Four lakes (Cook, Diamond, Fish, and Weaver) were sampled by the Commission in 1992 (Figures 2 and 3). 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.

Water quality parameters monitored for in 1992 are summarized in Table 3. Fish, Weaver, and Diamond Lakes were sampled monthly from May through September on the following dates. May 12, June 9, July 23, August 11 and September 15. Analyses of lake samples for alkalinity and chloride were conducted in May. All other parameters were monitored or analyzed monthly. Cook Lake was sampled in June, July and August. and September. Monitoring in May was not possible due to access problems. Samples were collected and delivered to the laboratory that same day. All samples were analyzed within the specified holding times.

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. All four lakes had their maximum concentrations of total phosphorus in July (Figure 5a). Fish Lake also peaked in TP concentration in September. Minimum total phosphorus concentrations were recorded at varying times for each lake. As expected, Diamond Lake had the highest mean concentration of total phosphorus, and Cook Lake had the lowest (Figure 6a). Both epilimnetic (surface) and hypolimnetic (bottom) samples were collected for Cook Lake (Figure 7). Generally hypolimnetic samples were substantially higher in phosphorus than epilimnetic samples. The May sample had hypolimnetic TP 6 times greater than the epilimnetic sample. High TP in the hypolimnion is indicative of internal loading of phosphorus from the sediments.

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 in Weaver Lake was fairly consistent for each of the monitoring dates(Figure 5b). Fish Lake had its lowest concentration in June and was high for the rest of the season. Cook Lake exhibited low chlorophyll concentrations for each month. Diamond Lake had high chlorophyll a concentrations all spring and summer but peaked at a very high 116 ug/L in July. Diamond Lake had the highest and Cook Lake had the lowest mean and median concentrations (Figure 6b).

Secchi disk transparency is a measure of water clarity. Higher Secchi disk transparency indicates greater water clarity. The maximum Secchi disk transparency occurred in June in Fish and Weaver Lakes (Figure 5c). Maximum transparency for Cook Lake occurred in August. Diamond Lake had its maximum transparency in May. Minimum transparency occurred in May in Weaver, July in Fish and June in Cook Lake. Transparency was very low in Diamond Lake in July through September, with its lowest transparency of .7 feet occurring in August. Weaver and Cook Lakes had average transparency values in excess of 7 feet (Figure 6c). Cook Lake had the highest average at 8.3 feet. Weaver Lake had an herbicide treatment to control algae on July 1, 1992. No treatments occurred on Fish Lake in 1992.

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 Fish, Weaver and Cook Lakes were stratified throughout the monitoring season (Figures 8 - 10). In May all the lakes were fairly well oxygenated to the bottom. However, profiles for the remainder of the season showed anoxia below approximately 18 to 24 feet. Diamond Lake remained fairly mixed throughout the spring and summer because of its shallow depth and wind movement across the lake (Figure 11). Although it is only weakly stratified, Diamond Lake exhibits lower oxygen concentrations due to its hypereutrophic state. 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 1992 are shown in Figure 12. Fish Lake is considered eutrophic. Cook Lake is classified as mesotrophic. Weaver Lake is classified as mesotrophic to eutrophic and Diamond Lake is classified as hypereutrophic. The TSI for transparency indicates how the lake appears. The TSI for phosphorus indicates the potential trophic state for the Lakes. High phosphorus concentrations suggests that either the Lake will exhibit dense macrophyte beds or heavy algal blooms throughout the summer.

Figure 12 also provides an indication of the usability of the lake. The water quality of Cook Lake indicates it would be good for swimming. However, it is not used much due to lack of access. Diamond Lake is on the opposite end of the scale. It does not have water quality that allows for swimming in the lake. Fish and Weaver Lakes are usable for swimming but somewhat impaired.

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 District, 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. Cook Lake is a category II lake and has somewhat less stringent goals. Diamond Lake is a category III lake and has the least stringent goals.

The 1992 mean phosphorus concentration for Fish Lake is above the upper limit listed in the Plan and is the highest on record. Mean concentrations of chlorophyll a and mean concentrations of total phosphorus (Figure 13) 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 appears to be gradually decreasing since 1987, and fell below the lower limit in 1992 (Figure 13). The Minnesota Pollution Control Agency (MPCA) lists a mean transparency of 5.2 feet for Fish Lake compared to a 1992 mean transparency of 4.5 feet. This 5.2 feet is based on 75 measurements from 1977-1989 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 14). However, the chlorophyll a 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 slightly higher in 1992 compared to 1990 and 1991 and remains above the lower limit specified in the Plan (Figure 14).

The mean concentration of total phosphorus in the Cook Lake appears to be on the rise since 1988 (Figure 15). However, the chlorophyll $_a$ concentration and mean Secchi disk transparency have remained fairly stable based on the 4 years of monitoring that have occurred (Figure 15). All parameters are within the less stringent category II limits of the plan.

