile portion of the ecoregion. Based on total phosphorus data collected in the last 14 years, the lake is experiencing a gradual increase in the phosphorus concentration. Further changes in land use in the immediate watershed, such as increased development and draining or filling of wetlands, could result in a continual increase in phosphorus loading and a resulting decrease in water quality.

The following recommendations are based on the 1991 assessment of Fox Lake.

1. Participation in the Citizens Lake Monitoring Program should continue since it is an effective way to assess long-term and year-to-year variations in algal productivity (lake trophic status). Monitoring should be conducted over the site of maximum depth near MPCA site 101.

2. The Forest Township Agri-Lakes Association (FTALA) should attempt to provide educational materials to homeowners with respect to lawn maintenance and shoreline protection. Protection of the existing vegetation along the shore will minimize erosion and preserve the aesthetic value of the lake. A lake lot with a diverse community of native vegetation will also provide habitat for songbird and other small animals. The MPCA, MDNR, and county offices may be able to provide assistance in this area. The book

Landscaping for Wildlife and the booklet A Citizens Guide to Lake Protection may also be a useful educational tool for the lake association.

3. Any development in the immediate watershed should be completed so that the impacts to lake water quality are minimized. Setback provisions and natural buffer strips should be strictly adhered to. Soil loss can be reduced by utilizing best management practices during construction or road building. Rice county's shoreland regulations will be important in this regard.

4. Activities in the Fox Lake watershed, such as wetland removal or major land use alterations that change the drainage or flow patterns, should be discouraged. Establishment and maintenance of effective buffers between agricultural areas and ditches, streams, and the lake will help to minimize nutrient rich runoff and provide wildlife habitat.

5. The members of FTALA should keep up to date on the progress of the French Lake Clean Water Project. Some of the projects management techniques may be applicable at Fox Lake. Those efforts which address shoreline management, and aquatic plant control will be of special interest to FTALA members.

6. Although it can be difficult to assess how much impact individual watershed projects will have on the lake, the cumulative effect of several projects can be significant. In addition to the

positive effects on water quality, watershed projects such as restoration of wetlands, protection of natural areas, and creation of buffer strips will improve the wildlife habitat, plant diversity and aesthetics of the watershed. The MDNR has constructed a map of the remaining natural areas and rare species in Rice County. These few remaining natural areas should be targeted for protection.

7. A few factors such as watershed size, lake depth and nutrient recycling may make Fox Lake a good candidate for in-lake treatment options (ie. alum addition, hypolimnetic aeration). These methods will require further analysis and are most effective after watershed loadings are controlled.

LAKE ASSESSMENT PROGRAM: 1991

Fox Lake

(I.D. #66-0029)

Rice County, Minnesota

INTRODUCTION

The Forest Township Agri-Lakes Association applied for consideration in the Lake Assessment Program in 1991 and listed in their application the following water quality concerns in Fox Lake:

* An increase in the frequency of the toxic blue green algae blooms in the last 10 years.
* A dramatic increase in the growth of aquatic vegetation.
* The potential for increased pressure on the lake resource as demographics change.

The group attributed the water quality problems to nutrient rich agricultural runoff which reaches the lake through the extensive drainage system in the watershed. Improperly maintained septic systems, extensive use of lawn fertilizers and the removal of natural lake shore vegetation were also cited as contributors to the water quality problems. Data gathered by Rice County in 1984 consistently showed fecal coliform bacteria contamination at two sites in the lake. The presence of fecal coliform bacteria indicates that the lake has been impacted by untreated animal and/or human waste.

The Lake Assessment Program was designed to assist lake associations or municipalities in the collection and analysis of baseline water quality data for the purpose of assessing the current trophic status of their lake. The work plan for participants in the Lake Assessment Program includes collection of lake transparency data through the Citizens Lake Monitoring Program (CLMP) and examination of the land-use and drainage patterns in the watershed. During the summer of 1991 staff of the Minnesota Pollution Control Agency (MPCA) collected baseline water quality data as a part of the LAP for Fox Lake. Conclusions and recommendations based on water quality and watershed data are included in the report.

BACKGROUND

Fox Lake was sampled five times during the summer of 1991 by Ed Weir and Ellen Snyder of the MPCA Rochester regional office and Will Munson of the MPCA St. Paul office. Craig Waterston provided the boat and motor for the sampling crew. The Citizens Lake Monitoring Program volunteer was Lois Stratmoen. Ann Passe and Sam Sunderlin gathered information about the watershed with the assistance of the Soil and Water Conservation District.

