Wisconsin Lakes Study (I): A Multiple Lake Method to Analyze Temporal Variations

Robert Clifford, Jr., Michael A. Meyer, Richard I. Sedlak, Jr. and Nicholas L. Clesceri

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ABSTRACT

A study was conducted to monitor the water quality of ten inland Wisconsin lakes during a period encompassing the imposition of a detergent phosphorus ban. Statistical analysis of the database sought to detect changes in water quality parameters during the study and determine whether or not these changes were a temporal function of the ban period. Lakes receiving treated municipal sewage effluent either directly or indirectly were monitored along with lakes not impacted by effluent discharges. Monitoring was conducted during a six-year period, 1978 - 1983. Measurements of physical and chemical parameters for lake sites and tributaries were made as well as the identification and enumeration of phytoplankton species within the epilimnion. This paper describes the selection and monitoring process, characterizes the data through means and temporal plots, and examines basic limnologic relationships between the data parameters. The statistical analyses performed to evaluate the detergent phosphorus ban will be presented in a subsequent paper.

INTRODUCTION

Phosphorus and nitrogen are two macronutrients whose relative changes in concentration are known to affect the production of algae in fresh water bodies (Wetzel, 1975, Hutchinson, 1957, Dillon and Rigler, 1974, Canfield, 1983). Excess algal production can lead to nuisance "blooms" which severely degrade the aesthetic quality of lakes and quicken the process of eutrophication. Of the two macronutrients, phosphorus has been reported to be more frequently the "limiting" nutrient, that is, the rate of algal production is primarily a function of the phosphorus concentration within the water column (Likens, ed., 1972, Schindler, 1977). Reductions in the amount of phosphorus contained in laundry detergents have been mandated in some areas as a means of improving water quality in lakes receiving municipal wastewater discharges or septic tank seepage. Bans prohibiting phosphorus in laundry detergents have been imposed in New York, Indiana, Vermont, Michigan, Minnesota, Dade County (FL) and the City of Chicago (IL). Subsequent analyses have given mixed reviews to the effectiveness of detergent phosphorus bans in improving surface water quality (Pieczonka and Hopson, 1974, Hartig and Horvath, 1982, Bell and Spacie, 1978, Runke, 1982, Maki, Porcella and Wendt, 1984). While it is generally agreed, within these reports, that phosphorus concentrations flowing into municipal or private treatment systems are reduced following a detergent phosphorus ban, it has been found that frequently the impact this reduction will have on effluent phosphorus levels is too small to affect the quality of receiving water bodies.

The Wisconsin state legislature enacted a multi-year detergent phosphorus ban effective 1 July 1979. The ban, originally intended to be in effect to 30 June 1981, was extended to 30 June 1982. The purpose of imposing a three year ban was to allow an assessment of any immediate impact the removal of phosphorus from laundry detergents might have on the water quality of lakes in the state. The Soap and Detergent Association initiated a lake study program in 1978, and continued it through 1983, in order to provide information which would contribute to an evaluation of the effectiveness of the ban. The study was designed to detect changes in the water quality of several Wisconsin lakes, as reflected in basic physical and chemical water quality parameters and/or algal species frequency or dominance, which might have occurred as a result of the ban.

Considering the imposition of the detergent phosphorus ban as an experiment in improving water quality, two groups of lakes were selected for investigation. The "experimental" group, or test lakes, were lakes determined or expected to receive a significant percentage of their phosphorus loading from sewage effluent, and would therefore be impacted by a reduction in the phosphorus concentration in that source. The "control" group, or reference lakes, were lakes for which sewage effluent was determined not to be a nutrient source. By monitoring the reference lakes, a baseline would be provided whereby natural fluctuations in water quality occurring throughout the year could be distinguished from any response, in the test lakes, which might be attributable to the ban. These natural fluctuations in water quality are chiefly a function of climatic conditions (e.g. temperature, rainfall amounts and frequency). Hence, in order to insure that comparisons were made between lakes being impacted equally by climatic conditions, geographically proximate lakes were paired during statistical analysis. Consequently, the variable factor between test and reference lakes might be reduced to whether or not the lake was impacted by wastewater containing detergent phosphorus.

ESTABLISHMENT OF FIELD STUDY SITES

It was intended that lakes selected for this study be those which would provide the best database for an evaluation of the effects of the detergent phosphorus ban in Wisconsin. Consideration was given primarily to those lakes for which historical data were available from sources such as the National Eutrophication Survey (NES) or the Wisconsin Department of Natural Resources (WDNR) Quarterly Monitoring program. Following the NES selection criteria (NES, 1974) lakes considered i) were greater than 100 acres (40.5 hectares), and ii) had a mean hydraulic residence time of no less than 30 days. For lakes not included in the NES, discussions with WDNR personnel involved with the Research Bureau and Inland Lakes Renewal Program were held to ascertain their suitability. Lakes were sought which also iii) were formed naturally; impoundments were excluded, iv) had maximum depths in excess of 3 meters, v) had mean hydraulic residence times of less than two years (the original extent of the ban), vi) were reasonably accessible, and vii) were fed by no more than four significant tributaries, to allow for ease in monitoring inputs. Lakes which were determined (by the NES) or expected to receive 30 percent or more of their annual phosphorus loading from municipal wastewater treatment plants were considered as test lakes.

The locations of the lakes selected for the study are shown in Figure 1. Eight of the ten lakes selected are located in the northern part of the state. This was not a prerequisite but a result of the lake selection process, and is consistent with the fact that a significantly greater percentage of Wisconsin's lakes occur in the north (WDNR, 1981, Lillie and Mason, 1983). Test lakes Butternut, Elk and Balsam were paired with reference lake Teal; test lakes Moss, Enterprise, and Townline were paired with reference lake Little Bearskin; test lake Swan was paired with reference lake Fish. Initially

Shawano Lake and Noquebay Lake, located in the northeastern region of the state were selected as a test - reference lake pair. However, in 1978 Shawano Lake was sewered and extensive weed harvesting was conducted in Noquebay Lake, necessitating their removal from the study. Of the lakes selected for this monitoring program, Butternut, Swan, Townline and Elk were investigated during the National Eutrophication Survey (National Eutrophication Survey, 1974a, 1974b, 1974c, 1974d).

Limnological, morphological, and drainage basin characteristics of the lakes are summarized in Table 1. Of note is the fact that dissimilarities between lakes are minimal for several parameters. Butternut Lake and its reference, Teal Lake, located approximately 50 kilometers apart, are virtually identical in terms of surface and drainage area, volume, mean and maximum depths, and hydraulic retention time. Teal Lake also serves as the reference to Balsam Lake and both drain watersheds which are approximately the same size. Little Bearskin Lake is similar, in terms of surface area and drainage area, to two of its associated test lakes, Moss and Townline. Most of the test and reference lakes have immediate drainage areas which are primarily forested, however, Swan Lake and its reference, Fish Lake, are unique and similar in the extensive agricultural development within their watersheds. It may also be noted that while not "pristine", the three reference lakes, when compared with the seven test lakes, have a lower percentage of shoreline area devoted to residential development.

The WDNR had previously sought some basis for regional aggregation of the state's lakes, and therefore divided the state into five lake regions based on bedrock and glacial geology as well as soil cover (Lillie and Mason, 1983). The three test - reference lake groups created in this study fall clearly into three of the five WDNR regions. The lakes paired with reference Teal Lake are located within the northwest region, the Little Bearskin Lake group is located within the northeast region, and the Swan - Fish lake pair are located within the southeast region.

In two cases the morphological characteristics of the lakes selected differ from the initial criteria employed in the selection process. Moss Lake has no tributary inputs and a hydraulic residence time of approximately 2.5 years (although, since the ban was extended to 3 years, this should not be considered a factor detrimental to the use of Moss Lake in the study), while the residence time of Elk Lake, initially estimated as 56 days, was re-estimated after initiation of the study to be less than the 30 day limit originally imposed. These factors will be considered during data analysis.

The mode of sewage treatment and disposal differs within each test lake basin and a summary is provided in Table 2. Although no municipal effluent is discharged to Enterprise Lake, it was chosen as a test lake because of its highly developed shoreline and the possibility of significant wastewater seepage from septic tank/tile field systems. For all other test lakes, sewage undergoes secondary treatment in local wastewater treatment plants before being released to the lake basins. Treated effluent in the Swan Lake watershed is released from the Pardeeville treatment facility into Spring Lake, approximately six to seven kilometers upstream from Swan Lake. Treated effluent in the Butternut Lake watershed is discharged approximately three kilometers upstream from the lake into Butternut Creek, while treated effluent is released directly into Elk Lake. Near Townline Lake, effluent is released into an intervening marsh from the Three Lakes treatment plant. A sewage stabilization pond with no surface discharge is located 0.4 kilometers away from Moss Lake. Seepage cell systems are located in the drainage basin of Balsam Lake.

MONITORING METHODOLOGY

Figure 2 shows a sampling timeline for each lake. The Wisconsin phosphorus ban was enacted in mid-1979 and so monitoring was restricted to reference lakes during this year, in order to maintain a continuous record of natural water quality fluctuations. Data taken from the test lakes during this year would be subject to any expected flux in phosphorus loadings resulting from the imposition of the ban and would not be of use in statistical analysis. Monitoring of some of the lakes was discontinued in 1982, however, Swan, Butternut and Teal lakes were monitored through 1983. Monitoring of Fish Lake was discontinued after 1981 because excessive macrophyte growth in the littoral zone was believed to differentiate it significantly from its test lake, Swan Lake. Analysis, however, will still consider Fish Lake as the reference to Swan Lake.

Field trips to the lakes to secure samples and record measurements occurred from 5 to 9 times per year, from ice-out (late April to mid-May) to fall overturn (late October to early November). Summer (July and August) trips occurred two weeks apart; at other times of the year the interval between sampling was typically four weeks. Samples and measurements were taken at the location of the deepest point on each lake as well as at one or two additional sites.

