Institute of Freshwater Ecology

Report

Phosphorus Dynamics in Windermere

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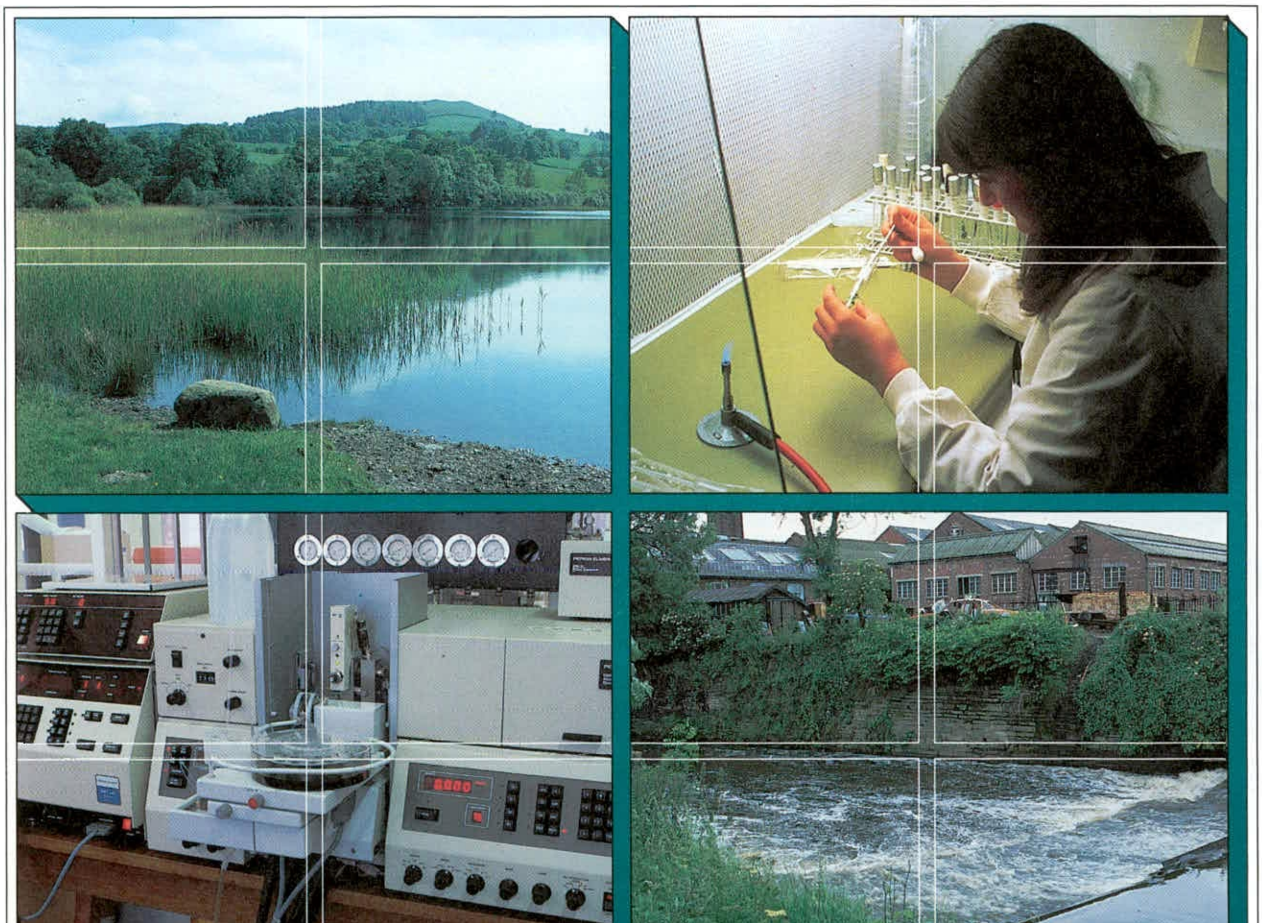

Natural Environment Research Council

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PHOSPHORUS DYNAMICS IN WINDERMERE

by

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1. Introduction

Windermere (area 14.8 Km^2) is the largest natural lake in England and is situated in an area affected by intensive tourism and recreation. It is a Site of Special Scientific Interest and provides part of the water supply to the North West. The lake is divided into two basins, a deeper North (NB:64m) and a shallower South Basin (SB:42m). Much work has been carried out on the lake and the results from 1945 to 1985 have been summarised in a report to North West Water (NWW) by Atkinson *et al*. (1986). This report has shown that the water quality of Windermere is deteriorating as a result of nutrient enrichment, particularly from sewage-borne phosphorus. A further study for NWW was more recently carried out by Heaney, Mills and Corry (1989). It provided an assessment of the nutrient status of the lake and its implications for the charr. This report recommended 80% removal of phosphorus from the sewage effluents of both the Tower Wood and Ambleside works, to produce a gradual improvement in water quality. A recent study on Esthwaite Water (Heaney *et al*. 1990), which drains into the South Basin of Windermere, stated that the mean annual concentration of hydroxide-extractable sediment phosphorus in the lake had been reduced following chemical precipitation of the sewage. Following the results from these studies North West Water plc (NWW) decided to undertake phosphorus stripping at its Tower Wood and Ambleside sewage plants. The Institute of Freshwater Ecology (IFE) was contracted to begin a two year programme of research into the phosphorus dynamics of Windermere to cover the changes in internal loading during the pre-stripping period. This work had two objectives. The first was to investigate the monthly changes in sedimentation to compare within-year differences as well as calculate an annual sedimentation rate with which to compare between-year differences.

The second objective was to determine the changes in sodium hydroxide-extractable soluble reactive phosphorus from the superficial sediment of Windermere. This alkali-extractable phosphorus or inorganic soil phosphorus corresponds to ligand exchangeable, occluded P (Drake and Heaney, 1987), adsorbed and non-occluded P, also P solubilized at high pH, ie. all sedimented phosphorus sources that may become bioavailable. It is well-known that the sediments can adsorb substantial amounts of phosphorus. This phosphorus may be released and used for algal production. As the sediment is a natural and ultimate sink for phosphorus it is likely that the first signs of any reduction in availability would be seen here. This report presents the results and conclusions from the study of these forms of phosphorus.

2. Methods

2.1 Sediment Trapping

The contract with NWW was to deploy duplicate traps close to the sediment near the deepest position of each lake basin. However, to investigate the pattern of sedimentation through the water column, duplicate traps were also deployed at 10m and 30m water depth. The traps consisted of polystyrene jars equipped with pre-drilled and sleeved caps suspended on a frame to keep them level (Reynolds 1979). There were two traps at each depth which initially contained deionised water and an excess of 0.06g mercuric iodide, as a preservative. The traps were changed every four or five weeks and their contents analyzed for total phosphorus.

