

Rice and Sturgeon Lakes Nutrient Budget Study

Release of Phosphorus from Rice Lake Sediments

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RELEASE OF PHOSPHORUS FROM RICE LAKE SEDIMENTS

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PREFACE

The Kawartha lakes are a large and economically important system of eight large lakes which are located in central Ontario. Sturgeon Lake and Rice Lake are located near the upper and lower ends of the Kawartha Lakes system respectively and both support significant amounts of urban and recreational development. They were chosen for detailed study because of their importance within the system and because both have shown the symptoms associated with excessive nutrient input for several years.

The Rice and Sturgeon Lakes Nutrient Budget Study was initiated to investigate linkages between point and non-point sources of nutrients, water quality, and aquatic life within the lakes and to estimate the impacts of these processes on in-lake water quality.

The study was supervised by the Rice - Sturgeon Lakes Nutrient Budget Technical Committee which had representatives from the Limnology Section (Water Resources Branch) and Central Region of the Ontario Ministry of the Environment and Energy, the Trent Severn Waterway (Environment Canada) and the Kawartha Lakes Fisheries Assessment Unit of the Ontario Ministry of Natural Resources.

This is one of a series of technical reports. These and the summary report (R/S Tech. Rep. No. 13) will provide a technical basis for the management of the Rice Lake and Sturgeon Lake ecosystems and for the use of land and water resources in the Kawartha Lakes region in general. A list of all reports in the R/S Tech. Rep. series is as follows:

1. Hutchinson N.J., B.J. Clark, J.R. Munro and B.P. Neary 1993. Hydrological data for the watersheds of Rice Lake and Sturgeon Lake. 1986 - 1989, 100 pp.
2. Hutchinson N.J., J.R. Munro, B.J. Clark and B.P. Neary. 1993. Water chemistry data for Rice Lake, Sturgeon Lake and their respective catchments. 1986-1989, 169 pp.
3. Hutchinson N.J., B.P. Neary, B.J. Clark and J.R. Munro 1993. Nutrient Budget data for the watersheds of Rice Lake and Sturgeon Lake. 120 pp.
4. Ryback, M. and I. Rybak. 1993. Sediment pigment stratigraphy as evidence of long term changes in primary productivity of Sturgeon and Rice Lakes (Kawartha Lakes). 24 pp.
5. Nicholls, K.H., M.F.P. Michalski and W. Gibson. 1993. Trophic interactions in Rice Lake I: An experimental demonstration of effects on water quality.

6. Limnos Ltd. 1993. Partitioning of phosphorus in *Potamogeton crispus*. 22 pp.
7. Limnos Ltd. 1993. Rice Lake macrophytes: distribution, composition, biomass, tissue nutrient content and ecological significance. 123 pp.
8. Beak Consultants Ltd. 1993. Release of phosphorus from Rice Lake sediments. 31 pp .
9. Limnos Ltd., Michael Michalski Associates and D.J. McQueen. 1993. Trophic interactions in Rice Lake II. Young-of-the-year yellow perch - *Daphnia* interactions, preliminary findings. 101 pp.
10. Badgery, J.E., D.J. McQueen, K.H. Nicholls and P.R.H. Schaap. 1993. Trophic interactions in Rice Lake HI: Potential for biomanipulation. 1988 and 1989 .
11. Standke, S. 1993. The zooplankton of Rice Lake and Sturgeon Lakes, 1986-1988, Kawartha Lakes, Ontario.
12. Nicholls, K.H. 1993. The phytoplankton- water quality relationships of the Kawartha Lakes, 1972-1989.
13. Hutchinson, N.J., K.H. Nicholls and S.H. Maude, 1993. Rice and Sturgeon Lake Nutrient Budget Study: Summary and recommendations.

DISCLAIMER

This report was prepared for the Ontario Ministry of Environment and Energy as part of the Rice and Sturgeon Lakes Nutrient Budget Study. The views and ideas expressed in this report are those of the authors and do not necessarily reflect the views and policies of the Ontario Ministry of Environment and Energy. The mention of trade names and products does not constitute endorsement or recommendation of their use.

ABSTRACT

Comparisons were made in the laboratory, under anoxic and aerobic conditions, of the phosphorus release rates from sediments collected from the deepest areas of Rice Lake. As well, cores containing sediment and lake water collected from two shallow locations were incubated *in situ* to determine if there were diurnal differences in the phosphorus release rates. The estimate of the average deep water phosphorus release rate of 0.53 mg P/m²/day was based on highly variable results among replicates and between sites and included estimates of release under both oxic and anoxic conditions. There was no evidence of any diurnal pattern of release over a 24-hour period of observation of the shallow water sediments in October.

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1.0 INTRODUCTION

Internal loading of phosphorus from sediments may represent a significant source of phosphorus in the nutrient budgets of temperate lakes (Holdren and Armstrong, 1980, Nurnberg, 1984; Nurnberg *et al.* 1986). In the Bay of Quinte, for example, nutrient modelling studies suggest that internal phosphorus loading currently exceeds external inputs of this nutrient (Minns *et al.* 1986).

Little is known of the relative significance of internal phosphorus loading in Rice Lake, a highly eutrophic lake forming part of the Trent Canal system. Studies in the early 1970's suggested that a significant decrease in phosphorus loading offered the greatest potential for reducing nuisance algal blooms for which the lake is well known (MOE 1972, 1976). Although measures have been taken since the mid-seventies to reduce external phosphorus loading to the Trent system, the importance of internal phosphorus loading in sustaining the high algal biomass has not been investigated.

Several mechanisms have been proposed to explain the release of phosphorus from lake sediments:

1. diffusion of dissolved interstitial or desorbed sedimentary phosphorus into the overlying water, primarily under anaerobic conditions;
2. aerobic decomposition of freshly sedimented material, including algae and macrophytic debris, at the sediment-water interface; and
3. turbulence-induced erosion and resuspension of surface sediments. This process results in the release of labile fractions of sedimentary phosphorus (Oloya and Logan, 1980) as well as in the mixing of interstitial water of high phosphorus concentration into the water column.

Phosphorus release from sediments is greatly affected by redox conditions at the sediment-water interface. Early studies by Mortimer (1941, 1942) in several British Lakes showed that, during periods of anoxia in bottom waters, phosphorus was desorbed from sediment particles and released into the water column. This process was related to the reduction of iron and subsequent breakdown of ferric-phosphate complexes. These and subsequent studies solidified the belief that phosphorus release occurs only under anoxic conditions.

TABLE 1: Examples of Phosphorus Release Rates Observed in Literature.

Lake	Investigator	Oxic Rate (mg.m ⁻² .d ⁻¹)	Anoxic Rate (mg.m ⁻² .d ⁻¹)	Comments
Esrom Denmark	Kamp-Nielsen (1975)	-8.0 -16.1	-	
Esrom Denmark	Kamp-Nielsen <i>et al.</i> (1982)	11-13	-	<ul style="list-style-type: none"> ▶ Examined effect of bioturbation on return rate. ▶ One species increased the return rate which the other decreased the rate 4%.
Ontario	Burns and Ross (1972)	0.68	-	
Michigan	Quigley and Robbins (1986)	0.17 - 0.57	-	
Lough Nugh Scotland	Rippey (1976)	2	-	<ul style="list-style-type: none"> ▶ 20°C; DO = 100% saturation. ▶ Release was pH dependent. ▶ Lab Experiments on Intact Cores
Castle	Neame (1976)	0.65	-	Box Corer, P-32 Tracer, Sediments from 4 m.
Warner Mass.	DiGiuano and Snow (1976)	6	-	<ul style="list-style-type: none"> ▶ Reservoir, 2 = 1.6 m; tw = 10 d. ▶ <i>In situ</i> measurement, lab experiments and modelling study.
Warner Mass.	Fillos and Swanson (1975)	0.4	8.5 (max.)	▶ Phosphorus release correlated with Fe release under anoxic conditions.
Muddy River Mass.	Fillos and Swanson (1975)	3.1	31 (max.)	Muddy River is same flow system as Warner Lake.
Mendota	Holdren and Armstrong (1980)	-1.9 - 83	0.65 - 65	
Little John	Holdren and Armstrong (1980)	0.02 - 1.1	0.02 - 3.8	

This concept was reflected in mathematical models of phosphorus dynamics appearing in the 1970's and early 1980's where the sediments were envisioned as a sink for phosphorus from which the rates of return to the water column were negligible (Dillon and Rigler, 1974; Snodgrass and O'Melia, 1975; Vollenweider, 1969, 1975; Lung *et al.* 1976; DiToro and Connolly, 1980; Snodgrass and Dillon, 1983).

However, further investigations have shown that phosphorus release does indeed occur under oxidized conditions, although at a much lower rate than under anaerobic conditions (Lee *et al.*, 1977; Neame, 1976; Holdren and Armstrong, 1980; Quigley and Robbins, 1986). Table 1 summarizes the results of selected studies where phosphorus release has been measured from lake sediments. More comprehensive compilations of phosphorus release rates can be found in Holdren and Armstrong (1980), Nurnberg (1984) and Quigley and Robbins (1986). Values range from -1.9 to 83 mg.m⁻².d⁻¹ and 0.02 to 31 mg.m⁻².d⁻¹ under aerobic and anaerobic conditions, respectively. In the case of the upper Bay of Quinte, mentioned above, phosphorus release from the sediments may figure significantly in the overall phosphorus budget, although bottom waters there never become anoxic (Minns *et al.* 1986).

Current regimes at the sediment surface also affect the flux of nutrients and chemicals, including phosphorus, across the sediment-water interface. Oxygen uptake in cores or in in situ incubations is known to increase significantly with stirring speed or water velocity (Carey, 1967; Edwards and Rolley, 1958; Boynton *et al.* 1981). Silicate release in cores was increased 40 to 50% on stirring the supernatant water (Andrews, 1980). Water currents increase the flux of dissolved materials across the sediment surface by decreasing the boundary layer thickness (Boudreau, 1981; Boudreau and Guinasso, 1982).

In response to a contract from the Ministry of the Environment (MOE), Beak Consultants has conducted a study of phosphorus release from Rice Lake. The study had the following goals:

1. to measure the release of phosphorus at one deep water station in both the east and west basins of Rice Lake twice during the summer;
2. to examine the effects of both redox conditions and current regimes on phosphorus release from Rice Lake sediments;
3. to measure the *in-situ* release of phosphorus from two shallow water stations twice during the summer,
4. to determine whether a diurnal pattern in phosphorus release is detectable in shallow water sediment and
5. to relate the release of phosphate to the overall phosphorus budget of Rice Lake.

2.0 METHODS

2.1 Direct Measurement of Phosphorus Release from Deep-Water Sediments

Phosphorus release from Rice Lake sediments was measured at two stations (R34 & R36) twice during the summer and early autumn (Figure 1, Table 2). Ten sediment cores (0.0032m² area) were collected by diver at each station and returned to Beak laboratories for measurements of phosphorus release and redox profiles (Section 2.4). Only those cores having a clear supernatant water on collection were selected for incubation. Incubation of cores was begun within 24 hours of collection. Bottom temperatures and O₂ concentrations were measured at each sampling station.

Eight cores from each station were incubated in the dark at *in situ* bottom temperatures. To simulate a range of natural bottom currents, the supernatant water in four of the cores was circulated and swept across the sediment surface by small in-line pumps (Figure 2A), while the other four cores were incubated under stagnant conditions. By periodic exposure of the supernatant water to the open air, oxic conditions were maintained in both stirred and unstirred cores.

Initially, water samples were taken every 1-2 days by syringe and analyzed for soluble reactive phosphate (SRP). At each sampling an equivalent volume of distilled deionized water was added to replace the water removed. All water samples were filtered through acid-washed 0.45 µm cellulose acetate filters and analyzed colorimetrically for SRP (HAMES, 1983). The detection limit for this analysis was 1 µgL⁻¹ PO₄-P while the precision was 5% at intermediate concentrations.

