Institute of Freshwater Ecology

Assessment of the Potential for Phosphorus Reduction in River Waters

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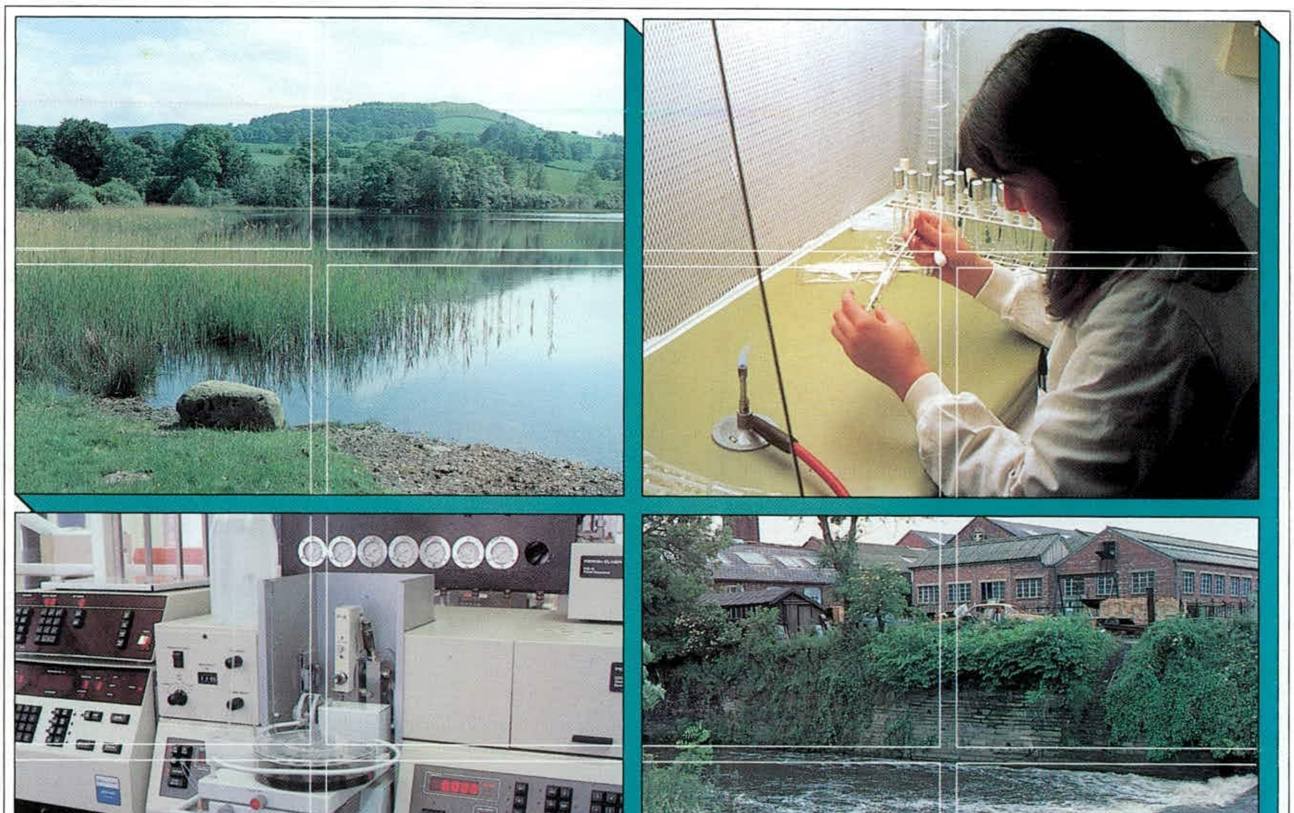

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GLOSSARY OF SYMBOLS

DO	Dissolved Oxygen expressed as a % percentage of the aqueous saturation at the field temperature and atmospheric pressure.
EPC	Equilibrium Phosphorus Concentration. The concentration of SRP in contact with a suspended sediment after 24 h contact in well-mixed conditions. The EPC_0 is the EPC of a sediment containing only native phosphorus i.e. when the sediment is in contact with a solution with $SRP=EPC_0$, there is no net flux of SRP.
K_d	Distribution coefficient in units of $dm^3\ kg^{-1}$ or $ml\ g^{-1}$. The ratio of the concentration of adsorbed SRP to the concentration in the solution after 24 h contact.
Native P	Native Phosphorus. That phosphorus in sediments prior to leaching or supplementation in laboratory experiments.
n_i	Initial adsorption amount. The initial concentration of SRP associated with the sediment prior to sorption. n_i is normally < BAP for sediments.
OM	Organic Matter content expressed as a percentage of the dry weight measured by combustion at 550 ^{0}C
PP	Particulate phosphorus. Difference between TP and TDP, i.e. that phosphorus associated with the particulate phase of size > 0.45 µm.
SRP	Soluble Reactive Phosphorus. Soluble phosphorus measured after filtration through a 0.45 µm membrane filter without acid digestion.
STW	Sewage Treatment Works.
TDP	Total Dissolved Phosphorus. Filtered through 0.45 µm membrane filter but subject to acid digestion prior to analysis.
TP	Total Phosphorus. Unfiltered and subject to acid digestion prior to analysis.

SUMMARY

The results of the first survey of the rivers Wey and Blackwater for 1997-98 completed in January 1998, are presented as part of the extension to this project, together with a summary of the results for the R. Wey for 1994-95. For this river, the estimated phosphorus flux, Equilibrium Phosphate Concentration (EPC_0) and amount of native phosphorus in the sediment were lower than on previous surveys.

The Equilibrium Phosphate Concentration method, which has been extensively used in this project, has been assessed in more detail using a sediment collected form the R. Blackwater near Aldershot. The results confirm findings obtained using a fluvarium channel, that a reduction in the redox status of the Blackwater, Gt. Ouse and Wey sediments leads to a systematic increase in the associated EPC_0. Oxic sediments were more adsorptive than anoxic but did not have as great affinity for soluble reactive phosphorus as pre-washed sediment.

Future work will concentrate on seasonal field surveys of the rivers Wey and Blackwater, a more in-depth examination of the porewater chemistry during EPC_0 determinations, and a detailed review of the experimental data obtained from the R. Blackwater catchment.

1. INTRODUCTION

Under the Urban Waste Water Treatment Directive (91/271/EEC), water bodies will be designated as sensitive areas if they fulfil certain criteria. Phosphorus removal will be required at sewage treatment works discharging into these phosphorus limited sensitive areas, the aim being to reduce phosphorus loading to the water body and therefore to reduce the biological symptoms of eutrophication. Member states also have to review and monitor eutrophication in their sensitive areas over the coming years.

There are uncertainties about how water bodies will respond to reductions in phosphorus loading and the time scale for the biological symptoms of eutrophication to be reduced. This project seeks to develop an understanding about how water bodies respond to reductions in phosphorus loading, and in particular how these reductions could be counteracted by phosphorus release from sediments.

The assessment of the effects of phosphorus removal from effluents must involve the development of criteria to establish the release of phosphorus from sediments after reducing phosphorus loading to a river. Sediments vary in their capacity for uptake and release of phosphorus depending on the nature of the binding and occurrence in the sediment. If the sediment has a high loading of exchangeable phosphorus caused by exposure to a diluted sewage effluent, a high release of phosphorus may be expected; this will largely negate the effects of tertiary treatment even in the longer-term. In other sediments, the phosphorus is likely to be fixed by heterogeneous reactions in the sediment. This phosphorus will not be easily released and will contribute a minor component of the phosphorus load in the river subsequent to tertiary treatment.

The objectives of the project are: (a) to develop criteria for predicting whether a sediment will remove/release a substantial flux of phosphorus following a reduction in the river water concentrations of phosphorus and (b) to validate a proposed procedure by prediction using criteria developed above and measured at selected sites.

2. LABORATORY METHODS

The following IFE (River Laboratory) Standard Operating Procedures (SOPs) were used in this work. When other methods are used they are explained or referenced in the text. The SOPs are available to the DoE on request.

SOP: 26/20.7.94 Update none.	Particle size analysis of sediment samples.
SOP: 23/18.4.94 Update none.	The determination of the organic matter content of a sediment.
SOP: 22/14.3.94 Update none.	An ignition method for the determination of the total phosphorus in sediments.
SOP: 21/4.3.94 Update none.	Total phosphorus determination by persulphate digestion.
SOP: 20/7.3.94 Update none.	The determination of bioavailable phosphorus by iron oxide stripping.
SOP: 19/8.3.94 Update none.	The determination of the soluble reactive phosphorus in water by flow-injection analysis.
SOP: 15/12.8.93 Update 5.11.93	Conductivity measurement using Ciba-Corning M90 field meter.
SOP: 14/12.8.93 Update 5.11.93	Oxygen measurement using Ciba-Corning M90 meter
SOP: 13/12.8.93 Update 5.11.93	pH measurement using Ciba-Corning field meter.
SOP: 36/16.5.95 Update none	Determination of total suspended solids in water.

3. FURTHER DEVELOPMENT OF THE EQUILIBRIUM PHOSPHATE CONCENTRATION METHOD (EPC) FOR SEDIMENTS

3.1 Methodology

3.1.1 Preparation of sediment samples:

Sediment collected from the river Blackwater for the spring channel experiment (March - June 1997) was used. The sediment was sieved < 125 μm before the start of the channel experiment and stored for *ca* 3 months. The sediment was diluted by adding *ca* 7 dm^3 of 2 mmol dm^{-3} $CaCl_2$ to 3 dm^3 of wet sediment. The 10 dm^3 suspension was split into 2 (5 dm^3) samples: the first was sealed until the start of the experiment and periodically mixed by shaking; the second was mixed with a flask stirrer and bubbled with humidified air for *ca* 1 month. An extra sample of *ca* 280 g wet sediment (65 g dry) was used. This sample was washed sequentially by extracting the porewater by centrifugation, then resuspending the concentrated sediment in 2 mmol dm^{-3} $CaCl_2$ solution. The sediment was washed with a total of 12 changes of $CaCl_2$ (total volume of 3.6 dm^3). Samples of all the extracted solutions were retained for analysis of: SRP, Mn, Fe, Ca, Mg, Na, K, Cl and SO_4.

Four days before the experiment was started, the anaerobic sediment was well-mixed and known weights were transferred rapidly into 250 ml centrifuge bottles. 1 g of sucrose was also added to each of 6 of the samples. The headspaces of all of the bottles were purged with N_2, and the bottles sealed.