The sampling days were effectively used as opportunities to discuss lake protection issues with interested people in the community. Members of the lake association hosted elected officials, St Olaf College students and staff, county officials, and other state agency staff on these trips. These informal meetings gave those involved in lake protection a first hand look at the concerns of the lakeshore residents and an opportunity for lake shore residents to meet those people who will be involved in various aspects of future lake protection issues.

Fox Lake is ten miles north of the City of Faribault in central Rice County. The surface area of the lake is just over 300 acres, placing it in the top 15 percent in terms of size statewide (MDNR, 1968). It is one of 17 lakes in Rice county larger than 200 acres. Fox Lake has a maximum depth of nearly 50 feet which is typical for lakes in the region north of Rice County but deeper than the lakes to the west. The mean depth of the lake is 20 feet, and the littoral zone (the lake zone which supports rooted vegetation) covers approximately 45 percent of the lake.

According to Zumberge (1952), Fox Lake was formed by the irregular deposition of glacial till; however, the depth of the lake is somewhat atypical for lakes of this origin which are usually shallow. Lakes of this type typically have gently sloping shoreland areas and the lake depth is determined by the maximum relief of the local topography. If the water and accumulated sediment were removed from the lake basin, the lake bed would occupy a natural position in the local topography.

Soils in the watershed belong to the Lester-Heyden associations which are moderately steep loams that formed in upland glacial till. Permeability is moderate and the water table is below 10 feet. The soils are moderately suited for use as septic tank drain fields for private homes except in areas where high slopes pose a problem. Runoff is moderate to rapid and the potential for erosion can be severe. The native vegetation was mixed deciduous trees and tall prairie grasses. Most of the area soils are used for crops. Some areas remain in trees or wooded pasture. Controlling erosion and maintaining good soil tilth are the principal management concerns. The Lester-Heyden associations are well suited as habitat for game and nongame species found in the area.

Since land use affects water quality, it is helpful to divide the state into areas of similar land use and water resources called ecoregions. Minnesota can be divided into seven ecoregions based on soils, land surface form, natural vegetation, and current land use (Figure 1). Fox Lake is located in the southern lobe of the North Central Hardwood Forest Ecoregion near the border of the Western Corn Belt Plains ecoregion. Land use composition in the watersheds of the North Central Hardwood Forest (NCHF) ecoregion is typically 22-50% cultivated, 11-25% pastured and open, 14-30% water or marsh, 6-25% forested and 2-9% developed. The land use in the

7587 acre Fox Lake watershed is more similar to the land use in the North Central Hardwood Forest Ecoregion than the typical land use in the Western Corn Belt Plain ecoregion (Table 1).

Water quality information was collected on May 20, June 11, July 9, August 6, and September 9, 1991 at two sites on the lake (Figure 2*). Site 101 near the center of the lake was chosen because it is the location of greatest depth. An additional site, 102, was chosen to gain an understanding of the water quality variability within the lake. Lake surface samples were collected with an integrated sampler, which is a PVC tube 6.6 feet (2 meters) in length with an inside diameter of 1.4 inches (3.5 cm). Near-bottom samples were collected with a 2-liter Kemmerer sampler, a 'water trap' that closes at a desired depth. Zooplankton samples were collected from 5-meter tows using a Wisconsin plankton net. A qualitative evaluation of the zooplankton sample was made in the field.

Sampling procedures were followed as described in the MPCA Quality Control Manual and analyzed by the Minnesota Department of Health for total phosphorus, total Kjeldahl nitrogen, nitrate-nitrite nitrogen, suspended solids, alkalinity, chloride, color, turbidity, and chlorophyll a. Field measurements for pH, conductivity, Secchi disk transparency, and temperature and dissolved oxygen profiles were taken by MPCA staff. Algal composition was determined by means of a rapid assessment method. Nearly two decades of CLMP transparency measurements along with water quality data collected in 1979, 1980, 1981, 1986, 1987 and 1989 are available for comparison (Table 4, Figure 7). All data with the exception of algal composition was stored in STORET, the U.S. Environmental Protection Agency's national water quality data bank. The following discussion assumes that the reader is familiar with basic water quality terminology as used in the Citizens Guide to Lake Protection.

RESULTS AND DISCUSSION - In-lake Conditions, 1991

Temperature

Lakes in temperate climates tend to stratify or separate into three layers due to differences in density (caused by differences in temperature). The metalimnion (also referred to as the thermocline) is the middle zone where the water temperature drops rapidly with small increases in depth. This zone separates the epilimnion (top layer) and the hypolimnion (bottom layer). The epilimnion is characterized by warmer water and is the zone where most plant growth occurs. The hypolimnion contains much colder water and is the zone where plant material accumulates and decomposes.

