Fish Lake and Weaver Lake were sampled by the Commission in 1993 (Figures 2 and 3). These two lakes are defined as category I critical lake drainage basins. The critical lake drainage basins as defined in the Elm Creek Watershed Management Plan are shown in Figure 4. Lake morphometry, watershed area and land use data are summarized for each lake in Table 2. Land uses with potentially adverse effects on water quality include, row crops, commercial, industrial and medium and high density residential uses. These land uses are classified as deleterious uses in the Elm Creek watershed plan. Land uses with potentially positive effects on water quality include grasslands, wetlands, woods and parks. These uses are classified as sustaining uses. The percentages of deleterious and sustaining use were determined from 1980 aerial photos.

The 1993 monitoring was conducted by Water Research & Management, Inc. of Sauk Rapids, Minnesota under contract with the Commission. Surface water samples were collected as composites of the upper two meters of water. The samples were analyzed by Environmental Protection Laboratories in St. Cloud, Minnesota.

Water quality parameters monitored for in 1993 are summarized in Table 3. Fish and Weaver Lakes were sampled monthly from May through September on the following dates. May 12 June 8, July 14, August 10 and September 7. Analyses of lake samples for chloride were conducted in May and August. All other parameters were monitored or analyzed monthly. Samples were collected and delivered to the laboratory that same day.

Phosphorus is a chemical element that is essential for plant growth. Concentrations of total phosphorus (TP) indicate the maximum growth potential for algae in a lake and may be used to classify a lake's trophic status. Maximum TP concentrations were observed in May and July for Fish and Weaver Lakes respectively. While Fish Lake was at its highest TP in May, Weaver exhibited its lowest TP concentration (Figure 5). The minimum total phosphorus concentration for Fish Lake occurred in June. Fish Lake had the highest mean TP concentration at 52 µg/l.

Chlorophyll a is a photosynthetic pigment found in all green plants. The concentration of chlorophyll a is a measure of algal abundance. Both lakes exhibited fairly low chlorophyll a concentrations throughout the summer (Figure 5). Fish Lake was at its lowest concentration in July. Weaver Lake was at its lowest in May. Fish Lake had the highest mean chlorophyll a concentration at 10.8 µg/l.

Secchi disk transparency is a measure of water clarity. Higher Secchi disk transparency indicates greater water clarity. Weaver Lake had a very high reading of 19.0 feet in May. The maximum Secchi disk transparency of 8.0 feet for Fish Lake occurred in June (Figure 5c). Minimum transparency occurred in July in Fish Lake and September in Weaver Lake. Weaver Lake had an average transparency of 10.5 feet. When the high May reading was removed from the data, the average dropped to 8.5 feet. This is an excellent average for the metropolitan area. Fish Lake had the lowest mean transparency (5.7 feet) of the two lakes.

Temperature and dissolved oxygen measurements were taken from all four lakes. Dissolved oxygen concentrations generally mirrored temperature profiles with a rapid decrease in dissolved oxygen below the Thermocline during stratification. Dissolved oxygen conditions varied from lake to lake. Temperature profiles show that both lakes were stratified throughout the monitoring season (Figures 7 - 8). In May all the lakes were fairly well oxygenated to the bottom. However, profiles for the remainder of the season showed anoxia below approximately 6 to 7 meters (20 to 23 feet). Oxygen concentrations should remain above 5 mg/l for long-term fish survival.

Lakes may be classified as to their trophic state based on Carlson's Trophic State Index (Carlson 1977). This index indicates nutrient enrichment and is calculated based on measured values for total phosphorus, chlorophyll a and Secchi disk transparency. Trophic state index values for the lakes sampled in 1993 are shown in Figure 9. Fish Lake is considered eutrophic. The index values for Weaver Lake placed it between mesotrophic to eutrophic (moderately nutrient rich to nutrient rich). The TSI for phosphorus indicates the potential trophic state for the lakes. High phosphorus concentrations suggests that either the lake may exhibit dense macrophyte beds or heavy algal blooms throughout the summer.

It is difficult to determine trends when extensive data is not available for a lake. The accuracy of these evaluations increases with increasing number of samples. The following trend analysis is based on limited data and therefore may not be an accurate assessment of water quality trends for the lakes. The Elm Creek Watershed Management Commission, in its Management Plan, established water quality goals for lakes within the watershed. These numerical goals differ depending upon lake classification. In order to simplify the meaning of these goals, they are referred to as upper or lower limits in this report. Weaver and Fish Lakes are category I lakes and have the most stringent water quality goals. In 1993 the management plan was amended to include revised goals for chlorophyll a. These goals were revised to 20 and 30 µg/l for category I & II lakes respectively.