3.1.2 Batch Adsorption experiments

Seven batches were prepared as follows:

Batch A: 12 samples were prepared by using *ca* 2 g of centrifuged washed sediment, adding *ca* 200 ml of pre-chilled (10 °C) 2 mmol dm^{-3} $CaCl_2$ solution by weight and a phosphate spike of KH_2PO_4 standards prepared in 2 mmol dm^{-3} $CaCl_2$ added volumetrically to give initial phosphate concentrations in the range of 0 - 1.5 mmol dm^{-3}.

Batch B: 17 samples were prepared by using *ca* 200 g of the bubbled sediment suspension for 14 of the samples, and 1, 5 and 10 g of the sediment made up to 200 g with $CaCl_2$ for the remaining 3 samples. A phosphate spike of KH_2PO_4 standards prepared in 2 mmol dm^{-3} $CaCl_2$ was added volumetrically to augment the initial phosphate concentrations by 0 - 7 mmol dm^{-3}. In addition the initial calcium concentration of three of the samples was increased by 8 mmol dm^{-3} by addition of 1 ml of 1.6 mol dm^{-3} $CaCl_2$.

Batches C, D and E: 6 samples were prepared for each of these 3 batches, by mixing the bubbled and anaerobic sediment suspensions. For batch C a mixture of *ca* 75% : 25% (bubbled : anaerobic) was prepared; for batch D a mixture of *ca* 50 : 50 and for batch E a mixture of *ca* 25 : 75. The bubbled sediment was added rapidly by weight to the anaerobic sediment which had been weighed into the bottles 4 days previously, the phosphate spike (KH_2PO_4 standards prepared in 2 mmol dm^{-3} $CaCl_2$) was added volumetrically to augment the initial phosphate concentrations by 0 - 5 mmol dm^{-3}, the headspaces of all of the bottles were purged with N_2, and the bottles sealed.

Batch F: 6 samples were prepared by using *ca* 200 g of the anaerobic sediment suspension weighed out 4 days previously. A phosphate spike of KH_2PO_4 standards prepared in 2 mmol dm^{-3} $CaCl_2$ was added volumetrically to augment the initial phosphate concentrations by 0 - 3 mmol dm^{-3}. The headspaces of all of the bottles were purged with N_2, and the bottles sealed.

Batch G: 6 samples were prepared by using *ca* 200 g of the anaerobic sediment suspension weighed out 4 days previously, to which 1 g of sucrose had been added to each. A phosphate spike of KH_2PO_4 standards prepared in 2 mmol dm^{-3} $CaCl_2$ was added volumetrically to augment the initial phosphate concentrations by 0 - 2 mmol dm^{-3}. The headspaces of all of the bottles were purged with N_2, and the bottles sealed.

All of the samples were shaken at 10 °C for 24 hours, centrifuged at 10,000 rpm for 15 min and a sample of the supernatant filtered (<0.45 μm) for analysis. The pH, redox potential and temperature of the remaining supernatant was measured before discarding, and the pelleted sediment retained for analysis.

3.1.3 Analytical methods

Soluble Reactive Phosphorus was measured by Flow-Injection Analysis (SOP: 19/8.3.94) "Dissolved Ionic" manganese was measured by Atomic Absorption Spectroscopy: calibration range 0-4 mg dm^{-3}, wavelength 279.5 nm, oxidising air-acetylene flame, standards prepared from electrolytic grade manganese washed in 50 % v/v HNO_3, rinsed in DW then acetone & dried rapidly with heating. "Total dissolved" manganese was measured as for "dissolved ionic" Mn, after an acidic persulphate digestion. Fe^{2+} was measured spectrophotometrically after reaction with o-phenanthroline in acid conditions. $Fe^{(ionic)}$ was measured as for Fe^{2+} after reduction of Fe^{3+} with $NH_2OH.HCl$. $Fe^{(dissolved)}$ was measured by Atomic Absorption Spectroscopy: calibration range 0-10 mg dm^{-3}, wavelength 248.3 nm, oxidising air-acetylene flame, standards prepared using fresh ferrous ammonium sulphate ($FeSO_4(NH_4)_2SO_4.6H_2O$). "Total dissolved" Fe was measured as for $Fe^{(dissolved)}$, after an acidic persulphate digestion. Calcium, magnesium, sodium, potassium, chloride and sulphate were measured by weak ion-exchange chromatography. pH was measured by a Radiometer combination glass electrode, calibrated against pH = 4 and 7 buffer solutions. Redox potential was measured with a cleaned platinum electrode (heated in 50 % v/v H_2SO_4 for 1 h at 80-100 °C, then soaked overnight). The potential of a standard solution ($K_4Fe(CN)_6.3H_2O$ / $K_3Fe(CN)_6$) was measured as 235 mV at 20.4 °C. Data are given relative to a Ag/AgCl reference electrode, and also converted to the standard H scale. The total phosphorus, iron, manganese, calcium and magnesium contents of the sediments were measured after combustion and acid digestion.

3.2 Summary of results

The measurements indicated the greatest sorption by the sediment which had been washed and therefore some part of the more labile phosphorus removed and so exposing sites for subsequent sorption of soluble phosphorus (see Figure 1). The aerated sediment followed a Freundlich isotherm over the large range in SRP (most EPC_0 determination have been for concentrations < 10 µmol dm^{-3}). In comparison the sediment which was anoxic had the least affinity for SRP and had the greatest EPC_0 value. A comparison of EPC_0 values with the redox state of the sediments reveals that the EPC_0 increases as the sediment becomes more anaerobic (Figure 2). This result is consistent with the findings obtained in the fluvarium channel experiments when EPC_0 increased after removal of dissolved oxygen from the overlying water. This did not lead to a large increase in the release of SRP from the sediment but acted to stop release as the EPC_0 approached the SRP concentration in the overlying water. If such sediments were mechanically disturbed, there is no doubt that porewater containing high concentrations of phosphorus would be released in to the overlying water. The EPC_0s obtained in oxic conditions were similar to those measured in the R. Blackwater over the duration of the field monitoring.

These experiments have provided new insights into measurements of EPC_0 for aquatic sediments. The parameter is particularly useful as it provides information on the direction of the phosphorus flux between sediment and the overlying water and when incorporated in a kinetic model, such as the parabolic model, helps provide information on the magnitude of the flux. The protocol for the EPC_0 measurement must take into account the chemical (including redox) conditions of the sediment.

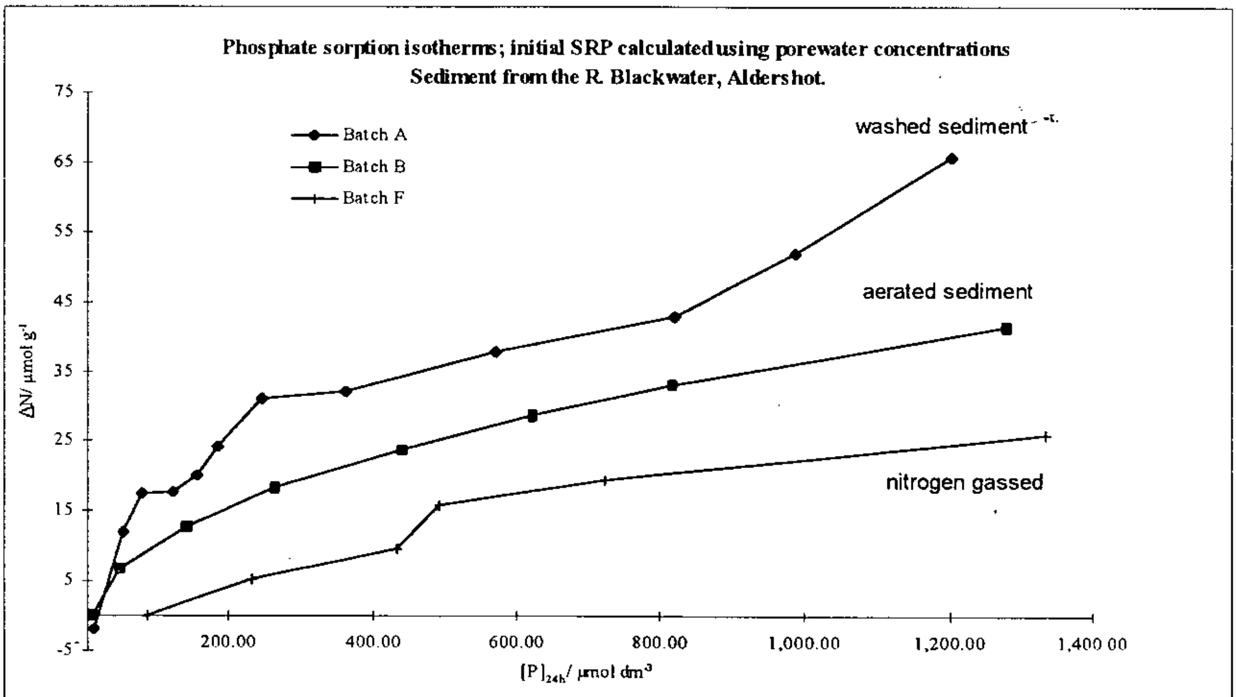


Figure 1. Comparison of the sorption isotherms for the R. Blackwater sediment measured for (a) a batch of washed sediment, (b) aerated sediment and (c) sediment which had been gassed with nitrogen.

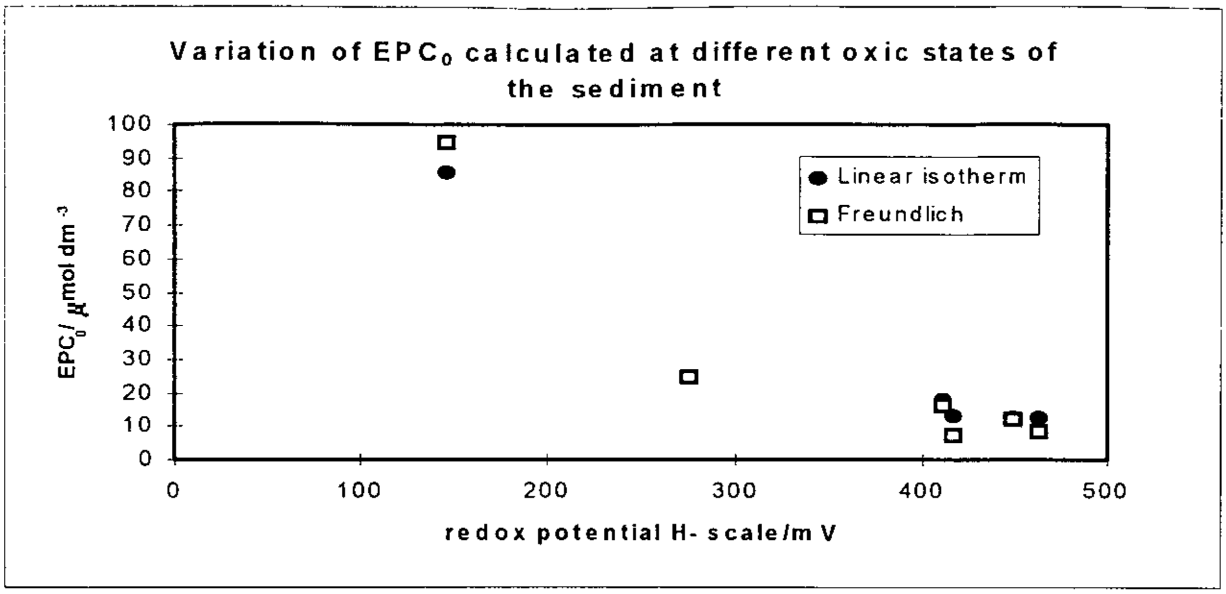


Figure 2. Variation of the EPC_0 values with the redox state of the sediments. EPC_0 values were calculated using either the linear isotherm (first 4 points) and the Freundlich isotherm using all the sorption points.

