The control of phosphorus in the catchment of the Rivers Ant and Bure

Interim Report

January to December 1992

Alison Chilvers
Dr Geoff Phillips

NRA Anglian Region

Anglian Regional Operational Investigation 540

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NRA

National Rivers Authority

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This research was commissioned to monitor and assess the effects of phosphorus control in the catchments of the Rivers Bure and Ant in the Norfolk Broads. The report provides details of the research undertaken during 1992, and an assessment of the effects that ferric sulphate dosing of sewage treatment effluent, prior to discharge, has on these rivers.

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1. SUMMARY

Phosphorus removal at the major sewage treatment works discharging to the rivers Ant and Bure has continued during 1992. This has lead to a decrease in the total phosphorus load discharged from the sewage treatment works on the river Bure. R.A.F. Coltishall, in particular, has shown a marked improvement in the performance of the phosphorus removal process. At both Horning and Stalham sewage treatment works, which discharge to the river Ant, the total phosphorus load has increased slightly. This increase is associated with a rise in particulate phosphorus load. South Repps was the only sewage treatment works discharging to the river Ant to show a sustained decrease in total phosphorus load.

In 1992, the research programme was extended to include an assessment of the effects of ferric sulphate dosing on the rivers Ant and Bure. Measurements were made of the concentration of sulphate in the final effluent and at key sites along the river Ant. A sulphate budget, constructed for the Ant, showed that the load discharged from Stalham sewage treatment works represented 2.8% of the river load. In addition, a survey was carried out to investigate the total iron content of the river sediments in the vicinity of the sewage treatment works outfall pipes. Measurements of total iron concentration were made on sediment taken from up and down river of three sewage treatment works which discharge to the rivers Ant and Bure. Significant increases in total iron concentration were found at both Aylsham, on the river Bure, and Stalham, on the river Ant.

The reduced phosphorus load discharged to the river Bure from the sewage treatment works is reflected by a reduction in the total phosphorus load in the river at key sites; Ingworth Guaging Station, Horstead Mill and Wroxham Rail Bridge. The assessment of the effectiveness of phosphorus control at reducing the phosphorus supply to Broadland is shown to be further complicated by diffuse sources of soluble phosphorus at Ingworth and Horstead, phytoplankton uptake at Wroxham Rail Bridge, and river discharge. The relationship between total phosphorus and chlorophyll a concentration was investigated for Wroxham Broad. A reduction in the chlorophyll a concentration for 1992 was found despite the low river flows and hence increased retention time of the broad, which combine to enhance phytoplankton productivity. These data suggest that the continued reduction in phosphorus supply to the broads is leading to a reduction in phytoplankton productivity.

General monitoring of the tidal river Bure and its associated broads has continued. A reduction in phosphorus concentration was detected as far down river as Horning Ferry, however, there was no reduction in chlorophyll a concentration. The phosphorus concentrations of the river and broads in the middle reaches are not only affected by phosphorus supply from the catchment but also by phosphorus release from the sediment and tidal mixing. The detection of the effects of phosphorus control is complicated by the increase in retention times down river and the reduction in river discharge since 1990, enhancing phytoplankton productivity.

Monitoring of the river Ant and Barton Broad showed that despite a reduced phosphorus load being discharged to the river, chlorophyll a concentrations in the river have risen. The decrease in river discharge not only increased retention time but enabled the phytoplankton rich water from the lower reaches and Barton Broad to penetrate further up river.

Key Words: phosphorus, nutrient budget, phosphorus control, Norfolk Broads.

2. INTRODUCTION

2.1 Introduction

This project is one of a series of research projects aimed at the restoration of the Norfolk Broads being undertaken by the National Rivers Authority. It is funded as part of the Anglian Regions Operational Investigation Programme with contributions to the funding made by the Broads Authority and English Nature.

2.2 The Restoration Programme - Phosphorus Control

Research carried out in the 1970's associated the steady eutrophication of the broads with increasing concentrations of nitrogen and phosphorus. This increase in nutrient supply was due to growing populations leading to expanding sewage systems and a change in agricultural practice. The eutrophication of the broads has resulted in the loss of extensive submerged macrophyte communities and the present dominance by phytoplankton. Associated with this change to turbid, phytoplankton dominated water, is the reduction in diversity of macroinvertebrate communities and fish stocks and also an increase in the rate of erosion of the river banks.

An initial step towards the improvement of the degraded broads was thought to be the reduction in concentration of one of the key nutrients; thus limiting phytoplankton growth. Phosphorus is the easiest of the two key nutrients to control. It mainly enters the river system from a few point sources such as sewage treatment works which represent an accessible and continuous source of phosphorus.

Phosphorus control was introduced at the major sewage treatment works discharging to the river Ant in 1981 and the river Bure in 1986. Ferric sulphate is used to precipitate the soluble phosphorus from the sewage effluent. Phosphorus combines with the ferric sulphate to form an insoluble floc which can be sedimented out in the final sediment tanks of the sewage treatment process.

The Phosphorus Control project was set up in 1986 to determine the biological response of the rivers and broads to the reduction in phosphorus supply. This report details and reviews the results obtained by the project in 1992. Figure 2.1 illustrates the principal sampling stations located along both the rivers Ant and Bure.

2.3 Current Restoration Strategy for the Broads

Although it was realised that the recovery of the broads may take several years little biological change has actually been recorded despite reductions in the phosphorus load discharged to the rivers. Nutrient budgets constructed for Barton Broad during the course of the research project showed that the sediments of the Broads and rivers were also acting as an important source of phosphorus to the system. The control of this 'historic' nutrient load is the focus of another research project which is currently being undertaken. Detailed reports on this research have been produced (Jackson and Phillips, 1990; Pitt and Phillips, 1992).

Other investigations and observations during the 1980's lead to an understanding that feedback mechanisms also operate in lakes and that these tend to preserve phytoplankton dominance. The effects of phosphorus control upon reducing phytoplankton abundance is likely therefore to be minimal when undertaken in

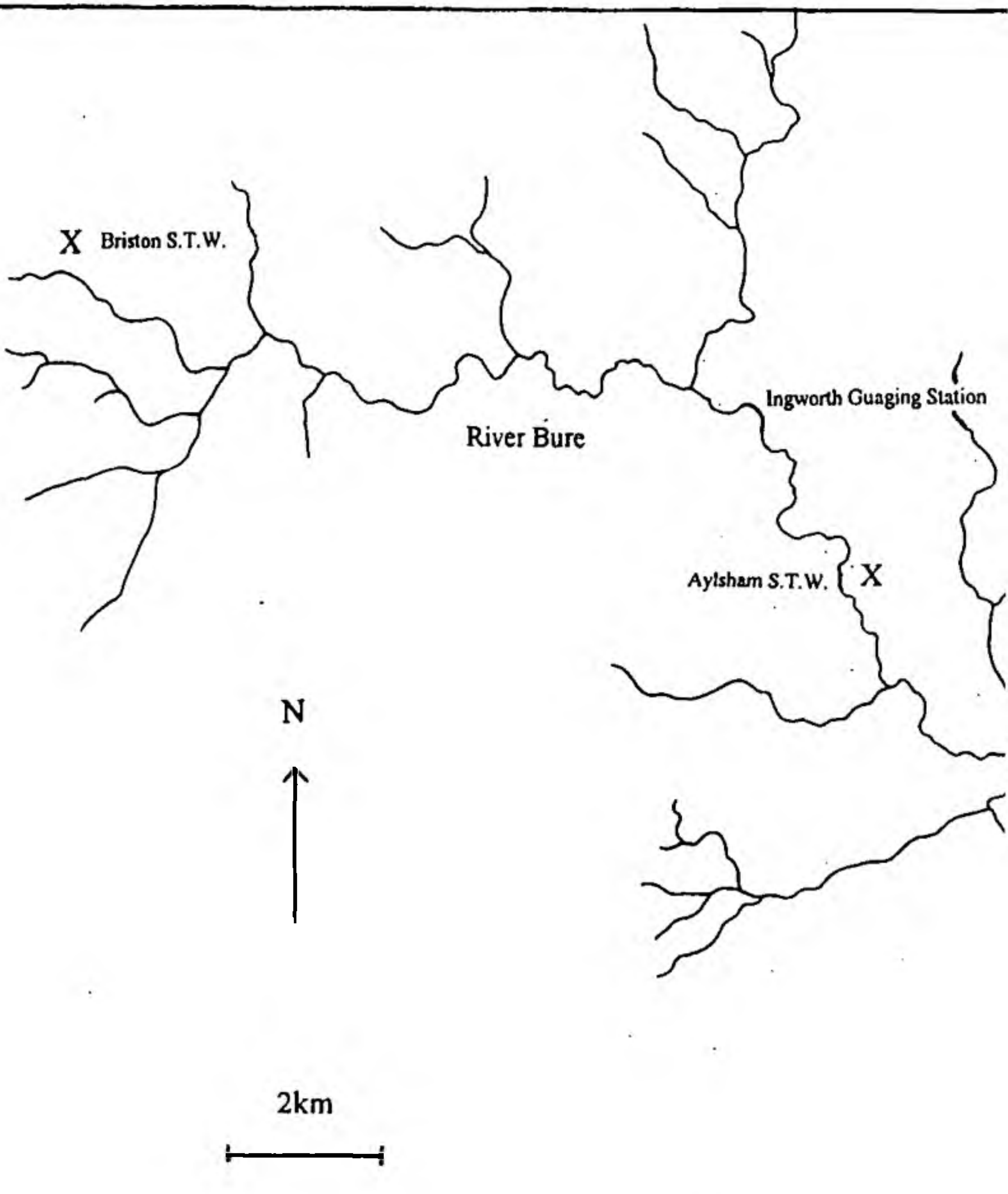
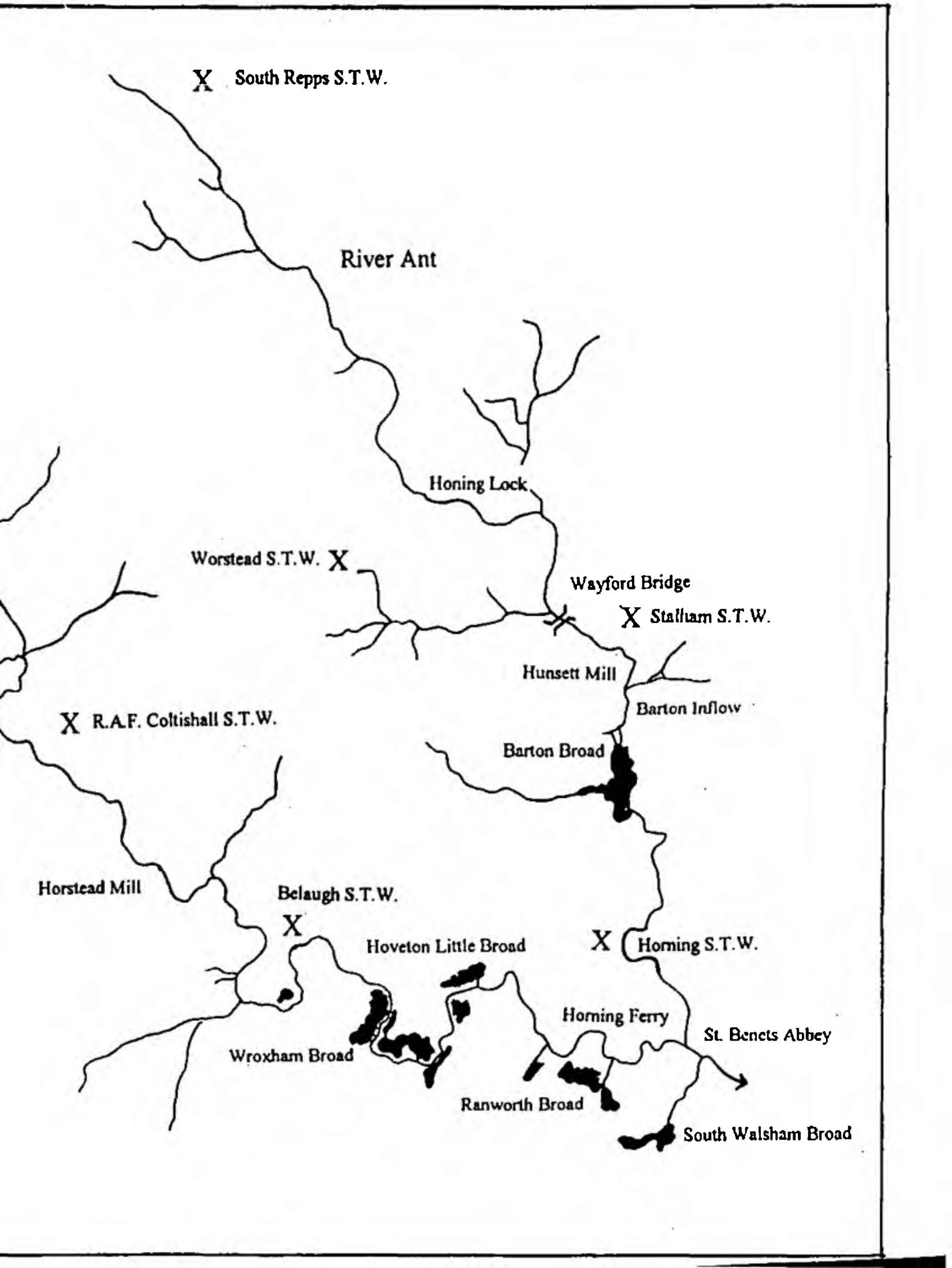


Figure 2.1 Map of sampling sites on Rivers Bure and Ant



South Repps S.T.W.
River Ant
Honing Lock
Worstead S.T.W.
Wayford Bridge
Stalham S.T.W.
Hunsett Mill
Barton Inflow
R.A.F. Coltishall S.T.W.
Barton Broad
Horstead Mill
Belaugh S.T.W.
Hoveton Little Broad
Horning S.T.W.
Horning Ferry
St. Benets Abbey
Wroxham Broad
Ranworth Broad
South Walsham Broad

isolation due to the stability of the phytoplankton dominated system. Research currently being carried out (Stansfield *et al*, 1993) utilising the management tool termed Bio-manipulation has resulted in the production of clear water environments within certain experimental broads. The use of bio-manipulation involves the promotion of grazing zooplankton by reducing the number of zoo-planktivorus fish. Grazing zooplankton assist in reducing phytoplankton numbers and hence provide the clear water necessary for macrophyte regeneration. Bio-manipulation is therefore important in that it enables a lake to move from a stable phytoplankton dominated system to one containing clear water. The stability of the clear water, plant dominated state is thought to be affected by increased nutrient supply and hence the control of phosphorus supply from the catchment is important if a clear water state is to be established.

The current restoration strategy for the Norfolk Broads is not based solely upon the reduction of nutrient supply but upon the interaction of a sequence of management steps which produce the desired switch from a turbid, phytoplankton dominated state to a clear water, macrophyte dominated state. The control of the supply of phosphorus to the rivers and broads is seen to be the inital step taken before other restoration measures,such as the use of bio-manipulation, can be sure of succeeding.

3. PHOSPHORUS REMOVAL FROM SEWAGE TREATMENT WORKS

3.1 Introduction

Monitoring of the phosphorus concentration discharged to the Rivers Ant and Bure has been maintained throughout 1992. Each sewage treatment works; Briston, Aylsham, R.A.F. Coltishall and Belaugh on the river Bure and Horning, Stalham, South Repps and Worstead on the river Ant, was visited weekly. Bulked samples were collected using automatic samplers which sampled the final effluent at hourly intervals over a seven day period.

The composite samples of final effluent were analysed for phosphorus (total P. and S.R.P.) at the Haddiscoe Laboratory. Sulphate analysis was also undertaken on a filtered sub-sample at the Peterborough Laboratory. Loading values were calculated using flows obtained for each works from Anglian Water plc.; where actual flows were not recorded an estimate was used.

Further to the phosphorus monitoring, samples were taken of the river sediment up and down river of the final effluent discharge and these were analysed for total iron.

3.2 Phosphorus Discharged From The Sewage Treatment Works

3.2.1 Phosphorus Discharged To The River Bure

The weekly fluctuations in the final effluent phosphorus concentration are illustrated in Figures 3.1 - 3.4. At Aylsham, Briston and Belaugh sewage treatment works the phosphorus concentration has been maintained at a reduced level throughout 1992. R.A.F. Coltishall, the P.S.A. controlled sewage treatment works, has shown a marked improvement in the performance of the phosphorus stripping process in comparison to previous years. Tables 3.1 and 3.2 provide a summary of the phosphorus concentration discharged in the form of quarterly and annual averages.

The phosphorus concentrations are converted to loadings in order to obtain a measure of the actual phosphorus load discharged to the river Bure and whether phosphorus stripping is having any effect on the phosphorus load in the river. Tables 3.3 and 3.4 show the quarterly and annual average final effluent phosphorus loadings. The changes in the loadings are much the same as those described for the phosphorus concentrations.

The annual total P. load discharged from Briston has continued to decrease despite an increased load in the January - March quarter. At Aylsham the total P. load has remained much the same for the past three years; representing a continuous period of effective stripping. The S.R.P. load, however, has decreased slightly in relation to the other years. This indicates an increase in particulate P. load being discharged to the river Bure. The phosphorus load discharged to the river Bure from Belaugh and R.A.F. Coltishall is the lowest since the phosphorus stripping was introduced.

Table 3.5 shows the percentage of phosphorus removed from the final effluent in comparison with the loading recorded prior to the introduction of phosphorus removal. At each of the three Anglian Water controlled sewage treatment works the percentage of phosphorus removed has been greater than 90%. The improvement in the

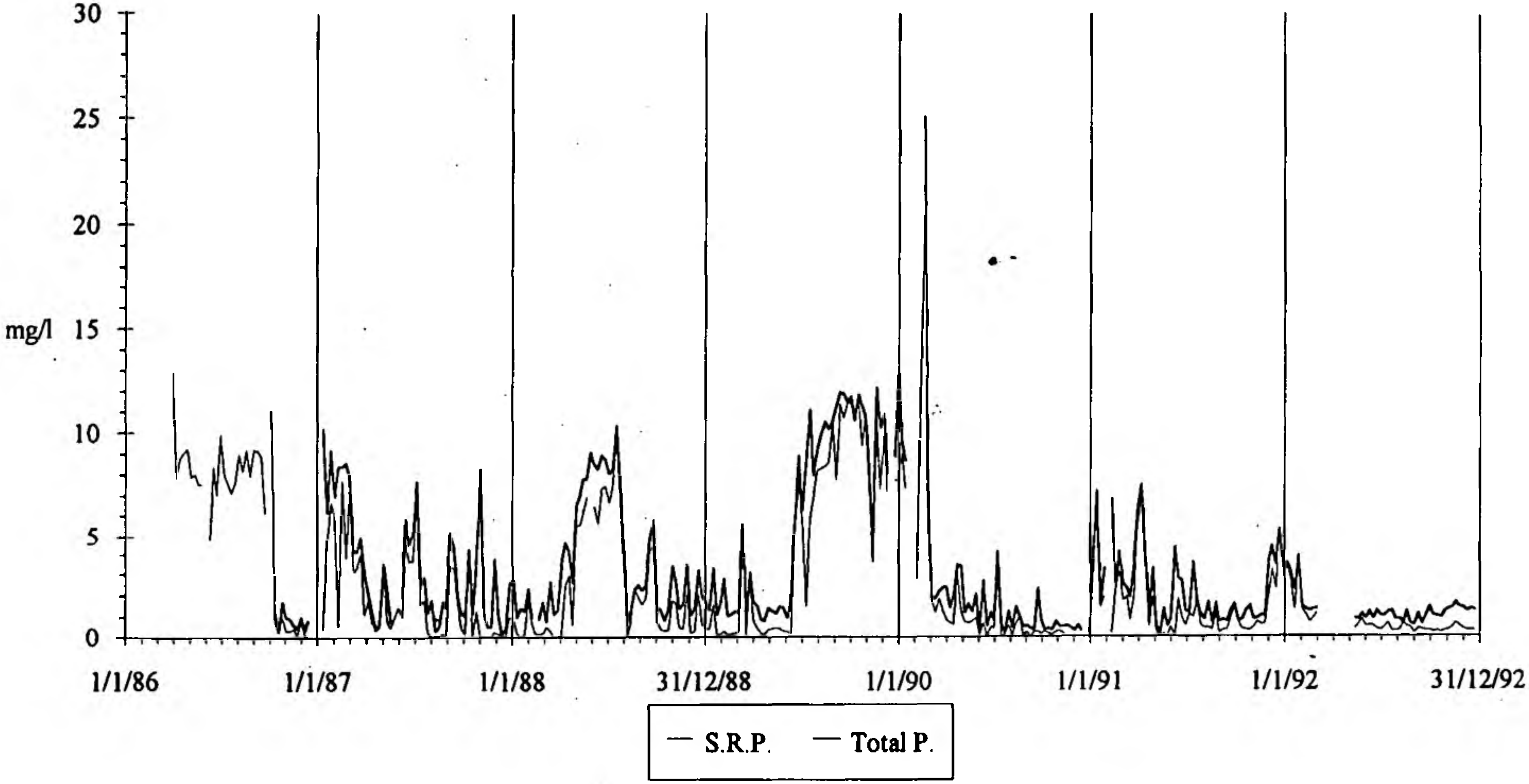


Figure 3.1 Briston Sewage Treatment Works: final effluent concentration (mg/l)

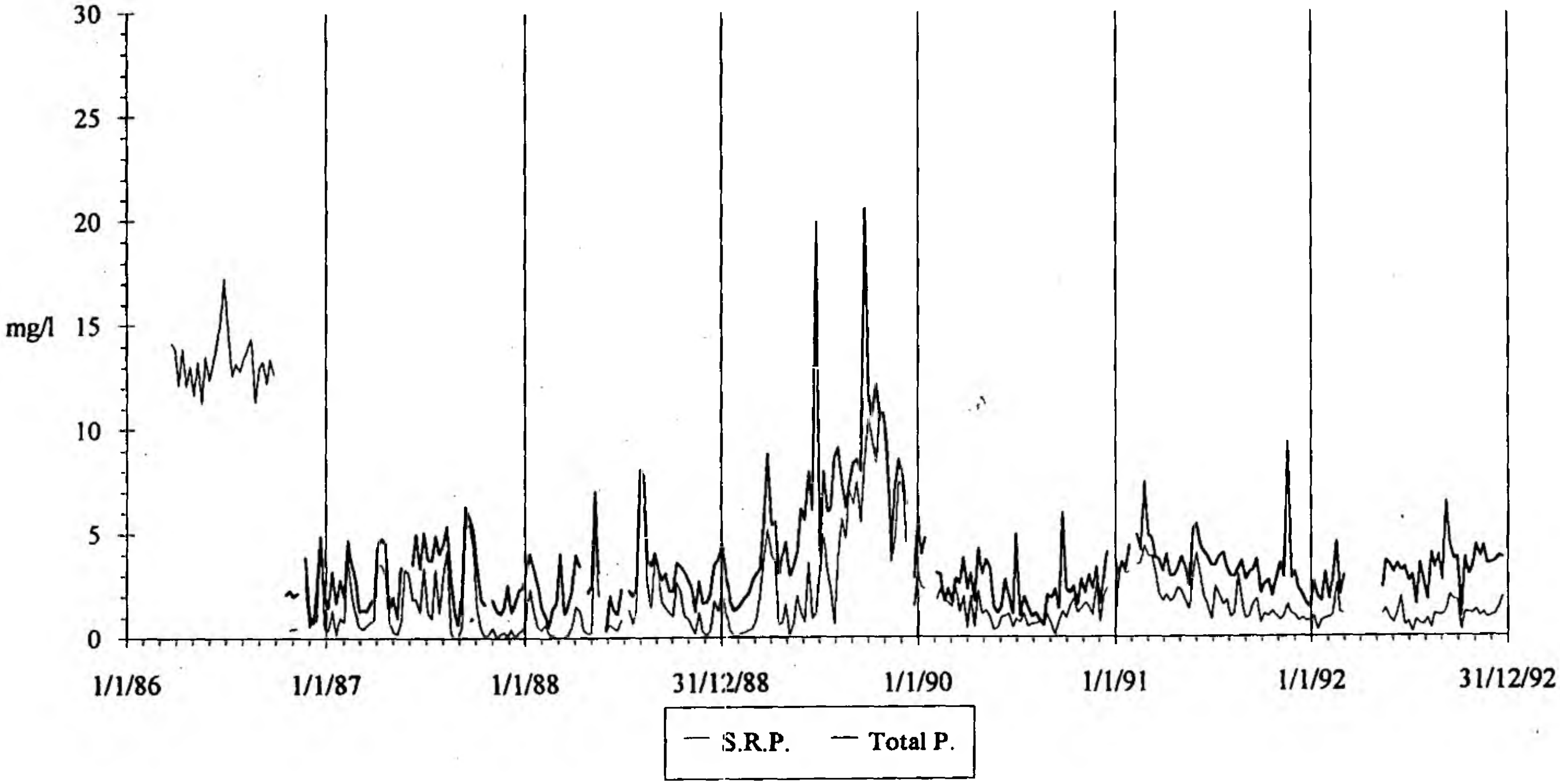


Figure 3.2 Aylsham Sewage Treatment Works: final effluent concentration (mg/l)

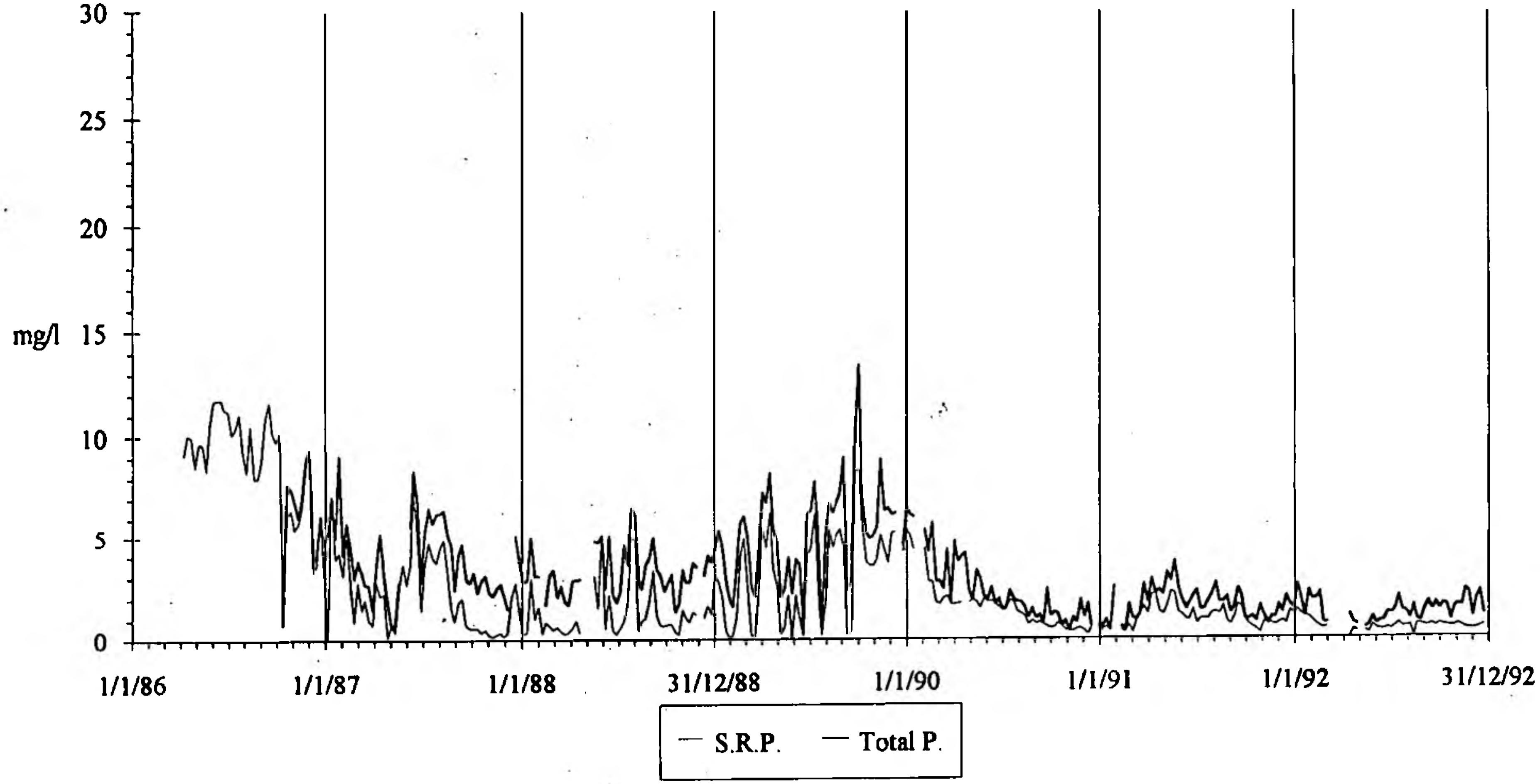


Figure 3.3 Belaugh Sewage Treatment Works: final effluent concentration (mg/l)

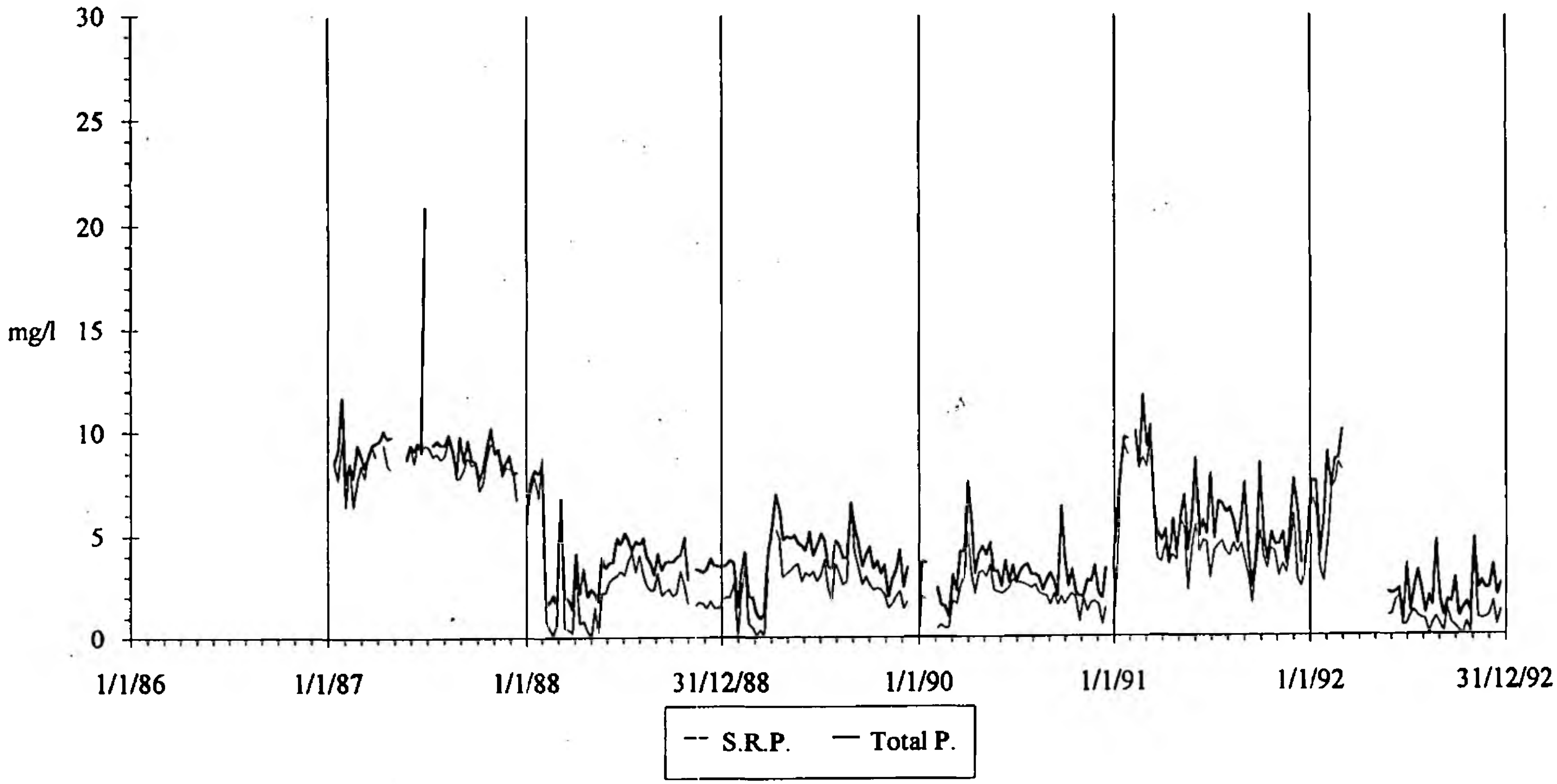


Figure 3.4 R.A.F. Coltishall Sewage Treatment Works: final effluent concentration (mg/l)

Table 3.1 River Bure, sewage treatment works total phosphorus concentrations

		mg/l Total -P			
		Briston	Aylsham	Belaugh	RAF Colt.
Quarterly					
April-June	1986	-	-	-	-
July-Sept	1986	-	-	-	-
Oct-Dec	1986	1.15	2.35	6.14	-
Jan-March	1987	6.84	2.31	4.03	8.93
April-June	1987	2.59	3.49	3.80	10.57
July-Sept	1987	2.54	2.87	4.90	9.18
Oct-Dec	1987	2.22	1.91	2.85	8.78
Jan-March	1988	1.53	2.18	2.82	4.30
April-June	1988	6.76	2.67	3.11	3.19
July-Sept	1988	4.70	3.76	3.88	2.96
Oct-Dec	1988	1.95	2.63	1.02	1.90
Jan-March	1989	2.04	3.17	3.86	1.38
April-June	1989	2.25	6.04	4.44	3.46
July-Sept	1989	10.40	8.33	5.86	3.31
Oct-Dec	1989	9.98	7.23	6.67	1.97
Jan-March	1990	7.97	3.22	4.43	2.78
April-June	1990	1.83	2.40	2.91	2.71
July-Sept	1990	1.09	2.02	1.59	2.20
Oct-Dec	1990	0.62	2.62	1.03	1.54
Jan-March	1991	3.58	4.33	1.18	8.57
April-June	1991	2.74	3.71	2.41	5.44
July-Sept	1991	1.37	3.23	1.88	5.78
Oct-Dec	1991	2.17	2.95	1.28	4.97
Jan-March	1992	2.07	2.56	1.53	7.24
April-June	1992	0.95	2.83	0.83	2.12
July-Sept	1992	0.98	3.35	1.40	2.20
Oct-Dec	1992	1.30	3.46	1.68	2.30
Annually					
1986 mean		1.15	2.35	6.14	-
1987 mean		3.52	2.89	3.92	9.31
1988 mean		3.78	2.80	3.23	3.84
1989 mean		6.02	6.46	5.18	3.90
1990 mean		2.45	2.54	2.41	3.22
1991 mean		2.47	3.56	1.69	6.19
1992 mean		1.31	3.11	1.38	3.39

Table 3.2 River Bure, sewage treatment works soluble reactive phosphorus concentration

		mg/l phosphate -P			
		Briston	Aylsham	Belaugh	RAF Colt.
Quarterly					
April-June	1986	8.01	13.31	10.30	-
July-Sept	1986	8.17	13.15	9.77	-
Oct-Dec	1986	1.49	1.60	5.78	-
Jan-March	1987	4.04	1.07	2.70	8.16
April-June	1987	1.81	2.06	2.70	8.78
July-Sept	1987	1.54	2.27	2.81	8.63
Oct-Dec	1987	0.52	0.31	0.75	8.25
Jan-March	1988	0.41	0.61	0.80	3.33
April-June	1988	4.79	1.13	1.38	1.66
July-Sept	1988	3.94	2.64	1.79	4.09
Oct-Dec	1988	0.88	1.04	3.04	3.63
Jan-March	1989	0.88	1.32	1.85	2.60
April-June	1989	1.31	1.61	2.52	5.01
July-Sept	1989	8.11	4.88	3.69	4.40
Oct-Dec	1989	8.92	8.48	4.74	3.21
Jan-March	1990	6.58	2.03	3.13	1.48
April-June	1990	0.84	0.99	1.79	3.77
July-Sept	1990	0.51	0.74	1.14	3.23
Oct-Dec	1990	0.12	1.44	0.43	2.58
Jan-March	1991	2.33	3.31	0.80	7.64
April-June	1991	1.75	2.13	1.55	4.32
July-Sept	1991	0.75	1.49	1.13	3.88
Oct-Dec	1991	1.53	0.97	0.74	3.87
Jan-March	1992	1.81	1.05	0.77	6.11
April-June	1992	0.45	0.93	0.34	1.31
July-Sept	1992	0.37	0.97	0.53	0.69
Oct-Dec	1992	0.34	1.08	0.51	0.98
Annually					
1986 mean		6.08	10.00	8.64	-
1987 mean		1.94	1.43	2.24	8.44
1988 mean		2.46	1.35	1.25	2.49
1989 mean		4.72	3.69	3.17	2.57
1990 mean		1.83	1.27	1.56	2.09
1991 mean		1.59	1.98	1.06	4.93
1992 mean		0.68	1.01	0.54	2.06

Table 3.3 River Bure, sewage treatment works total phosphorus loads

		kg/d Total -P			
		Briston	Aylsham	Belaugh	RAF Colt.
Quarterly					
April-June	1986	-	-	-	-
July-Sept	1986	-	-	-	-
Oct-Dec	1986	0.47	2.59	8.30	-
Jan-March	1987	2.81	2.46	4.94	6.04
April-June	1987	1.06	4.26	5.20	6.72
July-Sept	1987	1.04	4.93	8.13	5.84
Oct-Dec	1987	0.91	2.55	5.08	5.59
Jan-March	1988	0.63	3.21	5.96	2.73
April-June	1988	2.77	3.54	4.37	2.03
July-Sept	1988	1.93	4.97	4.94	2.60
Oct-Dec	1988	0.80	2.98	3.61	2.31
Jan-March	1989	0.84	3.96	4.84	1.66
April-June	1989	0.96	9.08	7.29	3.19
July-Sept	1989	4.19	11.71	8.46	2.80
Oct-Dec	1989	4.09	13.31	9.07	2.04
Jan-March	1990	3.27	4.08	5.83	1.77
April-June	1990	0.75	2.78	3.66	2.40
July-Sept	1990	0.45	2.39	2.08	2.06
Oct-Dec	1990	0.26	2.94	1.59	1.61
Jan-March	1991	1.47	4.39	1.42	5.45
April-June	1991	1.12	3.73	2.67	3.46
July-Sept	1991	0.56	2.87	2.10	3.87
Oct-Dec	1991	0.89	2.90	1.53	3.16
Jan-March	1992	0.85	2.39	1.80	4.60
April-June	1992	0.39	2.43	0.99	1.35
July-Sept	1992	0.40	4.08	1.68	1.40
Oct-Dec	1992	0.53	3.34	2.02	1.46
Annually					
1986 mean		-	-	-	-
1987 mean		1.44	3.54	5.88	5.92
1988 mean		1.55	3.66	4.73	2.44
1989 mean		2.48	9.44	7.38	2.48
1990 mean		1.01	3.00	3.19	2.04
1991 mean		0.98	3.42	1.95	3.92
1992 mean		0.54	3.20	1.65	2.15

Table 3.4 River Bure, sewage treatment works soluble phosphorus loads

		kg/d phosphate -P			
		Briston	Aylsham	Belaugh	RAF Colt.
Quarterly					
April-June	1986	3.28	14.75	13.01	-
July-Sept	1986	3.35	15.40	12.29	-
Oct-Dec	1986	0.26	1.78	7.62	-
Jan-March	1987	1.65	1.13	3.23	5.59
April-June	1987	0.74	2.51	3.66	5.58
July-Sept	1987	0.63	2.85	4.28	5.45
Oct-Dec	1987	0.21	0.46	1.22	5.25
Jan-March	1988	0.17	0.85	1.69	2.11
April-June	1988	1.97	1.52	2.18	1.06
July-Sept	1988	1.62	3.47	2.27	1.88
Oct-Dec	1988	0.36	1.19	1.21	1.21
Jan-March	1989	0.36	1.65	2.38	0.88
April-June	1989	0.54	2.22	4.41	2.20
July-Sept	1989	3.32	6.85	5.34	2.11
Oct-Dec	1989	3.66	11.35	6.44	1.25
Jan-March	1990	2.70	2.58	4.06	0.94
April-June	1990	0.35	1.15	2.25	1.72
July-Sept	1990	0.21	0.88	1.51	1.40
Oct-Dec	1990	0.05	1.59	0.68	0.98
Jan-March	1991	0.95	3.41	0.96	4.86
April-June	1991	0.71	2.13	1.73	2.74
July-Sept	1991	0.31	1.34	1.25	2.64
Oct-Dec	1991	0.63	0.92	0.87	2.46
Jan-March	1992	0.74	0.95	0.94	3.88
April-June	1992	0.19	0.80	0.41	0.84
July-Sept	1992	0.15	1.13	0.64	0.44
Oct-Dec	1992	0.14	1.04	0.61	0.63
Annually					
1986 mean		2.49	11.52	11.02	-
1987 mean		0.79	1.74	3.10	5.37
1988 mean		1.01	1.74	1.84	1.58
1989 mean		1.94	5.40	4.61	1.63
1990 mean		0.75	1.51	2.04	1.33
1991 mean		0.63	1.88	1.21	3.10
1992 mean		0.28	1.00	0.65	1.31

Table 3.5 River Bure, sewage treatment works quarterly % phosphate-P removal

		% removal			
		Briston	Aylsham	Belaugh	RAF Colt.
Quarterly					
Oct-Dec	1986	82	88	40	-
Jan-March	1987	51	93	75	-
April-June	1987	78	83	71	-
July-Sept	1987	81	81	66	-
Oct-Dec	1987	94	93	91	-
Jan-March	1988	95	94	87	62
April-June	1988	41	90	94	80
July-Sept	1988	52	77	82	66
Oct-Dec	1988	89	92	91	78
Jan-March	1989	89	89	81	84
April-June	1989	84	85	65	60
July-Sept	1989	1	55	58	62
Oct-Dec	1989	0	25	53	76
Jan-March	1990	19	82	68	83
April-June	1990	90	92	82	69
July-Sept	1990	94	94	88	75
Oct-Dec	1990	99	90	95	82
Jan-March	1991	71	77	92	11
April-June	1991	79	86	86	50
July-Sept	1991	91	91	90	52
Oct-Dec	1991	81	94	93	55
Jan-March	1992	78	92	93	30
April-June	1992	95	93	97	85
July-Sept	1992	96	93	95	92
Oct-Dec	1992	96	92	95	88

performance of the phosphorus stripping process at R.A.F. Coltishall in 1992 has lead to 90% of the phosphorus being removed.

The phosphorus load from all the sewage treatment works on the Bure has therefore continued to decrease and is being maintained at reduced levels. The impact of these declining loads is discussed in Chapter 4.

3.2.2 Phosphorus Discharged To The River Ant

Figures 3.5 - 3.8 illustrate the weekly changes in phosphorus concentration at each of the river Ant sewage treatment works. At both Horning and Stalham the improved performance reported in 1991 has been maintained in 1992. Peaks in phosphorus concentration of up to 10mg/l were recorded at Worstead sewage treatment works although the overall performance is much improved. Greater control over the changes in weekly phosphorus concentration has also been recorded at South Repps during 1992. S.R.P. concentrations for South Repps in 1992 have been at or just below experimental detection limits. The quarterly and annual averages of both total P. and S.R.P. concentration are shown in Tables 3.6 and 3.7.

