The Control of Phosphorus in the Catchment of The Rivers Ant and Bure

3rd Annual Report May 1989

Period Jan 1988 - Dec 1989

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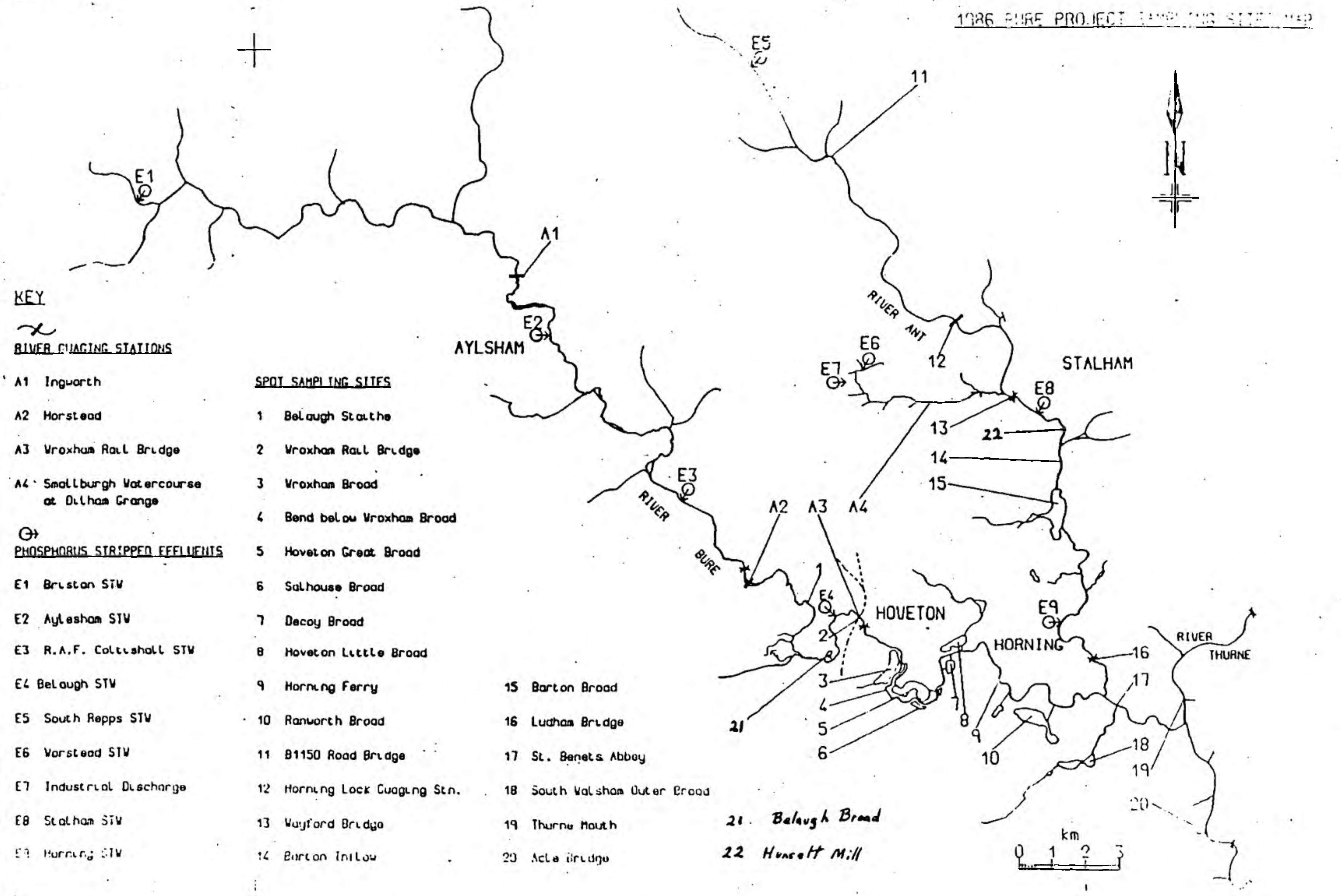


1986 BURE PROJECT
E5
11
E1
A1
N
KEY
RIVER GUAGING STATIONS
A1 Ingworth
A2 Horstead
A3 Wroxham Rail Bridge
A4 Smallburgh Watercourse at Dilham Grange
PHOSPHORUS STRIPPED EFFLUENTS
E1 Briston STW
E2 Aylesham STW
E3 R.A.F. Coltishall STW
E4 Belaugh STW
E5 South Repps STW
E6 Worstead STW
E7 Industrial Discharge
E8 Stalham STW
Horning STW
SPOT SAMPLING SITES
1 Belaugh Staithe
2 Wroxham Rail Bridge
3 Wroxham Broad
4 Bend below Wroxham Broad
5 Hoveton Great Broad
6 Salhouse Broad
7 Decoy Broad
8 Hoveton Little Broad
9 Horning Ferry
10 Ranworth Broad
11 B1150 Road Bridge
12 Horning Lock Guaging Stn.
13 Wayford Bridge
14 Barton Inflow
15 Barton Broad
16 Ludham Bridge
17 St. Benets Abbey
18 South Walsham Outer Broad
19 Thurne Mouth
20 Acle Bridge
21 Belaugh Broad
22 Hunsett Mill
AYLSHAM
E2
RIVER ANT
E6
E7
12
STALHAM
E8
13
22
14
15
E3
RIVER BURE
A2
A3
A4
E4
HOVETON
E9
HORNING
16
17
RIVER THURNE
18
19
20
km
0 1 2 3

1. SUMMARY

Phosphorus removal from sewage treatment works on both the River Ant and Bure has continued. During 1987 a redox based dose control system was shown to increase the efficiency of phosphorus removal but required continual attention to overcome problems of changes in the background redox potential of the effluent. A self adjusting redox control system has been developed during 1988 and has been installed at Briston, Aylsham, Belaugh and Stalham STW's. This has largely overcome the problems associated with background redox drift and all of these sites are now capable of achieving better than 90% removal of phosphorus. Unfortunately failure of pumps and other small plant has meant that there have been periods of relatively high phosphate input to the River Bure.

Phosphorus removal was started by the PSA at RAF Coltishall STW in February 1988 using a time controlled dosing system. Problems with rising sludge however meant that the dose rate had to be reduced between June and August 1988. Better management of the sludge has enabled the dose rate to be increased and the phosphorus concentration has now been reduced by about 75%

There was a slight decrease in the effectiveness of phosphorus removal at Stalham STW during 1988. This was a relatively small increase and installation of the self adjusting redox system should have removed most of these problems. However experience during 1988 has demonstrated the need for continual maintenance of dosing equipment to ensure the continuity of phosphorus removal especially during the critical summer period.

Despite these problems changes in the phosphorus load of the River Bure have occurred. Interpretation of this data is complicated by the effect of river discharge. It is now clear that particulate phosphorus is related to discharge. Higher than normal discharge in the River Bure, from the summer of 1987 until the spring of 1988 increased the particulate and hence the total phosphorus load of the river. However soluble reactive phosphorus load decreased at both Horstead Mill and Wroxham Rail Bridge. This was less clear at Ingworth and periods of high soluble reactive phosphorus associated with high river discharges at this site and further downstream suggest that phosphorus enters the river from other sources in the catchment.

The reduction in phosphorus can be seen in the tidal River Bure as far downstream as Horning Ferry and in the most riverine broads such as Wroxham and Salhouse. Further downstream water from the River Ant and South Walsham Broad influence the river and increase phosphorus concentrations. In the less well flushed broads such as Hoveton Great, Hoveton Little and Ranworth Broad phosphorus is released from the sediment and relatively high total phosphorus concentrations occur. Phosphorus release may also occur at other sites and in the river but this cannot be detected from the data available.

Chlorophyll a concentration has been reduced at the sites where phosphorus is lower. As explained above this has occurred in sites that are well flushed by the river. This flushing has an additional effect of washing out the phytoplankton and it is clear that phytoplankton crop is dependent on both phosphorus availability and the degree of flushing. The very low chlorophyll a concentration seen in Wroxham Broad during the summer of 1987 was due to the abnormally high river discharge. Despite this it is clear that phosphorus removal has resulted in a reduction in phytoplankton crops in some of the upper Bure broads. There has also been a decrease in chlorophyll a and total phosphorus in Decoy Broad during both 1987 and 1988.

The effectiveness of phosphorus reduction is however related to the hydrological regime of the broads. Sites such as Hoveton Great Broad, which are poorly flushed provide reservoirs of phytoplankton which "seed" the river and it is suggested that ways of reducing this should be investigated.

Zooplankton development has been monitored and few changes have been noted. The most important of these has been a change in the species composition of Wroxham Broad which has become more characteristic of a less enriched site.

Belaugh Broad has been monitored since July 1987, following mud pumping. The phytoplankton in the broad appears to be slowly increasing, although throughout most of 1988 chlorophyll a concentrations were relatively low. The zooplankton is very diverse, although low in abundance and the site is probably still developing a stable plankton community.

The pen experiments at Barton Broad were continued during 1988 and additional pens were placed in Belaugh Broad. All the pens developed higher populations of cladocerans than the open water. Plants flourished in all of the Belaugh pens but only one of the three shallow pens in Barton Broad developed any aquatic plants. Chlorophyll a concentrations in Barton Broad and in the pens was much greater than in 1987 and it is suspected that less edible filamentous blue-green algae may have developed in this site.

2. INTRODUCTION

2.1 Objectives

This is the third annual report of the River Ant/Bure project which began in April 1986. The overall aim of the project is to reduce phosphorus loadings from sewage treatment works effluents discharging to the Rivers Ant and Bure. It is hoped that this action will reduce phytoplankton populations and allow the return of a diverse aquatic plant dominated habitat in the littoral fringes of the Bure and Ant valley broads.

It is becoming clear that the control of phosphorus alone will not be sufficient to enable the desired changes in the community structure to occur. Other ways of manipulating the ecosystem are being investigated and experiments with fish exclosures described in the second annual report were extended to include Belaugh Broad during 1988.

The second year of a project to investigate the potential availability of sediment derived phosphorus was completed. This completes work associated with a Nature Conservancy Council contract and a separate report detailing this work is being completed. Further work, funded by Anglian Water and the Broads Authority is continuing.

2.2 Progress with stored samples

All zooplankton samples from Barton, Wroxham, Hoveton Great, Ranworth and Belaugh Broads, together with samples from pens in Barton and Belaugh Broads have been counted.

Phytoplankton samples for the above sites have been counted and entered onto the database with the exception of Barton Broad. Samples from Barton Broad are currently being examined.

Plankton samples have been collected from other sites on the River Bure but will not be counted unless there is a clear need to do so.

2.3 Sampling program

The overall river sampling program described in the first annual report has remained unchanged apart from the addition in 1987 of Hunsett Mill on the River Ant and Belaugh Broad

Sampling of sewage works has however undergone several changes during 1988 in preparation for the division of Anglian Water into NRA and PLc. Bulked weekly samples from Briston, Aylsham, Belaugh and RAF Coltishall final effluents have been collected since the start of the project and since November 1987 similar samples have been collected from Southrepps, Stalham, Worstead and Horning STW's. Before this date phosphorus loads from these latter works has been obtained from routine operational data.

More detailed sampling of individual sites within these Anglian Water works has been carried out during 1988 in order to improve phosphorus dosing control. This sampling program has been rationalised with sampling within the works being carried out by Anglian Water operations staff. The progressive hand over of responsibility for ferric sulphate dosing to operations staff was started in January 1989 and was completed by the end of March 1989.

In addition to analysis of zooplankton, chlorophyll a concentrations have been determined on samples from pens in Barton and Belaugh Broads.

3. PHOSPHORUS REMOVAL FROM SEWAGE TREATMENT WORKS

The phosphorus concentration and loads from each works are detailed in appendix figs 1-8 and summarised in table 3.1. These data are based on weekly bulked samples and from routine spot samples where the former have not been installed.

3.1 Redox-controlled chemical dosing of phosphate removal.

3.1.1 Introduction

During 1987, at three sites on the River Bure, the performance of timeclock- and redox-based dose control systems was evaluated. Redox control, by restricting dosing when phosphate load was low was shown to increase the efficiency of phosphate removal and to produce up to a 19% saving in chemical costs. However to function efficiently, the redox system needs regular attention. a self-regulating version had since been developed to prevent saving being eroded by maintenance costs, and now efficiently and routinely operates at major sites on the Rivers Ant and Bure.

Drift in the background redox of the effluents, and the progressive fouling of the redox probe was responsible for the unreliable dose control evident at all sites before the modified system was installed. Underdosing occurred if redox drifted upwards and overdosing if it drifted downwards. To minimise these effects, it was necessary regularly to adjust the set point of the proportional control hardware manually an operation that is now carried out automatically.

3.1.2 Modification of the redox control system to adjust set point automatically.

Digital data loggers which recorded redox potential at ten minute intervals in the prototype system were modified so that once a day they derived a 24 hour mean redox value. The analogue set-point potentiometer in the controller was replaced by a digital potentiometer which was driven by the 24 hour mean from the data logger. Set-point was thus automatically adjusted daily to coincide with the mean daily redox value. This effectively accommodated any drift in background redox and changes in responsiveness of the redox probe.

Table 3.1

RIVER BURE, SEWAGE TREATMENT WORKS
Quaterly Phosphate-P Loads

QUATER	Briston	Aylsham	Belaugh	RAF Coltishall
	Kg/d Phosphate-P			
April-June 1986	3.4	14.1	13.0	-
July -Sept 1986	3.4	16.2	12.5	-
Oct - Dec 1986	.6	3.1	8.1	-
Jan -March 1987	1.7	1.1	3.6	5.2
April-June 1987	.7	2.2	3.6	5.6
July -Sept 1987	.7	2.7	4.4	5.5
Oct - Dec 1987	.2	.8	1.1	5.2
Jan -March 1988	.2	.8	1.8	2.2
April-June 1988	1.7	1.5	2.2	1.1
July -Sept 1988	1.7	3.4	2.2	1.9
Oct - Dec 1988	.4	1.0	1.0	1.2

RIVER BURE, SEWAGE TREATMENT WORKS

QUATER	Briston	Aylsham	Belaugh	RAF Coltishall
	% Phosphate-P Removal			
Oct - Dec 1986	83	79	37	-
Jan -March 1987	50	92	71	-
April-June 1987	81	86	74	-
July -Sept 1987	79	83	71	-
Oct - Dec 1987	94	95	93	-
Jan -March 1988	94	95	91	58
April-June 1988	50	92	86	79
July -Sept 1988	50	80	82	64
Oct - Dec 1988	86	92	90	77

With these modifications, redox control achieves 90% phosphate removal from percolating filter effluents without overdosing. There is no longer the problem of regular overdosing in the afternoon when flow declines (which occurred under timeclock control), and during the night, when phosphate load is low, dosing and phosphate removal are efficient.

In addition, redox control is most effective if the probe is positioned in the inlet to the final sedimentation tank, and cleaned at two monthly intervals with dilute sulphuric acid. If positioned inside the tank, accumulating sludge interferes with its performance. Effective mixing of the effluent and chemical is essential for phosphate removal, and to prevent premature settlement of flocculated solids, which, when carried over to the probe cause alternate over and underdosing.

It has been necessary to link two dosing pumps to one redox control system at Belaugh STW to enable the second filter bed effluent to be controlled by redox. Similar changes have been made at Aylsham where one effluent stream had irregular but very marked changes in background redox. A further improvement would be to arrange the pipe work in these paired control systems, so that chemical can be dosed to either channel from one pump in the event of failure of the other pump.

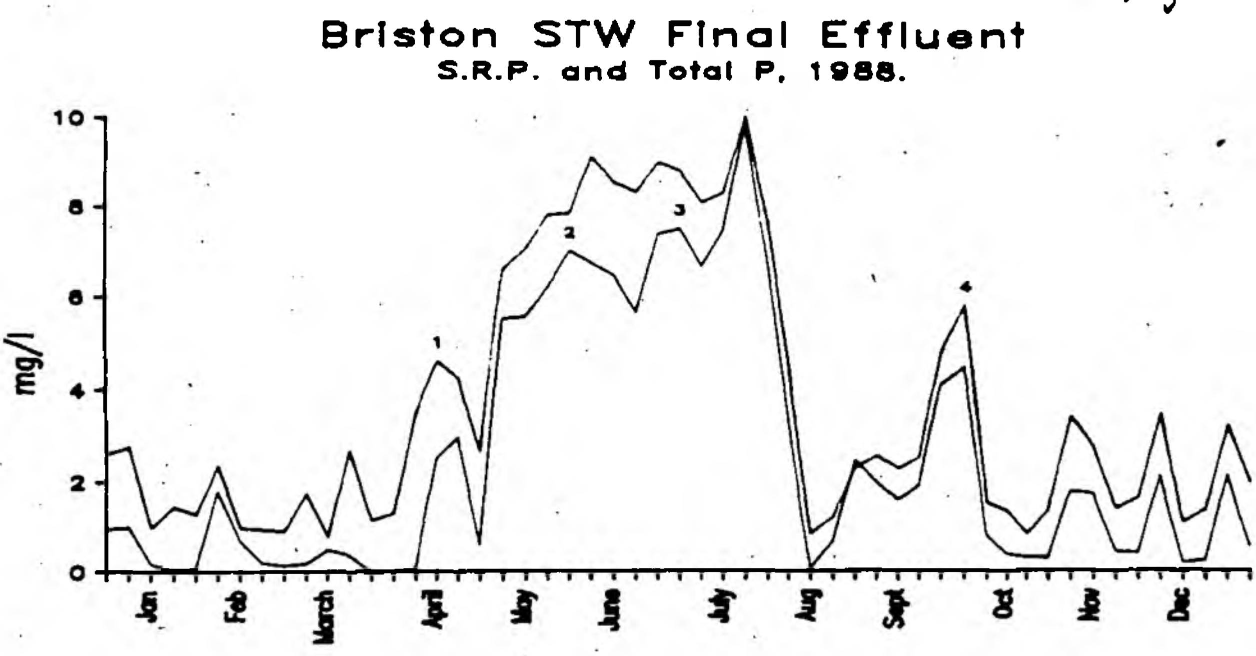
3.2 Discharges to the River Bure

The modified redox control of phosphorus dosing has eliminated most of the dosing problems associated with redox drift. However it has not been possible to maintain 90% or better phosphorus removal due to other operational problems. The major reasons for reduced stripping are detailed in fig 3.1-3.4 and are due to failure of pumps, line breakage etc. Short breaks in dosing often result from blockage of the in-line filter. This occurs particularly after the main ferric sulphate tank has been filled and regular cleaning of these filters is essential.

These problems prevented phosphorus removal for several months during the summer of 1988 at Briston STW reducing the average removal to 50% for the April-September period (Table 3.1). Aylsham and Belaugh performed much better, with a reduction in concentration of better than 80%. All three works now discharge approximately the same amount of soluble phosphorus ranging from 1 - 3 kgP d^{-1}.

Phosphorus removal was started at RAF Coltishall by the PSA on 9th February 1988 using a time controlled dose. Problems were experienced with rising humus tank sludge and dosing was reduced. Progressive increases in iron dosing have subsequently been made as management of the rising sludge was improved and phosphorus contribution from this works has been reduced to 1-2 kgP d^{-1}, a reduction of about 75%. With the design of the final settlement tanks in this works it is unlikely that any further improvement in phosphorus removal can be achieved.

Fig 3.1



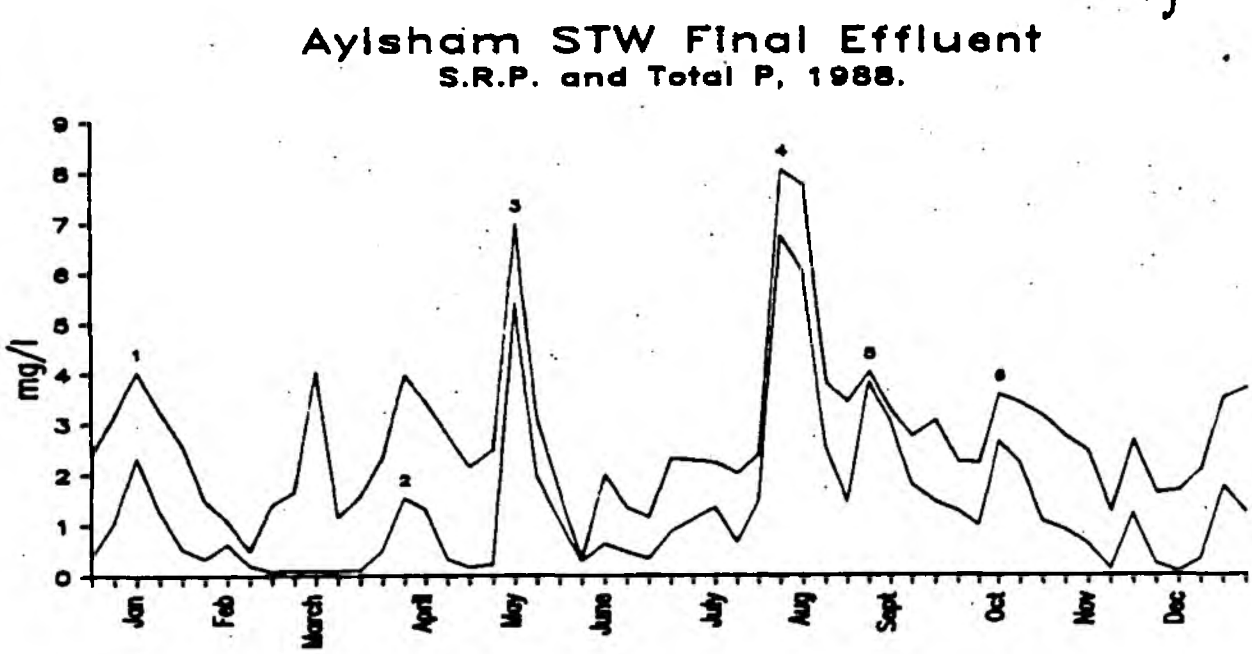
1 Background redox drift.

2 Dosing pump failure.

3 Main ferric tank empty.

4 Ballcock sticking, break tank empty.

Fig 3.2



1 Background redox drift.

2 Dosing pump failure.

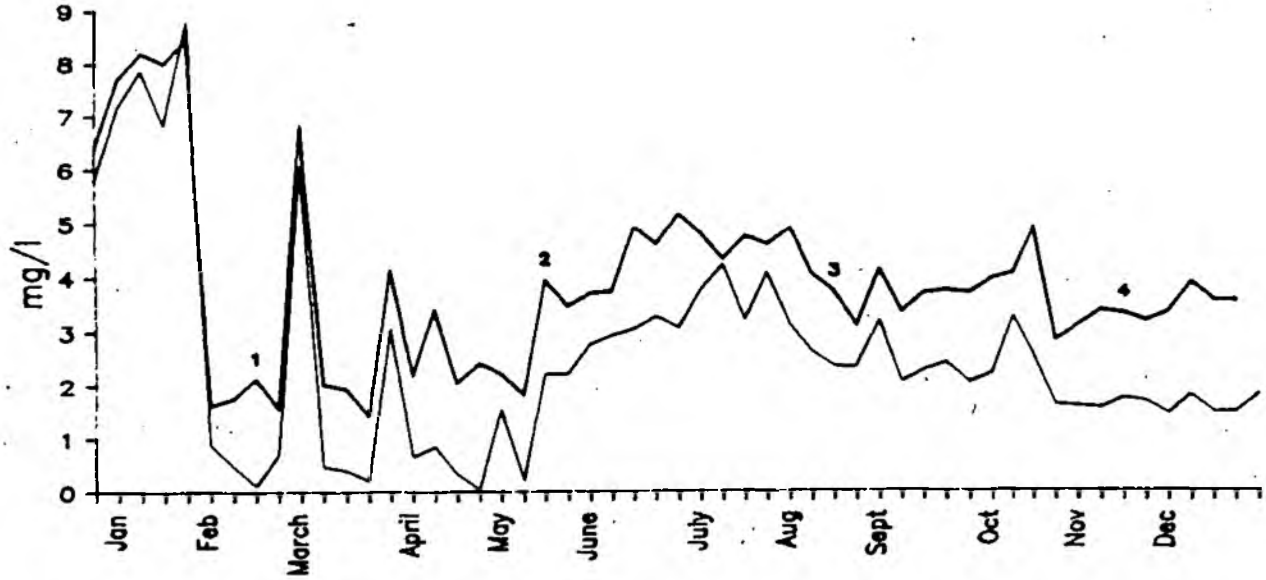
3 and 5 Main ferric tank empty.

4 Pipework split no ferric feed.

6 Power trip-outs.

Fig 3.3

R.A.F. Coltishall S.T.W. Final Effluent
S.R.P. and Total P



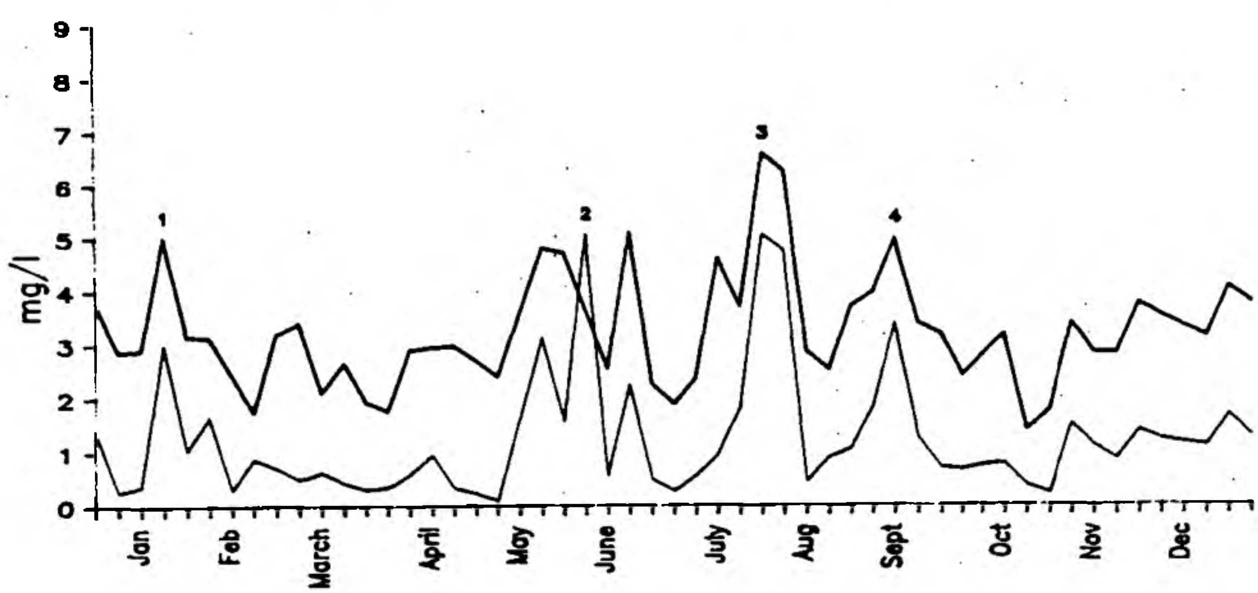
1 Stripping started.

2 Concern over rising sludge, dose rate reduced.

3 and 4 Progressive reinstatement of dosing rate.

Fig 3.4

Belaugh STW Final Effluent
S.R.P. and Total P



1 Pump failure.

2 and 4 Repeated power trip-outs.

3 Background redox drift.

3.3 Discharges to the River Ant

There has been a slight increase in the phosphorus discharged to the River Ant during 1988 (table 3.2). This has resulted from a combination of increased flow through the works and an increase in the concentration of phosphorus in the effluent. This change is most important at Stalham STW, due to its relative size and proximity to Barton Broad. The modified redox control system has now been installed at Stalham STWs and it is hoped that the temporary problems experienced at Stalham will be solved. Despite this the contribution from Stalham STW has only increased from 0.5 to 1.5kgP d^{-1}. (pre dosing value 1975-76 10kgP d^{-1})

Contributions from the Smallburgh tributary have remained similar to previous years at 2-4 kgP d^{-1}. the highest values occur during the spring period and are generally caused by increased particulate transport. (see section 4.2)

A summary of total phosphorus inputs to the River Ant, including the Smallburgh tributary are shown in fig 3.5

4. PHOSPHORUS LOADS IN THE RIVERS ANT AND BURE

4.1 Sampling.

Phosphorus and suspended solids loads have been obtained for three key sites on the River Bure at Ingworth, Horstead and Wroxham and for two sites on the River Ant at Honing Lock and Dilham Grange (on the Smallburgh tributary). At each of these sites except Honing Lock chemical data is derived from weekly bulked samples, at this site weekly spot samples are used due to persistent vandalism of auto samplers. Flows are derived from the gauged record or in the case of Wroxham and Dilham are derived from catchment area ratio's as detailed in the 1st annual report. These data are presented in graphical form in appendix figs 9-13.

Phosphorus loads have also been calculated for four other sites on the River Ant at B1150 bridge (North Walsham), Wayford Bridge, Barton Inflow and Barton Outflow. The latter site is derived from data from Barton Broad which is assumed to represent the outflow from the broad. Flows for each of these sites are calculated from a catchment area estimate following a detailed field investigation.

4.2 Phosphorus Load in the River Bure

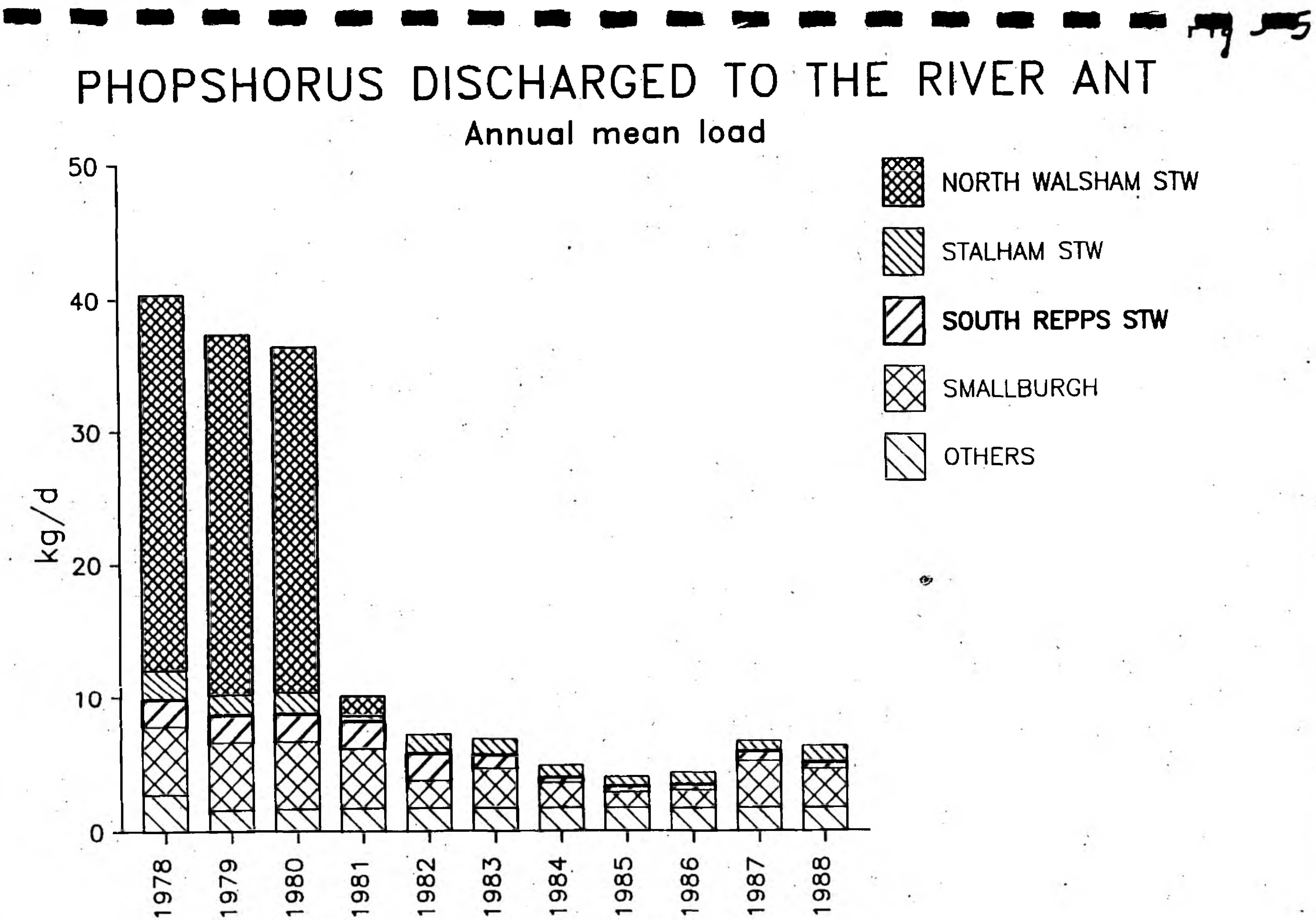
Quarterly phosphorus loads for the River Bure are given in table 4.1 and combined into winter and spring/summer periods in fig 4.1. These data show that despite phosphorus removal there has been an increase in total phosphorus load at Ingworth and only a slight decrease at Horstead Mill and Wroxham. However this increase in total phosphorus is due to the particulate phosphorus which has increased at all sites.

Table 3.2

RIVER ANT, SEWAGE TREATMENT WORKS

Quaterly Phosphate-P Loads

QUATER	Kg/d Phosphate-P Stalham	Horning	Worstead	Sth. Repps
Jan -March 1986	1	.4	-	.4
April-June 1986	1.2	.3	-	.2
July -Sept 1986	.7	.6	-	.1
Oct - Dec 1986	.5	.4	-	.2
Jan -March 1987	.4	.3	-	.6
April-June 1987	1.3	.6	-	.4
July -Sept 1987	.8	1.7	-	.2
Oct - Dec 1987	.4	1.0	-	.5
Jan -March 1988	1.4	.7	.0	.3
April-June 1988	1.2	.8	.1	.3
July -Sept 1988	1.4	2.3	.2	.9
Oct - Dec 1988	.8	1.6	.0	.5



PHOPSHORUS DISCHARGED TO THE RIVER ANT
Annual mean load
kg/d
0
10
20
30
40
50
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
NORTH WALSHAM STW
STALHAM STW
SOUTH REPPS STW
SMALLBURGH
OTHERS

RIVER BURE, LOADINGS OF PHOSPHORUS

	Kg/d phosphate-P		
QUATERLY	Ingworth	Horstead	Wroxham
April-June 1986	3.61	14.30	18.89
July -Sept 1986	3.91	16.36	22.65
Oct - Dec 1986	3.96	10.88	16.65
Jan -March 1987	4.30	12.73	10.05
April-June 1987	1.85	6.42	6.35
July -Sept 1987	6.30	13.45	16.30
Oct - Dec 1987	7.47	13.35	18.26
Jan -March 1988	5.69	12.73	10.05
April-June 1988	4.13	6.42	6.35
July -Sept 1988	3.90	13.45	16.30
Oct - Dec 1988	3.71	13.35	18.26
ANNUALLY			
1986 mean	3.85	14.05	19.42
1987 mean	4.95	11.34	12.79
1988 mean	4.95	11.34	12.79

	Kg/d Solids		
QUATERLY	Ingworth	Horstead	Wroxham
April-June 1986	.93	.77	2.46
July -Sept 1986	.53	.45	2.08
Oct - Dec 1986	.84	.67	.95
Jan -March 1987	2.90	3.37	7.69
April-June 1987	2.91	1.52	3.04
July -Sept 1987	1.97	2.47	5.43
Oct - Dec 1987	4.66	3.66	6.55
Jan -March 1988	10.04	14.51	15.07
April-June 1988	5.17	2.86	4.32
July -Sept 1988	1.06	1.21	5.08
Oct - Dec 1988	1.98	.73	1.57
ANNUALLY			
1986 mean	8.06	.83	1.68
1987 mean	22.92	2.70	5.69
1988 mean	4.47	4.93	6.46

Table 4·1

AND SOLIDS, FLOW.

Kg/d total-P

Ingworth	Horstead	Wroxham
9.0	22.6	39.2
9.8	21.6	39.0
13.9	17.5	26.6
16.2	37.8	42.4
13.2	19.9	23.6
18.5	25.3	49.0
27.7	30.8	52.9
16.2	37.8	42.4
13.2	19.9	23.6
18.5	25.3	49.0
27.7	30.8	52.9
11.3	22.3	33.5
19.2	27.6	42.2
19.2	27.6	42.2

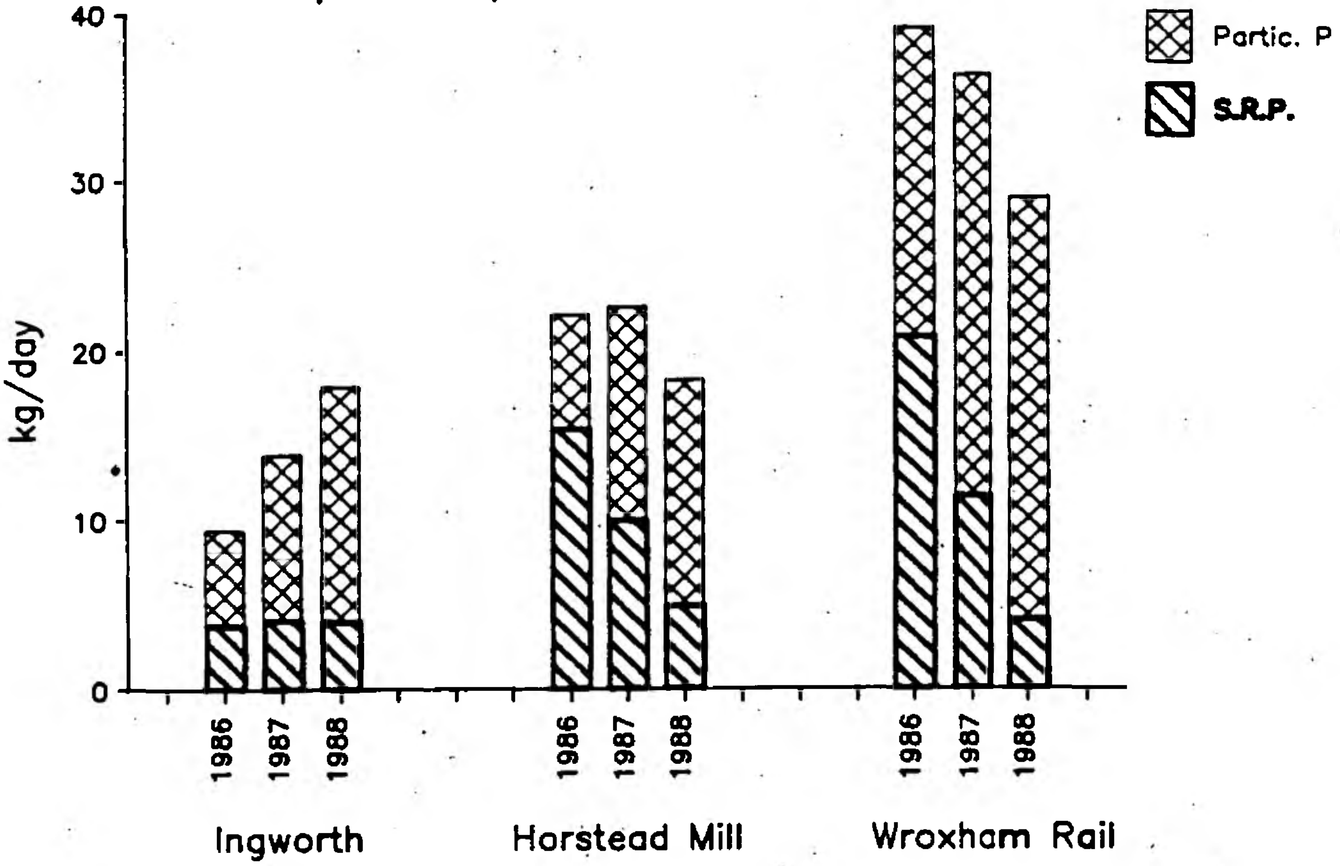
Flow cumecs

Ingworth	Horstead	Wroxham
1.145	2.141	2.551
.864	1.492	1.778
1.271	2.052	2.445
1.470	2.802	3.339
1.154	2.363	2.816
1.403	2.469	2.943
1.807	3.436	4.095
2.097	4.060	4.839
1.254	2.579	3.074
1.023	1.949	2.323
1.137	1.980	2.360
1.214	2.094	2.496
1.459	2.768	3.298
1.363	2.613	3.114

Fig 4·1

River Bure Phosphorus Loading

April to September 1986,1987 and 1988



Jan–March and Oct–Dec 1986,1987 and 1988

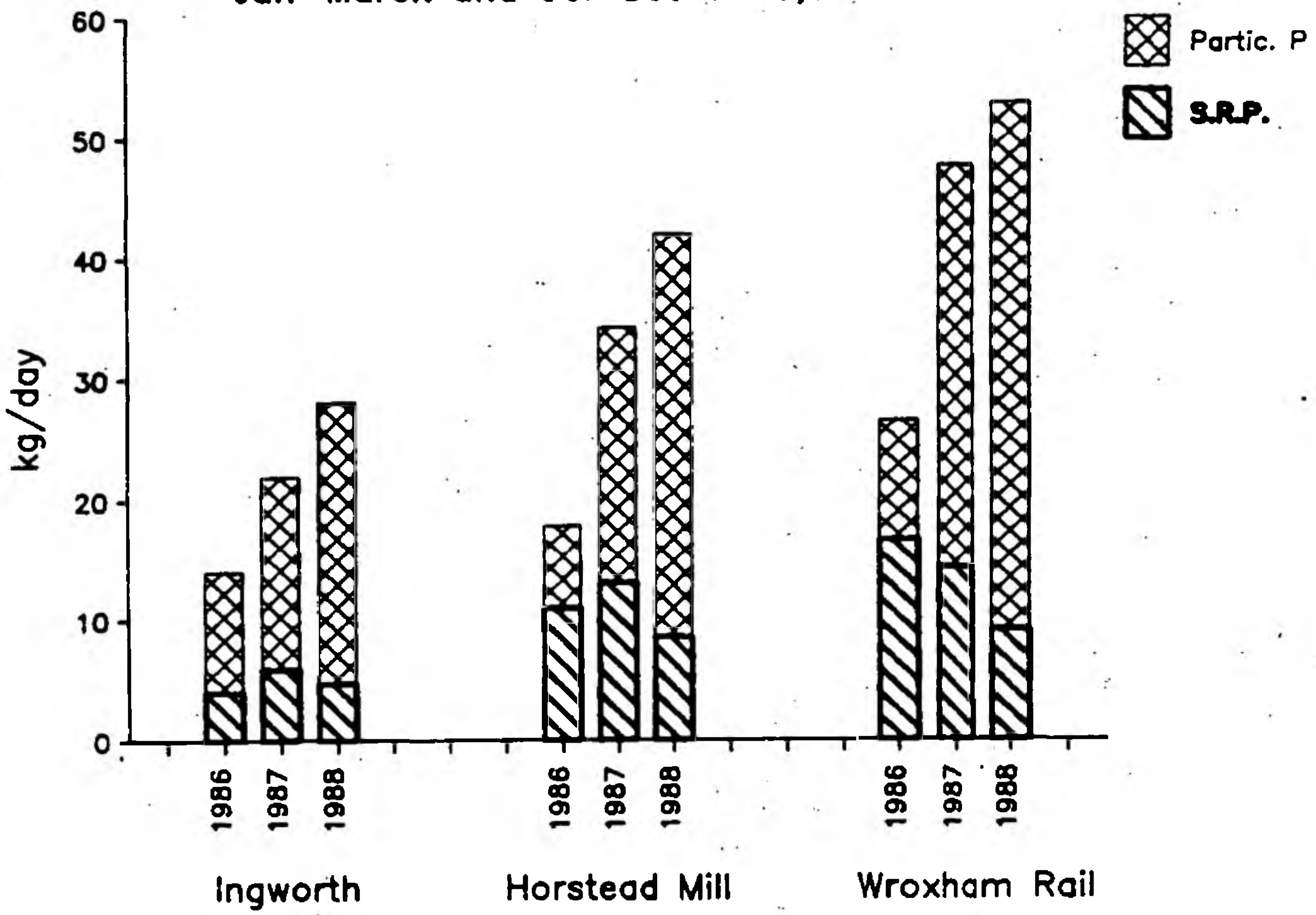
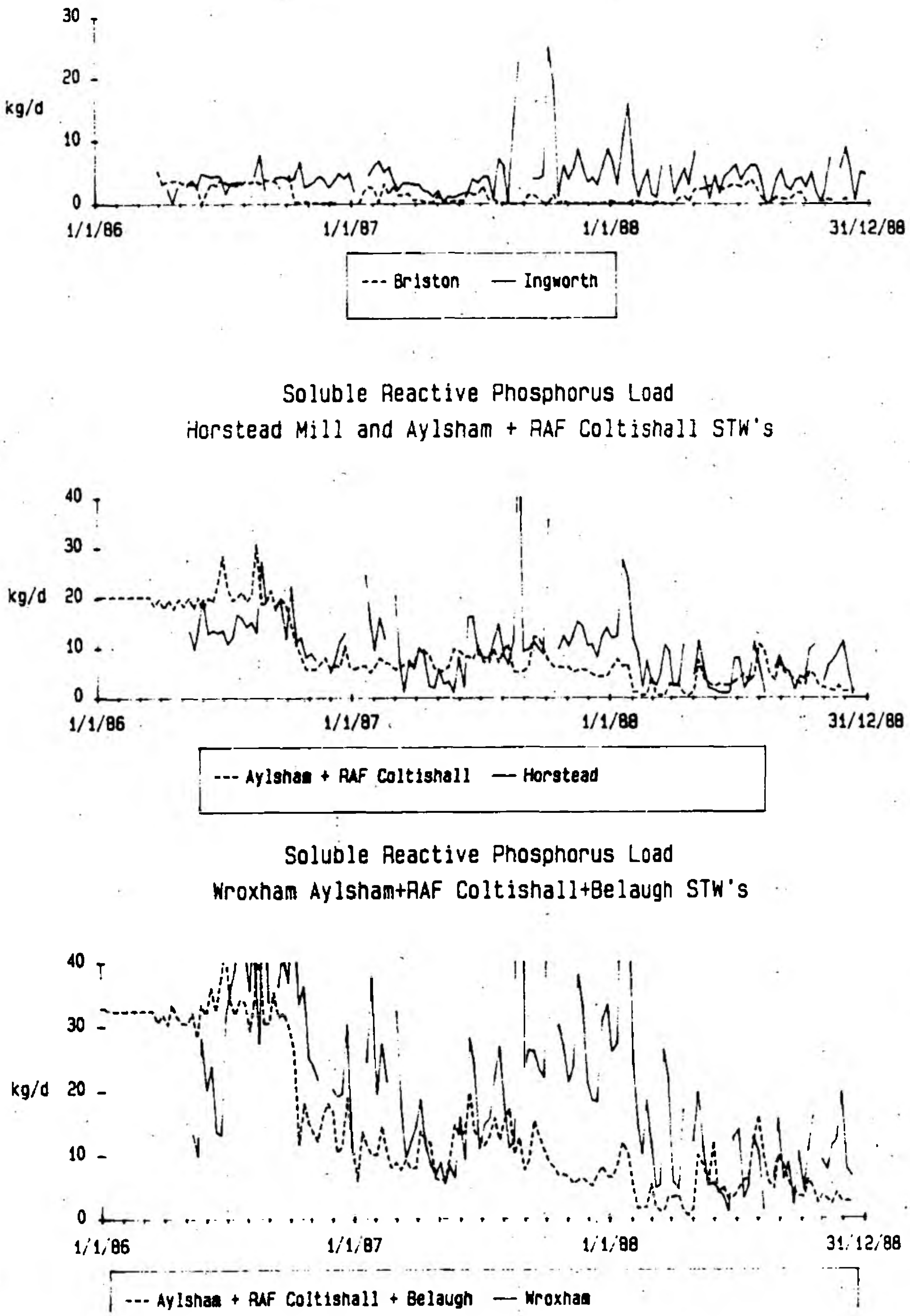


Fig 4·2

Soluble Reactive Phophorus Load
Briston STW and Ingworth Gauging Station

Soluble Reactive Phosphorus Load
Horstead Mill and Aylsham + RAF Coltishall STW's

Soluble Reactive Phosphorus Load
Wroxham Aylsham+RAF Coltishall+Belaugh STW's



In contrast soluble reactive phosphorus has decreased substantially at Horstead Mill and at Wroxham, although seasonal summaries show no decline at Ingworth. Comparing the average soluble reactive phosphorus concentrations and loadings at Horstead and Wroxham (Table 4.2) before and after removal of phosphorus from Aylsham and RAF Coltishall demonstrates that soluble phosphorus loads have been substantially reduced.