The full analysis of the results is not complete. Further work includes a detailed analysis of the composition of the porewaters using a chemical speciation program to obtain information about the likely mineralisation reactions. The initial results indicate that the porewaters are undersaturated or slightly oversaturated with respect to calcite and calcium phosphate minerals such as octacalcium phosphate, tricalcium phosphate and calcium hydroxyapatite. Further work is needed to examine possible reactions with iron/manganese and aluminium hydroxides/phosphates.

4. SUMMARY OF RESULTS OF FIELD SURVEYS

The results from the winter surveys of the R. Wey and Blackwater are shown in Appendix 1. The rivers were in high-flow following rainstorms in the catchments. The sites were the same as used in the field work reported in 1994-96. The river-bed sediments were analyzed for their contents of total calcium, iron and phosphorus as well as organic matter and used for isotherm determinations for the calculation of their EPC_0.

The results for the R. Wey over the period 21.9.94 - 7.8.95 are compared with the recent winter survey in Table 1. Site C is immediately downstream of the STW at Alton and site A is upstream of the STW (see Appendix 1 for the relative positions of the sampling sites). The river conditions on 6 January were close to those measured during a storm on 13 February 1995 but the water discharge was lower. The SRP concentrations measured during the winter surveys were similar but the soluble unreactive phosphorus (SUP) fraction (TDP-SRP) was much less in the last survey at all the sites. The TP concentrations were also lower during the last survey which again relates to the comparative importance of diffuse inputs of organic and particulate phosphorus during storm events. The SRP versus 1/Q relationship for the river reach (sites C to F, Appendix 1), are in good agreement with the equation for the dilution of a point input (r^2= 0.91) of 2.05 mmol s^{-1} which is lower than measured previously (7-9 mmol s^{-1}).

The results from the analysis of the bed-sediments are compared with previous results for sites A,C-F (Table 2). The EPC_0s and n_is are some of the lowest measured throughout the study but it is not clear whether this is a result of scouring of the bed sediments during the high flows experienced in the river during the 1997-98 winter, or a consequence of reduced phosphorus concentrations in the river. There is also an increase in the total iron content of the sediment compared with previous surveys for all the sites including site A which is upstream of the Alton STW. Future surveys will provide more information on seasonal aspects of these changes.

5. RELATED WORK

5.1 Paper accepted for publication in Water Research: Main results from the research on the R. Wey.

Phosphorus Transport in a Lowland River

William A. House and Frank H. Denison

Institute of Freshwater Ecology, River Laboratory, East Stoke, Wareham, Dorset, BH20 6BB, U.K.

Abstract - Seasonal changes in the concentration of phosphorus and other nutrients along a section of the river Wey in southern England are reported. Measurements of the water chemistry upstream and downstream of a point-discharge together with the analysis of surface bed-sediments indicates the accumulation of phosphorus in surface sediments in the spring and summer followed by a decrease in the autumn and winter. The profiles in the concentration of soluble reactive phosphorus (SRP) along a stretch of river are modelled by simulating the net loss of SRP using the Elovich equation and a parabolic equation. The results are compared with measurements of the release and uptake (in oxic and anoxic waters) in a laboratory fluvarium channel. The net loss of SRP in the spring survey are much greater than expected from the uptake of the bed-sediment alone as determined in the fluvarium channel experiments whereas the net uptakes estimated from the summer and autumn surveys are much less and in closer agreement with data from laboratory experiments.

5.2 LOIS research

The research on the Land Ocean Interaction Study (LOIS) has been completed and the results are in press. The special topics funded by NERC cover nutrient dynamics in the river Swale catchment in Yorkshire. The papers include:

House, W.A. and Warwick, M.S., (1998) Intensive measurements of nutrient dynamics in the River Swale, Sci. Tot. Environ., in press.

House, W.A. and Warwick, M.S., (1998) A mass-balance approach to quantifying the importance of in-stream processes during nutrient transport in a large river catchment, Sci. Tot. Environ., in press.

W.A. House and M.S. Warwick, (1998) Hysteresis of solute concentrations and discharge in rivers during storms, Water Res., in press.

5.3 Phosphorus detector

Progress on the Leverhulme Foundation project to develop a phosphate micro-electrode (10 μm tip) to measure phosphate concentration gradients in sediments and algal has been made with the testing of a ion-selective membrane. The initial results are encouraging with a linear calibration to approximately 1 μmol dm^{-3}.

7. FUTURE WORK

1. Field surveys will continue in the spring, summer and autumn in 1998 on the rivers Wey and Blackwater to access changes in phosphorus dynamics and phosphorus status of the river-bed sediments.
2. The porewaters from the assessment of the Equilibrium Phosphate Concentration (EPC_0) method will be investigated with respect to mineral equilibria using PHREEQ.
3. The data from the R. Blackwater will be assessed in more detail and summarized in the next report.

Table 1. Comparison of data obtained from the field surveys of the R. Wey from 1994-1998. Concentrations of phosphorus as soluble reactive, total dissolved , total (SRP, TDP and TP respectively) and dissolved silicon are in μmol dm^{-3}. Q is the river water discharge.

Date	SRP	TDP	TP	Si	Q/m^3 s^{-1}
site C					
21.9.94	68.80	74.70	73.70	253	0.25
13.2.95	16.43	44.48	>200	202	1.76
8.5.95	23.25	33.40	36.90	204	0.38
7.8.95	67.80	80.00	83.00	304	0.15
6.1.98	11.00	11.90	25.30	244	0.9
site D					
21.9.94	51.00	52.00	52.30	215.00	0.27
13.2.95	13.62	22.48	42.19	181.00	1.85
8.5.95	16.30	21.89	23.00	157.00	0.40
7.8.95	43.60	50.50	51.00	256.00	0.19
6.1.98	10.94	11.48	15.80	234.00	1.15
site E					
21.9.94	58.10	54.40	55.00	251.00	0.26
13.2.95	16.95	24.22	>200	219.00	2.34
8.5.95	13.88	18.40	19.40	161.00	0.54
7.8.95	41.00	53.50	54.00	299.00	0.19
6.1.98	10.56	11.04	13.80	253.00	1.22
site F					
21.9.94	48.60	44.90	-	267.00	0.55
13.2.95	13.04	25.07	>200	216.00	2.55
8.5.95	13.04	12.20	18.30	124.00	0.61
7.8.95	34.90	40.00	41.00	308.00	-
6.1.98	9.62	10.72	13.60	291.00	2.52
site A					
21.9.94	1.30	1.43	2.85	164.00	0.11
13.2.95	2.46	4.52	5.31	150.00	0.55
8.5.95	1.30	1.90	3.75	171.00	0.21
7.8.95	2.58	3.50	7.00	191.00	0.05
6.1.98	1.49	1.70	4.06	160.00	0.03

Table 2. . Comparison of data obtained from the field surveys of the R. Wey from 1994-1998. Key: EPC_0, Equilibrium Phosphate Concentration; n_i, "native" phosphorus; K_d, adsorption constant; TP, TCa and TFe are the total phosphorus, calcium and iron contents of the sediment respectively, and OM , organic matter content of the sediment (% by dry weight).