Diamond Lake has been sampled only three times. It is difficult to assess the occurrence of a trend based on this limited sampling. In 1989, the lake experienced super high concentrations of phosphorus (Figure 16). In comparison to that, the 1992 mean TP seems low. However, Diamond Lake is very nutrient rich compared to the other lakes sampled in 1992. The mean chlorophyll concentration for 1992 was also high. As expected based upon the chlorophyll

concentration, transparency in Diamond Lake was low but did go beyond the lower limit of 1.5 feet specified in the Plan for category III lakes. In July, the chlorophyll a concentration peaked at 116 ug/L. This concentration indicates severe nuisance algal blooms were occurring on the lake. This time of the year (usually July & August), often referred to as the "dog days of summer" is typically when the worst water quality is observed for a lake. Although the TP concentration did not meet the limit of the plan, the chlorophyll a and Secchi disk transparency were within the limits of the plan.

Diamond Lake is really more a type 5 wetland than a lake. It will never have good water quality due to its shallowness and tremendous sink of nutrients in the sediments. Diamond Lake receives a large load of nutrients from its agricultural watershed. There are row crops planted right up to the edge of the water and several feedlots from which runoff enters the lake. If the load of nutrients from the watershed was controlled the lake would still be eutrophic to hypereutrophic, but may experience a reduction in the frequency and severity of algal blooms.

Trend analysis was used to examine the long term mean values for Fish and Weaver Lakes. Cook and Diamond Lakes lack enough data to use the trend analysis. For Fish Lake (Figure 17) there is an obvious upward trend in phosphorus and chlorophyll concentrations and a downward trend in transparency (i.e. degrading water quality). The trend line was extended out to the year 2000 based upon mean data from 1986-1992. The graph shows that if conditions continue as they have in the past the water quality of Fish Lake will continue to be degraded and the recreational uses of the lake will be threatened. Because the watershed of Fish Lake is mostly developed, it is likely that the trend line will flatten because input from the watershed will not increase as much. However, internal loading will also be a factor in the water quality of Fish Lake.

The trend analysis on Weaver Lake showed a similar upward trend for phosphorus as did Fish Lake (Figure 18). However, the trend is much less reliable than that for Fish Lake. The trend analyses are based on least squares regression. The correlation coefficients for chlorophyll and transparency were low. For some reason the chlorophyll concentrations has deceased rather then increased. This may be due to weed growth or herbicide treatments that are used to control the algal blooms. It is unlikely that the chlorophyll a will continue to decrease as phosphorus increases.

Transparency is related to the chlorophyll concentrations and would also be affected by herbicide treatments. It is likely that the transparency will decrease as the phosphorus concentration increases if herbicide treatments or other factors such as weed growth do not limit algal production. The watershed of Weaver Lake is also highly developed. The increase in loading from the watershed should level off where the development in the watershed is completed.

The water quality of Fish and Weaver Lakes, as measured by total phosphorus, appears to be declining. This may also be true for Cook Lake. The Commission has taken steps in the past to reduce nutrient loading through erosion control and other practices. It is apparent that additional management practices or improvement projects are needed to reverse the trend in water quality for the Elm Creek Watershed.

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 19) (Wilson and Walker 1989). The Twin Cities Metropolitan area is within the ecoregion known as the North Central Hardwood Forests (I>TCHF). 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 and Cook and Diamond Lakes are 41, 64, 75, and 13 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. Diamond Lake is ranked as having very poor water quality in comparison with other NCHF lakes. Cook Lake exhibits very good water quality compared to other NCHF lakes. 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 (IQR) for the NCHF lakes (Table 5). Weaver has a mean total phosphorus concentration at the upper end and Fish Lake has a TP concentration beyond the upper end of the interquartile range. This indicates the potential water quality of these lakes is much better than existing conditions. Cook Lake's TP concentration is in the middle of the IQR. Mean total phosphorus for Diamond Lake is 3.5 times greater than the 75th percentile value for the ecoregion. This water body would not be considered minimally impacted. All the lakes are definitely impacted by pollutant loading from the watershed. However, some have been impacted much more so than others. The chlorophyll, and Secchi disk transparency values are similar in their relation to the interquartile range as the TP concentration. 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 runoff. The samples for chloride were collected in May when chloride concentrations in runoff are probably near their peak.

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 20. The 1992 mean data are plotted. The phosphorus concentration of Diamond Lake is so high it is beyond the boundaries but follows the trend of the graph. Data from Fish, Weaver and Cook Lakes do fit the general relationship shown in the graphs.