The dissolved oxygen and temperature profiles measured at site 101 on Fox Lake indicate that the lake was stratified throughout the summer of 1991. Stratification was first evident in June when a thermocline formed between 13-19 feet, and was stable through the August sampling date. By early September the stratification began to destabilize and the thermocline was located below 19 feet (Figures 3a-e). The temperature in the epilimnion was between 15 and 25 degrees C (59 and 77 F) and the hypolimnetic temperature ranged between 9.6 and 11 degrees C (49 and 52 F) throughout the summer. Fox Lake maintains a stable temperature stratification throughout the summer because of its depth and relatively small surface (i.e. small wind fetch).

Dissolved Oxygen

The dissolved oxygen concentrations in the epilimnion remained above 5 mg/l throughout the summer. Just below the epilimnion, concentrations decreased rapidly (Figure 3a-e). Dissolved oxygen concentrations greater than 5 mg/l are considered necessary for long-term survival of game fish. Concentrations below 5 mg/l were measured at all depths below 13 feet for all sampling dates except May 20, and concentrations less than 1 mg/l were measured at depths below 19 feet after the July sampling event.

The presence or absence of oxygen in the layers of the lake will determine where fish and other organisms will be found. Game fish which cannot tolerate oxygen concentrations below 5 mg/l will occupy the warmer more oxygenated waters in the epilimnion.

Stratification, a common occurrence in Minnesota lakes, can affect the availability of oxygen and nutrients in the lake.

Total Phosphorus

Total phosphorus (TP) is an important nutrient for plant growth, and in most lakes it is the nutrient which limits the amount of plant and algae growth. Total phosphorus concentrations in the epilimnion were highest in May and tended to decrease throughout the summer (Figure 4). The mean (average) epilimnetic TP concentration for the 1991 sampling period was 102 ug/l and ranged between 61 and 210 ug/l (Table 3). This average was based on only six of the eight samples that were collected between June and September. Two of the analyses were outlyers (possibility of laboratory error) and were excluded from the analysis of the mean summer concentration. It is likely that a mean based on a larger sampling would have yielded a lower mean concentration. No notable difference between site 101 and 102 was observed (Table 4). The mean TP value is significantly higher than concentrations measured in a set of representative lakes in the North Central Hardwood Forest ecoregion of Minnesota which tend to fall between 23 to 50 ug/l (Table 3). Based on total phosphorus concentrations measured in 436 lakes in the NCHF ecoregion, 70 percent of the lakes have TP concentrations less than 102 ug/l.

On all sample dates except May 20, samples collected from the hypolimnion had higher concentrations of TP than those collected from the epilimnion (Figure 4). The hypolimnetic concentrations ranged from 62 ug/l (May) to 846 ug/l (September). The TP concentrations measured in the hypolimnion started with a low value in May and steadily increased throughout the summer. This build up of phosphorus in the hypolimnion is typical for productive, stratified lakes and is largely the result of two processes. First, periods of low oxygen levels in the hypolimnion will stimulate the release of phosphorus from the sediments into the lake. Second, algae in the epilimnion assimilate phosphorus as they grow. When algae die, they settle out of the epilimnion and into the hypolimnion where the phosphorus is released into the water during decomposition. This process results in a decline in epilimnetic concentrations from spring to fall.

While phosphorus concentrations will likely increase in hypolimnetic waters under stratified conditions, much of the phosphorus will remain unavailable for the production of algae in the epilimnion. However, when stratification breaks down after the growing season phosphorus is mixed throughout the lake and may be available for phytoplankton growth the next spring.

In the North Central Hardwood forest ecoregion, distinct differences exist between lakes which maintain a stable stratification (referred to as dimictic lakes) and those which only stratify intermittently or do not stratify at all. In general, the phosphorus concentration of dimictic lakes tend to be two to three times lower than those lakes which do not remain stratified throughout the summer.

Transparency (Secchi disk)

The Secchi disk transparency is an indirect measurement of the amount of algae and other suspended material in the lake. Transparency values can often be accurately correlated to the chlorophyll and the total phosphorus concentrations. The average transparency measured during the lake assessment sampling was 3.85 feet (1.2 meters). The average transparency based on the values determined by volunteer measurements was equal to 5.4 feet (1.6 meters). The difference between the two averages is due to natural variability and the number of measurements. The transparency measured for Fox Lake is slightly lower than typical values for the ecoregion.

