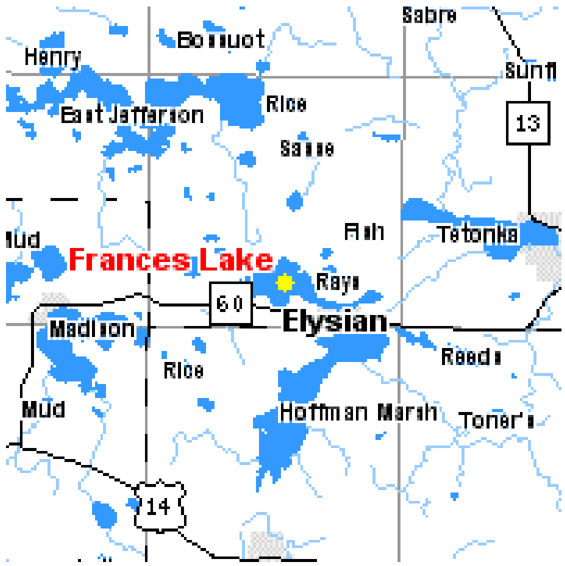
LAKE ASSESSMENT PROGRAM
1998
Lake Frances and Lake Tustin

(I.D.'s #40-0057 & 40-0061)

LeSueur County, Minnesota



Minnesota Pollution Control Agency
Regional Environmental Management
&
Environmental Outcomes Divisions

in cooperation with
Lake Frances Association

Minnesota Pollution Control Agency

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SUMMARY AND RECOMMENDATIONS

Lakes Frances and Tustin are located in southern LeSueur County in south central Minnesota. Lake Frances has a surface area of 800 acres, a mean depth of 13 feet, and a maximum depth of 60 feet. Lake Tustin has a surface area of 65 acres, a mean depth of about 3 feet, and a maximum depth of 5 feet. The watershed area of Lake Frances (including 135-acre Round Lake to the west) is approximately 3050 acres. The Lake Frances watershed, plus an additional 680 acres (including 145 acre Rays Lake) drains to Lake Tustin. Lake Tustin drains to Lake Tetonka of the Cannon River system.

The watershed of Lakes Frances and Tustin is fairly diverse. Although dominated by row-crop agriculture (48%), the watershed contains significant areas of forest (15%), grassland (15%) and wetland (14%). A portion of the City of Elysian plus developed lakeshore area account for 8% of the watershed. For the past two years, treated wastewater from the City of Elysian has been discharged directly to Lake Tustin. Previously, the wastewater was spray irrigated onto land adjacent to Lake Tustin.

In addition to the City of Elysian, Lake Frances has significant lakeshore development (218 dwellings and 2 resorts in 1986). Additional development both in the City, and in the County around the lakes, has occurred since 1986. About 60 homes on the north side of Lake Frances were connected to Elysian's sewer and water system in 1997. Lake Frances is an important recreational resource locally and regionally. In recent years, heavy use of the lake has created some user conflicts. Lake Tustin has very little lakeshore development and is not used heavily as a recreational resource.

Lakes Frances and Tustin were sampled during the summer of 1998 by Minnesota Pollution Control Agency (MPCA) staff as part of the MPCA's Lake Assessment Program (LAP). This study was conducted at the request of the Association, whose members were interested in identifying sources of pollution to the lakes, characterizing the quality of the lakes, and developing a program to assist in lake management.

Water quality data collected on Lake Frances during 1998 reveal a summer-mean total phosphorus (TP) concentration of 34 µg/L, a mean chlorophyll-a concentration of 19 µg/L, and a Secchi transparency of 4.3 feet (1.3 m). The TP and chlorophyll-a are within the range of values exhibited by reference lakes in the North Central Hardwood Forest Ecoregion. The Secchi transparency, however, is slightly less than the range for reference lakes. For Lake Tustin, the TP and chlorophyll-a values are much higher, and the Secchi transparency much less, than for the reference lakes (372 µg/L, 147 µg/L, and 1.4 feet, respectively). Total phosphorus, chlorophyll-a and Secchi transparency help to characterize the trophic status of a lake. For Lake Frances, these measures indicate eutrophic conditions; while Lake Tustin would be considered hypereutrophic. Lakes Frances and Tustin were also monitored by MPCA staff in the summer of 1996, and Lake Frances through the Citizen Lake-Monitoring Program (CLMP) since 1992. The Lake Frances CLMP data shows no statistically significant change in Secchi transparency since 1992.

Lake water quality models were used to predict water quality for Lake Frances based on the lake's morphometry and watershed characteristics. These models provide a means to compare the measured water quality of the lake relative to the predicted water quality.

The first model, MINLEAP, predicted a summer-mean phosphorus (P) concentration of 30 µg/L, which is not significantly different from the observed 1998 summer-mean of 34 µg/L. A regression model (Vighi and Chiaudani, 1985) estimates a "background" P concentration of 24 µg/L for Lake Frances.

The third model, Reckhow-Simpson, predicted a P concentration range of 36-58 µg/L for Lake Frances. Further, the model estimates that 56 percent of the phosphorus load entering the lake arises from urban and agricultural runoff. Seepage from septic systems and precipitation directly on the surface of the lake account for the remaining 44 percent of the phosphorus load.

The results from the models are mixed, but suggest that some improvements in water quality could be expected through watershed management activities.

Because of the small size of the Lake Frances watershed, opportunities exist for lake protection and improvement not available for many other lakes in this portion of Minnesota. The activities of relatively few people (lakeshore and other rural landowners) can have a strong, positive effect on water quality. Relative to it's size, Lake Tustin has a much larger watershed; creating additional challenges for watershed management.

The following recommendations are based on the 1998 Lake Assessment Program (LAP) study of Lakes Frances and Tustin:

1. **Lake Frances could be sensitive to further changes in trophic status with increases in nutrient loading rates from any watershed or in-lake sources.** These sources could increase the in-lake phosphorus concentration, which can degrade the lake. It is essential, therefore, that the goals of lake protection efforts be conveyed to all local government groups with land use/zoning authority for the lakeshore and watershed of Lake Frances

   The Association should be commended for their efforts to date, which includes playing a significant role in establishing centralized sewer and water service to a number of homes on the north side of the lake.

   As a next step, the Association may wish to develop a watershed management plan. The following activities could be included in such a plan:

   a. **The Lake Frances Association should commit to maintaining their participation in the Citizen Lake-Monitoring Program (CLMP).** Data from this program provides an excellent basis for assessing long-term and year-to-year variations in algal productivity (i.e., trophic status of the lake). At a minimum, measurements should be taken weekly during the summer at a consistent site.

b. **The Lake Frances Association should provide educational materials to lakeshore owners on shoreline and shoreland protection**. Protection of the existing vegetation along the shore will minimize erosion and preserve the aesthetic value of the lake. In addition to providing water quality and fishery benefits, lakeshore with a diverse community of native vegetation provides better habitat for songbirds and other small animals than do large areas of lawn. The MDNR, MPCA, and county offices may be able to provide assistance in this area. The booklet, *A Citizen's Guide to Lake Protection*, and the book, *Landscaping for Wildlife*, are good guides and may be useful educational tools for the Association.

c. **Further development in the watershed should occur in a manner that minimizes water quality impacts to the lakes**. Activities within the watershed such as wetland removal or major land use alterations that change the drainage or flow patterns should be discouraged. Although it can be difficult to assess how much impact individual projects within the watershed will have on the lake, the cumulative effect can be significant. The presence of the City of Elysian poses special challenges for watershed management. Pavement and urban stormwater systems increase water runoff, and urban dwellers often use more fertilizers and pesticides on a per acre basis than their agricultural neighbors.

For construction or road building activities that do occur, the use of best management practices (BMPs) can greatly reduce soil loss, and sediment transport to lakes. Maintenance of effective buffers between agricultural and urban areas, and ditches, streams, and the lake will help to minimize nutrient rich runoff.

County shoreland regulations are very important. The Association should continue their representation on boards or commissions that address land management activities so that their impact can be minimized. The booklet *Protecting Minnesota's Waters: The Land-Use Connection*, may be a useful educational book in this area.

Efforts such as the creation of buffer strips, in addition to benefiting water quality, improve wildlife habitat, plant diversity, and aesthetics in a watershed.

d. **The Lake Frances Association should work closely with the Minnesota Department of Natural Resources (MDNR) Division of Fisheries to maintain a healthy fish community**. A healthy fish community can benefit water quality and vice versa. Degraded water quality could shift the balance from desirable fish species to less desirable species of fish. Because changes in species composition are difficult to reverse, they should be avoided whenever possible.

e. **The Lake Frances Association should continue to foster a working relationship with the agricultural landowners in the watershed.** If changes in agricultural land should be needed to protect or improve water quality, they are most likely to be accomplished in a cooperative manner. In addition, small pieces of agricultural land may be needed in the future for lakeshore wastewater treatment and other projects.

f. **Lakeshore owners and lake users should avoid or minimize harvesting or other disturbance of aquatic plants like cattail, rushes, and native pondweeds.** These plants play an important role in the improved water quality of Lake Frances.

2. **It may not be reasonable to expect Lake Tustin to support the same kinds of uses supported by Lake Frances.** Tustin, however, could be viewed as a complement to Lake Frances. It adds a bit of "wildness" to the area and probably serves as an undeveloped haven for wildlife. It may also have some fishery potential, perhaps providing a northern pike reproduction area for Lake Frances and the Cannon River.

3. **This LAP report serves as a foundation upon which further studies and assessments may be based.** The next step could be to define water and nutrient sources to the lake in a much more detailed fashion. These detailed studies would allow the estimation of reasonably accurate phosphorus, nitrogen, and water income-outgo summaries. This should be accomplished prior to implementation of any extensive watershed or in-lake restoration projects. One source of funding for such work is the MPCA's Clean Water Partnership (CWP) program.

INTRODUCTION

Lake Frances and Lake Tustin were sampled by the Minnesota Pollution Control Agency (MPCA) during the summer of 1998 as part of the Lake Assessment Program (LAP). The LAP was designed to assist lake associations, counties, and municipalities in the collection and analysis of baseline water quality data for the purpose of assessing the current trophic status of "their" lake. Trophic status is defined by the degree of nutrient enrichment of a lake and by the secondary effects (e.g. amount of algae growth and condition of fishery) of this enrichment. The addition of nutrients to lakes is a natural process. Nutrients are found in even the most pristine runoff and are deposited from the atmosphere. Cultural eutrophication as a result of the activities of humans, however, is a frequent cause of water quality problems in lakes.

This study was conducted at the request of the Association, whose members are interested in identifying sources of pollution to the lake, characterizing the quality of the lake, and developing a program to assist in lake management. The general work plan for the LAP includes local participation in the Citizen Lake-Monitoring Program (CLMP), completion of a septic system survey, compilation of a watershed history, and a cooperative examination of land use and drainage patterns in the watershed.

Lake Frances was sampled five times, and Lake Tustin three times, during the summer of 1998 by Lee Ganske (MPCA-Rochester), with assistance provided by Association member Ivan Roettger. Betty Roettger, Ivan Roettger, and Dave Thayer of the Association provided information for inclusion in this report. Fisheries information was obtained from the Minnesota Department of Natural Resources (MDNR). Eric Strand was the CLMP volunteer. This report was written by Lee Ganske.