Table 4.2
Average Soluble Reactive Phosphorus load & concentration

	Horstead Mill conc mg/l	load kg/d
Pre-stripping	.114	15.8
Post Aylsham, Pre RAF	.048	11.6
Post RAF	.027	5.4

	Wroxham Rail Bridge conc mg/l	load kg/d
Pre-stripping	.138	22.0
Post Aylsham, Pre RAF	.046	14.0
Post RAF	.019	4.7

These results suggest little effect of phosphorus removal at Briston STW. However soluble reactive phosphorus loads from sewage works and those measured in the river show many similarities, (fig 4.2) and these data do suggest that changes at Briston can be seen at Ingworth.

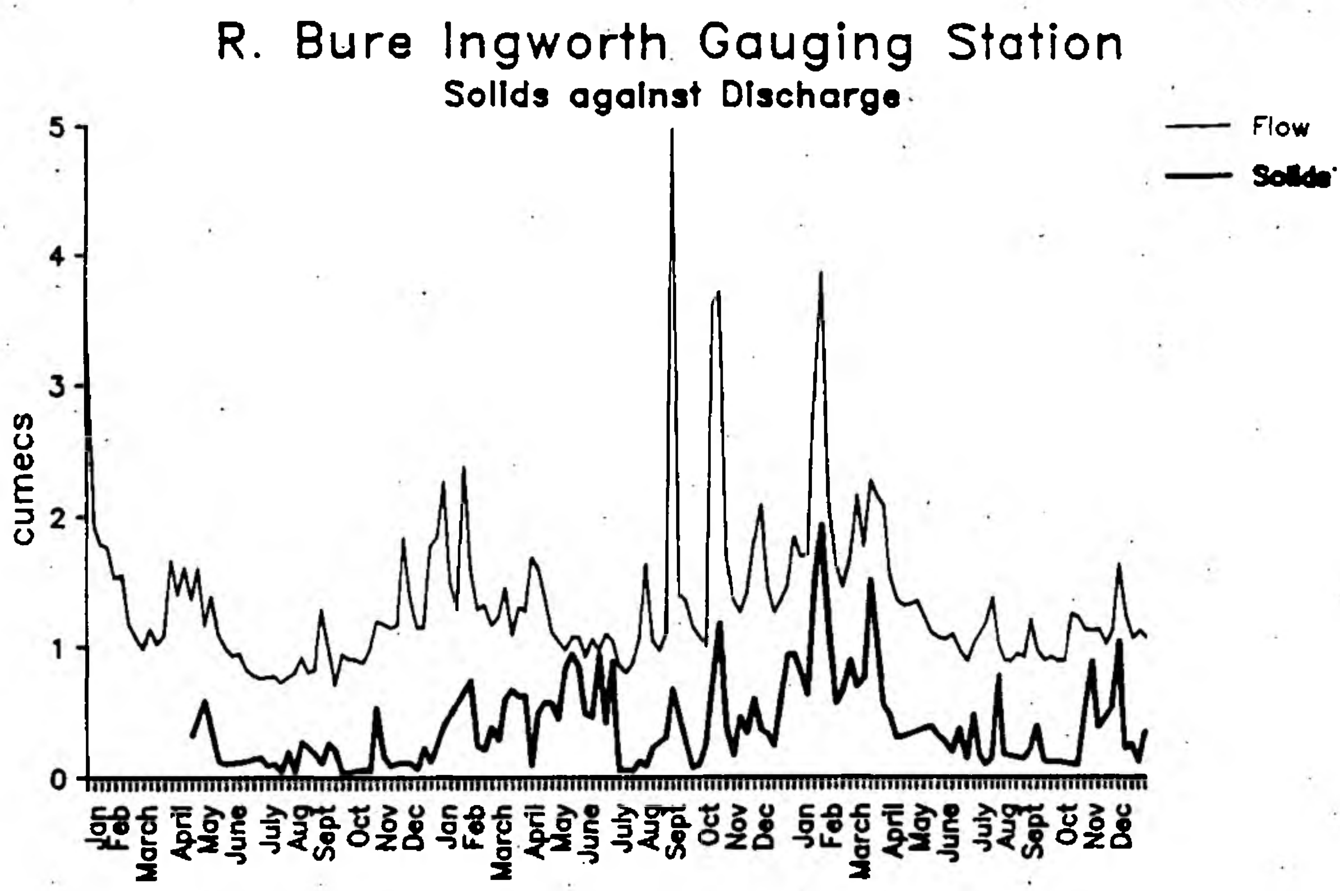
However there are several anomalies, particularly between Briston STW and Ingworth. The initial drop in soluble reactive phosphorus load from Briston in October 1986 was not reflected in a change at Ingworth and subsequently in the autumn and winter of 1987/88 soluble reactive phosphorus the load in the river was substantially higher than the Briston load. These high river loads during the autumn and winter of 1987 can be seen at Horstead and Wroxham. This was a period of higher than normal river discharge (see below) and there is some evidence for an additional source of soluble phosphorus during these high discharge periods.

However the interpretation of soluble phosphorus data is difficult as a result of uptake due to biological activity and it is possible that these winter maxima are a reflection of a reduction of these processes.

The increased particulate phosphorus in the river is also associated with high river discharge. Suspended solids is clearly related to river discharge at Ingworth (figs 4.3,4.4) and similar relationships can be seen for both particulate phosphorus and solids at the other two sites on the River Bure. The source of this particulate matter cannot be determined and catchment contributions and/or resuspension of the sediment may be involved.

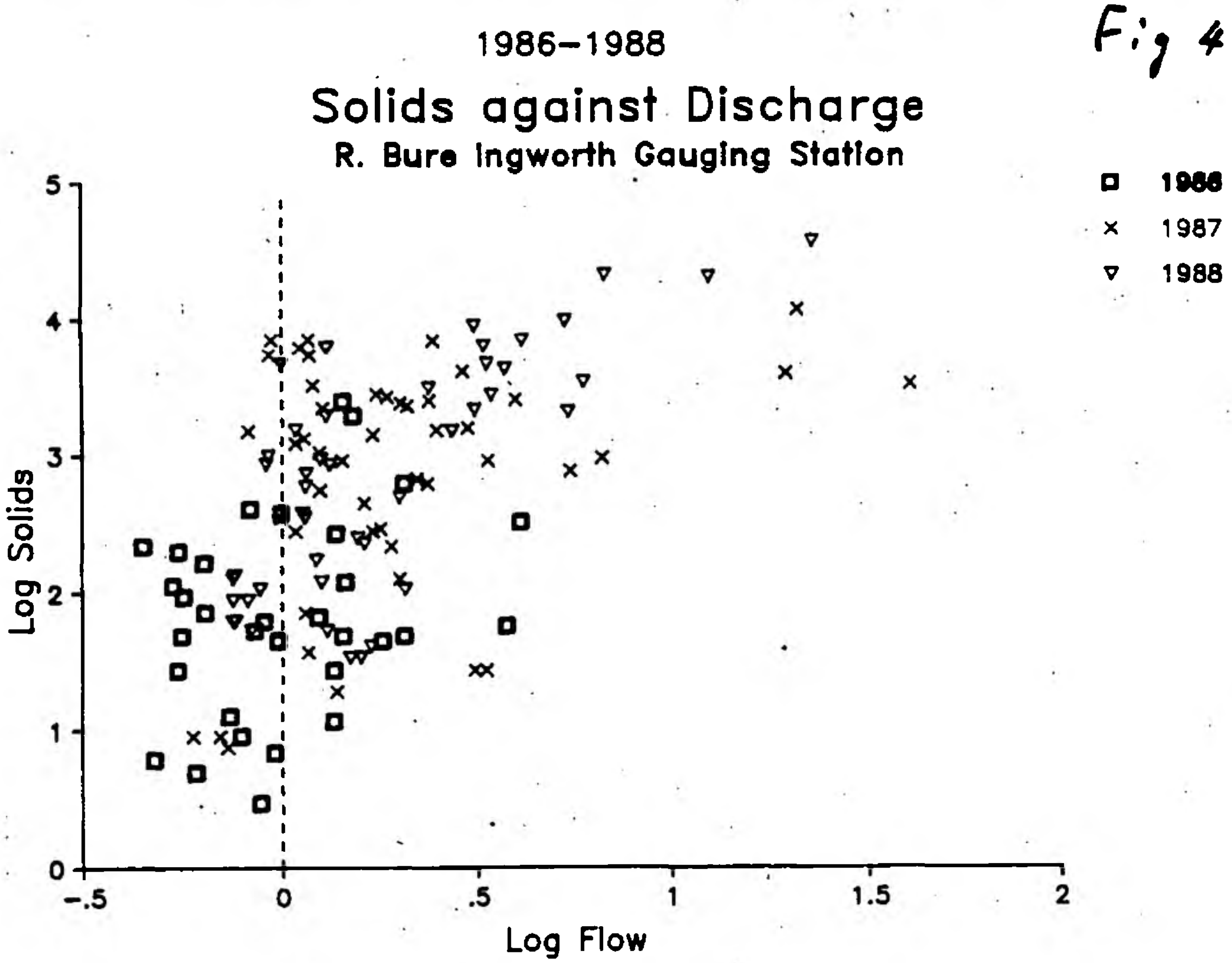
It is clear that further work is required to improve the efficacy of this data. This will take the form of a more extensive catchment survey of the upper River Bure to identify further phosphorus sources and more

Fig 4·3



R. Bure Ingworth Gauging Station
Solids against Discharge
Flow
Solids
cumecs
0
1
2
3
4
5
Jan Feb March April May June July Aug Sept Oct Nov Dec Jan Feb March April May June July Aug Sept Oct Nov Dec Jan Feb March April May June July Aug Sept Oct Nov Dec

Fig 4·4



1986–1988
Solids against Discharge
R. Bure Ingworth Gauging Station
1986
1987
1988
Log Solids
Log Flow
0
1
2
3
4
5
-.5
0
.5
1
1.5
2

detailed work to establish a relationship between river discharge and particulate phosphorus.

4.3 Phosphorus Load in the River Ant

Honing Lock gauging station and Dilham Grange on the Smallburgh tributary are the two key stations in the Ant catchment and data for these two sites are given in appendix figs 12 & 13. Data summaries for these and other stations on the River Ant are given in table 4.3 and fig 4.5.

Phosphorus loads in the River Ant have remained very similar to previous years. Slightly higher particulate phosphorus at Royston Bridge (B1150 North Walsham) probably reflects the high discharge of 1987/88 and dredging activity upstream of this site for two months in the autumn of 1988. A slight net loss of total phosphorus was apparent from the broad but as considerable phosphorus release has been recorded experimentally from Barton Broad, it is clear that a considerable amount of deposition of particulate phosphorus takes place.

Inputs from the Smallburgh tributary remain very similar to previous years, although again there is evidence of higher particulate inputs over the last two years associated with the higher discharges.

5. SEASONAL NUTRIENT AND PLANKTON CYCLES

5.1 River Bure.

5.1.1 Phosphorus

Data from spot samples taken at approximately two weekly intervals are shown in appendix fig 14 and summarised in tables 5.1 & 5.2. The phosphorus reduction has clearly influenced the phosphorus concentrations in the tidal River Bure and some of its associated broads. A reduction in total phosphorus can be seen in the river as far downstream as Horning Ferry and total phosphorus concentration are generally about 100ugP l^{-1}. Below this site the river is influenced by water from the River Ant and South Walsham broad which contain higher phosphorus concentrations.

The interpretation of these data is complex. Particulate phosphorus is kept in suspension in the river by boat traffic. This tends to settle out in the broads, with the result that in the upper half of the tidal River Bure the river tends to have higher total phosphorus concentrations than the broads themselves (eg Wroxham and Salhouse Broads are lower than the R Bure downstream of Wroxham Broad). Conversely soluble reactive phosphorus is taken up by phytoplankton and in the less flushed broads such as the Hoveton broads this algal particulate phosphorus tends to remain in suspension.

During July and August in both 1987 and 1988 increased soluble reactive phosphorus can be seen in the upper river sites where algal uptake is

TOTAL PHOSPHORUS LOAD RIVER ANT Table 4.3

		1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
B1150 Bridge	Annual	3.00	3.77	2.20		3.91	3.41	2.57	1.66	1.70	2.52	2.86
	Spring		6.10	2.50	2.90	2.70	4.34	3.62	.82	2.40	2.21	3.97
	Summer	1.00	2.00	2.60		4.40	2.52	.68	1.38	1.20	3.19	2.08
	Winter	5.00	3.20	1.50		4.64	3.96	.79	1.40	1.50	2.03	
Honing Lock	Annual	14.00	13.60	11.20	4.67	3.53	2.88	3.88	2.00	2.30	2.86	3.32
	Spring	14.00	14.70	15.40	5.90	4.60	4.20	5.42	2.27	2.90	2.30	3.62
	Summer	11.30	11.10	13.80	2.40	2.00	1.70	2.20	1.61	1.50	2.55	2.69
	Winter	16.70	15.00	4.40	5.70	4.00	3.63	3.21	2.94	2.10	4.45	
Tonnage Bridge	Annual			11.63	5.20	4.25	5.55	2.93	2.31			
	Spring			14.10	7.80	4.40	9.62	3.10	3.19			
	Summer			14.40	2.80	3.40	4.16	2.06	1.90			
	Winter		14.50	6.40	5.00	4.95	3.99	2.43				
Wayford Bridge	Annual	20.27	20.13	15.37	8.10	6.33	5.35	5.00	3.64	6.10	6.41	4.85
	Spring	22.70	21.90	16.70	11.10	5.50	5.73	7.12	2.60	7.60	4.10	4.72
	Summer	15.90	17.50	19.80	6.70	6.80	5.53	3.33	4.10	4.70	9.07	4.60
	Winter	22.20	21.00	9.60	6.50	6.68	5.01	3.33	4.50	5.90	6.15	
Barton Inflow	Annual	20.30	18.53	14.33	8.77	7.63	7.80	6.80	5.12	8.00	10.89	8.29
	Spring	18.20	22.90	17.40	14.00	5.40	8.30	7.50	3.33	11.00	8.30	7.75
	Summer	10.90	11.50	16.00	5.80	8.20	7.90	7.20	7.25	6.20	15.13	9.22
	Winter	31.80	21.20	9.60	6.50	9.30	5.50	4.17	5.20	6.30	6.78	
Neatishead Stream	Annual	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50
	Spring	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50
	Summer	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50
	Winter	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50
Barton Outflow	Annual	17.55	15.70	12.17	9.10	11.77	9.16	8.74	6.40	10.00	10.11	9.25
	Spring		16.80	11.90	12.50	7.40	7.10	9.70	5.30	9.80	7.40	9.45
	Summer	14.00	12.80	16.10	7.50	15.90	7.90	9.20	7.40	9.70	13.40	10.22
	Winter	21.10	17.50	8.50	7.30	12.00	6.60	4.72	6.90	9.44	6.82	
Net gain to or loss from the Broad	Annual	.00					-.87	-1.44	-.78	-1.50	1.28	-.46
	Spring		6.60	6.00	2.00	-1.50	1.70	-1.70	-1.47	1.70	1.40	-1.20
	Summer	-2.60	-.80	.40	-1.20	-7.20	.50	-1.50	.35	-3.00	2.23	-.50
	Winter	10.70	3.70	1.60	-.30	-2.20	-.60	-.05	-1.20	-2.64	.46	

Fig 4·5

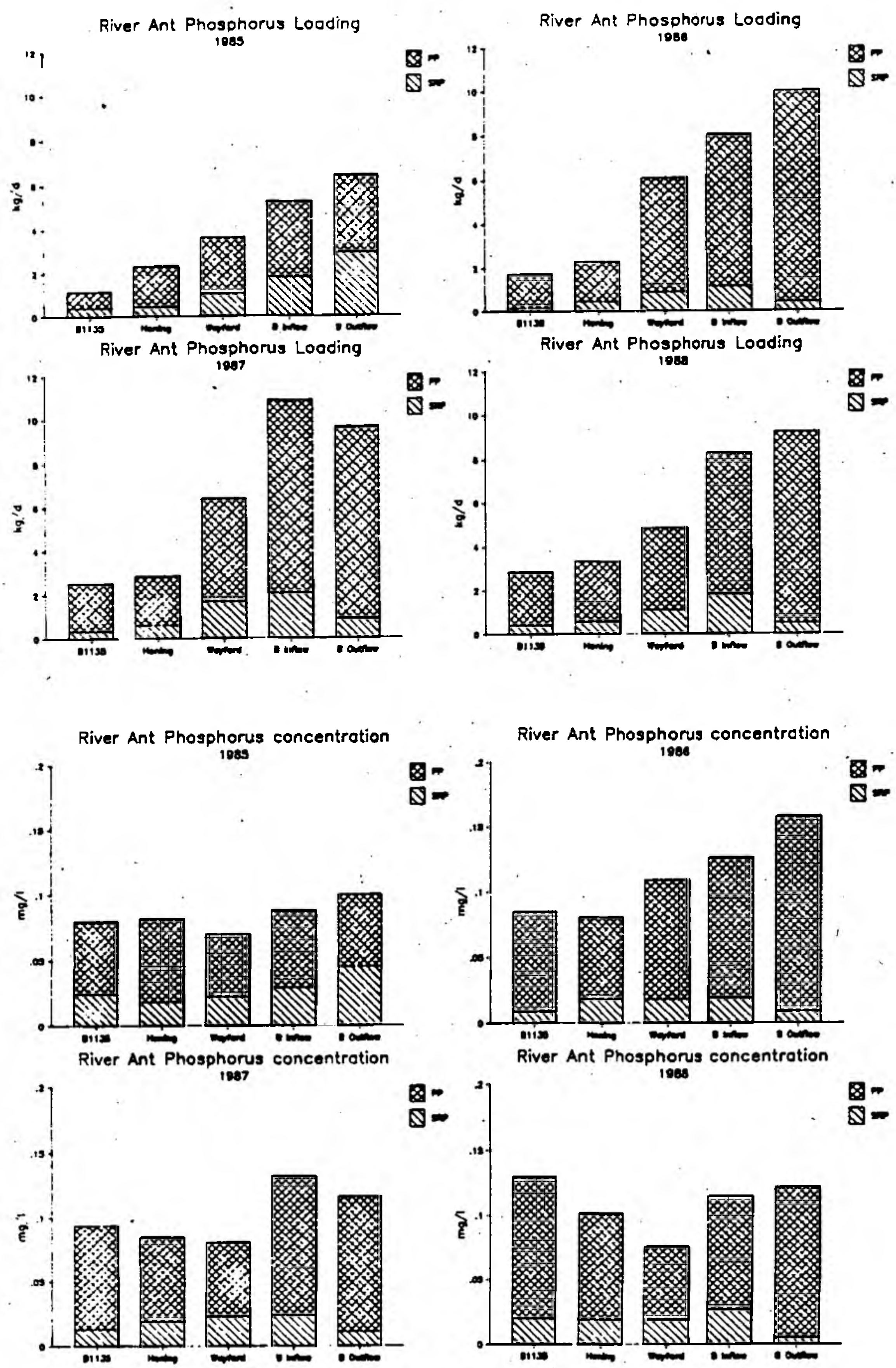

River Ant Phosphorus Loading
1985
kg/d
River Ant Phosphorus Loading
1986
kg/d
River Ant Phosphorus Loading
1987
kg/d
River Ant Phosphorus Loading
1988
kg/d
River Ant Phosphorus concentration
1985
mg/l
River Ant Phosphorus concentration
1986
mg/l
River Ant Phosphorus concentration
1987
mg/l
River Ant Phosphorus concentration
1988
mg/l

TABLE 5.1

River Sites Monitoring Data

Average Concentrations April-Sept 1986-1988.

		Total-P mg/l	S.R.P. mg/l	T.O.N. mg/l	Solids mg/l	Chlorophyll a ug/l
Belaugh Staithe	1986	.166	.089	5.53	12.2	23
	1987	.101	.035	5.51	6.6	7.3
	1988	.117	.033	6.14	13.2	12
Wroxham Rail Bridg	1986	.246	.140	5.27	12.2	31
	1987	.132	.052	5.85	8.9	6
	1988	.113	.033	6.13	9.7	27
D/S Wroxham Broad	1986	.187	.043	3.79	28	111
	1987	.114	.034	5.32	9.4	33
	1988	.121	.018	5.58	11.2	61
Horning Ferry	1986	.166	.029	1.69	30	129
	1987	.126	.020	2.96	20	66
	1988	.111	.014	3.83	21.4	73
St Benets Abbey	1986	.174	.020	.95	34	174
	1987	.148	.011	1.88	28	106
	1988	.141	.008	2.46	23.4	116
Ludham Bridge	1986	.220	.013	.83	56	182
	1987	.190	.006	.78	42	150
	1988	.192	.011	1.68	38.3	148
Thurne Mouth	1986	.205	.016	.73	54	163
	1987	.190	.015	1.33	43	129
	1988	.177	.010	2.14	33	115
Acle Bridge	1986	.179	.016	.87	44	149
	1987	.204	.016	1.43	43	127
	1988	.164	.014	2.25	29.1	129

TABLE 5.2

Broads Sites Monitoring Data

Average Concentrations April-Sept 1986-1988.

		Total-P mg/l	S.R.P. mg/l	T.O.N. mg/l	Solids mg/l	Chlorophyll a ug/l
Wroxham Broad	1986	.145	.023	3.27	20.0	106
	1987	.095	.038	4.90	7.0	24
	1988	.085	.014	5.44	11.6	65
Salhouse Broad	1986	.149	.012	2.40	26.0	138
	1987	.101	.019	3.97	11.0	59
	1988	.100	.012	4.29	15.7	87
Hoveton Great Broa	1986	.163	.011	.57	26.0	135
	1987	.139	.007	1.38	20.0	121
	1988	.127	.005	1.98	20.2	126
Decoy Broad	1986	.178	.046	.42	20.0	118
	1987	.153	.048	2.02	9.8	71
	1988	.075	.011	2.28	9.0	51
Hoveton Little Bro	1986	.154	.029	.70	32.0	118
	1987	.112	.009	1.41	18.0	101
	1988	.101	.007	2.46	17.2	105
Ranworth Broad	1986	.166	.011	.06	33.0	178
	1987	.140	.011	.73	18.0	112
	1988	.152	.003	1.15	25.3	201
South Walsham Broa	1986	.320	.060	.08	41.0	218
	1987	.275	.108	.19	22.0	107
	1988	.459	.255	.77	29.0	214
Barton Broad	1986	.179	.012	.69	36.6	163
	1987	.142	.013	1.07	19.9	111
	1988	.150	.004	1.26	31.2	184

least. The 1987 results may be associated with increased river discharge and catchment inputs as discussed in section 4.2 of this report. However the 1988 increases coincide with decreased performance of phosphorus removal at both Aylsham and Belaugh STW's (figs 3.2 & 3.4). Alternatively this phosphorus may be due to release from the sediment, although this seems the least likely explanation.

It is difficult to assess the extent of phosphorus input from the sediments in the River Bure. Between June and September the concentration of total phosphorus in the river below Wroxham Broad is higher than river sites upstream, suggesting an internal source of phosphorus. These periods are associated with soluble reactive phosphorus peaks and could be interpreted as phosphorus released from the sediment. Alternatively the soluble reactive phosphorus could result from decreased phosphorus removal, described above and the higher total phosphorus may be a result of sediment resuspended by boat traffic.

The situation is slightly clearer in broads such as Hoveton Great and Decoy, which are not subject to boat traffic, and peaks of total phosphorus during the summer are almost certainly due to phosphorus released from the sediment. This is most marked at South Walsham broad where exceptionally high phosphorus concentrations are seen, although at this site direct inputs from South Walsham STW are also involved.

In general phosphorus removal has resulted in a reduction in phosphorus concentration in the river upstream of Horning Ferry and in the most riverine broads such as Wroxham and Salhouse. However at all these sites soluble reactive phosphorus is available throughout most of the summer period, either as a result of sediment release or due to the poor performance of phosphorus removal at this time. Broads that are less influenced by the river tend to have lower total phosphorus during the winter and early summer but rapidly accumulate phosphorus from the sediment from June until September. The balance between these two opposing factors influences the average concentrations shown in table 5.2 and Decoy, Wroxham, Salhouse and Hoveton Little broads all show substantial reductions in average phosphorus concentrations although Decoy and Hoveton Little Broads both have relatively high summer maxima.

5.1.2 Chlorophyll a

Chlorophyll a concentrations are shown in appendix fig 15 and summarised in tables 5.1 and 5.2. The pattern of chlorophyll a has remained similar to that described in the 2nd annual report. There are two peaks of chlorophyll a, spring and summer with minimum values occurring during May or June and a trend of increasing concentrations in a downstream direction.

Chlorophyll a is clearly related to the phosphorus concentration and in general a reduction in chlorophyll a has occurred where there has been a reduction in phosphorus concentration. Thus the river sites from Wroxham downstream to Horning Ferry and the most riverine broads have a reduced chlorophyll a concentration compared to 1986.

A substantial change in the chlorophyll a concentration was noted in Wroxham Broad in 1987. Although chlorophyll a remained substantially lower than 1986, Wroxham Broad developed a small phytoplankton population during the summer of 1988, with a more substantial peak during September. In general all of the sites had similar spring chlorophyll a concentrations to 1987 but greater summer values. The chlorophyll a in Decoy Broad has decreased consistently and in 1988 this site had the lowest April-September average values, although as in previous years a substantial peak occurred in October.

5.1.3 Total Oxidised Nitrogen

Data are shown in appendix figs 16 and tables 5.1 & 5.2. The pattern for TON remain unchanged. Values are high during the winter and autumn and are rapidly depleted by biological activity during the spring and summer. The river upstream of Horning Ferry and the riverine broads show the least decline with concentrations generally above 1 mg l^{-1} while the lower river and the least well flushed broads reach undetectable levels for periods during the summer. This is most pronounced in South Walsham Broad where TON is undetectable for most of the summer period. In general 1988 values were greater than previous years. This reflects the influence of river flow with higher winter concentrations maintained for longer in the wet spring of 1988.

5.2 River Ant

Phosphorus, chlorophyll a, nitrogen and silicon concentrations are shown in appendix figs 18-21. Conditions remain similar to previous years with the same trends described for the River Bure. There is a rise in total phosphorus concentration from Wayford Bridge downstream. Soluble reactive phosphorus tends to increase in concentration from May until October. This partly reflects reduced algal activity in the river but as the total phosphorus also increases this is probably due to release of phosphorus from the sediment.

Phosphorus release from the sediment certainly occurs in Barton Broad, and here algal uptake is sufficient to deplete phosphorus concentrations to undetectable levels for most of the summer period.

5.3 Plankton

5.3.1 Phytoplankton

Phytoplankton results for the Belaugh, Wroxham, Hoveton Gt and Ranworth broads are not tabulated but the occurrence of major algal groups are shown in appendix figs 22-25.

The general algal succession described in both the 1st and 2nd annual reports has remained and can be seen through the season and along the length of the tidal River Bure from well to poorly flushed broads.

Centric Diatoms - Greens / Pennate Diatoms - Blue Greens - Centric Diatoms

Several changes in species composition have occurred during 1988. Pennate diatoms were more widespread, particularly Diatoma elongatum and Asterionella formosa and Pandorina morum appeared to replace Chlamydomonas sp during the summer. Scenedesmus, Pediastrum and Coelastrum species were not as common as they were in the drier year of 1986. During 1987 many of the sites failed to reach the end of the above succession but in 1988 blue green algae such as Oscillatoria were much more important.

Ranworth and Hoveton Broads showed the least variation between years with Wroxham Broad returning to conditions more like 1986 in the summer period. In 1986 green algae were dominant during the summer and in 1988 small populations were able to develop.

5.3.2 Zooplankton

The major invertebrate groups comprising the zooplankton are shown in appendix figs 26-30 There have been few changes of note in the zooplankton community. Significant populations of Cladocerans are usually restricted to the late spring early summer period and there has been only limited variation of this over the three years. Only Wroxham Broad shows any changes of interest with a reduction in the numbers of rotifers, cyclopoid copepods and Bosmina populations and an increase of Polyphemus pediculus which are indicative of a less eutrophic environment.

5.4 Belaugh Broad

Belaugh Broad was mud pumped in the summer of 1987 and monitoring commenced in July of that year. Phosphorus concentration in the broad has remained lower than the River Bure at Belaugh Staithe, usually below 100 ugP l^{-1} except for two short periods during May and July. Soluble reactive phosphorus remained undetectable for most of the spring of 1988 although small amounts were found between June and August 1988.

There has been a general increase in the phytoplankton crop during 1988, with two large peaks of chlorophyll a in July and September/October. Initially the algae were small centric diatoms and a number of flagellates such as Trachlemonas, Euglenoids and Cryptophyta, all characteristic of river phytoplankton. Although these were still present in 1988 other species more characteristic of broads further downstream began to appear more regularly. Pandorina morum formed a sharp peak in chlorophyll a during July 1988. This was coincident with heavy rain and was accompanied by an increase in total phosphorus greater than that found in the River Bure at that time. Phosphorus release from the sediment seems unlikely and inputs from the surrounding fen/carr seems the most likely explanation.

Belaugh Broad contained a diverse zooplankton with short lived populations of *Ceriodaphnia* spp and *Diaphanosoma brachyurum* and rather small populations of *Daphnia* spp. None of these populations was substantial enough to influence the phytoplankton and the general impression is of a site that has not developed a stable open-water plankton community. This is probably a reflection of its recent origin, the original site having almost no open water, but it may also reflect its relationship to the river with a mixture of species being introduced via the inflow channel. The broad is however capable of generating large phytoplankton crops and if these become more sustained consideration should be given to increasing the flushing of the site.

6. PEN EXPERIMENTS

An introduction to the use of small mesh pens was given in the second annual report. Experience in Alderfen Broad in 1973 has shown that submerged aquatic plants grow well inside fine mesh pens. The pens allow large populations of cladocerans to develop, free from fish predation, and the clear water is assumed to encourage plant growth. A brief report of these experiments is included in this report although a more detailed report will be prepared during 1989.

6.1 Belaugh Broad

Following the success in establishing aquatic plants in small mesh pens in Barton Broad in 1987 six similar pens were placed in Belaugh Broad during 1988. Three of these were constructed from wood and were placed in the broad on 28 April 1988 and planted with a variety of aquatic plants on 3 May 1988. The remaining three were placed in the broad and planted on 10 June 1988. Samples of water and zooplankton were collected from these pens at fortnightly intervals by Broads Authority staff and analysed by Anglian Water.

The zooplankton species found in the open water of Belaugh Broad and the pens are given in table 6.1

Table 6.1 Zooplankton of Belaugh Broad and Pens

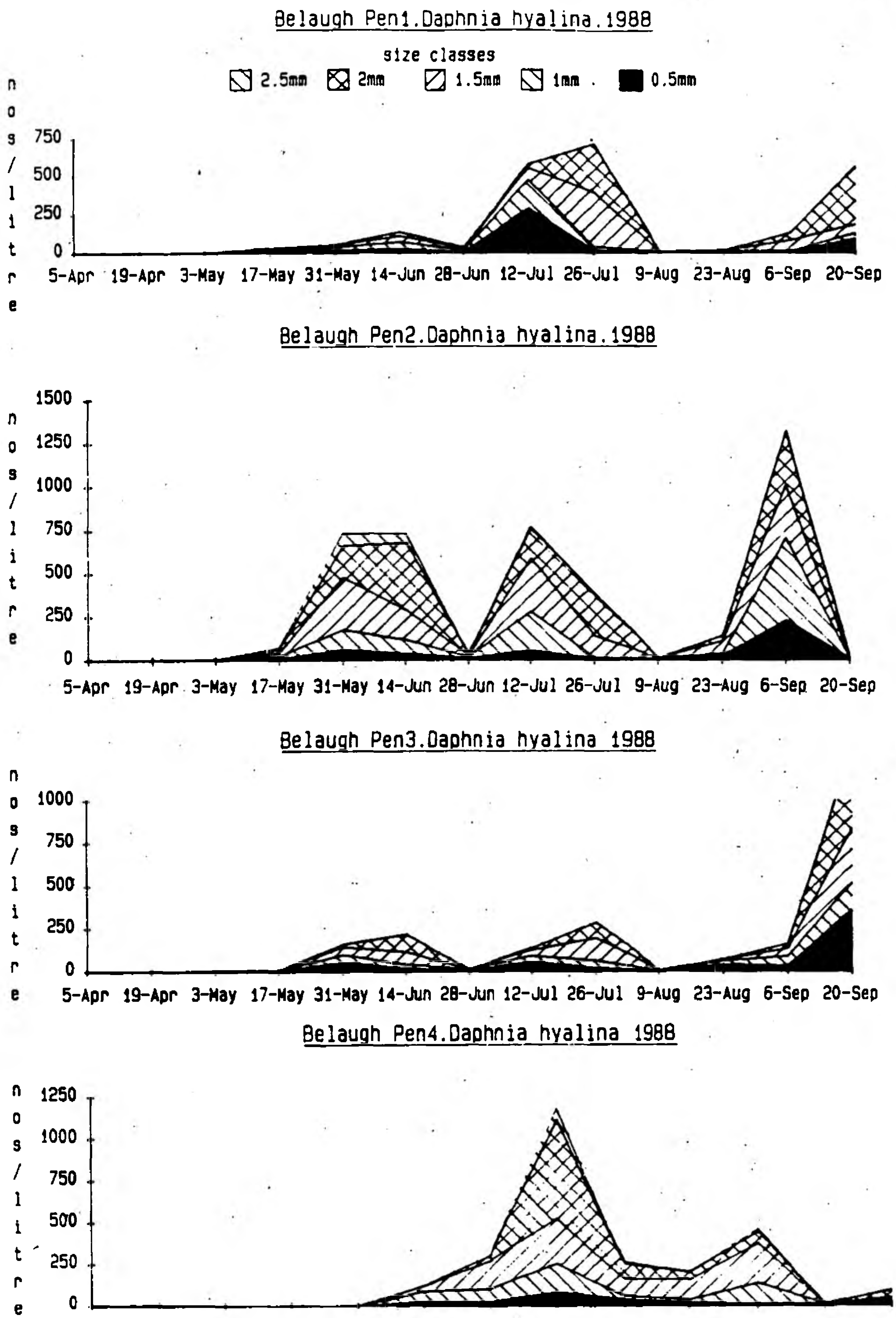
Open Water Belaugh Broad	Pens
Alona affinis	Alona affinis
Alona quadrangularis	Alona quadrangularis
Alona rectangula	Alona rectangula
	Alonella excisa
Bosmina longirostris	Bosmina longirostris
Ceriodaphnia sp.	Ceriodaphnia sp.
Chydorus sphaericus	Chydorus sphaericus
Daphnia hyalina	Daphnia hyalina
Daphnia magna	Daphnia magna
Daphnia pulex	Daphnia pulex
Diaphanosoma brachyurum	Diaphanosoma brachyurum
Eurycercus lamellatus	Eurycercus lamellatus
Pleuroxus aduncus	Pleuroxus aduncus
Pleuroxus trigonellus	Pleuroxus trigonellus
	Pleuroxus uncinatus
Polyphemus pediculus	Polyphemus pediculus
	Scapholeberis mucronata
Simocephalus vetulus	Simocephalus vetulus

Although the abundance of zooplankton was much greater in the pens (eg Daphnia hyalina figs 6.1 & 6.2) species composition in and out of the pens was similar with several species associated with aquatic plants being found. Grazing potential is roughly proportional to body size and hence the larger cladocerans are most important in determining the amount of phytoplankton that is removed and the clarity of the water. The grazing potential within each of the pens has been assessed by taking the number of individuals of selected groups of species multiplied by the cube of body length. These are plotted together with the difference in chlorophyll a between the pen and the open water of Belaugh Broad in Figs 6.3 & 6.4. Actual chlorophyll a is shown in comparison with the open water in fig 6.5.

Plant growth in all the pens was prolific, with a variety of plant species abundant from July onwards. No plants grew in the open water of the broad. Chlorophyll a concentrations in Belaugh Broad were relatively low with a peak on 12 July and an increase in September. The pens followed the same general pattern as the open water although in most cases the chlorophyll a was lower than the open water. In general the water clarity of the pens was greater than that of the open water of the broad with a secchi disc depth of +1-1.3m in the pens and between 0.7 and 1.0m in the broad.