Tables 3.8 and 3.9 show the quarterly and annual average final effluent phosphorus loadings. At both Horning and Stalham sewage treatment works the annual total P. loads discharged have increased slightly in comparison to 1991, but are still lower than annual averages recorded for the other years. However, at Stalham there has been little change in the S.R.P. load and at Horning it has in fact decreased. The quarterly changes in phosphorus loads at Horning show an increase in particulate P. during the latter part of the year. This is due to both an increase in the total P. load and a decrease in the S.R.P. load. The total P. and S.R.P. annual average loadings have remained unchanged at Worstead sewage treatment works. The quarterly averages, however, show improvement throughout the duration of 1992. At South Repps the annual average total P. load has continued to decrease since its peak in 1989. This is despite an increase in phosphorus load in the first quarter of the year. The S.R.P. load for the remainder of the year has been at or just above the experimental detection limits.

3.3 Affect Of Dosing With Ferric Sulphate Upon The Rivers Bure And Ant

In order to assess whether dosing with ferric sulphate was having an affect upon the rivers, the sulphate concentration of the final effluent was measured routinely. A separate investigation into the total iron content of the river sediments up and down river of three sewage treatment works outfall pipes was undertaken.

3.3.1 Sulphate Concentration And Load Discharged To The Rivers Ant And Bure.

Table 3.10 shows the average quarterly sulphate concentrations discharged from the sewage treatment works where phosphorus control has been introduced. There is little variation in sulphate concentration between each of the works with only Aylsham and South Repps remaining above 200mg/l for each quarter. The sulphate load discharged to the river is affected by the size of the sewage treatment works and hence volume of final effluent discharged (Table 3.11). The highest loadings are from the largest works; Stalham, Belaugh and Aylsham.

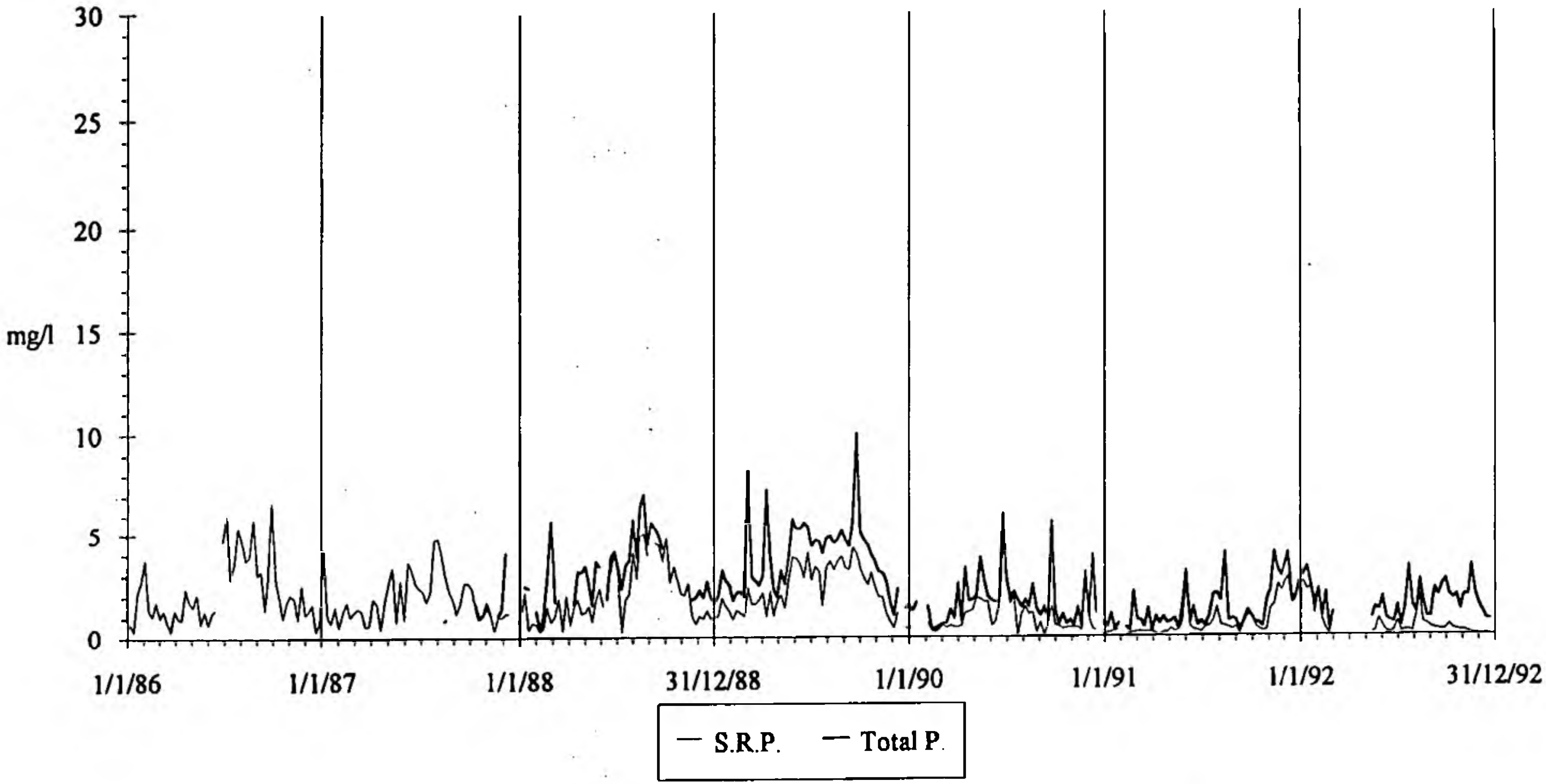


Figure 3.5 Horning Sewage Treatment Works: final effluent concentration (mg/l)

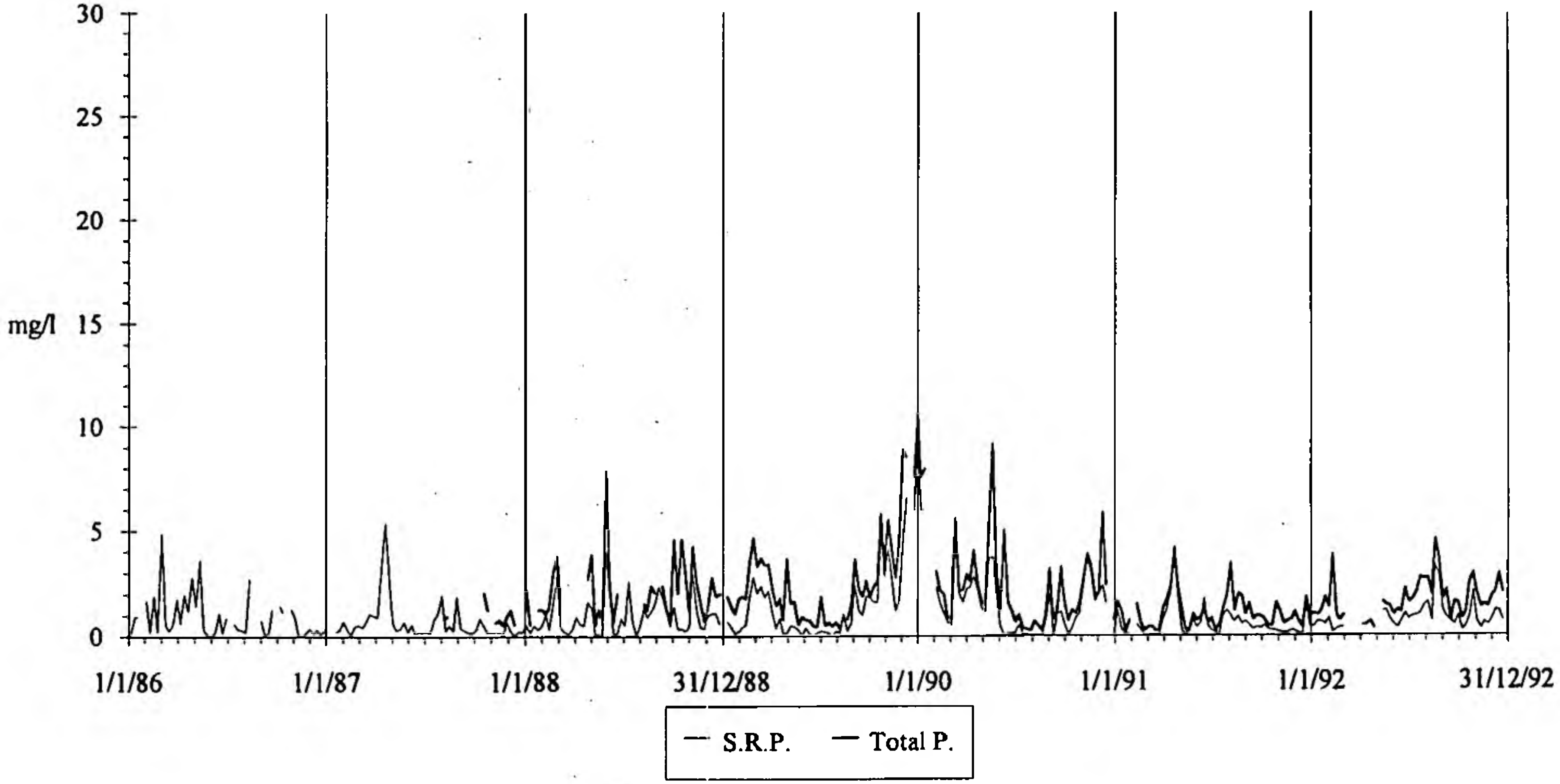


Figure 3.6 Stalham Sewage Treatment Works: final effluent concentration (mg/l)

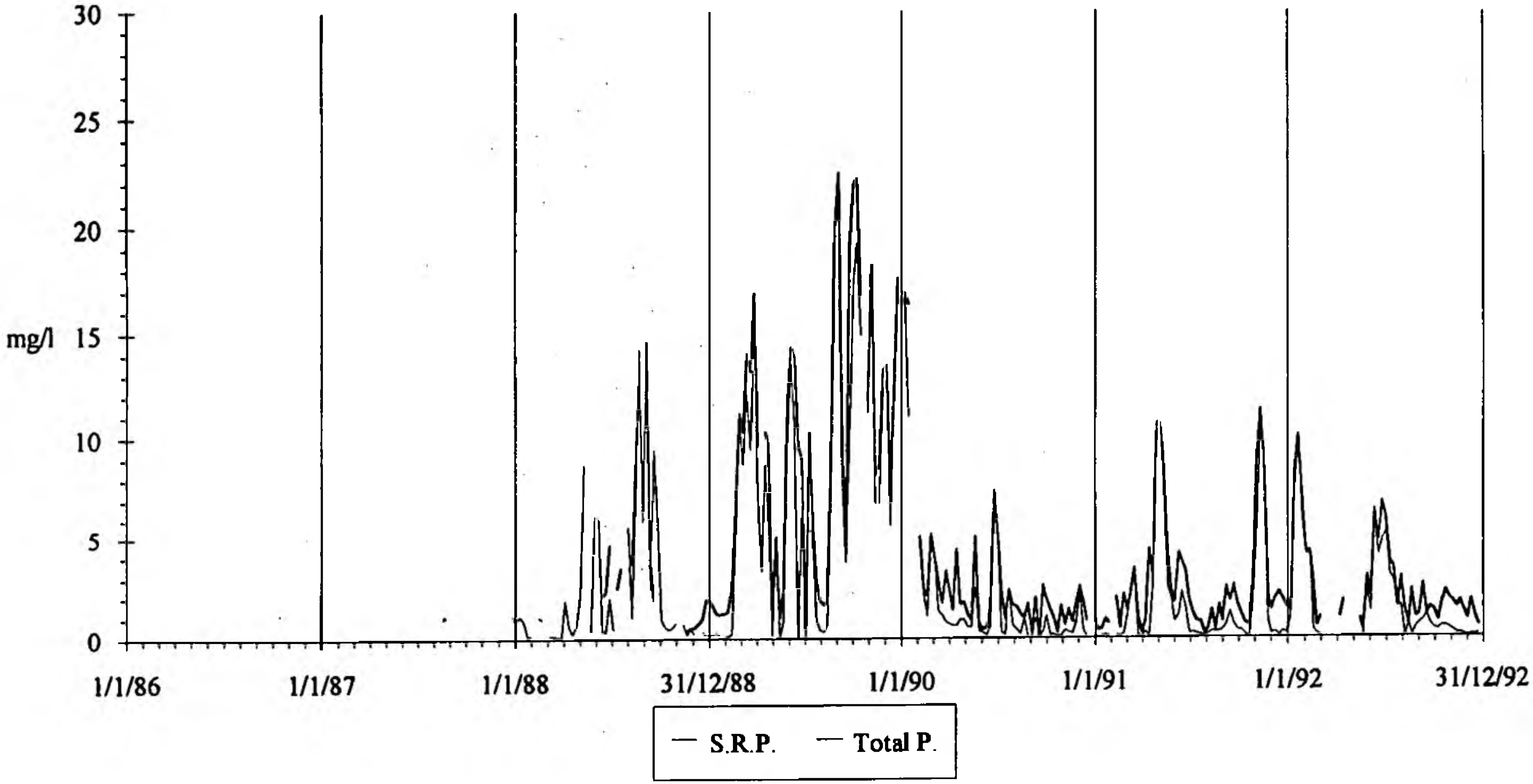


Figure 3.7 Worstead Sewage Treatment Works: final effluent concentration (mg/l)

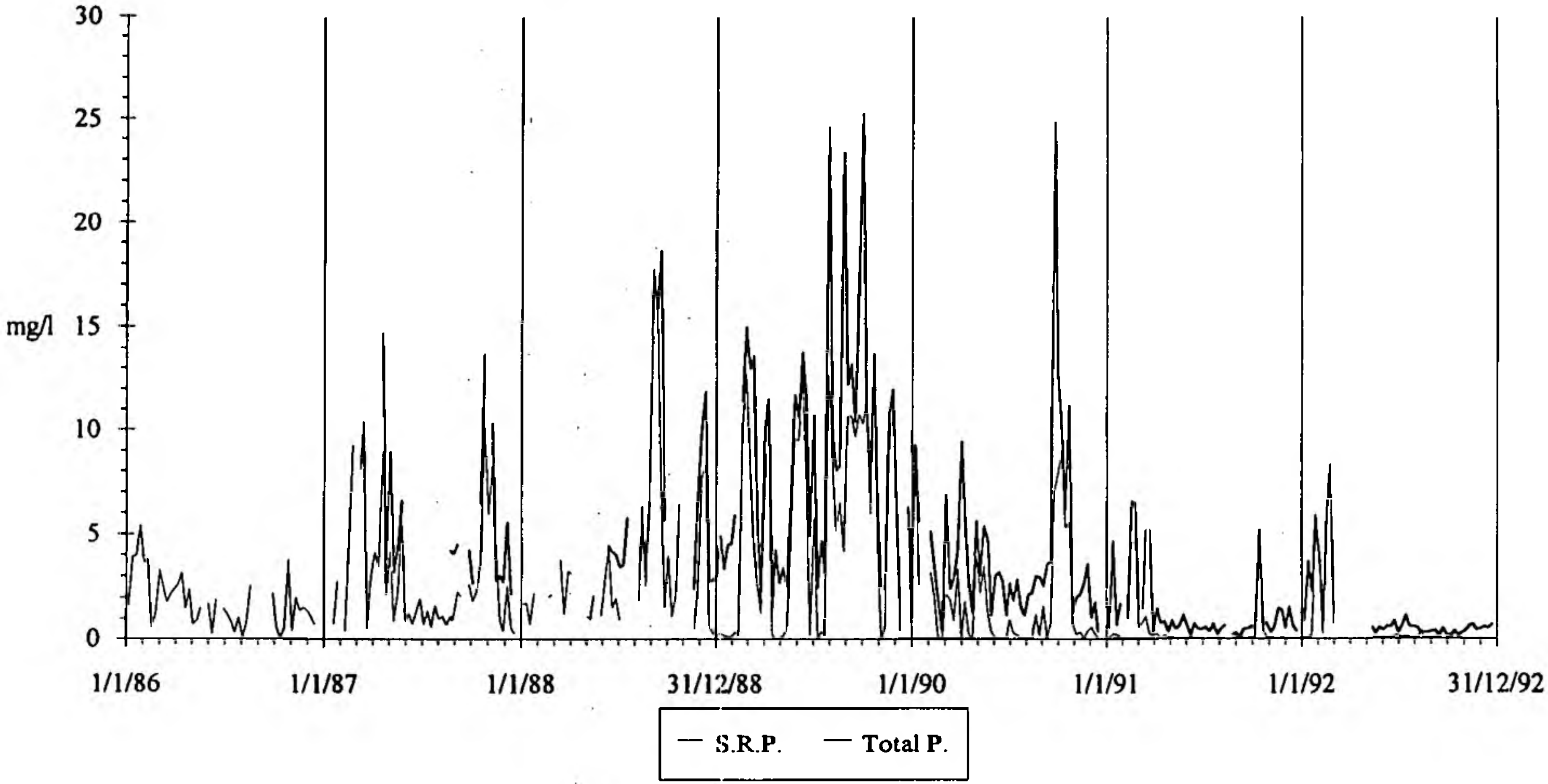


Figure 3.8 South Repps Sewage Treatment Works: final effluent concentration (mg/l)

Table 3.6 River Ant, sewage treatment works total phosphorus concentration

		mg/l Total -P			
		Horning	Stalham	Worstead	South Repps
Quarterly					
April-June	1986	-	-	-	2.49
July-Sept	1986	-	-	-	2.80
Oct-Dec	1986	-	-	-	2.76
Jan-March	1987	-	-	-	-
April-June	1987	-	-	-	6.10
July-Sept	1987	3.20	1.12	-	4.24
Oct-Dec	1987	1.61	0.94	-	5.50
Jan-March	1988	2.38	1.76	0.66	4.11
April-June	1988	2.97	2.24	3.20	6.10
July-Sept	1988	3.23	1.41	6.32	7.42
Oct-Dec	1988	2.25	2.52	1.24	6.10
Jan-March	1989	2.82	2.64	6.40	7.26
April-June	1989	4.28	1.32	8.18	7.27
July-Sept	1989	5.18	1.43	9.13	11.40
Oct-Dec	1989	3.11	4.80	14.43	8.80
Jan-March	1990	1.00	4.07	6.03	4.12
April-June	1990	2.45	3.19	2.78	3.81
July-Sept	1990	2.00	1.05	1.80	4.25
Oct-Dec	1990	1.29	2.24	1.33	4.43
Jan-March	1991	0.79	0.68	1.42	3.19
April-June	1991	0.96	1.40	4.49	0.70
July-Sept	1991	1.26	1.33	1.31	0.43
Oct-Dec	1991	2.25	0.97	3.08	1.17
Jan-March	1992	1.87	1.44	4.13	3.04
April-June	1992	1.00	1.11	3.01	0.52
July-Sept	1992	1.75	2.25	2.23	0.45
Oct-Dec	1992	1.68	1.89	1.48	0.45
Annually					
1986 mean		-	-	-	3.14
1987 mean		1.77	0.96	-	5.46
1988 mean		3.25	1.98	2.91	6.03
1989 mean		3.86	2.52	9.47	8.71
1990 mean		1.71	2.58	2.66	4.16
1991 mean		1.03	1.09	2.46	1.30
1992 mean		1.61	1.72	2.62	1.08

Table 3.7 River Ant, sewage treatment works soluble reactive phosphorus concentrations

		mg/l phosphate -P			
		Horning	Stalham	Worstead	South Repps
Quarterly					
April-June	1986	1.64	1.12	-	1.65
July-Sept	1986	4.09	0.72	-	1.16
Oct-Dec	1986	1.56	0.54	-	1.18
Jan-March	1987	1.32	0.49	-	4.42
April-June	1987	2.17	1.20	-	2.90
July-Sept	1987	2.68	0.63	-	1.35
Oct-Dec	1987	1.14	0.30	-	3.40
Jan-March	1988	1.02	0.64	0.50	2.01
April-June	1988	1.81	0.95	2.50	2.32
July-Sept	1988	1.79	1.17	6.02	6.63
Oct-Dec	1988	2.14	0.90	0.50	3.36
Jan-March	1989	1.43	1.29	4.80	3.17
April-June	1989	2.49	0.35	5.82	4.78
July-Sept	1989	3.33	0.72	6.88	6.53
Oct-Dec	1989	1.83	3.29	12.72	6.47
Jan-March	1990	0.44	3.22	5.90	2.32
April-June	1990	1.51	1.69	1.23	1.04
July-Sept	1990	1.09	0.46	0.91	0.94
Oct-Dec	1990	0.57	1.51	0.45	2.32
Jan-March	1991	0.18	0.25	0.72	1.21
April-June	1991	0.44	1.07	3.17	0.83
July-Sept	1991	0.57	0.57	0.38	0.06
Oct-Dec	1991	1.53	0.36	1.78	0.47
Jan-March	1992	1.36	0.49	3.38	2.33
April-June	1992	0.30	0.54	2.25	0.07
July-Sept	1992	0.50	1.26	1.38	0.08
Oct-Dec	1992	0.17	0.80	0.25	0.01
Annually					
1986 mean		2.19	0.91	-	1.77
1987 mean		1.84	0.66	-	2.93
1988 mean		2.04	0.92	2.38	3.58
1989 mean		2.28	1.40	7.49	5.21
1990 mean		0.93	1.66	1.97	1.63
1991 mean		0.38	0.56	1.49	0.43
1992 mean		0.56	0.82	1.7	0.57

Table 3.8 River Ant, sewage treatment works total phosphorus loads

		kg/d Total -P.			
		Horning	Stalham	Worstead	South Repps
Quarterly					
April-June	1986	-	-	-	0.34
July-Sept	1986	-	-	-	0.38
Oct-Dec	1986	-	-	-	0.37
Jan-March	1987	-	-	-	-
April-June	1987	-	-	-	0.82
July-Sept	1987	1.87	1.87	-	0.57
Oct-Dec	1987	1.15	1.25	-	0.74
Jan-March	1988	2.56	3.45	0.03	0.75
April-June	1988	1.23	2.87	0.13	0.71
July-Sept	1988	2.58	1.64	0.22	1.08
Oct-Dec	1988	2.08	2.41	0.04	0.92
Jan-March	1989	1.12	2.44	0.28	1.09
April-June	1989	1.39	1.24	0.37	1.09
July-Sept	1989	1.58	1.21	0.41	1.64
Oct-Dec	1989	1.70	3.71	0.76	1.22
Jan-March	1990	0.61	3.97	0.28	0.62
April-June	1990	1.23	3.36	0.10	0.57
July-Sept	1990	0.87	1.10	0.09	0.64
Oct-Dec	1990	0.53	2.27	0.07	0.67
Jan-March	1991	0.27	0.69	0.08	0.37
April-June	1991	0.36	1.37	0.25	0.11
July-Sept	1991	0.47	1.38	0.07	0.07
Oct-Dec	1991	0.89	0.91	0.20	0.16
Jan-March	1992	0.60	0.92	0.23	0.27
April-June	1992	0.35	0.83	0.17	0.05
July-Sept	1992	0.72	2.20	0.12	0.05
Oct-Dec	1992	1.26	1.31	0.08	0.04
Annually					
1986 mean		-	-	-	0.42
1987 mean		1.22	1.32	-	0.74
1988 mean		2.10	2.58	0.11	0.90
1989 mean		1.41	2.13	0.45	1.27
1990 mean		0.74	2.62	0.13	0.63
1991 mean		0.50	1.19	0.14	0.21
1992 mean		0.78	1.34	0.14	0.10

Table 3.9 River Ant, sewage treatment works soluble reactive phosphorus loads

		kg/d phosphate -P			
		Horning	Stalham	Worstead	South Repps
Quarterly					
April-June	1986	0.29	1.11	-	0.22
July-Sept	1986	0.63	0.64	-	0.16
Oct-Dec	1986	0.37	0.51	-	0.16
Jan-March	1987	0.30	0.46	-	0.60
April-June	1987	0.63	1.24	-	0.39
July-Sept	1987	1.79	0.84	-	0.18
Oct-Dec	1987	0.81	0.45	-	0.46
Jan-March	1988	0.75	1.41	0.02	0.34
April-June	1988	0.76	1.28	0.10	0.30
July-Sept	1988	1.86	1.35	0.21	0.97
Oct-Dec	1988	1.51	0.84	0.02	0.51
Jan-March	1989	0.52	1.23	0.21	0.48
April-June	1989	0.81	0.33	0.27	0.72
July-Sept	1989	1.02	0.60	0.31	0.98
Oct-Dec	1989	0.94	2.61	0.67	0.97
Jan-March	1990	0.29	3.14	0.27	0.35
April-June	1990	0.49	1.82	0.06	0.16
July-Sept	1990	0.40	0.48	0.05	0.14
Oct-Dec	1990	0.24	1.53	0.02	0.35
Jan-March	1991	0.06	0.25	0.04	0.13
April-June	1991	0.17	1.05	0.17	0.01
July-Sept	1991	0.22	0.59	0.02	0.01
Oct-Dec	1991	0.62	0.32	0.12	0.07
Jan-March	1992	0.44	0.32	0.19	0.21
April-June	1992	0.10	0.46	0.14	0.01
July-Sept	1992	0.21	1.28	0.08	0.01
Oct-Dec	1992	0.09	0.55	0.01	0.001
Annually					
1986 mean		0.42	0.87	-	0.24
1987 mean		0.88	0.75	-	0.40
1988 mean		1.22	1.22	0.09	0.53
1989 mean		0.81	1.16	0.36	0.78
1990 mean		0.36	1.69	0.09	0.25
1991 mean		0.27	0.67	0.08	0.07
1992 mean		0.21	0.67	0.09	0.05

Table 3.10 River Bure and Ant, sewage treatment works sulphate concentrations

		mg/l							
		Briston	Aylsham	Belaugh	RAF Colt.	Horning	Stalham	Worstead	South Repps
Quarterly									
Jan-March	1992	-	-	-	-	-	-	-	-
April-June	1992	184.0	219.0	235.5	155.0	168.5	204.0	132.5	256.0
July-Sept	1992	175.7	212.4	193.4	150.2	149.1	168.3	223.7	232.4
Oct-Dec	1992	164.8	207.0	170.8	180.6	148.7	160.2	222.6	220.8

Table 3.11 River Bure and Ant, sewage treatment works sulphate loads

		kg/d							
		Briston	Aylsham	Belaugh	RAF Colt.	Horning	Stalham	Worstead	South Repps
Quarterly									
Jan-March	1992	-	-	-	-	-	-	-	-
April-June	1992	75.4	185.7	282.6	98.6	57.9	190.1	7.3	23.2
July-Sept	1992	72.0	278.2	232.1	95.5	60.3	152.3	12.3	25.7
Oct-Dec	1992	67.6	200.4	204.9	114.9	88.3	122.8	12.2	21.0

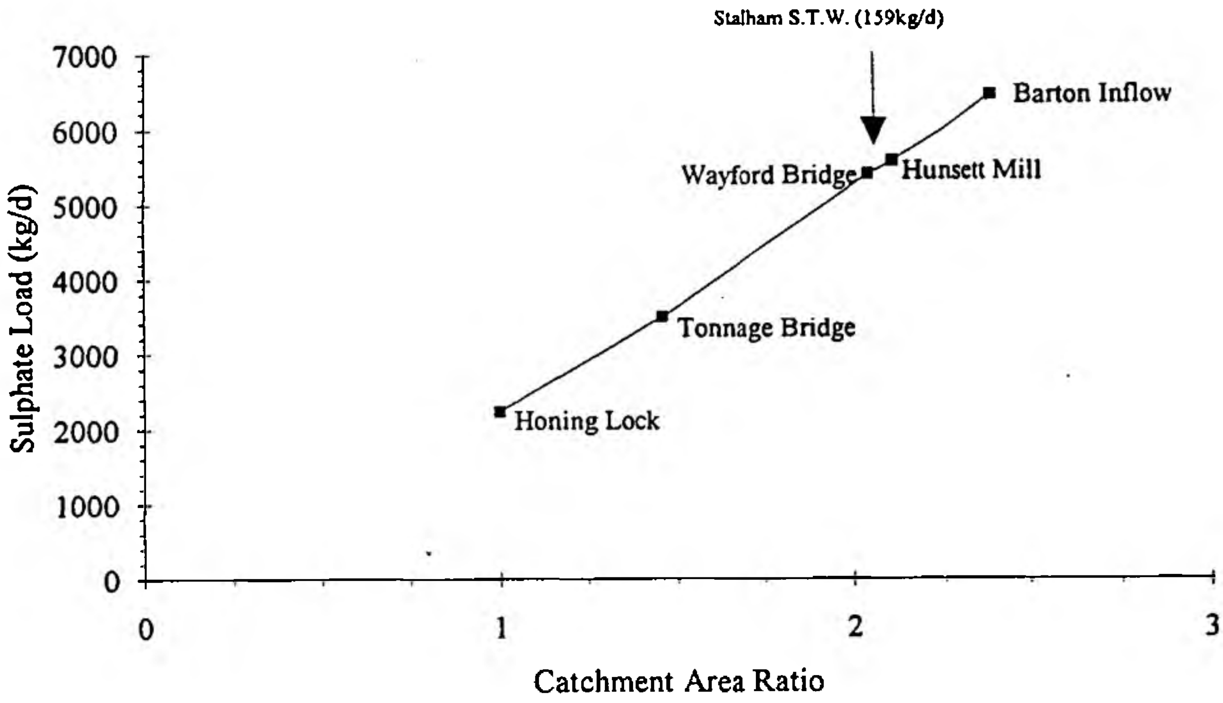


Figure 3.9 Sulphate load for the river Ant (kg/d)

In order to assess whether the discharge of sulphate from the sewage treatment works is having an impact on the river loadings one of the larger works, Stalham, was investigated in more detail. The average sulphate load in the river Ant for the period April - September, 1992, increased down river as shown in Figure 3.9. However, there is no large rise in the river loading between Wayford Bridge and Hunsett Mill indicating that Stalham sewage treatment works is not increasing the sulphate load of the river appreciably. In fact the load discharged from Stalham during the summer months (April - September) represents only 2.8% of the river load at Hunsett Mill.

3.3.2 Total Iron Concentration In River Sediments

An investigation was undertaken during the autumn and winter of 1992 to establish whether there was a greater amount of total iron in the sediments down river of the sewage treatment works outfall in relation to those up river of the outfall. This increase in total iron may be a result of the use of ferric sulphate dosing as a means of phosphorus control.

For this initial survey the three larger sewage treatment works were chosen; Stalham, Belaugh and Aylsham. Sediment was sampled using an Eckman Grab from which small cores were taken of the surface sediments for analysis. Twenty cores were collected at each site; ten up and ten down river of the outfall. The cores were sampled along a transect passing the outfall at approximately thirty metres intervals. However, some variation in the sampling distance did occur due to the necessity to select sites of deposition especially at Aylsham and Stalham. The total iron content of the sediment samples was determined at Haddiscoe laboratory using the method described in Jackson and Phillips (1990).

The results of this survey are presented in Figure 3.10 and Table 3.12. A significant difference was found between the up and down river sediment total iron concentrations at both Aylsham and Stalham. The highest concentrations of iron were found down river of the final effluent outfall at both sites. This may be a direct affect of the use of ferric dosing as a means of lowering the phosphorus discharged from the sewage treatment works. However, at Aylsham especially, the nature of the sediment varied between the up river and down river sample; with the river bed being more gravelly up river and sites of deposition harder to find. Therefore the results may also be a result of natural variation within the river. No significant increase in the iron concentration was found down river of Belaugh sewage treatment works outfall. This may be due to increased boat or tidal activity causing greater mixing of the river sediments in comparison to the other sites surveyed.

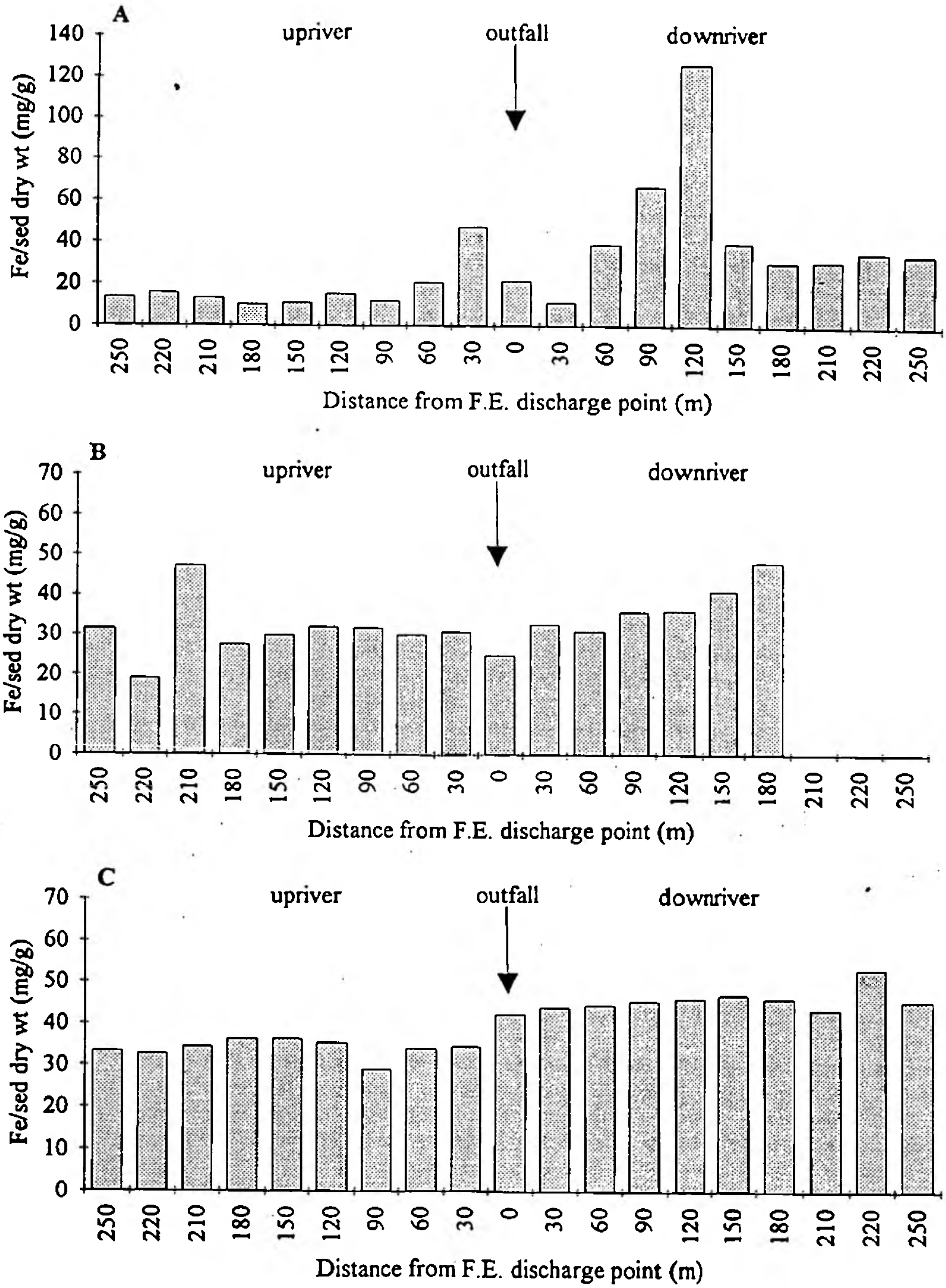


Figure 3.10 River sediment total iron concentration (mg/g) with distance up and down river of sewage treatment works final effluent outfall (A) Aylsham (B) Belaugh (C) Stalham

Table 3.12 Comparison of river sediment total iron concentration (mg/g) up and down river of final effluent outfall

Site	Upriver	Downriver	T-Test
Aylsham S.T.W.	15.83 ± 10.45 (n = 12)	42.77 ± 29.82 (n = 12)	$p = 0.02$ sig. difference
Belaugh S.T.W.	30.48 ± 7.17 (n = 10)	35.77 ± 7.38 (n = 7)	$p > 0.1$ no sig. difference
Stalham S.T.W.	34.26 ± 2.22 (n = 10)	46.31 ± 2.79 (n = 10)	$p = 0.001$ sig. difference

4. PHOSPHORUS LOAD IN THE RIVER BURE AT KEY SITES

4.1 Introduction

To assess long term changes, the phosphorus load of the river Bure is determined at key sampling sites located along the length of the non-tidal and upper tidal reaches of the river. In the upper, non-tidal reach there are two sites - Ingworth Guaging Station and Horstead Mill (which represents the rivers upper tidal limit). A third river site is at Wroxham Rail Bridge; situated down river of Belaugh sewage treatment works and up river of the Broads the site provides a good record of the phosphorus load which is entering the Broads system. At each of these three sites water samples are collected fortnightly (weekly prior to 1991) and analysed for total phosphorus (total P.), soluble reactive phosphorus (S.R.P.) and total suspended solids (T.S.S.). Chlorophyll a concentration is also measured at both Horstead Mill and Wroxham Rail Bridge. Phosphorus loads are calculated using a guaged flow at Ingworth and Horstead Mill. The flows for Wroxham Rail Bridge are calculated from catchment ratios and the flow recorded at Horstead Mill.

4.2 Phosphorus Budget For The Key Sites

4.2.1 Phosphorus Concentration

Figure 4.1 illustrates the weekly/ fortnightly fluctuations in phosphorus concentration. The quarterly and annual average concentration of phosphorus (S.R.P., particulate P. and total P.) and suspended solids are shown in Tables 4.1 - 4.2.

In comparison to previous years there is a reduction in the concentration of total P. at all three river sites; maintaining the reduction first noticed in 1991. S.R.P. concentrations, however, have remained consistently reduced at Horstead Mill and Wroxham Rail Bridge since phosphorus stripping was introduced in 1986. The only exception to this is during 1989 when there was a period of ineffective phosphorus removal and the S.R.P. concentration increased. At Ingworth Guaging Station the S.R.P. concentration has remained relatively constant since 1986 with no obvious reduction in concentration brought about by the introduction of phosphorus removal at Briston sewage treatment works.. A reduction in the concentration of particulate P. is apparent at all three sites for 1991 and 1992. The pattern of suspended solids concentration change is a little more variable. At Ingworth Guaging Station the suspended solids concentration was highest in 1987 and 1988 whereas at Horstead Mill and Wroxham Rail Bridge the highest concentrations were in 1988 and 1990.

4.2.2 Chlorophyll Concentration

An increase in the concentration of chlorophyll a during the spring quarter is apparent at both Horstead Mill and Wroxham Rail Bridge (Table 4.3). This increase is associated with a rise in phytoplankton productivity. The chlorophyll a concentrations are higher at the down river site of Wroxham Rail Bridge in comparison to Horstead Mill. A peak in the annual average was recorded at both sites for 1990.