BACKGROUND

Watershed Description

Lakes Frances and Tustin are located adjacent to the City of Elysian on the southern border of LeSueur County. Lake Frances covers 800 acres (324 ha), placing it in the upper 5 percent of all lakes in the state in terms of its size. Compared to 760 Minnesota lakes in the North Central Hardwood Forest ecoregion, it is in the top 15-20 percent in terms of size (Minnesota Lake Water Quality Assessment Data: 1997, MPCA). Lake Frances has a maximum depth of 60 feet (18.3 m). This is deeper than about 80 percent of the same 760 lakes. The mean depth of the lake is approximately 13 feet (4 m), and the littoral zone (the lake zone which can potentially support rooted vegetation) covers approximately 50-60 percent of the lake. Lake Tustin has a surface area of 65 acres, a mean depth of about 3 feet, and a maximum depth of 5 feet.

Lake Frances was formed from a glacial ice block left behind in a preglacial valley (Zumberge, 1952). Soils in the Frances/Tustin watershed belong primarily to the Lester-Estherville and Lester-Hawick-Storden complexes. The soils in these complexes range from gently to steeply sloping and are generally well drained to excessively drained. Soil erosion is a concern, particularly on steeper slopes.

Lake Frances has a watershed area of approximately 3050 acres (1235 ha). Including the Lake Frances watershed, about 3730 acres drain to Lake Tustin.

Since landscape conditions affect water quality, it is helpful to divide the state into areas where land and water resources show similarities. Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation, and current land use. Data gathered from representative, minimally-impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. Lakes Frances and Tustin are located in the North Central Hardwood Forests (NCHF) Ecoregion, although they lie close to the divide with the Western Corn Belt Plains Ecoregion (Figure 1).

Land Use

The native vegetation of the watershed, following the last glaciation, was dominated by "big woods" forests of oak, elm, basswood, ash, and maple (Marschner, 1930). Based on land use information assembled for this report, cultivated land uses now account for 48% percent of the Frances/Tustin watershed. This percentage is slightly higher than the typical range for this ecoregion (Table 1). Moderate percentages of residential land (8%), water/marsh land (14%), forest (15%), and pasture/grassland/CRP (15%) are typical for this ecoregion.

Precipitation and Runoff

Precipitation is an important factor affecting water quality in lakes. The timing and amount of rainfall in a watershed can affect whether, and to what extent, pollutants are carried to a lake in runoff. Based on a State Climatology map (Appendix 1), precipitation was 30-32 inches in the Frances/Tustin watershed for the water year October 1997 through September 1998. This is slightly higher than "normal" for this part of the state. Evaporation typically exceeds precipitation in this part of the state and averages 37 inches. Runoff averages about 4.5 inches with one-in-ten year low and high values of 1.2 inches and 7.9 inches, respectively, for this area (Gunnard, 1985).

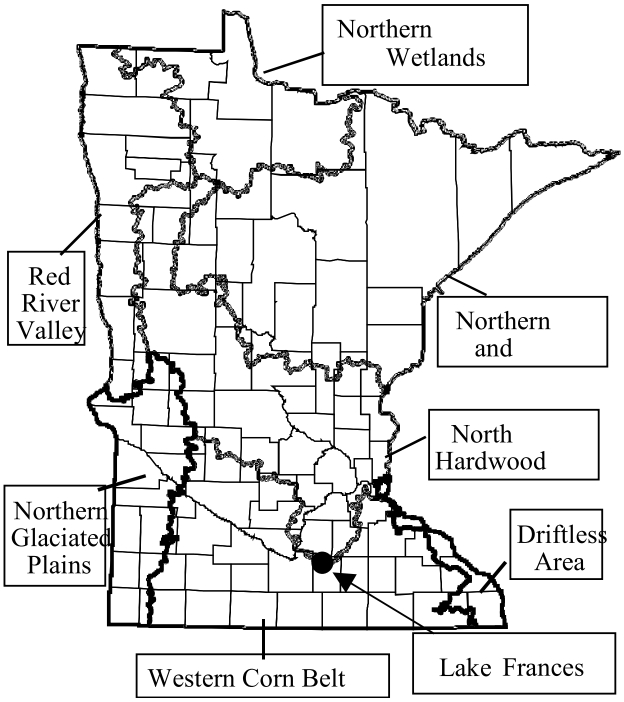
Lake Level

The MDNR has information on the water level of Lake Frances dating back to 1939 (Appendix 2). An ordinary high water (OHW) elevation has been established at 1023.5 feet. The water runs out of Lake Frances to Lake Tustin at an elevation of 1022 feet. The highest recorded water level was 1024.5 feet in 1986. The lowest was 1011.3 feet in 1939. The average of the water levels recorded was 1022.3 feet.

Fishery

Reports from fish surveys conducted by the MDNR in 1996 and 2001 describe Lake Francis as a clear water lake with abundant small bluegills and a consistent walleye population. Both reports emphasize the importance of the aquatic plant community as fish habitat. The 2001 report can be obtained from *Lake Finder* program on the MDNR web site (www.dnr.state.mn.us).

Figure 1. MAPS SHOWING MINNESOTA ECOREGIONS, LAKE LOCATION, AND THE LAKE FRANCES/TUSTIN WATERSHED.



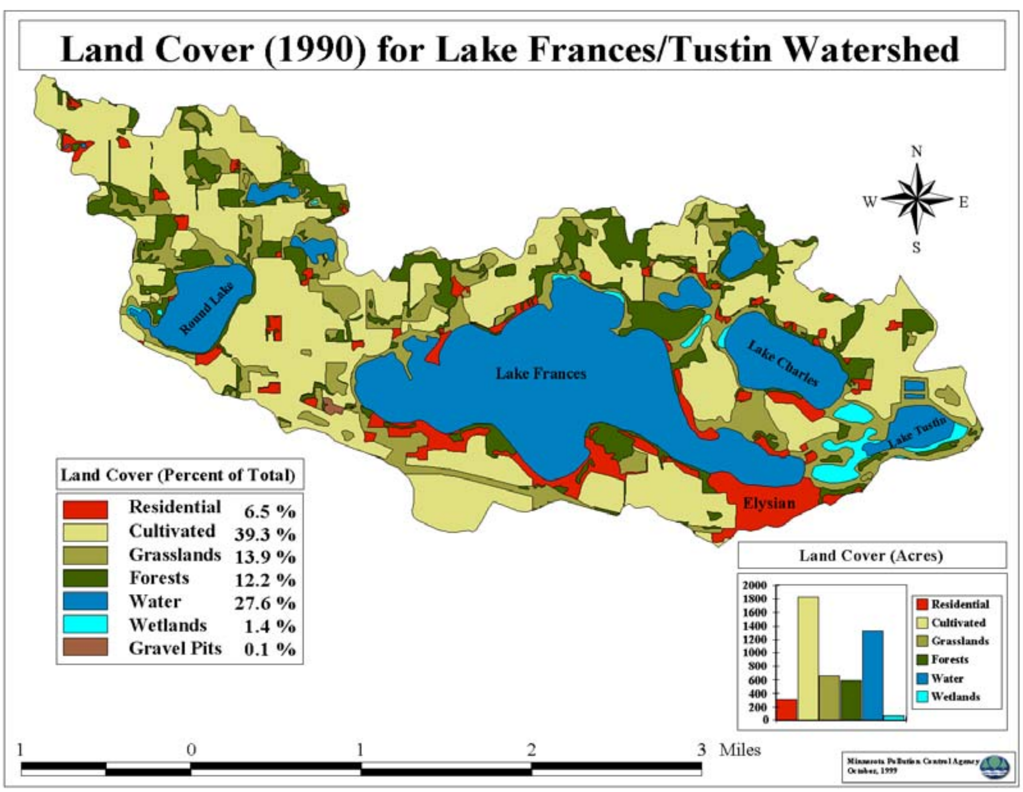


Table 1. MORPHOMETRIC, WATERSHED, AND FISHERY CHARACTERISTICS

Lake Frances	**Lake Tustin**
MDNR I.D.#: 40-0057	40-0061
Area : 800 acres (324 ha)	65 acres
Mean Depth: 13 feet (4 meters)	3 feet
Maximum Depth: 60 feet (18.3 meters)	5 feet
Volume[1]: 10,400 acre-feet	
Littoral Area: 62.5 %	
Shoreline Length[2]: 8 miles	
Watershed Area: 3050 acres (1235 ha) (excluding lake surface)	3730 acres
Watershed Area/Lake Surface Area Ratio: 3.8 : 1	57:1
Estimated Average Water Residence Time[1]: 7.4 years	
Ecological Classification[3]: Centrarchid	
Management Classification[3]: Warm-Water Gamefish	

Land Use (percentage):

	Forests	**Water/Marsh**	**Pasture/CRP**	**Cultivated**	**Urban**
Lakes Frances and Tustin[4]	15	14	15	48	8
NCHF[5]	6-25	14-30	11-25	22-50	2-9

Public Access[3]: 2
Inlets[3]: multiple
Outlets[3]: 1

Shoreland Class[3]: Recreational Development

Development[3]**:**
1986 – 218 dwellings; 2 resorts with 14 units

1 - Estimated using MINLEAP and Reckhow-Simpson model
2 - Estimated from lake contour map
3 - Minnesota Department of Natural Resources Lakes Data Bases
4 - 1990 Statewide Land Use/Land Cover, Minnesota Planning
5- 25-75th percentile for representative lakes in the Western Corn Belt Plains ecoregion (Heiskary & Wilson, 1990)

RESULTS AND DISCUSSION

Water quality information was collected on May 12, June 9, July 13, August 26, and September 14, 1998 at site 101 on Lake Frances (Figure 2); and on the latter three dates at site 101 on Lake Tustin (center of lake). Lake surface samples were collected with an integrated sampler - a PVC tube 2 meters (6.6 ft.) in length with an inside diameter of 3.5 centimeters (1.4 inches). Near-bottom samples on Lake Frances were collected with a Van Dorn sampler; a "water trap" that is triggered to close at the depth a sample is desired. Zooplankton samples were collected from a 5-meter tow using a Wisconsin plankton net.

Sampling procedures were followed as described in the MPCA Quality Control Manual and analyzed by the Minnesota Department of Health for total phosphorus (TP), total Kjeldahl nitrogen, nitrate-nitrite nitrogen, suspended solids, alkalinity, chloride, color, turbidity, and chlorophyll-a. Duplicate sampling for total phosphorus conducted by the MPCA in 1995 revealed a mean difference of about 7 µg/L and a percent difference of 16 percent. For chlorophyll-a duplicate samples, the mean difference was 1.4 µg/l and the percent difference was 10 percent. Field measurements of pH, conductivity, Secchi disk transparency and temperature and dissolved oxygen profiles were taken by MPCA staff. Algal composition was determined from surface samples by means of a rapid assessment method. A qualitative evaluation of the zooplankton sample was made in the field.