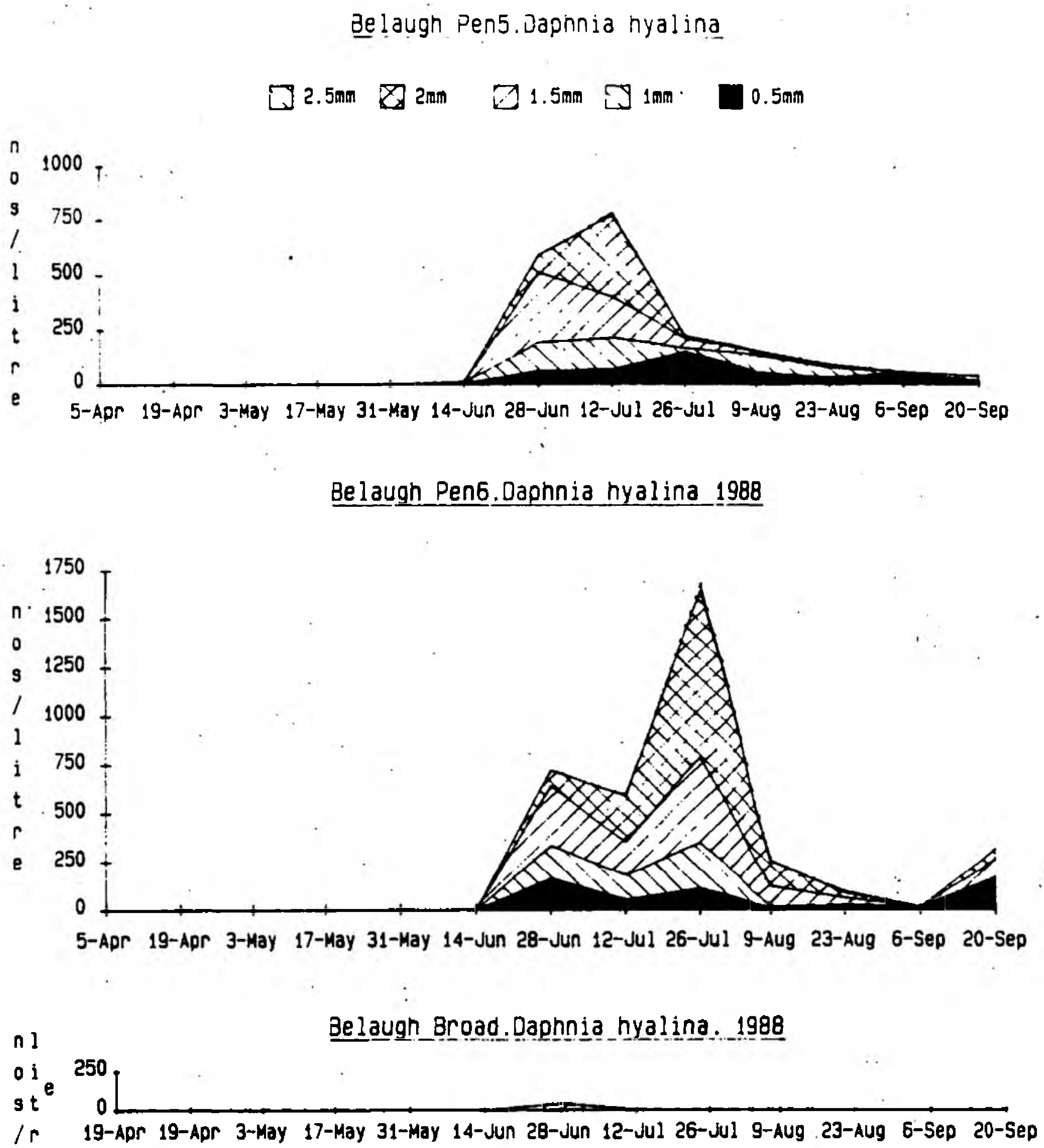
Grazing, as measured by estimated total cladoceran volume, is clearly related to depression of the chlorophyll a. This was most marked on 12 July when a substantial population of Pandorina and Centric diatoms occurred. Pen 3 contained much smaller numbers of zooplankton and consequently there was very little depression of chlorophyll a concentrations. From late July when the plants had become established chlorophyll a concentrations were considerably lower than the open water in all of the pens. In most of the pens this was associated with

Fig 6·1



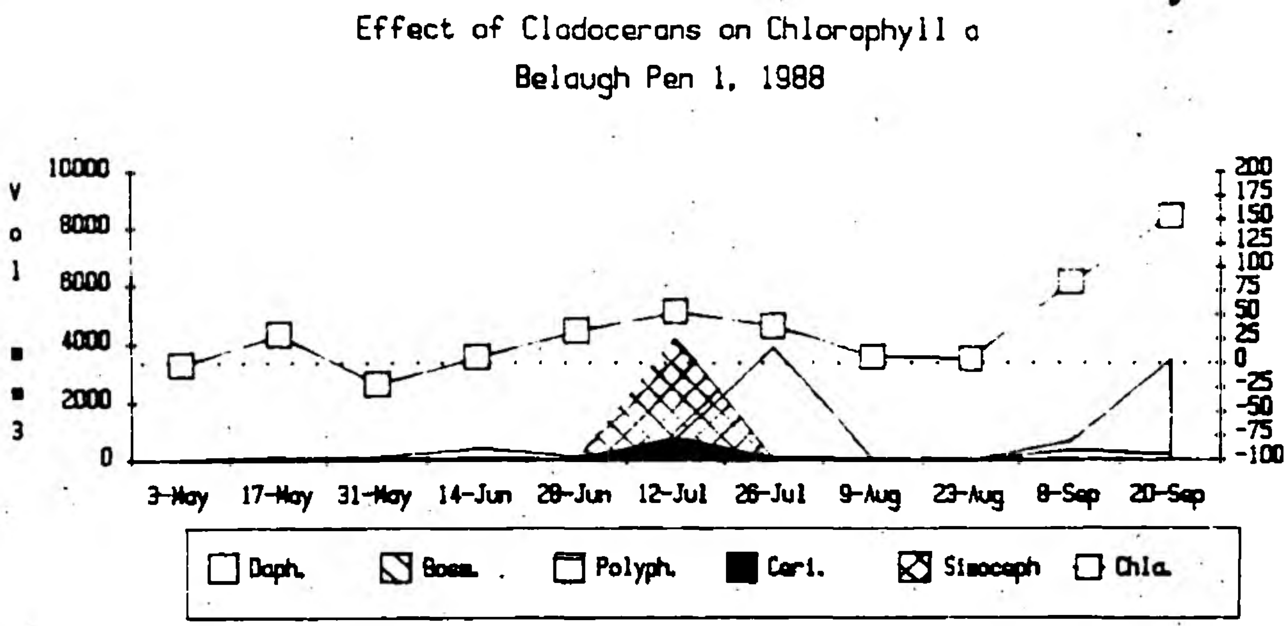
Belaugh Pen1.Daphnia hyalina.1988
size classes
2.5mm
2mm
1.5mm
1mm
0.5mm
nos/litre
750
500
250
0
5-Apr 19-Apr 3-May 17-May 31-May 14-Jun 28-Jun 12-Jul 26-Jul 9-Aug 23-Aug 6-Sep 20-Sep
Belaugh Pen2.Daphnia hyalina.1988
nos/litre
1500
1250
1000
750
500
250
0
5-Apr 19-Apr 3-May 17-May 31-May 14-Jun 28-Jun 12-Jul 26-Jul 9-Aug 23-Aug 6-Sep 20-Sep
Belaugh Pen3.Daphnia hyalina 1988
nos/litre
1000
750
500
250
0
5-Apr 19-Apr 3-May 17-May 31-May 14-Jun 28-Jun 12-Jul 26-Jul 9-Aug 23-Aug 6-Sep 20-Sep
Belaugh Pen4.Daphnia hyalina 1988
nos/litre
1250
1000
750
500
250
0

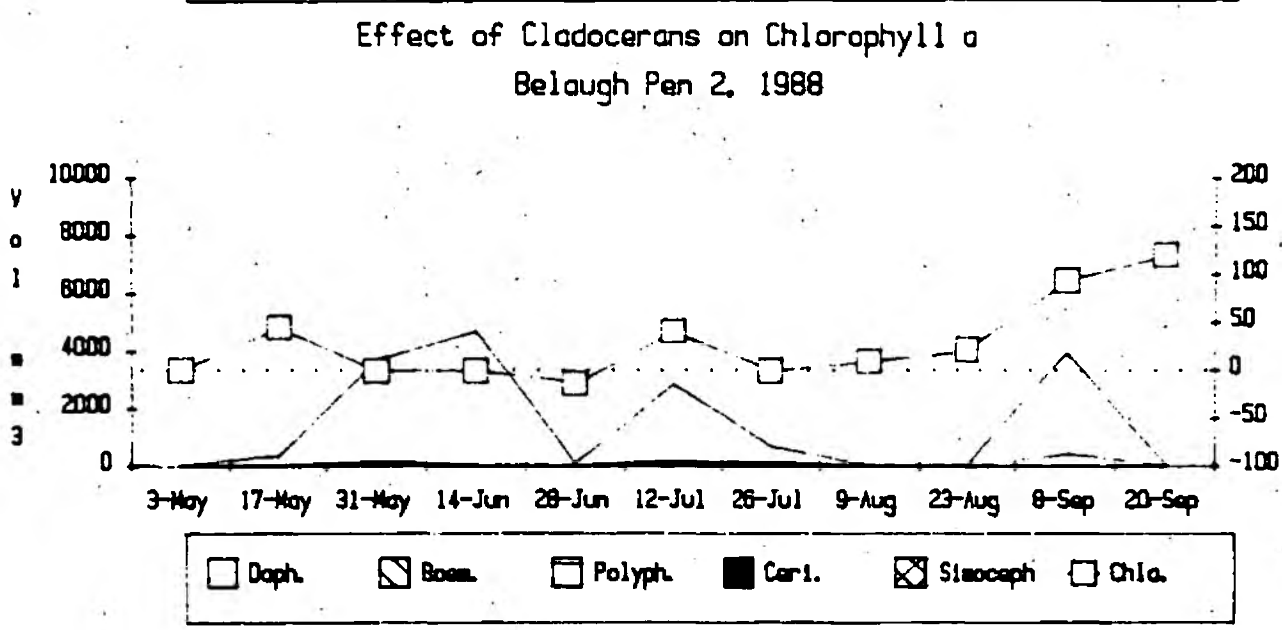
Fig 6.2



Belaugh Pen5.Daphnia hyalina
2.5mm
2mm
1.5mm
1mm
0.5mm
nos/litre
1000
750
500
250
0
5-Apr 19-Apr 3-May 17-May 31-May 14-Jun 28-Jun 12-Jul 26-Jul 9-Aug 23-Aug 6-Sep 20-Sep
Belaugh Pen6.Daphnia hyalina 1988
nos/litre
1750
1500
1250
1000
750
500
250
0
5-Apr 19-Apr 3-May 17-May 31-May 14-Jun 28-Jun 12-Jul 26-Jul 9-Aug 23-Aug 6-Sep 20-Sep
Belaugh Broad.Daphnia hyalina. 1988
nos/litre
250
0
19-Apr 19-Apr 3-May 17-May 31-May 14-Jun 28-Jun 12-Jul 26-Jul 9-Aug 23-Aug 6-Sep 20-Sep

Fig 6·3


Effect of Cladocerans on Chlorophyll a
Belaugh Pen 1, 1988
vol. m3
10000
8000
6000
4000
2000
0
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
3-May
17-May
31-May
14-Jun
28-Jun
12-Jul
26-Jul
9-Aug
23-Aug
8-Sep
20-Sep
Daph.
Bosm.
Polyph.
Cer1.
Simoceph
Chla.


Effect of Cladocerans on Chlorophyll a
Belaugh Pen 2, 1988
vol. m3
10000
8000
6000
4000
2000
0
200
150
100
50
0
-50
-100
3-May
17-May
31-May
14-Jun
28-Jun
12-Jul
26-Jul
9-Aug
23-Aug
8-Sep
20-Sep
Daph.
Bosm.
Polyph.
Cer1.
Simoceph
Chla.

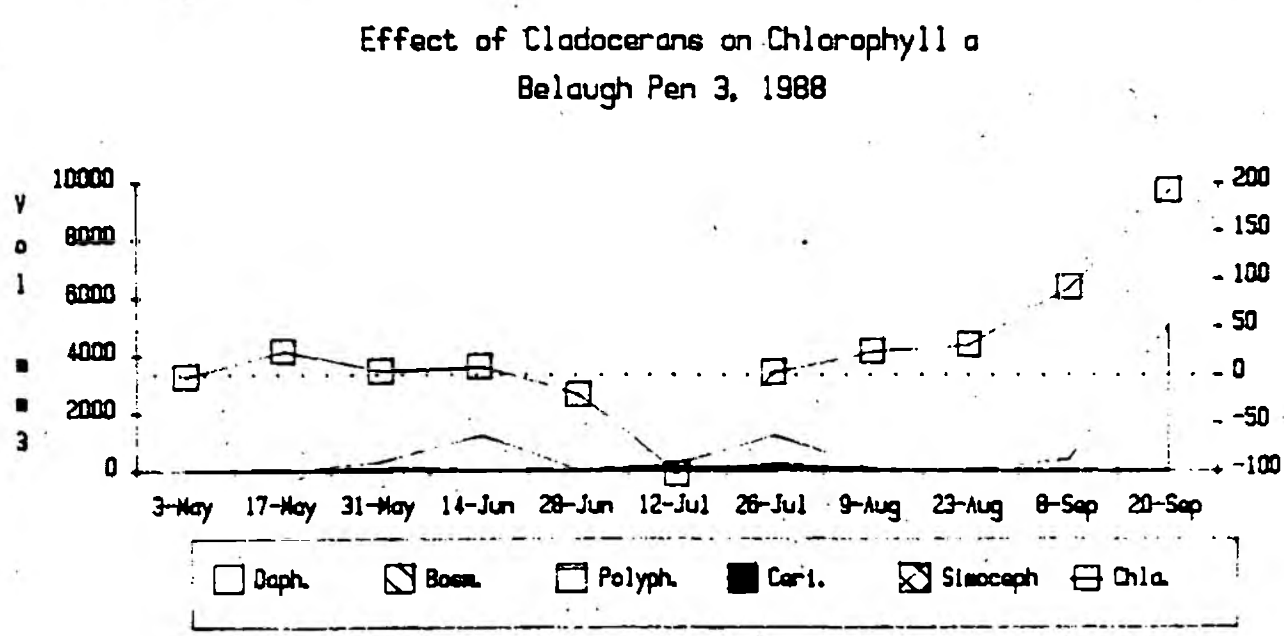
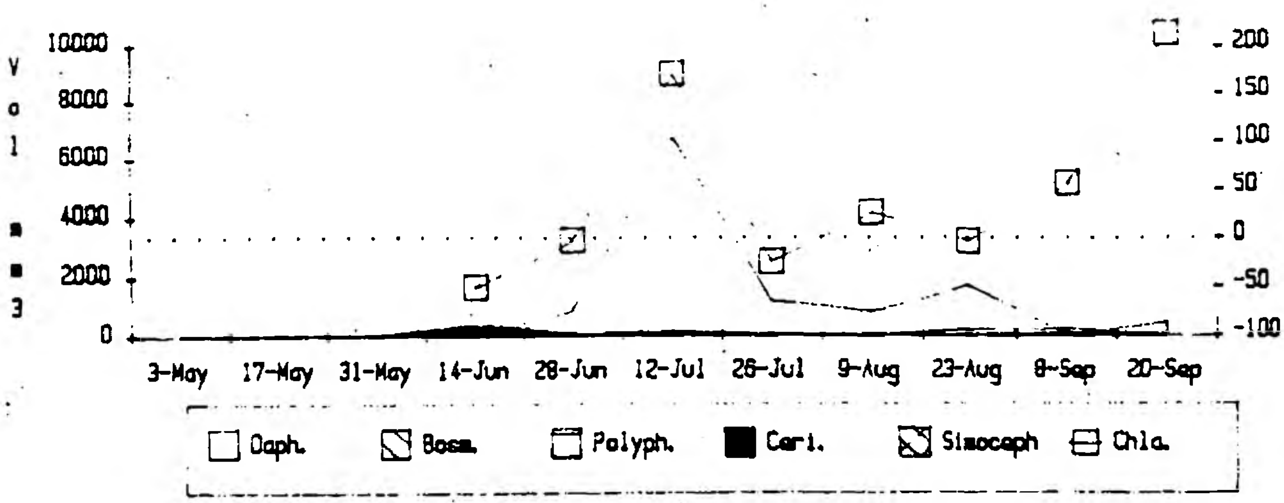
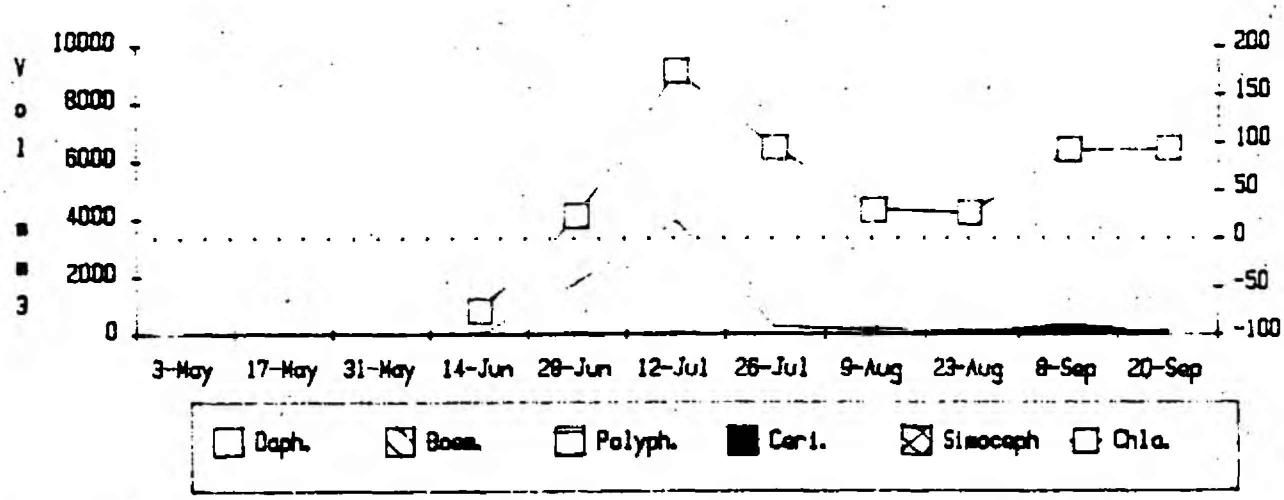

Effect of Cladocerans on Chlorophyll a
Belaugh Pen 3, 1988
vol. m3
10000
8000
6000
4000
2000
0
200
150
100
50
0
-50
-100
3-May
17-May
31-May
14-Jun
28-Jun
12-Jul
26-Jul
9-Aug
23-Aug
8-Sep
20-Sep
Daph.
Bosm.
Polyph.
Cer1.
Simoceph
Chla.

Fig 6.4

Effect of Cladocerans on Chlorophyll a
Belaugh Pen 4, 1988



Effect of Cladocerans on Chlorophyll a
Belaugh Pen 5, 1988



Effect of Cladocerans on Chlorophyll a
Belaugh Pen 6, 1988

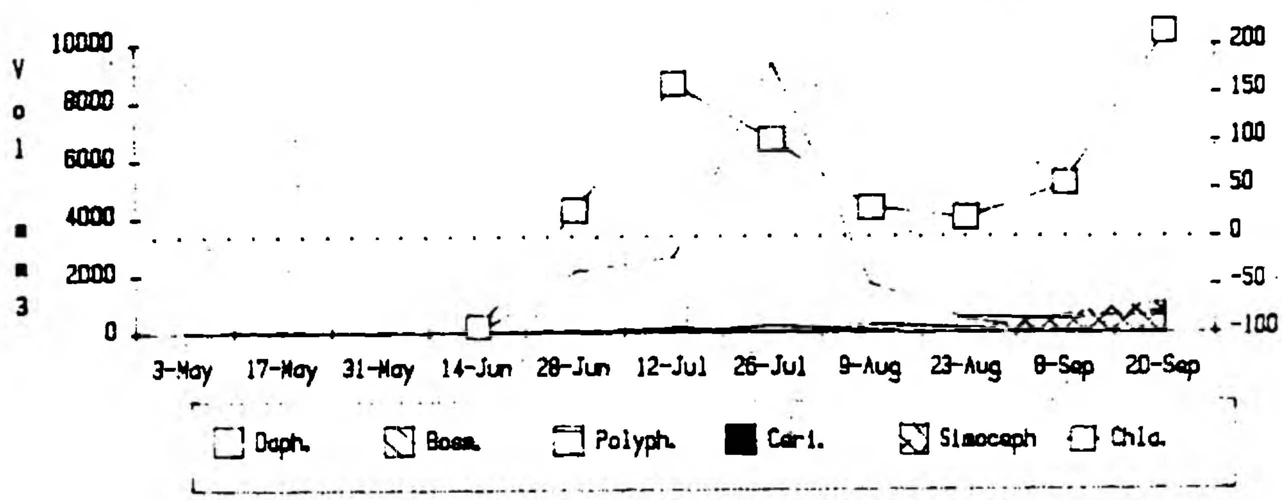
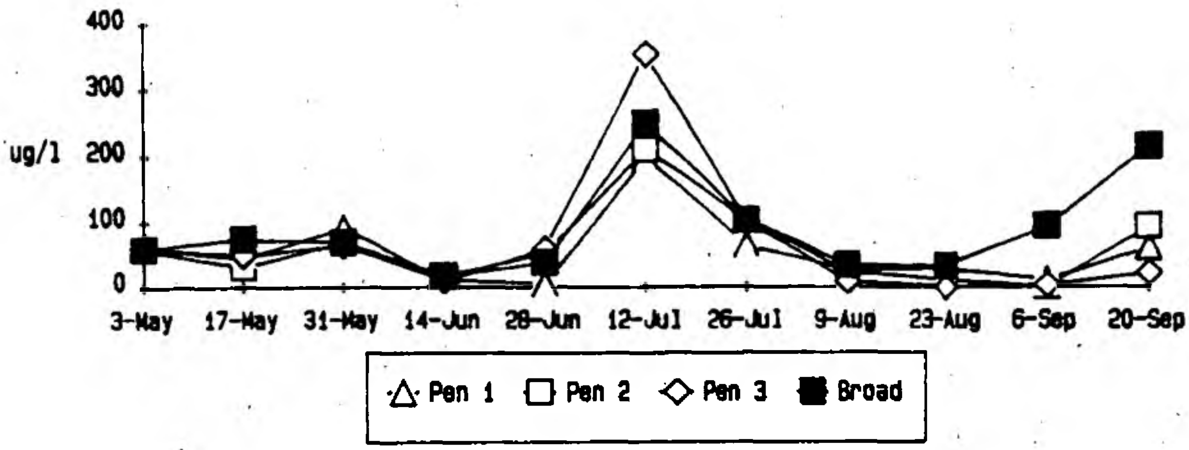
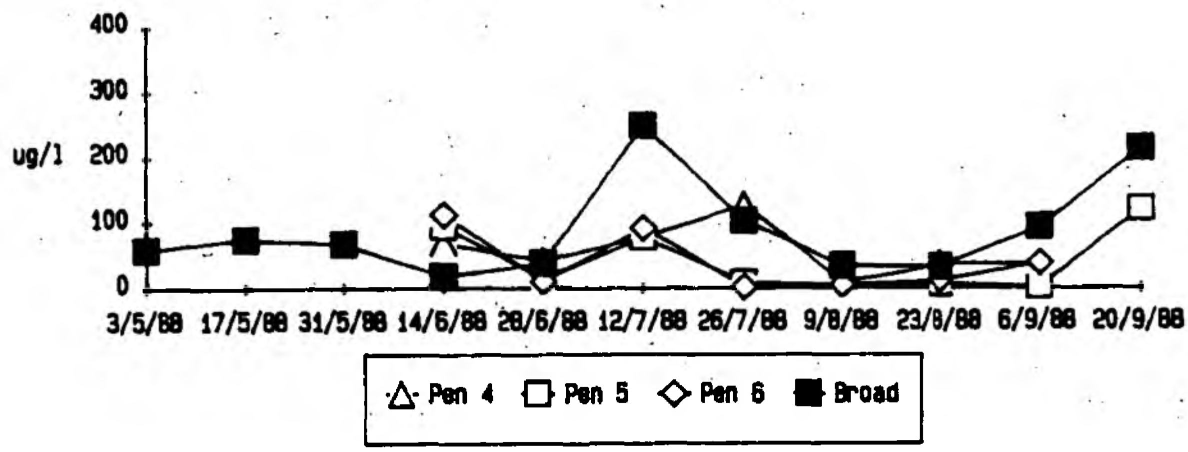


FIG 6.5

Chlorophyll a Concentration in Belaugh Broad
and pens 1 - 3
1988



Chlorophyll a Concentration in Belaugh Broad
and pens 4 - 6
1988



an increase in cladocerans although in pens 4,5,6 total volume was relatively low at this time.

In conclusion the pens in Belaugh Broad provided conditions suitable for the growth of a variety of submerged aquatic plants. In all but one of the pens zooplankton populations were considerably enhanced and chlorophyll a concentrations reduced from July onwards. However water clarity was high, in the open water of Belaugh Broad during June

6.2 Barton Broad

Sampling of the six pens and two control sites in Barton Broad continued during 1988. Samples were only taken at two-weekly intervals compared to weekly in 1987 and hence it was more difficult to interpret zooplankton population changes.

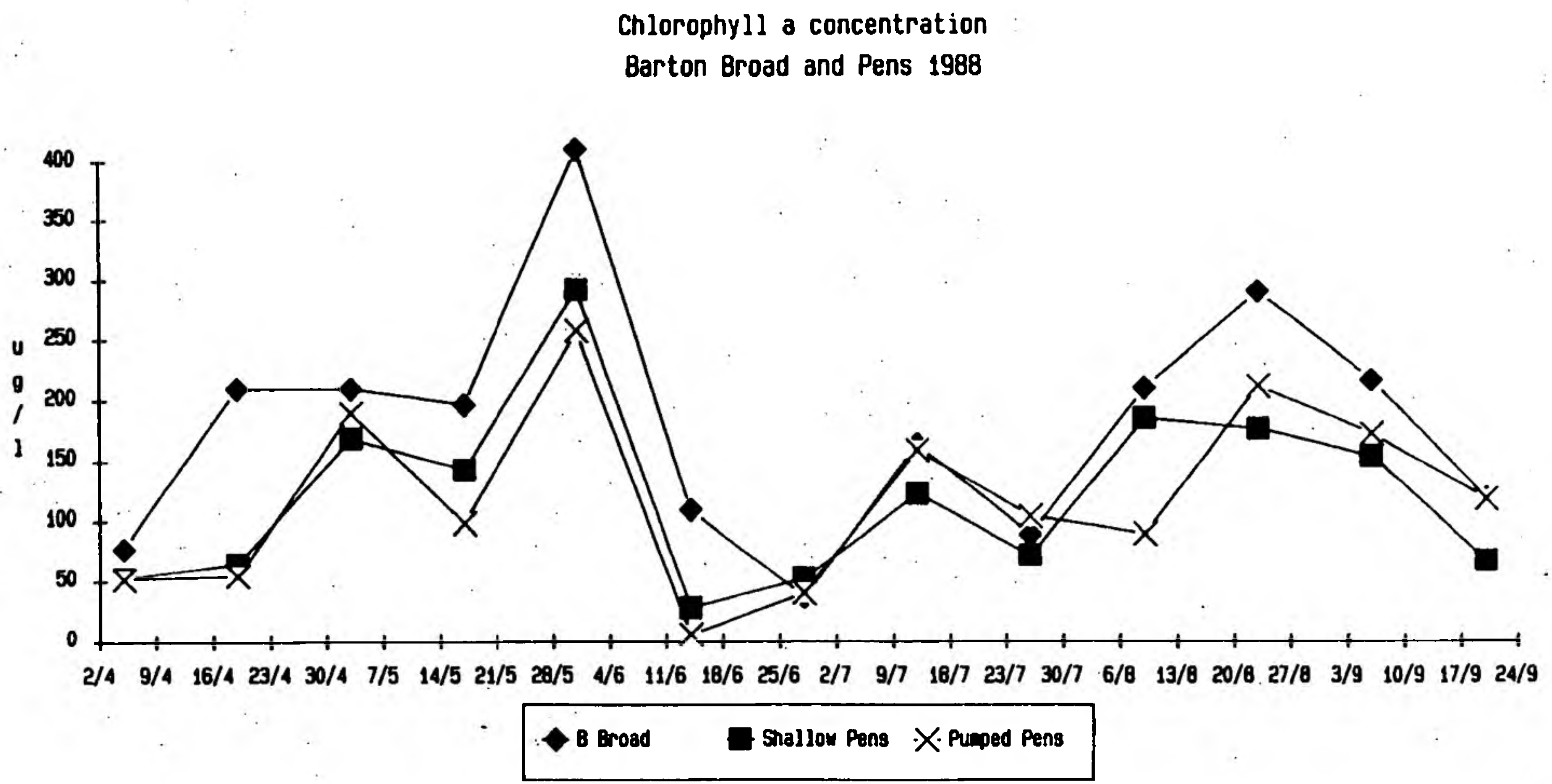
During 1987 the three shallow pens all contained a substantial crop of aquatic plants. In 1988 the same three pens had a greatly reduced abundance of plants with only pen 3 achieving a substantial growth of <u>Ceratophyllum</u> <u>demersum</u> and <u>Elodea</u> <u>canadensis</u>. As in 1987, no growth took place in the deeper pens where the sediment had been removed.

In general chlorophyll a concentration was considerably greater in both the open water and the pens in 1988 (fig 6.6). Although the pens had lower chlorophyll a than the open water this was often higher than the open water of the broad in 1987. A short relatively clear period occurred in the pens during June, as it did in 1987, but this was followed by an increase in phytoplankton with only a slight decrease in late July before again increasing to values approaching 200 ug l^{-1}

Zooplankton abundance in the pens was generally similar to 1987. The dominant cladoceran was <u>Daphnia</u> <u>hyalina</u> although pen 6 (deep pen) developed a population of <u>D. pulex</u> and <u>D. magna</u> towards the end of the summer. As in 1987 the deep pens tended to have larger populations of <u>D. hyalina</u> than the shallow pens and appeared to have three, rather than two generations, although the sampling interval makes this observation slightly tentative. The larger populations in the deep pens was less marked than in 1987 and the shallow pen population densities were very similar in the two years.

Data on size structure has not been analysed but if grazing pressure in the pens was similar in the two years then it seems likely that the phytoplankton was less edible. Filamentous blue-green algae usually dominate the phytoplankton in Barton Broad, these were much less important in 1987 and although phytoplankton counts remain to be carried out for 1988 it is possible that these less edible species maintained the chlorophyll a in the pens during 1988.

FIG 6.6



Chlorophyll a concentration
Barton Broad and Pens 1988
u g / l
400
350
300
250
200
150
100
50
0
2/4 9/4 16/4 23/4 30/4 7/5 14/5 21/5 28/5 4/6 11/6 18/6 25/6 2/7 9/7 16/7 23/7 30/7 6/8 13/8 20/8 27/8 3/9 10/9 17/9 24/9
B Broad
Shallow Pens
Pumped Pens

7. DISCUSSION

7.1 Effects of Phosphorus Reduction and River Flow

The reduction of both phosphorus and chlorophyll a in the upper part of the tidal River Bure and the most riverine broads, identified in the 2nd annual report has continued. The summer of 1987 was abnormally wet and high river discharge, together with cooler and less sunny weather, complicated the interpretation of changes associated with the phosphorus reduction program. Higher than normal river discharges continued during the winter and spring of 1988, only returning to typical values in early summer.

The effect of river discharge can now be seen more clearly. In the river and the most riverine broads chlorophyll a is relatively low throughout the winter period as result of low growth rate and high river flows. In contrast sites such as Hoveton Great, Decoy and Ranworth Broads tend to maintain their autumn phytoplankton populations for longer. The high winter discharge of 1987/88 depressed chlorophyll a in these sites between December and March, although the faster growth rates of spring phytoplankton species are less affected by flushing and higher river flows can enhance algal growth at this time of year in these sites, by increasing nitrogen and silica supplies.

However during the summer of 1988 river flows were more typical and all of the broads tended to have higher chlorophyll a concentrations than in 1987. This was most marked in Wroxham Broad where chlorophyll a had remained exceptionally low throughout the summer of 1987. During 1988 a substantial summer phytoplankton was able to develop and the chlorophyll a concentration was only slightly lower than previous years (fig 7.1).

There is a clear relationship between chlorophyll a and total phosphorus for the Bure and Ant broads. Data for Barton Broad (1977-1988) and Wroxham (1981-1988) are shown in fig 7.2, together with the best fit line for the Barton Broad data. It is clear that Wroxham Broad fits the general relationship, although data for 1988,1987 and 1985 fall below the best fit line. River discharge was high during the summer during each of these years (table 7.1), particularly so in 1987 and it is clear that the absence of phytoplankton in the summer of 1987 in Wroxham Broad was a direct result of high river flows. This was probably due to flushing of the broad but the reduction of tidal back-flow of algal rich water from the middle Bure may also have been important.

Relationship between Chlorophyll a and Flushing

Fig 7.1

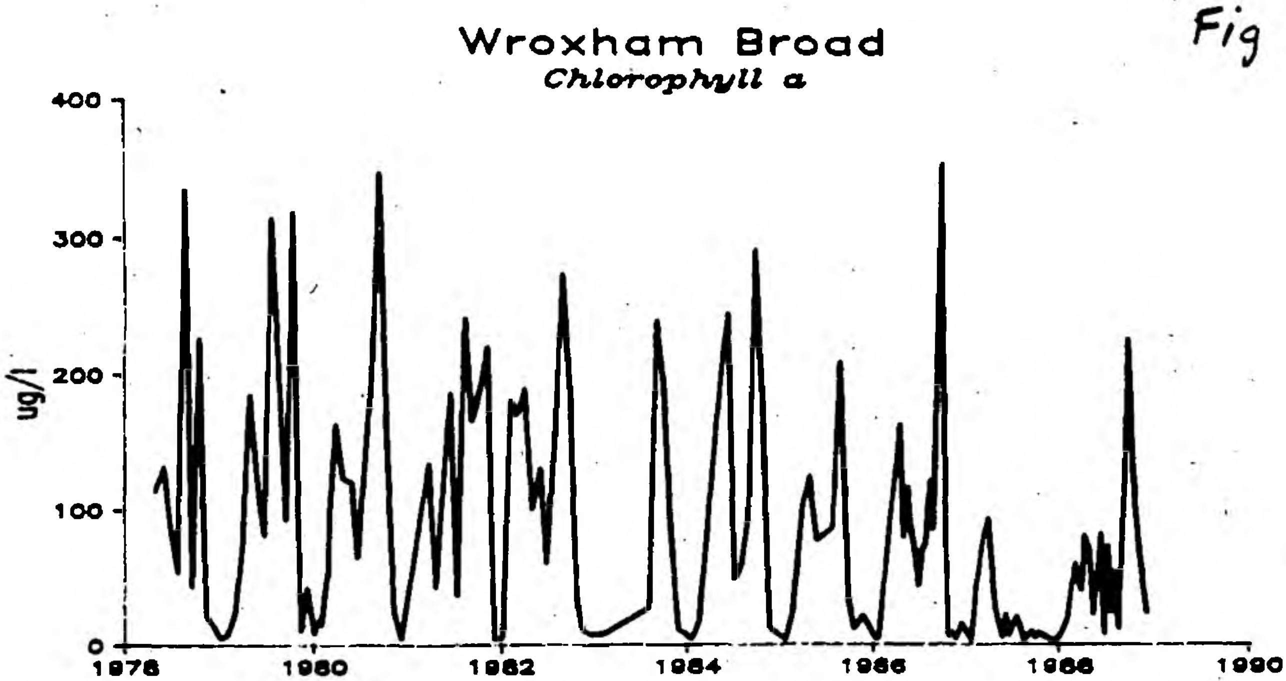


Fig 7.3

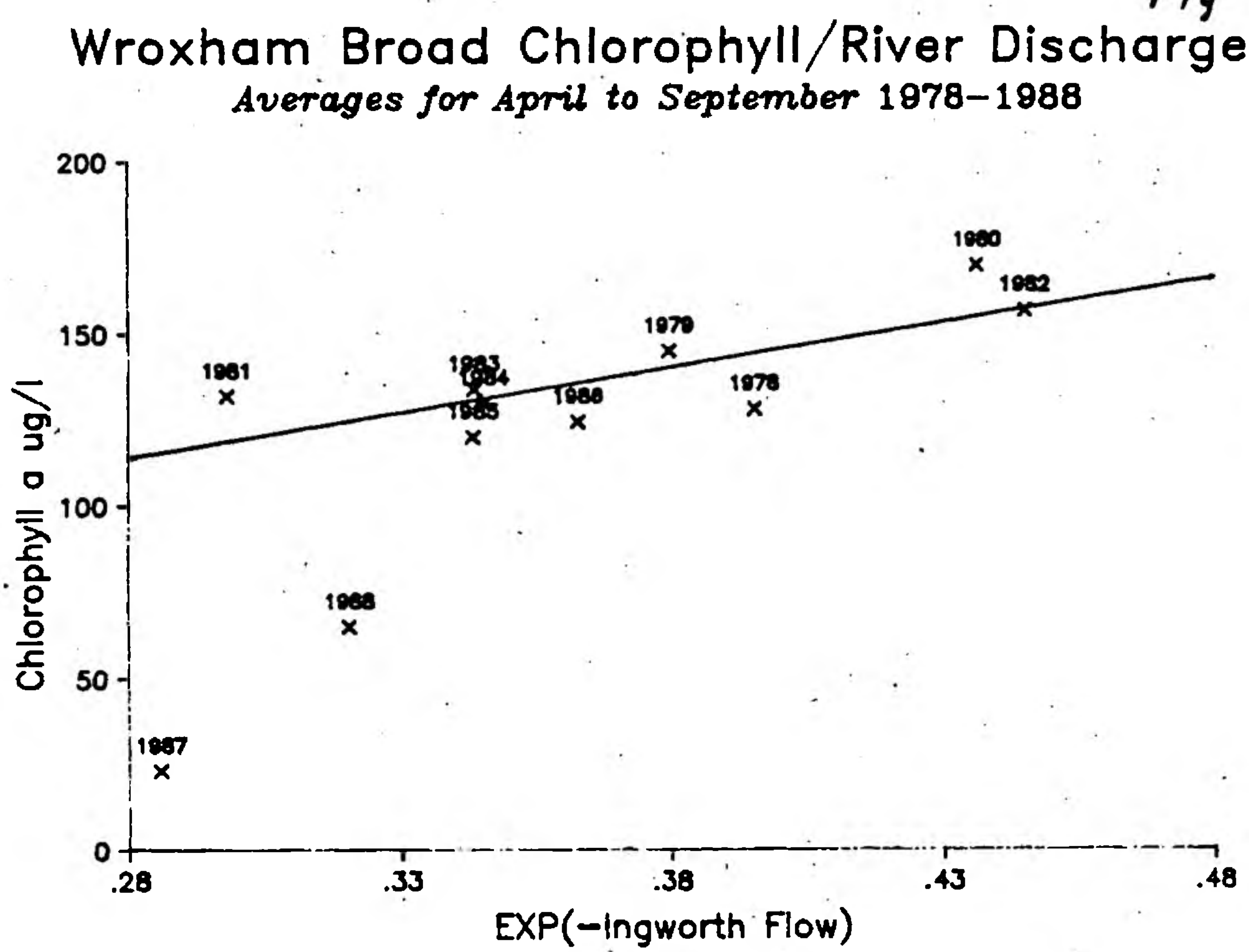


FIG 7.2

BARTON BROAD and WROXHAM BROAD
Chlorophyll a v Total P
(April-Sept mean)

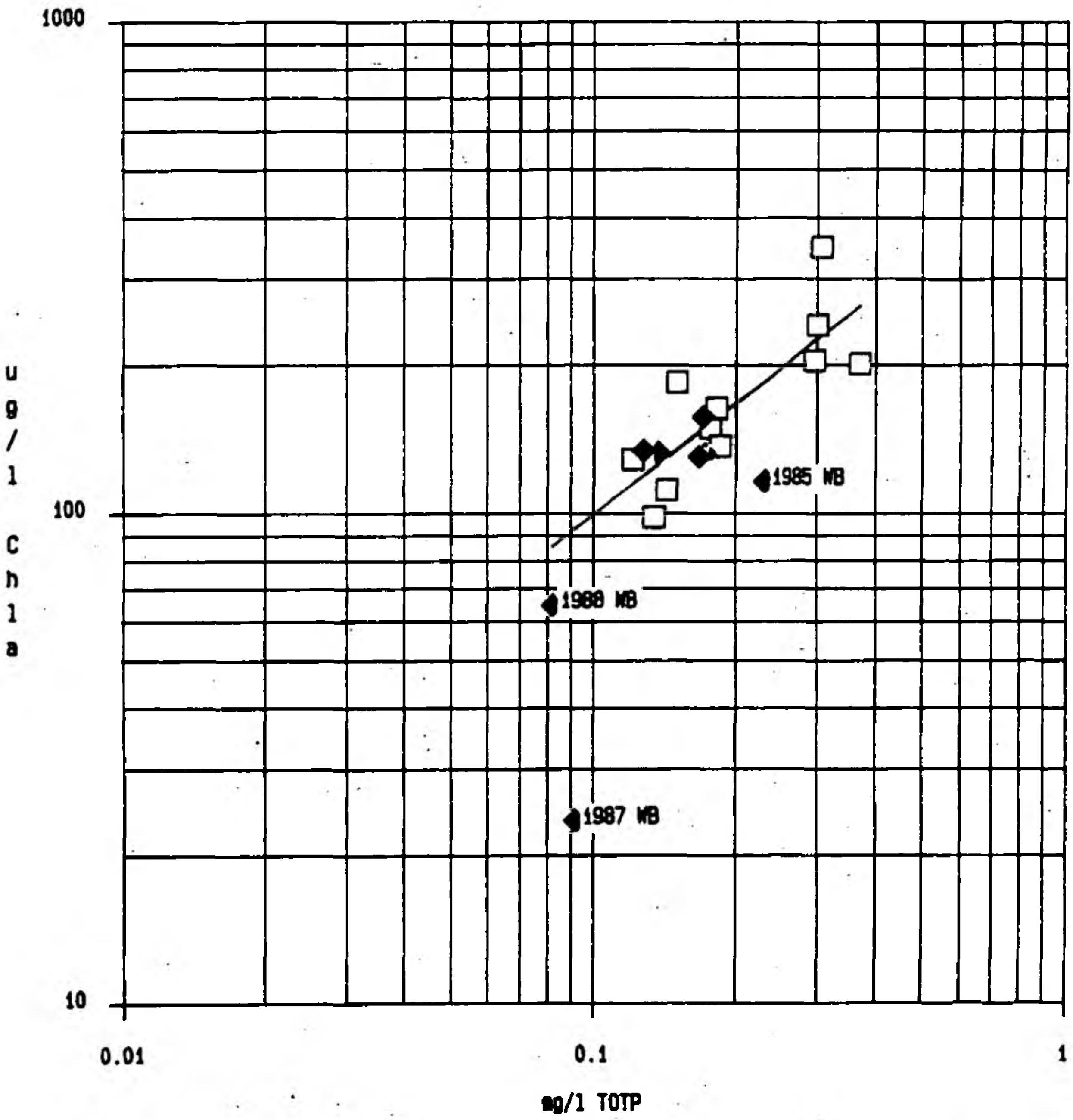


Table 7.1
Mean Daily Flow River Bure at Ingworth
cumecs

	1978	1979	1982	1983	1980	1981	1986	1984	1985	1988	1987	mean
Winter	1.46	1.80	1.15	1.36	1.61	1.65	1.44	1.57	1.44	1.26	1.42	1.5
Spring	1.00	1.26	.87	1.33	.85	1.55	1.14	1.18	1.14	1.03	1.09	1.10
Summer	.86	.68	.75	.81	.81	.87	.89	.95	1.00	1.13	1.41	.85
Autumn	.81	.94	1.74	1.15	1.33	1.09	1.27	1.14	1.26	1.14	1.87	1.21

The effect of flushing can be seen by plotting average chlorophyll a against e river discharge (fig 7.3). Data for 1981-1986 are clearly different from 1987 and 1988, probably due to the effect of lower phosphorus. Thus phosphorus removal in the Bure catchment has had some effect in Wroxham and other riverine broads, although fig 7.2 suggests that an average total phosphorus concentration of less than 30 ugP l^{-1} would be required to sustain low chlorophyll concentrations under more typical flow conditions.

At present the total phosphorus in the river upstream of Wroxham is typically about 100ugP l^{-1}. During the winter, in some of the more isolated broads such as Hoveton Great or Decoy Broads, particulate matter settles out and total phosphorus is reduced to 50ugP l^{-1} but in most of these sites phosphorus is released from the sediment during the summer and the lack of flushing allows relatively high total phosphorus and chlorophyll a to develop. Decoy Broad seems an exception to this with relatively low phosphorus and phytoplankton populations during the summer months suggesting little release of phosphorus from the sediment.

Significant phytoplankton populations only develop in the broadland rivers downstream of broads where water residence is sufficient to allow them to develop. Thus during the summer of 1987 the river below Wroxham Broad had a relatively low chlorophyll a concentration. Salhouse Broad however contained a series of chlorophyll a peaks demonstrating the slightly less effective flushing of the site. Salhouse Broad is very close to Hoveton Great Broad, where much larger phytoplankton populations are able to develop. Algal rich water enters the river at this point and from here downstream algal populations are generally much greater. Tidal mixing will allow this water to enter Salhouse Broad and it seems likely that Hoveton Great Broad is the primary source of much of the summer phytoplankton in the upper section of the tidal River Bure.