Because significant release of soluble phosphorus could not be measured in most of the cores and the circulating water appeared to stimulate algal growth even in the dark, the experimental design was modified during the course of the first experiment. After consultation with the scientific authority the experiment was changed from one investigating the role of currents in phosphorus release to one measuring phosphorus release under oxic and anoxic conditions. Anoxic release of phosphorus was measured in four of the eight cores from each station by capping them after purging the supernatant water of oxygen with nitrogen. Levels of oxygen in the capped cores were measured periodically by a YSI oxygen probe and fell to values of about 0.5 mgL⁻¹ in five days.

Figure 1: Location of Sampling Stations in Rice Lake.

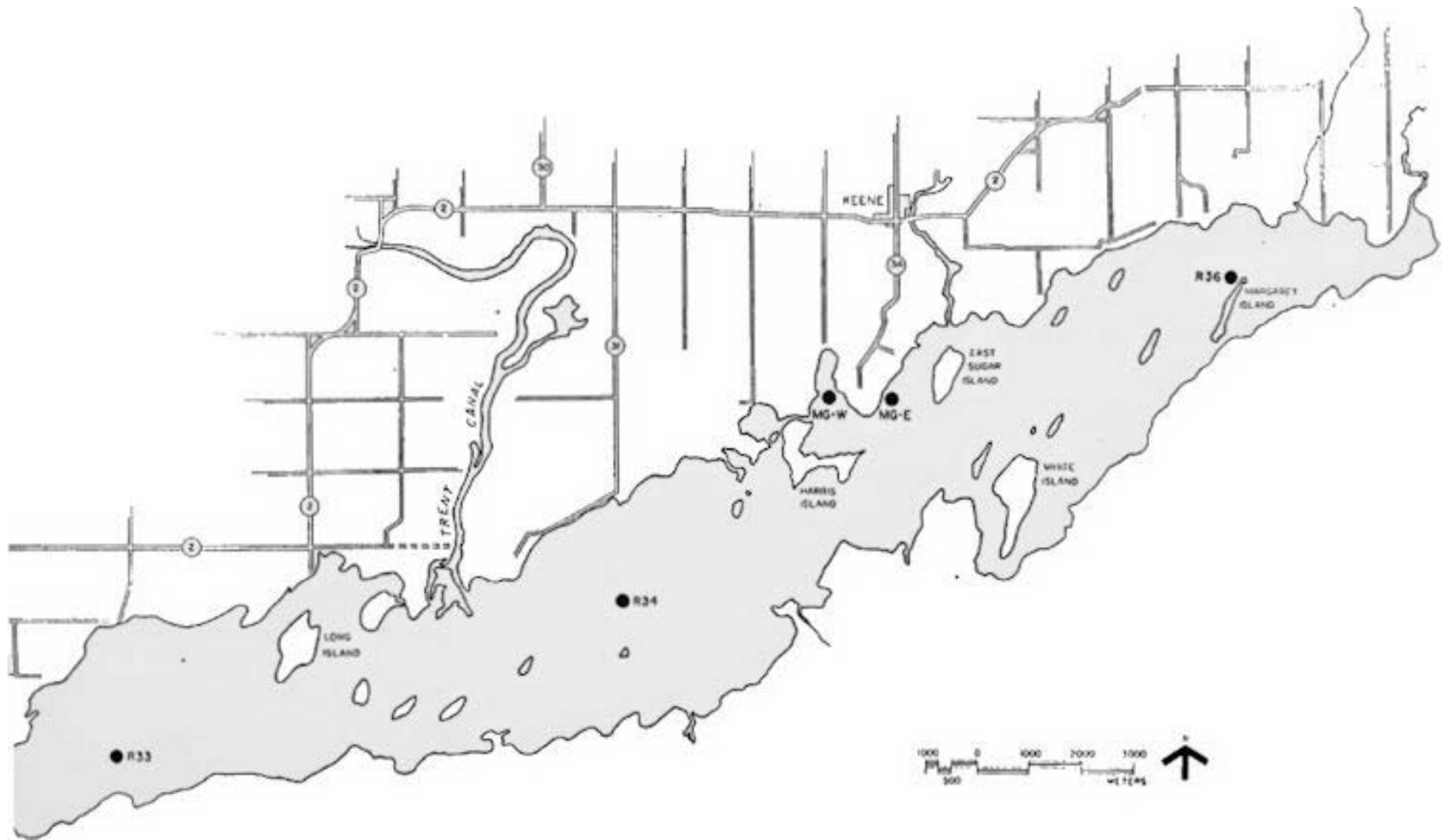


TABLE 2: Sampling Dates, Temperature, and Dissolved Oxygen From Rice Lake.

Date (D/M/Y)	Station ¹	Depth (m)	Temperature (°C)		Dissolved O ₂ mg/L	
			Bottom	Surface	Bottom	Surface
21/07/87	MG-E	1.5	25.5	-	12.4	-
21/07/87	MG-W	1.2	27.8	-	16.2	-
21/07/87	R36	7.1	24.0	25.0	8.3	10.7
21/07/87	R34	4.2	24.0	25.0	9.1	10.4
19/10/87	MG-E	1.5	9.0	-	9.3	-
19/10/87	MG-W	1.2	9.5	-	9.0	-
19/10/87	R36	7.0	8.5	8.5	9.3	9.6
19/10/87	R34	4.2	8.5	8.7	10.0	10.5

¹ For Location See Figure 1.

Oxic conditions were maintained as above in the four remaining cores. Since preliminary analyses indicated that much of the total phosphorus in the supernatant water was in the particulates, the filters used for analysis of SRP were digested in sulphuric-persulphate to obtain an estimate of particulate phosphate on each water sample (HAMES, 1983). The detection limit of the particulate analysis was $2.4 \mu\text{gL}^{-1}$. Precision was somewhat less than that for SRP at about 8% at the lower concentrations. Cores were always stirred gently with a stainless steel spatula before sampling. To ensure a measurable change in phosphorus concentration in the supernatant water, the incubation period was lengthened from 10 days to about 25 days. These modifications were then applied to the second set of cores taken later in the season.

2.2 *In-situ* Measurements of Phosphorus Release from Shallow-Water Sediments

In-situ measurements of diurnal phosphorus release were made at two shallow-water stations, one in McGregor Bay (Station MG-W, 1.2 m) and the other on the East side of Serpent Mounds Provincial Park (Station MG-E, 1.5 m). In the first sampling period, July 21, ten polycarbonate core tubes (0.0032 m^2 in area) were inserted into the sediments at each station by SCUBA diver and were capped to contain approximately 150 ml of supernatant water. Each cap consisted of a rubber bung fitted with two serum caps. One serum cap allowed the diver to withdraw a water sample by syringe while the other allowed bottom water in through a needle to replace the water removed.

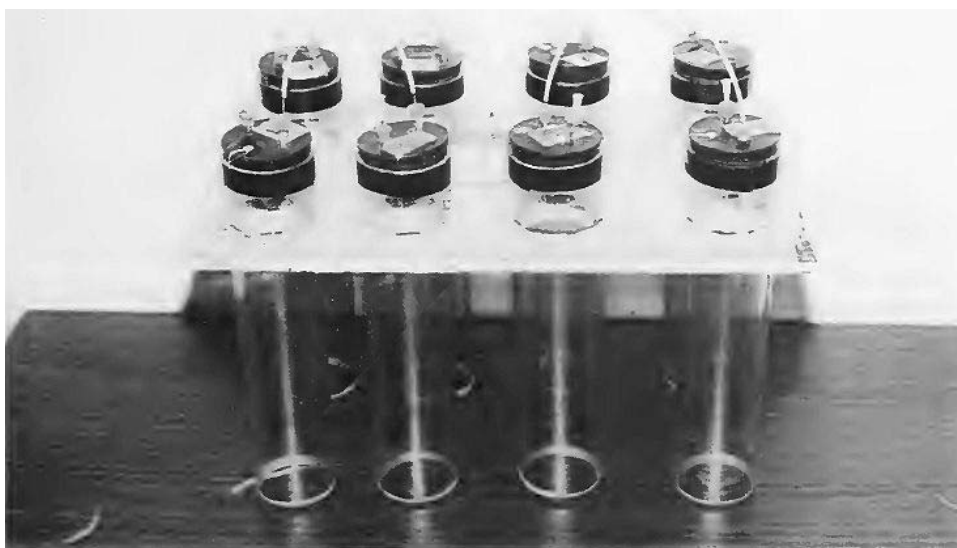
Because of poor visibility in the dense phytoplankton, it was impossible for the divers to sample the cores as intended at the *in-situ* depths. Therefore, the divers carefully removed the cores by reaching under each tube and inserting rubber stoppers at the bottom. The cores were transferred to shallower waters where they could be sampled more easily. Although this transfer meant that the cores were no longer strictly *in situ* they were exposed to the same water temperature and similar light regime as they would have been in their original location. Water samples were taken four times during the day and four times during the following night to examine diurnal trends in phosphorus release.

For the second sampling trip (October 19), a special *in-situ* sampler was devised to avoid the initial problems of poor visibility. Eight core tubes were mounted on a weighted board and fitted with rubber bungs having two serum caps as before (Figure 2b). Instead of requiring sampling by diver, however, each core was sampled by syringe through a long, fine, polyethylene tube which floated at the water surface.

Figure 2A: Sediment Core Fitted with In-line Pump.



Figure 2B: Remote *In-Situ* Sampler.



The volume of water in the polyethylene tube (about 5 ml) was accounted for in each sampling. The sampling apparatus was inserted in the sediments to a predetermined depth to ensure a constant volume of supernatant water.

2.3 Calculation of Phosphorus Release Rates

Where a trend of increasing phosphorus was evident, phosphorus release rates were calculated from the slope of a line fitted by least squares to plots of soluble reactive or particulate phosphorus in the supernatant water of each core vs accumulated time. In all cases a minimum of three points was used to calculate the slope (see Section 3.2). The slopes were then multiplied by the volume of the supernatant water and divided by the cross-sectional area of the core.

After each sampling of the cores, the phosphorus concentrations were corrected for dilution with the formula:

$$C_c = \frac{CV - CV_s}{V}$$

Where C_c is the corrected phosphorus concentration of the supernatant water,
 C is the measured phosphorus concentration,
 V is the total volume of the supernatant water, and
 V_s is the sample volume

When fitting a line to the data, a point midway between the corrected P concentration at each sampling time and the measured concentration was chosen. This procedure avoided the problem of having two points (the final concentration of the previous sampling and the initial concentration of the next sampling interval) at each sampling time.

2.4 Measurements of Redox Profiles

Two additional cores collected at each station were used for measurements of Eh profiles. Redox profiles were taken at 0.5 or 1 cm intervals in the sediments with a small-scale platinum electrode constructed in the laboratory. A thin platinum wire was allowed "to bead" at one end in an oxyacetylene flame. The thin end of the wire was then threaded through the delivery-end of a 1 ml plastic pipette and sealed with epoxy. The platinum bead having a diameter of 2 mm served as the actual electrode. Electrical contact between the reference calomel electrode and the supernatant water was maintained with a salt bridge. The probe was checked against "Zobell's" solution, a standard ferrous, ferri-cyanide solution having a known oxidation potential (Zobell, 1946). Measurements of Eh in millivolts were made on a Radiometer pH-mV meter.

3.0 RESULTS

3.1 Redox Conditions at the Sediment Surface

Temperature and oxygen measurements at both the deep water stations (R34, R36) and the shallow water stations (MG-W, MG-E) in Rice Lake (Table 2) suggest that the water column was well mixed and well oxygenated at both sampling periods. Near-bottom temperatures differed from surface temperatures by only 1°C. Oxygen concentrations close to the sediment surface never fell below 8 mgL⁻¹ at any of the sampling sites. These results suggest that the sediment surface at both shallow and deep stations is continually exposed to oxygenated water during the summer and early autumn.

The Eh profiles (Figures 3, 4) also suggest that the surface sediments are oxidized at both shallow and deep areas in Rice Lake. Surface values of Eh were consistently high, between +400 and +500 mV at the two study periods. However, Eh dropped quickly over the upper few centimeters of sediment to values between 0 and +100. If +200 mV is used as a criterion of oxygen depletion (Hutchinson, 1957), most of the oxygen is depleted by 1-1.5 cm depth in the sediment.