2.2 Sediment Coring

Coring was undertaken three-monthly from October 1989 to July 1991 using a Jenkin sampler. The upper 0-4 cm sediment layer was obtained using a hydraulically operated extruder (Jones and Ohnstad 1982) then analyzed for hydroxide extractable phosphorus. A sample of 30 sediment cores were to be collected, 16 from the North Basin and 14 from the South (Fig. 1) using a randomly stratified sampling design. Four of these sites had to be abandoned due to their rocky substrata leaving, in the North Basin, eight deep (> 10m water depth) and six shallow (< 10m water depth) sites and in the South Basin, six deep and six shallow sites. The two basins were sampled within one week of each other, weather permitting.

2.3 Chemical Analyses

Inorganic soil phosphate was determined on duplicate homogenised aliquots from the 0-4 cm layer after the method of Petersen and Carey (1966). Approximately 2g wet sediment was accurately weighed out into 10 ml plastic tubes. At the same time a separate sample was taken for dry weight determination and dried at 60°C for 1-2 days. Next, 8 ml of 0.125 M NaOH was added to each tube containing the weighed 2g of wet sediment, stoppered and mixed gently until homogenised. The tubes were fitted onto racks in a Denby RM 200 rotator and rotated at c. 20 r.p.m. for 17 hours to extract the phosphate. It was determined by experimentation that no phosphate was obtained after further extractions. The suspension was then centrifuged for 15 minutes at 2400 r.p.m. and the supernatant transferred to another plastic tube. Then 40 μl of concentrated H_2SO_4 was added to the suspension and swirled gently to flocculate the organic matter, and then centrifuged again for 15 minutes at 2400 r.p.m. A suitable aliquot was taken, neutralized and phosphorus measured using the lower-sensitivity method for phosphate in Mackereth *et al.* (1989).

Total phosphorus was determined on duplicated homogenous aliquots from the sediment traps after the method of Eisenreich, Bannerman and Armstrong (1975). A suitable aliquot was taken and made up to 90 ml with deionised water in a pressure bottle. 0.7g of potassium persulphate and 5 ml of 1.02 N H_2SO_4 were added and the bottle autoclaved for 60 minutes at 15lb in^{-2} (1.1 bar) in a pressure cooker. The solution was cooled then mixed with 5 ml of freshly prepared "mixed reagent" (sulphuric acid-antimoney-molybdate reagent plus ascorbic acid). Phosphorus was measured as above.

3. Results and Discussion

3.1 Variations in sedimentary flux of particulate phosphorus

The results of sediment trapping in the North and South Basins of Windermere are shown in Tables 1 and 2. There were three occasions when traps were lost, owing to bad weather or human interference.

Relatively low levels of sedimentation were observed in both basins of the lake during the winter of 1989-90 (Figs. 2 and 3). This is to be expected as previous studies in Atkinson *et al.* (1986) have shown that phytoplankton production is at a minimum at this time of year. However, over the 1990-91 winter period and especially in the South Basin, there were two instances when the traps yielded very high concentrations of phosphorus. It has been assumed that these traps have been heavily affected by wind-induced secondary resuspension of shallow-water sediments which have been redeposited in deeper more sheltered waters. This phenomenon has been observed before, in the South Basin of Windermere, by Reynolds *et al.* (1982).

There were substantial peaks in sedimented phosphorus during the spring of either year (maxima in the deepest traps of NB: 80.15, SB: 106.73 $\mu g\ cm^{-2}\ month^{-1}$). These coincide with the annual increase in diatom biomass, the fate of most of which is to fall to the sediments (Atkinson *et al.* 1986). The flux to the sediments attributable to diatoms is greater than for other algae because

of their high density and lack of motility and the effect of the onset of stratification in the lake during April-May. That the trapped phosphorus is areally greater in the South Basin reflects the larger standing crop. A second, smaller autumn peak, other than the resuspension episodes described above, was also a regular feature. It coincided with the increased phytoplankton production of the autumn algal peak. In 1990-91, this consisted mainly of blue-green algae and although the biomass was greater than that produced during the diatom bloom, proportionally less phosphorus reached the sediments. Hamilton-Taylor *et al.* (1984) and Reynolds *et al.* (1982) attributed this to differences in sinking behaviour, susceptibility to decomposition and consumption as well as lake stratification. They concluded that most non-diatoms were decomposed in the water column before they sedimented out, whereas the diatoms underwent little dissolution prior to their deposition intact onto the sediments.

Annual fluxes ($\mu g\ cm^{-2}\ yr^{-1}$) in both basins were calculated by summing the monthly figures, missing values were interpolated using the mean weekly value over the period considered. As the results were heavily weighted by resuspended material, three annual flux estimates were calculated; a "non-resuspension" year (9-89 to 9-90), a mean year (overall period) and a year with heavy "resuspension" (7-90 to 7-91) (Table 3). These results show the wide possible range in annual fluxes at the deepest point of each basin. If a "non-resuspension" year is considered, there is a remarkably similar amount of phosphorus in the deepest traps, equivalent to direct sediment loading, for both basins. In the upper waters, there is approximately 1.25 times more phosphorus available in the South basin than the North. If the "mean year", which has been heavily weighted, or a "resuspension year" is considered, a similar but more exaggerated pattern can be seen. There is approximately twice as much phosphorus reaching the sediments in the North Basin than the South but there is up to 10 times more phosphorus available for recycling in the upper waters of the South basin. The "non-resuspension year" provides a more representative comparison of fluxes in both basins as it reflects a uniform sedimentation of new material, rather than resedimentation of existing material subjected to differing resuspension forces in each basin and focusing on deep water sites. This quantity should be selected as the baseline for determining amelioration in future phosphorus recruitment.

3.2 Phosphorus content of the sediments

Tables 4 and 5 show the concentrations of hydroxide-extractable soluble reactive phosphorus in the superficial sediments of the North and South Basins of Windermere. There are very large differences between site results over the lake and, because of this contagious distribution, the results are plotted (Figs. 4 and 5) as the arithmetic means with 95% confidence limits calculated using Taylor's Power Law transformation (Elliott, 1977).

The mean phosphorus of the lake sediments (Fig. 4) did not vary significantly over the period investigated. The confidence limits are very wide for each sampling occasion, reflecting the variability between stations across the lake.