The 1993 mean phosphorus concentration for Fish Lake is above the upper limit listed in the Plan but is lower than it has been for the past 4 years. Until 1993, mean concentrations of chlorophyll a and mean concentrations of total phosphorus (Figure 10) have increased since 1989. The chlorophyll a concentration peaked above the upper limit for the first time since 1985. Mean Secchi disk transparency for Fish Lake has remained fairly stable since 1987 but fell below the lower limit in 1992 (Figure 10). The mean transparency in 1993 was above the lower limit. The Minnesota Pollution Control Agency (MPCA) lists a mean transparency of 5.2 feet for Fish Lake. This value is based on 75 measurements from 1977-1989 and provides a means for comparison to a long term average. The MPCA (1977-89) mean concentration of total phosphorus is well below the mean concentration observed in 1992. The MPCA mean is based on 24 samples.

Mean total phosphorus for Weaver Lake appears to be increasing over time and has exceeded the upper limit specified in the Plan since 1989 (Figure 11). However, the 1993 mean concentration is lower than it has been for the last 4 years. The chlorophyll concentration appears to be decreasing over time and remains well below the upper limit. This may be due in part to the chemical treatments used to control the algal blooms and increase transparency. Mean Secchi disk transparency in Weaver Lake was the highest on record and remains above the lower limit specified in the Plan (Figure 11). The mean transparency of 10.6 feet was highly influenced by the May reading of 19 feet. Excluding that data point from the average results in a mean of 8.5 feet.

The water quality of Fish and Weaver Lakes, as measured by total phosphorus, appears to be declining. However as development in the watersheds of these two lakes reaches completion, the nutrient loading to the lakes should stabilize. The Commission has taken steps in the past to reduce nutrient loading through requiring erosion control plans and stormwater treatment for new development. Although these practices have reduced the impact of new development on water quality, it is apparent that additional management practices or improvement projects are needed to improve water quality of the lakes in the Elm Creek Watershed. Beginning in 1994, the Commission will be undertaking a revision of its management plan. The revised management plan will include administrative and structural methods to be implemented in order to protect and improve the water and soil resources of the Elm Creek Watershed. The Commission, in 1993, also sponsored several

demonstration projects and studies to investigate and implement nonpoint source pollution controls.

The water quality of Elm Creek Watershed lakes may be compared to that of lakes that should be similar in water quality based on location, land use, soils, land form and potential natural vegetation. The MPCA in cooperation with the Environmental Protection Agency (EPA) has developed a means to group Minnesota Lakes based on the above characteristics. These areas are called aquatic ecoregions. There are seven of these ecoregions in the state (Figure 12) (Wilson and Walker 1989). The Twin Cities Metropolitan area is within the ecoregion known as the North Central Hardwood Forests (NCHF). Lakes within an ecoregion should be somewhat similar to each other. Elm Creek Watershed lakes may be compared with other NCHF lakes. The MPCA rankings for Fish and Weaver Lakes are 41 and percentile respectively. These rankings are based on limited data and may change somewhat with additional data. The rankings are percentile values with a value of 0 indicating the poorest water quality and 100 indicating the best water quality in comparison with other lakes in the ecoregion. Fish and Weaver were both ranked approximately at midrange for the ecoregion.

Ecoregions also provide a means for gathering useful information for setting water quality goals. The potential water quality of a lake may be estimated based on data for the lakes having the best water quality for the ecoregion. The MPCA refers to these lakes as minimally impacted lakes. Mean values for monitored lakes may be compared to interquartile ranges for the NCHF lakes (Table 5). The 1993 total phosphorus concentration for Fish Lake was at the upper end of the interquartile range. This indicates the potential water quality of Fish Lake is much better than existing conditions. It has been impacted by pollutant loading from the watershed. The 1993 mean phosphorus concentration for Weaver Lake is within the interquartile range. It has been less impacted by nutrient loading from the watershed. The remainder of the water quality parameters listed in Table 5 are generally within the interquartile range for the ecoregion except for chlorides. The high chlorides may be due to high concentrations of chloride left behind from road salting and carried in snowmelt and rainfall runoff.