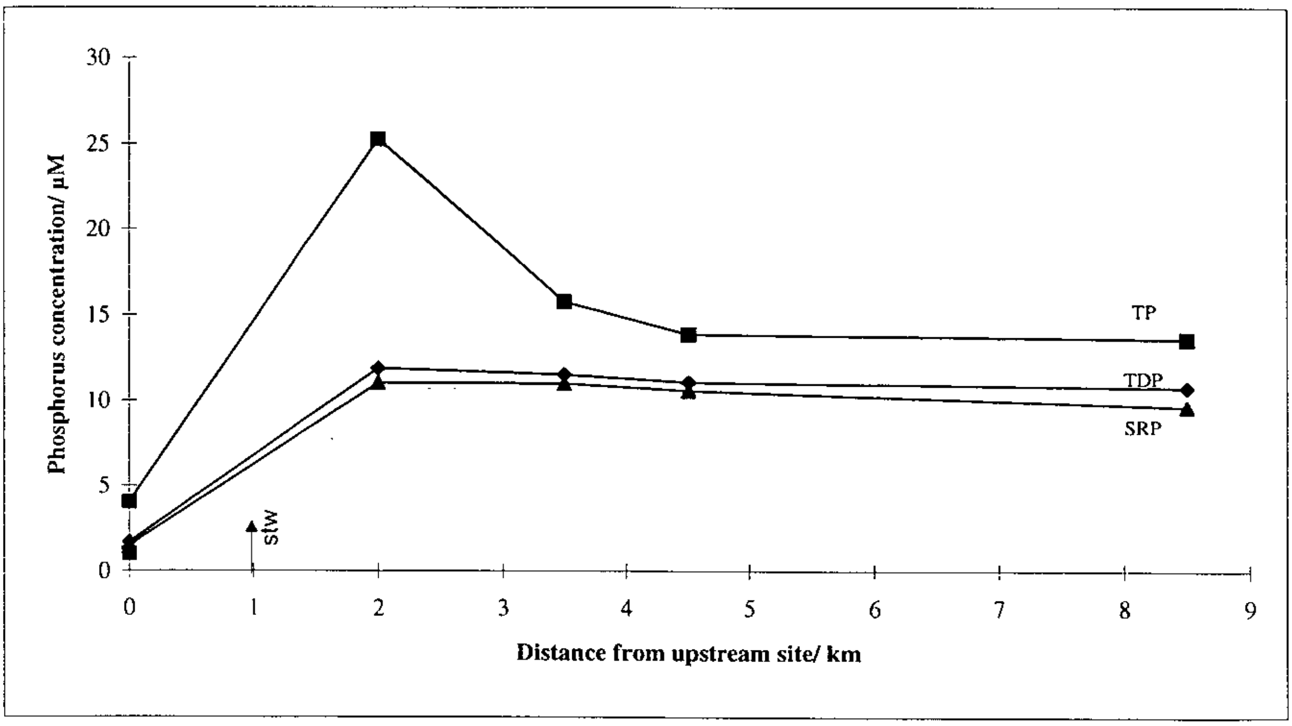
	EPC_0 /μmol dm^{-3}	n_i /μmol g^{-1}	K_d / ml g^{-1}	TP / μmol g^{-1}	TCa / μmol g^{-1}	TFe /μmol g^{-1}	OM /%
site C							
21.9.94	14.4	0.5	36.7	5.9	-	-	1.6
13.2.95	9.3	0.9	94.2	19.1	1177.0	417.0	1.6
8.5.95	10.2	0.6	54.0	22.4	1439.0	240.0	1.7
7.8.95	5.3	0.4	70.3	28.9	1692.0	146.5	2.7
6.1.98	2.7	0.1	41.0	39.0	1443.0	1036.0	3.6
site D							
21.9.94	1.9	2.0	1062.0	287.3	-	-	4.5
13.2.95	3.8	0.5	140.4	28.0	1084.0	596.0	3.1
8.5.95	13.3	0.8	56.6	24.5	1270.0	670.5	2.4
7.8.95	2.5	1.1	444.9	216.8	1460.0	708.2	4.2
6.1.98	1.8	0.2	92.0	86.0	3026.0	2172.0	2.9
site E							
21.9.94	6.9	0.5	65.4	4.1	-		2.0
13.2.95	5.9	0.6	95.3	14.0	1021.0	227.0	1.9
8.5.95	11.8	0.8	65.0	17.9	1566.0	230.4	3.0
7.8.95	4.0	0.5	131.1	40.4	1138.0	175.8	3.9
6.1.98	3.6	0.1	37.0	3.0	1615.0	1159.0	2.7
site F							
21.9.94	7.3	0.3	36.9	3.8	-	-	1.3
13.2.95	5.3	0.3	64.3	10.1	898.0	249.0	1.7
8.5.95	13.2	0.5	35.4	-	-	-	1.7
7.8.95	4.1	0.4	103.3	45.3	1441.0	115.4	2.3
6.1.98	7.6	0.3	33.0	49.0	1417.0	1017.0	6.9
site A							
21.9.94	2.2	0.2	68.1	1.9	-	-	1.5
13.2.95	1.7	0.1	77.7	4.3	1245.0	270.0	1.5
8.5.95	2.6	0.1	55.4	4.7	894.0	168.6	1.5
7.8.95	0.5	0.3	691.2	2.7	1204.0	348.0	6.0
6.1.98	0.3	0.2	528.0	11.0	1253.0	899.0	2.6

APPENDIX 1

RESULTS OF THE WINTER 1997/98 FIELD SURVEYS OF THE RIVERS WEY AND BLACKWATER

SITE VISIT TO RIVER WEY
06/01/98

SITE	A	B (tributary)	C	D	E	F
NGR of site	SU 724 396	SU 730 387	SU 733 403	SU 745 412	SU 756 417	SU 786 432
Distance from upstream site/ km	0.0	n/a	2.0	3.5	4.5	8.5
pH	7.30	7.25	7.13	7.03	7.18	7.00
Conductivity /µS cm^{-1}	646	504	551	625	551	540
Dissolved Oxygen /%	79	99	98	99	102	100
Temperature /°C	9.2	6.8	6.9	7.3	7.4	7.8
Flow $/m^3 s^{-1}$	0.03	-	0.90	1.15	1.22	2.52
Filtered water (0.45 µm)						
Ca^{2+} /mmol dm^{-3}	-	-	-	-	-	-
Mg^{2+} /mmol dm^{-3}	-	-	-	-	-	-
Na+ /mmol dm^{-3}	-	-	-	-	-	-
K^+ /mmol dm^{-3}	-	-	-	-	-	-
Alkalinity /mEq	-	-	-	-	-	-
NO_3^- /mmol dm^{-3}	0.29	0.00	0.63	0.66	0.67	0.67
Silicon /µmol dm^{-3}	160	281	244	234	253	291
Soluble Reactive Phosphorus /µmol dm^{-3}	1.49	11.3	11.0	10.94	10.56	9.62
Total Dissolved Phosphorus /µmol dm^{-3}	1.70	12.3	11.9	11.48	11.04	10.72
Non - MR Reactive fraction /µmol dm^{-3}	0.21	0.98	0.85	0.54	0.48	1.10
Unfiltered water						
Total Phosphorus /µmol dm^{-3}	4.06	13.7	25.3	15.8	13.8	13.6
Particulate Phosphorus /µmol dm^{-3}	2.36	1.4	13.4	4.3	2.8	2.9
Suspended Solids /mg dm^{-3}	20	25	234	75	33	32
Sediment sieved 2mm						
% water	21.2	-	23.2	27.7	22.7	53.8
Organic Matter (% of dry wt)	2.6	-	3.6	2.9	2.7	6.9
Total Phosphorus /µmol g^{-1}(dry weight)	11	-	39	86	3	49
Total Calcium /µmol g^{-1} (dry weight)	1253	-	1443	3026	1615	1417
Total Iron /µmol g^{-1}(dry weight)	899	-	1036	2172	1159	1017
Bioavailable Phosphorus /µmol g^{-1}	-	-	-	-	-	-
Equilibrium Phosphorus Concentration /µmol dm^{-3}	0.3	-	2.7	1.8	3.6	7.6
Kd $/dm^3 kg^{-1}$	528	-	41	92	37	33
n /µmol g^{-1}	0.16	-	0.11	0.16	0.13	0.25

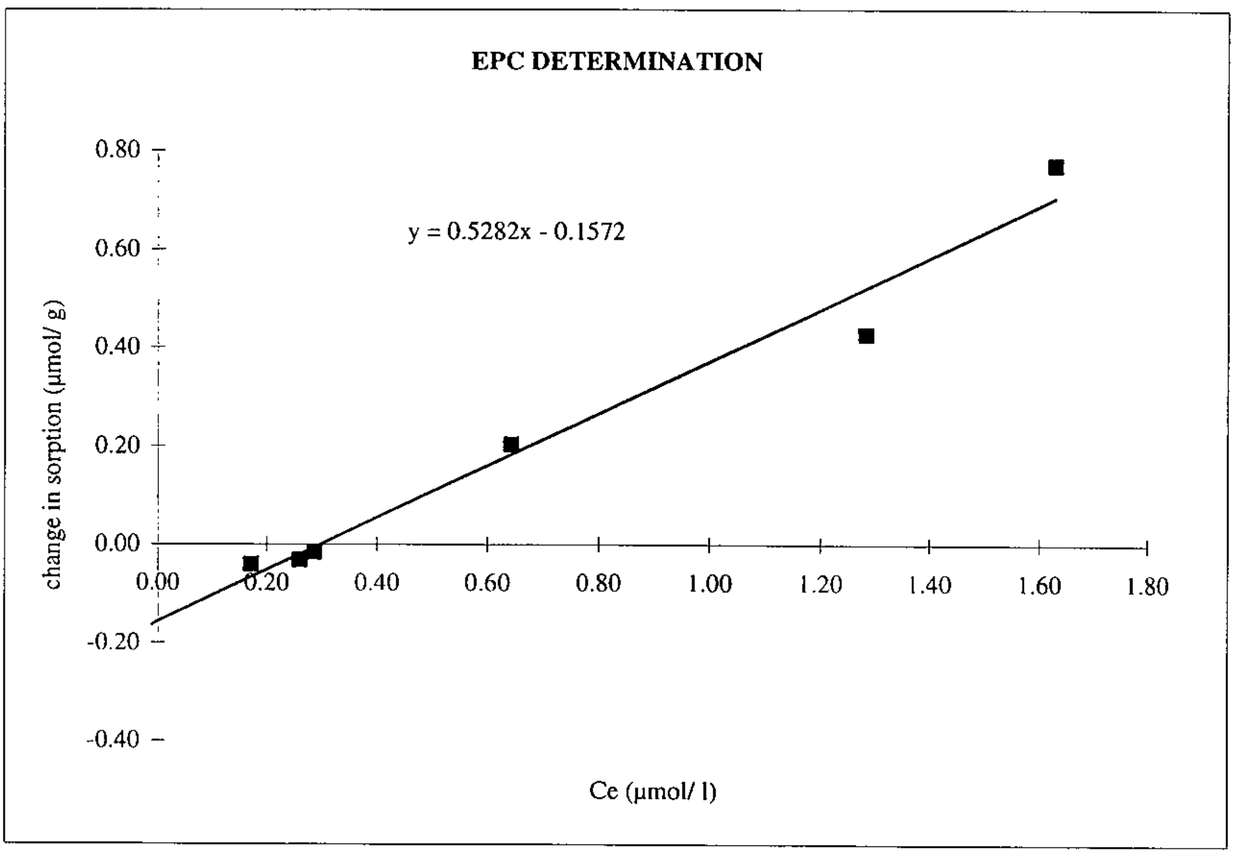


SITE A WEY. SEDIMENT & WATER COLLECTED 6/1/98

EPCo DETERMINATION				
weight of wet sediment/ g	weight of dry sediment/ g	initial [P] (μmol/ l)	[P] at 24 h (μmol/ l)	dN (μmol/ g dry wt)
1.0840	0.85	0.00	0.17	-0.04
2.1225	1.67	8.07	1.63	0.77
2.1040	1.66	0.00	0.26	-0.03
4.0315	3.18	8.07	1.28	0.43
4.2308	3.34	4.04	0.64	0.20
4.8049	3.79	0.00	0.29	-0.02

% water of sediment = 21.2
Organic matter of sediment as % of dry weight 2.6
Total phosphorus of sediment = 11 μmol/g
Total calcium of sediment = 1253 μmol/g
Total iron of sediment = 899 μmol/g

SRP of river water = 1.49 μmol/l
TDP of river water = 1.70 μmol/l
TP of river water = 4.06 μmol/l
EPCo = 0.3 μmol/l
Kd = 528 l/kg
ni = 0.16 μmol/g