At the deep site, transparency was measured using a standard fresh-water Secchi disk. Profile measurements were made at one meter depth increments for temperature, dissolved oxygen, and conductivity. An integrated two meter sample of the epilimnion was obtained using a 37 mm (I.D.) PVC pipe. In the event that profile measurements determined that the thermocline was closer than two meters to the surface, the integrated sample was taken only to the top of the thermocline.

Aliquots of the integrated sample were stored in amber Nalgene bottles at 4°C and earmarked for specific chemical analyses; i.e. total phosphorus, total oxidized nitrogen (NO2 + NO3), ammonia, total kjeldahl nitrogen, and alkalinity. An aliquot to be measured for pH was stored in a clear Nalgene bottle. Another aliquot was collected for chemical determination of dissolved oxygen. Part of the integrated sample was filtered in the field through a 0.45 micron membrane filter (Millipore Corp.), and the filter frozen with dry ice prior to analysis for chlorophyll-a. An aliquot of the integrated sample to be used for identification and enumeration of phytoplankton species was stored in an amber glass bottle and preserved with Lugol's solution (APHA, 1976). Chemical analysis of the samples was initiated as soon as possible, typically within 48 hours.

On all of the lakes secchi depth measurements and two meter integrated samples were also taken at one or two additional sites. Aliquots of the integrated samples were analyzed for chlorophyll-a and all of the aforementioned chemical species. Grab samples were taken at all tributary inlets and outlets to the lakes and analyzed for total phosphorus, total kjeldahl nitrogen, ammonia, and total oxidized nitrogen. Grab samples were taken at the outlets of all test lake treatment plants from 1978 to 1982 and analyzed for total phosphorus. In 1982 and 1983 additional portions of the integrated samples were used in algal nutrient enrichment bioassays.

ANALYTICAL METHODOLOGY

A Yellow Springs Instrument (YSI) model 51A meter was used in the field measurement of temperature and dissolved oxygen. Conductivity was measured using a YSI Model 33 meter. In the lab dissolved oxygen measurements were calibrated on grab samples using the Winkler titration method, pH was measured using a glass electrode, alkalinity was determined using titrimetric methods, and chlorophyll-a was determined using trichromatic methods (APHA, 1976).

During 1978 wet chemistry determinations of total phosphorus, total oxidized nitrogen, total kjeldahl nitrogen, and ammonia were conducted manually. Total phosphorus determinations followed persulfate digestion (Menzyl and Corwin, 1965). The color reaction for orthophosphate was the technique of Murphy and Riley (1962) (Strickland and Parsons, 1978). Total oxidized nitrogen ($NO2 + NO3$) was determined by the cadmium reduction method (Strickland and Parsons, 1978). Ammonia was determined using the technique of Solorzano (1969). Total kjeldahl nitrogen was determined following EPA methods (U.S. EPA, 1976). After 1978, analysis of all chemical species followed EPA methods for automated analyzers (U.S. EPA, 1979).

RESULTS

All numerical analyses were performed using computer assisted data handling, statistical analysis, and graphical plotting packages available on the IBM 3081D main frame computer under the Michigan Terminal System (MTS).

Yearly Means

A summary of the yearly minimum, maximum, and mean values, by lake, for the physical and chemical parameters measured at the deep site is presented in Table 3. The parameters listed are secchi depth (SD), chlorophyll-a (CHL), total phosphorus (TP), total oxidized nitrogen (TON), ammonia (NH4), total kjeldahl nitrogen (TKN), alkalinity (ALK), and pH (PH). The phytoplankton data obtained during the study will be presented in a subsequent paper. Evident in the table is the fluctuation of yearly means, particularly in the concentrations of the chemical species. Overall, a monotonic increase or decrease in yearly means throughout the study is not readily apparent. It should be noted that total phosphorus means range from 25-93 µg/L. Based on the relationships of Dillon and Rigler (1975) and Chapra and Reckhow (1979) these total phosphorus means would classify the lakes in this study as mesotrophic to eutrophic.

Study means for the test lakes will not be considered because of the anticipated flux resulting for the imposition of the detergent phosphorus ban. Means for the entire monitoring period are listed in Table 4, however, for the three reference lakes. For comparison, regional means recorded by the WDNR (Lillie and Mason, 1983) are provided for the parameters common to this dataset. A striking similarity in water quality parameters is seen between Teal and Little Bearskin lakes, located in the northwest and northeast regions of the state. Both lakes also have a measured water clarity commensurate with other lakes in their respective regions, although their chlorophyll-α and total phosphorus concentrations are elevated above regional means. Fish Lake is significantly clearer and lower in chlorophyll-α and total phosphorus than other southeast region lakes. High alkalinity and pH means, however, show that Fish Lake shares the glaciated limestone soil matrix common to other lakes in the region (Prescott, 1962).

Temporal Plots

Figures 3 (a-i) present temporal plots of secchi depth, chlorophyll-α concentration and total phosphorus concentration. Values for test and reference lakes are plotted on common axes to facilitate comparisons. Evident in each temporal plot is the fluctuation of measured values from one sampling date to the next. Seasonal trends in the data are difficult to discern. Likewise, monotonic trends occuring from year to year over the course of the study are not evident for either secchi depth, total phosphorus or chlorophyll-a values. This observation agrees with the yearly means recorded for these parameters, which also did not relate a monotonic increase or decrease in water quality parameter measurements throughout the study.

Of importance in evaluating the test-reference lake approach, being used in this study to determine the impact of the detergent phosphorus ban, is the degree of "tracking" between geographically proximate test and reference lakes. Here "tracking" is defined as a synchronous correspondance between the test and reference lake plots for a particular parameter exclusive of differences in the magnitude of the responses. "Good" tracking of parameter measurements between the lake pairs would indicate that the pair is being uniformly impacted by, and responding similarly to, natural climatic fluctuations, such as temperature changes and rainfall events. In many cases test-reference lake pairs exhibit a near perfect synchronicity in the fluctuations of either secchi depth, total phosphorus or chlorophyll-a over some years (i.e. Figures 3 (c), (e), (g)), while, in some cases, subjectively quantifying the tracking between lake pairs is impossible. It would be imprudent to derive conclusions solely on the basis of temporal plots. For this reason regression models were used to quantify the degree of "tracking", between lakes and to evaluate the detergent phosphorus ban.

General Limnologic Relationships

The linear relationship between total phosphorus, chlorophyll-a and secchi depth has been well documented (Carlson, 1977, Dillon and Rigler, 1974, Canfield, 1983) and is a basic tenet behind the strategy of phosphorus loading controls as a means towards improving water quality. Graphs of the log-linear relationships between chlorophyll-a and secchi depth, total phosphorus and secchi depth and chlorophyll-a and total phosphorus for all samples taken throughout this study are presented in Figures 4 (a-c). A linear relationship is visually suggested for all three combinations. However, a distinct definition is hampered by the clustering of the data, a result of the limited range of values encountered on these Wisconsin lakes. Regression equation correlation coefficents (r^2) fell below 0.23 for all three relationships. When yearly mean values were considered, however, an improvement in the r^2 values was noted. A regression of yearly mean chlorophyll-a concentrations versus yearly mean total phosphorus concentrations yeilded the equation:

$$\log(\text{CHLA}) = 0.97 \log(\text{TP}) - 0.43 \quad (r^2 = 0.37,\ n = 45). \tag{1}$$

No change in the regression was noted when only summer (July and August) values were considered. Although a linear relationship is frequently the rule when considering chlorophyll-a and total phosphorus data from individual or groups of lakes, the regression coefficents for the various models vary widely. In comparing this model for the Wisconsin lakes data (1) with other models (as reviewed by Canfield (1983) and Smith and Shapiro (1981)) a similarity was noted with the relation found by Edmondson for Lake Washington,

$$\log(\text{CHLA}) = 1.20 \log(\text{TP}) - 0.55 \quad (r^2=0.94), \tag{2}$$

and that found by Bindloss for Gravenhurst Bay,

$$\log(\text{CHLA}) = 1.00 \log(\text{TP}) - 0.67 \quad (r^2=0.64). \tag{3}$$

A greater similarity in coefficents and r^2 values is found when comparisons are made with regressions calculated from WDNR data for other Wisconsin lakes (Lillie and Mason, 1983). The WDNR reports a greater correlation between the inverse transform of summer (July and August) secchi depths and chlorophyll-*a* concentrations than between the logarithmic transform of secchi depth:

$$1/SDS = 0.015\ (CHLA) + 0.44\ (r^2{=}0.76), \quad (4)$$

and this is substantiated by data from this study:

$$1/SDS = 0.012\ (CHLA) + 0.45\ (r^2{=}0.42). \quad (5)$$

In addition, several similar regressions were obtained when regional data was considered between WDNR lakes and the lakes of this study. Overall, the linear relationship between secchi depth, total phosphorus and chlorophyll-*a* concentrations appears to be as intact for this data set as would be expected given the relationships reported from other studies.

CONCLUSION

The Wisconsin lakes monitoring study, carried on from 1978 through 1983, has yielded an extensive database for assessing the effectiveness of the detergent phosphorus ban to improve the water quality of inland lakes. An examination of yearly means or temporal plots, however, does not show clearcut evidence of a monotonic trend in water quality, evidenced by secchi depth, total phosphorus concentration or chlorophyll-*a* concentration, resulting from imposition of the ban. Instead, the dataset exhibits the highly variable nature of physical and chemical water quality measurements throughout the growing season. In order to take into account natural fluctuations in water quality parameters when statistically analyzing data for trends expected from a nutrient management measure, the use of data from lakes not affected by the measure may be used to establish a baseline for comparisons. The statistical methodology employed in this comparison will be presented in the following paper.

