Nutrients, Phytoplankton, and the Flow of Water Through Lyman Lakes, Carleton College

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ABSTRACT

Lyman lakes in Northfield, Minnesota have a combined volume of 30,600 cubic meters and are fed sequentially by a stream which drains agricultural land and has a minimum discharge of .25 cubic meters per second. Temperature, pH, and concentrations of phytoplankton in the water increase steadily moving downstream through the lakes. Because concentrations of nitrogen are very high relative to concentrations of phosphorus, it would at first appear that phosphorus is the limiting factor which controls the growth of phytoplankton in the lake. However, because the average residence time of water in the lake is only 36 hours and the doubling time of the most prolific populations of phytoplankton is rougly 2 days, it is the rate of flushing by spring creek which limits the growth of algae in the lakes, keeping the concentrations of chlorophyl a orders of magninitude lower than what phosphorus concentrations would otherwise predict.

INTRODUCTION

Lyman lakes, situated on the campus of Carleton College in Northfield, Minnesota, are formed by two consecutive dams in Spring creek. Draining an area of roughly four square miles of agricultural and residential

should be about 26

land, the creek meanders through glacial till and over calcareous bedrock of the Prairie du Chien group. Because of the large amounts of sediments which have settled into the lakes within the past 20 years as well as the annual spring bloom of attatched algae which leaves the lake filled with unattractive, decaying organic matter, there has been a growing interest in the geology and ecology of this system which in turn has led to a project funded by the college to study the problem. The purpose of this paper is to discuss the ecology of the lakes, in particular to determine how nutrients and other factors influence the concentrations and distribution of phytoplankton.

METHODS

Data for the project was collected on two occasions; may 15, after a number of days of intermittent rainfall which did not change the discharge of the creek appreciably, and may 18, after 3 days of clear weather. Six water samples were taken at various points along spring creek and in Lyman lakes in the hopes that they might show trends in the data, in particular the distribution of chlorophyll a, as an index to concentration of phytoplankton. Samples which were not used immediately were stored in nalgene bottles in a freezer. Velocity of the creek was measured 100 meters upstream of Upper lyman lake and appears to be roughly constant along the length of the stream. For each sample,

ammonia, phosphorous, and Chlorophyll a were measured; ammonia with an AN-10 CHEMetrics ammonia nitrogen test kit, phosphorus with a PO-10 phosphate test kit and chlorophyll a spectrophotometrically using a Bausch and Laumb Spectronic 20 according to the method described by Taras et al (1971). In all cases, the test kits yielded readings less than .1ppm, the lower threshold for the kits. For that reason and also because the kit used for ammonia was outdated by three years, ammonia was also measured by the nessler method using a Bausch and Laumb spectronic 20 according to the procedure described by Taras et al (1971) PH was measured for each sample in the second group using an electronic pH meter, and temperature was measured at each station and at various depths in the lakes.

Data provided by Schilling Environmental Consultants (Schilling, 1984) was much more extensive and therefore more useful than was the data collected exclusively for this paper. Schilling analysed samples which were taken on seven occasions during the summer of 1984 at three stations in Lyman lakes; one in upper Lyman and two in lower Lyman. Schilling provided data for pH, temperature and volume of the lakes as well as concentrations of chlorophyll a, ammonia, inorganic nitrogen and phosphorous (tables I-VI)

The literature (Chiaudani and Vighi, 1974, Schindler, 1974, Jones and Bachmann, 1976, Dillon and Rigler, 1974) suggests that phosphorus, and less often, nitrogen, is usually the factor which limits the growth of phytoplankton in lakes. To investigate this possibility, the concentrations of total phosphorus were plotted against the concentration of chlorophyll a for each lake and a regression line fitted to the data.

RESULTS

Concentrations of ammonia and phosphorus were to low to detect using either the CHEMetric test kits or for ammonia, the nessler method. For the nessler method, a Bausch and Laumb Spectronic 20 was used to measure change in color of the samples when nessler solution was added. Unfortunately, because the nessler solution itself has a slight tint and the concentrations of ammonia were so low in the samples, the optical density of the sample varied substantially with a small change in the concentration of nessler solution regardless of the concentration of ammonia. As a result, the figures for ammonia and phosphate concentrations are ambiguous.

Data for chlorophyll a is more useful; apart from two figures which are clearly out of order, the data shows a steady increase in concentrations of chlorophyll a in the water column as the water flows downstream and through the lakes, a fact which is not surprising considering that

the water is first exposed to the open sun only 100 meters above upper Lyman lake. The only other anomaly is a high figure of 21.6 ppb of chlorophyll a for the sample taken from the west side of Mai-fete island in lower Lyman lake, in comparison with 17.9 ppb below lower Lyman. Considering that the water doubtless does not flow evenly through the entire lake, it is possible that the high concentrations of phytoplankton mark places where the water tends to stagnate.