The sediment collected from the deep-water sites contained much more phosphorus than that collected from shallow-water sites (Fig. 5). To determine whether this was a statistically significant difference the mean concentrations for the whole period were compared using the "normal deviate (d) test". The numbers of sub-samples were sufficiently great to require the use of the Central-limit Theorem. Therefore, it was assumed that the sample means were normally distributed around the mean, which was itself equal to the population mean. The null hypothesis was that there would be no statistical difference between sample means. The calculated value for d was 12.33, indicating that the deep-water sites were significantly different from the shallow-water sites, at the 0.1% level. The variances were also compared using the "variance-ratio" or "F-test" and these were found to be significantly different at the 2% level (F= 2.84). It is likely that the greater concentration of phosphorus in the deep-water sites is due to "sediment focusing" of resuspended shallow-water sediments into the deeper more undisturbed waters of the lake, as described by Likens and Davis (1975) and as indicated by the trapping programme.

The mean and transformed 95% confidence limits of samples from the North and South Basins were plotted (Fig. 6) and found to vary at times throughout the period of study. The means over the whole period were compared and it was found there was no significant difference between samples from the North and South Basins at the 5% level ($\underline{d}$= 1.42). However, comparison of the variances showed a significant difference between basins ($F=2.89$: $P<0.002$) reflecting the larger between site differences in the South Basin.

4. Summary and Recommendations

1. This report provides additional information on Windermere to that contained in the commissioned Reports to NWW by Atkinson *et al.* (1986), Heaney and Talling (1988) and Heaney, Mills and Corry (1989). There is evidence of deteriorating water quality as a result of nutrient enrichment, particularly from sewage-borne phosphorus.

2. NWW decided to undertake a programme of phosphorus removal from the Ambleside and Tower Wood sewage works. IFE was commissioned to determine a baseline condition pertaining to the annual sedimentation of particulate phosphorus and the levels of alkali-extractable soluble reactive phosphorus from the superficial sediment of Windermere.

3. Total phosphorus was determined from duplicate traps suspended at 10m, 30m and 60m in the North Basin and 10m, 30m and 40m in the South Basin. These were removed at 4 or 5 -weekly intervals. Alkali-extractable phosphorus was determined from samples of cores obtained at 3-monthly intervals. A date-collection consisted of 14 cores from the North or 12 cores from the South Basin according to a random sampling design incorporating sites in shallow

(< 10m) and deep (> 10m) water.

4. Total sedimentary phosphorus intercepted by traps peaked twice during the year, April and August/September, the Spring peak being much larger than the autumn peak. These peaks coincided with the increase in algal biomass in the upper waters and their size reflected the sinking behaviour and mineralization characteristics of the algae concerned. Annual flux estimates were calculated but were heavily weighted in some cases due to phosphorus peaks caused by sedimentation of material resuspended from shallow waters. If the more representative, "non-contamination year" is considered, similar amounts of total phosphorus reach the sediments in both basins but the South Basin has a higher concentration of phosphorus available in the upper waters.

5. There are large between site differences in alkali-extractable phosphorus over the whole lake. Although these differences were significantly smaller in the North Basin than in the South, the mean phosphorus did not differ between the two basins. There was significantly more extractable phosphorus in sediments under deep water than there was in sediments under shallow water.

6. These results provide a basis for future comparisons. Phosphorus removal from the sewage effluents of the Tower Wood and Ambleside sewage works will only lead to a

gradual improvement of water quality. Accumulated phosphorus is expected to be released from the sediments over a number of years, eventually diminishing to result in a reduction in algal biomass. It is recommended that the rate of phosphorus decline in the sediments and the flux of phosphorus to the sediments be measured to determine the rate of recovery of the lake and to follow the changes in the amount of algal-derived phosphorus reaching the sediments.

5. Acknowledgements

We would like to thank Peter Cubby and Ben James for their invaluable help with field work and Colin Reynolds for his comments on the manuscript.

6. References

Atkinson, K. M. *et al.* (1986). A general assessment of environmental and biological features of Windermere and their susceptibility to change. Commissioned Report edited by J.F. Talling from the Freshwater Biological Association to North West Water. 80pp

Drake, J.C. and Heaney, S.I. (1987). Occurrence of phosphorus and its potential remobilization in the littoral sediments of a productive lake. Freshwat. Biol.,17; 513-523

Eisenreich, S.J., Bannerman, R.T. and Armstrong, D.E. (1975). A simplified phosphorus analysis technique. Environ. Lett.,9; 45-53

Elliott, J.M. (1977). Some methods for the statistical analysis of samples of benthic invertebrates. 2nd edition. Sci. Publs. Freshwat. Biol. Ass. No. 25, 156pp

Hamilton-Taylor, J., Willis, M. and Reynolds, C.S. (1984). Depositional fluxes of metals and phytoplankton in Windermere as measured by sediment traps. Limnol. Oceanogr.,29; 695-710

Heaney,S.I., Corry, J.E., Lishman, J.P., Butterwick, C. and Talling, J.F. (ed) (1990). Changes in the content of the sediment of Esthwaite Water and water quality in response to a decreasing input of sewage-borne phosphorus. Commissioned Report from the Freshwater Biological Association to Nature Conservancy Council. 17pp

Heaney, S.I., Mills, C.A. and Corry, J.E. (1989). An assessment of changing nutrient inputs to Windermere and their influence on water quality and charr population dynamics. Commissioned Report from the Institute of Freshwater Ecology to North West Water. 38pp

Jones, J.G. and Ohnstad, F.R. (1982). The Jenkin surface-mud sampler user manual. Occ. Publs. Freshwat. Biol. Ass. No. 15, 45pp

Mackereth, F.J.M., Heron, J. and Talling, J.F. (1989). Water analysis: some revised methods for limnologists (second impression). Sci. Publ. Freshwat. Biol. Ass. No. 36, 124pp

Petersen, G.W. and Carey, R.B. (1966). A modified Cheng and Jackson procedure for routine fractionation of inorganic soil phosphates. Proc. Soil Sci. Soc. Amer.,30; 563-565

Reynolds, C.S. (1979). Seston sedimentation: experiments with *Lycopodium* spores in a closed system. Freshwat. Biol.,9;55-76

Reynolds, C.S., Morison, H.R. and Butterwick, C. (1982). The sedimentary flux of phytoplankton in the South Basin of Windermere. Limnol. Oceanogr.,27; 1162-1175

TABLE 1. Particulate phosphorus content of paired sediment traps (Mean ± SE) suspended at selected depths in the North basin of Windermere. Results in $\mu g\ cm^{-2}$ per 4-week month.