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Figure 1: Locations of the Wisconsin Study Lakes


LAKE SUPERIOR
MI.
WI.
TEAL
R
T
BUTTERNUT
T
ELK
T
BALSAM
MOSS
T
TOWNLINE
T
R
LITTLE BEARSKIN
T
ENTERPRISE
WISCONSIN
WI.
MN.
LAKE
MICHIGAN
SWAN
T
R
FISH
MADISON
WI.
IA.
KEY
R - REFERENCE LAKE
T - TEST LAKE
WI.
IL.

Table 1: Limnological, Morphological, and Drainage Basin Characteristics of the Study Lakes

Lake	County	Surface Area (ha.) [1]	Volume (10**6 cu m.) [2]	Mean Depth (m) [3]	Max Depth (m)	Mean Hydraulic Residence Time (days) [4]	Number of Tributaries In [5]	Number of Tributaries Out	Immed. Drain. Basin Area [6] (sq.km.)	Number of Residences in 1981 [7]	Immediate Drainage Basin [% by category] [6] Forest	Marsh	Agri	Shoreline Resident
Butternut	Price	407	17.10	4.2	10.0	180	4	1	8.5	265	[40.0	16.5	341	9.4]
Elk	Price	36	0.55	1.5	8.0	<5	1	1	3.8	7	[18.4	7.9	29.9	44.8]
Balsam	Washburn	119	8.74	7.3	15.0	70	2	1	9.6	24	[44.8	35.4	18.8	1.0]
Teal	Sawyer	425	16.15	3.8	9.0	210	2	1	9.7	137	[61.9	35.2	0.5	2.4]
Moss	Vilas	79	2.36	3.0	9.0	900	0	1	3.0	40	[70.0	16.8	3.3	6.6]
Townline	Oneida	62	2.15	3.5	6.0	220	2	1	1.7	71	[64.7	11.8	17.6	5.8]
Enterprise	Langlade	204	7.26	3.6	8.0	620	1	1	10.9	124	[70.7	239	2.7	2.7]
Little Bearskin	Oneida	66	1.57	2.4	8.0	50	1	1	5.0	43	[76.3	21.5	0	2.2]
Swan	Columbia	164	16.03	9.8	25.0	160	1	1	21.3	104	[12.7	24.0	61.0	12.7]
Fish	Dane	102	6.34	6.2	19.0	1410	0	0	7.7	66	[19.3	0.8	74.4	0.9]

(1): Source - Wisconsin Department of Natural Resources (1981)

(2): Volumes estimated planimetrically using depth contours from maps prepared by The Clarkson Company, Kaukauna, WI

(3): Lake volume divided by surface area

(4): Lake volume divided by the mean annual flow

(5): Intermittent streams are not listed as tributaries

(6): Source - Wisconsin Department of Natural Resources (1975)

(7): Visual survey conducted by the Environmental Research Group, Inc., St. Paul, MN.
(Note: A resort was counted equivalent to 20 residences, a scout camp equivalent to 40 residences)

Table 2: Modes of wastewater treatment within study lake basins.

Lake	Name of Municipal WWTP	Final Application of Treated Wastewater
Elk	Phillips	Direct discharge to lake
Butternut	Butternut	Indirect discharge to surface water
Townline	Three Lakes	"
Swan	Pardeeville	"
Balsam	Birchwood	Land disposal
Moss	Lac du Flambeau	"
Enterprise	---	Septic tank / tile fields

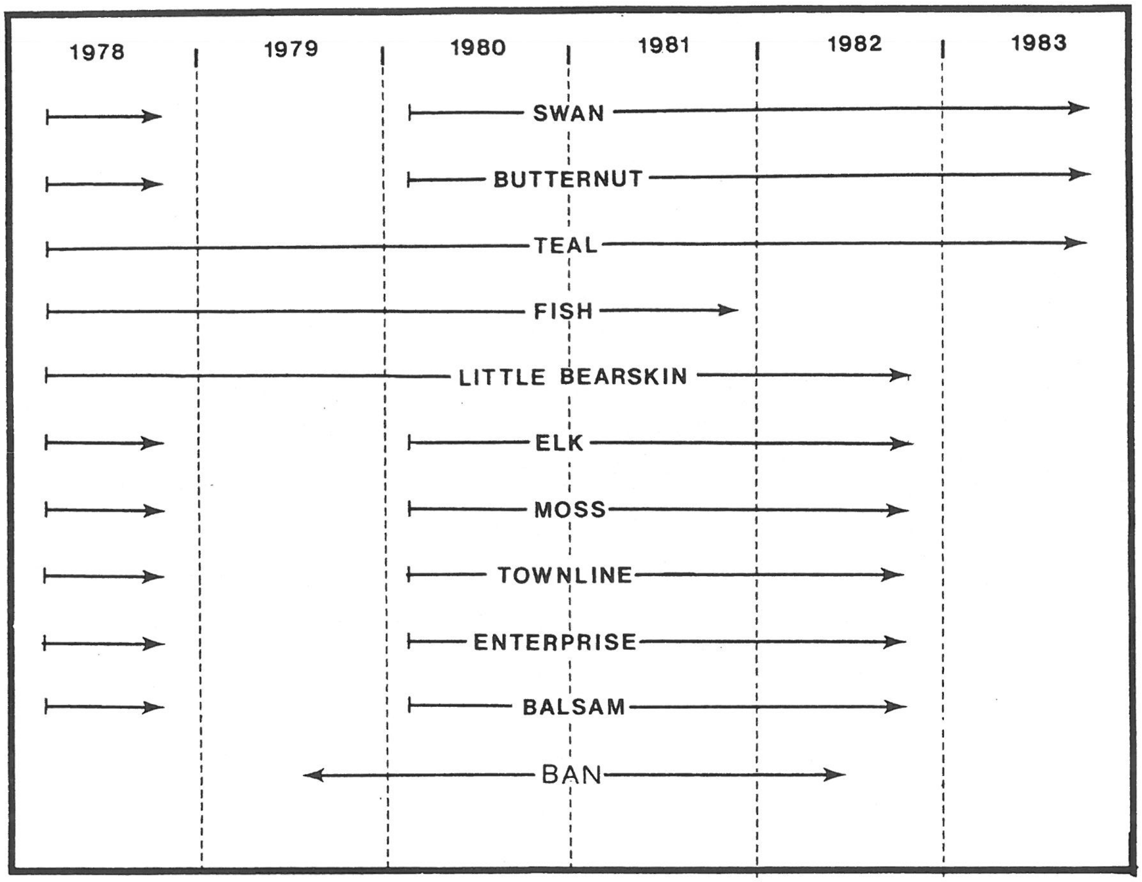


Figure 2: Sampling Timeline for the Wisconsin Lakes Study

Table 3 : Data Summary for the Wisconsin Lakes Study

Lake (Test/Ref)	1978				1979				1980				1981				1982				1983			
	n	min	max	mean	n	min	max	mean	n	min	max	mean	n	min	max	mean	n	min	max	mean	n	min	max	mean
Butternut (Test)																								
SD	8	0.3	2.1	1.0					9	0.8	2.7	1.5	6	0.8	2.0	1.3	8	1.1	1.8	1.4	6	0.5	2.8	2.1
CHL	8	3	177	45					9	2	63	30	6	2	82	42	8	1	59	23	6	1	101	23
TP	8	22	100	74					9	41	248	85	6	67	121	93	8	35	110	64	6	11	97	45
TON	8	3	351	94					9	17	248	93	6	5	92	34	8	1	160	67	5	4	85	37
NH4	8	44	318	77					9	33	149	75	6	31	324	155	8	22	122	72	6	1	72	37
TKN	8	0.54	1.91	0.10					9	0.5	1.57	1.04	6	0.71	2.07	1.41	8	0.12	1.60	0.82	6	0.32	1.98	0.77
ALK	8	38	44	40					9	36	56	45	6	32	41	36	8	33	43	38	6	37	47	41
PH	8	6.6	7.9	7.3					9	7.0	8.6	7.6	6	6.9	7.9	7.2	8	6.9	8.6	7.5	6	7.3	9.3	8.0
Balsam (Test)																								
SD	8	0.9	2.4	1.6					9	1.4	3.4	2.3	8	1.5	3.5	2.4	8	1.5	3.1	2.2				
CHL	8	6	48	27					9	1	42	17	8	3	39	25	8	1	44	23				
TP	8	26	71	42					9	10	93	43	8	40	410	110	8	33	128	49				
TON	7	1	24	6					9	7	152	59	8	6	253	55	8	8	157	56				
NH4	8	3	352	50					9	4	126	46	8	17	357	107	8	22	268	86				
TKN	8	0.42	1.18	0.74					9	0.43	1.20	0.71	8	0.53	1.57	0.96	8	0.12	1.4	0.64				
ALK	8	66	83	73					9	64	96	78	8	64	78	70	8	68	81	72				
PH	8	7.2	9.2	8.3					9	7.3	8.9	8.2	8	6.7	8.5	7.8	8	7.0	8.7	8.0				
Elk (Test)																								
SD	8	0.5	0.9	0.7					9	0.5	1.4	0.9	8	0.8	1.5	1.2	8	0.9	1.5	1.2				
CHL	8	4	13	8					9	5	95	30	8	10	34	20	8	1	33	14				
TP	8	20	104	65					9	39	124	82	8	28	114	60	8	32	72	46				
TON	8	2	193	94					9	25	196	95	8	7	238	74	8	6	147	62				
NH4	8	3	95	56					9	8	140	71	8	25	136	69	8	26	95	61				
TKN	8	0.55	1.45	0.86					9	0.60	1.92	1.12	8	0.55	1.41	0.95	8	0.06	1.50	0.76				
ALK	8	25	35	30					9	17	54	37	8	17	50	33	8	17	44	34				
PH	8	6.4	8.2	7.3					9	6.4	8.2	7.3	8	6.1	7.4	6.8	8	6.9	7.5	7.2				
Teal (Ref)																								
SD	8	1.3	3.4	1.8	5	1.4	2.8	2.1	9	1.4	4.6	2.4	8	1.4	4.1	2.3	8	1.3	3.3	1.9	6	2.0	4.0	3.0
CHL	8	4	33	15	5	6	61	21	8	6	21	15	8	2	76	21	8	2	34	15	6	1	18	7
TP	8	19	35	27	5	20	78	42	9	7	105	46	8	15	355	79	8	14	69	36	5	10	42	29
TON	8	1	21	6	5	1	162	50	9	9	112	58	8	3	102	31	8	1	146	63	4	4	93	46
NH4	8	3	17	10	5	4	83	48	9	1	62	32	8	17	169	46	8	23	75	46	3	12	12	12
TKN	8	0.26	1.08	0.53	5	0.45	0.86	0.58	9	0.48	0.94	0.68	8	0.31	1.23	0.77	8	0.07	2.1	0.72	6	0.31	0.85	0.48
ALK	8	33	38	36	5	32	38	35	9	32	42	35	8	23	36	32	8	28	38	33	6	27	32	30
PH	8	6.8	8.5	7.4	5	5.6	7.6	6.8	9	6.9	7.8	7.5	8	6.5	7.3	7.1	8	6.7	7.6	7.3	6	7.2	8.0	7.5
Moss (Test)																								
SD	8	1.9	3.2	2.5					9	2.0	4.1	3.1	7	1.8	4.9	3.5	8	2.4	5.8	3.9				
CHL	8	3	10	5					9	3	15	6	7	2	27	9	8	1	8	5				
TP	8	14	42	27					9	1	75	38	7	24	92	47	8	8	40	25				
TON	8	2	18	7					9	15	112	50	7	7	69	21	8	11	74	27				
NH4	8	1	30	11					9	12	173	58	7	15	91	43	8	34	296	83				
TKN	8	0.21	0.61	0.38					9	0.41	0.87	0.62	7	0.58	1.51	0.79	8	0.09	0.60	0.38				
ALK	8	28	32	30					9	26	34	29	7	26	32	28	8	22	36	30				
PH	8	6.4	8.5	7.3					9	6.6	7.6	7.3	7	6.9	8.1	7.3	8	7.0	8.3	7.5				

