DATA ANALYSIS AND MODEL DEVELOPMENT FOR THE LAKE MOREY 314 DIAGNOSTIC STUDY

prepared for

Vermont Agency of Environmental Conservation
Department of Water Resources
Lakes Program
Montpelier, Vermont

by

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June 1983

1. Introduction

This report contributes to the Clean Lakes Diagnostic Study of Lake Morey, Fairlee, Vermont, being conducted by the Vermont Department of Water Resources (VDWR,1982). Key objectives are to provide the VDWR with:

(1) analysis and interpretation of monitoring data from Lake Morey and its tributaries with an emphasis on factors controlling lake eutrophication;

(2) a mathematical model which can be used to predict lake water quality responses to watershed and inlake management techniques;

(3) demonstration of useful tools or analytical approaches which can be applied to other lake diagnostic studies;

The basic analytical approach focuses on the mass balance and lake processing of phosphorus, the key factor controlling algal productivity and related water quality conditions. Details on the lake setting, monitoring procedures, etc. are described elewhere (VDWR, 1982) and are not repeated here. The report organized in the following sections:

2. Loading Estimation Methods
3. Average Mass Balances
4. Transient Mass Balances
5. Factors Contributing to Internal Phosphorus Recycling
6. Model Development
7. Conclusions

Appendices contain the following supporting materials:

A. Flow-Interval Loading Calculation Algorithms and Results
B. Transient Mass Balance Listings
C. Diagnostic Plots - Time Series
D. Diagnostic Plots - Depth/Date Contour Diagrams

2. Loading Estimation Methods

A number of alternative loading calculation methods have been tested on the Lake Morey tributary monitoring data. Given a continuous time series of mean daily flow measurements and intermittent nutrient concentrations derived from grab samples, the problem is to estimate the average (or total) flux of nutrients past a given station over a given time period. The literature contains a wide range of techniques which can be used for this purpose (Johnson, A.H., 1979, Westerdahl et al., 1981, Walker, 1981). The methods have various degrees of efficiency and data requirements; some methods (e.g., Whitfield, 1982) should not have made it to the literature and will yield biased loading estimates in many situations. Given that these types of calculations are frequently employed in lake studies and given the importance of deriving accurate loading estimates for the Lake Morey study, an emphasis on this problem is warranted. Results also provide a basis for evaluating tributary sampling strategies.

The appropriate technique for a given application depends upon the following factors:

(1) desired time scale (averaging period) for the loading estimates;

(2) concentration sampling freqency and duration;

(3) nutrient concentration dynamics of the stream, as influenced by hydrologic variations, season, sediment transport characteristics, point-sources, non-point sources, etc.;

For application of lake nutrient loading models, the desired averaging period is typically a year or longer. In some cases (e.g., rapidly flushed impoundments or dynamic modeling) higher freqency estimates (seasonal, monthly, weekly, daily) may be desired. Generally, the expected level of accuracy depends upon the frequency of concentration observations in relation to time or, better, in relation to cumulative flow volume.

Desired properties of the estimates include minimum bias and minimum variance. The distinction between bias and variance is

important. If the concentration data set is taken randomly with respect to flow regime, then direct averaging of instantaneous loadings provides an unbiased estimate which usually has relatively high variance (because loading varies with flow and flow information from the days when concentration is not sampled is not being used). Averaging flow and concentration separately and subsequently multiplying the averages together to estimate loading will yield a biased estimate if concentration and flow are (even weakly) correlated (Walker, 1981). A biased procedure will give the wrong answer, even for an infinite number of samples, whereas variance can generally be reduced by increasing the number of concentration measurements. The seriousness of bias depends upon it size relative to the variance or standard error of the estimate.

Calculation methods can be classified in the following categories:

1. random sample
   - average loading
   - average flow x average concentration
   - average flow x flow-weighted average concentration
   - concentration/flow regression
2. stratified random sample
   - flow interval
   - seasonal
   - other
3. serially dependent sample
   - interpolation
   - substitution
   - time series

The first category treats the concentration data as random samples without regard to sequence. One advantage of these methods is that they permit direct estimation of error variance and construction of confidence limits for the mean. The error variance estimate will be influenced by auto-correlation (non-randomness) which may exist in the concentration time series data.

The second category essentially divides the data set into a series of groups and applies random sample techniques separately to each group. In many cases, appropriate grouping reduces the error variance of the mean estimate (Cochran, 1977). The flow-interval method was orginally developed by the U.S. Army Corps of Engineers for use in estimating loadings to Lake Erie (U.S. Army Engineer District, Buffalo, 1975). According to this method, data are grouped by flow range and the average-loading method is applied separately within each interval. The interval loading estimates are subsequently combined using weighting factors which reflect the complete flow distribution (including days without concentration measurements). Any of the random-sample methods could also be applied separately to different groups defined by season or by both season and flow. Estimates of error variance derived from stratified random sample methods also assume serial independence.

The third group of methods treats the concentration and flow records as time series. Direct interpolation or substitution of missing concentration data can be done to generate a complete time series of daily loadings. In one sense, these methods are at the opposite extreme from the random-sample methods because they assume that the data are completely non-random and strongly serially correlated. The applicability of these methods depends upon the spacing of the concentration measurements and the time-series behavior, as measured by an auto-correlation function, for example. Problems with direct interpolation or substitution will arise, however, if major changes in flow occur between concentration samples.

A more elaborate method involves construction of a time series model which may consider serial correlation as well as deterministic factors such as trend, season, and/or flow. The model is used to generate a complete concentration history. A disadvantage of the dependent-sample methods is that they require a large data base and direct estimates of error variance cannot be easily derived, although such techniques as subsampling or jacknifing might be used (Mosteller and Tukey, 1978).

The selection and use of an appropriate calculation technique

depends upon the characteristics of the sampled concentration and flow time series. The sampling strategy should also be considered. All methods will perform better if the concentration data set encompasses the ranges of flow and season encountered over the desired averaging period. Storm and seasonal flood sampling should also include periods of rising and falling flows, since concentrations are often higher on the rising limb of a flood hydrograph, as compared with the falling limb, for a given flow.

Results of applying seven different calculation methods to estimate total phosphorus loadings from each of the Lake Morey tributaries are summarized in Table 1. The first four methods are the unstratified, random-sample techniques summarized above and described in detail elsewhere (Walker, 1981). Methods 5 and 6 are stratified sample techniques with groups based upon flow interval. Method 7 treats the measurements as a time series and substitutes the previous concentration observation for each missing value in the daily-average flow and concentration sequence.

A comparison of the first six techniques indicates that the stratified sample methods generally provide estimates of lower variance than the simple random sample methods. Method 5 is the standard flow-interval method (USAE Buffalo 1975, Westerdahl et al., 1981); method 6 is a modification which uses the flow-weighted-mean concentration instead of the mean loading within each flow interval to develop the total loading estimate. This modification reduces error variance in most cases, especially as the number of concentration samples is reduced. The reduction in variance reflects the fact that concentrations tend to be less variable than loadings within a given flow interval. Note that for one flow interval, method 1 is a special case of method 5 and method 3 is a special case of method 6. The methods based upon flow-weighted concentration (3 and 6) are actually "ratio estimates" according to classical sampling theory (Cochran,1977).

Details on Methods 5 and 6 are presented in the Appendix, along with calculation results for each tributary and a documented SAS program which can be applied to other loading estimation problems. As discussed

Table 1
Comparisons of Total Phosphorus Loading Estimates Derived from Various Calculation Methods

	Random Sample Methods						
	Unstratified				Stratified by Flow Regime		Direct
	Lm	QmxCm	QmxCqw	Regress.	Lm	QmxCqw	Interpol.
	1	2	3	4	5	6	7
Station 502791	n = 154	b = -.03					
Mean	53.8	17.8	30.1	30.7	24.9	24.2	23.3
Var	227.0	146.3	34.4	52.0	15.6	13.1	-
Station 502792	n = 121	b = .118					
Mean	33.2	9.4	14.8	13.6	13.5	12.5	13.0
Var	108.0	82.1	14.6	14.0	8.1	6.6	-
Station 502793	n = 169	b =.158					
Mean	76.7	19.7	47.8	44.4	36.2	36.3	33.9
Var	707.2	598.6	185.3	194.2	87.3	83.6	-
Station 502794	n = 93	b = -.942					
Mean	4.8	9.0	3.2	4.6	4.7	3.7	3.2
Var	.41	2.17	.22	.42	.68	.33	-
Station 502795	n = 169	b = .207					
Mean	96.3	23.9	60.2	54.5	47.6	46.4	39.6
Var	730.5	591.4	163.8	175.0	91.9	82.4	
Station 502796	n = 169	b = .351					
Mean	72.2	14.8	47.0	40.5	36.5	34.2	29.4
Var	562.8	493.1	147.8	137.5	75.4	65.6	
Station 502797	n = 165	b = .334					
Mean	41.0	13.2	27.5	24.1	19.6	19.6	21.2
Var	176.6	139.1	47.8	36.5	11.6	11.8	-
Station 502798	n = 165	b = .276					
Mean	35.6	18.1	25.2	23.0	27.1	25.5	24.9
Var	34.5	16.9	6.5	4.8	11.3	5.0	-
Station 502799	n = 162	b = .486					
Mean	80.0	14.9	51.9	42.0	37.0	35.6	31.3
Var	828.8	726.5	200.6	146.3	52.8	38.5	
Station 502800	n = 165	b = .103					
Mean	384.4	261.1	300.4	292.9	291.7	290.7	277.1
Var	2024.5	1142.9	672.2	652.2	653.7	640.7	

Loading Estimates in Kg Total P / Year
Mean = estimated mean, Var = variance of mean
n = number of concentration observations
b = slope of log concentration vs. log flow regression

by Westerdahl et al. (1981), the definition of flow intervals for implementation of these methods is arbitrary. Experimentation indicates that setting the boundaries at equally-spaced intervals on a square root of flow scale is preferable to defining them on a linear scale because of the skewness of the flow distributions. When defined on a linear scale, the frequency of concentration observations in the upper flow intervals tends to be too low. Subjective definition of flow interval boundaries is also valid, possibly aided by upon examination of scatter plots of concentration against flow. The number of intervals is also arbitrary and is partially limited by the number and distribution of concentration measurements, since at least two concentration measurements are required per flow interval. Five flow intervals have been used to develop estimates for the Lake Morey tributaries and outlet. Variance induced by using different numbers of flow intervals and/or different definitions for interval boundaries is generally insignificant when compared with estimated error variances.

The major advantage of the stratified (5-6) over the unstratified (1-4) techniques is that the former adjust for differences between the distributions of sampled flows and unsampled flows. For this data set, the simple random sample methods (except 2) tend to over-estimate the total loadings in most cases because the concentration measurements were not taken randomly with respect to flow regime, i.e., a greater fraction of the high flow regimes were sampled for concentration. Method 2 (average flow x average concentration) tends to under-predict loadings because it assumes that flow and concentration are independent, contrary the general tendancy for higher concentrations to occur in these tributaries during peak runoff periods.

Possibly because they do not account for concentration increases during storm events which intervene sampling periods, estimates from the direct substitution method (7) tend to be slightly lower than those derived from the stratified random sample methods, but the differences are generally not statistically significant in relation to the error variances. The estimate of total gauged tributary loading derived from method 7 is 219 kg/yr, compared with 247 kg/y for method 5 and 238 kg/yr

for method 6. For less intense sampling regimes, however, the applicability of method 7 would become increasingly limited because of the increased influences of intervening flow variations. In such cases, more elaborate time series models might be constructed, as described above, if a continuous loading history is desired.

Estimated error variances for the random-sample and flow-interval methods are approximate partially because they assume that the residuals are serially independent. Diagnostic plots of method 6 residuals against flow and time have been reviewed to assess residual dependencies. For most stations, serial dependence of errors is relatively weak and would not be expected to have major influences on the estimated error variances. For total phosphorus loading estimates in ten out of the eleven tributaries, first-order autocorrelation coefficients (log scale) range from .12 to .35. Diagnostic plots indicate that most of the serial correlation occurs in the first two months of the time series, during and following the unusual February 1981 runoff. Residuals from Station 794 are strongly serially correlated (.60), this station is heavily influenced by a camp septic system and serial correlation probably reflects seasonal variations in loading which are independent of flow. Generally, residuals from method 6 appear more random when plotted against flow or time than residuals from method 5.

The stratified sample methods provide breakdowns of load and error variance sources by flow interval (see Appendix). These are particularly useful for considering alternative sampling strategies. For most tributary stations, flow-weighted-mean concentrations tend to be higher in the higher flow intervals and most of the variance in the total loading estimate originates in the higher flow intervals. More cost-effective monitoring programs can be designed by reducing sampling frequency during low-flow periods. For example, for station 502795, 51% of the concentration samples were taken in the lowest flow interval, which accounts for only 0.02% of the variance in the total loading estimate. Cutting back on the low-flow sampling frequency by a factor of 10, for example, would reduce total sampling effort by 46% but

increase the variance in the total loading estimate by only 0.18%, since the variance component of each flow interval is inversely related to number of concentration observations. While this is a rather extreme example, it illustrates a rational approach which can be used to improve monitoring efficiency.

Increased attention to sampling and data reduction in the high-flow intervals is warranted. Because of the possibility of within-day variations in concentration during storm events, instantaneous flow measurements should accompany grab concentration samples, including rising limb and falling limb components. Instantaneous measurements could be used directly in the estimation procedure; alternatively, daily-average concentrations during storm periods could be weighted by instantaneous flow and used in the procedure.

Within-day variations may tend to be less significant during high-flow periods resulting from seasonal snowmelt, because flows (and concentrations) would tend to be more stable than those experienced during a summer thunderstorm, for example. In Vermont, snowmelt periods account for a large portion of the high-flow and high-loading regimes. Because snowmelt periods are seasonal, more steady, and more predictable than thunderstorms, the problem of sampling design and scheduling for load estimation is somewhat less complicated.

The stratified sample methods could also be applied by year and/or season. In situations where only instantaneous flow and concentration data are available (i.e., no continuous flow monitor), the complete flow distribution needed for use of the flow-interval method might be approximated by (1) fitting a distribution function to the instantaneous flows (e.g., 3-parameter log-normal), provided that the distribution of instantaneous flows is representative; or (2) correlating the observed flows with a nearby benchmark station that has continuous flow monitoring and preferably a reasonably similar watershed (size, land use, topography). The second method is preferable and would be generally feasible because of the density of USGS gauges in Vermont.

3. Average Mass Balances

This section integrates tributary flow and water quality information to develop average water and phosphorus balances for Lake Morey during the monitoring period.

Table 2 presents a water balance for the period from February 1981 to December 1982. Stream gauging stations effectively monitored 81% of the watershed area, exclusive of the lake surface. Average unit runoff from the gauged stations ranged from .45 to .50 m/yr, with the exception of the Aloha Camp culvert, DH#ACC (.09 m/yr), a small intermittent groundwater stream which was less extensively monitored and influenced by a septic system. To estimate flow from the ungauged portion of the watershed, the average unit runoff from the gauged watersheds (exclusive of DH#ACC), .49 m/yr, has been applied to the ungauged watershed area. Wagner et al. (1983) estimated direct groundwater input at .38 ft3/sec or .34 hm3/yr; this would be included in the total ungauged estimate (1.76 hm3/yr) in Table 2. A regional literature value for evaporation rate, .64 m/yr, (Kohler et al., 1959) has been used along with measured precipitation and lake discharge rates for the remaining components of the balance.

A change in storage term has not been included in the water balance because lake level data were available for only a portion of the monitoring period (May-October 1982). Levels varied over a range of about .2 meters; applied to the lake surface area, a .2-meter change in level would correspond to a maximum volume change of .43 hm3, or .23 hm3/yr over the monitoring period, if extremes in elevation were experienced at the beginning and end of the monitoring period (unlikely). Ignoring the change-in-storage term, total inputs and outputs balance to within .12 hm3/yr or 1.1% of the total input. This level of agreement indicates that the hydrologic data are adequate as a basis for nutrient balance computations.

Excluding evaporation, a total volume of 17.8 hm3 was discharged from the lake during the monitoring period. Compared with the lake volume of 18.5 hm3, slightly less than one displacement is indicated. The mean hydraulic residence time over this period (volume/discharge,

Table 2
Summary of Water Balance

STREAM	STORET CODE	Name	Drainage Area (km2)	Mean Flow (hm3/yr)	Unit Runoff (m/yr)
DH#1	791		1.761	.820	.466
DH#2	792		1.606	.738	.460
DH#3	793	Glen Falls	4.248	2.138	.503
DH#ACC	794		.544	.050	.092
DH#4	795	Big Brook	3.678	1.792	.487
DH#5	796		.958	.482	.502
DH#6	797		1.502	.725	.482
DH#7	798		.725	.336	.451
DH#8	799		.440	.205	.466
		Total Gauged	15.462	7.287	.471
		Ungauged (a)	3.620	1.756	.486
		Precipitation	2.138	2.132	.997
		Total Input	21.220	11.175	.527
		Evaporation	2.138	1.460	.683
DH#9	800	Outlet	21.220	9.592	.452
		Total Output	21.220	11.052	.540
		Net (Error)		.123	
		Percent of Output		1.1%	

Period Feb 1, 1981 through Dec 12, 1982
Period length = 680 days = 1.86 years
Precipitation total = 73 inches
Estimated evaporation total = 50 inches (Kohler, 1959)
(a) ungauged inflow estimated from drainage area and average unit runoff from gauged watersheds excluding DH#ACC

excluding evaporation) was about 2 years.

Figure 1 provides some historical perspective on hydrologic conditions based upon monthly streamflow data from the nearby USGS Wells River gauge over the previous 10 years. The long-term average runoff at this location is .49 m/yr, compared with values of .54 m/yr and .63 m/yr measured during water years 1981 and 1982, respectively. Based upon the past 15 years of record, an annual runoff of .63 m/yr is roughly in the 75th percentile. Hydrologic conditions during 1981 were unusual in two respects: (1) "spring" runoff occurred in late February (3.69 inches vs. a maximum of 2.02 inches and mean of 1.04 inches in the previous 14 years of record); and (2) an unusual fall runoff period occurred in October (3.95 inches vs. a maximum of 2.77 inches and a mean of 1.11 inches in the previous 14 years of record). Conditions were more "normal" during 1982, with low flows in winter and peak runoff in April.

Table 3 summarizes total and dissolved phosphorus balance calculations. Gauged loadings have been calculated using the modified flow interval method(6) described in the previous section. Coefficients of variation for the individual tributary loadings range from 9 to 24% for total phosphorus and from 7 to 11% for dissolved phosphorus. The coefficients of variation (7% and 3%, respectively) of the total gauged loadings have been estimated by adding the tributary variance components and are probably optimistic. Errors in the individual tributary loadings may not be statistically independent because concentration samples were generally taken on the same days for each tributary. The main function of the error analysis is to provide perspectives on the relative accuracies of the individual loading components.

Ungauged loadings have been estimated using the same drainage area approximation used to develop the water balance. The direct groundwater loading of dissolved phosphorus estimated by Wagner et al. (1983), 2.7 kg/yr, would be partially reflected in the ungauged loading estimates and is negligible in relation to the total loading estimates of 333 kg total P/yr and 91 kg dissolved P/yr. Atmospheric loadings have been estimated from the average monitored loading rate (18 kg/km2-yr); half of the atmospheric loadings are assumed to be in dissolved form.

Figure 1
Historical Record of Mean Monthly Runoff at the USGS Wells River Gauge

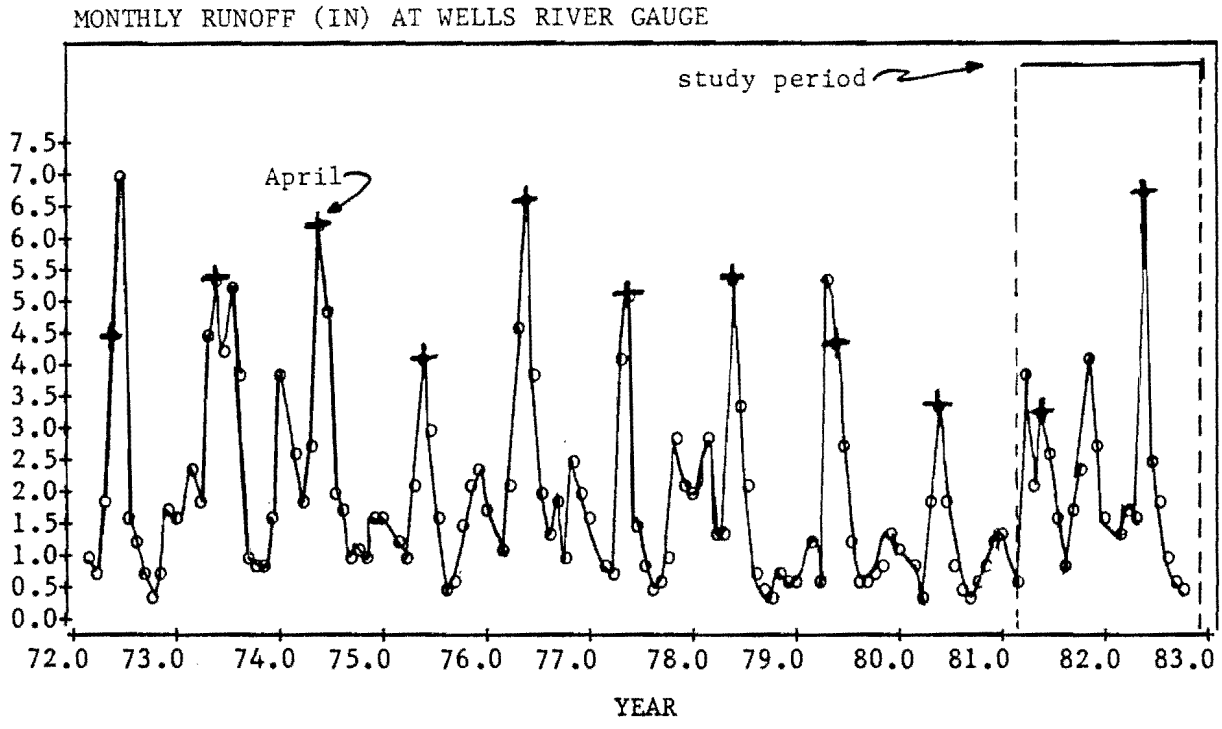


Table 3
Summary of Lake Morey Phosphorus Balances - Entire Monitoring Period

STORET STATION CODE	Drainage Area km2	Mean Flow hm3/yr	Unit Runoff m/y	Total P Load kg/y	Total P Cqw ug/l	Total P cv -	Total P % -	Dissolved P Load kg/y	Dissolved P Cqw ug/l	Dissolved P cv -	Dissolved P % -
791	1.761	.820	.466	24.3	30	15	7.3	7.8	9.5	9	8.6
792	1.606	.738	.460	12.5	17	21	3.8	4.1	5.5	7	4.5
793	4.248	2.138	.503	36.3	17	25	10.9	11.6	5.5	8	12.8
794	.544	.050	.092	3.7	74	15	1.1	2.4	47.9	11	2.6
795	3.678	1.792	.486	46.4	26	20	13.9	10.9	6.1	9	12.0
796	.958	.482	.502	34.2	71	24	10.3	2.9	5.9	7	3.2
797	1.502	.725	.482	19.6	27	18	5.9	5.8	8.0	8	6.4
798	.725	.336	.451	25.5	76	9	7.7	9.2	27.6	10	10.1
799	.440	.205	.466	35.6	173	17	10.7	3.5	17.1	7	3.8
Total Gaug.	15.462	7.287	.470	237.9	33	7	71.4	58.3	8.0	3	63.9
Ungauged (a)	3.620	1.756	.485	56.8	32		17.1	13.6	7.7		14.9
Atmos	2.138	2.132	.997	38.5	18		11.6	19.3	9.0		21.2
Total Input	21.220	11.175	.525	333.2	32		100.0	91.2	8.2		100.0
Evaporation	2.138	1.460	.680								
Outlet	21.220	9.592	.452	290.7	30	9	87.2	113.4	11.8	6	124.3
Total Out	21.220	11.052	.540								
Change In Storage (b)				-99.0			-29.7	-41.0			-45.0
Net Retention (c)		.123		141.5			42.5	18.8			20.1

Period Feb 1, 1981 through Dec 10, 1982, length = 678 days
Cqw = flow-weighted concentration = load / flow
cv = coefficient of variation of mean loading estimate (%)
% = percent of total input

(a) ungauged inflow and loadings estimated from drainage area and average unit runoff and loading from gauged watersheds excluding DH#ACC (794);

(b) change in storage terms estimated from volume-weighted lake concentrations at beginning and end of monitoring period;

(c) net retention values primarily reflect large changes in storage and are misleading because of seasonal factors (see text).

Total phosphorus inputs and outputs are nearly in balance over the period (333 kg/yr vs. 291 kg/yr total phosphorus and 91 vs. 113 kg/yr dissolved phosphorus). Changes in nutrient storage also have to be considered in order to estimate net retention by the lake sediments. These changes have been calculated from volume-weighted mean concentrations in the lake at the beginning and end of the monitoring period. As described in the next section, the change in storage term is highly variable because of seasonal factors influencing lake nutrient dynamics. Another problem with the change in storage term relates to the fact that only about one lake volume was displaced during the monitoring period; ideally, at least two volumes would be desired to obtain an adequate picture of a lake's steady-state response to a given loading regime. This objective would be impractical in the case of Lake Morey, however, because of its long hydraulic residence time and year-to-year variations in loading. The estimates of net retention including the storage terms (142 kg total P/yr and 19 kg dissolved P/yr) depend strongly upon the timing of the first and last lake sampling date and should be interpreted cautiously. Consideration of seasonal factors is essential to understanding phosphorus dynamics in Lake Morey, as discussed in the next section.

The flow-weighted concentrations listed for each tributary in Table 3 normalize the loadings for differences in flow (and watershed area) and provide indications of relative quality which are useful for identifying nutrient source areas. Compared with the flow-weighted average of all gauged tributaries (33 mg/m3), four tributaries stand out as having unusually high total phosphorus concentrations: station 794 (74 mg/m3), station 796 (71 mg/m3), station 798 (71 mg/m3) and station 799 (173 mg/m3). These account for 30% and 20% of the total and dissolved phosphorus loadings, respectively, and are possible targets for future lake restoration activities. Unusually high percentages of the total phosphorus loadings were in particulate form in watersheds 796 (92%) and 798 (90%). This may reflect higher erosion rates attributed to geologic or other factors and warrant additional investigation as part of the feasiblity study.

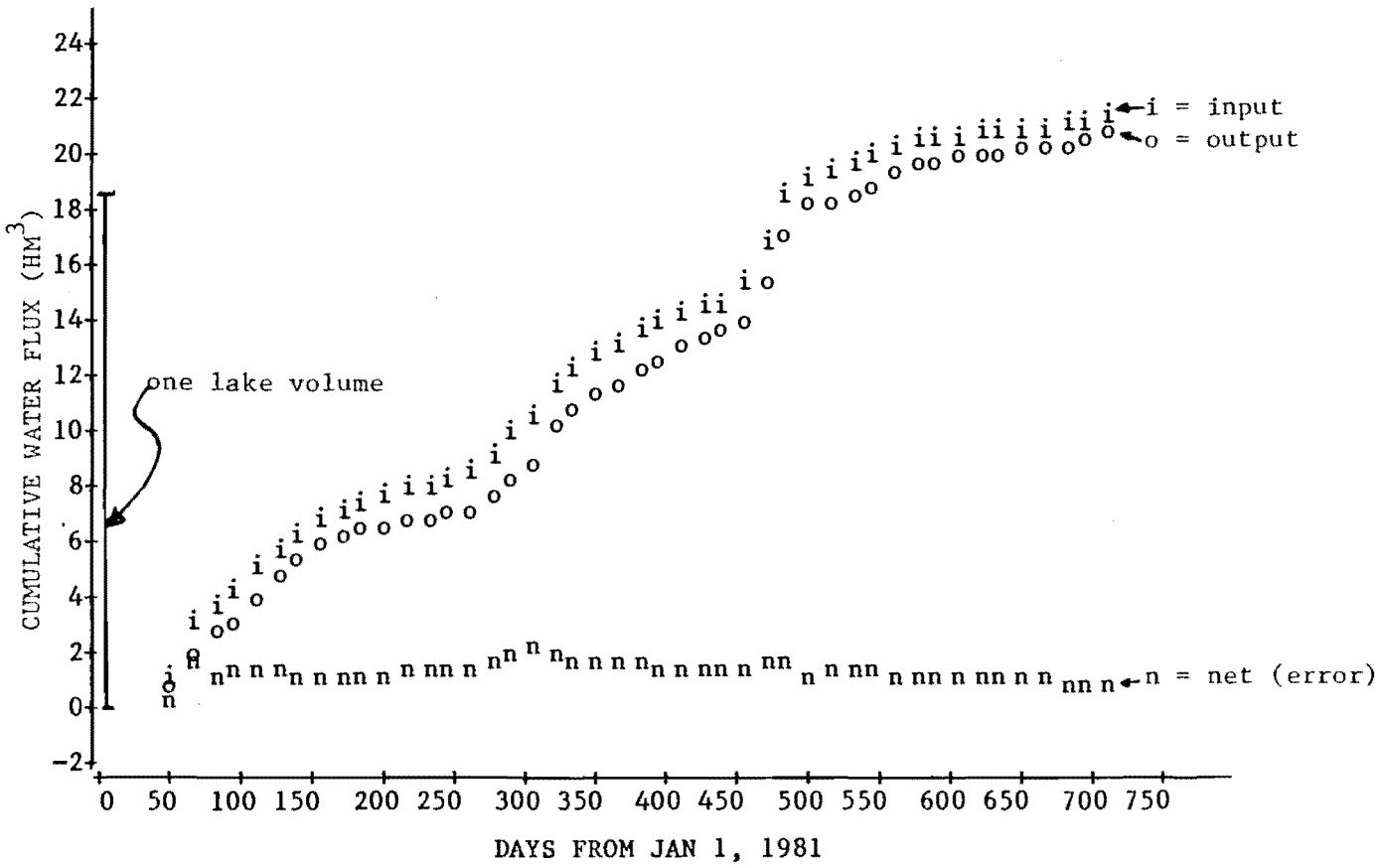


Figure 2
Cumulative Water Balance

Water and nutrient balances have also been calculated separately for two, year-long periods: February 1, 1981-82 (Table 4) and December 10, 1981-82 (Table 5). This provides perspectives on variations in annual-average loading conditions. The 50-day overlap in these periods results from the fact that the monitoring period did not extend over a complete two-year cycle. Because of the reduced number of concentration observations, 3 flow intervals have been used to develop tributary loading estimates in these cases. Water and nutrient loadings were considerably higher during the first period, particularly because of the unusual runoff periods in February and October of 1981. The water balances are in error by 6.3% and -10.1% for the first and second periods, respectively, possibly as a result of the unknown change in storage component. The estimated total phosphorus loadings were 409 and 237 kg/yr for the two periods, respectively. Average lake outflow varied from 11.0 hm3/yr to 8.0 hm3/yr. Discharge of phosphorus from the lake was less than total loading in the first period (334 kg/yr) but exceeded the external loading in the second period (263 kg/yr). A large negative change in total phosphorus storage was experienced in the second period (-322 kg/yr). Comparisons of the balances during the two periods generally indicate that large external loadings experienced during 1981 were still influencing lake conditions during 1982. This lag in lake/outflow response is expected because of the long hydraulic residence time and low phosphorus retention capacity.

4. Transient Mass Balances

Transient mass balances are effective means of summarizing water and nutrient loading data. They provide perspectives on seasonal variations, long-term trends, and data adequacy which are not available from annual or long-term summaries, especially with respect to lake processing of external phosphorus loadings and internal recycling characteristics.

The formulation of a cumulative mass balance first involves dividing the monitoring period into a number of fixed-length time periods. In this case, 15-day intervals have been used. The lake water balance is formulated separately for each interval:

$$QIN_i + QPREC_i = QEVAP_i + QOUT_i + QSTOR_i + QNET_i$$

where,

i = subscript denoting time interval i, i=1,n

QIN = input volume (hm3 , cubic hectameters or million cubic meters)

QPREC = precipitation (hm3)

QEVAP = evaporation (hm3)

QOUT = discharge from lake (hm3)

QSTOR = change in storage (hm3)

QNET = net input (hm3)

The change-in-storage term is positive if there is a net increase in lake volume over the interval. The interval balance is converted to a cumulative balance by integrating each term from the start of the monitoring period to interval i, for example:

$$QIN_{ic} = \underset{j=1,i}{SUM} (QIN_j)$$

The mass balance also holds for the cumulative terms:

$$QIN_{ic} + QPREC_{ic} = QEVAP_{ic} + QOUT_{ic} + QSTOR_{ic} + QNET_{ic}$$

Since water is a conservative substance, the QNET terms, which are estimated by difference from the other terms, should be zero. Thus, QNET behavior provides a check on the water balance. In practice, non-zero QNET values would be expected because of random errors in the measurements from one interval to the next. Advantages of the cumulative balances over the interval balances include:

(1) effects of random errors from one interval to the next are averaged out ("smoothed");

(2) average, or total, balances between any two time periods can be readily calculated by difference;

Cumulative water balance terms are listed in the Appendix and plotted in

Table 4
Lake Morey Water and Phosphorus Balances - 1981

STORET STATION CODE	Drainage Area km2	Mean Flow hm3/yr	Total P Load kg/y	Total P Cqw ug/l	Total P cv -	Dissolved P Load kg/y	Dissolved P Cqw ug/l	Dissolved P cv -
791	1.761	1.002	23.3	23	21	9.2	9.2	15
792	1.606	.922	13.9	15	34	5.2	5.6	6
793	4.248	2.499	42.7	17	35	14.4	5.8	9
794	.544	.050	3.8	73	24	2.4	47.0	16
795	3.678	2.150	64.4	30	27	13.1	6.1	13
796	.958	.576	43.2	75	26	3.4	5.8	10
797	1.502	.898	30.5	34	33	7.7	8.6	13
798	.725	.367	28.6	78	12	11.0	29.9	11
799	.440	.218	48.5	222	27	4.1	18.9	9
Total Gaug.	15.462	8.683	298.6	34	11	70.4	8.1	4
Ungauged	3.620	2.094	71.5	34		16.5	7.9	
Atmos	2.138	2.525	38.5	18		19.3	7.6	
Total Input	21.220	13.302	408.6	31		106.2	8.0	
Evaporation	2.138	1.460						
Outlet	21.220	11.010	333.5	30	7	126.1	11.4	9
Total Out	21.220	12.470						
Change In Storage			+1.9			+229.4		
Net Retention		.832	73.2			-249.3		
Percent of Input		6.3%	18%			-235%		

Period Feb 1, 1981 through Feb 1, 1982

Table 5
Lake Morey Water and Phosphorus Balances - 1982

STORET	Drainage Area km2	Mean Flow hm3/yr	Total P Load kg/y	Total P Cqw ug/l	Total P cv -	Dissolved P Load kg/y	Dissolved P Cqw ug/l	Dissolved P cv -
791	1.761	.601	21.2	35	16	6.3	10.5	9
792	1.606	.524	10.1	19	22	3.0	5.7	10
793	4.248	1.654	24.8	15	26	9.2	5.6	12
794	.544	.052	3.0	58	15	1.9	36.2	13
795	3.678	1.334	27.7	21	19	8.6	6.5	8
796	.958	.369	15.4	42	20	2.1	5.6	6
797	1.502	.526	13.0	25	18	4.2	8.0	7
798	.725	.287	19.1	66	11	6.5	22.5	14
799	.440	.186	23.5	126	22	2.7	14.5	6
Total Gaug.	15.462	5.533	157.8	29	7	44.4	8.0	4
Ungauged	3.620	1.330	40.3	30		10.3	7.7	
Atmos.	2.138	1.710	38.5	18		19.3	11.3	
Total Input	21.220	8.573	236.7	32		74.0	8.6	
Evaporation	2.138	1.460						
Outlet	21.220	7.978	263.0	33	21	107.7	13.5	5
Total Out	21.220	9.438						
Change In Storage			-342.3			+81.4		
Net Retention		-.865	316.0			-115.1		
Percent of Input		-10.1%	134%			-155%		

Period Dec 10, 1981 through Dec 10, 1982

Figure 2. Daily monitoring indicated that lake levels fluctuated less than .2 meters (vs. total depth of 13 meters) during 1982; accordingly the change-in-storage term of the water balance equation has been neglected. In the cumulative display, changes in flux rate are reflected by changes slope. The net flow or error curve is fairly flat and insignificant in relation to the cumulative total input and output curves. This reflects the general adequacy of the flow information for the water balance and nutrient balance calculations.

Corresponding balances can be formulated for total phosphorus and dissolved phosphorus:

Interval:

$$WIN_i + WATM_i = WOUT_i + WSTOR_i + WNET_i$$

Cumulative:

$$WIN_{ic} + WATM_{ic} = WOUT_{ic} + WSTOR_{ic} + WNET_{ic}$$

where,

i = subscript denoting time interval i, i=1,n

WIN = input nutrient load (kg)

WATM = atmospheric load (kg)

WOUT = discharge from lake (kg)

WSTOR = change in nutrient storage (kg)

WNET = net nutrient sedimentation (kg)

In the case of total phosphorus, the WNET term is not an error term but an estimate of the net deposition of phosphorus to the sediments during a given interval. For total dissolved phosphorus, the term also reflects processing of particulate phosphorus into dissolved forms and vice versa.

The nutrient flux terms have been estimated from the time series of daily tributary flow and concentration data, with missing concentration data estimated from the previous sample at a given station. As demonstrated in the previous sections, this procedure gives roughly the same estimates of total loadings over the monitoring period as those

derived from flow-interval methods. The change-in-storage term has been estimated from volume-weighted concentrations calculated from nutrient profile data using the following procedure:

(1) For each lake sampling date, interpolate by depth to provide estimates of concentration at 1-meter intervals from 0.5 to 12.5 meters.