The weekly/fortnightly fluctuations in chlorophyll concentrations for both sites are shown in Figure 4.3. Clearly illustrated are the seasonal fluctuations in phytoplankton productivity along with a general rise in chlorophyll concentration since 1987 at both

Table 4.1 River Bure, concentration of total and dissolved phosphorus

	mg/l phosphorus -P			mg/l Total -P		
	Ingworth	Horstead	Wroxham	Ingworth	Horstead	Wroxham
Quarterly						
April-June 1986	0.047	0.095	0.092	0.103	0.135	0.170
July-Sept 1986	0.051	0.128	0.158	0.128	0.169	0.262
Oct-Dec 1986	0.036	0.068	0.076	0.114	0.105	0.123
Jan-March 1987	0.037	0.048	0.037	0.125	0.142	0.151
April-June 1987	0.018	0.031	0.027	0.142	0.097	0.094
July-Sept 1987	0.051	0.059	0.050	0.133	0.094	0.163
Oct-Dec 1987	0.044	0.049	0.050	0.159	0.108	0.135
Jan-March 1988	0.028	0.022	0.031	0.224	0.180	0.189
April-June 1988	0.042	0.018	0.020	0.220	0.096	0.098
July-Sept 1988	0.042	0.032	0.012	0.116	0.089	0.150
Oct-Dec 1988	0.041	0.035	0.022	0.132	0.071	0.088
Jan-March 1989	0.035	0.036	0.043	0.203	0.092	0.118
April-June 1989	0.012	0.019	0.035	0.127	0.103	0.120
July-Sept 1989	0.057	0.058	0.106	0.014	0.117	0.151
Oct-Dec 1989	0.044	0.112	0.073	0.167	0.136	0.250
Jan-March 1990	0.050	0.034	0.052	0.188	0.104	0.211
April-June 1990	0.015	0.016	0.013	0.194	0.147	0.113
July-Sept 1990	0.032	0.051	0.057	0.176	0.101	0.285
Oct-Dec 1990	0.046	0.053	0.059	0.145	0.080	0.211
Jan-March 1991	0.031	0.040	0.021	0.091	0.088	0.085
April-June 1991	0.029	0.027	0.019	0.083	0.065	0.101
July-Sept 1991	0.035	0.032	0.046	0.075	0.066	0.132
Oct-Dec 1991	0.050	0.047	0.048	0.109	0.075	0.093
Jan-March 1992	0.045	0.037	0.018	0.107	0.088	0.065
April-June 1992	0.030	0.010	0.011	0.104	0.066	0.091
July-Sept 1992	0.043	0.028	0.055	0.105	0.051	0.118
Oct-Dec 1992	0.039	0.034	0.055	0.102	0.077	0.107
Annually						
1986 mean	0.043	0.097	0.111	0.116	0.139	0.191
1987 mean	0.037	0.047	0.042	0.143	0.108	0.136
1988 mean	0.038	0.029	0.021	0.170	0.111	0.132
1989 mean	0.037	0.055	0.062	0.154	0.112	0.154
1990 mean	0.034	0.038	0.044	0.182	0.109	0.212
1991 mean	0.035	0.035	0.034	0.087	0.071	0.106
1992 mean	0.040	0.037	0.034	0.104	0.088	0.096

Table 4.2 River Bure, concentration of particulate phosphorus and solids

	mg/l Particulate -P.			mg/l T.S.S.		
	Ingworth	Horstead	Wroxham	Ingworth	Horstead	Wroxham
Quarterly						
April-June 1986	0.059	0.043	0.099	9.48	4.26	13.47
July-Sept 1986	0.072	0.044	0.098	6.86	3.56	12.87
Oct-Dec 1986	0.084	0.038	0.047	8.95	3.63	4.62
Jan-March 1987	0.901	0.087	0.115	22.47	11.42	28.33
April-June 1987	0.122	0.068	0.078	30.49	7.81	14.30
July-Sept 1987	0.081	0.030	0.106	9.80	7.14	15.42
Oct-Dec 1987	0.125	0.066	0.084	27.89	13.68	14.19
Jan-March 1988	0.186	0.081	0.163	48.05	33.59	31.93
April-June 1988	0.183	0.076	0.081	44.82	12.17	17.80
July-Sept 1988	0.074	0.054	0.135	10.69	7.07	24.05
Oct-Dec 1988	0.091	0.038	0.063	19.82	4.55	6.93
Jan-March 1989	0.167	0.061	0.081	17.86	6.89	13.52
April-June 1989	0.115	0.083	0.077	10.02	9.31	16.05
July-Sept 1989	0.075	0.055	0.049	7.18	4.83	13.23
Oct-Dec 1989	0.126	0.025	0.174	12.73	3.05	18.92
Jan-March 1990	0.137	0.069	0.163	20.11	11.11	12.64
April-June 1990	0.179	0.131	0.094	9.94	11.19	13.09
July-Sept 1990	0.143	0.049	0.228	8.81	6.84	34.49
Oct-Dec 1990	0.099	0.033	0.152	6.49	2.21	18.71
Jan-March 1991	0.061	0.048	0.064	7.76	5.25	8.12
April-June 1991	0.054	0.038	0.082	5.22	3.09	12.88
July-Sept 1991	0.041	0.034	0.086	3.86	2.16	11.41
Oct-Dec 1991	0.047	0.028	0.030	9.13	2.13	4.19
Jan-March 1992	0.062	0.050	0.047	15.10	11.60	5.79
April-June 1992	0.074	0.055	0.081	10.53	6.96	16.10
July-Sept 1992	0.061	0.022	0.063	6.80	1.59	11.55
Oct-Dec 1992	0.064	0.043	0.052	5.31	2.68	3.45
Annually						
1986 mean	0.073	0.076	0.076	8.41	4.45	9.65
1987 mean	0.106	0.061	0.094	23.49	9.86	17.93
1988 mean	0.131	0.148	0.112	30.89	14.73	20.26
1989 mean	0.116	0.056	0.092	11.23	6.08	15.21
1990 mean	0.149	0.072	0.173	11.96	67.93	21.51
1991 mean	0.051	0.037	0.072	5.95	3.05	9.75
1992 mean	0.065	0.050	0.062	9.05	11.60	10.21

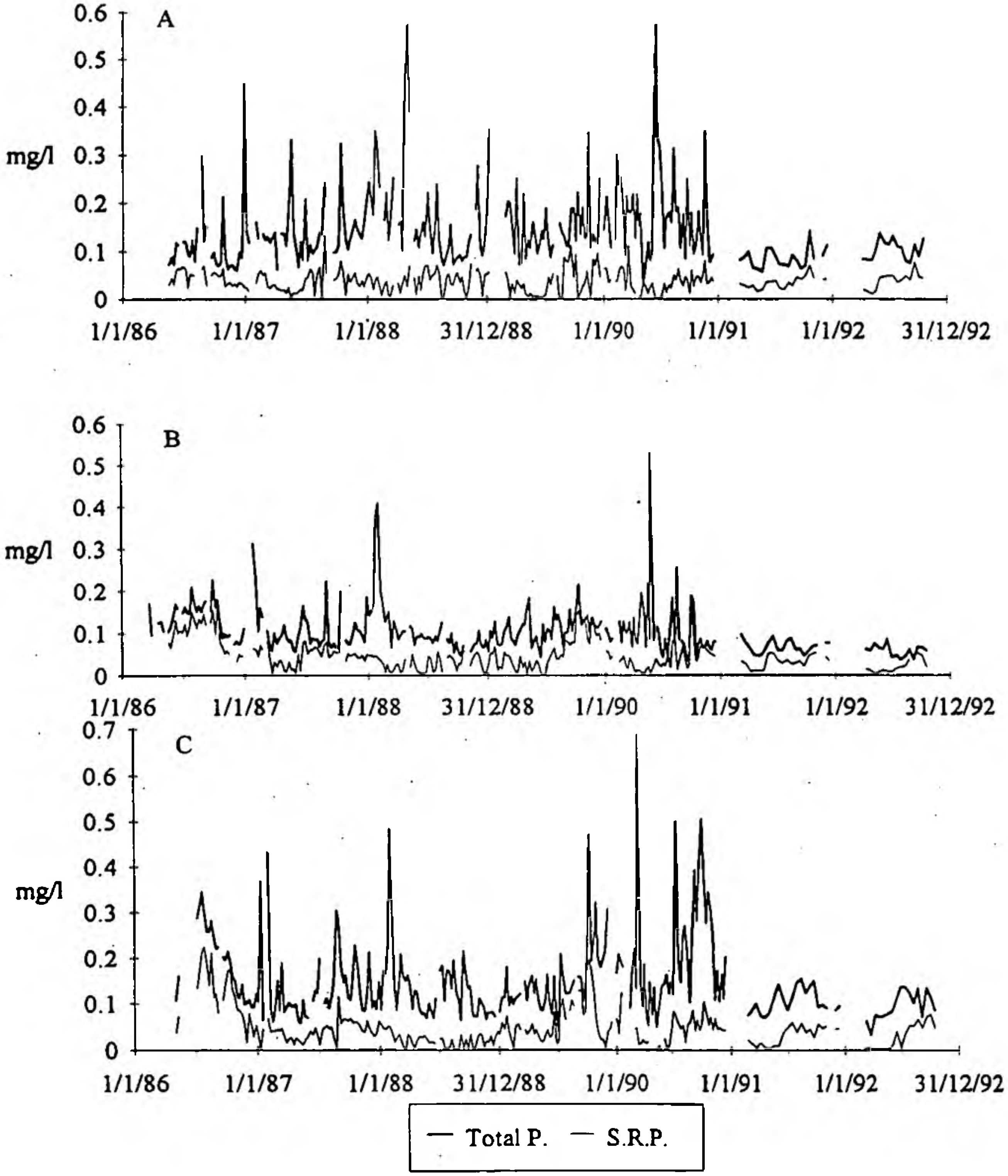


Figure 4.1 **Total and soluble phosphorus concentration at (A) Ingworth Guaging Station (B) Horstead Mill (C) Wroxham Rail Bridge**

sites. There is a difference between the two sites in 1992, with an increase in chlorophyll at Horstead Mill and a decrease at Wroxham Rail Bridge. This difference may be due to the presence of a bloom of cyanobacteria (*Aphanisomenon sp.*) at Horstead Mill, which was not detected at Wroxham Rail Bridge. The source of this alga was a series of trout lakes situated up river of Ingworth Guaging Station. The alga was unable to grow within the riverine environment and therefore the population was diminishing by the time it reached Wroxham.

4.2.3 River Flow

River flows are highest in the spring and winter quarters when there is an increase in the amount of rainfall and surface runoff. Table 4.4 shows the quarterly and annual averages of river flow at all three key sites on the Bure. The annual averages also show a trend of decreasing river flows during the past couple of years. This decrease in river flow has lead to an increase in phytoplankton productivity at Horstead Mill and Wroxham Rail Bridge, as shown by an increase in chlorophyll a concentration. The highest flow rates were recorded for 1987 and 1988.

4.2.4 Phosphorus Loadings

Tables 4.5 and 4.6 show the quarterly and annual average loadings of phosphorus (total, particulate and soluble) and suspended solids in the river at each of the three sites. The total P. loadings at all of the three sites for 1992 are similar to the reduced loadings recorded in 1991. A peak in the loadings of total P. was recorded for 1987 and 1988, due to increased loadings of particulate P. and suspended solids. S.R.P. loadings at Ingworth Guaging Station have remained constant for the past four years. The highest loading for this site was recorded in 1987. At Horstead Mill and Wroxham Rail Bridge the S.R.P. loadings are lower than those for 1990. Also, the S.R.P. loadings at both of these sites have not risen above the pre-stripping levels recorded in 1986.

4.2.5 The Effect Of Phosphorus Removal From Sewage Treatment Works Upon The Phosphorus Load In The River Bure

The total P. load discharged to the river Bure from the sewage treatment works was successfully reduced in 1987 after the introduction of the phosphorus stripping process at three of the works. A further reduction in discharged load is seen in 1988 when phosphorus removal was extended to the P.S.A. controlled works of R.A.F. Coltishall. However, due to a period of transition during the formation of the N.R.A. and the responsibility for the phosphorus removal being taken over by Anglian Water plc. an increase in the total P. discharged was recorded in 1989. A marked recovery in the effectiveness of the phosphorus stripping process followed during 1990 - 1992. Figure 4.3 illustrates the pattern of change in the annual load of total P. discharged from the works.

The changes in the mean phosphorus loads at the three key river sites (Figure 4.4) do not appear to follow the changes in the total P. load discharged to the river. The total P. load increases from the 1986 level in both 1987 and 1988. In 1989 when the total P. load discharged increased, there was a decrease in the total P. load in the river. However, a pattern of continuing decline in total P. load for the following years 1990 - 1992 corresponds to the further reduction in the load discharged from the sewage treatment works.

Table 4.3 River Bure, concentration of chlorophyll

	ug/l Chlorophyll a	
	Horstead	Wroxham
Quarterly		
April-June 1986	2.41	42.00
July-Sept 1986	5.63	27.60
Oct-Dec 1986	3.98	7.34
Jan-March 1987	6.04	5.97
April-June 1987	12.47	21.57
July-Sept 1987	3.45	18.38
Oct-Dec 1987	3.74	3.15
Jan-March 1988	8.35	14.03
April-June 1988	19.22	34.16
July-Sept 1988	3.35	18.37
Oct-Dec 1988	6.23	14.87
Jan-March 1989	13.13	25.62
April-June 1989	13.34	60.83
July-Sept 1989	2.13	17.11
Oct-Dec 1989	3.46	7.53
Jan-March 1990	12.94	53.90
April-June 1990	25.88	86.73
July-Sept 1990	12.49	40.71
Oct-Dec 1990	2.30	4.34
Jan-March 1991	11.63	41.73
April-June 1991	11.63	65.18
July-Sept 1991	3.16	29.44
Oct-Dec 1991	5.17	6.56
Jan-March 1992	4.38	17.38
April-June 1992	32.56	58.86
July-Sept 1992	4.37	39.00
Oct-Dec 1992	5.47	12.00
Annually		
1986 mean	4.76	27.48
1987 mean	6.44	14.59
1988 mean	9.35	22.95
1989 mean	8.21	30.26
1990 mean	13.09	47.40
1991 mean	7.58	36.21
1992 mean	13.95	28.07

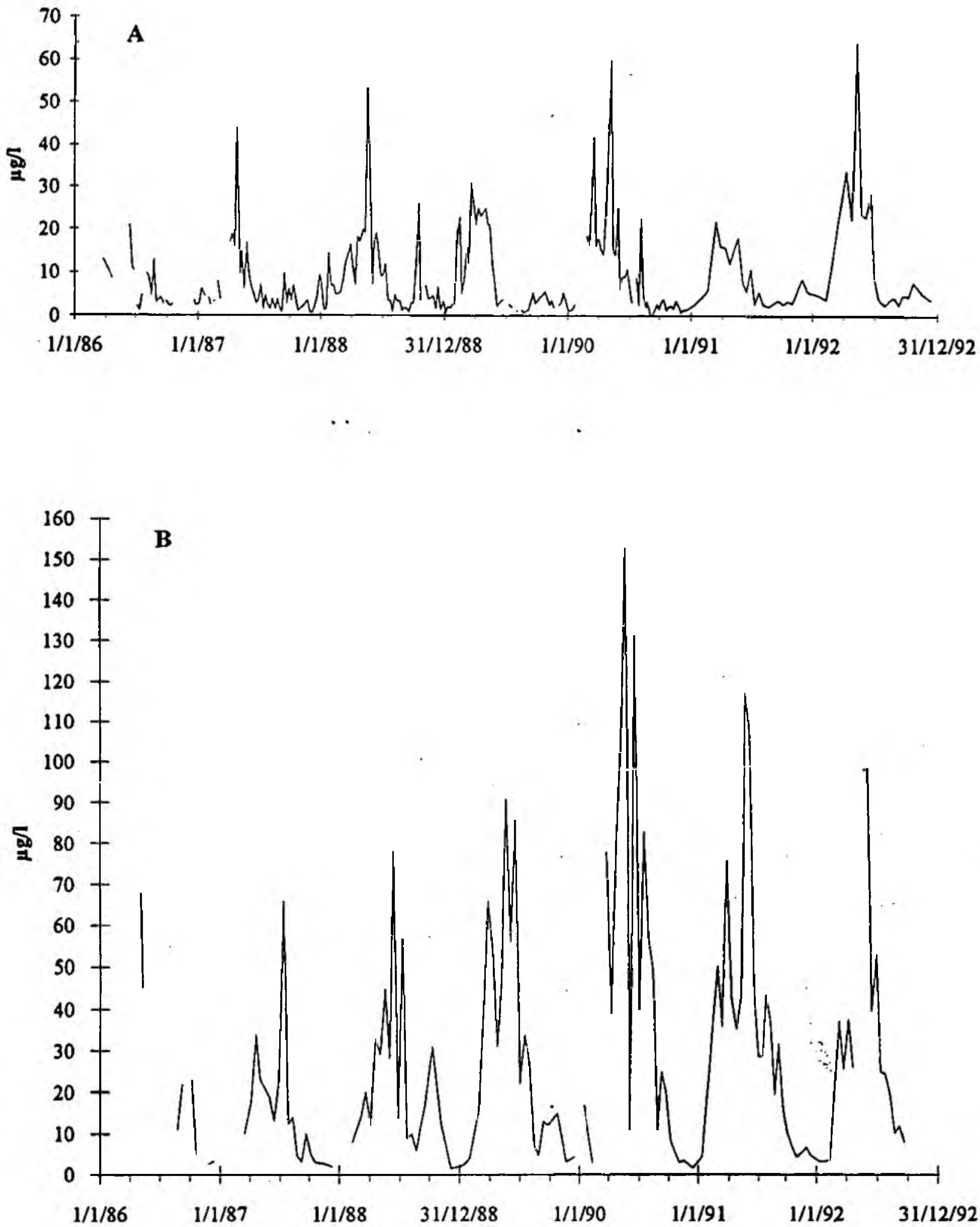


Figure 4.2 Chlorophyll a concentration (µg/l) at (A) Horstead Mill and (B) Wroxham Rail Bridge

Table 4.4 River Bure flow

		Flow cumecs		
		Ingworth	Horstead	Wroxham
Quarterly				
April-June	1986	1.15	2.14	2.55
July-Sept	1986	0.86	1.49	1.78
Oct-Dec	1986	1.27	2.05	2.45
Jan-March	1987	1.47	2.80	3.34
April-June	1987	1.54	2.36	2.82
July-Sept	1987	1.40	2.47	2.94
Oct-Dec	1987	1.81	3.44	4.10
Jan-March	1988	2.10	4.06	4.84
April-June	1988	1.25	2.58	3.07
July-Sept	1988	1.02	1.95	2.32
Oct-Dec	1988	1.14	1.98	2.36
Jan-March	1989	1.05	2.06	2.44
April-June	1989	0.91	1.71	1.98
July-Sept	1989	0.68	1.23	1.46
Oct-Dec	1989	1.00	1.93	2.36
Jan-March	1990	1.33	2.93	3.49
April-June	1990	0.73	1.50	1.79
July-Sept	1990	0.56	0.99	1.17
Oct-Dec	1990	0.83	1.67	2.02
Jan-March	1991	1.00	2.13	2.54
April-June	1991	0.67	1.52	1.81
July-Sept	1991	0.53	0.93	1.11
Oct-Dec	1991	0.81	1.78	2.13
Jan-March	1992	1.20	1.63	2.41
April-June	1992	0.65	1.42	1.68
July-Sept	1992	0.57	1.16	1.38
Oct-Dec	1992	0.95	1.95	2.25
Annually				
1986 mean		1.21	2.09	2.50
1987 mean		1.46	3.30	3.30
1988 mean		1.36	2.61	3.11
1989 mean		0.91	1.73	2.07
1990 mean		0.86	1.77	2.11
1991 mean		0.75	1.59	1.89
1992 mean		0.77	1.48	1.79

Table 4.5 River Bure, loadings of total and dissolved phosphorus

	kg/d phosphate-P			kg/d Total-P		
	Ingworth	Horstead	Wroxham	Ingworth	Horstead	Wroxham
Quarterly						
April-June 1986	3.67	14.34	18.69	8.85	22.18	39.09
July-Sept 1986	3.92	16.20	23.28	9.63	22.76	38.36
Oct-Dec 1986	4.01	10.79	15.57	15.61	17.26	27.47
Jan-March 1987	4.13	12.03	9.85	14.41	36.19	41.77
April-June 1987	1.87	6.65	5.84	12.97	19.94	24.06
July-Sept 1987	6.41	13.45	17.17	18.81	24.43	47.31
Oct-Dec 1987	7.79	13.80	18.71	29.95	33.31	53.69
Jan-March 1988	5.47	10.49	13.67	43.13	71.15	90.87
April-June 1988	4.15	4.22	5.01	28.83	20.02	25.52
July-Sept 1988	3.74	5.22	2.59	10.28	14.54	29.35
Oct-Dec 1988	4.18	6.17	5.42	13.74	12.48	16.96
Jan-March 1989	3.28	6.13	9.09	18.82	17.01	26.08
April-June 1989	1.04	3.21	6.00	10.02	16.17	19.80
July-Sept 1989	3.44	7.29	13.87	7.93	12.85	19.30
Oct-Dec 1989	3.45	15.48	12.53	13.52	20.00	41.23
Jan-March 1990	5.69	7.29	12.57	21.78	22.12	51.57
April-June 1990	0.96	1.96	1.89	11.72	18.39	15.61
July-Sept 1990	1.53	4.51	5.98	8.36	8.24	29.36
Oct-Dec 1990	3.08	7.39	9.66	9.96	10.95	33.25
Jan-March 1991	2.75	7.80	4.85	8.17	16.72	17.89
April-June 1991	1.61	3.52	3.08	4.59	8.93	15.80
July-Sept 1991	1.47	2.62	4.24	3.21	5.14	12.07
Oct-Dec 1991	3.58	7.47	9.01	7.60	11.74	17.61
Jan-March 1992	4.97	4.99	3.81	11.30	12.76	13.47
April-June 1992	1.48	1.33	1.22	5.63	7.97	12.41
July-Sept 1992	2.45	3.16	6.58	5.22	5.11	14.26
Oct-Dec 1992	2.94	5.72	9.47	8.20	13.63	18.18
Annually						
1986 mean	3.88	14.05	19.16	11.27	22.33	33.76
1987 mean	5.03	11.40	12.95	19.39	27.88	41.95
1988 mean	4.37	6.61	6.48	22.06	30.77	41.03
1989 mean	2.71	7.88	10.27	11.89	16.44	25.72
1990 mean	2.69	4.88	7.16	13.31	16.33	36.42
1991 mean	2.18	4.73	4.93	5.51	9.65	15.42
1992 mean	2.59	3.31	5.10	6.87	8.98	14.08

Table 4.6 River Bure, loadings of particulate phosphorus and solids

	kg/d Particulate P.			kg/d Solids		
	Ingworth	Horstead	Wroxham	Ingworth	Horstead	Wroxham
Quarterly						
April-June 1986	5.25	6.62	19.57	0.86	0.72	2.52
July-Sept 1986	5.50	5.56	15.08	0.52	0.45	1.90
Oct-Dec 1986	11.60	6.80	11.90	1.15	0.72	1.19
Jan-March 1987	8.98	24.16	31.93	2.60	3.18	7.72
April-June 1987	11.19	13.28	18.38	2.87	1.51	3.18
July-Sept 1987	12.39	10.98	29.27	2.06	2.42	5.13
Oct-Dec 1987	22.16	19.51	34.98	5.15	4.06	6.55
Jan-March 1988	37.25	60.66	77.19	9.83	14.40	15.45
April-June 1988	19.68	15.80	20.51	4.94	2.64	4.35
July-Sept 1988	6.54	9.32	26.76	0.93	1.14	4.83
Oct-Dec 1988	9.56	6.72	12.76	2.15	0.81	1.41
Jan-March 1989	15.54	10.88	16.99	1.71	1.25	2.85
April-June 1989	8.97	12.96	13.80	0.79	1.37	2.70
July-Sept 1989	4.48	5.56	6.29	0.43	0.51	1.61
Oct-Dec 1989	10.06	4.52	29.08	1.11	0.53	3.13
Jan-March 1990	16.10	14.83	35.51	2.19	2.54	3.09
April-June 1990	10.27	16.42	13.73	0.68	1.52	2.00
July-Sept 1990	6.83	4.04	23.38	0.41	0.53	3.88
Oct-Dec 1990	6.88	4.32	23.59	0.46	0.29	1.15
Jan-March 1991	5.42	8.92	13.04	0.75	1.00	1.65
April-June 1991	2.98	5.41	12.72	0.29	0.43	2.04
July-Sept 1991	1.73	2.52	7.82	0.16	0.17	1.05
Oct-Dec 1991	4.02	4.27	8.61	0.63	0.25	0.80
Jan-March 1992	6.33	7.77	9.67	2.00	1.88	1.20
April-June 1992	4.15	6.67	11.19	0.57	0.82	2.14
July-Sept 1992	2.78	2.48	7.68	0.34	0.16	1.40
Oct-Dec 1992	5.26	7.91	8.71	0.51	0.50	0.59
Annually						
1986 mean	7.91	6.45	14.45	0.85	0.83	1.75
1987 mean	13.99	16.48	28.77	3.27	2.76	5.65
1988 mean	17.62	24.25	35.01	4.49	4.94	6.48
1989 mean	9.20	8.56	16.16	0.92	0.94	2.55
1990 mean	10.51	10.06	24.71	0.96	1.43	3.19
1991 mean	3.33	4.92	10.49	0.42	0.42	1.41
1992 mean	4.29	5.83	8.98	0.70	0.72	1.41

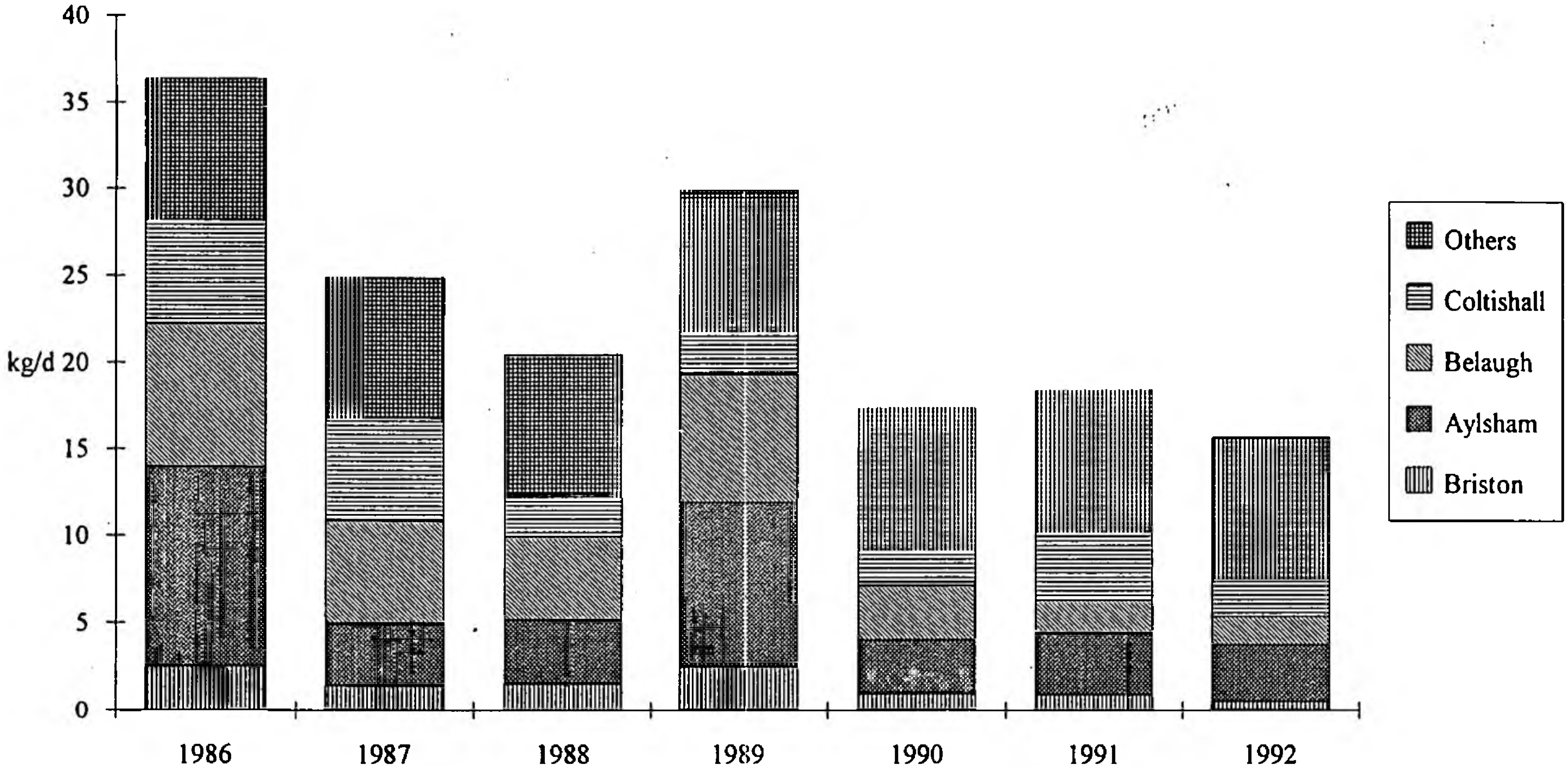


Figure 4.3 Total phosphorus discharged to the River Bure from the sewage treatment works

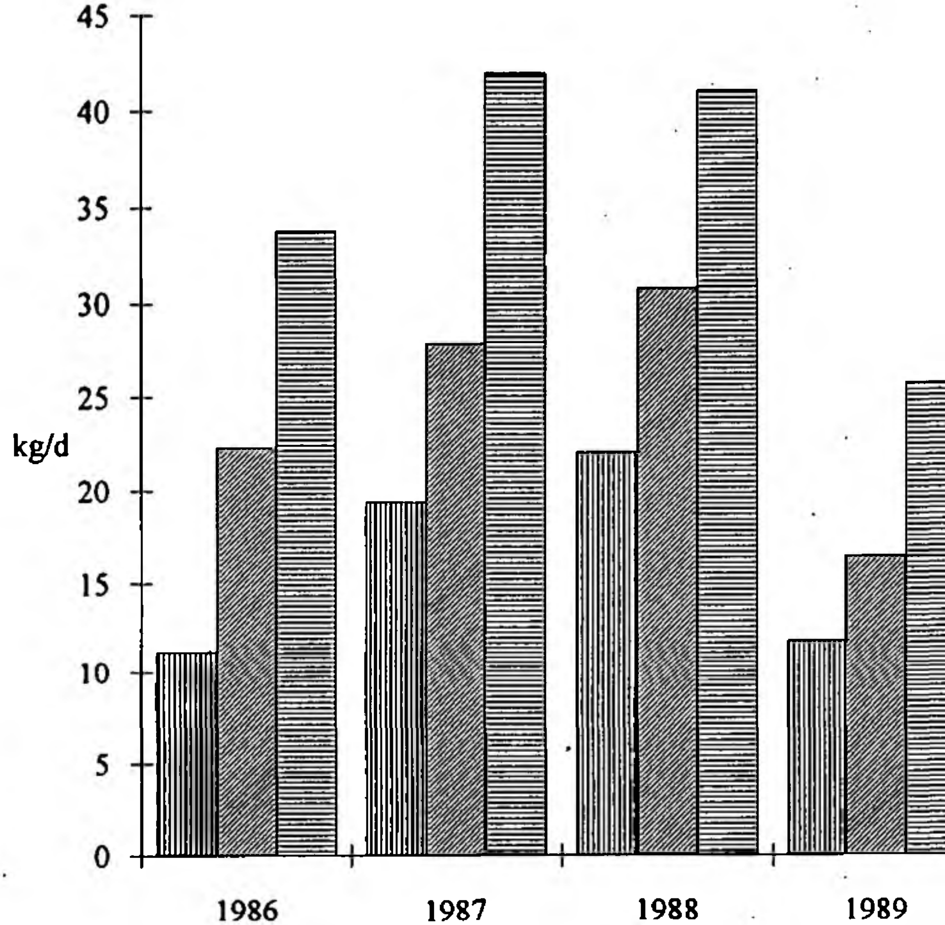
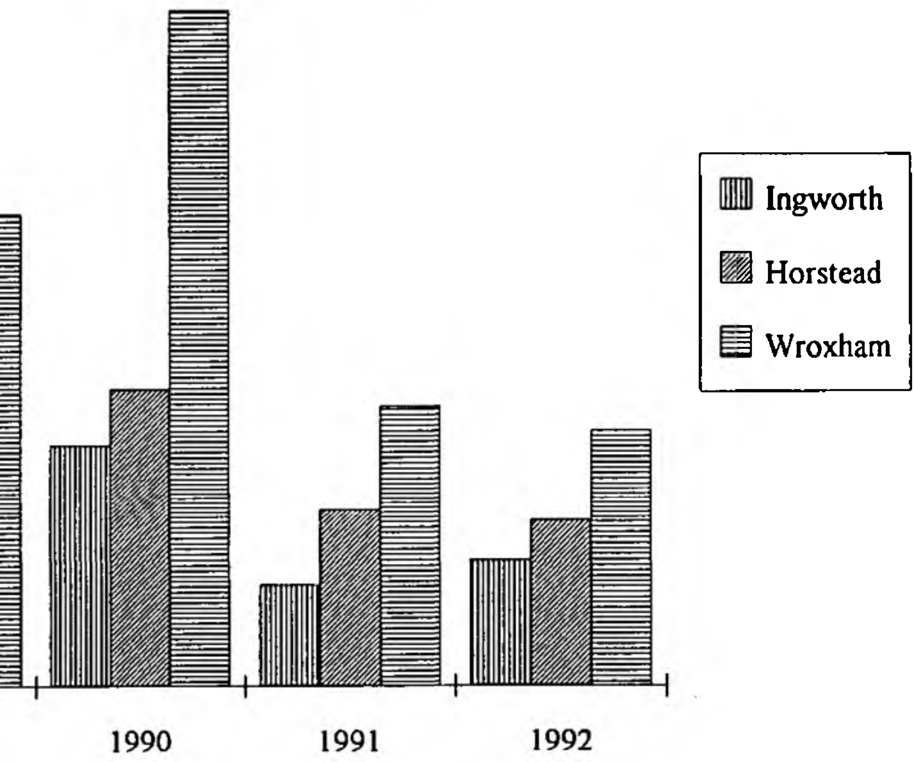


Figure 4.4 Total phosphorus load in the River Bure



Ingworth
Horstead
Wroxham
1990
1991
1992

In order to understand these changes in total P. load in the river it is necessary to look at the two main components of the total P.; S.R.P. and particulate P. separately.

Particulate P. load can be affected by river discharge. An increase in river flow will re-suspend phosphate-rich river sediments. Also, high river flows are associated with increased surface runoff and the supply of nutrient enriched soil. It therefore follows that the total P. load in the river will be affected by river flow. Figure 4.5 illustrates the relationship between the change in river total P. load and flow; when the river flows were high in 1987 and 1988, the total P. load in the river was also high and when river flows decreased the total P. load also decreased.

The majority of the phosphorus discharged from the sewage treatment works is in the soluble form. A comparison of the mean S.R.P. loads in the river with S.R.P. discharged from the sewage treatment works (Figure 4.6) shows a reduction in the S.R.P. load in the river at Horstead Mill and Wroxham Rail Bridge. Further, an increase in the river load in 1989 is associated with an increase in the phosphorus discharged. The continued lowering of the phosphorus load discharged from 1990- 1992 has been reflected by a reduced river S.R.P. load at Horstead Mill and Wroxham Rail Bridge. The relationship at Ingworth Guaging Station is not as clear, with the changes in S.R.P. load following those described for total P.. It would therefore appear that at Ingworth a relationship also exists between the S.R.P. load and river discharge.

These relationships between sewage treatment works discharge, river load and river flow were investigated in the 1990 report (Phillips and Chilvers. 1991). However, since that report the level of phosphorus being discharged into the river from the sewage treatment works has been continuously maintained at a reduced level. It would therefore be of interest to see if the relationships are still valid.

Ingworth Guaging Station and Horstead Mill

By looking at the relationship between total P. load in the river and the load discharged from the S.T.W.'s during periods when the river flow is below average the interference from the particulate P. fraction should be reduced. At Ingworth Guaging Station (Figure 4.7) no relationship is apparent. However, at Horstead Mill (Figure 4.8), a relationship can be seen, although there are still many occasions when the total P. load in the river is high and the total P. load discharged is reduced. The correlation coefficient (r) is 0.364 which is just significant at the 99.9% level of confidence. It would appear from this that increased inputs from the S.T.W.'s have increased the total P. load in the river at Horstead Mill, although the scatter plot suggests that there are other sources of phosphorus.

In order to fully assess the effectiveness of the phosphorus stripping process, the relationship between the S.R.P. input from the S.T.W.'s and S.R.P. load in the river should be investigated. However, the catchment contribution of S.R.P. may be affected by increased rainfall and the associated increase in river discharge will increase effluent dilution. During periods of high rainfall surface runoff increases, which will in turn increase the potential supply of S.R.P. to the river. The relationship between S.R.P. load in the river and input from the S.T.W.'s is therefore investigated during periods of low discharge.

A general trend of increasing river load with S.R.P. input from the S.T.W's is seen at Horstead Mill (Figure 4.9). The correlation coefficient (r) is 0.709 and is significant at the 99.9% confidence limit. However, at Ingworth the relationship is not as clear,

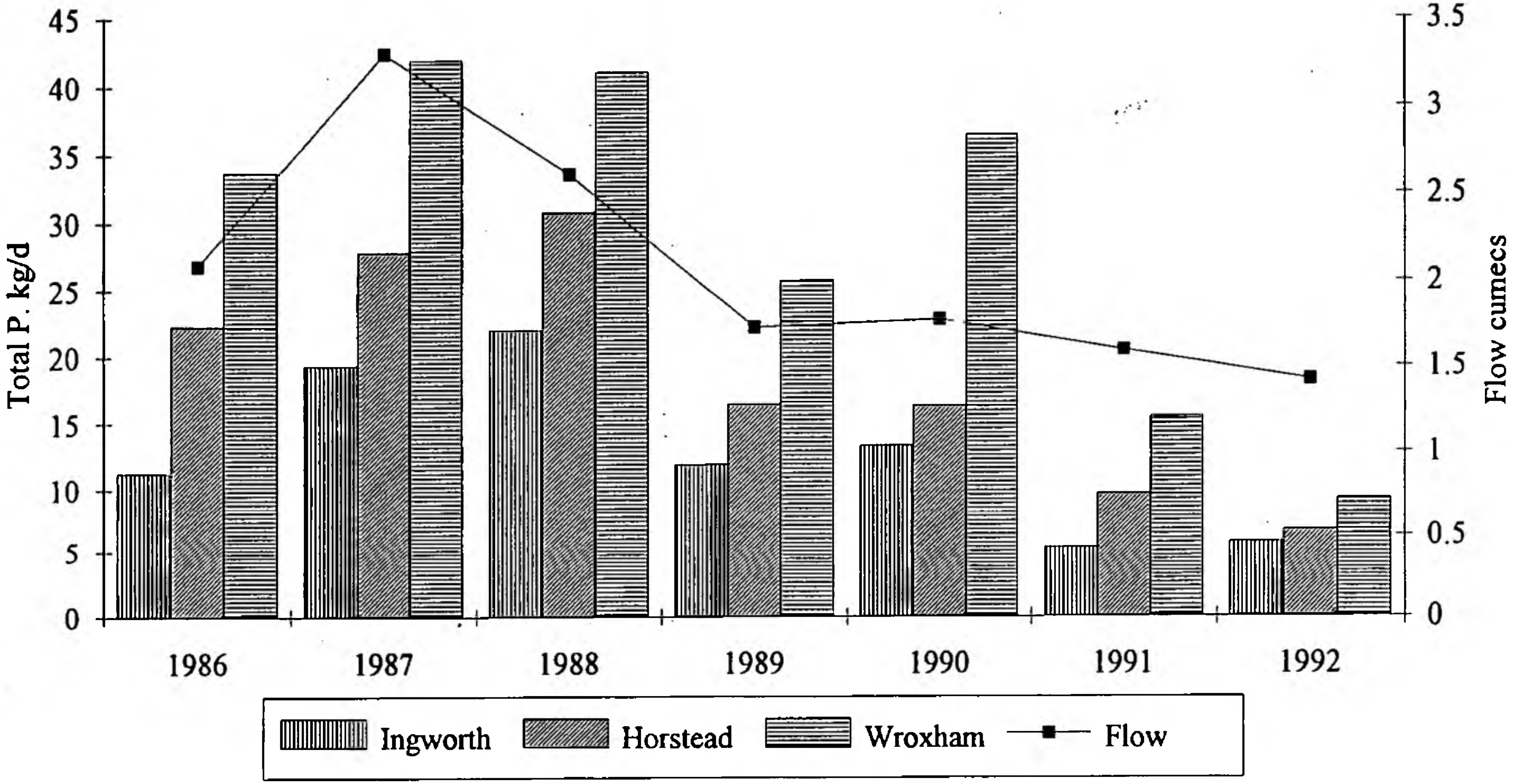


Figure 4.5 Soluble reactive phosphorus load in the River Bure and flow recorded at Horstead Mill Guaging Station

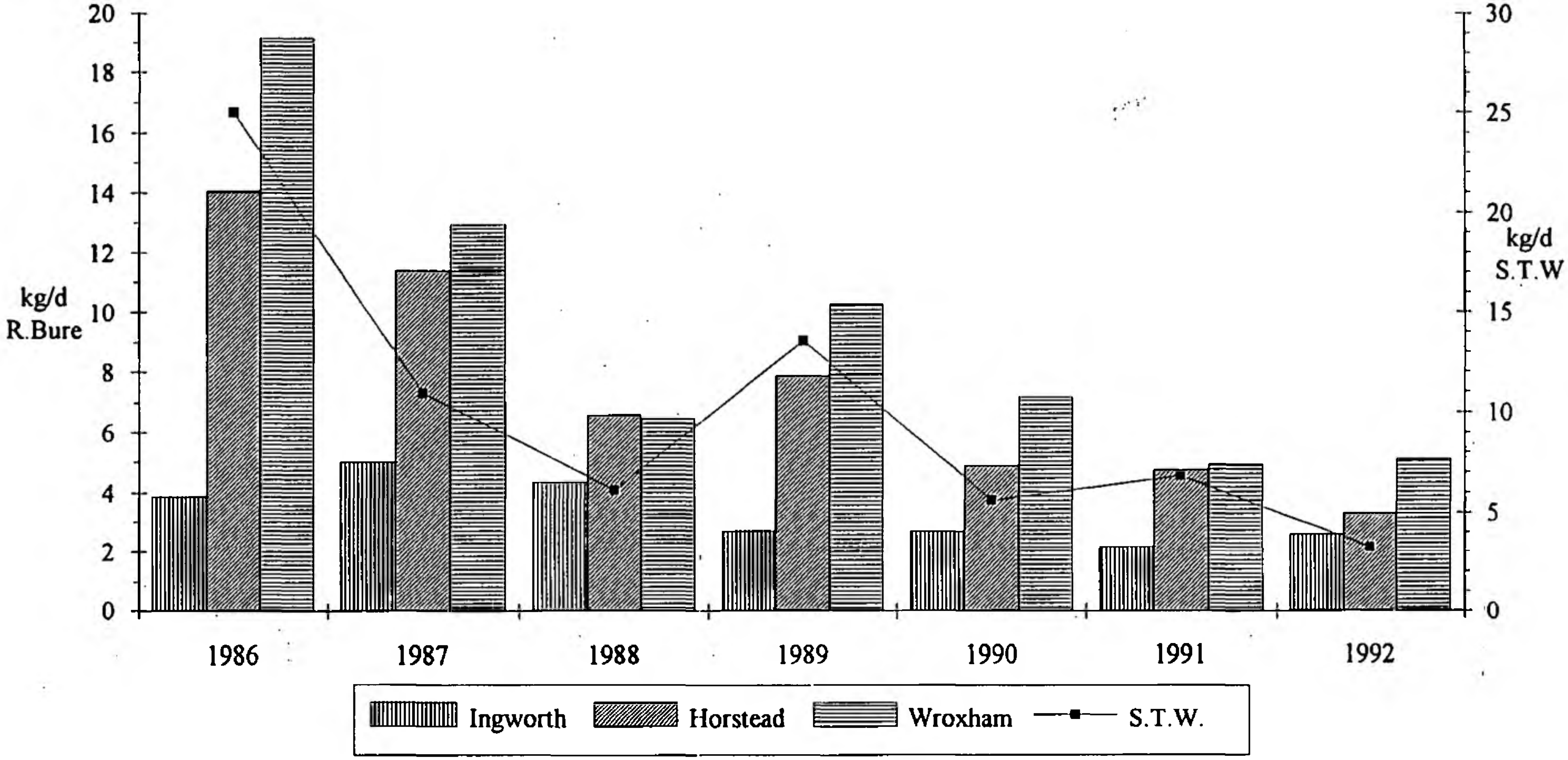


Figure 4.6 Soluble reactive phosphorus load in the River Bure and soluble reactive phosphorus input from the sewage treatment works

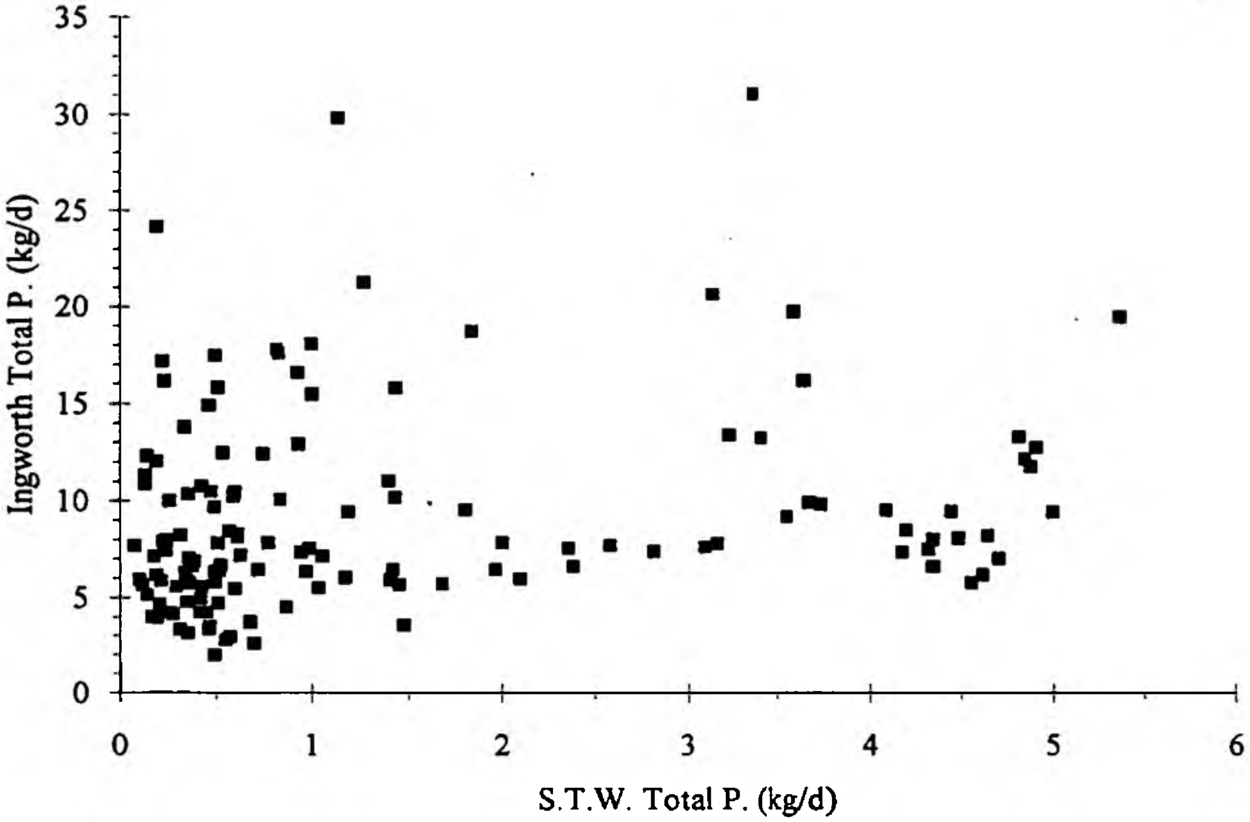


Figure 4.7 Relationship between total phosphorus load at Ingworth Guaging Station and sewage treatment works input when flows are below average

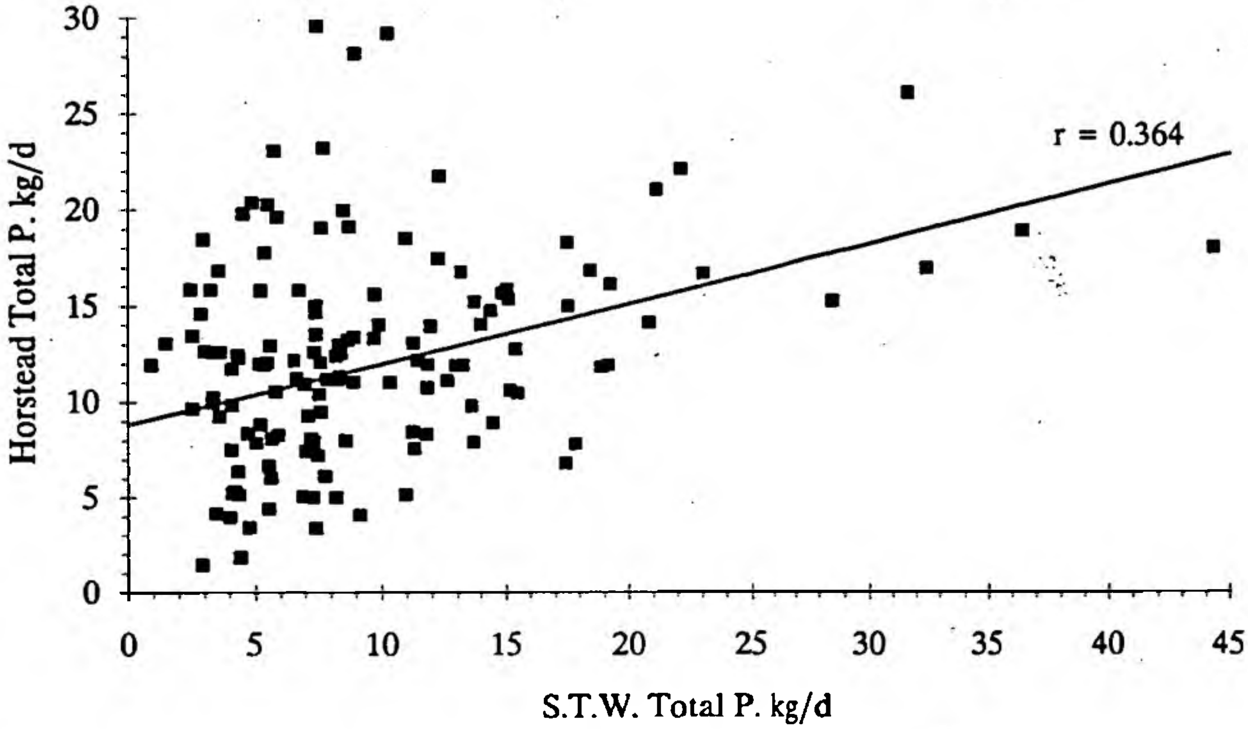


Figure 4.8 Relationship between total phosphorus load at Horstead Mill and sewage treatment works input when flows are below average

indicating that other sources of phosphorus are influencing the S.R.P. load of the river (Figure 4.10). If a year, which covers periods of both ineffective and effective phosphorus stripping, is looked at in isolation a different picture is seen (Figure 4.11). One such period of time is that from the summer of 1989 to the summer of 1990. These data appear to fall into two clusters; reduced S.T.W. input and low river loadings and increased S.T.W. inputs and greater river loadings. Obviously the improvement in the phosphorus stripping performance in early 1990 at Briston did reduce the S.R.P. loads in the river Bure at Ingworth Guaging Station. The relationship at Ingworth is complicated by possible catchment contributions and the uptake of available phosphorus by submerged macrophytes within the river channel.