One other significant feature of the data for chlorophyll a is that the concentrations of chlorophyll a reported for the second round of sampling are substantially lower than those reported for the first round. Although there may be a true difference in concentrations from the first week to the next, it is also possible that because the two sets of samples were not treated exactly the same way before extraction of the pigment, the figures represent that difference in procedure; the first set of samples may have released more chlorophyll because the cells were thoroughly destroyed when they were frozen, in addition to being macerated manually, as were the fresh cells of the second set.

If the two samples represent a true drop in concentrations of chlorophyll a from one week to the next, the difference may be explained by a drop in the rate of photosynthesis coupled with a flushing of the

phytoplankton by the creek. Considering the bright days and lack of precipitation between the dates of the two samples, this seems unlikely.

Measurements of pH were consistently high; all of the six samples measured yielded a pH of 8.0-8.1. This is in contrast to the data for the summer of 1984, where the pH consistently dropped from the upper lake to the lower.

Measurements of temperature indicate a smooth gradient starting at 12 degrees celsius in spring creek rising to 16 degrees between the two lakes and then to 19 degrees at the dam below lower Lyman lake, with no substantial stratification vertically; the lakes are for the most part less than a meter deep. This data agrees with that of Schilling; although Schilling did not measure temperature vertically, in all cases except one the temperature was higher in lower Lyman than it was in upper Lyman lake.

Measurements of nutrients in 1984 by Schilling yield numbers which do not contradict those taken personally; concentrations of phosphates are on the order of .01 ppm, those of ammonia .1 ppm, and inorganic nitrogen 10 ppm and the ratios of nitrogen to phosphorus are on the orders of tens to hundreds.

The high pH levels in the stream and lake are almost undoubtedly a result of the stream cutting through calcareous sediments of the Prairie du Chien group above the lakes. The subsequent drop in pH from one lake to the next which consistently shows up in the data provided by Schilling is probably a result of the assimilation of CO2 by photosynthetic plants; CO2 dissociates in water to form carbonic acid, so the assimilation of CO2 due to photosynthesis tends to raise the pH (Goldman and Horne, 1983). A corresponding rise in the concentration of O2 in the lakes due to photosynthesis is also reflected in the data provided by Schilling. This rise in both pH and concentrations of O2 suggest that time, rather than nutrients are the factor limiting the growth of phytoplankton in the upper lake; the potential for growth is not realized immediately and so growth in the population of phytoplankton continues in the lower lake with a corresponding rise in pH and O2 concentrations in the water. The data for temperature lends credence to this theory; because the temperature steadily increases downstream through the lakes, it appears that the temperature is increasing with the amount of time the water spends in the lakes, rather than being in equilibrium with ambient air temperature.

The literature (Reynolds, 1976) suggests that the relative concentrations of nutrients has a substantial effect on the ecosystem of a lake. In particular, the

absolute concentrations of phosphorus and nitrogen as well as their relative concentrations often determine the density of photosynthetic material in a lake.

Megard (1972) discusses the relationships among phosphorus and photosynthesis in lake Minnetonka and comes to the conclusion that there is a strong correlation between the two. Jones and Bachmann (1976) argue even more persuasivly that there is a strong correlation between the concentration of total phosphorus and concentrations of chlorophyll a in lakes of various types and from a broad geographic area. In their study, they found a straight-line relationship between the two variables, a phenomenon observed by Dillon and Rigler, (1974). Crucial to this argument is the premise that phosphorus is the limiting nutrient, the nutrient which is in short supply for the phytoplankton. Chiaudani and Vighi (1974) studied the question of nutrient limitations, growing phytoplankton in cultures with various concentrations of nitrogen and phosphorus. They learned that the atomic ratios of nitrogen to phosphorus in algal cells ranges from 10:1 to 20:1 which corresponds to a ratio in weight from roughly 4.5:1 to 9:1. The results of their study indicated that phosphorus, rather than nitrogen, will be the limiting nutrient if the nitrogen to phosphorus ratio is less than 10:1. Forsberg (1980) accepts that principle, but places the ratio higher, at 17:1, although he does not offer data to defend that

ratio. Schindler (1984) dramatically demonstrated this principle in a lake in northwestern Ontario, where he divided the lake with a plastic curtain into two basins, adding nitrogen and sucrose to both basins, and phosphorus to only one. Schindler states that photosynthesis was not affected in the basin receiving only nitrogen and sucrose, whereas the basin receiving phosphorus as well rapidly became highly eutrophic, demonstrating that the population of phytoplankton in the lake was limited in growth by low concentrations of phosphorus.