3.2 Direct Measurement of Phosphorus Release from Rice Lake Sediments

Phosphorus release from the sediments of Rice Lake was found to be highly variable and the data were difficult to interpret. In many cases phosphorus release could not be observed. Controls consisting of core tubes filled with filtered bottom water without sediments showed no significant increases in soluble or particulate phosphorus over time. Increases in particulate phosphorus in the supernatant water will be referred to as particulate phosphorus release although the phosphorus is almost certainly released from the sediments in a soluble form. The soluble phosphorus then co-precipitates with iron, is adsorbed to existing particles or is taken up heterotrophically by micro-organisms. The results of the in situ incubations at MG-E and MG-W are discussed separately from those of the deep-water stations, R36 and R34.

Figure 3: EH Profiles in Rice Lake Sediments from Stations R36, R34 and McGregor Bay - July 23, 1987.

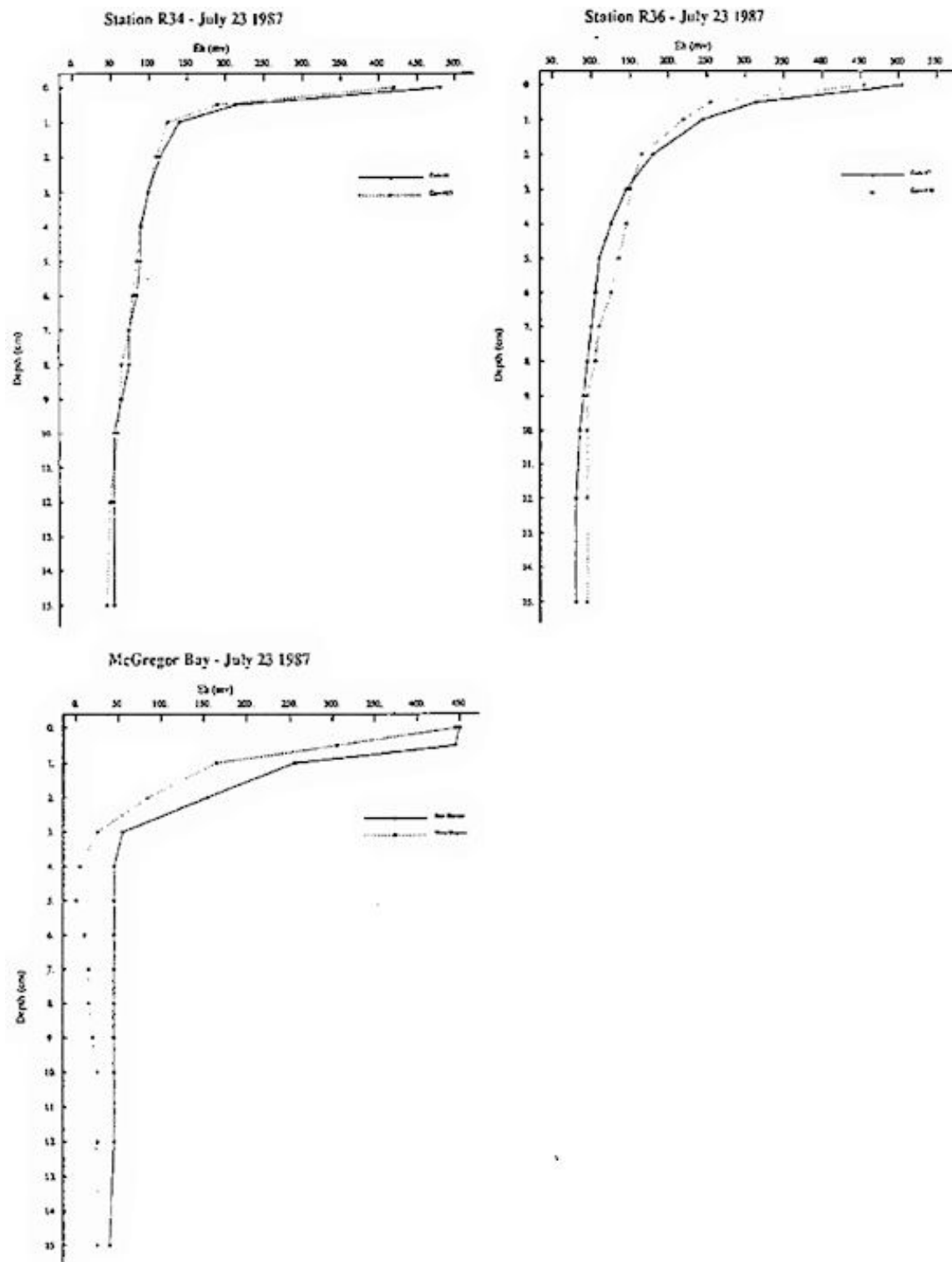
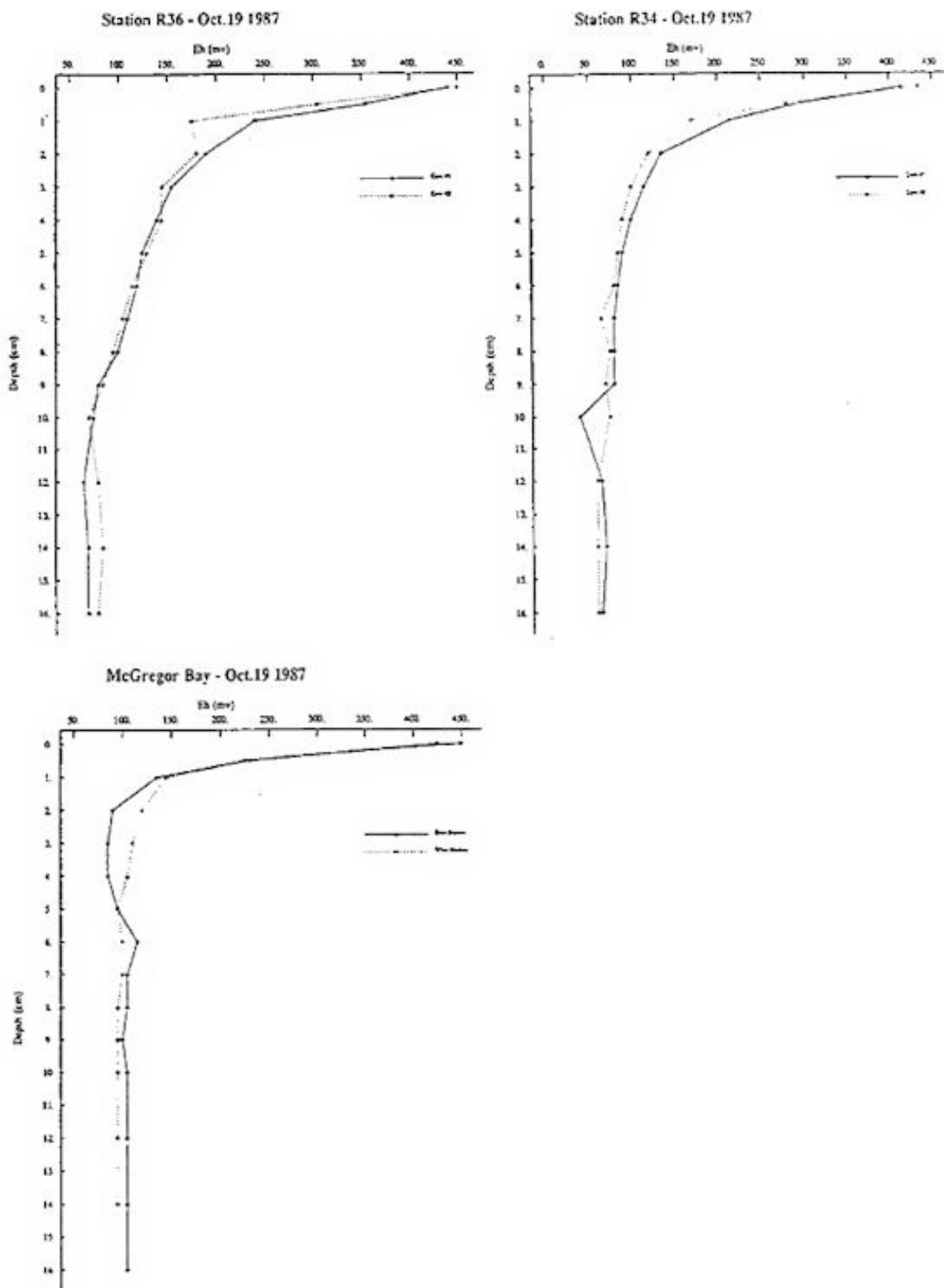


Figure 4: EH Profiles in Rice Lake Sediments from Stations R36, R34 and McGregor Bay - Oct. 19, 1987.



3.2.1 Diurnal Phosphorus Release - Results of the In Situ Incubations

No diurnal pattern of phosphorus release (or uptake) was observed in the in situ incubations. Figure 5, combining the data from 10 sediment cores in July, shows that soluble phosphorus concentration in the supernatant water remained close to the detection limit ($2 \mu\text{gL}^{-1}$) over the 24 hour incubation. The increase in SRP at Station MG-E (Figure 5) at the fourth and seventh sampling period were caused by unusually high concentrations of SRP in samples from two or three cores. Since phosphorus concentrations returned to their normal low levels ($< 2 \mu\text{gL}^{-1}$) in samplings subsequent to the fourth sampling period, the higher phosphorus concentrations in these cores almost certainly represent contaminated samples. Similar negative results were obtained in the fall using the remote sampler. Since negative results were anticipated at this time samples from only 2 cores were analyzed to avoid incurring needless analytical expenses. The results of these analyses and those from the first experiment are presented in the Appendix.

3.2.2 Phosphorus Release from Deep Water Stations (R36, R34)

Concentrations of SRP and PP in the supernatant water of summer cores from Stations R36 and R34 were observed to follow several patterns:

- (1) An increase to a maximum value followed by a levelling-off.
- (2) An increase to a maximum value followed by a decrease in SRP or PP with time.
- (3) A lag period followed by a significant increase in SRP or PP.
- (4) A steady increase in concentration over the entire incubation period, and
- (5) A decrease in PP or SRP over the entire incubation, and
- (6) No recognizable increase or decrease over the experiment.

Figures 6 and 7 present plots of SRP and PP concentrations in cores from July to illustrate some of these trends. The full data set can be found in the Appendix for both SRP and PP. In most cores data for particulate P were available only from day 10 (Figure 7) after the experimental conditions were changed (see Section 2.1).

In calculations of efflux rates for both particulate phosphorus and soluble reactive phosphorus the following assumptions were made:

Figure 5: SRP in Supernatant Water in Cores from the *In-Situ* Incubation, Pooled Data - July 21.