Probably the most important information that can be taken from Figure 20 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 ug/L. When concentrations exceed this range and up to a concentration of about 30 ug/L, the result is a substantial reduction in transparency. Once concentrations exceed about 30 ug/L, there is only a small decrease in transparency with increases in chlorophyll a. Similarly, at TP concentrations greater than 10 ug/L there is a rapid decrease in transparency with increases in TP up to a concentration of about 60 ug/L. Cook and Weaver Lakes fall within this "critical range" for phosphorus and chlorophyll A. Any increase in phosphorus would result in an increase in chlorophyll a . and increased chlorophyll a concentrations are likely to result in noticeable decreases in transparency. For example, if mean chlorophyll $_a$ was increased from 15 to 15 ug/L in Cook Lake, mean transparency is expected to drop from its existing 8.3 feet down to about 5 feet. Fish Lake and especially Diamond Lake's TP concentrations are 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. Diamond Lake's transparency is also influenced by the amount of suspended solids in the water in addition to algae. Its transparency would not be as affected by increases or decreases in phosphorus as would the other lakes since it is shallow and wind mixing continually moves the bottom sediments up into the water column. Weaver Lake is at the tail end of the critical range of phosphorus. Increases in phosphorus will result in only minor reductions in transparency.

Regressions of several parameters were completed for Fish, Weaver, Cook and Diamond Lakes. The r-squared values (percent variance explained) are presented in Table 6 and Figures 21 and 22. Fish Lake showed a significant correlation between phosphorus, chlorophyll $_a$ and transparency. Diamond Lake also showed a significant correlation between phosphorus and chlorophyll A. The coefficient of determination (r^2) indicates the correlation between estimated and actual values. An r^2 of 1 indicates a perfect correlation. If a significant correlation is present, the regression equation may be used to predict for example, chlorophyll a concentration based on TP concentration. The regression equations for Fish Lake are:

TP-CHI. CHL = 5.061(TP) - 2.167

TP-SDT SDT =-.052(TP) + 8.339

CHL-SDT SDT = -.09(CHL) + 7.69

where TP and CHL are in ug/L and SDT is in feet. Diamond Lake's chlorophyll a concentration's may be predicted using the following equation: CHL = .534(TP) - 20.69

The computer model "MINLEAP" was used to compare the 1992 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, Weaver and Diamond Lakes indicated potentially improved water quality compared to observed values. MINLEAP predicted poorer water quality than observed in Cook Lake. Cook Lake's water quality is better than expected based upon watershed size, location, lake depth and existing conditions.

Several lakes within the Elm Creek Watershed area were monitored by other organizations. The City of Maple Grove conducts a lake monitoring program through their Lake Quality Commission. In 1992 they sampled Fish, Weaver and Rice Lakes.

The data from their sampling programs was combined with that of the Elm Creek Watershed Commission and is presented in the appendix. A comparison of the mean values calculated using data for the individual sampling programs and the data combined is also shown. The three monitoring programs were coordinated at the beginning of the season so that the sampling events occurred spaced out over the period from May to October, without much overlap in sampling dates.

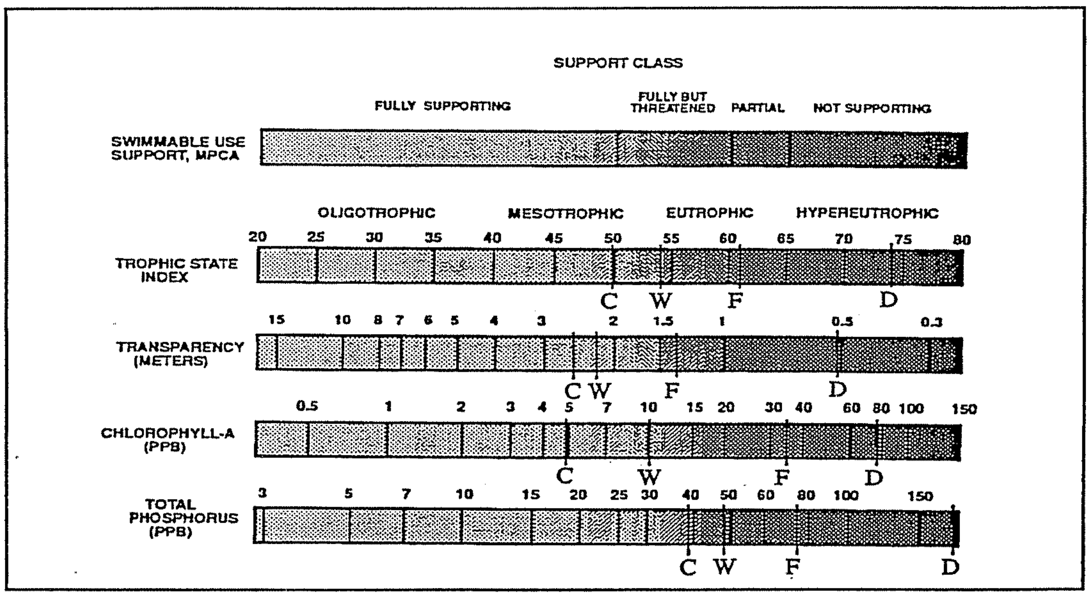
Mean values for the three parameters, phosphorus, chlorophyll and transparency were quite comparable between the programs and combined. A table and graphs of the data are included in the appendix. With the combined monitoring program, Weaver Lake was sampled eleven times. It has been shown that a minimum of ten samples per year is necessary for good statistical analysis of a lake (Osgood 1989). This number may be reduced when a lake is sampled multiple years. The combined mean for Weaver Lake was 46.2 ug/L for phosphorus, 9.4 ug/L for chlorophyll, and 8 feet for transparency. A herbicide treatment to control algae occurred on July 1, 1992. For Fish Lake the combined means were 65.6 ug/L, 27.5 ug/L and 4.7 feet. Nine readings were taken at Fish Lake.