Citizen Lake-Monitoring Program (CLMP) Secchi transparency measurements taken during the study and in previous years, along with water quality data collected in 1980, 1986, and 1996 is available for comparison. All data, with the exception of algal composition, was stored in STORET - the U.S. Environmental Protection Agency's national water quality data bank.

Much of the following discussion assumes the reader is familiar with basic water quality terminology as used in the booklet: *A Citizens Guide to Lake Protection*.

In-lake Conditions:

Dissolved oxygen and **temperature** readings were taken from near the surface to the bottom in both lakes. In temperate climates, deeper lakes such as Frances typically stratify into three layers during the summer as a result of temperature-caused water-density differences. The metalimnion, or thermocline (layer of rapid temperature change), separates the epilimnion (warmer surface water) from the hypolimnion (cooler, deeper water). This stratification often remains stable through the summer. Shallow lakes, like Tustin, usually do not stratify as they are easily mixed by the wind. Whether a lake stratifies, and how stable the stratification is, can greatly affect dissolved oxygen concentrations in a lake and how a lake responds to nutrient loading. The 1998 temperature and dissolved oxygen profiles for Lake Frances show fairly weak stratification on all dates except July 13 (Figures 3 and 4), when the temperature difference between surface and bottom water was over 8°C. Surface water temperatures for Lake Frances ranged from 17^{o}C in May, peaked at nearly 27 degrees C in July, and cooled back down to about 23^{o}C in September. The surface temperature for Lake Tustin peaked at nearly 31°C in July.

The amount of dissolved oxygen at different depths and areas of a lake will determine where, and if, fish and other organisms are found. Dissolved oxygen concentrations greater than 5 mg/l (milligrams per liter) are considered necessary for long-term survival of game fish. From July on, dissolved oxygen concentrations in the deeper water of Lake Frances did fall below this threshold (which is typical for many lakes in Minnesota), although levels remained adequate in the upper portion of the water column. Concentrations near the bottom of Lake Tustin fell to 3 mg/l on September 14. This would not have been a long-term situation, however, as even a light wind could mix in oxygen from the surface. Surface dissolved oxygen concentrations were very high on this date, as a result of intense oxygen-producing photosynthesis from the abundant algae in Lake Tustin.

Very low dissolved oxygen at the sediment/water interface can allow for the release of phosphorus from the sediments into the water column. As oxygen concentrations approach zero, iron compounds in the sediments lose their ability to bind phosphorus. This may occur at times in both Lakes Frances and Tustin.

Total phosphorus (TP) is an important nutrient for plant growth. In most lakes it is the nutrient which limits the amount of aquatic plant and algae growth. The 1998 summer mean TP concentrations were 34 µg/L (micrograms per liter) for Lake Frances and 372 µg/L for Lake Tustin. Summer mean TP concentrations in a set of 38 representative, minimally-impacted, reference lakes in the NCHF ecoregion of Minnesota fell between 23 and 50 µg/L (Table 2). Based on total phosphorus concentrations measured in 593 lakes in the ecoregion, about 40 percent of the lakes have mean TP concentrations less than 34 µg/L, and over 95 percent of the lakes have concentrations less than 372 µg/L (MPCA, 1997). Monthly TP concentrations for Lakes Frances showed minimal variation across the summer (Figure 5). Tustin Lake, in contrast, showed a large increase from July through September, which absent large phosphorus loads from the watershed, may have been related to internal recycling from the sediments and algal growth.

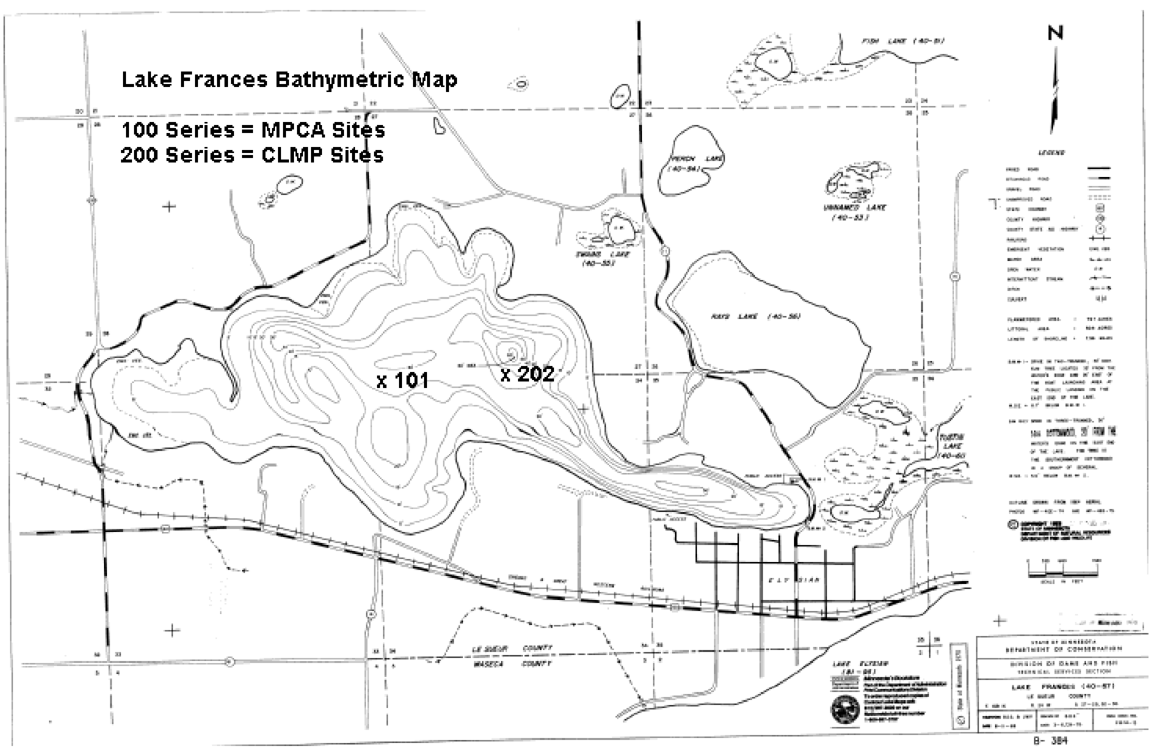
Algae in the surface waters of lakes assimilate phosphorus as they grow. When algae die, they settle into the deep water and lake sediments. In stratified lakes, the phosphorus tends to remain in the deep water, at least during the warm months. In shallow lakes, this phosphorus may more easily find its way back into the surface water through physical or chemical processes. This is referred to as internal loading. Deep- water TP samples for Lake Frances were relatively low and similar to surface TP concentrations (Appendix 3) and further attests to the well-mixed conditions in the lake. Likewise it appears that internal recycling of TP may not be a large source of phosphorus to the lake at this time.

Total nitrogen (TN) concentrations, which consist of total Kjeldahl nitrogen and nitrite and nitrate-N, averaged 0.9 and 3.0 for Lakes Frances and Tustin respectively. These values are within the NCHF minimally impacted lakes range for Lake Frances, but significantly higher than the expected range for Lake Tustin.

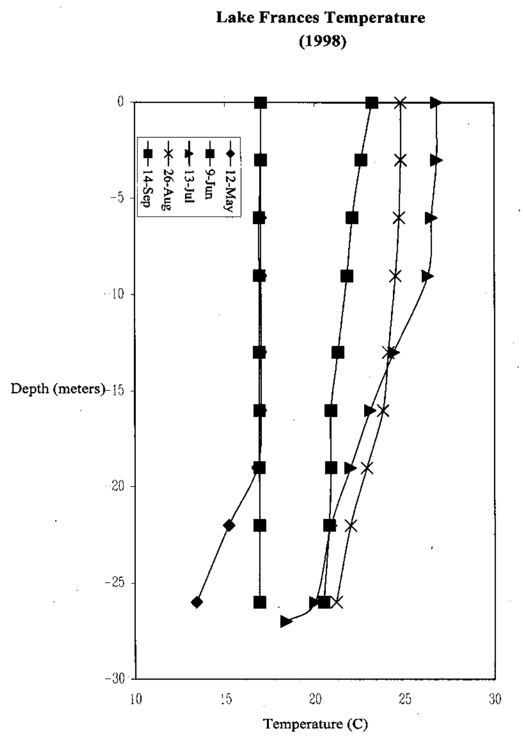
Nitrogen, as well as phosphorus, is required for growth of aquatic plants and algae. Although phosphorus is usually the nutrient limiting the productivity of a lake, nitrogen may be the limiting nutrient in some situations. The ratio of TN:TP can indicate which nutrient is limiting the growth of algae and aquatic plants in the lake. The ratios for Lakes Frances and Tustin were 26:1 and 8:1, respectively. The low ratio for Lake Tustin indicates that nitrogen could be limiting the growth of algae. As such, management of Lake Tustin should include the control of nitrogen, as well as phosphorus, inputs.

Chlorophyll-a (a pigment produced by algae) concentrations provide an estimate of the amount of algae in the lake. Summer-mean concentrations for Lakes Frances and Tustin were 19.4 µg/L and 146.8 µg/L, respectively (Table 2). The Lake Frances concentration was within the range of concentrations (5-22 µg/L) exhibited by reference lakes in this ecoregion, while the Tustin value was much higher. For Lake Frances, concentrations ranged from a low of 6.9 µg/L on July 13 to 33.4 µg/L on September 14 (Figure 6). For Lake Tustin, concentrations ranged from 31.4 µg/L on July 13 to over 200 µg/L in August and September. Concentrations from 10 to 20 µg/L would be perceived as a mild algal bloom and concentrations greater than 30 µg/L would often be perceived as severe nuisance conditions (Heiskary and Walker, 1988).

Figure 2. LAKE FRANCES BOTTOM CONTOUR AND SAMPLING SITE MAP



Figures 3 & 4. TEMPERATURE AND DISSOLVED OXYGEN PROFILES (Site 101)



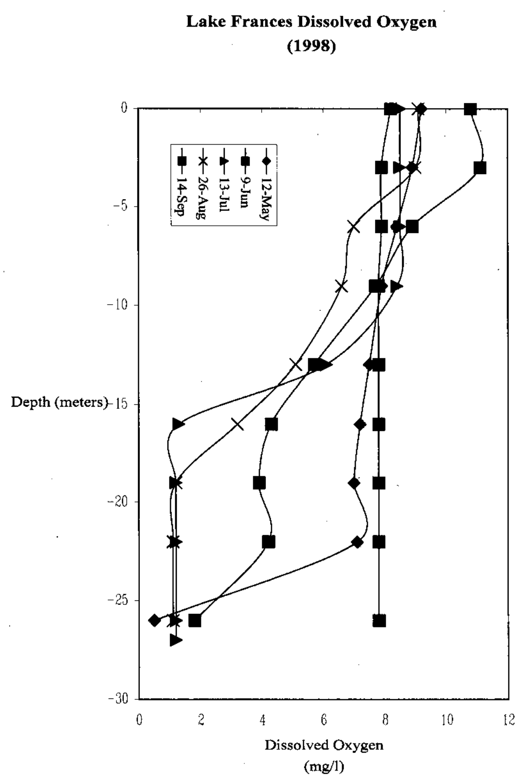


TABLE 2: LAKES FRANCES AND TUSTIN AVERAGE SUMMER WATER QUALITY AND TROPHIC STATUS INDICATORS for 1998.