It would be in the general interests of the restoration of the River Bure to decrease the effectiveness of Hoveton Great Broad in seeding the river with phytoplankton. This could be achieved by isolating the broad from the river although the release of phosphorus from the sediment would ensure that the site remained eutrophic and the long residence times would allow high phytoplankton populations similar to Ranworth Broad to develop with a dominance of poorly grazed filamentous blue green algae. Alternatively flushing of the broad could be encouraged by reinstating the entrance known as Gravel Dyke as shown on fig 7.4. This action should minimise algal development and encourage the recovery of this section of the river.

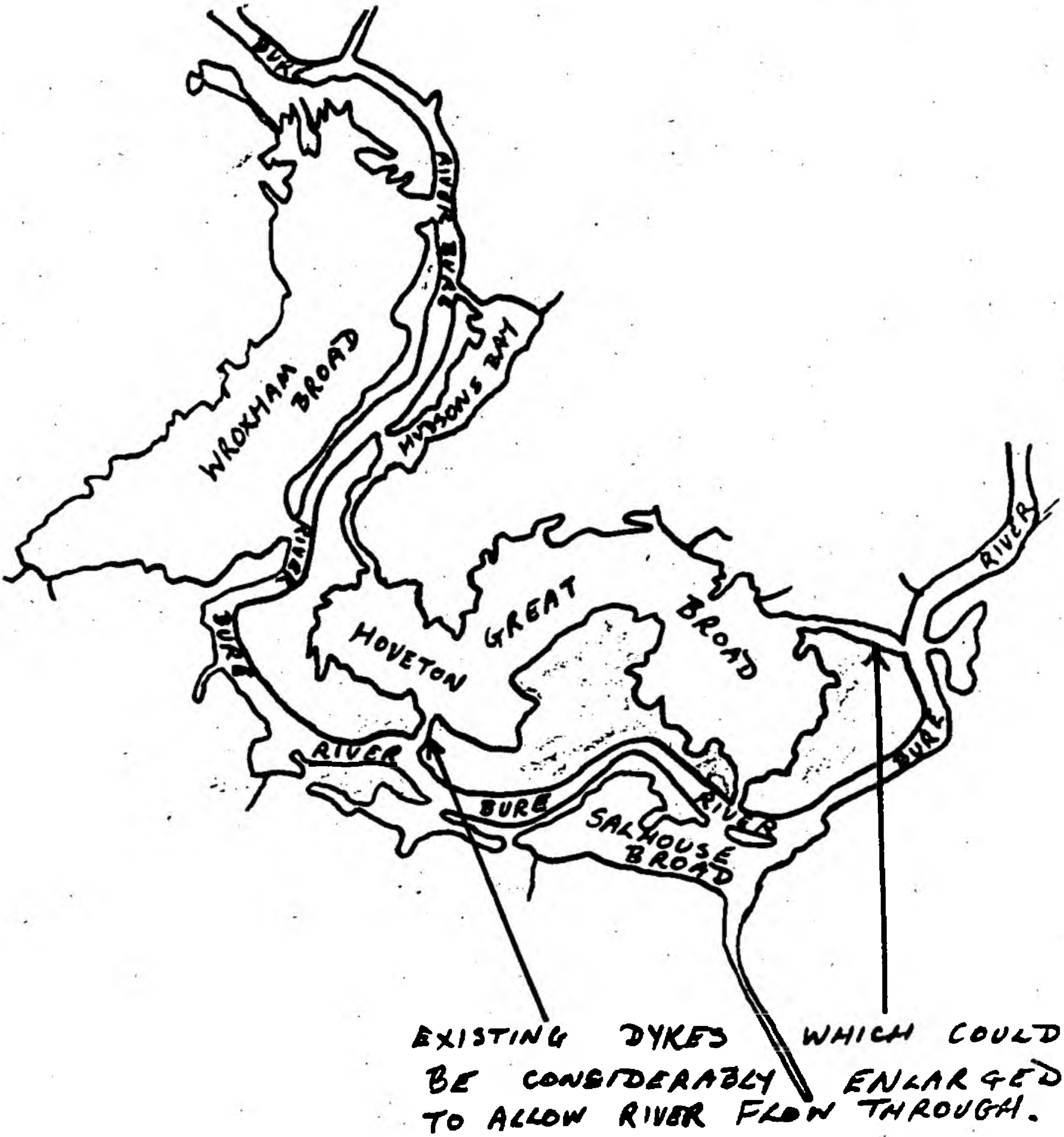
7.2 The effect of Zooplankton Grazing.

In the Bure and Ant broads examined larger cladocera likely to exert a significant grazing pressure on the phytoplankton are usually found between May and July. At this time in most of the sites the phytoplankton is dominated by diatoms or green algae and it is clear that the zooplankton can substantially reduce the chlorophyll a concentration under these conditions (fig 7.5 - 7.9)

However the extent of this reduction is very variable and not clearly related to the density of D hyalina. The least flushed broads such as Ranworth tend to develop a phytoplankton dominated by filamentous blue-green algae which may be less edible and this may explain some of the variation at this site. However at other sites such as Wroxham this is less likely and other factors such as tidal input of phytoplankton or riverine washout are also important.

The pen experiments give some additional information regarding the importance of zooplankton in controlling phytoplankton but the continual input of fresh phytoplankton into these small enclosures makes interpretation difficult. The general impression gained is that the dominant cladoceran D. hyalina can substantially reduce phytoplankton during the spring when flushing rates are relatively high and incoming water is not algal rich. If larger populations could be encouraged later in the year their effectiveness might be limited in sites where filamentous blue-green algal species dominate. This suggests that any attempt to manipulate fish populations should be undertaken in sites where flushing is high. Isolated broads are perhaps least likely to respond unless sediment removal has lowered phosphorus inputs sufficiently to prevent the production of large blue-green dominated phytoplankton populations

Figure 7.4.


BURE
RIVER BURE
WROXHAM BROAD
HUDSONS BAY
BURE
HOVETON GREAT BROAD
RIVER
BURE
RIVER
SALHOUSE BROAD
RIVER
BURE
EXISTING DYKES WHICH COULD BE CONSIDERABLY ENLARGED TO ALLOW RIVER FLOW THROUGH.

Belaugh Broad Monitoring

Relationship between Daphnia and Chlorophyll a

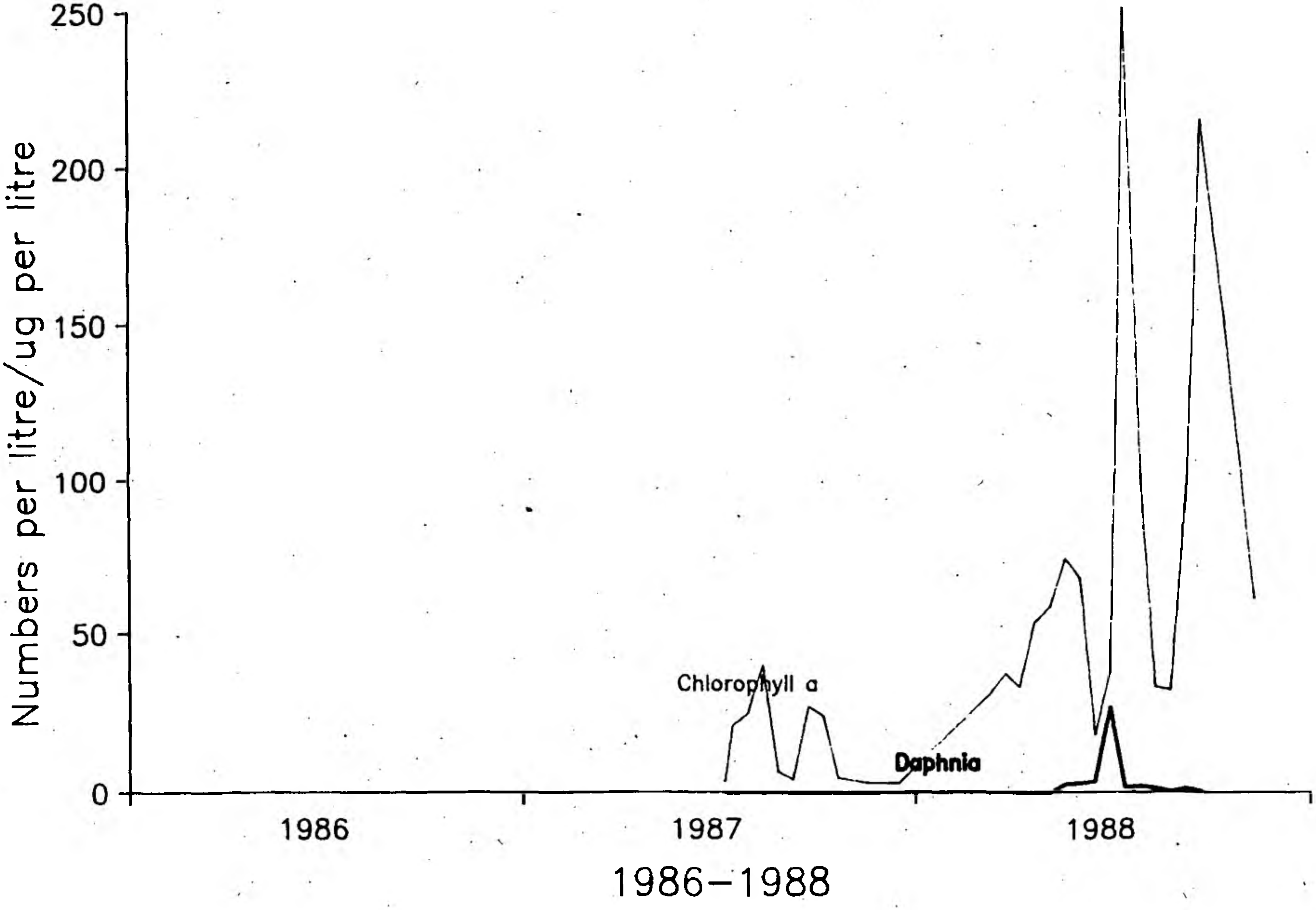


Fig 7.5

Wroxham Broad Monitoring

Relationship between Daphnia and Chlorophyll a

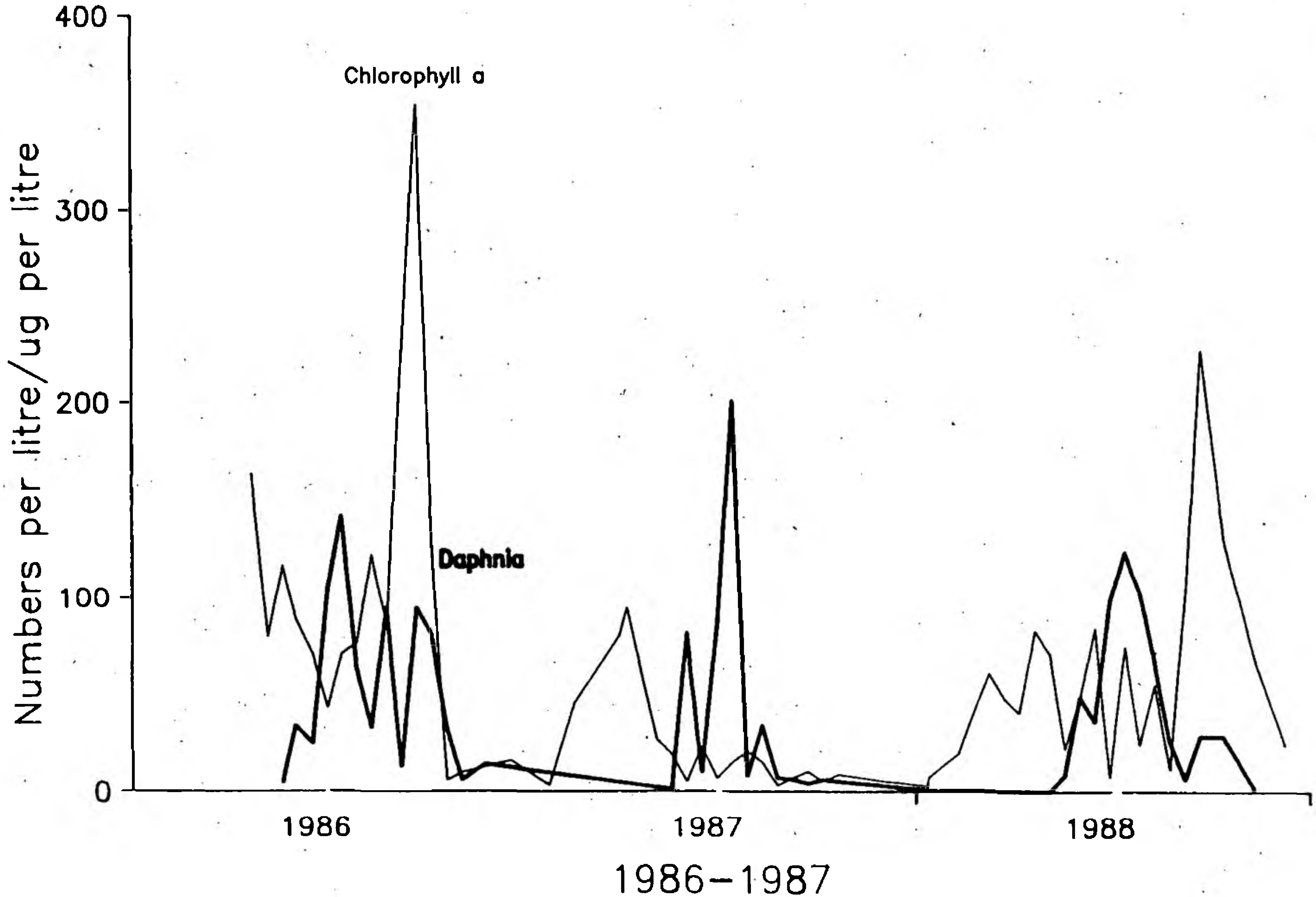


Fig 7.6

Hoveton Great Broad Monitoring

Relationship between Daphnia and Chlorophyll a

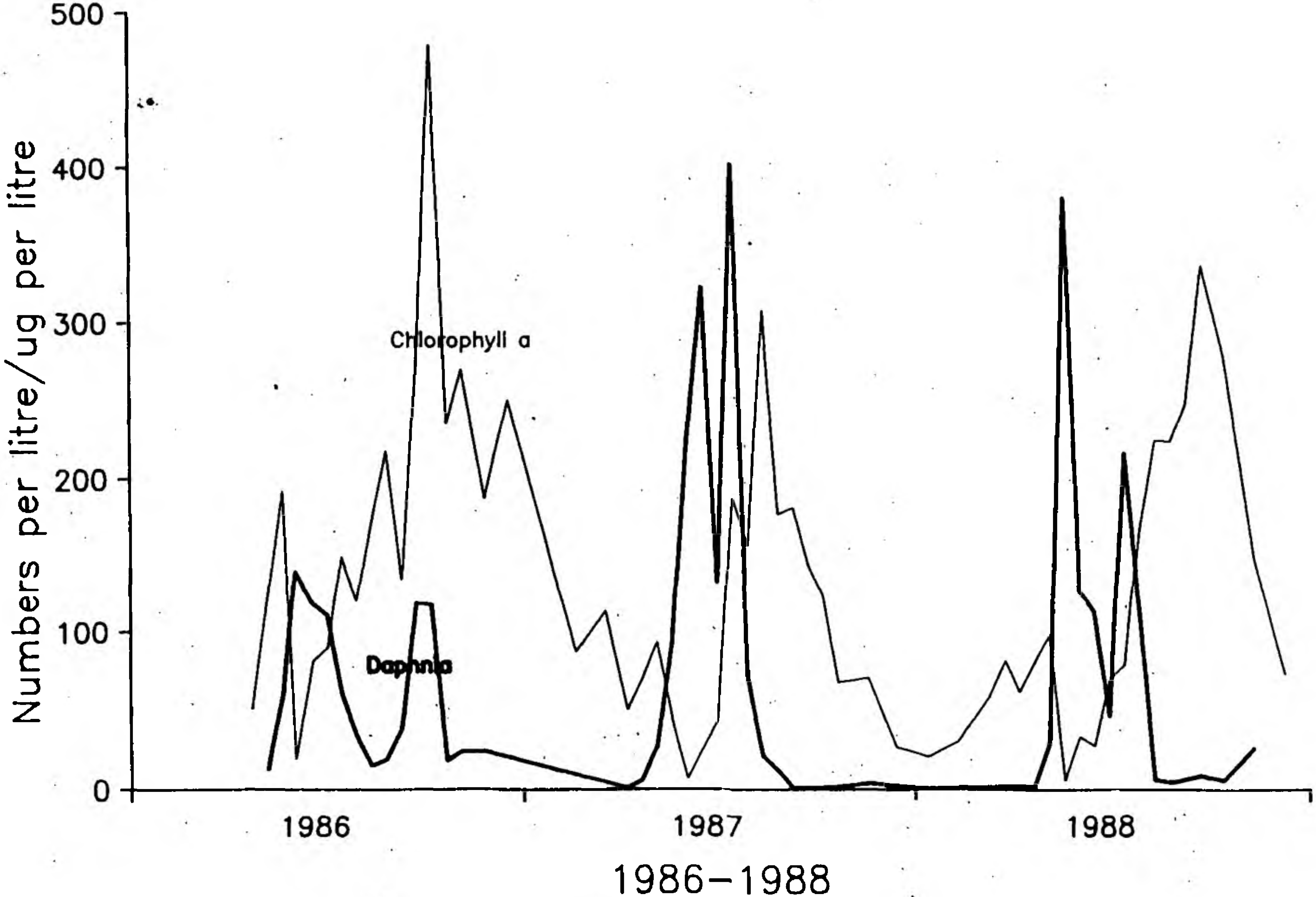


Fig 7.7

Ranworth Broad Monitoring

Relationship between Daphnia and Chlorophyll a

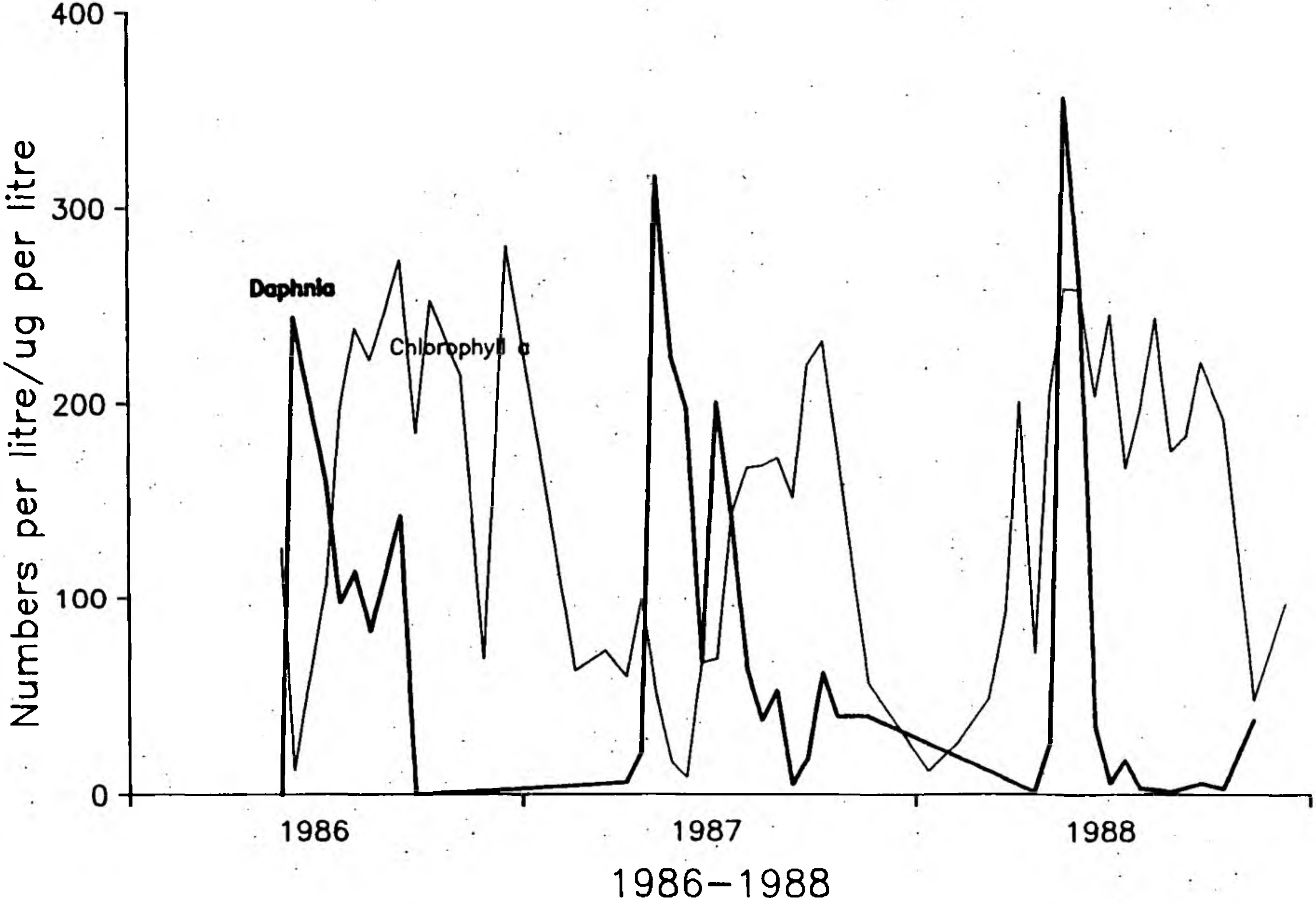


Fig 7.8

Barton Broad Monitoring.

Retationship between Daphnia and Chlorophyll a

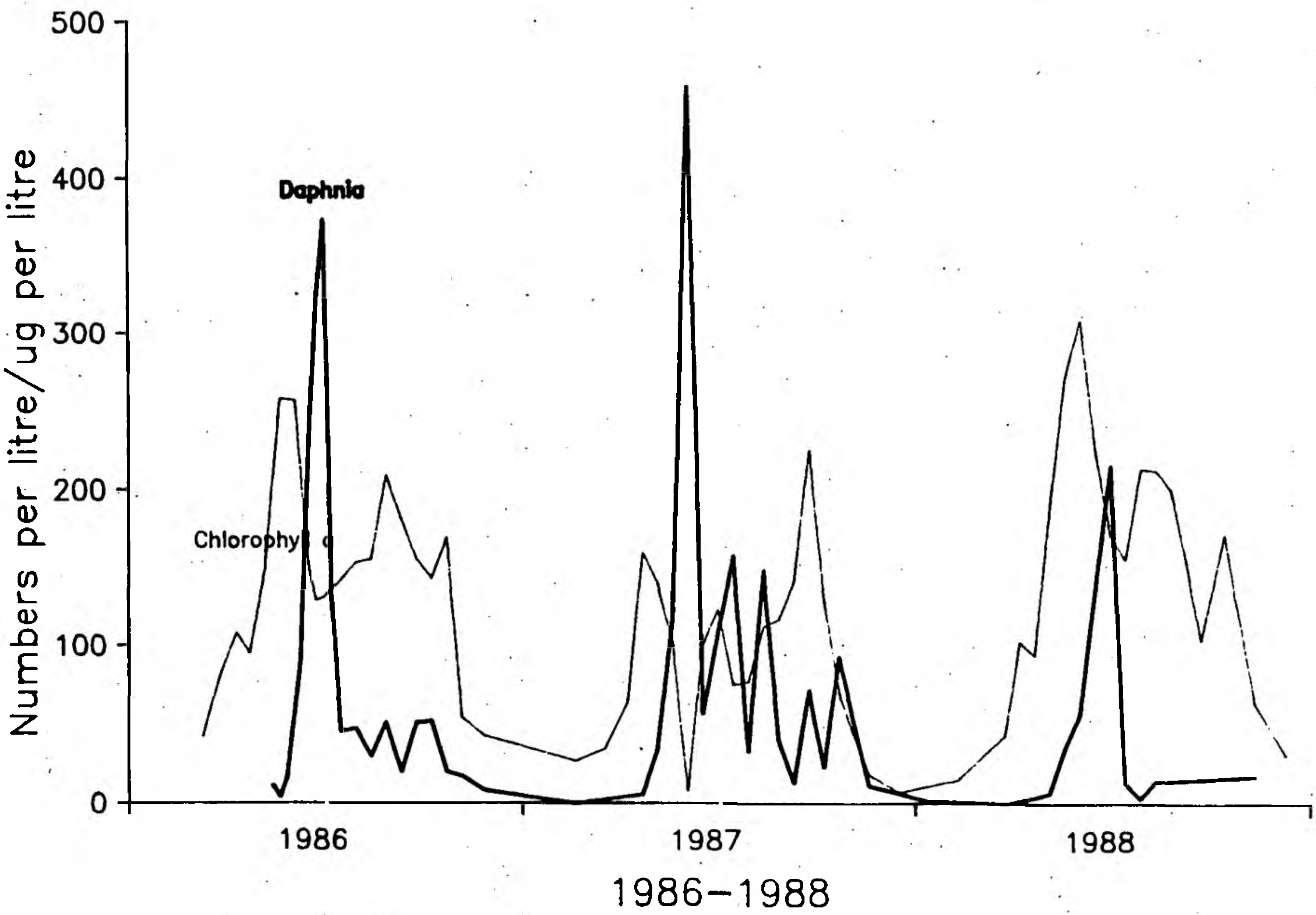
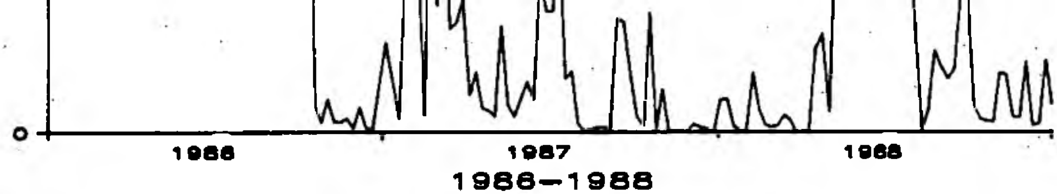


Fig 7.9

8. APPENDIX FIGURES


0
1986
1987
1988
1986–1988

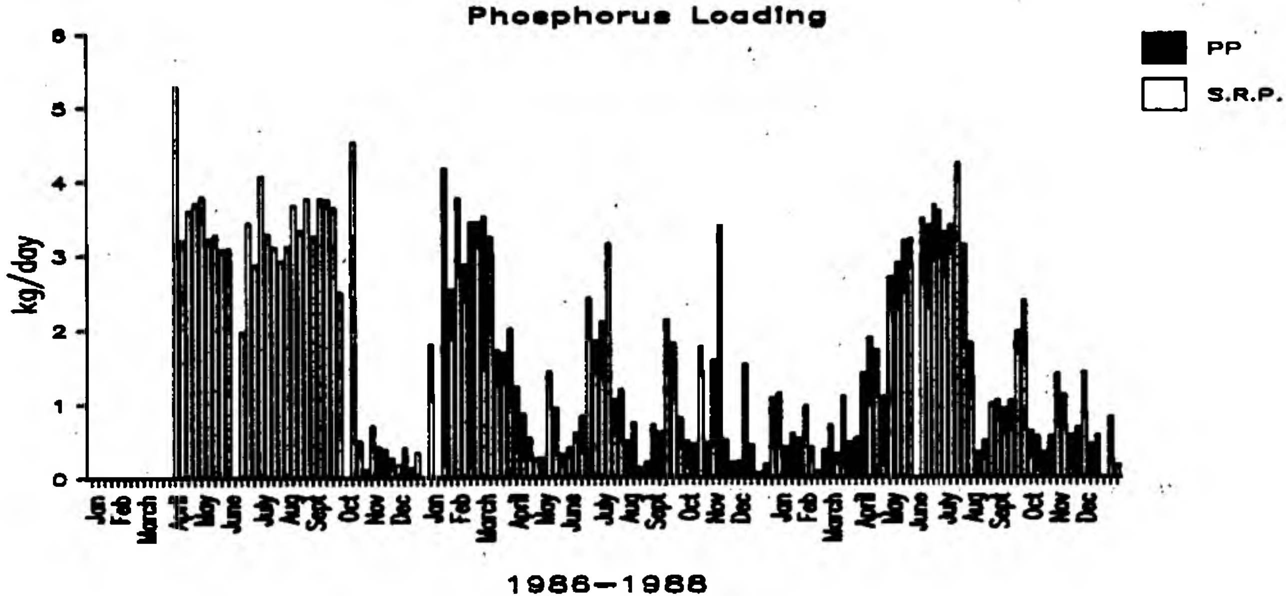
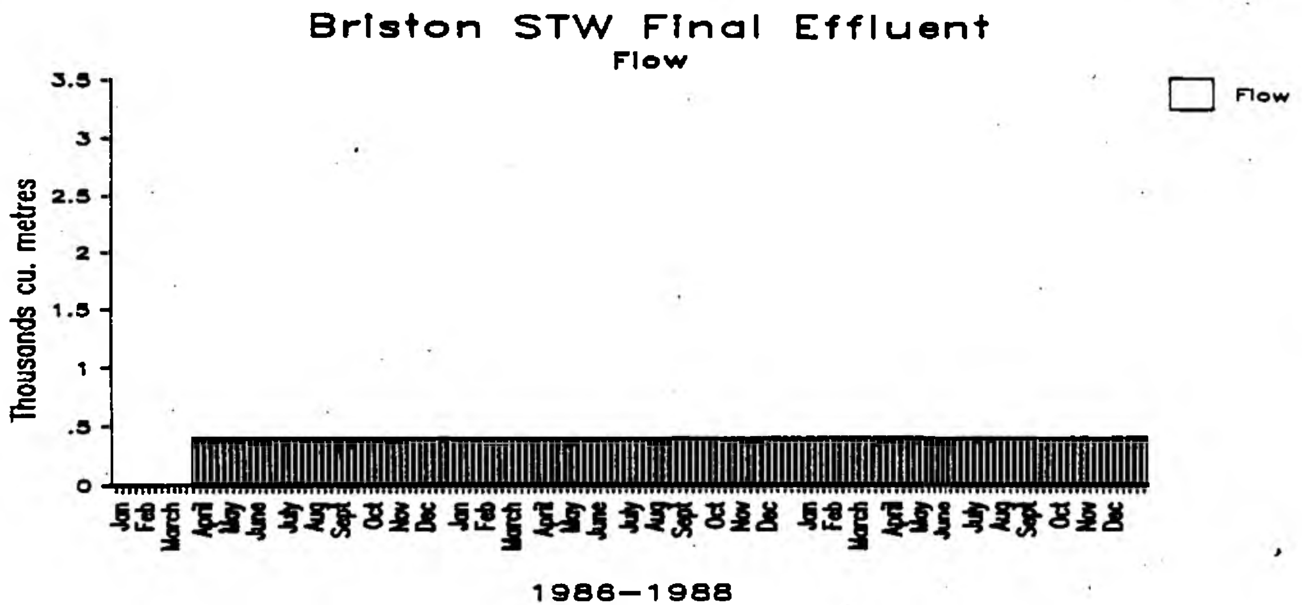
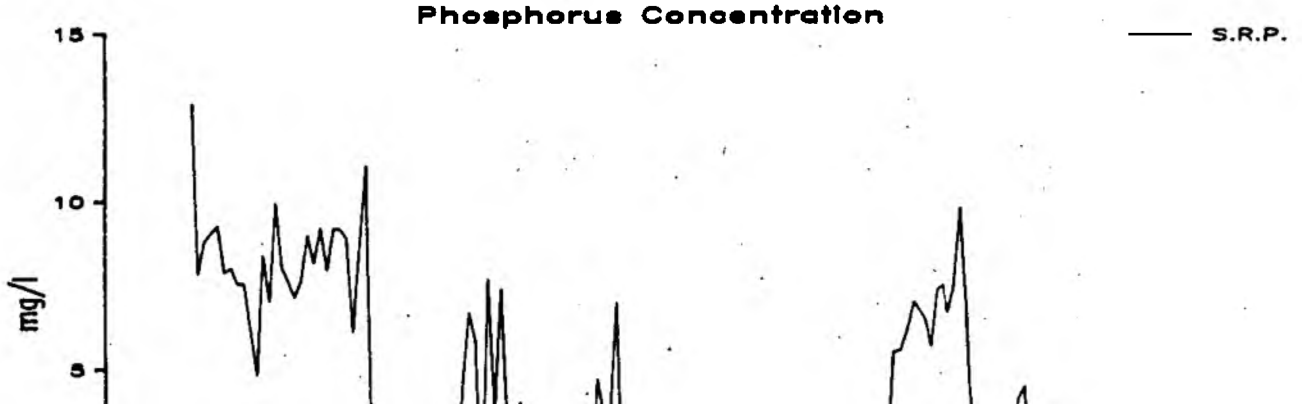

Phosphorus Loading
kg/day
0
1
2
3
4
5
6
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
1986–1988
PP
S.R.P.

Fig 1



Briston STW Final Effluent
Flow
Thousands cu. metres
3.5
3
2.5
2
1.5
1
.5
0
Flow
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
1986—1988



Phosphorus Concentration
mg/l
15
10
5
S.R.P.

Fig 2

Aylsham STW Final Effluent

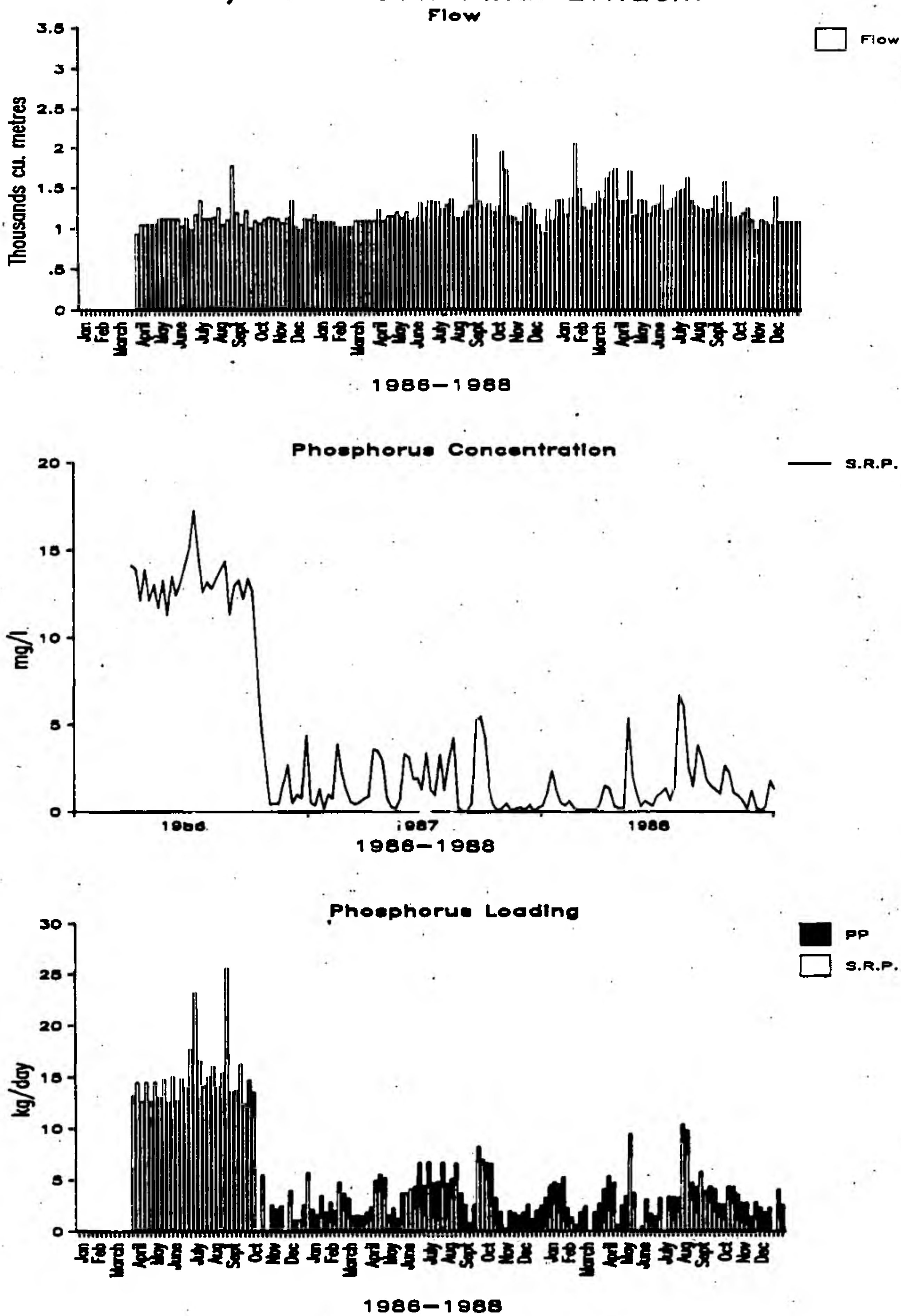


Fig 3

R.A.F. Coltishall S.T.W. Final Effluent

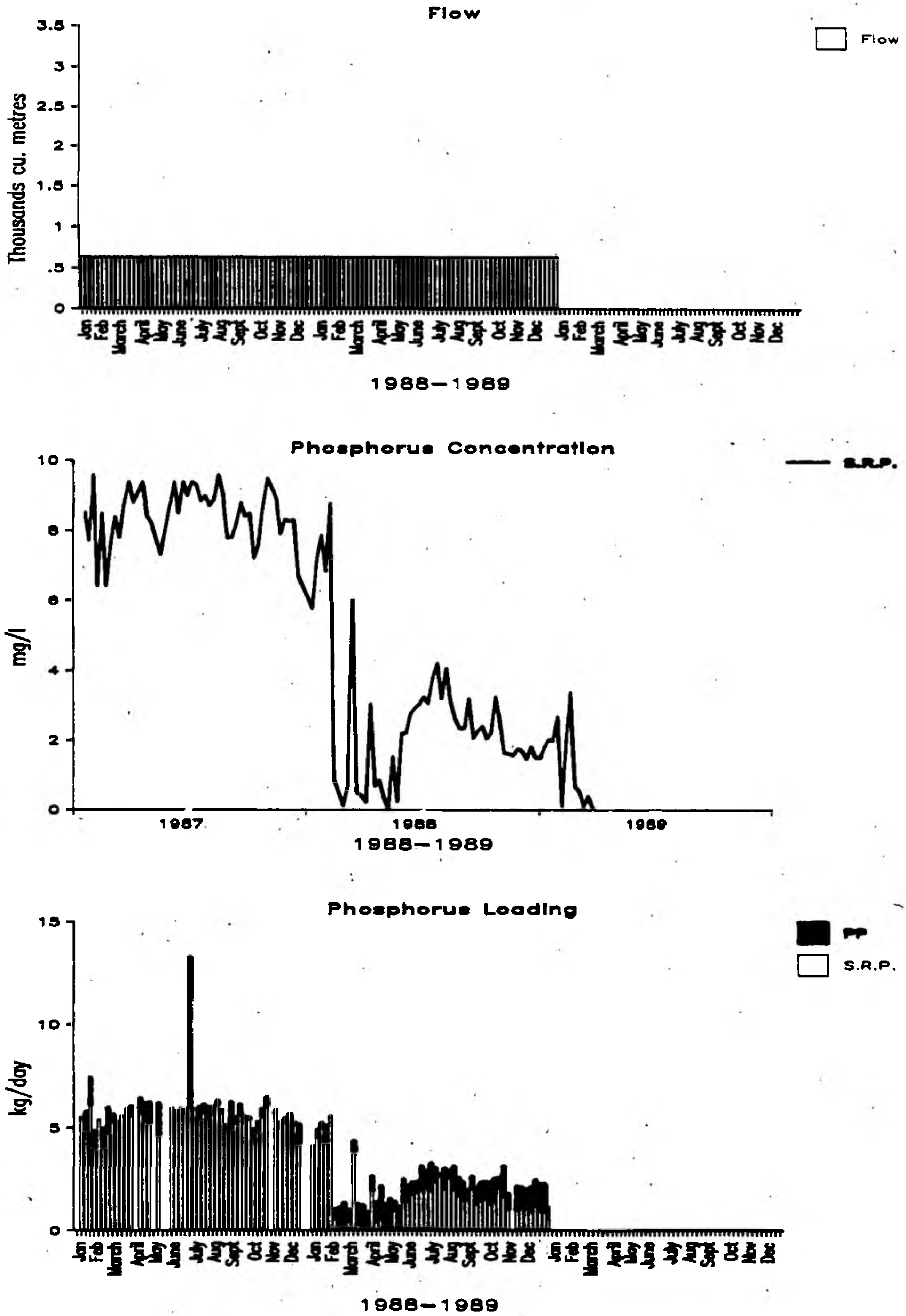


Fig 4

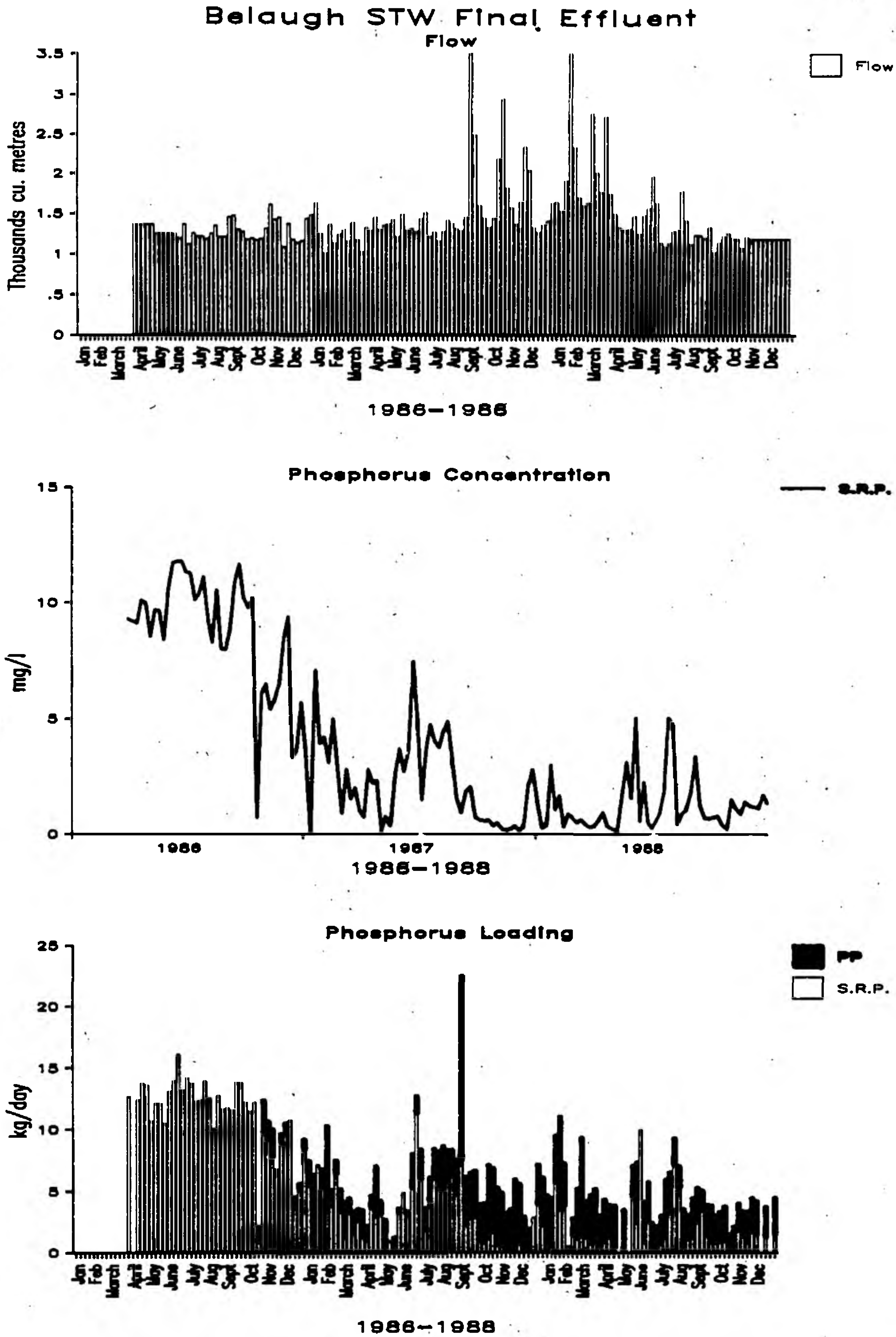
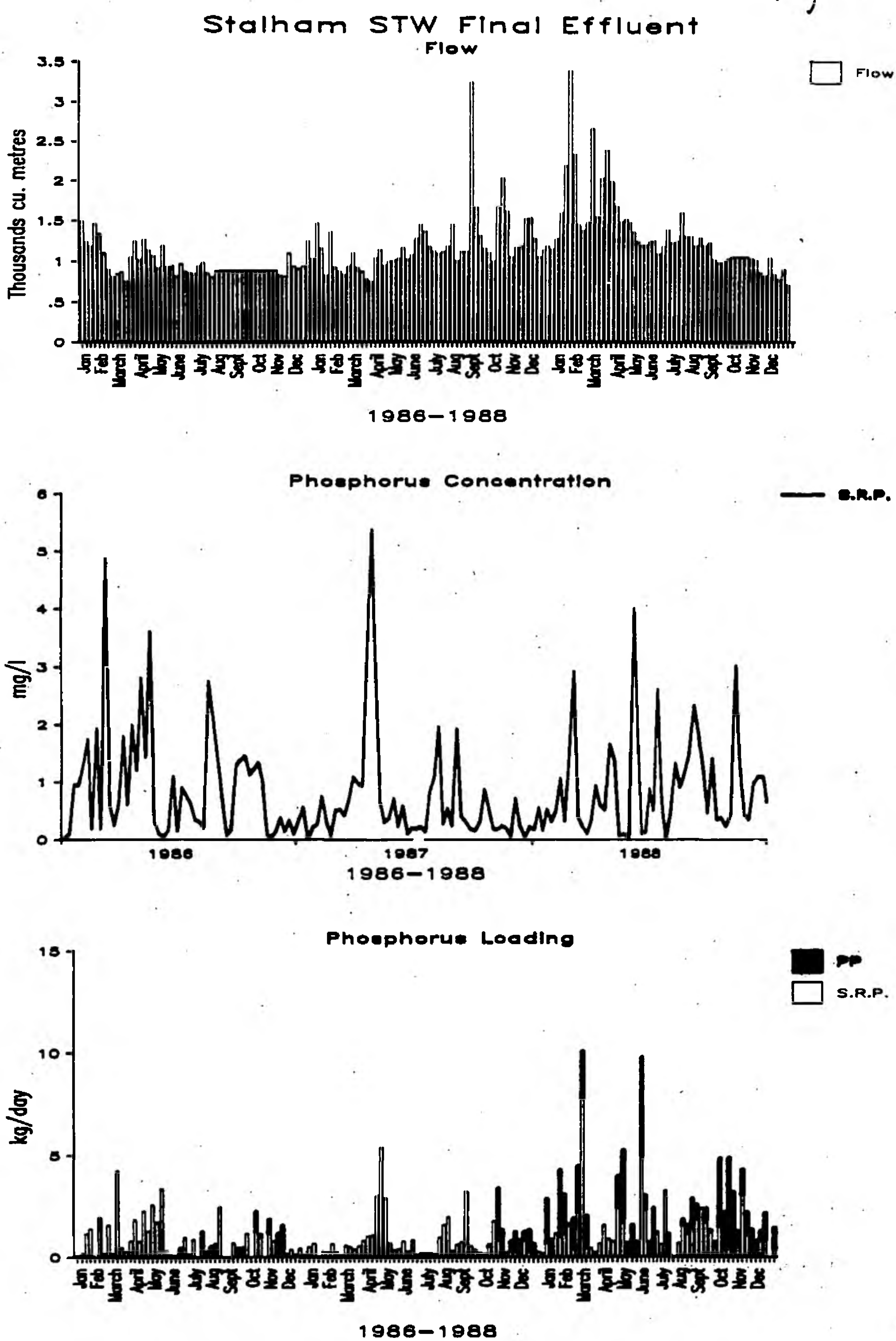