(2) Calculate the volume-weighted mean concentration on each date as the average concentration over the depth intervals, weighted by surface area at each depth.

(3) Interpolate between lake sampling dates to estimate average concentrations at the fixed date (15-day) intervals used in mass balance plots.

(4) Multiply by lake volume to estimate mass and subtract from previous interval to estimate change in storage.

Cumulative mass balances developed according to these procedures are listed in the Appendix and displayed in Figures 3 and 4.

The relative magnitudes and dynamics of the mass balance terms indicate that total phosphorus concentrations in Lake Morey are controlled largely by internal cycling characteristics. For example, over the entire 675-day balance period, the total inputs amount to about 650 kg while the mass of total phosphorus in the lake fluctuated by as much as 1200 kg. Variations in net sedimentation are contolled largely by the change in storage term, instead of the total input or outflow terms.

Figure 5 focuses on the cumulative net sedimentation terms for total phosphorus and dissolved phosphorus. For total phosphorus, this term reflects the net effects of phosphorus sedimentation (attributed to direct sedimentation of inflowing particulates and to algal phosphorus uptake and settling) and releases from bottom sediments into the water column. A positive slope for this curve indicates that net deposition of phosphorus to the sediments is occuring; a negative slope indicates a net release. For dissolved phosphorus, the curve also reflects net conversions between dissolved and particulate phosphorus in the water

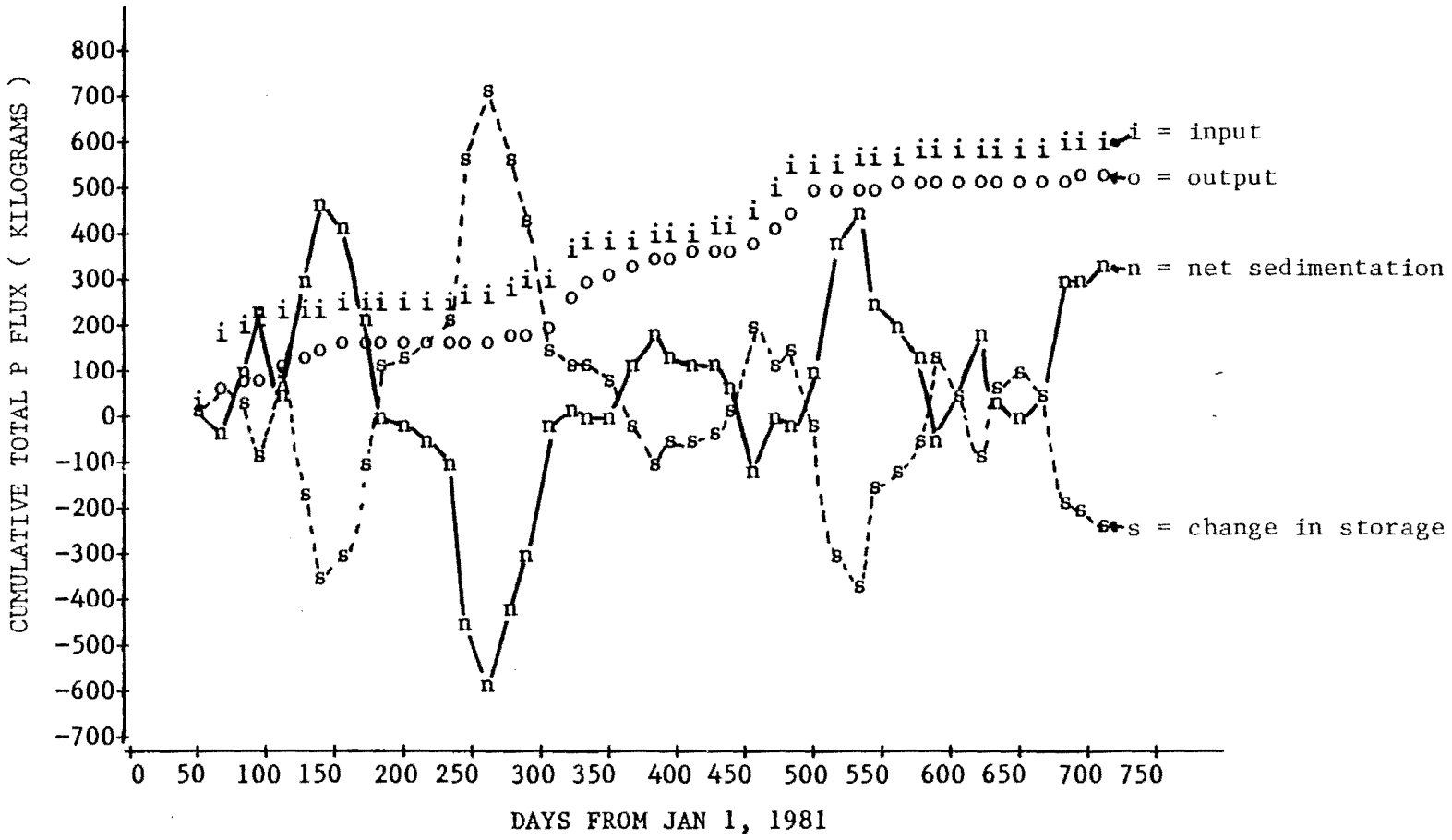


Figure 3
Cumulative Total Phosphorus Balance

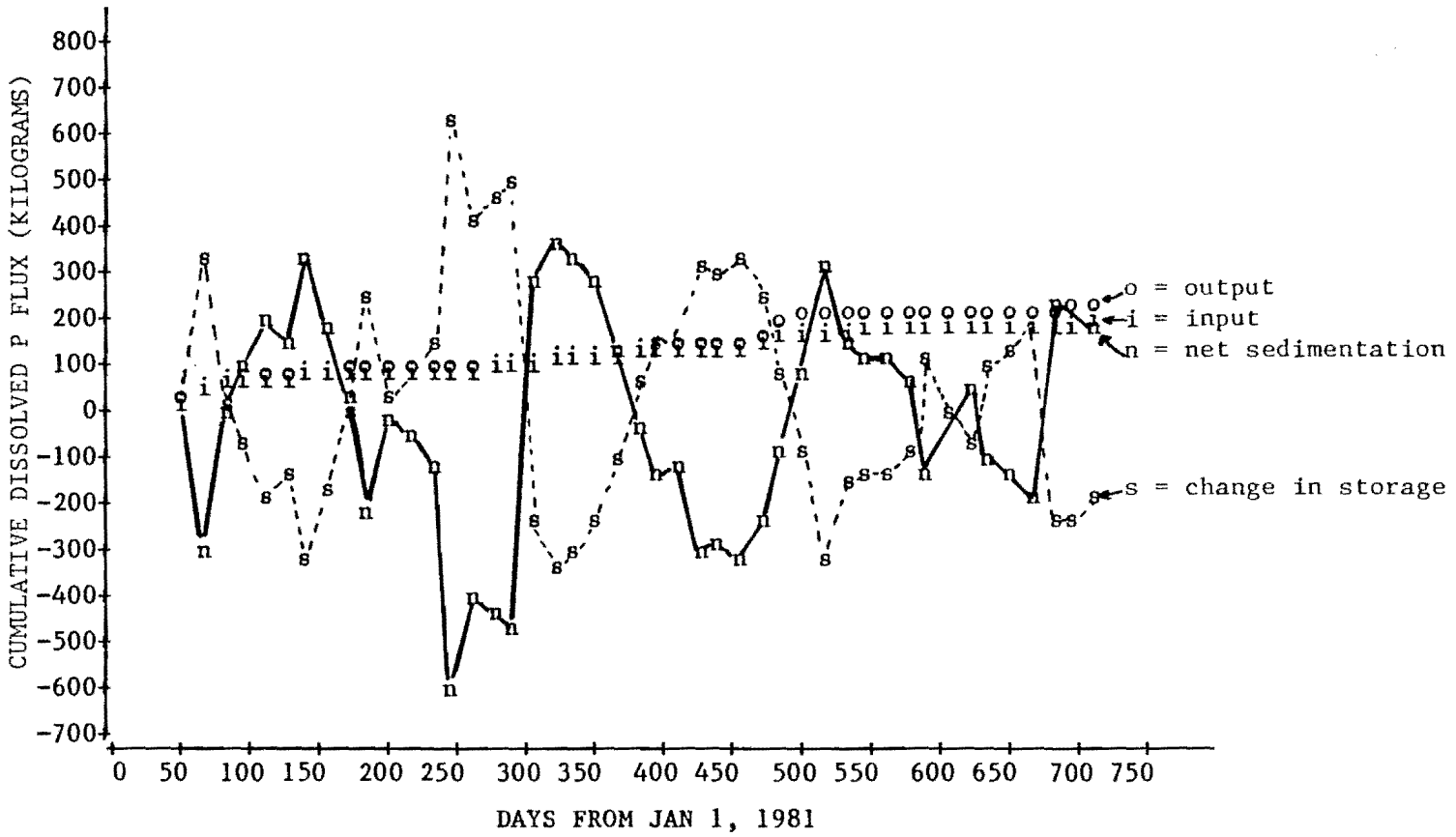


Figure 4
Cumulative Dissolved Phosphorus Balance

Figure 5
Total and Dissolved Phosphorus Cumulative Net Sedimentation Curves

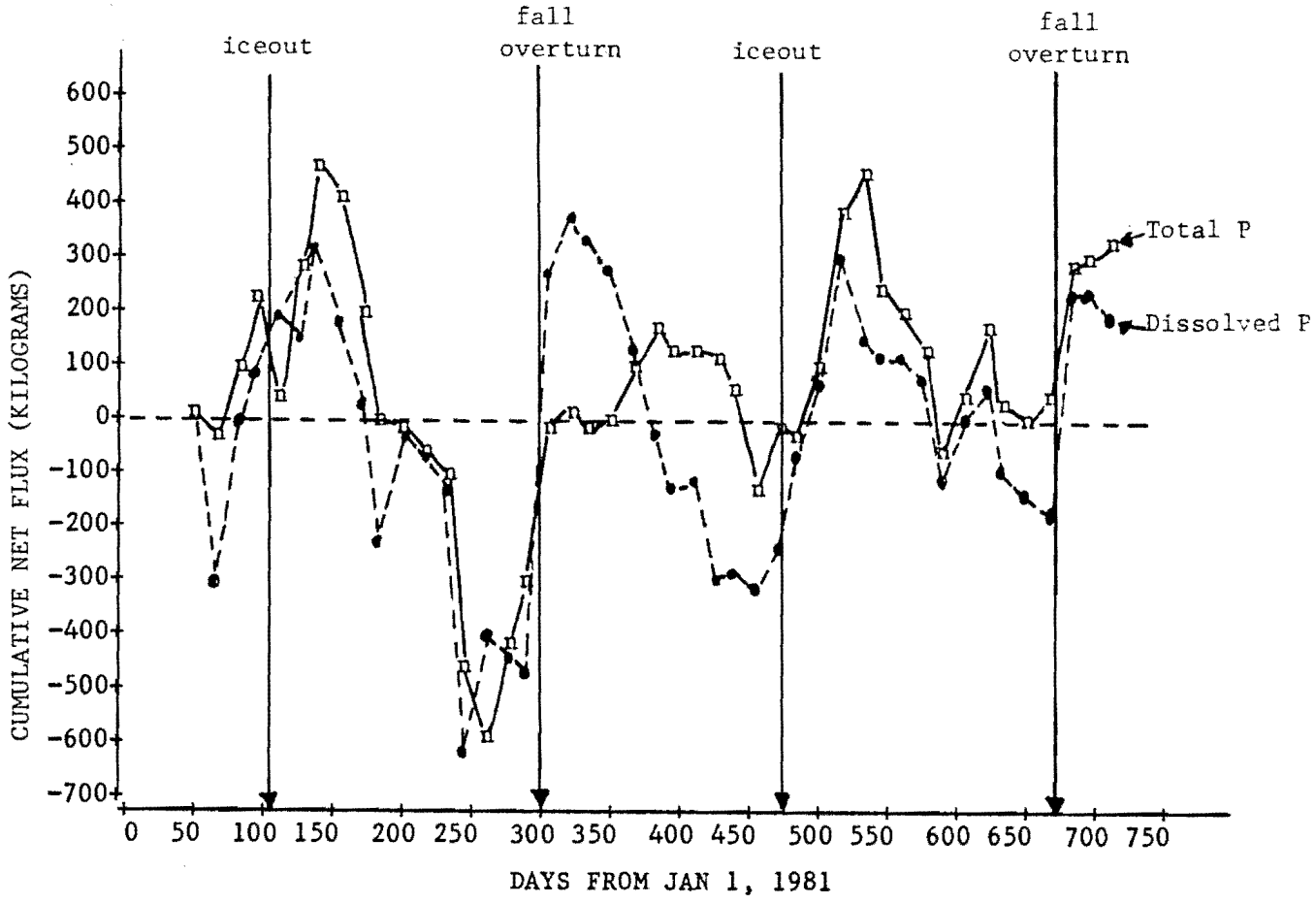
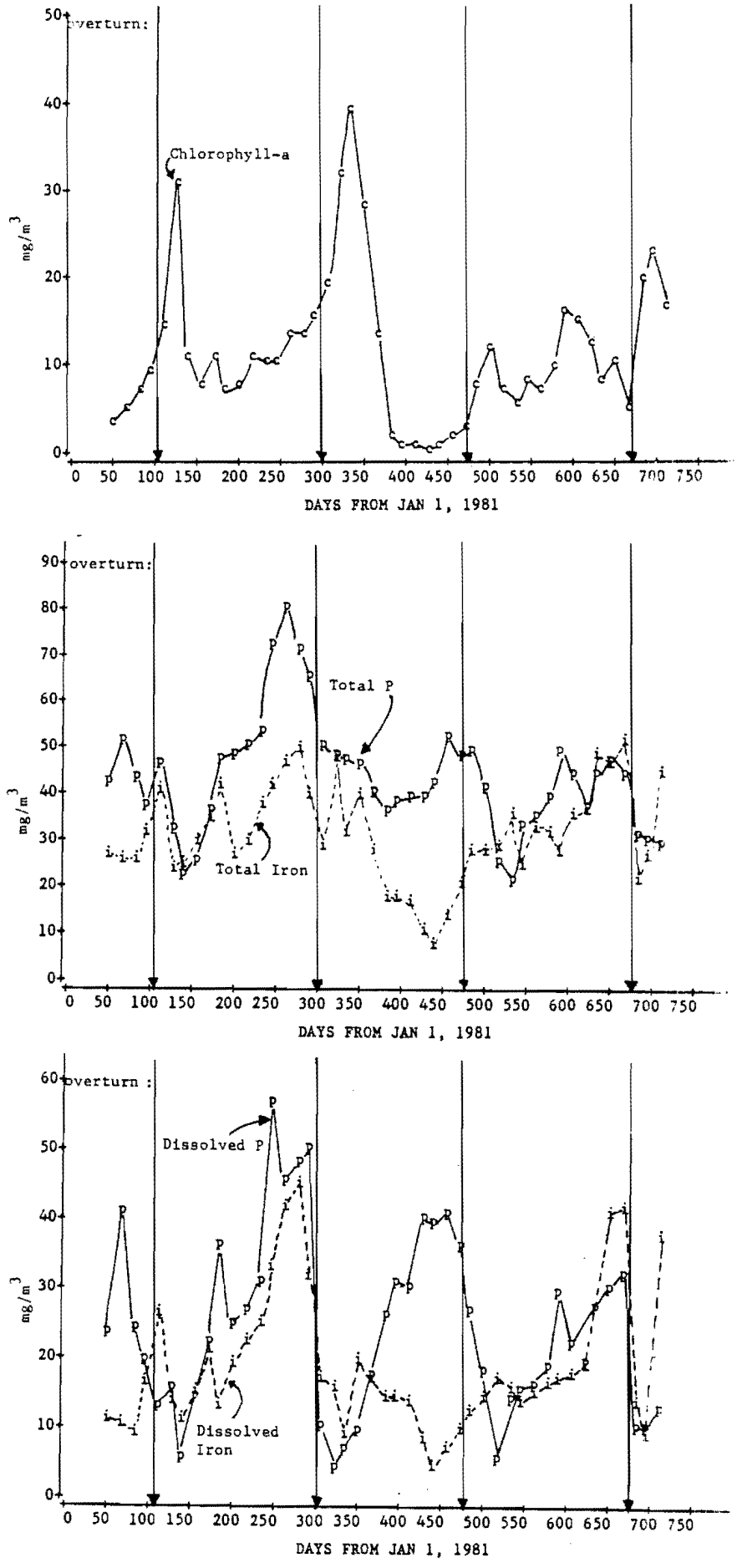


Figure 6

Time Series of Volume-Weighted Water Quality Measurements



column. Note that the cumulative sedimentation curves are derived directly from mass balances and do not rely upon any model of phosphorus dynamics within the lake.

The periodic behavior of the cumulative sedimentation curves reflect seasonal variations in the factors controlling phosphorus deposition and release and provide considerable insight into lake dynamics. Interpretation of these curves is aided by time series of volume-weighted chlorophyll-a, total phosphorus, total iron, dissolved phosphorus, and dissolved iron in Figure 6 and by the other time series and contour diagrams in the Appendix. To facilitate comparisons with the mass balances in Figures 3-5, the volume-weighted concentration time series have been interpolated at the same 15-day intervals.

Periods of positive net sedimentation for total P and dissolved P (positive slopes in Figure 5) correspond closely to spring and fall overturn periods. These, in turn, correspond to periods of peak algal growth rate (spring and fall) and periods of iron deposition (fall). This correlation reflects the importance of (a) algal uptake and sedimentation and (b) coprecipitation with iron as net removal mechanisms during periods when the water column is primarily mixed and oxic. Periods of positive net deposition generally bracket the overturn periods and last for approximately 60 days. In fall, they begin with erosion of the thermocline into anoxic zones and subsequent introduction of dissolved iron and phosphorus into the mixed layer.

Periods of negative deposition (negative slope) develop during summer stratification and are generally similar for dissolved and total phosphorus. During the 1981 season, a net release of about 1000 kg occurred between days 150 and 250. During this period, releases from bottom sediments overwhelmed any deposition attributed to algal uptake and settling or direct settling of inflowing particulates. The source of the net release would include:

(1) mineralization of algal and allochthonous particulate phosphorus deposited during previous net sedimentation cycles (particularly, the spring chlorophyll burst);

(2) release of phosphorus (and iron) from geologic sediments during

anoxic periods attributed to diffusion and low redox potential;

(3) phosphorus releases from littoral zones, partially mediated by macrophytes;

Compared with 1981, net releases were lower during the 1982 summer season and amounted to about 500 kilograms. Possible explanations for this difference include:

(1) differences in stratification and oxygen depletion, which developed somewhat earlier and was somewhat more severe in 1981 vs. 1982, probably as a result of the early spring runoff in 1981;

(2) lower algal densities in 1982, particularly in the spring and fall bloom periods; this would cause less deposition of phosphorus for subsequent release and less reducing power to drive redox reactions in the hypolimnion;

(3) differences in dominant algal species between the two years; during most of the stratified season, the 1981 population contained a higher percentage of blue greens and the 1982 population, a higher percentage of diatoms and other algal types; phosphorus associated with blue greens would be more amenable to recycling than phosphorus associated with diatoms because of the stabilizing influence of silica shells;

(4) differences in the iron/sulfur/phosphorus chemistry of the lake hypolimnion between the two summer seasons; sulfate levels were depleted on one monitoring date in 1981; Fe/P ratios in the hypolimnion were also higher in 1982; according to the model discussed by Stauffer (1981), this would increase the potential for net phosphorus releases from bottom sediments because of iron sulfide precipitation (see below);

Differences in the dynamics of dissolved vs. total phosphorus are apparent between fall overturn in 1981 and spring overturn in 1982. While the total phosphorus balance was fairly stable (no net sedimentation), there was a marked source of dissolved phosphorus, amounting to about 800 kilograms over this period. Because of the stability of the total phosphorus balance, the dissolved phosphorus

Table 6
Dissolved Phosphorus Balances at Fall Overturn

		1981	1982
Days from Jan 1, 1981		250-350	650-700
Decrease in Dissolved Iron		35	30
Increase in Chlorophyll		30	15
Decrease in Dissolved P		40	22
Taken up by Algae	*	30	15
Precipitated with Iron	**	11	9
Unaccounted for		-1	-2

entries based upon volume-weighted concentrations, mg/m3 (Figure 6)

* assuming 1 mg P / mg Chl-a in algal cells (Zison et al.,1978)
** assuming .3 mg P/mg Fe in iron precipitate (Stauffer,1981)

note: Winter regeneration of dissolved phosphorus between days 350 and 450 roughly equals 30 mg/m3, algal uptake at fall overturn 1981.

source must be explained by conversion of particulate to dissolved phosphorus compounds in the water column. The particulate phosphorus would include algae produced at fall overturn (see Figure 6) and watershed loadings, especially those entering the lake during the (unusual) fall runoff period in 1981, which contained a relatively high percentage of particulate phosphorus, possibly associated with leaves.

Figure 5 shows that dissolved phosphorus concentrations are highly dynamic at fall overturn. Calculations in Table 6 further indicate that the reductions in dissolved phosphorus are consistent with the observed increases in chlorophyll and decreases in dissolved iron. Losses in dissolved phosphorus can be largely explained by algal uptake and iron precipitation in both 1981 and 1982 using reasonable stoichiometric coefficients. Algal uptake dominates in both years. The estimated algal uptake during fall overturn in 1981 roughly equals the dissolved phosphorus regenerated during the following winter. Because severe reducing conditions are not reached in the hypolimnion during the winter, phosphorus precipitated with iron at fall overturn would not contribute to water column conditions at spring overturn. In a "normal" lake with a higher Fe/P ratio, iron precipitation would be expected to dominate and a relatively small percentage of the dissolved phosphorus lost at fall overturn would be regenerated over the winter for subsequent use in the spring.

If the total phosphorus balance is formulated from the start of the sedimentation cycle prior to spring overturn in 1981 (day 50) to just after fall overturn 1981 (day 350) or to the start of the sedimentation cycle prior to spring overturn in 1982 (day 450) the net sedimentation of phosphorus is zero and external inputs are in balance with the lake discharge. Essentially, any sedimentation is balanced by net releases during the stratified periods.

If the total phosphorus balance is formulated from the start of the sedimentation cycle prior to spring overturn on 1982 (day 450) to the end of the monitoring period (day 725), a net phosphorus sedimentation of about 400 kilograms is indicated. This does not include a complete cycle, however; the cumulative phosphorus sedimentation curve dipped

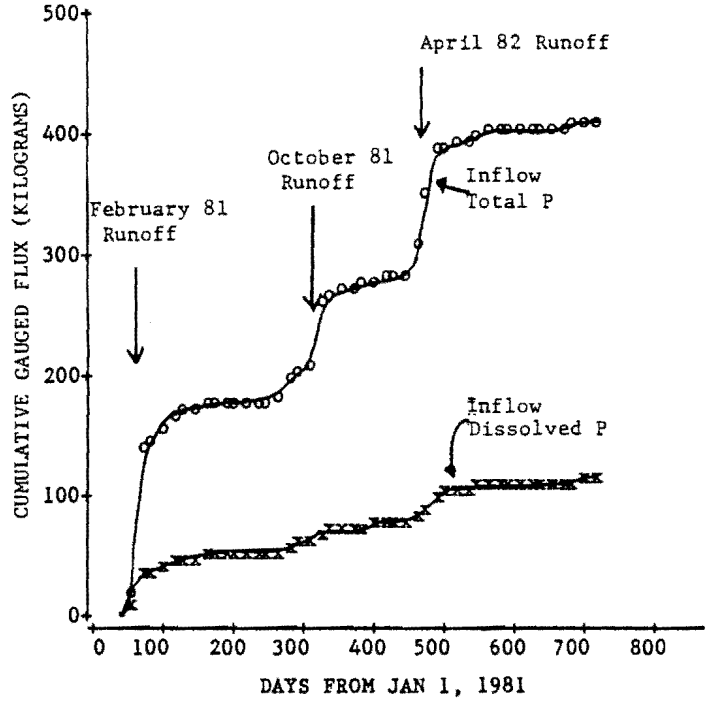
downward somewhat during the latter half of the winter cycle in 1982 (days 375-450), possibly due to decay of algae deposited after the fall overturn bloom. It seems possible that a similar decline would have been observed, had the monitoring period been extended through the winter season from December 1982 through February 1983.

Figure 7 plots cumulative gauged loadings from all monitored tributaries (excluding DH#ACC) against time and cumulative inflow volume. Steps in the cumulative total phosphorus load against time reflect the importance of runoff periods. The steps are smoothed somewhat when load is plotted against volume; in this case, changes in slope reflect changes in average concentration which also tend to occur during runoff periods. Generally, the dissolved phosphorus loading curves are more steady because the dissolved phosphorus fraction tends to vary less with flow than the particulate fraction.

Figure 8 presents alternative views of the total loading (all sources) and outflow flux curves. Cumulative flow volume is used in place of time as the x ordinate. By dividing load by volume, cumulative mean concentration curves can be developed. The inflow concentration curve illustrates the relatively high concentrations which were monitored during the runoff period at the beginning of the survey (February 1981). The stability of the cumulative inflow and outflow concentration curves in the latter portion of the survey indicates that reasonable estimates of average conditions over this period have been reached.

Despite the large seasonal variations in storage and sedimentation, input and output data indicate that the bottom sediments of Lake Morey only a small portion of the external phosphorus loading on an annual-average basis. This is relatively unusual for a lake with a hydraulic residence time in excess of 1 year, which would normally be expected to trap about half of the inflowing phosphorus, based upon the Larsen-Mercier (1976) phosphorus trapping function. The low retention capacity is related to lake morphometry (conducive to oxygen depletion), and to iron/phosphorus/sulfur chemistry, as discussed in the following section.

Figure 7
Total and Dissolved Phosphorus Cumulative Loadings
vs. Time and Cumulative Volume



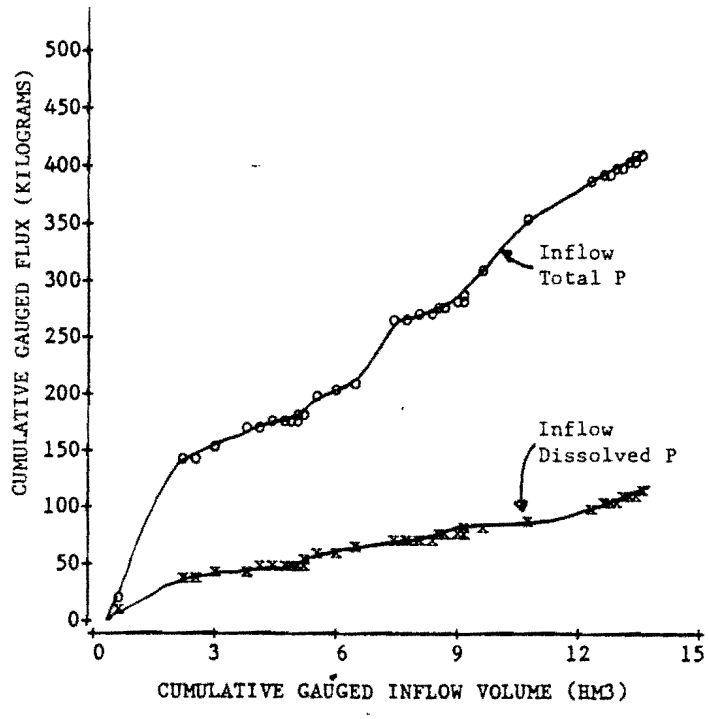
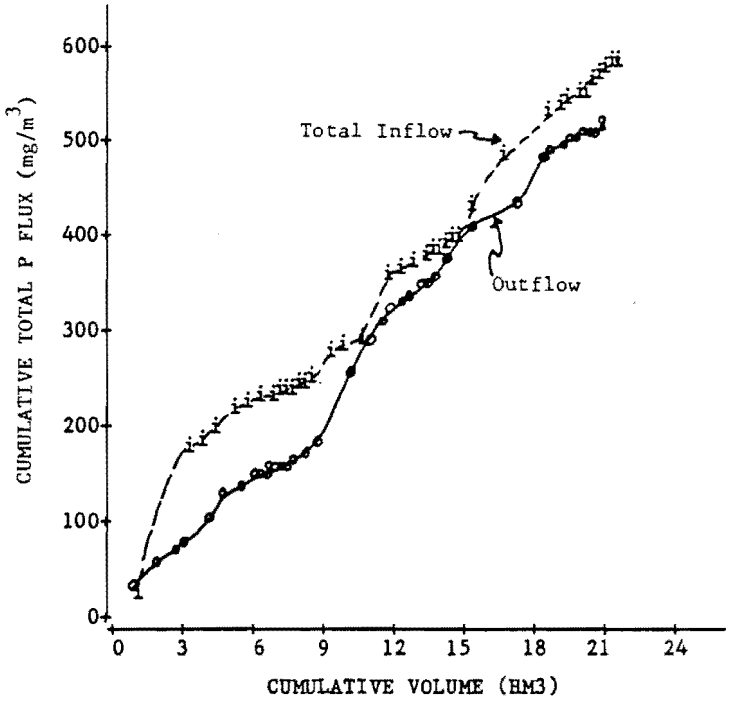
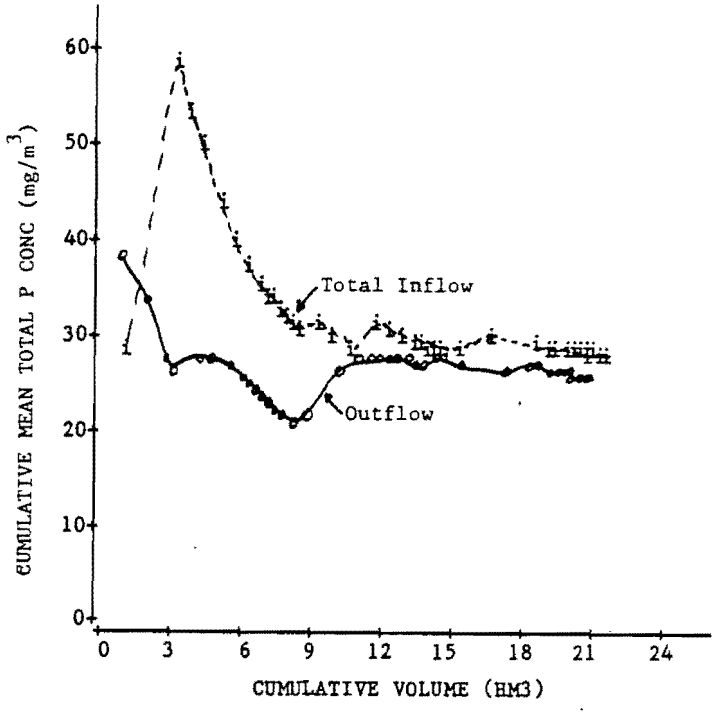


Figure 8
Cumulative Total Phosphorus Inputs and Outputs vs. Cumulative Volume





5. Factors Contributing to Phosphorus Recycling

The morphometry of the Lake Morey basin renders it relatively susceptible to oxygen depletion and redox-related recycling of phosphorus from bottom sediments. Important controlling factors include:

(1) stable thermal stratification, reflecting the depth and sheltered nature of the basin; this causes low rates of oxygen transport into the hypolimnion during the summer;

(2) a relatively thin hypolimnion (mean depth 2 meters); this provides a relatively low supply of oxygen per unit area at spring turnover;

(3) a high ratio of hypolimnetic to epilimnetic surface area (.59); this increases the significance of internal loadings generated in and over anoxic sediments;

While the above morphometric factors and resulting susceptability to oxygen depletion are of prime importance, certain chemical aspects also contribute to internal recycling efficiency, as discussed below.

Total and dissolved Fe/P ratios in the hypolimnion were extremely low during both summers (generally between .25 and .65 on a mass basis) but slightly higher in 1982. Stauffer's (1981) model indicates that phosphorus in excess of .3 times the reduced iron concentration (mass basis) is free to migrate. At the above Fe/P ratios, this indicates that only 8-20 percent of the phosphorus which accumulates in the hypolimnion would be tied up by iron oxidation and precipitation or that 80-92 percent is free to migrate into the mixed layer and promote algal growth.

Vertical migration occurs by diffusion during stratified periods, thermocline erosion (late summer and fall), and fall overturn. Based upon review of phosphorus stratification data, the above mechanisms are listed in order of increasing importance. Epilimnetic phosphorus concentrations do not show significant increases until relatively late in the season (late August/early September) after appreciable seasonal

migration of the thermocline has occurred. This partially reflects thermal stability and the sheltered nature of the lake basin. Vertical phosphorus transport and stratification characteristics are undoubtedly responsible for the development of high algal densities in the metalimnion during the summer period, however.

Table 7 summarizes data on water quality conditions at spring overturn and periods of peak hypolimnetic phosphorus accumulation for each year. Calculations indicate that free dissolved P in the hypolimnion amounted to 46-47% of the total dissolved phosphorus in the water column at the peak accumulation (generally mid-late September). Thus, a major portion of the recycling and transport into the mixed layer occurs at or near fall overturn. Since the cumulative mass balance indicates that total phosphorus is relatively conservative over the winter, the vertical transport which occurs at turnover is of prime importance to spring overturn and initial epilimnetic phosphorus concentrations in the following year.

Detailed calculations aimed at estimating the vertical transport of phosphorus during the summer (Stauffer,1981) do not seem warranted in this case because most of the recycling into the mixed layer occurs at or near fall turnover. They would have some bearing on predictions of metalimnetic algal densities, but these are probably of less significance from a management perspective than surface algae. In any case, the types of management strategies which would be examined in a feasibility study would likely be aimed at reducing external phosphorus loading and reducing phosphorus accumulation in the hypolimnion (through chemical treatment, aeration, etc.) and would not hinge on a detailed vertical transport analysis, since there are no feasible strategies for reducing vertical eddy diffusion rates or thermocline migration.

Lake Morey has abnormally high sulfate concentrations (by about a factor of 2-3) in comparison with other Vermont Lakes (VDWR, 1982). Approximate mass balance calculations indicate that two tributaries (DH#6 and DH#7) draining the into the northeastern portion of the lake have abnormally high sulfate levels (averaging 122-158 mg/liter vs. c.a. 10 mg/liter for other tributaries); they account for about 70% of the

Table 7
Summary of Hypolimnetic Conditions at Srping Overturn and Peak Phosphorus Accumulation

Year	1981	1981	1982	1982
	Spring Overturn	Peak Accum.	Spring Overturn	Peak Accum.
Dates	15-23 Apr	15 Sep	28 Apr/ 03 May	23-Sep/ 08 Oct
Total P	43	760	23	420
Dissolved P	15	685	8	350
Total N	488	2760	540	2050
NO2+NO3-N	58	22	100	20
Ammonia N	3	2140	52	1500
Total Silica	1.5	6.1	2.9	8.1
Total Iron	37	255	30	295
Dissolved Iron	21	245	9	295
Total Manganese	89	2140(2 Sep)	-	2300
Sulfate	39	18	19.5	8.8
pH	6.9	6.8	7.2	6.7
Temperature	4.9	8.9	5.2	8.5
Oxygen	11.0	0.0	10.1	0.0
Total Fe/P	.86	.34	1.30	.70
Dissolved Fe/P	1.40	.36	.39	.84
Free Dissolved P				
mg/m3	-	612	-	262
% of Dissolved P	-	89%	-	75%
Kilograms:				
Water Column Dissolved P		1191		518
Free Dissolved Hypol. P		557 (47%)		238 (46%)

Notes:
all units mg/m3 except temperature (deg C), oxygen, sulfate, silica (g/m3)

Free Dissolved P = Total Dissolved P - .30 Total Dissolved Iron

Kilograms computed from volume-weighted concentrations using total lake volume of 18.5 hm3 and hypolimnetic volume (below 10.5 meters) of .91 hm3

sulfate loading but only about 15% of the water loading to the lake. The source of these sulfates appears to be materials used in building Route 91 (VDWR, 1983). The iron-poor nature of Lake Morey may be partially attributed to these abnormally high sulfate loadings.

Extremely high sulfide concentrations accumulate in the hypolimnion of the lake (in excess of 21-22 mg/liter on September 9, 1982) as a result of sulfate reduction under anaerobic conditions. Iron precipitates as iron sulfide under these conditions at neutral to alkaline pH's (Hutchinson, 1975, Stauffer, 1981). Iron/phosphorus/sulfate stoichiometry indicates a high potential for enhancement of internal phosphorus loadings via this mechanism. For example, 1 mole of sulfide could tie up 1 mole of iron which would release .55 moles of phosphorus. Expressed on a mass basis, reduction of 1 g/m3 of sulfate and subsequent conversion to iron sulfide would free 180 mg/m3 of phosphorus. Considering that sulfate levels in the lake average about 20-30 g/m3, there is an adequate sulfate supply for this mechanism to operate and have a significant effect on the iron and phosphorus balances.

As discussed by Stauffer (1981), lakes with hypolimnetic pH values above 6 can have appreciable reduced iron <u>or</u> hydrogen sulfide concentrations <u>but not both</u> because of the limited solubility of iron sulfide. On September 7, 1982, the hypolimnion of Lake Morey had a pH of 6.7, hydrogen sulfide concentration of 21 g/m3, and dissolved iron concentration of 200 mg/m3. Based upon approximate FeS solubility data presented by Hutchinson (1975), only 1.7 mg/m3 of reduced iron could exist at the above pH and hydrogen sulfide concentration at equilibrium with solid FeS. Thus, either the solubility data are off by two orders of magnitude or an appreciable portion of the observed dissolved iron is not ferrous iron. Organic chelation of dissolved iron in the hypolimnion could be important (Stumm and Morgan, 1970). If the solubility products are correct, then the calculations in Table 7 probably underestimate the concentrations of free phosphorus in the hypolimnion at the end of the stratified period; essentially all of the dissolved phosphorus would be mobile.