Total Nitrogen

Total nitrogen (TN) which is defined as the sum of the total Kjeldahl nitrogen and nitrate-nitrite nitrogen averaged 4.47 mg/l during the summer of 1991. This is higher than the typical TN value for the ecoregion which ranges between 0.6 to 1.2 mg/l. Both the average total Kjeldahl nitrogen and the nitrate-nitrite concentrations measured in Fox Lake (3.27 and 1.2 mg/l respectively) are much higher than those measured in other lakes in the region (Table 3). Values this high indicate that nitrogen sources which include nitrogen fertilizer, septic system effluent, and animal waste are strongly influencing the concentrations in Fox lake.

TN:TP

Nitrogen is a nutrient required for growth of aquatic plants and algae. Although phosphorus is usually the nutrient limiting the productivity in most Minnesota lakes, nitrogen may be the limiting nutrient in some situations. The ratio of TN:TP can indicate which nutrient is limiting. For Fox Lake the TN:TP ratio is 57:1 which suggests an overabundance of nitrogen in the lake (as indicated in the previous discussion). The TN:TP ratio measured in Fox Lake is considerably higher than the typical ratios for the ecoregion which range from 25:1 to 35:1. This suggests that increases in the in-lake phosphorus concentration may increase the production of algae and aquatic plants.

Chlorophyll a

Chlorophyll (a pigment produced by algae) concentrations provide an estimate of the amount of algae in the lake. During the summer, lake chlorophyll concentrations ranged from 13 to 204 ug/l with a mean concentration of 104 ug/l (Table 3). Based on surveys of CLMP volunteers, concentrations from 10 to 20 ug/l would be perceived as a mild algal bloom, and concentrations greater than 30 ug/l would be perceived as severe nuisance conditions (Heiskary and Walker, 1988). The chlorophyll values reported for Fox Lake exceeded the nuisance conditions for all sampling dates except May, and are much higher than typical values determined for the ecoregion which range between 5 and 22 ug/l.

Phytoplankton (algae)

Phytoplankton samples from May, July, and September were analyzed and found to contain an algal population dominated by the blue-green algae *Aphanizomenon flos aquae*. Aphanizomenon grows in small bunches which resemble small grass clippings. In both June and July, Aphanizomenon accounted for 90 percent of the algal volume on the lake. The remaining 10 percent was a combination of several species of green and blue-green algae.

Zooplankton

Zooplankton (microscopic animals) were collected and analyzed qualitatively during each sampling event. Abundant small varieties were observed during May, but few zooplankton were present during the months with peak algal blooms (June - August). No significant populations of large bodied zooplankton were observed during any sampling. Large bodied zooplankton can be beneficial for lakes because of their ability to consume large quantities of algae which can have a noticeable affect on lake transparency.

Physical Condition/Recreational Suitability

Along with the CLMP transparency measurements, subjective measures of the lake's "physical appearance" and "recreational suitability" (Heiskary and Wilson, 1988) were made by the CLMP observer (Table 2). Physical appearance ratings range from "crystal clear" (class 1) to "dense algal bloom, odor, etc." (class 5), and recreational suitability ratings range from "beautiful, could not be nicer" (class 1) to "no recreation possible" (class 5). Transparency, physical appearance, and recreational suitability values from the CLMP records are summarized below for 1991:

Month	Transparency (mean)	Physical Condition (mean class)	Recreational Suitability (mean class)
June	7.3 feet	4	4
July	3.0 feet	3	4
August	3.4 feet	3	4
September	8.0 feet	3	2

These data show that transparency, physical condition, and recreational suitability do not always agree. Since transparency is an indication of water quality, one would expect high transparency to correspond to high physical condition and recreational suitability (low scale values). In June, the month with the highest transparency, the lake was given poor ratings for the two other categories ("high algae levels" "no swimming"). This is likely due to the condition of the algae present. During this time, the algae formed thick scums or clumps which increased the transparency of the lake, but seriously decreased the lake aesthetics. During July and August the transparency decreased but the physical condition was characterized as "definite algal green" possibly due to the disappearance of the thick scums of algae. In September, transparency, physical condition, and recreational suitability all increased. The change in physical condition and recreational suitability rankings corresponded to lower algal concentrations based on the chlorophyll a measurements in Table 4.

Other Parameters

Other water quality parameters including color, total suspended solids, total suspended inorganic solids, pH, and turbidity were all higher than typical ecoregion values. Alkalinity and conductivity fell within the ranges typical for the ecoregion.

TROPHIC STATUS

One means of evaluating the trophic status or productivity of a lake and interpreting the relationship between total phosphorus, chlorophyll, and Secchi disk transparency is Carlson's Trophic State Index (Carlson, 1977). This index was developed from the relationships of summer Secchi disk transparency and the surface water concentrations of total phosphorus and chlorophyll. Trophic state index (TSI) values are calculated as follows:

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

Chlorophyll TSI (TSIC) = $9.81 \ln(Chl\ \underline{a}) + 30.6$

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

Note units: TP in ug/l, Chlorophyll in ug/l, Secchi disk transparency disk in meters.