At this time Rice Lake is not classified in the Elm Creek Plan. No data were available to characterize the lake. The 1991-1992 monitoring program of the Maple Grove Lake Quality Commission provided this data. Rice Lake is actually an impoundment created by a dam in Elm Creek. It is fairly large (306 acres) but shallow. The maximum depth is 11 feet Rice Lake has a history of nuisance algal blooms. The data collected in 1991 and 1992 indicate Rice Lake is eutrophic to hypereutrophic. Mean values for phosphorus, chlorophyll and transparency were 218 ug/L, 32 ug/L and 4.1 feet in 1992 based upon 9 sampling events. Phosphorus concentrations in Rice Lake are extremely high. Algal blooms in the lake are limited by other factors such as turbidity, as evidenced by the lower chlorophyll, mean value. Rice Lake also received two herbicide treatments to control algae (July 23 and August 13). The approximate dates of these treatments are shown on the graphs in the appendix. Transparency was fairly low throughout the summer. The mean of 4.1 feet was influenced by an unusually high transparency of 10 feet on October 1. The mean transparency without that value is only 3.3 feet. Based upon the phosphorus concentration measured for Rice Lake, it could exhibit potentially much worse conditions than observed. A mean phosphorus concentration of 218 ug/L could support severe algal blooms and very limited transparencies. Dissolved oxygen and temperature was measured in Rice Lake. Although it is shallow and has stream flow through it, Rice Lake was stratified, with oxygen concentration dropping below 1 mg/L at depths of about 8-10 feet. Surface dissolved oxygen concentrations ranged from 8-10 ug/L.

DIAMOND LAKE	SDT feet	TP ug/L	CHL ug/L	NO2+ NO3 mg/L	NH3 mg/L	TKN mg/L	TN mg/L	pH	COND umhos/ cm	ALK mg/L	CL mg/L
MAY	3.0	113	33.0	0.06	0.08	1.82	1.88	8.35	280	108	27.5
JUNE	2.5	138	59.2	0.10	0.59	2.12	2.22	8.40	292		
JULY	1.2	258	116.0	0.25	0.61	1.34	1.60	7.95	284		
AUG	0.7	186	58.1	0.12	0.44	1.85	1.97	8.25	293		
SEPT	1.6	181	98.0	0.44	0.44	4.58	5.01	8.35	556		
Mean	1.8	175	72.9	0.19	0.43	2.34	2.54	8.26	341		
Median	1.7	178	66.0	0.16	0.44	1.99	2.09	8.31	293		
Std. Deviation	0.9	55	33.5	0.16	0.21	1.28	1.40	0.18	120		
TSI mear 73	69	79	73								

	Ecoregion*	Fish	Weaver	Cook Lake	Diamond
TP (ug/L	23 - 50	74	48	39	175
CHL a (ug/L)	5 - 22	35.2	10.1	4.8	72.9
SDT (ft)	4.9 - 10.5	4.5	7.5	8.3	1.8
Chloride (mg/L)	4 - 10	31	39	31	28
Alkalinity (mg/L)	75 - 150	138	118	139	108
TKN (mg/L)	<.6 - 1.2	1.26	1.2	0.8	2.34
NO2 + NO3 (mg/L)	<.01	0.14	0.16	0.14	0.19
pH	8.6 - 8.8	8.13	8.11	7.62	8.26
Conductivity	300 - 400	332	333	287	341
TN:TP	25:1 - 35:1	19:1	25:1	23:1	15:1