By looking at the relationship between flow and river load it may be possible to determine whether other sources of phosphorus are having an influence on the budget. At both Ingworth Guaging Station and Horstead Mill there is an increase in river load with increasing flow (Figures 4.12-13). It would be expected that as flow increases point sources of phosphorus, such as S.T.W.'s effluent, would become diluted resulting in constant phosphorus load. However, the increase in soluble phosphorus load within the river suggests that other diffuse sources of phosphorus are affecting the river load and that these increase with discharge. Also of note are the outlying points of increased S.R.P. load when the river is in spate. Usually spate conditions are associated with an increase in surface runoff which not only increase the supply of S.R.P. directly entering the river, but will also increase the supply of surface sediment to the river. This increase in particulate P. will increase the amount of potentially available soluble P.. The labile phosphorus fraction of soils may only constitute a small part of the total particulate fraction but it includes phosphate that is adsorbed, easily hydrolysed or dissolved. In the same way, resuspension of river sediments during periods of increased flow can increase the potential soluble P. load. Any available phosphorus discharged to the river from the S.T.W.'s, which is either taken up by macrophytes or adsorbed to sediment, may therefore act as a future source of phosphorus to the broads further down river.

Wroxham Rail Bridge

The interpretation of the phosphorus budget at this site is complicated by the effects of tidal movement and phytoplankton growth. A trend which is clearly illustrated at Wroxham is the seasonal fluctuation in S.R.P.. The low levels of S.R.P. at this site in the late spring correspond to an increase in chlorophyll a concentration, illustrating the effect of phytoplankton uptake (Figure 4.14). The effects of the introduction of phosphorus stripping at the up river sewage treatment works is illustrated by the drop in S.R.P. concentration within the river at the end of 1986. The S.R.P. levels rose again in the latter part of 1989 which coincided with the period of reduced effectiveness of the phosphorus stripping process. This increase in the winter 1989 and spring 1990 levels of S.R.P. was followed by an exceptionally high peak in the chlorophyll a concentration. Despite the reduction in S.R.P. input for the years 1990 - 1992 from the S.T.W.'s the chlorophyll a concentration did not fall to the levels achieved immediately after the introduction of phosphorus stripping. A further factor which influences the productivity of phytoplankton within the river is the rate of discharge. When the change in chlorophyll a concentration is plotted with the change in river discharge a relationship can be seen (Figure 4.15). When the flow rate is high then the chlorophyll concentration is reduced; this is especially the case for the years 1987 and 1988. The decline in river flows due to low rainfall in recent years has encouraged phytoplankton growth and hence increased chlorophyll a concentrations. The exceptional increase in phytoplankton numbers in 1990 was due, therefore, to a combination of increased S.R.P. input and reduced river flows.

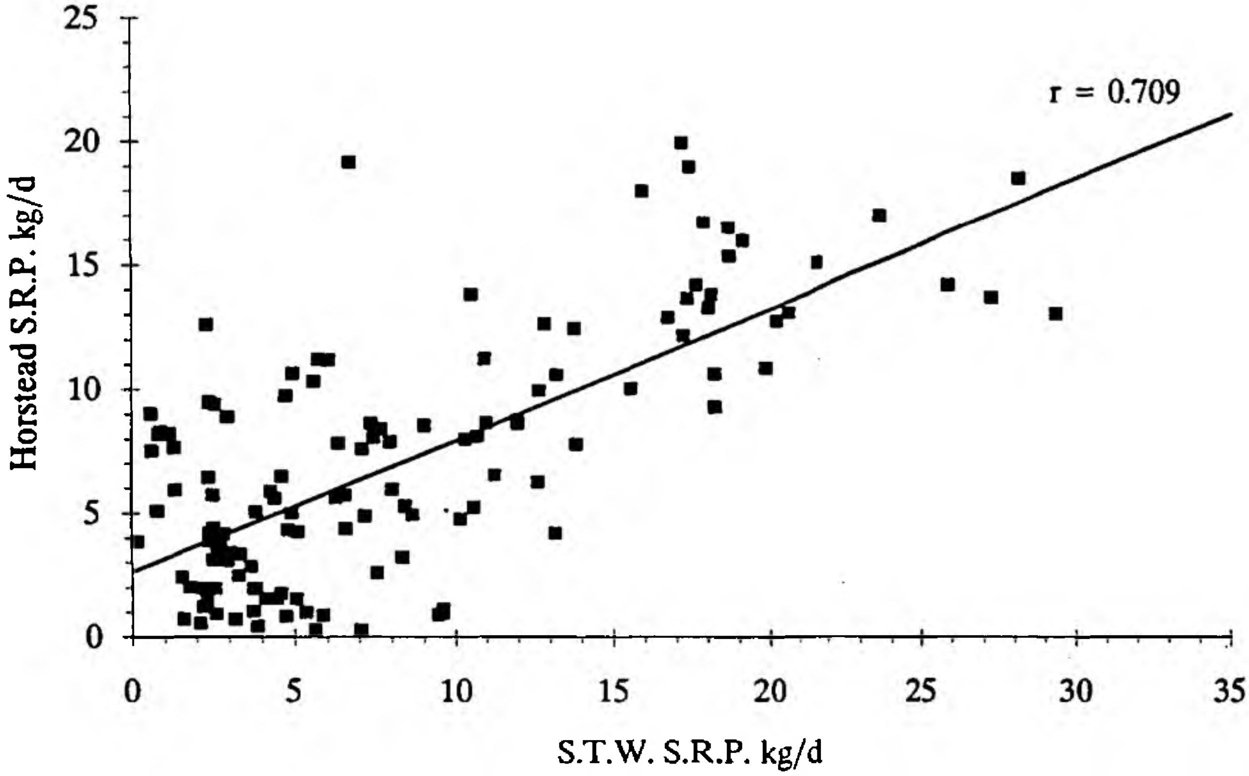


Figure 4.9 **Relationship between soluble reactive phosphorus load at Horstead Mill and sewage treatment works input when flows are below average**

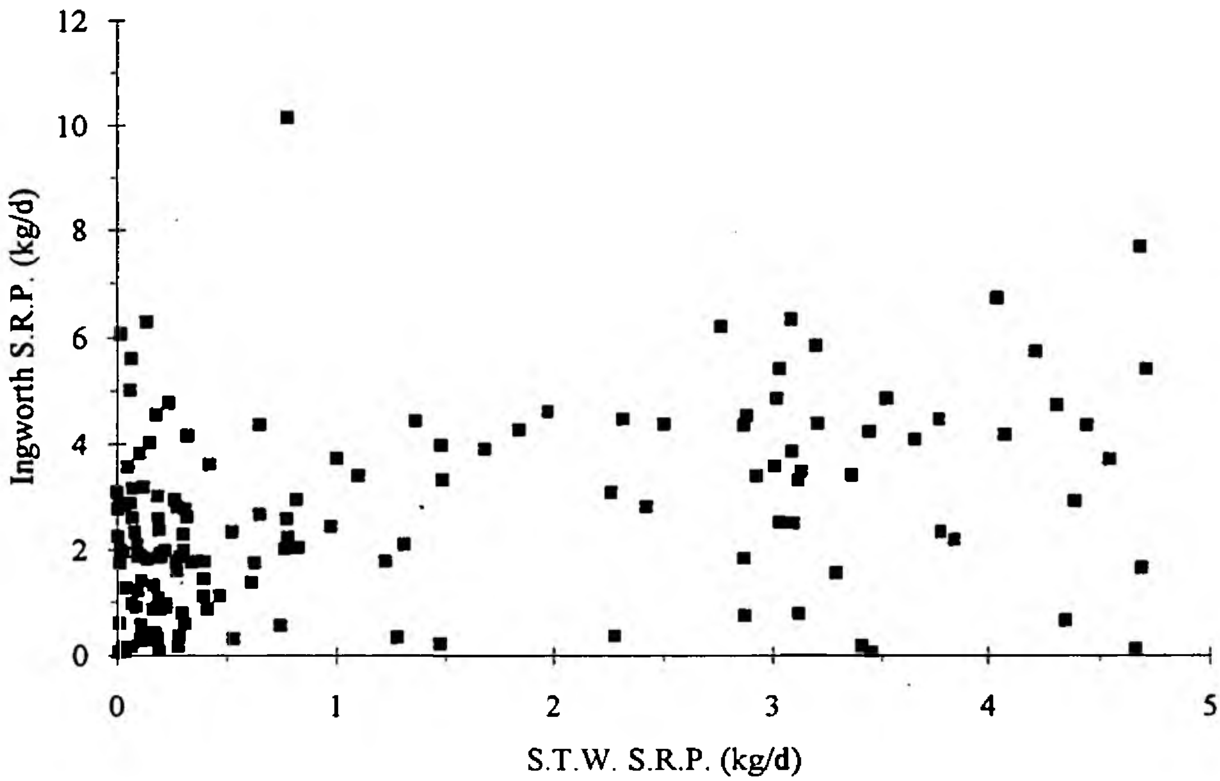


Figure 4.10 Relationship between soluble reactive phosphorus load at Ingworth Guaging Station and sewage treatment works input when flows are below average

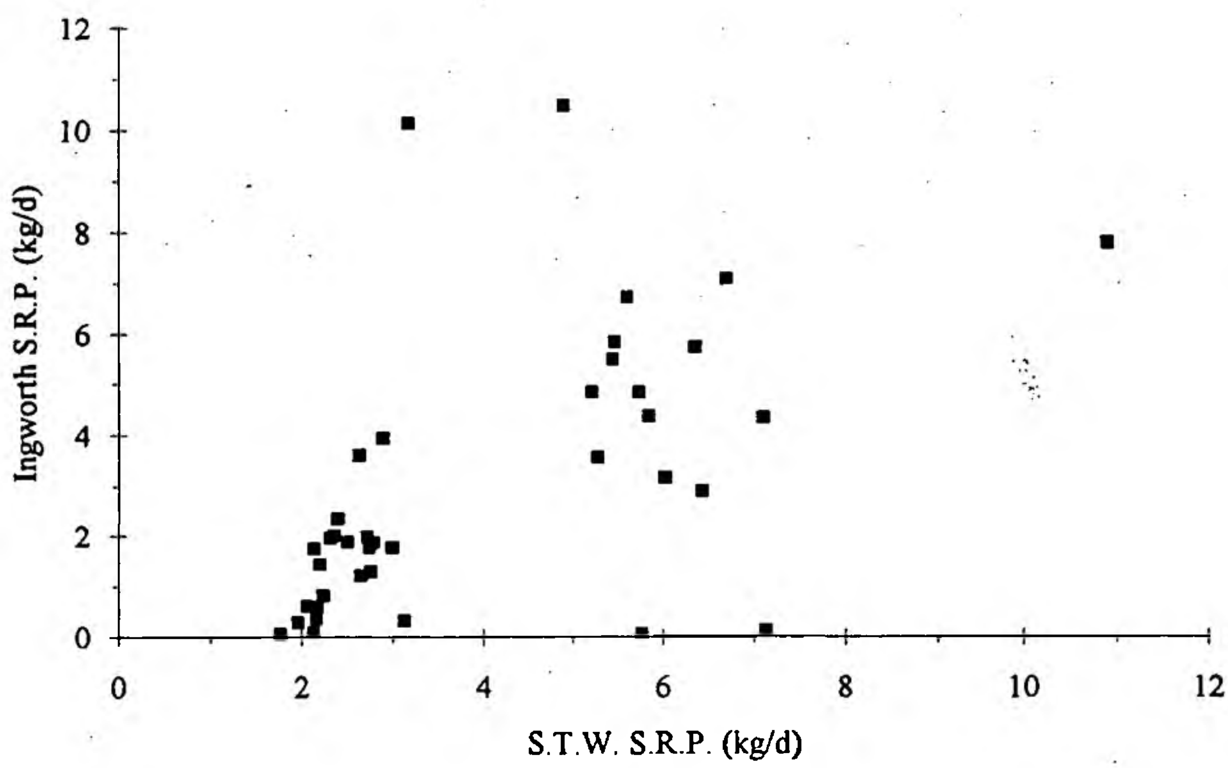


Figure 4.11 Relationship between soluble reactive phosphorus load at Ingworth Guaging Station and sewage treatment works input for 1989

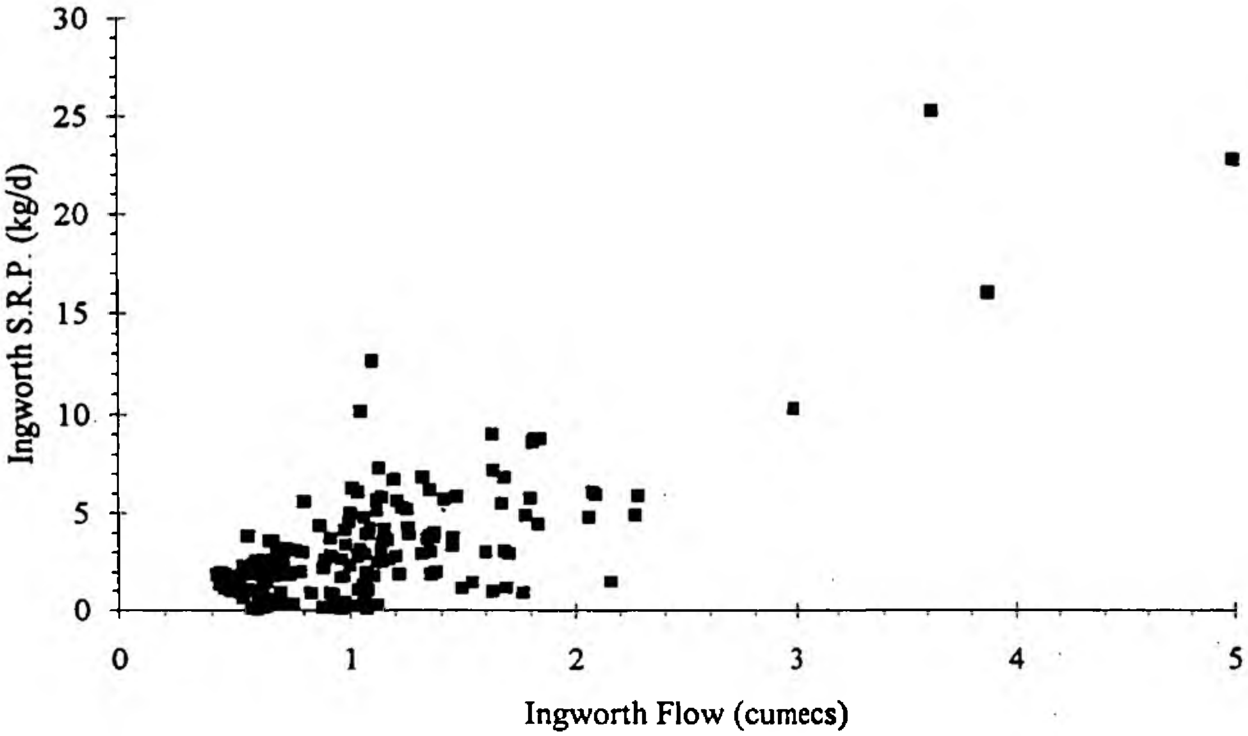


Figure 4.12 Relationship between soluble reactive phosphorus load at Ingworth Guaging Station and river discharge when phosphorus input from the sewage treatment works is reduced

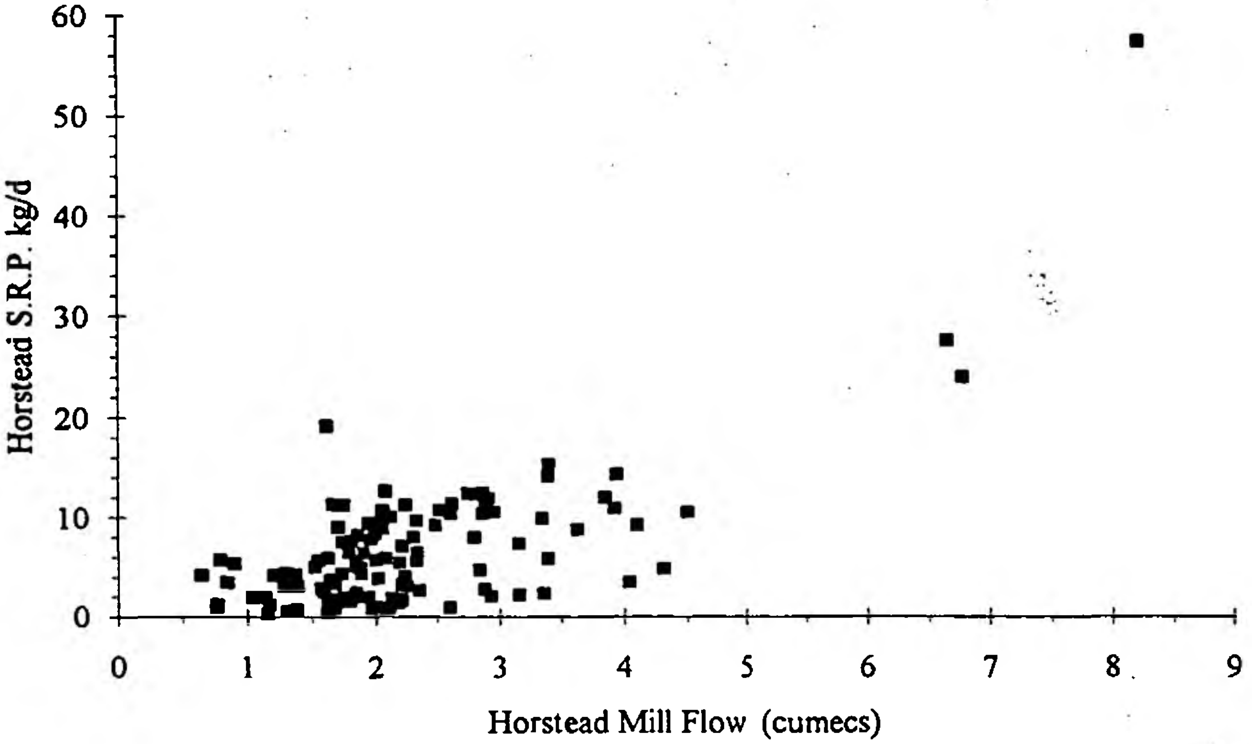


Figure 4.13 Relationship between soluble reactive phosphorus load at Horstead Mill and river discharge when phosphorus input from the sewage treatment works is reduced

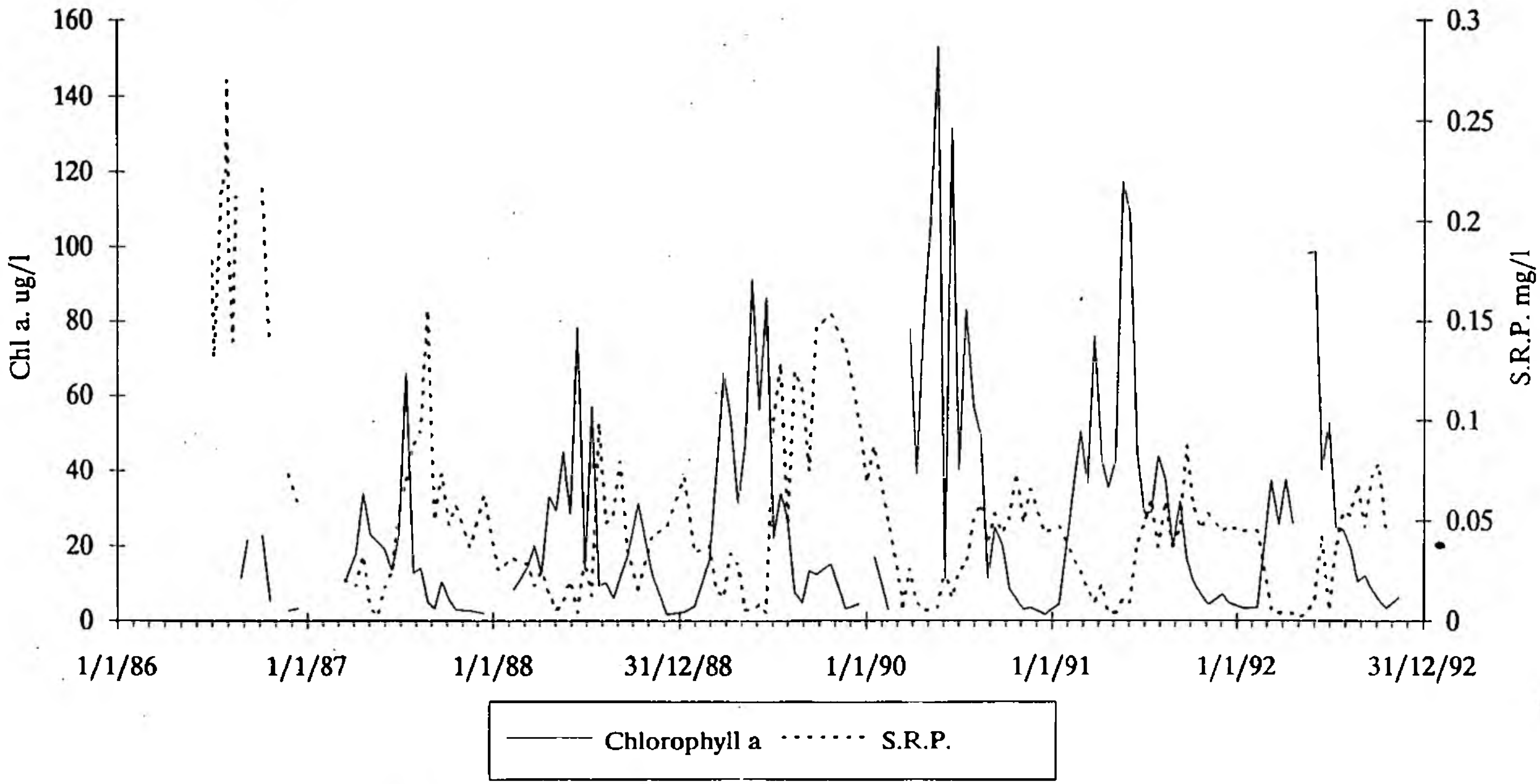


Figure 4.14 Chlorophyll a and soluble reactive phosphorus concentration for Wroxham Rail Bridge

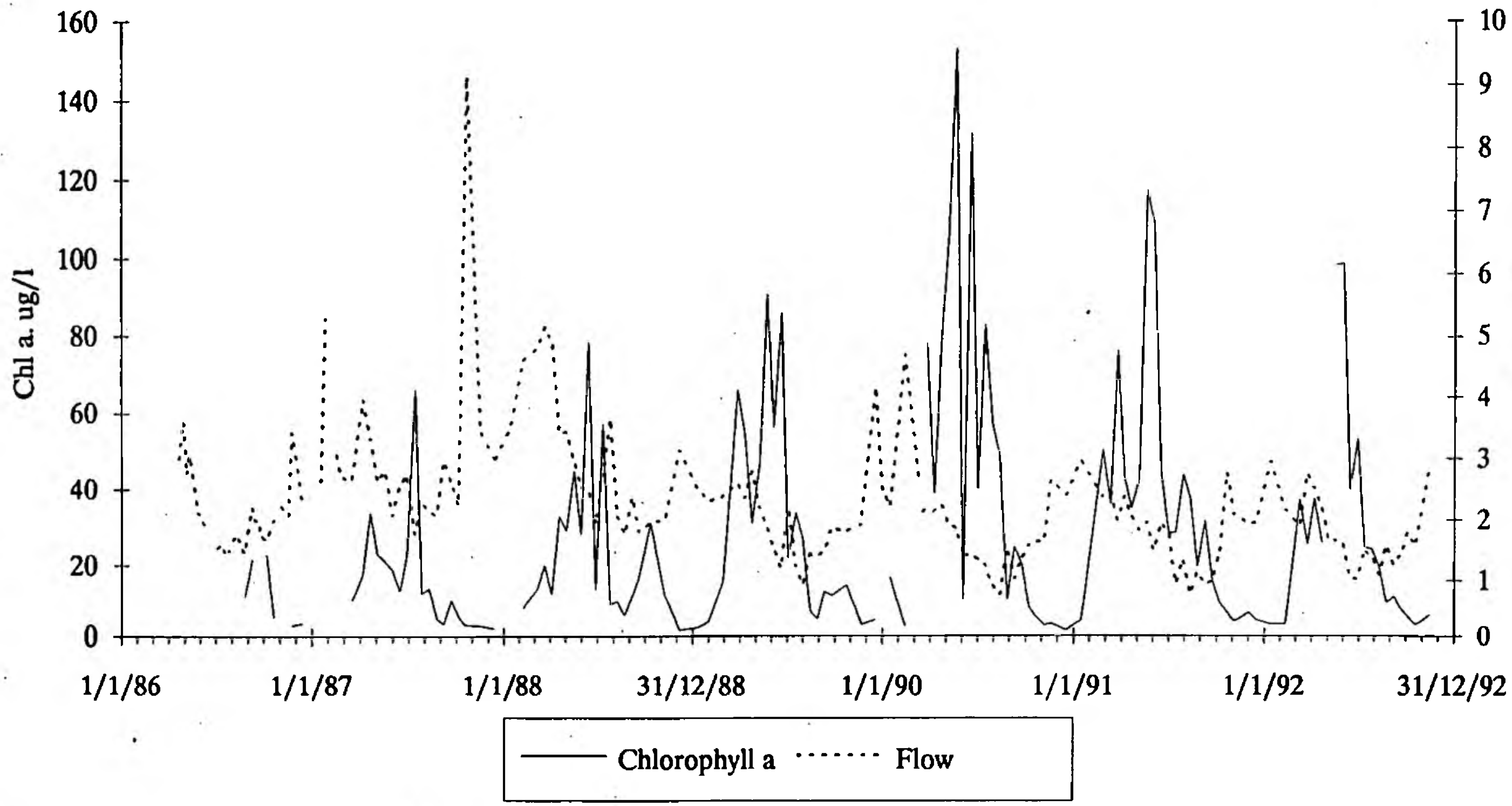


Figure 4.15 Chlorophyll a concentration and river discharge for Wroxham Rail Bridge

4.3 The Effect Of Phosphorus Control Upon Wroxham Broad.

The aim of the introduction of phosphorus control was to limit the productivity of phytoplankton within the broads and therefore provide a clear water environment in which macrophytes can begin to flourish. Phytoplankton development within the broads will be affected by a number of variables which include phosphorus supply, retention time of the water and the number of predatory zooplankton. In order to ascertain whether there has been a reduction in phytoplankton productivity in association with reduced phosphorus supply, the relationship between chlorophyll a and Total P. should be investigated. The total P. within a broad is comprised of both S.R.P. and particulate P.; with phytoplankton representing the majority of the particulate fraction during the summer months.

The relationship between mean summer total P. and chlorophyll a is shown in Figure 4.16. As expected there is a significant, positive correlation ($r = 0.702$). The lowest chlorophyll a concentrations were recorded in 1987 and 1988, following the introduction of phosphorus removal. The poor performance of this removal in 1989 was reflected by an increase in both total P. and chlorophyll a, but subsequent improvements in 1990 and 1991 did not result in reduction in either total P. or chlorophyll a. In addition results in 1987 and 1991 showed marked variation from the regression line.

These data illustrate the complexity of the Broads system even in Wroxham Broad, a relatively well flushed lake in the upper tidal river. Phytoplankton growth is not only related to phosphorus supply, but to water retention time. Thus the abnormally low chlorophyll noted in 1987 was associated with a very high river discharge. Conversely the dry summers of 1989 - 1992 resulted in higher chlorophyll concentrations. In addition the river Bure is tidal; phytoplankton development increases down river of Wroxham Broad, due to increased retention time and the effect of a large number of lakes which act as 'dead zones' enabling phytoplankton to develop. In wet years Wroxham Broad is well flushed and fluvial flow is sufficient to prevent tidal ingress of phytoplankton rich water. However, in dry years tidal movement becomes more significant and phytoplankton from further down river enter Wroxham Broad and can become established.

4.4 Conclusions

The input of phosphorus to the river Bure from the S.T.W's has now been controlled for a number of years and a reduction in phosphorus load entering the broads can be clearly demonstrated. The effects of the reduced load could be observed at Wroxham Rail Bridge with a reduction in chlorophyll concentration being associated with the reduction in phosphorus load. The interpretation of the effects at both Ingworth Guaging Station and Horstead Mill is complicated by the interaction of diffuse catchment sources and river discharge upon the supply and removal of phosphorus. An initial investigation into the effects of phosphorus control upon Wroxham Broad shows that chlorophyll a concentration has decreased in line with the reduction in phosphorus supply from the river and that the response is complicated by the combined effects of fluvial and tidal water movement. The continuation of phosphorus control at the S.T.W.'s is important if the reduction in phytoplankton productivity is to be maintained and allow further progress to be made towards the restoration of the Norfolk Broads.

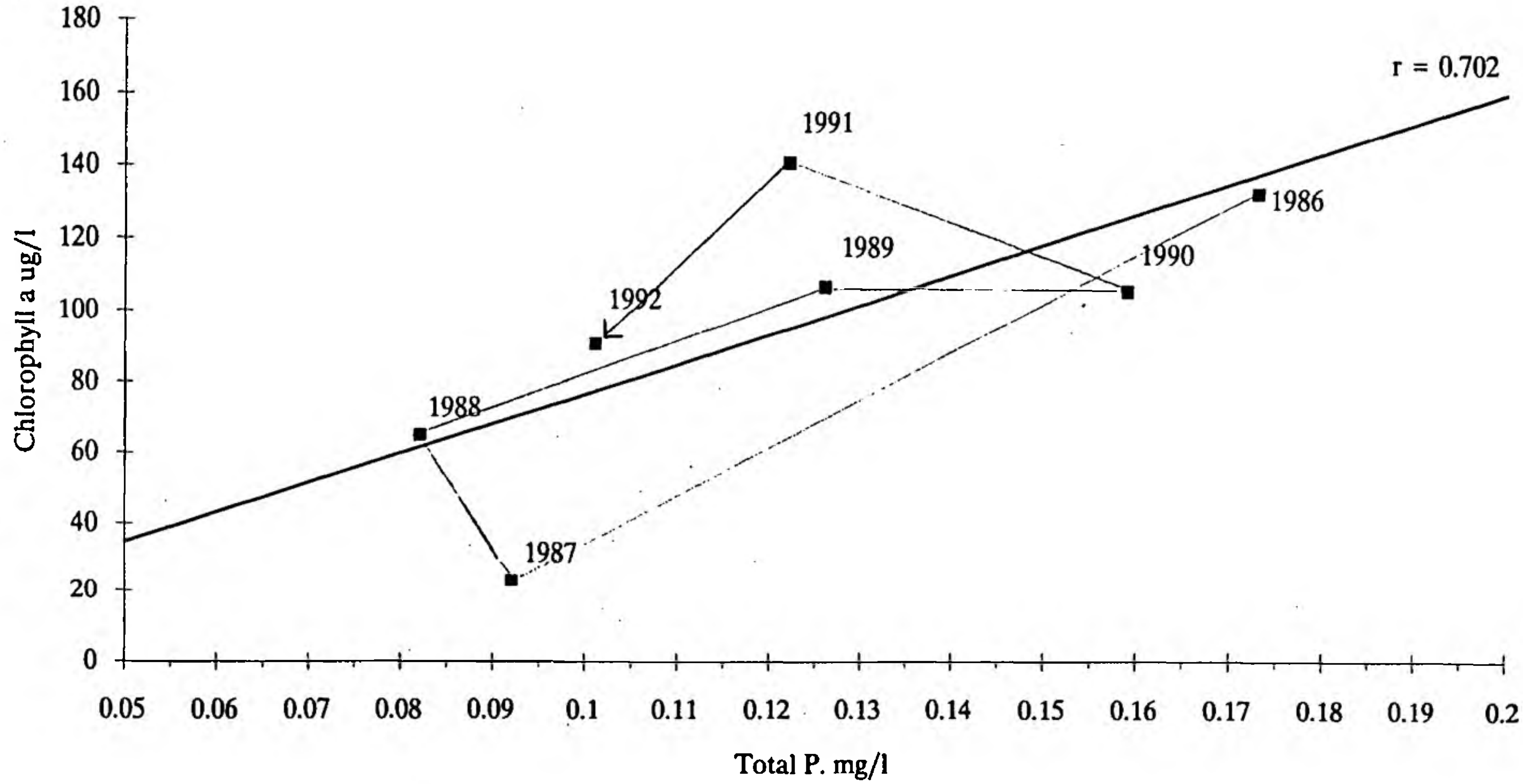


Figure 4.16 Relationship between chlorophyll a and total phosphorus concentration for Wroxham Broad

5. LIMNOLOGY OF THE BURE BROADS AND RIVER

5.1 Introduction

Fortnightly monitoring of the upper tidal reaches of the river Bure and associated Broads has continued throughout 1992. During the winter the sampling frequency is reduced to once every four weeks. Water samples are collected and a number of chemical determinands analysed to assess what changes, if any, have occurred within the river Bure and its associated Broads either as a result of the phosphorus stripping programme or other factors. To compliment this data field measurements of temperature, pH and secchi depth are taken. Also, the population changes in both phytoplankton and zooplankton are monitored.

5.2 Water Chemistry

Data from the fortnightly spot samples are shown in figures 5.1 - 5.18 and a summary of the summer averages of the determinands measured is listed in Tables 5.1 - 5.2.

5.2.1 Phosphorus Concentration

The introduction of the phosphorus stripping programme has lead to a reduction in the phosphorus concentration in the upper river Bure. The pattern of change in phosphorus concentration at Horstead Mill and Wroxham Rail Bridge sampling sites has already been discussed in chapter 4. The reduction in phosphorus concentration recorded for both of these sites in 1987 can also be seen further down the tidal river at Horning Ferry. An increase in concentration, especially S.R.P., is associated with the period of ineffective phosphorus stripping in the latter part of 1989. Any impact upon the phosphorus concentration in the lower reaches of the river is complicated by the effects of tide and the input of water from the river Ant. Also, South Walsham Broad receives effluent, rich in phosphorus, from a small sewage treatment works. The effects of the phosphorus removal programme upon Wroxham Broad, a well flushed broad situated in the upper tidal reaches of the river, is discussed in chapter 4.

The seasonal and annual patterns of phosphorus concentration change within the broads are affected by the supply of phosphorus from the river, retention time, extent of internal phosphorus recycling, uptake of phosphorus by phytoplankton and the numbers of predatory zooplankton.