The three main parameters, total phosphorus, chlorophyll a and Secchi disk transparency are all interrelated. For most lakes in this area, phosphorus is the nutrient that determines the amount of algae and macrophyte growth in a lake. High phosphorus concentrations will generally result in either dense macrophyte growth or algal blooms. The frequency and severity of these algal blooms is dependent upon phosphorus concentrations. Chlorophyll a is a measure of the amount of algae in a lake and Secchi disk transparency is dependent upon chlorophyll a concentrations. Transparency may also be limited by other dissolved or suspended materials in the lake.

The interrelationships described above are shown graphically on scatterplots in Figure 18. The 1993 mean data are plotted. Data from Fish and Weaver Lakes fit the general relationship shown in the graphs.

Probably the most important information that can be taken from Figure 13 is noting the critical points for TP and chlorophyll a as they affect transparency. On the middle graph, the "critical area" is at a concentration of about 5 to 10 µg/l. When concentrations exceed this range and up to a concentration of about 30 µg/l, the result is a substantial reduction in transparency. Once concentrations exceed about 30 µg/l, there is only a small decrease in transparency with increases in chlorophyll a. Similarly, at TP concentrations greater than 10 µg/l there is a rapid decrease in transparency with increases in TP up to a concentration of about 60 µg/1. Fish Lake's TP concentration is already beyond the critical point. Any increases in TP will result in increases in the frequency and severity of algal blooms and reduced transparency or increases in macrophyte density and coverage, however they will likely not be dramatic changes Weaver Lake is at the tail end of the

critical range. Increases in phosphorus will result in reductions in transparency.

The computer model "MINLEAP" was used to compare the 1993 data to water quality values expected for minimally impacted lakes in the ecoregion (Wilson 1988). The modeling results also provided predictions of lake conditions in terms of algal blooms. The results are presented in Table 7. The predicted parameters for Fish and Weaver Lakes indicated potentially improved water quality compared to observed values. MINLEAP predicted lower phosphorus than was observed in both Fish and Weaver Lakes. MINLEAP predicts phosphorus based upon parameters including watershed size, location, lake depth and existing conditions.

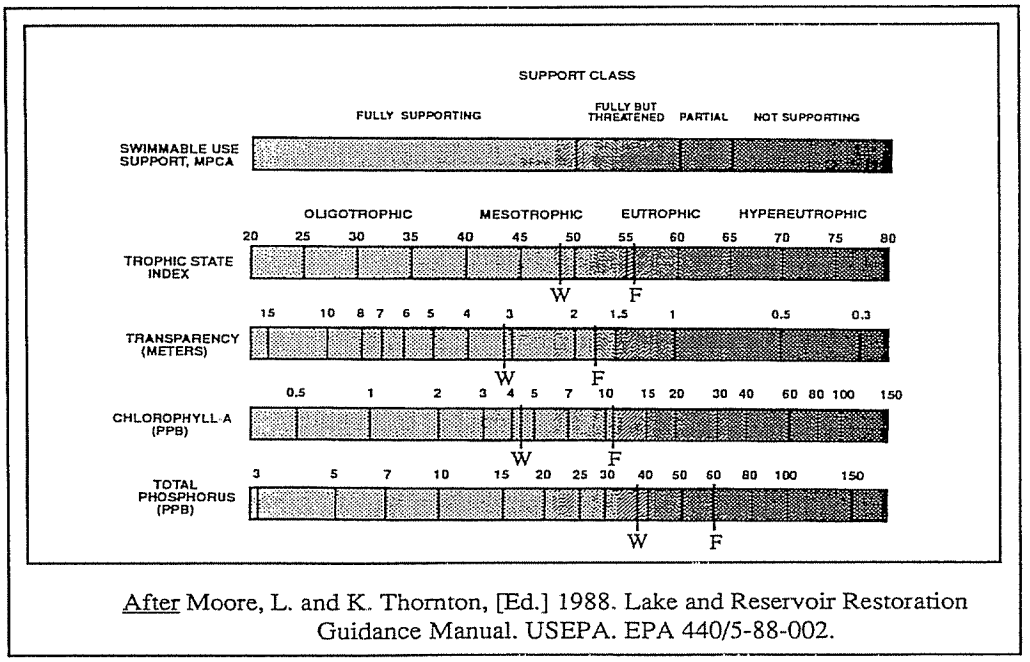
MINLEAP also provides rough estimates of phosphorus loading to the lakes from the watershed. For Fish and Weaver lakes the estimated phosphorus load was 163 kg/yr and 46 kg/yr respectively. The water estimated residence time for the lakes is 5.7 years for Fish Lake and 20 years for Weaver Lake.