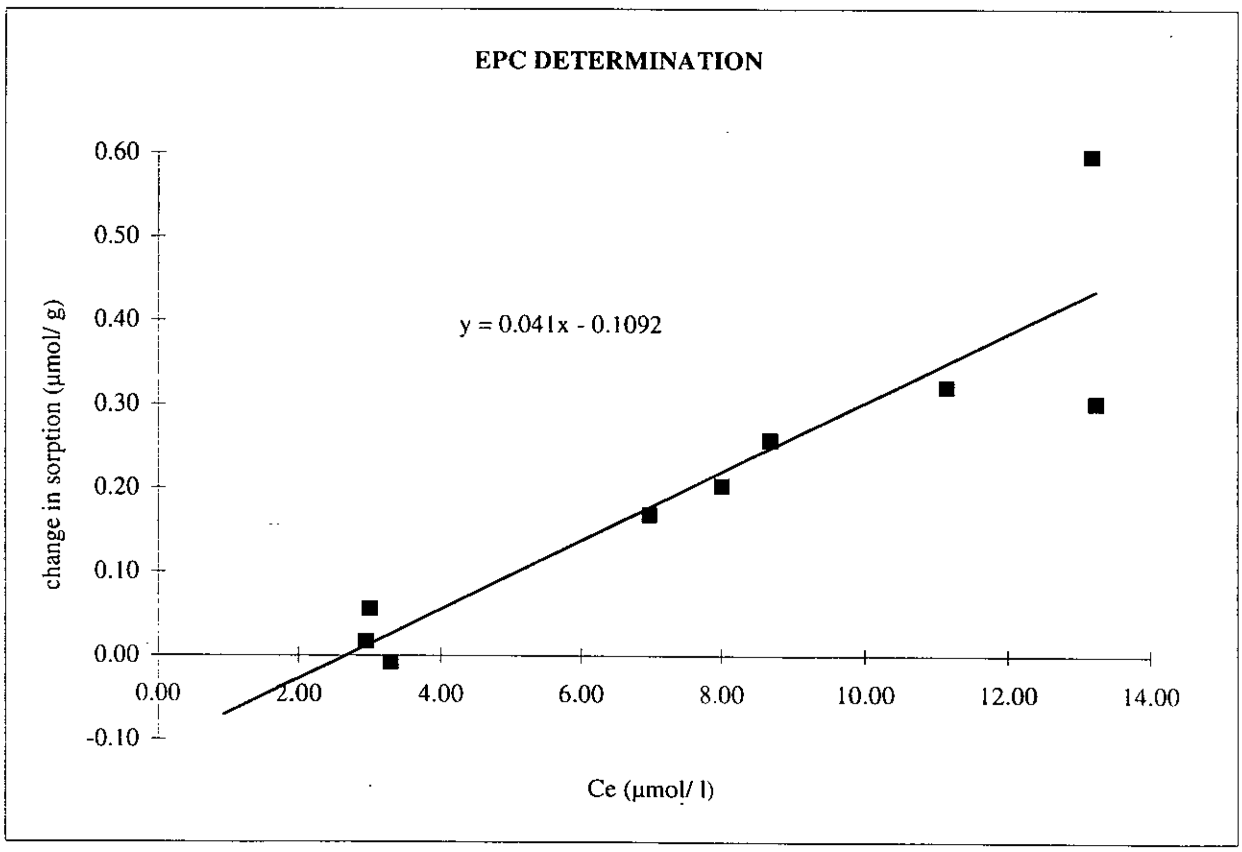


SITE C WEY. SEDIMENT & WATER COLLECTED 6/1/98

EPCo DETERMINATION				
weight of wet sediment/ g	weight of dry sediment/ g	initial [P] (μmol/ l)	[P] at 24 h (μmol/ l)	dN (μmol/ g dry wt)
1.2983	1.00	16.14	13.17	0.60
1.0155	0.78	9.69	8.68	0.26
1.0914	0.84	3.23	2.99	0.06
2.5125	1.93	16.14	13.24	0.30
2.1588	1.66	9.69	8.01	0.20
2.0534	1.58	3.23	3.29	-0.01
4.0723	3.13	16.14	11.14	0.32
4.2068	3.23	9.69	6.97	0.17
4.4511	3.42	3.23	2.94	0.02

% water of sediment = 23.2
Organic matter of sediment as % of dry weight 3.6
Total phosphorus of sediment = 39 μmol/g
Total calcium of sediment = 1443 μmol/g
Total iron of sediment = 1036 μmol/g

SRP of river water = 11.0 μmol/l
TDP of river water = 11.9 μmol/l
TP of river water = 25.3 μmol/l
EPCo = 2.7 μmol/l
Kd = 41 l/kg
ni = 0.11 μmol/g

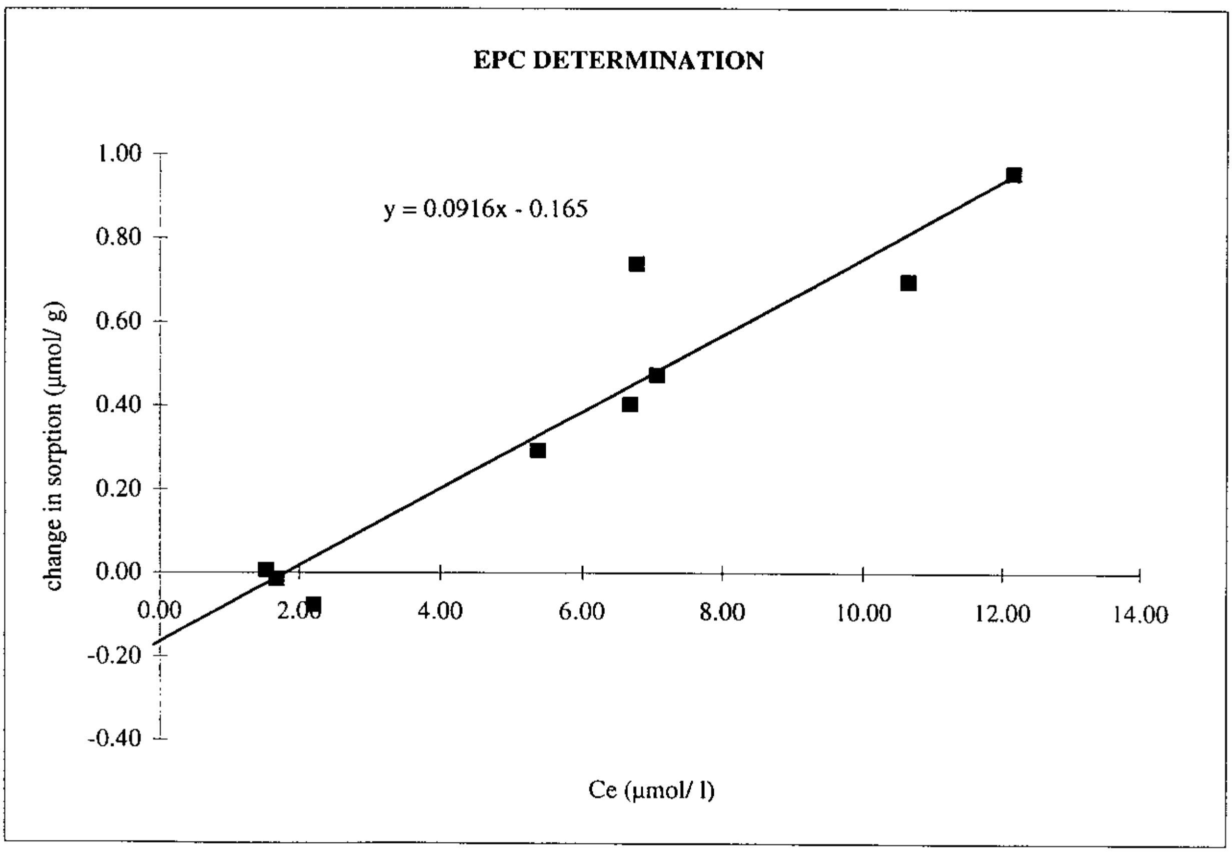


SITE D WEY. SEDIMENT & WATER COLLECTED 6/1/98

EPCo DETERMINATION				
weight of wet sediment/ g	weight of dry sediment/ g	initial [P] (μmol/ l)	[P] at 24 h (μmol/ l)	dN (μmol/ g dry wt)
1.1503	0.83	16.14	12.17	0.95
1.0857	0.79	9.69	6.78	0.74
1.1456	0.83	1.61	1.68	-0.01
2.1808	1.58	16.14	10.65	0.70
2.0601	1.49	9.69	6.68	0.40
2.1165	1.53	1.61	2.20	-0.08
5.2969	3.83	16.14	7.07	0.47
4.0404	2.92	9.69	5.39	0.29
4.0303	2.92	1.61	1.52	0.01

% water of sediment = 27.7
Organic matter of sediment as % of dry weight 2.9
Total phosphorus of sediment = 86 μmol/g
Total calcium of sediment = 3026 μmol/g
Total iron of sediment = 2172 μmol/g

SRP of river water = 10.94 μmol/l
TDP of river water = 11.48 μmol/l
TP of river water = 15.8 μmol/l
EPCo = 1.8 μmol/l
Kd = 92 l/kg
ni = 0.16 μmol/g