During the spring and early summer S.R.P. concentrations fall to levels at or below the detection limit whereas, the total P. concentration remains relatively unchanged. This is because the available phosphorus is incorporated into the particulate fraction i.e. the phytoplankton. Interrupting the spring and summer decline in S.R.P. concentrations are short lived increases in concentration. These peaks may be a result of direct recycling of phosphorus from the particulate fraction by excretion from zooplankton or by a change in phytoplankton flora. However, some peaks are associated with an increase in total P. and therefore represent an increase in the internal phosphorus supply possibly via sediment release. An increase in total P. was recorded in the late summer for most of the broads, especially those in the less flushed middle or lower reaches of the river. Total P. concentrations were highest for these broads during 1989, 1990 and 1991. During these years river flows and hence flushing rates were much reduced enabling the effect of any input of phosphorus from the sediment to be magnified by enhanced

Table 5.1 River Bure Sites monitoring data: mean concentrations April - September 1986 - 1993

Site	Year	Total P. mg/l	S.R.P. mg/l	T.O.N. mg/l	Ammonium mg/l	Chlorophyll a μg/l
Wroxham Rail Bridge	1986	0.252	0.139	5.24	0.04	36.6
	1987	0.132	0.052	5.54	0.04	20.1
	1988	0.113	0.033	6.13	0.03	26.9
	1989	0.150	0.063	4.95	0.07	37.3
	1990	0.113	0.028	4.31	0.12	62.0
	1991	0.116	0.035	4.98	0.04	45.9
	1992	0.103	0.031	4.86	0.06	37.6
D/S Wroxham Broad	1986	0.187	0.044	3.79	0.05	111.4
	1987	0.114	0.034	5.04	0.04	32.2
	1988	0.121	0.018	5.58	0.03	61.1
	1989	0.145	0.026	3.74	0.06	84.5
	1990	0.163	0.030	2.76	0.05	109.2
	1991	0.156	0.013	2.25	0.02	142.9
	1992	0.117	0.009	3.47	0.03	92.6
U/S Horning Village	1986	no data	no data	no data	no data	no data
	1987	no data	no data	no data	no data	no data
	1988	no data	no data	no data	no data	no data
	1989	no data	no data	no data	no data	no data
	1990	0.189	0.031	1.35	0.09	122.3
	1991	0.185	0.020	1.43	0.02	123.5
	1992	0.148	0.016	1.91	0.03	112.9
Horning Ferry	1986	0.163	0.048	1.57	0.06	100.6
	1987	0.128	0.021	3.05	0.08	66.3
	1988	0.111	0.014	3.83	0.04	73.1
	1989	0.162	0.027	1.61	0.07	119.1
	1990	0.202	0.039	1.15	0.10	155.3
	1991	0.179	0.019	1.18	0.02	119.2
	1992	0.164	0.008	1.42	0.03	119.2
St. Benet's Abbey	1986	0.174	0.020	1.02	0.04	173.8
	1987	0.148	0.011	1.97	0.05	106.5
	1988	0.141	0.008	2.46	0.02	115.8
	1989	0.197	0.026	0.99	0.05	140.4
	1990	0.215	0.026	1.55	0.04	126.7
	1991	0.230	0.016	0.64	0.02	162.5
	1992	0.203	0.010	0.85	0.03	145.1

Table 5.2 River Bure Broads monitoring data: mean concentrations April - September 1986 - 1993

Site	Year	Total P. mg/l	S.R.P. mg/l	T.O.N. mg/l	Ammonium mg/l	Chlorophyll a µg/l
Belaugh Broad	1986	no data	no data	no data	no data	no data
	1987	0.087	0.035	3.77	0.10	18.1
	1988	0.087	0.012	4.26	0.04	82.1
	1989	0.084	0.022	3.31	0.10	33.3
	1990	0.098	0.030	3.03	0.07	26.7
	1991	0.088	0.019	3.15	0.04	50.8
	1992	0.087	0.019	2.99	0.09	44.0
Wroxham Broad	1986	0.173	0.038	3.23	0.04	132.0
	1987	0.092	0.038	4.66	0.10	23.6
	1988	0.082	0.014	5.44	0.04	64.9
	1989	0.126	0.028	3.68	0.07	106.4
	1990	0.159	0.029	2.51	0.06	105.1
	1991	0.135	0.007	2.00	0.02	163.0
	1992	0.101	0.012	2.84	0.03	90.5
Hoveton Little Broad	1986	0.148	0.031	1.08	0.12	124.3
	1987	0.112	0.009	1.42	0.10	101.4
	1988	0.101	0.007	2.46	0.06	105.5
	1989	0.148	0.015	1.11	0.20	108.3
	1990	0.147	0.007	0.85	0.06	140.9
	1991	0.124	0.005	0.67	0.02	96.0
	1992	0.091	0.004	0.85	0.02	96.2
Ranworth Broad	1986	0.166	0.011	0.24	0.12	178.3
	1987	0.134	0.009	0.92	0.09	106.5
	1988	0.152	0.003	1.06	0.03	200.9
	1989	0.166	0.014	0.69	0.10	130.6
	1990	0.172	0.012	0.55	0.14	186.4
	1991	0.198	0.005	0.32	0.02	192.2
	1992	0.158	0.006	0.54	0.02	145.4
South Walsham Broad	1986	0.308	0.077	0.27	0.03	218.0
	1987	0.275	0.113	0.55	0.07	106.8
	1988	0.459	0.255	0.60	0.03	213.5
	1989	0.486	0.139	2.27	0.10	244.2
	1990	0.450	0.128	0.81	0.04	208.8
	1991	0.321	0.026	0.25	0.02	198.8
	1992	0.378	0.054	0.23	0.03	231.7

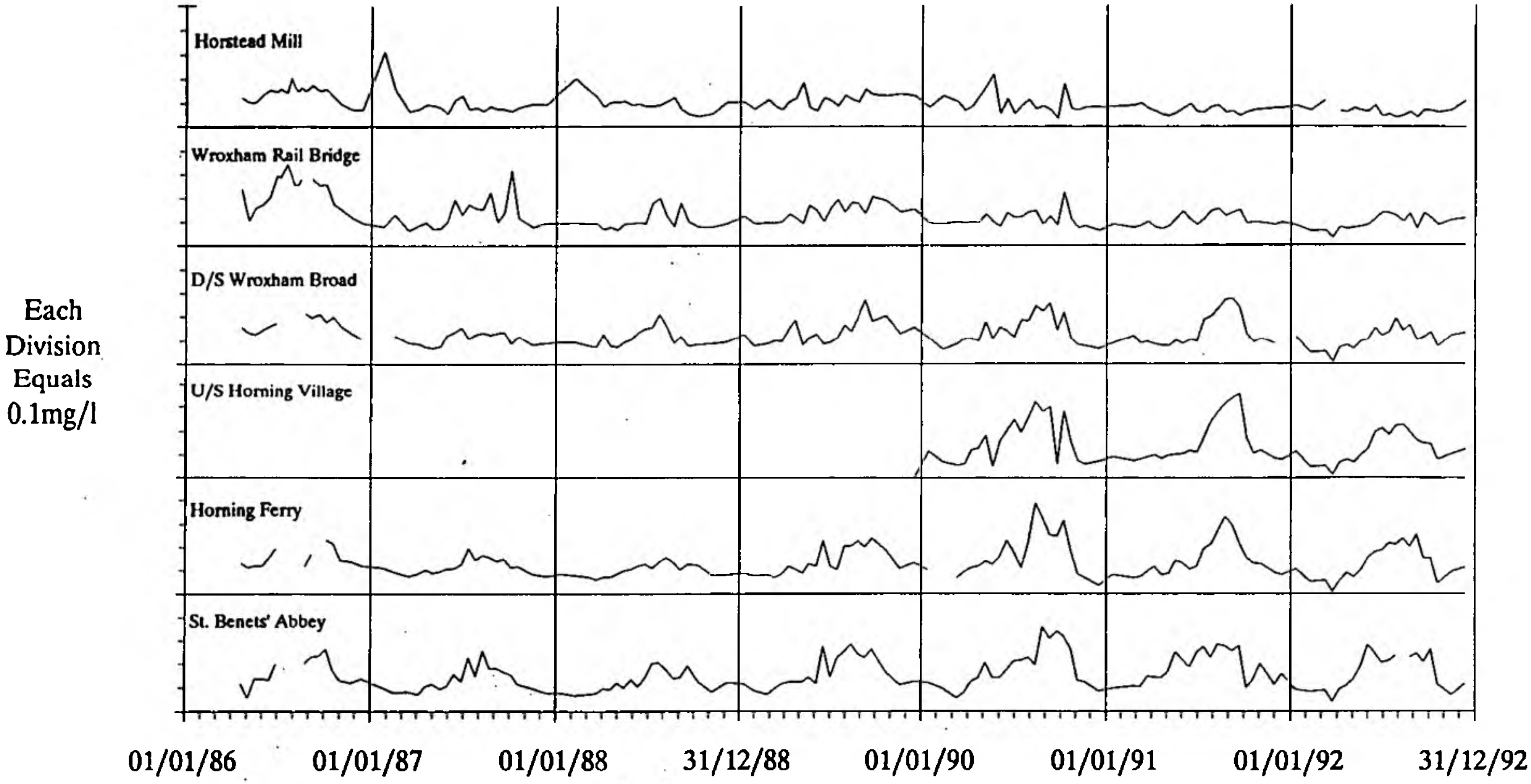


Figure 5.1 River Bure: total phosphorus concentration

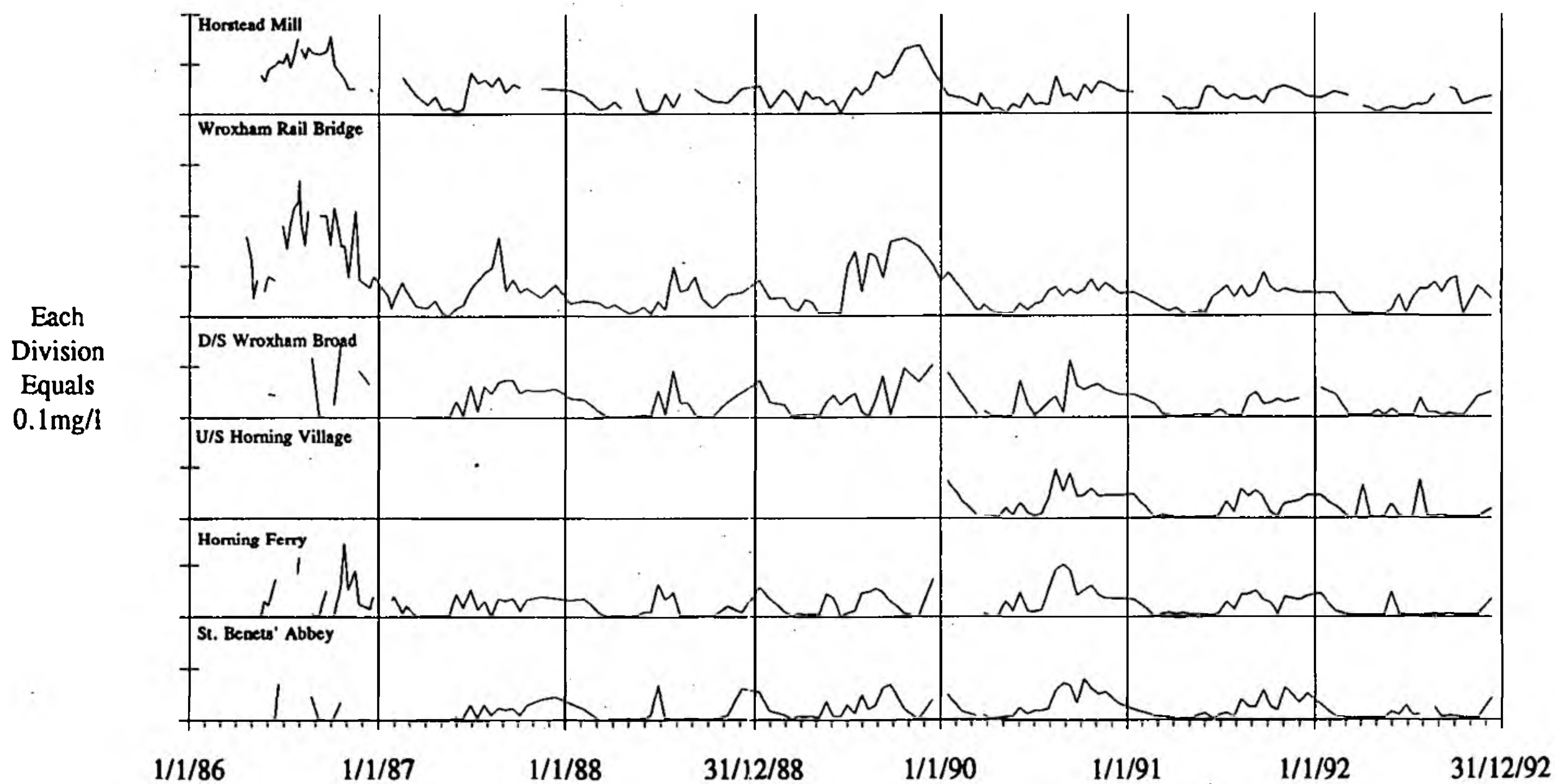


Figure 5.2 River Bure: soluble reactive phosphorus concentration

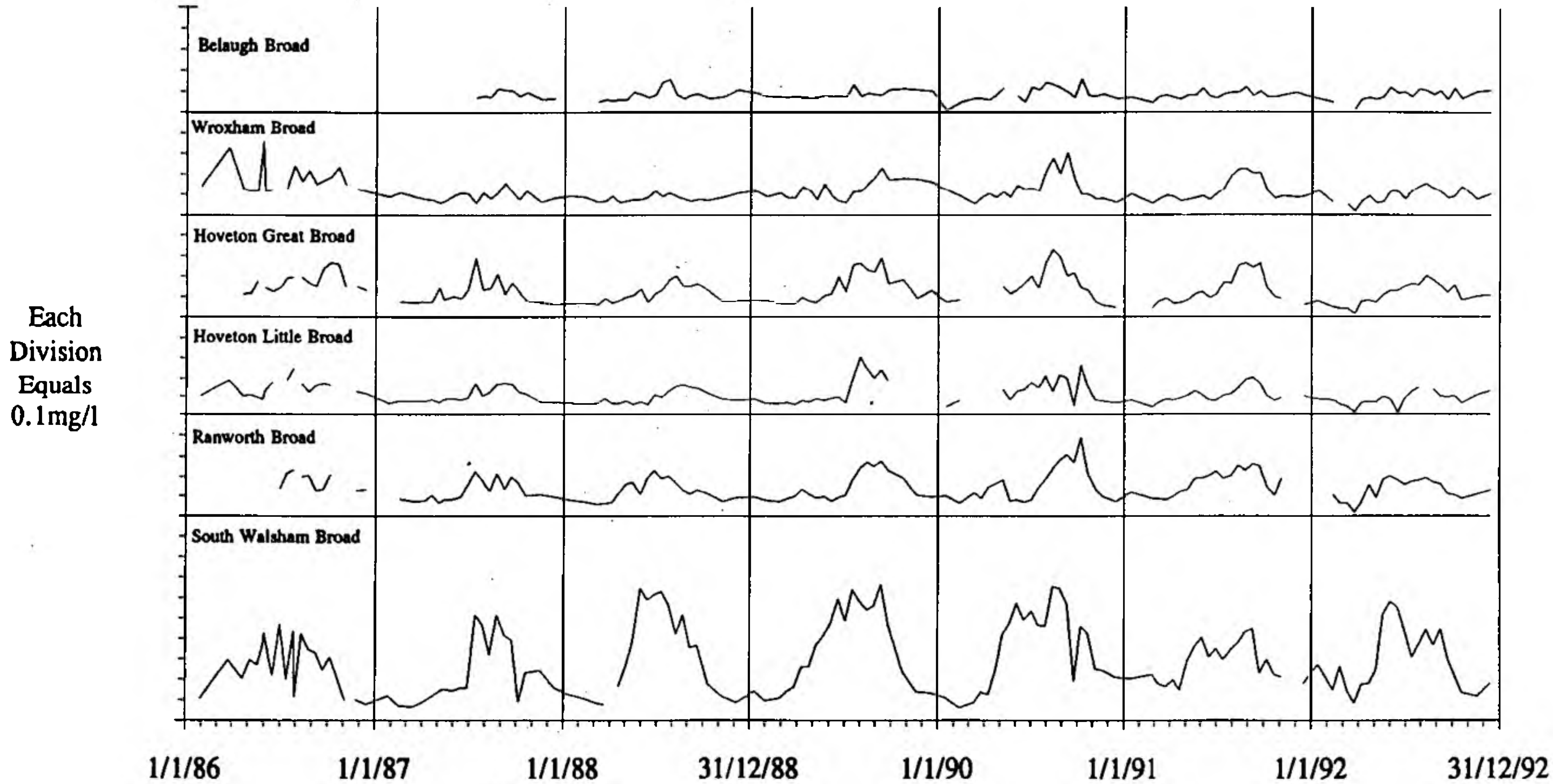


Figure 5.3 River Bure Broads: total phosphorus concentration

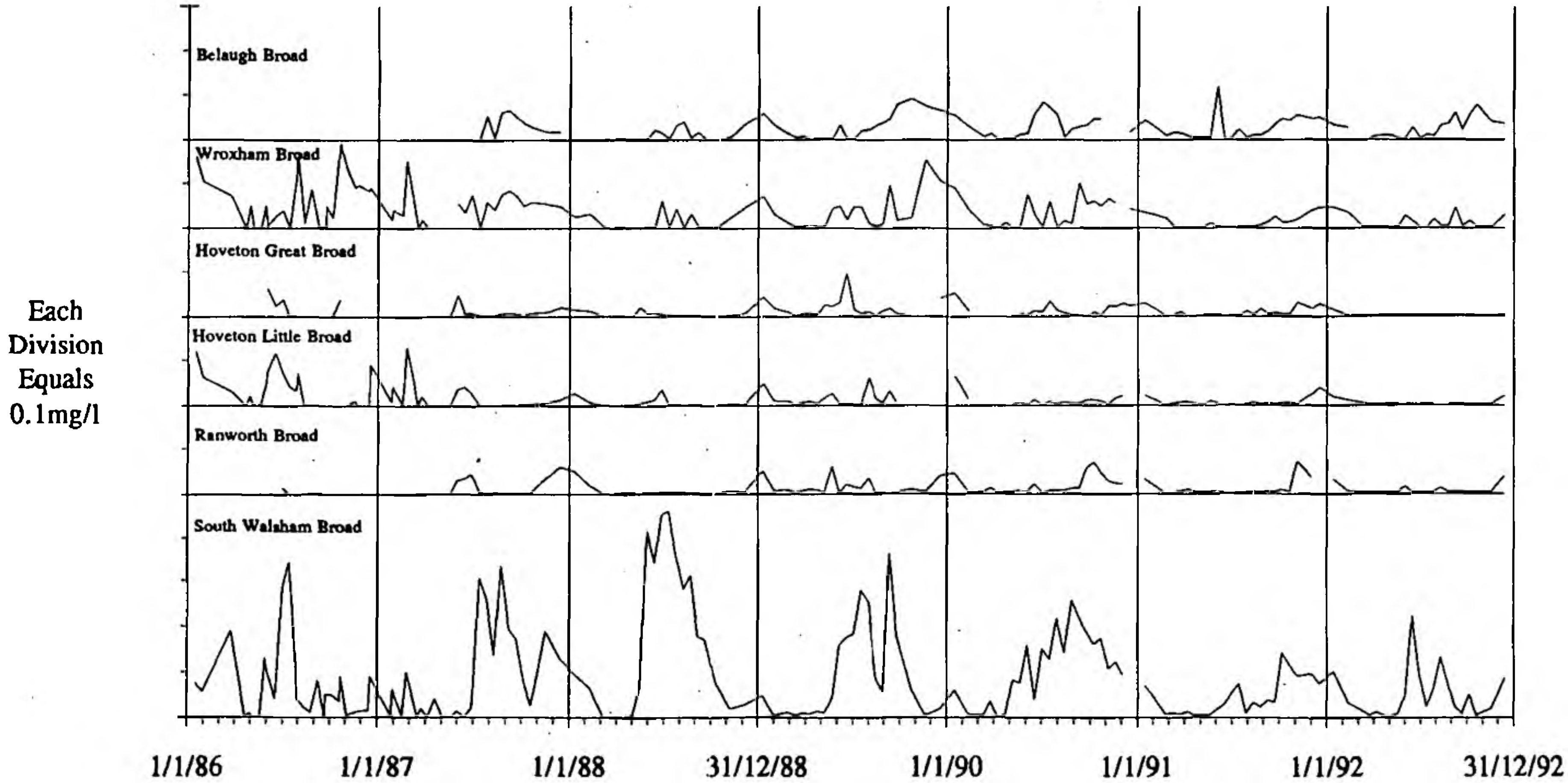


Figure 5.4 River Bure Broads: soluble reactive phosphorus concentration

phytoplankton uptake. Peaks in S.R.P. concentration were most pronounced in 1989 for Hoveton Great, Hoveton little and Ranworth broads. Also, in 1990 and 1991 there were numerous small peaks throughout the duration of the summer. However, few peaks in S.R.P concentration were recorded in 1992. Sediment release rates were determined for Ranworth Broad in 1992 and found to be significantly reduced in comparison to previous years (Pitt and Phillips, 1992).

The seasonal changes in phosphorus concentration at South Walsham Broad differ from those described previously. The levels of phosphorus are influenced by tide, the direct discharge of effluent from South Walsham S.t.W. and high rates of sediment release (Jackson and Phillips, 1990). S.R.P. concentrations are much higher than recorded for the other broads varying between 100 and 400μg/l. A spring decline in concentration is evident but rather than short lived peaks the phosphorus concentration increases during the summer months and then declines again in the winter. These increases in S.R.P. are associated with increases in total P. and are therefore indicative of release from the sediment. Although available phosphorus concentration has been declining since a maxima in 1988, total P. concentrations have changed very little and the particulate fraction has increased in more recent years. The reduced river flows since 1989 will increase the retention time of the broad and thus increase phytoplankton productivity which will cause a depletion in the available phosphorus.

5.2.2 Chlorophyll Concentration

Chlorophyll a concentration reflects the phytoplankton biomass and can therefore be used to describe changes in productivity. The seasonal and annual fluctuations in chlorophyll illustrated in Figure 5.5 - 5.6 are affected by changes in phosphorus concentration, river flow rates, retention time of the broads and the presence of zooplankton.

Characterising the general pattern of change recorded for both the river sampling sites and the broads are two peaks in concentration, one in the spring and one in the summer, with minimum values occurring in May/June. There is also a general trend of increasing chlorophyll concentration down river.

The supply of phosphorus has already been shown to have an effect upon the upper river, both non-tidal and tidal sections, in chapter 4. A decrease in phytoplankton productivity in 1987 which coincided with the introduction of the phosphorus stripping programme was recorded as far down river as Horning Ferry and in the upper river broads. However, the reduced flow rates and increased retention times in subsequent years have lead to an increase in chlorophyll a concentration. The supply of phosphorus from the sewage treatment works has not been maintained at a continuously low level since its introduction. This therefore makes any assessment of the impact of phosphorus control upon phytoplankton productivity difficult. However, with the improved performance of the phosphorus reduction programme throughout 1991 and 1992 it would be hoped that there would be a corresponding decrease in chlorophyll a concentration, even with the reduced flows. For the upper river sites and broads situated in the upper and middle reaches the chlorophyll a concentration has been reduced from the higher concentrations recorded in 1989 and 1990. Of note though is the lack of a significant decline in the May/June concentration for both the river and broads for both 1991 and 1992.

Obviously the broads and lower reaches of the river are not only influenced by phosphorus supply from the catchment, but also from sediment release and tidal mixing.

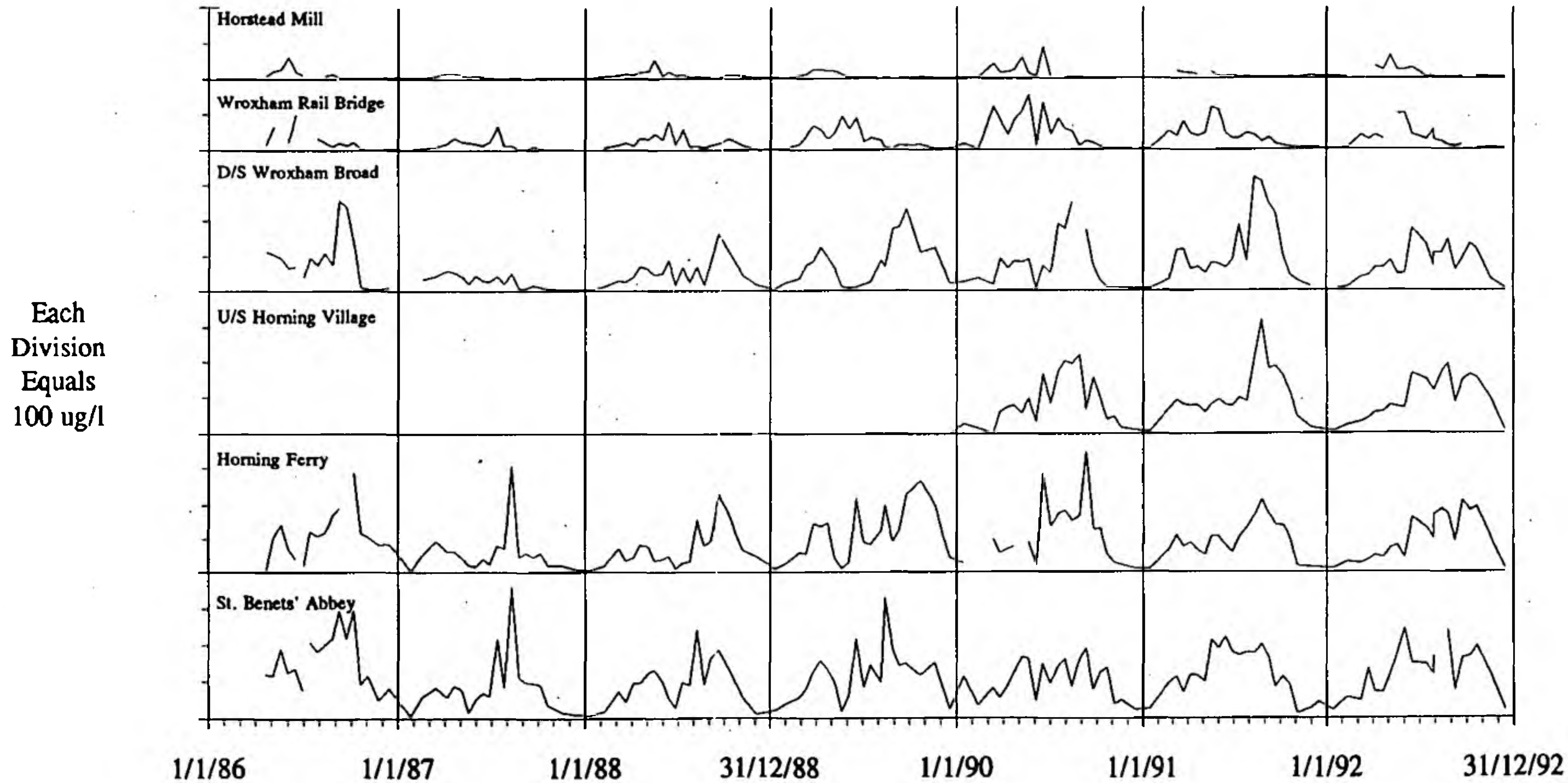


Figure 5.5 River Bure: chlorophyll a concentration

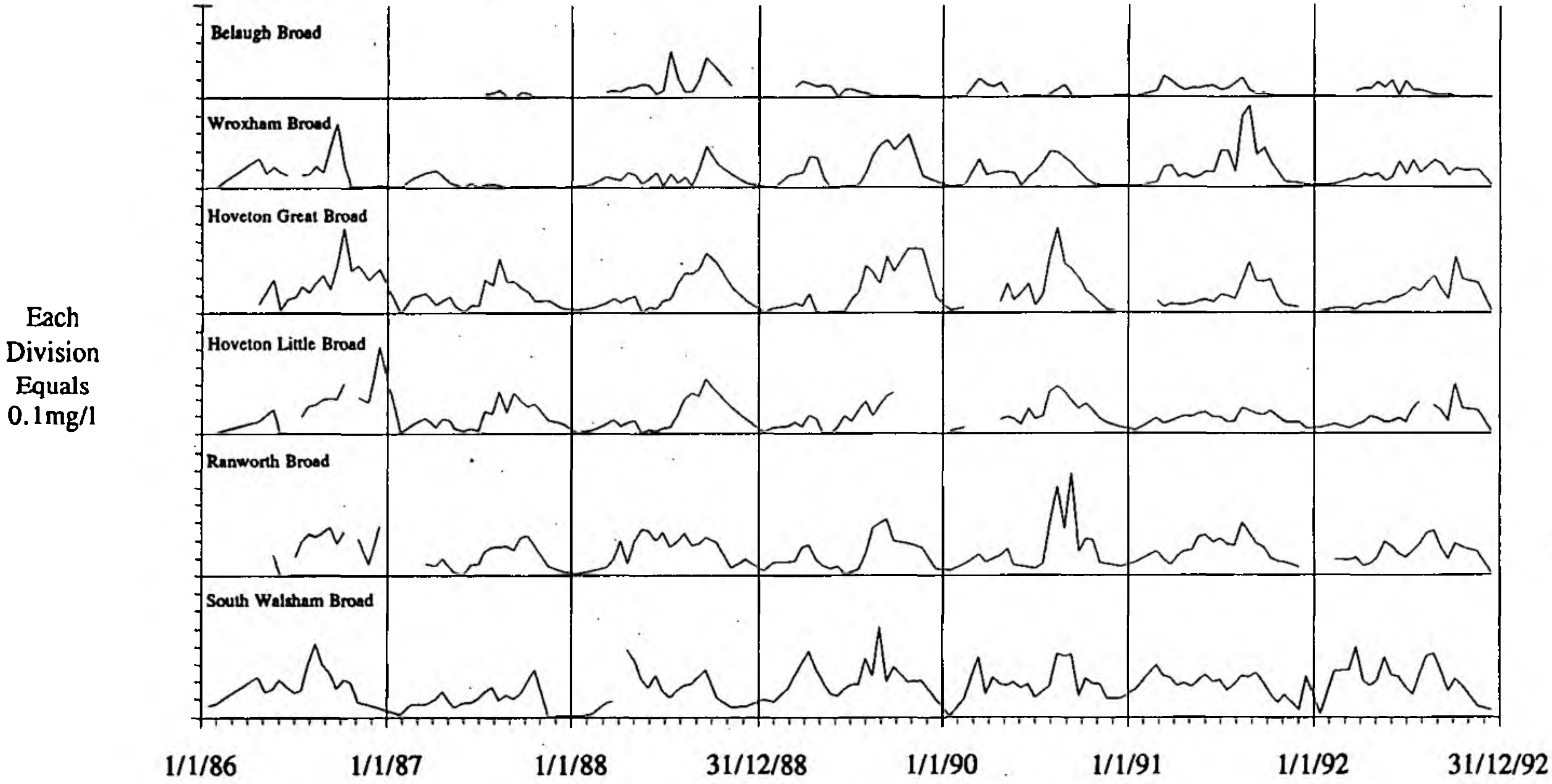


Figure 5.6 River Bure Broads: chlorophyll a concentration

The chlorophyll concentration has changed little at either St. Benets Abbey or South Walsham Broad since the introduction of phosphorus control.

5.2.3 Total Oxidised Nitrogen And Ammonium

Phytoplankton productivity is also controlled by the availability of nitrogen. Measurements are made of both T.O.N. (= nitrate + nitrite nitrogen) and ammonium. The seasonal and annual fluctuations in concentration are illustrated in figures 5.7 - 5.10.

Nitrogen usually enters the waterway from diffuse catchment sources with sewage treatment works representing only a small part of the total input. Generally the concentration of T.O.N. decreases down river, due to a combination of phytoplankton uptake and bacterial denitrification.

The seasonal reduction in the summer T.O.N concentration is found in both the river and the broads. In the middle and lower reaches of the river the summer levels often fall to below detectable levels, suggesting that these broads are nitrogen limited during the summer months. Over the period of monitoring the concentration of T.O.N. has also decreased, leading to an extended summer period of nitrogen depletion. This reduction in T.O.N., especially in 1991 and 1992, is also associated with lower chlorophyll a levels.

Due to the fact that most nitrogen is from catchment sources its supply to the river Bure and broads will be affected by the amount of rainfall and land drainage. T.O.N. concentrations were increased during the wetter years of 1987 and 1988. Rainfall levels have decreased since then along with the T.O.N. concentration.

Further down the tidal river at St. Benets Abbey and South Walsham Broad T.O.N. concentrations have changed very little and follow the expected pattern of summer depletion.

Nitrogen in the form of ammonium is directly available for uptake by phytoplankton. The concentration does appear to fluctuate seasonally with an increase in availability over the winter. However, during the summer many short lived increases in concentration occur, either as a result of an increase in excretory products or directly from the sediment. Aquatic sediments also act as a source of nitrogen as well as phosphorus, via the breakdown of organic matter. Some of the ammonium may be nitrified in the presence of oxygen and subsequently denitrified by bacteria within the sediment surface. The peak in concentration in May/June coincides with an increase in grazing zooplankton which excrete ammonium directly to the water column.

5.2.4 Silicate Concentration

Like nitrogen, concentrations of silicate reflect uptake by phytoplankton, particularly diatoms. Figures 5.11 and 5.12 clearly show the spring uptake of silica by diatoms followed by a second depletion in late summer, which is often more variable in extent. Smaller, fast growing diatoms are usually associated with the spring decrease in silicate concentration. These diatoms are less affected by the higher river flows and increased flushing rates at this time of the year than the larger, slower growing diatoms which are associated with the second dip in concentration in the late summer. The extent of the silicate depletion increases down river along with retention times. Also, the larger, slow growing diatoms will benefit from the reduced flows experienced since 1989.

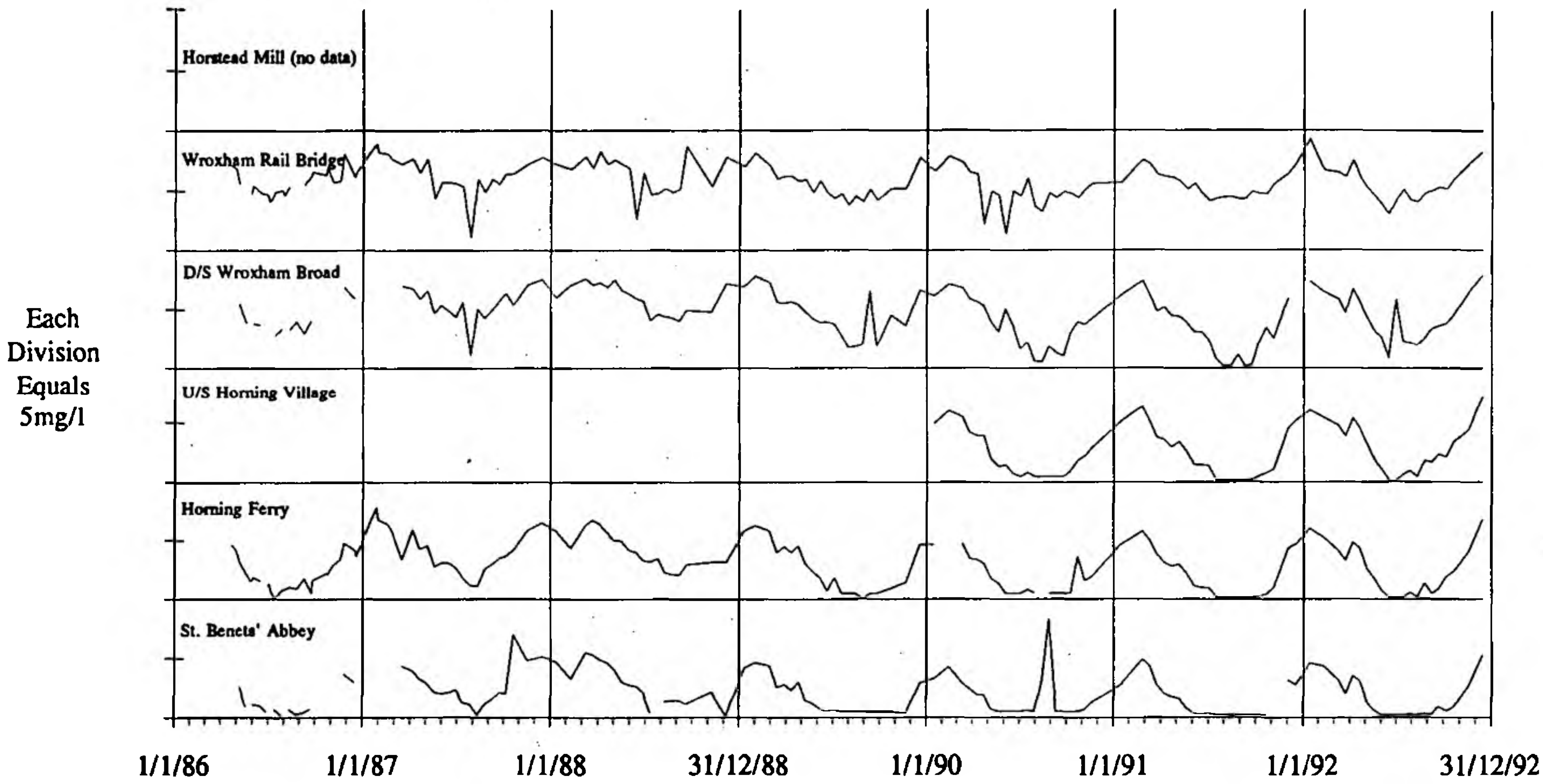


Figure 5.7 River Bure: total oxidised nitrogen concentration

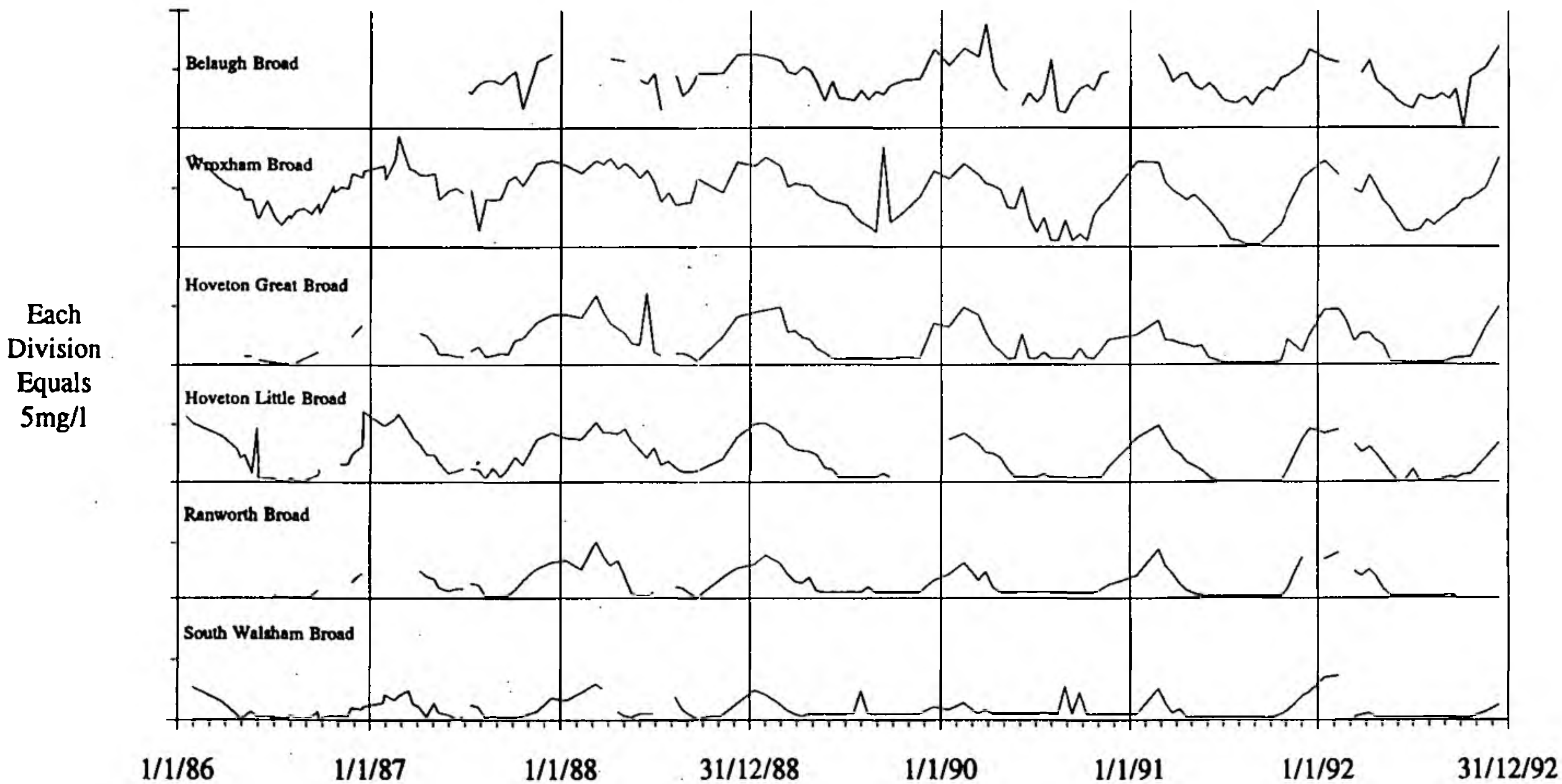


Figure 5.8 River Bure Broads: total oxidised nitrogen concentration

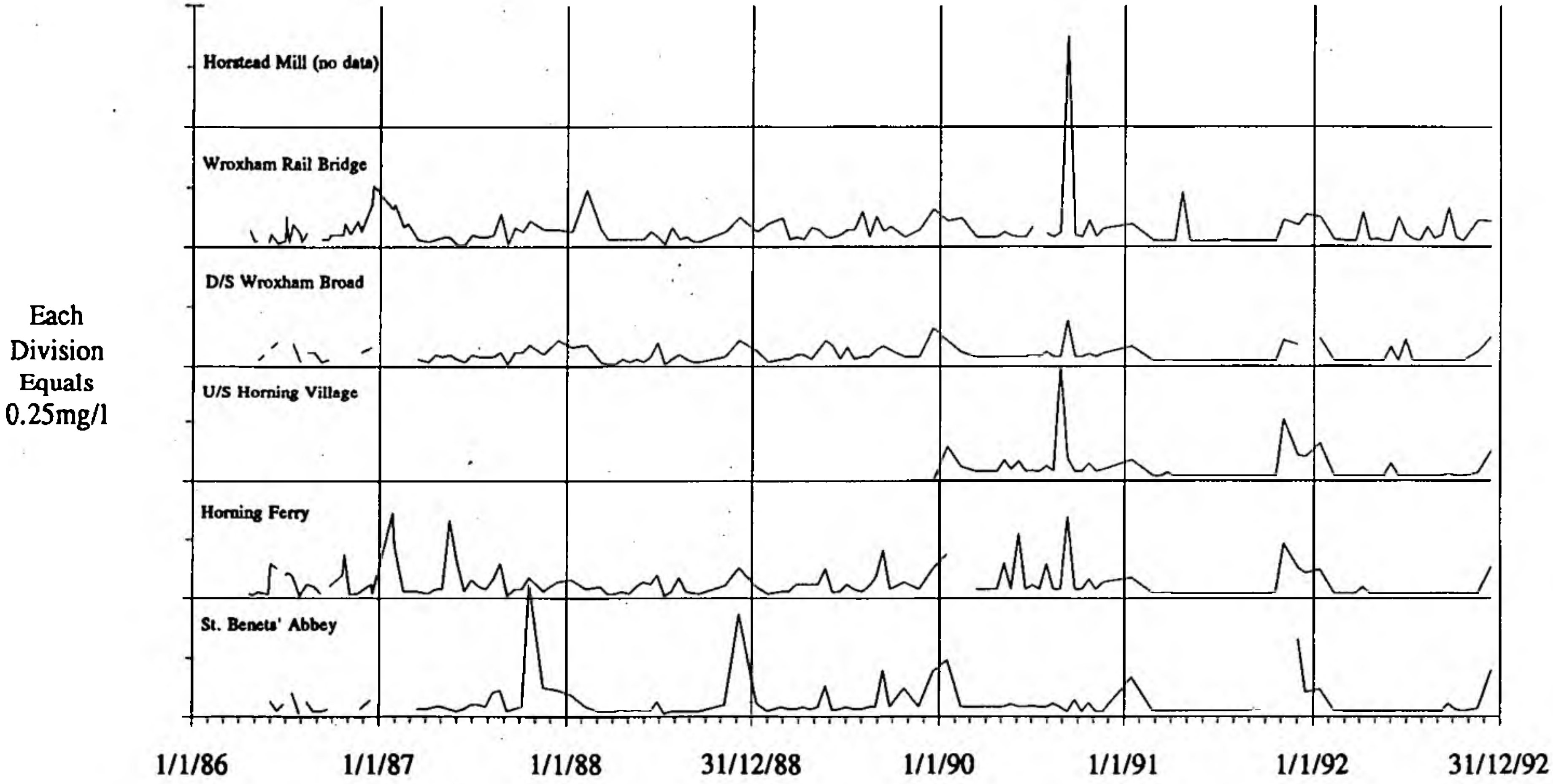


Figure 5.9 River Bure: ammonium concentration

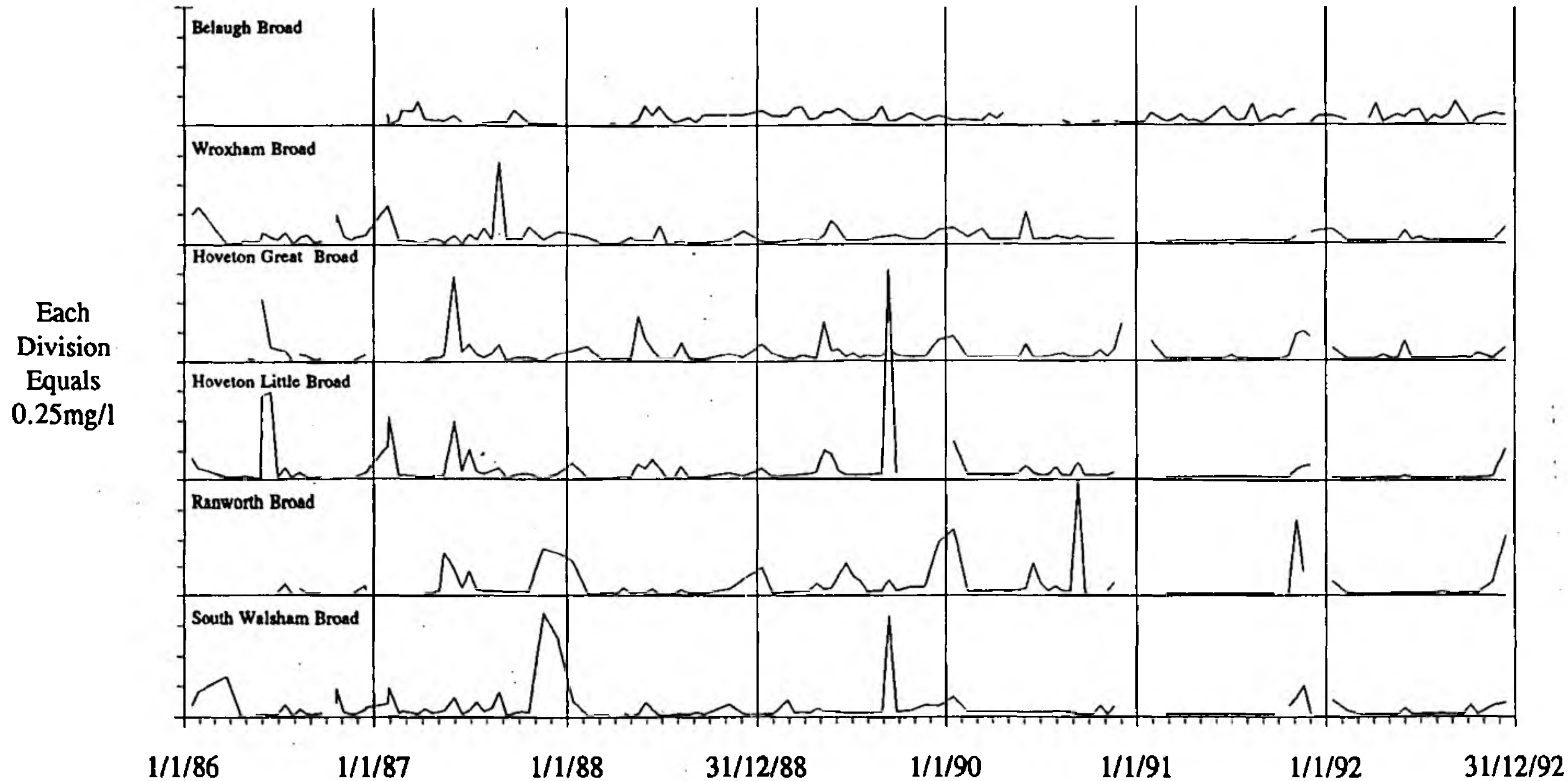


Figure 5.10 River Bure Broads: ammonium concentration

5.2.5 Chloride Concentration

The changes in chloride concentration provides information about the extent of the tidal movement of water up river. This regular movement of nutrient and phytoplankton rich water from the lower reaches of the river will influence the nutrient and chlorophyll a concentrations recorded for the river and broads. As figures 5.13 and 5.14 illustrate Ranworth and South Walsham Broads are subject to frequent changes in chloride concentration and therefore the water chemistry, phytoplankton and zooplankton populations will reflect this. Surge events in the spring and autumn are especially important with the effects of the tide being felt much further up river than normal. These short lived and sporadic increases in salinity will have an impact upon the existing fish, invertebrate and phytoplankton communities. The effect of the tide upon the broads will be governed by retention time of broad with the salinity levels falling the fastest in the well flushed broads. Two exceptional tidal surges were recorded in the late summer of 1990 and 1991 with an increase in chloride concentration being detected as far up stream as Wroxham Broad. The impact of these surges was probably enhanced by the low river flows and increased retention times.