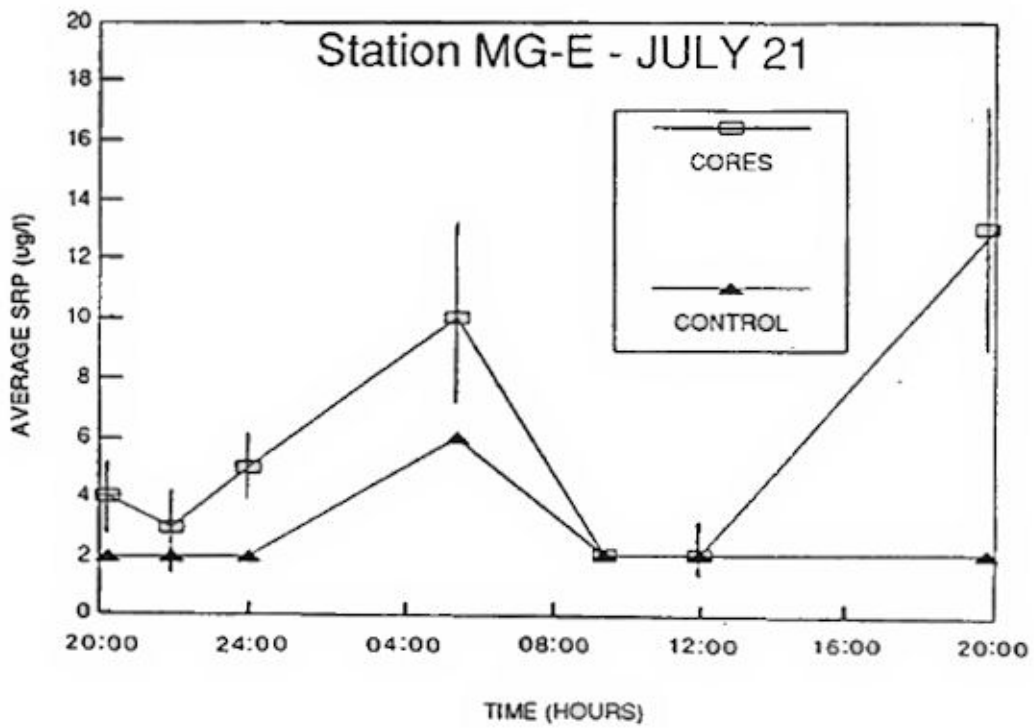
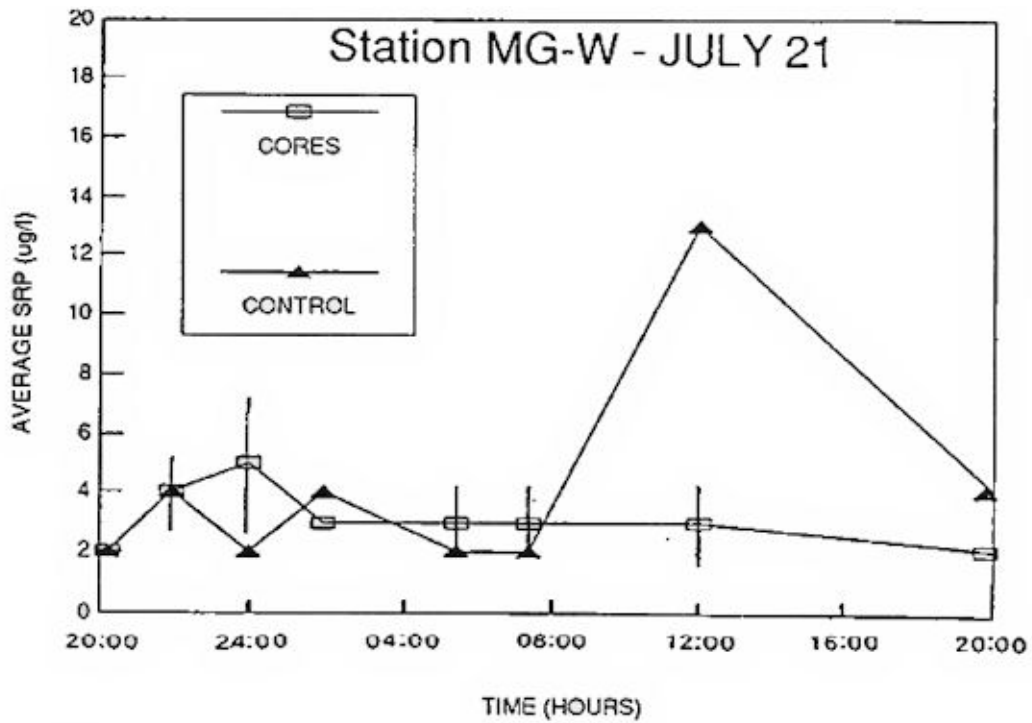


Figure 6: SRP in Supernatant Water of Rice Lake Cores from Deep-Water Stations - July 21.

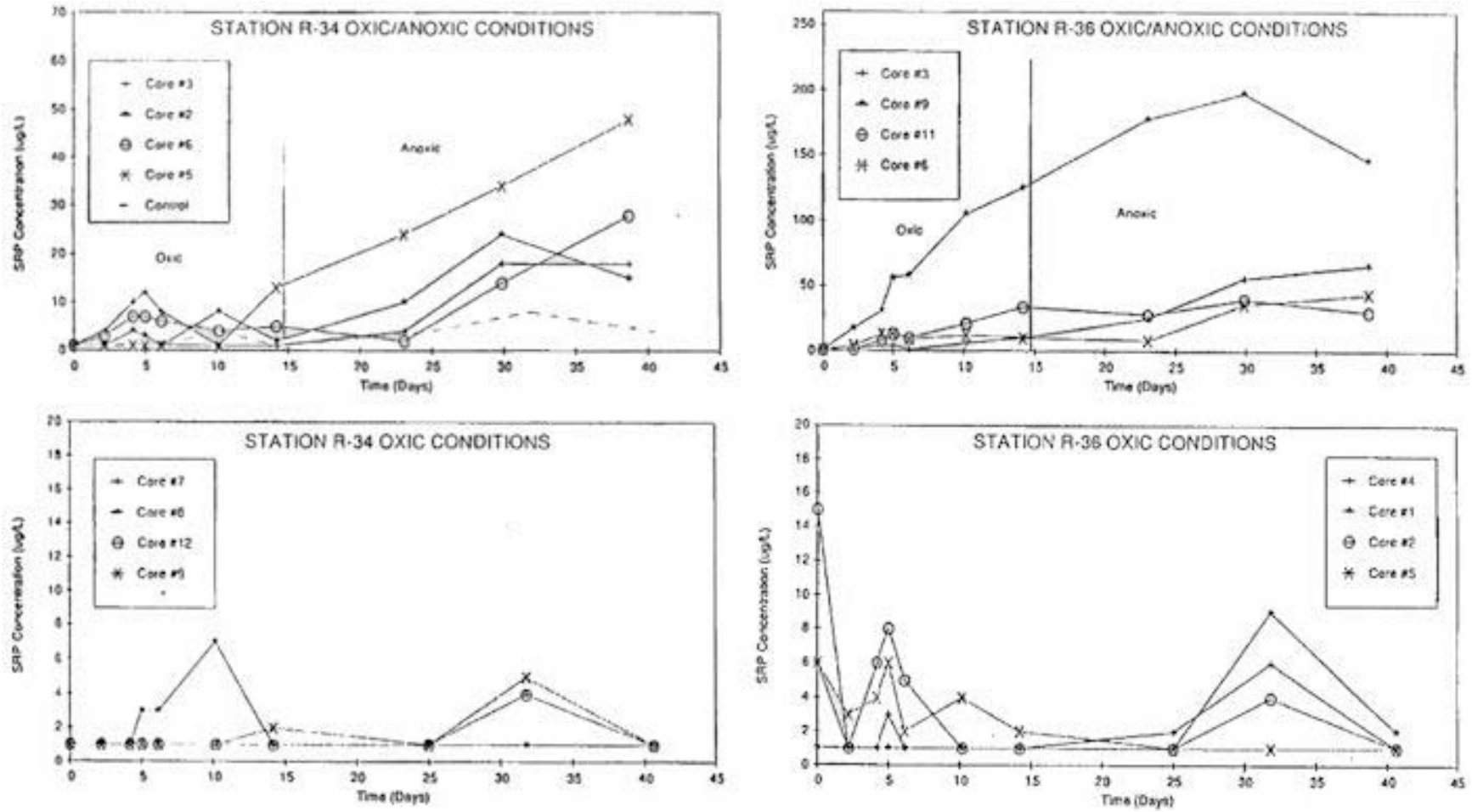
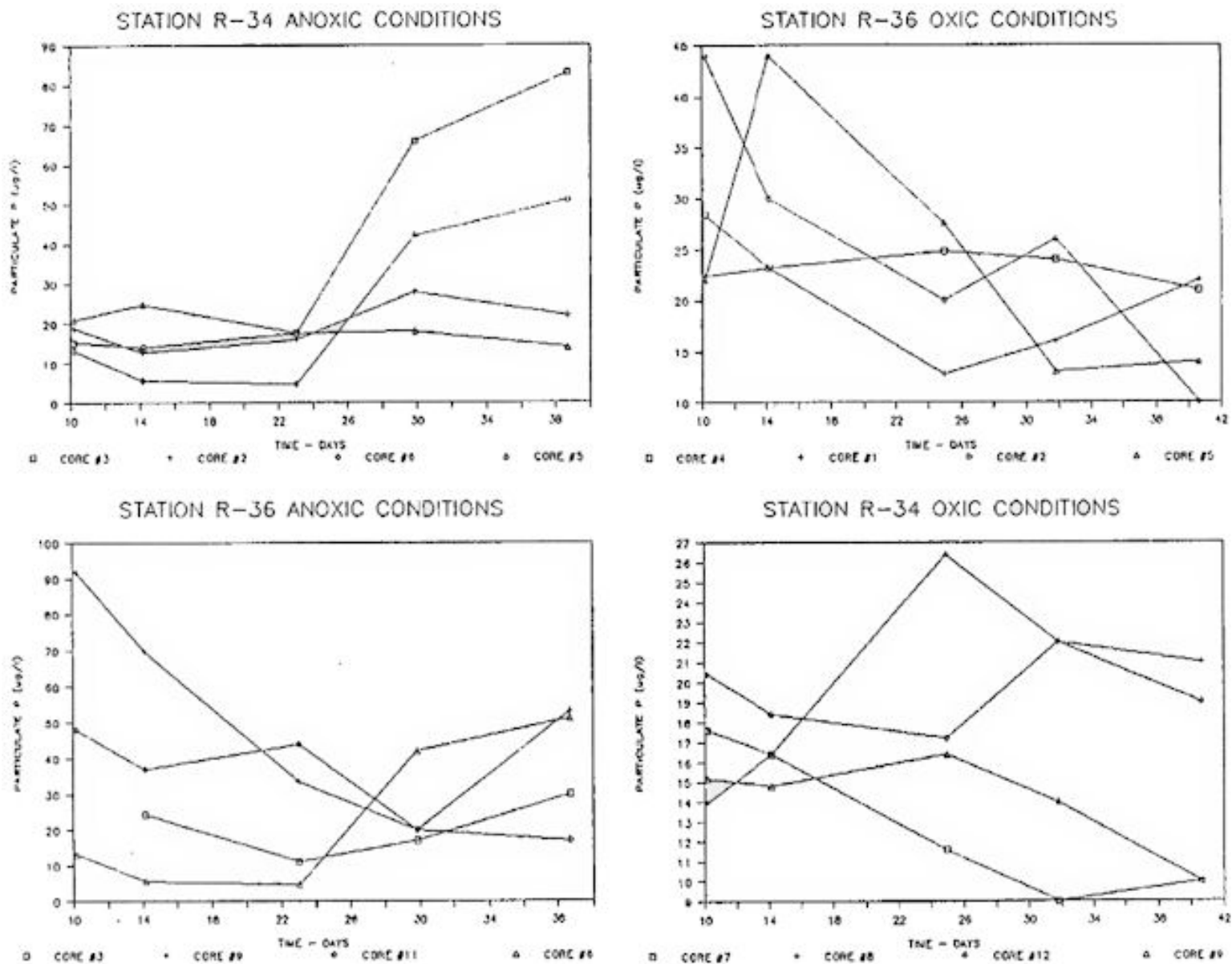


Figure 7: Particulate P in Supernatant Water of Rice Lake Cores from Deep-Water Stations - July 21.



- (1) For those cores in which the supernatant phosphorus concentrations increased to a maximum value then level off or fall, release rates were calculated only from the initial samples when phosphorus is increasing. Rates calculated in this manner correspond closely to the initial, maximal rate (V_{max}) characteristic of reactions following saturation kinetics (for example Michaelis-Menten).
- (2) For those cores exhibiting an initial period of little change followed by an increase in soluble or particulate phosphorus, release rates were calculated over the entire interval including the lag period.
- (3) In the July experiment, separate estimates of phosphorus release on each core were made for both oxic and anoxic conditions.
- (4) For those cores showing no recognizable trend or a decrease in supernatant P concentration with time, rates were assumed to be immeasurable and taken as zero.