Water Quality Parameter	Frances	Tustin	Typical Range for NCHF Ecoregion[1]
Total Phosphorus µg/L	34	372	23-50
Chlorophyll-a µg/L:			
Mean	19	147	5-22
Maximum	33	205	7-37
Secchi disk (feet)	4.3 (1.3 m)	1.4 (0.4 m)	4.9-10.5
Total Kjeldahl Nitrogen (mg/l)	0.9	3	0.6-1.2
Alkalinity (mg/l)	138	110	75-150
Color (Pt-Co Units)	9	43	10-20
pH (SU)	8.6	9.0	8.6-8.8
Chloride (mg/l)	11	21	4-10
Total Suspended Solids (mg/l)	7.1	39.2	2-6
Total Suspended Inorganic Solids (mg/l)	1.5	3.5	1-2
Conductivity (umhos/cm)	251	265	300-400
TN:TP Ratio	26:1	8:1	25:1-35:1

Trophic Status Indicators:

Carlson Trophic State Index Values	Frances	Tustin
TP TSIP =	55	90
Chl-a TSIC =	56	72
Secchi TSIS =	60	80
Mean(All)TSI =	57	81
NCHF Ecoregion Percentile[2]	50	<5

1: 25-75th percentile for representative, minimally impacted lakes in the NCHF ecoregion (Heiskary and Wilson, 1990).
2: Relative to 787 assessed lakes in the NCHF ecoregion. One hundred percent level implies lowest TP and chlorophyll-a concentration and deepest Secchi disk measurement.

Figure 5. 1998 Lakes Francis and Tustin Monthly TP Concentrations

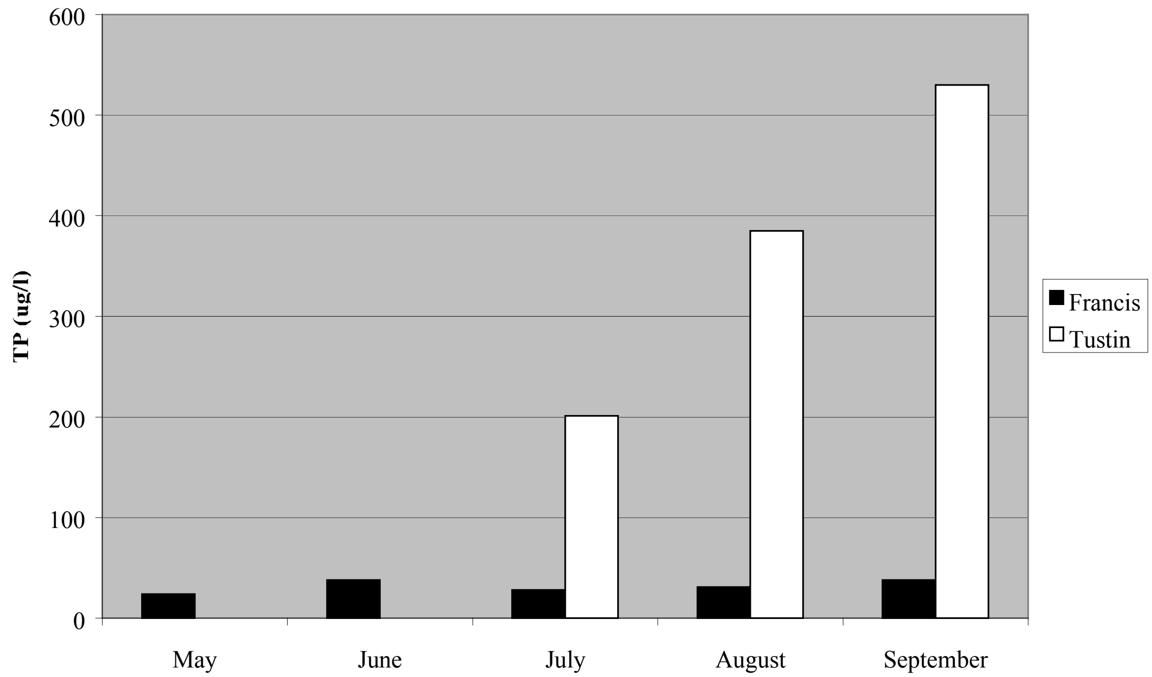


Figure 6. 1998 Lakes Francis and Tustin Monthly Chlorophyll-a Concentrations

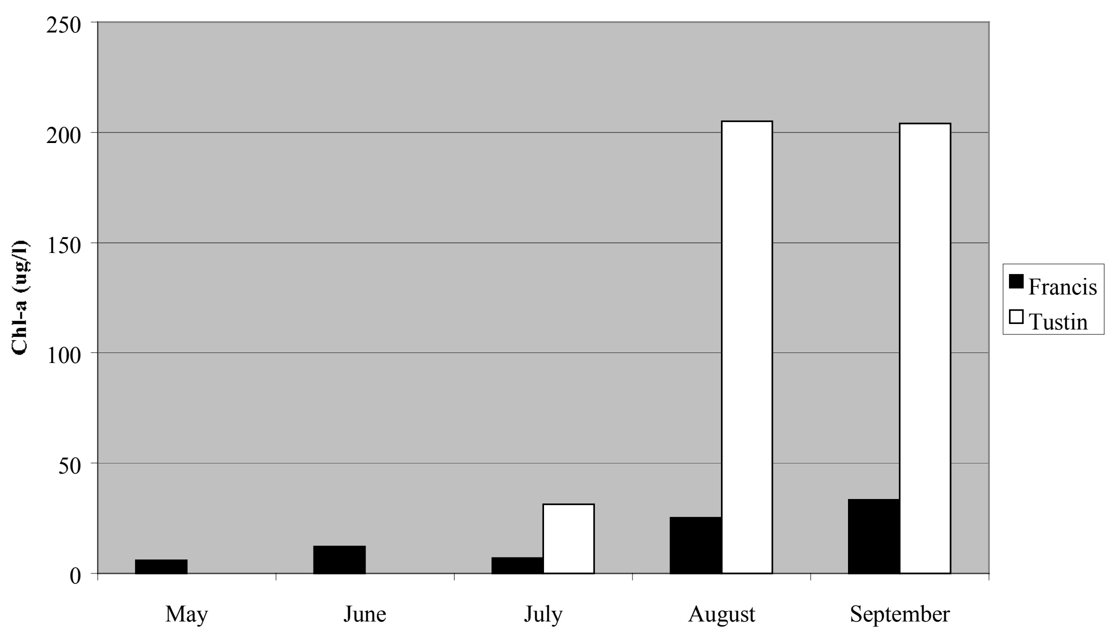
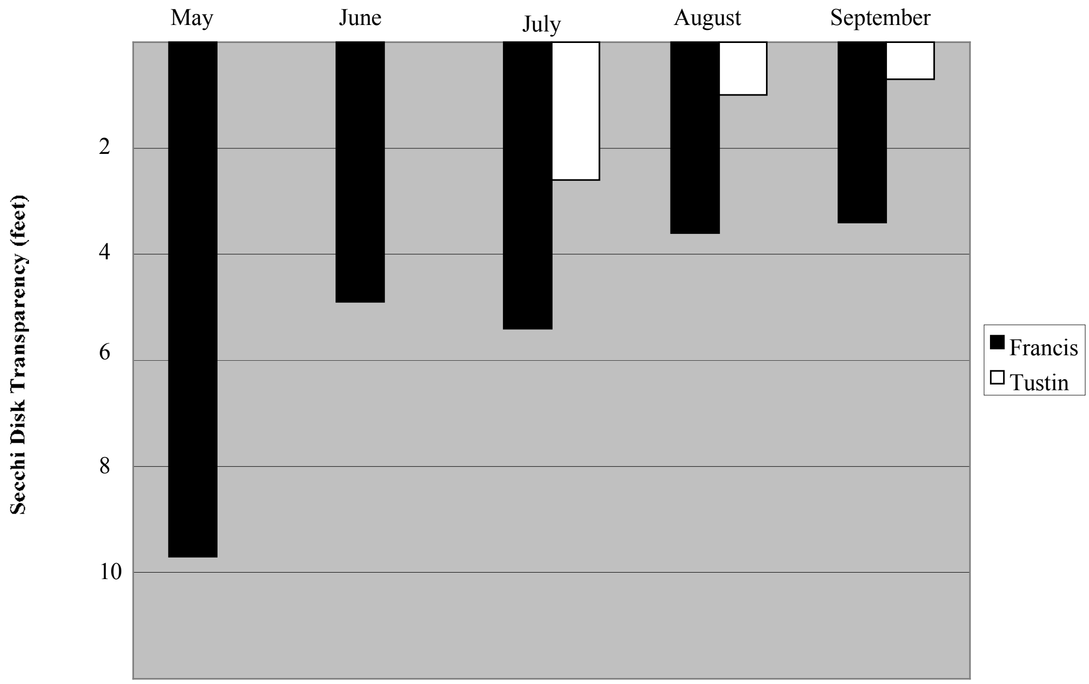


Figure 7. 1998 Lakes Francis and Tustin Monthly Secchi Transparency



Phytoplankton

In addition to looking at the amount of algae in a lake (through chlorophyll-a measurements), it can be important to assess the types of algae present. Phytoplankton (algae) samples were collected on each sampling date. Results of the analysis show a transition from mainly Chrysophyta (golden or yellow-brown algae; diatoms) in May and June, to mainly blue-green algae (Cyanophyta) in July, August and September. Low numbers of green algae (Chloropyta) were present in June, August and September. Blue-green algae domination is a sign of eutrophic to hypereutrophic conditions in a lake. Blue-greens are generally responsible for heavy, sometimes odorous, algae scums. In addition, certain types of blue-greens release toxins that may pose a threat to domestic animals and wildlife. A seasonal transition in algal types from diatoms to greens to blue-greens is typical for mesotrophic and eutrophic lakes in Minnesota.

Zooplankton

Zooplankton (microscopic and near-microscopic, free-swimming animals) were collected and analyzed qualitatively for all sampling events. Zooplankton, particularly large-bodied varieties, can be beneficial for lakes because of their ability to consume large quantities of algae. It should be noted, however, that even large-bodied zooplankton might not feed on all algae varieties, such as some blue-greens. In general, zooplankton feed preferentially on small algal forms. Zooplankton are a major source of food for small fish. Few large-bodied zooplankton were observed on either

Lakes Frances or Tustin. Small varieties were abundant at times, while few zooplankton were present at other times.

Secchi disk transparency is generally a function of the amount of algae in the water. Suspended material, such as sediment, or color due to dissolved organic material in the lake, may also reduce water transparency. Transparency values can often be correlated to chlorophyll-a and total phosphorus concentrations. The summer average transparencies for Lake Frances and Tustin were 4.3 and 1.4 feet, respectively (Table 3). For Frances, this transparency is just slightly lower than the expected range for ecoregion reference lakes; however for LakeTustin, the transparency is much lower than expected. In general the change in transparency in Frances corresponded to changes in chlorophyll-a (algae) concentrations (Figure 6).