The considerable hydrogen sulfide accumulations in the presence of dissolved iron suggest that not all of the reduced sulfate is converted to iron sulfide and precipitated. The fact that appreciable sulfate concentrations remain in the hypolimnion at the end of the stratified period further indicates that the generation and precipitation of sulfides may not be first-order in sulfate concentration but limited by some other factor, such as energy supply or chelation. If this is the case, then a reduction in external sulfate supply would not necessarily result in proportionate reductions in sulfide generation, iron sulfide precipitation and phosphorus releases. Hypolimnetic sulfate levels were nearly depleted (< 2 g/m3) on only one sampling date (July 8, 1981) but subsequently increased to 18 g/m3 on September 9, 1981. The presence of purple sulfur bacteria in the hypolimnion (VDWR,1983) complicates analysis of the iron/sulfur interactions because they oxidize hydrogen sulfide to sulfate.

Sediment core samples indicate a reduction of about 40% in iron content and an increase of about 50% in manganese content between 1972 and 1982. According to sediment dating (Brugham,1983), an increase in sediment deposition also occured over this period. Between 1955 and 1972, the average deposition rate was .29 cm/year, compared with .80 cm/year between 1972 and 1982. These changes are correlated with construction of Route 91 in the early 70's. Hypothetically, the above data indicate that sediments contributed from the interstate area are rich in manganese and poor in iron. Goundwater seeps sampled in the watershed of DH#6 on December 23, 1982 indicated total iron concentrations of .24-.52 g/m3 and total manganese concentrations of 29-30 g/m3 (VDWR,1983). Deposits of precipitated iron were also noted at these locations and would be expected because of the relatively rapid oxidation kinetics of iron. Sediments contributed from the area may have lower Mn/Fe ratios. Aside from the increased sulfate loadings, an alternative explanation for the depletion of iron in Lake Morey is that the bottom is being coated by iron-poor sediments from portions of the watershed. Additional sampling and analysis would be required to test this hypothesis.

In summary, the efficiency of phosphorus recycling in Lake Morey is related to morphometric characteristics which render the lake relatively susceptible to hypolimnetic oxygen depletion. The iron-poor nature of sediments and hypolimnetic waters are also important. High sulfate loadings may be partially responsible for the iron depletion, but sulfate and sulfide concentrations appear to be in excess most of the time. Iron sulfide precipitation and phosphorus releases would not necessarily be proportional to external sulfate loadings. The iron depletion may also be related to recent increases in the input of iron-poor sediments from portions of the watershed.

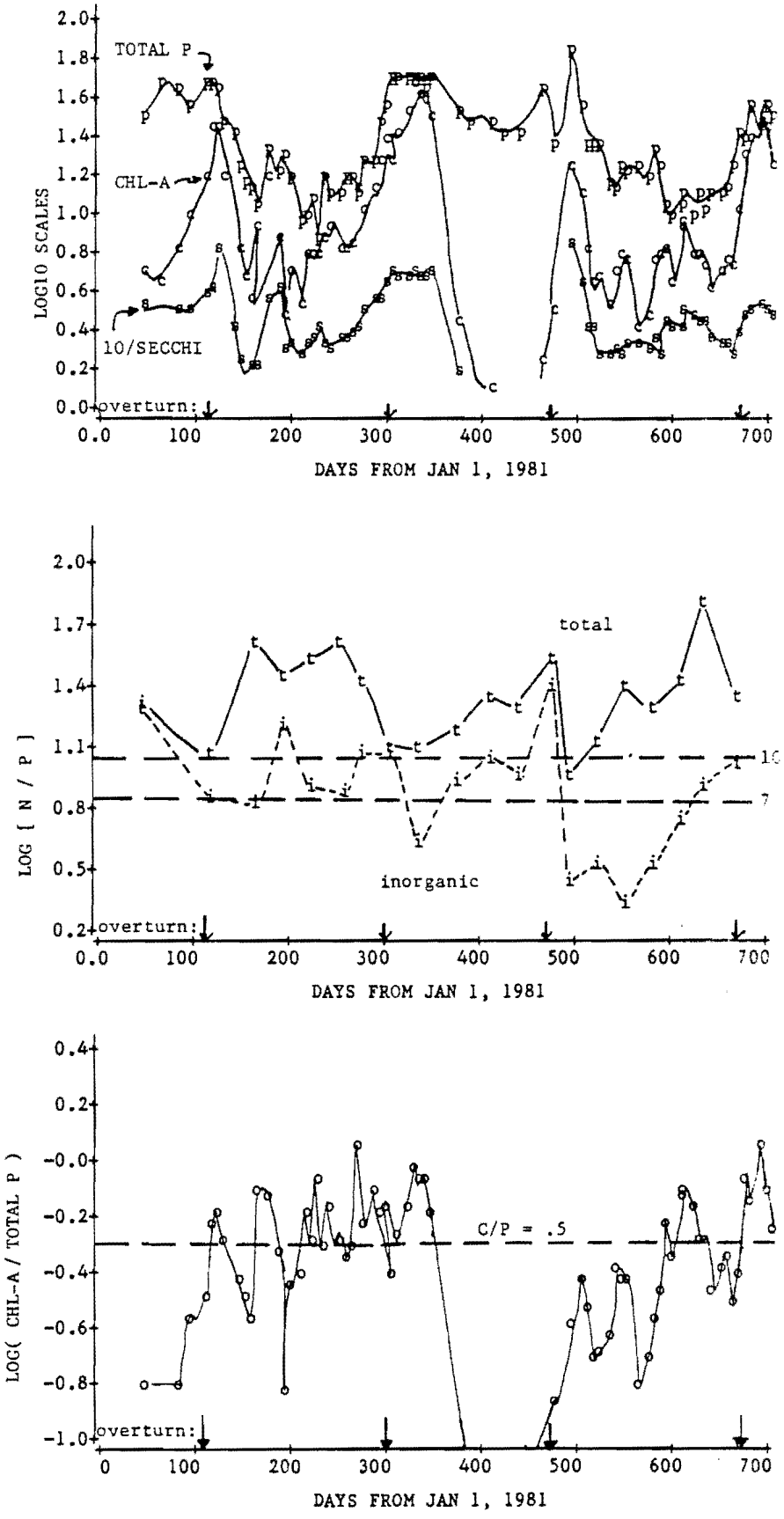
6. Model Development

This section develops a methodology for predicting Lake Morey water quality responses to changes external phosphorus loading and internal recycling characteristics. Using observed loading, hydrologic, and lake water quality data, the Lake Eutrophication Analysis Procedure (Walker, 1982), previously developed and tested on data from over 40 Vermont Lakes, is calibrated for use in predicting average, May-September, surface-layer concentrations of total phosphorus, chlorophyll-a, and transparency and hypolimnetic oxygen depletion rate.

Use of phosphorus mass balance models for predicting lake trophic status relies upon the covariance between phosphorus, as a limiting factor for algal growth, and lake response indicators, such as chlorophyll, transparency, and hypolimnetic oxygen depletion rate. Time series plots of surface-layer (0-4 meter average) water quality data from Lake Morey are given in Figure 9. A strong temporal covariance among phosphorus, chlorophyll, and inverse Secchi depth is indicated betweeen spring and fall overturn periods. Seasonally maximum concentrations are generally experienced at or near spring overturn. This is followed by a period of rapid decline probably associated with algal uptake and sedimentation, as indicated by the mass balances discussed above. Rapid declines in phosphorus levels following spring overturn have been observed in other stratified lakes (Pepas and Trew, 1983). Seasonally minimum concentrations occur in August and are followed by increases attributed to thermocline erosion and release of

Figure 9

Time Series of Eplimnetic Water Quality Measurements



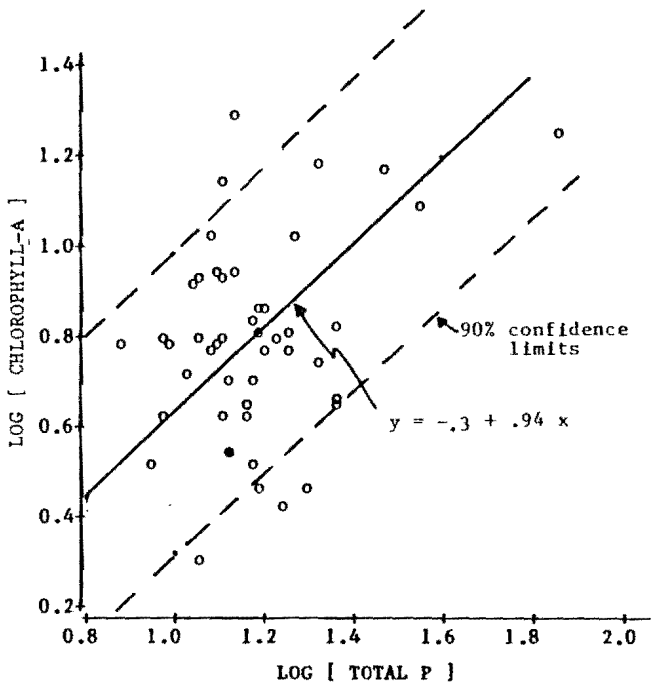
the dissolved phosphorus stored in the hypolimnion.

Time series of inorganic and total N/P ratios (Figure 9) indicate a period of nitrogen limitation during the 1982 season (days 500-600), when the inorganic N/P ratio fell below algal physiologic requirements (c.a. 7). The chlorophyll/total phosphorus ratio was also suppressed during this period, as would be expected under nitrogen-limited conditions. The development of nitrogen limitation in 1982 may reflect unusually high external and internal phosphorus loadings experienced the previous year. Nitrogen limitation was strongest immediately following spring overturn and the system reverted to phosphorus limitation later in the season. The inorganic N/P ratio computed using total dissolved phosphorus may over-assess nitrogen limitation because some of the total dissolved phosphorus may not be biologically available (Peters, 1979).

Figure 10 compares growing season (May-September) data with the chlorophyll/phosphorus and chlorophyll/transparency relationships previously calibrated to other Vermont lakes and used in LEAP (Walker, 1982). Considerable scatter is expected in these plots because the models are designed to predict average conditions, as opposed to discrete measurements. The plots indicate that the Lake Morey data are generally consistent with these LEAP submodels. The transient nitrogen limitation which developed in 1982 does not severely limit the validity of a phosphorus-based model for predicting average growing-season chlorophyll concentrations.

Table 8 summarizes average trophic state indicator data for each monitored year. Because of the rapid decline in surface phosphorus levels following spring overturn, May-September phosphorus concentrations averaged about one third of the spring overturn concentrations in each year (46 vs. 15 and 54 vs. 18 mg/m3, respectively). This seasonal behavior was not directly incorporated in the LEAP model framework, primarily because summer phosphorus measurements were generally unavailable for Vermont Lakes. Below, the LEAP phosphorus trapping function is recalibrated for predicting average, surface-layer, May-September conditions in Lake Morey, which are more significant from a management perspective than those at spring

Figure 10
Surface Water Quality Variations in Relation to LEAP Submodel Predictions



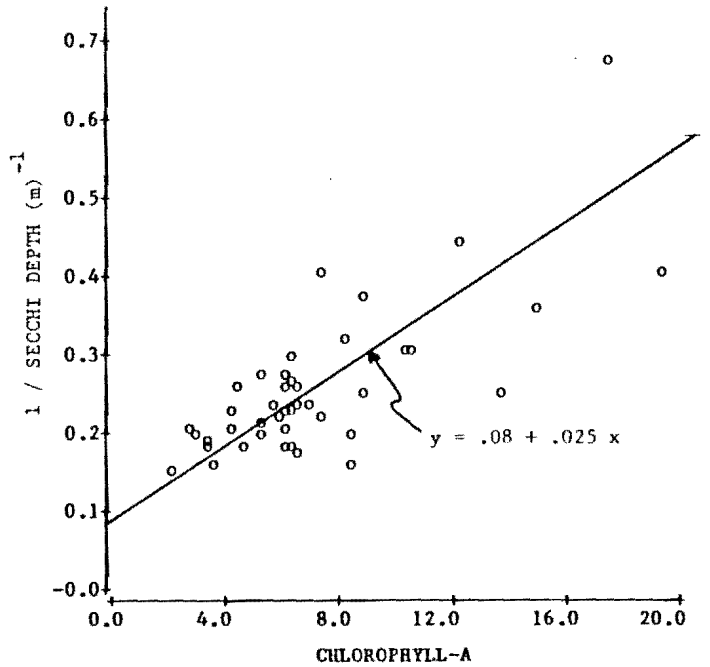


Table 8
Summary of Input Values for Phosphorus Mass Balance Modeling

Input Variables	Units	Value(s)
Watershed Area (excluding lake)	km2	19.1
Lake Area	km2	2.2
Lake Volume	hm3	18.5
Mean Depth	m	8.4
Maximum Depth	m	13.1
Thermocline Depth	m	9.0
Mean Hypol. Depth	m	2.1
Hypol. Surface Area	km2	1.30
Atmospheric P Loading	kg/km2-yr	18
Tributary P Loading	kg/yr	295
Tributary Water Loading	hm3/yr	9.0
Watershed Runoff Rate	m/yr	.47
Excess Precipitation (Precip. - Evaporation)	m/yr	.32

Observed Lake Conditions

			1981		1982		1981/82	
Variable		Units	mean	cv	mean	cv	mean	cv
HOD		g/m2-day	.53	-	.55	-	.54	-
Spring P		mg/m3	46.4	-	54.3	-	50.4	-
Summer P	*	mg/m3	15.0	.08	18.3	.15	16.7	.09
Mean Chl-a	*	mg/m3	7.3	.11	6.1	.12	6.7	.08
Maximum Chl-a	*	mg/m3	14.8	-	17.2	-	16.0	-
Secchi	*	mg/m3	4.6	.05	4.2	.06	4.4	.04

* May-September, 0-4 meter average

overturn.

Table 9 lists LEAP input values for a total of seven cases which have been run in the calibration process. Model output for each case is compared with observed loadings and water quality conditions in Table 10. A minor change in the hydrologic portion of the model code has been made to account explicitly for excess precipitation (precipitation - evaporation), as outlined in Table 9. Cases A-C use the LEAP land-use/phosphorus export model to estimate total external loadings, which range from 241-275 kg/year, as compared with the values of 408 and 237 kg/yr measured in 1981 and 1982, respectively.

Cases D and E bypass the land/use portion of the model and substitute the measured average external loading (335 kg/yr). In Case E, the model error input values (subscripts 40-44) are used to calibrate the framework to the observed response data. Because of the seasonal declines in phosphorus discussed above, a downward adjustment in phosphorus error term (40) from 1.0 to .65 is required in order to calibrate the model to average growing-season conditions. Only minor adjustments in the chlorophyll and transparency terms are required once the model is calibrated for phosphorus, as indicated by Figure 10. The increase in the oxygen depletion term from 1.0 to 1.25 is also related to seasonal phosphorus declines. Depletion rates are measured early in the season (May), before oxygen is lost from the hypolimnion. In the model, depletion rates are computed as a function of morphometry and the predicted lake phosphorus concentration; since the latter has been calibrated to average growing-season conditions, the upward adjustment in the oxygen depletion rate is needed to reflect that fact that phosphorus levels (and productivity) in May tend to be higher than the growing-season average.

Cases F and G employ the calibrated model (E) to investigate sensitivity to loading and hydrologic regime, using measured values for 1981 and 1982, respectively. Predicted lake phosphorus concentrations are 17.8 mg/m3 for the 1981 loading conditions and 12.2 mg/m3 for 1981 conditions. As discussed in previous sections, the lake would not necessarily equilibrate with the loading regime in any given year

Table 9
Input Variables for LEAP Application to Lake Morey

INPUT VARIABLE *		CASE A	B	C	D	E	F	G
1 Undev Non-Sedim	ac	3924.54						
3 Untilled Non-Sedim	ac	459.00						
5 Tilled Non-Sedim	ac	51.00						
7 Urban Area	ac	128.00						
8 Lake Surface Area	ac	538.46	544					
10 Mean Depth	m	8.30	8.4					
11 Basin Mean Depth	m	8.30	8.4					
12 Maximum Depth	m	13.10						
13 Thermocline Depth	m	9.00						
14 Hypolimnion Depth	m	2.00	2.1					
15 Hypol Surface Area	ac	288.99	321					
16 Runoff	m/yr	0.56		.47			.58	.37
17 Shoreln Septic	cap/yr	382.80						
18 Extra P Load	kg/yr	0.00			295		370	198
19 Chl/Secchi Int	1/m	0.08						
20 Obs Spring P	mg/m3	27.07	16.7					
21 Obs Mean Chla	mg/m3	9.52	6.7					
22 Obs Max Chla	mg/m3	20.46	16.0					
23 Obs Secchi Depth	m	4.72	4.4					
24 Obs HOD	g/m2-day	0.51	.54					
25 Excess Precip	m/yr **	-	.32					
27 Septic P Fac	kg/cap-yr	0.05			0			
28 Spring DO	g/m3	12.00						
29 Undev Non-Sed P	mg/m3	15.00			0			
31 Untld Non-Sed P	mg/m3	30.00			0			
33 Tilled Non-Sed P	mg/m3	57.00			0			
35 Urban P	mg/m3	139.00			0			
36 Atmos P Load	kg/km2-yr	20.00			18			
37 Internal Load Param		8.00						
38 Chl/Secchi Slope	m2/mg	.025						
39 Mod Error - Watershed		1.00						
40 Mod Error - P Retent		1.00				.65		
41 Mod Error - Chl-a		1.00				.96		
42 Mod Error - Chl-max		1.00				1.15		
43 Mod Error - Secchi		1.00				1.09		
44 Mod Error - HOD		1.00				1.25		

* unlisted input variables are zero or inconsequential
blank entries assume value to left

** new model input variable (precipitation - evaporation) accounts for excess precipitation on lake surface and requires change of code in line 3610 to:

```
Y(9) = A1*X(16)/X(8) + X(25)
```

Cases:

A = original LEAP run (Walker, 1981)
B = A with new morphometric information and excess precipitation
C = B with hydrology (runoff) adjusted to 1981-1982 conditions
D = observed mean tributary loadings and atmospheric loadings
E = calibrated, observed mean tributary loadings and runoff
F = calibrated, observed tributary loadings and runoff - 1981
G = calibrated, observed mean tributary loadings and runoff - 1982

Table 10

Observed and Predicted Conditions

	CASE							OBSERVED		
Variable	A	B	C	D	E	F	G	mean	1981	1982
External Load	274	275	241	335	335	408	237	335	408	237
Net Internal Load	81	89	76	205	135	186	69	-	-	-
Runoff m/yr	.56	.56	.47	.47	.47	.58	.37	.47	.58	.37
Spring P								50.4	46.4	54.3
Summer P	15.3	15.9	16.0	32.5	16.5	17.8	12.2	16.7	15.0	18.3
Mean Chl-a	6.5	6.7	6.8	13.2	6.7	7.2	5.0	6.7	7.3	6.1
Max Chl-a	13.5	14.0	14.2	30.3	16.0	17.4	11.6	16.0	14.8	17.2
Secchi Depth	4.2	4.0	4.0	2.4	4.4	4.2	5.3	4.4	4.2	4.4
Areal HOD	.40	.42	.42	.82	.54	.58	.41	.54	.53	.55

because of the long hydraulic residence time and limited phosphorus retention capacity.

Calibrated in the above way, LEAP can be used to assess lake responses to changes in external loading and internal recycling characteristics. Predicted summer phosphorus concentrations are plotted against external tributary loading (exclusive of atmospheric loading) in Figure 11 for various values of the LEAP internal loading parameter (subscript 37). The latter parameter relates net internal loading to oxygen depletion rate and the ratio of hypolimnetic to epilimnetic surface area. Management strategies aimed at reducing internal loading (aeration, alum treatment, etc.) could be represented by a downward adjustment from 8.0, the originally calibrated value. Complete destratification or complete elimination of redox-related internal recycling would be represented by a value of zero.

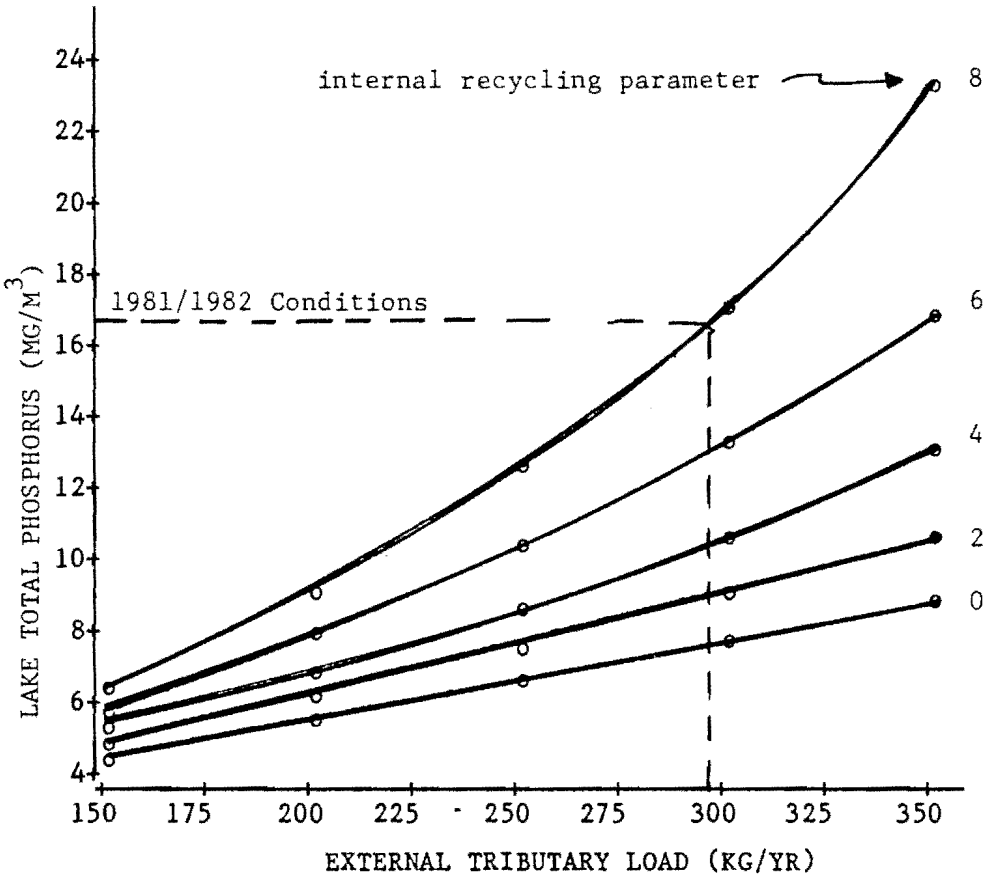
The dashed lines in Figure 11 indicate existing conditions, based upon the 1981/82 average. The apparent sensitivity to internal loading is consistent with results of the transient mass balance analysis. More detailed analysis of specific watershed and in-lake management options can be done by setting up the calibrated version of LEAP on the VDWR computer, using the input values for Case E in Table 9.

Epilimnetic chlorophyll-a concentrations represent only a portion of the total productivity picture of Lake Morey because of the significance of metalimnetic algae. A much more elaborate model which explicitly accounts for vertical nutrient transport and algal population kinetics would be required to predict metalimnetic algae concentrations and total productivity per unit area. If the lake vertical stratification and internal recycling regimes are not altered, responses of metalimnetic algae to reductions in external loading and/or internal recycling would be qualitatively similar to those predicted for surface algae. Management strategies which reduce the accumulation and/or vertical transport of phosphorus in the hypolimnion during the growing season would also reduce the accumulation of metalimnetic algae, since phosphorus appears to be limiting.

Seasonal declines in surface phosphorus and chlorophyll attributed

Figure 11

Predicted Responses of Mean Epilimnetic Phosphorus to Changes in External Tributary Loading and Internal Recycling Coefficient



to algal uptake and sedimentation are implicit in the model calibration. Model predictions would be invalid if the management strategy altered the vertical stratification regime and increased the vertical transport of phosphorus during the growing season. If the engineering aspects are feasible, hypolimnetic aeration without destratification would probably be preferable to complete destratification.

Model predictions refer to long-term steady-state conditions. Instantaneous responses to changes in external loading and internal recycling characteristics would not be expected. A measure of response time is given by the "phosphorus residence time", or ratio of average mass in the lake to annual external loading. Based upon a mass balance, this statistic can be computed from:

$$Tp = Tw\ (1 - Rp)$$

where,

Tp = phosphorus residence time (years)

Tw = hydraulic residence time (years)

Rp = annual phosphorus retention coefficient

Under existing conditions, the net retention coefficient is near zero, so that the phosphorus residence time can be approximated by the hydraulic residence time, or roughly 2 years. A time period of roughly twice the phosphorus residence time would be required for a 90% response of the system to changes in loading. Reductions of internal loading (recycling is a better term) would reduce both the equilibrium phosphorus level and phosphorus residence time because of increases in the retention coefficient. Thus, the lake response to changes in internal recycling would be considerably more rapid than the response to changes in external loading.

7. Conclusions

(1) Monitoring data from Lake Morey and its tributaries collected under this study provide a good basis for assessment of eutrophication-related water quality conditions and controlling factors.

(2) The modified flow-interval method is a valid and useful technique for calculating average loadings based upon tributary flow and concentration data. Compared with alternative schemes, the method is less sensitive to random variations in sampling design and scheduling because it corrects for differences in the distributions of sampled vs. unsampled flows and provides approximate estimates of error variance which can be used to improve monitoring efficiency.

(3) Transient mass balances expressed in terms of cumulative flux (including input, output, change in storage, and net sedimentation terms) are useful for assessing long-term and seasonal variations in phosphorus dynamics without resorting to a detailed kinetic model.

(4) Mass balances over a two-year period indicate that, on the average, only a relatively small portion of external total phosphorus loadings are deposited to Lake Morey bottom sediments. Thus, the lake has a relatively low assimilative capacity for external loadings.

(5) External phosphorus loadings consist of gauged lake tributaries (71%), estimated direct ungauged inputs (17%) and atmospheric inputs (12%). An independent estimate of phosphorus input from septic systems via groundwater amounts to less than 1% of the total loading. Unusually high total and/or dissolved phosphorus concentrations and loadings were detected in a few tributaries; these are possible targets for lake restoration activities.

(6) The total phosphorus mass balance is controlled largely by seasonal factors influencing the sedimentation and recycling of phosphorus.

Deposition rates are positive (net sedimentation) during overturn periods and negative (net regeneration) during summer stratification. Total phosphorus appears to be relatively conservative in the water column during the winter (no net sedimentation).

(7) Approximately 75% and 25% of the the dissolved phosphorus lost from the water column during dynamic fall-overturn periods is explained by algal uptake and co-precipitation with dissolved iron, respectively. Mass balances indicate that most of the phosphorus taken up by algae during this period is later regenerated for use the following spring.

(8) Both morphometric and chemical factors contribute to oxygen depletion, internal phosphorus recycling, and low assimilative capacity.

(9) While a transient period of nitrogen limitation may have developed early in the 1982 growing season, algal populations are primarily phosphorus-limited and relationships among surface phosphorus, chlorophyll-a, and transparency are typical of those found in other Vermont lakes.

(10) A calibrated version of LEAP can be used to project lake responses to changes in external phosphorus loading and internal recycling characteristics, provided that thermal stratification is unaltered.

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APPENDIX A

Flow-Interval Loading Calculation Algorithms and Results

A-1 Equations for Direct Flow Interval Method

A-2 Output - Total Phosphorus, Direct Flow-Interval Method

A-3 Output - Dissolved Phosphorus, Direct Flow-Interval Method

A-4 Equations for Modified Flow Interval Method

A-5 Output - Total Phosphorus, Modified Flow-Interval Method

A-6 Output - Dissolved Phosphorus, Modified Flow-Interval Method

A-7 Guide to SAS Program for Flow-Interval Loading Calculations

A-8 SAS Program Listing

Table A-1
Equations for Flow-Interval Loading Estimates - Direct Method

ID=502791 (Total P)

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	678	154	0.821	1.465	53.881	227.044	.	.	36.782	0.280
1	460	83	0.173	0.196	3.244	0.969	0.446	744.476	16.560	0.303
1	178	51	1.363	1.361	24.695	31.503	2.171	2044.241	18.143	0.227
1	28	12	4.259	4.656	100.165	813.834	1.388	1185.877	21.512	0.285
1	9	5	7.798	7.867	659.235	58815.379	10.364	2711.443	83.795	0.368
1	3	3	14.900	14.900	756.919	63654.602	1.246	1310.982	50.800	0.333
2	678	154	0.821	1.465	24.921	15.616	15.616	.	30.364	0.159

TYPE = 0 estimate pooled across all flow regimes (unstratified estimate)
= 1 estimate for a given flow interval
= 2 weighted average of _TYPE_=1 estimates (stratified estimate)

NQ = number of flow observations
NQS = number of concentration observations
QMEAN = mean flow on all days (hm3/yr)
QSMEAN = mean flow on days with concentration data (hm3/yr)
LMEAN = estimated mean loading in flow interval (kg/yr)
LVAR = error variance of LMEAN
NSIG = NQS x standard deviation of Loading in flow interval
VARC = contribution of flow interval to variance of _TYPE_=2 estimate
CONC = flow-weighted mean concentration in interval (mg/m3)
CV = coefficient of variation

LOADi = load on sample day i (kg/yr)
SUMi = sum over all sample days
SUMj = sum over flow intervals

Flow intervals spaced equally on square root of flow scale from 0 to maximum measured flow.

Equations for _TYPE_ = 0 or 1 estimates:

$$LMEAN = SUMi [LOADi] / NQS$$

$$LVAR = SUMi[(LOADi - LMEAN)^2] / (NS \times (NS -1))$$

$$CV = SQRT(LVAR) / LMEAN$$

$$VARC = NQ \times NQ \times LVAR / (SUMj [NQ]^2)$$

$$CONC = LMEAN / QMEAN$$

Equations for _TYPE_ = 2 estimate:

$$LMEAN = SUMj [NQ \times LMEAN] / SUMj [NQ]$$

$$LVAR = SUMj [VARC]$$

Table A-2
Output - Total Phosphorus, Direct Flow-Interval Method

```
  1    427  87  0.
LOAD CALCS STRAT= 5  QEXP= 0.5  VAR= TP
DIRECT FLOW-INTERVAL METHOD
ID=502791
```

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	678	154	0.821	1.465	53.881	227.844	.	.	36.782	0.280
1	468	83	0.173	0.196	3.244	0.969	0.446	744.476	16.568	0.383
1	178	51	1.363	1.361	24.695	31.583	2.171	2044.241	18.143	0.227
1	28	12	4.259	4.656	100.165	813.834	1.388	1185.877	21.512	0.285
1	9	5	7.798	7.867	659.235	50815.379	10.364	2711.443	83.795	0.368
1	3	3	14.900	14.900	756.919	63654.602	1.246	1310.982	50.800	0.333
2	678	154	0.821	1.465	24.921	15.616	15.616	.	30.364	0.159

ID=502792

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	678	121	0.730	1.644	33.180	109.000	.	.	20.105	0.315
1	462	54	0.130	0.287	2.297	0.470	0.210	272.100	0.010	0.299
1	170	45	1.212	1.252	13.547	19.698	1.230	1339.761	10.821	0.328
1	32	13	3.600	3.762	40.627	309.829	0.690	825.042	12.927	0.362
1	12	7	6.943	6.973	312.925	10896.203	5.919	2545.059	44.875	0.439
1	2	2	14.706	14.706	229.758	1661.001	0.014	115.304	15.623	0.177
2	678	121	0.730	1.644	13.473	0.001	0.001	.	10.240	0.211

ID=502793

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	677	169	2.139	3.427	76.739	707.271	.	.	22.392	0.347
1	436	89	0.500	0.596	3.490	0.392	0.162	525.490	5.869	0.179
1	193	57	2.973	3.047	23.090	66.859	5.434	3518.774	7.500	0.354
1	35	14	9.224	9.703	156.041	3503.035	9.577	3135.570	15.950	0.304
1	10	6	18.506	17.502	970.003	315471	60.831	8254.793	55.220	0.579
1	3	3	36.654	36.654	1110.347	169441	3.327	2130.904	30.293	0.371
2	677	169	2.139	3.427	36.166	87.331	87.331	.	16.910	0.250

ID=502794

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	544	93	0.050	0.075	4.751	0.400	.	.	63.447	0.134
1	226	20	0.005	0.009	5.361	2.939	0.507	153.333	599.649	0.320
1	49	11	0.030	0.027	3.149	0.565	0.005	27.411	117.394	0.239
1	166	29	0.070	0.071	4.001	1.369	0.127	102.700	56.190	0.292
1	03	24	0.112	0.112	4.001	1.012	0.042	150.264	42.679	0.200
1	20	9	0.192	0.192	7.630	1.010	0.001	27.141	39.039	0.132
2	544	93	0.050	0.075	4.745	0.603	0.603	.	94.402	0.174

ID=502795

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	677	169	1.792	2.070	96.337	730.635	.	.	33.564	0.201
1	427	87	0.450	0.470	2.579	0.003	0.033	233.122	5.399	0.111
1	197	56	2.410	2.470	26.526	46.256	3.917	2050.140	10.741	0.256
1	37	15	7.229	7.295	300.020	16532.502	49.302	7469.770	41.127	0.429
1	11	0	13.090	13.057	029.105	134407	35.404	0295.559	59.039	0.442
1	5	3	25.211	20.310	1145.009	56961.059	3.107	1240.140	40.474	0.200
2	677	169	1.792	2.070	47.677	91.922	91.922	.	26.600	0.201

ID=502796

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	677	169	0.402	0.739	72.240	562.037	.	.	97.764	0.320
1	376	71	0.110	0.112	1.115	0.020	0.009	99.553	9.970	0.149
1	247	74	0.597	0.595	12.373	7.209	0.970	1710.573	20.000	0.210
1	40	16	1.055	2.006	156.069	3542.099	12.360	3009.424	70.203	0.379
1	10	5	3.710	4.059	1009.415	266057	50.049	5766.090	240.700	0.511
1	4	3	6.401	6.054	1219.416	115103	4.010	1762.007	177.913	0.270
2	677	169	0.402	0.739	36.517	75.414	75.414	.	75.037	0.230

ID=502797

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	676	165	0.725	1.000	41.071	176.265	.	.	30.044	0.323
1	307	73	0.262	0.272	3.603	0.462	0.152	424.143	13.552	0.135
1	250	71	0.957	0.955	19.124	10.129	2.490	2547.209	20.021	0.223
1	33	16	3.137	3.112	72.403	179.720	0.420	050.000	23.264	0.105
1	4	3	5.476	5.513	677.055	222000	7.773	2440.265	122.011	0.696
1	2	2	12.069	12.069	900.270	86247.313	0.755	030.649	01.222	0.300
2	676	165	0.725	1.000	19.622	11.587	11.587	.	27.065	0.173

ID=502798

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	677	165	0.336	0.494	41.421	77.177	.	.	03.099	0.212
1	244	50	0.070	0.075	2.012	0.100	0.014	116.202	37.440	0.117
1	316	69	0.245	0.270	16.306	7.005	1.701	1601.275	60.599	0.170
1	02	20	0.715	0.714	44.205	55.074	0.020	1107.493	62.050	0.169
1	20	11	1.440	1.479	119.259	549.657	0.400	055.332	00.626	0.197
1	15	7	3.004	3.257	430.205	16011.699	0.253	2401.336	132.090	0.391
2	677	165	0.336	0.494	27.001	11.267	11.267	.	00.709	0.124

ID=502799

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	678	162	0.205	0.317	00.049	029.500	.	.	252.042	0.360
1	409	04	0.053	0.059	2.220	0.192	0.070	337.699	37.710	0.197
1	217	54	0.264	0.276	13.403	3.309	0.339	721.052	40.796	0.135
1	37	15	0.040	0.096	140.009	3092.240	11.592	3624.400	166.120	0.419
1	12	7	1.676	1.673	659.644	75197.250	23.556	5070.645	394.274	0.414
1	3	2	2.900	3.129	2601.530	001157	17.252	2655.044	031.420	0.361
2	678	162	0.205	0.317	36.966	52.009	52.009	.	100.912	0.1[illegible]

ID=502000

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	677	165	9.592	12.270	304.407	2024.706	.	.	31.316	0.117
1	105	37	0.700	0.952	22.036	21.401	1.604	1043.103	23.142	0.210
1	230	46	5.570	5.620	115.975	07.056	10.759	2910.960	20.606	0.099
1	170	49	13.894	14.122	405.006	0221.422	510.403	31100.512	34.402	0.107
1	61	23	27.054	25.926	762.659	7160.340	50.132	9333.005	29.417	0.111
1	23	10	43.045	44.342	1594.440	55660.430	64.252	7461.125	35.950	0.140
2	677	165	9.592	12.270	291.670	653.150	653.150	.	30.407	0.09[illegible]

```
LOAD CALCS STRAT= 5  QEXP= 0.5  VAR= TP
BUDGET SUMMARY  - DIRECT FLOW INTERVAL METHOD
```

ID	QMEAN	QSMEAN	LMEAN	LVAR	CONC	CV
502791	0.02075	1.4649	24.921	15.616	30.364	0.150565
502792	0.73033	1.6442	13.473	0.001	10.240	0.210907
502793	2.13068	3.4270	36.166	07.331	16.910	0.250395
502794	0.05022	0.0749	4.745	0.603	94.402	0.174141
502795	1.79241	2.0702	47.677	91.922	26.600	0.201093
502796	0.40152	0.7390	36.517	75.414	75.037	0.237012
502797	0.72499	1.0796	19.622	11.587	27.065	0.173401
502798	0.33553	0.4937	27.001	11.267	00.709	0.123950
502799	0.20536	0.3166	36.966	52.009	100.012	0.196502
000OUT	9.59221	12.2777	291.670	653.150	30.407	0.007622
TOTIN	7.20779	12.1101	247.169	354.709	33.915	0.076190