The data from Schilling indicates that the nitrogen: phosphorus ratios for Lyman lakes are always well above 10:1 and so it is impossible that nitrogen is limiting the growth of phytoplankton in the lakes. A plot of concentration of phosphorus against concentration of chlorophyll a, provided by Dillon and Rigler (1974) shows that for phytoplankton limited by phosphorus, there is a straight line relationship between the two variables, with a slope of about 1.5 and an r of .97 (fig. I). Plots of the same variables for upper and lower Lyman lakes yield regression equations with slopes of .02 and .05, and values of .68 and .27, respectively; concentrations of chlorophyll a in the lakes would have to be orders of magnitude higher for its growth to be limited by phosphorus.

Dillon (1975) discusses the importance of the rate of flushing on the degree of eutrophication of Cameron lake, Ontario. The upshot of his argument is that although the annual flux of phosphorus into the lake is very high, on the order of grams per square meter per year, the lake is not eutrophic because of a high rate of flushing; 14 to 19 exchanges per year, which translates into an average residence time for water in the lake of less than a month. Reynolds (1976) points out that the lowest doubling time for the most prolific populations of phytoplankton is about 2 days, so that a population would on the average double at most a dozen times in cameron lake before being flushed out of the lake.

At a velocity of .33 m/sec, it takes just under an hour and a half for water to travel the one mile length of spring creek above Lyman lakes. With the total volume of both lakes at 30,600 cubic meters and a base flow of Spring creek of .25 m/sec, the maximum average residence time of water in the spring creek/Lyman lakes system is 36 hours, less than the doubling time for the most prolific phytoplankton. The inescapable conclusion is that it is residence time, not nutrients, which limits the growth of phytoplankton in Lyman lakes.

DATA

ROW	5/15/85 Chl-a I	5/18/85 Chl-a II
1	22.25	0.04
2	17.29	2.38
3	17.46	1.56
4	31.80	9.58
5	41.52	21.63
6	41.10	17.95

MTB > Chlorophyll a 5/15/85

1. one mile Southeast (upstream) of Lyman Lakes, in Spring creek.
2. 100 meters upstream of upper Lyman Lake.
3. Wooden bridge, entrance of Spring Creek to Lyman Lakes.
4. Waterfall between upper and lower Lyman Lakes
5. Dam below lower Lyman Lakes – South end
6. Dam below Lower Lyman Lakes – north end

Chlorophyll a 5/18/85

1. 100 meters upstream of Lymen Lakes,
2. wooden bridge, entrance of Spring Creek to Lyman Lakes.
3. middle of upper Lyman Lake.
4. waterfall between lakes
5. middle of Lower Lyman Lake, west side of island.
6. Dam below lower Lyman Lake.

Minimum discharge: 0.25 m^3/sec (Schilling, 1985)
(base flow)

Volume
upper Lyman: 5300 m^3
Lower Lymen: 25,300 m^3 (Schilling, 1984)