Estimates of a lake's water quality prior to the influences of man can be made using a relationship developed to estimate the fraction of phosphorus due only to natural phosphorus sources. Phosphorus concentrations due to natural, background loading can be predicted from the morphoedaphic index which is calculated from the alkalinity or conductivity of the water and mean depth using an equation developed by Vighi and Chiaudani (1985). The method provides a prediction of the potential attainable phosphorus concentration and can be used as one of several tools to help establish water quality goals. Monthly alkalinity measurements were collected from both lakes. The calculations indicate that Fish Lake has a potential total phosphorus concentration of 21.4 µg/1 and Weaver Lake has a potential phosphorus concentration of 20 µg/1.

WEAVER LAKE	SDT	TP	CHL	NO2 + NO3-N	NH3-N	TKN	TN	Lab	COND	ALK.	CL
	feet	ug/L	ug/l	mg/l	mg/l	mg/l	mg/l	pH	umho/cm2	CaCO3	mg/l
May-12	19.0	28	0.4	<0.05	0.09	0.90	0.99	8.57	842	127	50
Jun-08	9.5	41	9.0	<0.05	0.11	0.81	0.92	8.74	595	122	
Jul-14	5.5	44	8.0	<0.05	0.14	1.11	1.25	8.53	1595	119.5	
Aug-10	7.0	37	3.0	<0.01	0.10	0.84	0.94	8.48	315	114	63
Sep-07	12.0	35	2.0	<0.01	0.10	0.82	0.92	8.18	326	112	
Mean	10.6	37	4.5		0.11	0.90	1.00	8.50	735	119	56
Median	9.5	37	3.0		0.10	0.84	0.94	8.53	595	120	56
Std. Deviation	5.3	6	3.8		0.02	0.12	0.14	0.20	528	6	9
TSI											

	Ecoregion*	1993 Fish Lake	1993 Weaver Lake
TP (µg/l	23 - 50	52	37
CHL a (µg/l)	5 - 22	10.8	4.5
SDT (ft)	4.9 - 10.5	5.7	10.6
Chloride (mg/L)	4 - 10	51	56
Alkalinity (mg/L)	75 - 150	138	119
TKN (mg/L)	<.6 - 1.2	1.3	0.9
NO2 + NO3 (mg/L)	<.01	<.05	<.05
pH	8.6 - 8.8	8.53	8.5
Conductivity	300 - 400	723	735
TN:TP	25:1 - 35:1	15:1	27:1

*Interquartile (25th to 75th percentile) values for minimally impacted lakes



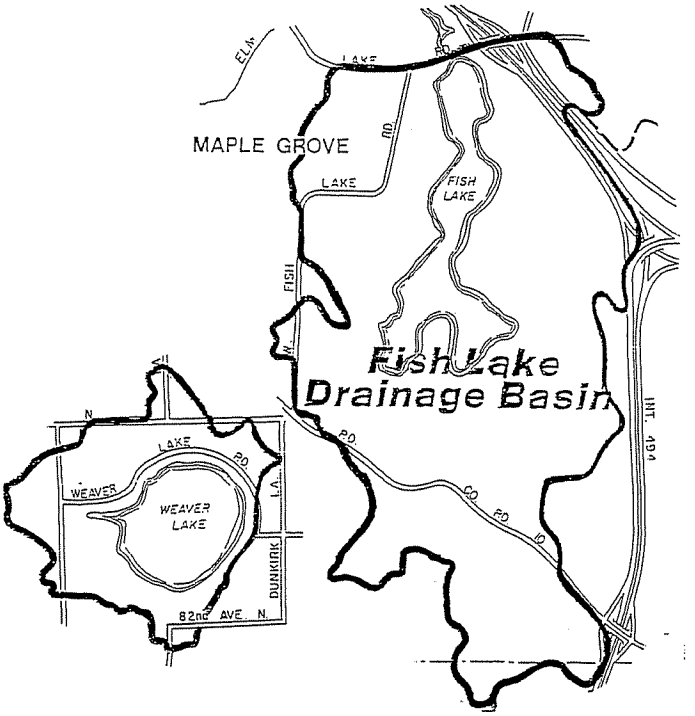
After Moore, L. and K. Thornton, [Ed.] 1988. Lake and Reservoir Restoration Guidance Manual. USEPA. EPA 440/5-88-002.