Possible values for TSI range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). With this index, each increase of 10 units represents a doubling of algal biomass.

The TSI values of total phosphorus, chlorophyll, and Secchi disk transparency for Fox Lake are between 58 and 76 with an average of 67 (Table 3, Figures 5,6). Based on these values the lake would be considered eutrophic to hypereutrophic or very nutrient rich.

Usually the three TSI values are more similar than those determined for Fox lake. Part of the discrepancy may be due to the dominance of the blue-green algae Aphanizomenon. Under these conditions, Secchi disk transparencies tend to be higher than would be expected based the TP and chlorophyll concentrations. Taking this into account, Secchi disk monitoring of Fox Lake can still provide a reliable indication of the algal and phosphorus trends in the lake.

Comparison of TSI values for Fox Lake to those of other lakes in the North Central Hardwood Forest ecoregion can provide a basis for evaluating the water quality of the lake. A TSI value of 67 ranks in the 26th percentile for the ecoregion. In other words, 74 percent of the lakes in the region have TSI values less (are less eutrophic) than Fox Lake.

Another way to compare the trophic status variables is on scatterplots. Figure 6 illustrates the general relationships between total phosphorus, chlorophyll, and Secchi disk transparency and where the Fox Lake data plot on the graphs. The three parameters generally are closely correlated since phosphorous is often the nutrient limiting algal production, and Secchi disk transparency is dependent upon the algal levels in the lake. The plots show that increases in phosphorus will result in an increase in chlorophyll and a decrease in Secchi disk transparency depth. Alternately, a decrease in phosphorus will result in an increase in water quality as measured by chlorophyll concentrations and transparency readings. It is important to note that because Fox Lake data plots on the upper ends of Figures 6b and 6c, fairly large reductions in total phosphorus or chlorophyll will be required for noticeable increase in transparency.

TREND ANALYSIS/HISTORICAL DATA

A relatively large amount of historical data is available for Fox Lake and other lakes in Rice county. National Biocentric completed a water quality evaluation of Rice county in 1972. Secchi disk measurements for Fox Lake taken by the CLMP volunteers are available from 1974 to present. Water quality data from county and state sampling efforts are available for 1979-1981, 1986,1987,1989, and 1991. Although other water quality information is available, only those years with two or more measurements for any parameter will be considered in this discussion. Mean summer total phosphorus, chlorophyll, and Secchi disk measurements from previous samplings are shown below:

Year	TP (ug/l)	# of obs	chl a (ug/l)	# of obs	SD (feet)	# of obs
1979	41	(2)	11.7	(1)	5.0	(9)
1980	47	(3)			7.2	(12)
1981	36	(4)			3.9	(14)
1986	77	(6)	64.6	(5)	3.1	(15)

Year	TP (ug/l)	# of obs	chl a (ug/l)	# of obs	SD (feet)	# of obs
1987	65	(8)	37.6	(8)	3.7	(8)
1989	64	(5)	16.2	(5)	7.8	(18)
1991	101	(6)	104.3	(8)	3.9	(8)

Based on this data, it appears that TP and chlorophyll have increased in the past 12 years. The total phosphorus concentrations reported for the years 1979 through 1981 suggest the concentrations were on the order of 60 percent of the present concentrations. Some of the difference may be attributed to natural factors (such as climate) which influence the concentrations of phosphorus and chlorophyll; however, statistical tests (Kendall's Tau) using summer mean values suggest that the increasing trend for total phosphorus is significant.

The mean trophic status index (TSIP) for the years 1979-1981 was 58 This value would categorize the lake as eutrophic as compared to the eutrophic/hypereutrophic classification based on the 1991 TSIP value of 71.

Based on a study of the lakes in Rice County conducted by National Biocentrics in 1972, Fox Lake had the highest water quality index of all the lakes in the county. The water quality index was based on Secchi disk transparency, biological oxygen demand, available phosphate, ammonia, pH, and total coliform. A direct comparison of data collected for the lake assessment and data collected in the 1972 study is not meaningful, but the Biocentric study does provide an idea of the relative water quality in the lakes of Rice County. Mazaska was determined to have the best water quality after Fox and Circle Lake was noted to be among the three lakes with the poorest water quality (National Biocentrics, 1972).