DATE SAMPLED	NORTH BASIN 10m	NORTH BASIN 30m	NORTH BASIN 60m
10-10-89	26.33 ± 1.51	17.23 ± 0.66	24.04 ± 1.24
7-11-89	20.48 ± 0.69	21.89 ± 4.23	16.63 ± 0.97
5-12-89	24.58 ± 0.82	14.60 ± 0.18	17.57 ± 0.72
2- 1-90	19.66 ± 0.51	16.94 ± 0.81	21.12 ± 1.17
30- 1-90	36.89 ± 0.59	34.29 ± 0.46	14.99 ± 1.91
6- 3-90	56.03 ± 0.48	61.72 ± 1.32	78.81 ± 3.26
Traps Lost	-	-	-
24- 4-90	59.52 ± 0.60	57.52 ± 0.25	80.15 ± 5.98
22- 5-90	23.66 ± 0.55	26.43 ± 0.09	48.67 ± 1.43
19- 6-90	16.74 ± 0.65	15.38 ± 0.33	28.47 ± 1.10
17- 7-90	23.22 ± 0.26	14.84 ± 0.16	30.47 ± 2.77
14- 8-90	23.07 ± 0.84	31.97 ± 0.55	45.36 ± 1.03
11- 9-90	26.52 ± 0.61	16.79 ± 0.61	26.77 ± 1.48
9-10-90	17.38 ± 0.31	24.34 ± 2.03	751.13 ± 11.8
6-11-90	28.67 ± 0.56	26.15 ± 2.80	23.02 ± 5.31
4-12-90	27.64 ± 2.08	36.11 ± 3.46	173.79 ± 7.4
2- 1-91	79.96 ± 4.17	99.18 ± 3.82	180.85 ± 5.24
29- 1-91	71.74 ± 1.23	69.16 ± 1.85	113.30 ± 1.20
26- 2-91	25.21 ± 0.75	22.78 ± 0.35	27.89 ± 0.39
26- 3-91	54.70 ± 3.51	21.76 ± 1.65	37.86 ± 2.79
23- 4-91	52.66 ± 1.34	59.18 ± 0.14	99.19 ± 2.73
28- 5-91	36.80 ± 1.11	46.65 ± 0.82	76.20 ± 1.47
25- 6-91	22.34 ± 0.51	19.37 ± 0.13	24.04 ± 0.97
30- 7-91	23.48 ± 1.78	16.16 ± 0.62	23.25 ± 0.44

TABLE 2. Particulate phosphorus content of paired sediment traps (Mean ± SE) suspended at selected depths in the South basin of Windermere. Results in µg cm^{-2} per 4-week month.

DATE SAMPLED	SOUTH BASIN 10m	SOUTH BASIN 30m	SOUTH BASIN 40m
10-10-89	25.84 ± 0.37	34.43 ± 1.56	25.31 ± 0.18
7-11-89	25.35 ± 0.59	38.24 ± 1.06	31.93 ± 3.96
5-12-89	32.27 ± 3.46	34.17 ± 0.30	23.75 ± 0.48
2- 1-90	23.75 ± 0.40	21.07 ± 0.29	25.07 ± 0.47
30- 1-90	37.09 ± 0.89	25.26 ± 2.19	16.30 ± 5.30
Traps Lost	-	-	-
Traps Lost	-	-	-
24- 4-90	60.06 ± 1.25	81.62 ± 0.89	106.73 ± 19.42
22- 5-90	29.01 ± 0.51	38.60 ± 0.76	9.13 ± 1.20
19- 6-90	24.19 ± 0.70	30.57 ± 1.11	34.72 ± 1.26
17- 7-90	44.58 ± 0.73	39.76 ± 2.37	15.29 ± 2.53
14- 8-90	20.88 ± 0.18	16.45 ± 0.17	25.85 ± 0.39
11- 9-90	29.54 ± 0.59	25.02 ± 5.24	51.78 ± 1.45
9-10-90	51.39 ± 1.77	20.93 ± 3.21	42.73 ± 1.65
6-11-90	35.51 ± 0.74	40.88 ± 5.65	127.54 ± 9.92
4-12-90	26.77 ± 0.33	26.67 ± 0.69	29.54 ± 3.43
2- 1-91	2870 ± 848	487.8 ± 282	70.52 ± 3.47
29- 1-91	47.06 ± 0.48	46.53 ± 1.76	-
26- 2-91	31.20 ± 3.59	23.70 ± 0.65	26.23 ± 1.47
26- 3-91	29.88 ± 0.74	19.37 ± 0.52	15.04 ± 3.71
23- 4-91	94.46 ± 5.74	86.73 ± 2.09	104.69 ± 4.21
28- 5-91	38.90 ± 1.40	35.55 ± 0.86	42.60 ± 1.54
25- 6-91	50.08 ± 2.90	38.45 ± 0.70	53.97 ± 2.39
30- 7-91	51.55 ± 1.05	29.67 ± 0.59	37.07 ± 1.69

TABLE 3. Estimates of annual flux (± SE) in the North and South Basins of Windermere. Results in $\mu g\ cm^{-2}\ yr^{-1}$.

	NORTH BASIN		
	10m	**30m**	**60m**
12-9-89 to 11-9-90	386.43 ± 8.79	357.07 ± 10.45	469.14 ± 24.98
Mean Annual Flux	450.64 ± 14.80	435.47 ± 15.44	1109.84 ± 35.50
31-7-90 to 30-7-91	485.28 ± 18.68	475.94 ± 19.01	1619.58 ± 42.87
	SOUTH BASIN		
	10m	**30m**	**40m**
12-9-89 to 11-9-90	416.66 ± 11.43	455.23 ± 18.84	432.38 ± 43.30
Mean Annual Flux	2174.17 ± 517.88	733.60 ± 185.94	566.92 ± 43.41
31-7-90 to 30-7-91	3490.59 ± 902.02	916.55 ± 316.12	680.19 ± 39.49

TABLE 4. Hydroxide-extractable soluble reactive phosphorus content of sediments in the North basin of Windermere. Results in µg P/g dry sediment.

Site No.	Date of Sample			
Sites <10m	11-10-89	8- 1-90	18- 4-90	11- 7-90
4	488.00	272.00	293.00	385.58
5	774.00	769.10	464.40	230.71
8	-	967.20	1162.30	839.27
9	765.00	786.60	919.40	157.74
12	496.00	414.50	655.80	1608.50
16	493.00	593.20	412.70	644.71
Sites >10m				
1	1616.00	1383.00	1353.80	1508.44
2	2258.00	1309.00	1735.70	996.55
3	1784.00	2061.00	1972.50	1905.72
6	1914.00	2350.10	2176.60	1664.00
7	1683.00	1256.00	1534.30	1565.79
10	1096.00	1264.90	1226.80	980.20
14	1442.00	1892.00	1608.50	1898.46
15	1385.00	1345.60	1131.10	1689.20

Site No.	Date of Sample			
Sites <10m	10-10-90	8- 1-91	2- 5-91	11- 7-91
4	478.16	333.08	775.96	332.25
5	414.90	599.08	436.90	501.73
8	1106.36	883.74	997.97	587.49
9	503.25	529.67	880.78	619.14
12	441.72	789.80	596.71	524.20
16	401.66	656.51	495.36	547.97
Sites >10m				
1	643.26	1639.76	1153.14	1749.82
2	1538.00	1347.67	1482.28	885.37
3	1873.30	1028.29	927.91	1207.93
6	1553.41	2074.52	1974.32	1114.76
7	652.13	1655.68	1592.69	1836.97
10	545.98	913.57	1462.34	849.30
14	1103.02	1388.58	1601.06	1471.19
15	956.81	1462.00	1652.11	1642.74

TABLE 5. Hydroxide-extractable soluble reactive phosphorus content of sediments from the South basin of Windermere. Results in µg P/g dry sediment.