5.2.6 Sulphate Concentration

Monitoring of sulphate concentration on a routine basis was initiated in 1991. However, it is not possible to ascertain what impact, if any, ferric sulphate dosing at sewage treatment works is having upon the river from such a data set. Sulphate is a nutrient which is found in higher concentrations in sea-water and therefore the concentration increases down river. The effect of the tidal incursion in the autumn of 1991 can be clearly seen in figures 5.15 - 5.16. Also, there is a general decrease in the concentration of sulphate during the summer months within both the river and broads.

5.2.7 Iron Concentration

The concentration of iron fluctuates more in the river and is higher than that recorded for the broads (figures 5.17 - 5.18). This is due to inputs of iron from land drainage and the river sediment. Fluctuations in iron concentration are also recorded for the well flushed, upper river broads such as Wroxham Broad. In comparison the iron concentration is lower and comparatively stable in the more isolated broads.

5.2.8 Alkalinity And pH

PH values greater than 7 were recorded for the river Bure and Broads (Tables 5.3 - 5.4) which may indicate either a high alkalinity or carbon dioxide depletion as a result of photosynthesis or both.

The variation in pH recorded for both the river and broads is actually only within a very narrow range due to buffering of the effects of the large standing crops of phytoplankton. This buffering is a result of the calcareous nature of the water; as carbon dioxide is withdrawn carbonates are formed and the inorganic carbon equilibria is thus reset. Despite this buffering capacity there is a general trend of increasing pH down river corresponding to the increase in phytoplankton biomass. This variation in pH between sampling stations along the river was greatest in 1987 and 1992. During the summer the mean pH was below 8 at the upper tidal site of Wroxham Rail Bridge and

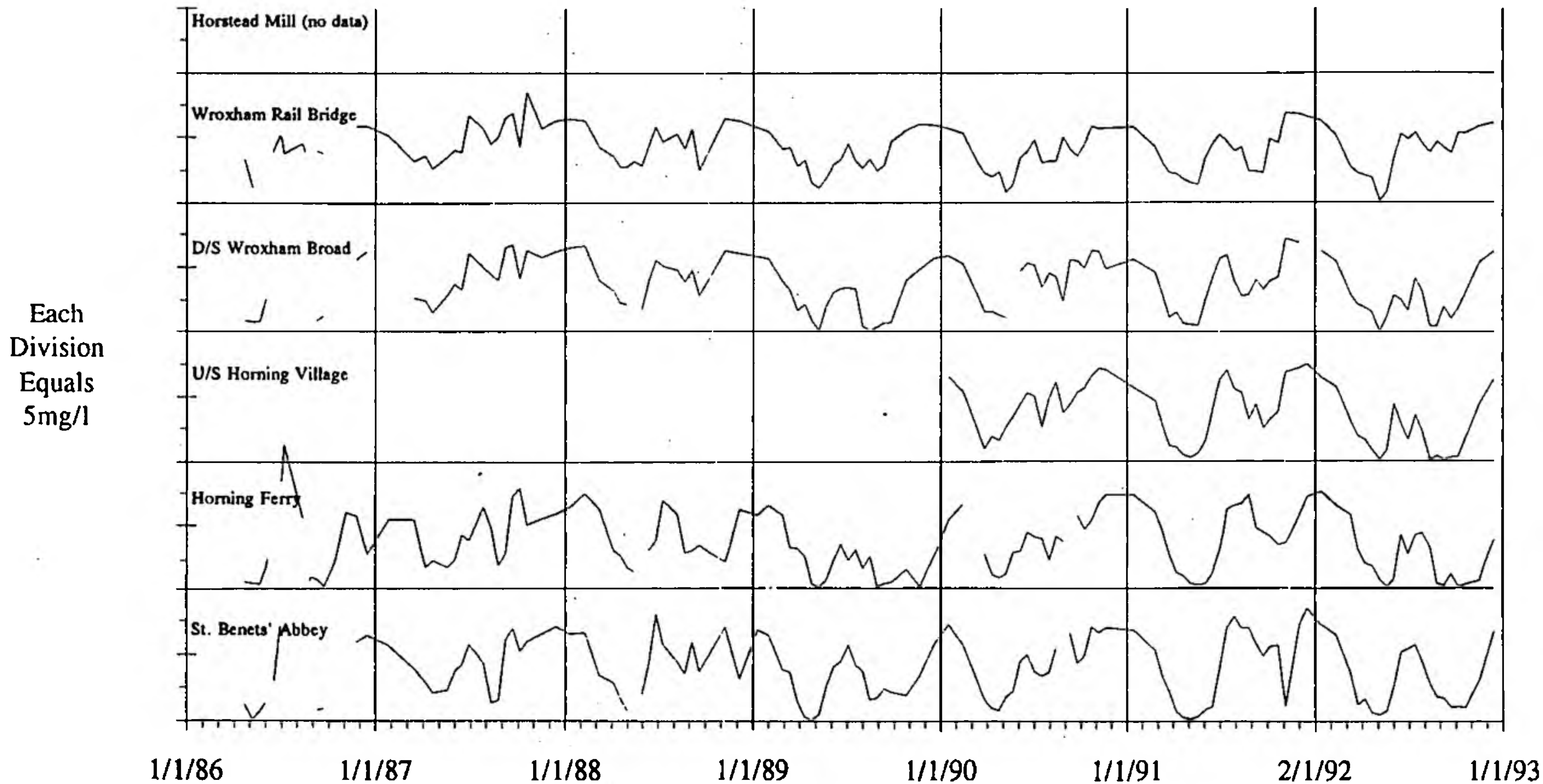


Figure 5.11 River Bure: silica concentration

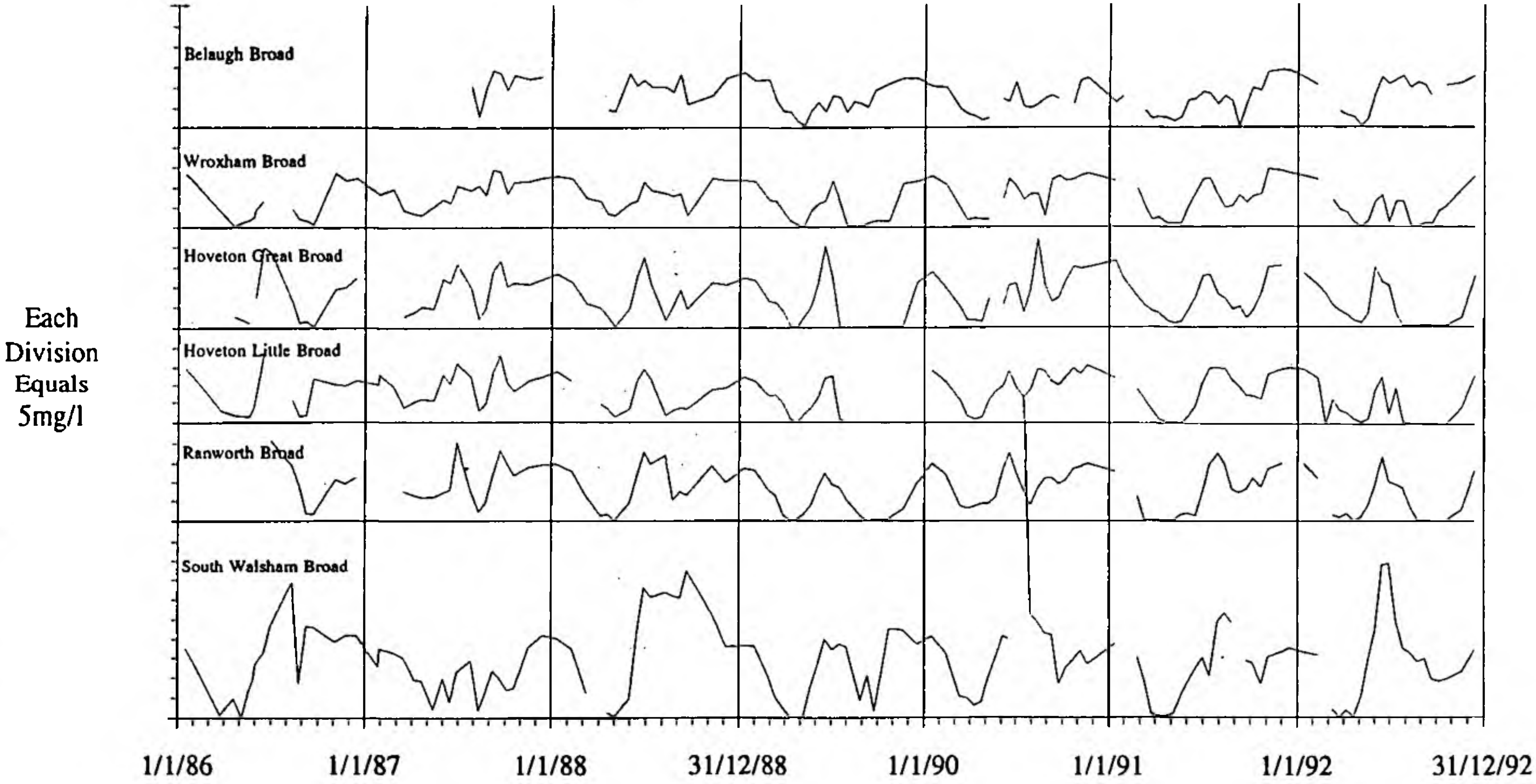


Figure 5.12 River Bure Broads: silica concentration

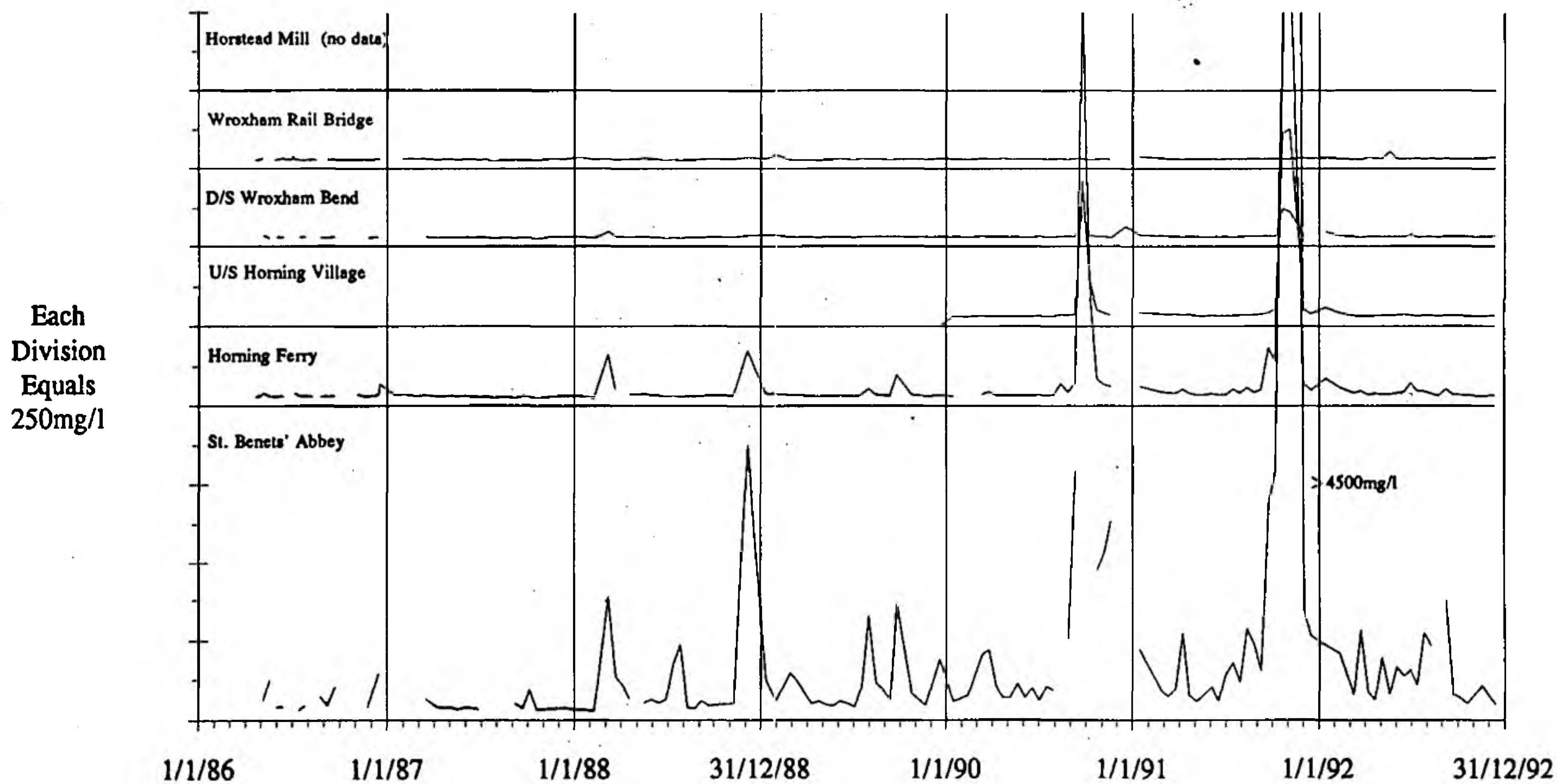


Figure 5.13 River Bure: chloride concentration

Each
Division
Equals
250mg/l

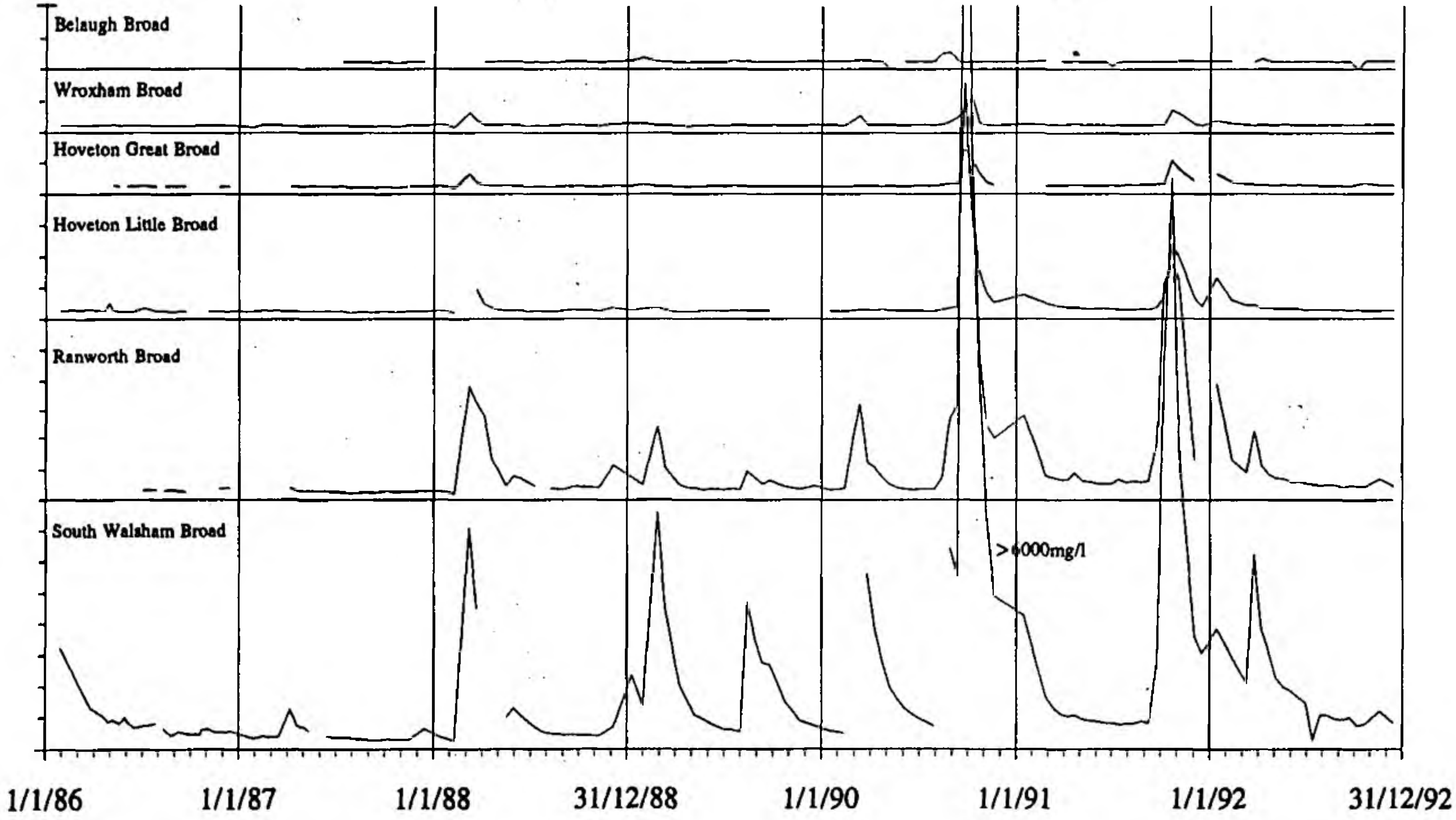


Figure 5.14 River Bure Broads: chloride concentration

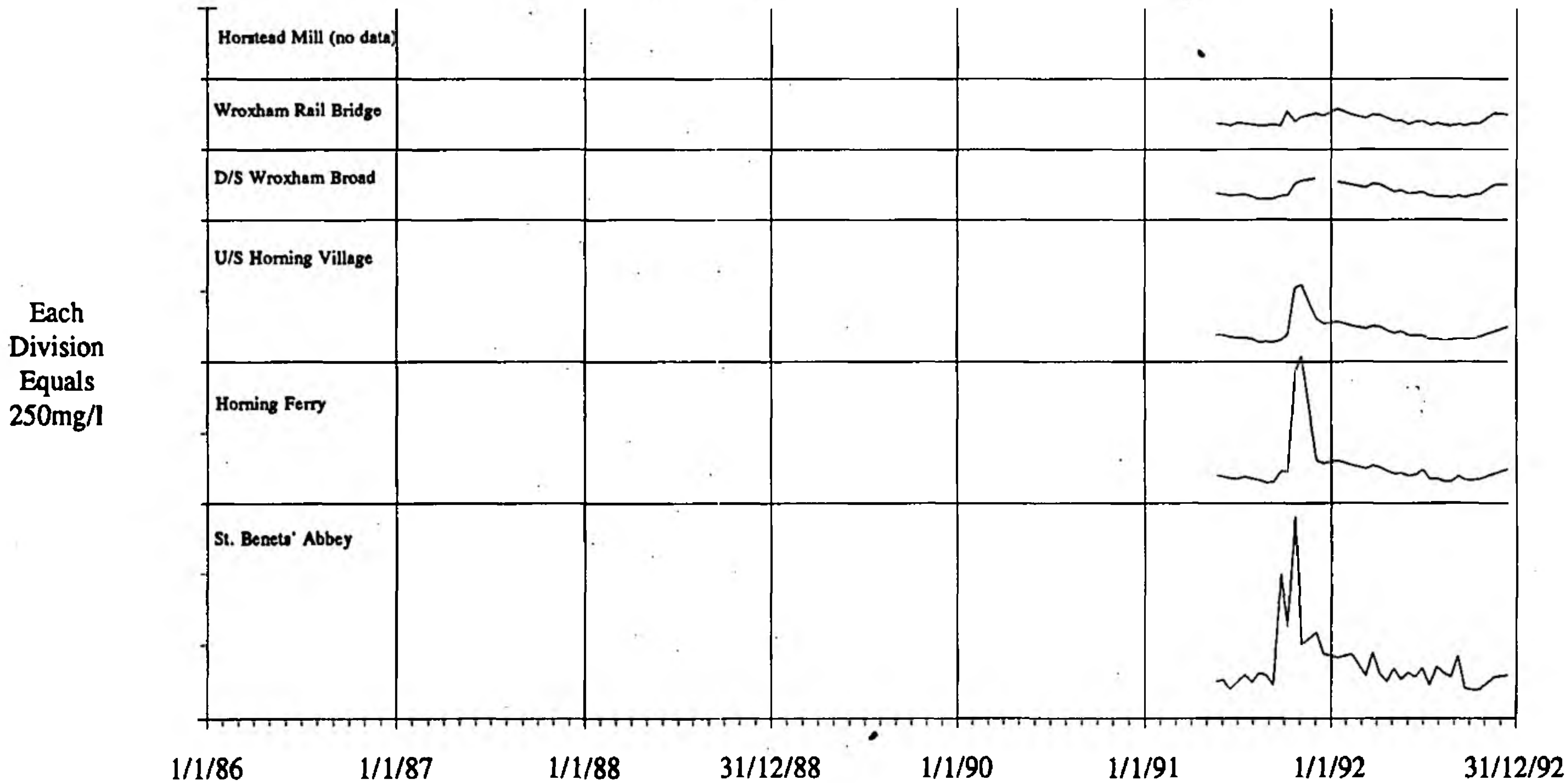


Figure 5.15 River Bure: sulphate concentration

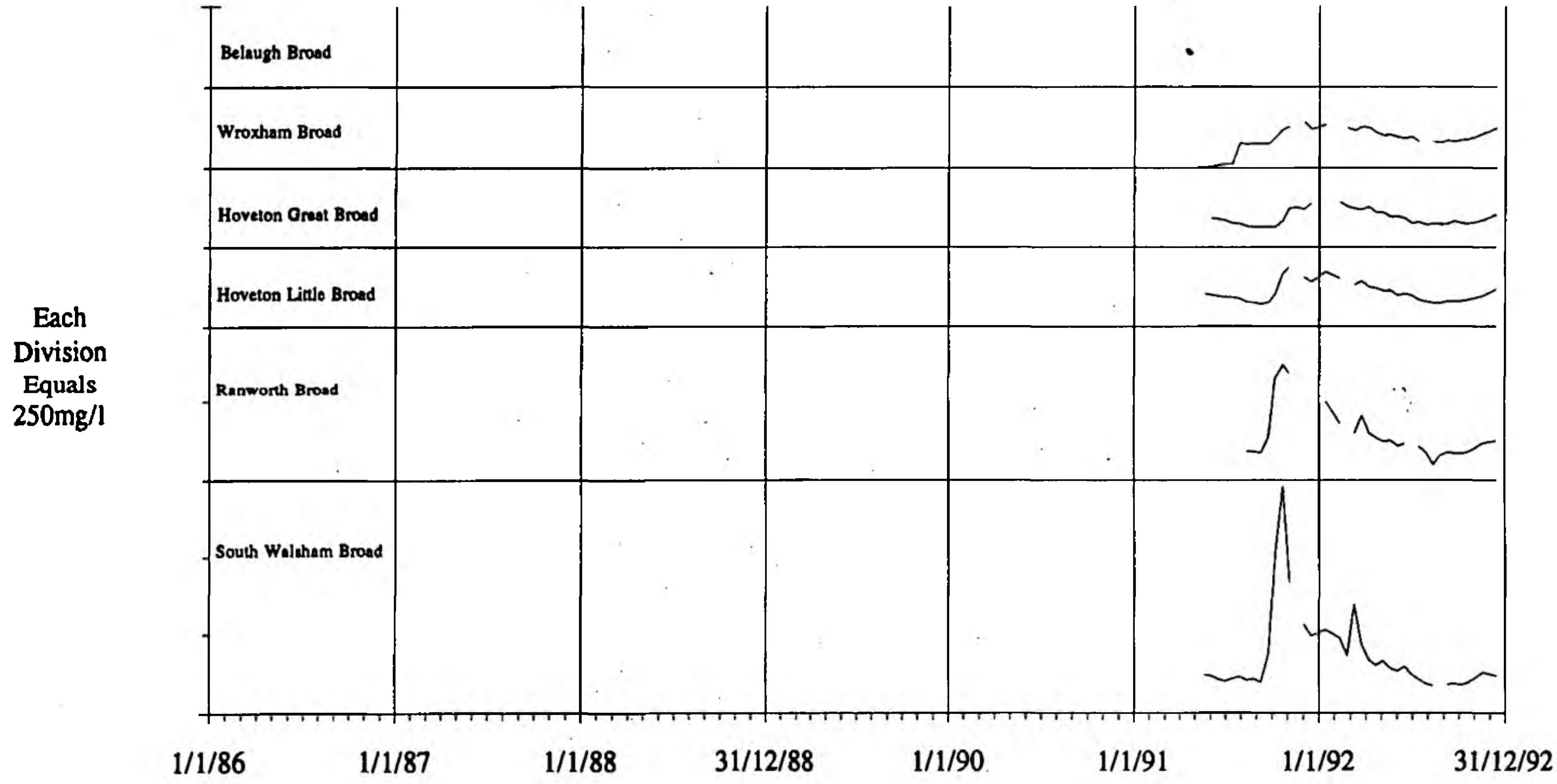


Figure 5.16 River Bure Broads: sulphate concentration

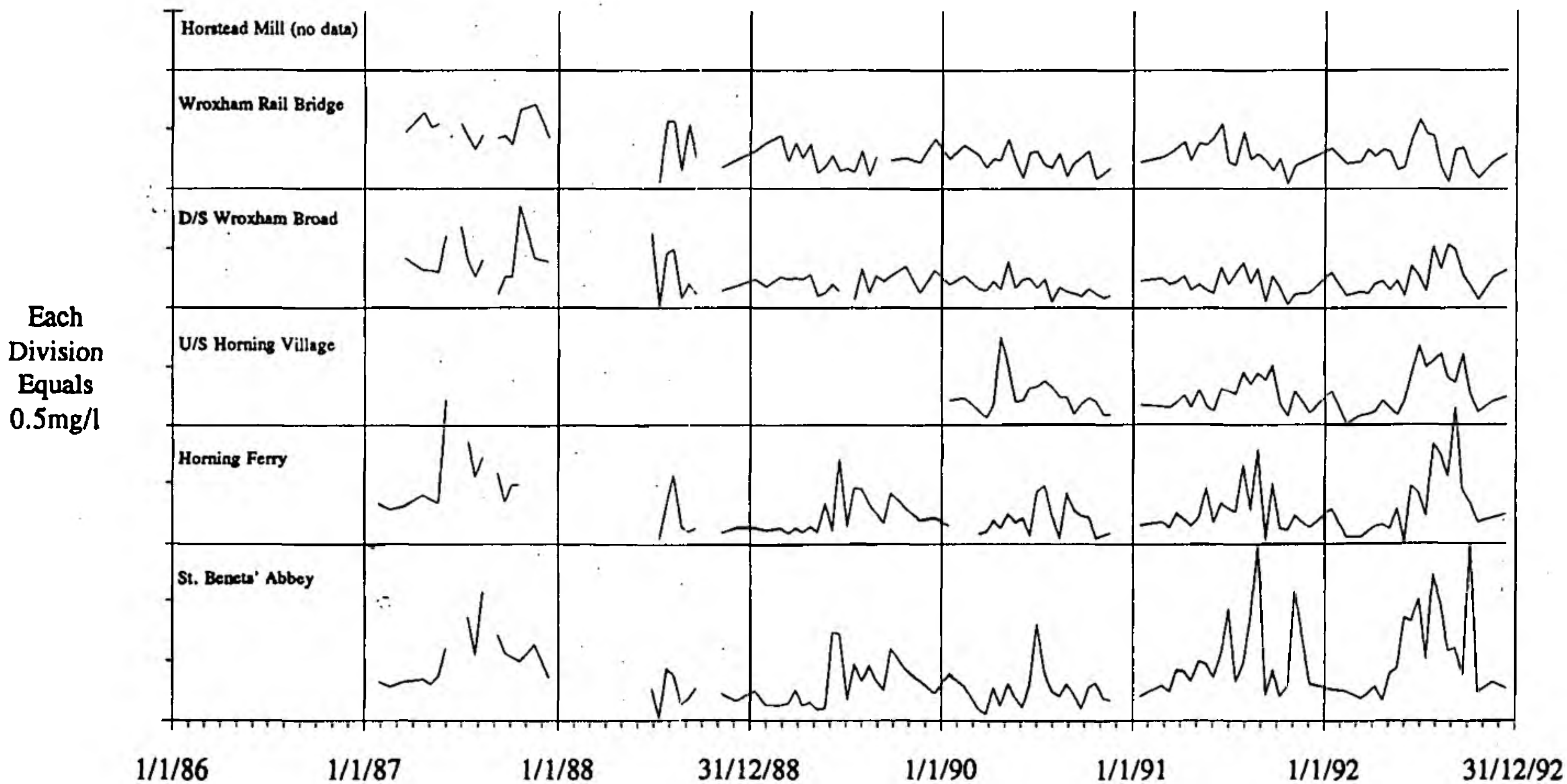


Figure 5.17 River Bure: iron concentration

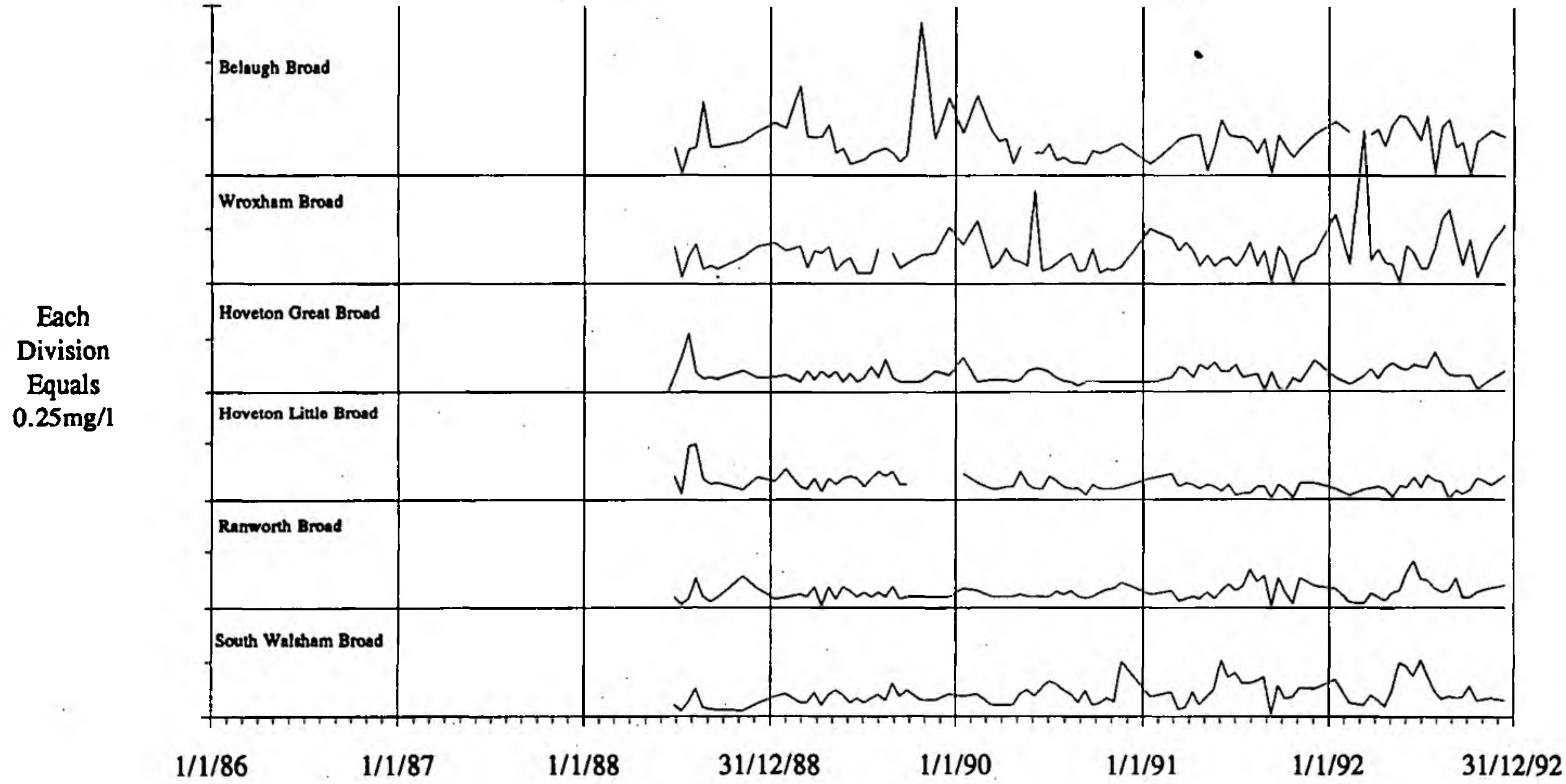


Figure 5.18 River Bure Broads: iron concentration

Table 5.3 River Bure sampling sites, mean pH

		pH				
		Wrox. R.Bdg.	D/S Wrox.	U/S Horning	Horn. Ferry	St. Bens. Abbey
1986						
Winter	Oct.-March	-	-	-	-	-
Summer	April-Sept.	-	-	-	-	-
1987						
Winter	Oct.-March	-	-	-	-	-
Summer	April-Sept.	8.0	8.2	-	8.2	8.2
1988						
Winter	Oct.-March	7.7	7.6	-	7.9	7.9
Summer	April-Sept.	7.7	8.2	-	8.1	8.1
1989						
Winter	Oct.-March	8.1	8.3	-	8.3	8.2
Summer	April-Sept.	8.2	8.3	-	8.2	8.3
1990						
Winter	Oct.-March	8.3	8.5	-	-	-
Summer	April-Sept.	8.5	8.5	8.5	8.3	8.4
1991						
Winter	Oct.-March	8.1	8.3	8.4	8.4	8.4
Summer	April-Sept.	8.4	8.6	8.5	8.5	8.5
1992						
Winter	Oct.-March	8.3	8.4	8.5	8.3	8.6
Summer	April-Sept.	8.0	8.2	8.2	8.2	8.3

* Note: the winter season is from the October of the preceeding year to the spring of the current year.

Table 5.4 River Bure Broads sampling sites, mean seasonal pH

		pH					
		Belaugh	Wroxham	Hoveton Gt.	Hoveton Ltl	Ranworth	Sth. Walsham
1986							
Winter	Oct.-March	-	-	-	-	-	-
Summer	April-Sept.	-	-	-	-	-	-
1987							
Winter	Oct.-March	-	-	-	-	-	-
Summer	April-Sept.	-	8.3	8.5	8.5	8.6	8.6
1988							
Winter	Oct.-March	-	8.0	8.0	8.3	8.2	8.2
Summer	April-Sept.	-	8.1	8.2	8.3	8.8	8.8
1989							
Winter	Oct.-March	-	8.4	8.5	8.4	8.4	8.6
Summer	April-Sept.	-	8.3	8.7	8.5	8.7	9.1
1990							
Winter	Oct.-March	-	7.3	8.8	-	-	8.7
Summer	April-Sept.	8.0	8.5	8.9	8.8	8.7	9.1
1991							
Winter	Oct.-March	7.8	8.6	8.6	8.6	8.7	8.9
Summer	April-Sept.	8.2	8.9	8.8	8.8	9.0	9.0
1992							
Winter	Oct.-March	7.8	8.7	-	-	8.8	8.8
Summer	April-Sept.	7.9	8.4	8.5	8.6	8.7	9.0

* Note: the winter season is from the October of the preceeding year to the spring of the current year.

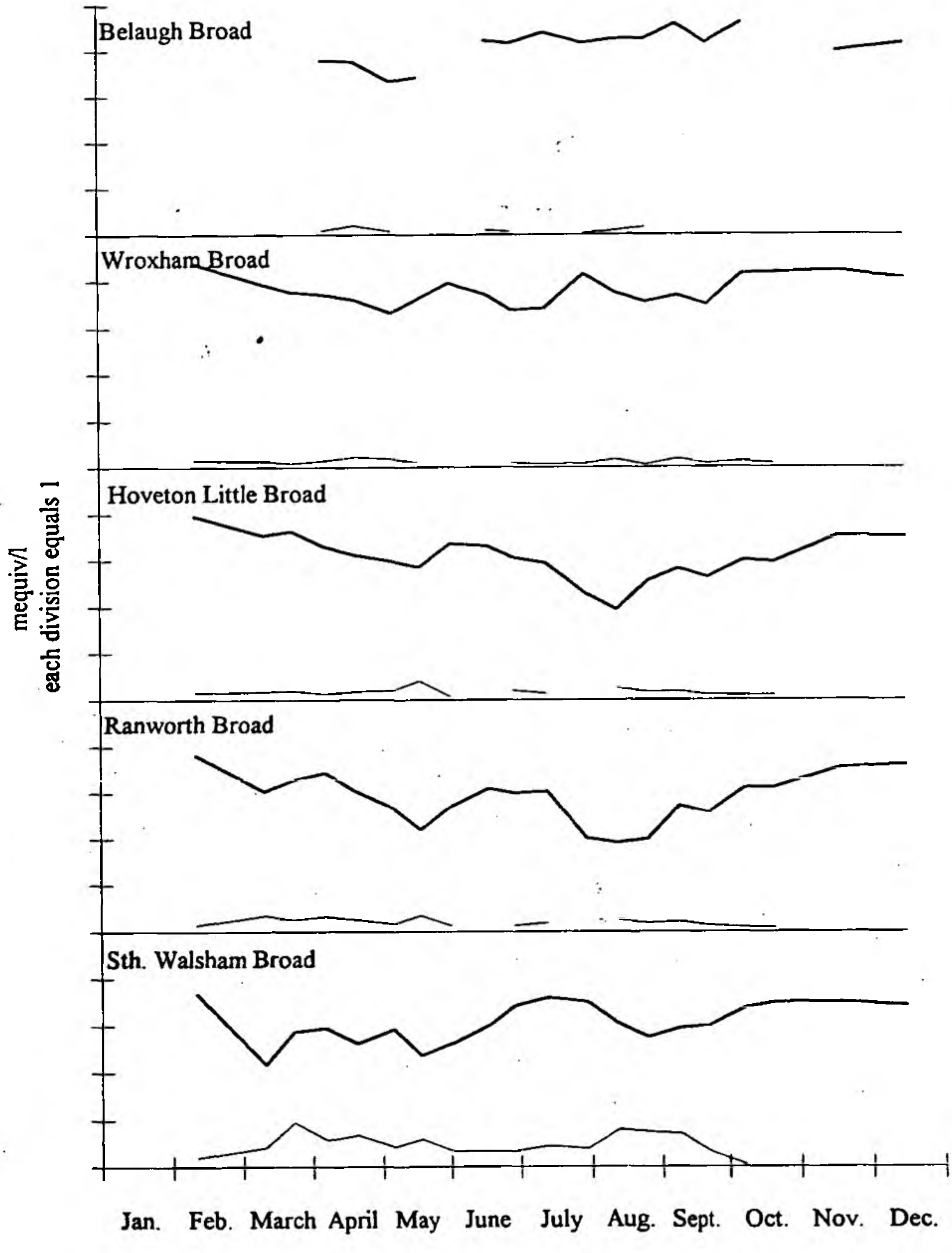


Figure 5.19 River Bure Broads: alkalinity

rose to above 8 further down river. For 1989, 1990 and 1991 the variation between sites was not as great and the pH remained above 8 even at the upper tidal sites. This may be due to the lower river flows in these years and hence the enhancement of photosynthetic activity. The pH generally decreases in the winter season for both the river and Broads again reflecting the changes in phytoplankton populations.

Alkalinity is a good measure of the bicarbonate and carbonate content of the Broads water. The changes in the concentrations of these two anions are shown in figure 5.19. Total alkalinity is a measure of both the bicarbonate and carbonate content of the water whereas the phenolpthalein alkalinity is a measure of carbonate. Therefore, the total alkalinity minus the phenolpthalein alkalinity gives the bicarbonate alkalinity.

Generally, the total alkalinity decreases down river and there is less variation in the bicarbonate content in the upper river broads in comparison with those situated further down river. At both Ranworth and South Walsham Broads the total alkalinity decreases during the summer months coinciding with the increase in phytoplankton biomass. Also, as the bicarbonate content decreases the carbonate content increases. Carbonate is likely to be present when photosynthetic activity is most intense and therefore disturbing the inorganic equilibria by removing the carbon dioxide. The carbonate content of the water is more reduced in the upper river broads such as Belaugh. Here carbonate is only recorded when the pH is greater than 8.4.

5.3 Field Determinands

5.3.1 Water Temperature

Tables 5.5 and 5.6 show the seasonal average water temperatures for both the river sampling stations and the Broads monitored on the river bure. There is little variation in water temperature between sites for any specific year. However, variation does exist between years. The warmest water temperatures were recorded during the summer season of 1989, 1990 and 1992; with temperatures at these times above 17^{o}C for the river sites and 17.5^{o}C for the Broads. The coldest winter quarter was recorded in 1989 with the average temperature not rising above 6.6^{o}C for any of the sites monitored. Therefore, the greatest recorded difference in winter and summer temperatures was in 1989.

5.3.2 Secchi Disc

Secchi Disc readings provide a measure of the depth to which light penetrates the water column and is affected by both the amount of suspended solids and the number of phytoplankton. Tables 5.7 - 3.8 show the mean summer and winter averages for the years 1986 - 1992. The effect of an increase in phytoplankton productivity can be clearly seen with decreasing secchi readings. The secchi depth is greatest in the upper tidal reaches of the river with readings usually above a 1.0m during the summer and winter at Wroxham Rail bridge. Further down river, at downstream of Wroxham Broad and upstream of Horning Village, the secchi readings also reach a meter but only during the winter season. In the lower tidal reaches of the river the secchi readings do not increase above 0.7m even in the winter months. The standing crop of phytoplankton increases down river and hence secchi readings will decrease accordingly. A similar pattern of decreasing water clarity down river is seen with in the broads. The smallest secchi readings were obtained at South Walsham Broad while the generally well flushed upper river broads achieved deeper secchi depth readings.