Velocity of Spring Creek 100 m South of upper Lyman: 0.33 m/sec

Residence time of Spring Creek/Lyman lakes System: 36 hours

Figure I

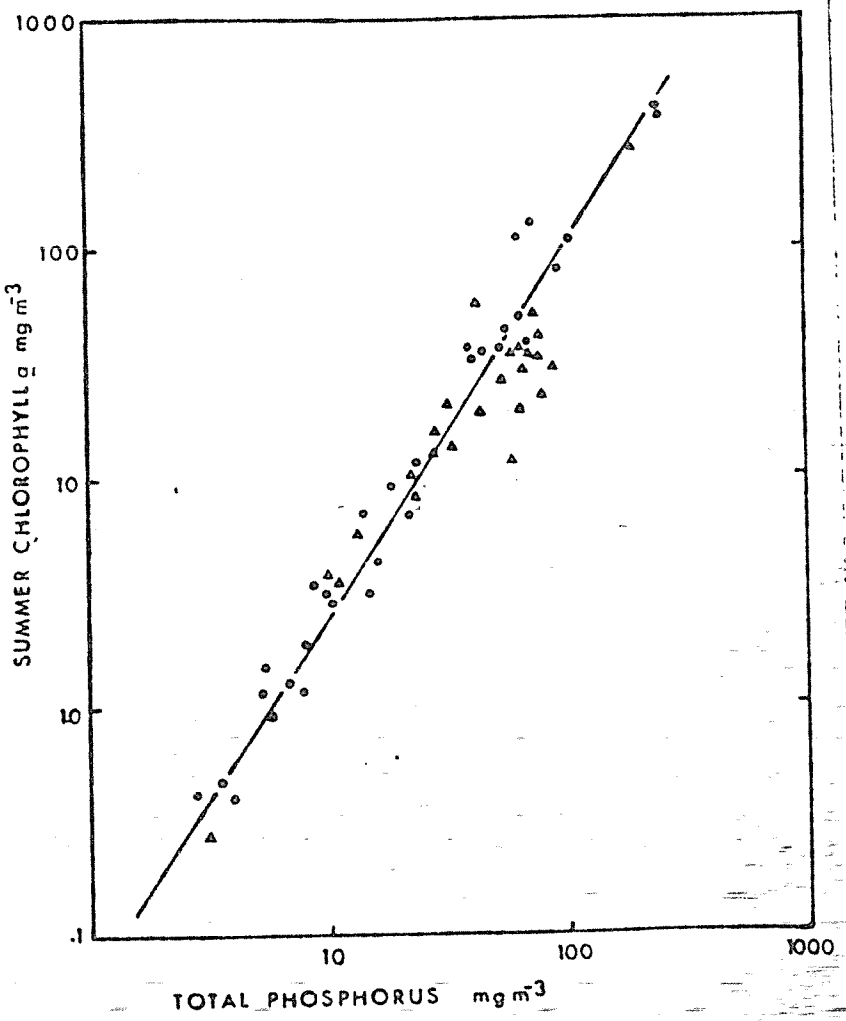


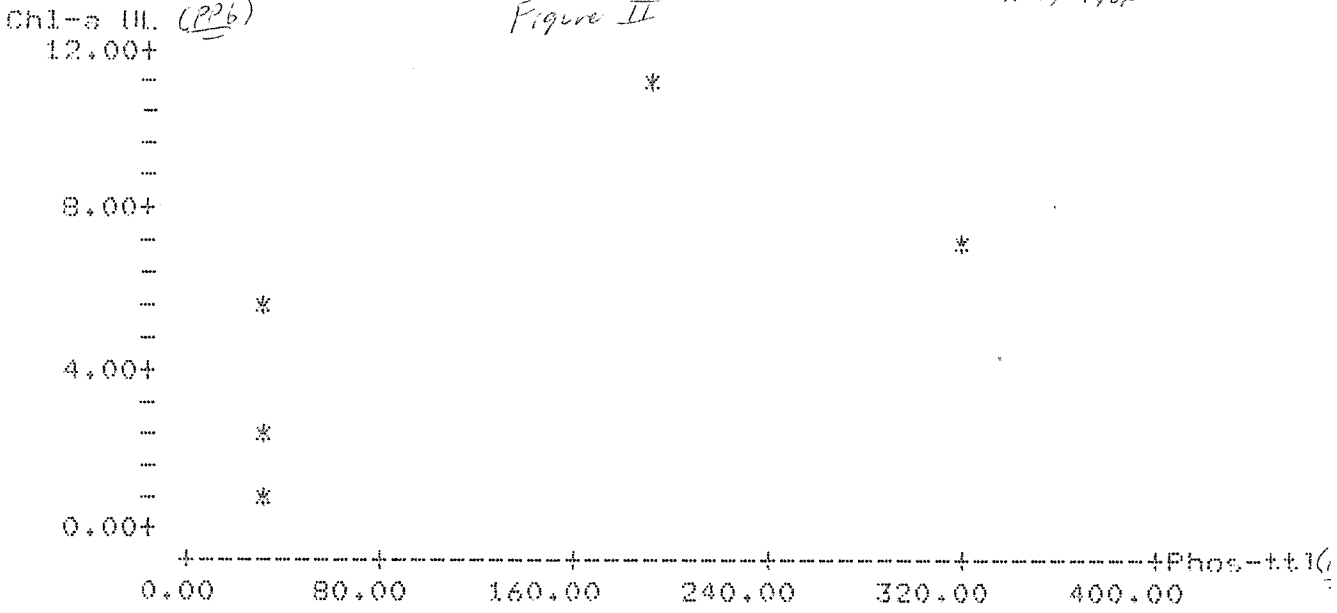
Fig. 1. Summer average chlorophyll concentration vs. total phosphorus concentration at spring overturn. Circles—data from Sakamoto (1966), chlorophyll measured by the method of Hogetsu and Ichimura (1954) and Ichimura (1956); triangles—data for other lakes reported in the literature, chlorophyll measured as chlorophyll *a*. The line shown is the regression line for Sakamoto's data. $r = 0.925$

$\log_{10} Chl = 1.583 \log_{10} P - 1.134$

From Dillon and Rigler, 1974

Plot of total Phosphorus Concentrations vs. Chl-a for Upper Lyman Lake Summer, 1984