Table A-3
Output - Dissolved Phosphorus, Direct Flow-Interval Method

LOAD CALCS STRAT= 5 QEXP= 0.5 VAR= TDP
DIRECT FLOW-INTERVAL METHOD

ID=502791

TYPE	NO	NOS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	678	155	0.821	1.585	14.584	6.744	.	.	9.688	0.178
1	460	83	0.173	0.192	2.867	0.204	0.094	341.319	10.752	0.218
1	178	50	1.363	1.379	12.142	4.497	0.310	749.775	8.802	0.175
1	28	14	4.259	4.598	38.474	96.037	0.164	513.346	8.368	0.255
1	9	5	7.798	7.867	94.764	498.402	0.088	249.600	12.045	0.236
1	3	3	14.900	14.900	156.450	1218.832	0.024	181.407	10.500	0.223
2	678	155	0.821	1.585	8.129	0.679	0.679	.	9.905	0.101

ID=502792

TYPE	NO	NOS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	678	120	0.738	1.656	9.924	4.440	.	.	5.992	0.212
1	462	53	0.138	0.288	1.626	0.041	0.019	78.032	5.645	0.124
1	170	45	1.212	1.252	6.511	0.623	0.039	238.271	5.200	0.121
1	32	13	3.688	3.762	19.427	11.226	0.025	157.045	5.165	0.172
1	12	7	6.943	6.973	35.236	125.043	0.039	207.098	5.053	0.317
1	2	2	14.706	14.706	156.226	1206.300	0.010	98.236	10.623	0.222
2	678	120	0.738	1.656	4.742	0.133	0.133	.	6.423	0.077

ID=502793

TYPE	NO	NOS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	677	168	2.139	3.427	22.318	31.787	.	.	6.511	0.253
1	436	86	0.588	0.585	2.781	0.086	0.036	242.009	4.750	0.105
1	193	57	2.973	3.013	13.852	1.088	0.088	448.894	4.332	0.080
1	35	14	9.224	9.783	51.124	81.347	0.217	472.458	5.226	0.176
1	10	6	18.506	17.582	103.555	312.896	0.068	259.972	5.890	0.171
1	3	3	36.654	36.654	474.117	26902.313	0.528	852.269	12.935	0.346
2	677	168	2.139	3.427	11.785	0.938	0.938	.	5.511	0.082

ID=502794

TYPE	NO	NOS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	544	91	0.050	0.076	2.929	0.072	.	.	30.365	0.092
1	226	18	0.005	0.009	4.313	0.999	0.172	76.329	402.444	0.232
1	49	11	0.030	0.027	2.362	0.418	0.003	23.587	80.061	0.274
1	166	29	0.070	0.071	2.163	0.125	0.012	55.161	30.377	0.163
1	83	24	0.112	0.112	2.500	0.070	0.002	31.003	22.930	0.102
1	20	9	0.192	0.192	4.249	0.332	0.000	15.556	22.166	0.136
2	544	91	0.050	0.076	3.214	0.109	0.109	.	64.005	0.135

ID=502795

TYPE	NO	NOS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	677	169	1.792	2.070	20.434	24.355	.	.	7.119	0.242
1	427	87	0.450	0.470	2.259	0.070	0.028	215.230	4.729	0.117
1	197	56	2.410	2.470	10.860	0.675	0.057	344.291	4.390	0.076
1	37	15	7.229	7.295	40.147	30.120	0.090	310.833	5.503	0.137
1	11	8	13.890	13.857	102.698	250.430	0.066	350.079	7.411	0.154
1	5	3	25.211	28.310	400.260	20575.820	1.122	745.350	14.421	0.351
2	677	169	1.792	2.070	11.463	1.364	1.364	.	6.395	0.102

ID=502796

TYPE	NO	NOS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	677	169	0.482	0.739	4.611	0.668	.	.	6.240	0.177
1	376	71	0.110	0.112	0.619	0.005	0.002	42.673	5.533	0.115
1	247	74	0.597	0.595	3.371	0.154	0.020	249.673	5.670	0.116
1	40	16	1.855	2.006	9.258	1.794	0.006	85.470	4.616	0.144
1	10	5	3.710	4.059	36.797	59.484	0.013	86.229	9.066	0.210
1	4	3	6.481	6.054	51.256	529.982	0.019	119.622	7.470	0.449
2	677	169	0.482	0.739	2.967	0.060	0.060	.	6.162	0.082

ID=502797

TYPE	NO	NOS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	676	165	0.725	1.081	9.006	4.600	.	.	9.147	0.217
1	387	73	0.262	0.275	2.115	0.035	0.012	116.929	7.699	0.089
1	250	71	0.957	0.955	6.753	0.970	0.133	589.231	7.070	0.146
1	33	16	3.137	3.112	20.026	14.336	0.034	242.323	6.434	0.169
1	4	3	5.476	5.513	86.196	935.776	0.033	150.953	15.635	0.355
1	2	2	12.069	12.069	209.196	3481.456	0.030	166.000	17.333	0.202
2	676	165	0.725	1.081	5.815	0.242	0.242	.	8.021	0.005

ID=502798

TYPE	NO	NOS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	677	165	0.336	0.494	14.201	6.033	.	.	20.927	0.103
1	244	50	0.070	0.075	1.453	0.013	0.002	39.965	19.343	0.076
1	316	69	0.245	0.270	6.477	0.994	0.217	571.381	23.952	0.154
1	82	20	0.715	0.714	19.966	17.700	0.260	623.403	27.979	0.211
1	20	11	1.440	1.479	42.530	64.640	0.056	293.337	20.750	0.109
1	15	7	3.004	3.257	115.709	1561.201	0.766	731.792	35.529	0.341
2	677	165	0.336	0.494	9.765	1.301	1.301	.	29.163	0.117

ID=502799

TYPE	NO	NOS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	678	161	0.205	0.319	5.945	1.146	.	.	10.667	0.100
1	409	83	0.053	0.060	0.021	0.000	0.003	65.770	13.755	0.106
1	217	54	0.264	0.276	4.029	0.159	0.016	150.049	14.502	0.099
1	37	15	0.040	0.096	16.700	12.652	0.030	206.639	10.651	0.213
1	12	7	1.476	1.673	32.669	20.063	0.007	84.594	19.527	0.140
1	3	2	2.900	3.129	96.105	57.745	0.001	21.493	30.714	0.079
2	678	161	0.205	0.319	3.700	0.064	0.064	.	10.017	0.069

ID=502800

TYPE	NO	NOS	QMEAN	QSMEAN	LMEAN	LVAR	VARC	NSIG	CONC	CV
0	677	166	9.592	12.263	150.206	261.155	.	.	12.249	0.100
1	185	37	0.700	0.920	4.995	0.393	0.029	141.136	5.302	0.126
1	230	46	5.570	5.620	50.602	43.719	5.403	2062.876	10.412	0.113
1	170	50	13.894	14.054	150.442	254.755	16.064	5643.006	10.705	0.106
1	61	23	27.054	25.926	330.106	1904.946	15.466	4014.297	13.041	0.127
1	23	10	43.045	44.342	675.506	8101.305	9.443	2060.290	15.234	0.134
2	677	166	9.592	12.263	113.150	46.405	46.405	.	11.757	0.060

LOAD CALCS STRAT= 5 QEXP= 0.5 VAR= TDP
BUDGET SUMMARY

ID	QMEAN	QSMEAN	LMEAN	LVAR	CONC	CV
502791	0.02075	1.5054	0.129	0.0792	9.9040	0.101300
502792	0.73033	1.6561	4.742	0.1320	6.4229	0.076055
502793	2.13060	3.4266	11.705	0.9300	5.5106	0.002100
502794	0.05022	0.0763	3.214	0.1095	64.0049	0.135423
502795	1.79241	2.0702	11.463	1.3635	6.3953	0.101060
502796	0.40152	0.7390	2.967	0.0590	6.1617	0.002300
502797	0.72499	1.0009	5.015	0.2416	0.0206	0.004529
502798	0.33553	0.4937	9.705	1.3009	29.1634	0.116557
502799	0.20536	0.3105	3.700	0.0643	10.0174	0.060559
000OUT	9.59221	12.2629	113.150	46.4045	11.7960	0.060200
TOTIN	7.20779	12.1660	61.602	4.9697	0.4527	0.036109

Table A-4
Equations for Flow-Interval Loading Estimates - Ratio Method

ID=502791 (Total P)

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	678	154	0.821	1.465	30.189	34.266	.	.	36.782	0.194
1	460	83	0.173	0.196	2.869	0.664	616.250	0.306	16.560	0.284
1	178	51	1.363	1.361	24.730	27.413	1906.911	1.889	18.143	0.212
1	28	12	4.259	4.656	91.625	507.395	936.365	0.865	21.512	0.246
1	9	5	7.798	7.867	653.409	48200.191	2454.592	8.493	83.795	0.336
1	3	3	14.900	14.900	756.919	76601.813	1438.141	1.500	50.800	0.366
2	678	154	0.821	1.465	24.246	13.054	.	13.054	29.541	0.149

TYPE = 0 estimate pooled across all flow regimes (unstratified estimate)
= 1 estimate for a given flow interval
= 2 weighted average of _TYPE_=1 estimates (stratified estimate)

ID = station code
NQ = number of flow observations
NQS = number of concentration observations
QMEAN = mean flow on all days (hm3/yr)
QSMEAN = mean flow on days with concentration data (hm3/yr)
LMEAN = estimated mean loading in flow interval (kg/yr)
LVAR = error variance of LMEAN
NSIG = NQS x standard deviation of CONC in flow interval
VARC = contribution of flow interval to variance of _TYPE_=2 estimate
CONC = flow-weighted mean concentration in interval (mg/m3)
CV = coefficient of variation

QSi = flow in sample day i (hm3/yr)
LOADi = load on sample day i (kg/yr)
SUMi = sum over all sample days
SUMj = sum over flow intervals

Flow intervals spaced equally on square root of flow scale from 0 to maximum measured flow.

Equations for _TYPE_ = 0 or 1 estimates:

CONC = SUMi [LOADi] / SUMi [QSi]

LMEAN = QMEAN x CONC

$$LVAR = (QMEAN/QSMEAN)^2 \times SUMi[(LOADi - CONC \times QSi)^2] / (NS \times (NS -1))$$

CV = SQRT(LVAR) / LMEAN

$$VARC = NQ \times NQ \times LVAR / (SUMj [NQ])^2$$

Equations for _TYPE_ = 2 estimate:

LMEAN = SUMj [NQ x LMEAN] / SUMj [NQ]

LVAR = SUMj [VARC]

Table A-5
Output - Total Phosphorus, Modified Flow-Interval Method

LOAD CALCS STRAT= 5 QEXP= 0.5 VAR= TP
FLOW-WEIGHTED AVERAGE METHOD

ID=502791

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	678	154	0.821	1.465	30.189	34.266	.	.	36.782	0.194
1	460	83	0.173	0.196	2.869	0.664	616.250	0.306	16.560	0.284
1	178	51	1.363	1.361	24.730	27.413	1986.911	1.889	18.143	0.212
1	28	12	4.259	4.656	91.625	507.395	936.365	0.865	21.512	0.246
1	9	5	7.798	7.867	653.489	48200.191	2454.592	0.493	83.795	0.336
1	3	3	14.900	14.900	756.919	76601.813	1438.141	1.500	50.800	0.366
2	678	154	0.821	1.465	24.246	13.054	.	13.054	29.541	0.149

ID=502792

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	678	121	0.738	1.644	14.983	14.543	.	.	20.185	0.256
1	462	54	0.139	0.287	1.108	0.108	125.436	0.046	8.010	0.285
1	170	45	1.212	1.252	13.109	18.622	1302.677	1.171	10.821	0.329
1	32	13	3.688	3.762	47.671	322.169	841.311	0.718	12.927	0.377
1	12	7	6.943	6.973	311.588	14723.570	2247.262	4.612	44.875	0.389
1	2	2	14.706	14.706	229.758	480.001	61.973	0.004	15.623	0.095
2	678	121	0.738	1.644	12.484	6.551	.	6.551	16.909	0.205

ID=502793

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	677	169	2.139	3.427	47.890	185.307	.	.	22.392	0.284
1	436	89	0.588	0.596	3.450	0.292	453.892	0.121	5.869	0.157
1	193	57	2.973	3.047	22.533	60.167	3338.049	4.890	7.580	0.344
1	35	14	9.224	9.783	147.119	3314.742	3015.900	8.859	15.950	0.391
1	10	6	18.586	17.582	1021.896	298832	8034.160	65.200	55.220	0.535
1	3	3	36.654	36.654	1110.347	229025	2486.699	4.497	30.293	0.431
2	677	169	2.139	3.427	36.266	83.560	.	83.560	16.957	0.252

ID=502794

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	544	93	0.050	0.075	3.186	0.222	.	.	63.447	0.148
1	226	20	0.005	0.009	2.910	0.071	83.451	0.150	599.649	0.320
1	49	11	0.030	0.027	3.470	1.172	39.489	0.010	117.394	0.312
1	166	29	0.070	0.071	3.920	1.337	100.577	0.124	56.190	0.294
1	83	24	0.112	0.112	4.799	1.056	160.167	0.043	42.679	0.284
1	20	9	0.192	0.192	7.640	0.712	22.775	0.001	39.839	0.110
2	544	93	0.050	0.075	3.736	0.320	.	0.320	74.397	0.153

ID=502795

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	677	169	1.792	2.070	60.161	164.434	.	.	33.564	0.213
1	427	87	0.450	0.470	2.431	0.035	151.020	0.014	5.399	0.077
1	197	56	2.410	2.470	25.007	41.213	2690.290	3.490	10.741	0.240
1	37	15	7.229	7.295	297.317	16060.071	7364.266	47.997	41.127	0.426
1	11	8	13.090	13.057	831.616	100933	7460.184	20.759	59.039	0.397
1	5	3	25.211	20.310	1020.373	30507.539	1019.650	2.100	40.474	0.192
2	677	169	1.792	2.070	46.363	82.359	.	82.359	25.067	0.196

ID=502796

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	677	169	0.482	0.739	47.075	140.465	.	.	97.764	0.259
1	376	71	0.110	0.112	1.094	0.010	79.499	0.005	9.970	0.121
1	247	74	0.597	0.595	12.427	6.736	1652.133	0.097	20.000	0.209
1	40	16	1.055	2.006	145.071	3020.422	3521.990	10.572	70.203	0.379
1	10	5	3.710	4.059	922.703	232146	5306.059	50.651	240.700	0.522
1	4	3	6.401	6.054	1153.143	100060	1650.221	3.521	177.913	0.275
2	677	169	0.482	0.739	34.155	65.646	.	65.646	70.932	0.237

ID=502797

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	676	165	0.725	1.000	27.581	47.000	.	.	30.044	0.251
1	307	73	0.262	0.272	3.540	0.301	304.757	0.125	13.552	0.174
1	250	71	0.957	0.955	19.156	14.605	2206.290	1.997	20.021	0.230
1	33	16	3.137	3.112	72.902	110.970	690.069	0.204	23.264	0.149
1	4	3	5.476	5.513	672.401	250592	2642.346	9.054	122.011	0.756
1	2	2	12.069	12.069	900.270	34136.266	522.500	0.299	01.222	0.100
2	676	165	0.725	1.000	19.550	11.759	.	11.759	26.977	0.175

ID=502798

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	677	165	0.336	0.494	20.151	11.614	.	.	03.099	0.121
1	244	50	0.070	0.075	2.613	0.060	99.932	0.010	37.440	0.100
1	316	69	0.245	0.270	14.057	5.535	1340.476	1.206	60.599	0.150
1	02	20	0.715	0.714	44.370	47.624	1022.473	0.699	62.050	0.156
1	20	11	1.440	1.479	116.769	391.205	721.591	0.341	00.626	0.169
1	15	7	3.004	3.257	396.001	5596.205	1305.469	2.747	132.090	0.109
2	677	165	0.336	0.494	25.492	5.004	.	5.004	75.975	0.000

ID=502799

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	678	162	0.205	0.317	51.923	200.632	.	.	252.042	0.273
1	409	04	0.053	0.059	2.003	0.120	275.314	0.047	37.710	0.179
1	217	54	0.264	0.276	12.902	2.004	572.704	0.213	40.796	0.112
1	37	15	0.040	0.096	139.521	3236.070	3304.005	9.637	166.120	0.400
1	12	7	1.676	1.673	660.902	72950.625	5002.207	22.052	394.274	0.409
1	3	2	2.900	3.129	2477.656	291656	1527.497	5.710	031.420	0.210
2	678	162	0.205	0.317	35.612	30.460	.	30.460	173.419	0.174

ID=502000

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	677	165	9.592	12.278	300.390	671.956	.	.	31.316	0.006
1	195	37	0.700	0.952	10.220	10.593	732.507	0.791	23.142	0.179
1	230	46	5.570	5.620	114.933	40.303	1900.635	4.901	20.606	0.355
1	170	49	13.094	14.122	477.972	7722.055	30142.766	406.966	34.402	0.104
1	61	23	27.054	25.926	795.056	7462.277	9520.563	60.503	29.417	0.139
1	23	10	43.045	44.342	1576.558	75744.013	0703.140	07.424	35.956	0.175
2	677	165	9.592	12.278	290.679	640.745	.	640.745	30.304	0.007

LOAD CALCS STRAT= 5 QEXP= 0.5 VAR= TP
BUDGET SUMMARY - TP FLOW-WEIGHTED AVERAGE METHOD

ID	QMEAN	QSMEAN	LMEAN	LVAR	CONC	CV
502791	0.02075	1.4649	24.246	13.054	29.541	0.149013
502792	0.73033	1.6442	12.484	6.551	16.909	0.205021
502793	2.13068	3.4270	36.266	03.560	16.957	0.252069
502794	0.05022	0.0749	3.736	0.320	74.397	0.153375
502795	1.79241	2.0702	46.363	02.359	25.067	0.195741
502796	0.40152	0.7390	34.155	65.646	70.932	0.237217
502797	0.72499	1.0796	19.550	11.759	26.977	0.175331
502798	0.33553	0.4937	25.492	5.004	75.975	0.007740
502799	0.20536	0.3166	35.612	30.460	173.410	0.174142
000OUT	9.59221	12.2777	290.679	640.745	30.304	0.007002
TOTIN	7.20779	12.1101	237.914	306.729	32.646	0.073614

Table A-6
Output - Dissolved Phosphorus, Modified Flow-Interval Method

LOAD CALCS STRAT= 5 QEXP= 0.5 VAR= TDP
FLOW-WEIGHTED AVERAGE METHOD
ID=502791

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	678	155	0.821	1.505	7.951	0.585	.	.	9.688	0.089
1	460	83	0.173	0.192	1.863	0.136	278.926	0.063	10.752	0.198
1	178	50	1.363	1.379	11.998	3.998	786.969	0.276	8.882	0.167
1	28	14	4.259	4.598	35.642	66.987	428.476	0.114	8.368	0.229
1	9	5	7.798	7.867	93.926	448.834	236.863	0.079	12.045	0.226
1	3	3	14.900	14.900	156.450	554.469	122.355	0.011	10.500	0.151
2	678	155	0.821	1.505	7.825	0.542	.	0.542	9.534	0.094

ID=502792

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	678	120	0.738	1.656	4.424	0.243	.	.	5.992	0.111
1	462	53	0.138	0.288	0.781	0.084	24.017	0.002	5.645	0.080
1	170	45	1.212	1.252	6.300	0.452	203.042	0.028	5.200	0.107
1	32	13	3.688	3.762	19.045	10.176	149.518	0.023	5.165	0.167
1	12	7	6.943	6.973	35.086	88.201	173.933	0.028	5.053	0.268
1	2	2	14.706	14.706	156.226	480.086	61.973	0.004	10.623	0.140
2	678	120	0.738	1.656	4.092	0.085	.	0.085	5.543	0.071

ID=502793

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	677	168	2.139	3.427	13.925	4.772	.	.	6.511	0.157
1	436	80	0.580	0.585	2.792	0.036	157.112	0.015	4.750	0.068
1	193	57	2.973	3.013	12.878	0.525	311.809	0.043	4.332	0.056
1	35	14	9.224	9.783	48.201	86.571	487.393	0.231	5.226	0.193
1	10	6	18.506	17.502	100.996	275.618	243.995	0.060	5.890	0.152
1	3	3	36.654	36.654	474.110	21509.207	762.069	0.422	12.935	0.309
2	677	168	2.139	3.427	11.672	0.772	.	0.772	5.458	0.075

ID=502794

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	544	91	0.050	0.076	1.927	0.053	.	.	38.365	0.120
1	226	18	0.005	0.009	2.347	0.296	41.542	0.051	482.444	0.232
1	49	11	0.030	0.027	2.603	0.793	32.482	0.006	88.061	0.342
1	166	29	0.070	0.071	2.123	0.117	53.469	0.011	30.377	0.161
1	83	24	0.112	0.112	2.579	0.076	32.382	0.002	22.930	0.107
1	20	9	0.192	0.192	4.251	0.337	15.666	0.000	22.166	0.137
2	544	91	0.050	0.076	2.497	0.071	.	0.071	47.933	0.110

LOAD CALCS STRAT= 5 QEXP= 0.5 VAR= TDP
FLOW-WEIGHTED AVERAGE METHOD
ID=502795

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	677	169	1.792	2.870	12.760	3.570	.	.	7.119	0.148
1	427	87	0.450	0.478	2.129	0.029	137.237	0.011	4.729	0.079
1	197	56	2.410	2.470	10.599	0.533	305.902	0.045	4.398	0.069
1	37	15	7.229	7.295	39.785	42.486	378.670	0.127	5.503	0.164
1	11	8	13.898	13.857	102.999	133.931	261.864	0.035	7.411	0.112
1	5	3	25.211	28.310	363.566	11910.215	567.076	0.650	14.421	0.300
2	677	169	1.792	2.870	10.960	0.868	.	0.868	6.115	0.085

ID=502796

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	677	169	0.482	0.739	3.005	0.081	.	.	6.240	0.095
1	376	71	0.110	0.112	0.607	0.002	27.030	0.001	5.533	0.077
1	247	74	0.597	0.595	3.306	0.119	219.046	0.016	5.670	0.102
1	40	16	1.855	2.006	8.562	1.510	78.643	0.005	4.616	0.144
1	10	5	3.710	4.059	33.636	47.618	77.151	0.010	9.066	0.205
1	4	3	6.401	6.054	48.470	295.985	89.396	0.010	7.470	0.355
2	677	169	0.482	0.739	2.962	0.043	.	0.043	5.943	0.072

ID=502797

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	676	165	0.725	1.001	6.631	0.695	.	.	9.147	0.126
1	387	73	0.262	0.275	2.016	0.019	85.412	0.006	7.699	0.060
1	250	71	0.957	0.955	6.765	0.010	541.200	0.112	7.070	0.134
1	33	16	3.137	3.112	20.106	0.242	103.733	0.020	6.434	0.142
1	4	3	5.476	5.513	85.614	1309.250	100.016	0.046	15.635	0.423
1	2	2	12.069	12.069	209.196	1270.753	101.144	0.011	17.333	0.171
2	676	165	0.725	1.001	5.767	0.195	.	0.195	7.954	0.077

ID=502798

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	677	165	0.336	0.494	9.706	1.105	.	.	28.927	0.100
1	244	50	0.070	0.075	1.350	0.009	34.092	0.001	19.343	0.071
1	316	69	0.245	0.270	5.072	0.614	449.265	0.134	23.952	0.133
1	82	20	0.715	0.714	20.004	10.339	634.495	0.269	27.979	0.214
1	20	11	1.440	1.479	41.650	53.740	267.440	0.047	20.758	0.176
1	15	7	3.004	3.257	106.725	695.500	400.425	0.341	35.529	0.247
2	677	165	0.336	0.494	9.246	0.792	.	0.792	27.555	0.096

ID=502799

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	670	161	0.205	0.319	3.033	0.119	.	.	10.667	0.090
1	409	83	0.053	0.060	0.731	0.003	37.070	0.001	13.755	0.069
1	217	54	0.264	0.276	3.056	0.090	119.197	0.009	14.502	0.070
1	37	15	0.840	0.896	15.665	11.520	197.103	0.034	10.651	0.217
1	12	7	1.676	1.673	32.732	33.641	107.419	0.011	19.527	0.177
1	3	2	2.900	3.129	91.520	34.090	16.514	0.001	30.714	0.064
2	670	161	0.205	0.319	3.514	0.056	.	0.056	17.112	0.067

ID=502800

TYPE	NQ	NQS	QMEAN	QSMEAN	LMEAN	LVAR	NSIG	VARC	CONC	CV
0	677	166	9.592	12.263	117.493	54.410	.	.	12.249	0.063
1	185	37	0.700	0.928	4.240	0.090	70.501	0.007	5.302	0.074
1	230	46	5.570	5.620	50.075	25.395	1572.226	3.139	10.412	0.007
1	170	50	13.894	14.054	140.731	200.649	5000.105	12.652	10.705	0.095
1	61	23	27.054	25.926	352.023	1929.607	4045.359	15.666	13.041	0.125
1	23	10	43.045	44.342	667.927	8752.570	2958.475	10.102	15.234	0.140
2	677	166	9.592	12.263	113.405	41.566	.	41.566	11.023	0.057

LOAD CALCS STRAT= 5 QEXP= 0.5 VAR= TDP
BUDGET SUMMARY FLOW-WEIGHTED AVERAGE METHOD

ID	QMEAN	QSMEAN	LMEAN	LVAR	CONC	CV
502791	0.02075	1.5054	7.025	0.5423	9.5339	0.094109
502792	0.73033	1.6561	4.092	0.0047	5.5420	0.071122
502793	2.13068	3.4266	11.672	0.7716	5.4577	0.075254
502794	0.05022	0.0763	2.407	0.0706	47.9332	0.110406
502795	1.79241	2.8702	10.960	0.8634	6.1140	0.005025
502796	0.48152	0.7390	2.062	0.0425	5.9420	0.072075
502797	0.72499	1.0009	5.767	0.1947	7.9542	0.076526
502798	0.33553	0.4937	9.246	0.7925	27.5551	0.096203
502799	0.20536	0.3105	3.514	0.0557	17.1116	0.067145
8000UT	9.59221	12.2629	113.405	41.5658	11.0226	0.056051
TOTIN	7.20779	12.1668	50.345	3.4230	0.0059	0.031710

Table A-7

Guide to SAS Programs for Flow-Interval Loading Calculations

SAS MACROS employed (see Table A-8):

```
MACSET  - sets up input file for MACCQW and MACFIM
          and computes summary statistics
MACCQW  - uses ratio method (flow-weighted concentration)
MACFIM  - uses direct method (load averaging)
```

Both require an input data set named INSET with the following variables:

```
ID    = identification code (e.g., station, year, etc)
C     = concentration (mg/m3)
Q     = flow (hm3/yr)        (no missing values)
QINT  = flow value to be used in defining intervals
        ( typically = square root of Q )
```

The ID variable is treated as a BY group; i.e., the analysis is repeated for each value of ID and INSET should be sorted by ID before calling either program.

In addition, the following parameter must be defined in a MACRO statement at the beginning of the program:

```
MACN   = number of flow intervals to be used
```

MACSET must be called before MACFIM or MACCQW. The latter return an output file named RESULT which can be used in further processing if desired. The contents of the RESULT file are described in the printed output.

Example:

```
*;
    (include MACRO programs at top )
*;
    MACRO MACN    5  %  *number of intervals;
*;
    DATA INSET;
      SET YOUR.DATA;
      LENGTH DEFAULT=4;
        ID = STATION;  Q = FLOW;
        QINT = Q**.5;  C = TOTALP;
      IF Q = . THEN DELETE;
      KEEP ID Q QINT C;
      TITLE TOTAL P LOADING ESTIMATES;
*;
    PROC SORT; BY ID;
*;
MACSET;   * call set-up algorithm;
*;
MACCQW;   * call flow-weighted-averaging algorithm;
*;              ( and/or )
MACFIM;   * call direct flow integral algorithm;
*;
```

Table A-8
SAS Program Listings

```
*****************************************;
* MACROS FOR FLOW-INTERVAL LOAD ESTIMATION ;
* W. WALKER          JUNE 1983             ;
*****************************************;
* INPUT FILE 'INSET' CONTAINS ID,Q,QINT,C  ;
* NUMBER OF FLOW INTERVALS IN MACRO 'MACN' ;
*;
MACRO MACSET
*;
* SETS UP FILE FOR FLOW-INTERVAL LOAD CALCULATION;
*    AND COMPUTES SUMMARY STATISTICS;
*;
PROC MEANS DATA=INSET NOPRINT MAX; BY ID; VAR QINT;
           OUTPUT OUT=TEMP1 MAX=QMAX;
*;
DATA TEMP2; MERGE INSET TEMP1 ;BY ID; LENGTH DEFAULT=4;
  INTER=INT(1+MACN*QINT/QMAX);
  IF INTER > MACN THEN INTER=MACN;
  IF C NE . THEN DO;
       LOAD=Q*C;LOADQ=LOAD*Q;QS=Q; END;
*;
PROC SUMMARY DATA=TEMP2;BY ID;CLASS INTER;VAR Q QS LOAD LOADQ;
OUTPUT OUT= STATS  N = NQ NQS   MEAN = QMEAN QSMEAN LMEAN LOADQ
       STDERR( LOAD ) = LVAR   USS(QS LOAD) = USQS USL ;
%
****************** END OF MACRO MACSET;
*;
```

(continued)

```
MACRO MACCQW
*;
* STRATIFIED SAMPLE ESTIMATE ON CLASS VARIABLE INTER ;
* FLOW-WEIGHTED (RATIO) ESTIMATE                     ;
*;
DATA RESULT;SET STATS; BY ID;LENGTH DEFAULT=4;
 KEEP ID   VARC _TYPE_ NQ NQS QMEAN QSMEAN LMEAN
     LVAR CONC CV INTER LOADC;
 RETAIN LTOT VTOT NTOT QSTOT QTOT NSTOT;
 IF FIRST.ID THEN DO;VTOT=0;LTOT=0;END;
 CONC = LMEAN/QSMEAN; LMEAN=QMEAN*CONC;
IF NQS>1 THEN LVAR=(USL+CONC*CONC*USQS-2*LOADQ*CONC*NQS)/(NQS*(NQS-1));
 LVAR=LVAR*((QMEAN/QSMEAN)**2); CV = SQRT(LVAR)/LMEAN;
 IF _TYPE_=0 THEN DO;
   NTOT = NQ;NSTOT=NQS;QSTOT=QSMEAN;QTOT = QMEAN;END;
 ELSE DO;
   VTOT= VTOT + LVAR*NQ*NQ;LTOT=LTOT+LMEAN*NQ;
VARC=LVAR*(NQ/NTOT)**2;
   LOADC=LMEAN*NQ/NTOT;END;
 OUTPUT;
 IF LAST.ID THEN DO;
   NQ=NTOT;NQS=NSTOT;QSMEAN=QSTOT;QMEAN=QTOT;
   LMEAN=LTOT/NTOT;LVAR = VTOT/(NTOT*NTOT);
   CV = SQRT(LVAR)/LMEAN;VARC=LVAR;LOADC=LMEAN;
   CONC = LMEAN/QMEAN;_TYPE_=2;OUTPUT;END;
*;
PROC PRINT; BY ID; ID _TYPE_;
 VAR NQ NQS QMEAN QSMEAN LMEAN LVAR   VARC LOADC CONC CV;
 FORMAT QMEAN QSMEAN LMEAN LVAR   VARC LOADC CONC CV 9.3;
 TITLE2 FLOW-WEIGHTED AVERAGE METHOD;
%
******************** END OF MACRO MACCQW;
*;
```

(continued)

```
MACRO MACFIM
*;
* STRATIFIED SAMPLE ESTIMATE ON CLASS VARIABLE INTER  ;
* DIRECT FLOW-INTERVAL METHOD                         ;
*;
DATA RESULT;SET STATS;BY ID;LENGTH DEFAULT=4;
 KEEP   ID VARC _TYPE_ NQ NQS QMEAN QSMEAN LMEAN
   LVAR CONC CV INTER LOADC ;
 RETAIN LTOT VTOT NTOT QSTOT QTOT NSTOT;
 IF FIRST.ID THEN DO;VTOT=0;LTOT=0;END;
 LVAR=LVAR**2;CONC = LMEAN/QSMEAN; CV=SQRT(LVAR)/LMEAN;
 IF _TYPE_=0 THEN DO;
   NTOT = NQ;NSTOT=NQS;QSTOT=QSMEAN;QTOT = QMEAN; END;
 ELSE DO;
   VTOT= VTOT + LVAR*NQ*NQ;LTOT=LTOT+LMEAN*NQ;
  VARC=LVAR*(NQ/NTOT)**2;
  LOADC=LMEAN*NQ/NTOT;END;
 OUTPUT;
 IF LAST.ID THEN DO;
   NQ=NTOT;NQS=NSTOT;QSMEAN=QSTOT;QMEAN=QTOT;
   LMEAN=LTOT/NTOT;LVAR = VTOT/(NTOT*NTOT);
   CV = SQRT(LVAR)/LMEAN; VARC=LVAR; LOADC=LMEAN;
   CONC = LMEAN/QMEAN; _TYPE_=2; OUTPUT; END;
*;
PROC PRINT; BY ID; ID _TYPE_;
 VAR NQ NQS QMEAN QSMEAN LMEAN LVAR VARC LOADC   CONC CV;
 FORMAT QMEAN QSMEAN LMEAN LVAR VARC   CONC LOADC CV 9.3;
 TITLE2 DIRECT FLOW-INTERVAL METHOD;
%
******************* END OF MACRO MACFIM;
```

APPENDIX B

Transient Mass Balance Listings

B-1 Cumulative Water Balance

B-2 Cumulative Total Phosphorus Balance

B-3 Cumulative Dissolved Phosphorus Balance

Table B-1
Cumulative Water Balance

Units : million cubic meters
SEQ = SAS Date (days from 1 JAN 60), 15-day intervals
A = gauged tributary input
B = ungauged tributary input
C = gauged input from DHACC
D = total tributary input
E = precipitation
F = total inflow
G = lake discharge
H = evaporation
I = total outflow
J = net inflow (F - I)

DATE	SEQ	A	B	C	D	E	F	G	H	I	J
14FEB81	7715	0.42	0.10	0.00	0.52	0.19	0.71	0.59	0.04	0.62	0.09
01MAR81	7730	2.08	0.51	0.00	2.59	0.39	2.98	1.59	0.07	1.67	1.31
16MAR81	7745	2.43	0.59	0.01	3.03	0.41	3.43	2.36	0.12	2.48	0.96
31MAR81	7760	2.86	0.70	0.01	3.57	0.43	3.99	2.69	0.17	2.86	1.14
15APR81	7775	3.59	0.87	0.01	4.47	0.52	4.99	3.53	0.23	3.76	1.22
30APR81	7790	3.95	0.96	0.01	4.92	0.61	5.53	4.20	0.29	4.49	1.04
15MAY81	7805	4.29	1.04	0.01	5.35	0.72	6.07	4.73	0.35	5.08	0.99
30MAY81	7820	4.64	1.13	0.02	5.78	0.82	6.60	5.25	0.42	5.67	0.93
14JUN81	7835	4.78	1.16	0.02	5.96	0.93	6.89	5.50	0.50	6.00	0.89
29JUN81	7850	4.84	1.18	0.02	6.04	1.04	7.08	5.64	0.57	6.22	0.86
14JUL81	7865	4.88	1.19	0.02	6.08	1.27	7.35	5.71	0.67	6.38	0.97
29JUL81	7880	4.91	1.19	0.02	6.13	1.50	7.62	5.75	0.76	6.51	1.11
13AUG81	7895	4.95	1.20	0.02	6.18	1.60	7.78	5.84	0.86	6.70	1.08
28AUG81	7910	5.01	1.22	0.02	6.25	1.71	7.96	5.93	0.96	6.89	1.07
12SEP81	7925	5.05	1.23	0.02	6.30	1.91	8.21	5.95	1.04	6.99	1.22
27SEP81	7940	5.43	1.32	0.02	6.78	2.12	8.90	6.21	1.12	7.33	1.56
12OCT81	7955	5.88	1.43	0.03	7.34	2.27	9.61	6.82	1.17	7.99	1.63
27OCT81	7970	6.33	1.54	0.03	7.90	2.43	10.32	7.23	1.22	8.45	1.87
11NOV81	7985	7.23	1.76	0.04	9.03	2.50	11.53	8.67	1.26	9.92	1.61
26NOV81	8000	7.64	1.86	0.04	9.54	2.50	12.12	9.35	1.29	10.64	1.48
11DEC81	8015	7.97	1.94	0.04	9.95	2.66	12.61	9.85	1.33	11.17	1.43
26DEC81	8030	8.20	1.99	0.05	10.24	2.73	12.97	10.20	1.36	11.56	1.41
10JAN82	8045	8.43	2.05	0.05	10.53	2.80	13.33	10.60	1.40	12.00	1.33
25JAN82	8060	8.57	2.08	0.05	10.71	2.87	13.58	10.88	1.44	12.32	1.27
09FEB82	8075	8.80	2.14	0.06	10.99	2.94	13.93	11.27	1.47	12.74	1.20
24FEB82	8090	8.96	2.18	0.06	11.19	3.01	14.20	11.55	1.51	13.06	1.14
11MAR82	8105	9.07	2.20	0.06	11.33	3.07	14.40	11.80	1.56	13.35	1.05
26MAR82	8120	9.53	2.32	0.07	11.91	3.14	15.05	12.22	1.61	13.83	1.23
10APR82	8135	10.59	2.57	0.07	13.23	3.21	16.44	13.46	1.67	15.13	1.32
25APR82	8150	12.10	2.94	0.08	15.12	3.28	18.39	15.11	1.72	16.83	1.56
10MAY82	8165	12.49	3.04	0.08	15.61	3.31	18.92	16.18	1.79	17.96	0.96
25MAY82	8180	12.66	3.08	0.08	15.82	3.34	19.16	16.24	1.85	18.10	1.06
09JUN82	8195	12.80	3.11	0.09	16.00	3.51	19.51	16.46	1.93	18.39	1.12
24JUN82	8210	12.92	3.14	0.09	16.14	3.67	19.82	16.69	2.01	18.70	1.12
09JUL82	8225	13.05	3.17	0.09	16.32	3.74	20.06	17.02	2.10	19.12	0.93
24JUL82	8240	13.09	3.18	0.09	16.37	3.80	20.17	17.14	2.20	19.33	0.83
08AUG82	8255	13.13	3.19	0.09	16.41	3.87	20.27	17.18	2.30	19.48	0.79
23AUG82	8270	13.15	3.20	0.09	16.44	3.93	20.37	17.23	2.40	19.63	0.75
07SEP82	8285	13.16	3.20	0.09	16.46	3.99	20.45	17.24	2.48	19.71	0.74
22SEP82	8300	13.17	3.20	0.09	16.47	4.06	20.53	17.25	2.55	19.80	0.72
07OCT82	8315	13.19	3.20	0.09	16.49	4.10	20.58	17.26	2.60	19.86	0.72
22OCT82	8330	13.21	3.21	0.09	16.51	4.14	20.66	17.26	2.66	19.92	0.74
06NOV82	8345	13.26	3.22	0.09	16.57	4.20	20.77	17.39	2.69	20.08	0.69
21NOV82	8360	13.31	3.24	0.09	16.64	4.30	20.95	17.61	2.73	20.34	0.61
06DEC82	8375	13.41	3.26	0.10	16.77	4.37	21.14	17.76	2.76	20.52	0.62