F-Fish Lake W-Weaver Lake

OBSERVED MEAN LAKE TP (UG/L) ? 37
OBSERVED MEAN CHL-A (UG/L) ? 4.5
OBSERVED MEAN SECCHI (M) ? 3.28

INPUT DATA:
LAKE NAME =WEAVER ECOREGION=CHF
LAKE AREA = 64 HA
WATERSHED AREA (EXCLUDING LAKE) = 140 HA
MEAN DEPTH = 6.5 METERS
OBSERVED MEAN TP = 37 UG/L
OBSERVED MEAN CHL-A = 4.5 UG/L
OBSERVED MEAN SECCHI = 3.28 METERS

(press ENTER to view results)



LAKE = WEAVER ECOREGION = CHF
AVERAGE INFLOW TP = 222.2861 UG/L TOTAL P LOAD = 46.136 KG/YR
LAKE OUTFLOW = .2078 HM3/YR AREAL WATER LOAD = .324375 M/YR
RESIDENCE TIME = 20.03854 YRS P RETENTION COEF = .5171834

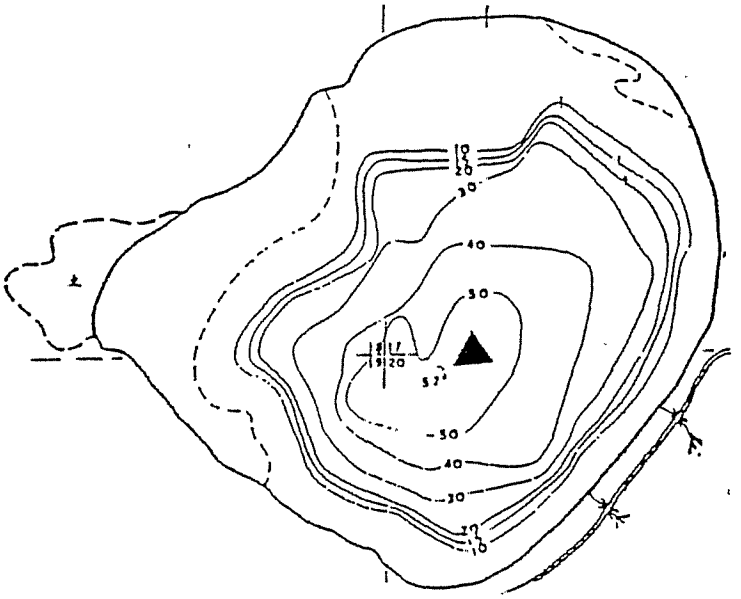
VARIABLE	UNITS	OBSERVED	PREDICTED	STD ERROR	RESIDUAL	T-TEST
TOTAL P	(UG/L)	37.00	26.63	8.79	0.25	1.25
CHL-A	(UG/L)	4.50	8.49	8.93	-0.08	-0.26
SECCHI	(METERS)	3.28	2.84	1.82	0.06	0.28

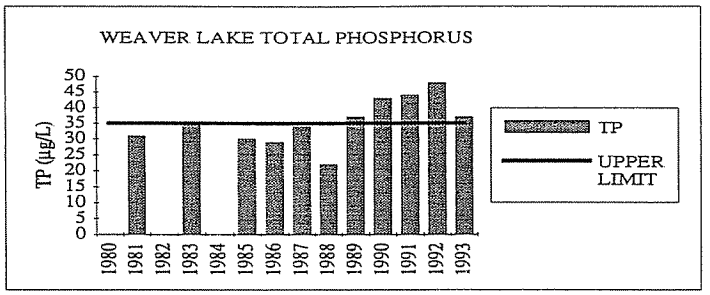
NOTE: RESIDUAL = LOG10(OBSERVED/PREDICTED)
T-TEST FOR SIGNIFICANT DIFFERENCE BETWEEN OBS. AND PREDICTED