Lake (Test/Ref)	1978				1979				1980				1981				1982				1983			
	n	min	max	mean	n	min	max	mean	n	min	max	mean	n	min	max	mean	n	min	max	mean	n	min	max	mean
Townline (Test)																								
SD	8	0.8	1.2	1.0					9	1.1	2.3	1.5	8	1.1	2.6	1.8	8	1.2	3.1	2.1				
CHL	8	9	36	24					9	4	35	22	8	11	35	21	8	2	33	15				
TP	8	28	91	49					9	20	100	54	8	25	65	47	8	11	110	57				
TON	8	2	247	61					9	2	126	52	7	1	261	47	8	5	153	43				
NH4	8	2	247	61					9	12	346	85	8	10	120	50	8	1	123	53				
TKN	8	0.63	2.7	1.11					9	0.49	1.07	0.81	8	0.46	1.28	0.76	8	0.12	0.84	0.54				
ALK	8	35	38	36					9	24	36	29	8	22	33	28	8	26	38	35				
PH	8	6.3	8.2	7.4					9	6.6	7.9	7.1	8	6.6	8.0	7.2	8	7.0	7.8	7.3				
Enterprise (Test)																								
SD	8	1.1	2.7	1.8	1	-	-	2.00	9	0.9	3.0	2.0	8	1.2	3.5	2.5	8	1.1	4.6	2.4				
CHL	8	3	20	10	1	-	-	4	9	1	51	18	8	4	39	14	8	3	43	14				
TP	8	5	41	25	1	-	-	27	9	2	100	45	8	32	275	74	8	13	71	36				
TON	8	2	106	23	1	-	-	176	9	11	145	47	8	1	148	34	8	8	130	40				
NH4	8	2	45	17	1	-	-	57	9	11	121	36	8	9	69	28	8	39	72	49				
TKN	8	0.34	0.82	0.53	1	-	-	0.51	9	0.45	1.17	0.76	8	0.36	1.51	0.82	8	0.04	1.20	0.57				
ALK	8	13	17	16	1	-	-	14	9	8	25	14	8	11	20	14	8	10	25	15				
PH	8	6.3	8.7	7.7	1	-	-	7.5	9	6.40	8.1	7.0	8	6.4	6.9	6.7	8	6.5	9.0	7.1				
L.Bearskin (Ref)																								
SD	8	1.2	2.6	2.0	5	1.6	2.9	2.2	9	1.5	3.8	2.4	8	1.7	2.7	2.1	8	1.7	3.9	2.8				
CHL	8	4	40	18	5	13	42	23	9	5	19	12	8	3	38	16	7	2	40	15				
TP	8	21	58	37	5	24	58	41	9	9	92	42	8	45	88	55	8	17	65	37				
TON	8	2	25	7	5	5	15	8	9	10	129	43	8	3	210	45	8	1	117	27				
NH4	8	3	30	11	5	13	121	50	9	4	123	37	8	9	79	42	8	42	147	67				
TKN	8	0.35	0.98	0.53	5	0.51	0.72	0.64	9	0.44	0.83	0.63	8	0.32	1.15	0.69	8	0.05	0.81	0.51				
ALK	8	38	46	42	5	36	46	41	9	28	47	37	8	34	40	38	8	37	45	40				
PH	8	6.5	7.7	7.2	5	5.8	7.9	7.0	9	6.8	7.5	7.2	8	6.3	7.2	6.8	8	7.0	7.6	7.4				
Swan (Test)																								
SD	8	1.4	3.7	2.1					9	1.1	4.0	2.1	8	0.9	3.4	2.1	8	1.2	2.7	1.8	6	1.0	4.0	2.2
CHL	8	1	42	17					9	9	110	30	8	4	73	28	8	5	45	20	6	4	84	29
TP	8	24	108	56					8	7	151	68	8	42	89	63	8	18	140	59	5	21	54	40
TON	8	1	320	68					9	3	750	180	8	4	1540	264	8	6	756	141	4	20	600	182
NH4	8	5	2119	296					9	11	2360	308	8	16	581	169	8	34	1080	182	6	1	72	31
TKN	8	0.49	2.54	1.01					9	0.89	1.70	1.33	8	0.81	1.50	1.14	8	0.18	1.70	0.95	6	0.55	1.12	0.77
ALK	8	172	205	185					9	148	233	177	8	169	230	190	8	141	210	186	6	178	197	189
PH	8	7.9	8.9	8.5					9	7.6	8.6	8.1	8	7.6	8.4	8.1	8	7.5	8.7	8.3	6	8.2	8.6	8.5
Fish (Ref)																								
SD	8	1.5	4.0	2.5	5	1.6	3.2	2.4	9	2.4	5.3	4.0	8	3.4	4.9	4.0								
CHL	8	4	10	6	5	4	12	6	9	1	56	10	8	2	14	7								
TP	8	18	42	31	5	7	115	43	9	17	88	45	8	25	185	59								
TON	8	3	34	10	5	1	69	23	9	9	91	39	8	2	180	47								
NH4	7	4	49	17	5	25	120	60	9	5	203	41	8	4	82	36								
TKN	8	0.44	1.09	0.68	5	0.67	0.94	0.83	9	0.63	1.56	0.90	8	0.60	1.96	1.00								
ALK	8	103	142	127	5	114	148	134	9	98	166	119	8	104	130	114								
PH	8	7.7	8.9	8.4	5	7.6	8.1	7.9	9	7.4	9.2	8.7	8	7.4	8.9	8.4								

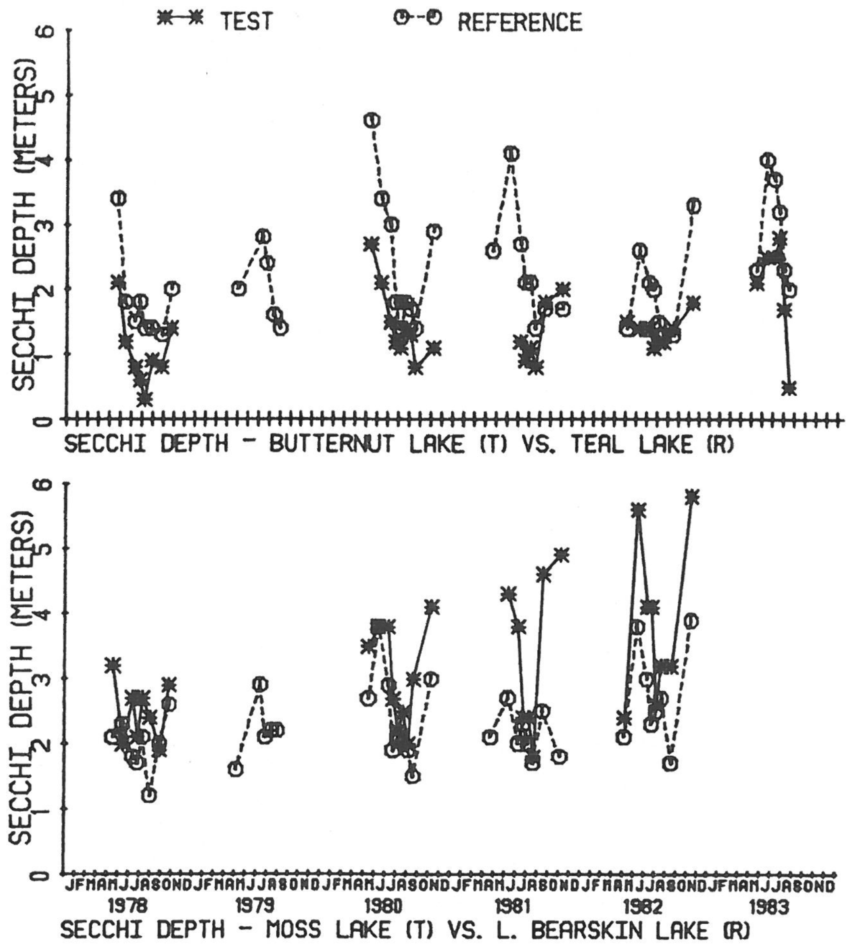
KFY: SD (Secchi depth, meters); CHL (chlorophyll-a, µg/L); TP (total phosphorus, µg/L); TON (total oxidized nitrogen, µg/L); NH4 (ammonia, µg/L); TKN (total kjeldahl nitrogen, mg/L); ALK (alkalinity, mg/L).