Table 5.5 Sampling sites on the River Bure, mean seasonal temperature

		temperature oC				
		Wrox. R.Bdg.	D/S Wrox.	U/S Horning	Horn. Ferry	St. Bens. Abbey
1986						
Winter	Oct.-March	-	-	-	-	-
Summer	April-Sept.	-	-	-	-	-
1987						
Winter	Oct.-March	-	-	-	-	-
Summer	April-Sept.	14.2	15.2	-	15.8	16.1
1988						
Winter	Oct.-March	7.1	7.1	-	7.0	6.9
Summer	April-Sept.	15.3	15.6	-	15.9	15.8
1989						
Winter	Oct.-March	6.6	6.6	-	6.6	6.5
Summer	April-Sept.	17.4	17.9	-	18.1	17.8
1990						
Winter	Oct.-March	8.3	8.1	-	8.6	8.0
Summer	April-Sept.	17.8	17.7	19.1	17.9	17.8
1991						
Winter	Oct.-March	8.1	8.1	7.9	7.9	7.7
Summer	April-Sept.	-	16.3	16.4	16.5	16.5
1992						
Winter	Oct.-March	7.4	7.9	10.1	7.6	7.5
Summer	April-Sept.	17.5	18.2	18.0	18.0	17.4

* Note: the winter season is from the October of the preceeding year to the spring of the current year.

Table 5.6 River Bure Broads sampling sites, mean seasonal temperature

		temperature oC					
		Belaugh	Wroxham	Hoveton Gt.	Hoveton Ltl	Ranworth	Sth. Walsham
1986							
Winter	Oct.-March	-	6.9	-	6.2	-	-
Summer	April-Sept.	-	-	-	-	-	-
1987							
Winter	Oct.-March	-	-	-	-	-	0.2
Summer	April-Sept.	-	15.5	15.8	15.7	15.8	0.5
1988							
Winter	Oct.-March	-	7.1	6.8	7.0	6.9	-
Summer	April-Sept.	-	15.9	16.0	16.1	16.4	0.3
1989							
Winter	Oct.-March	-	6.5	6.6	6.5	6.6	0.7
Summer	April-Sept.	-	18.0	18.0	18.2	18.0	0.2
1990							
Winter	Oct.-March	-	7.9	7.6	-	8.0	0.7
Summer	April-Sept.	17.8	17.6	18.2	17.9	17.7	0.3
1991							
Winter	Oct.-March	8.2	7.9	7.1	7.6	7.7	0.5
Summer	April-Sept.	17.7	16.4	15.7	16.3	16.2	0.3
1992							
Winter	Oct.-March	7.5	7.0	7.4	6.9	7.8	0.7
Summer	April-Sept.	18.5	18.3	18.6	18.1	17.7	0.3

* Note: the winter season is from the October of the preceeding year to the spring of the current year.

Table 5.7 Sampling sites on the River Bure, mean seasonal secchi depth

		secchi depth m				
		Wrox. R.Bdg.	D/S Wrox.	U/S Horning	Horn. Ferry	St. Bens. Abbey
1986						
Winter	Oct.-March	-	-	-	-	-
Summer	April-Sept.	-	-	-	-	-
1987						
Winter	Oct.-March	-	-	-	-	-
Summer	April-Sept.	1.30	1.06	-	0.60	0.49
1988						
Winter	Oct.-March	1.40	1.51	-	-	-
Summer	April-Sept.	1.03	0.74	-	0.69	0.54
1989						
Winter	Oct.-March	1.30	1.15	-	0.95	0.67
Summer	April-Sept.	1.10	0.82	-	0.52	0.41
1990						
Winter	Oct.-March	1.32	1.16	-	0.85	0.62
Summer	April-Sept.	0.91	0.58	0.42	0.44	0.38
1991						
Winter	Oct.-March	1.63	1.33	1.08	0.94	0.60
Summer	April-Sept.	0.92	0.59	0.50	0.43	0.32
1992						
Winter	Oct.-March	1.66	1.37	0.90	0.94	0.61
Summer	April-Sept.	0.95	0.65	0.56	0.47	0.37

* Note: the winter season is from the October of the preceeding year to the spring of the current year.

Table 5.8 River Bure Broads sampling sites, mean seasonal secchi depth

		secchi depth m					
		Belaugh	Wroxham	Hoveton Gt.	Hoveton Ltl	Ranworth	Sth. Walsham
1986							
Winter	Oct.-March	-	-	-	-	-	-
Summer	April-Sept.	-	-	-	-	-	-
1987							
Winter	Oct.-March	-	-	-	-	-	-
Summer	April-Sept.	1.34	1.48	0.56	0.66	0.58	0.46
1988							
Winter	Oct.-March	-	1.44	-	-	-	-
Summer	April-Sept.	0.91	1.02	0.62	0.91	0.36	0.32
1989							
Winter	Oct.-March	1.15	1.04	1.03	1.11	0.74	0.67
Summer	April-Sept.	1.08	1.09	0.78	0.79	0.46	0.24
1990							
Winter	Oct.-March	1.07	1.21	0.98	-	0.73	0.69
Summer	April-Sept.	0.96	0.70	0.39	0.49	0.53	0.28
1991							
Winter	Oct.-March	1.99	1.36	0.82	0.86	0.63	0.49
Summer	April-Sept.	0.89	0.62	0.47	0.48	0.33	0.29
1992							
Winter	Oct.-March	1.26	1.14	0.84	0.97	0.68	0.68
Summer	April-Sept.	0.86	0.72	0.57	0.59	0.4	0.32

* Note: the winter season is from the October of the preceeding year to the spring of the current year.

Variation in secchi readings between years are also possibly due to the changes in phytoplankton populations. Secchi depths are generally lower during years of reduced flow when phytoplankton productivity is enhanced and can also be supported further up river.

5.4 Zooplankton Populations

The population changes for Belaugh, Wroxham, Hoveton Little and Ranworth Broads for the period 1989 - 1992 are shown in figures 5.20 - 5.23. Of particular interest are the fluctuations in the population of *Daphnia sp.* at each of the broads. *Daphnia sp.* are effective phytoplankton grazers and therefore will improve water clarity when present in sufficient numbers. At all of the sites *Daphnia sp.* populations peak in the late spring and are then replaced by a much more abundant population of *Bosmina longirostris*, which are represented by the category 'other Cladocera' on the charts. The decline in *Daphnia sp.* numbers is associated with an increase in the numbers of young, predatory fish.

This extent of this annual cycle does vary between broads as well as between each year. The numbers of *Daphnia sp.* are generally higher in each of the broads in 1989 and 1990. At Belaugh broad *Daphnia sp.* were only detected in significant numbers in 1990. This increase coincided with a decrease in the chlorophyll concentration recorded between May and June. Also during this year there was a peak in the number of *Bosmina longirostris*. At Wroxham Broad , however, the peak in *Daphnia sp.* occurred in 1990. Hoveton Little Broad *Daphnia sp.* populations are the most stable with a late spring increase being recorded each year. The decrease in the number of *Daphnia sp.* is most marked at Ranworth Broad where significant populations were recorded in 1989 and 1990 but very few individuals have been recorded in the past two years. This decline in numbers may be due to an increase in chloride levels due to the lower river flows and surge tide events recorded in these years. Also associated with the increase in salinity is the presence of *Neomysis integer* which prey on *Daphnia sp.* Further, the reduced flushing rate may provide improved conditions for the growth of larger, less palatable algae (such as cyanobacteria). The chlorophyll concentration at Ranworth Broad also remained high throughout the summer of both 1991 and 1992.

The smaller and faster zooplankton species are less affected by fish predation and the numbers are therefore sustained throughout the year and only decline during the winter months. The numbers of Copepoda generally increase down river with greater numbers being recorded at Ranworth Broad in comparison to Belaugh Broad. There is also little variation within the populations from year to year for each broad.

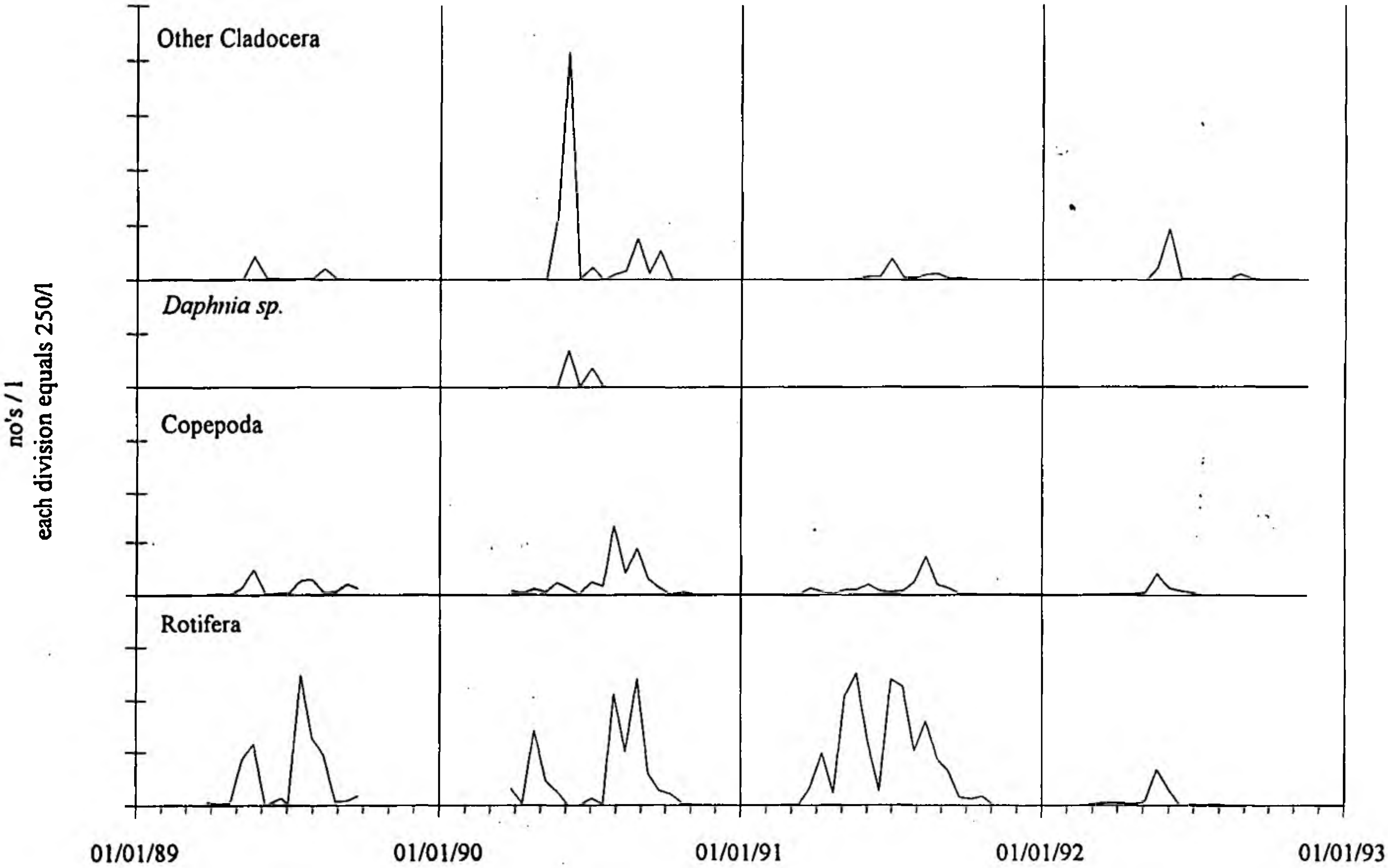


Figure 5.20 Belaugh Broad: zooplankton population

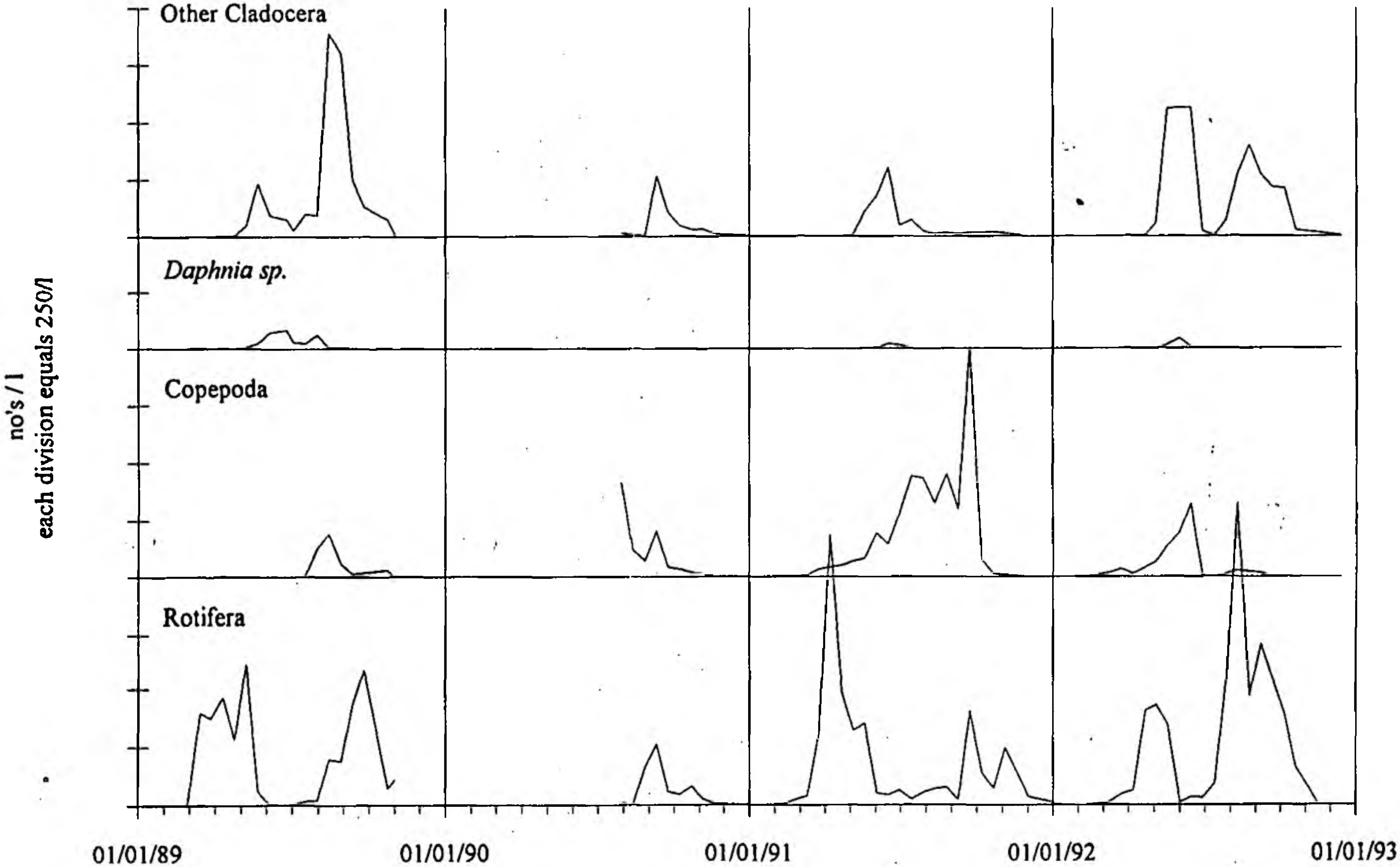


Figure 5.21 Wroxham Broad: zooplankton population

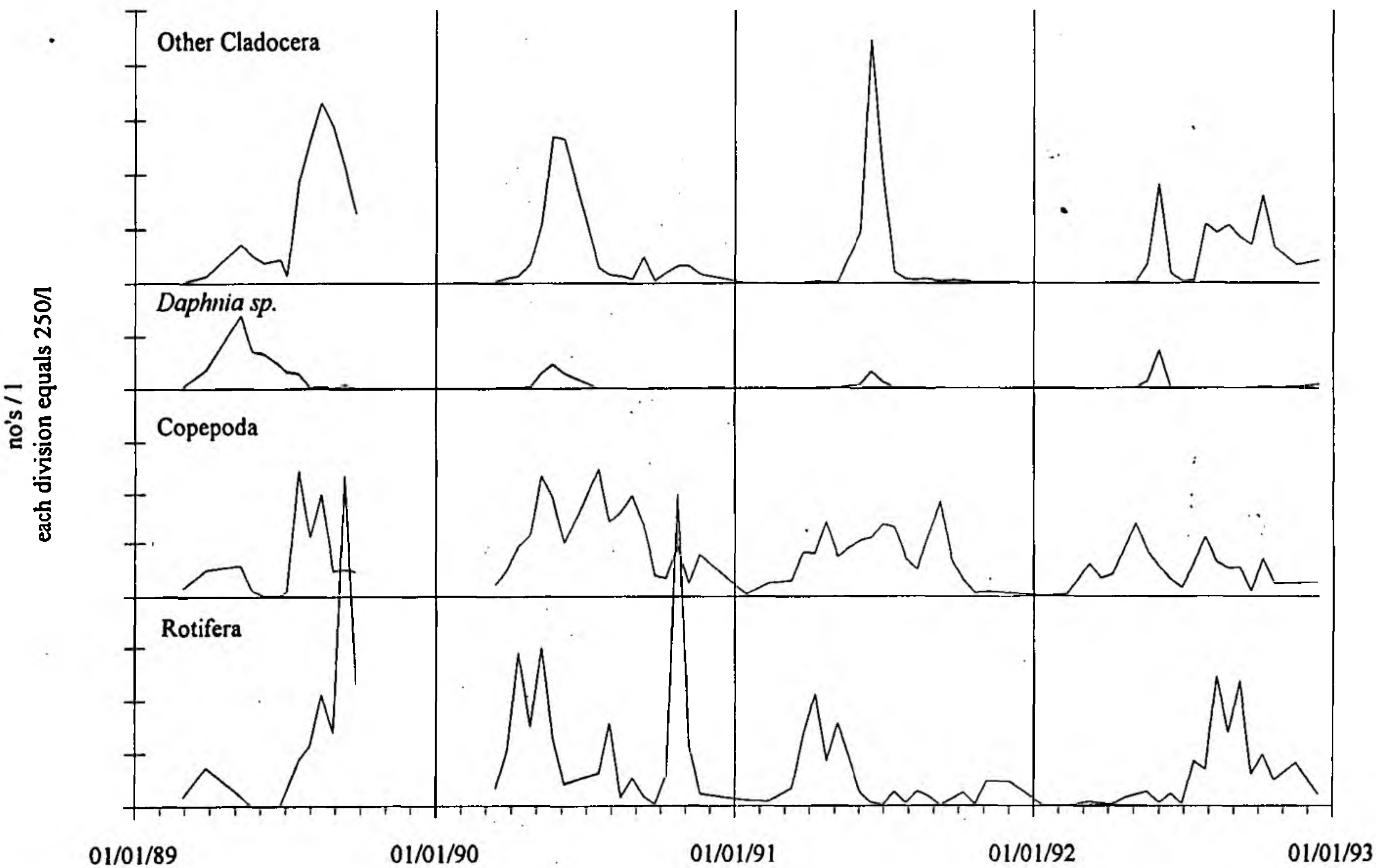


Figure 5.22 Hoveton Little Broad: zooplankton population

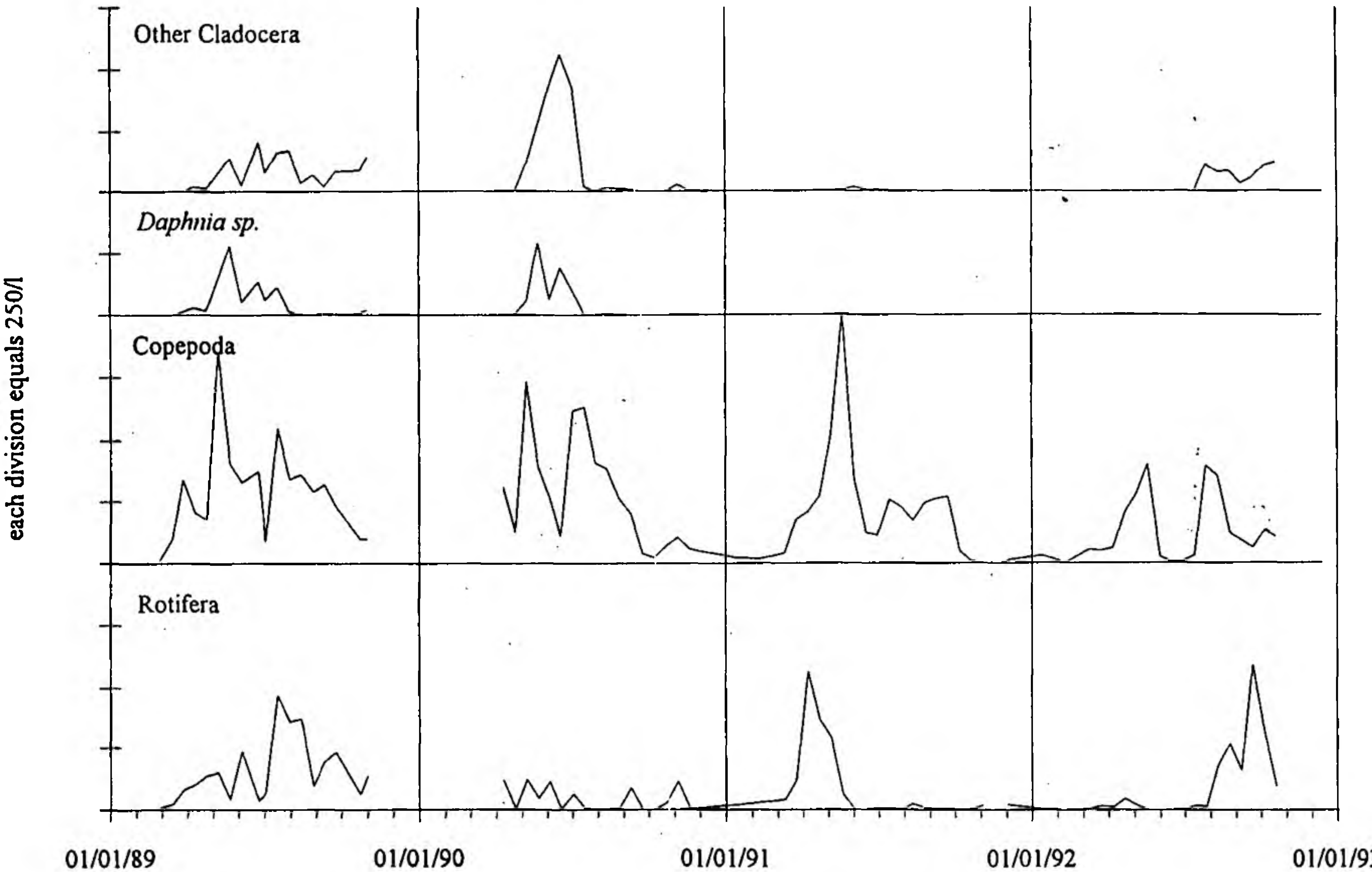


Figure 5.23 Ranworth Broad: zooplankton population

6. LIMNOLOGY OF BARTON BROAD AND RIVER ANT

6.1 Introduction

Water samples have continued to be collected on a fortnightly basis from a number of sites along the river Ant and from Barton Broad to ensure that any changes in water quality are detected. These samples are analysed for a variety of chemical determinands. Also measurements of water temperature, pH and secchi depth are recorded in the field. Monitoring of changes in the phytoplankton and zooplankton populations has also continued.

6.2 Water Chemistry

Data for the fortnightly spot samples are shown in figures 6.1 - 6. and a summary of the summer means for the determinands measured is listed in Table 6.1.

6.2.1 Phosphorus Concentration

There is little seasonal variation in the total P concentration at Honing Lock, the upper tidal limit of the river Ant (Figures 6.1 and 6.2). The short-lived peaks in concentration recorded are due to an increase in particulate P. and therefore may represent periods of storm flow with associated increases in land runoff and resuspension of river bed. Further, during 1991 and 1992 when river flows where reduced no peaks in total P. concentration were recorded. The mean summer total P. concentrations in 1991 and 1992 are lower than those of previous years (Table 6.1). S.R.P. concentrations, however, have changed little since 1986.

Further down river at Wayford Bridge there is also little seasonal change in the total P. concentration and the short-lived peaks are less pronounced. A spring decrease in S.R.P. concentration is recorded each year due to uptake by diatoms. Unlike Honing lock the mean summer total P. concentration has increased for 1991 and 1992. This increase corresponds to a decrease in river discharge which will allow phytoplankton rich water from the lower reaches to penetrate further up the river via tidal action. The mean summer S.R.P. concentrations are very similar to those recorded for Honing Lock and have also changed very little since 1986. A further supply of phosphorus to the river is via sediment release processes. In 1992 a maximum rate of phosphorus release (13.39 $mg/m^2/d$) was calculated for July (Chilvers and Phillips, 1992).

The final effluent from Stalham S.T.W. discharges into the river below Wayford Bridge and accounts for the higher levels of phosphorus recorded at Hunsett Mill. During the latter part of 1989 the phosphorus concentration discharged from Stalham S.T.W. increased due to the poor performance of the phosphorus removal process at this time. Total P. concentrations showed little seasonal variation until 1989 when a pattern of increasing total P. in the late summer developed at both Hunsett Mill and Barton Inflow. This is probably due to the increased retention time of the river which enables the phytoplankton to fully utilise the available phosphorus. Also, the reduced river flows will allow the phytoplankton rich water from the broad to penetrate further up river. There is also a change to the seasonal variation in S.R.P. concentration. In addition to the expected spring uptake of available phosphorus by diatoms the decreased S.R.P. concentrations extended into the mid summer period.

Table 6.1 River Ant and Barton Broad monitoring data: mean concentrations April - September 1986 - 1993

Site	Year	Total P. mg/l	S.R.P. mg/l	T.O.N. mg/l	Ammonium mg/l	Chlorophyll a µg/l
Honing Lock	1986	no data	no data	no data	no data	no data
	1987	no data	no data	no data	no data	no data
	1988	0.093	0.022	no data	no data	no data
	1989	0.121	0.028	no data	no data	no data
	1990	0.093	0.024	no data	no data	no data
	1991	0.052	0.023	no data	no data	no data
	1992	0.059	0.035	3.72	0.14	no data
Wayford Bridge	1986	0.119	0.028	2.65	0.30	21.2
	1987	0.089	0.028	2.10	0.27	8.5
	1988	0.079	0.022	2.72	0.11	7.6
	1989	0.101	0.031	1.66	0.16	12.7
	1990	0.130	0.023	1.31	0.07	43.2
	1991	0.149	0.022	no data	no data	103.2
	1992	0.149	0.039	1.30	0.08	44.7
Hunsett Mill	1986	no data	no data	no data	no data	no data
	1987	0.126	0.032	2.71	0.14	13.9
	1988	0.131	0.029	3.65	0.15	20.2
	1989	0.168	0.041	3.06	0.20	38.7
	1990	0.190	0.041	3.14	0.06	89.8
	1991	0.214	0.054	3.80	0.03	152.8
	1992	0.183	0.082	3.16	0.04	63.5
Barton Inflow	1986	0.135	0.015	2.75	0.10	59.5
	1987	0.158	0.030	2.65	0.11	35.4
	1988	0.131	0.027	3.49	0.09	48.6
	1989	0.163	0.029	2.37	0.12	78.4
	1990	0.255	0.066	2.29	0.05	172.9
	1991	0.241	0.035	1.58	0.03	207.2
	1992	0.177	0.048	1.98	0.08	108.5
Barton Broad	1986	0.179	0.012	0.69	0.03	162.9
	1987	0.143	0.013	1.07	0.13	111.3
	1988	0.150	0.004	1.27	0.03	184.2
	1989	0.195	0.010	0.62	0.05	148.9
	1990	0.213	0.030	0.51	0.10	158.4
	1991	0.268	0.018	0.23	0.02	238.9
	1992	0.229	0.007	0.29	0.03	224.9

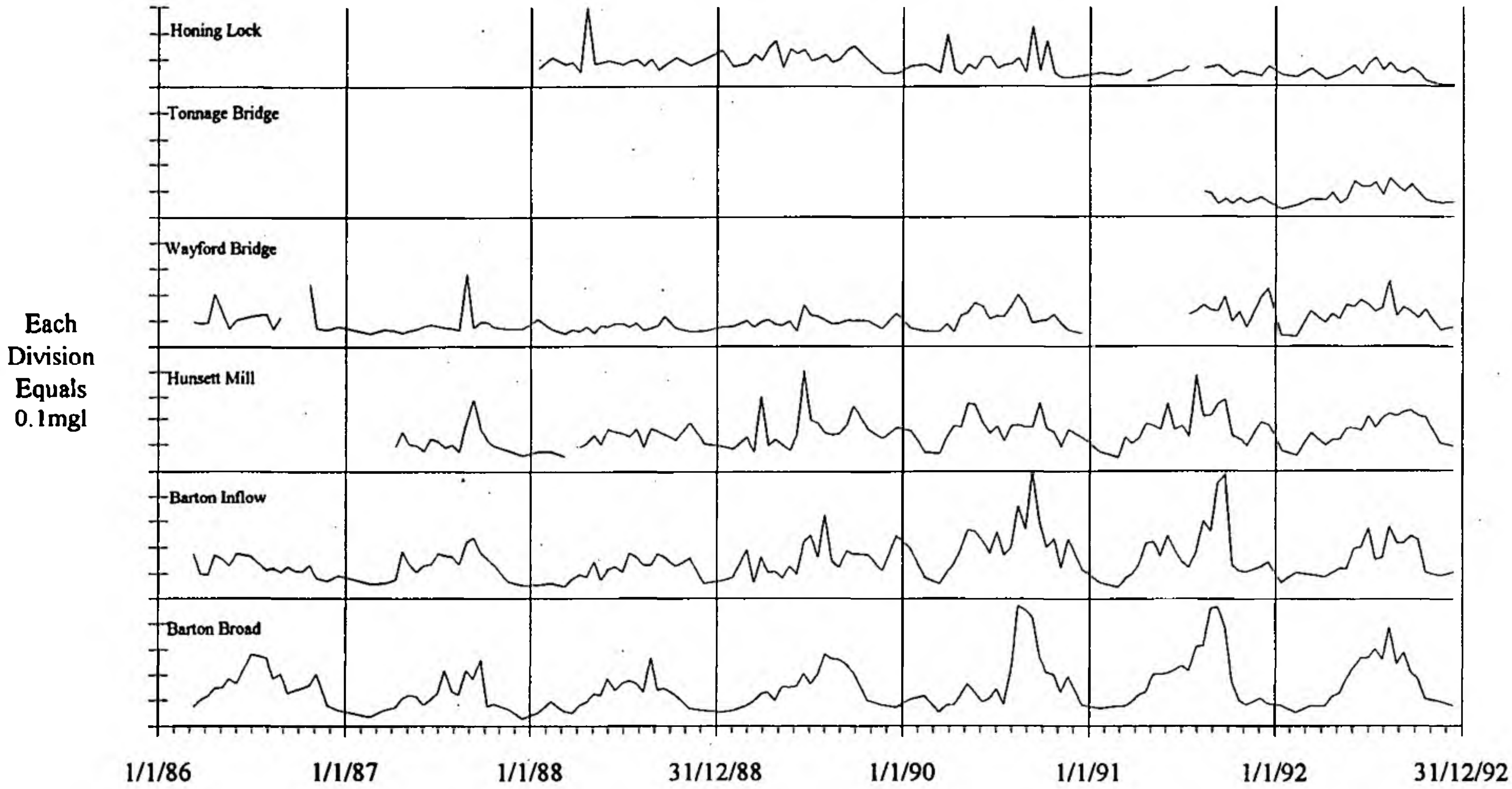


Figure 6.1 River Ant: total phosphorus concentration

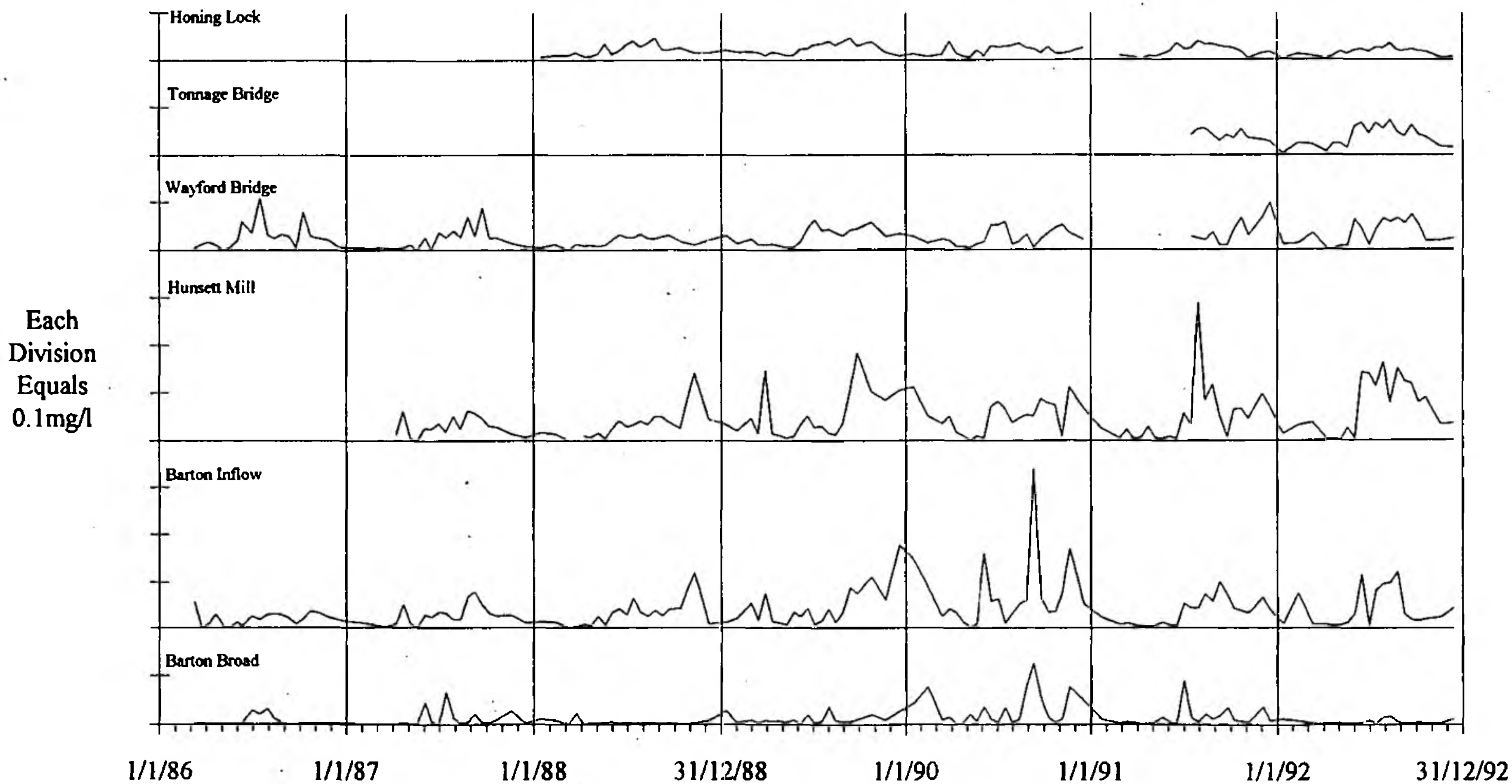


Figure 6.2 River Ant: soluble reactive phosphorus concentration

Phosphorus concentrations within Barton Broad will not only be affected by the supply of phosphorus from the river, but also by retention time and the number of grazing zooplankton. The seasonal pattern of increasing total P. concentration during the summer months became more pronounced from 1990. As the river flows lowered the retention time of Barton Broad increased, allowing greater phytoplankton productivity. The S.R.P. concentration remains at very low levels throughout the year with the exception of short-lived peaks in concentration. These inputs of phosphorus probably represent either the recycling of particulate phosphorus by zooplankton, grazing upon phytoplankton or release from the sediment (Chilvers and Phillips, 1992). The winter S.R.P. concentrations, when phytoplankton uptake is minimal, reflect the S.R.P. load being supplied by the river and also that being recycled back to the water column by decaying phytoplankton. During the winter of 1989 the S.R.P. concentration within the broad increased in association with the increased river inputs due to the ineffectiveness of phosphorus removal at Stalham S.T.W. during that period.

6.2.2 Chlorophyll a Concentration

Seasonal fluctuations in phytoplankton productivity, as represented by chlorophyll a concentration, are illustrated in Figure 6.3. Within both the river and broad the chlorophyll a concentration peaks in the spring and late summer. The first peak is associated with a rise in the numbers of faster growing diatoms while the second peak, later in the year, represents an increase in the slower growing larger phytoplankton.

Generally, there is an increase in chlorophyll concentration down river with Barton Broad supporting higher numbers of phytoplankton. However, since 1990 the chlorophyll a concentrations of both Hunsett Mill and Barton Inflow have increased with concentrations reaching those usually associated with the broad. This is probably a result of the reduction in river flows both increasing the retention time of the river and also allowing the broad to extend further up river.

6.2.3 Total Oxidised Nitrogen and Ammonium Concentration

The annual and seasonal fluctuations of both T.O.N. and ammonium are shown in Figures 6.4 and 6.5.

T.O.N. concentrations are highest during the winter when runoff is greatest. Most of the nitrogen which enters the river is from diffuse catchment sources and loadings are therefore affected by rainfall levels. T.O.N. levels at Wayford Bridge are generally lower during the drier years since 1989. Due to the effect of phytoplankton uptake and bacterial denitrification. T.O.N. concentrations would be expected to decrease down river. However, the mean summer concentration actually increases between Wayford Bridge and Hunsett Mill (Table 6.1). This is due to an input of nitrate from Stalham S.T.W. (Boar, 1992).

The seasonal fluctuation within Barton Broad is more pronounced with the summer concentrations falling at or below detection levels. This would suggest some degree of nitrogen limitation, which would encourage the growth of nitrogen fixing cyanobacteria. However, there is a continuous supply of T.O.N. from the river to the broad throughout the summer months. During the wetter years of 1987 and 1988 the phytoplankton were less able to fully utilise the nitrogen supply due to increased flushing rates and T.O.N. was detectable during the summer months.

