Four lakes (Weaver, Fish, Cook and French) were sampled by the Commission in 1990 (Figure 2). Lake morphometry, watershed area and land use data are summarized for each lake in Table 1. 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.

Water quality parameters monitored in 1990 are summarized in Table 2. Fish and Weaver were sampled monthly from May through September. Analyses of lake samples for nitrogen compounds, alkalinity and chloride were conducted in May and August. All other parameters were monitored or analyzed monthly. Cook Lake was sampled monthly from July through September. May and June sampling was not possible due to access problems. Alkalinity, chloride and nitrogen analyses were completed in June and August. French Lake was sampled monthly from June through September with alkalinity, chloride and nitrogen analyses performed only on the June samples. All other parameters were monitored or analyzed monthly. With the exception of the June sample, the samples for French Lake are grab samples rather than mid-lake samples because lake access was not possible due to floating bogs.

Secchi disk transparency is a measure of water clarity. Higher Secchi disk transparency indicates greater water clarity. The maximum Secchi disk transparency occurred in May in both Weaver and Fish Lakes. Transparency for Cook Lake was at 8.5 to 9.0 feet for all three samples. Transparency may have been greater in the Spring when transparency measurements were not taken. No transparency data are available for French Lake due to access problems. Minimum transparency occurred in July in Weaver and Fish Lakes (Figure 4 and 5). Weaver, Fish and Cook Lakes all had average transparency values in excess of 5 feet. Cook Lake had the highest median value (8.8 feet). However, the average for Cook Lake did not include May and June measurements. Fish Lake had the lowest mean and median values for transparency. Transparency for French Lake may be estimated based on measured total phosphorus and chlorophyll a. Predicted Secchi disk transparency for French Lake is 3 feet or less.

Phosphorus is a chemical element that is essential for plant growth. Concentrations of total phosphorus indicate the maximum growth potential for algae in a lake and may be used to classify a lake's trophic status. Weaver and Fish Lakes had their maximum concentrations of total phosphorus in May. Cook and French Lakes had their lowest concentrations of total phosphorus in August and July respectively. Minimum total phosphorus concentrations were recorded in September for Weaver and Cook Lakes, and in June for Fish and French Lakes (Figure 5, 6). French Lake had the highest mean and median concentrations of total phosphorus. Cook Lake had the lowest mean concentration and Weaver Lake the lowest median concentration (Figure 11, 12).

Chlorophyll a is a photosynthetic pigment found in all green plants. The concentration of chlorophyll a is a measure of algal abundance. The concentration of chlorophyll a in Weaver and Fish Lake peaked in July and was lowest in May (Figure 5, 7). Cook Lake had its lowest concentration in September but was stable throughout the summer. The chlorophyll a peak in French Lake was similar in timing to that of Fish and Weaver Lakes. However, French Lake samples were shoreline grab samples which are very much dependent upon wind direction. Algal blooms may shift from one side of the lake to the other with wind direction. Concentrations may be high or low dependent upon wind direction. Shoreline grab samples are not ideal for comparison purposes.

Temperature profiles show that Fish and Weaver Lakes were stratified in May. The bottom of the epilimnion moved upward through July and then increased in depth. Profiles for Cook Lake are available for July through September only. Cook Lake was virtually isothermal by September but Weaver and fish Lakes remained stratified (figures 8-10). Profiles for French Lake are not shown due to their lack of depth and access. Dissolved oxygen concentrations mirrored temperature profiles with a rapid decrease in dissolved oxygen below the thelmocline during stratification and nearly uniform dissolved oxygen concentrations during isotheizeial conditions. Dissolved oxygen conditions varied from lake to lake. By August, the hypolimnions of Fish and Weaver Lakes were anoxic below about 25 to 30 feet. Oxygen concentrations dropped below 5 mg/L at about 30 feet in May and up to 15 feet in July and August in Fish lake. Oxygen concentrations should remain above 5 mg/L for long-term fish survival. Weaver lake oxygen profiles were similar to Fish Lake except oxygen concentrations remained above 5 mg/L to greater depths. Cook Lake was oxygenated to the bottom on all three sampling dates. Oxygen concentrations did drop below 5 mg/L at about 15 feet in July and August. A peak at 12 feet for the August sampling date may indicate concentrations of algae producing oxygen through photosysthesis at that depth.

pH and dissolved oxygen profiles reflect the pattern of thermal stratification in the individual lakes (figures 11-13). pH in the epilimnion is higher than in the metalimnion and hypolimnion due to utilization of C02 in photosynthesis by the algae which are located in the

epilimnion. pH was fairly unifoin throughout the epilimnion and then decreased with depth. This is typical for a eutrophic lake. Specific conductance varied seasonally in <u>all</u> lakes but did not demonstrate a consistent variation with depth (figures 11-13).

Phosphorus samples were collected for all four lakes. Extremely high TP was measured in the hypolimnetic samples. This is often indicative of internal loading. Internal loading is the recycling of nutrients from the bottom sediments back into the water column. Phosphorus migration from the sediments to the water can occur by diffusion. Anoxic conditions (which occurred in the lakes) near the sediments enhance the process. Wind mixing then carries the phosphorus upward, making it available for use by plants and algae. French Lake is shallow and probably remains mixed. The hypolimnetic sample is not much different in TP concentration than the epilimnetic sample. Weaver Lake had hypolimnetic phosphorus as much as 13 times greater than surface samples (Figure 14). Fish Lake had samples 11 times greater, and Cook Lake had for the July sample, a hypolimnetic ^{T}IP of 740 ug/L. This was 25 times greater than the epilimnetic sample at 29 ug/L. The September samples did not show increased epilimnetic phosphorus, which would have indicated that wind mixing had carried the hypolimnetic '1'P rich waters up to the surface. The lakes remained weakly stratified in September.

Lakes may be classified as to their trophic state based on Carlson's Trophic State Index. 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 1990 are shown in Figure 15. Individual TSI values may be calculated for phosphorus, chlorophyll a and transparency. The different TSIs for a lake may vary. The TSI shown on the top of Figure 15 is the mean of the three values. It is not always appropriate to use a mean TSI. An individual TSI may be more appropriate to classify a lake if values for the others do not appear to adequately reflect the lake's condition. Weaver and Fish Lakes are considered eutrophic. Cook Lake is at the lower end of the mesotrophic classification. French Lake is classified as hypereutrophic. Conditions associated with these classifications are described in Figure 15.

Mean Secchi disk transparency in Weaver Lake declined in 1990 compared to 1989 (Figure 16). Mean Secchi disk transparency in Weaver Lake in 1989 .is the highest average Secchi disk transparency on record. Many lakes exhibited improved water quality in 1989 with the reduced runoff conditions. Mean concentrations of chlorophyll a and total phosphorus increased. Mean total phosphorus was significantly higher in 1990 than in 1989 and is the highest observed average concentration.

Mean Secchi disk transparency for Fish Lake has remained fairly stable since 1987 (Figure 17). The 1986 transparency is the highest on record. The 1990 .mean Secchi disk transparency is near the median of all mean values since 1980. Data from the Minnesota Pollution Control Agency (MPCA) are available for comparison. The MPCA lists a mean transparency of 5.2 feet for Fish Lake. This value is based on 75 measurements from 1977-1989 and is quite comparable to recent transparency measurements for Fish Lake. Mean concentrations of chlorophyll a and mean concentrations of total phosphorus increased slightly over 1989. The increase in mean concentrations of total phosphorus was more pronounced than the increase in the mean concentration of chlorophyll a. The MPCA (1977-89) mean concentration of total phosphorus is well below the mean concentration observed in 1990. The 1990 mean concentration of chlorophyll a is also lower than the MPCA mean. The MPCA means are based on 24 and 23 samples respectively.