Belaugh STW Final Effluent
Flow
Flow
Thousands cu. metres
3.5
3
2.5
2
1.5
1
.5
0
1986–1988
Phosphorus Concentration
S.R.P.
mg/l
15
10
5
0
1986
1987
1988
1986–1988
Phosphorus Loading
PP
S.R.P.
kg/day
25
20
15
10
5
0
1986–1988

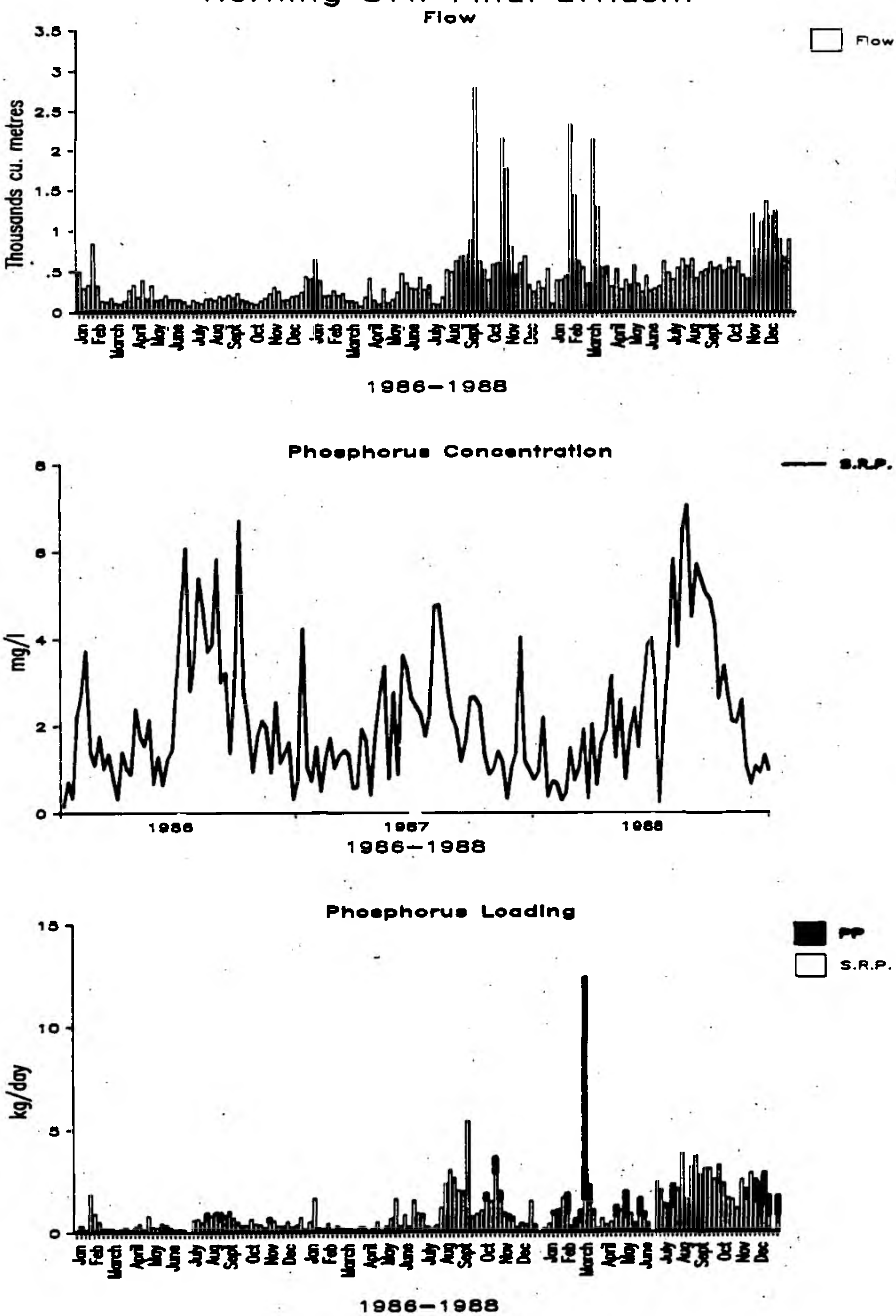
Fig 5

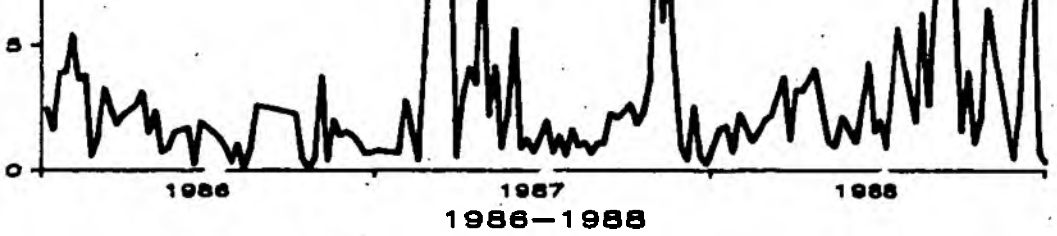


Stalham STW Final Effluent
Flow
Flow
Thousands cu. metres
1986—1988
Phosphorus Concentration
S.R.P.
mg/l
1986
1987
1988
1986—1988
Phosphorus Loading
PP
S.R.P.
kg/day
1986—1988

Fig 6

Horning STW Final Effluent




5
0
1986
1987
1988
1986—1988

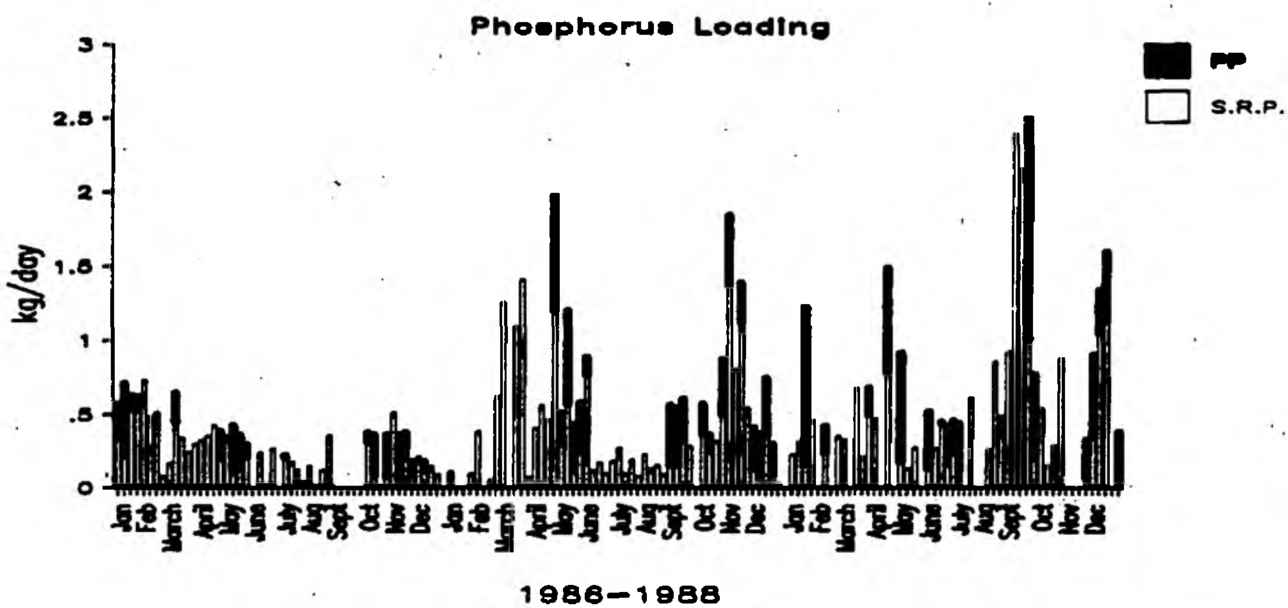
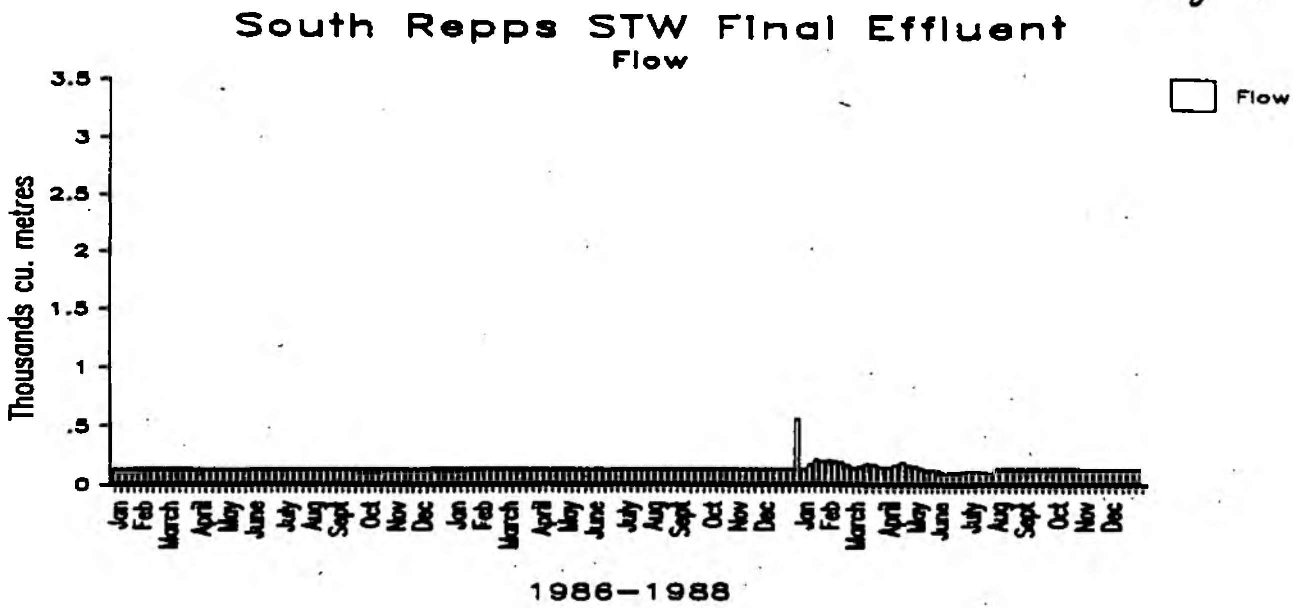

Phosphorus Loading
PP
S.R.P.
kg/day
0
.5
1
1.5
2
2.5
3
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
1986—1988

Fig 7


South Repps STW Final Effluent
Flow
Thousands cu. metres
Flow
1986—1988

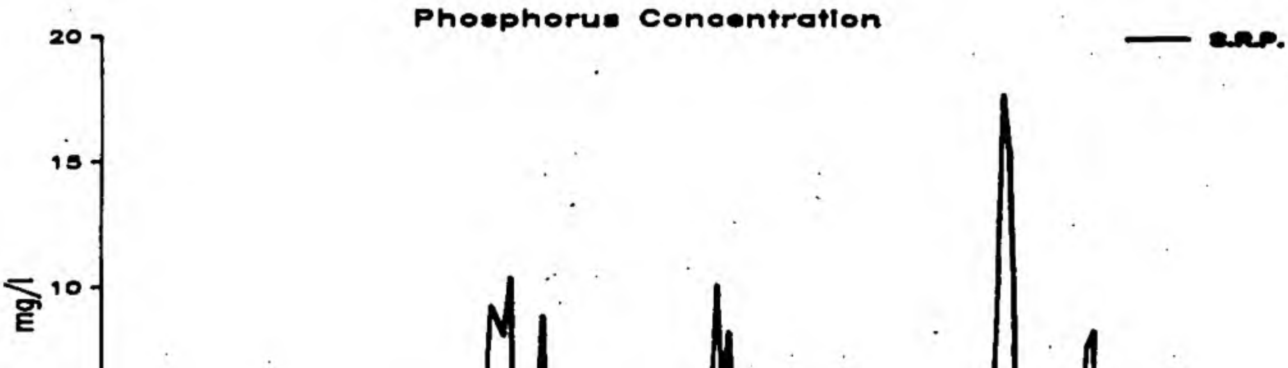
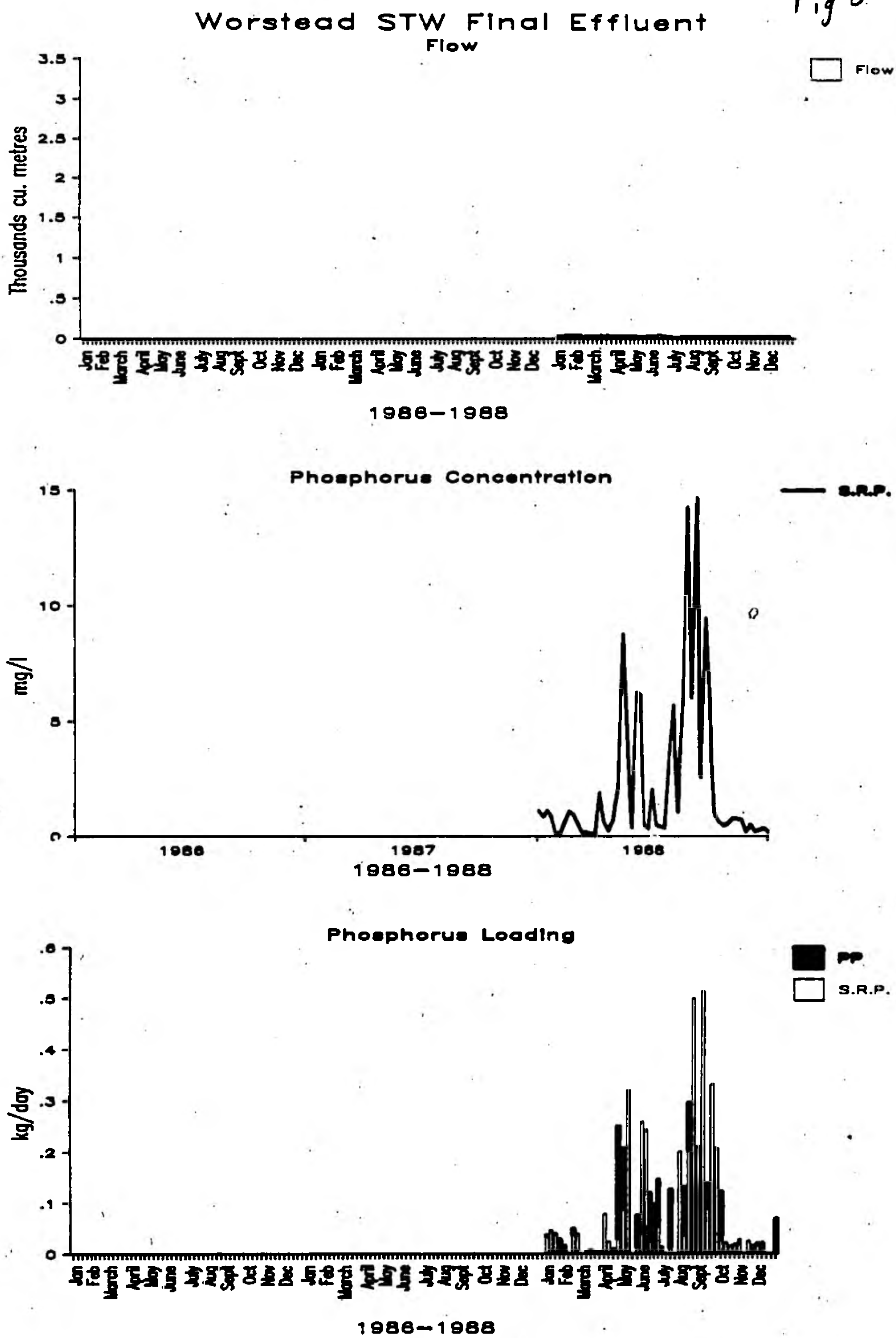

Phosphorus Concentration
mg/l
S.R.P.

Fig 8



Worstead STW Final Effluent
Flow
Flow
Thousands cu. metres
3.5
3
2.5
2
1.5
1
.5
0
1986—1988
Phosphorus Concentration
S.R.P.
mg/l
15
10
5
0
1986
1987
1988
1986—1988
Phosphorus Loading
PP
S.R.P.
kg/day
.6
.5
.4
.3
.2
.1
0
1986—1988

Fig 9

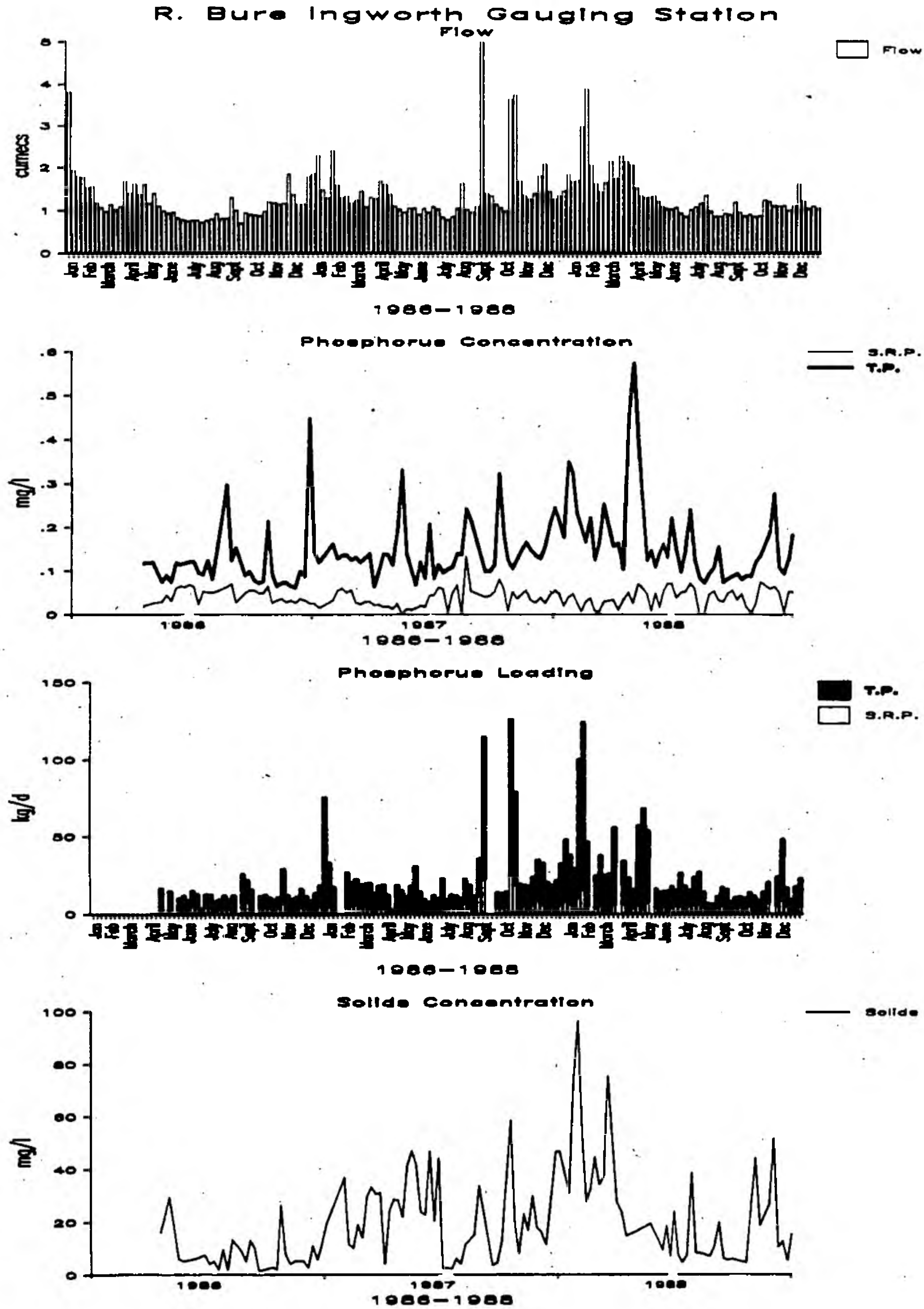

R. Bure Ingworth Gauging Station
Flow
Flow
cumecs
0
1
2
3
4
5
1986—1988
Phosphorus Concentration
S.R.P.
T.P.
mg/l
0
.1
.2
.3
.4
.5
.6
1986
1987
1988
1986—1988
Phosphorus Loading
T.P.
S.R.P.
kg/d
0
50
100
150
1986—1988
Solids Concentration
Solids
mg/l
0
20
40
60
80
100
1986
1987
1988
1986—1988

Fig 10

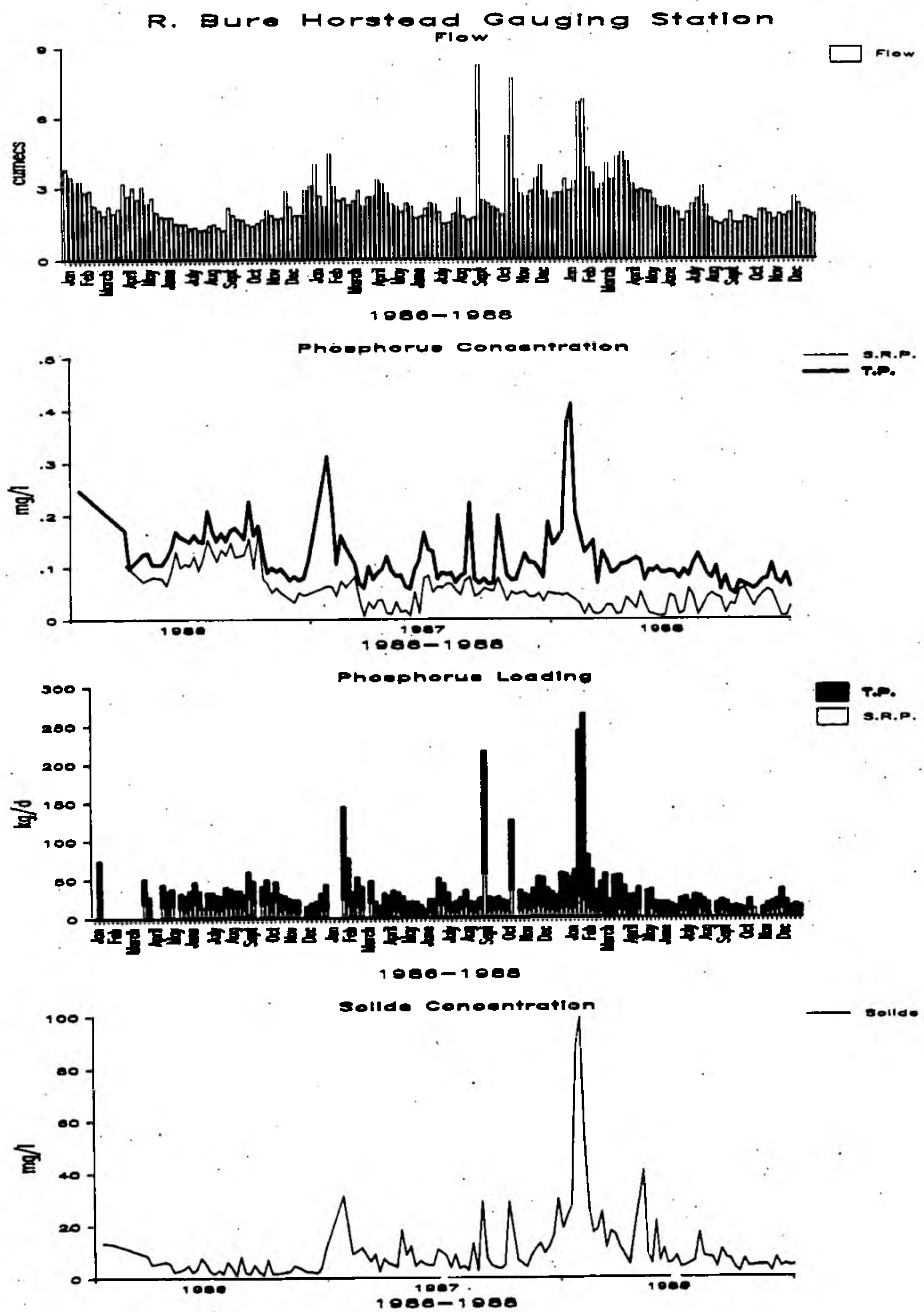

R. Bure Horstead Gauging Station
Flow
Flow
cumecs
9
6
3
0
1986—1988
Phosphorus Concentration
S.R.P.
T.P.
mg/l
.5
.4
.3
.2
.1
0
1986
1987
1988
1986—1988
Phosphorus Loading
T.P.
S.R.P.
kg/d
300
250
200
150
100
50
0
1986—1988
Solids Concentration
Solids
mg/l
100
80
60
40
20
0
1986
1987
1988
1986—1988

Fig 11

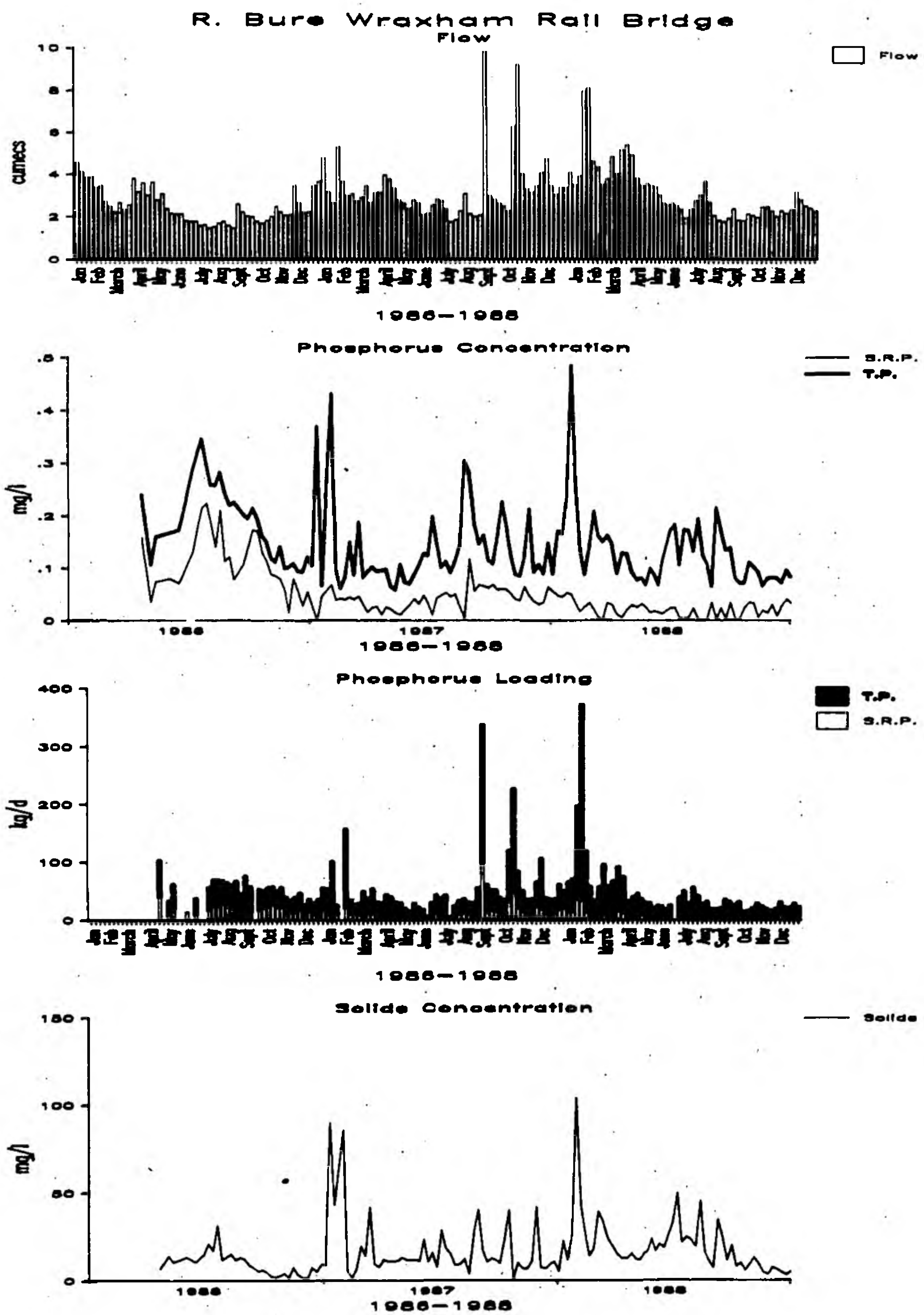

R. Bure Wraxham Rail Bridge
Flow
Flow
cumecs
1986—1988
Phosphorus Concentration
S.R.P.
T.P.
mg/l
1986
1987
1988
1986—1988
Phosphorus Loading
T.P.
S.R.P.
kg/d
1986—1988
Solids Concentration
Solids
mg/l
1986
1987
1988
1986—1988

Fig 12

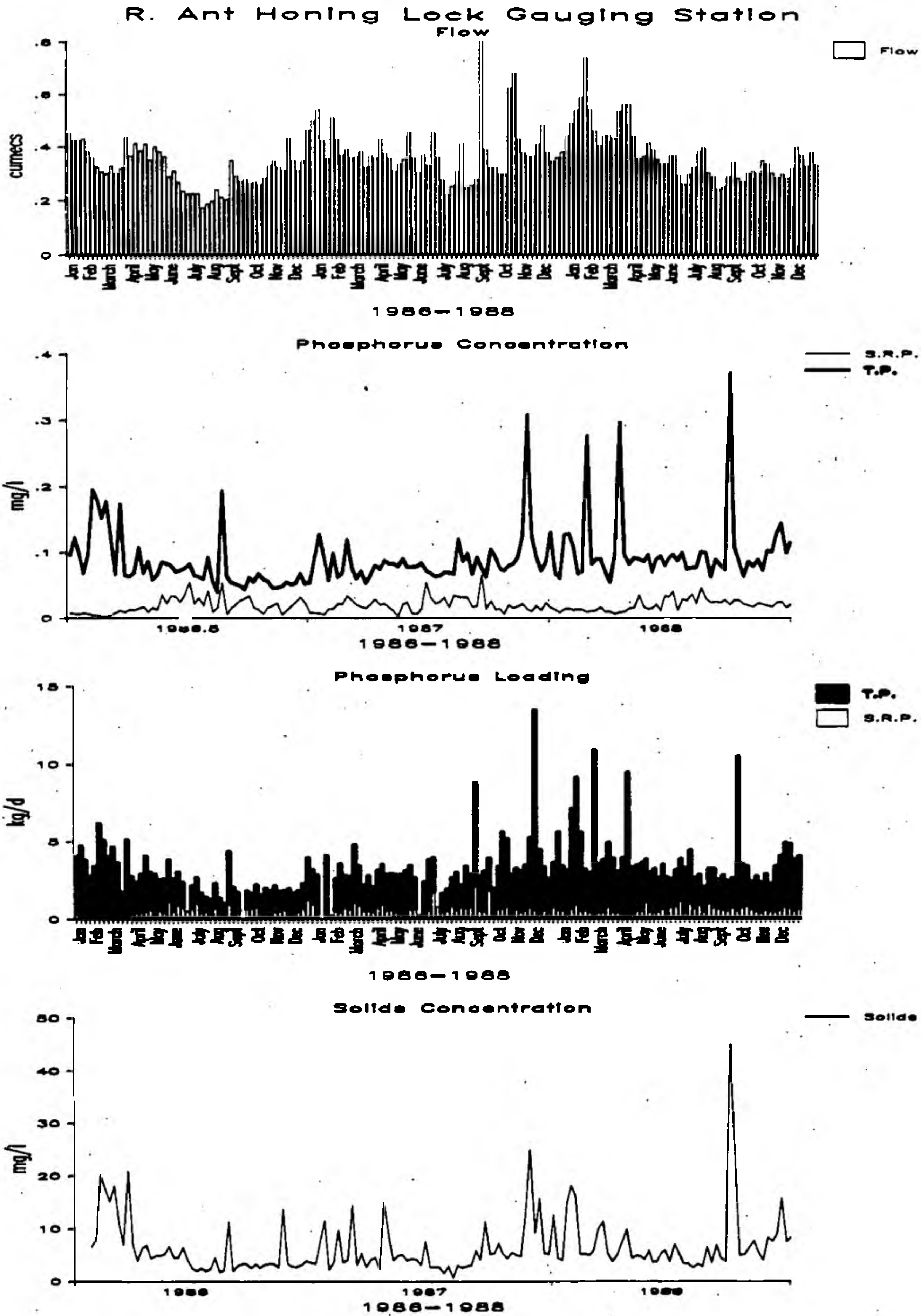
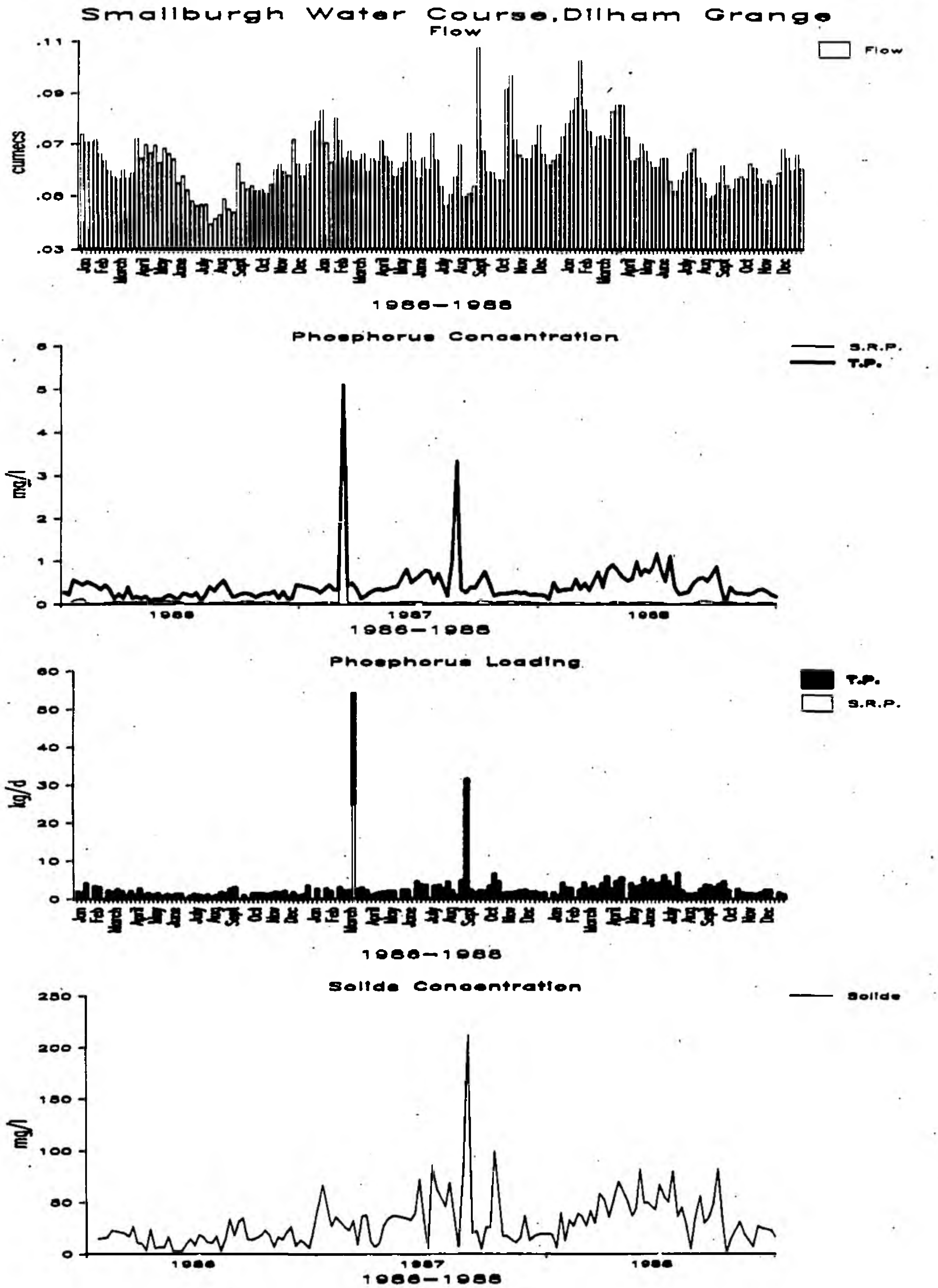

R. Ant Honing Lock Gauging Station
Flow
Flow
cumecs
.8
.6
.4
.2
0
1986—1988
Phosphorus Concentration
S.R.P.
T.P.
mg/l
.4
.3
.2
.1
0
1986.5
1987
1988
1986—1988
Phosphorus Loading
T.P.
S.R.P.
kg/d
15
10
5
0
1986—1988
Solids Concentration
Solids
mg/l
50
40
30
20
10
0
1986
1987
1988
1986—1988

Fig 13



Smallburgh Water Course, Dilham Grange
Flow
Flow
cumecs
.11
.09
.07
.05
.03
1986—1988
Phosphorus Concentration
S.R.P.
T.P.
mg/l
0
1
2
3
4
5
6
1986
1987
1988
1986—1988
Phosphorus Loading
T.P.
S.R.P.
kg/d
0
10
20
30
40
50
60
1986—1988
Solids Concentration
Solids
mg/l
0
50
100
150
200
250
1986
1987
1988
1986—1988