Table 4: A Comparison of Study Means for Reference Lakes with Regional Means (*)

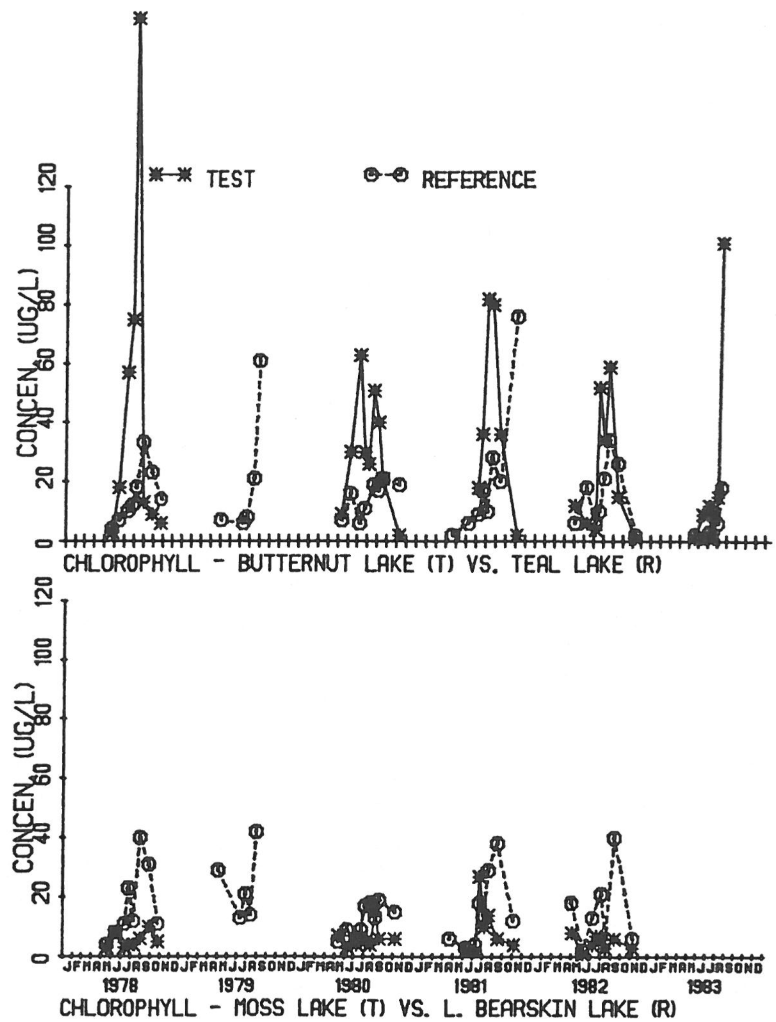
Lake	Monitor Period	Secchi (m)	CHLA	TP	TON	NH4	TKN	ALK.	pH
			(ug/L)				(mg/L)		
Teal	1978-83	2.2	16	44	42	34	0.64	33	7.3
Northwest region	-	2.1	12.4	28				27	7.0
Little Bearskin	1978-82	2.3	16	42	28	41	0.60	39	7.1
Northeast region	-	2.7	9.3	19				37	6.9
Fish	1978-81	3.4	7	45	31	37	0.86	122	8.4
Southeast region	-	1.5	43.3	79				173	8.1

(*) Reference: Lillie and Mason (1983), characteristics of Wisconsin lakes, by region, from a random data set

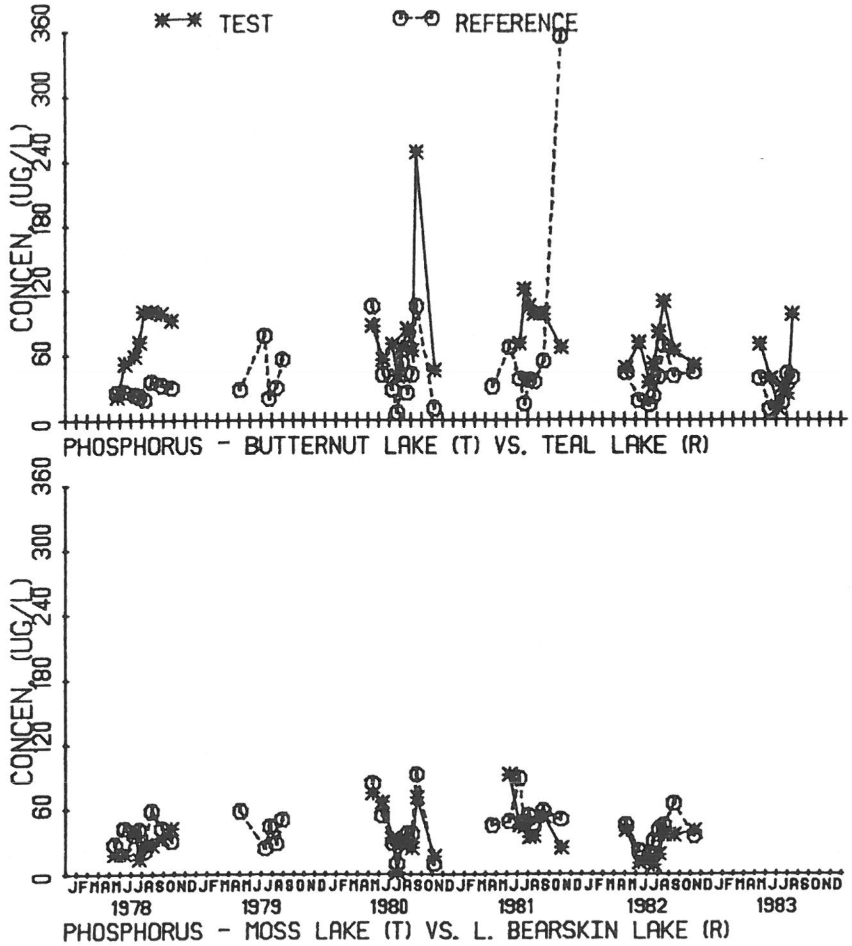
Figures 3 (a - i): Temporal Plots of Secchi Depth, Total Phosphorus, and Chlorophyll-*a* Data for the Test/Reference Lake Pairs


TEST
REFERENCE
SECCHI DEPTH (METERS)
SECCHI DEPTH - BUTTERNUT LAKE (T) VS. TEAL LAKE (R)
SECCHI DEPTH (METERS)
JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASOND
1978
1979
1980
1981
1982
1983
SECCHI DEPTH - MOSS LAKE (T) VS. L. BEARSKIN LAKE (R)

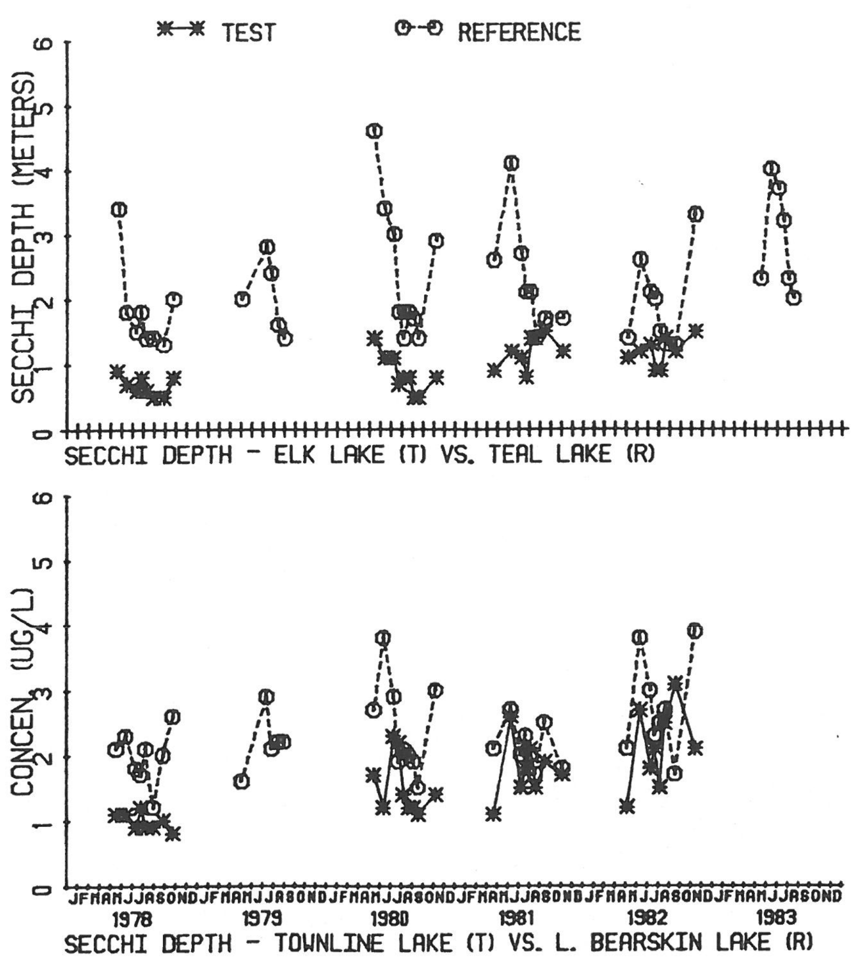
a)