Mean Secchi disk transparency in Cook Lake increased in 1990 compared to 1988 (Figure 18). The mean concentrations of total phosphorus was slightly higher in 1990 than 1988. However, the chlorophyll a concentration was substantially lower than measured in 1988. Chlorophyll a concentrations may vary significantly from day to day depending on the rise and fall of algal blooms. The sampling for Cook Lake may have occurred just before or after an algal bloom. Additionally, the average did not include May and June.

Very little data is available for French Lake. It appears to have improved water quality since the 1988 sampling, but not enough data is available to verify the existence of any trend (Figure 19).

Cook Lake, with its limited sampling schedule had the best overall water quality in 1990. Fish and Weaver Lakes exhibited water quality similar to each other. Weaver and Fish Lakes were chemically treated to reduce the algal growth in 1990 and previous years. The dying and decaying algae resulting from chemical treatment could explain the increase in total phosphorus accompanied by the decrease in chlorophyll a concentrations. French Lake exhibited the poorest water quality. However mid-lake samples may have revealed lower phosphorus and chlorophyll a concentration than did the near shore samples.

A Fish Lake homeowner took daily to weekly Secchi disk readings at three locations in the lake (Figure 26). The mid-lake site should be comparable to the site monitored by the Commission. The transparency recorded by the lakeshore resident was lower than the recorded during the monitoring. This may be due to differences in individual's measurements, time of day, wind conditions and other possible effects. When readings are taken more often, a more accurate picture of transparency can be seen. The amount of daily variation is evident in Figure 26. Monthly readings may not provide an accurate measure of transparency. A reading taken on July 16 was 2.75 feet. Five days later it was 4 feet. Figure 26 also shows the effect of an algae treatment which occurred on July 5. Transparency increased from 2.5 feet to 4.5 feet, but dropped back down within two weeks.

The distribution of biologically important substances in lakes is affected by differences in water density that can impede mixing of surface and bottom waters. Water density varies with temperature. Temperature profiles in lakes indicate the degree of thermal stratification or layering present at the time of sampling. Profiles of temperature (density), pH, specific conductivity and dissolved oxygen in Fish and Weaver Lakes showed variability seasonally and with depth. Specific conductance was least affected by changes in depth. All lakes demonstrated reduced concentrations of dissolved oxygen in deeper waters during summer stratification. Low concentrations of dissolved oxygen in deep waters are typical of eutrophic lakes. French Lake is shallow and likely remains mixed throughout the summer.

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. The goals for phosphorus and chlorophyll a are values not to be exceeded. For Secchi disk transparency, the goal is a minimum value. Comparisons of water quality data from 1985 to 1990 show that for transparency and chlorophyll a, the lakes are within the goals. French Lake has extremely high total phosphorus concentrations. Despite its high phosphorus, chlorophyll a concentrations are much lower than expected and do not exceed the goal level. French Lake is a shallow lake. Turbidity in the lake may reduce light penetration and control algal growth. Cook Lake is a category II lake and therefore has less stringent goals. Cook Lake values were well below established goals. In fact, Cook lake measured concentrations were within the goal concentrations for category I lakes. Weaver Lake total phosphorus concentrations exceeded upper goal concentrations in both 1989 and 1990. Fish Lake phosphorus has exceeded or equaled goal concentration since 1985. .Chlorophyll a goals were not exceeded in any of the lakes. Transparency for all lakes was above the minimum goals. This may be due to the chemical treatments which controlled the algal blooms and increased transparency to some extent. However, lake residents reported that the 1990 treatments were not long-lasting.

Regressions were perfoluled on the lake quality data for 1990 (Figure 20). For Cook Lake, an R-square of .94 indicated that the amount of chlorophyll a in the water, expressed in algal growth, is proportional to the amount of total phosphorus in the water column . For Fish and Weaver Lakes, this was not the case. The lower R-square values indicate some other processes may be affecting the relationship between chlorophyll a and total phosphorus. The treatment of the water with herbicides for control of algae and weeds is likely a contributing factor. Algal growth may be limited by light restrictions due to non-algal turbidity. Weaver Lake received construction site runoff which carried suspended sediment into the lake. The lake appeared brown in color at times.

The water quality of 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

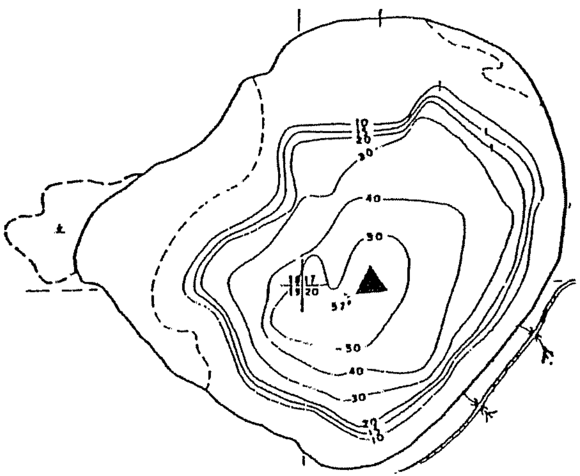
MPCA along with the EPA has developed a means to group Minnesota Lakes based on the above characteristics. These areas are called aquatic ecoregions. There are seven of these ecoregions in the state. The Twin Cities Metropolitan area is within the ecoregion known as the North Central Hardwood Forests (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, Weaver, Cook and French lakes are 57, 54, 82 and O. 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. French Lake is ranked as having very poor water quality in comparison with other NCHF lakes. Cook Lake has a fairly high rank indicating it has a lower phosphorus and chlorophyll a concentration than 81 percent of the lakes in the ecoregion. Fish and Weaver were both ranked at approximately mid-range for the ecoregion.

Ecoregions are also useful when 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 lake values for monitored lakes may be compared to the interquartile ranges for the NCHF lakes.

	Ecoregion	Weaver	Fish	Cook	French
TP (ug/L)	23 - 50	42.6	50.6	30.7	279
Chl a (ug/L)	5 - 22	14.2	12.7	4.6	33.1
SDT (ft)	4.9 - 10.5	7	6	8.8	<1

French Lake has very poor water quality for the ecoregion. Total phosphorus is almost six time higher than the seventy-fifth percentile value. Fish and Weaver have mean total phosphorus concentrations at the upper end of the range. This indicates the potential water quality of these lakes is much better than existing conditions. The water quality of Cook Lake is quite good in comparison with ecoregions values, but also may possibly be improved.