Fig 14 a

TOTAL and SOLUBLE PHOSPHORUS

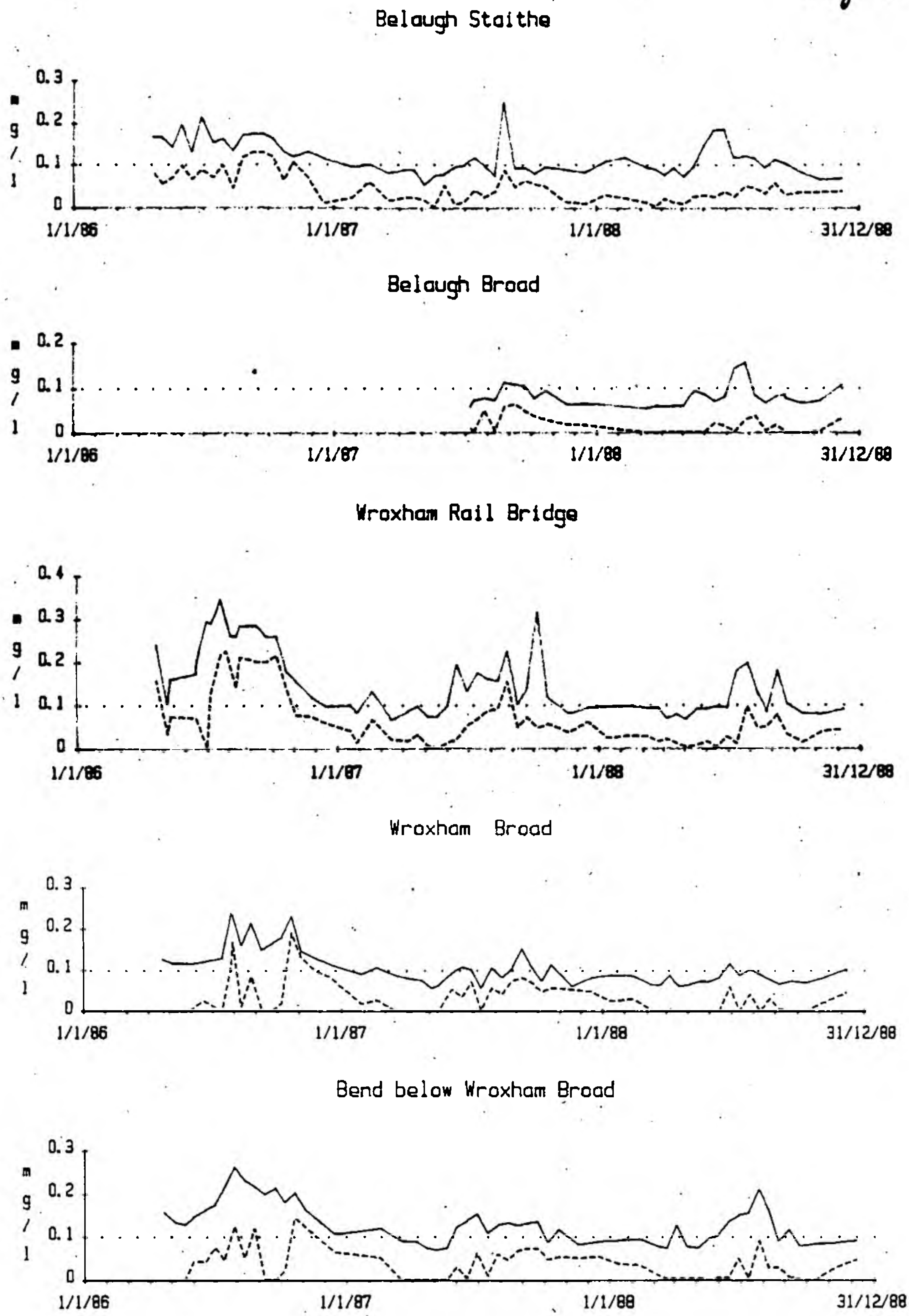


Fig 14 b

TOTAL and SOLUBLE PHOSPHORUS

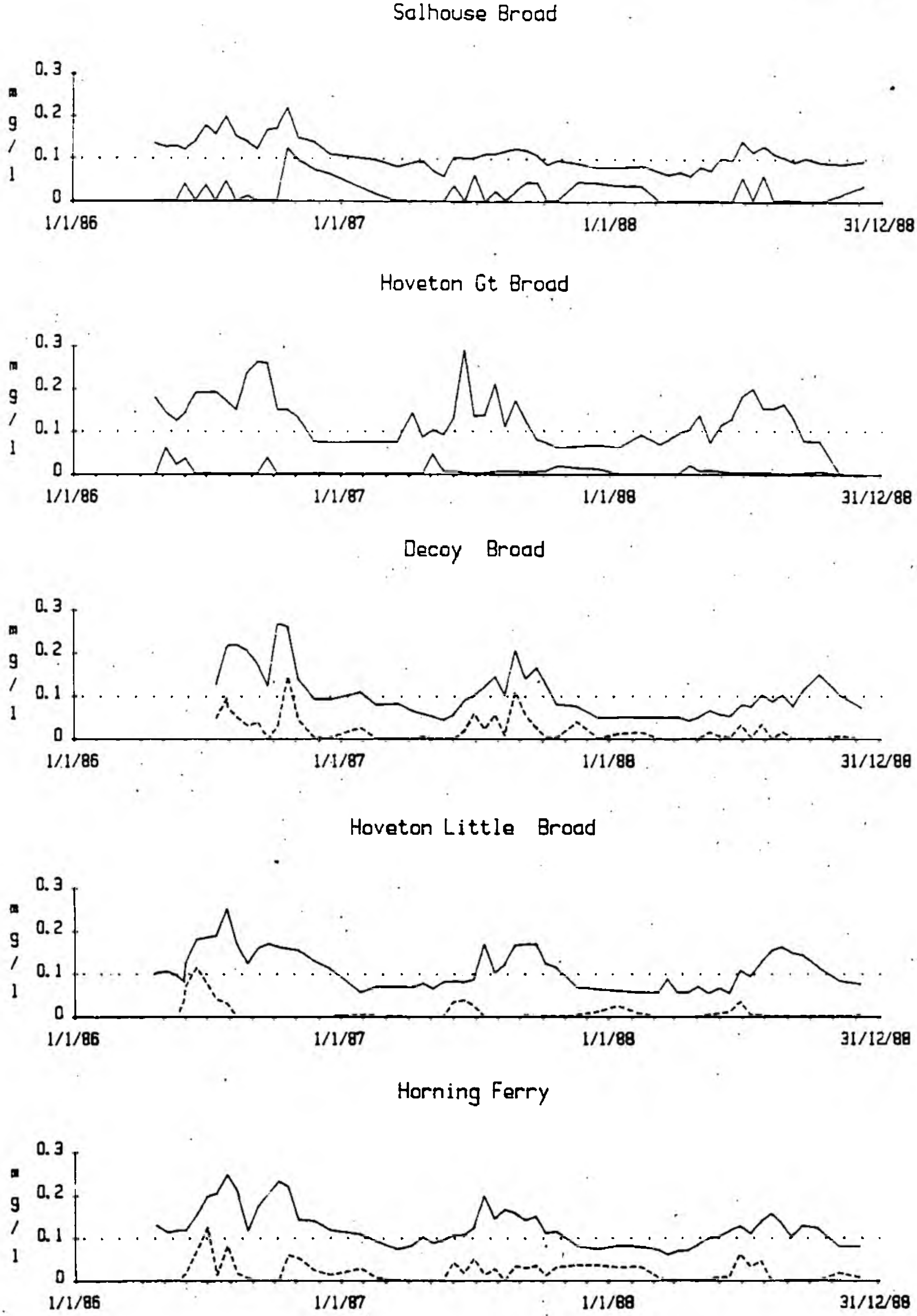


Fig 14c

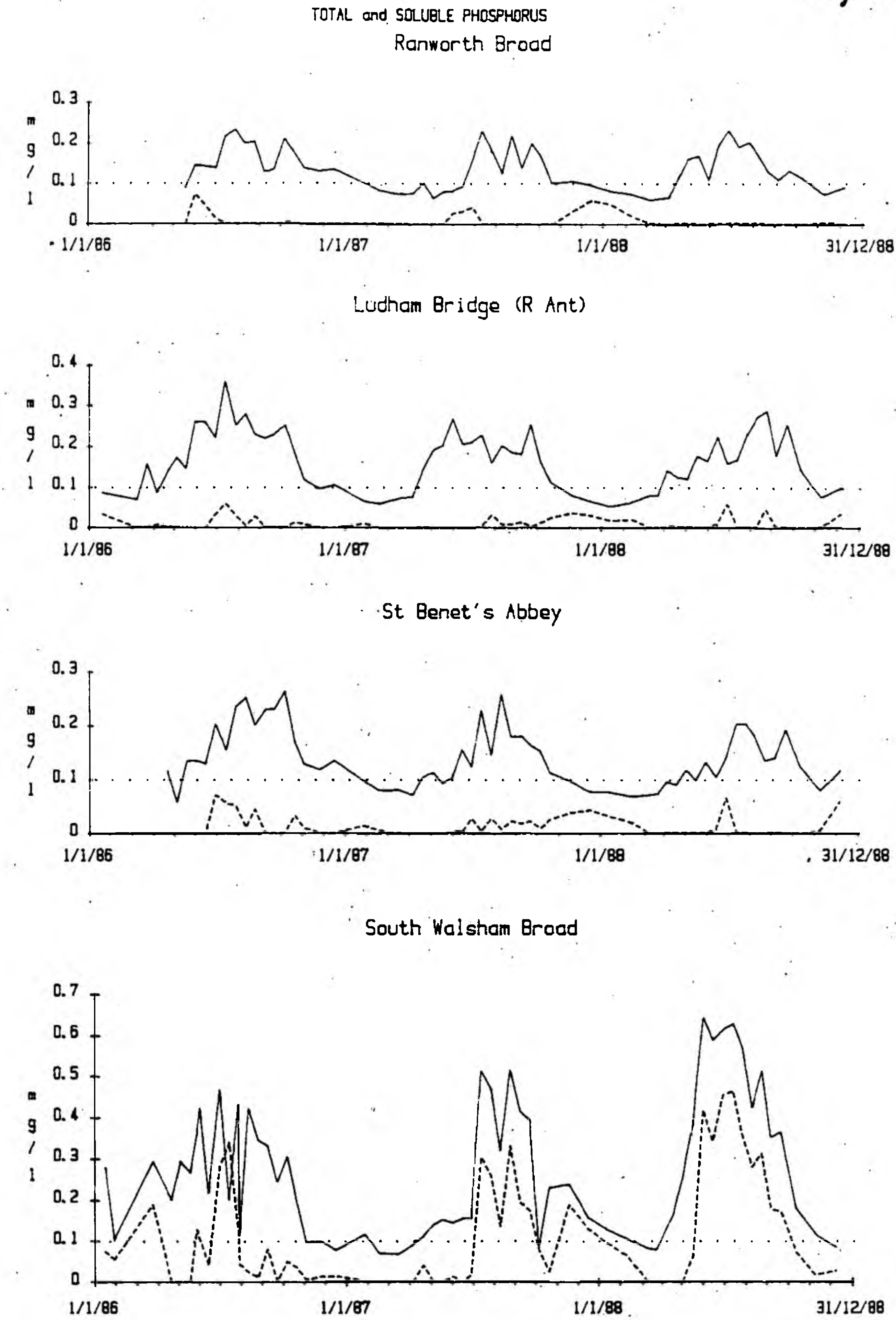
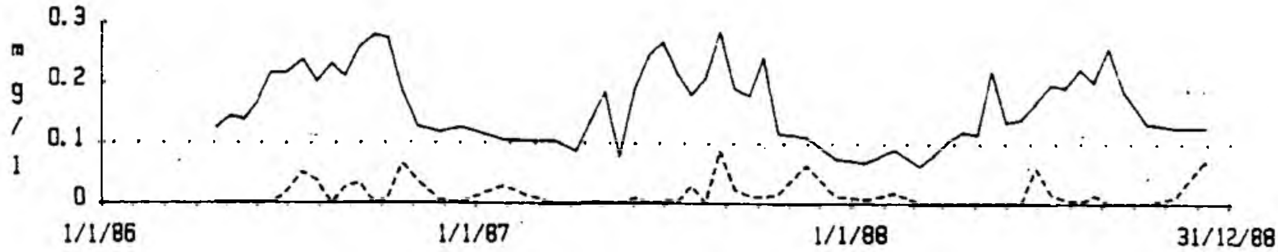

TOTAL and SOLUBLE PHOSPHORUS
Ranworth Broad
0.3
0.2
0.1
0
m
g
/
l
1/1/86
1/1/87
1/1/88
31/12/88
Ludham Bridge (R Ant)
0.4
0.3
0.2
0.1
0
1/1/86
1/1/87
1/1/88
31/12/88
St Benet's Abbey
0.3
0.2
0.1
0
1/1/86
1/1/87
1/1/88
31/12/88
South Walsham Broad
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1/1/86
1/1/87
1/1/88
31/12/88

Fig 14d

TOTAL and SOLUBLE PHOSPHORUS

Thurne Mouth (R Thurne)



Acle Bridge

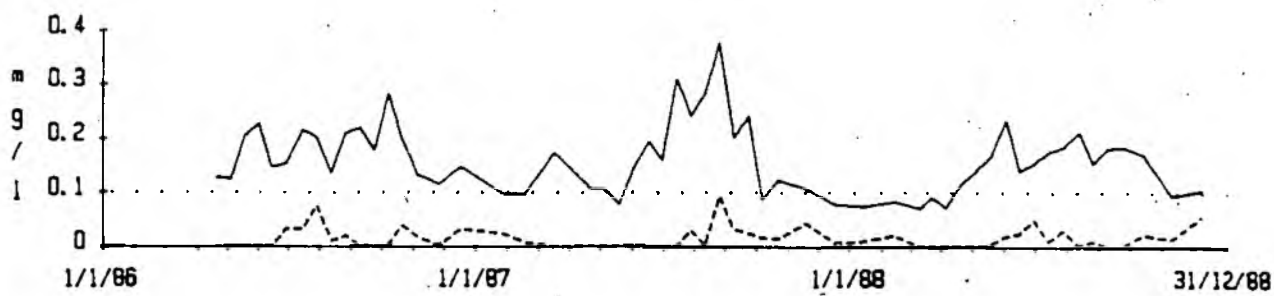
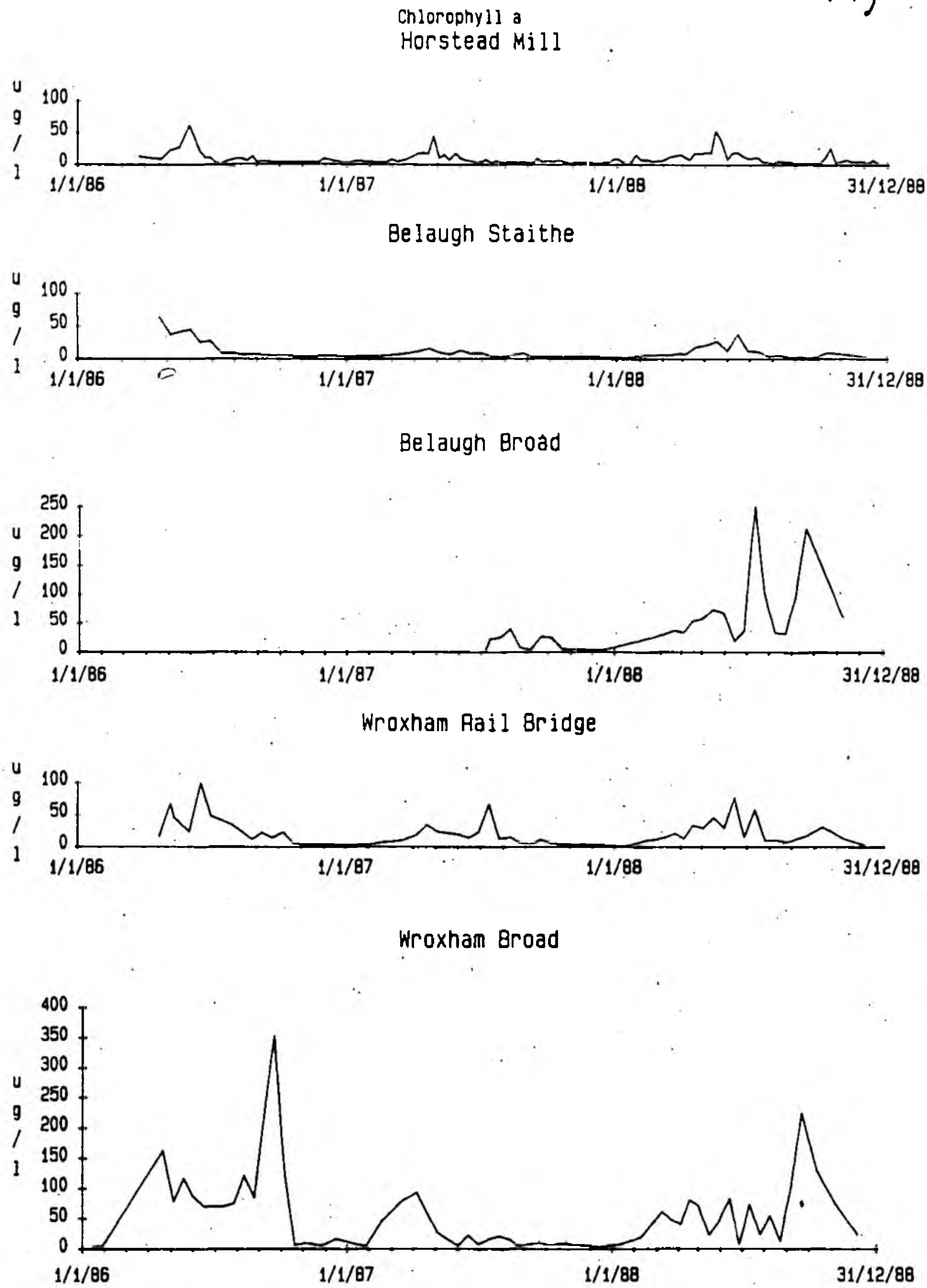


Fig 15 a



Chlorophyll a
Horstead Mill
ug/l
100
50
0
1/1/86
1/1/87
1/1/88
31/12/88
Belaugh Staithe
ug/l
100
50
0
1/1/86
1/1/87
1/1/88
31/12/88
Belaugh Broad
ug/l
250
200
150
100
50
0
1/1/86
1/1/87
1/1/88
31/12/88
Wroxham Rail Bridge
ug/l
100
50
0
1/1/86
1/1/87
1/1/88
31/12/88
Wroxham Broad
ug/l
400
350
300
250
200
150
100
50
0
1/1/86
1/1/87
1/1/88
31/12/88

Fig 15b

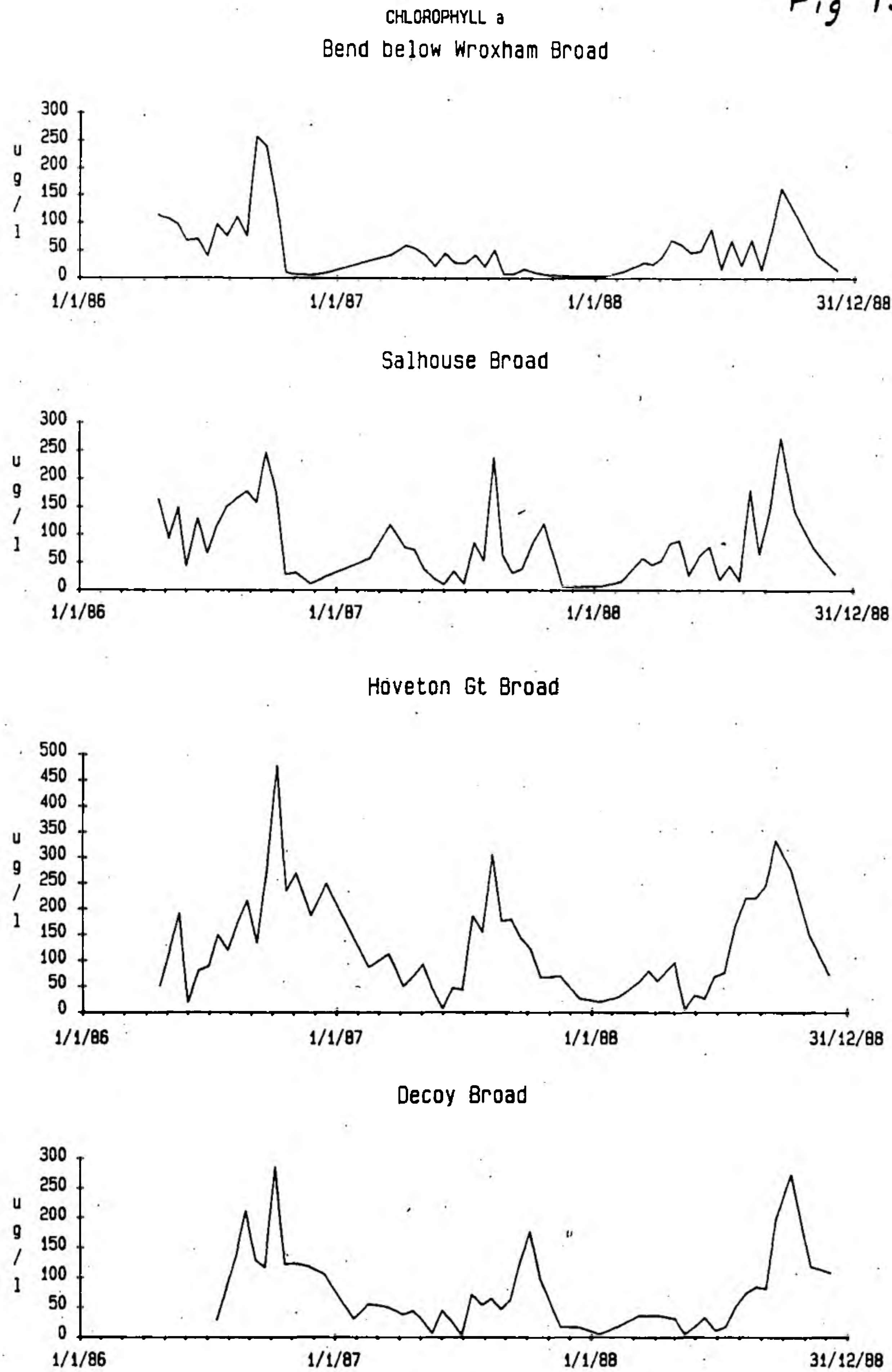
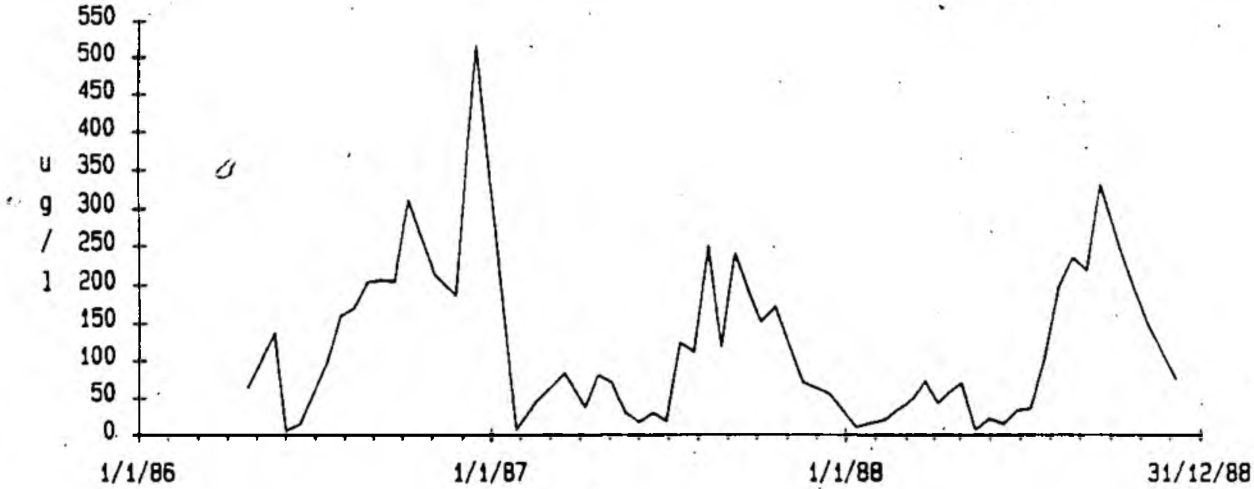

CHLOROPHYLL a
Bend below Wroxham Broad
Salhouse Broad
Hoveton Gt Broad
Decoy Broad
ug/l
0
50
100
150
200
250
300
350
400
450
500
1/1/86
1/1/87
1/1/88
31/12/88

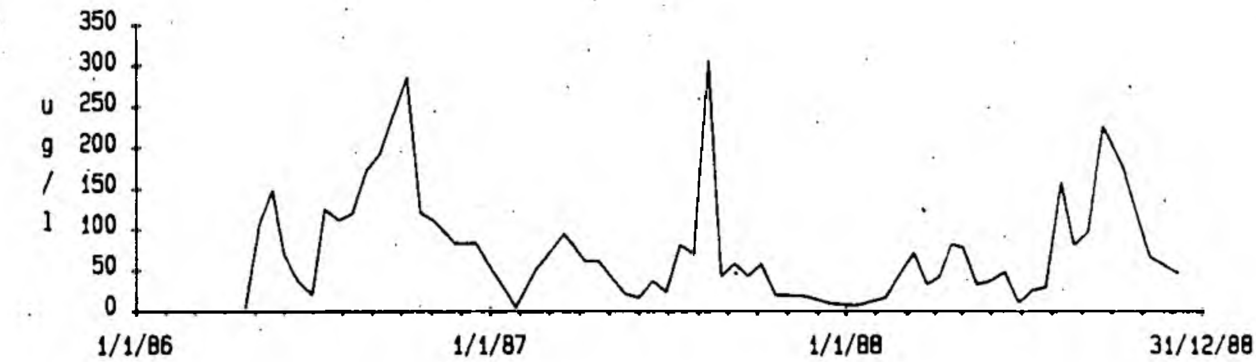
Fig 15c

CHLOROPHYLL a

Hoveton Little Broad



Horning Ferry



Ranworth Broad

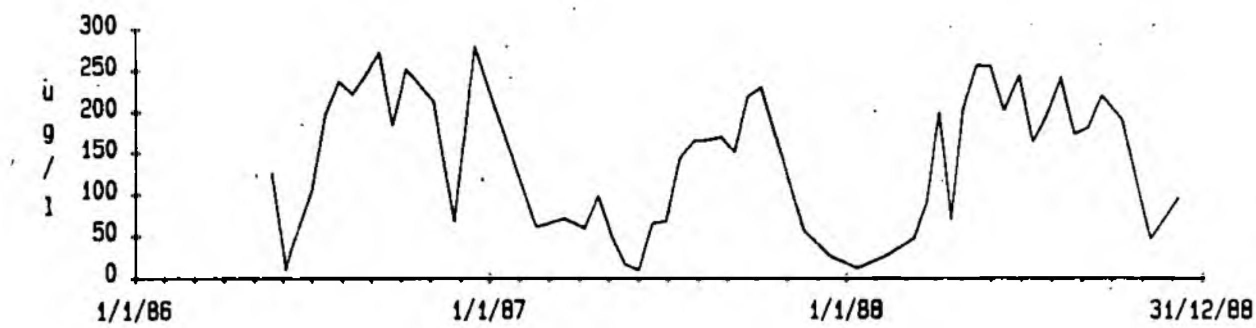
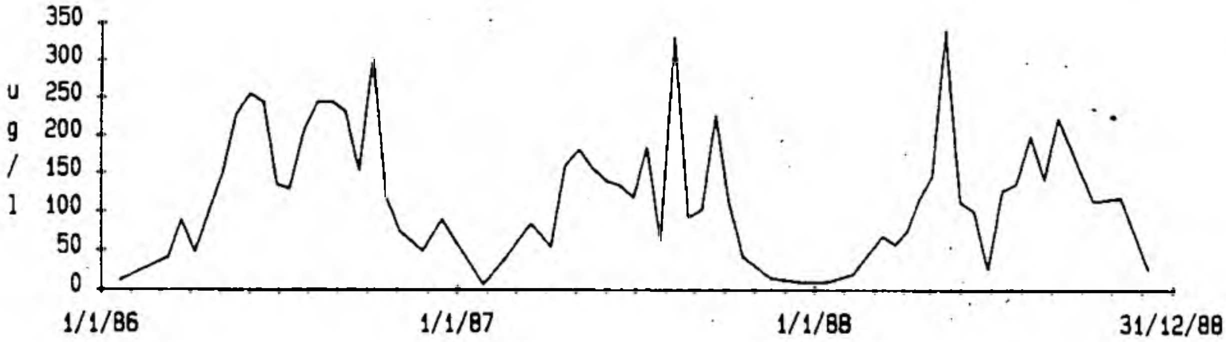


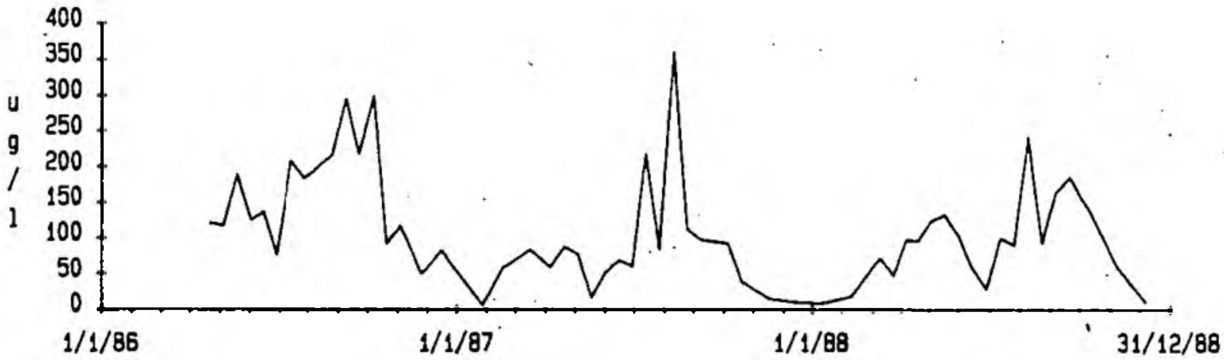
Fig 15 d

CLOROPHYLL a

Ludham Bridge (R Ant)



St Benet's Abbey



South Walsham Broad

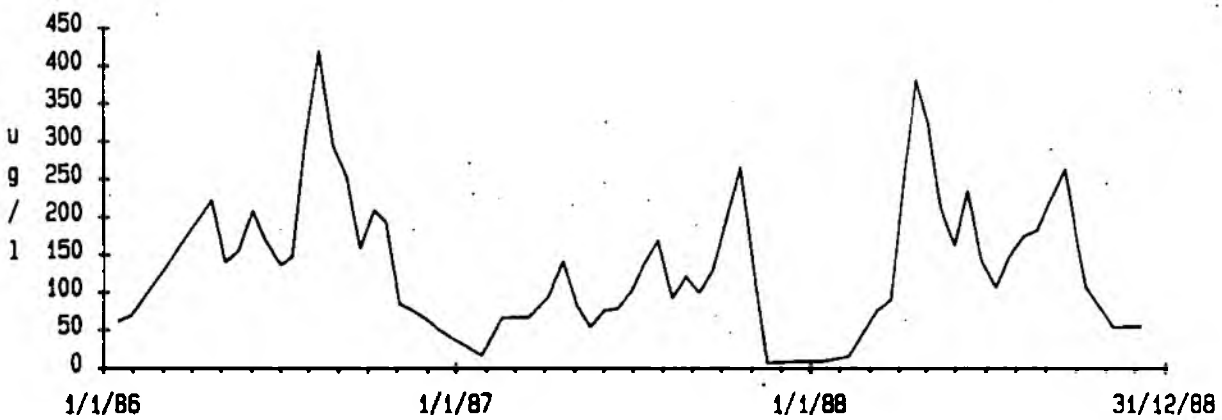
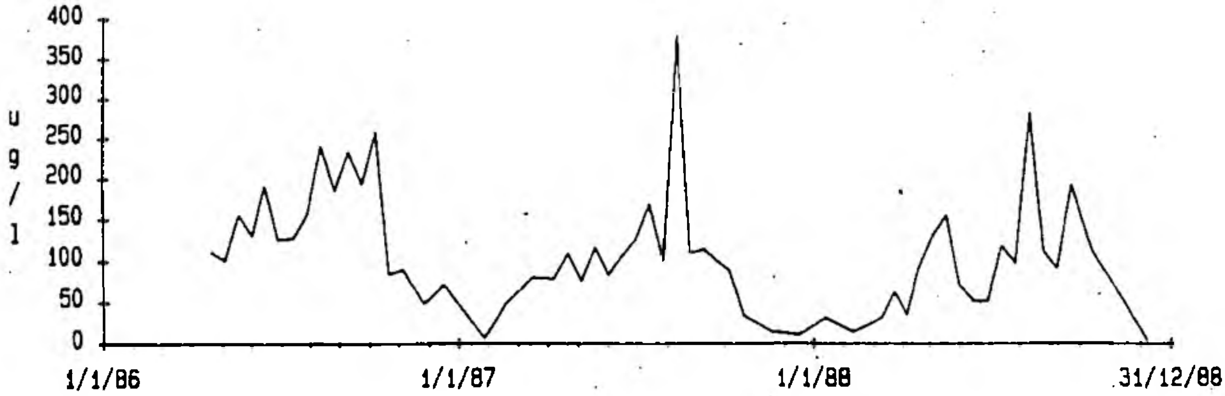


Fig 15 e

CHLOROPHYLL a

Thurne Mouth (R Thurne)



Acle Bridge

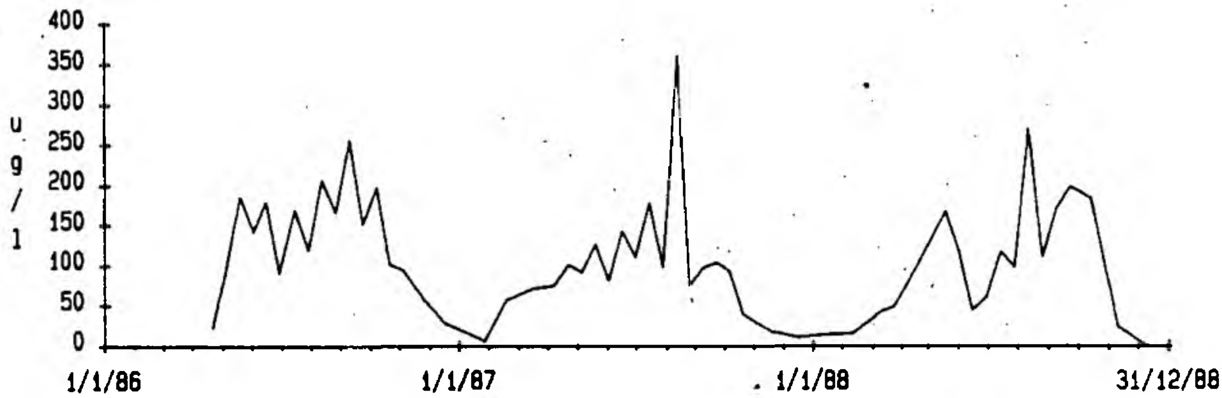


Fig 16a

TOTAL OXIDISED NITROGEN

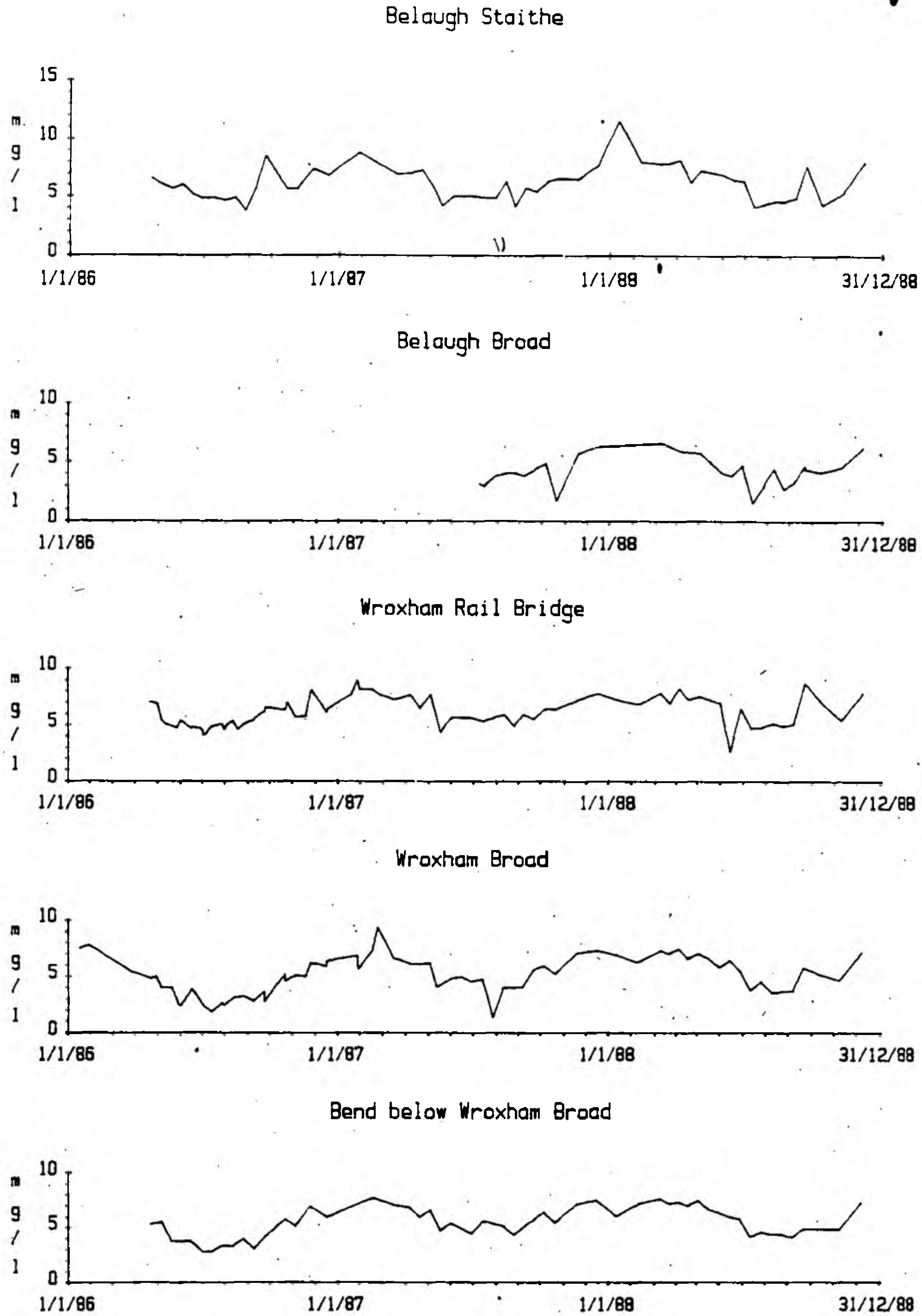
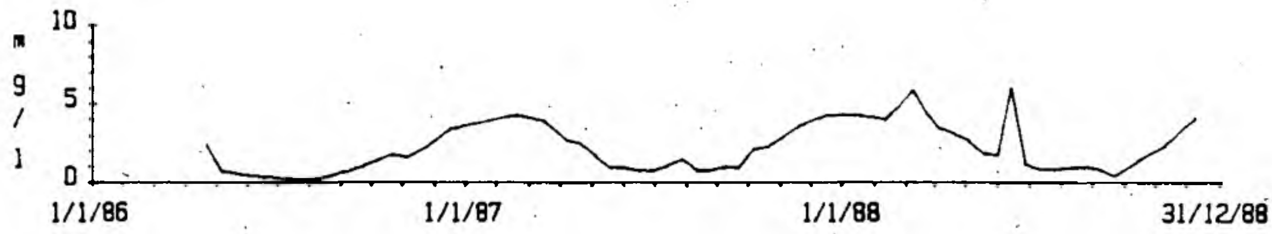


Fig 16 b

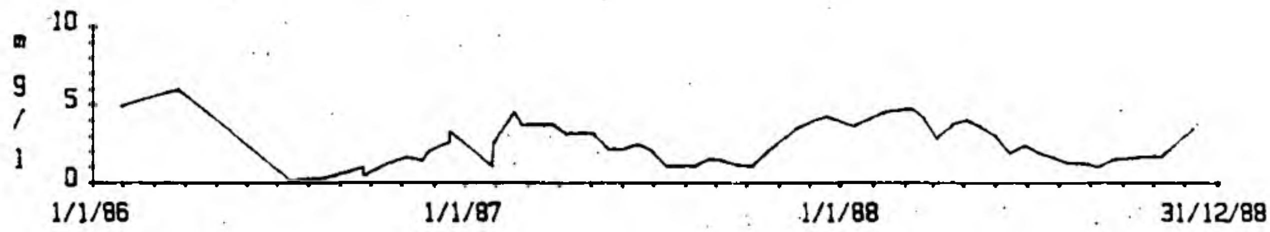
TOTAL OXIDISED NITROGEN

Salhouse Broad

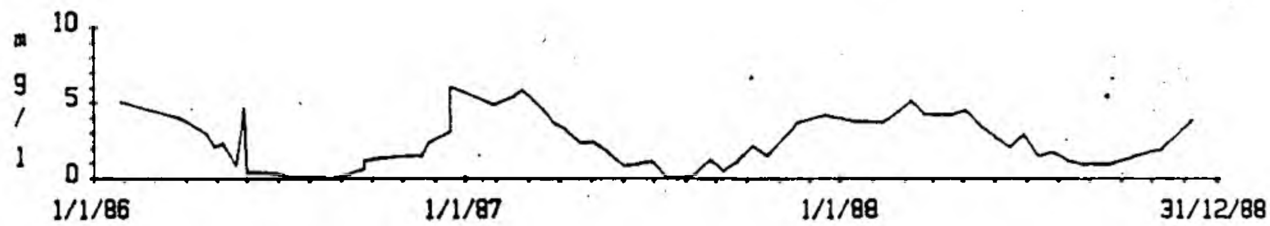
Hoveton Gt Broad



Decoy Broad



Hoveton Little Broad



Horning Ferry

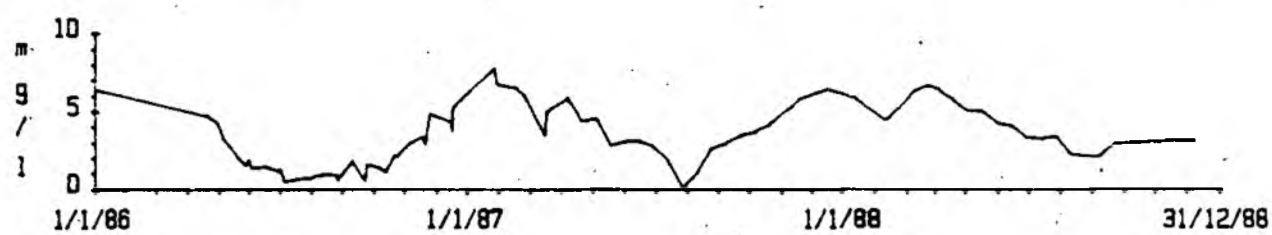
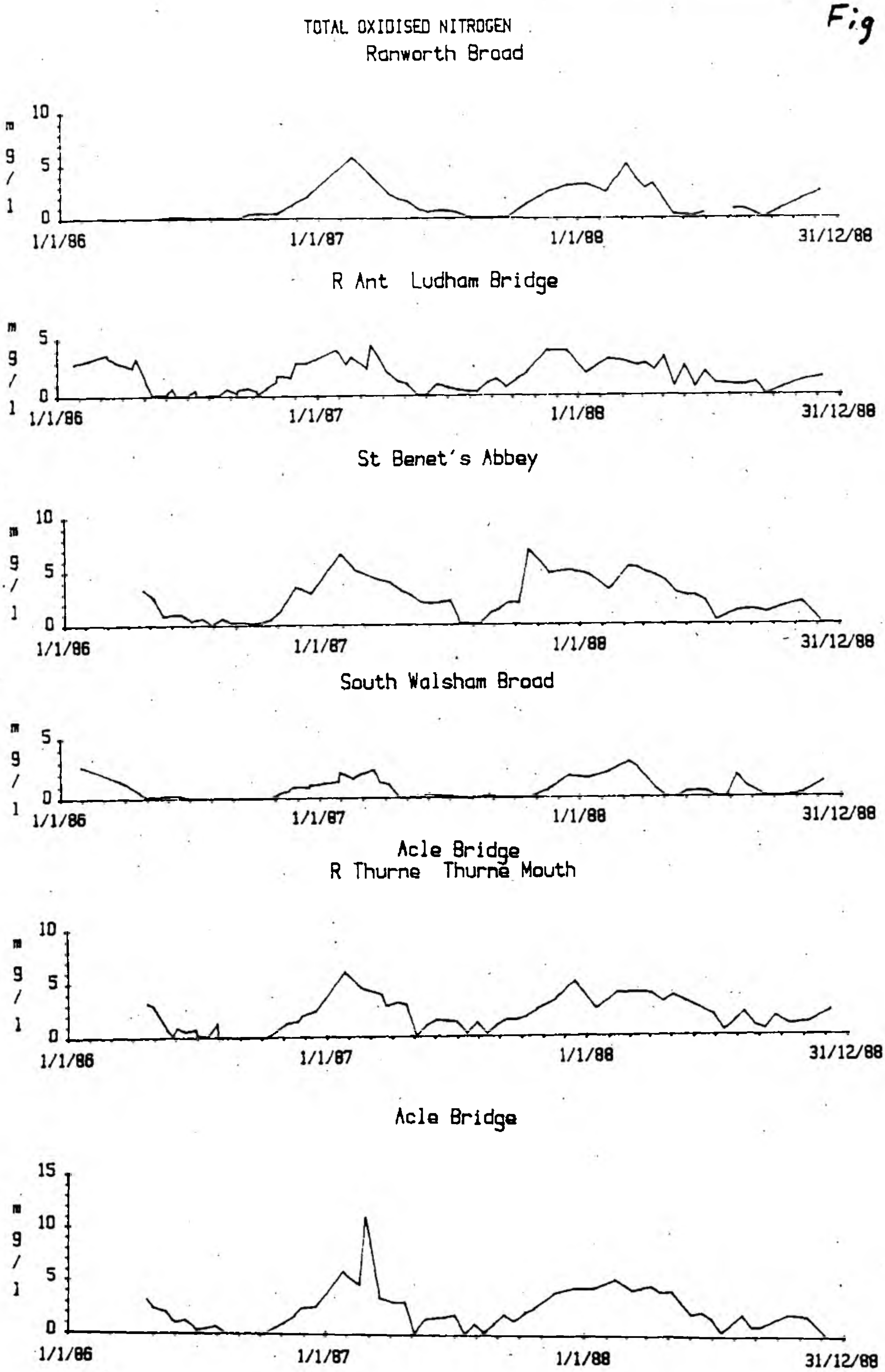