TEST
REFERENCE
CONCEN (UG/L)
CHLOROPHYLL - BUTTERNUT LAKE (T) VS. TEAL LAKE (R)
CONCEN (UG/L)
JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASOND
1978
1979
1980
1981
1982
1983
CHLOROPHYLL - MOSS LAKE (T) VS. L. BEARSKIN LAKE (R)

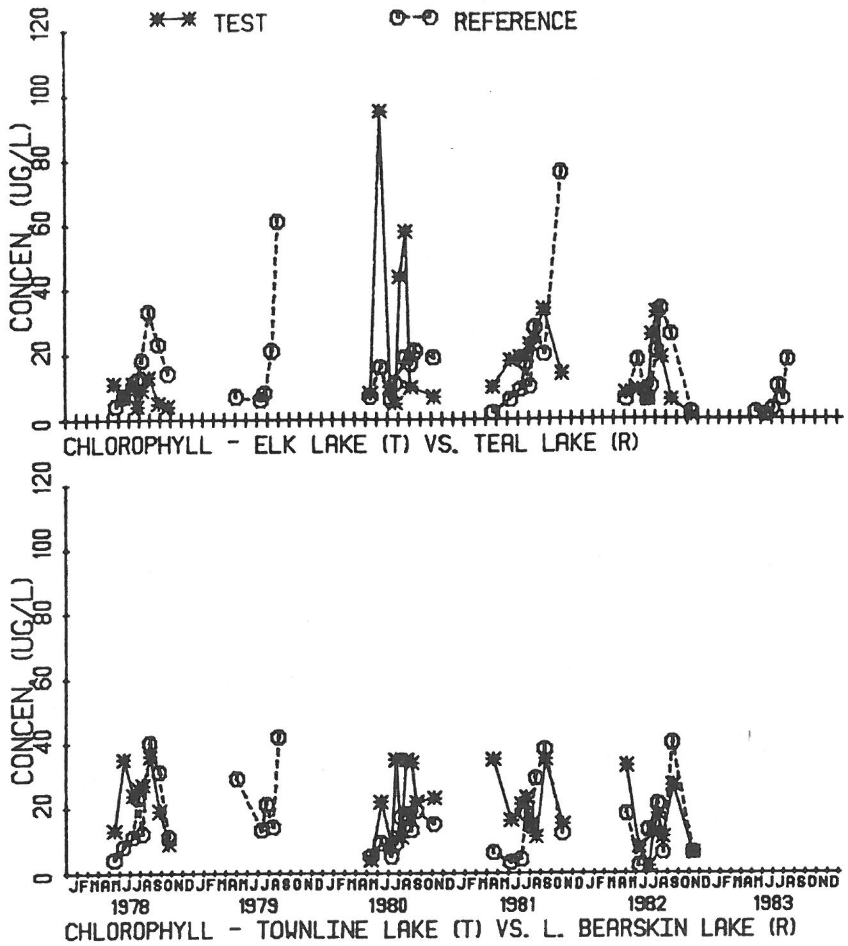
b)


TEST
REFERENCE
CONCEN. (UG/L)
PHOSPHORUS - BUTTERNUT LAKE (T) VS. TEAL LAKE (R)
CONCEN. (UG/L)
JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASOND
1978 1979 1980 1981 1982 1983
PHOSPHORUS - MOSS LAKE (T) VS. L. BEARSKIN LAKE (R)

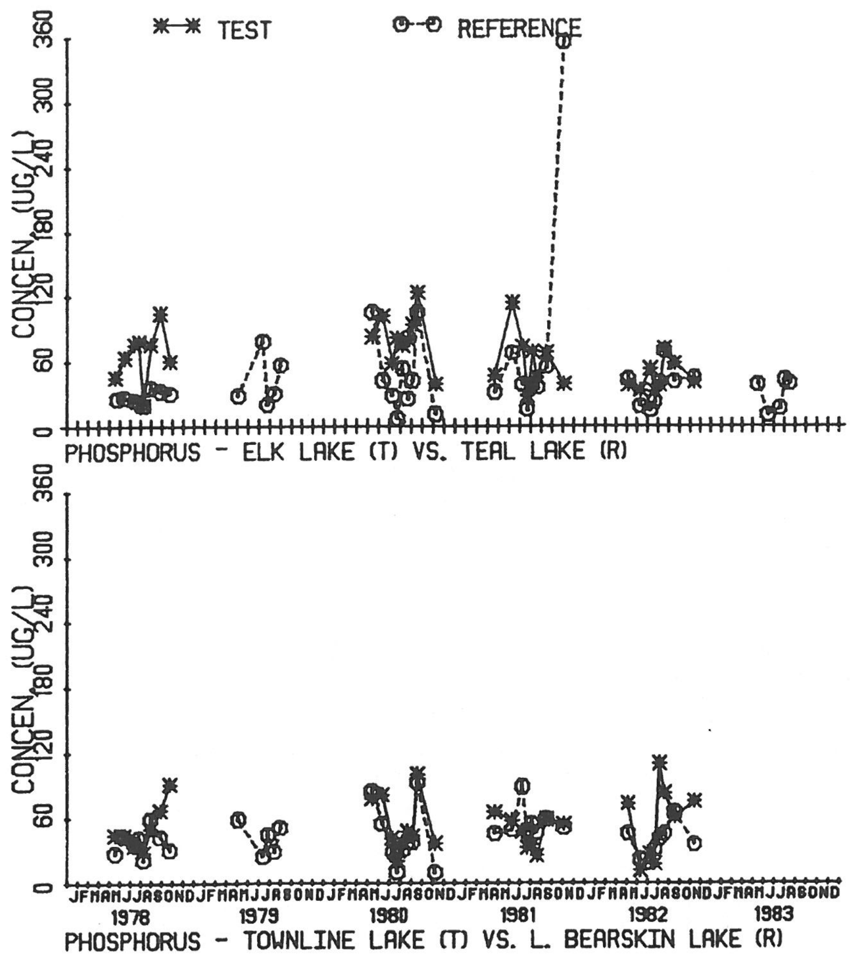
c)


TEST
REFERENCE
SECCHI DEPTH (METERS)
SECCHI DEPTH - ELK LAKE (T) VS. TEAL LAKE (R)
CONCEN. (UG/L)
JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASOND
1978 1979 1980 1981 1982 1983
SECCHI DEPTH - TOWNLINE LAKE (T) VS. L. BEARSKIN LAKE (R)

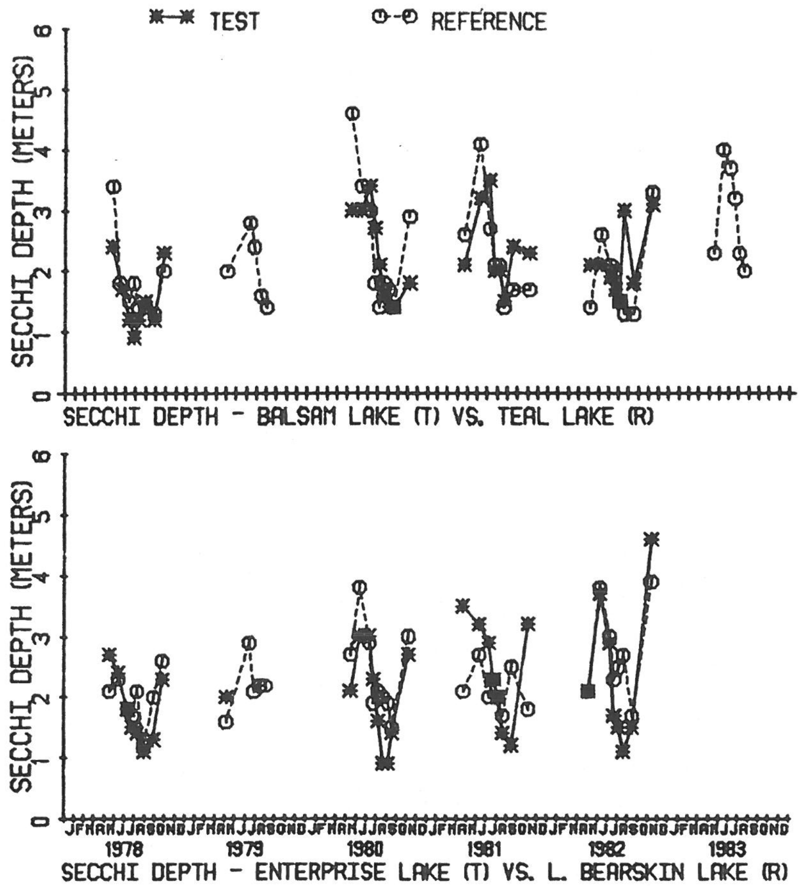
d)


TEST
REFERENCE
CONCEN (UG/L)
0
20
40
60
80
100
120
CHLOROPHYLL - ELK LAKE (T) VS. TEAL LAKE (R)
JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASOND
1978
1979
1980
1981
1982
1983
CHLOROPHYLL - TOWNLINE LAKE (T) VS. L. BEARSKIN LAKE (R)