In 1986 Rice County staff compiled a water quality evaluation for the county which was a comparison of historical data and data collected by Rice county in 1984. A decrease in transparency and an increase in TP between the 1979-1981 period and the 1984-85 period was noted. Both animal waste and malfunctioning on-site systems were targeted as potential sources of the fecal coliform contamination detected during the sampling in 1984.

The mean summer Secchi disk transparencies have been collected since 1974 (Figure 7). Summer records with less than 4 measurements were not included in this data set. Although it seems that the total phosphorus concentrations have increased in the last decade, the Secchi disk values do not reflect this trend very well. Following a period of stable values from 1981 to 1987, the summer means were especially erratic from 1988 to present. This may represent an instability in the lake algal community from one dominated by green algae species to one dominated by blue-green algae species.

NUTRIENT SOURCES

Watershed

Wolf Creek is the major stream inlet into Fox Lake. Wolf Creek follows the natural creek bed in some stretches and a straightened channel in stretches which serve as a drainage ditch. The main branch of the creek originates in Lake Mazaska. The north and south branches of the creek are actually drainage ditches which drain three large wetlands in the Fox Lake watershed. Wolf Creek drains a majority of the Fox Lake watershed and probably represents the major source of the nutrients from the watershed.

Based on what is known/observed for the region, nonpoint source pollution is likely a major source of nutrients to Fox Lake. Nonpoint pollution sources include: agricultural runoff; pesticide and fertilizer use; feedlot runoff; urban runoff from streets, yards, and construction sites; leachate from septic systems; dredging and drainage activities; and the impacts from the loss of wetlands.

Although it is unrealistic to expect that all nonpoint pollution sources can be eliminated, the implementation of Best Management Practices (BMP's) and other land use changes can minimize human impacts on water quality.

To control soil erosion, reduce the use of fertilizers and pesticides, and improve manure management, best management practices should be selected that meet the water quality goal as well as the individual farm operation. Refer to the MPCA's Agriculture and Water Quality publication for more information on agricultural BMP's.

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

Livestock

Cattle allowed to wade in a lake tend to increase erosion along the shoreline and degrade water quality in the lake. Animal manure deposited directly to the lake contributes nutrients, oxygen demanding material and bacteria. A buffer of vegetation between permanent pasture and the lake with an alternate water source will effectively reduce the pollutant load from the this area.

On-sites treatment systems/lawn care

A survey form was sent out to about 30 property owners around Lake Fox by the FTALA copy of the form and a summary of the results is included in Appendix 2. The purpose of this survey is to provide the Association with some basic information regarding the type of on-site systems on the lake, age of the systems, type of dwelling, frequency of pumping, and the use of lawn fertilizers. This information should assist the Association and county in determining whether more education is needed with respect to design and maintenance of on-site systems and lake safe lawn care practices.

The Association was able to survey all the lake residents. The table below summarizes the responses. The majority of the on-site systems (75 percent) were 20 years old or less, while 25 percent were greater than 25 years of age or unknown. About 71 percent of the respondents pumped their systems at least once every two years. About 20 percent responded that they had not pumped their system since installation. Minnesota Extension Service recommends pumping every one to three years for a 1,000 gallons tank serving a three bedroom house and four occupants (assumes year round use).

Lawn maintenance

Lawn fertilizers can be a source of nitrogen and phosphorus, and therefore, are not recommended for use around lakes. In particular, those high in phosphorus should be used only in the quantities needed, as determined by present soil nutrient conditions. A buffer of unfertilized natural vegetation should be maintained along the shoreline to help control erosion and trap some nutrients that may run off the lawn and into the lake. Leaving grass clippings on a lawn can reduce the need for fertilizers; however, in areas where clippings and leaves could wash into the lake, removal to a compost site away from the lake is recommended.

Septic System Survey Results

Participation

About 31 surveys were sent to property owners around Fox Lake, and all surveys were returned (100%). Of the 31 residents, 20 are year-round residents and 11 are seasonal residents. Five of the seasonal residents plan to change to year-round.

System Types

Septic tank - drainfield	20	(64%)
Septic tank - drywell	7	(22%)
Privy	2	(6%)
Other	3	(9%)

System Ages

0-5 yr	9	(29%)
6-10 yr	8	(26%)
11-15 yr	2	(6.5%)
16-20 yr	4	(13%)
21-25 yr	2	(6.5%)
26-30 yr	0	(0%)
31+ yr	2	(6.5%)
unknown	1	(3%)
N/A or N/R	3	(10%)

Type of Dwelling

Seasonal	11	(35%)
Year round	20	(64%)

Distance from lake to closest point of system (in feet)

0-50	1	(3%)
51-100	5	(16%)
101-150	7	(23%)
151-200	3	(9%)
201-250	8	(25%)
251+	6	(19%)
no response	1	(3%)