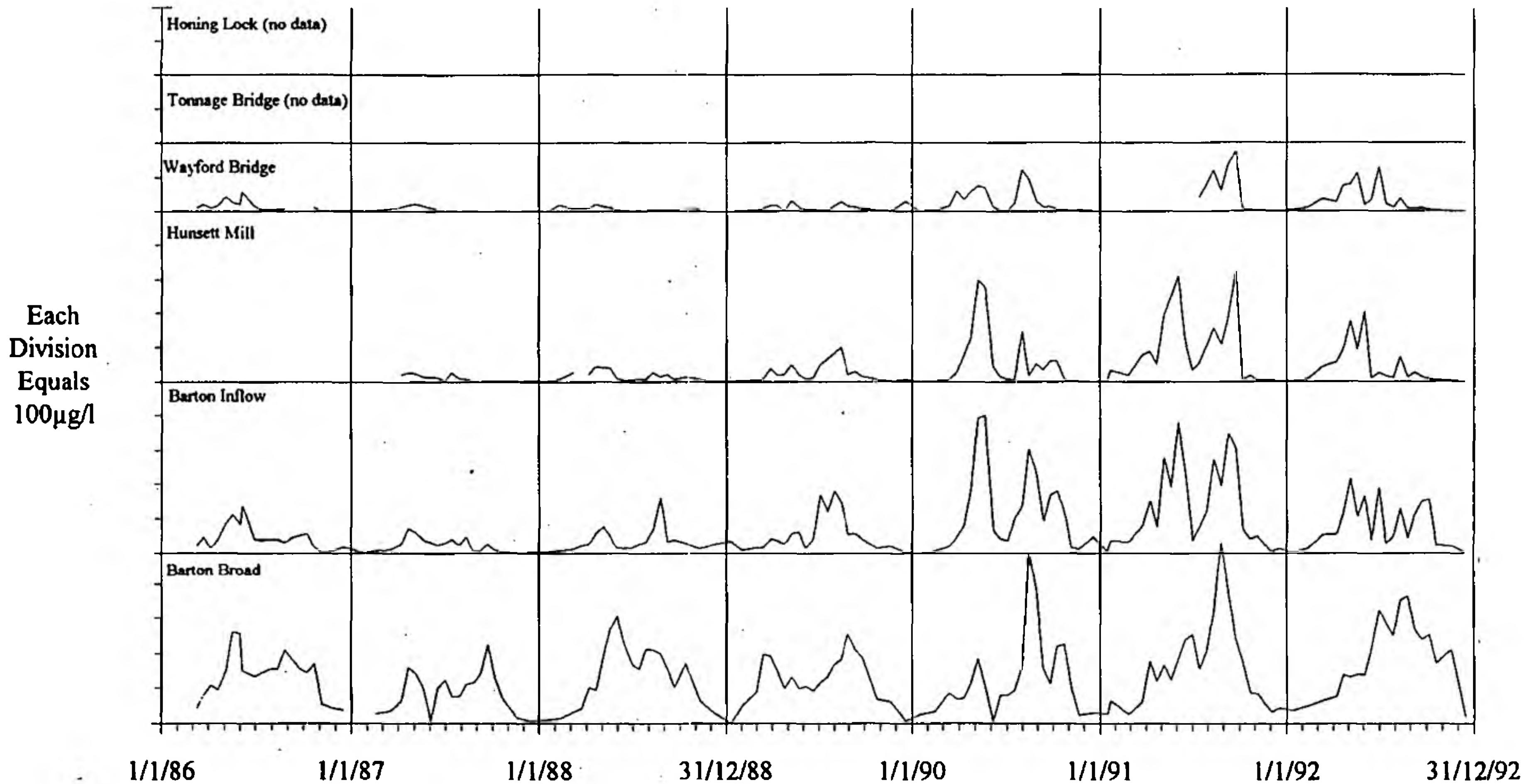


Figure 6.3 River Ant: chlorophyll a concentration

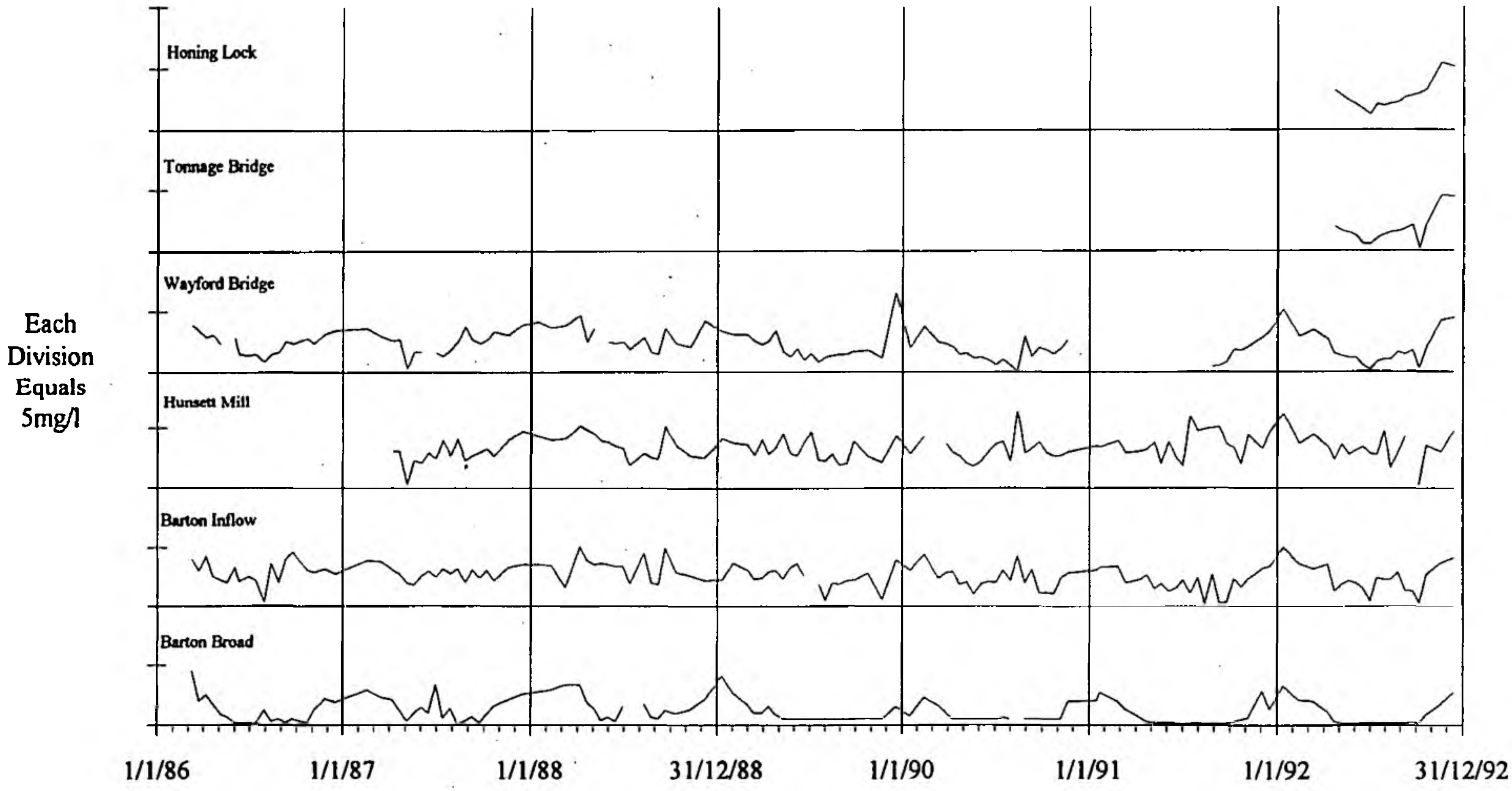


Figure 6.4 River Ant: total oxidised nitrogen

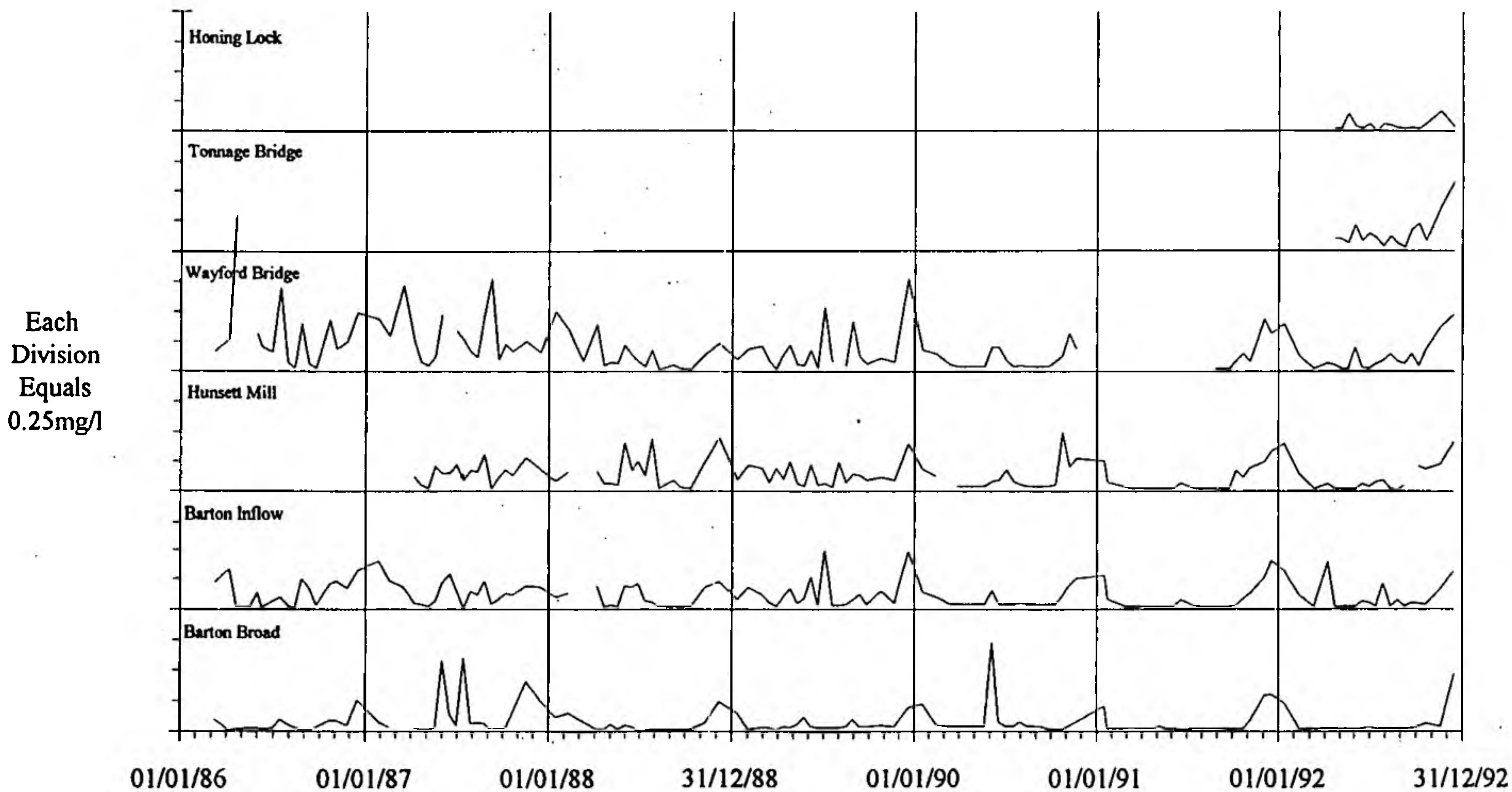


Figure 6.5 River Ant: ammonium concentration

Ammonium concentrations fluctuate seasonally in line with phytoplankton productivity. Within the river as flows have decreased the concentration of ammonium has declined, especially during the summer months. This is because the phytoplankton are better able to utilise the supply of nutrients when flushing rates are reduced. Since 1990 Barton Inflow and to some extent Hunsett Mill have been acting as an extension to Barton broad rather than as a river. During the summer months short lived peaks in ammonium are detected both in the river and broad. These could be as a result of sediment release via the breakdown of organic matter (Chilvers and Phillips, 1992).

6.2.4 Silicate Concentration

Figure 6.6 clearly show the seasonal fluctuations in silicate concentration. In both the river and broad a decrease in concentration is seen during the spring due to uptake by diatoms. These diatoms are usually small and fast growing and hence are less affected by the higher river flows and increased flushing rates usually associated with the season. A second period of diatom uptake occurs in the late summer when larger slower growing diatoms are able to make use of the increased retention times. The extent of this second reduction in silicate concentration does vary from year to year. However, the reduced river flows since 1990 have lead to both periods of silicate depletion becoming more pronounced.

6.2.5 Chloride Concentration

Information about the extent of the regular tidal movement of water up river is provided by measuring the changes in chloride concentration. The fluctuations in concentration, for both the river Ant sites and Barton Broad, are illustrated in Figure 6.7. Generally, there is little regular change in the chloride concentration of both the river and broad with surge events in the spring and autumn having the most notable effect. The reduction in river flows has lead to the effects of the surge event being recorded further up river. Also the reduction in flushing rates will also enhance the impact of the autumn surge events in 1990 and 1991 with the chloride levels remaining higher for a longer length of time during the winter.

6.2.6 Sulphate Concentration

Measurement of sulphate concentration was initiated in 1991 in order to assess whether the ferric sulphate dosing at the sewage treatment works was having an impact on the river (Figure 6.5). There is no notable increase in sulphate concentration between Wayford Bridge and Hunsett Mill. Seawater has a higher natural concentration of sulphate and therefore acts as a source of sulphate to the river Ant via the tidal movement of water up river. An increase in the sulphate concentration was recorded in Barton Broad during the tidal surge in the autumn of 1991. During the summer season the sulphate concentration decreases at all of the sites.

6.2.7 Iron Concentration

Generally the total iron concentration within the river is higher and fluctuates to a much greater extent than within the broad (Figure 6.6). Most inputs of iron are from land drainage or resuspended river sediment and the concentration is therefore affected by both river flows and rainfall.

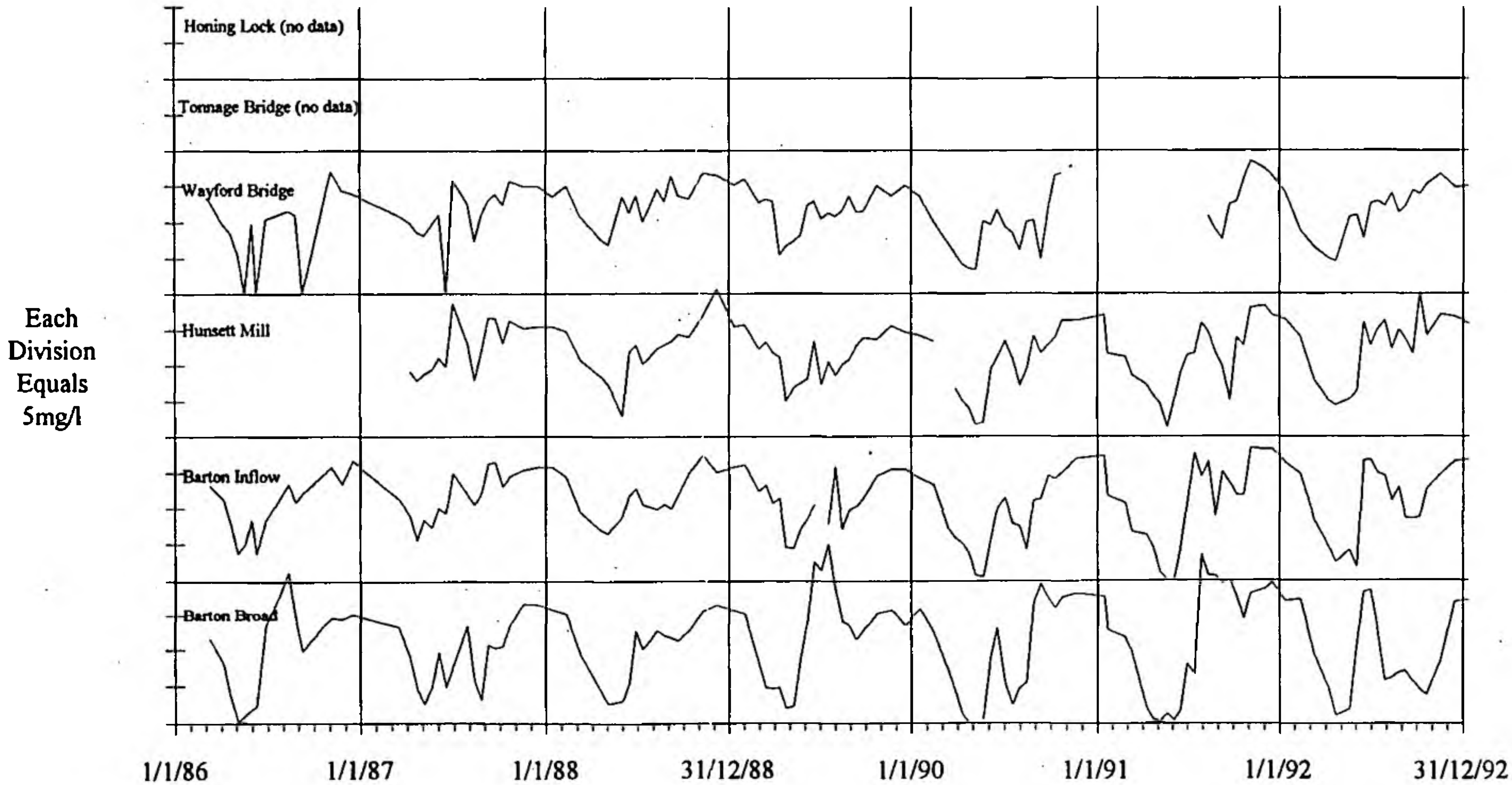


Figure 6.6 River Ant: silica concentration

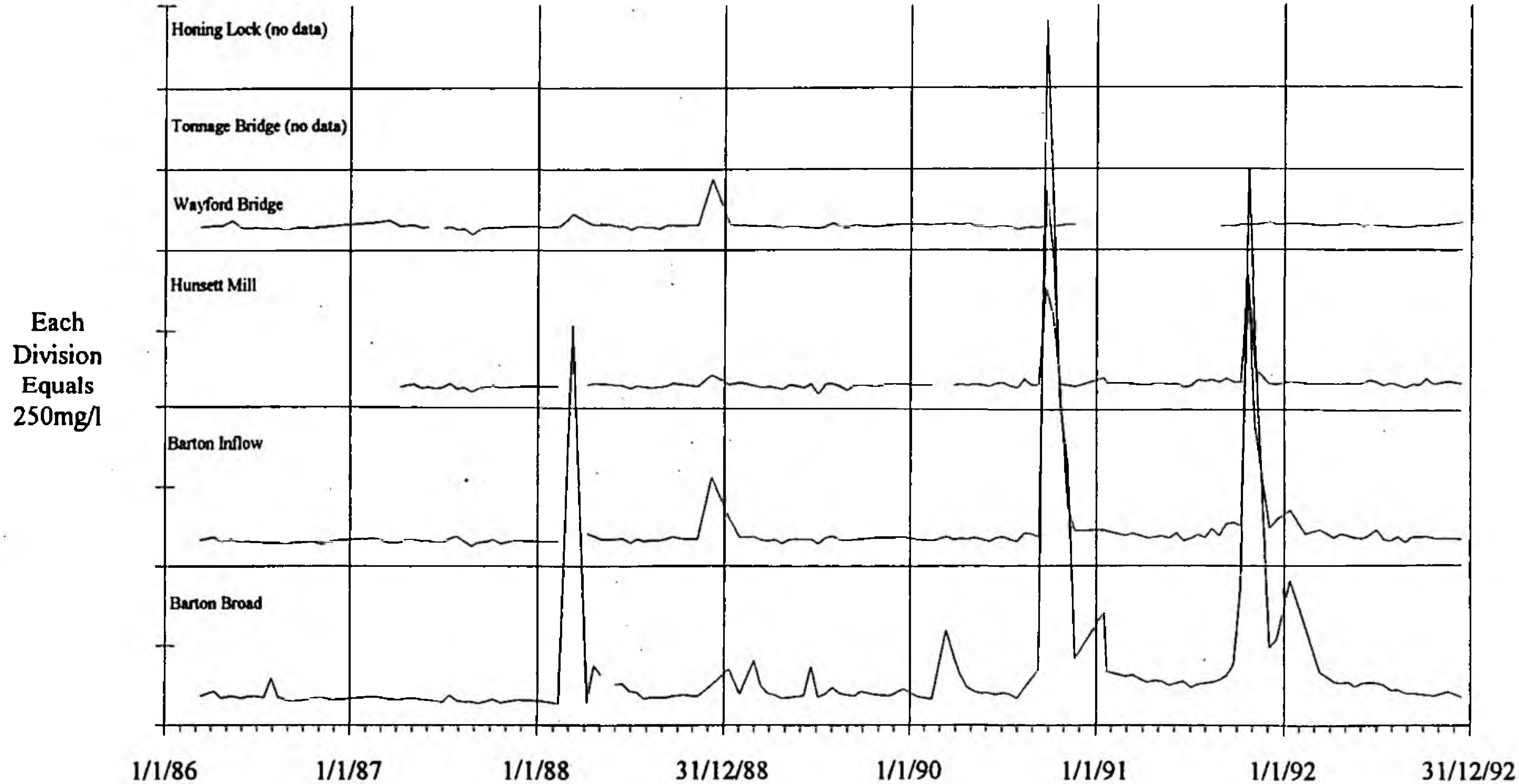


Figure 6.7 River Ant: chloride concentration

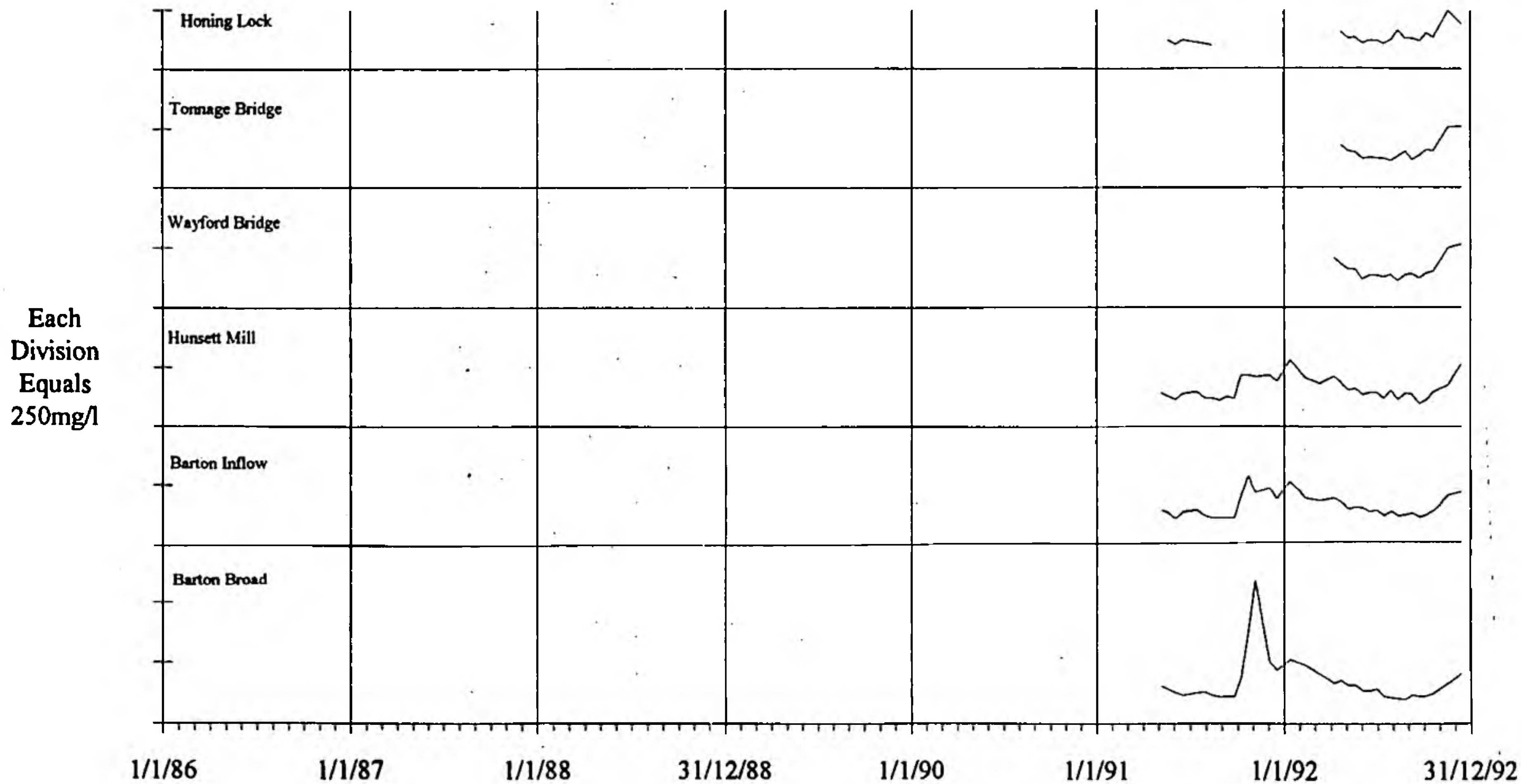


Figure 6.8 River Ant: sulphate concentration

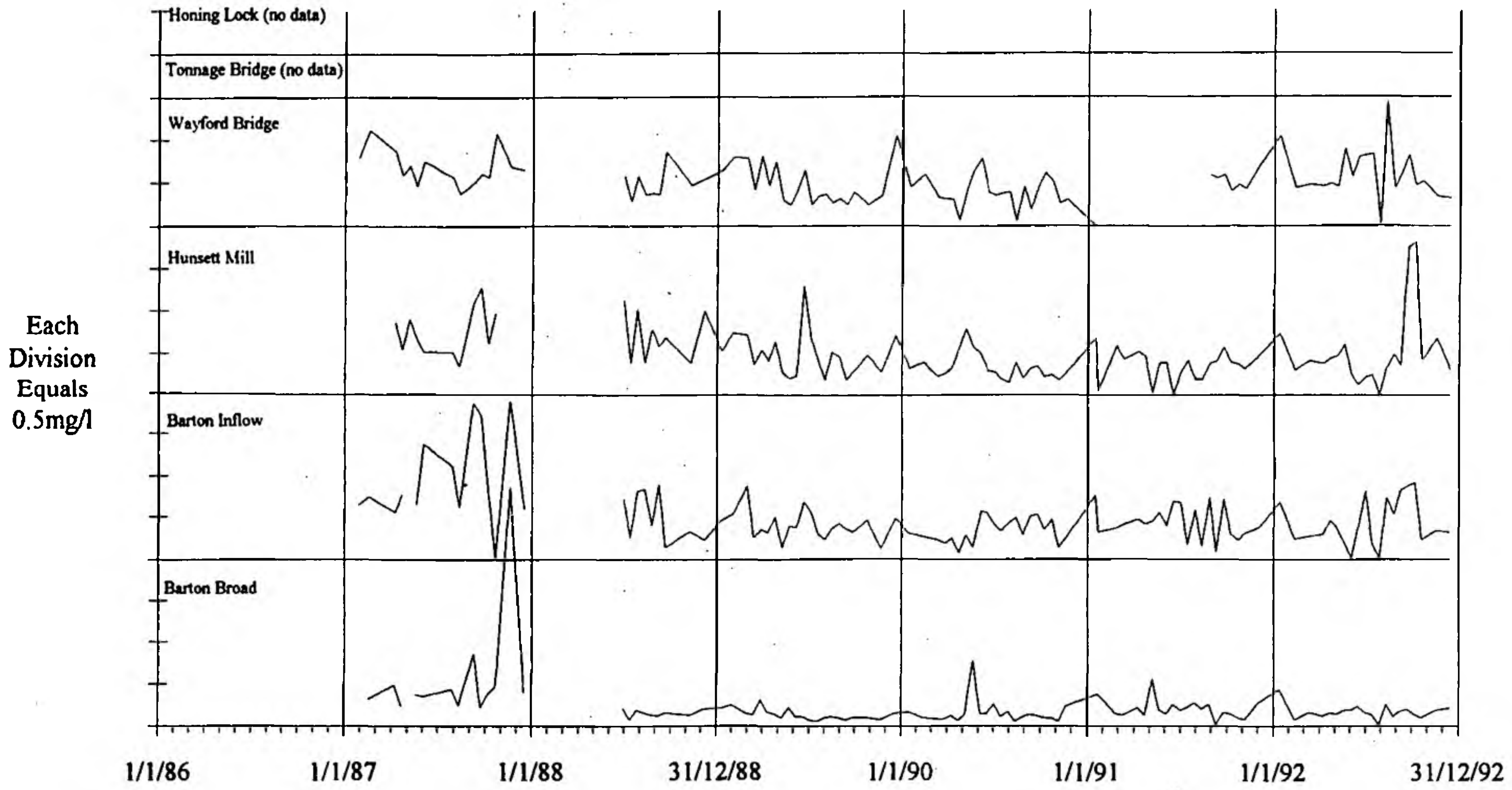


Figure 6.9 River Ant: iron concentration

6.2.8 Alkalinity And pH

The pH values recorded for both the river and Barton Broad are above 7.5 (Table 6.2) suggesting either a high alkalinity or carbon dioxide depletion as a result of photosynthetic activity. There is little variation in pH down river in 1987 and 1988 with only an increase in pH being recorded at Barton Broad. This pattern represents the increase in phytoplankton productivity within the broad as suggested by the higher chlorophyll a concentrations. With the reduction in river flows the pH values increased in the river corresponding to an increase in photosynthetic activity. Also, from 1989 - 1992 a seasonal variation in pH was recorded with pH values falling in the winter months.

The large phytoplankton densities also affect the alkalinity of Barton broad. Total alkalinity, which is a measure of both the bicarbonate and carbonate content of the water, decreased during the summer months. Whereas the phenolpthalein alkalinity, a measure of the carbonate content, increased. These changes are as a result of the withdrawal of carbon dioxide by the increased photosynthetic activity disturbing the organic equilibria leading to the formation of marl.

6.3 Field Determinands

6.3.1 Water Temperature

The mean summer and winter water temperatures are shown in Table 6.3. Generally there is little variation between sites during the winter months. However, in the summer the water temperature is higher in the broad than the river. This trend of increasing water temperature down river becomes less defined as the river flows are reduced, especially in 1991. As the retention time of the broad and river increases the temperatures also increase. Warmest temperatures were recorded in the summers of 1989 an 1990.

6.3.2 Secchi Disc

Secchi disc depth measurements (Table 6.4) are affected by both the amount of suspended solids and phytoplankton thereby providing an indication of the extent to which light is able to penetrate the water column. There is an overall pattern of decreasing secchi depth down river, with the smallest readings being obtained for Barton Broad. These changes reflect the differences in the phytoplankton communities within the river and broad. The secchi depths are also lower during years of reduced flows when phytoplankton productivities are enhanced.

6.4 Barton Broad Zooplankton Population

Figure 6.10 illustrates the population changes within Barton for the period 1989 - 1992. *Daphnia sp*. are effective phytoplankton grazers and can therefore influence water clarity. The numbers of *Daphnia sp.* have declined with the largest population being recorded in 1989 and no individuals recorded in 1992. This may be as a result of increased chloride levels brought about by surge tide events in the autumn of both 1990 and 1991. Any increase in numbers within the broad in spring is very short lived due to

Table 6.2 River Ant sampling sites, mean pH

		pH			
		Wayford Bdg.	Hunsett Mill	Barton Inflow	Barton Bd.
1986					
Winter	Oct.-March	-	-	-	-
Summer	April-Sept.	-	-	-	-
1987					
Winter	Oct.-March		-		-
Summer	April-Sept.	7.7	7.7	7.7	8.5
1988					
Winter	Oct.-March	7.6	7.6	7.6	8.0
Summer	April-Sept.	7.5	7.6	7.6	8.5
1989					
Winter	Oct.-March	7.9	7.9	8.0	8.5
Summer	April-Sept.	8.3	8.2	8.4	8.9
1990					
Winter	Oct.-March	7.8	7.9	8.1	8.5
Summer	April-Sept.	8.1	8.3	8.3	8.9
1991					
Winter	Oct.-March	8.3	8.2	8.2	8.7
Summer	April-Sept.	-	8.5	8.7	9.3
1992					
Winter	Oct.-March	-	-	-	-
Summer	April-Sept.	7.8	7.9	8.0	8.7

* Note: the winter season is from the October of the preceeding year to the spring of the current year.

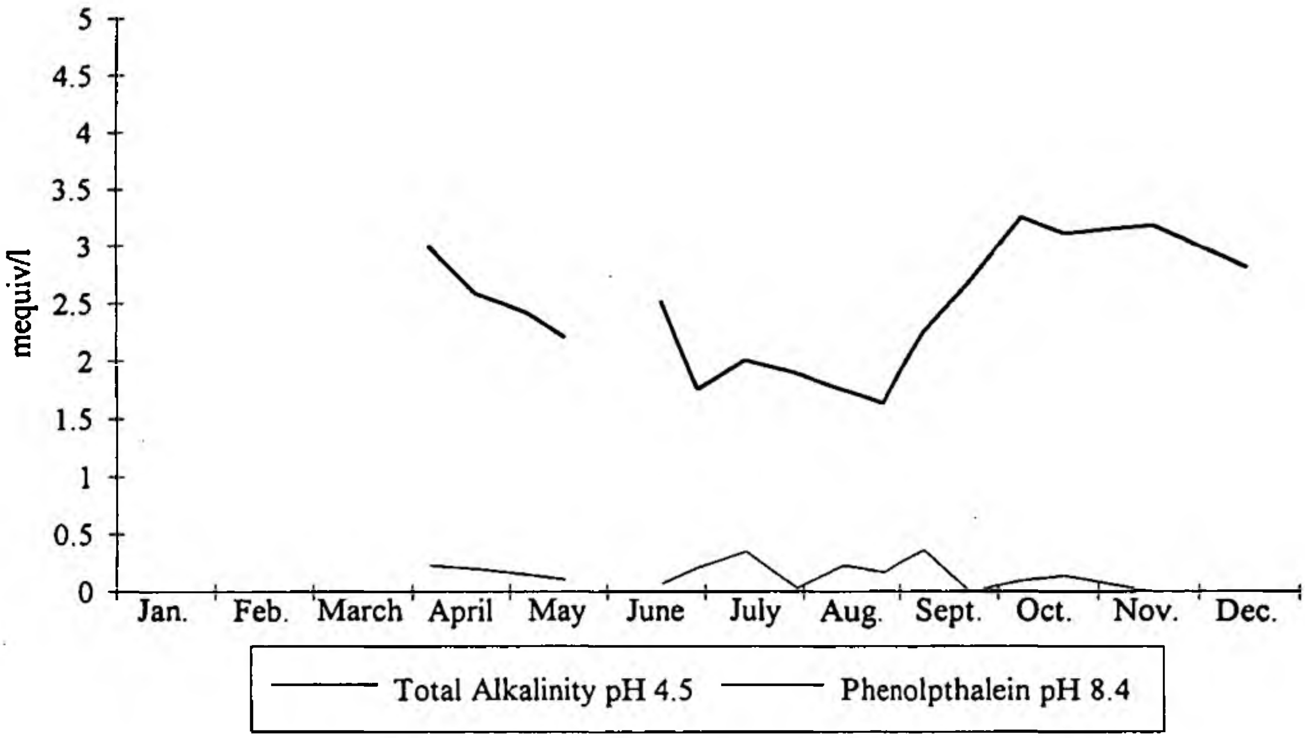


Figure 6.10 River Ant: alkalinity

Table 6.3 River Ant sampling sites, mean temperature

		temperature oC			
		Wayford Bdg.	Hunsett Mill	Barton Inflow	Barton Bd.
1986					
Winter	Oct.-March	3.6	-		-
Summer	April-Sept.	-	-	-	-
1987					
Winter	Oct.-March		-		
Summer	April-Sept.	13.38	14.47	14.78	15.18
1988					
Winter	Oct.-March	7.64	6.97	7.20	7.15
Summer	April-Sept.	14.10	15.33	15.18	15.68
1989					
Winter	Oct.-March	-	6.58	6.56	6.44
Summer	April-Sept.	17.27	17.82	17.80	18.15
1990					
Winter	Oct.-March	8.80	8.70	8.67	8.76
Summer	April-Sept.	16.71	17.18	17.41	17.54
1991					
Winter	Oct.-March	7.90	8.56	8.78	8.39
Summer	April-Sept.	-	15.75	15.82	15.80
1992					
Winter	Oct.-March	6.85	6.79	6.85	6.68
Summer	April-Sept.	16.17	16.54	16.73	16.91

* Note: the winter season is from the October of the preceeding year to the spring of the current year.

Table 6.4 River Ant sampling sites, mean secchi depth

		secchi depth m			
		Wayford Bdg.	Hunsett Mill	Barton Inflow	Barton Bd.
1986					
Winter	Oct.-March	-	-	-	-
Summer	April-Sept.	-	-	-	-
1987					
Winter	Oct.-March	-	-	-	-
Summer	April-Sept.	-	1.14	0.69	0.51
1988					
Winter	Oct.-March	-	-	-	-
Summer	April-Sept.	-	1.06	0.96	0.52
1989					
Winter	Oct.-March	1.36	1.68	1.19	0.86
Summer	April-Sept.	1.20	1.06	0.72	0.42
1990					
Winter	Oct.-March	1.40	1.44	1.33	1.05
Summer	April-Sept.		0.89	0.46	0.43
1991					
Winter	Oct.-March	1.55	1.41	0.82	0.72
Summer	April-Sept.	0.92	0.62	0.44	0.31
1992					
Winter	Oct.-March	1.23	1.51	1.21	0.93
Summer	April-Sept.	0.86	0.92	0.63	0.33

* Note: the winter season is from the October of the preceeding year to the spring of the current year.

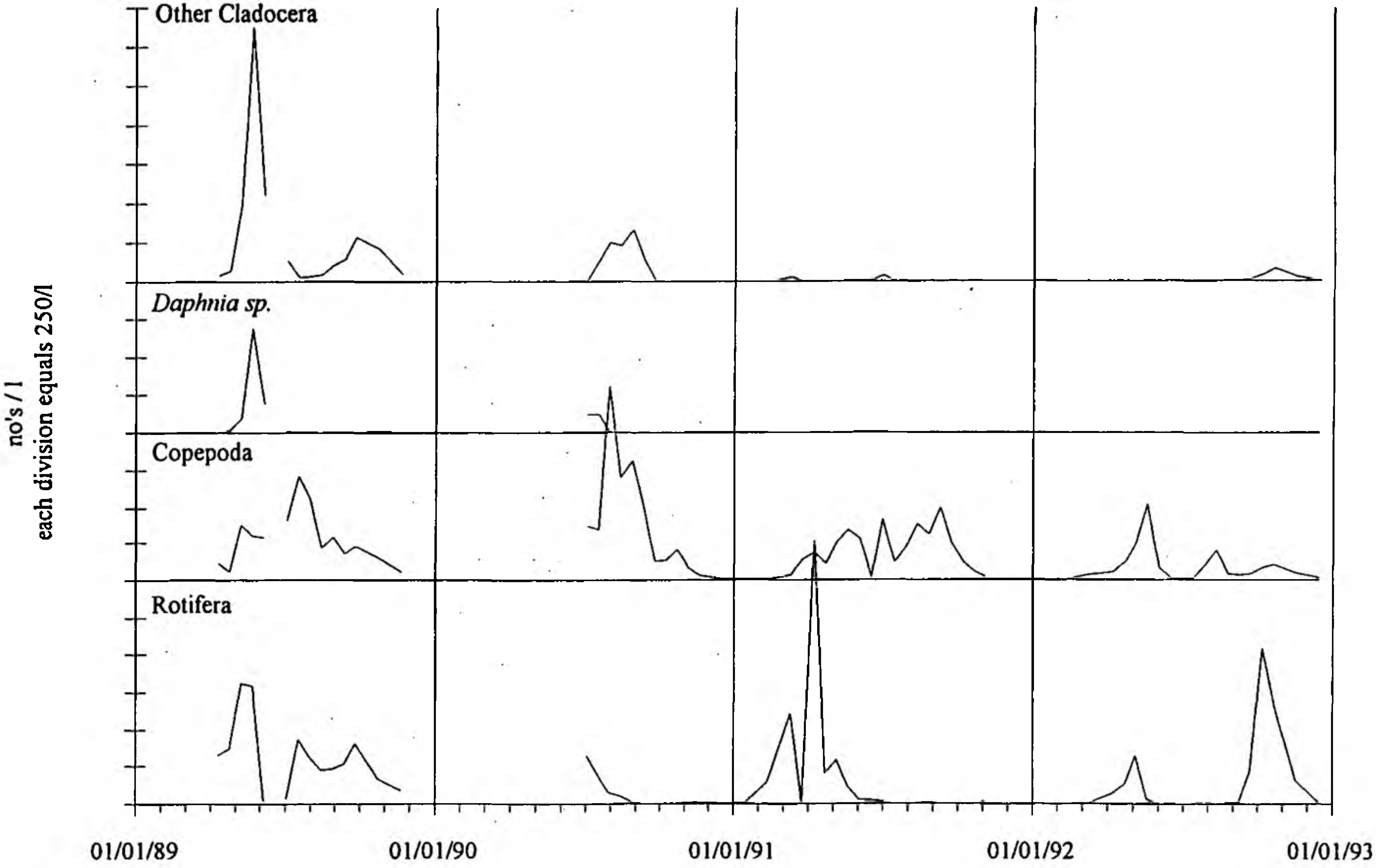


Figure 6.11 Barton Broad: zooplankton population

fish predation. The other cladocera, mainly *Bosmina longirostris*, have also followed the same pattern of declining populations since 1989. The faster Copepoda species are less affected by fish predation and populations are therefore sustained throughout the year, declining only in the winter months. Populations have fallen in numbers since 1989 but have continued to dominate the zooplankton.

7. REFERENCES

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Appendix A

Sampling Programme 1992 O.I. Project 550540

Sampling Site	Freq.	Phyto.	Zoop.	T.S.S.	Chl. A	S.R.P.	Tot. P.	Chem.	Alk.	pH	Temp.	Secchi
River Bure												
Ingworth Guaging Station	Ftnly			X		X	X					
Horstead Mill	Ftnly			X	X	X	X					
Wroxham Rail Bridge	Ftnly			X	X	X	X	X		X	X	X
Bend D/S Wroxham Broad	Ftnly			X	X	X	X	X		X	X	X
U/S Horning Village	Ftnly			X	X	X	X	X		X	X	X
Horning Ferry	Ftnly			X	X	X	X	X		X	X	X
St. Benets Abbey	Ftnly			X	X	X	X	X		X	X	X
River Bure Broads												
Wroxham Broad	Ftnly	X	X	X	X	X	X	X	X	X	X	X
Hoveton Great Broad	Ftnly	X	X	X	X	X	X	X	X	X	X	X
Hoveton Little Broad	Ftnly	X	X	X	X	X	X	X	X	X	X	X
Ranworth Broad	Ftnly	X	X	X	X	X	X	X	X	X	X	X
South Walsham Broad	Ftnly	X	X	X	X	X	X	X	X	X	X	X
Sewage Treatment Works												
Briston	Wkly					X	X	X*				
Aylsham	Wkly					X	X	X*				
R.A.F. Coltishall	Wkly					X	X	X*				
Belaugh	Wkly					X	X	X*				

Sampling Site	Freq.	Phyto.	Zoop.	T.S.S.	Chl. A	S.R.P.	Tot. P.	Chem.	Alk.	pH	Temp.	Secchi
River Ant												
Dilham Grange Trib.	Ftnly			X		X	X	X				
Honing Lock	Ftnly			X		X	X	X				
Wayford Bridge	Ftnly			X	X	X	X	X		X	X	X
Hunsett Mill	Ftnly			X	X	X	X	X		X	X	X
Barton Inflow	Ftnly			X	X	X	X	X		X	X	X
River Ant Broads												
Barton Broad	Ftnly	X	X	X	X	X	X	X	X	X	X	X
Sewage Treatment Works												
Worstead	Wkly					X	X	X*				
South Repps	Wkly					X	X	X*				
Stalham	Wkly					X	X	X*				
Horning	Wkly					X	X	X*				

X* : sulphate concentration only measured

Appendix B

River Bure Broads: alkalinity (mequiv/l)

Date	Belaugh	Wroxham	Hoveton Ltl.	Ranworth	Sth. Walsham
			total alkalinity (pH4.5)		
11/02/92	-	4.38	3.96	3.81	3.67
12/03/92	-	3.94	3.54	3.03	2.18
24/03/92	-	3.78	3.63	3.28	2.87
07/04/92	3.79	3.71	3.30	3.43	2.95
21/04/92	3.77	3.61	3.12	3.03	2.62
07/05/92	3.33	3.32	2.98	2.66	2.92
19/05/92	3.41	3.62	2.85	2.19	2.37
02/06/92	-	3.96	3.37	2.70	2.63
18/06/92	4.23	3.71	3.31	3.10	3.01
29/06/92	4.16	3.38	3.07	2.99	3.41
14/07/92	4.40	3.42	2.94	3.03	3.59
30/07/92	4.17	4.15	2.29	2.01	3.50
13/08/92	4.27	3.75	1.93	1.90	3.04
26/08/92	4.27	3.55	2.54	1.98	2.75
08/09/92	4.60	3.69	2.82	2.71	2.94
22/09/92	4.20	3.50	2.63	2.56	3.00
08/10/92	4.63	4.16	3.00	3.11	3.38
21/10/92	-	4.18	2.96	3.12	3.49
17/11/92	4.02	4.22	3.54	3.53	3.50
15/12/92	4.18	4.05	3.50	3.60	3.42

River Bure Broads: alkalinity (mequiv/l)

Date	Belaugh	Wroxham	Hoveton Ltl.	Ranworth	Sth. Walsham
			alkalinity (phenolphthalein pH8.4)		
11/02/92	-	0.15	0.16	0.14	0.20
12/03/92	-	0.14	0.17	0.34	0.41
24/03/92	-	0.09	0.20	0.25	0.96
07/04/92	0.08	0.14	0.13	0.32	0.57
21/04/92	0.20	0.23	0.18	0.26	0.68
07/05/92	0.07	0.19	0.20	0.16	0.42
19/05/92	0.00	0.10	0.41	0.34	0.59
02/06/92	-	0.00	0.06	0.11	0.34
18/06/92	0.10	0.00	0.00	0.00	0.34
29/06/92	0.06	0.10	0.20	0.12	0.34
14/07/92	0.00	0.07	0.14	0.18	0.44
30/07/92	0.03	0.08	0.00	0.00	0.39
13/08/92	0.08	0.17	0.26	0.26	0.80
26/08/92	0.16	0.06	0.17	0.18	0.74
08/09/92	0.00	0.18	0.18	0.21	0.70
22/09/92	0.00	0.08	0.11	0.13	0.33
08/10/92	0.00	0.13	0.10	0.09	0.05
21/10/92	-	0.08	0.10	0.08	0.00
17/11/92	0.00	0.00	0.00	0.00	0.00
15/12/92	0.00	0.00	0.00	0.00	0.00

Appendix C

River Ant: alkalinity (mequiv/l)

Date	total alkalinity (pH 4.5) Barton	alkalinity (phenolphthalein pH8.4) Barton
12/03/92	3.36	0.08
07/04/92	2.99	0.23
21/04/92	2.59	0.20
07/05/92	2.42	0.15
19/05/92	2.21	0.11
02/06/92	-	-
18/06/92	2.51	0.07
29/06/92	1.76	0.21
14/07/92	2.01	0.35
30/07/92	1.89	0.03
13/08/92	1.75	0.08
26/08/92	1.63	0.17
08/09/92	2.25	0.36
22/09/92	2.69	-
08/10/92	3.24	0.10
21/10/92	3.10	0.14
17/11/92	3.17	-
15/12/92	2.80	0.00

Appendix D

Total iron content of river sediment up and down river of S.T.W. outfall.

Aylsham S.T.W.

Sample (m from outfall)	Fe/sed dry wt (mg/g)
Upriver	
250	13.42
220	15.39
210	13.03
180	10.34
150	10.95
120	15.28
90	12.24
60	20.96
30	47.31
0	10.36
Outfall	
Downriver	
0	32.31
30	11.15
60	39.04
90	66.84
120	126.86
150	39.75
180	30.73
210	31.44
220	35.71
250	34.76

Belaugh S.T.W.

Sample (m from outfall)	Fe/sed dry wt (mg/g)
Upriver	
250	31.56
220	19.02
210	47.29
180	27.48
150	30.00
120	32.07
90	31.79
60	30.14
30	30.80
0	24.67
Outfall	
Downriver	
0	25.16
30	32.74
60	31.09
90	35.87
120	36.21
150	41.11
180	48.20
210	-
220	-
250	-

Stalham S.T.W.

Sample (m from outfall)	Fe/sed dry wt (mg/g)
Upriver	
250	33.29
220	32.77
210	34.50
180	36.38
150	36.48
120	35.47
90	29.07
60	33.98
30	34.60
0	36.04
Outfall	
Downriver	
0	48.58
30	43.98
60	44.44
90	45.43
120	46.03
150	46.85
180	45.92
210	43.35
220	53.02
250	45.48