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River Wylye

Analysis and Modelling of Phosphates

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1 INTRODUCTION

1.1 Background

This report was written as part of an ongoing study of the Upper Hampshire Avon catchment initiated in response to concerns raised by English Nature about the levels of phosphates in this area.

Statutory requirements which may enable the Agency to control phosphate levels are the Urban Waste Water Treatment Directive and the Habitats Directive. The UWWTD can be used to force nutrient stripping at PLC STW discharges if appropriate qualifying conditions are met. The Habitats Directive has been recently introduced and is designed to protect flora and fauna in designated areas.

So far, in the Hampshire Avon catchment, Salisbury STW is to have nutrient stripping applied so as to ameliorate the phosphate levels in the lower Avon. This was done under the UWWTD regulations. Other discharges in the catchment which come under the scope of the UWWTD are Christchurch STW and Warminster STW, the latter being situated on the River Wylye.

This report is concerned with the River Wylye from its source near Kingston Deverill south of Warminster to its confluence with the Nadder at Wilton. It is known, in general terms, that diffuse and point sources contribute to phosphate levels in the river. Diffuse sources arise from runoff from agricultural land. A rule of thumb appears to be that about 1% of phosphates put onto the land will find its way into the river. Point sources may be large or small; the large ones being the PLC STWs.

The purpose of this report is to examine in some detail the point source contributions to phosphate levels in the Wylye. The intention is to provide information on which decisions about management of the catchment may be based, but not to make those decisions.

1.2 Objectives

The objectives are to:

A determine the spatial and temporal trends of phosphate concentrations along the River Wylye
B quantify the seasonal and annual in-river and discharge phosphate loads
C perform discharge modelling to quantify the impact of nutrient stripping

2 UPPER HAMPSHIRE AVON RIVER SYSTEM

2.1 Location

The major rivers of the Upper Hampshire Avon catchment are shown below:

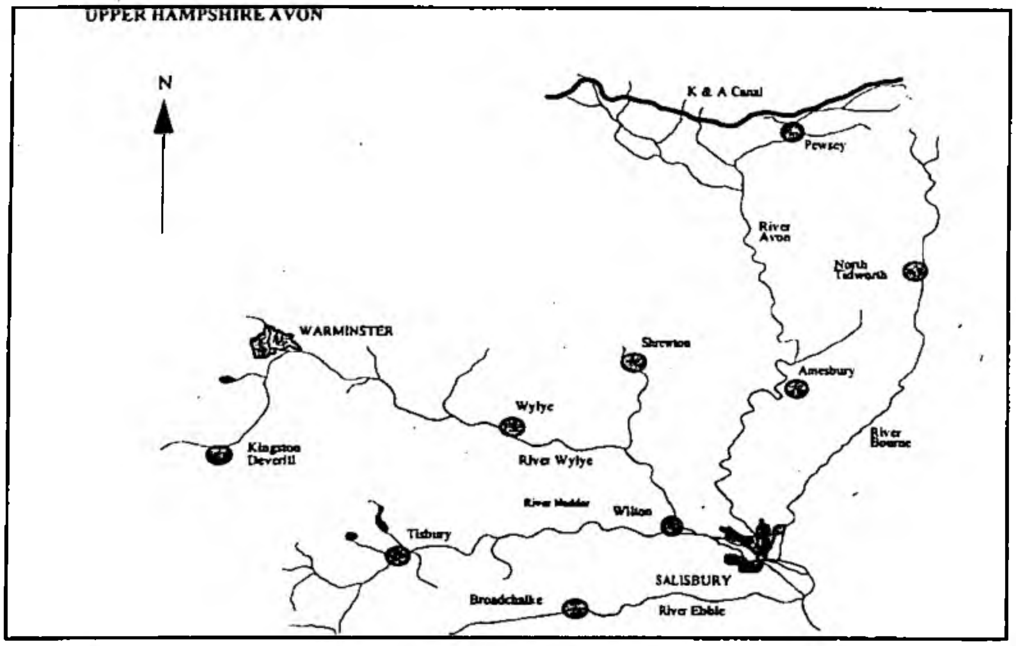


Fig. 1

2.2 Point Source Discharges

The map below shows the monitored discharges in the upper Avon catchment.