Site No.	Date of Sample			
Sites <10m	12-10-89	18- 1-90	25- 4-90	18- 7-90
2	635.00	581.20	381.30	598.57
4	734.00	296.00	495.10	587.79
5	618.00	465.00	2834.30	3095.30
10	678.00	405.40	382.90	348.82
11	323.00	502.70	452.70	300.45
12	904.00	681.80	787.70	743.70
Sites >10m				
1	904.00	757.00	1314.60	729.87
3	1682.00	2089.80	1871.10	3295.69
6	2557.00	2834.30	3030.50	2986.42
7	2587.00	3095.30	2983.50	2852.43
13	1102.00	1218.00	910.00	1008.86
14	939.00	857.00	834.60	1109.40

Site No.	Date of Sample			
Sites <10m	18-10-90	16- 1-91	9- 5-91	25- 7-91
2	539.27	1148.55	563.22	539.66
4	495.92	619.21	651.09	731.66
5	325.32	956.52	509.78	949.28
10	351.23	718.59	578.67	561.29
11	720.84	641.36	762.88	577.29
12	438.03	715.87	875.92	762.79
Sites >10m				
1	1071.97	1034.64	900.40	1208.08
3	2728.09	2653.03	1709.21	2744.24
6	2852.86	3308.32	2819.48	3296.86
7	3122.97	1682.71	2131.24	2844.34
13	1107.72	977.78	1089.29	945.40
14	948.47	1096.83	963.58	824.53

Fig. 1 North and South Basins of Windermere showing the 10m depth contours, trapping sites A and B and coring sites 1-16 in the North Basin and 1-14 in the South Basin.

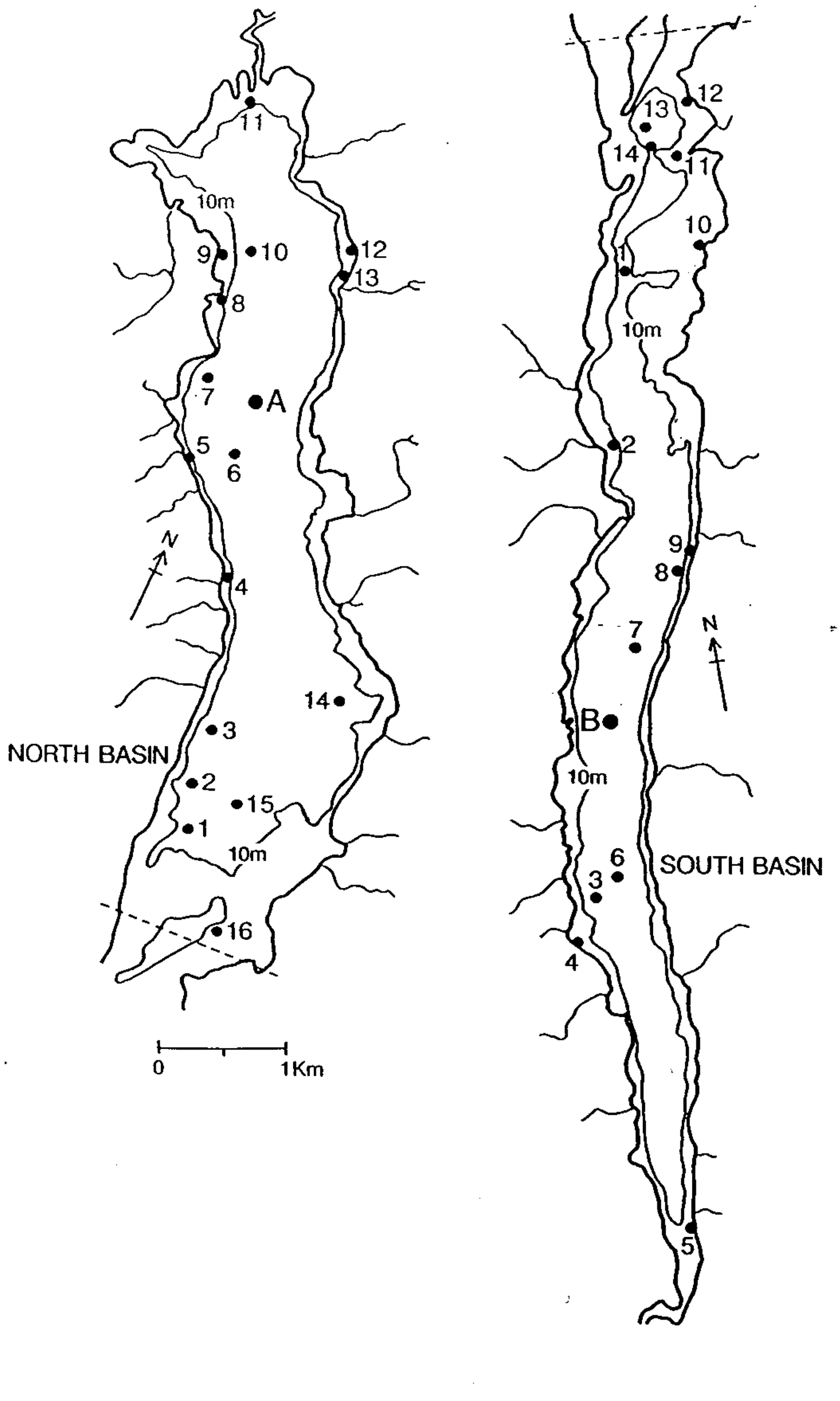


Fig. 2 Time-series of the mean total phosphorus (μg/cm^2/month) collected in sediment traps suspended in the North Basin of Windermere at 10m, 30m and 60m.