Figure II



MTB >

CORRELATION OF Chl-a UL AND Phos-ttl= 0.680

MTB >

THE REGRESSION EQUATION IS
Chl-a UL = 2.78 + 0.0209 Phos-ttl

COLUMN	COFFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
	2.778	2.183	1.27
Phos-ttl	0.02085	0.01299	1.61

S = 3.417

R-SQUARED = 46.2 PERCENT
R-SQUARED = 28.3 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

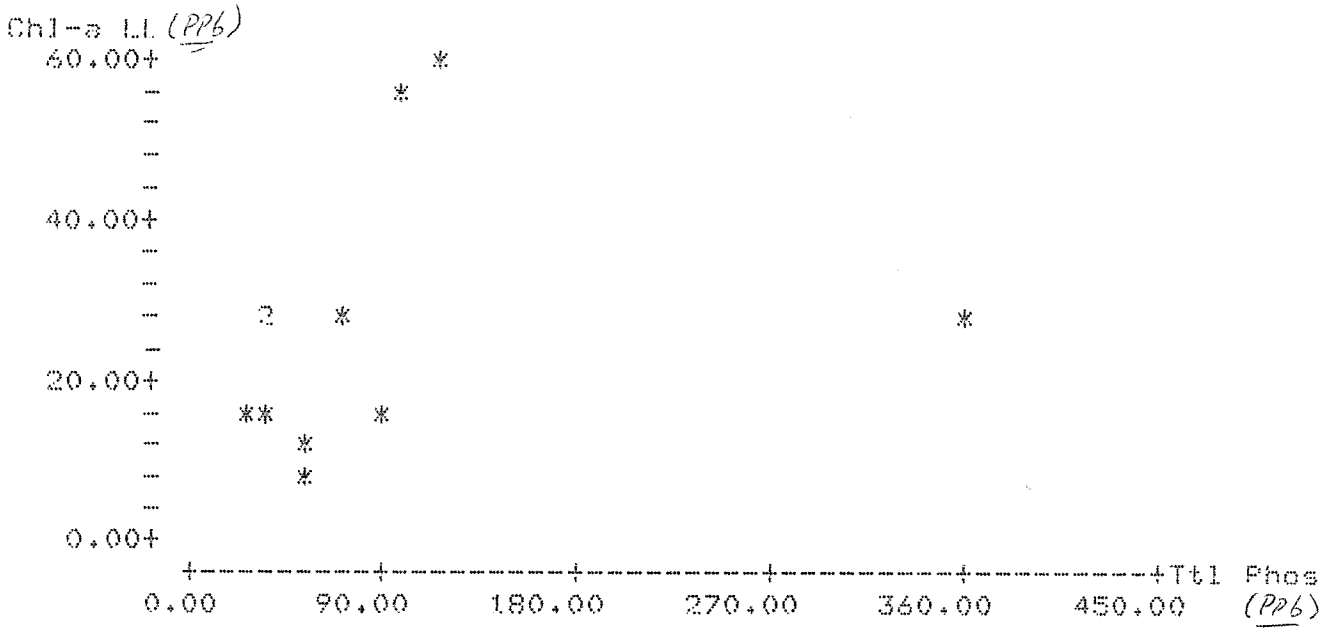
DUE TO	DF	SS	MS=SS/DF
REGRESSION	1	30.09	30.09
RESIDUAL	3	35.02	11.67
TOTAL	4	65.11	

DURBIN-WATSON STATISTIC = 2.11

MTB >

Plot of Total Phosphorous Concentrations vs. Chl-a for Lower Lyman Lake
Summer, 1986

Figure III



MTB >

CORRELATION OF Chl-a LL AND Ttl Phos= 0.269

MTB >

THE REGRESSION EQUATION IS
Chl-a LL = 22.4 + 0.0481 Ttl Phos

COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
	22.448	7.316	3.07
Ttl Phos	0.04815	0.05756	0.84

S = 17.13

R-SQUARED = 7.2 PERCENT
R-SQUARED = 0.0 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS=SS/DF
REGRESSION	1	205.4	205.4
RESIDUAL	9	2641.8	293.5
TOTAL	10	2847.2	