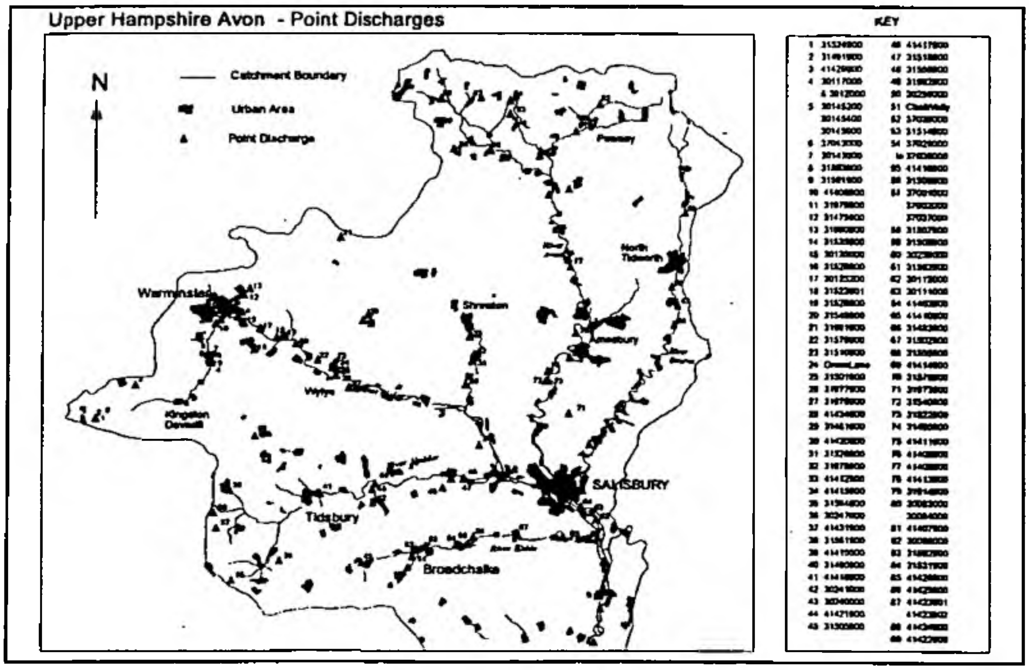


Fig.2

2.3 Routine Monitoring Sites

The map below shows the river sites routinely monitored in the upper Avon catchment.

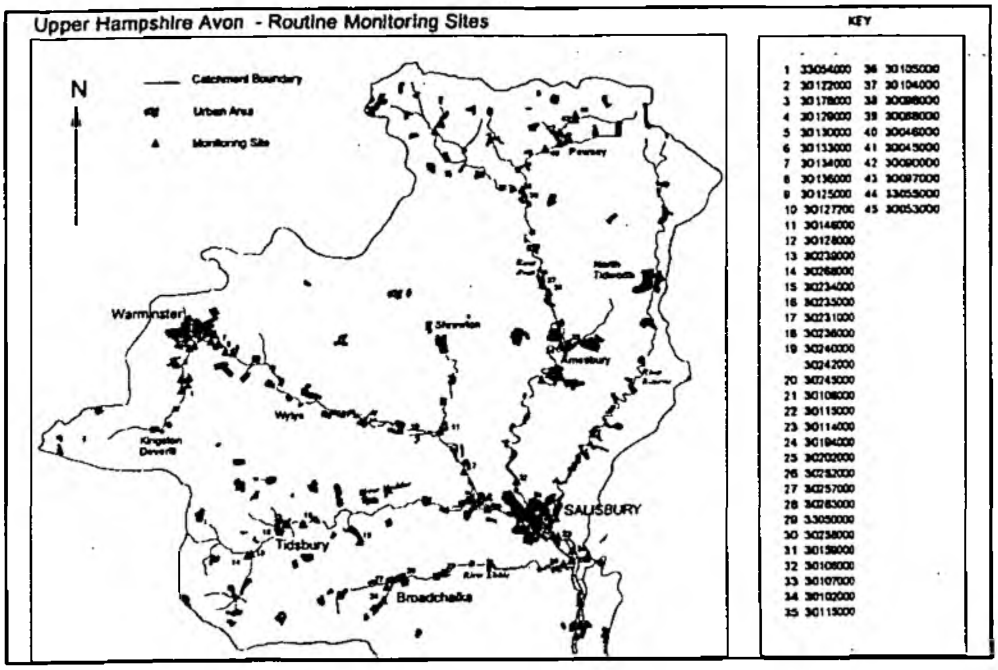


Fig.3

3 DATA ANALYSIS

3.1 Selected Data

The present analysis is restricted to the River Wylye, which is shown schematically in Figure 4 from Kingston Deverill to its confluence with the River Nadder.