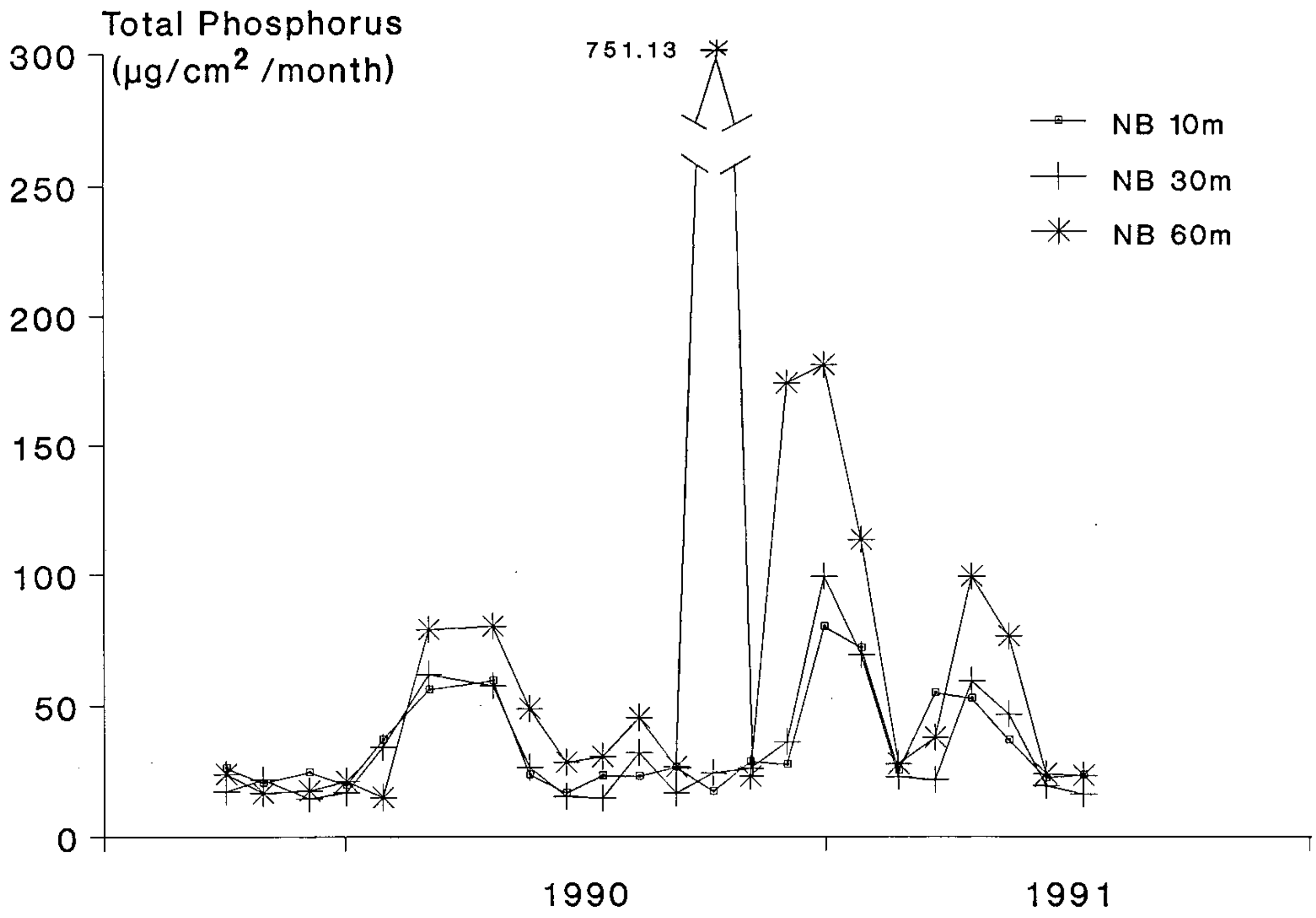


Fig. 3 Time-series of the mean total phosphorus (µg/cm²/month) collected in sediment traps suspended in the South Basin of Windermere at 10m, 30m and 40m.