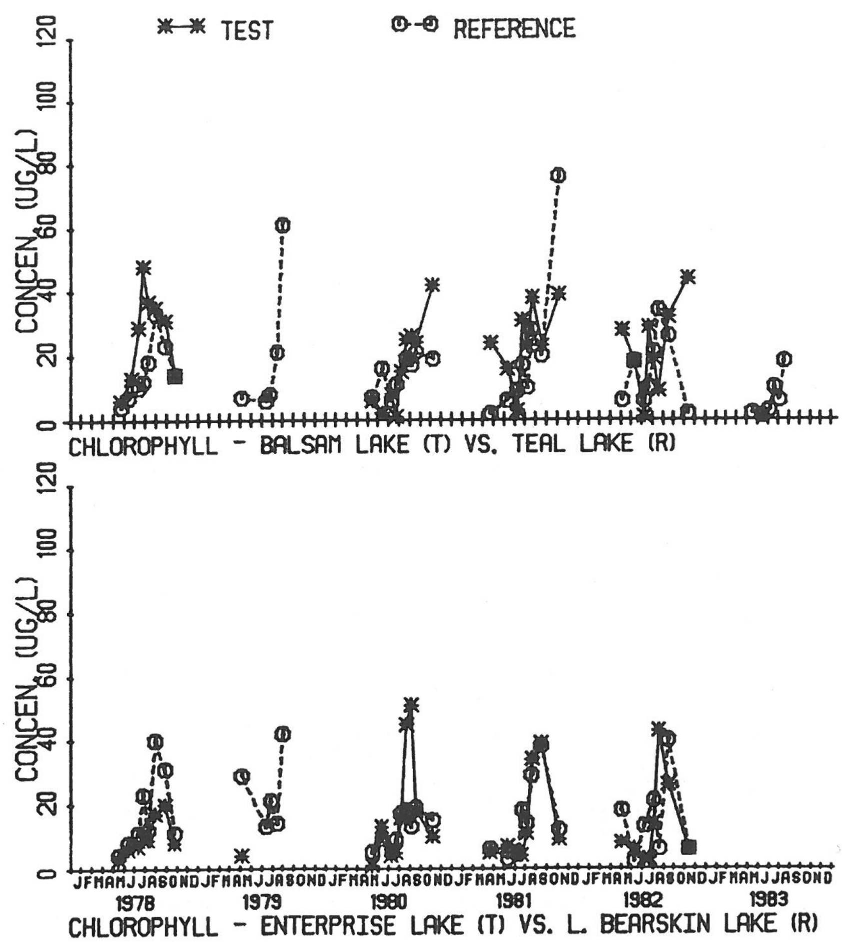
e)


TEST
REFERENCE
CONCEN (UG/L)
0
60
120
180
240
300
360
PHOSPHORUS - ELK LAKE (T) VS. TEAL LAKE (R)
JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASOND
1978
1979
1980
1981
1982
1983
PHOSPHORUS - TOWNLINE LAKE (T) VS. L. BEARSKIN LAKE (R)

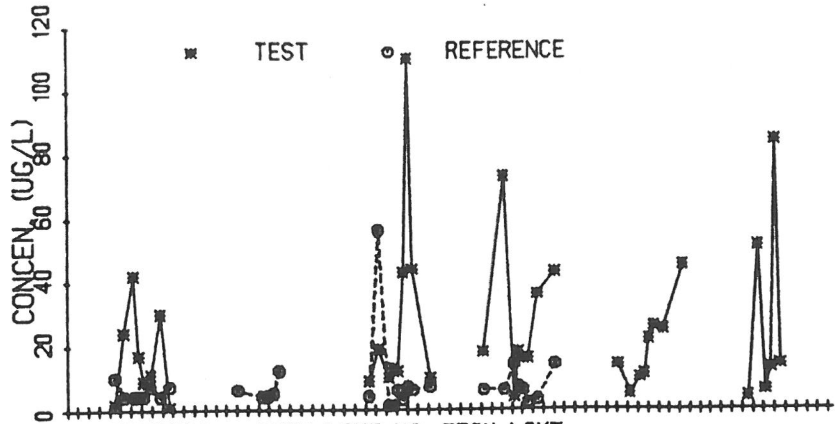
f)


TEST
REFERENCE
SECCHI DEPTH (METERS)
SECCHI DEPTH - BALSAM LAKE (T) VS. TEAL LAKE (R)
SECCHI DEPTH (METERS)
JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASOND
1978
1979
1980
1981
1982
1983
SECCHI DEPTH - ENTERPRISE LAKE (T) VS. L. BEARSKIN LAKE (R)

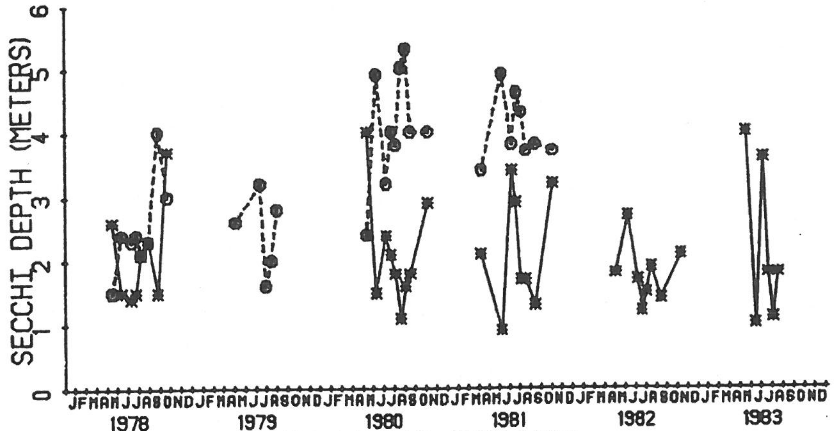
g)


TEST
REFERENCE
CONCEN. (UG/L)
CHLOROPHYLL - BALSAM LAKE (T) VS. TEAL LAKE (R)
CONCEN. (UG/L)
JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASOND
1978
1979
1980
1981
1982
1983
CHLOROPHYLL - ENTERPRISE LAKE (T) VS. L. BEARSKIN LAKE (R)

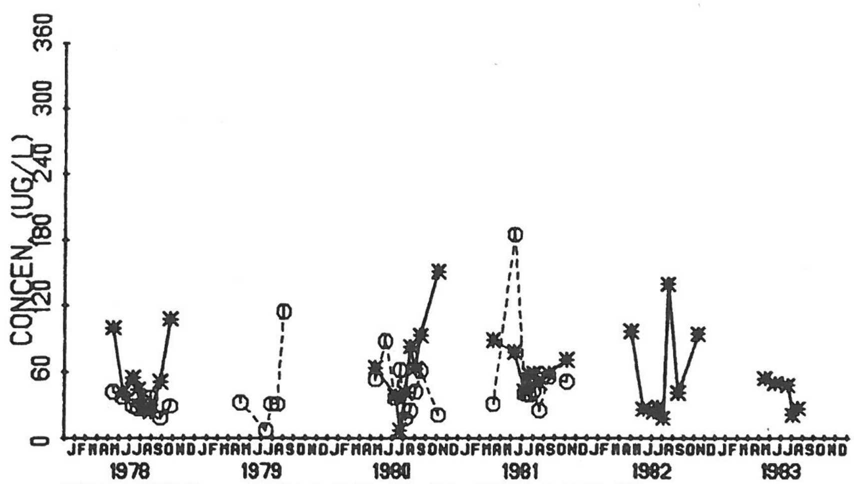
h)