Fig 16c



TOTAL OXIDISED NITROGEN
Ranworth Broad
mg/l
10
5
0
1/1/86
1/1/87
1/1/88
31/12/88
R Ant Ludham Bridge
mg/l
5
0
1/1/86
1/1/87
1/1/88
31/12/88
St Benet's Abbey
mg/l
10
5
0
1/1/86
1/1/87
1/1/88
31/12/88
South Walsham Broad
mg/l
5
0
1/1/86
1/1/87
1/1/88
31/12/88
Acle Bridge
R Thurne Thurne Mouth
mg/l
10
5
0
1/1/86
1/1/87
1/1/88
31/12/88
Acle Bridge
mg/l
15
10
5
0
1/1/86
1/1/87
1/1/88
31/12/88

Fig 17 a

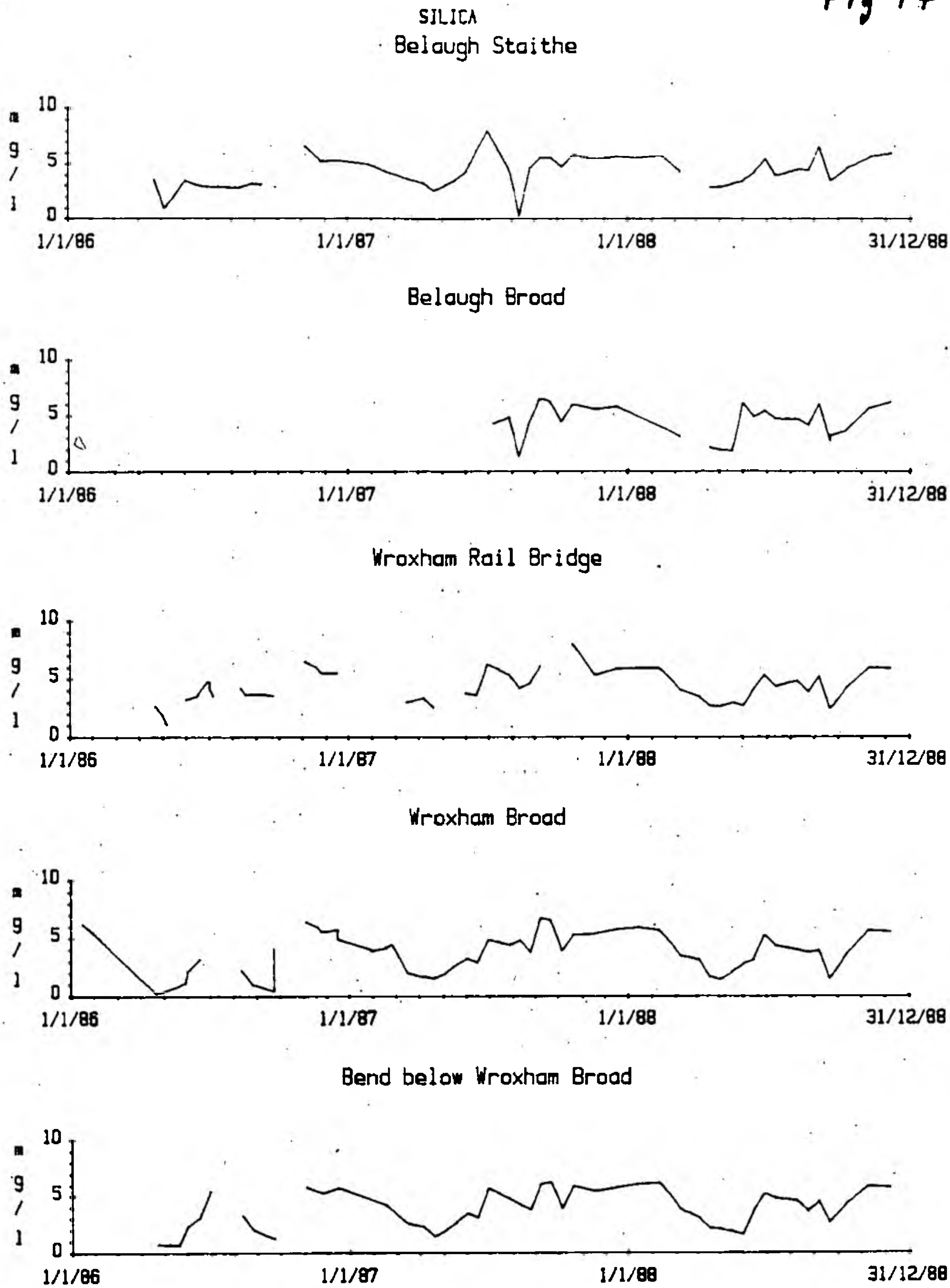

SILICA
Belaugh Staithe
mg/l
10
5
0
1/1/86
1/1/87
1/1/88
31/12/88
Belaugh Broad
mg/l
10
5
0
1/1/86
1/1/87
1/1/88
31/12/88
Wroxham Rail Bridge
mg/l
10
5
0
1/1/86
1/1/87
1/1/88
31/12/88
Wroxham Broad
mg/l
10
5
0
1/1/86
1/1/87
1/1/88
31/12/88
Bend below Wroxham Broad
mg/l
10
5
0
1/1/86
1/1/87
1/1/88
31/12/88

Fig 17 b

SILICA

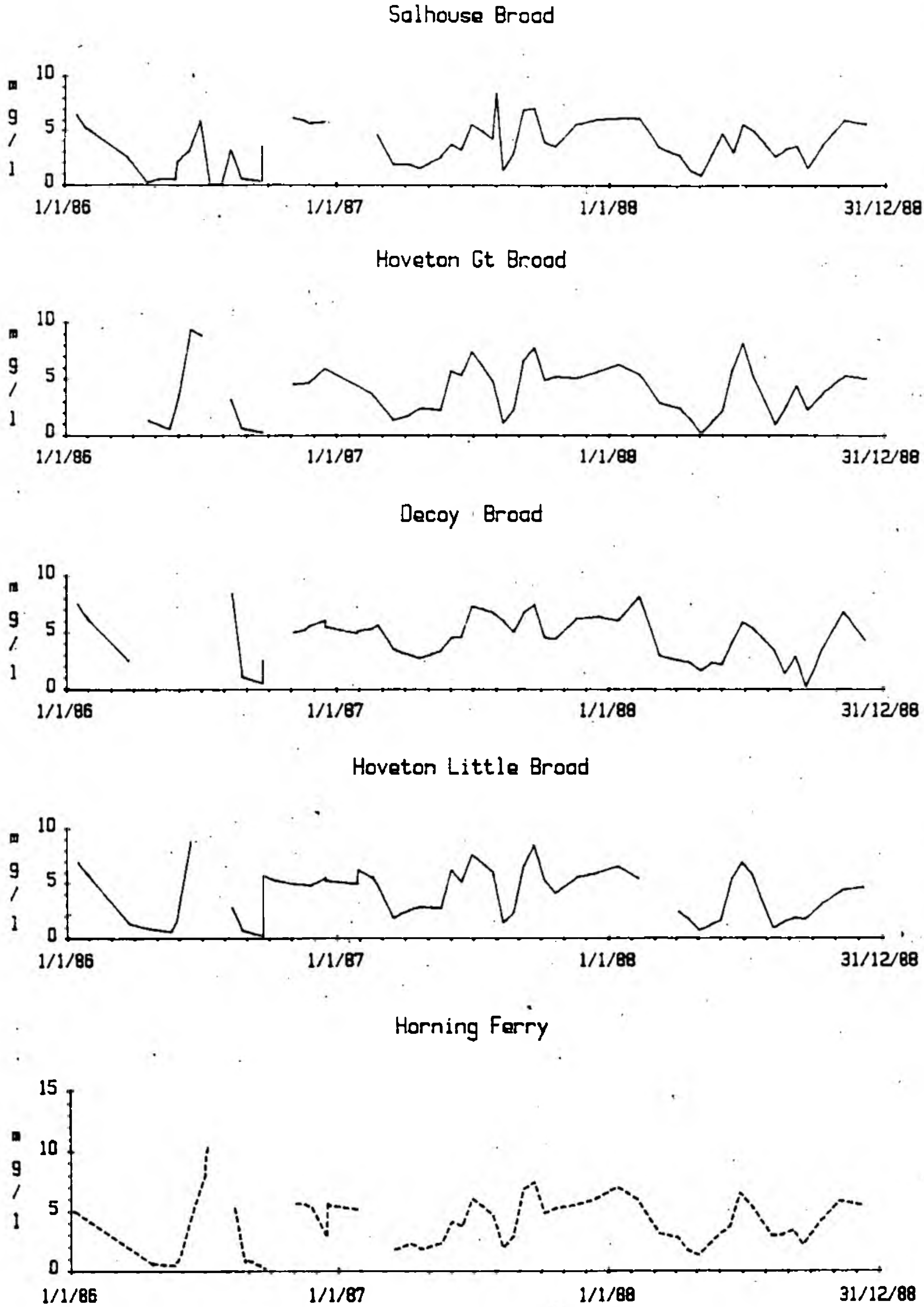


Fig 17c

SILICA

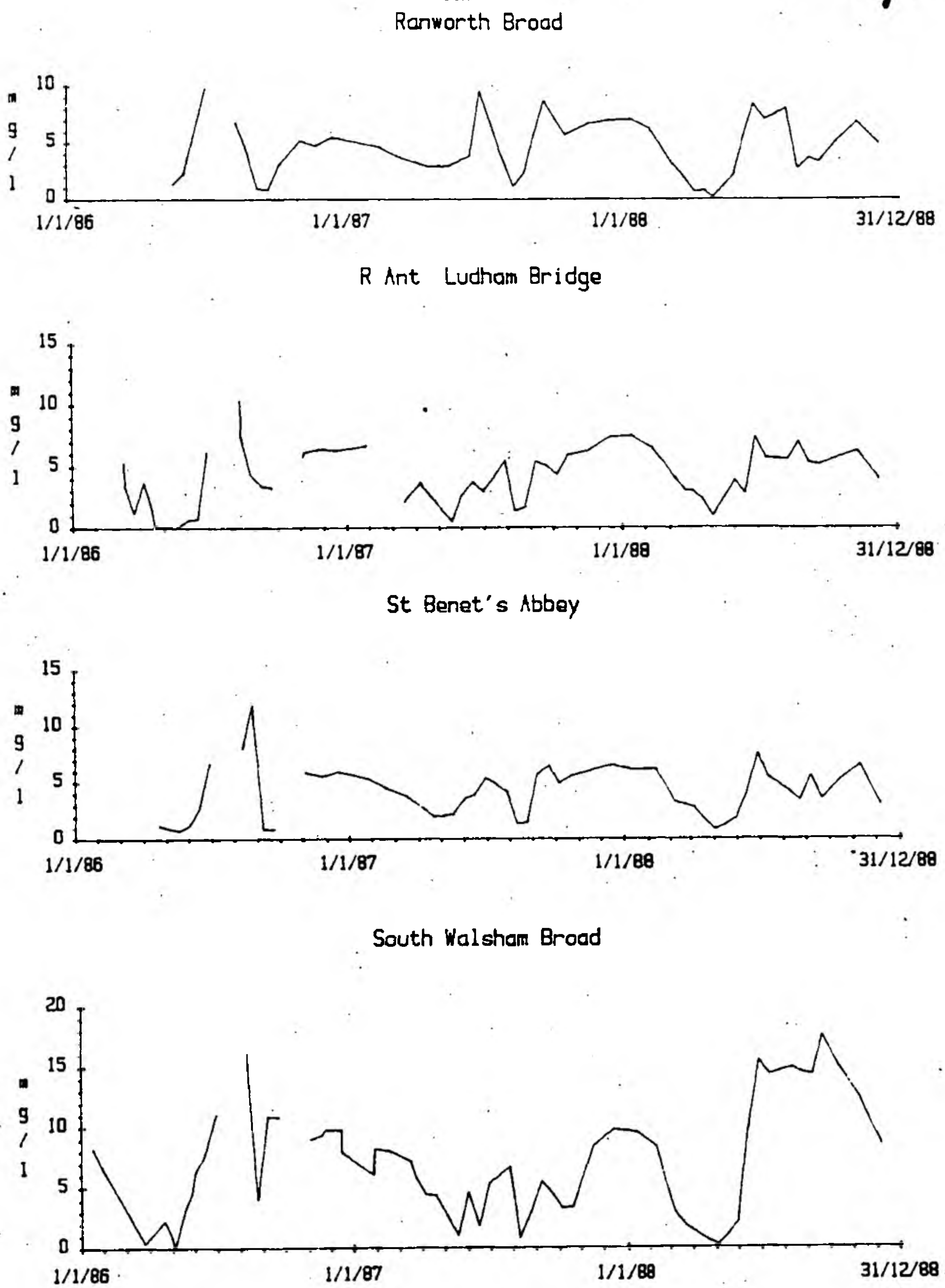


Fig 17 d

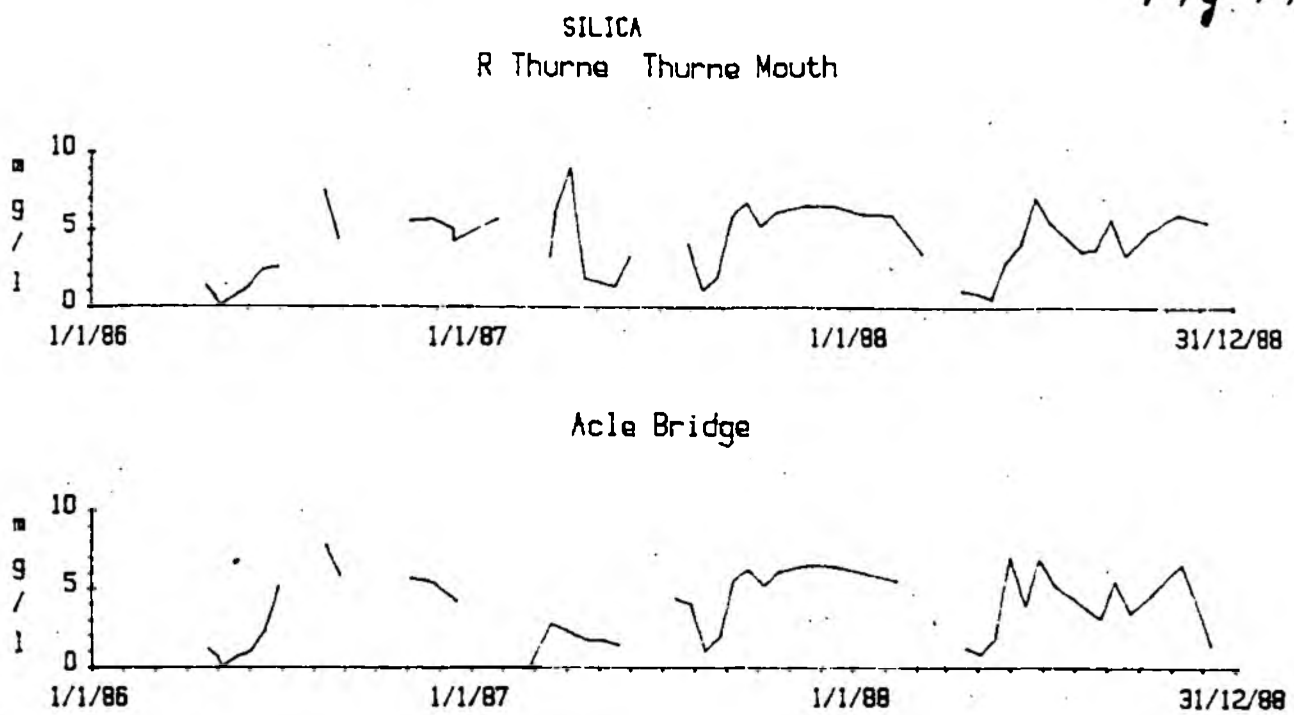
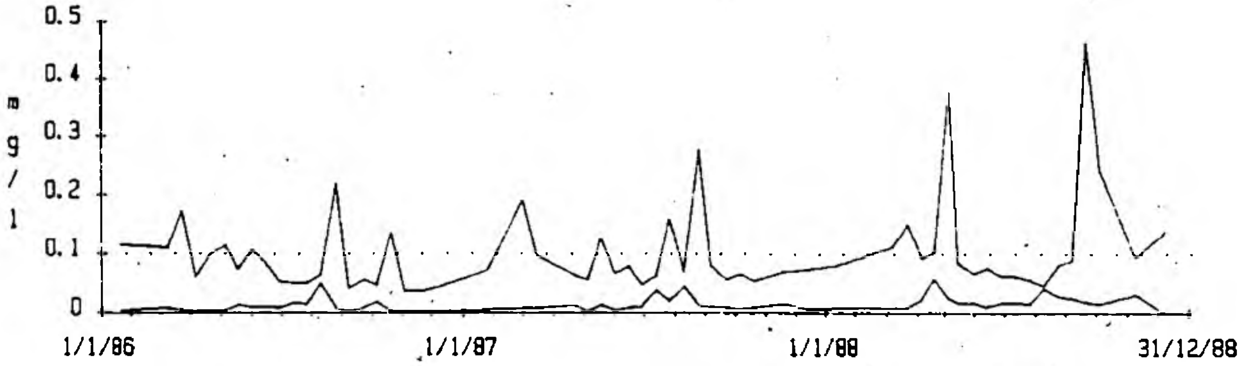

SILICA
R Thurne Thurne Mouth
10
5
0
mg/l
1/1/86
1/1/87
1/1/88
31/12/88
Acle Bridge
10
5
0
mg/l
1/1/86
1/1/87
1/1/88
31/12/88

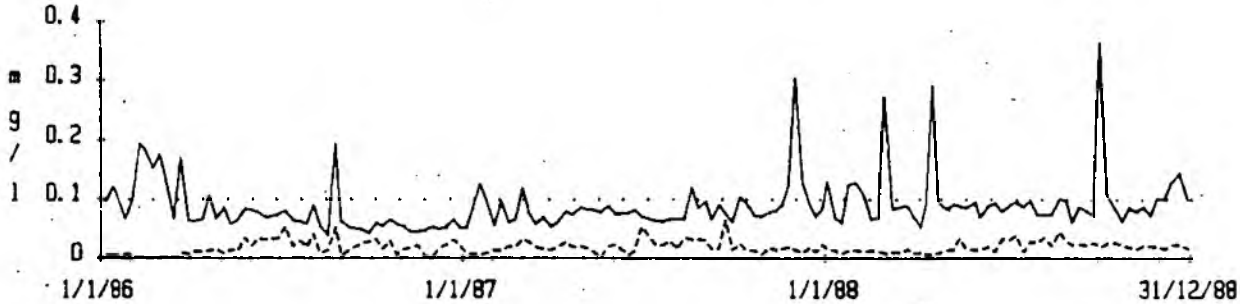
Fig 18a

Total and Soluble Phosphorus

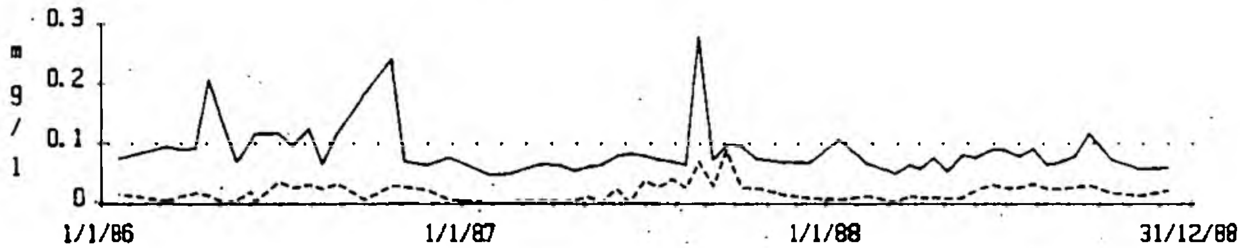
B1135 Bridge, North Walsham



Honing Lock



Wayford Bridge



Hunset Mill

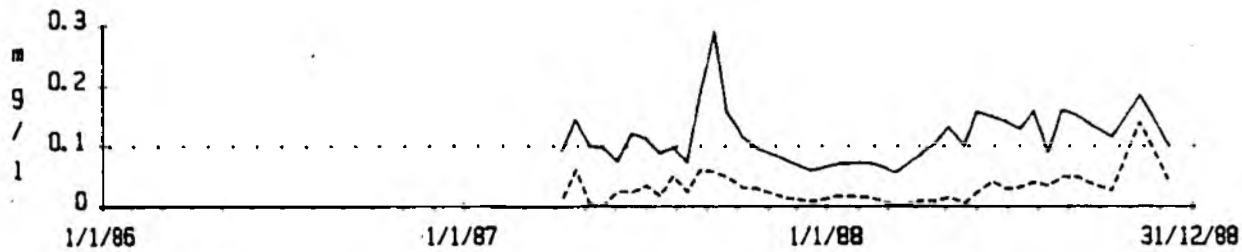
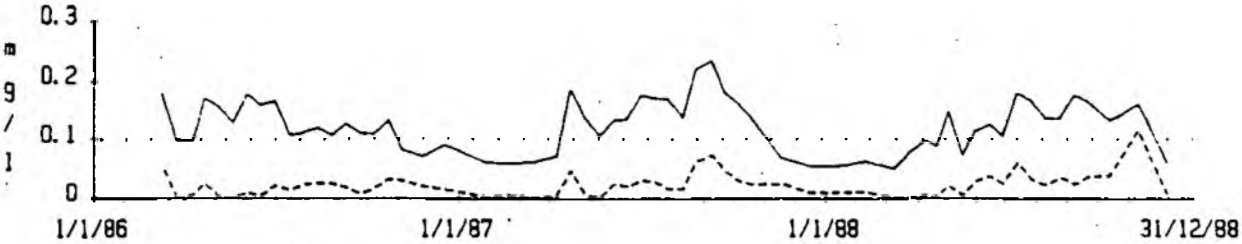


Fig 18 b

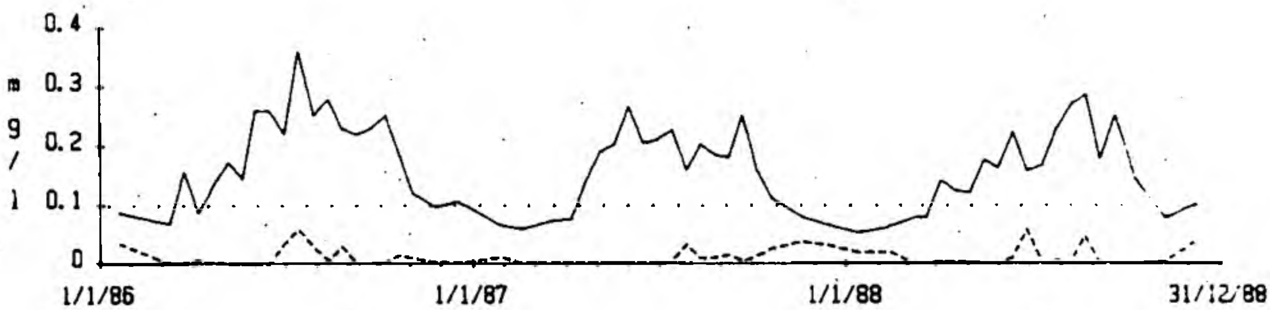
Total and Soluble Phosphorus

Barton Inflow



Barton Broad

Ludham Bridge (R Ant)



Cromes Broad

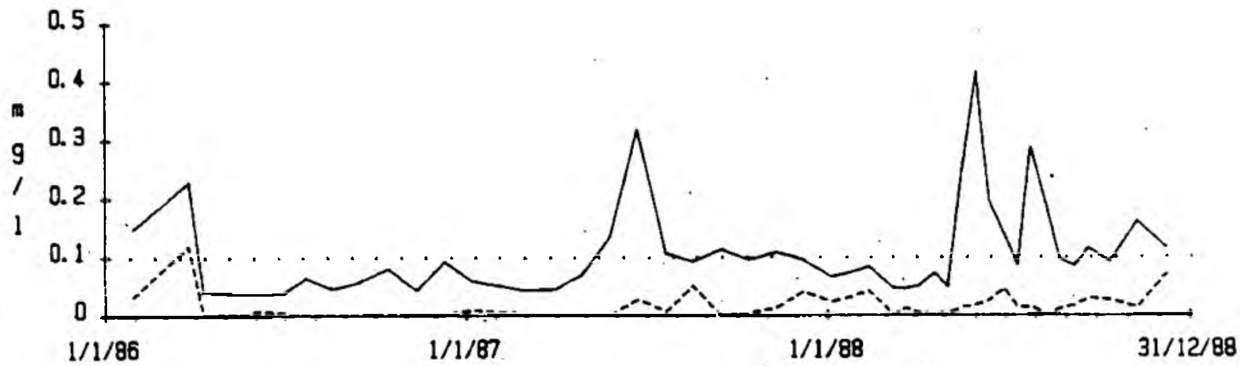


Fig 19

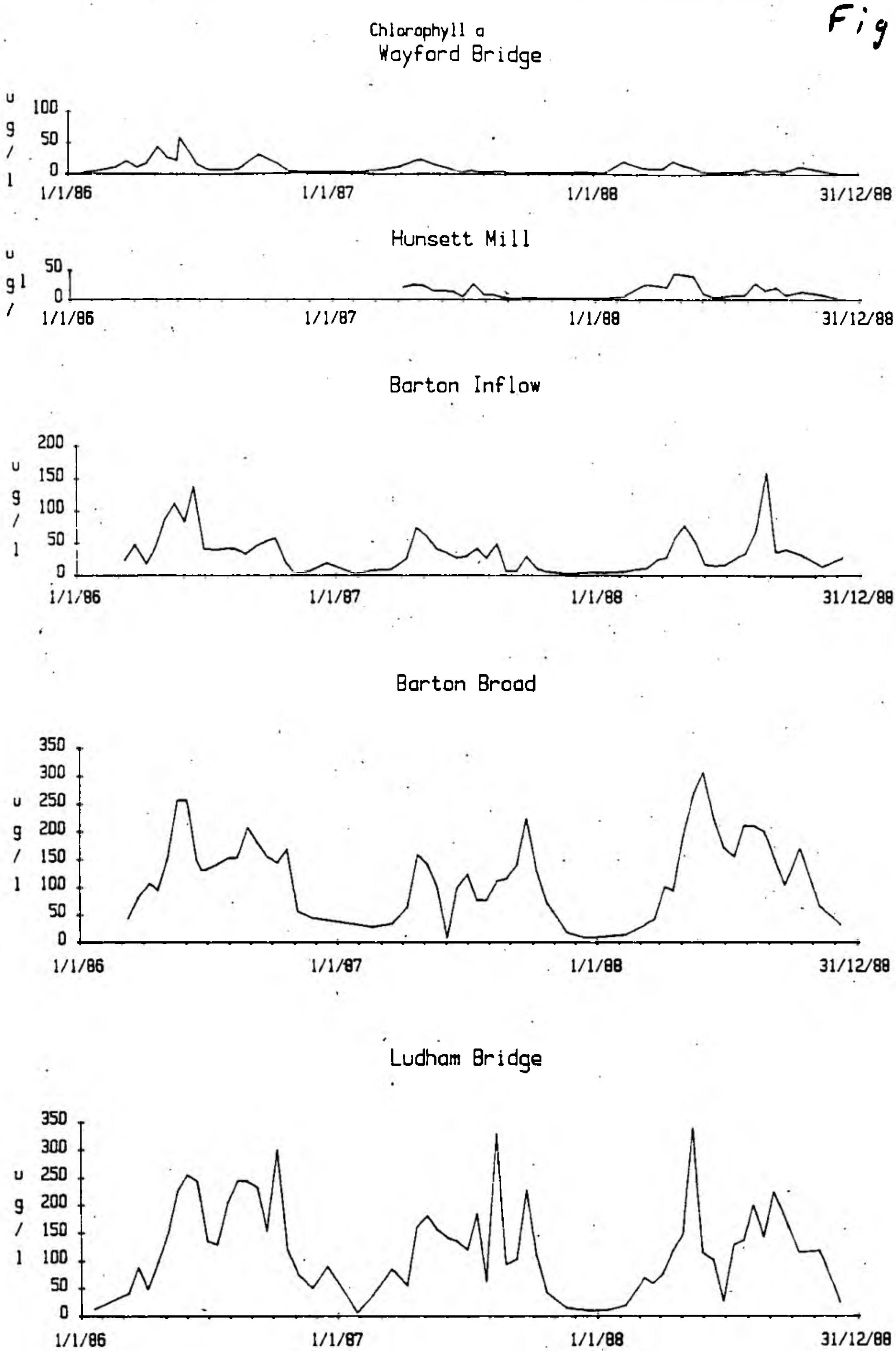
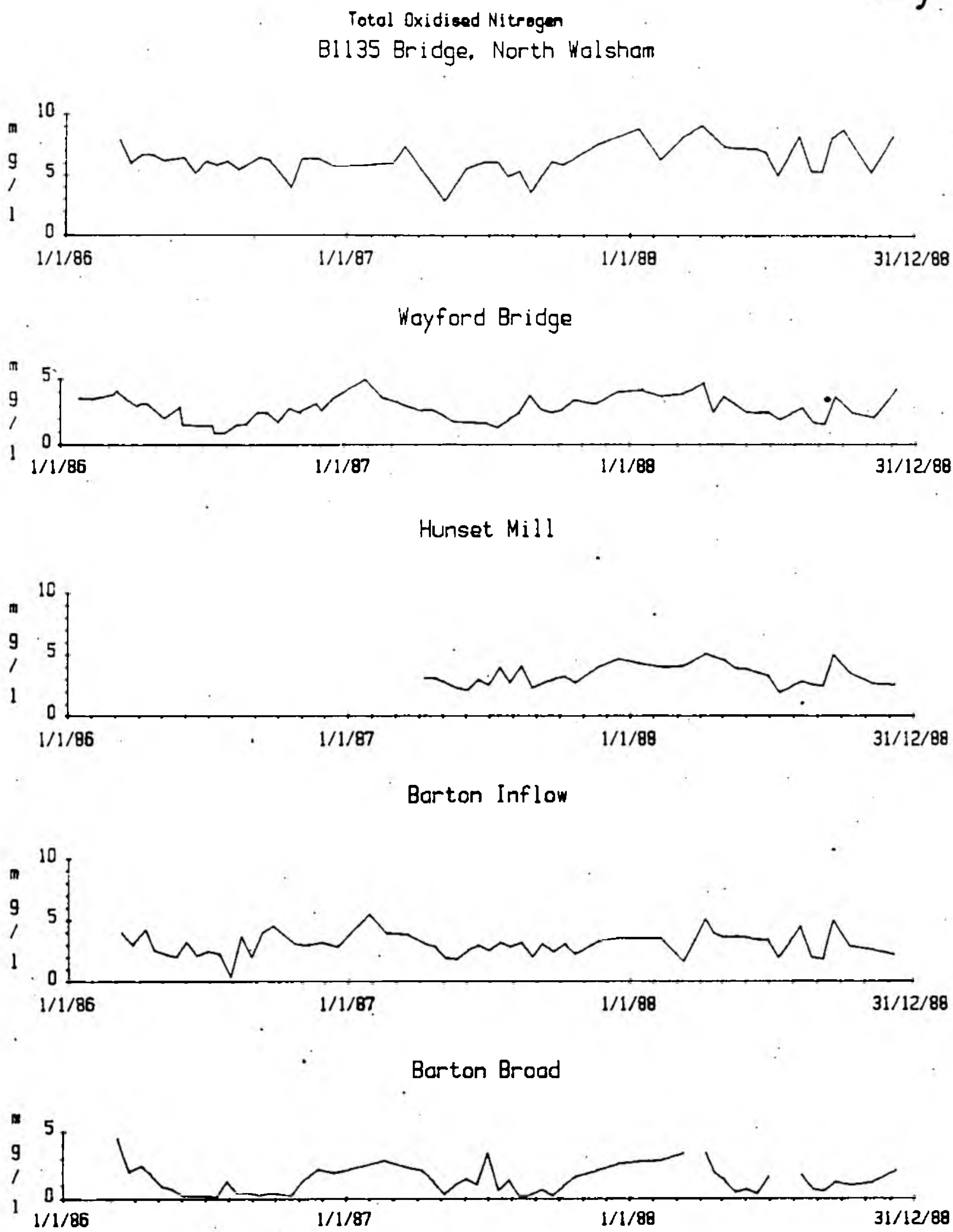
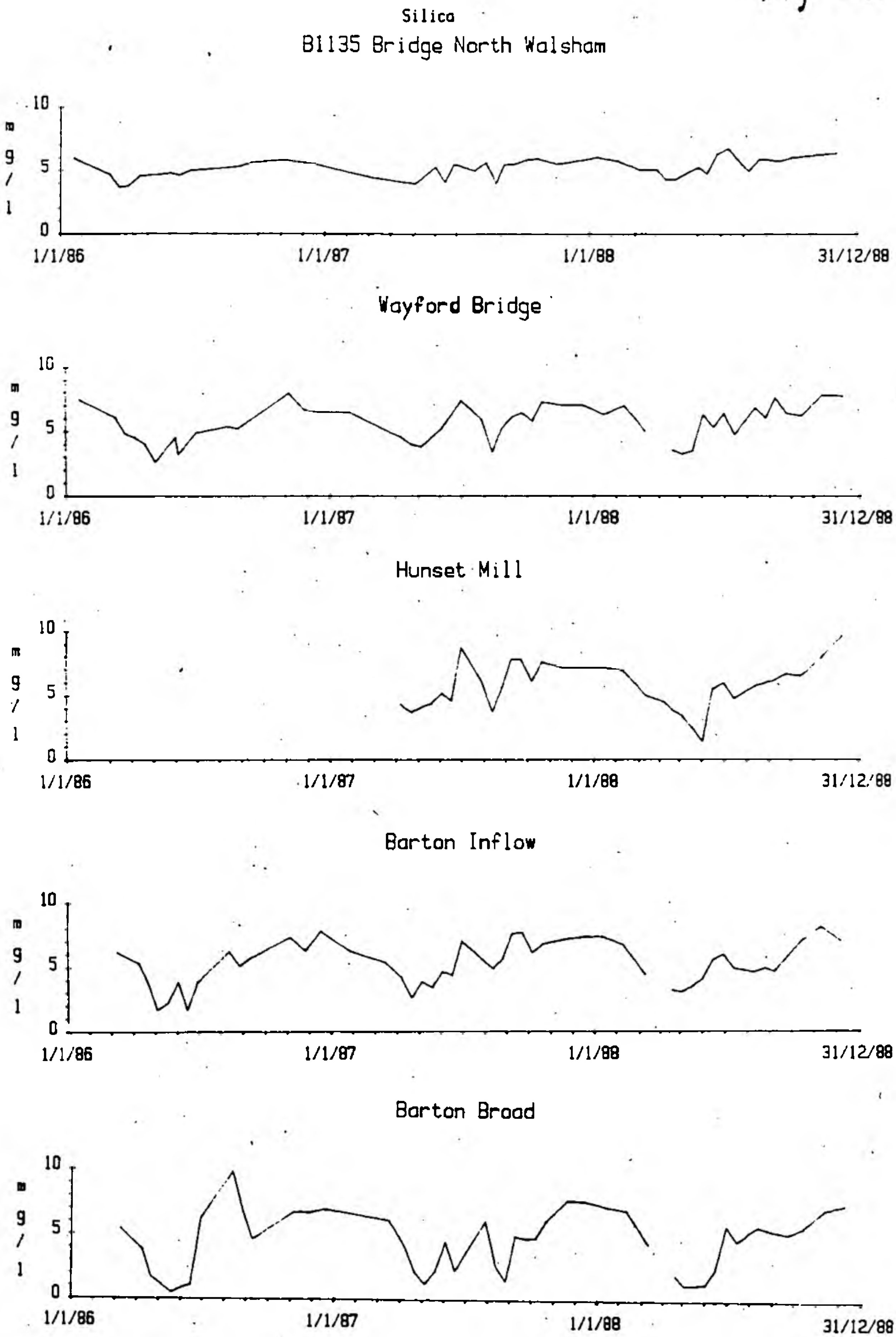

Chlorophyll a
Wayford Bridge
u g / l
100
50
0
1/1/86
1/1/87
1/1/88
31/12/88
Hunsett Mill
u g l /
50
0
1/1/86
1/1/87
1/1/88
31/12/88
Barton Inflow
u g / l
200
150
100
50
0
1/1/86
1/1/87
1/1/88
31/12/88
Barton Broad
u g / l
350
300
250
200
150
100
50
0
1/1/86
1/1/87
1/1/88
31/12/88
Ludham Bridge
u g / l
350
300
250
200
150
100
50
0
1/1/86
1/1/87
1/1/88
31/12/88

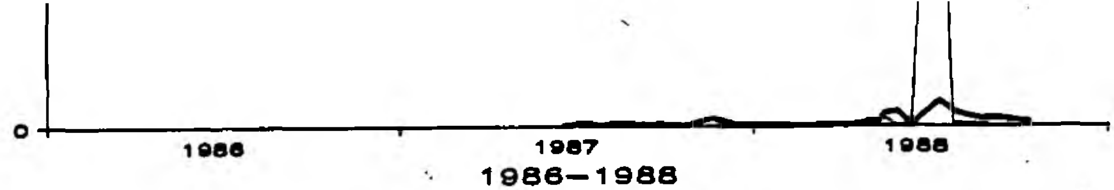
Fig 20



Total Oxidised Nitrogen
B1135 Bridge, North Walsham
mg/l
0
5
10
1/1/86
1/1/87
1/1/88
31/12/88
Wayford Bridge
mg/l
0
5
1/1/86
1/1/87
1/1/88
31/12/88
Hunset Mill
mg/l
0
5
10
1/1/86
1/1/87
1/1/88
31/12/88
Barton Inflow
mg/l
0
5
10
1/1/86
1/1/87
1/1/88
31/12/88
Barton Broad
mg/l
0
5
1/1/86
1/1/87
1/1/88
31/12/88

Fig 21


Silica
B1135 Bridge North Walsham
10
5
0
mg/l
1/1/86
1/1/87
1/1/88
31/12/88
Wayford Bridge
10
5
0
mg/l
1/1/86
1/1/87
1/1/88
31/12/88
Hunset Mill
10
5
0
mg/l
1/1/86
1/1/87
1/1/88
31/12/88
Barton Inflow
10
5
0
mg/l
1/1/86
1/1/87
1/1/88
31/12/88
Barton Broad
10
5
0
mg/l
1/1/86
1/1/87
1/1/88
31/12/88