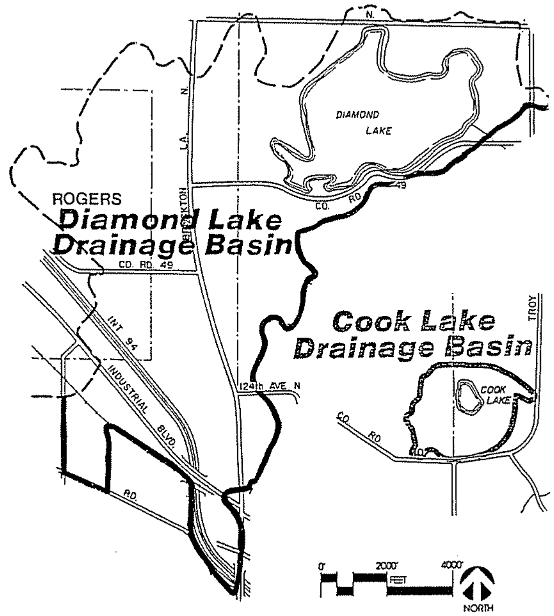
*Interquartile (25th to 75th percentile) values for minimally impacted lakes



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 C-Cook Lake D-Diamond Lake

Minnesota Lake Eutrophication Analysis Procedure
ENTER INPUT VARIABLES
LAKE NAME ? Diamond
ECOREGION NUMBER 1=NLF,2=CHF,3=WCP,4=NGP ? 2
WATERSHED AREA (HA) ? 797
LAKE SURFACE AREA (HA) ? 163
LAKE MEAN DEPTH (M) ? .6
OBSERVED MEAN LAKE TP (UG/L) ? 175
OBSERVED MEAN CHL-A (UG/L) ? 72.9
OBSERVED MEAN SECCHI (M) ? .6



INPUT DATA:
LAKE NAME =Diamond ECOREGION=CHF
LAKE AREA = 163 HA
WATERSHED AREA (EXCLUDING LAKE) = 797 HA
MEAN DEPTH = .6 METERS
OBSERVED MEAN TP = 175 UG/L
OBSERVED MEAN CHL-A = 72.9 UG/L
OBSERVED MEAN SECCHI = .6 METERS

<press ENTER to view results>

LAKE = Diamond ECOREGION = CHF
AVERAGE INFLOW TP = 183.6401 UG/L TOTAL P LOAD = 202.2428 KG/YR
LAKE OUTFLOW = 1.1013 HM3/YR AREAL WATER LOAD = .6756442 M/YR
RESIDENCE TIME = .8880414 YRS P RETENTION COEF = .6231711

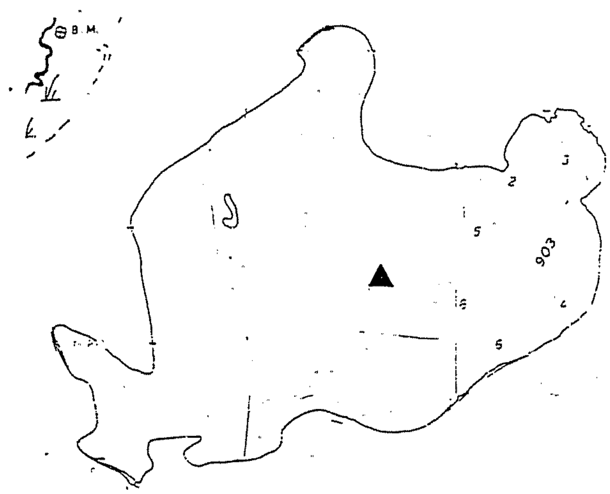
VARIABLE	UNITS	OBSERVED	PREDICTED	STD ERROR	RESIDUAL	T-TEST
TOTAL P	(UG/L)	175.00	69.20	21.84	0.40	2.61
CHL-A	(UG/L)	72.90	32.12	18.68	0.36	1.28
SECCHI	(METERS)	0.60	1.00	0.40	-0.22	-1.23

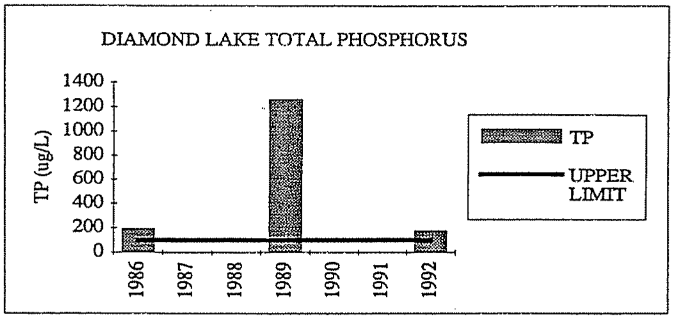
NOTE: RESIDUAL = LOG10(OBSERVED/PREDICTED)
T-TEST FOR SIGNIFICANT DIFFERENCE BETWEEN OBS. AND PREDICTED