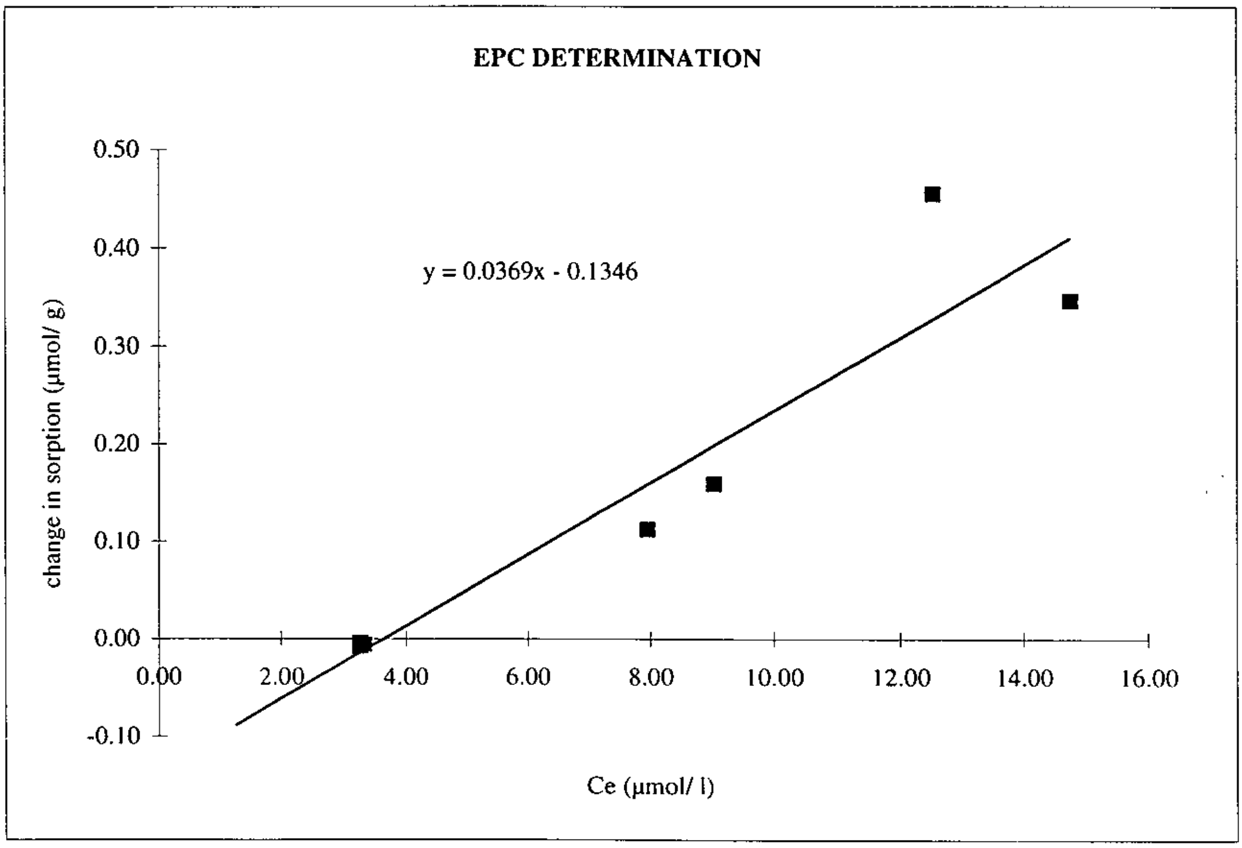


SITE E WEY. SEDIMENT & WATER COLLECTED 6/1/98

EPCo DETERMINATION				
weight of wet sediment/ g	weight of dry sediment/ g	initial [P] (μmol/ l)	[P] at 24 h (μmol/ l)	dN (μmol/ g dry wt)
1.0372	0.80	16.14	14.75	0.35
1.0492	0.81	9.69	9.04	0.16
1.0793	0.83	3.23	3.26	-0.01
2.0422	1.58	3.23	3.26	0.00
2.0553	1.59	16.14	12.53	0.45
4.0083	3.10	9.69	7.94	0.11
4.1181	3.18	3.23	3.33	-0.01
4.3673	3.38	0.00	0.00	0.00

% water of sediment =	22.7
Organic matter of sediment as % of dry weight	2.7
Total phosphorus of sediment =	3 μmol/g
Total calcium of sediment =	1615. μmol/g
Total iron of sediment =	1159. μmol/g

SRP of river water =	10.56 μmol/l
TDP of river water =	11.04 μmol/l
TP of river water =	13.8 μmol/l
EPCo =	3.6 μmol/l
Kd =	37 l/kg
ni =	0.13 μmol/g

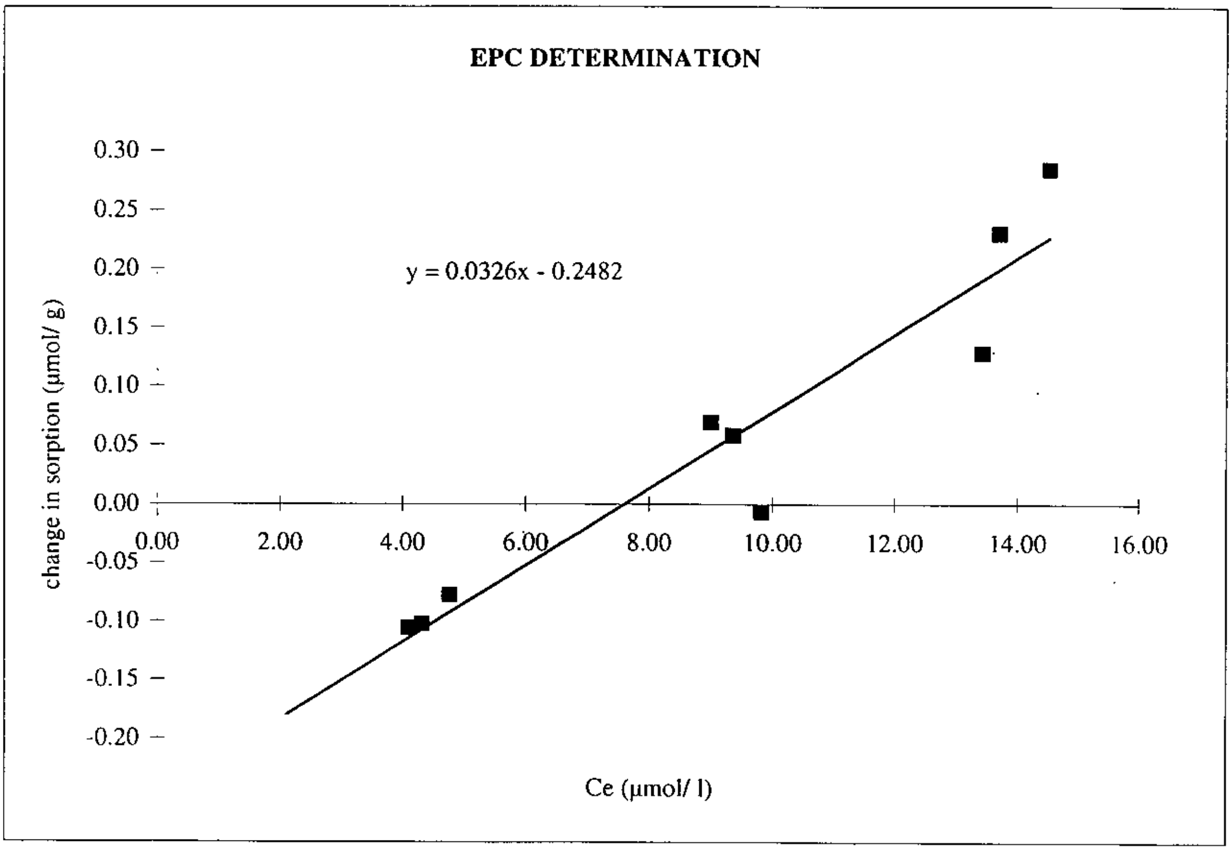


SITE F WEY. SEDIMENT & WATER COLLECTED 6/1/98

EPCo DETERMINATION				
weight of wet sediment/ g	weight of dry sediment/ g	initial [P] (µmol/ l)	[P] at 24 h (µmol/ l)	dN (µmol/ g dry wt)
1.1355	1.14	16.14	14.53	0.28
1.9628	1.96	9.69	9.01	0.07
1.6480	1.65	3.23	4.10	-0.11
2.1105	2.11	16.14	13.72	0.23
1.1083	1.11	9.69	9.36	0.06
2.1420	2.14	3.23	4.33	-0.10
4.2399	4.24	16.14	13.43	0.13
3.9220	3.92	9.69	9.81	-0.01
3.9970	4.00	3.23	4.78	-0.08

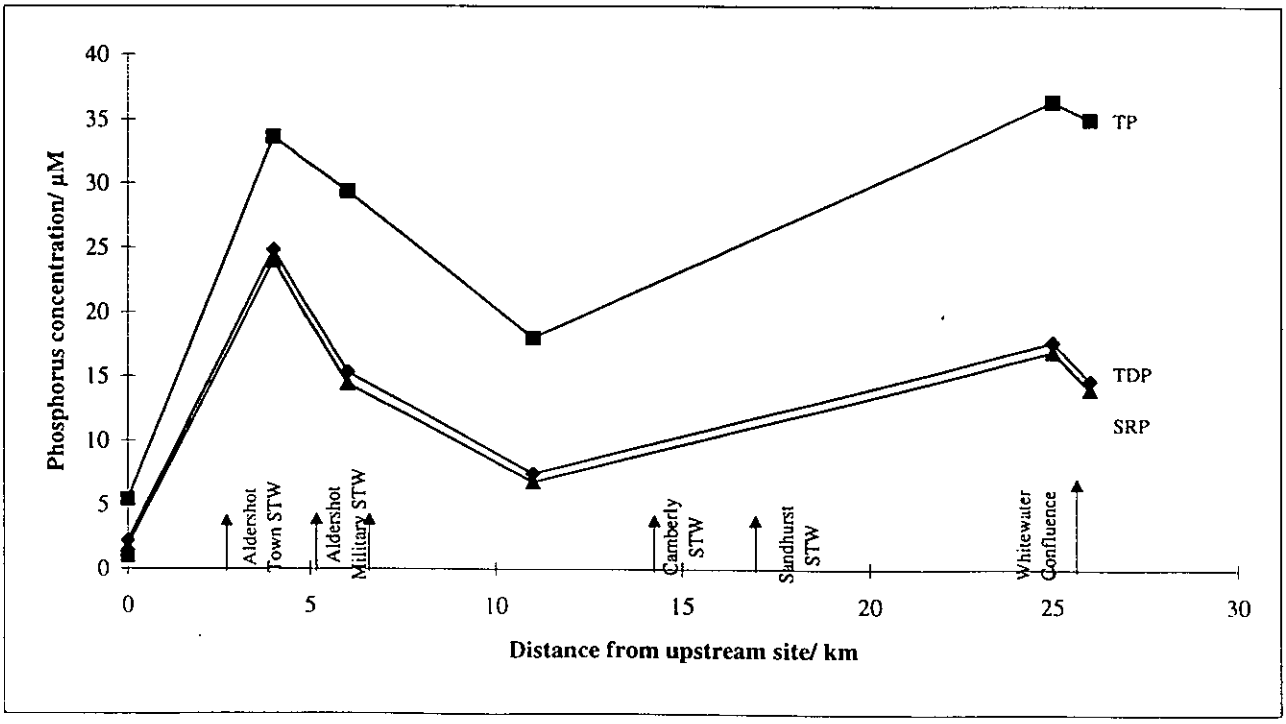
% water of sediment = 53.8
Organic matter of sediment as % of dry weight 6.9
Total phosphorus of sediment = 49 µmol/g
Total calcium of sediment = 1417 µmol/g
Total iron of sediment = 1017 µmol/g