CHLOROPHYLL - SWAN LAKE VS. FISH LAKE



SECCHI DEPTH - SWAN LAKE VS. FISH LAKE

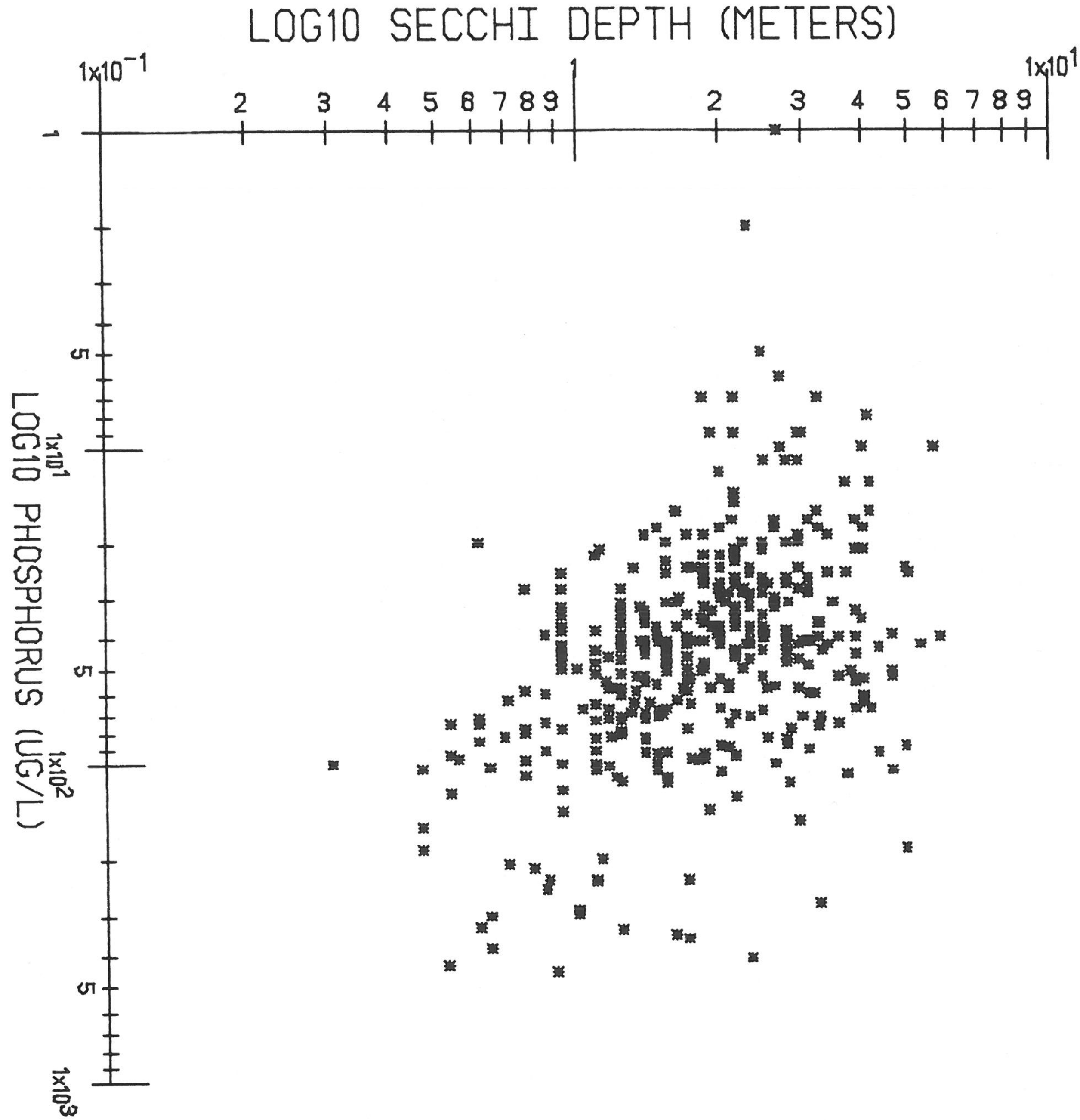


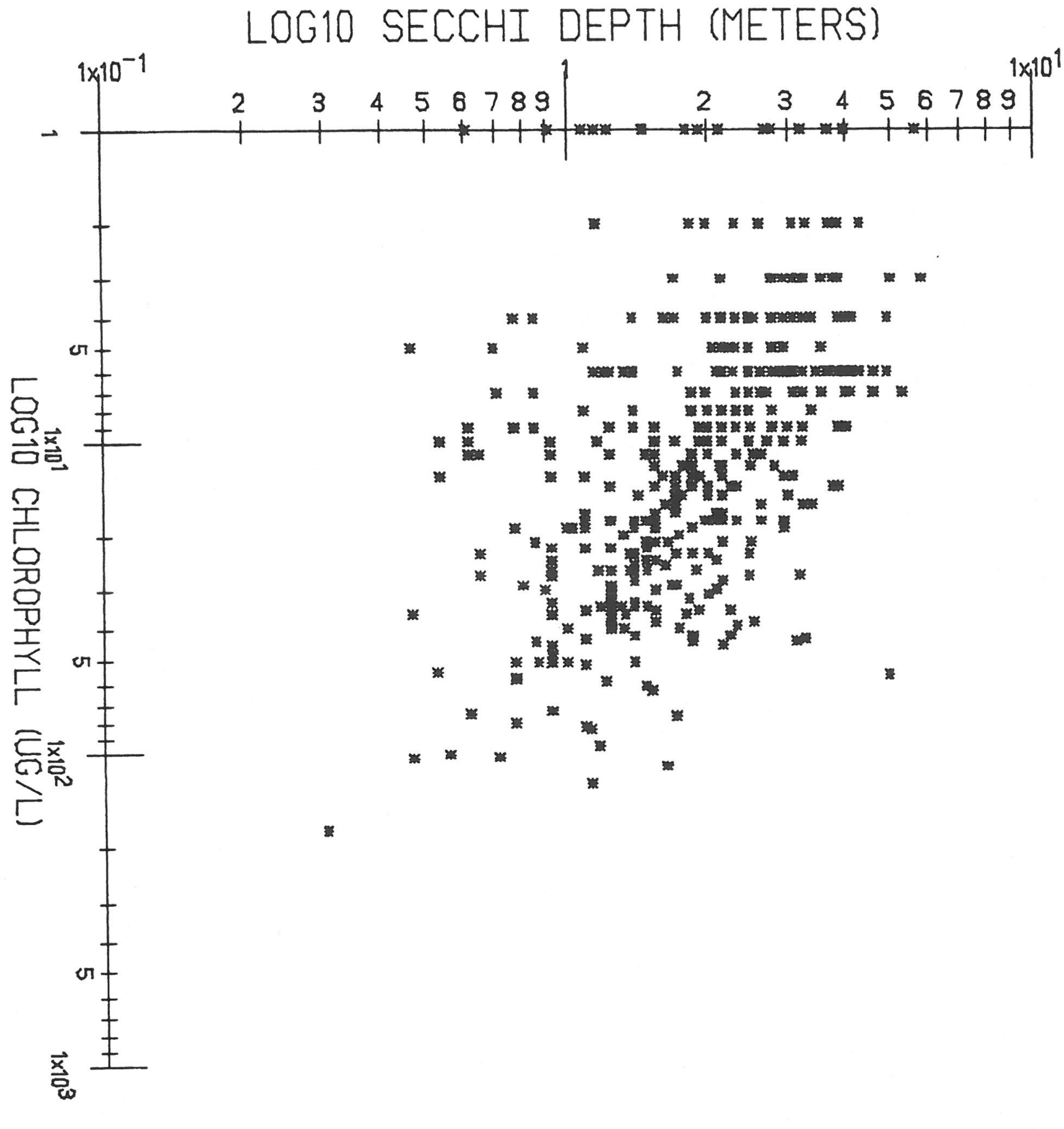
i) PHOSPHORUS - SWAN LAKE (T) VS. FISH LAKE (R)

Figure 4 (a): Log (Secchi Depth) vs. Log (Phosphorus)

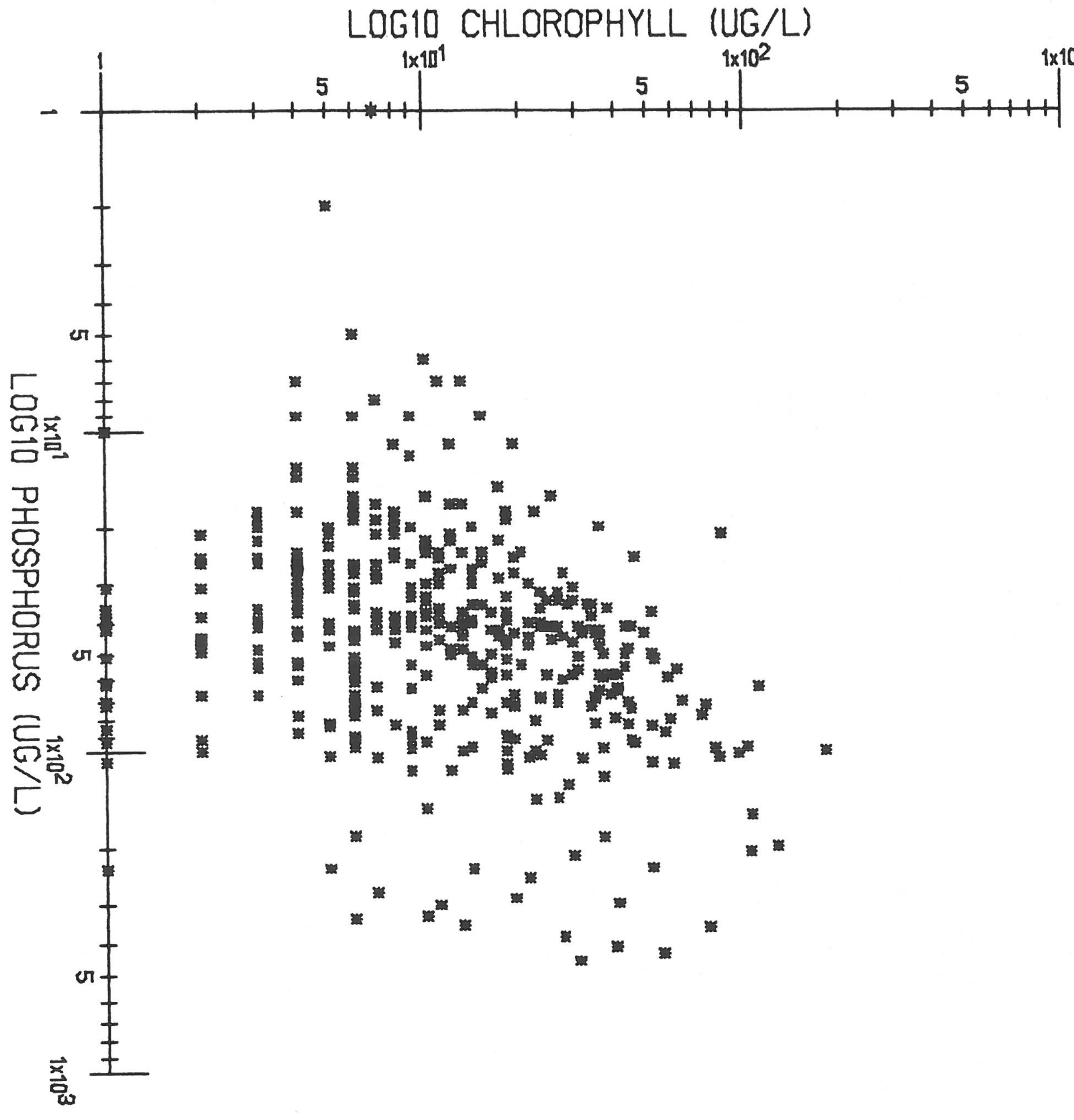
Figure 4 (b): Log (Secchi Depth) vs. Log (Chlorophyll-a)

Figure 4 (c): Log (Chlorophyll-a) vs. Log (Phosphorus)


LOG10 SECCHI DEPTH (METERS)
1x10⁻¹
1
1x10¹
2 3 4 5 6 7 8 9
LOG10 PHOSPHORUS (UG/L)
1x10¹
1x10²
1x10³
5



LOG10 SECCHI DEPTH (METERS)
1x10^-1
1
1x10^1
2
3
4
5
6
7
8
9
LOG10 CHLOROPHYLL (UG/L)
1x10^1
1x10^2
1x10^3



LOG10 CHLOROPHYLL (UG/L)
1
5
1x10^1
5
1x10^2
5
1x10^3
1
5
1x10^1
5
1x10^2
5
1x10^3
LOG10 PHOSPHORUS (UG/L)