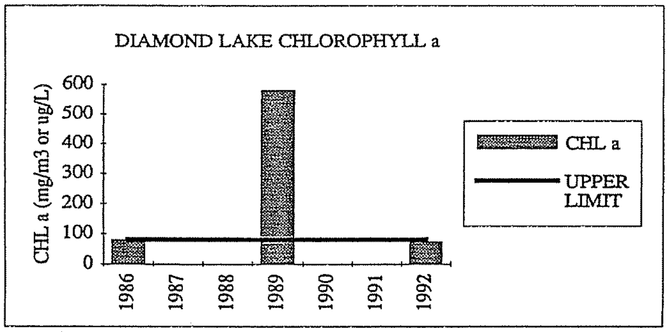
CHLOROPHYLL-A INTERVAL FREQUENCIES (%)

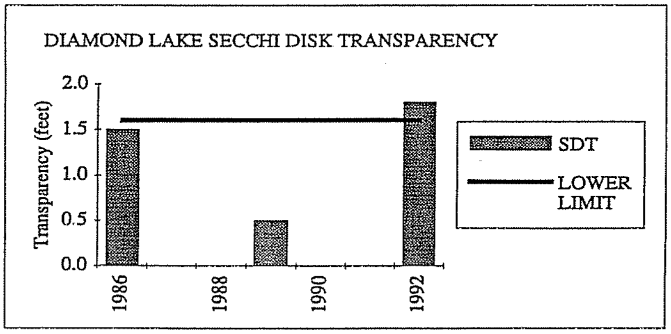
CHL-A PPB	OBSERVED	PREDICTED CASE A	PREDICTED CASE B	PREDICTED CASE C
10	100.00	98.58	97.85	91.13
20	99.29	77.28	75.51	67.75
30	94.64	46.04	46.34	47.53
60	56.64	6.15	7.72	17.12

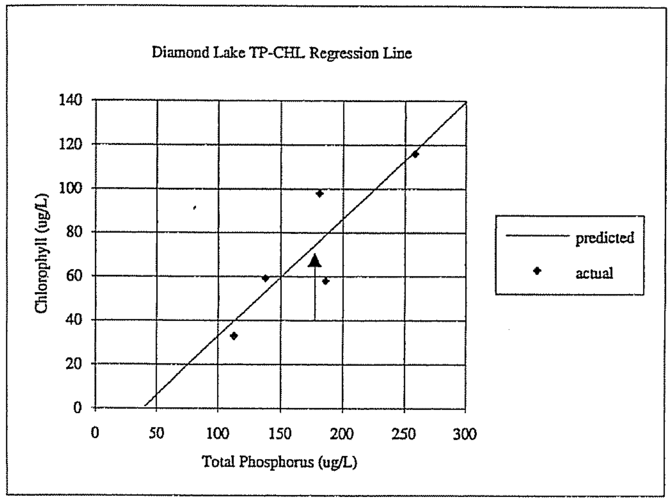
CASE A = WITHIN-YEAR VARIATION CONSIDERED
CASE B = WITHIN-YEAR + YEAR-TO-YEAR VARIATION CONSIDERED
CASE C = CASE B + MODEL ERROR CONSIDERED
0