Table B-2
Cumulative Total Phosphorus Balance

Units: Kilograms
SEQ = SAS Date (Days from 1 Jan 60), 15-day intervals
A = gauged tributary input
B = gauged input from DHACC
C = ungauged tributary input
D = atmospheric input
E = total input
F = lake discharge
G = change in storage
H = net sedimentation

DATE	SEQ	A	B	C	D	E	F	G	H
14FEB81	7715	14.5	0.2	3.5	1.6	19.8	23.8	0.0	-4.0
01MAR81	7730	136.9	0.4	33.3	3.2	173.7	55.2	164.7	-46.2
16MAR81	7745	141.0	0.6	34.3	4.7	180.5	67.3	24.6	88.6
31MAR81	7760	152.4	0.8	37.0	6.3	196.5	74.1	-94.6	217.0
15APR81	7775	165.6	1.0	40.3	7.9	214.8	101.8	78.5	34.4
30APR81	7790	167.8	1.2	40.8	9.5	219.2	123.5	-181.5	277.3
15MAY81	7805	170.0	1.4	41.3	11.1	223.7	136.7	-366.0	453.1
30MAY81	7820	172.1	1.6	41.8	12.6	228.2	144.4	-309.8	393.6
14JUN81	7835	173.2	1.8	42.1	14.2	231.3	147.4	-108.8	192.8
29JUN81	7850	173.7	2.0	42.2	15.8	233.7	149.4	95.9	-11.7
14JUL81	7865	174.1	2.2	42.3	17.4	236.0	151.1	115.8	-30.9
29JUL81	7880	174.6	2.6	42.4	19.0	238.5	152.1	152.4	-65.9
13AUG81	7895	175.2	2.7	42.6	20.5	241.0	153.3	200.3	-112.7
28AUG81	7910	175.7	2.7	42.7	22.1	243.2	154.3	555.9	-467.0
12SEP81	7925	176.4	2.8	42.9	23.7	245.8	155.0	697.8	-607.0
27SEP81	7940	196.9	3.1	47.9	25.3	273.2	158.3	542.9	-428.0
12OCT81	7955	200.9	3.3	48.8	26.9	280.0	167.0	424.1	-311.1
27OCT81	7970	204.2	3.5	49.6	28.4	285.7	179.7	137.4	-31.5
11NOV81	7985	258.8	3.6	62.9	30.0	355.3	256.2	99.9	-0.8
26NOV81	8000	263.5	3.7	64.0	31.6	362.8	287.6	99.3	-24.2
11DEC81	8015	266.4	3.8	64.7	33.2	368.1	307.5	71.1	-10.5
26DEC81	8030	268.5	3.8	65.3	34.8	372.4	318.7	-39.1	92.8
10JAN82	8045	272.0	3.9	66.1	36.3	378.4	329.8	-114.1	162.7
25JAN82	8060	274.4	4.0	66.7	37.9	383.0	336.4	-71.3	117.8
09FEB82	8075	278.6	4.0	67.7	39.5	389.8	344.8	-62.8	107.7
24FEB82	8090	280.1	4.1	68.1	41.1	393.3	349.8	-51.2	94.7
11MAR82	8105	280.9	4.1	68.3	42.7	395.9	354.3	-5.2	46.8
26MAR82	8120	303.2	4.3	73.7	44.2	425.5	373.3	188.9	-136.8
10APR82	8135	347.7	4.5	84.5	45.8	482.6	404.0	101.6	-23.1
25APR82	8150	383.3	4.6	93.1	47.4	528.3	435.6	130.5	-37.7
10MAY82	8165	386.4	4.7	93.9	49.0	534.0	478.3	-28.8	84.5
25MAY82	8180	387.7	4.8	94.2	50.6	537.3	480.5	-310.3	367.1
09JUN82	8195	392.1	5.1	95.3	52.1	544.6	487.1	-383.2	440.7
24JUN82	8210	394.0	5.3	95.7	53.7	548.8	491.4	-174.8	232.2
09JUL82	8225	398.7	5.9	96.9	55.3	556.8	499.4	-130.7	188.0
24JUL82	8240	399.2	6.0	97.0	56.9	559.1	501.6	-59.8	117.3
08AUG82	8255	399.7	6.1	97.1	58.5	561.5	502.6	124.5	-65.7
23AUG82	8270	400.2	6.3	97.2	60.0	563.7	504.5	28.7	30.5
07SEP82	8285	400.3	6.6	97.3	61.6	565.7	504.6	-100.0	161.1
22SEP82	8300	400.6	6.7	97.3	63.2	567.8	504.7	43.0	20.1
07OCT82	8315	400.8	6.7	97.4	64.8	569.6	505.0	81.4	-16.9
22OCT82	8330	401.2	6.7	97.5	66.4	571.7	505.2	40.2	26.3
06NOV82	8345	403.1	6.7	98.0	67.9	575.8	508.1	-208.1	275.8
21NOV82	8360	404.2	6.7	98.2	69.5	578.7	514.7	-215.9	279.9
06DEC82	8375	405.1	6.8	98.4	71.1	581.4	518.4	-250.2	313.2

Table B-3
Cumulative Dissolved Phosphorus Balance

Units: Kilograms
SEQ = SAS Date (days from 1 JAN 60), 15-day intervals
A = gauged tributary input
B = input from DHACC
C = ungauged tributary input
D = atmospheric input
E = total input
F = lake discharge
G = change in storage
H = net sedimentation

DATE	SEQ	A	B	C	D	E	F	G	H
14FEB81	7715	5.8	0.1	1.4	0.8	8.1	10.3	0.0	-2.3
01MAR81	7730	31.3	0.2	7.6	1.6	40.8	35.1	324.0	-318.3
16MAR81	7745	33.8	0.4	8.2	2.4	44.7	45.2	8.1	-8.6
31MAR81	7760	36.7	0.5	8.9	3.2	49.2	49.0	-76.5	76.7
15APR81	7775	40.4	0.6	9.8	4.0	54.8	60.7	-195.3	189.4
30APR81	7790	42.2	0.7	10.3	4.7	57.9	68.8	-147.2	136.4
15MAY81	7805	43.7	0.8	10.6	5.5	60.7	72.1	-331.1	319.8
30MAY81	7820	45.0	1.0	10.9	6.3	63.3	74.6	-180.3	169.0
14JUN81	7835	45.6	1.1	11.1	7.1	64.9	75.8	-24.9	14.0
29JUN81	7850	46.0	1.2	11.2	7.9	66.2	76.3	228.3	-238.3
14JUL81	7865	46.2	1.3	11.2	8.7	67.5	76.7	16.1	-25.4
29JUL81	7880	46.4	1.6	11.3	9.5	68.8	76.9	62.4	-70.5
13AUG81	7895	46.7	1.7	11.3	10.3	70.0	77.2	132.2	-139.4
28AUG81	7910	47.1	1.8	11.4	11.1	71.3	77.6	615.5	-621.8
12SEP81	7925	47.6	1.8	11.6	11.9	72.9	77.8	404.5	-409.4
27SEP81	7940	53.2	1.9	12.9	12.6	80.7	79.0	453.5	-451.8
12OCT81	7955	56.0	2.1	13.6	13.4	85.1	81.4	485.9	-482.1
27OCT81	7970	58.5	2.2	14.2	14.2	89.1	84.3	-255.6	260.5
11NOV81	7985	65.0	2.3	15.8	15.0	98.1	95.9	-355.4	357.6
26NOV81	8000	66.6	2.4	16.2	15.8	101.0	98.7	-311.8	314.0
11DEC81	8015	68.1	2.4	16.5	16.6	103.6	102.0	-257.3	258.9
26DEC81	8030	69.3	2.5	16.9	17.4	106.1	106.4	-111.3	111.0
10JAN82	8045	70.9	2.5	17.2	18.2	108.9	113.5	42.2	-46.9
25JAN82	8060	72.4	2.6	17.6	19.0	111.5	119.3	136.7	-144.5
09FEB82	8075	73.8	2.6	17.9	19.8	114.1	125.7	114.6	-126.2
24FEB82	8090	74.8	2.7	18.2	20.5	116.1	129.9	304.3	-318.0
11MAR82	8105	75.4	2.7	18.3	21.3	117.8	134.0	287.6	-303.8
26MAR82	8120	78.9	2.8	19.2	22.1	123.0	140.1	315.6	-332.7
10APR82	8135	84.7	2.9	20.6	22.9	131.1	156.5	230.4	-255.8
25APR82	8150	95.8	3.0	23.3	23.7	145.8	176.9	60.8	-92.0
10MAY82	8165	99.3	3.1	24.1	24.5	151.0	196.1	-106.8	61.7
25MAY82	8180	100.3	3.1	24.4	25.3	153.1	196.7	-335.6	292.0
09JUN82	8195	102.2	3.3	24.8	26.1	156.4	198.1	-171.5	129.8
24JUN82	8210	103.1	3.4	25.1	26.9	158.5	200.2	-146.5	104.7
09JUL82	8225	104.8	3.6	25.5	27.7	161.4	203.8	-144.2	101.8
24JUL82	8240	105.1	3.6	25.5	28.4	162.8	205.0	-92.7	50.5
08AUG82	8255	105.5	3.8	25.6	29.2	164.2	205.4	104.6	-145.8
23AUG82	8270	105.9	3.9	25.7	30.0	165.5	205.6	-21.9	-18.1
07SEP82	8285	106.0	4.2	25.8	30.8	166.8	205.7	-76.2	37.3
22SEP82	8300	106.2	4.3	25.8	31.6	167.9	205.7	75.3	-113.1
07OCT82	8315	106.3	4.3	25.8	32.4	168.9	205.9	117.3	-154.3
22OCT82	8330	106.7	4.3	25.9	33.2	170.1	205.9	163.6	-199.5
06NOV82	8345	107.5	4.3	26.1	34.0	171.9	207.1	-252.3	217.2
21NOV82	8360	108.2	4.3	26.3	34.8	173.5	209.6	-254.6	218.6
06DEC82	8375	108.8	4.4	26.4	35.6	175.1	211.0	-204.8	168.9

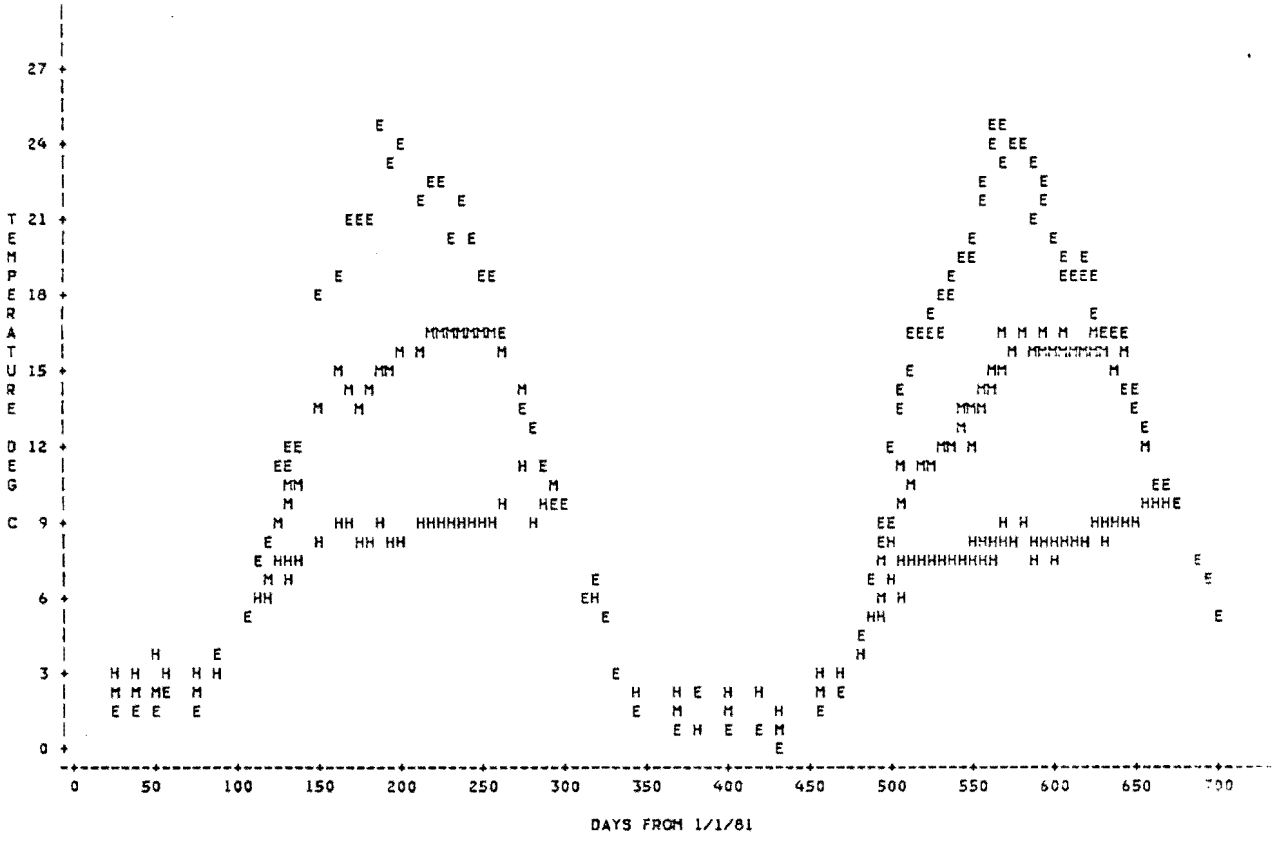
APPENDIX C

Diagnostic Plots - Time Series

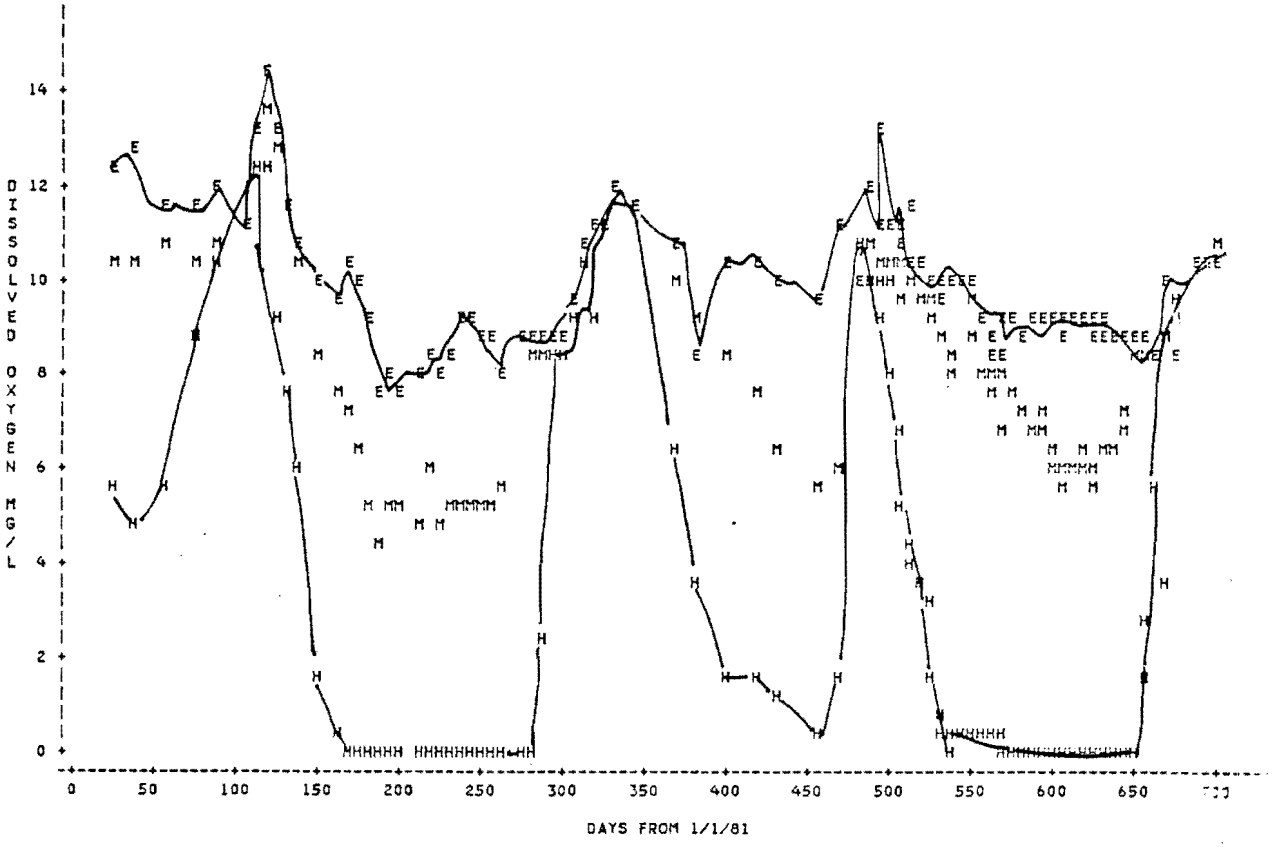
Symbol	Meaning
E	0-4 meter average
M	5-9 meter average
H	10-12 meter average

Note: These plots are intended to provide an approximate picture of water quality variations as a function of date and depth. The location of the metalimnion varies with season, but samples above four meters are generally within the epilimnion and samples below 10 meters, within the hypolimnion. More detailed pictures of vertical stratification are given in Appendix D.

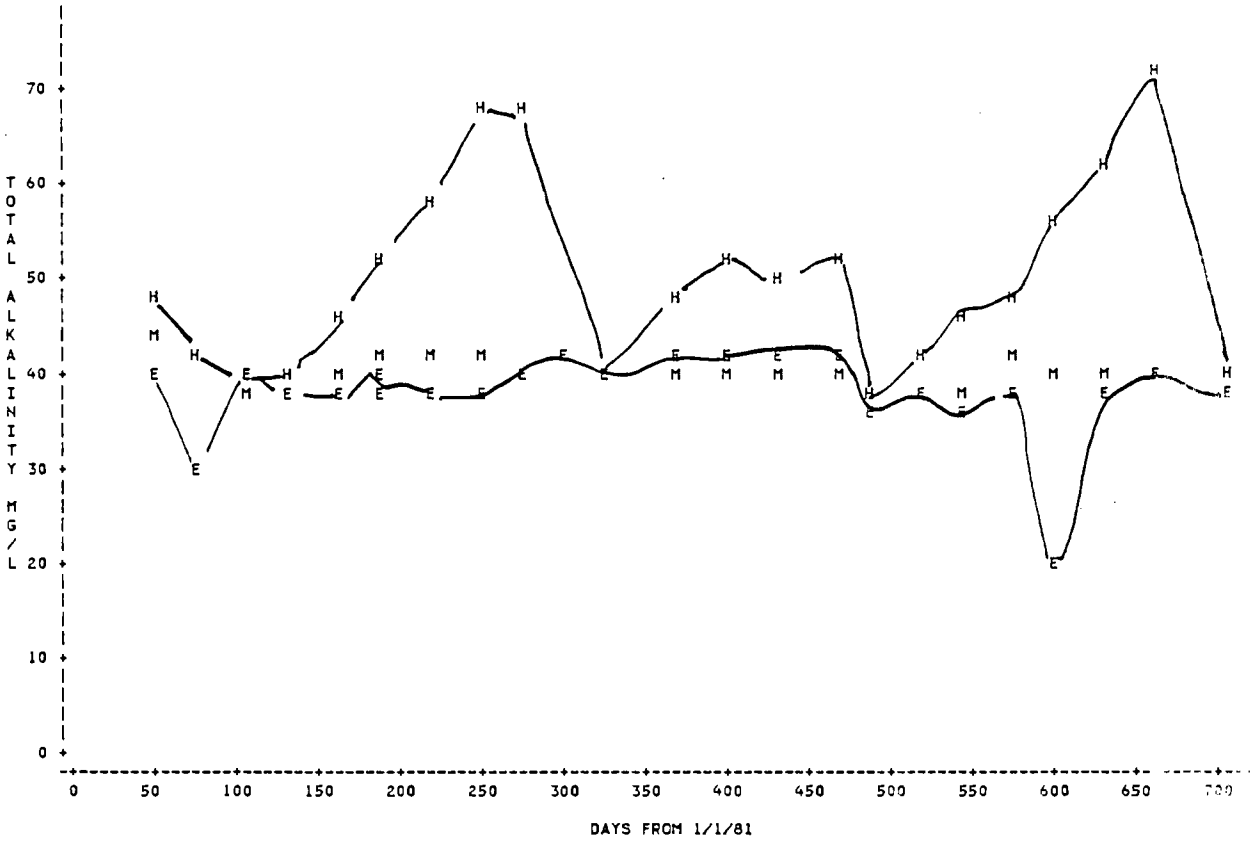
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12)



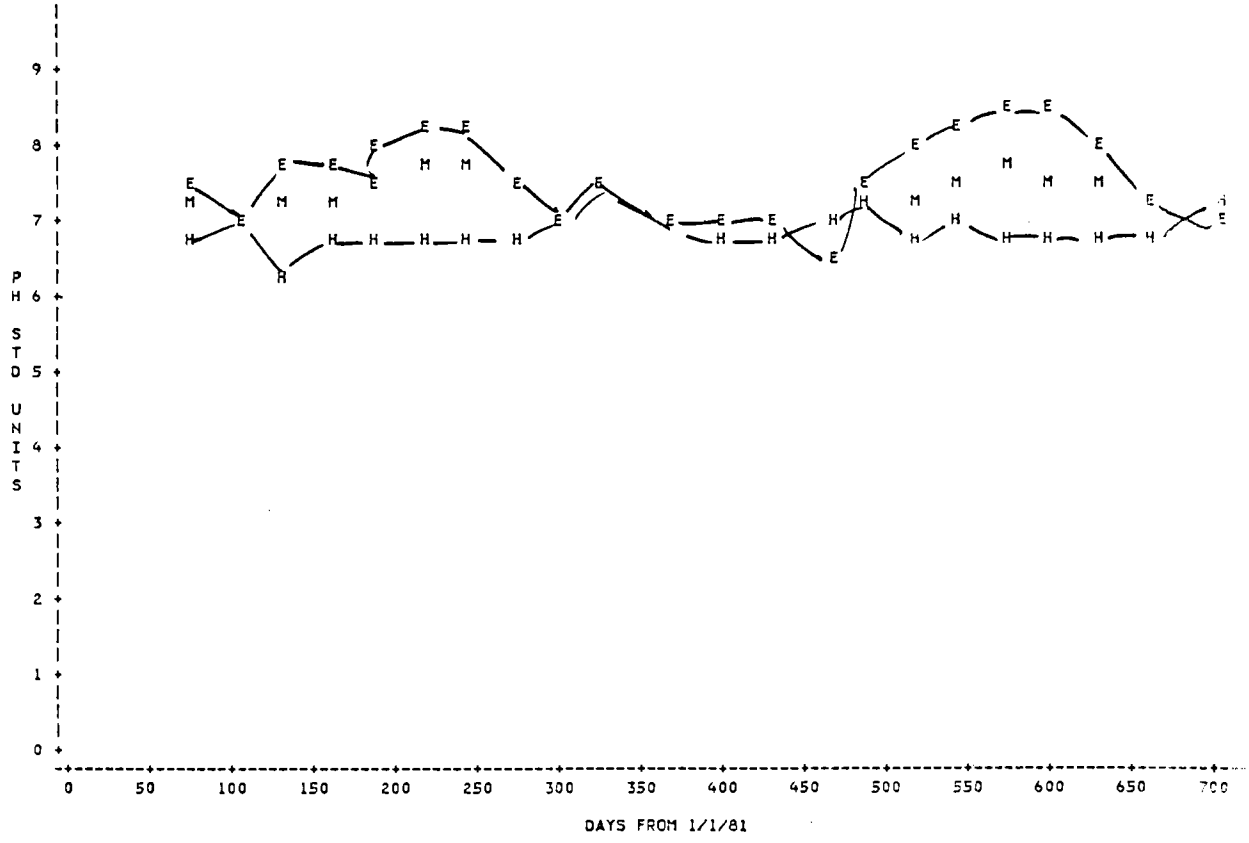
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12)



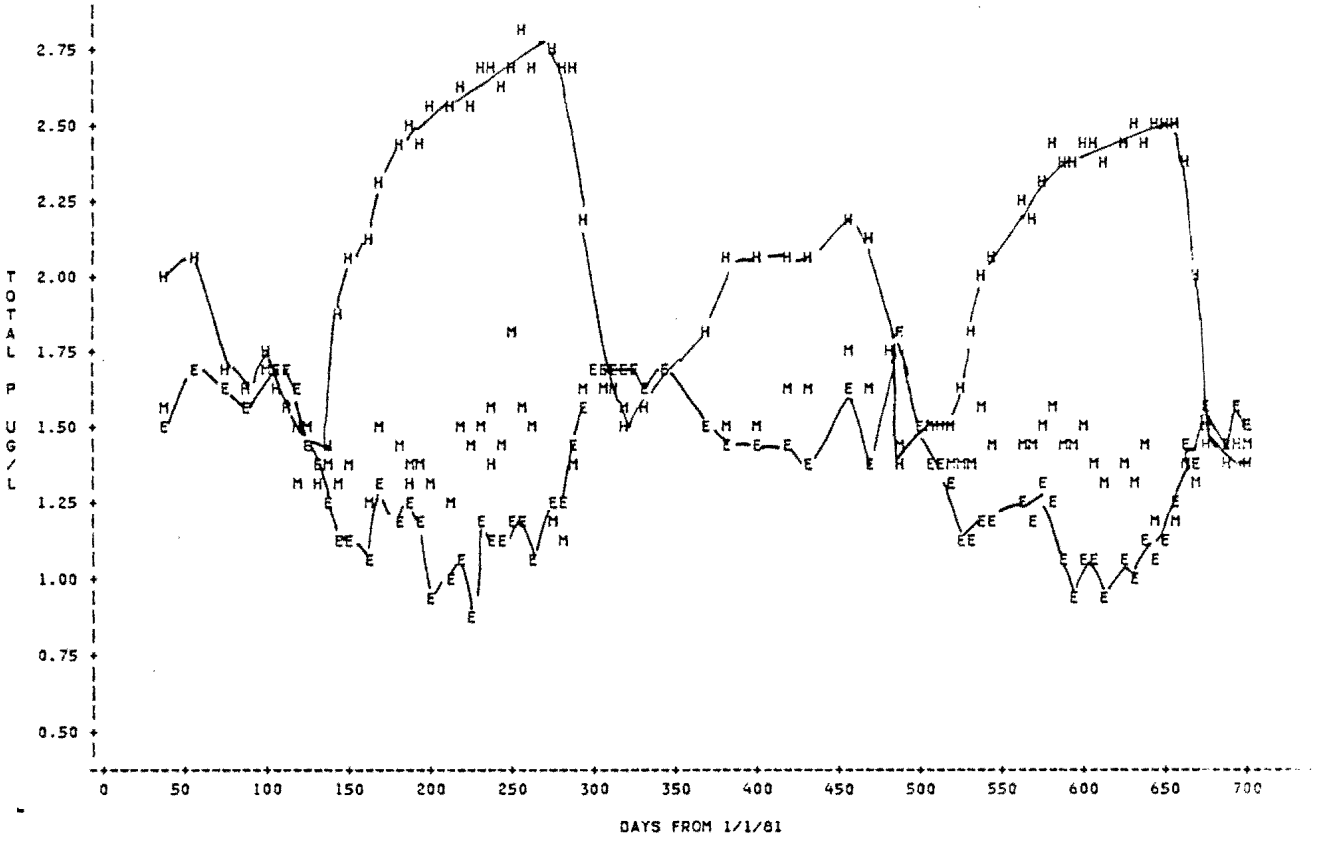
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12)



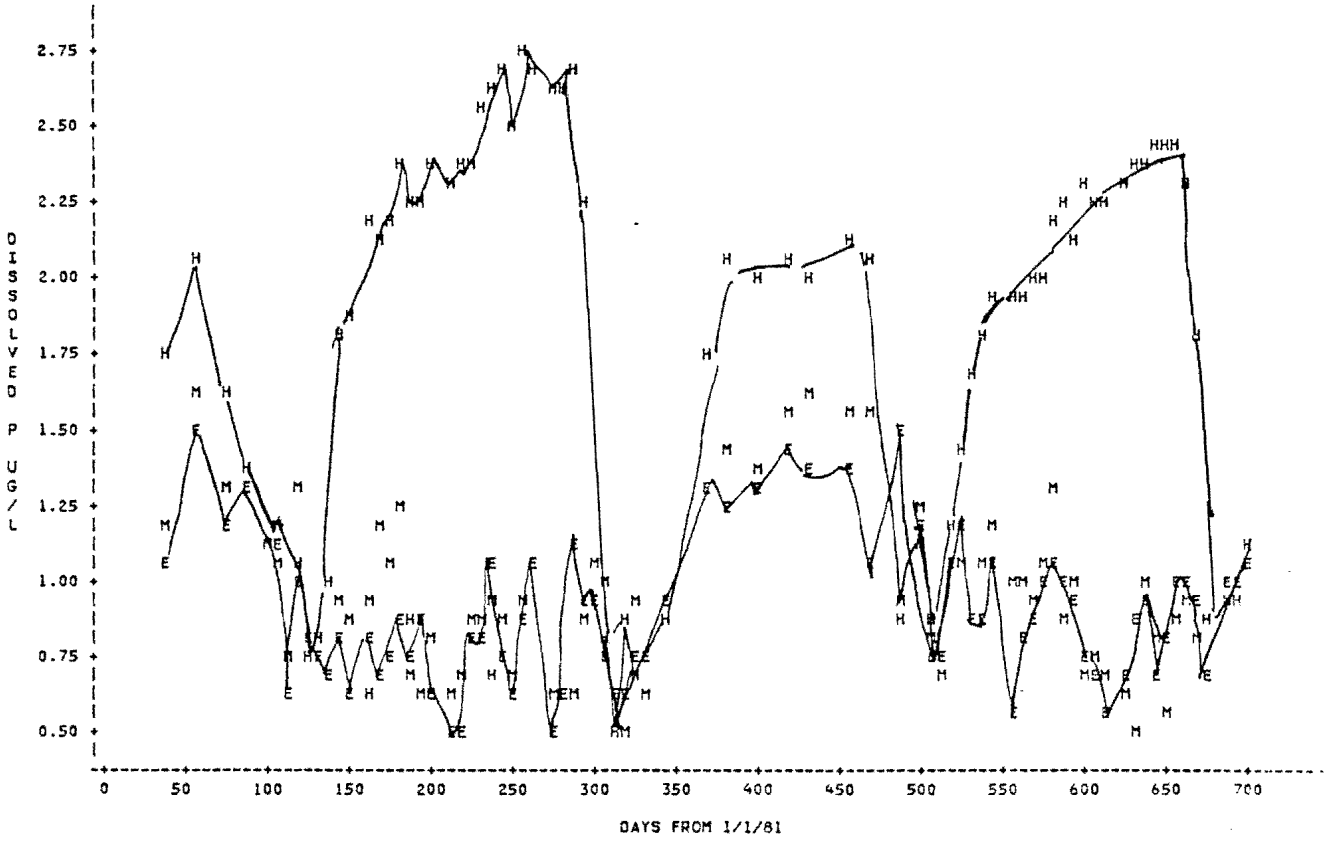
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12)



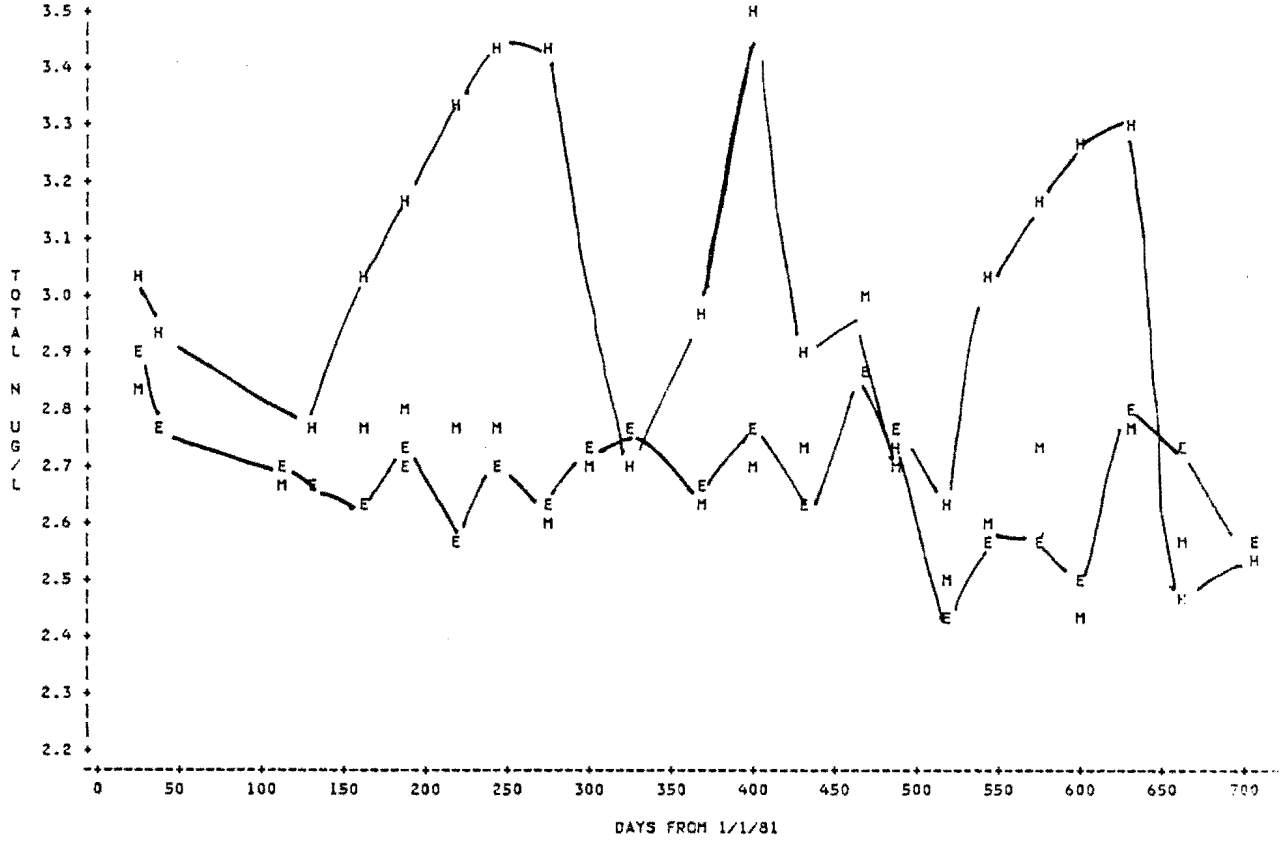
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