3.1.1 Discharges

The main discharge to the River Wylye is from Warminster STW. Other larger discharges include those from Hurds (Hill Deverill) Fish Farm, Bishopstrow Fish Farm and Great Wishford STW - details of all these are given below.

Discharge	URN	Flow (m3/s) (1)
Hurds Fish Farm	30117000	0.11 (MAX)
Warminster STW	41406900	0.03 (DWF)
Bishopstrow Fish Farm	30135000	0.16 (MAX)
Gt Wishford STW	41415900	0.01 (DWF)

Table 1

(1) These values are taken from the associated discharge consents

3.1.2 Tributaries

The tributaries considered are shown below. In the case of the Were tributary the monitoring point 30131000 - Were Calveswater - has not been sampled since October 1995 and there is some uncertainty about its location; the concentration levels of phosphate at this URN are relatively high, perhaps indicating some influence from Warminster STW.

Tributary	URN	MeanFlow (m3/s) (2)
Shear Water	30179000	0.136
Were	30131000	0.19
Chitterne Brook	30138000	0.668
Till River	30146000	0.896

Table 2

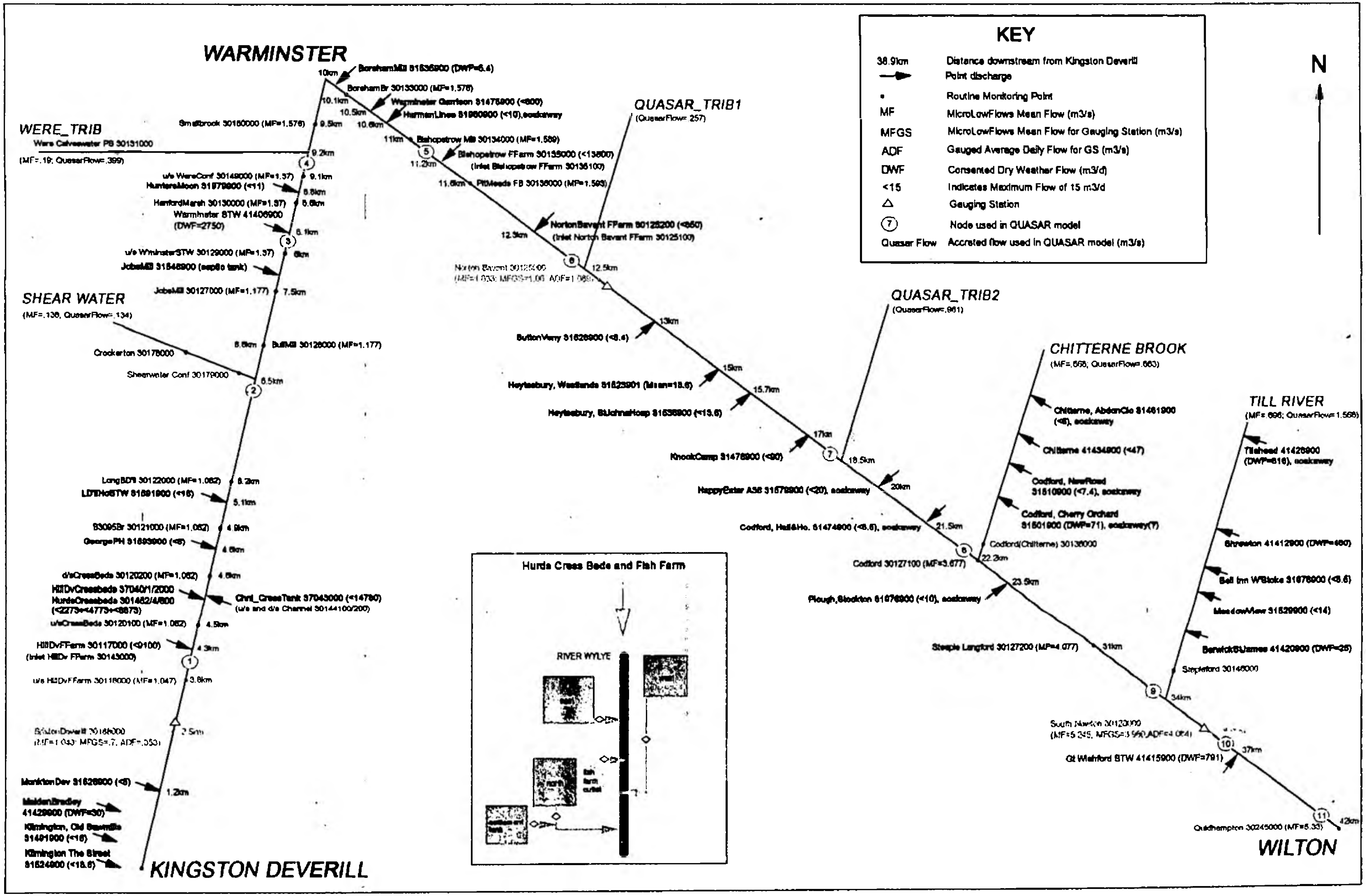
(2) These values are derived from the program Micro Low Flows.