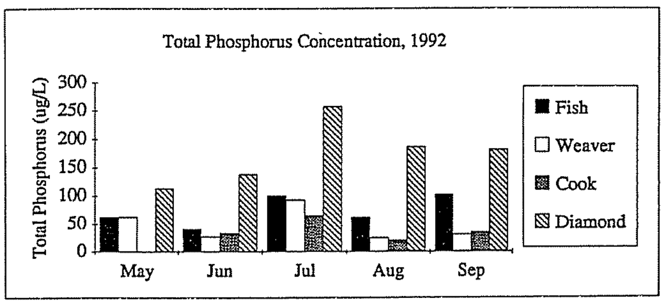


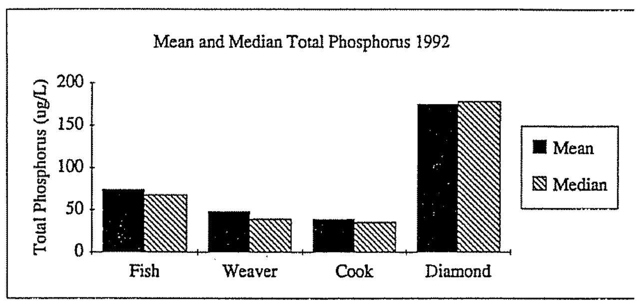


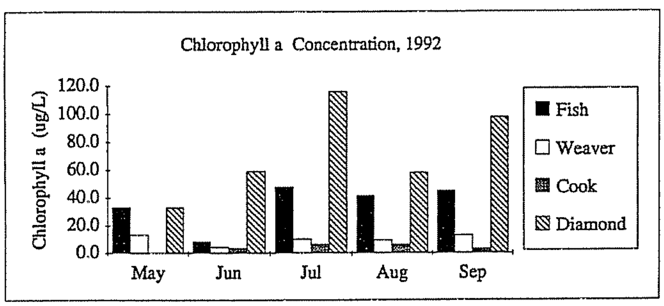


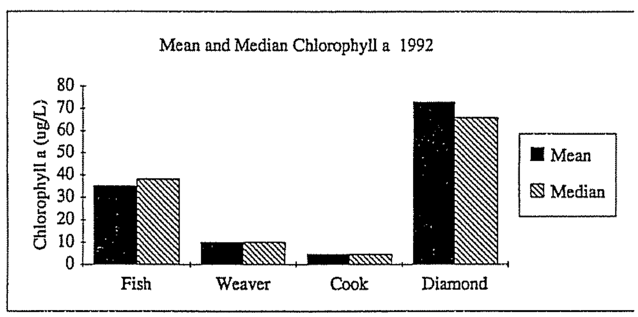


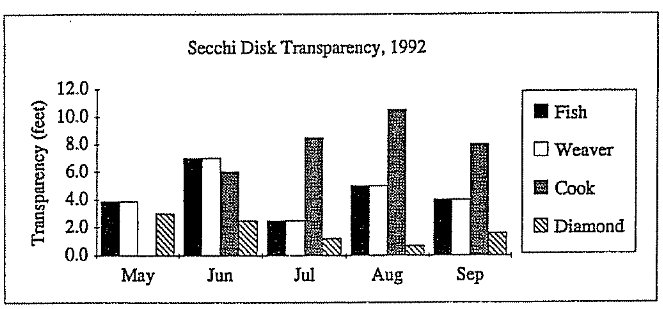
Arrow indicates 1992 conditions

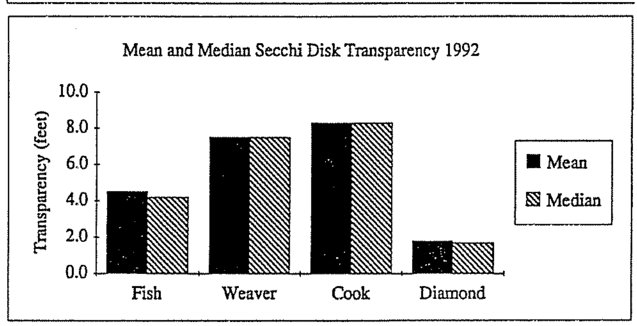


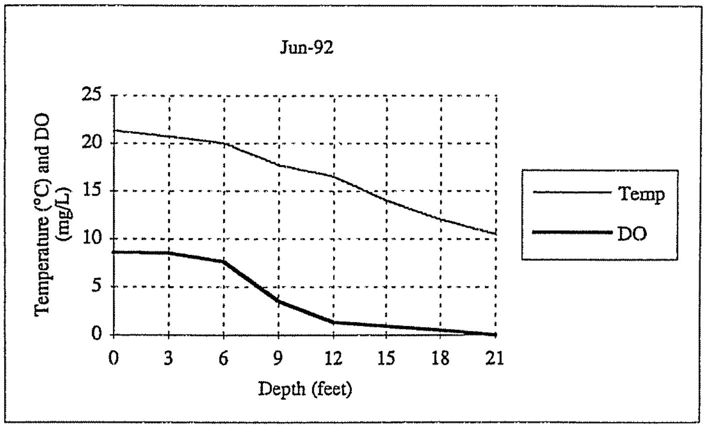


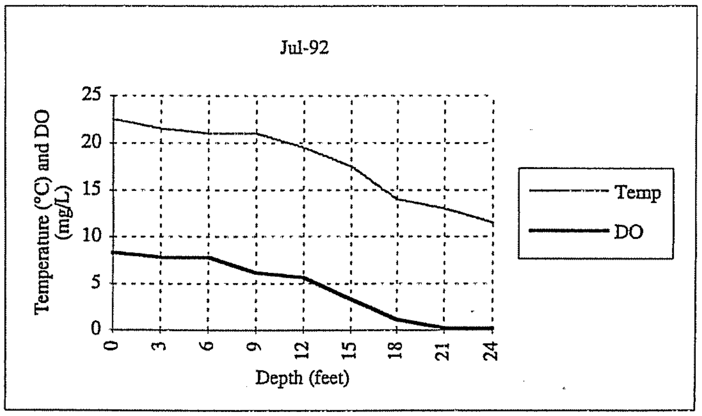