Continue? y

ROW	Ttl Phos	Chl-a LL	Y PRED. Y VALUE	ST.DEV. PRED. Y	RESIDUAL	ST.RES.
3	360	29.00	39.78	16.38	-10.78	-2.14RX

R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 1.92

TABLE I

Parameter - Units

ROW	Parameter	Description	Units
#1	STATION	Lake Sample	---
#2	DATE	Date of Sample	Year-Month-Day
#3	TALKA	Total Alkalinity	mg/L*
#4	CHL-a	Chlorophyll a	mg/L**
#5	COLOR	Color (apparent)	Platinum-Cobalt Units
#6	NH_3-N	Ammonia Nitrogen	mg/L
#7	NO_3+NO_2-N	Nitrate + Nitrite Nitrogen	mg/L
#8	TKN	Total Kjeldahl Nitrogen	mg/L
#9	ORG-N	Organic Nitrogen	mg/L
#10	pH	pH	Standard Unit
#11	TPHOS	Total Phosphorus	mg/L
#12	OPHOS	Ortho Phosphorus	mg/L
#13	SUS-SOLIDS	Suspended Solids	mg/L
#14	SPEC-COND	Specific Conductivity	µmhos
#15	TURB	Turbidity	Nephelometric Turbidity Unit
#16	FCOL	Fecal Coliform	No./100 ml
#17	FSTREP	Fecal Streptococcus	No./100 ml
#18	N:P (SOL)	Inorganic Nitrogen to Ortho Phosphorus ratio	--
#19	N:P (TOT)	Total Nitrogen to Total Phosphorus ratio	--
#20	SECCHI	Secchi disc transparency	meters
#21	TEMP C	Temperature degrees Centigrade	°C
#22	DO	Dissolved Oxygen	mg/L
#23	FC:FS	Fecal Coliform to Fecal Streptococcus ratio	--

* milligrams per liter or parts per million
** micrograms per liter or parts per billion

TABLE II

	1	2	3	4	5	6	7
1	Station ULL-01						
2	DATE	840625	840710	840726	840807	840829	840919
3	TALKA	280.00	140.00	272.00	290.00	290.00	280.00
4	CHL-a	N/A	11.00	7.10	2.10	5.30	<1.0
5	COLOR	20.00	50.00	15.00	20.00	10.00	15.00
6	NH3-N	0.17	0.31	0.22	0.34	0.09	0.09
7	NO3+NO2-N	9.80	3.90	8.80	9.90	8.90	8.70
8	TKN	0.59	1.40	0.64	0.59	1.00	0.37
9	ORG-N	0.42	1.09	0.42	0.25	0.91	0.28
10	pH	7.85	7.68	7.92	7.47	7.67	7.80
11	TPHOS	0.04	0.19	0.32	0.03	0.03	0.03
12	OPHOS	0.01	0.02	<0.01	<0.01	<0.01	<0.01
13	SUS-SOLIDS	12.00	57.00	16.00	7.00	4.00	8.00
14	SPEC-COND	680.00	290.00	570.00	500.00	540.00	580.00
15	TURB	4.00	34.00	4.70.	2.40	1.50	18.00
16	FCOL	N/A	N/A	54.00	160.00	54.00	92.00
17	FSTREP	N/A	N/A	100	540	50.00	73.00
18	N:P(SOL)	997:1	210:1	1804:1	2048:1	1798:1	1758:1
19	N:P(TOT)	260:1	28:1	29:1	350:1	330:1	302:1
20	SECCHI	0.8*	0.4	0.75*	0.75*	0.75*	0.70*
21	TEMP C	19.00	22.5	20.00	18.00	18.50	14.50
22	D O	11.20	6.4 **	13.60	12.80	5.80	5.20
23	FC:FS	N/A	N/A	0.50	0.30	1.10	1.30
24							
25							
26	*Secchi disc resting on bottom.						
27	**Suspect value.						
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PPb