User perception ratings, usually done in conjunction with Secchi readings, were recorded by MPCA staff and the CLMP volunteer. These subjective measures of a lake's "physical condition" and "recreational suitability" were developed to create a link between water quality measurements and the perceptions of citizens and resource managers (Heiskary and Wilson, 1988). Physical condition 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). For Lake Frances, all physical condition ratings were "some algae present." All recreational suitability rankings were "minor aesthetic problem," with the exception of June 9, when MPCA staff rated the lake "beautiful, could not be better." For Lake Tustin, physical condition ratings were "definite algae present" and "high algal color;" while recreation suitability was deemed "no swimming, boating OK."

Good transparency is desirable not only from the standpoint of aesthetics or recreation. The aquatic plants, fish, waterfowl, reptiles, and amphibians that make up a lake ecosystem can also benefit from clearer water. Figure 8 shows monthly Secchi transparency readings.

For Lake Frances, other water quality parameters including color, total suspended solids, total suspended inorganic solids, pH, turbidity, alkalinity, chloride, and conductivity were generally within the range of values for the reference lakes in the NCHF ecoregion (Table 2). For Lake Tustin, the values were generally outside of this range. The total suspended solids concentration in Lake Tustin, for example, was 7-20 times higher than the reference range. This might be expected in a shallow basin such as Tustin, where wind-driven wave action can stir sediment into the water column. All water quality data for individual sampling dates are found in Appendix 3.

One means to evaluate the **trophic status** (overall health) of a lake and to interpret the relationship between total phosphorus, chlorophyll-a, and Secchi disk transparency is Carlson's Trophic State Index (Carlson, 1977). This index was developed from the interrelationships of summer Secchi disk transparency and the surface water concentrations of total phosphorus and chlorophyll-a. Trophic state index (TSI) values are calculated as follows:

Total phosphorus TSI (TSIP) = 14.42 ln(TP) + 4.15
Chlorophyll TSI (TSIC) = 9.81 ln(Chl a) + 30.6
Secchi disk TSI (TSIS) = 60 - 14.41 ln(SD)

TP and chlorophyll-a are in µg/L, and Secchi disk transparency is 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 average TSI values for Lake Frances and Lake Tustin were 57 and 81 respectively. For Lake Tustin, the phosphorus index value is significantly higher than the chlorophyll values. This indicates that something besides phosphorus may be limiting algae growth. The high suspended inorganic sediment in Lake Tustin may be blocking some of the light necessary for algae growth. The low nitrogen to phosphorus ratio also points to nitrogen limitation.

Comparison of TSI values for to those of other lakes in the NCHF ecoregion can provide a basis for evaluating the water quality of the lake. Lake Frances falls right in the middle of 787 NCHF lakes, while less than 5 percent of lakes in the ecoregion have a mean TSI value greater than Lake Tustin. The TSI values, and their relationships to phosphorus, chlorophyll-a, and Secchi transparency are shown in Table 2 and as part of the MNLEAP modeling results (Table 4). Further description of the values are also provided in Figure 9.

Water Quality Trends

Minimal water chemistry data is available for determining long-term trends in water quality for either Lake Frances or Lake Tustin. The available data (Table 3) do not indicate any trends but are useful for characterizing variability in the trophic status variables over time. A better opportunity for assessing trends is provided by Citizen Lake-Monitoring Program data that have been collected since 1992 (Figure 8) at site 202 (Figure 2). An analysis of this data contained in the 1998 Report on the Transparency of Minnesota Lakes indicated no statistically significant trend in transparency over this time period. In other words; no improvement or decline in transparency. A closer inspection of these data suggest that transparency has been quite variable from 1992 through 2001 with summer-mean Secchi ranging from 4.6 feet (1999) to 12 feet (1995), however no significant increase or decrease over time is indicated. Some data from 1976-1977 suggest transparency was on the order of 5 feet. Again data from the 1992 – 2001 time frame compare favorably and do not suggest a significant decline nor improvement.

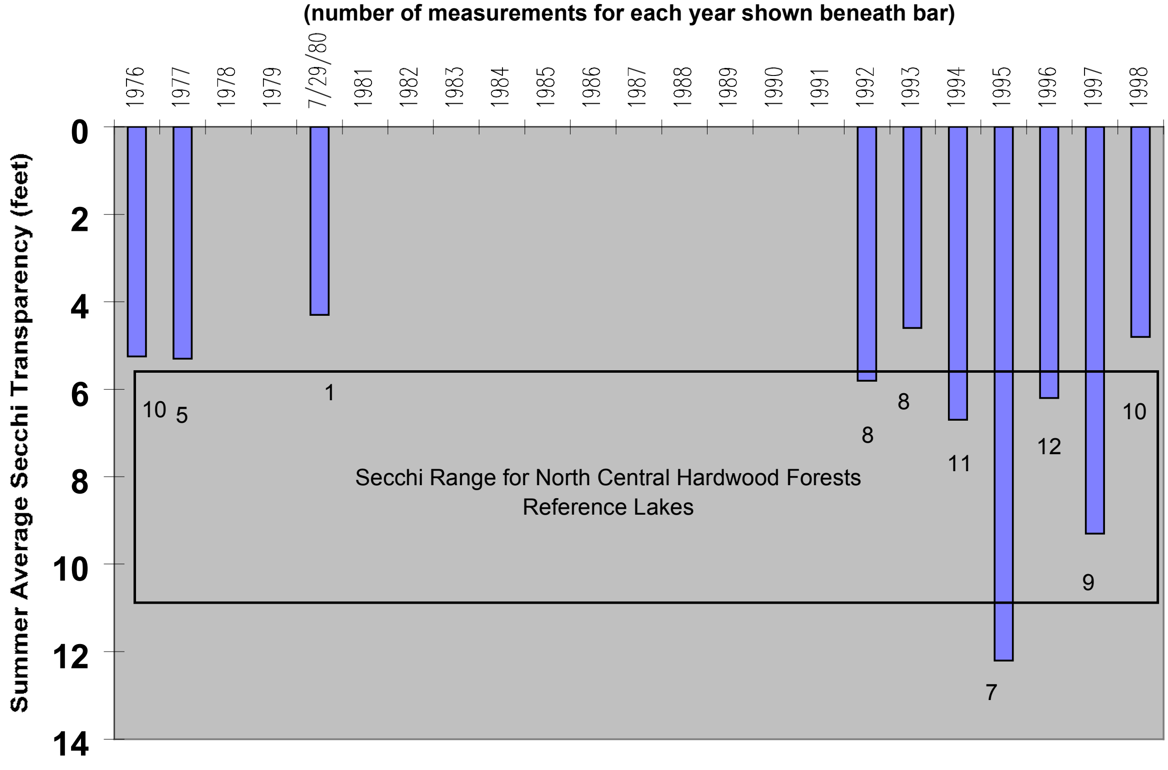
Table 3. TP, Chlorophyll-a and Secchi Transparency: Long-Term Summer-means.

Year	Secchi Transparency (feet)			Total Phosphorus (µg/L)			Chlorophyll-a (µg/L)		
	feet	n	se	(µg/l)	n	se	(µg/l)	n	se
Frances									
1980	4.3	1	-	48	1	-	19.2	1	-
1996	6.6	4	0.7	28	4	4.0	11.4	4	3
1998	4.3	4	1.0	34	4	5.1	19.0	4	12
Tustin									
1996	2.6	4	1.0	207	4	48	126	4	85
1998	1.4	3	1.0	372	3	165	147	3	100

se = standard error;
n = number of observations

Figure 8. Lake Frances Water Transparency

(number of measurements for each year shown beneath bar)



(Additional data not shown on chart – 1999, mean transparency = 4.6 feet, 7 obs.; 2001, mean transparency = 5.4 feet, 7 obs.)

Figure 9. Carlson's Trophic State Index for Lake Frances, LeSueur County
R.E. Carlson

TSI < 30 Classical Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes.

TSI 30 - 40 Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.

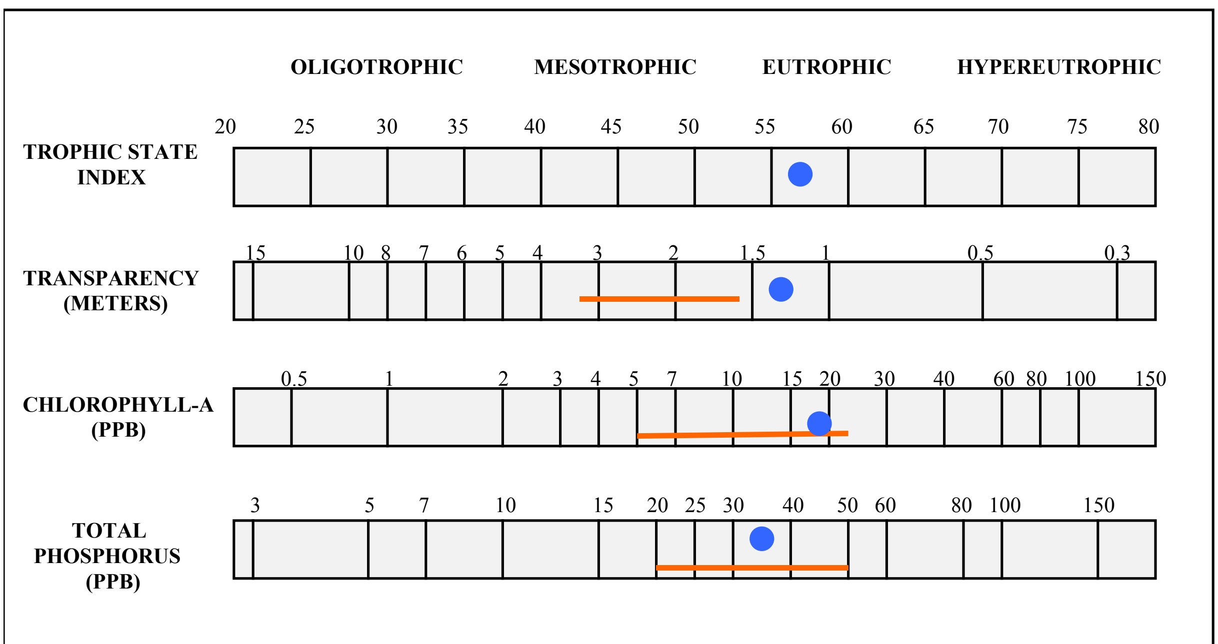
TSI 40 - 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

TSI 50 - 60 Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.

TSI 60 - 70 Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.

TSI 70 - 80 Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.

TSI > 80 Algal scums, summer fish kills, few macrophytes, dominance of rough fish.



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

NCHF Ecoregion Range: Lake Frances:

Aquatic Plants (Macrophytes)

No formal macrophyte survey was conducted as part of the LAP. Based on informal observation, however, there appears to be a variety of native aquatic plants present in both Lakes Frances and Tustin. Curlyleaf pondweed is also found in both lakes. Curlyleaf pondweed (*Potamogeton crispus*) is a very aggressive exotic (from Europe) that can dominate the macrophyte community of a lake; however in 1998, it did not appear to be dominant in either lake.