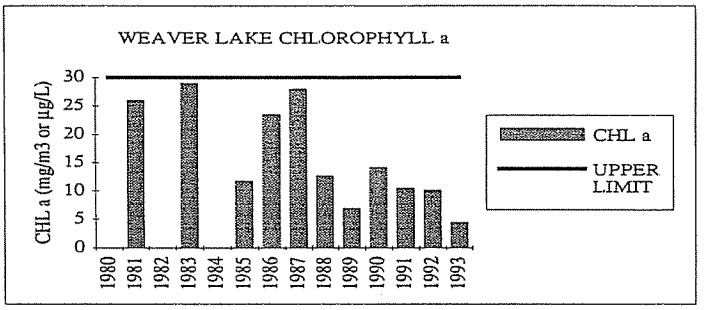
CHLOROPHYLL-A INTERVAL FREQUENCIES (%)

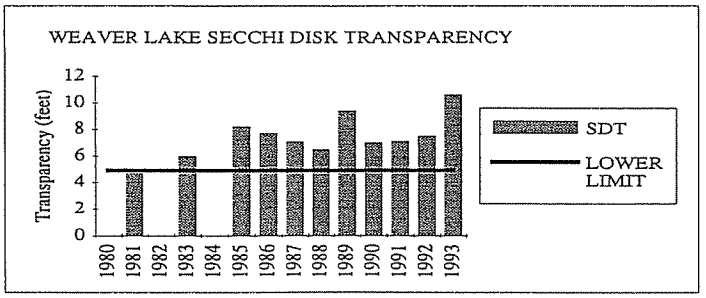
CHL-A		PREDICTED	PREDICTED	PREDICTED
PPB	OBSERVED	CASE A	CASE B	CASE C
10	2.84	6.80	8.44	30.82
20	0.04	0.17	0.84	5.57
30	0.00	0.01	0.02	2.02
60	0.00	0.00	0.00	0.23

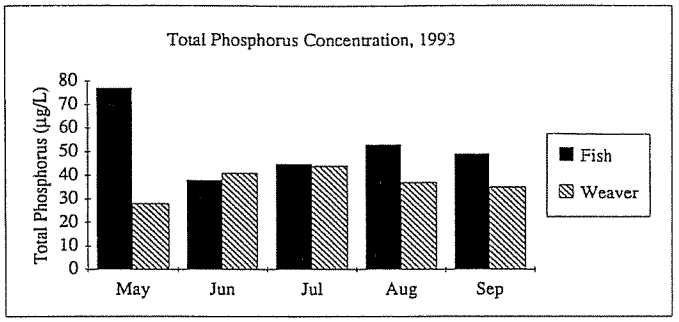
CASE A = WITHIN-YEAR VARIATION CONSIDERED
CASE B = WITHIN-YEAR + YEAR-TO-YEAR VARIATION CONSIDERED
CASE C = CASE B + MODEL ERROR CONSIDERED
C

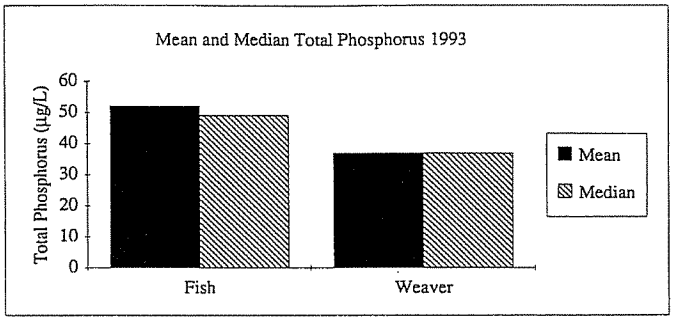


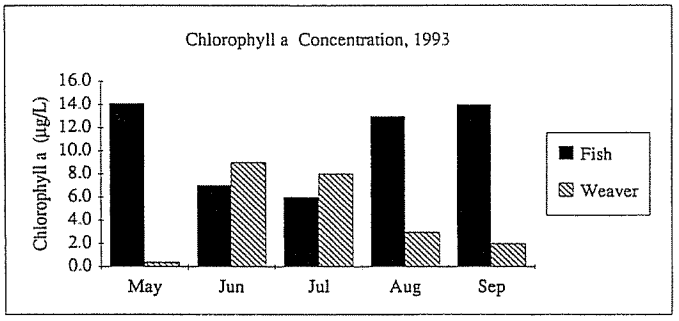

WEAVER LAKE TOTAL PHOSPHORUS
TP (µg/L)
50
45
40
35
30
25
20
15
10
5
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
TP
UPPER LIMIT