Rates of phosphorus released from each core collected at Stations R34 and R36 on July 21 are presented in Tables (3-4) and are summarized in Table (5). SRP release ranges from 0-0.66 $\text{mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ while particulate P release ranges from 0-1.19 $\text{mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ over all the experimental conditions. Total phosphorus varied from 0 to 1.85 $\text{mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$. These estimates fit in well with the wide range of rates obtained by other authors for eutrophic lakes (Table 1). Table 5 indicates that the anticipated increase in phosphorus release when the supernatant water is circulated across the sediment surface was not observed. In fact, no release of soluble phosphorus was measurable in stirred cores from either station. A small release of particulate phosphorus (0.04 $\text{mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$), however, was observed in stirred cores from Station R34 (Table 5). The highest rates of phosphorus release (1.85 $\text{mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) were observed in unstirred cores from Station R36 incubated under oxic conditions. These high rates of phosphorus release were not observed at Station R34 under the same conditions. The anticipated increase in phosphorus release in the anoxic cores versus the oxic cores was not observed consistently between the two stations.

Significant phosphorus release was not observed in cores taken in the early fall (October 19) at either Station R36 or R34. These cores were incubated under oxic or anoxic conditions without any circulation of the supernatant water. In an attempt to detect any trends, the total soluble phosphorus and total particulate phosphorus in the supernatant water were averaged over oxic and anoxic cores at each station (Figures 8, 9).

TABLE 3: Rice Lake - Sediment Phosphorus Release At Stations R34.

Core #	Incubation ¹ Conditions	Phosphorus Release (mg.m ⁻² .d ⁻¹)		Regression Coefficients to Line	
		Soluble	Particulate	Soluble	Particulate
R34-7	S/O	NMR ²	-	-	-
R34-8	S/O	NMR	0.15	-	0.997
R34-12	S/O	NMR	-	-	-
R34-9	S/O	NMR	-	-	-
R34-3	U/O	0.41	-	0.986	-
	U/A	0.19	0.57	0.908	0.937
R34-2	U/O	NMR	-	-	-
	U/A	0.25	0.17	0.973	0.922
R34-6	U/O	NMR	NMR	-	-
	U/A	0.30	0.52	0.999	0.916
R34-5	U/O	NMR	0.28	-	0.935
	U/A	0.26	NMR	0.998	-

¹ Incubation Conditions were the following: Supernatant stirred under oxic conditions (S/O); supernatant unstirred under oxic conditions (U/O); supernatant unstirred (U/A) under anoxic conditions.

² No measurable P release rate.

TABLE 4: Rice Lake - Sediment Phosphorus Release At Station R36.

Core #	Incubation ¹ Conditions	Phosphorus Release (mg.m ⁻² .d ⁻¹)		Regression Coefficients to Line	
		Soluble	Particulate	Soluble	Particulate
R36-4	S/O	NMR ²	-	-	-
R36-1	S/O	NMR	-	-	-
R36-2	S/O	NMR	-	-	-
R36-5	S/O	NMR	-	-	-
R36-3	U/O	NMR	-	-	-
	U/A	0.43	NMR	0.974	-
R36-9	U/O	1.68	1.06	0.989	0.907
	U/A	0.96	NMR	0.989	
R36-11	U/O	0.43	1.31	0.978	0.999
	U/A	NMR	NMR	-	-
R36-6	U/O	0.52	-	0.954	-
	U/A	0.41	NMR	0.938	-

¹ Incubation Conditions were the following: Supernatant stirred under oxic conditions (S/O); supernatant unstirred under oxic conditions (U/O); supernatant unstirred (U/A) under anoxic conditions.

² No measurable P release rate

TABLE 5: Summary of Phosphorus Release Measurements From Rice Lake (Stations R34, P36).

Station	Incubation ¹ Conditions	Mean Rate of P Release (mg.m ⁻² .d ⁻¹) ⁴			% Particulate P Release
		Soluble	Particulate	Total	
R36	S/O	NMR ²	NMR	-	-
	U/O	0.66 ± 0.71	1.19 ± 0.18 ³	1.85 ± 0.38	64
	U/A	0.45 ± 0.39	NMR	0.45 ± 0.39	0
R34	S/O	NMR	0.04 ± 0.08	0.04 ± 0.08	100
	U/O	0.10 ± 0.21	0.14 ± 0.19 ³	0.24 ± 0.17	58
	U/A	0.25 ± 0.05	0.32 ± 0.28	0.57 ± 0.14	56

¹ Incubation Conditions were the following: Supernatant stirred under oxic conditions (S/O); supernatant unstirred under oxic conditions (U/O); supernatant unstirred (U/A) under anoxic conditions.

² No measurable P release rate

³ Based on only two cores

⁴ Values expressed as mean rate ±1 S.D.

Figure 8: SRP in Supernatant Water of Rice Lake Cores from Deep-Water Stations, Pooled Data - October 19.

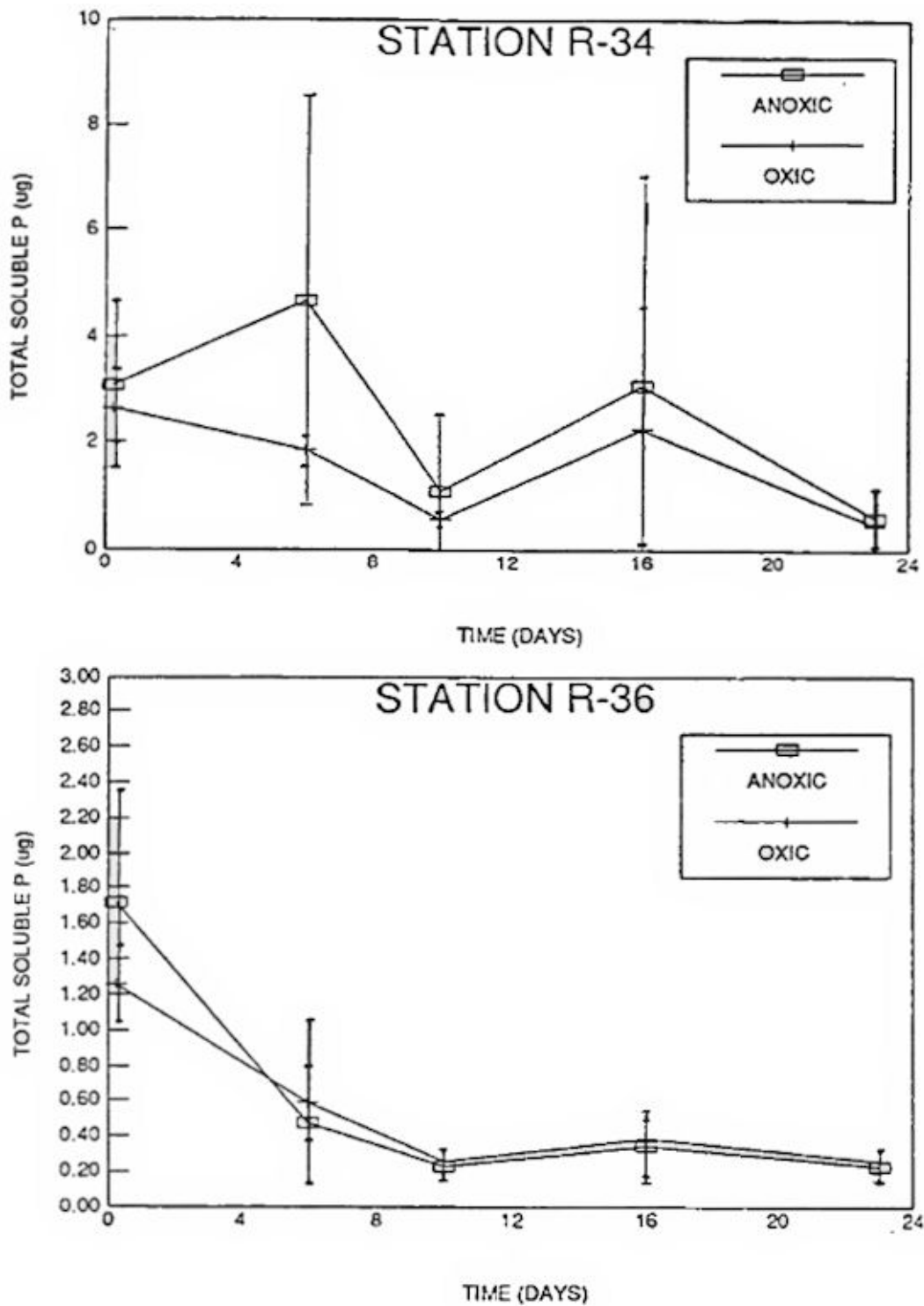
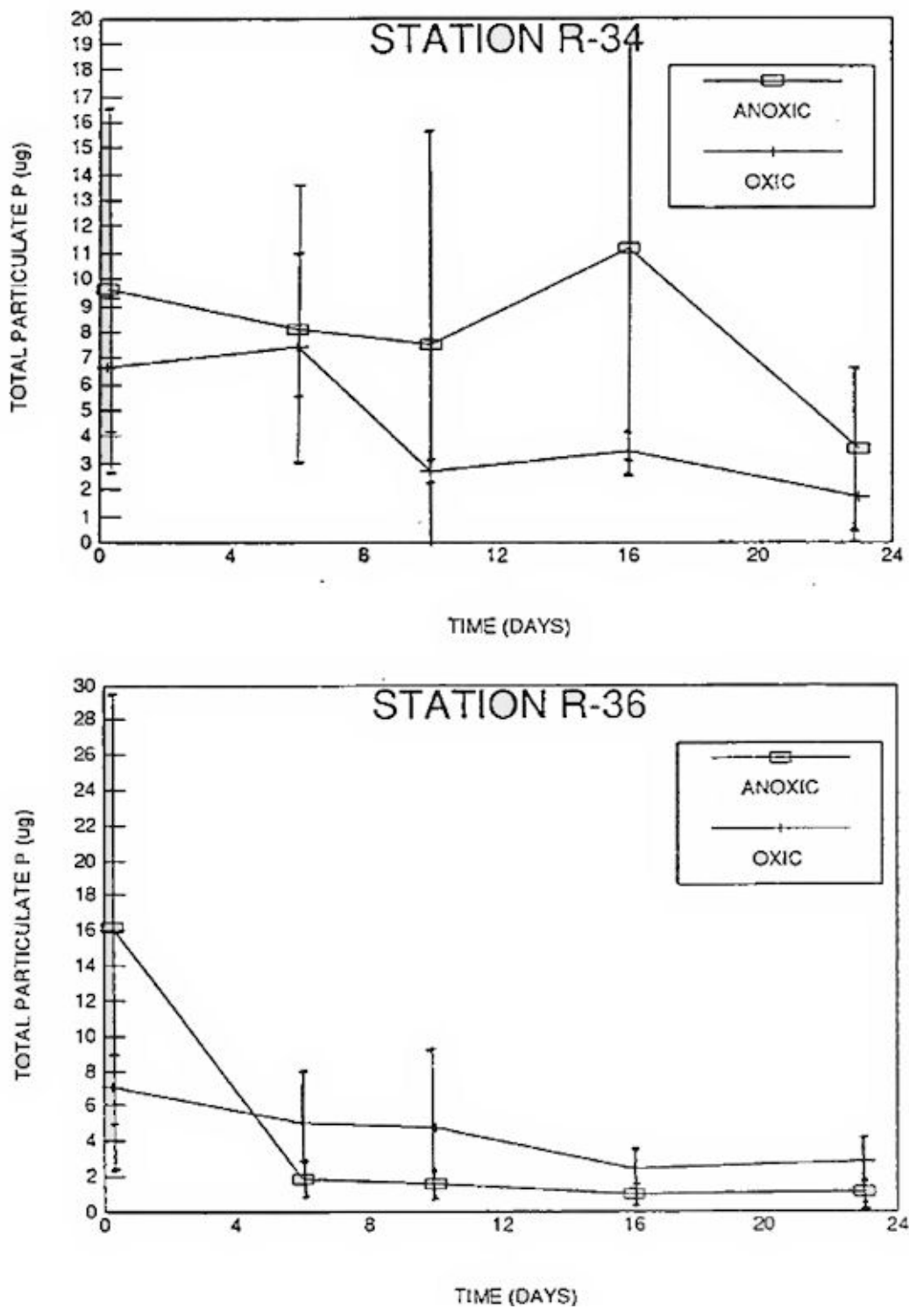


Figure 9: Particulate P in Supernatant Water of Rice Lake Cores from Deep-Water Stations, Pooled Data - October 19.