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

Dense aquatic plant growth in the "wrong areas" is a nuisance to some lake users. A number of techniques may be used to control nuisance macrophytes in small areas. Manual or mechanical harvesting can be an effective control technique for small swimming areas or boat paths. Sediment covers or surface shading are experimental techniques which may effectively control weed growth by controlling light. The Lake and Reservoir Restoration Guidance Manual (USEPA 1990) contains information on this topic. Although the benefit would be small, harvesting removes small amounts of nutrients from a lake. If low oxygen is a problem, the removal of plant material that depletes oxygen as it decays may be a more beneficial activity. All plants must be removed from the lake during any harvesting operation. In many cases permits from the DNR are required for aquatic weed control.

Pollution Sources

Watershed

The dominant use of land in the Frances/Tustin watershed is row crop agriculture. The City of Elysian and developed lakeshore also make up a significant portion of the watershed. Both of these land uses are important sources of nonpoint source pollution. Nonpoint pollution sources include: runoff of eroded soil; pesticide and fertilizer runoff from agricultural land, lawns, and other urban land; feedlot runoff; runoff from streets, yards, and construction sites; seepage from septic systems; dredging and drainage activities; and impacts from the loss of wetlands. On an acre for acre basis, the water quality of unban runoff can be worse than from agricultural land.

While it is unrealistic to expect that all nonpoint pollution sources can be eliminated, the implementation of Best Management Practices (BMPs) and other land use changes can minimize human impacts on water quality. To control soil erosion, reduce the use of fertilizers and pesticides, and improve manure management on agricultural land, BMPs should be selected that meet water quality goals and fit individual farm operations. The MPCA's *Agriculture and Water Quality* publication is one of many sources of information on agricultural BMP's. Best management practices are also available for construction activities and for lakeshore property owners.

Livestock

Livestock waste contains nutrients, organic material, and bacteria that can enter streams and lakes if not managed properly. Proper management includes containing manure on any open lots, and land application at rates that can be used by crops and in a manner that reduces runoff. In recent years, there has been increasing discussion about basing manure application rates near lakes on the phosphorus, rather than the nitrogen, needs of crops. Using the nitrogen needs of crops generally results in excess phosphorus. There is at least one active livestock facility in the Frances/Tustin watershed. It should be noted that the manure from this or other facilities could be land applied on fields outside of the watershed. Likewise, manure from facilities some distance away could be applied on fields within the watershed.

Sewage Treatment Systems

Old, malfunctioning, or improperly installed on-site sewage treatment systems can contribute to the amount of nutrients and disease-causing organisms entering a lake. A number of such systems along the northeast shore of the lake were replaced with centralized sewer and water service in 1997 and 1998. Many other systems should be upgraded.

In and of itself, replacing aging on-site sewage treatment systems with centralized treatment will improve the water quality of Lake Frances over the long term. Sometimes, however, the installation of sewer and water allows for increase development near lakes. Benefits of the improved wastewater treatment can be offset by increase runoff from lawns, driveways, streets, etc.

Even properly designed, functioning on-site systems need to be properly maintained. Minnesota Extension Service recommends pumping every one to three years for a 1,000 gallons tank serving a three-bedroom house and four occupants (this assumes year-round use). Water conservation practices and care in regard to the types of products placed in a system can also be very important for good operation and system longevity.

Lawn Care

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

In-lake

A portion of the nutrients which enter a lake from the watershed settle out and become bound to the lake sediments. As discussed previously, some of these nutrients can be released back into the lake under certain temperature and oxygen conditions. Phosphorus, for example, is released from sediments when the layer of water near the sediment becomes very low in oxygen. In addition, in shallow lakes like Tustin, sediment and nutrients can be physically mixed into the water column by wind action. In either case, the contribution of phosphorus from the sediment can represent a significant part of the phosphorus load to a lake. It is important to note, however, that most lakes with excessive internal phosphorus loading have or have had excessive external phosphorus loading. An ultimate solution to internal loading could be a reduction in external loading.

Modeling Summary

Numerous mathematical models are available for assessing lake water quality. Models can be used to predict conditions in a lake based on characteristics of its watershed. Models 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 a lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow of water entering the lake. The "Minnesota Eutrophication Analysis Procedure" (MINLEAP) model and the Reckhow and Simpson (1980) model were used to assess the water quality of Lake Frances.

MINLEAP was developed by MPCA staff based on an analysis of data collected from a set of minimally-impacted reference lakes for each ecoregion. Total phosphorus (TP), chlorophyll-a, and Secchi 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 Lake Frances. It is intended to be used as a screening tool for estimating lake condition with minimal data input and is described in greater detail in Heiskary and Wilson (1990). The **MINLEAP model** predicts an in-lake TP of 30µg/L, a chlorophyll-a concentration of 9.7 µg/L, and a Secchi transparency of 2.0 meters for Lake Frances (Table 4). Statistically, 1998 observed water quality values are not significantly different from these predicted values. This suggests that Lake Frances exhibits fairly good water quality for its watershed and morphometry. Based on MINLEAP, Lake Frances retains about 84 percent of the P that enters the lake. Its water residence time (time it would take to fill the lake if it were empty) is on the order of 7 years. The P loading rate for Lake Frances is estimated at 335 kg P/yr. In addition to the MINLEAP model, a simple regression model referred to as the Vighi and Chiaudani (1985) model was used to estimate "background" P concentrations for the lake. The model predicted an in-lake P concentration of about 24 µg/L, which is lower than the observed and MINLEAP values. This suggests that background P, based on the lake's depth and alkalinity (mineral content) may account for about 70 percent of the modern-day P concentration (34 µg/L).

Table 4. MINLEAP Modeling Results for Lake Frances

Input data:
Lake Name: Frances
Ecoregion: North Central Hardwood Forests
Watershed Area (HA): 1234
Lake Surface Area (HA): 324

Water Quality Parameter	Observed	Predicted
Mean Total Phosphorus (µg/L)	34	30
Mean Chlorophyll-a (µg/L)	19	9.7
Mean Secchi (M)	1.3	2.0
Mean Alkalinity - Ca (mg/L)	138	

Results:

Average Inflow TP = 193 ug/l
Lake Outflow = 1.73 HM^3/yr
Residence Time = 7.4 years

Total P Load = 335 kg/yr
Areal Water Load = 0.54 M/yr
P Retention Coef. = 0.84

Vighi and Chiaudani (1985) Estimated TP = 24 (µg/L)

T-Test Values for differences between observed and predicted values:

Water Quality Parameter	t-test value
Mean Total Phosphorus (µg/L)	0.26
Mean Chlorophyll-a (µg/L)	0.92
Mean Secchi (M)	-0.94

Chlorophyll-a Frequencies (percent of time exceeding concentrations):

Chlorophyll-a Concentration (µg/L)	frequency
10	86 %
20	36 %
30	12 %
60	0 %

≥ 20µg/L = nuisance conditions
≥ 30µg/L = severe nuisance conditions

The **Reckhow and Simpson model** was also used to estimate the water quality of Lake Frances. Inputs to the model included estimates of precipitation, evaporation, runoff, and land use in the watershed. P loading to the lake, based on the land use composition and P export coefficients, is shown in Appendix 4. P export coefficients were taken from the literature (Prairie and Kalff, 1986; Reckhow and Simpson, 1980) and were comparable to coefficients used in previous LAP studies. The uncertainty associated with this model's assessment requires that the output be expressed as a range of values (low, average, and high).

The "low" P export coefficients provided the best estimate of in-lake P for Lake Francis (36 μg/L), even though this is still more than the observed mean (Table 5). The estimated P loading rate associated with this concentration is 433 kg P/yr. This loading rate is somewhat higher than the loading rate estimated by MINLEAP (335 kg P/yr, Table 4). The contribution of this load from the watershed is estimated at 56%. Of this amount, the majority arises from agricultural and urban uses in the watershed. P deposition of phosphorus from precipitation, directly on the surface of the lake, and septic systems, are also significant contributors to this load.

As part of the Reckhow and Simpson modeling (output section 4), estimates are made of the potential contribution of phosphorus to the lake from livestock. For illustrative purposes, a figure of 20 cattle was input to the model. It is estimated that if all the manure from these cattle entered the lake, it could account for about 14% of the annual P load.

For the Reckhow and Simpson model, "low" predicted chlorophyll and transparency values are slightly better than those observed, while predicted phosphorus levels are not significantly different from the observed phosphorus levels. The Reckhow-Simpson model estimates a water residence time of 8.8 years, which is also comparable to the MINLEAP model estimate of 7.4 years.

Goal Setting

To place goal setting in perspective for this Lake Frances, it is useful to review the data record, along with the model estimates shown in the following table.

Table 5. 1998 Summer-Mean P Data and Model Estimates

Lake	1998 Mean P	MINLEAP P	Vighi -P	Reckhow-Simpson P overall (low-high)
Frances	34 µg/L	30 µg/L	24 µg/L	36-58 µg/L

Based on these data, it is evident that the 1998 summer-mean is comparable to the MINLEAP, and Reckhow-Simpson (using "low" P export coefficients) predictions but is slightly higher than the Vighi/Chiaudani (background P) prediction. Given that the observed total phosphorus is near predicted value for two of the models, it may not be reasonable to expect large reductions in in-lake total phosphorus concentrations. Considered along with the trend analysis showing no significant transparency change over time, an appropriate goal may be to maintain the current in-lake P concentration. Given continued land use changes in the watershed, development pressure around the lake, this is an aggressive goal.

Efforts to improve the water quality of Lake Frances will benefit Lake Tustin. However, given it's depth, and large watershed-to-lake area ratio, substantial reductions in phosphorus may be very difficult to achieve. Alternatively, shallow lake management strategies, which maximize the growth of desirable aquatic macrophytes could be pursued. In addition to providing excellent fish and wildlife habitat, aquatic macrophytes can suppress algae growth. In certain situations, this results in lakes with very good transparency despite relatively high phosphorus levels.

REFERENCES

Canfield, D.E., K.A. Langeland, S.B. Linda, and W.T. Haller. 1985. Relations between water transparency and maximum depth of macrophyte colonization in lakes. J. Aquat. Plant Manage. 23:25-8.

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

Gunnard, Kurt T. 1985. U.S. Geologic Survey. Water Supply Paper 2300. U.S.G.S.702 Post Office Building, St. Paul, MN.

Heiskary, S.A. Trophic Status of Minnesota Lakes. 1985. Minnesota Pollution Control Agency. 39 pages.

Heiskary, S.A. and W.W. Walker Jr. 1988. Developing phosphorus criteria for Minnesota lakes. Lake Reserv. Manage. (1) 1-9.

Heiskary, S.A. and C.B. Wilson. 1988. Minnesota Lake Water Quality Assessment. Minnesota Pollution Control Agency. St. Paul, Minnesota.

Heiskary, S.A. and C.B. Wilson. 1990. Minnesota Lake Water Quality Assessment Report. Minnesota Pollution Control Agency. St. Paul, Minnesota.