WEAVER LAKE				Hypolimnetic		
	SDT (ft)	CHL a ug/L	TP ug/L	TP ug/L		
MEAN (5 samples)	7.0	14.2	42.6	214.2		
MEDIAN	6.0	10.1	28.0	161.0		
STD DEVIATION	3.3	11.9	24.4	84.9		
	N02+N03	NH3	TKN	TN	ALK	CL
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
MEAN (2 samples)	0.02	0.29	0.72	0.74	105	47
STD DEVIATION	0.01	0.25	0.18	0.20		



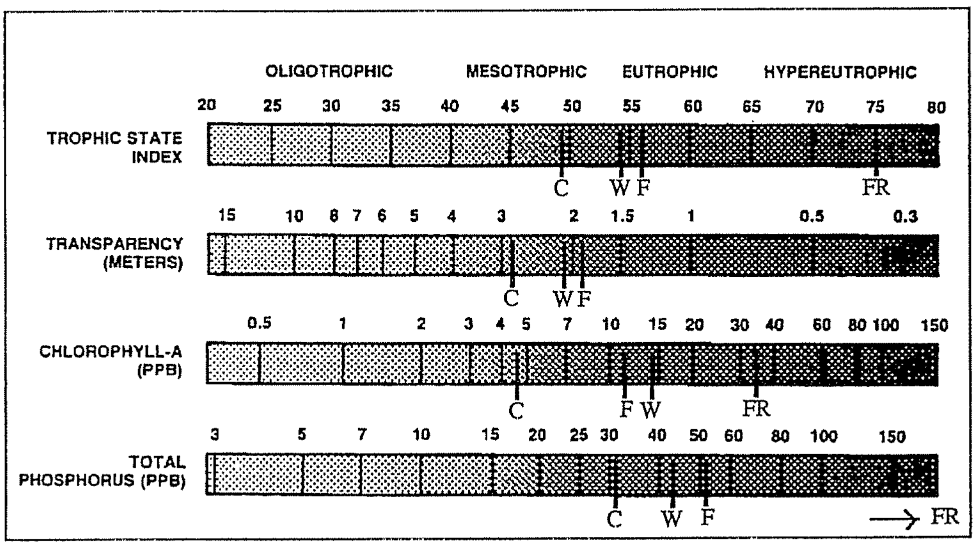
Chlorophyll a versus Total Phosphorus
Weaver Lake 1990
REGRESSION

Dependent Variable: Chlorophyll a

Variable	Mean	Parameter Estimate	Standard Error	T for H0: parameter=0
Intercept		18.78	13.18	1.43
TP	42.60	-0.11	0.28	-0.39

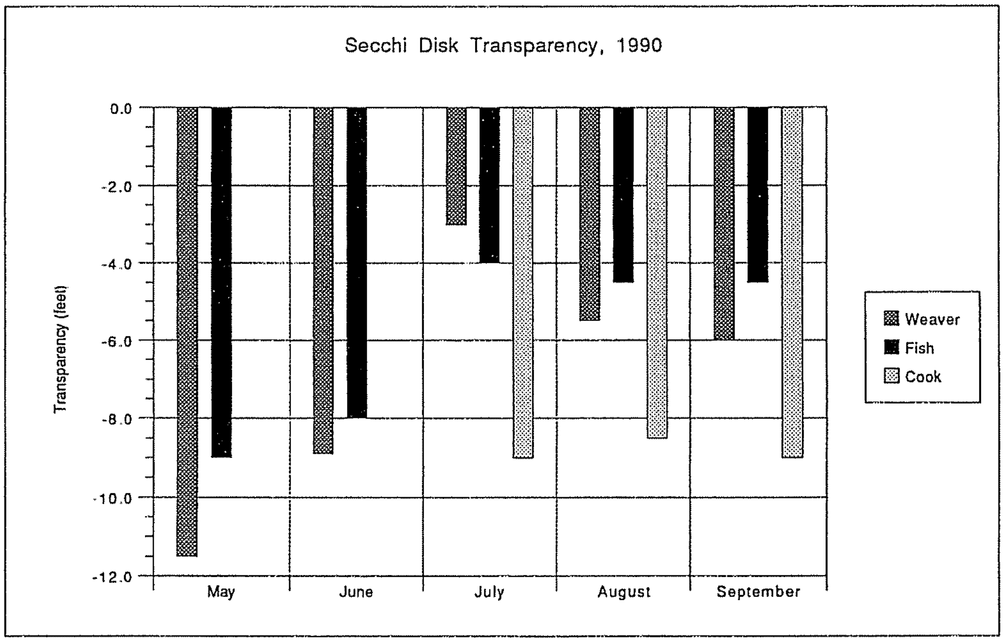
Source	DF	Sum of Squares	Mean Square	F-Value
Model	1.00	27.75	27.75	0.15
Error	3.00	542.03	180.68	
Total	4.00	569.78		

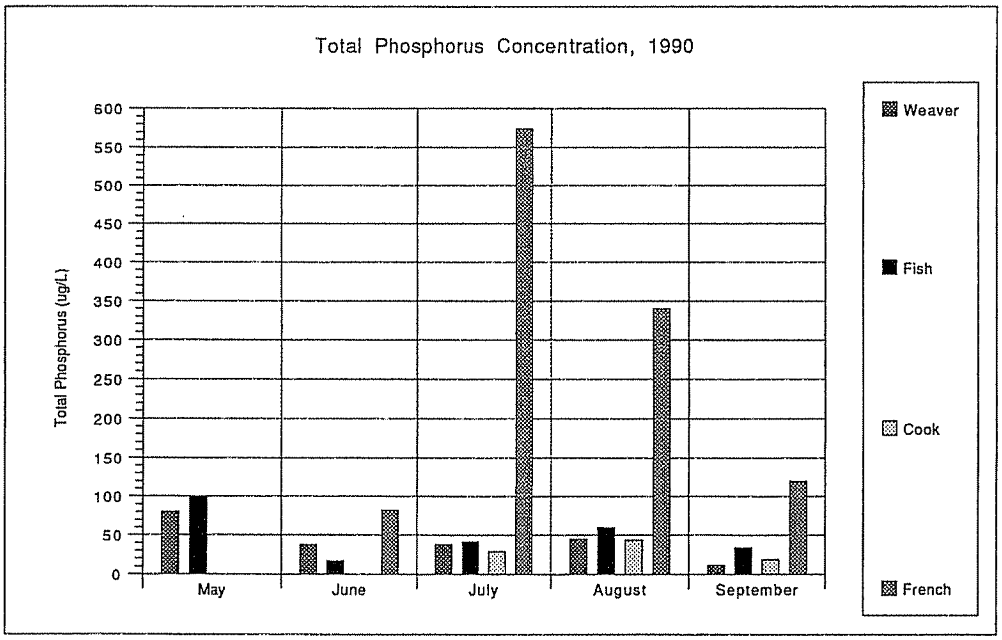
Dependent Mean	14.19
Root Mean Square Error	13.44
Coefficient of Variation	94.75
R-Square	0.05
Adjusted R-Square	-0.27