Total phosphorus was calculated to eliminate problems arising from different volumes in each core. The pooled data also fail to show consistent trends in phosphorus release. The large error bars around many of the points, representing one standard deviation, emphasize the erratic nature of the data. If any trend is evident it's that of a decrease in soluble and particulate phosphorus over the incubation. In only one core (R34-2, see Appendix), was a significant increase in particulate phosphorus observed over the incubation.

4.0 DISCUSSION OF RESULTS

4.1 Relation of the Measured Rates of Phosphorus Release to the Phosphorus Budget of Rice Lake

The highly erratic nature of the data and the variety of experimental conditions under which the measurements were made, make it difficult to relate the rates of phosphorus release in this study to the phosphorus budget of the lake. Since the surface sediments in Rice Lake are oxidized, at least during the summer and early autumn (Section 3.1), the rates obtained under oxic conditions are probably closest to natural release rates. If we assume that natural P release rates are between those rates measured on stagnant and stirred cores, we obtain an average summer P release rate of $0.53 \text{ mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ (mean of the P release rates under oxic conditions in Table 5).

Since we have little information on the phosphorus budget of Rice Lake, it is difficult to comment on the significance of this estimate of internal loading. Our estimate of $0.53 \text{ mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ is low relative to the range of phosphorus release from eutrophic lake sediments (Quigley and Robbins, 1986) and relative to phosphorus release rates in the upper Bay of Quinte, further downstream of Rice Lake. Internal phosphorus loading in the upper Bay of Quinte during the summer was measured at $2.0 \text{ mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ and estimated from nutrient models to be $5.0 \text{ mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ (Minns *et al.*, 1986; BEAK 1988). Both values are an order of magnitude greater than that obtained in Rice Lake in this study. Given the lack of background information we can only compare our estimate of sediment phosphorus release to the total phosphorus in the water column. Assuming a mean P concentration in Rice Lake of 0.056 mgL^{-1} , a lake volume of $2.4 \times 10^8 \text{ m}^3$ and an area of 100.1 km^2 (MOE, 1976), we obtain a turnover time of total lake phosphorus from internal loading at 250 days. For comparison, similar calculation on the Upper Bay of Quinte indicate a much smaller water column turnover of only 38 days (Minns *et al.*, 1986).

4.2 Phosphorus Release from Rice Lake Sediments

The patterns of phosphorus release in this study (Figures 5, 6) corroborate the results of other studies (for example Holdren and Armstrong, 1980; Twinch and Peters 1984) by indicating that phosphorus exchange across the sediment-water interface is not a simple process of diffusion or dissolution.

Holdren and Armstrong (1980), studying phosphorus release in cores from Wisconsin Lakes, observed similar patterns of SRP release to the supernatant water as we observed in this study. SRP release was often irregular; in some cores SRP levels reached an equilibrium, while in

other cores SRP levels increased slowly over the entire period. These authors also found that SRP release increased with temperature, decreased in the presence of suspended particulates and depended to a great extent on the presence of burrowing macrofauna. Tracer studies suggest that phosphorus movement across the sediment-water interface represents a dynamic exchange with aerobic sediments acting as a source or sink depending upon the phosphorus concentration of the overlying water. (Twinch and Peters, 1984).

This study also demonstrates the importance of considering the particulate fraction of phosphorus in both measuring phosphorus release and in determining phosphorus dynamics within the water column. Particulate phosphorus accounted for over 50% of the total phosphorus release (Table 5). While some of this particulate release may be due to inadvertent resuspension of the sediments during sampling, resuspension cannot explain the consistency of this fraction throughout the course of many of the incubations nor can resuspension account for the similarity in the increase in this fraction with SRP in some cores.

The source of this particulate fraction, if not representing resuspended material, is uncertain. The fraction may represent soluble phosphorus released from the sediments which has adsorbed to existing suspended particles or co-precipitated with iron in the presence of oxygen. Clasen and Bernhart (1982) also found that most of the phosphorus released from the sediments of a European reservoir was in particulate form. A similarity in profiles of particulate phosphorus and particulate iron in the water column near the sediments implied that the particulate phosphorus had co-precipitated with iron. It therefore seems likely that a fraction of the SRP released from the sediments precipitates in the supernatant water or adsorbs to particles already there. In any event, both SRP and PP must be monitored to obtain true measurements of phosphorus exchange between the sediments and the water column.

Careful examination of the data (Tables 3-5) also suggests that suspended particles may control levels of soluble phosphorus in the water column of Rice Lake. An increase in soluble phosphorus could not be observed in any of the stirred cores. Particulate phosphorus increased slightly in only one of the stirred cores (R34-8).

These facts suggest that, somehow, stirring the cores either decreased the rate of phosphorus efflux or removed the phosphorus released from the sediments. Since increasing the rate of stirring should increase diffusional release of phosphorus (by decreasing the thickness of the viscous diffusional sublayer (Boudreau, 1981) the second alternative may apply. One explanation is that stirring continually suspends very fine particles which strip the water of soluble phosphorus by adsorption or chemical reaction. The particles continually settle out and are replaced by fresh particles low in phosphorus. Particulate phosphorus therefore does not increase either in the supernatant water.

The role of suspended sediments in mediating the concentration of dissolved phosphorus in natural waters is well known from earlier studies on water-sediment suspensions (Pomeroy *et al.*, 1965; and Berner, 1980). As mentioned above, Holdren and Armstrong (1980) also found a decrease in release of SRP in the presence of suspended particulates. In a shallow lake, such as Rice Lake, where suspension of surface sediments is a frequent phenomenon, resuspended particles may play an important role in controlling levels of soluble phosphorus.

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6.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from this study:

- (1) Exchange of phosphorus across Rice Lake sediments is highly erratic and can occur in both directions.
- (2) No evidence was available suggesting a diurnal pattern of phosphorus release in shallow littoral sediments.
- (3) The best estimate of summer phosphorus release is $0.53 \text{ mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$, a value low when compared with the literature and the eutrophic Bay of Quinte.
- (4) Particulate phosphorus accounted for over 50% of the phosphorus release. This fraction may represent soluble phosphorus that adsorbed to existing suspended particles or co-precipitated with iron in the presence of oxygen.
- (5) Evidence suggests that suspended sediment particles may control levels of soluble phosphorus in the water column of Rice Lake.

It is recommended that the role of particulates in controlling levels of soluble phosphorus be investigated in further studies.

APPENDIX 1

Soluble and Particulate Phosphorus Concentration in Cores from Rice Lake

Core	Date	Sample	TIME (DAYS)	CUMULATED TIME (DY)	VOLUME ML	Oxic / Anoxic	STP-RAW µg/L	Soluble P UG/L	Corrected SRP	Partic. P µg/L	Sum µg/L	Total	SRP/Sum
R34-3	July 21/87	1	0	0	576	O	-2	1	1				
R34-3	July 21/87	2	2.17	2.17	576	O	4	4	4				
R34-3	July 21/87	3	2	4.17	576	O	10	10	9				
R34-3	July 21/87	4	0.83	5	576	O	12	12	11				
R34-3	July 21/87	5	1.15	6.15	576	O	8	9	7				
R34-3	July 21/87	6	4.02	10.17	576	O	-2	1	1	15.2	16.2		0.06
R34-3	July 21/87	7	4	14.17	576	O/A	-2	1	1	14	15		0.07
R34-3	July 21/87	8	8.88	23.05	749	A	4	4	4	17.6	21.6		0.19
R34-3	July 21/87	9	6.83	29.88	749	A	18	18	17	66	84		0.21
R34-3	July 21/87	10	8.83	38.71	749	A	19	19	17	83	101		0.18
R34-2	July 21/87	1	0	0	576	O	-2	1	1				
R34-2	July 21/87	2	2.17	2.17	576	O	-2	1	1				
R34-2	July 21/87	3	2	4.17	576	O	4	4	4				
R34-2	July 21/87	4	0.83	5	576	O	3	3	3				
R34-2	July 21/87	5	1.15	6.15	576	O	-2	1	1				
R34-2	July 21/87	6	4.02	10.17	576	O	9	8	7	18.8	26.8		0.30
R34-2	July 21/87	7	4	14.17	576	O/A	2	2	2	12.8	14.8		0.14
R34-2	July 21/87	8	8.88	23.05	758	A	10	10	9	16	26		0.38
R34-2	July 21/87	9	6.83	29.88	758	A	24	24	23	28	52		0.46
R34-2	July 21/87	10	8.83	38.71	758	A	15	15	14	22	37		0.41
R34-7	July 21/87	1	0	0	576	O	-2	1	1				
R34-7	July 21/87	2	2.17	2.17	576	O	-2	1	1				
R34-7	July 21/87	3	2	4.17	576	O	-2	1	1				
R34-7	July 21/87	4	0.83	5	576	O	-2	1	1				
R34-7	July 21/87	5	1.15	6.15	576	O	-2	1	1				
R34-7	July 21/87	6	4.02	10.17	575	O	-2	1	1	17.6	15.6		0.05
R34-7	July 21/87	7	4	14.17	576	O	-2	1	1	16.4	17.4		0.06
R34-7	July 21/87	8	10.8	24.93	576	O	-2	1	1	11.6	12.6		0.08
R34-7	July 21/87	9	6.83	31.8	575	O	4	4	4	8	13		0.31
R34-7	July 21/87	10	8.83	40.63	576	O	-2	1	1	10	11		0.09
R34-6	July 21/87	1	0	0	575	O	-2	1	1	12	13		0.08
R34-6	July 21/87	2	2.17	2.17	575	O	3	3	3	7.7	10.7		0.28
R34-6	July 21/87	3	2	4.17	570	O	7	7	7	5	15		0.47
R34-6	July 21/87	4	0.83	5	576	O	7	7	7	5.7	12.7		0.55
R34-6	July 21/87	5	1.15	6.15	576	O	6	6	6	15	21		0.29
R34-6	July 21/87	6	4.02	10.17	576	O	4	4	4	13.2	17.2		0.23
R34-6	July 21/87	7	4	14.17	576	O/A	5	5	5	5.7	10.7		0.47
R34-6	July 21/87	8	8.86	23.55	781	A	3	2	2	4.7	6.7	10	0.39
R34-6	July 21/87	9	6.83	29.88	781	A	14	14	13	42	56		0.25
R34-6	July 21/87	10	8.83	38.71	781	A	25	23	17	51	79		0.35
R34-8	July 21/87	1	3	0	575	O	-2	1	1				
R34-8	July 21/87	2	2.17	2.17	576	O	-3	1	1				
R34-8	July 21/87	3	2	4.17	576	O	-2	1	1				
R34-8	July 21/87	4	5.23	5	576	O	3	3	3				
R34-8	July 21/87	5	1.15	6.15	576	O	3	3	3				
R34-8	July 21/87	6	4.82	18.17	576	O	3	7	7	15	21		0.33
R34-8	July 21/87	7	4	14.17	574	O	-2	1	1	16.4	17.4		0.08
R34-8	July 21/87	8	15.8	34.37	576	O	-2	1	1	16.4	27.4		0.04
R34-8	July 21/87	9	6.83	31.8	576	O	-2	1	1	11	23		0.04
R34-8	July 21/87	10	3.83	40.63	576	O	-2	1	1	11	22		0.25