SRP of river water = 9.62 µmol/l
TDP of river water = 10.72 µmol/l
TP of river water = 13.6 µmol/l
EPCo = 7.6 µmol/l
Kd = 33 l/kg
ni = 0.25 µmol/g



SITE VISIT TO RIVER BLACKWATER
16/01/98

SITE	A	B	C	D	E	G (Whitewater)	F
NGR of site	SU 882 499	SU 885 538	SU 880 559	SU 859 594	SU 742 634	SU 742 635	SU 740 638
Distance from upstream site/ km	0	4	6	11	25		26
pH	7.39	7.06	7.09	7.09	6.98	7.20	7.18
Conductivity /$\mu S\ cm^{-1}$	506	623	550	460	485	456	462
Dissolved Oxygen /%	86	81	82	88	86	93	89
Temperature /°C	8.3	8.3	8.9	8.5	8.4	7.6	8.7
Flow /$m^3 s^{-1}$	0.16	0.83	1.13	1.81	-	-	-
Filtered water (0.45 μm)							
Ca^{2+} /mmol dm^{-3}	-	-	-	-	-	-	-
Mg^{2+} /mmol dm^{-3}	-	-	-	-	-	-	-
Na+ /mmol dm^{-3}	-	-	-	-	-	-	-
K^+ /mmol dm^{-3}	-	-	-	-	-	-	-
Alkalinity /mEq	-	-	-	-	-	-	-
NO_3^- /mmol dm^{-3}	0.27	0.29	0.31	0.20	0.31	0.38	0.33
Silicon /μmol dm^{-3}	174	192	204	192	195	191	191
Soluble Reactive Phosphorus /μmol dm^{-3}	1.76	24.0	14.4	6.8	16.95	8.33	14.0
Total Dissolved Phosphorus /μmol dm^{-3}	2.20	24.8	15.3	7.4	17.7	9.19	14.7
Non - MR Reactive fraction /μmol dm^{-3}	0.44	0.8	0.9	0.6	0.7	6.40	0.7
Unfiltered water							
Total Phosphorus /μmol dm^{-3}	5.40	33.6	29.4	17.9	36.3	23.9	34.9
Particulate Phosphorus /μmol dm^{-3}	3.20	8.8	14.1	10.6	18.7	14.7	20.2
Suspended Solids /mg dm^{-3}	32	43	38	33	32	74	372
Sediment sieved 2mm							
% water	18.9	26.6	74.0	16.2	-	-	-
Organic Matter (% of dry wt)	2.4	2.8	19.1	13.6	-	-	-
Total Phosphorus /μmol g^{-1}	18	72	505	22	-	-	-
Total Calcium /μmol g^{-1}	275	147	704	12	-	-	-
Total Iron /μmol g^{-1}	198	105	505	9	-	-	-
Bioavailable Phosphorus /μmol g^{-1}	-	-	-	-	-	-	-
Equilibrium Phosphorus Concentration /μmol dm^{-3}	0.13	8.37	2.98	4.17	-	-	-
Kd /$dm^3 kg^{-1}$	408	481	3645	59	-	-	-
ni /μmol g^{-1}	0.05	4.02	10.85	0.25	-	-	-

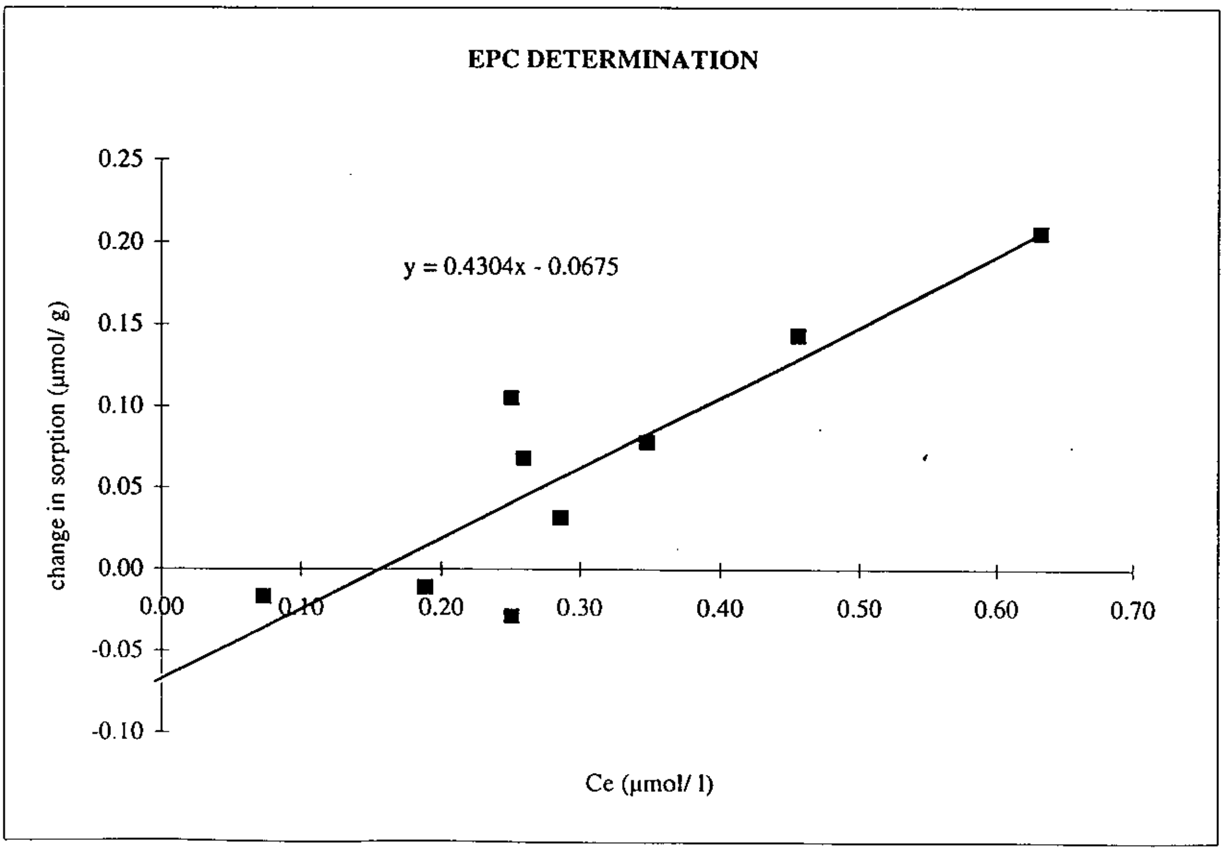


SITE A BLACKWATER, SEDIMENT & WATER COLLECTED 14/1/98

EPCo DETERMINATION				
weight of wet sediment/ g	weight of dry sediment/ g	initial [P] (μmol/ l)	[P] at 24 h (μmol/ l)	dN (μmol/ g dry wt)
1.1810	0.96	1.61	0.63	0.20
1.3083	1.06	0.81	0.25	0.10
1.0800	0.88	0.00	0.07	-0.02
1.9956	1.62	1.61	0.46	0.14
1.9848	1.61	0.81	0.26	0.07
2.1348	1.73	0.00	0.25	-0.03
3.9986	3.24	1.61	0.35	0.08
4.0327	3.27	0.81	0.29	0.03
4.2625	3.46	0.00	0.19	-0.01

% water of sediment = 18.9
Organic matter of sediment as % of dry weight 2.4
Total phosphorus of sediment = 18 μmol/g
Total calcium of sediment = 275 μmol/g
Total iron of sediment = 198 μmol/g

SRP of river water = 1.76 μmol/l
TDP of river water = 2.20 μmol/l
TP of river water = 5.40 μmol/l
EPCo = 0.13 μmol/l
Kd = 408 l/kg
ni = 0.05 μmol/g

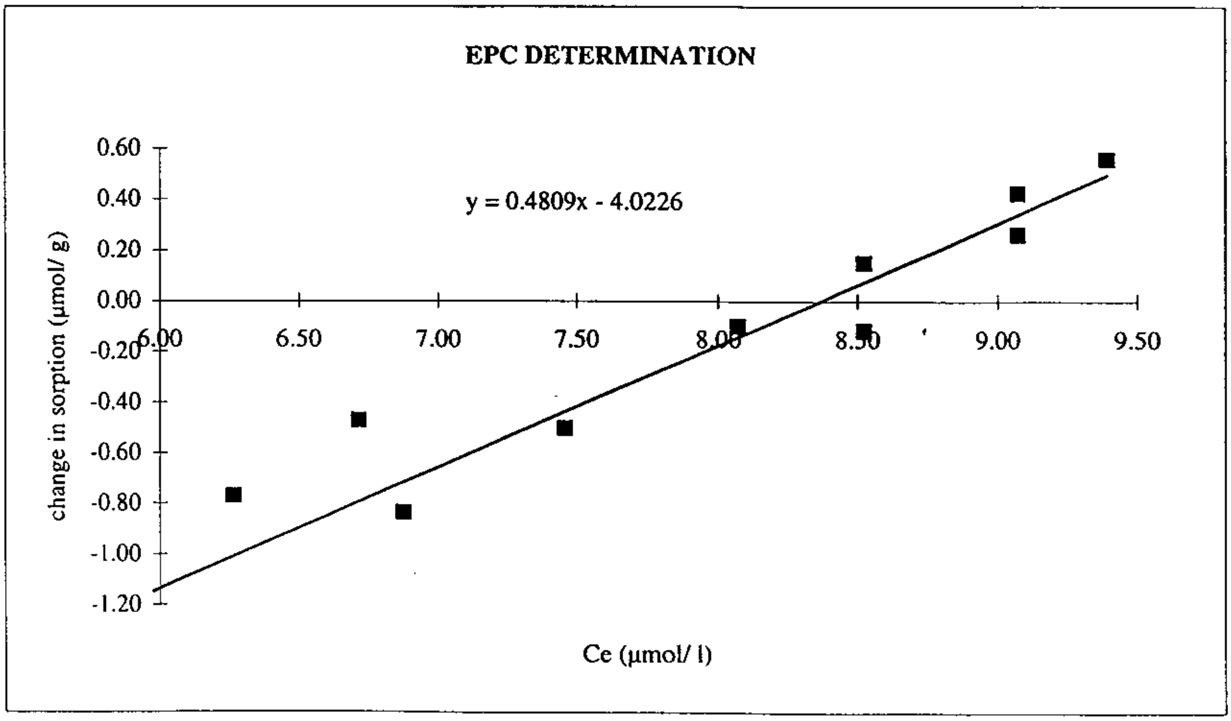


SITE B BLACKWATER, SEDIMENT & WATER COLLECTED 14/1/98

EPCo DETERMINATION				
weight of wet sediment/ g	weight of dry sediment/ g	initial [P] (µmol/ l)	[P] at 24 h (µmol/ l)	dN (µmol/ g dry wt)
4.5230	3.32	6.46	8.07	-0.10
1.1926	0.88	3.23	6.88	-0.83
1.2701	0.93	0.00	6.33	-1.36
4.8230	3.54	6.46	8.52	-0.12
2.0196	1.48	3.23	6.72	-0.47
2.2180	1.63	0.00	6.26	-0.77
4.0534	2.98	0.00	7.46	-0.50
3.2999	2.42	16.14	9.40	0.56
2.4703	1.81	12.91	9.07	0.42
2.3058	1.69	11.30	9.07	0.26
2.0957	1.54	9.69	8.52	0.15