System Pumping

> once per year	2	(6%)
Every year	4	(12%)
Every 2 years	16	(52%)
Every 3 years	0	(0%)
Every 4 years	1	(3%)
Every 5 years	1	(3%)
Every 10 years		
Last in '88		
Last in '89		
Last in '90		
As needed		
Never	5	(15%)
No response	3	(10%)

Aware of county ordinances pertaining to on-site systems

yes	13	(42%)
no	17	(55%)
NR	1	(3%)

Use of P containing fertilizers or commercial lawn service

yes	5	(16%)	(all expressed willingness to change practice)
no	26	(84%)	

Summary

Most of the systems around the lake are the conventional septic tank - drainfield type. Most are less than 20 years old, and seemed to be maintained properly. Based on the results of the survey it appears that some education on septic tank maintenance and lawn care may be appropriate.

In-lake

Some portion of the nutrients which enter a lake from the watershed become bound to the lake sediments. These nutrients can be released under certain conditions. Phosphorus, for example, is released from sediments when the hypolimnion contains no oxygen. The contribution of phosphorus from the sediment can represent a significant part of the phosphorus load to the lake, and in some cases, may be the major source of phosphorus.

Estimates of the sediment contribution can be made with volume and phosphorus data (Appendix 3). Estimates of the internal phosphorus loading for Fox Lake based on 1991 data show sediment phosphorus contributions are slightly greater than 1400 kg for the summer. Although calculations of sediment contributions on an annual basis would likely yield a lower value (since phosphorus is lost to the sediments at other times of the year), the sediment loading estimate is useful for making qualitative comparisons. The sediment contribution was compared to the watershed loading estimates from the water quality models. The comparison suggests that the sediment contribution is approximately equal to the contribution from the agricultural land surrounding Fox Lake. This and a number of other factors may make Fox Lake a candidate for in-lake restoration techniques (at some future date) such as aeration or alum treatment which control the release of phosphorus from the sediments. These in-lake restoration techniques are most effective after the watershed loading is adequately controlled.

AQUATIC PLANTS (Macrophytes)

The Lake Association expressed concern about the increased growth of curly-leaf pondweeed (*Potamogeton crispus*) along the shoreline of Fox Lake. The curly-leaf pondweed is an exotic species which tends to dominate the aquatic plant community at the expense of more desirable native species.

Fish surveys conducted by MDNR staff show that Fox Lake never had an abundance of aquatic plants. The Waterfowl and Muskrat Habitat Survey conducted by the Department of Conservation (1951), listed Canada waterweed as common and a variety of other species as present. This survey did not note the presence of Curly-leaf pondweed. Occasional sightings of curly-leaf pondweed were noted in most DNR fish surveys since 1970. This suggests the species was introduces between 1951 and 1970. New concerns about the Curly-leaf pondweed may be the result of the gradual increase in density and areal extent of the curly-leaf pondweed beds. Fortunately, the relatively steep slope of the lake bed will naturally limit area which the plant will grow.

A direct relationship between Secchi disk transparency and the maximum depth of colonization (MDC) by macrophytes has been established to determine the areas of a lake which can support macrophyte growth (Canfield et al, 1985):

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

Over the period of Secchi disk monitoring the average transparency depth was approximately 5.0 feet. Using this value, the formula above yields a MDC of 8.1 feet. At eight feet the plant growth will likely be sparse with progressively more plants in progressively shallower water. In most areas, the lake is deeper than eight feet within 300 feet of the shoreline. Only about 35% of the lake is less than 5 feet where most of the plants will grow. However, a ring of thick weeds may be considered a nuisance for boating and swimming.

A number of techniques may be used to control nuisance macrophytes in small areas. Manual or mechanical harvesting can be an effective, short-term control technique for small swimming areas or boat paths. This also has the added benefit of removing nutrients from the lake. All plants must be removed from the lake during any harvesting operation. In some cases permits from the DNR are required for weed control.

Sediment covers or surface shading are experimental techniques which may effectively control weed growth by controlling light in small areas. See the Lake and Reservoir Restoration Guidance Manual (USEPA 1990) for more information. Remember, when deciding on an appropriate control techniques that many aquatic plants play an essential role in the health of the lake community. Although Curly-leaf pondweed is an exotic species, removal of large areas of weed without a reestablishment of native perennial species may result in an increase in the severity and frequency of algal blooms.