Core	Date	Sample	TIME (DAYS)	CUMULATED TIME (DY)	VOLUME ML	Oxic / Anoxic	STP-RAW µg/L	Soluble P UG/L	Corrected SRP	Partic. P µg/L	Sum µg/L	Total	SRP/Sum
R34-12	July 21/87	1	0	0	576	O	-2	1	1				
R34-12	July 21/87	2	2.17	2.17	576	O	-2	1	1				
R34-12	July 21/87	3	2	4.17	576	O	-2	1	1				
R34-12	July 21/87	4	0.83	5	576	O	-2	1	1				
R34-12	July 21/87	5	1.15	6.15	576	O	-2	1	1				
R34-12	July 21/87	6	4.02	10.17	576	O	-2	1	1	20.4	21.4		0.05
R34-12	July 21/87	7	4	14.17	576	O	-2	1	1	18.4	19.4		0.05
R34-12	July 21/87	8	10.8	24.97	576	O	-2	1	1	17.2	18.2		0.05
R34-12	July 21/87	9	6.83	31.8	576	O	4	4	4	22	26		0.15
R34-12	July 21/87	10	8.83	40.63	576	O	-2	1	1	19	20	34	0.05
R34-5	July 21/87	1	0	0	576	O	-2	1	1	3.4	4.4		0.23
R34-5	July 21/87	2	2.17	2.17	576	O	-2	1	1	10	11		0.09
R34-5	July 21/87	3	2	4.17	573	O	-2	1	1	6.2	7.2		0.14
R34-5	July 21/87	4	0.83	5	576	O	-2	1	1	11.2	12.2		0.08
R34-5	July 21/87	5	1.15	6.15	576	O	-2	1	1	18	19		0.05
R34-5	July 21/87	6	4.02	10.17	576	O	-2	1	1	21	22		0.05
R34-5	July 21/87	7	4	14.17	749	O/A	13	13	12	25	38		0.34
R34-5	July 21/87	8	8.89	23.05	749	A	24	24	23	17.6	41.6		0.58
R34-5	July 21/87	9	6.83	29.88	749	A	34	34	32	18	52		0.65
R34-9	July 21/87	10	5.83	38.71	749	A	48	48	45	14	62		0.77
R34-9	July 21/87	1	0	0	576	O	-2	1	1				
R34-9	July 21/87	2	2.17	2.17	575	O	-2	1	1				
R34-9	July 21/87	3	2	4.17	576	O	-2	1	1				
R34-9	July 21/87	4	0.83	5	576	O	-2	1	1				
R34-9	July 21/87	5	1.15	6.15	576	O	-2	1	1				
R34-9	July 21/87	6	4.82	10.17	576	O	-2	1	1	15.2	16.3		0.06
R34-9	July 21/87	7	4	14.17	576	O	2	2	2	14.8	16.8		0.12
R34-9	July 21/87	8	10.8	24.97	576	O	-2	1	1	16.4	17.4		0.06
R34-9	July 21/87	9	6.83	31.3	576	O	5	5	5	14	18		0.26
R34-9	July 21/87	10	3.83	40.63	576	O	-2	1	1	15	11		0.09

Core	Date	Sample	TIME (DAYS)	CUMULATED TIME (DY)	VOLUME ML	Oxic / Anoxic	STP-RAW µg/L	Soluble P UG/L	Corrected SRP	Partic. P µg/L	Sum µg/L	Total	SRP/Sum
R34CTL	July 21/87	1	0	0			-2	1					
R34CTL	July 21/87	2	2.17	2.17			-2	1					
R34CTL	July 21/87	3	0	4.17			-2	1					
R34CTL	July 21/87	4	0.83	5			-2	1					
R34CTL	July 21/87	5	1.15	6.15			-2	1					
R34CTL	July 21/87	6	4.02	10.17			4	4		7.7	11.7		0.34
R34CTL	July 21/87	7	4	14.17			-2	.5		1.1	1.1		0.45
R34CTL	July 21/87	8	10.8	24.97			4	4			4		1.00
R34CTL	July 21/87	9	6.83	31.3			3	3		1.6	3.6		0.83
R34CTL	July 21/87	10	3.83	40.63			6	4		1.4	6.4		0.63

Core	Date	Sample	TIME (DAYS)	CUMULATED TIME (DY)	VOLUME ML	Oxic / Anoxic	STP-RAW µg/L	Soluble P UG/L	Corrected SRP	Partic. P µg/L	Sum µg/L	Total	SRP/Sum
R36-4	July 21/87	1	0	0	576	O	6	6	6				
R36-4	July 21/87	2	2.17	2.17	576	O	-2	1	1				
R36-4	July 21/87	3	0	4.17	576	O	-2	1	1				
R36-4	July 21/87	4	0.83	5	576	O	3	3	3				
R36-4	July 21/87	5	1.15	6.15	576	O	-2	1	1				
R36-4	July 21/87	6	4.02	10.17	576	O	-2	1	1	29.4	29.4		0.03
R36-4	July 21/87	7	1	14.17	576	O	-2	1	1	23.2	24.2	22	0.04
R36-4	July 21/87	8	10.8	24.97	576	O	2	2	2	24.8	26.8		0.07
R36-4	July 21/87	9	6.83	31.8	576	O	6	6	6	24	30		0.20
R36-4	July 21/87	10	3.83	40.63	576	O	-2	1	1	21	22		0.05
R36-1	July 21/87	1	0	0	576	O	-2	1	1				
R36-1	July 21/87	2	2.17	2.17	576	O	-2	1	1				
R36-1	July 21/87	3	2	4.17	576	O	-2	1	1				
R36-1	July 21/87	4	0.83	5	576	O	-2	1	1				
R36-1	July 21/87	5	1.15	6.15	576	O	-2	1	1				
R36-1	July 21/87	6	4.02	10.17	576	O	-2	1	1	22.4	24.4		0.04
R36-1	July 21/87	7	4	14.17	576	O	-2	1	1	23.2	25.2		0.04
R36-1	July 21/87	8	10.8	24.97	576	O	-2	1	1	12.9	14.8	16	0.07
R36-1	July 21/87	9	6.83	31.8	576	O	9	9	8	16	25		0.18
R36-1	July 21/87	10	8.83	40.63	576	O	2	2	2	12	24		0.04
R36-2	July 21/87	1	0	0	576	O	15	15	14				
R36-2	July 21/87	2	2.17	2.17	576	O	-2	1	1				
R36-2	July 21/87	3	2	4.17	576	O	6	6	6				
R36-2	July 21/87	4	0.83	5	575	O	8	8	7				
R36-2	July 21/87	5	1.15	6.15	576	O	5	5	5				
R35-2	July 21/87	6	4.02	10.17	576	O	-2	1	1	44	43		0.03
R36-2	July 21/87	7	4	14.17	576	O	-2	1	1	38	32		0.03
R36-2	July 21/87	8	10.8	24.97	576	O	-2	1	1	20	22		0.05
R36-2	July 21/87	9	6.23	31.8	576	O	4	4	4	26	30		0.07
R36-2	July 21/87	10	3.83	40.63	576	O	-2	1	1	10	12		0.08
R36-3	July 21/87	1	0	0	576	O	-2	1	1				
R36-3	July 21/87	2	2.17	2.17	576	O	-2	1	1				
R36-3	July 21/87	3	2	4.17	576	O	4	4	4				
R36-3	July 21/87	4	0.83	5	576	O	4	4	4				
R36-3	July 21/87	5	1.15	6.15	576	O	-2	1	1				
R36-3	July 21/87	6	4.02	10.17	576	O	6	6	6				
R36-3	July 21/87	7	4	14.17	576	O/A	10	10	9	24.4	34.4		0.28
R36-3	July 21/87	8	9.83	23.05	776	A	25	25	24	11.2	36.2		0.68
R36-3	July 21/87	9	6.53	28.88	778	A	56	56	53	17	73		0.77
R36-3	July 21/87	10	3.83	38.71	778	A	66	66	63	30	88		0.69
R36-9	July 21/87	1	0	0	576	O	-2	1	1	11.2	16.2		0.06
R36-9	July 21/87	2	2.17	2.17	576	O	17	17	16	8	25		0.63
R36-9	July 21/87	3	1	4.17	576	O	31	31	29	12	43		0.71
R36-9	July 21/87	4	0.83	5	576	O	56	56	32	33.4	82.4		0.38
R36-9	July 21/87	5	1.15	6.15	576	O	59	59	54	18.6	127.3		0.46
R36-9	July 21/87	5	4.02	15.17	576	O	105	105	83	72	157		0.53
R36-9	July 21/87	7	4	14.17	576	O/A	135	125	118	65.6	184.5	173	0.64
R36-9	July 21/87	8	3.88	23.05	746	A	175	175	168	33.5	200.6		0.84
R36-9	July 21/87	9	6.83	29.85	746	A	193	193	187	35	218		0.81
R36-9	July 21/87	10	3.83	38.71	746	A	148	146	138	53	188		0.73

Core	Date	Sample	TIME (DAYS)	CUMULATED TIME (DY)	VOLUME ML	Oxic / Anoxic	STP-RAW µg/L	Soluble P UG/L	Corrected SRP	Partic. P µg/L	Sum µg/L	Total	SRP/Sum
R36-5	JULY 21/87	1	0	0	576	O	6	6	6				
R36-5	JULY 21/87	2	2.17	2.17	576	O	3	3	3				
R36-5	JULY 21/87	3	2	4.17	576	O	4	4	4				
R36-5	JULY 21/67	4	0.83	5	576	O	6	6	6				
R36-5	JULY 21/87	5	1.15	6.15	576	O	2	2	2				
R36-5	JULY 21/87	6	4.02	10.17	576	O	4	4	4	22	26		0.15
R36-5	JULY 21/87	7	4	14.17	576	O	2	2	2	44	46		0.04
R36-5	JULY 21/87	8	10.8	24.97	576	O	-2	1	1	27.6	28.6		0.03
R36-5	JULY 21/87	9	6.83	31.8	576	O	-2	1	1	13	14		0.07
R36-5	JULY 21/87	10	8.83	40.53	576	O	-2	1	1	14	15		0.07
R36-11	JULY 21/87	1	0	0	576	O	-2	1	1	6.7	7.7		0.13
R36-11	JULY 21/87	2	2.17	2.17	575	O	-2	1	1	6.2	7.2		0.14
R36-11	JULY 21/67	3	2	4.17	576	O	8	8	7	5.8	13.8		0.53
R36-11	JULY 21/87	4	0.83	5	576	O	13	13	12	9.6	22.6		0.53
R36-11	JULY 21/87	5	1.15	6.15	576	O	10	10	9	18	28		0.36
R36-11	JULY 21/87	6	4.02	10.17	576	O	21	21	20	48	69		0.30
R36-11	JULY 21/87	7	4	14.17	576	O/A	34	34	32	37	71		0.48
R36-11	JULY 21/87	8	1.83	23.05	755	A	28	28	27	44	72		0.38
R36-11	JULY 21/87	9	6.83	29.88	755	A	40	40	38	20	60	36	0.67
R36-11	JULY 21/87	10	8.83	38.71	755	A	30	30	28	17	47	48	0.64
R36-6	JULY 21/87	1	0	0	576	O	-2	1	1				
R36-6	JULY 21/87	2	2.17	2.17	576	O	4	4	4				
R36-6	JULY 21/67	3	2	4.17	576	O	13	13	12				
R36-6	JULY 21/87	4	0.83	5	576	O	13	13	12				
R36-6	JULY 21/87	5	1.15	6.15	576	O	9	9	8				
R36-6	JULY 21/87	6	4.02	10.17	576	O	12	12	11	27.2	39.2		0.31
R36-6	JULY 21/87	7	4	14.17	576	O/A	10	10	9	24.4	34.4		0.29
R36-6	JULY 21/87	8	8.88	23.05	755	A	8	8	8	11.2	19.2		0.42
R36-6	JULY 21/87	9	6.83	29.88	755	A	36	36	34	8	44		0.82
R36-6	JULY 21/87	10	8.83	38.71	755	A	44	44	43	10	54		0.81