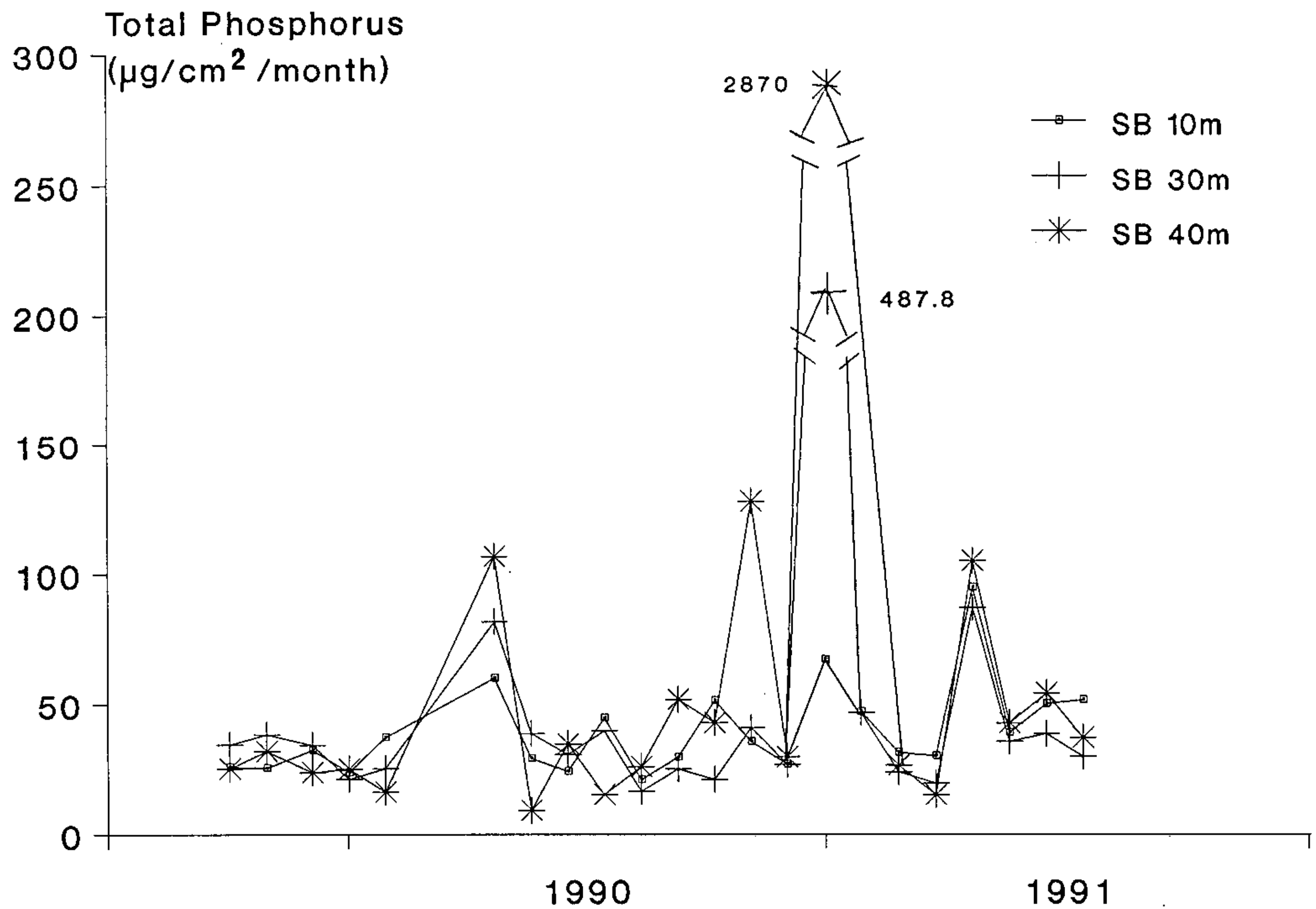


Fig. 4 Time-series of the mean concentration and 95% CL of alkali-extractable soluble reactive phosphorus in the upper (0-4 cm) layer of sediment from samples of cores from Windermere.

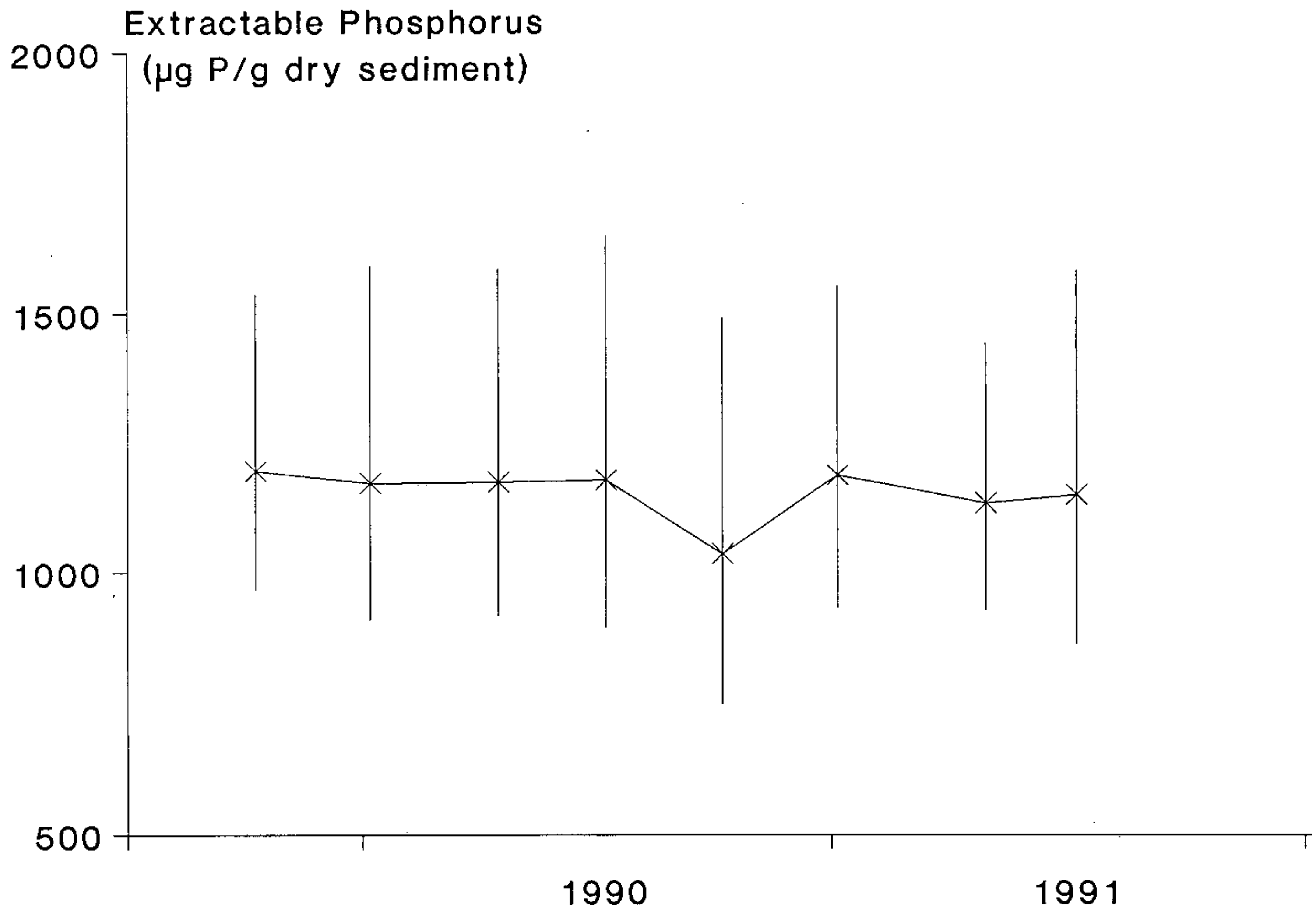


Fig. 5 Time-series of mean concentration and 95% CL of alkali-extractable soluble reactive phosphorus in the upper (0-4 cm) layer of sediment core samples collected from deep (>10m) and shallow (<10m) sites.