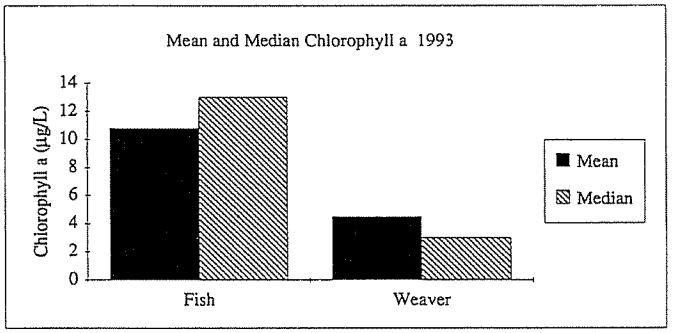

WEAVER LAKE CHLOROPHYLL a
CHL a (mg/m3 or µg/L)
30
25
20
15
10
5
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
CHL a
UPPER LIMIT

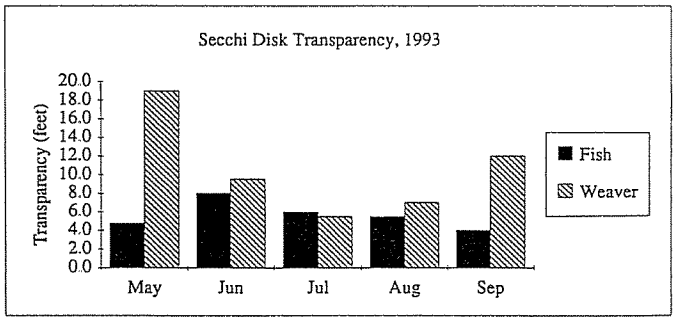

WEAVER LAKE SECCHI DISK TRANSPARENCY
Transparency (feet)
12
10
8
6
4
2
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
SDT
LOWER LIMIT

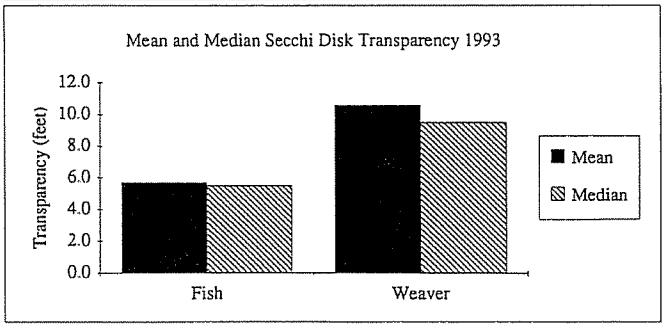

Total Phosphorus Concentration, 1993
Total Phosphorus (µg/L)
80
70
60
50
40
30
20
10
0
May
Jun
Jul
Aug
Sep
Fish
Weaver

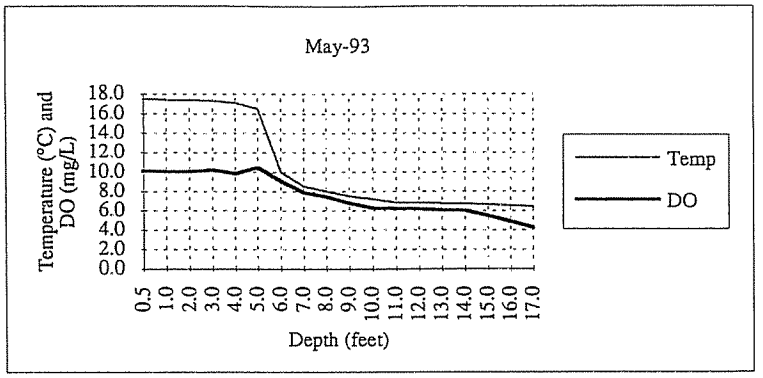

Mean and Median Total Phosphorus 1993
Total Phosphorus (µg/L)
60
50
40
30
20
10
0
Fish
Weaver
Mean
Median

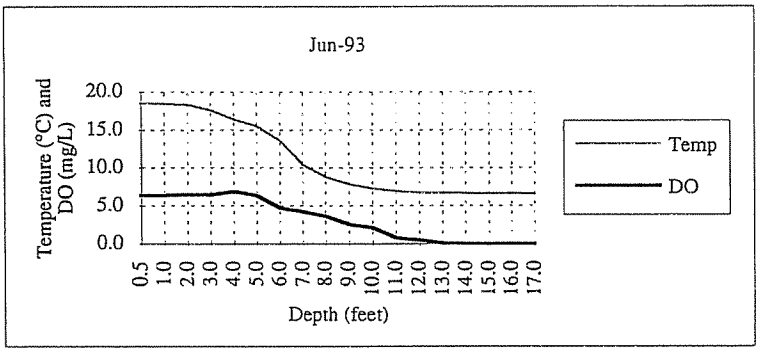

Chlorophyll a Concentration, 1993
Chlorophyll a (µg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
May
Jun
Jul
Aug
Sep
Fish
Weaver