Hendersen, C.L. 1987. Landscaping for Wildlife. Minnesota Department of Natural Resources. Minnesota Bookstore, St. Paul, MN.

Marshner. 1930. Map of the Original Vegetation of Minnesota

Minnesota Department of Natural Resources. 1968. An Inventory of Minnesota Lakes: Bulletin 25. MDNR. St. Paul, Minnesota 452 pages.

Minnesota Planning Agency. SWIM Data Base. St. Paul, MN.

Minnesota Pollution Control Agency. 1994. Appendix 1. Minnesota Lake Water Quality Assessment Data.

Minnesota Pollution Control Agency. Agriculture and Water Quality, Best management practices for Minnesota. 520 Lafayette Rd. St Paul, MN.

Minnesota Pollution Control Agency, St. Paul, Minnesota and Freshwater Society, Navarre, Minnesota. 1985. Citizens' Guide to Lake Protection. 16 pages.

Minnesota Pollution Control Agency. 1990. Protecting Minnesota's Waters...The Land-Use Connection. St. Paul, MN. 28 pages.

Minnesota Pollution Control Agency. 1991. Running Your Feedlot. St. Paul, MN. 16 pages.

Olem, H. and G. Flock, eds. 1990. Lake and Reservoir Restoration Guidance Manual. 2nd edition. EPA 440/4-90-006. Prep. by N. Am. Lake Manage. Soc. for U.S. Environ. Prot. Agency, Washington, DC.

Prairie, Y.T. and J. Kalff. 1986. Effect of catchment size on phosphorus export. Water Resource Bulletin 22(3):465-470.

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

Riley, E.T. and E.E. Prepas. 1985. Comparison of the phosphorus-chlorophyll relationships in mixed and stratified lakes. Can. J. Fish. Aquat. Sci. 42: 831-835

State Climatology Office. MDNR Division of Waters.

United States Department of Agriculture. 1983. Soil Associations of Minnesota. Soils map produced in association with the Minnesota Agricultural Experiment Station.

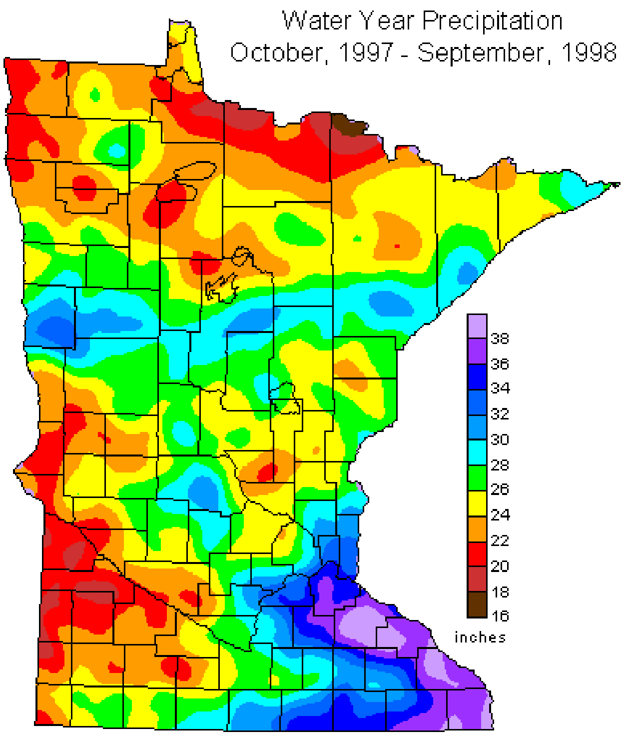
Vighi and Chiaudani. 1985. A simple method to estimate lake phosphorus concentrations resulting from natural background loadings. Wat. Res. 19:987-991

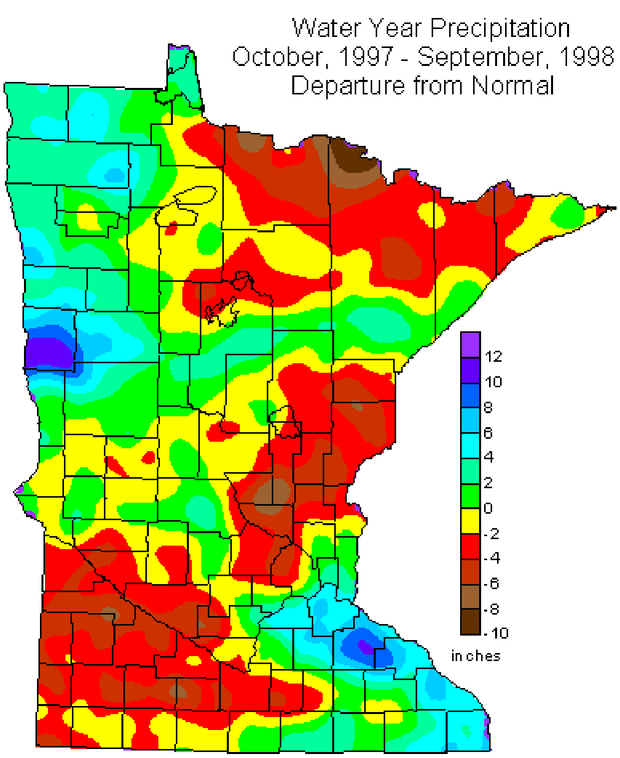
Walker, W.W. Jr. 1985. Empirical Methods for Predicting Eutrophication in Impoundments. Report 4. Phase III: Applications Manual. Technical Report E-81-9. U.S. ACE Waterway Experiment Station. Vicksburg, Mississippi.

Wilson, C.B. 1988. Lake water quality modeling used in Minnesota. Presented at National Conference on Enhancing State Management Projects. May 12-13, 1988. Chicago, Illinois.

Zumberge, J.H. 1952. The Lakes of Minnesota. Their origin and classification. Minnesota Geological Survey. University of Minnesota Press. Minneapolis, Minnesota.

APPENDIX 1


Water Year Precipitation
October, 1997 - September, 1998
38
36
34
32
30
28
26
24
22
20
18
16
inches


Water Year Precipitation
October, 1997 - September, 1998
Departure from Normal
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
inches

APPENDIX 2

Lake water level report: Minnesota DNR - Netscape

File Edit View Go Communicator Help

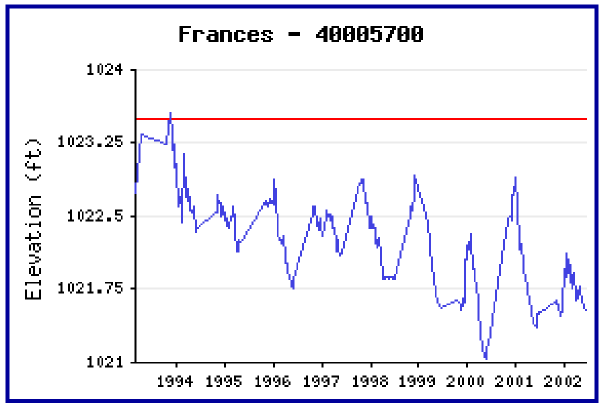
Lake water level report

Lake name: Frances

County: Le Sueur

Water Level Data

Period of record: 01/06/1939 to 11/22/2002
# of readings: 336
Highest recorded: 1024.5 ft (07/15/1986)
Lowest recorded: 1011.36 ft (01/06/1939)
Recorded range: 13.14 ft
Average water level: 1022.14 ft
Last reading: 1021.54 ft (11/22/2002)
OHW elevation: 1023.5 ft
Datum: 1929 (ft)



Last 10 years of data, click to enlarge.

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APPENDIX 3 – WATER QUALITY DATA

LAKEID	=40-00	57	**Frances**																			
DATE	SITE	D	TPUG	RP	TKN	TN:TP	N2	RN	TSS	TSIN	ALK	PHF	CL	CONF	TURB	COL	CHLA	PHEO	SDF	PHYS	DO	TEMP
7/29/80	101	0	48		1.14		0.01	K	.	.	130	.	.	.	2.6	20	19.2	.	4.3		8.6	25.5
5/28/86	106	0	28		0.92		0.08		2.7	.	140	.	4.9	.	1.3	20	0.32	.	6.6		10.5	18.5
5/29/96	.	18	25		.		.		.	.	.	.	.	.	.	.	.	.	.		.	.
5/29/96	101	0	32		0.74		0.05	K	3.6	1.6	130	.	10	300	1.4	10	7.37	1.28	8.5	2	9.4	17
6/24/96	101	0	20		0.76		0.05	K	2.4	0.8	120	.	10	270	1.8	10	7.37	2.56	9.8	2	9.5	21.9
6/24/96	101	19	46		.		.		.	.	.	.	.	.	.	.	.	.	.		4.5	16.2
7/15/96	101	0	25		0.94		0.05	K	6.4	2.2	130	.	11	260	2.6	10	10.9	2.56	5.6	3	9.7	23.5
7/15/96	101	16	26		.		.		.	.	.	.	.	.	.	.	.	.	.		7.3	21.9
9/4/96	101	0	37		0.91		0.05	K	7.6	2	120	.	11	.	3.2	10	7.05	1.6	3.9	3	8.7	24.3
9/4/96	101	24	34		.		.		.	.	.	.	.	.	.	.	.	.	.		.	.
9/25/96	101	0	32		0.92		0.05	K	6.4	2	120	.	11	.	3.5	5	20.1	1.39	9.8	2	8.7	16.9
5/12/98	101	0	24		0.69	28.75	.		4	2	140	8	.	250	.	10	5.82	1.01	9.7		.	.
6/9/98	101	0	38		0.79	20.789	.		5.2	2.4	130	8	11	270	.	5	12.2	2.18	4.9	2	8.2	17
7/13/98	101	0	28		0.75	26.786	.		5.2	2	130	8	11	240	.	10	6.92	0.93	5.4	2	8.5	26.8
7/13/98	101	26	33		.		.		.	.	.	.	.	.	.	.	.	.	.		1.2	20
8/26/98	101	0	31		0.92	29.677	.		8	1.6	110	9.1	11	260	.	10	25.2	1.61	3.6	2	9.1	24.8
9/14/98	101	0	38		1.08	28.421			10	0	180	9.2	11	235		10	33.4	2.16	3.4			
9/14/98	101	24	60		.		.		.	.	.	.	.	.	.	.	.	.	.		.	.
smr. Mean			33.75		0.885	26.418			7.1	1.5	137.5	8.575	11	251.25		8.75	19.43	1.72	4.325			
			5.058														12.0724		0.978			
LAKEID	=40-00	61	**Tustin**																			
DATE	SITE	D	TPUG	RP	TKN		N2	RN	TSS	TSIN	ALK	PHF	CL	CONF	TURB	COL	CHLA	PHEO	SDF	PHYS	DO	TEMP
5/29/96	101	0	50		1.1		0.05	K	1	0	130	.	12	290	1.6	20	1.6	0.32	4.9	3	10.8	17
6/24/96	101	0	176		1.29		0.05	K	2.8	0.8	94	.	12	210	1.7	20	14.1	0.64	4.3	3	15.4	24
7/15/96	101	0	96		1.37		0.05	K	3.2	1.2	86	.	13	210	1.6	20	10.9	3.84	4.1	3	13.3	24.5
8/19/96	101	0	326		4.86		0.05	K	40	6	100	.	15	242	23	30	372	3.2	1.3	4	7.8	22.2
9/25/96	101	0	231		3.64		0.05	K	17	1	130	.	15	.	12	20	108	8.68	1.3	3	9.1	16.1
7/13/98	101	0	201		1.82	9.0547	.		7.6	1.6	110	7.9	16	230	.	40	31.4	11.7	2.6	3	9.5	30.6
8/26/98	101	0	385		3.54	9.1948	.		46	3	100	9.5	22	275	.	40	205	18.2	1	4	10.4	25
9/14/98	101	0	530		3.71	7	.		64	6	120	9.7	25	290	.	50	204	24.9	0.7	4	16.2	24.1
smr. Mean			372		3.0233	8.4165			39.2	3.533	110	9.033	21	265		43.33	146.8	18.267	1.433			
			164.88														99.9406		1.021			