% water of sediment = 26.6
Organic matter of sediment as % of dry weight 2.8
Total phosphorus of sediment = 72 µmol/g
Total calcium of sediment = 147 µmol/g
Total iron of sediment = 105 µmol/g

SRP of river water = 24.0 µmol/l
TDP of river water = 24.8 µmol/l
TP of river water = 33.6 µmol/l
EPCo = 8.37 µmol/l
Kd = 481 l/kg
ni = 4.02 µmol/g

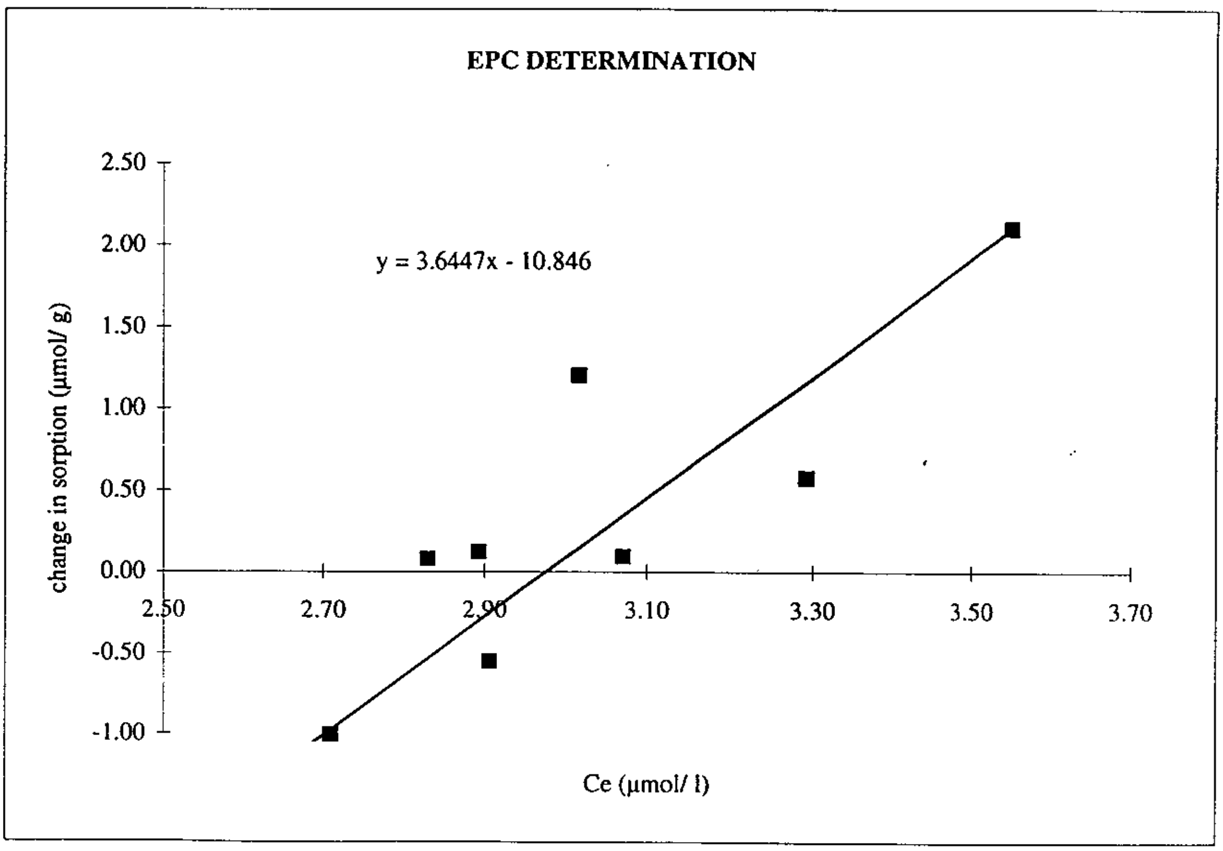


SITE C BLACKWATER, SEDIMENT & WATER COLLECTED 14/1/98

EPCo DETERMINATION				
weight of wet sediment/ g	weight of dry sediment/ g	initial [P] (µmol/ l)	[P] at 24 h (µmol/ l)	dN (µmol/ g dry wt)
1.0642	0.28	6.46	3.55	2.10
1.0653	0.28	0.00	2.70	-1.95
1.2529	0.33	3.23	3.07	0.10
2.2025	0.57	6.46	3.02	1.20
2.0970	0.55	3.23	2.89	0.12
2.0853	0.54	0.00	2.71	-1.00
4.2020	1.09	6.46	3.29	0.58
3.9330	1.02	3.23	2.83	0.08
4.0435	1.05	0.00	2.91	-0.55

% water of sediment =	74.0
Organic matter of sediment as % of dry weight	19.1
Total phosphorus of sediment	505 µmol/g
Total calcium of sediment =	704 µmol/g
Total iron of sediment =	505 µmol/g

SRP of river water =	14.4 µmol/l
TDP of river water =	15.3 µmol/l
TP of river water =	29.4 µmol/l
EPCo =	2.98 µmol/l
Kd =	3645 l/kg
ni =	10.85 µmol/g

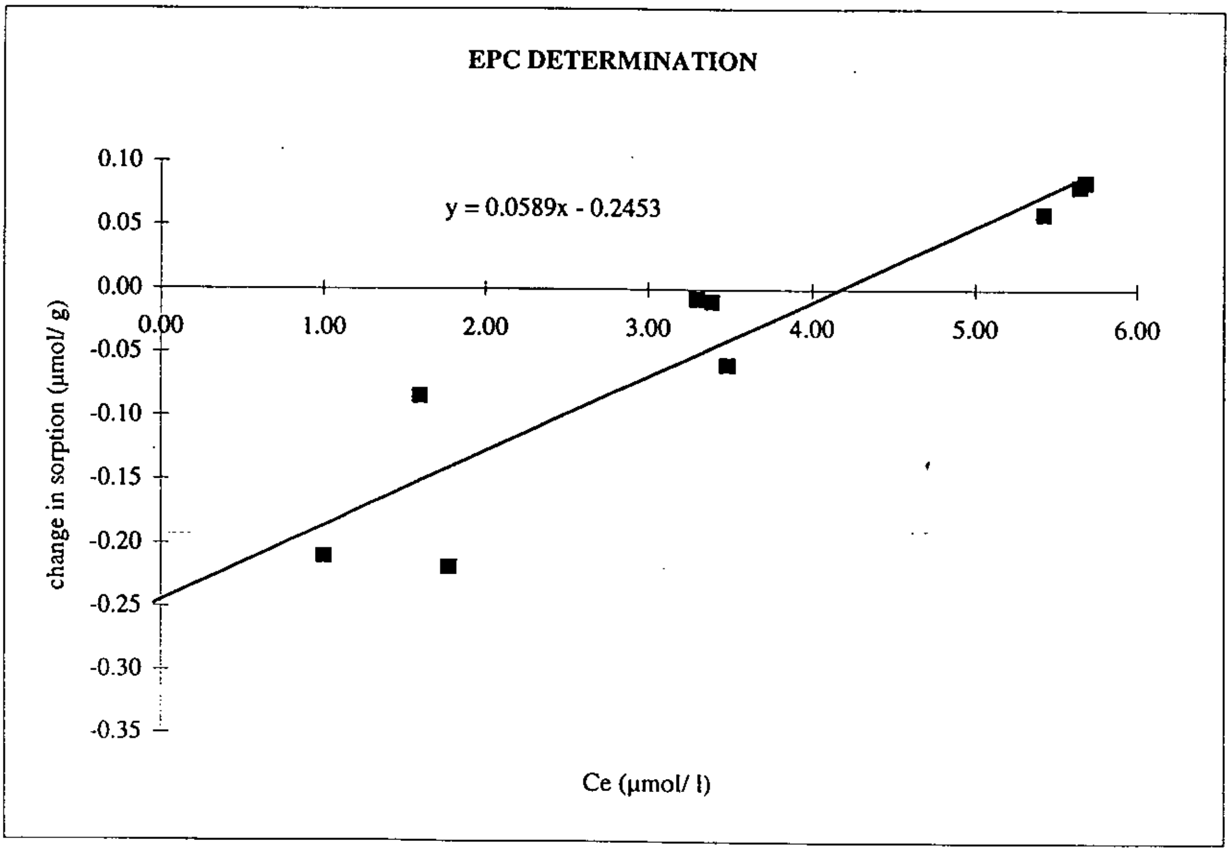


SITE D BLACKWATER, SEDIMENT & WATER COLLECTED 14/1/98

EPCo DETERMINATION				
weight of wet sediment/ g	weight of dry sediment/ g	initial [P] (μmol/ l)	[P] at 24 h (μmol/ l)	dN (μmol/ g dry wt)
2.3920	2.00	6.46	5.65	0.08
1.0419	0.87	3.23	3.49	-0.06
1.1395	0.95	0.00	1.00	-0.21
2.2055	1.85	6.46	5.68	0.08
2.0267	1.70	3.23	3.29	-0.01
1.9424	1.63	0.00	1.78	-0.22
4.1499	3.48	6.46	5.42	0.06
4.0320	3.38	3.23	3.39	-0.01
4.5363	3.80	0.00	1.60	-0.08

% water of sediment = 16.2
Organic matter of sediment as % of dry weight 13.6
Total phosphorus of sediment = 22 μmol/g
Total calcium of sediment = 12 μmol/g
Total iron of sediment = 9 μmol/g

SRP of river water = 6.78 μmol/l
TDP of river water = 7.38 μmol/l
TP of river water = 17.94 μmol/l
EPCo = 4.17 μmol/l
Kd = 59 l/kg
ni = 0.25 μmol/g



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