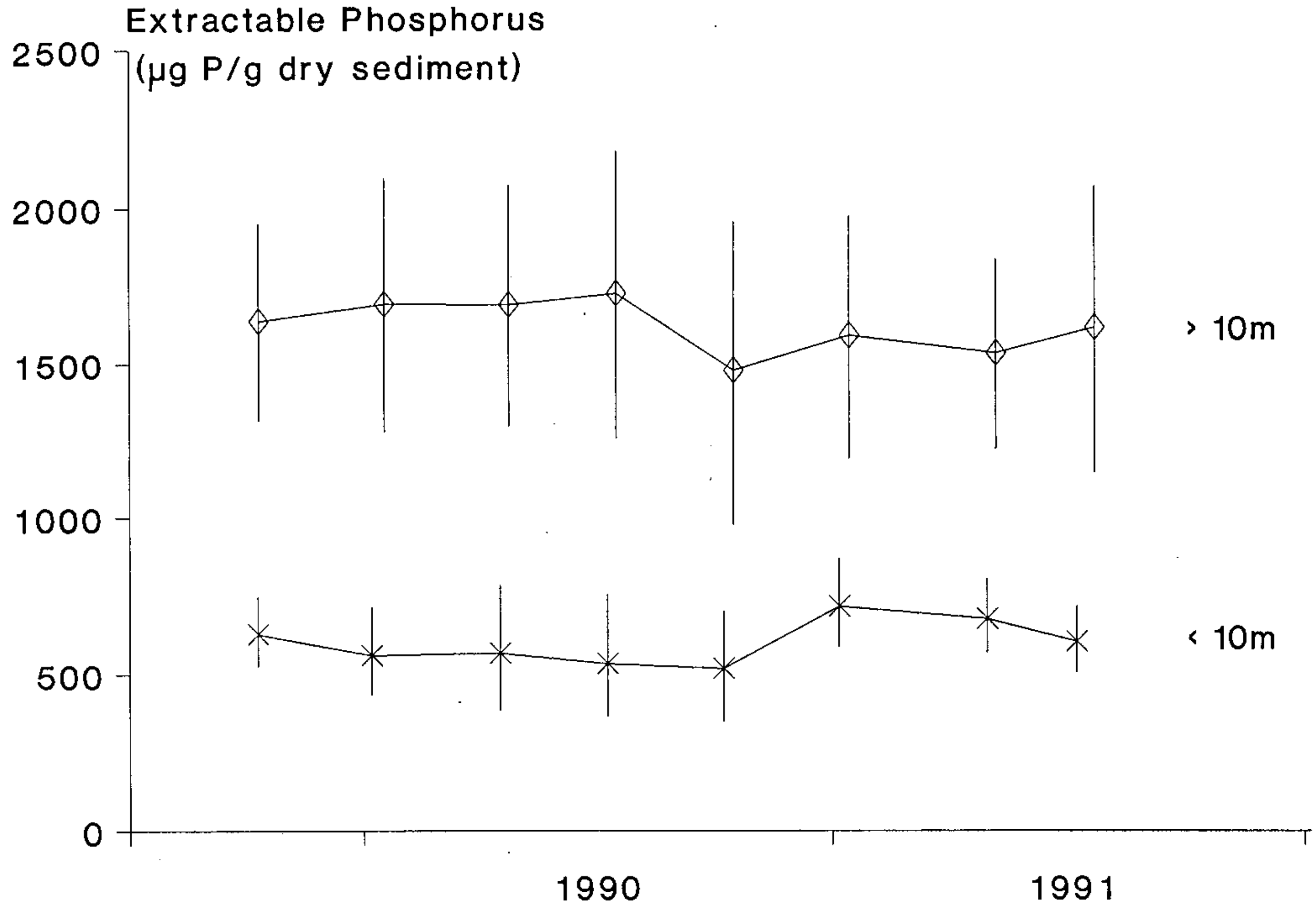
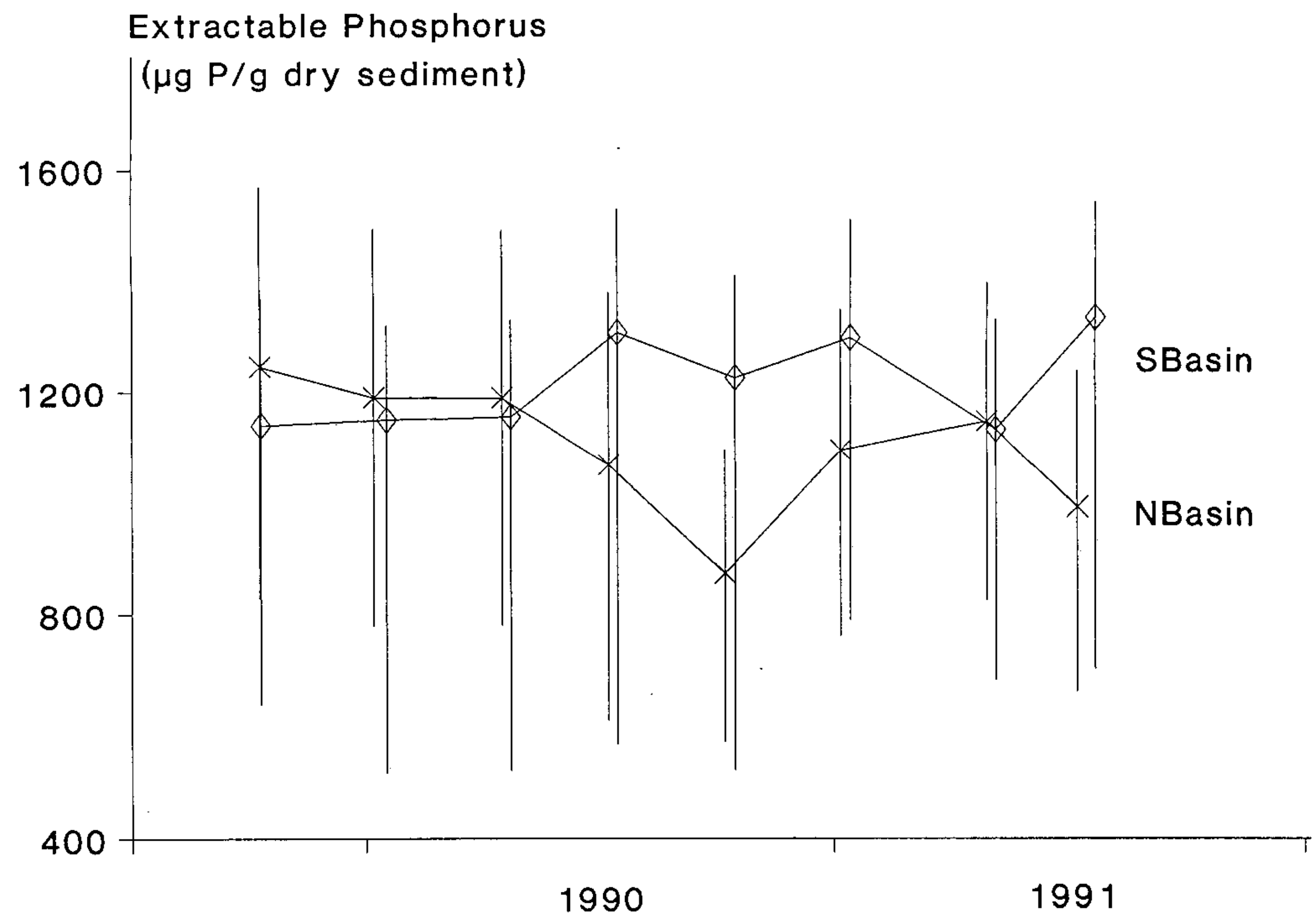


Fig. 6 Time-series of mean concentration and 95% CL of alkali-extractable soluble reactive phosphorus in the upper (0-4 cm) layer of sediment core samples collected from sites in the North and South Basins.



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