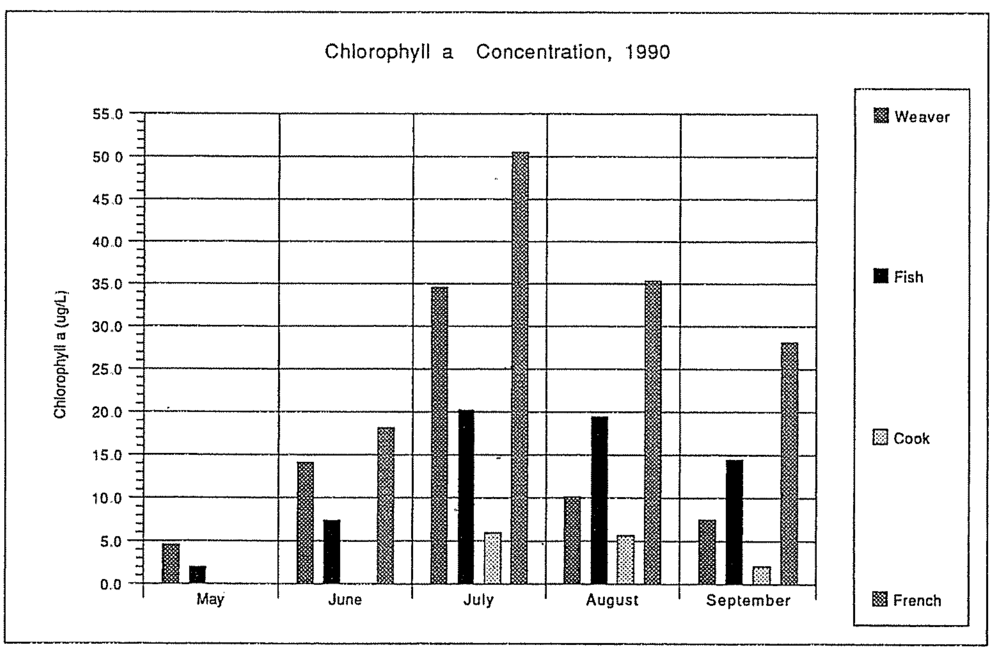


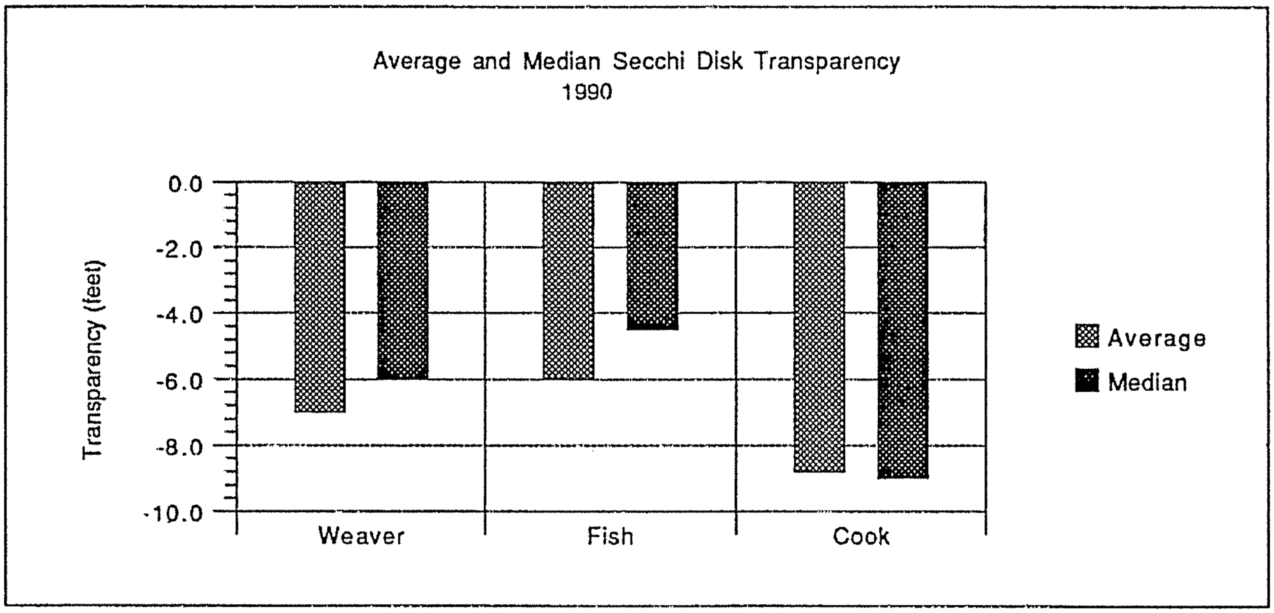
After Moore, L. and K. Thornton, [Ed.] 1988. Lake and Reservoir Restoration Guidance Manual. USEPA. EPA 440/5-88-002.