Blue–Green Algae/Cryptophyta

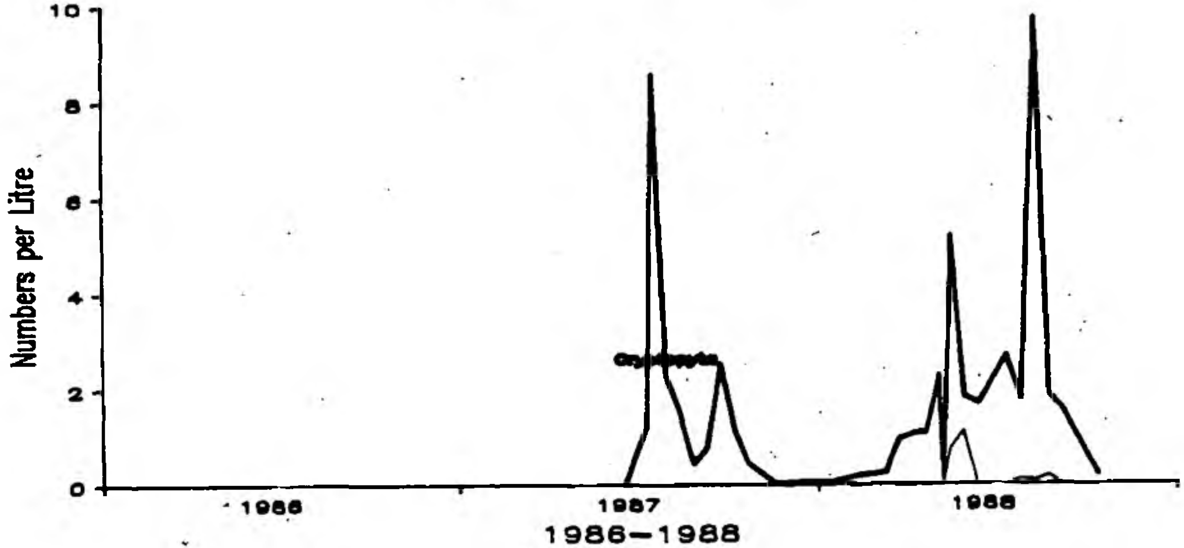


Fig 22

Belaugh Broad Phytoplankton 1987–1988

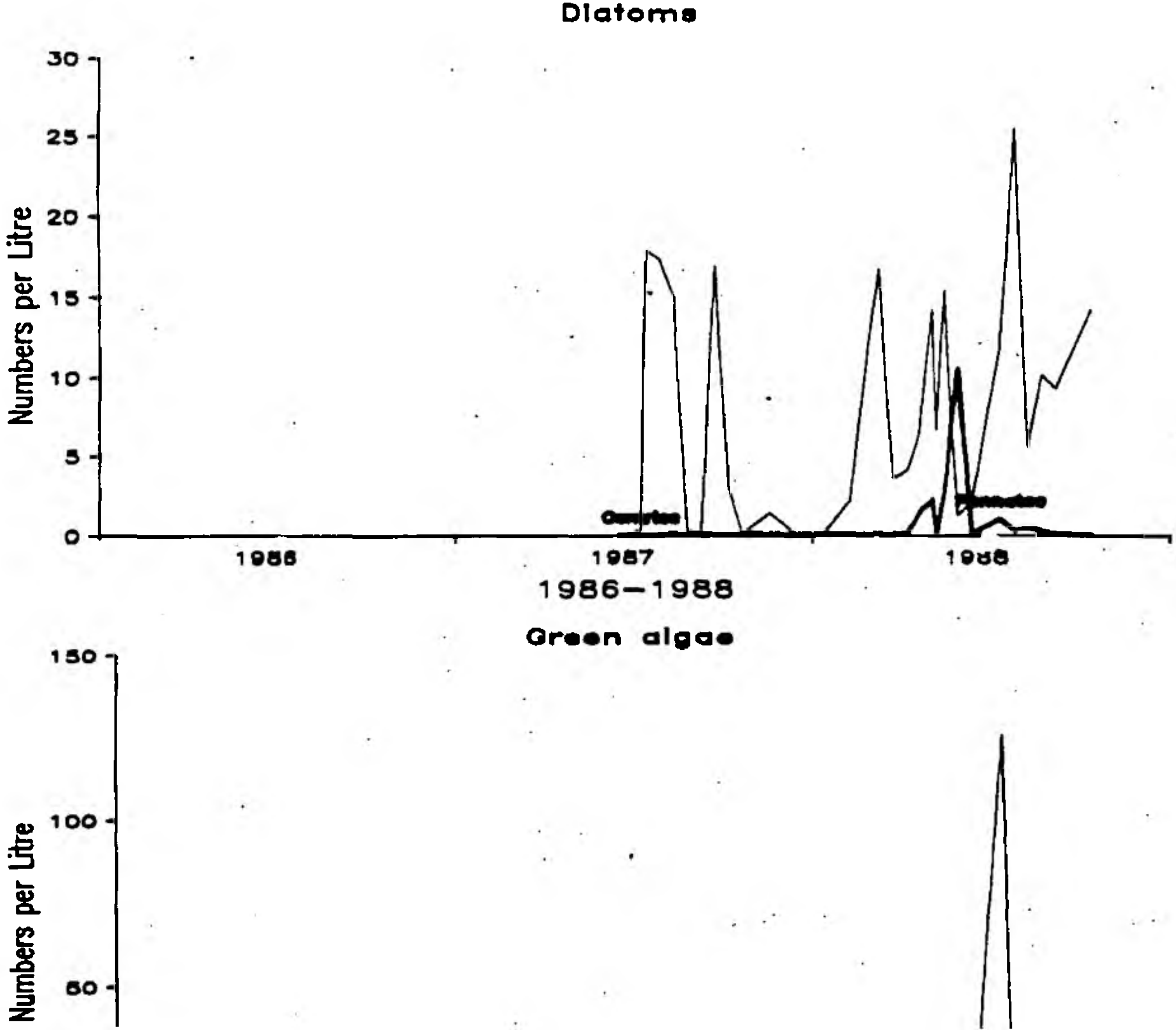
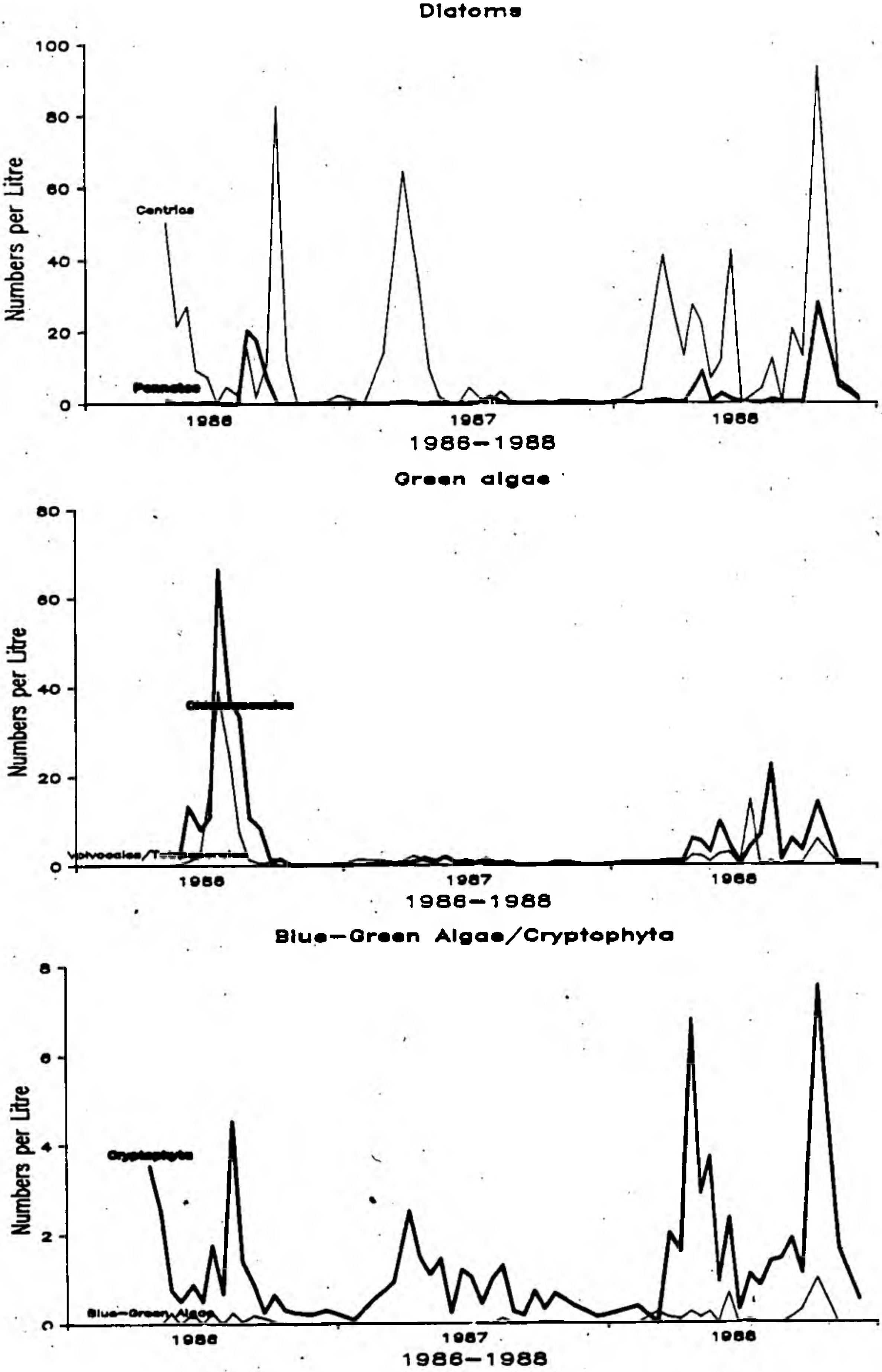
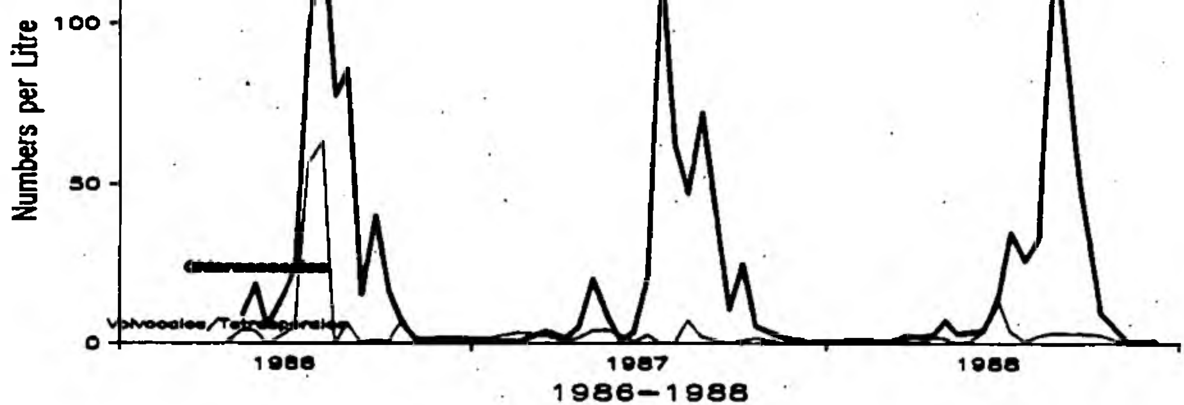


Fig 23

Wroxham Broad Phytoplankton 1986–1988





Blue—Green Algae/Cryptophyta

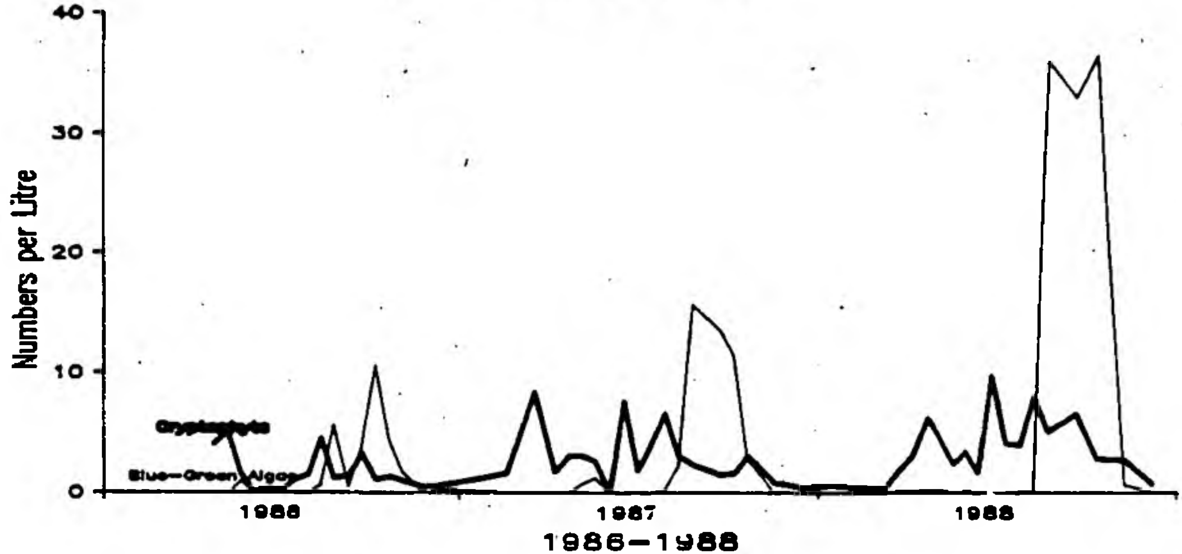
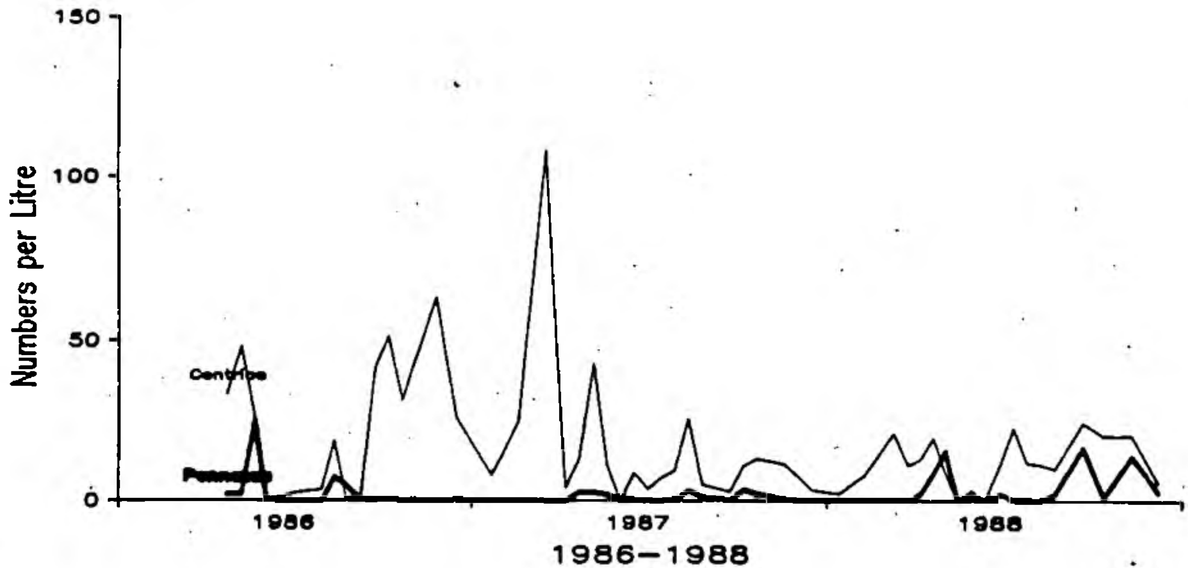


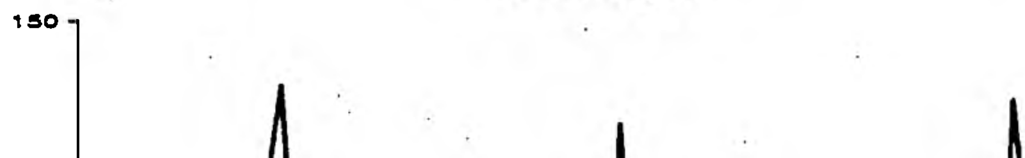
Fig 24

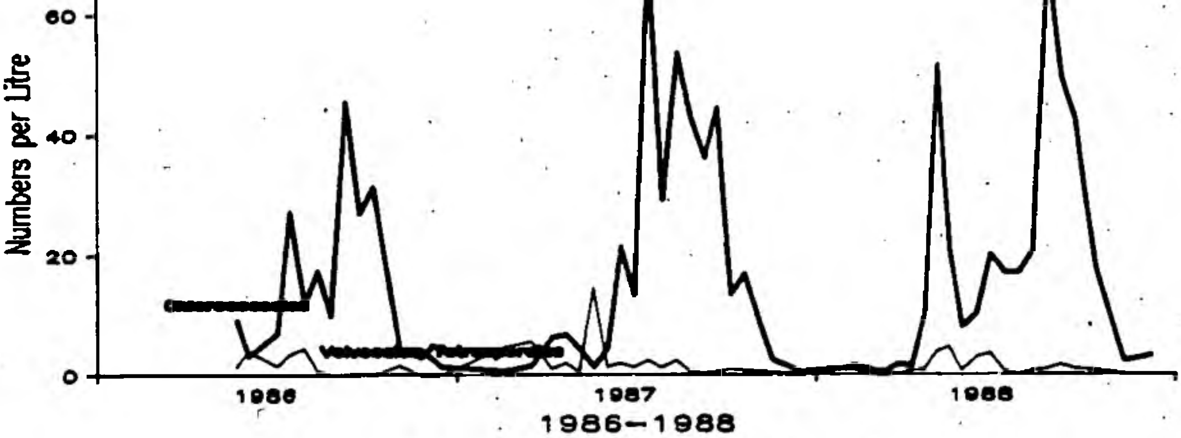
Hoveton Great Broad Phytoplankton 1986–1988

Diatoms



Green algae





Blue—Green Algae/Cryptophyta

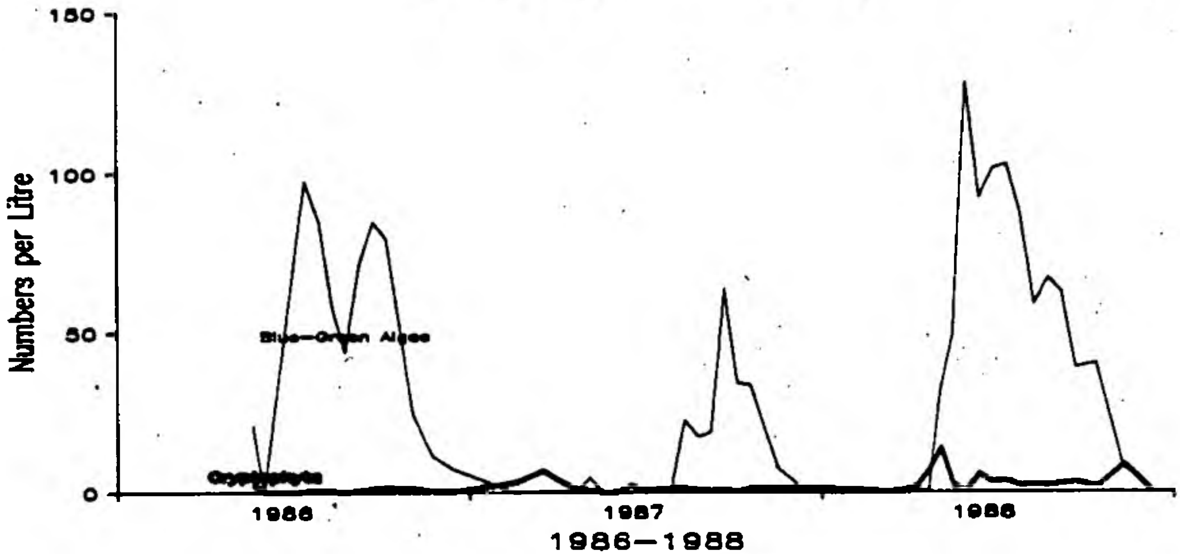
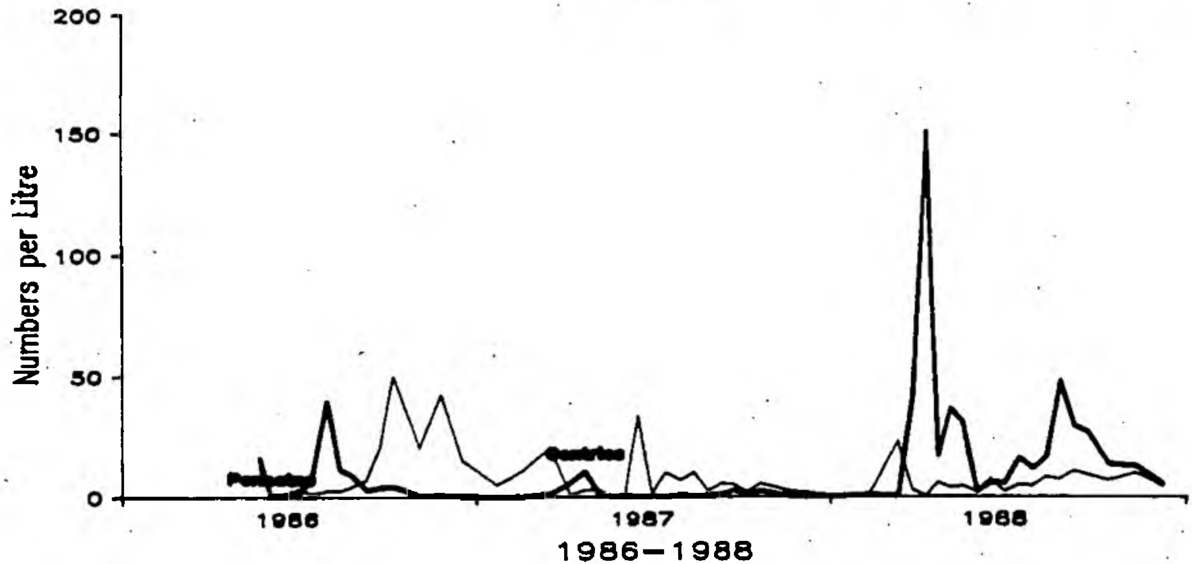


Fig 25

Ranworth Broad Phytoplankton 1986–1988

Diatoms

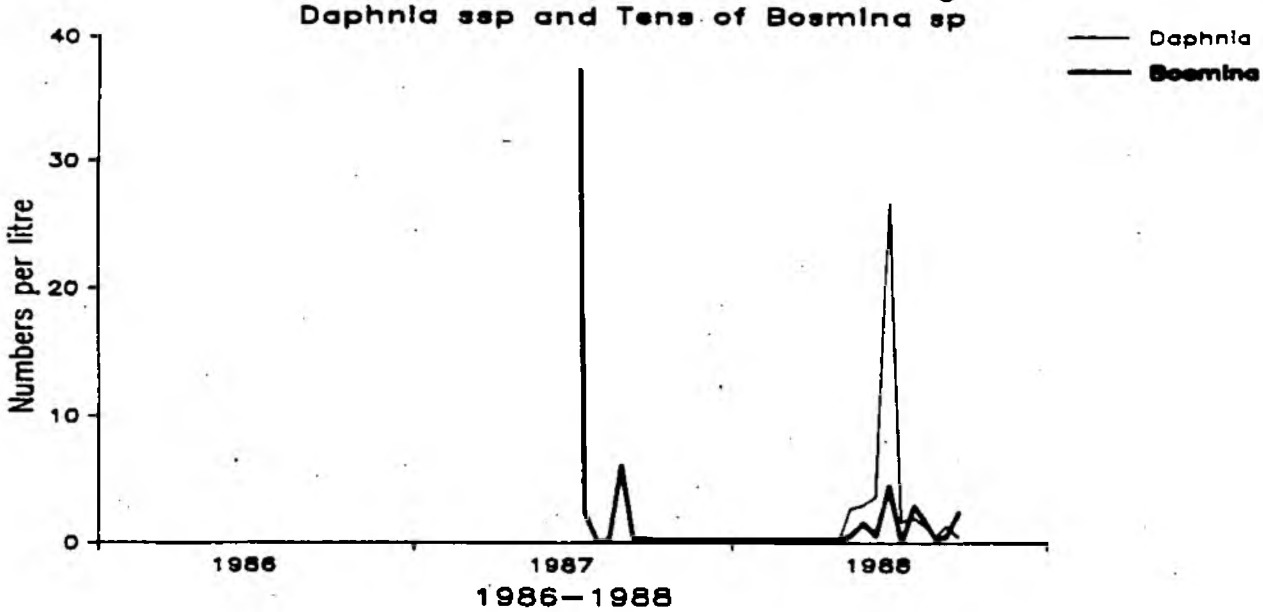


Green algae

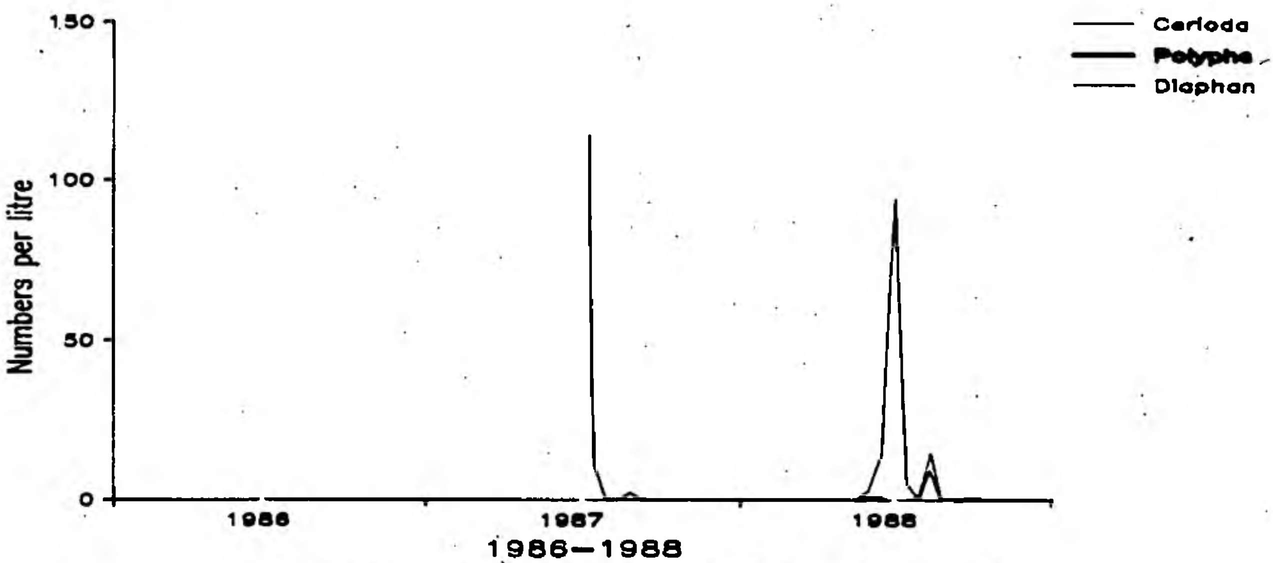
Fig 26

Belaugh Broad Monitoring

Daphnia ssp and Tens of Bosmina sp



Ceriodaphnia ssp.,Polyphemus and Diaphanosoma



Cyclopoid copepodites and total Rotatoria

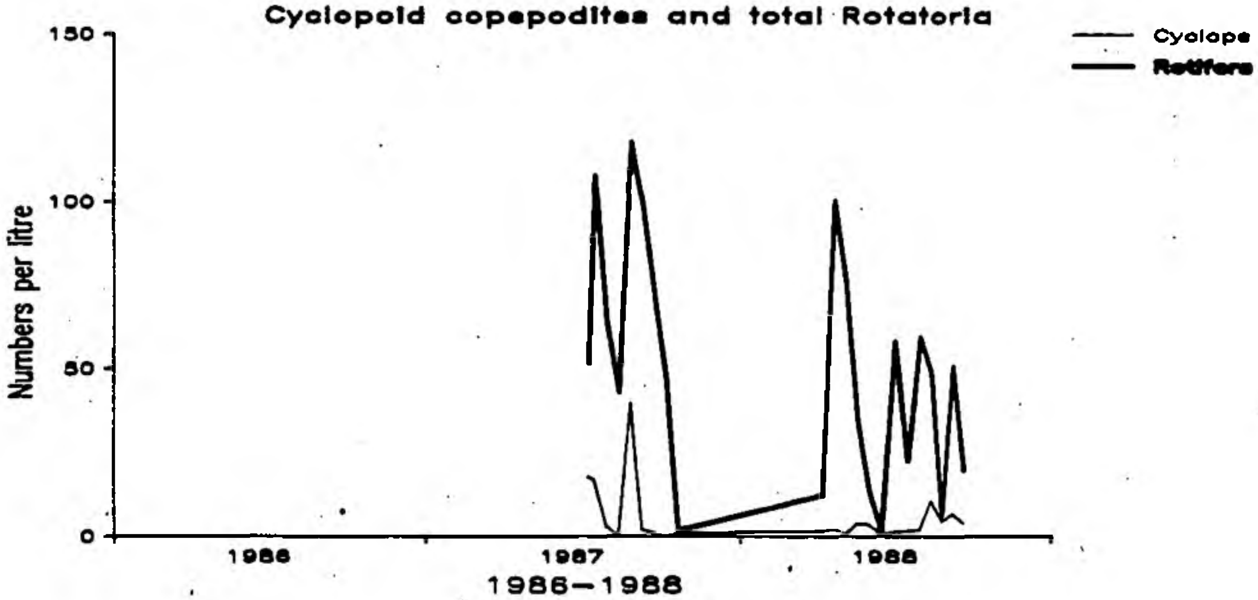


Fig 27.

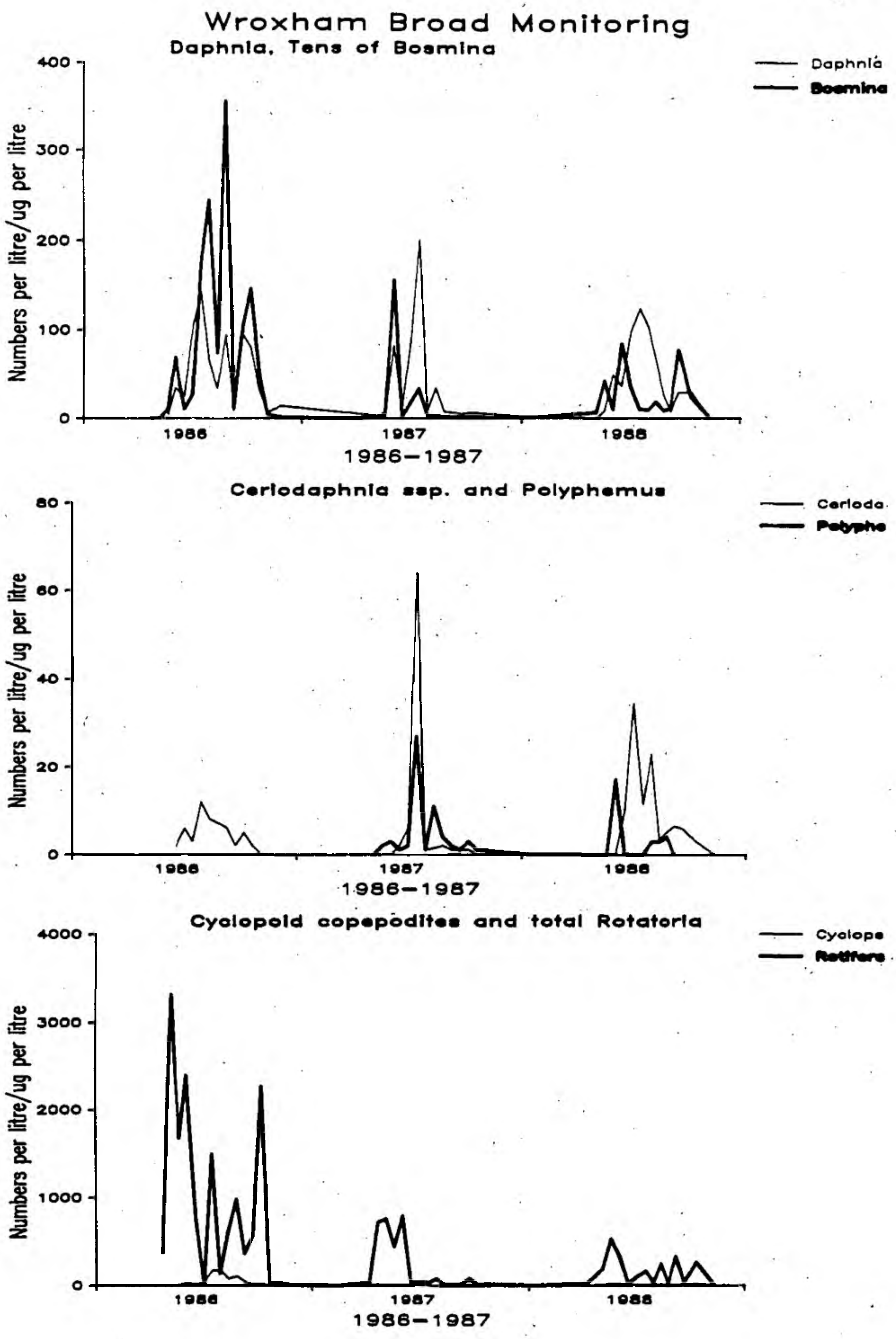
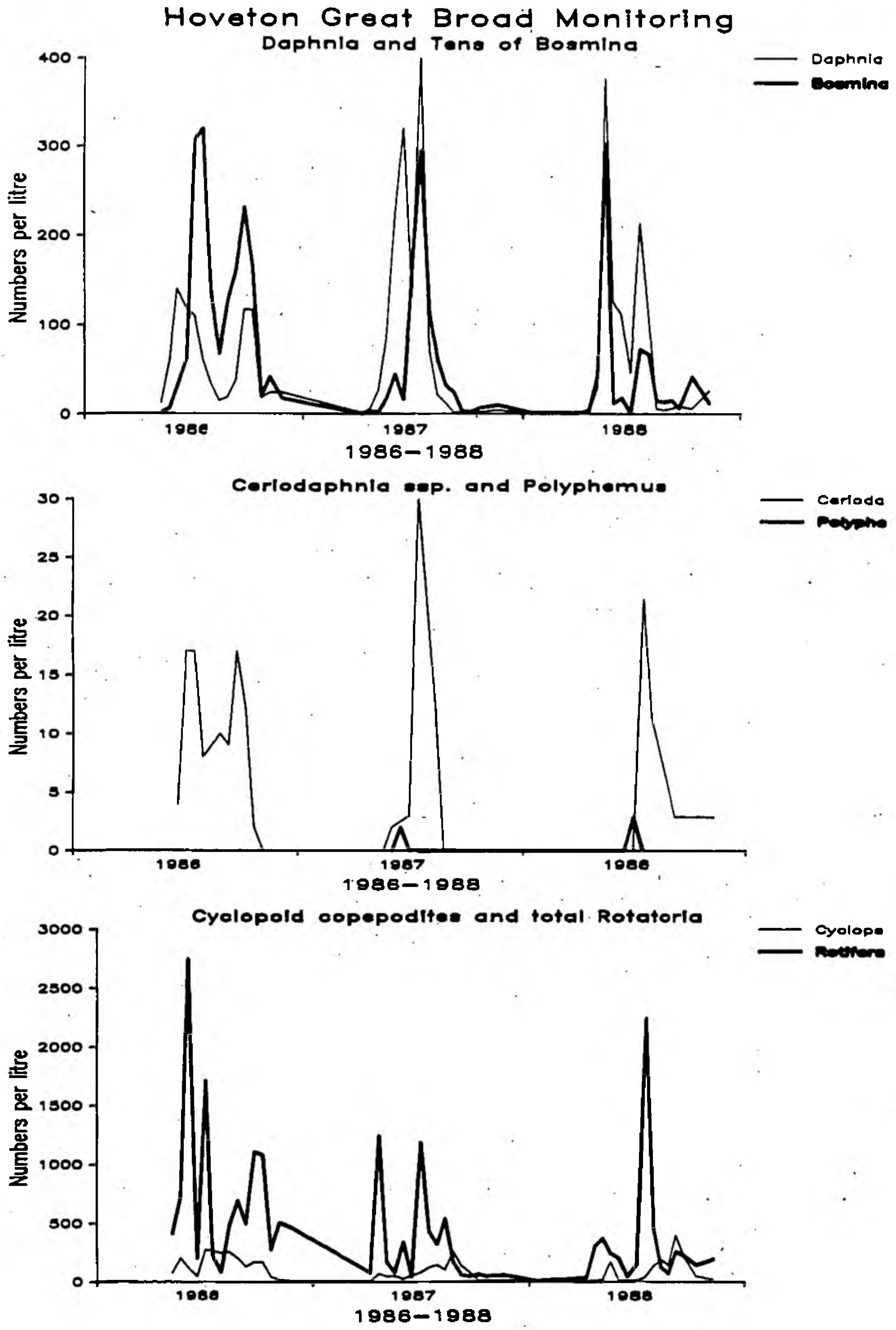
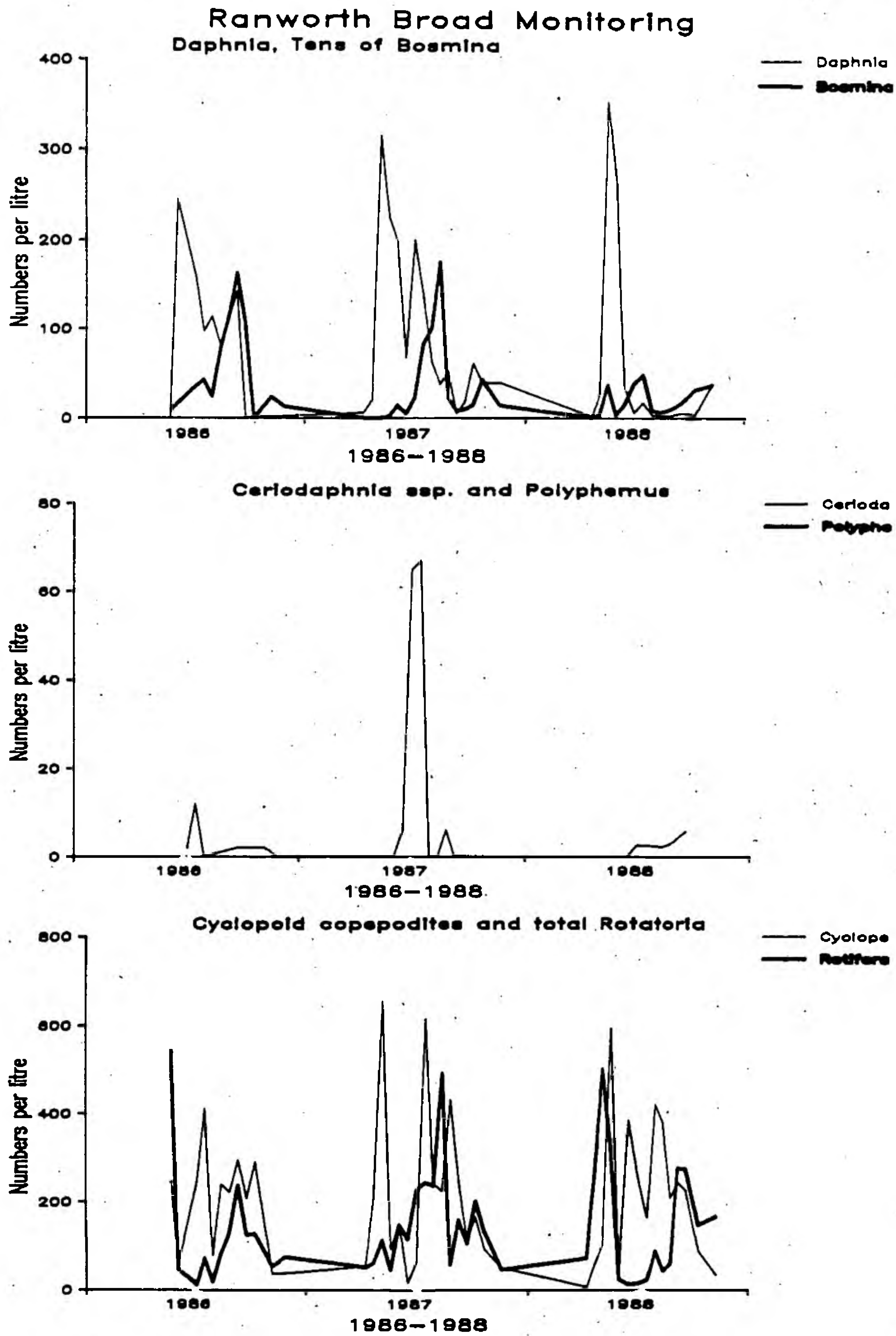

Wroxham Broad Monitoring
Daphnia, Tens of Bosmina
Numbers per litre/ug per litre
400
300
200
100
0
1986
1987
1988
1986–1987
Daphnia
Bosmina
Ceriodaphnia ssp. and Polyphemus
Numbers per litre/ug per litre
80
60
40
20
0
1986
1987
1988
1986–1987
Cerioda
Polyphe
Cyclopoid copepodites and total Rotatoria
Numbers per litre/ug per litre
4000
3000
2000
1000
0
1986
1987
1988
1986–1987
Cyclops
Rotifera

Fig 28



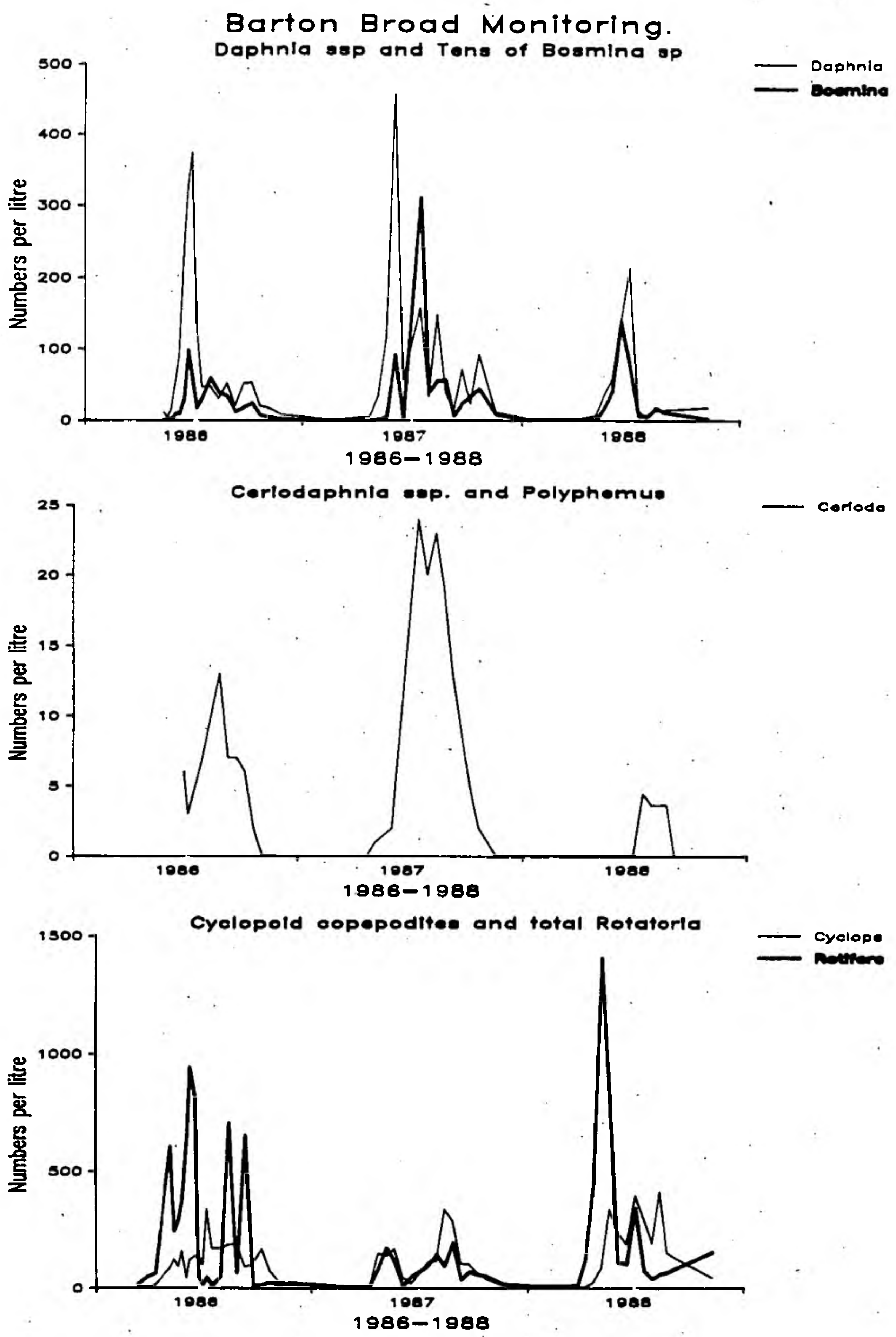
Hoveton Great Broad Monitoring
Daphnia and Tens of Bosmina
Daphnia
Bosmina
Numbers per litre
400
300
200
100
0
1986
1987
1988
1986—1988
Ceriodaphnia ssp. and Polyphemus
Erioda
Polyphe
30
25
20
15
10
5
0
Cyclopoid copepodites and total Rotatoria
Cyclops
Rotifers
3000
2500
2000
1500
1000
500

Fig 29



Ranworth Broad Monitoring
Daphnia, Tens of Bosmina
Daphnia
Bosmina
Numbers per litre
400
300
200
100
0
1986
1987
1988
1986—1988
Ceriodaphnia ssp. and Polyphemus
Cerioda
Polyphe
80
60
40
20
0
1986
1987
1988
1986—1988
Cyclopoid copepodites and total Rotatoria
Cyclops
Rotifers
800
600
400
200
0
1986
1987
1988
1986—1988

Fig 30


Barton Broad Monitoring.
Daphnia ssp and Tens of Bosmina sp
Daphnia
Bosmina
Numbers per litre
500
400
300
200
100
0
1986
1987
1988
1986—1988
Ceriodaphnia ssp. and Polyphemus
Carioda
25
20
15
10
5
0
1986
1987
1988
1986—1988
Cyclopoid copepodites and total Rotatoria
Cyclops
Rotifers
1500
1000
500
0
1986
1987
1988
1986—1988