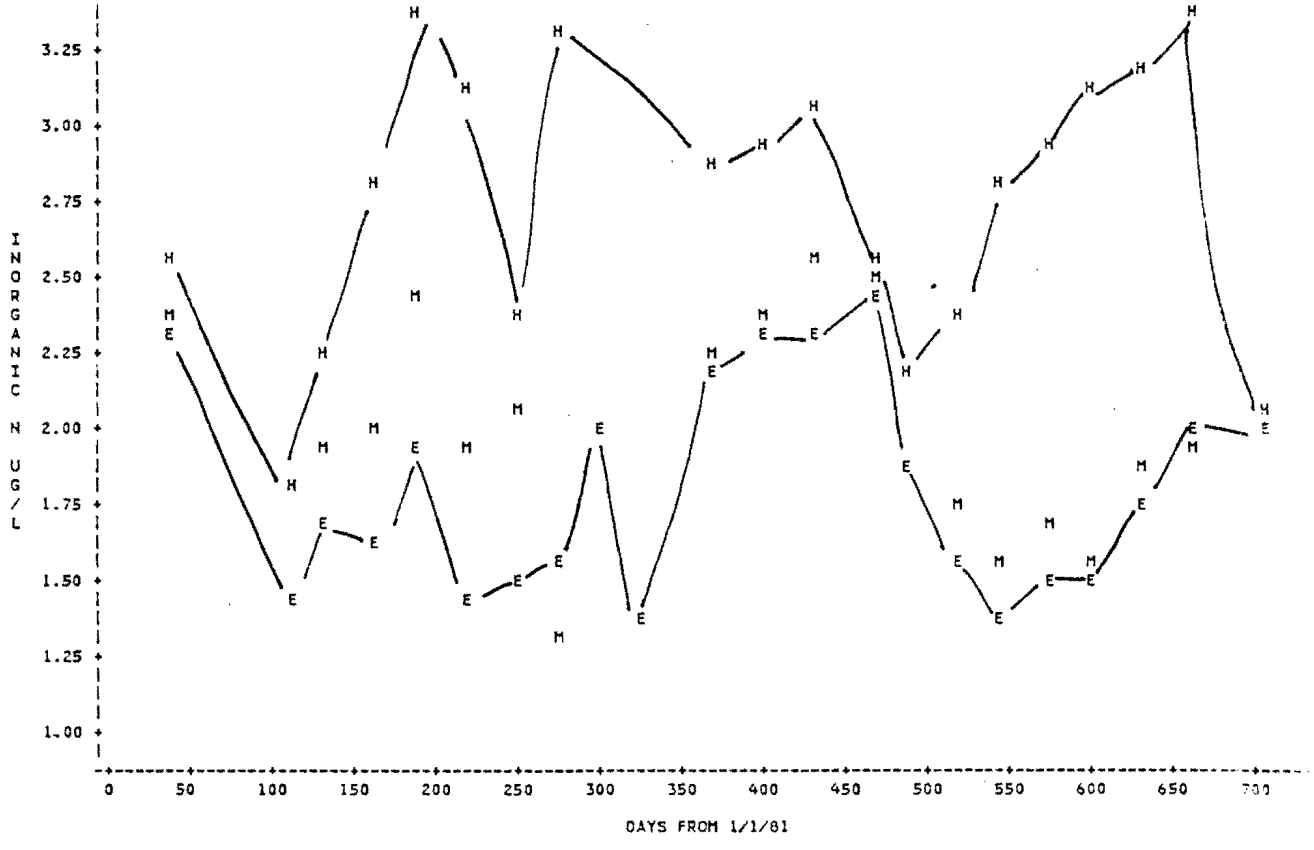
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



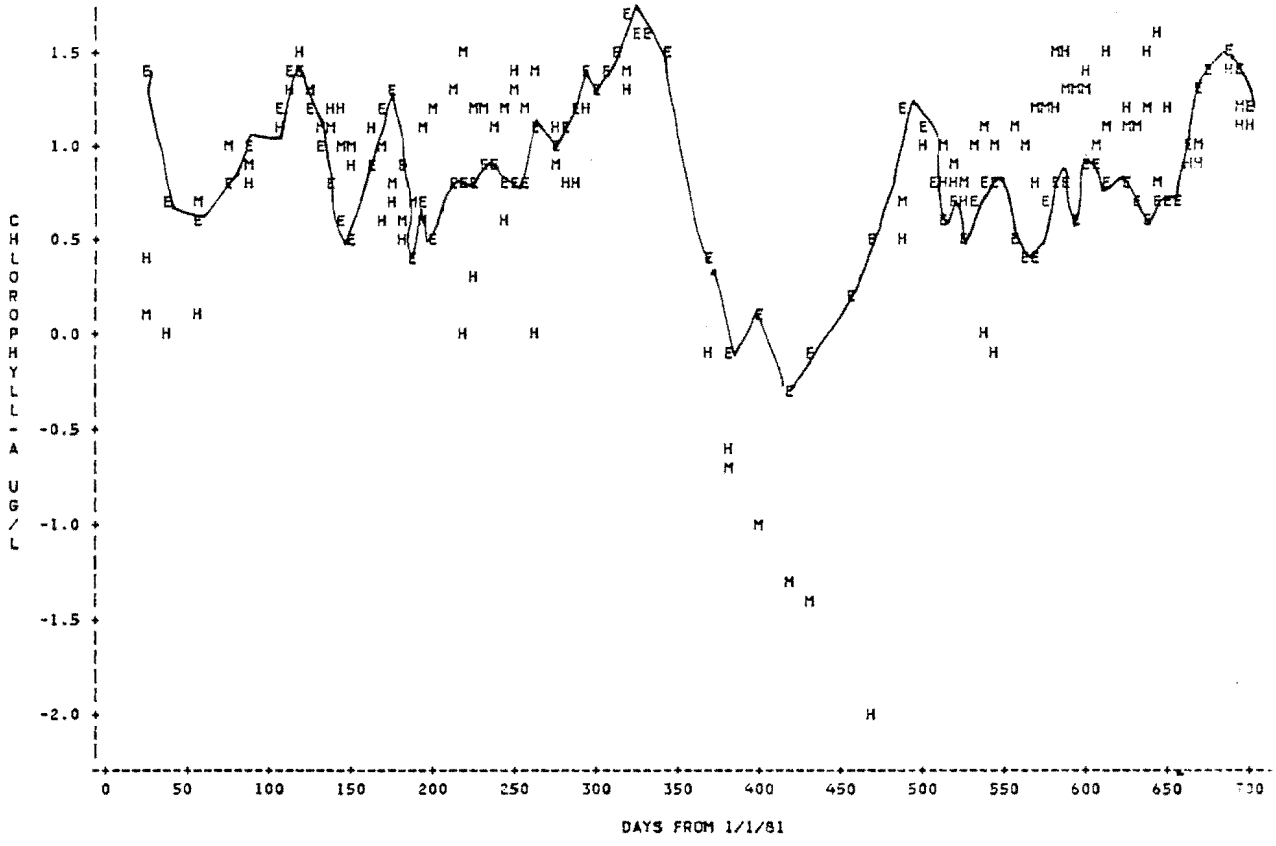
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



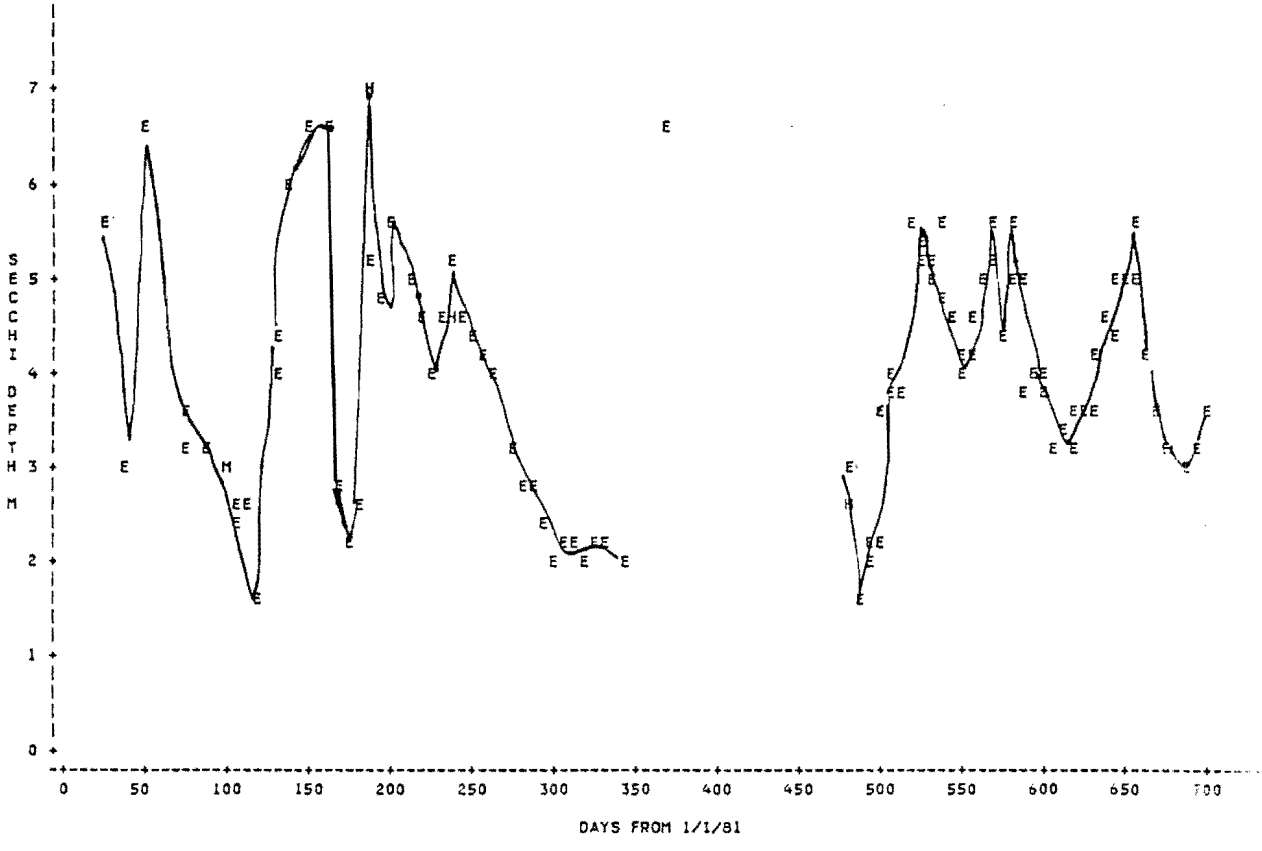
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



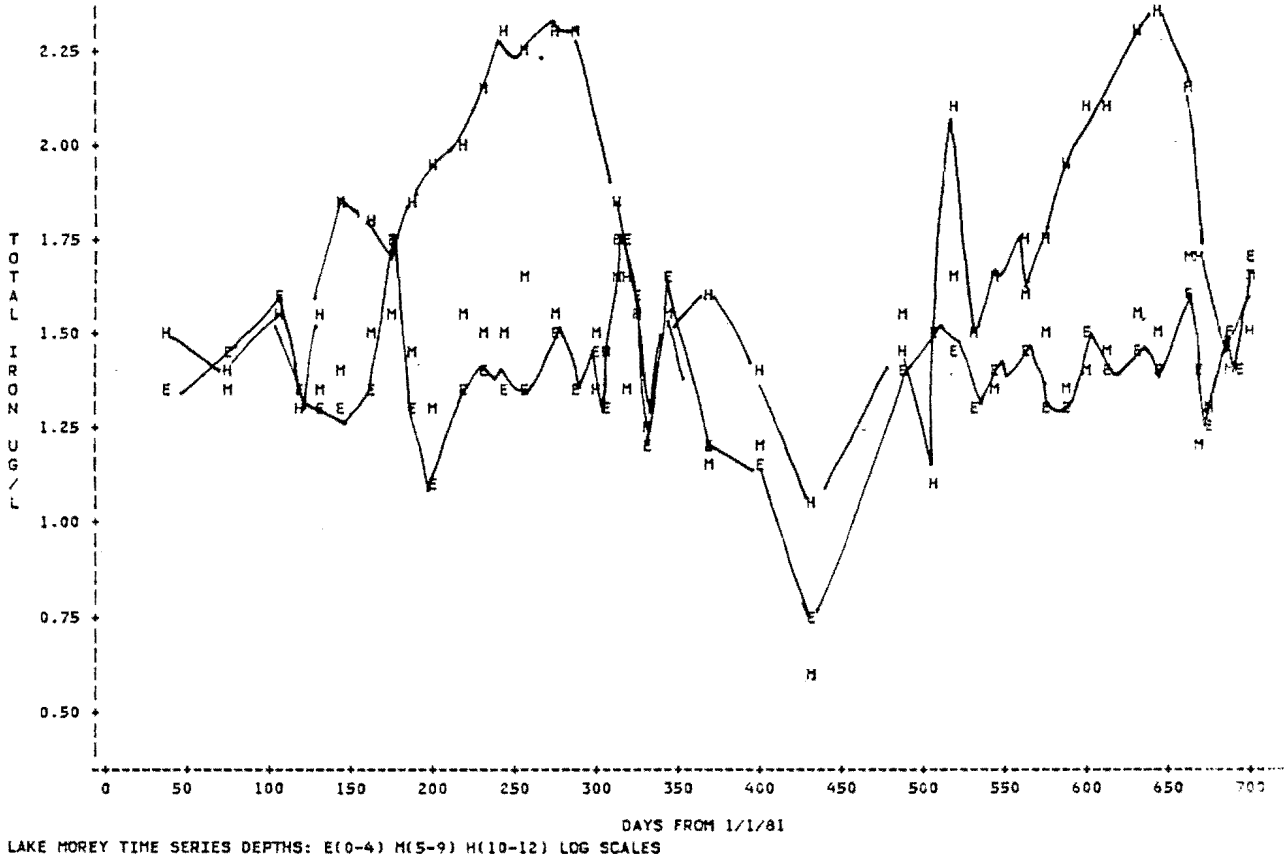
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



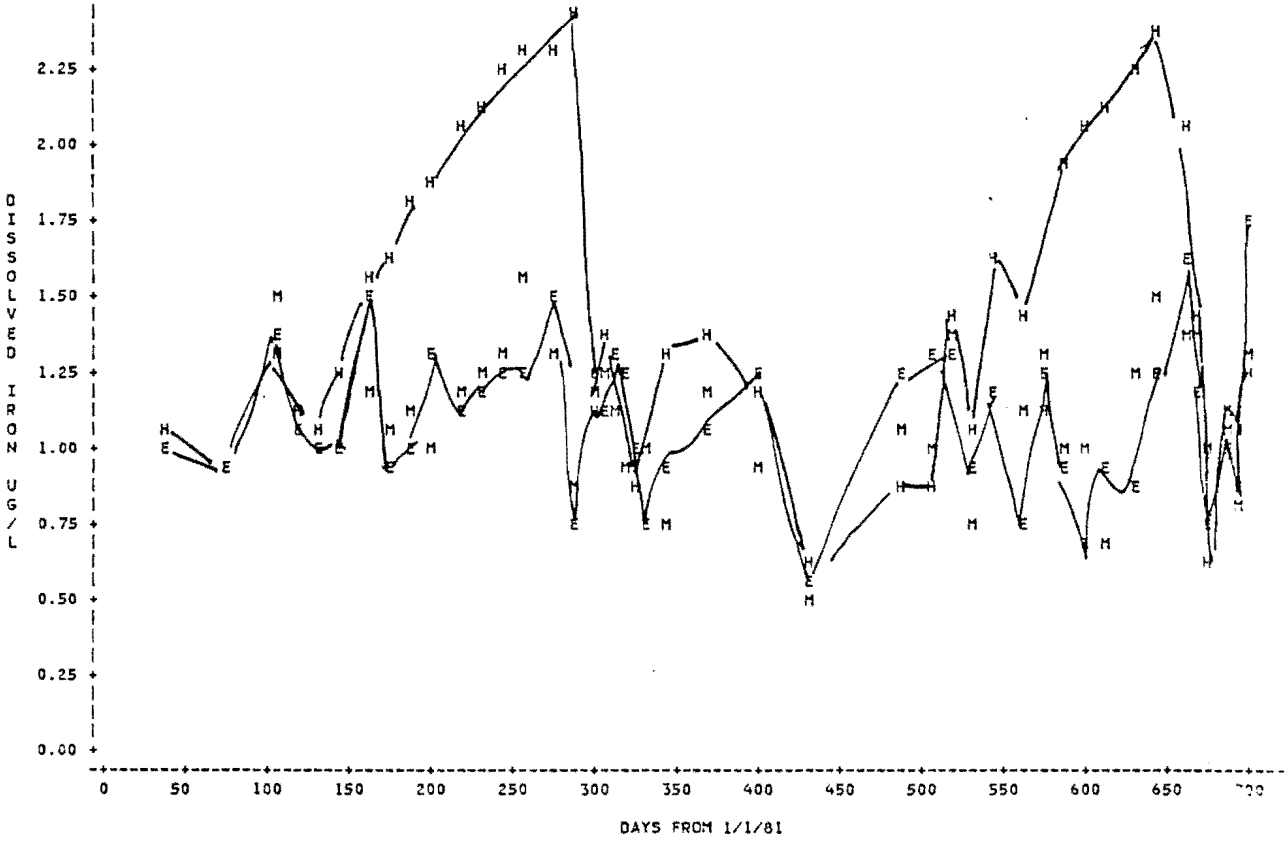
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12)



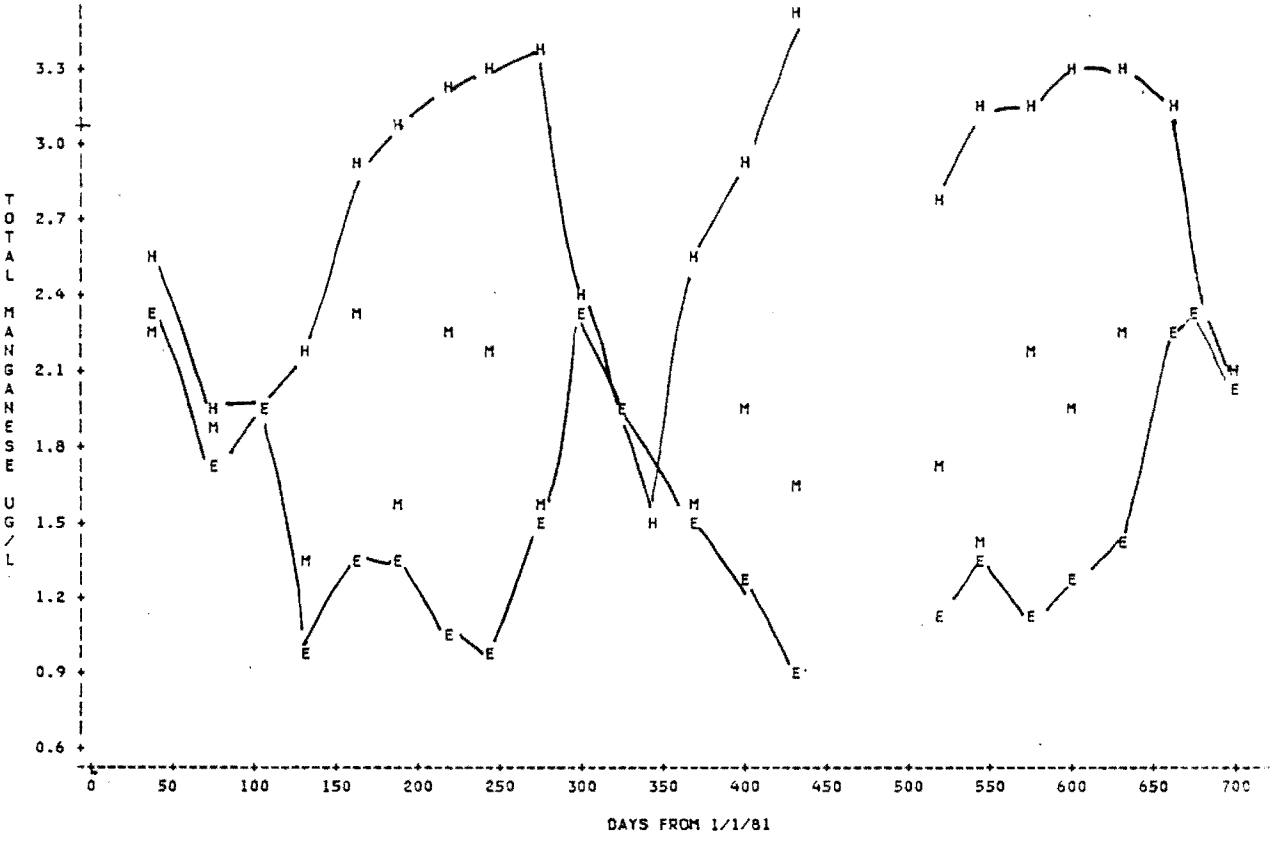
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



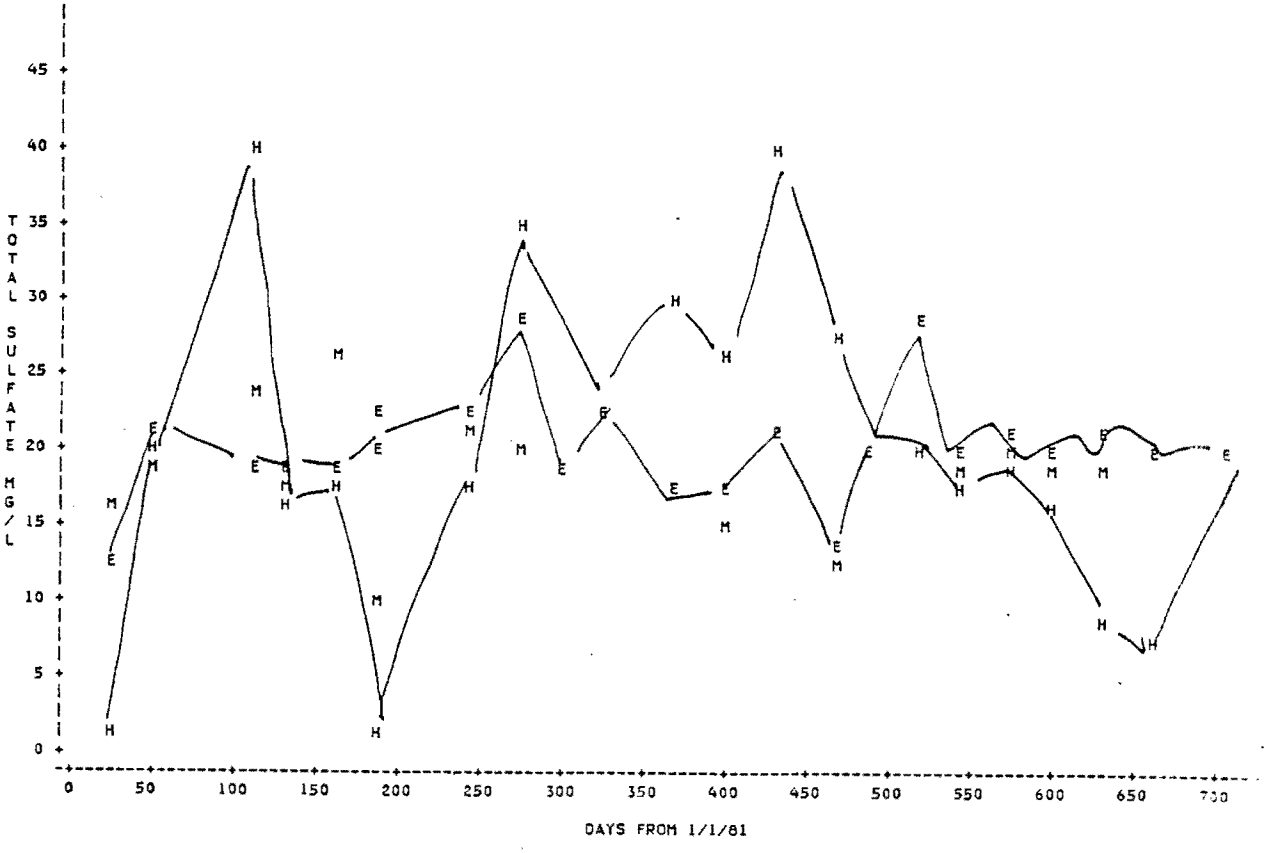
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



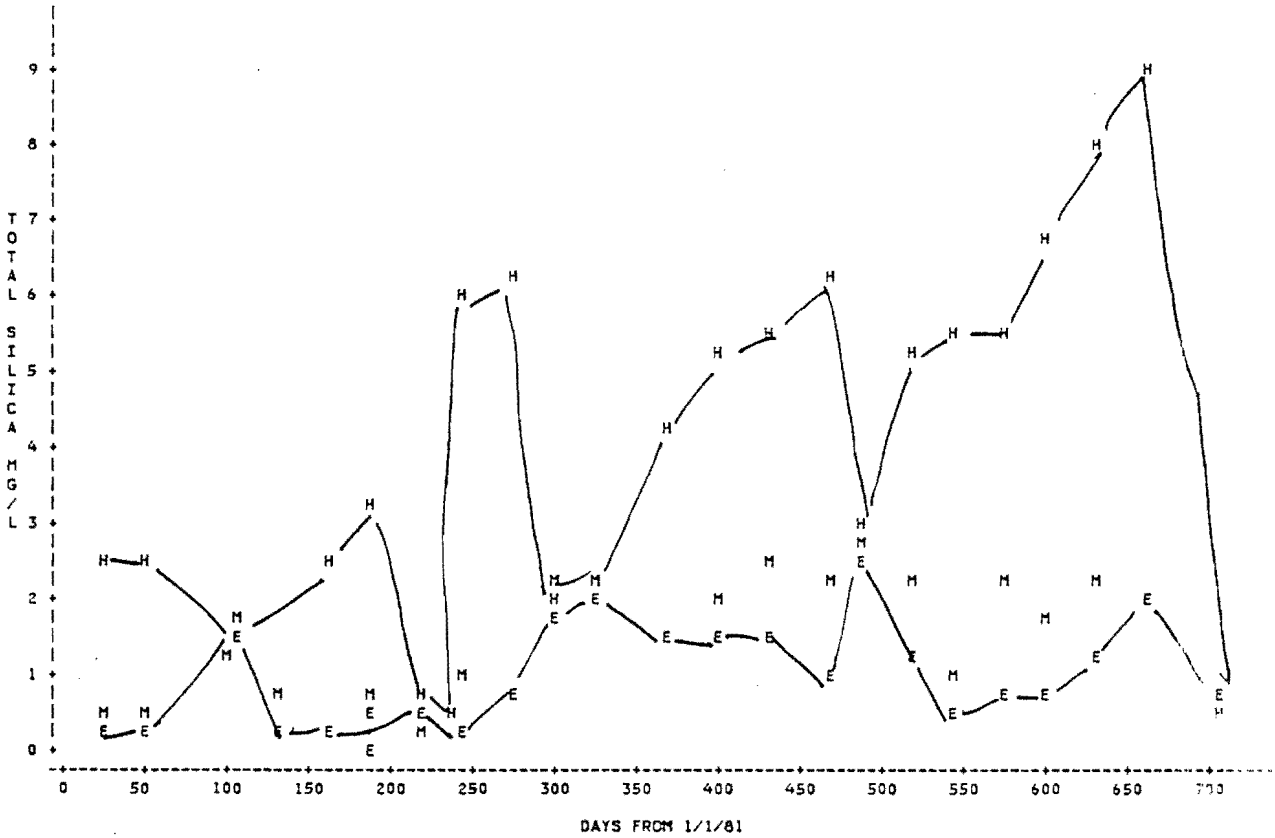
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



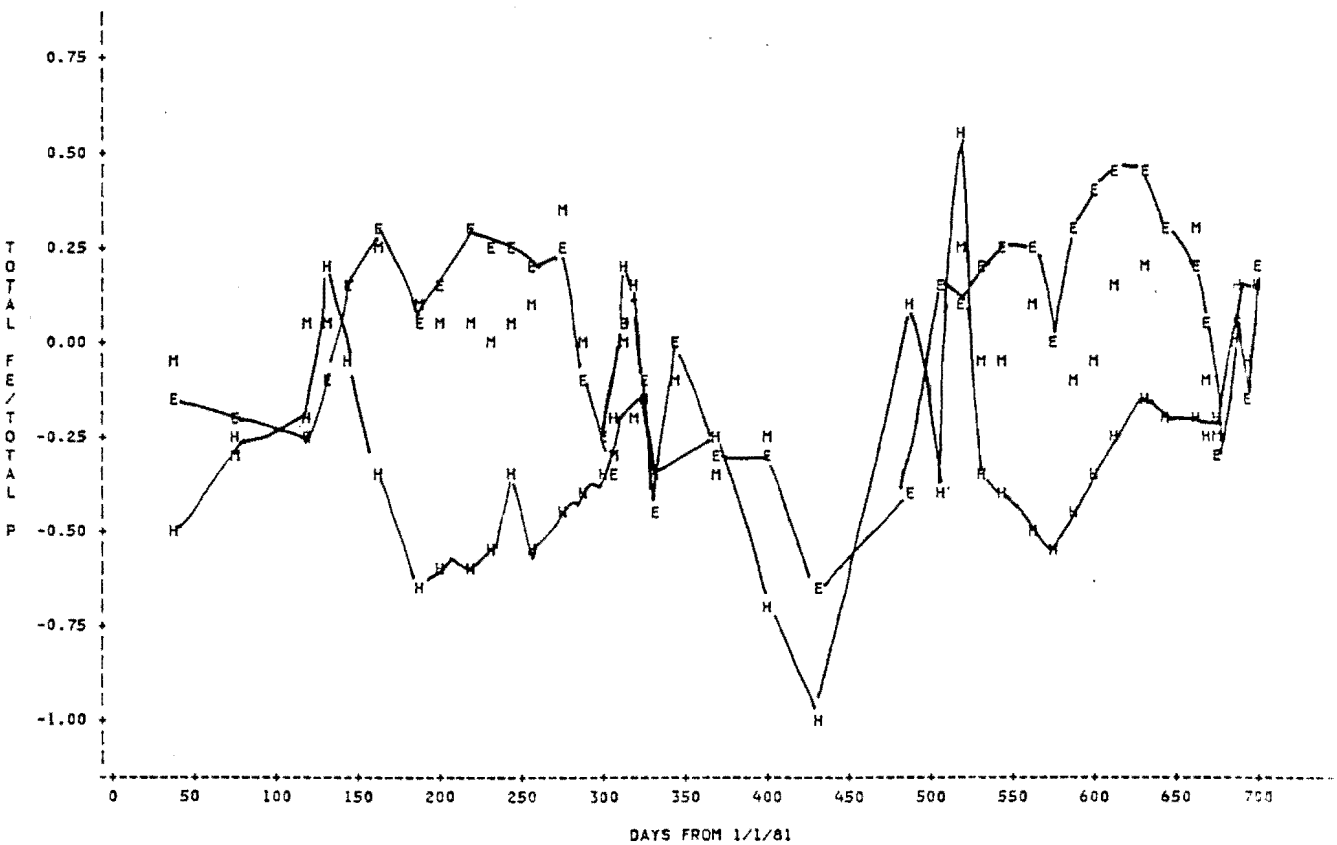
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12)



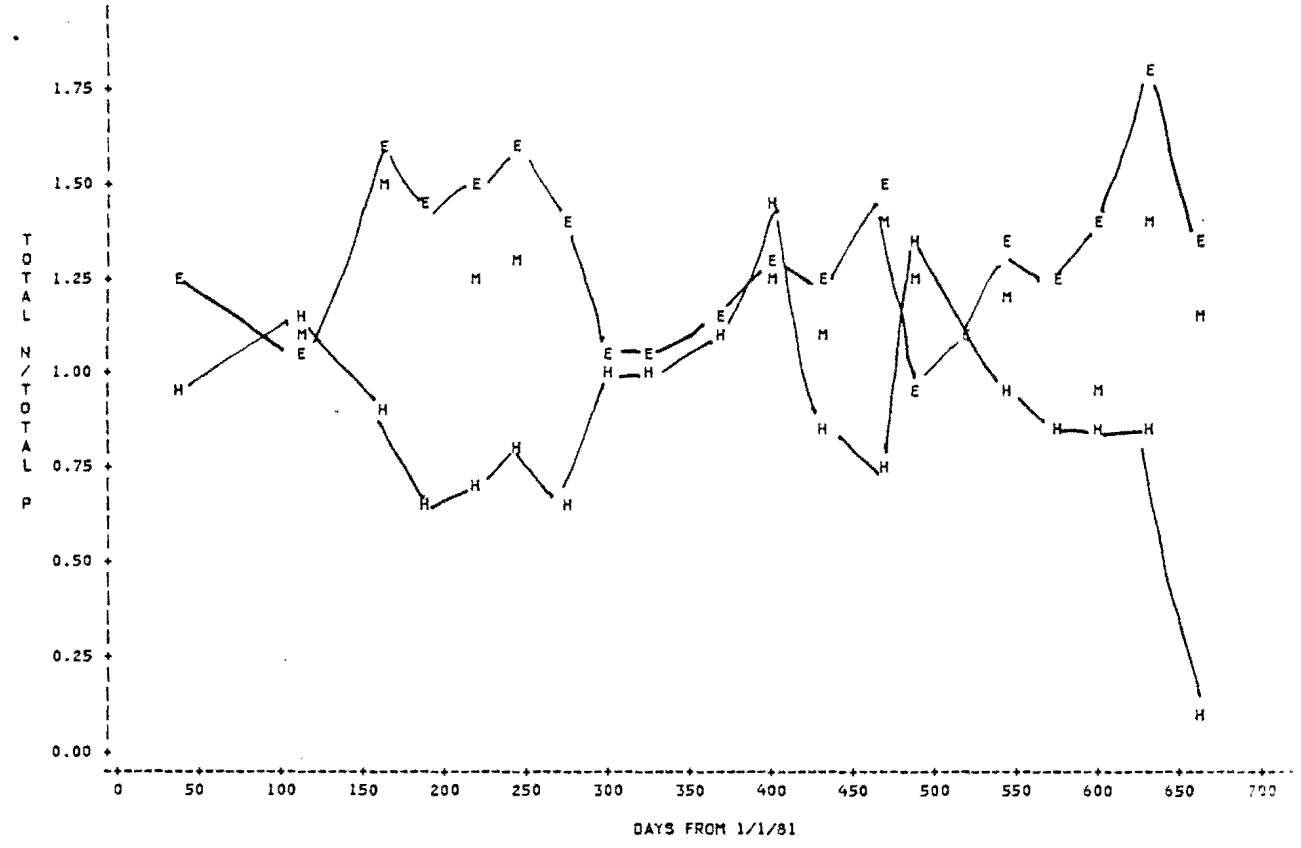
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12)



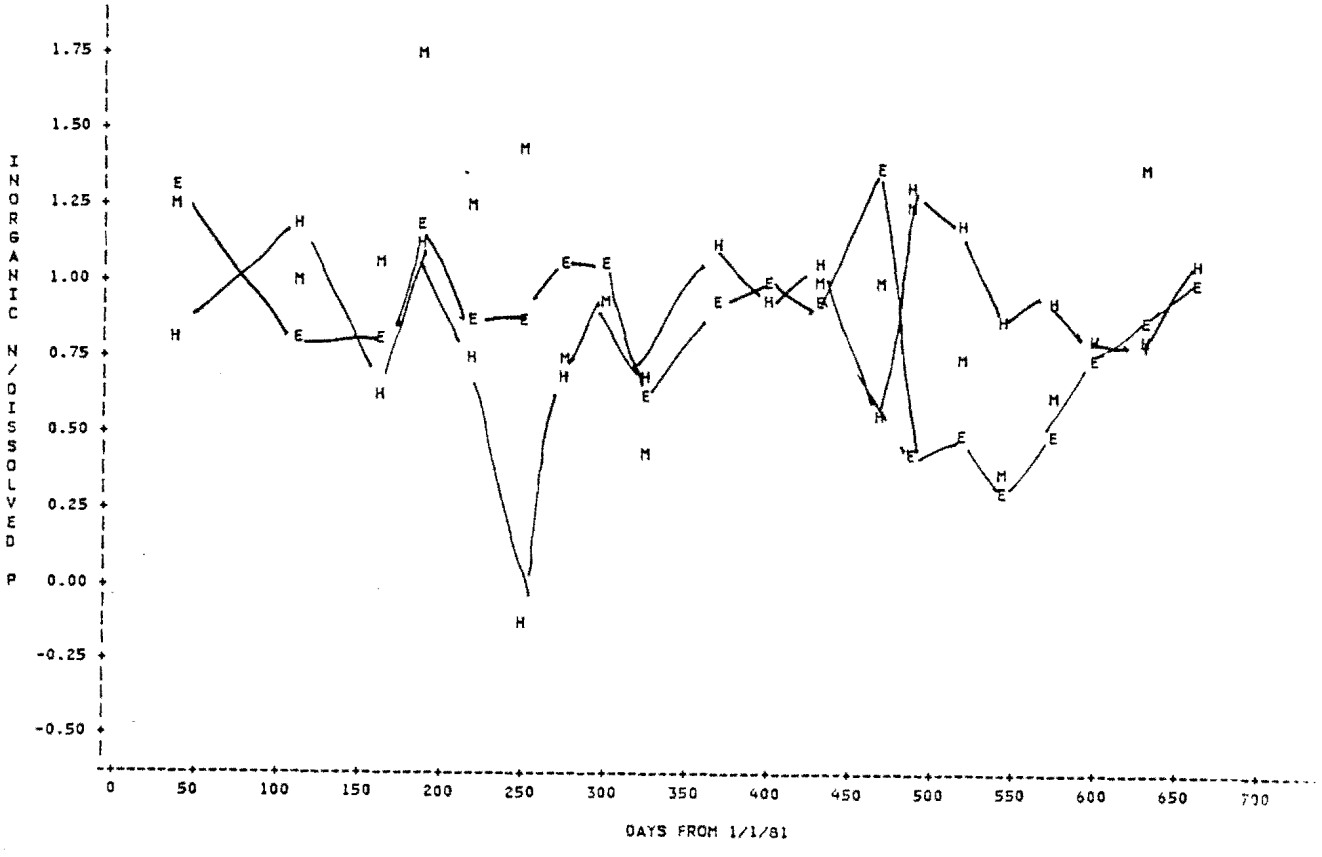
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