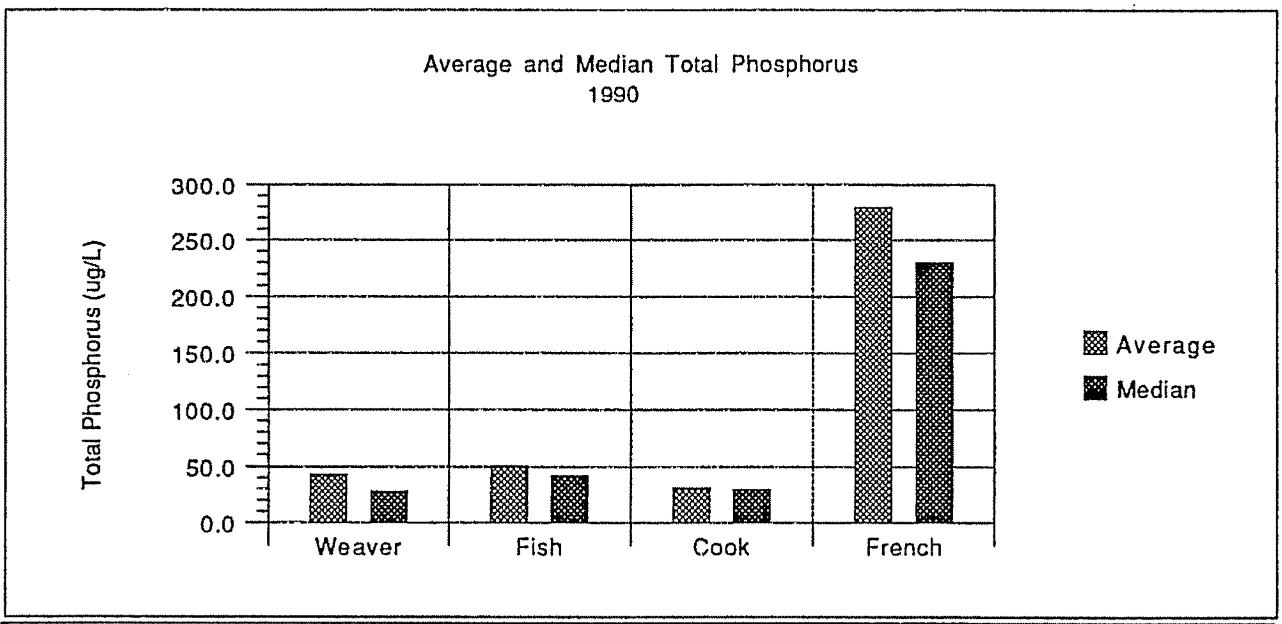
C-Cook W - Weaver F - Fish FR - French

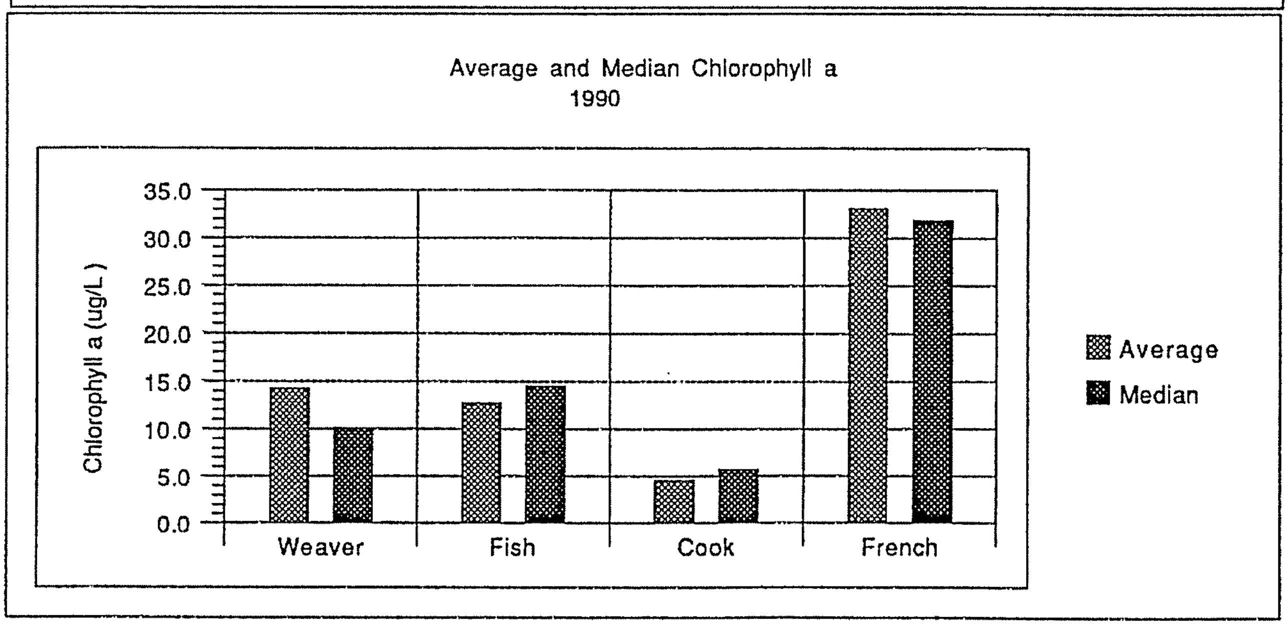

Secchi Disk Transparency, 1990
Transparency (feet)
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
May
June
July
August
September
Weaver
Fish
Cook

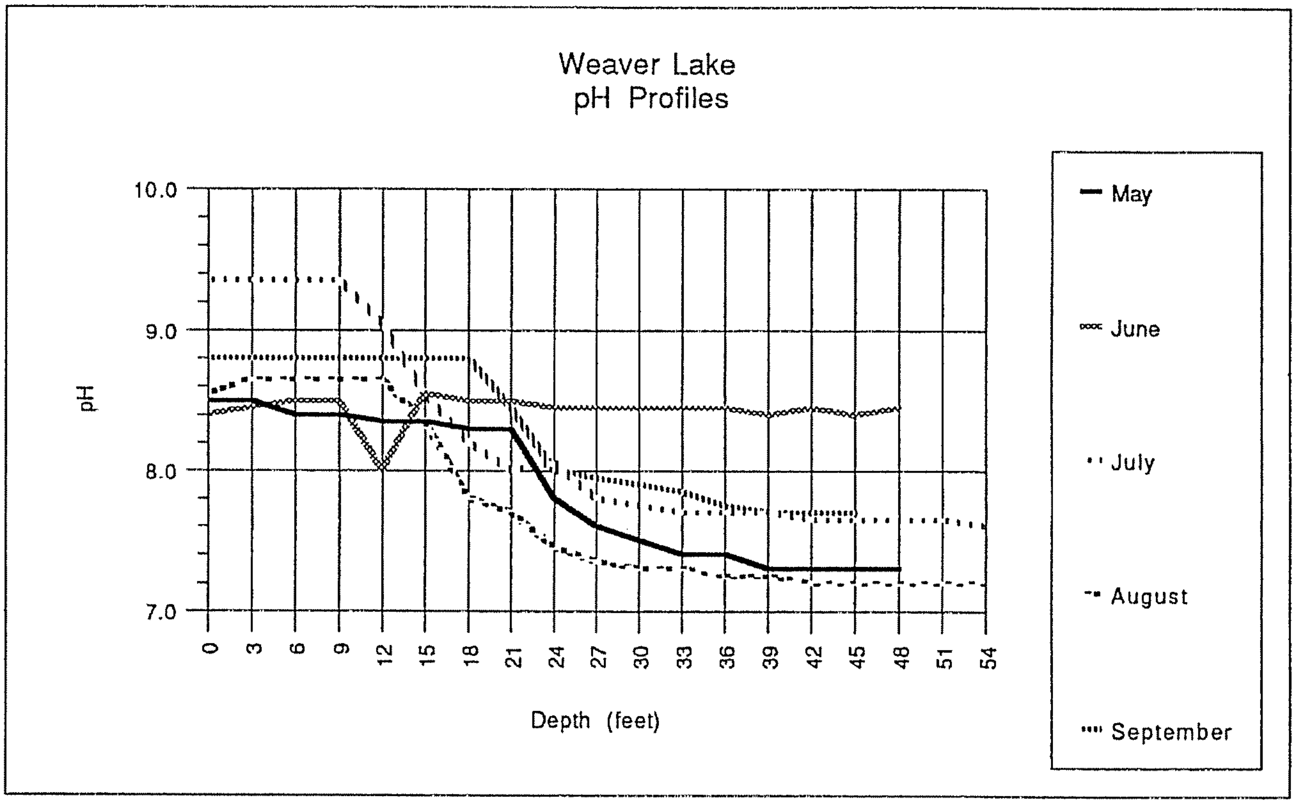

Total Phosphorus Concentration, 1990
Total Phosphorus (ug/L)
600
550
500
450
400
350
300
250
200
150
100
50
0
May
June
July
August
September
Weaver
Fish
Cook
French


Chlorophyll a Concentration, 1990
Chlorophyll a (ug/L)
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
May
June
July
August
September
Weaver
Fish
Cook
French