Core	Date	Sample	TIME (DAYS)	CUMULATED TIME (DY)	VOLUME ML	Oxic / Anoxic	STP-RAW $\mu\text{g/L}$	Soluble P UG/L	Corrected SRP	Partic. P $\mu\text{g/L}$	Sum $\mu\text{g/L}$	Total	SRP/Sum
R36-CTL	OCT. 21/87	1	0	0			4	4		-0.4	4		1.11
R36-CTL	OCT. 21/87	2	6	6			-2	1		1.6	3		0.38
R36-CTL	OCT. 21/87	3	4	10			-2	1		2.4	3		0.29
R36-CTL	OCT. 21/87	4	6	16			7	7		0.0	8		0.90
R36-CTL	OCT. 21/87	5	7	23			-2	1		1.6	3		0.36
R36-1	OCT. 21/87	1	0	0	272	A	5	5	4	88	93		0.05
R36-1	OCT. 21/87	2	6	6	272	A	2	2	2	6.8	9	24	0.23
R36-1	OCT. 21/87	3	4	10	272	A	-2	1	1	8.8	10	19	0.10
R36-1	OCT. 21/87	4	6	16	272	A	-2	1	1	8	9	27	0.11
R36-1	OCT. 21/87	5	7	23	272	A	-2	1		6.8	8	9	1.13
R36-2	OCT. 21/87	1	0	0	237	A	10	10	8	144	154		0.06
R35-2	OCT. 21/87	2	6	6	237	A	4	4	3	13.6	18		0.23
R36-2	OCT. 21/87	3	4	10	237	A	-2	1	1	7.2	8		0.12
R36-2	OCT. 21/87	4	6	16	237	A	3	3	2	2	5		0.60
R36-2	OCT. 21/87	5	7	23	237	A	-2	1		3.2	4		0.24
R36-3	OCT. 21/87	1	0	0	220	A	4	4	3	4	8	18.8	0.50
R36-3	OCT. 21/87	2	6	6	220	A	-2	1	1	-2	2	23.2	0.50
R36-3	OCT. 21/87	3	4	10	220	A	-2	1	1	-2	2	12.8	0.50
R36-3	OCT. 21/87	4	6	16	220	A	-2	1	1	-2	2	12.8	0.50
R36-3	OCT. 21/87	5	7	23	220	a	-2	1		-2	2	24	0.50
R26-4	OCT. 21/87	1	0	0	206	A	11	11	9	28.8	40		0.28
R36-4	OCT. 21/87	2	6	6	206	A	-2	1	1	10.4	11		0.09
R36-4	OCT. 21/87	3	4	10	206	A	-2	1	1	7.6	9		0.12
R36-4	OCT. 21/87	4	6	16	206	A	-2	1	1	5.2	6		0.16
R36-4	OCT. 21/87	5	7	23	206	A	-2	1		8.4	9		0.11
R36-5	OCT. 21/87	1	0	0	218	O	4	4	3	35.2	38		0.10
R36-5	OCT. 21/87	2	6	6	218	O	-2	1	1	16.8	18		0.06
R36-5	OCT. 21/87	3	4	12	218	O	-2	1	1	19.2	20		0.05
R36-5	OCT. 21/87	4	6	16	218	O	-2	1	1	11.6	13		0.08
R36-5	OCT. 21/87	5	7	23	218	O	-2	1		20.8	20		0.05
R36-6	OCT. 21/87	1	0	0	260	O	5	5	4	29.8	34		0.15
R36-6	OCT. 21/87	2	6	6	260	O	5	5	4	25.0	30		0.17
R36-6	OCT. 21/87	3	4	10	260	O	-1	1	1	7.2	8		0.12
R36-6	OCT. 21/87	a	6	16	260	O	3	3	3	5.6	8		0.35
R36-6	OCT. 21/87	5	7	23	260	O	-2	1		5.6	7		0.18
R36-7	OCT. 21/87	1	0	0	306	O	5	5	1	12.4	10		0.05
R36-7	OCT. 21/87	2	6	6	306	O	-2	1	1	6.4	7		0.14
R36-7	OCT. 21/87	3	4	10	306	O	-2	1	1	7.2	8		0.12
R36-7	OCT. 21/87	4	6	16	306	O	-2	1	1	4.5	6		0.17
R36-7	OCT. 21/87	5	7	23	306	O	-2	1		5.2	6		0.16
R36-8	OCT. 21/87	1	0	0	261	O	5	5	1	35.6	41		0.10
R36-8	OCT. 21/87	2	6	6	261	O	2	2	2	30.4	30		0.06
R36-8	OCT. 21/87	3	4	10	261	O	-2	1	1	42.4	41		0.02
R36-8	OCT. 21/87	4	6	16	261	O	-2	1	1	17.2	18		0.05
R36-8	OCT. 21/87	5	7	23	261	O	-2	1		14.3	18		0.06

Core	Date	Sample	TIME (DAYS)	CUMULATED TIME (DY)	VOLUME ML	Oxic / Anoxic	STP-RAW $\mu\text{g/L}$	Soluble P UG/L	Corrected SRP	Partic. P $\mu\text{g/L}$	Sum $\mu\text{g/L}$	Total	SRP/Sum
R34 CTL	OCT. 21/87	1	0	0			3	1		-0.4	1		1.67
R34 CTL	OCT. 21/87	2	6	6			-2	1		-0.4	1		1.67
R34 CTL	OCT. 21/87	3	4	10			-2	1		1.6	3		0.38
R34 CTL	OCT. 21/87	4	6	16			-2	1		2.4	3		0.29
R34 CTL	OCT. 21/87	5	7	23			-2	1		1.6	3		0.38
R34-1	OCT. 21/87	1	0	0	417	A	5	5	5	58.8	56		0.09
R34-1	OCT. 21/87	2	6	6	417	A	5	5	5	15.2	20	43	0.25
R34-1	OCT. 21/87	3	4	10	417	A	-2	1	1	4	5	14	0.20
R34-1	OCT. 21/87	4	4	16	417	A	-2	1	1	20.4	21	92	0.05
R34-1	OCT. 21/87	5	7	23	417	A	-2	1		3.2	4	3	0.24
R34-2	OCT. 21/87	1	0	0	648	A	9	9	8	9.2	18		0.49
R34-2	OCT. 21/87	2	6	6	648	A	17	17	16	16.4	33		0.51
R34-2	OCT. 21/87	3	4	10	648	A	5	5	5	32.4	37		0.13
R34-2	OCT. 21/87	4	6	16	648	A	14	14	13	37.2	51		0.27
R34-2	OCT. 21/87	5	7	23	648	A	2	2		13.2	15		0.13
R34-3	OCT. 21/87	1	0	0	414	A	7	7	6	12.8	20		0.33
R34-3	OCT. 21/87	2	6	6	414	A	7	7	6	24.4	31		0.22
R34-3	OCT. 21/87	3	4	10	414	A	-2	1	1	12.4	13		0.07
R34-3	OCT. 21/87	4	4	16	414	A	4	4	4	18	22		0.18
R34-3	OCT. 21/87	5	7	23	414	A	-2	1		4.8	6		0.17
R34-4	OCT. 21/87	1	0	0	392	A	4	4	4	15.5	20		0.20
R34-4	OCT. 21/87	2	4	6	392	A	7	7	6	13.6	21		0.34
R34-4	OCT. 21/87	3	4	10	392	A	-2	1	1	5.6	7		0.15
R34-4	OCT. 21/87	4	6	16	392	A	3	3	3	12	15		0.20
R34-4	OCT. 21/87	5	7	23	392	A	-2	1		6.4	7		0.14
R34-5	OCT. 21/87	1	0	0	540	O	7	7	6	6.4	13		0.52
R34-5	OCT. 21/87	2	6	6	540	O	4	4	4	32.6	37		0.11
R34-5	OCT. 21/87	3	4	10	540	O	-2	1	1	4	5		0.20
R34-5	OCT. 21/87	4	6	16	540	O	-2	1	1	6.8	8		0.13
R34-5	OCT. 21/87	5	7	23	540	O	-2	1		4	5		0.20
R34-6	OCT. 21/87	1	0	0	427	O	5	5	5	22	27		0.19
R34-6	OCT. 21/87	2	6	6	427	O	4	4	4	11.2	15		0.26
R34-6	OCT. 21/87	3	4	10	427	O	-3	1.5	1	7.6	9		0.16
R34-6	OCT. 21/87	4	6	16	427	O	-2	1	1	11.2	12		0.05
R34-6	OCT. 21/87	5	7	23	427	O	-2	1		-	5		0.20
R34-7	OCT. 21/87	1	0	5	446	O	5	4	5	17.2	20		0.23
R34-7	OCT. 21/87	2	6	6	446	O	4	4	4	9.2	13		0.30
R34-7	OCT. 21/87	3	4	10	446	O	-2	1	1	6	7		0.14
R34-7	OCT. 21/87	4	6	16	446	O	14	14	13	3.4	22		0.62
R34-7	OCT. 21/87	5	7	23	446	O	-2	1		5.4	7		0.15
R34-8	OCT. 21/87	1	0	0	477	O	5	5	5	12.3	18	30	0.28
R34-8	OCT. 21/87	2	6	6	477	O	4	4	4	5.5	11		0.37
R34-8	OCT. 21/87	3	4	10	477	O	-3	1.5	1	6	8		0.20
R34-8	OCT. 21/87	4	6	16	477	O	4	4	5	3.6	8		0.53
R34-8	OCT. 21/87	5	7	23	477	O	-2	1		-0.8	8		0.03

APPENDIX 2

Soluble and Particulate Phosphorus Concentrations in *In Situ* Cores at Stations MG-E and MG-W

DIURNAL INCUBATION OF CORES - SRP IN SUPERNATANT (mg/L); STATION MG-E, JULY 19,1987.

TIME	TIME (HR)	CORE #1	CORE #2	CORE #3	CORE #4	CORE #5	CORE #6	CORE #7	CORE #8	CORE #9	CORE #10	AVE.	ST. DEV.	CONTROL
9:00 PM	0	0.004	0.002	0.004	0.006	0.016	0.002	0.002	0.002	0.002	0.002	0.004	0.004	0.002
11:00 PM	2	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003		0.003	0.003	0.000	0.002
1:00 AM	2	0.005	0.004	0.004	0.002	0.012	0.005	0.004	0.004	0.002	0.004	0.005	0.003	0.002
6:30 AM	9.5	0.005	0.010	0.013	0.012	0.014	0.035	0.002	0.002	0.002	0.002	0.010	0.010	0.006
10:30 AM	13.5	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.004	0.004	0.002	0.002	0.001	0.002
1:00 PM	16	0.002	0.092	0.002	0.002	0.005	0.002	0.003	0.002	0.002	0.002	0.002	0.001	0.002
9:00 PM	24	0.048	0.002	0.002	0.050	0.002	0.015	0.002	0.007	0.004	0.002	0.013	0.018	0.002

DIURNAL INCUBATION OF CORES - SRP IN SUPERNATANT (mg/L); STATION MG-W, JULY 19,1987.

TIME	TIME (HR)	CORE #1	CORE #2	CORE #3	CORE #4	CORE #5	CORE #6	CORE #7	CORE #8	CORE #9	CORE #10	AVE.	ST. DEV.	CONTROL
8:30 PM	0	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.052	0.002	0.000	0.002
10:30 PM	2	0.002	0.002	0.002	0.902	0.002	0.005	0.002	0.016	0.002	0.002	0.004	0.004	0.004
12:30 AM	4	0.002	0.010	0.002	0.002	0.002	0.002	0.002	0.022	0.002	0.002	0.005	0.006	0.002
2:30 AM	6	0.005	0.002	0.002	0.004	0.002	0.002	0.002	0.005	0.002	0.002	0.003	0.001	0.004
6:00 AM	9.5	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.008	0.002	0.002	0.003	0.002	0.002
8:00 AM	11.5	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.009	0.002	0.002	0.003	0.002	0.002
12:30 PM	16	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.004	0.006	0.006	0.003	0.002	0.013
9:00 PM	24.5	0.002	0.002	0.002	0.002	0.002	0.002	0.006	0.002	0.002	0.002	0.002	0.001	0.004

DIURNAL INCUBATION OF CORES - SRP AND PP IN SUPERNATANT (mg/L); STATION MG-E, OCT.19, 1987.

TIME	TIME (HR)	CORE E2	CORE E2	CORE E8	CORE E8
		SRP	PP	SRP	PP
10:15 AM	0	0.002	22.0	0.002	20.0
4:00 PM	5.75	0.002	15.6	0.002	19.2
8:00 PM	9.75	0.002	22.0	0.002	18.0
12:00 AM	13.75	0.002	21.0	0.002	18.0
4:00 AM	17.75	0.002	19.4	0.002	18.0
8:00 AM	21.75	0.032	16.4	0.002	13.6