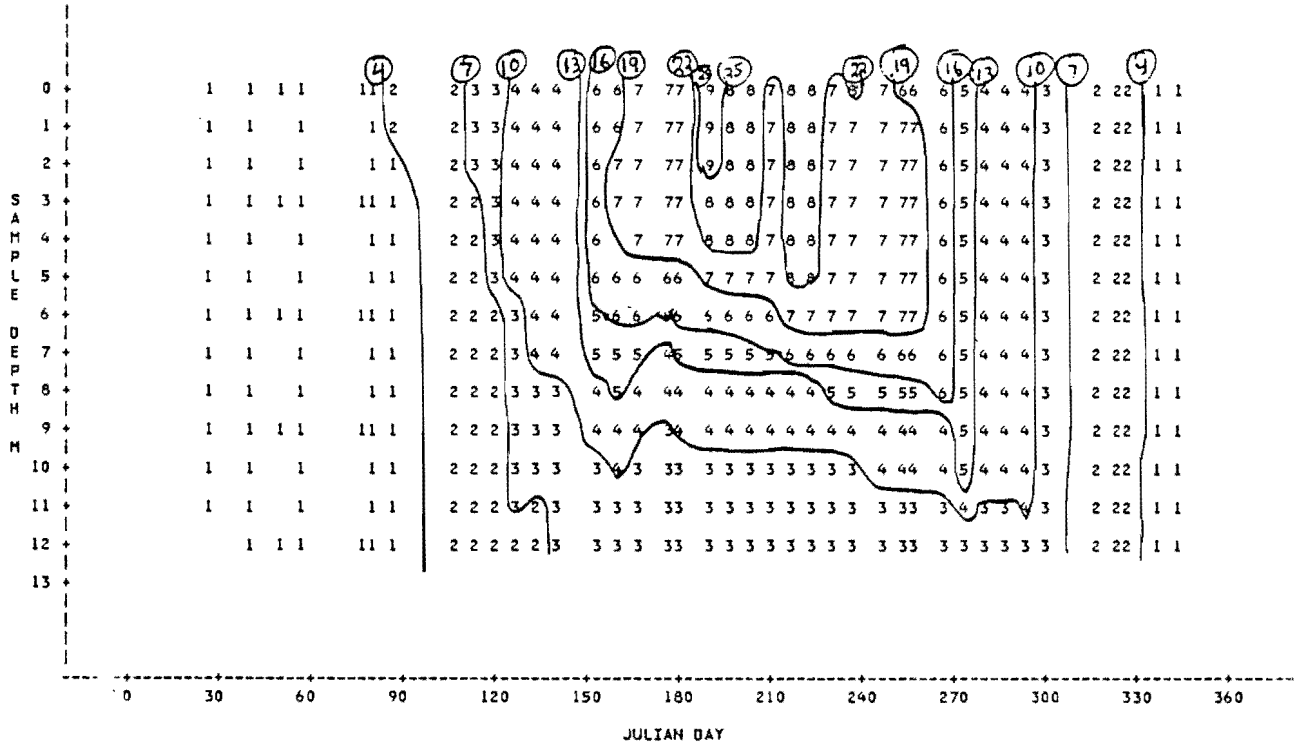
LAKE MOREY TIME SERIES DEPTHS: E(0-4) M(5-9) H(10-12) LOG SCALES



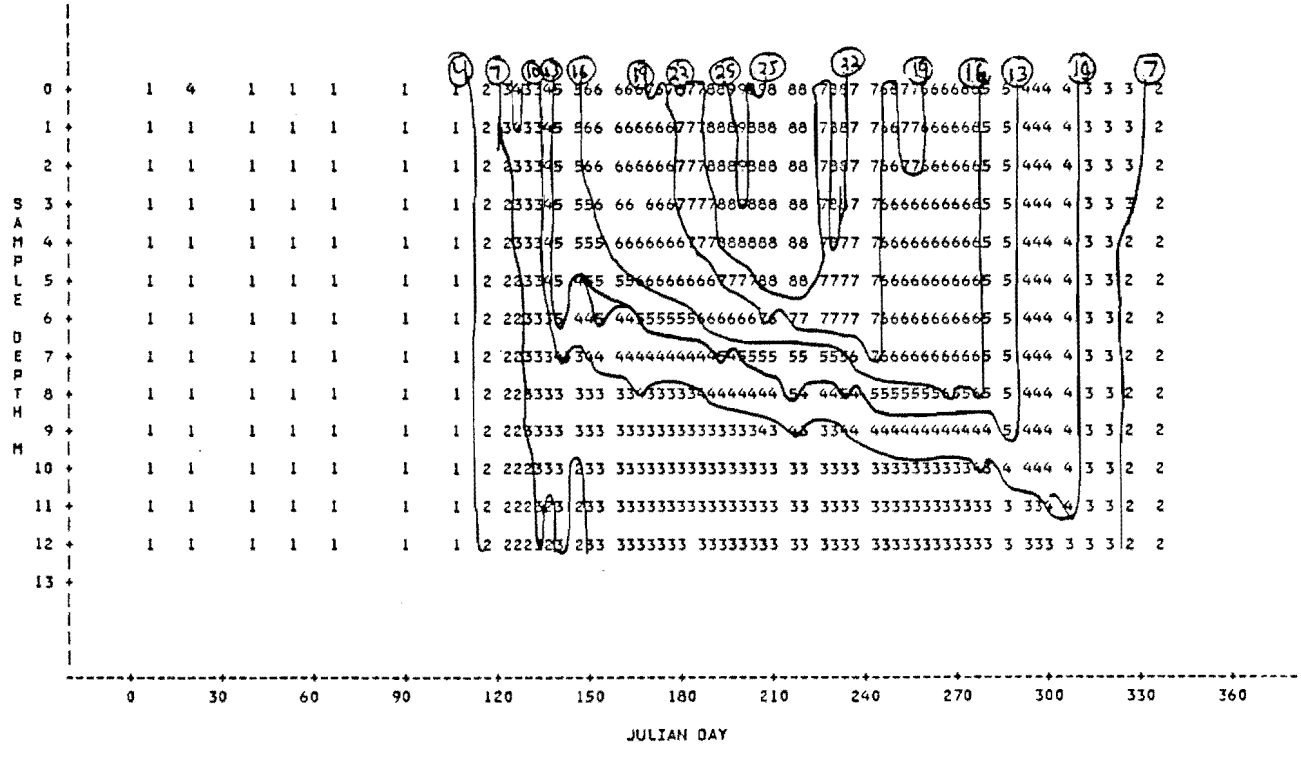
APPENDIX D

Diagnostic Plots - Depth/Date Contour Diagrams

TEMPERATURE DEG C (4,7,10,13,16,19,22,25,28)
YEAR=81



TEMPERATURE DEG C (4,7,10,13,16,19,22,25,28)
YEAR=82



DISSOLVED OXYGEN G/M3 (1,2,3,4,5,6,8,10,12)
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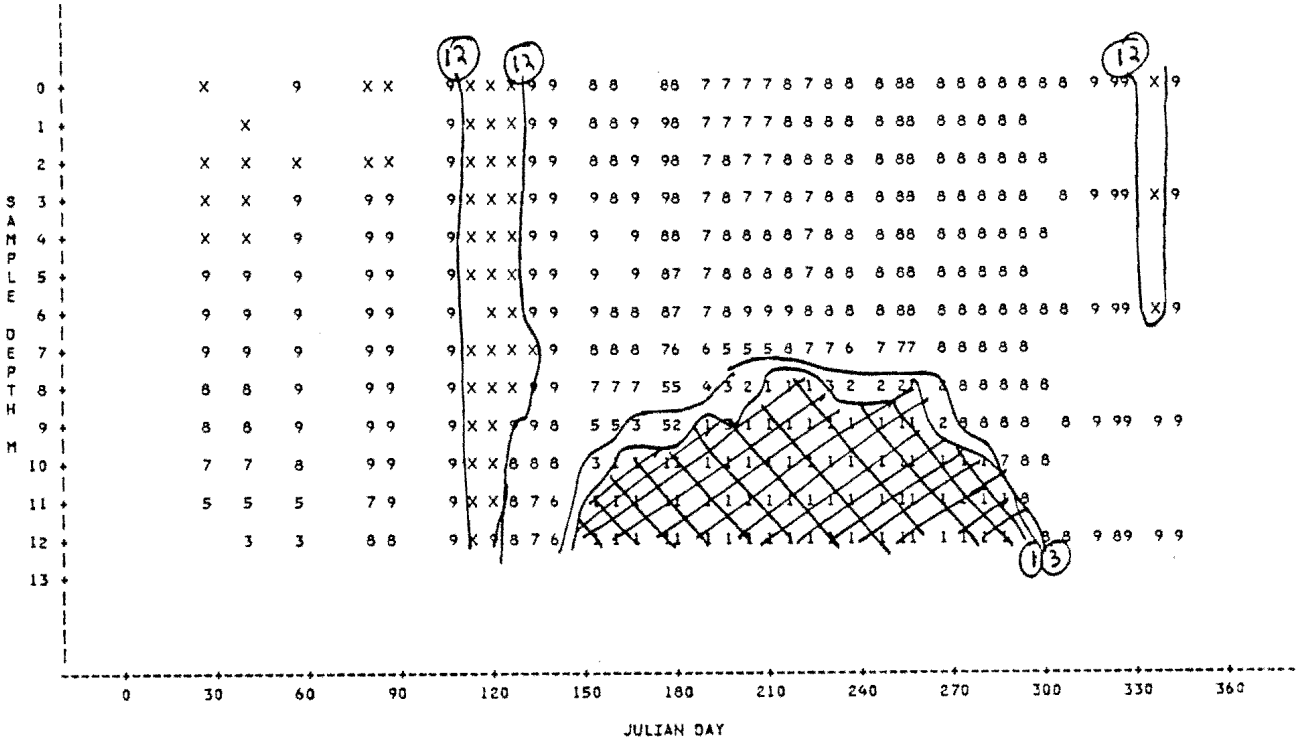

DISSOLVED OXYGEN G/M3 (1,2,3,4,5,6,8,10,12)
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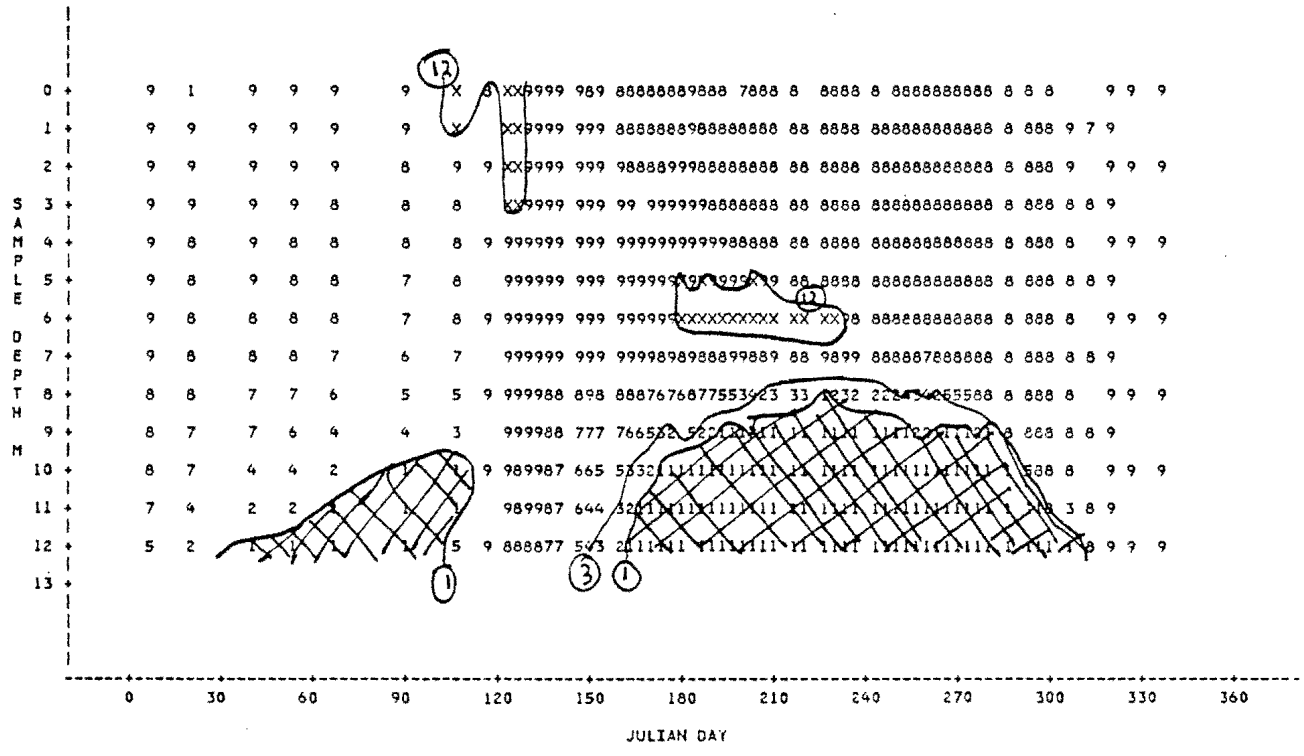
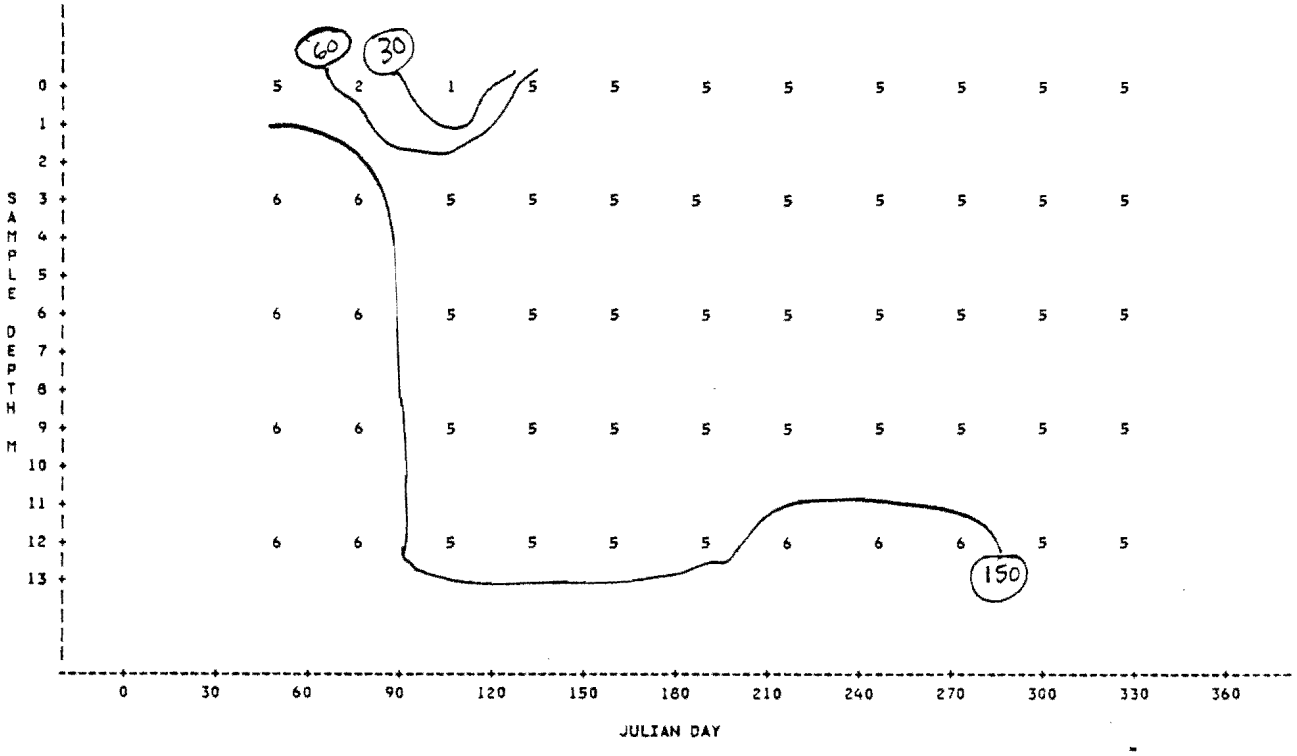
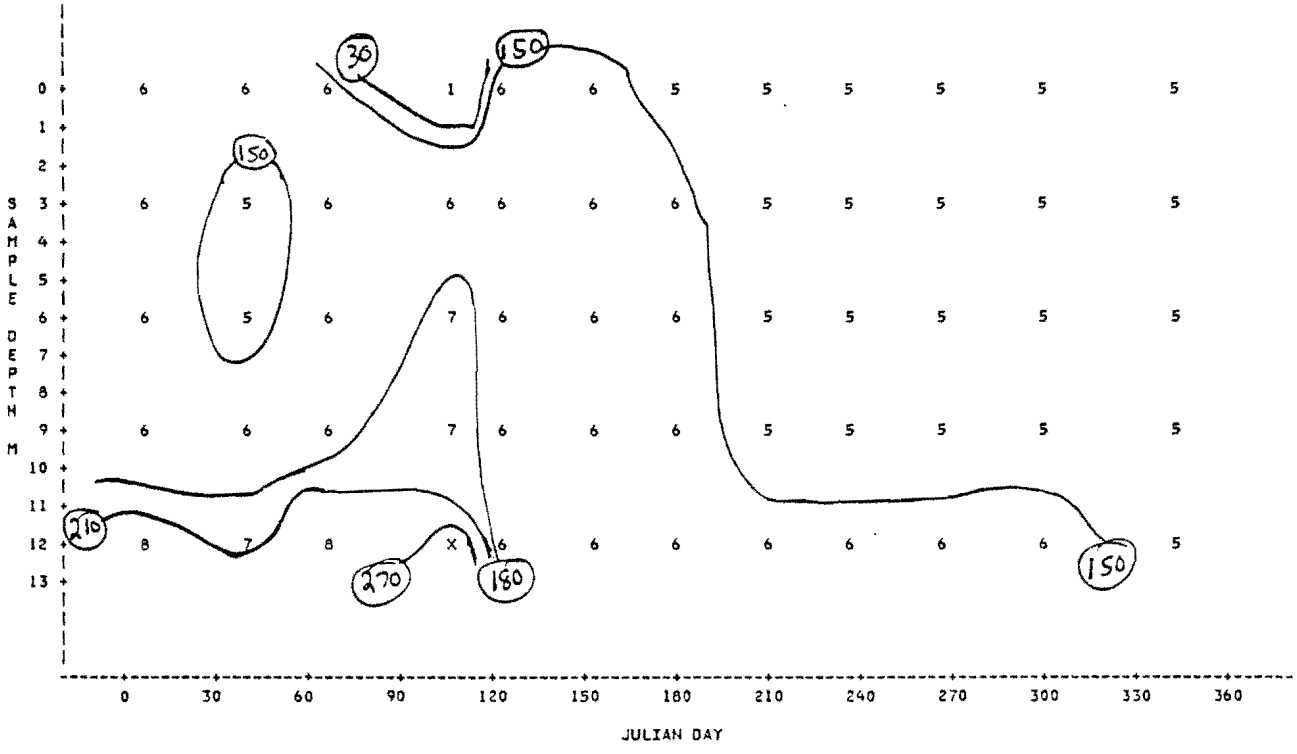


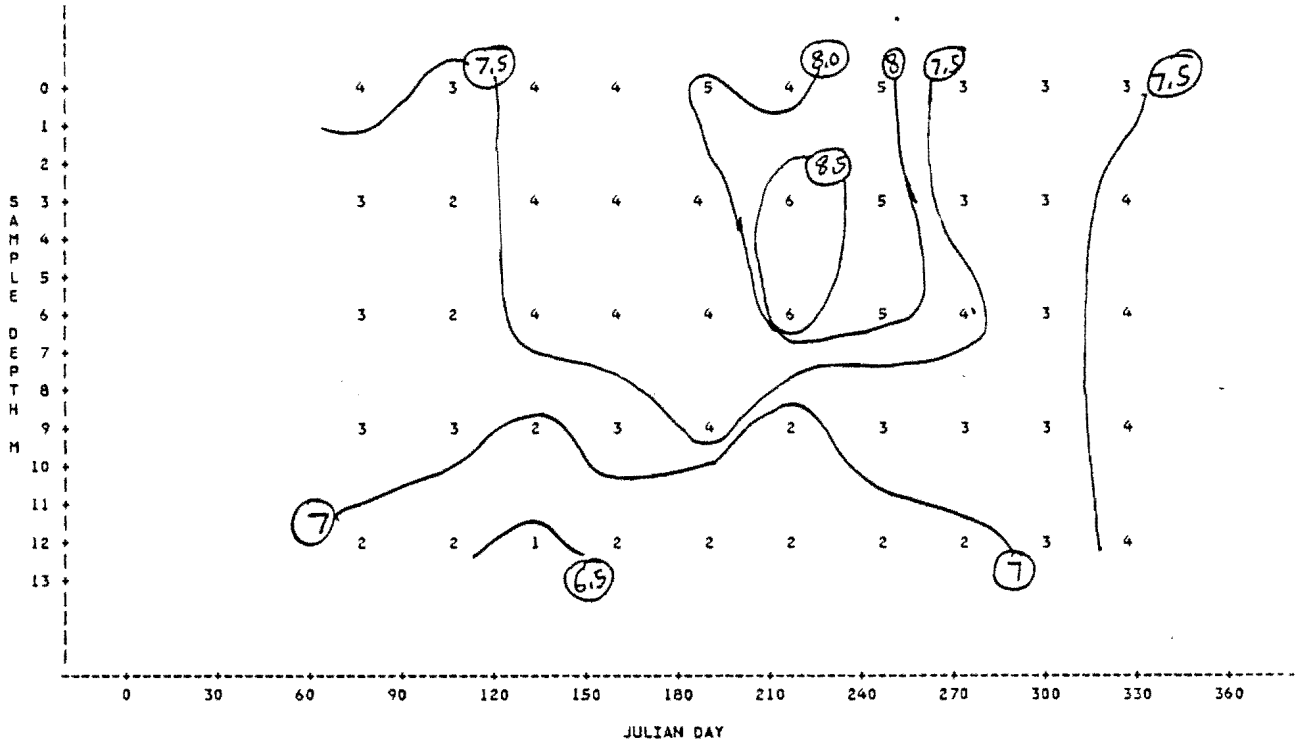
CONDUCTIVITY UMHOS/CM (30,60,90,120,150,180,210,240,270)
YEAR=81



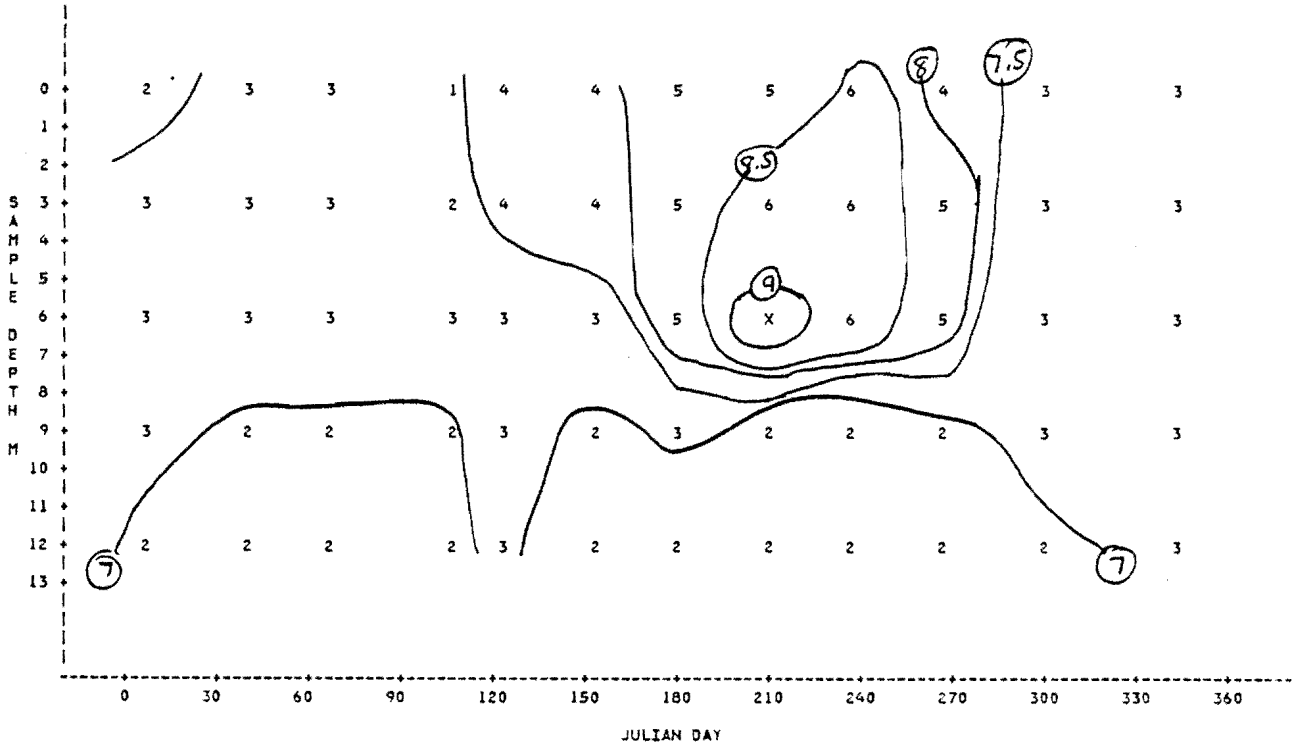
CONDUCTIVITY UMHOS/CM (30,60,90,120,150,180,210,240,270)
YEAR=82



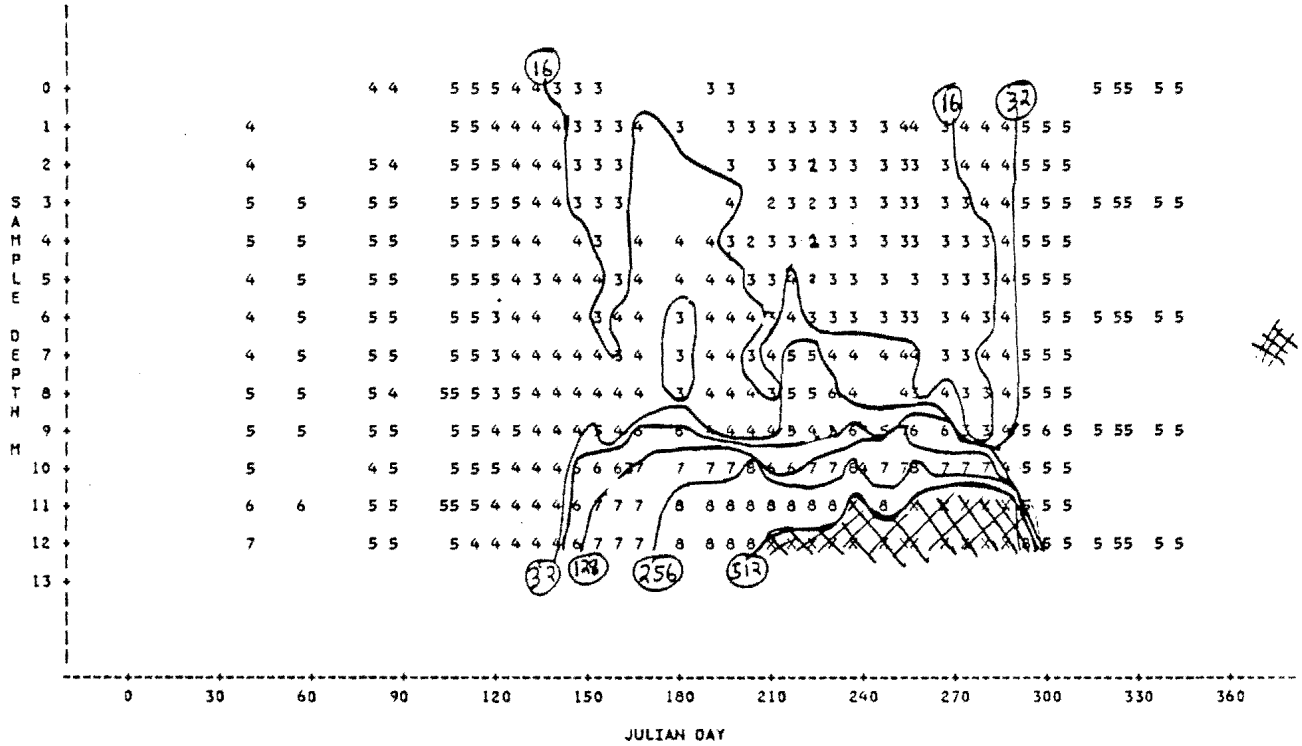
PH (6.5,7.0,7.5,8.0,8.5,9.0)
YEAR=81



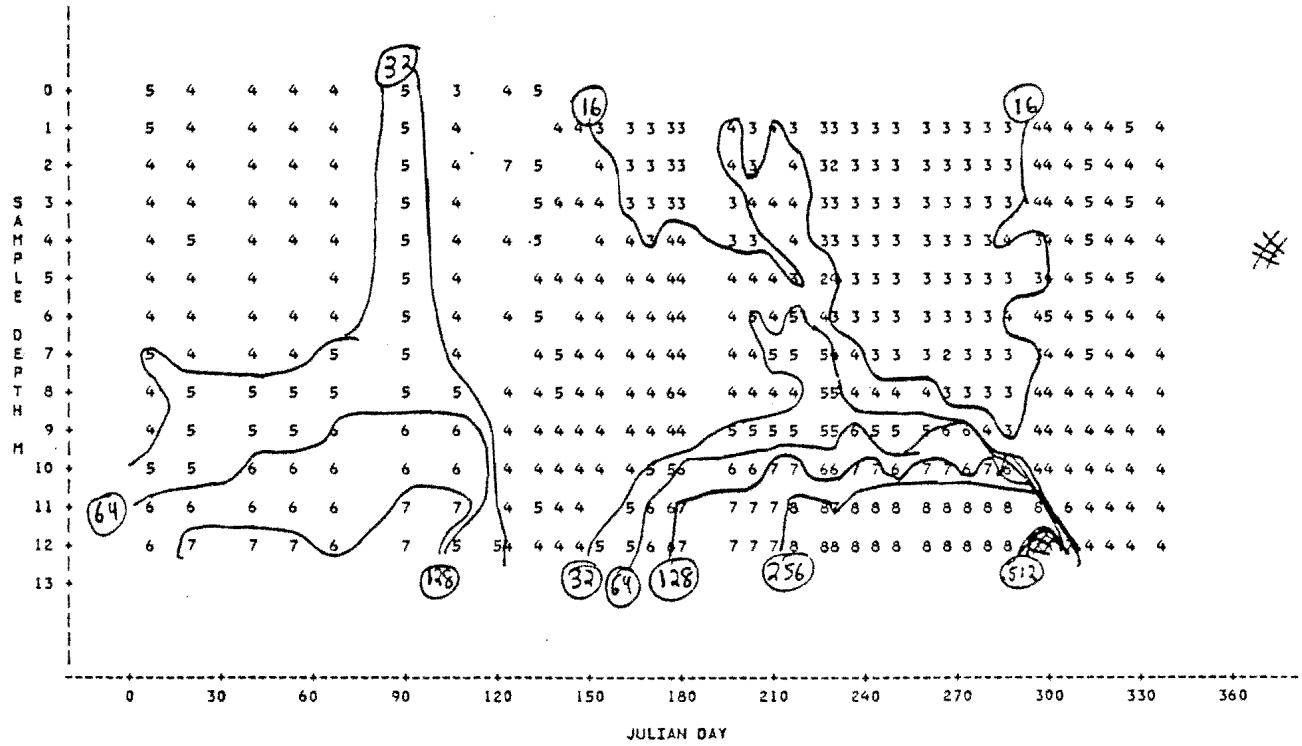
PH (6.5,7.0,7.5,8.0,8.5,9.0)
YEAR=82



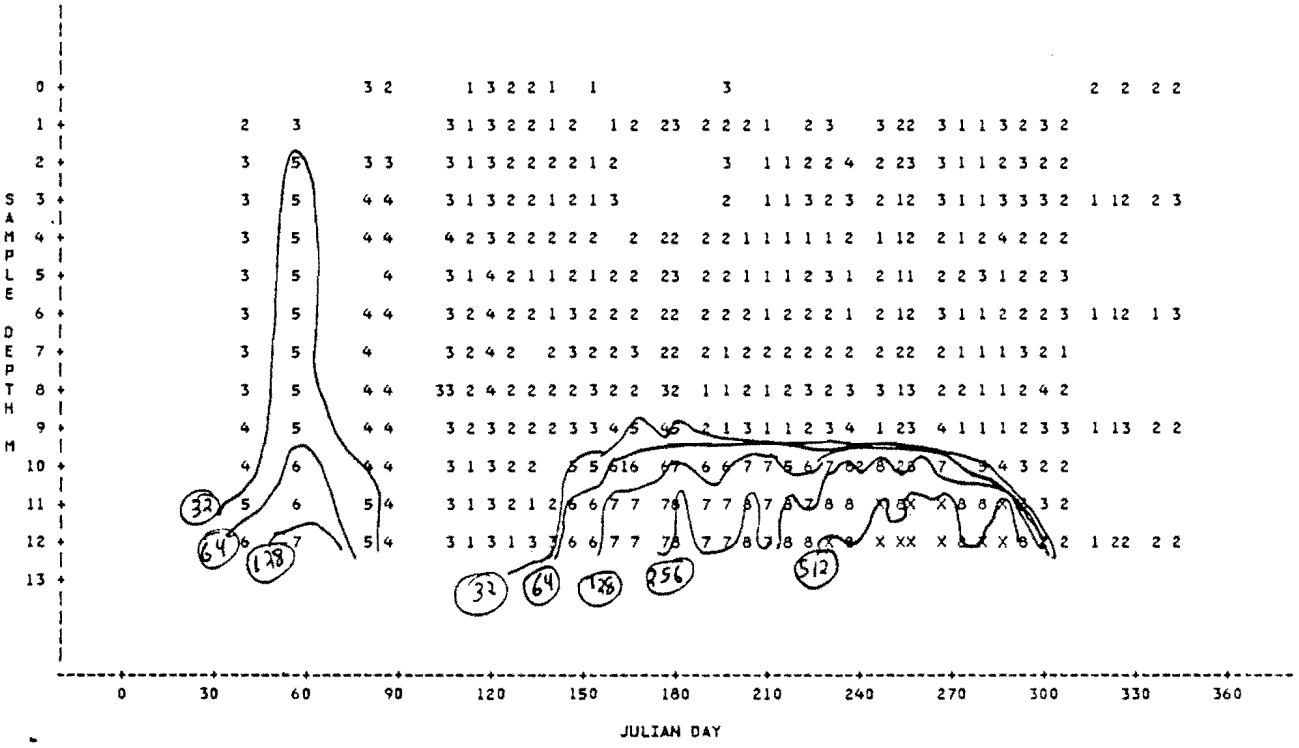
TOTAL PHOSPHORUS MG/M3 (4,8,16,32,64,128,256,512)
YEAR=81



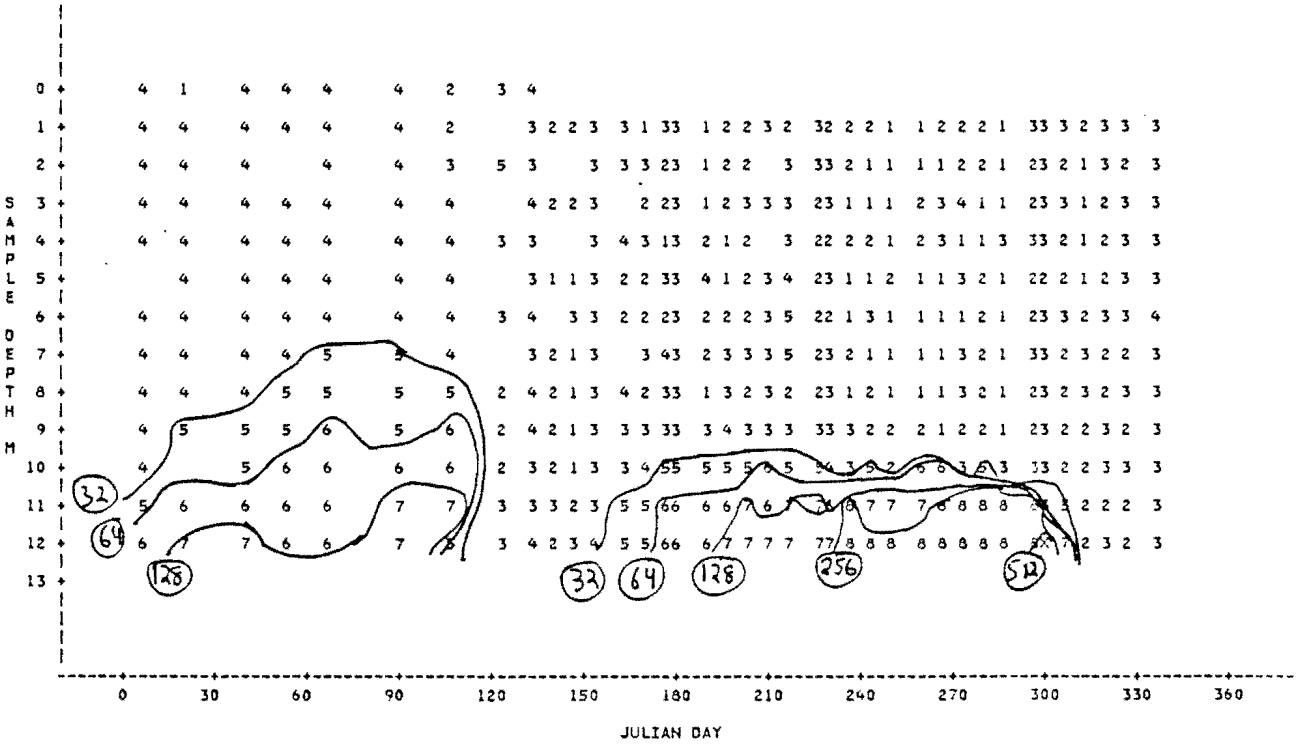
TOTAL PHOSPHORUS MG/M3 (4,8,16,32,64,128,256,512)
YEAR=82