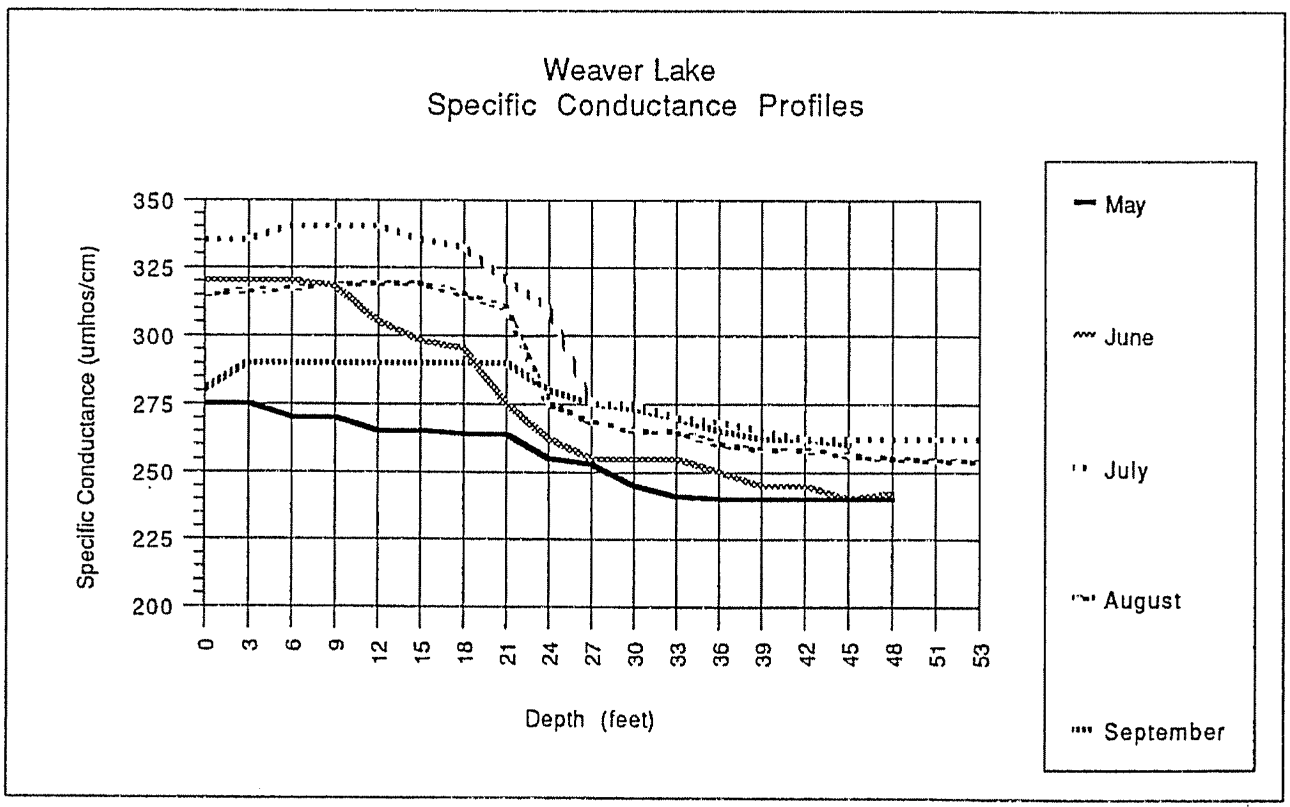

Average and Median Secchi Disk Transparency
1990
Transparency (feet)
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
Weaver
Fish
Cook
Average
Median


Average and Median Total Phosphorus
1990
Total Phosphorus (ug/L)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Weaver
Fish
Cook
French
Average
Median

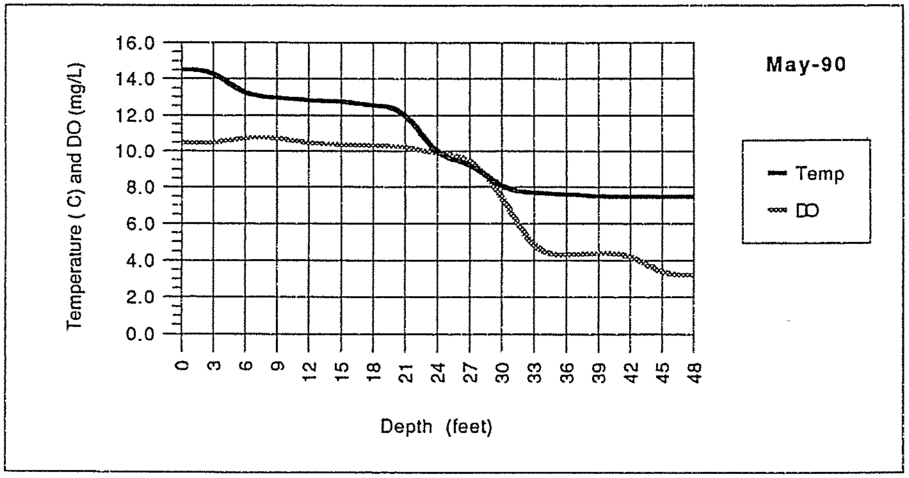

Average and Median Chlorophyll a
1990
Chlorophyll a (ug/L)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Weaver
Fish
Cook
French
Average
Median

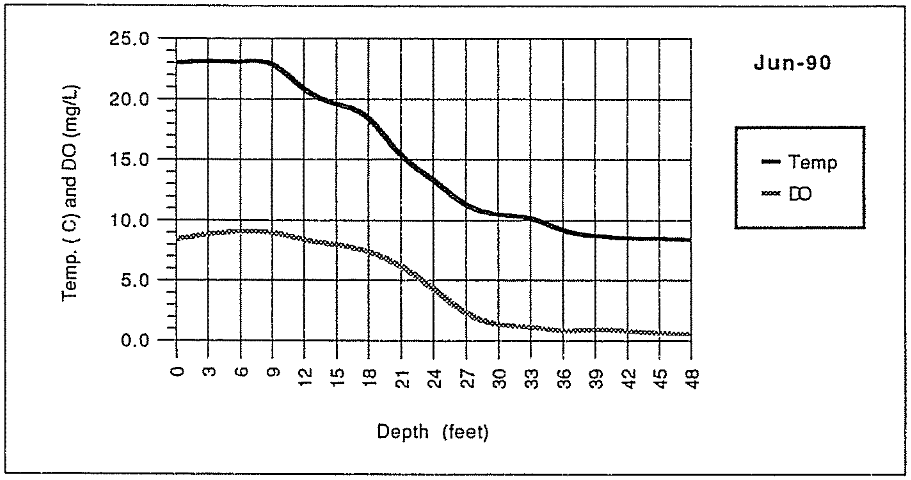


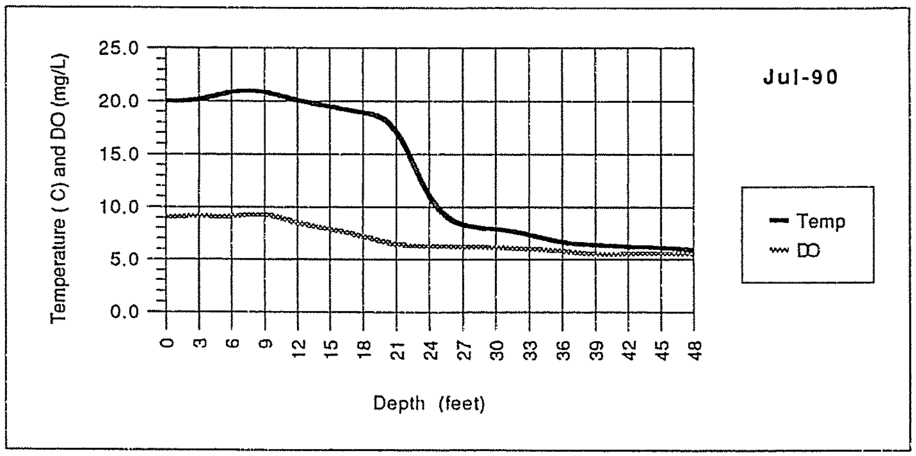
Weaver Lake
pH Profiles
10.0
9.0
8.0
7.0
pH
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
51
54
Depth (feet)
May
June
July
August
September