APPENDIX 3 (CONTINUED) – DEPTH, TEMPERATURE, AND DISSOLVED OXYGEN DATA

LAKEID		-17 **Frances**		
DATE	SITE	D	DO	TEMP
5/12/98	101	0	9.2	17
5/12/98	101	3	8.9	17
5/12/98	101	6	8.4	17
5/12/98	101	9	7.9	17
5/12/98	101	13	7.5	17
5/12/98	101	16	7.2	17
5/12/98	101	19	7	16.8
5/12/98	101	22	7.1	15.2
5/12/98	101	26	0.5	13.4
6/9/98	101	0	8.2	17
6/9/98	101	3	7.9	17
6/9/98	101	6	7.9	16.9
6/9/98	101	9	7.8	16.9
6/9/98	101	13	7.8	16.9
6/9/98	101	16	7.8	16.9
6/9/98	101	19	7.8	16.9
6/9/98	101	22	7.8	16.9
6/9/98	101	26	7.8	16.9
7/13/98	101	0	8.5	26.8
7/13/98	101	3	8.5	26.8
7/13/98	101	6	8.5	26.5
7/13/98	101	9	8.4	26.3
7/13/98	101	13	6.1	24.4
7/13/98	101	16	1.3	23.1
7/13/98	101	19	1.2	22
7/13/98	101	22	1.2	20.9
7/13/98	101	26	1.2	20
7/13/98	101	27	1.2	18.4
8/26/98	101	0	9.1	24.8
8/26/98	101	3	9	24.8
8/26/98	101	6	7	24.7
8/26/98	101	9	6.6	24.5
8/26/98	101	13	5.1	24.1
8/26/98	101	16	3.2	23.8
8/26/98	101	19	1.2	22.9
8/26/98	101	22	1.1	22
8/26/98	101	26	1.1	21.2
9/14/98	101	0	10.8	23.2
9/14/98	101	3	11.1	22.6
9/14/98	101	6	8.9	22.1
9/14/98	101	9	7.7	21.8
9/14/98	101	13	5.7	21.3
9/14/98	101	16	4.3	20.9
9/14/98	101	19	3.9	20.9
9/14/98	101	22	4.2	20.8
9/14/98	101	26	1.8	20.5

LAKEID		-21 **Tustin**		
DATE	SITE	D	DO	TEMP
7/13/98	101	0	9.5	30.6
7/13/98	101	3	7.3	26.9
8/26/98	101	0	10.4	25
8/26/98	101	3	8.2	24.5
9/14/98	101	0	16.2	24.1
9/14/98	101	3	3	21.5

APPENDIX 4: RECKHOW-SIMPSON MODEL OUTPUT

This software was developed by Bruce Wilson for research use by the
Minnesota Pollution Control Agency, 520 Lafayette Road, St.Paul, MN 55155.
This software should be considered draft and not used for commercial applications.
February, 1994 Version 2.0 (Wilson and Heiskary, 1994). Use at Your Own Risk.
(612)296-9210. (Revised Feb. 1991 to include Prairie and Kalff, 1986 TP export and Carlson TSI calc.)
(Revised 2/26/94 to estimate nutrient loading from livestock).

Model 1 is described in Reckow, K.H., and J.T. Simpson. 1980. A procedure using modeling and error analysis for the prediction of lake phosphorus concentration from land use information analysis for the prediction of lake phosphorus concentration from land use information. Can.J.Fish.Aq.Sci.37(9):1439-1448.

INPUT SECTION

==

	Frances		
Watershed Area (ha)	1234	0.034	= Observed TP (mg/l)
Lake Area (ha)	324	0.005	= Observed TP Standard Deviation
Water Runoff (m)	0.12	4	= N
Precipitation (m)	0.79	19	= Observed Chla (ug/l)
Mean Evaporation (m)	0.94	1.3	= Observed Secchi (m)
Mean Depth (m)	4	12.96	= Calculated Volume (Hm3)
County capitas/cabin	2.8		
No. Seasonal Cabins	100		
No. Permanent Res.	60		

*Fill in estimated animal units at cell A102

	Before	**After**	**Delta**	**%Total**
Forest Area (ha)	185	185	0	15%
Agric Area (ha)	592	592	0	48%
Urban Area (ha)	99	99	0	8%
Wetland Area (ha)	173	173	0	14%
Pasture/Open (ha)	185	185	0	15%
Sum of land uses	1234	1234		100%

Export Values	**units**	**Low**	**Average**	**High**
Forest P Export	(kg/ha)	0.1	0.12	0.15
Agric P Export	(kg/ha)	0.2	0.4	0.8
Urban P Export	(kg/ha)	0.5	1	1.25
Wetland P Export	(kg/ha)	0.1	0.1	0.1
Pasture/open Export	(kg/ha)	0.2	0.3	0.4
Atmospheric Export	(kg/ha)	0.3	0.3	0.5
Soil Retention Coef	(percent)	0.6	0.6	0.6
Point Source Before	(kg/yr)	0	0	0
Point Source After	(kg/yr)	0	0	0
Delta Point Source	(kg/yr)	0	0	0
Unaccounted for P	(kg/yr)	0	0	0
Capita Years	(years)	237.8	237.8	237.8

Reference Phosphorus export coefficients corrected for catchment size.

Prairie and Kalff, 1986. Effect of catchment size on phosphorus export.Wat. Res. Bull. 22:465-470

Wilson & Walker, 1989. Development of la on the aquatic ecoregion concept. Lake and Res. Mngmt. 5:11-22

Use	**Hectares**	**P export**	**Ecoreg.**	**Dominant Landuse**	***Net P Export**
Forest	185	0.08	NCHF	Cul+Mixed	0.19
Ag-mix	592	0.68	NLF	For (75%)	0.12
Row crop ag.#	500	0.39	NGP	Cul (83%)	0.76
Non-row ag.#	92	0.76	WCBP	Cul (84%)	0.74
Pasture	185	0.28			

APPENDIX 4 (CONTINUED)

OUTPUT SECTION #1
Reckhow-Simpson Modeling Summary

Low	Average	High	kg P/year
19	22	28	Forested Flux
118	237	474	Ag flux
50	99	124	Urban flux
17	17	17	Vetland flux
37	56	74	Pasture/Open Flux
97	97	162	Ppt flux
95	95	95	Septic flux
0	0	0	Point Source
0	0	0	Unaccounted for P
433	623	974	Total P Flux
134	192	301	P LOAD (kg)
293	421	658	Inflow P ug/l

			CANFIELD/BACHMANN
36	45	58	Predicted inlake P (ug/l)

OUTPUT SECTION #2
Estimated phosphorus contributions by different sources in the watershed.

	Low Flux	%	Average Flux	%	High Flux	%
Wshed	241	56%	431	69%	717	74%
Septic	95	22%	95	15%	95	10%
Ppt	97	22%	97	16%	162	17%
Point	0	0%	0	0%	0	0%
Unacc for P	0		0		0	
Sum kg/yr	433		623		974	

APPENDIX 4 (CONTINUED)

OUTPUT SECTION 3. Reckhow-Simpson and MINLEAP modeling summary, predicted change
Secchi disk transparency, chlorophyll concentrations, and trophic status based on observed
or predicted total phosphorus concentrations.

		Observed lake conditions	Low TP conc. (predicted)*	Average TP conc. (predicted)*	High TP conc. (predicted)*	MINLEAP values (predicted)
LAKE TP	mg/l	0.034	0.036	0.045	0.058	0.030
LAKE CHLA	ug/l	19	12.4	17.1	24.8	9.7
LAKE SECCHI	m	1.3	1.8	1.5	1.2	2
MINLEAP load prediction (kg/yr)						335
TSI TP		55	56	59	63	53
TSI CHLA		60	55	59	62	53
TSI SD		56	52	54	57	50

* Fill in predicted TP concentrations from output section 1 (Canfield and Bachman), or use other estimates.

Hydrologic Summary Information

Estimated Flow	1480751.4	(m3/year)	1.48	(hm3)
Estimated Q	0.46	(m/yr)		
Residence time	8.80	(years)		

Useful conversions: 1hm3 = 1,000,000 m3; hm3 = Acre-feet/811; Ha = Acres/2.47: km2 = 2.59(mile2)

APPENDIX 4 (CONTINUED)

OUTPUT SECTION 4: Contribution of phosphorus to the lake from livestock.
Estimated phosphorus production from animal waste (kg/yr).

	Low	Most likely	High
Cows	3	6	12
Pigs	0.9	1.6	3.8
Sheep	0.5	0.75	1.1
Poultry	0.1	0.1	0.2
Horses	3	5	7.8

Estimated mass of phosphorus produced by livestock in the watershed (kg/yr).

Estimated Number Cows	20	60	120	240	
Estimated Number Pigs	0	0	0	0	
Estimated Number Sheep	0	0	0	0	
Estimated Number Poultry	0	0	0	0	
Number Horses	0	0	0	0	
Total mass of phosphorus produced by livestock		60	120	240	kg/yr
Modeled watershed load w/o livestock-cells J84, L84, N		433	623	974	kg/yr
Livestock P compared to sum of other sources		14%	19%	25%	

Sensitivity Analysis: Estimated phosphorus load from livestock.

Mass of P from		Low	Most likely	High
Livestock		60	120	240
	1%	1	1	2
Percent	5%	3	6	12
delivered	10%	6	12	24
to the lake	20%	12	24	48
	30%	18	36	72
	50%	30	60	120
	75%	45	90	180

Use most likely value to estimate in-lake P increase from livestock. **120**

Percent delivered to lake	Most likely	Adjusted load (kg/yr)	Predicted areal areal load (kg/m2/yr)	InflowP (ug/l)	Predicted P
1%	1	624	193	422	45
5%	6	629	194	425	45
10%	12	635	196	429	45
20%	24	647	200	437	46
30%	36	659	203	445	46
50%	60	683	211	461	47
75%	90	713	220	482	49

Percent of the total P produced by estimated livestock numbers.
This is for illustrative purposes and should be further researched with watershed assessment information.