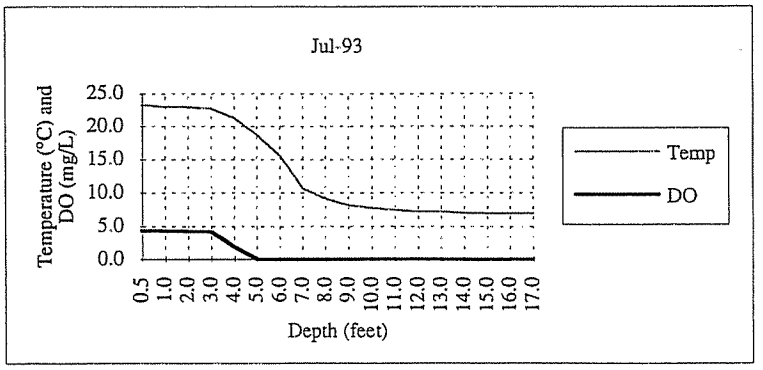

Mean and Median Chlorophyll a 1993
Chlorophyll a (µg/L)
14
12
10
8
6
4
2
0
Fish
Weaver
Mean
Median

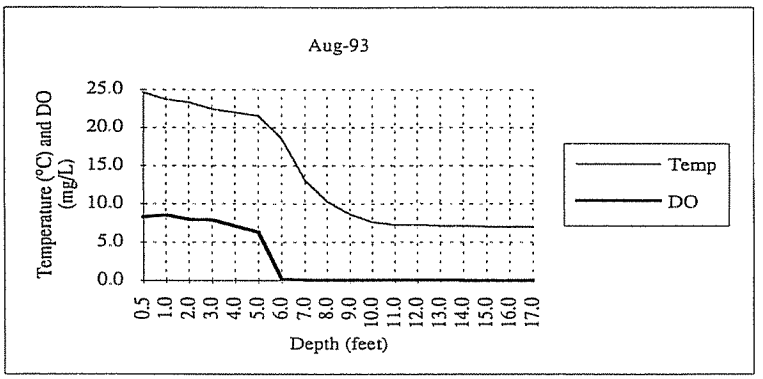

Secchi Disk Transparency, 1993
Transparency (feet)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
May
Jun
Jul
Aug
Sep
Fish
Weaver

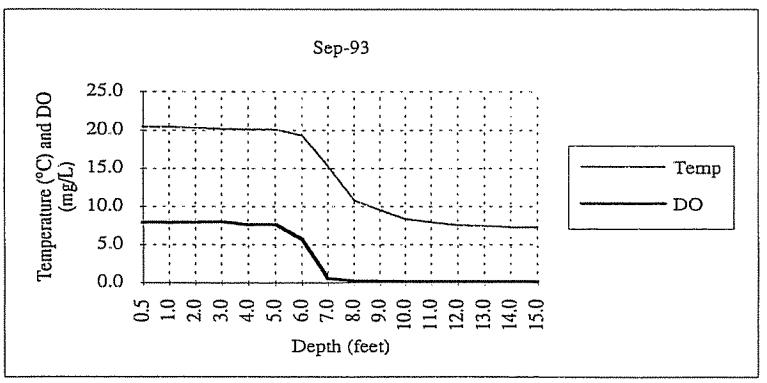

Mean and Median Secchi Disk Transparency 1993
Transparency (feet)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Fish
Weaver
Mean
Median


May-93
Temperature (°C) and DO (mg/L)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.5 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0
Depth (feet)
Temp
DO


Jun-93
Temperature (°C) and DO (mg/L)
20.0
15.0
10.0
5.0
0.0
0.5 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0
Depth (feet)
Temp
DO


Jul-93
Temperature (°C) and DO (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
0.5 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0
Depth (feet)
Temp
DO


Aug-93
Temperature (°C) and DO (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
0.5 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0
Depth (feet)
Temp
DO


Sep-93
Temperature (°C) and DO (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
0.5 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0
Depth (feet)
Temp
DO