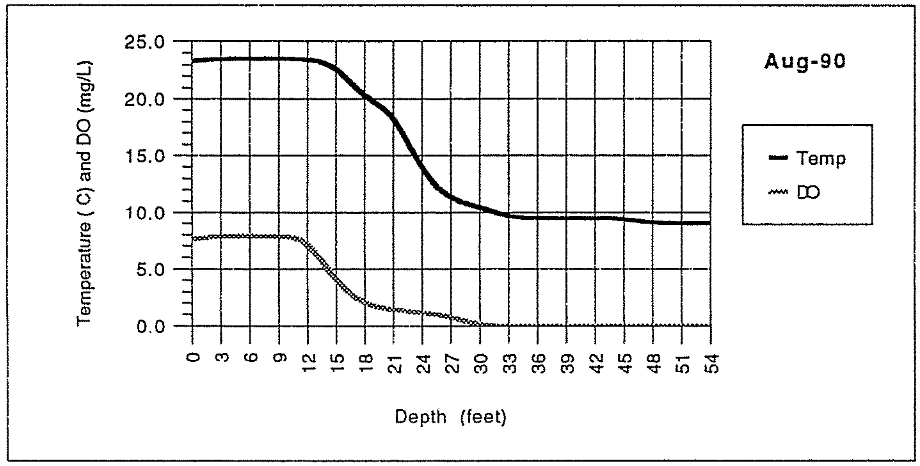


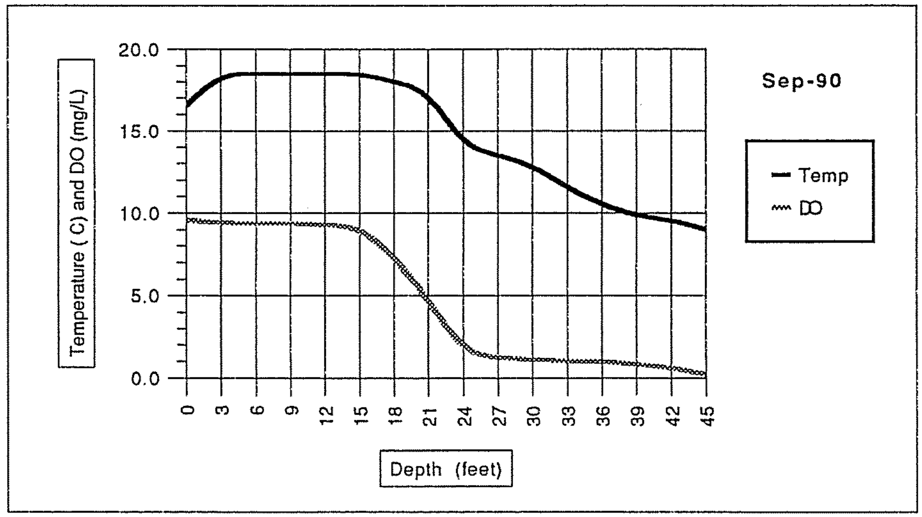
Weaver Lake
Specific Conductance Profiles
350
325
300
275
250
225
200
Specific Conductance (umhos/cm)
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
51
53
Depth (feet)
May
June
July
August
September

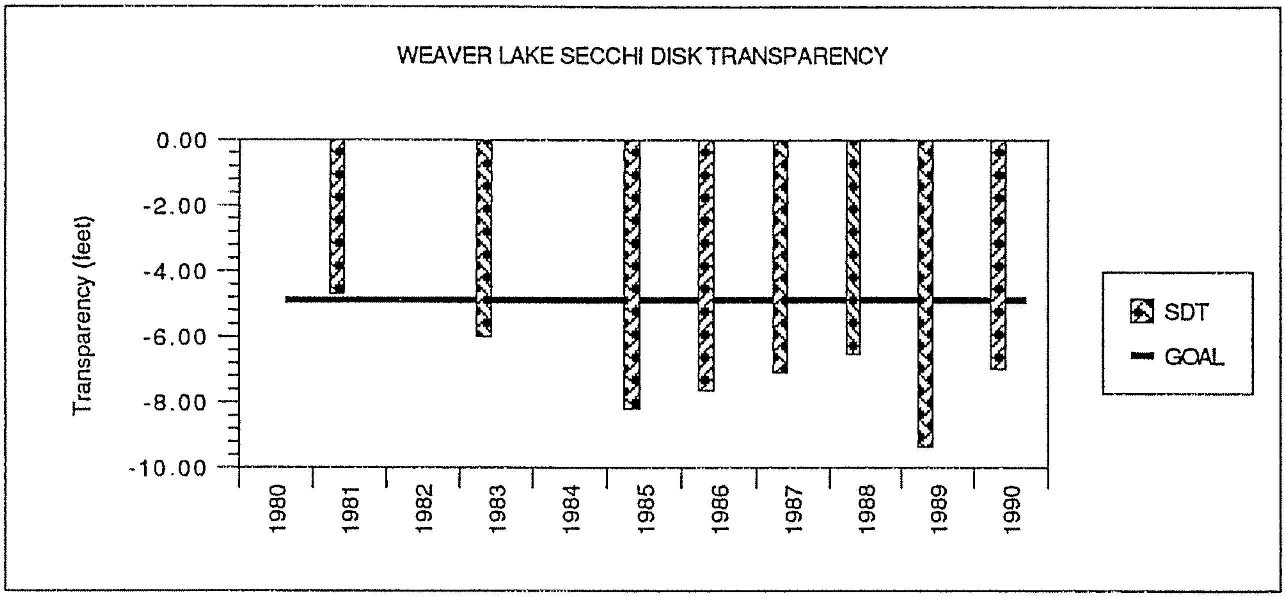

May-90
Temperature (C) and DO (mg/L)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48
Depth (feet)
Temp
DO

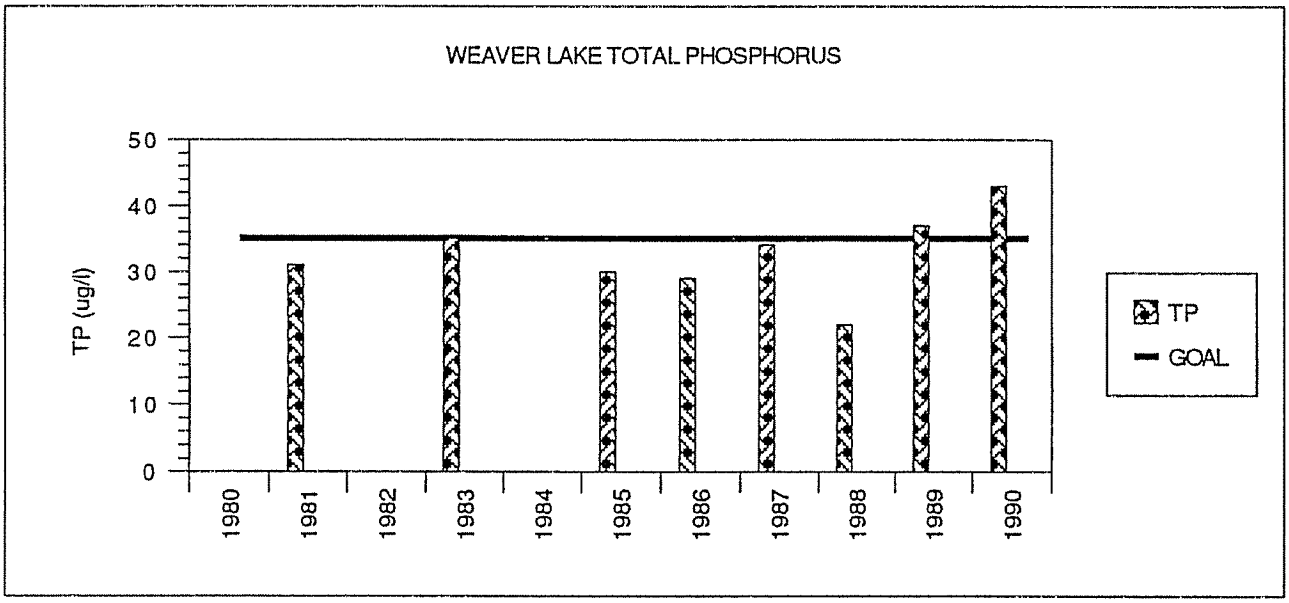

Jun-90
Temp. (C) and DO (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48
Depth (feet)
Temp
DO