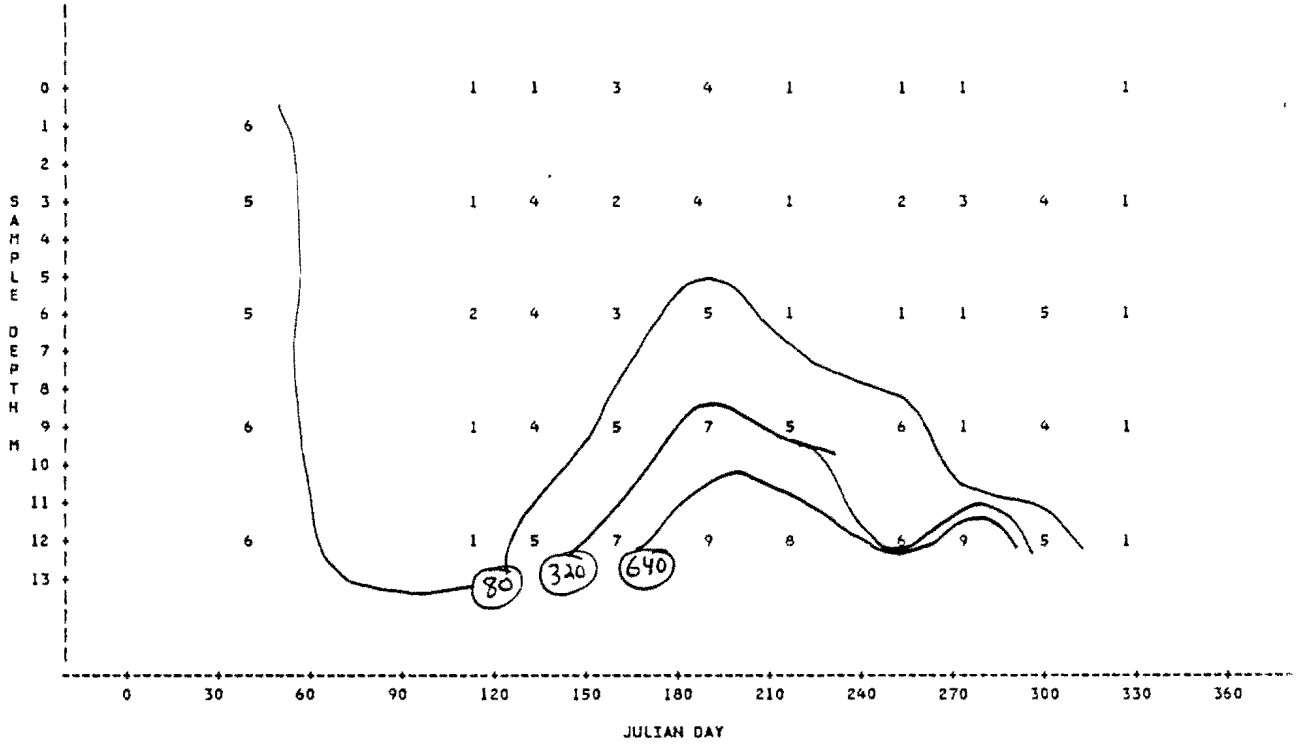
DISSOLVED PHOSPHORUS MG/M3 (4,8,16,32,64,128,256,512)
YEAR=81



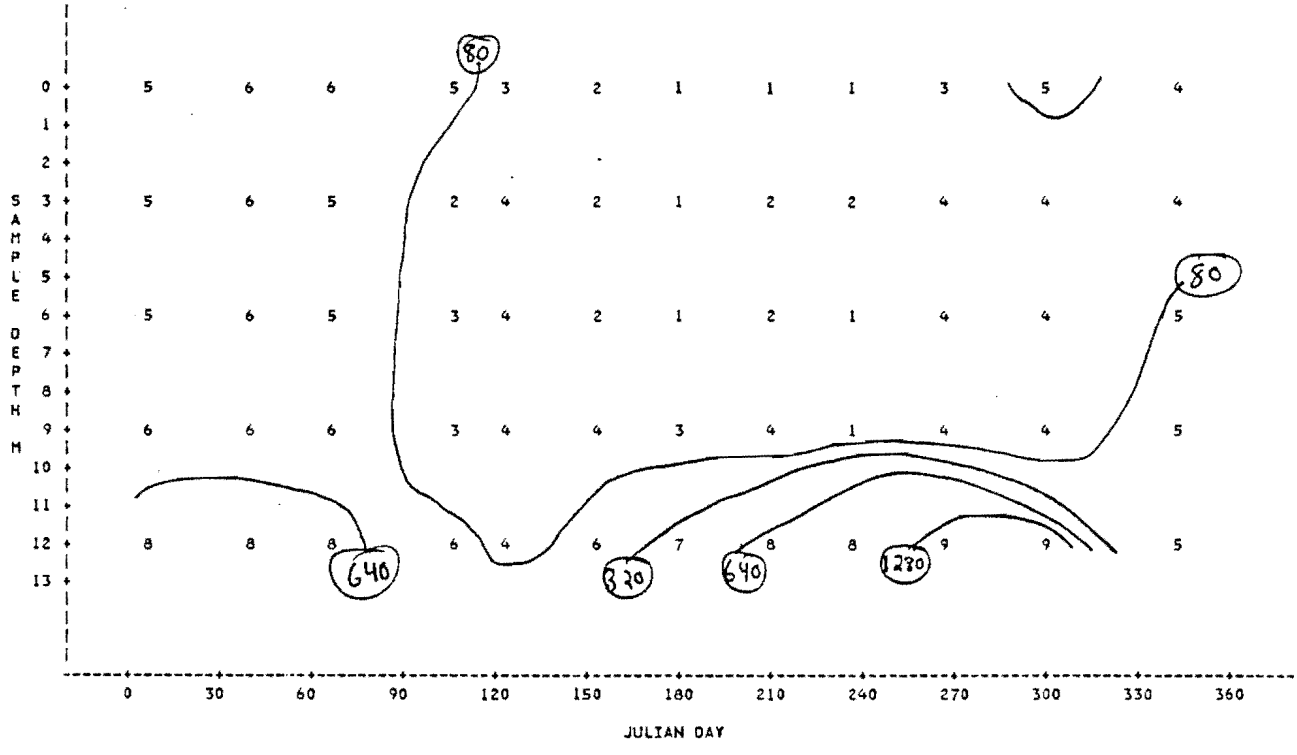
DISSOLVED PHOSPHORUS MG/M3 (4,8,16,32,64,128,256,512)
YEAR=82



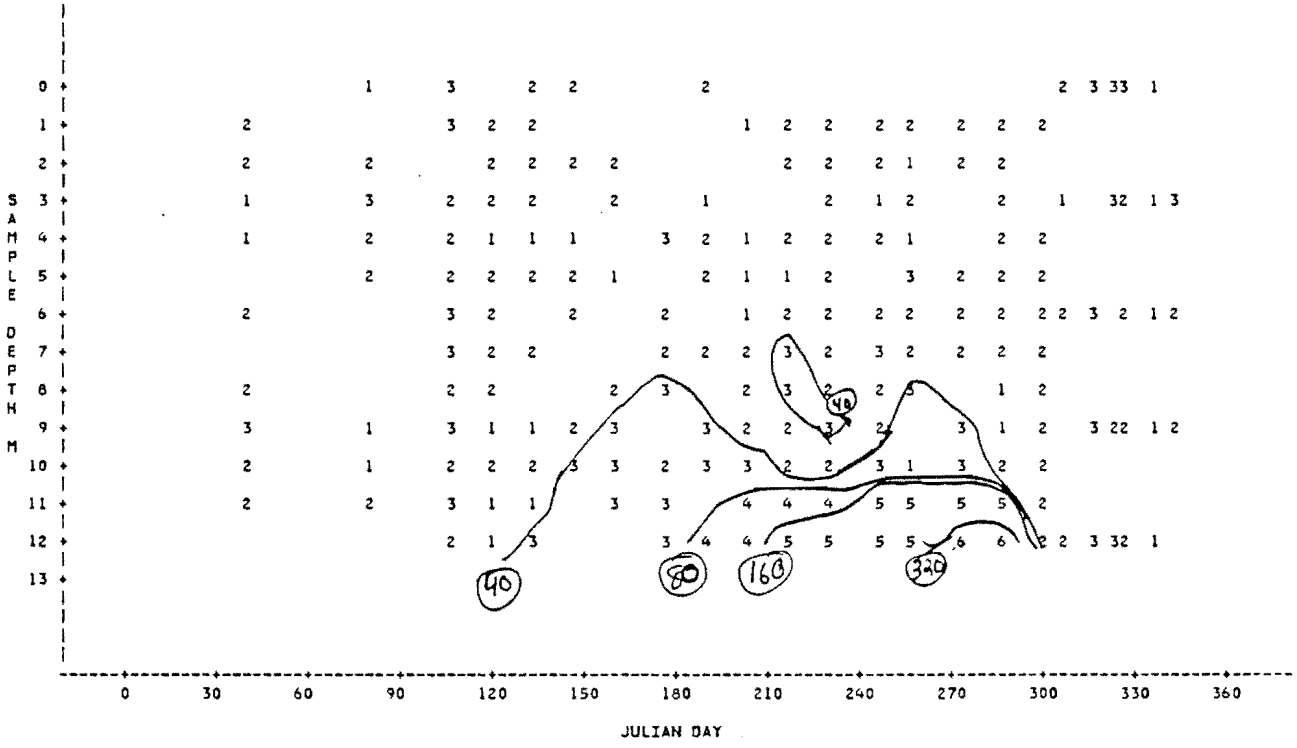
AMMONIA N MG/M3 (10,20,40,80,160,320,640,1280,2560)
YEAR=81



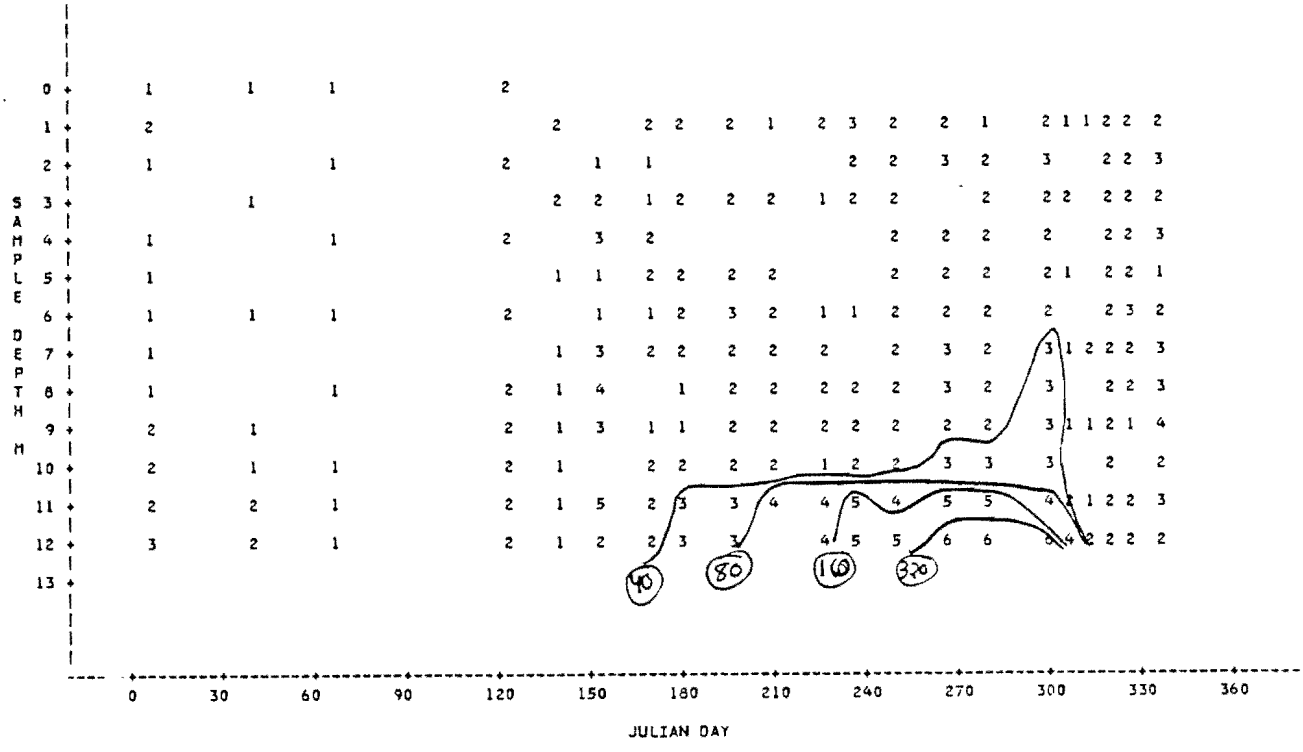
AMMONIA N MG/M3 (10,20,40,80,160,320,640,1280,2560)
YEAR=82



TOTAL IRON MG/M3 (20,40,80,160,320,640,1280,2560)
YEAR=81



TOTAL IRON MG/M3 (20,40,80,160,320,640,1280,2560)
YEAR=82



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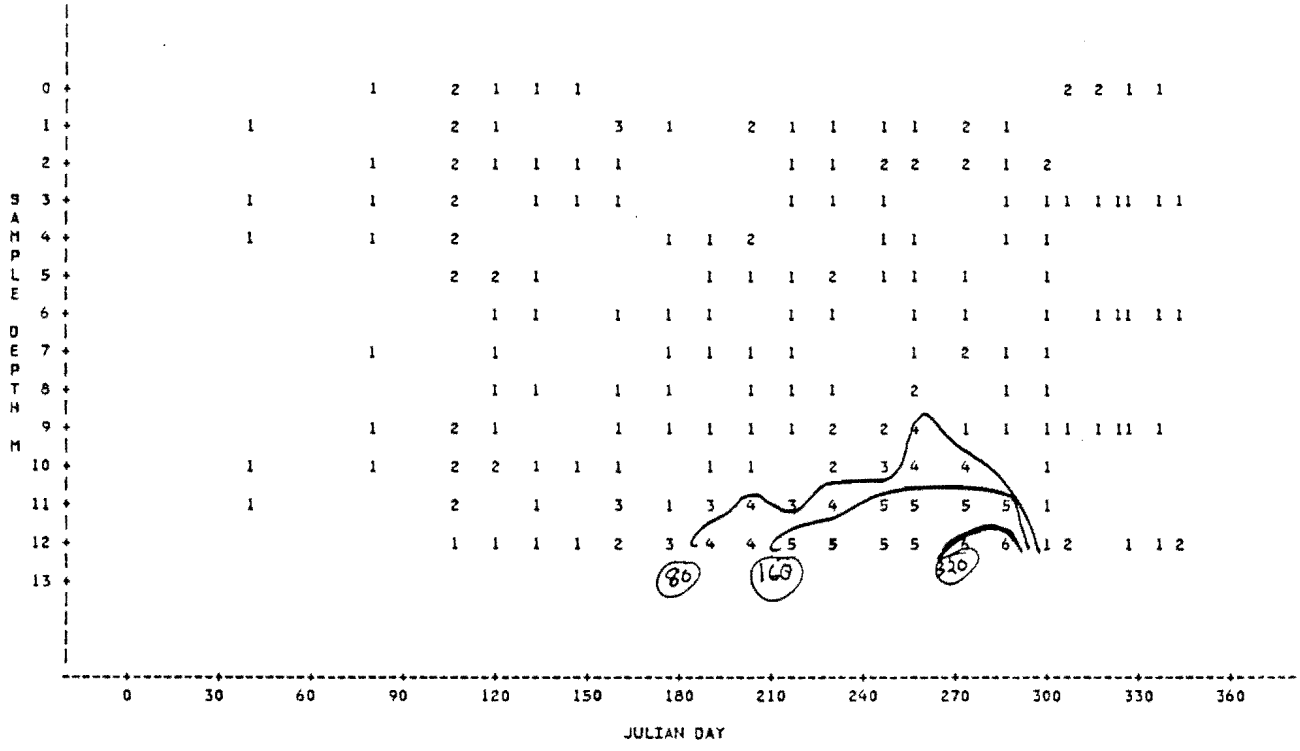

DISSOLVED IRON MG/M3 (20,40,80,160,320,640,1280,2560)
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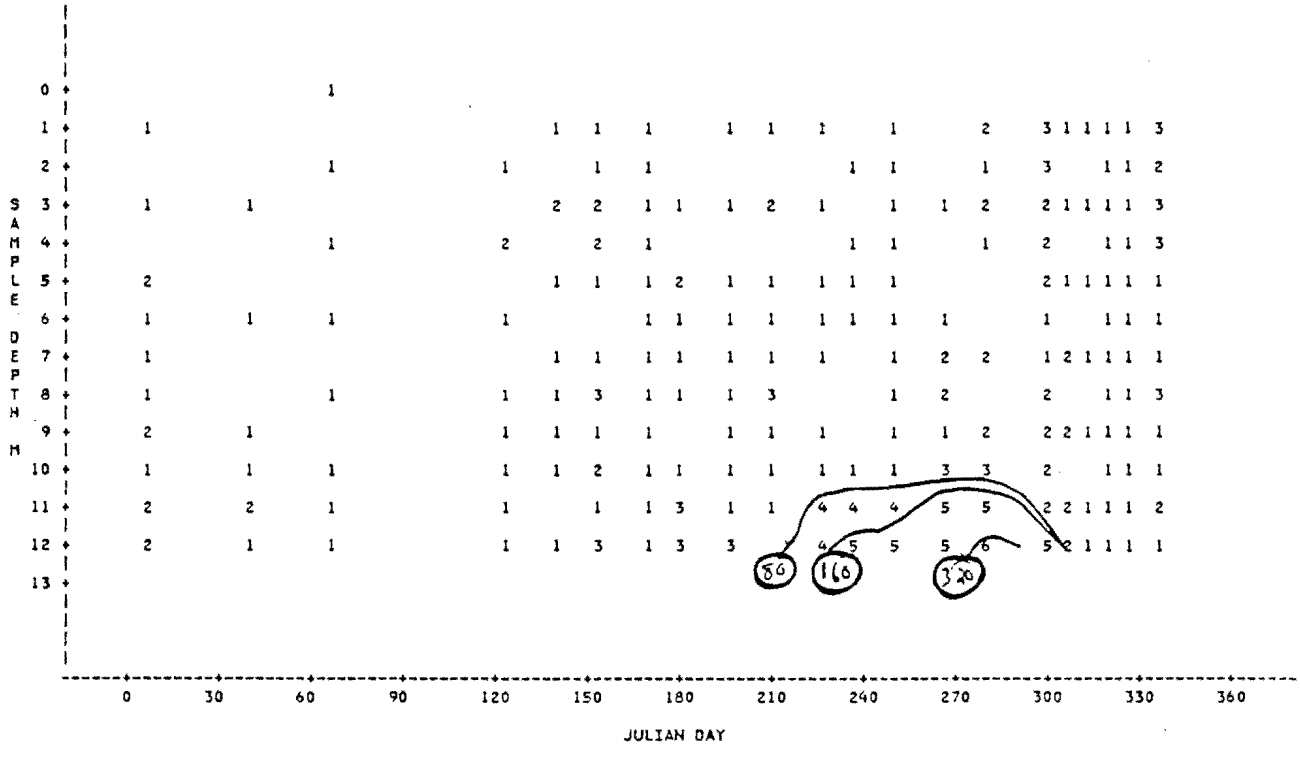
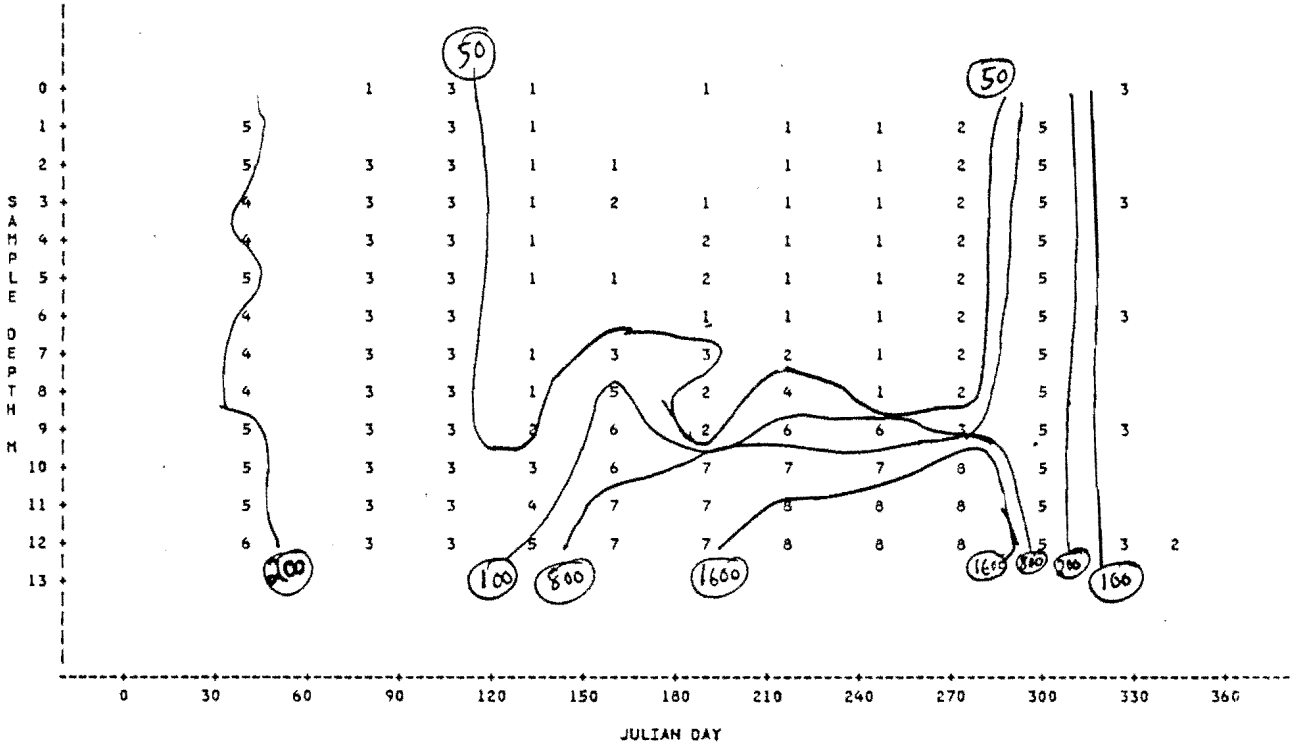
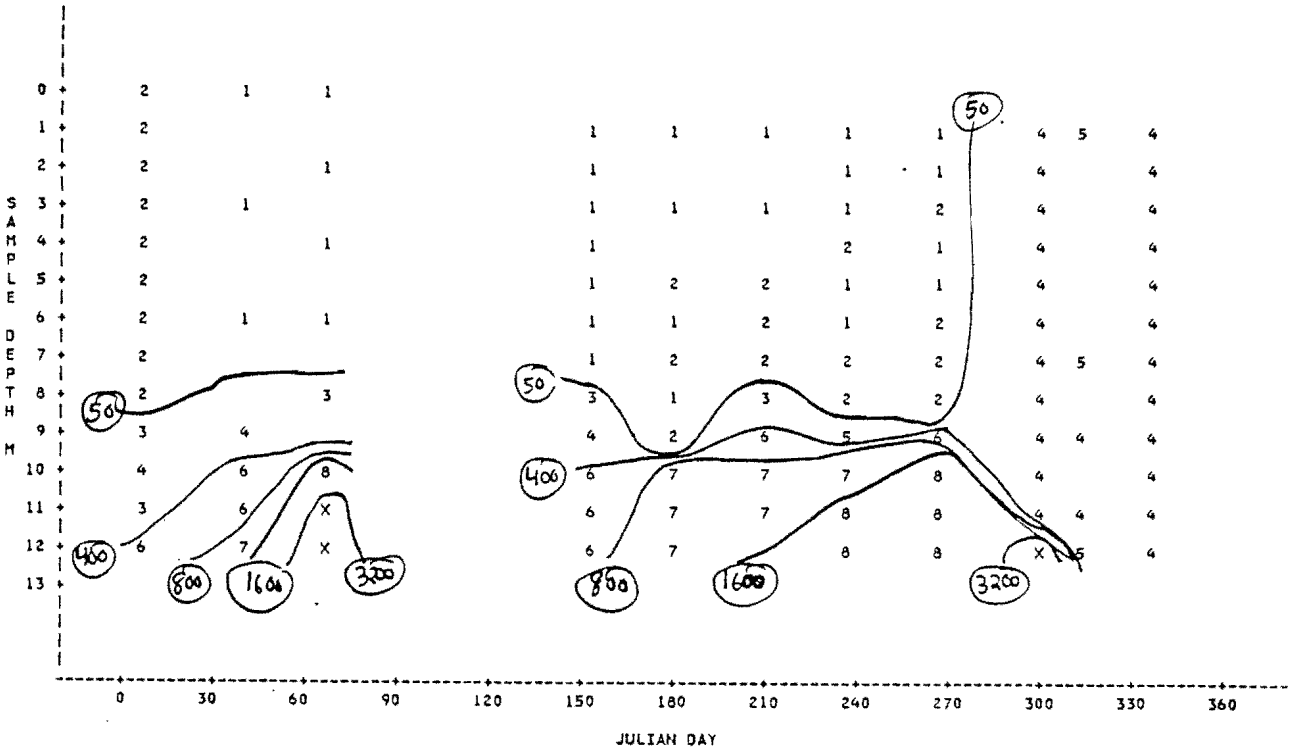


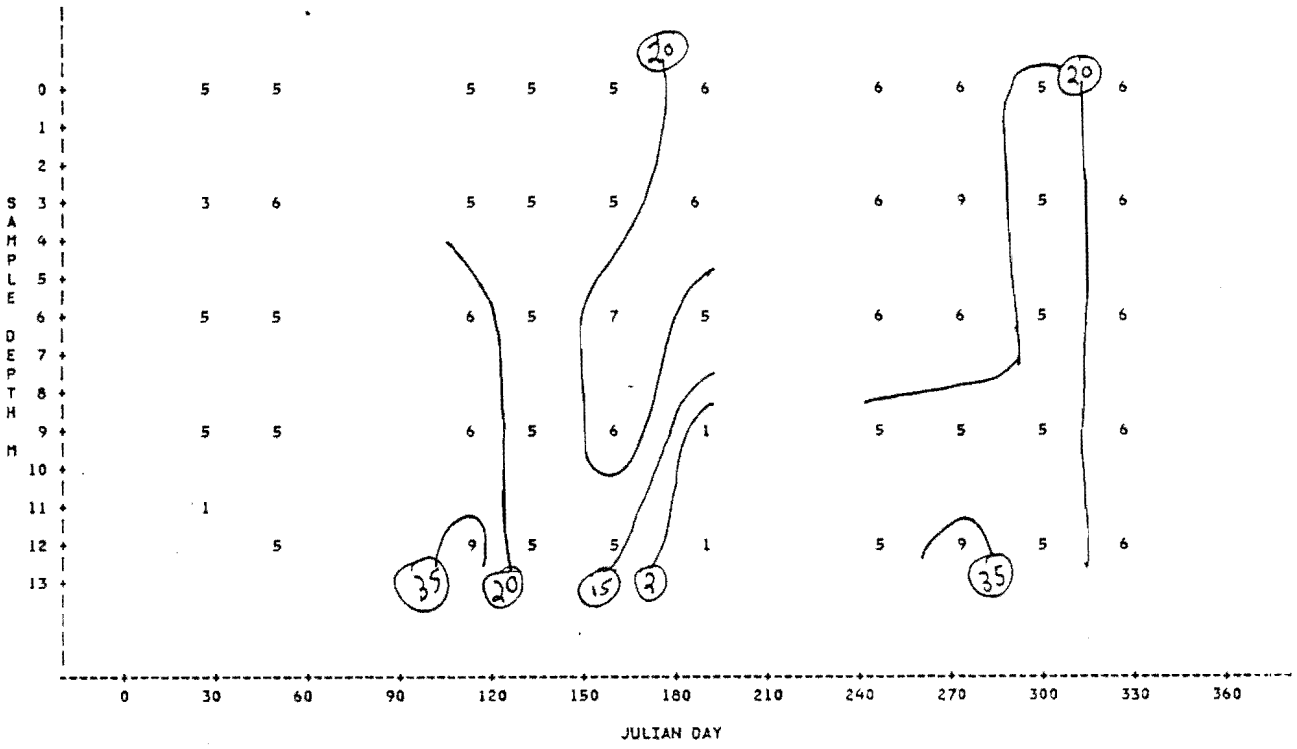
TOTAL MANGANESE MG/M3 (25,50,100,200,400,800,1600,3200)
YEAR=81



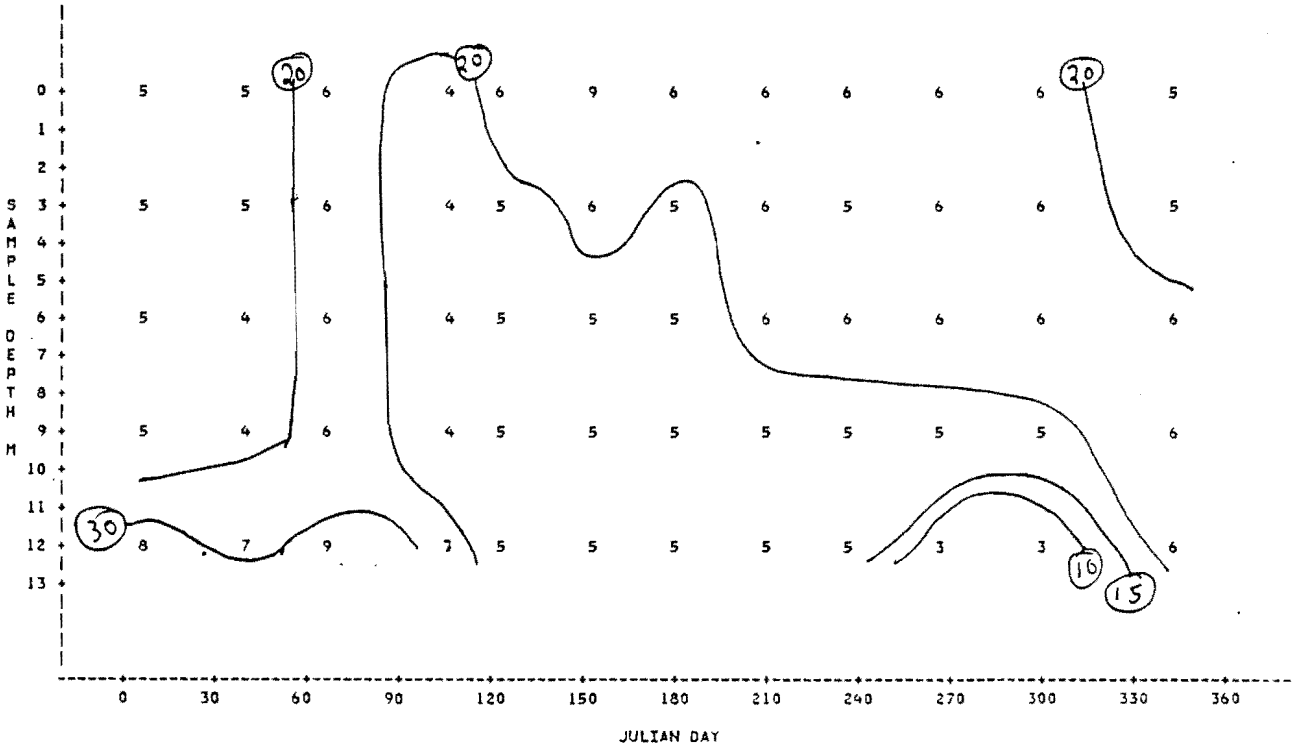
TOTAL MANGANESE MG/M3 (25,50,100,200,400,800,1600,3200)
YEAR=82



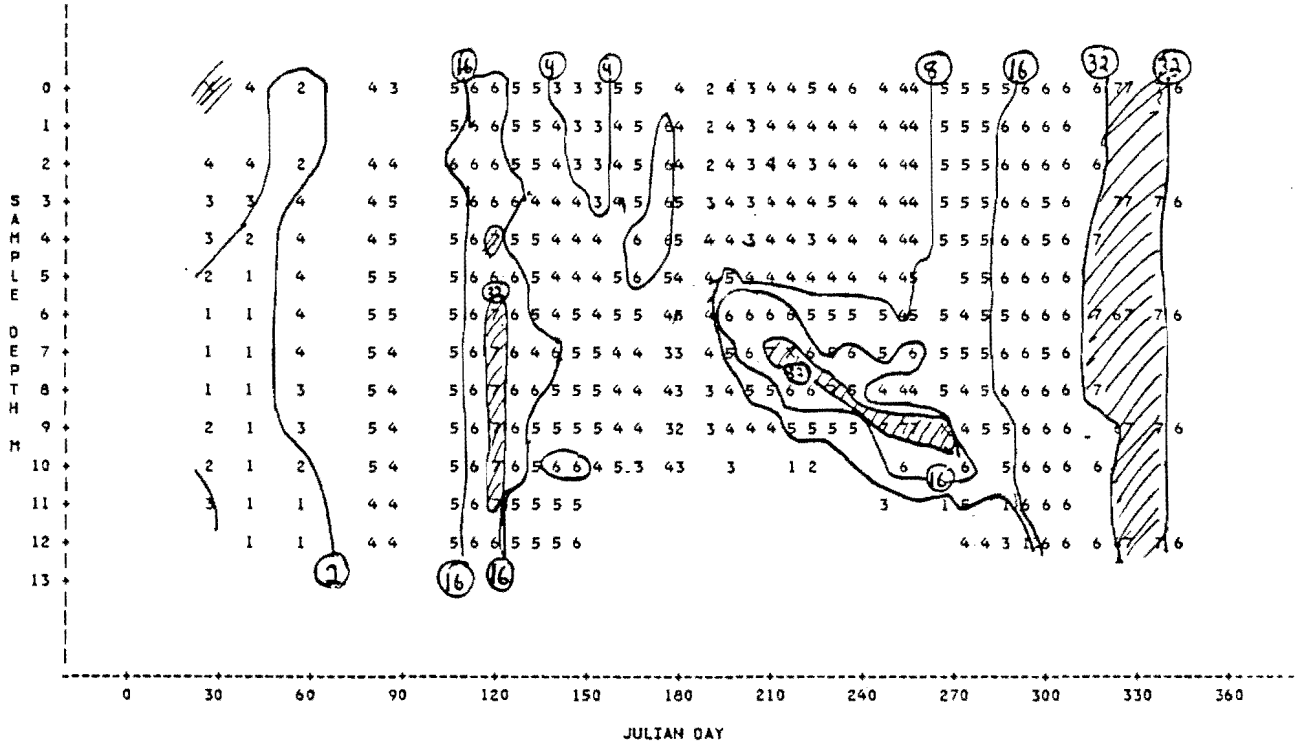
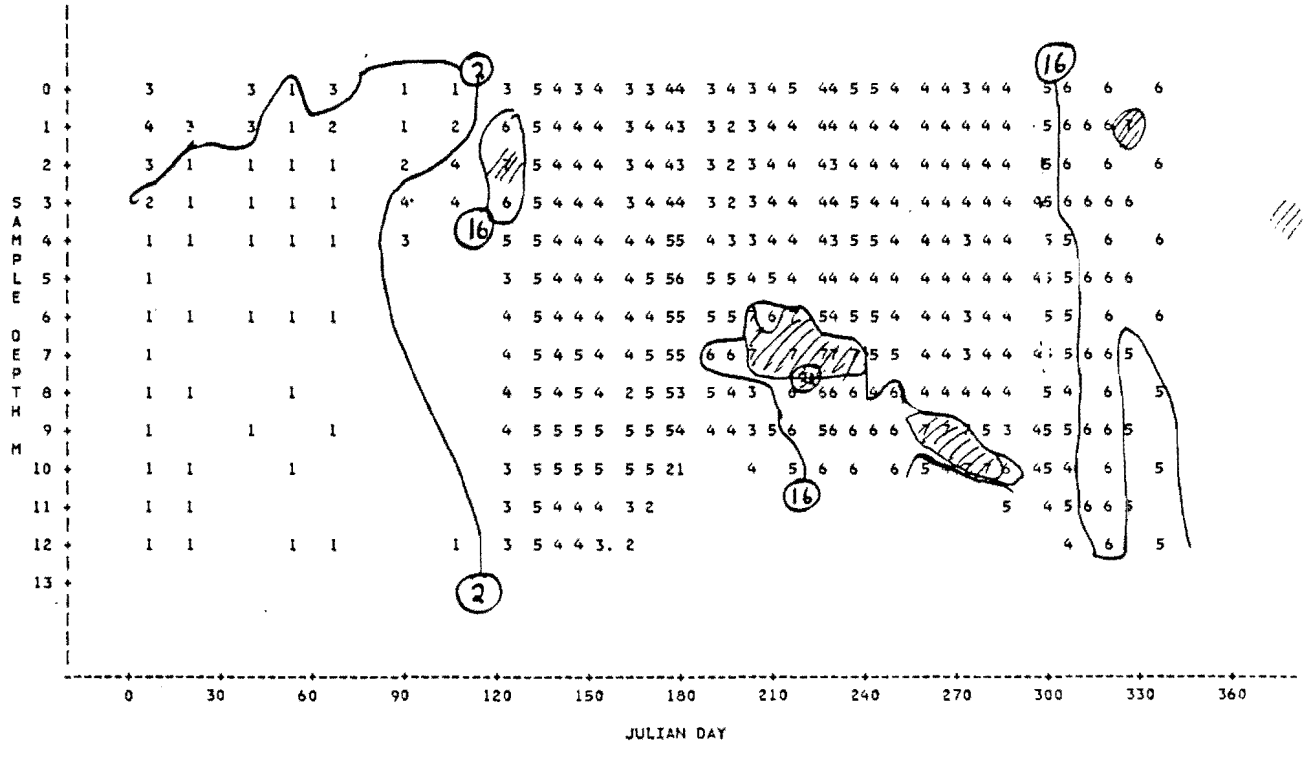
TOTAL SULFATE G/M3 (2,5,10,15,20,25,30,35,40)
YEAR=81



TOTAL SULFATE G/M3 (2,5,10,15,20,25,30,35,40)
YEAR=82



CHLOROPHYLL-A MG/M3 (1,2,4,8,16,32,64)
YEAR=81



CHLOROPHYLL-A MG/M3 (1,2,4,8,16,32,64)
YEAR=82