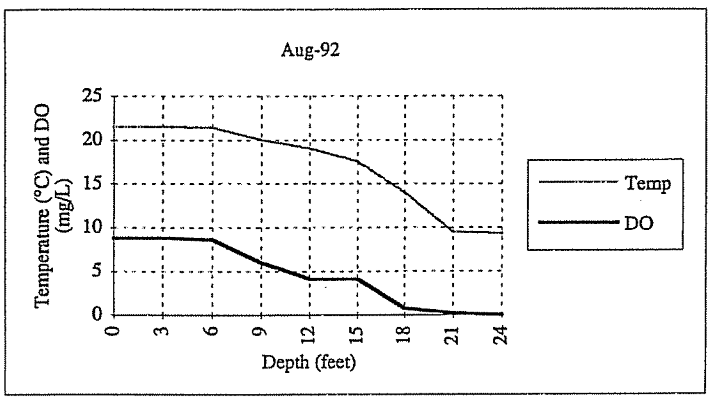


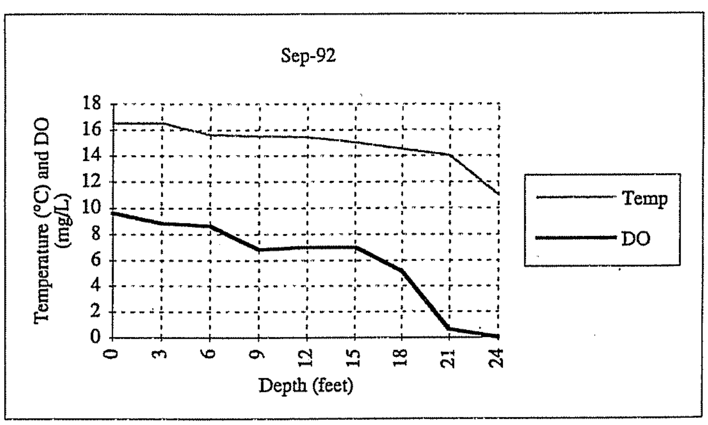


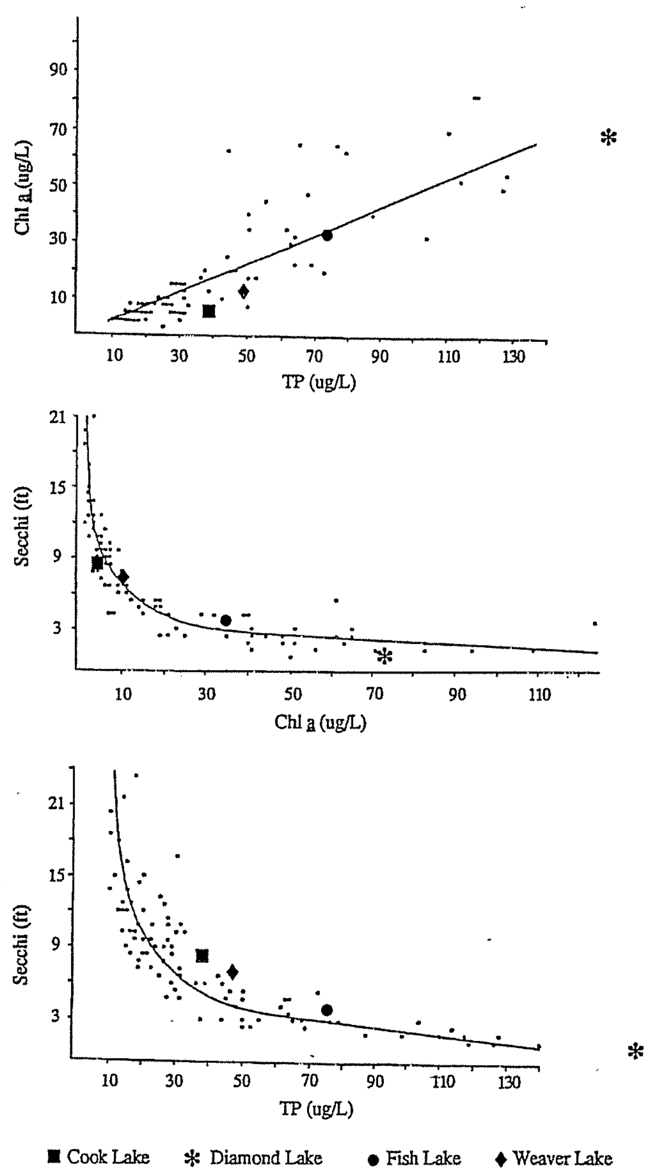












Diamond Lake R-squared Values

		Dependent Variable			
		CHL	SDT	LOG(CHL)	LOG(SDT)
Independent Variable	TP	0.78 *	0.62	0.75 *	0.47
	CHL		0.33		0.16
	TN	0.10	0.00	0.13	0.00
	LOG(CHL)				1.00 *

* indicates statistically significant