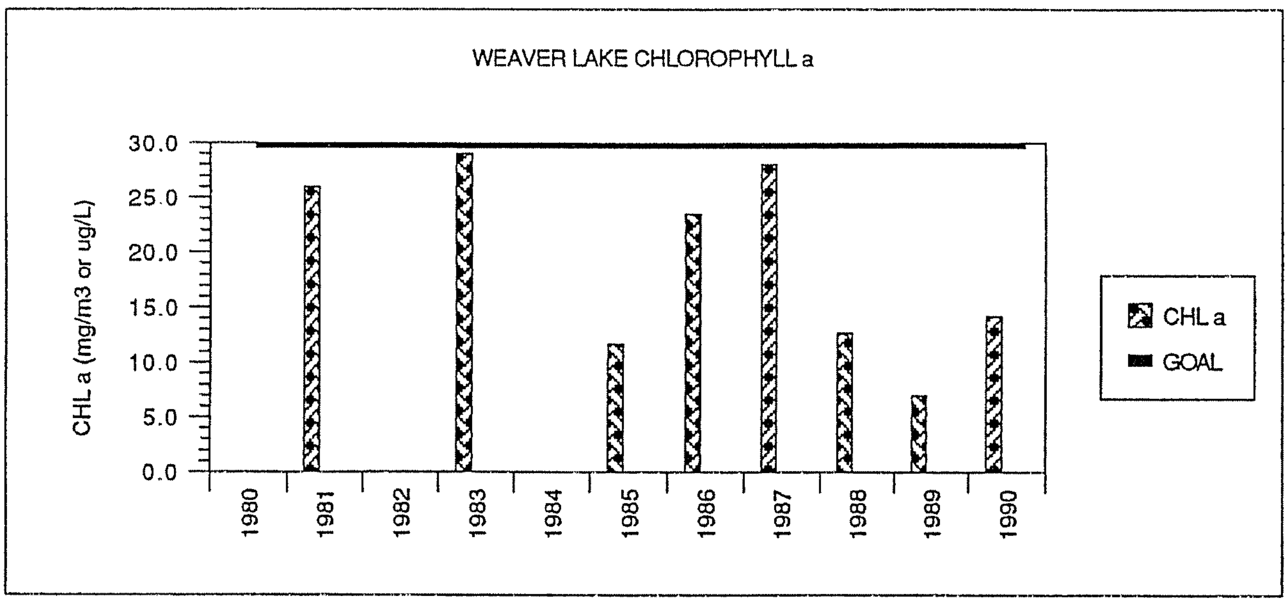

Jul-90
Temperature (C) and DO (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48
Depth (feet)
Temp
DO

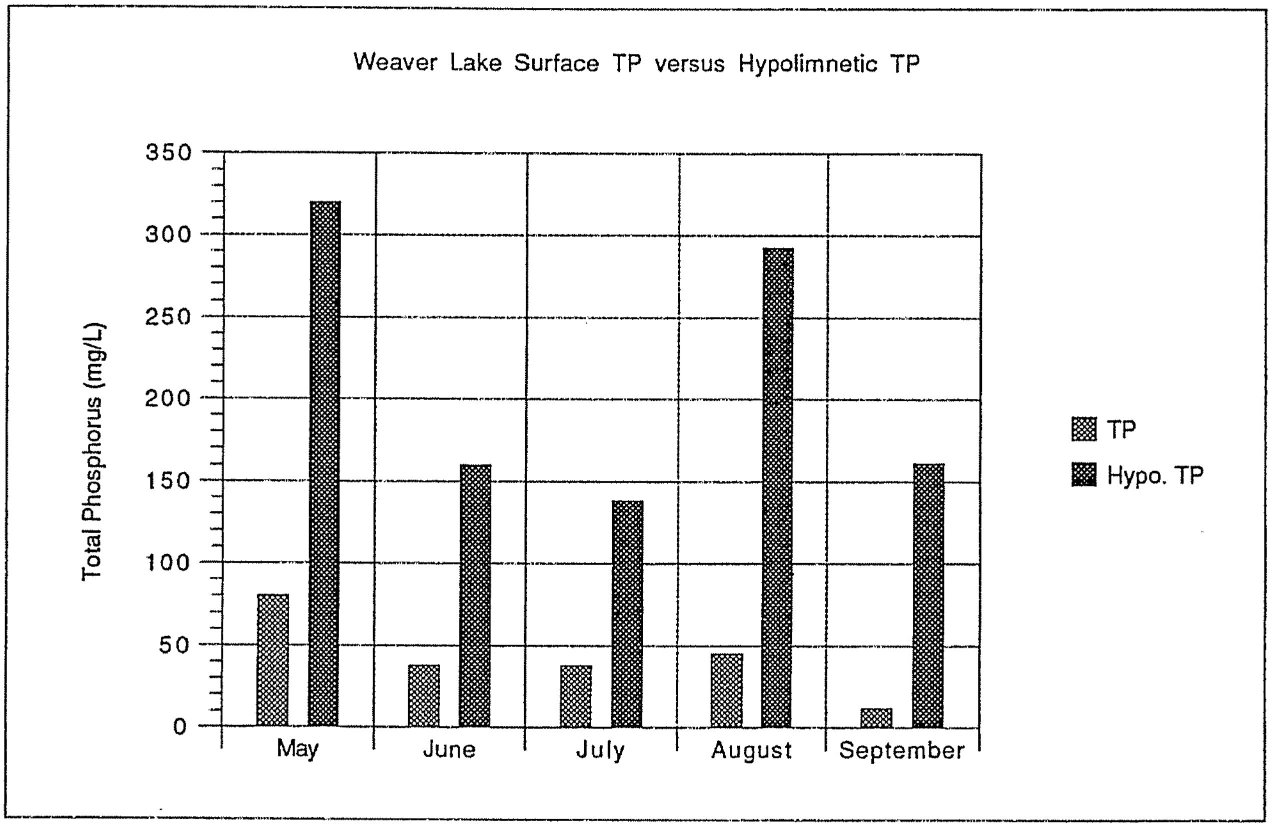

Aug-90
Temperature (C) and DO (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54
Depth (feet)
Temp
DO


Sep-90
Temperature (C) and DO (mg/L)
20.0
15.0
10.0
5.0
0.0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45
Depth (feet)
Temp
DO


WEAVER LAKE SECCHI DISK TRANSPARENCY
Transparency (feet)
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
SDT
GOAL


WEAVER LAKE TOTAL PHOSPHORUS
TP (ug/l)
50
40
30
20
10
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
TP
GOAL


WEAVER LAKE CHLOROPHYLL a
CHL a (mg/m3 or ug/L)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
CHL a
GOAL


Weaver Lake Surface TP versus Hypolimnetic TP
Total Phosphorus (mg/L)
350
300
250
200
150
100
50
0
May
June
July
August
September
TP
Hypo. TP