TABLE III

	1	2	3	4	5	6	7
1	Station LLL-01						
2	DATE	840625	840710	840726	840807	840829	840919
3	TALKA	270	250.00	237.00	240.00	270.00	260.00
4	CHL-a	60	13.00	29.00	15.00	28.00	26.00
5	COLOR	35.00	30.00	25.00	35.00	20.00	20.00
6	NH3-N	0.09	0.21	0.06	0.50	0.04	0.29
7	NO3+NO2-N	6.50	4.90	4.40	7.60	6.60	6.20
8	TKN	1.10	1.10	0.90	0.86	1.10	1.00
9	ORG-N	1.01	0.89	0.84	0.36	1.06	0.71
10	pH	8.04	7.93	7.99	7.88	8.22	8.13
11	TPHOS	0.12	0.05	0.36	0.03	0.04	0.07
12	OPHOS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
13	SUS-SOLIDS	28.00	11.00	15.00	3.00	7.00	13.00
14	SPEC-COND	650.00	470.00	830.00	380.00	490.00	520.00
15	TURB	9.50	6.00	5.40	3.40	3.80	38.00
16	FCOL	N/A	N/A	13.00	92.00	92.00	24.00
17	FSTREP	N/A	N/A	0.00	30.00	70.00	3.00
18	N:P(SOL)	1316:1	1022:1	892:1	1620:1	1328:1	1298:1
19	N:P(TOT)	63:1	120:1	15:1	282:1	192:1	103:1
20	SECCHI	0.60	0.85	0.80	1.10	1.15	0.95
21	TEMP C	21.00	20.50	23.50	24.00	23.00	16.50
22	D O	13.60	7.50	17.10	11.90	10.90	12.60
23	FC:FS	N/A	N/A	13.00	3.10	1.30	8.00
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	1	2	3	4	5	6	7
1	Station LLL-02						
2	DATE	840625	840710	840726	840807	840829	840919
3	TALKA	270.00	260.00	241.00	240.00	270.00	260.00
4	CHL-a	56.00	14.00	<1**	17.00	27.00	9.60
5	COLOR	25.00	30.00	20.00	35.00	15.00	20.00
6	NH3-N	0.08	0.11	0.11	0.07	0.04	0.03
7	NO3+NO2-N	6.90	7.20	3.00	7.00	6.50	6.20
8	TKN	0.94	1.30	0.71	0.86	1.30	0.73
9	ORG-N	0.86	1.19	0.60	0.79	1.26	0.70
10	pH	8.05	8.09	8.02	7.87	8.20	8.04
11	TPHOS	0.10	0.09	0.31	0.04	0.04	0.05
12	OPHOS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
13	SUS-SOLIDS	17.00	8.00	16.00	10.00	7.00	12.00
14	SPEC-COND	590.00	500.00	530.00	390.00	460.00	530.00
15	TURB	6.00	5.80	3.70	4.40	3.40	26.00
16	FCOL	N/A	N/A	N/A	35.00	92.00	24.00
17	FSTREP	N/A	N/A	N/A	20.00	20.00	29.00
18	N:P(SOL)	1396:1	1462:1	622:1	1414:1	1308:1	1246:1
19	N:P(TOT)	78:1	94:1	12:1	196:1	195:1	139:1
20	SECCHI	0.90	0.85	1.05	1.20	1.10	1.30
21	TEMP C	22.00	20.50	23.50	24.00	22.50	15.50
22	D O	10.60	7.50	14.50	12.30	12.10	11.70
23	FC:FS	N/A	N/A	N/A	1.75	4.60	0.60
24							
25	**Suspect value.						
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	1	2	3	4	5	6	7
1	Station LLL-02						
2	DATE	840625	840710	840726	840807	840829	840919
3	TALKA	270.00	260.00	241.00	240.00	270.00	260.00
4	CHL-a	56.00	14.00	<1**	17.00	27.00	9.60
5	COLOR	25.00	30.00	20.00	35.00	15.00	20.00
6	NH3-N	0.08	0.11	0.11	0.07	0.04	0.03
7	NO3+NO2-N	6.90	7.20	3.00	7.00	6.50	6.20
8	TKN	0.94	1.30	0.71	0.86	1.30	0.73
9	ORG-N	0.86	1.19	0.60	0.79	1.26	0.70
10	pH	8.05	8.09	8.02	7.87	8.20	8.04
11	TPHOS	0.10	0.09	0.31	0.04	0.04	0.05
12	OPHOS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
13	SUS-SOLIDS	17.00	8.00	16.00	10.00	7.00	12.00
14	SPEC-COND	590.00	500.00	530.00	390.00	460.00	530.00
15	TURB	6.00	5.80	3.70	4.40	3.40	26.00
16	FCOL	N/A	N/A	N/A	35.00	92.00	24.00
17	FSTREP	N/A	N/A	N/A	20.00	20.00	29.00
18	N:P(SOL)	1396:1	1462:1	622:1	1414:1	1308:1	1246:1
19	N:P(TOT)	78:1	94:1	12:1	196:1	195:1	139:1
20	SECCHI	0.90	0.85	1.05	1.20	1.10	1.30
21	TEMP C	22.00	20.50	23.50	24.00	22.50	15.50
22	D O	10.60	7.50	14.50	12.30	12.10	11.70
23	FC:FS	N/A	N/A	N/A	1.75	4.60	0.80
24							
25	**Suspect value.						
26							
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TABLE V