MODELING SUMMARY

Numerous models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in a lake. Alternately, they may be used for estimating changes in the quality of lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow or amount of water entering the lake. The "Minnesota Eutrophication Analysis Procedure" (MINLEAP) model and the Reckhow and Simpson (1980) model were used to assess the current water quality of Fox Lake. MINLEAP was developed by MPCA staff based on an analysis of data collected from a set of representative minimally impacted lakes for each ecoregion. Total phosphorus, chlorophyll, and transparency values calculated by MINLEAP should reflect the values found in a minimally impacted lake with the watershed size, lake morphometry, and geographic location of Fox Lake. It is intended to be used as a screening tool for estimating lake condition with minimal data input and is described in greater detail in Heiskary and Wilson (1990).

Published runoff coefficients, precipitation and evaporation data, and nutrient export coefficients were used in this modeling effort. Precipitation and evaporation data were derived from Gunnard (1985) and data from the State Climatology Office (1989). Inputs to the models are noted in Tables 5 and 6.

The TP and chlorophyll concentrations for Fox Lake predicted by MINLEAP were 47 and 18 ug/l respectively which is between 2 to 6 times lower than the values determined in the 1991 sampling (Table 5). The observed Secchi disk depth was slightly lower than the predicted value. The predicted Fox Lake TP values may seem unrealistically low; however, further comparison shows them to be similar to those measured between 1979 and 1981. Predicted chlorophyll values are also much lower than present concentrations but similar to a measurements taken in July of 1980. This suggests that the water quality of Fox Lake in the early 1980's was typical of a minimally impacted lake in the Central Hardwood Forest ecoregion. Running MINLEAP with land use typical for the Western Corn Belt Plains ecoregion yields in-lake phosphorus concentrations very close to observed concentrations. This suggests that the

phosphorus loading to Fox Lake from the watershed is more similar to that of the WCBP ecoregion than the CHF ecoregion.
The second model used was Reckow and Simpson (1980) which predicts the impact of watershed characteristics and management on lake phosphorus concentrations. The uncertainty associated with this simplified assessment requires that the model output be expressed in a range of values with a "most likely" value specified.

The Reckow and Simpson model predicts in-lake total phosphorus concentrations for the present watershed ranging from a low value of 55 to a high of 72 ug/l with a most likely value of 64 ug/l (Table 6). The results were higher than those predicted by MINLEAP and reflect land use in the watershed which has more agriculture than most watersheds in the ecoregion. These values agree well with the observed concentrations measured in the early 1980's (summer average); however, 1991 observed values were significantly higher than those predicted by the model. Typical phosphorus export values for the area were used in the model. Based on these estimates, agricultural land use contributes approximately 83 percent of the watershed phosphorus load to the lake. The sum of other land uses make up the remaining 17 percent of the phosphorus load from the watershed.

For illustration, a watershed of the same size but with point source of phosphorus (ie. a waste treatment plant) was run to determine the load required to yield the observed lake phosphorus concentrations. When a point source of phosphorus of 800-1000 kg/yr) was added to the model, the predicted levels were similar to those observed in 1991 (Table 6). This indicates a substantial phosphorus load (approximately 900 kg/yr) is not accounted for based on the export calculations using a reasonable range of values for the region. This excess phosphorus could be accounted for by the in-lake loading (approximately 1400 kg in 1991) as discussed previously.

GOAL SETTING

Based on historical data and model predictions, attaining a phosphorus concentration of 45 to 55 ug/l is a reasonable goal for Fox Lake. This would correspond to a mean summer chlorophyll concentration of 20 to 40 ug/l. In order to maintain the fisheries, aesthetics, and full recreation, phosphorus levels below 40 ug/l are desirable for a majority of the states lakes. This may be just out of reach for Fox Lake. However, if levels are maintained between 45-55 ug/l the lake would support fishing and swimming most of the time. Although some algae would be present most of the summer, the periods of severe algal blooms (chlorophyll concentrations greater than 30 ug/l) would exist only about 20 percent of the summer. Presently, chlorophyll concentration exceed 30 ug/l over 90 percent of the summer.

Reduction in the phosphorus loading will be required to reach the goals stated above. Loading from the watershed should be controlled before in-lake treatments are attempted. If present conditions and inputs continue, a gradual worsening of the lake's condition and suitability for recreation will result.

The lake is a reflection of its watershed. The quality of the lake water is determined by not only the lake's shape, and ecology, but also the activities that occur in the watershed. The results of this study suggest that excessive phosphorus is reaching the lake from the watershed and the lake sediments. Implementation of best management practices on cultivated land, feedlots, and the immediate watershed should help to reduce the phosphorus loading. Once watershed contributions are adequately controlled, some in-lake treatment which addresses the sediment contributions may be appropriate. A more detailed study would be necessary to predict the lakes response to watershed and in-lake treatment methods.

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