	1	2	3	4	5	6	7
1	Mean: (LLL-01 + LLL - 02)						
2	DATE	840625	840710	840729	840807	840829	840919
3	TALKA	270.00	255.00	239.00	240.00	270.00	260.00
4	CHL-a	58.00	13.00	14**	16.00	27.00	18.00
5	COLOR	30.00	30.00	22.00	35.00	17.00	20.00
6	NH3-N	0.08	0.16	0.08	0.28	0.04	0.16
7	NO3+NO2-N	6.70	6.05	3.70	7.30	6.55	6.20
8	TKN	1.02	1.20	0.80	0.86	1.20	0.86
9	ORG-N	0.93	1.04	0.72	0.57	1.16	0.70
10	pH	8.04	8.01	8.00	7.87	8.21	8.08
11	TPHOS	0.11	0.07	0.33	0.03	0.04	0.06
12	OPHOS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
13	SUS-SOLIDS	22.00	9.00	15.00	6.00	7.00	12.00
14	SPEC-COND	620.00	485.00	680.00	385.00	475.00	525.00
15	TURB	7.70	5.90	4.50	3.90	3.60	32.00
16	FCOL *	N/A	N/A	13.00	57.00	92.00	24.00
17	FSTREP *	N/A	N/A	0.00	24.00	37.00	9.00
18	N:P(SOL)	1357:1	1242:1	757:1	1517:1	1318:1	1272:1
19	N:P(TOT)	70:1	107:1	13:1	239:1	193:1	118:1
20	SECCHI	0.70	0.85	0.90	1.10	1.10	1.10
21	TEMP C	16.70	20.50	23.50	24.00	22.70	16.00
22	D O	12.10	7.50	15.80	12.10	11.50	12.10
23	FC:FS	N/A	N/A	13.00	2.40	2.50	2.70
24							
25	*Logarithmic mean.						
26	** Suspect value.						
27							
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TABLE VI

	1	2	3	4	5	6	7
1	Percent Change: ULL - 01 vs Mean (LLL - 01 + LLL - 02)						
2	DATE	840625	840726	840726	840807	840829	840919
3	TALKA	NEG	POS	NEG	NEG	NEG	NEG
4	CHL-a	0	POS	POS	POS	POS	POS
5	COLOR	POS	NEG	POS	POS	POS	POS
6	NH3-N	NEG	NEG	NEG	NEG	NEG	POS
7	NO3+NO2-N	NEG	POS	NEG	NEG	NEG	NEG
8	TKN	POS	NEG	POS	POS	POS	POS
9	ORG-N	POS	NEG	POS	POS	POS	POS
10	pH	POS	POS	POS	POS	POS	POS
11	TPHOS	POS	NEG	POS	0	POS	POS
12	OPHOS	NEG	NEG	0	0	0	0
13	SUS-SOLIDS	POS	NEG	NEG	NEG	POS	POS
14	SPEC-COND	NEG	POS	POS	NEG	NEG	NEG
15	TURB	POS	NEG	NEG	POS	POS	POS
16	FCOL	0	0	NEG	NEG	POS	NEG
17	FSTREP	0	0	NEG	NEG	NEG	NEG
18	N:P(SOL)	POS	POS	NEG	NEG	NEG	NEG
19	N:P(TOT)	NEG	POS	NEG	NEG	NEG	NEG
20	SECCHI	0	POS	0	0	0	0
21	TEMP C	POS	NEG	POS	POS	POS	POS
22	D O	POS	0	POS	NEG	POS	POS
23							
24							
25							
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REFERENCES

Chiaudani, G. and Vighi, M. 1974 The N:P ratio and tests with Selenastrum to predict eutrophcation in lakes. Water Research 8:1063-1069

Dillon, P.J. 1975 The phosphorus budget of Cameron lake, Ontario: the importance of flushing rate to degree of eutrophy of lakes. Limnology and Oceanography 20:28-36

Dillon, P.J. and Rigler, F.H. 1974 The phosphorus-chlorophyll relationship in lakes. Limnology and Oceanography 19(5):767-773

Forsberg, C. 1980 Present knowledge of limiting nutrients. In: Restoration of Lakes and Inland Waters. USEPA. EPA 440/5-81-010, Washington, D.C.

Goldman, C.R. and Horne, A.J. 1983 Limnology. New York: McGraw-Hill Book Company

Jones, J.R. and Bachmann, R.W. 1976 Prediction of phosphorus and chlorophyll levels in lakes. Water Pollution Control Federation Journal 48(9):2176-2182

Megard, R.O. 1972 Phytoplankton, photosynthesis and phosphorus in lake Minnetonka, Minnesota. Limnology and Oceanography 17:68-77

Reynolds, C.S. 1976 Succesion and vertical distribution of phytoplankton in response to thermal stratification in a lowland mere, with special reference to nutrient availability. Journal of Ecology 64 (1):529-551

Schilling Environmental Consultants, 1984 Carleton College Lyman lakes interim report on lake sampling. St. Paul. unpublished data

Schindler, D.W. 1984 Eutrophication and recovery in experimental lakes: implications for lake management. Science 184:897-898

Taras, M.J., Greenberg, A.E., Hoak, R.D. and Rand, M.C. 1971 Standard Methods For the Examination of Water and Wastewater. Washington: American Public Health Association