3.1.3 Determinand

The determinand studied is ortho-phosphate, which has determinand code number 0180.

Figure 4: River Wylye

Diagrammatic representation of Point Discharges and Routine Monitoring Points



3.1.4 Water Quality Monitoring

Figure 4 is a schematic representation of the River Wylye showing all monitored discharge points and routinely sampled river sites. Essentially, these are the sites which exist on the WIMS archive and have been sampled at some time during the period 1994-97.

Many of them are very small discharges and have been included solely for the purposes of completeness. A number of them do not discharge directly into the river - where it is known that the discharge is into a soakaway, this has been indicated on the figure.

In retrospect, the inclusion of 1997 in the data analysis was superfluous, as monitoring of discharges for ortho-phosphate concentrations was only carried out at UWWTD designated sites during 1994-6. The year 1997 has been excluded from some of the analysis and from the modelling due to the lack of ortho-phosphate discharge data.

Shown in Figure 4 is a diagram of point discharges and routine monitoring points. The text in red indicates those points which have been incorporated into the model - see Section 4.

3.1.5 River Flows

The program MicroLowFlows (MLF) was used to derive the mean flows along the length of the Wylye and the mean flows of the main tributaries at their point of confluence. MLF is essentially a database of natural flows (no account is taken of abstractions and discharges), based on geology, topography, precipitation, etc.

Gauging Stations: There are three gauging stations on the Wylye.

Station Name	NGR	Ref. No.	Q95(1995) (m3/s)	ADF(1995) (m3/s)
Brixton Deverill	ST 8580 3810	432310	0.065	0.353
Norton Bavant	ST 9090 4280	432320	0.441	1.089
South Newton	SU 0860 3430	432330	1.170	4.084

The associated MLF mean flows for these points give mean flow values of 1.043, 1.833 and 5.245 m3/s at these gauging stations, which are significantly higher than the ADF's given above, particularly near the head of the river at Brixton Deverill. This highlights the problem of abstractions and subsequent low flows in the river.

Average monthly flows at each of the gauging stations for 1994-97 were downloaded from the archives and used both for calculating the loads and for the modelling. This was done by scaling the monthly flows for the nearest gauging station by the ratio of the MLF mean flow at the point in question and the MLF mean flow at the gauging station.

3.2 Seasonal and Longitudinal Variations in Phosphate Concentrations

Shown in Figures 5 and 6 are yearly time series (1994-7) for ortho-phosphate concentrations upstream and downstream respectively of Warminster STW (URN's 30129000 and 30130000).

Seasonal Variations

The main point to note at both sites is that there is a strong seasonal cycle. The concentration generally peaks during late summer and autumn in all years, when flows are low, and is frequently higher in 1997, a year of low rainfall, than in earlier years. When flows are low there is less available water for dilution, and it is at these times that the impact of the constant point sources predominates over that of diffuse sources resulting from land runoff.

Longitudinal Variations

Due to exigencies of time, a detailed analysis on variations in concentration along the length of the river has not been done. Figures 5 and 6 show the impact of Warminster STW - concentrations downstream of the STW are generally an order of magnitude higher than those upstream. Variations in average annual and summer river concentrations along the length of the River Wylye are shown in "bar chart" form in Figures 10 to 12 and 16 to 18 respectively.

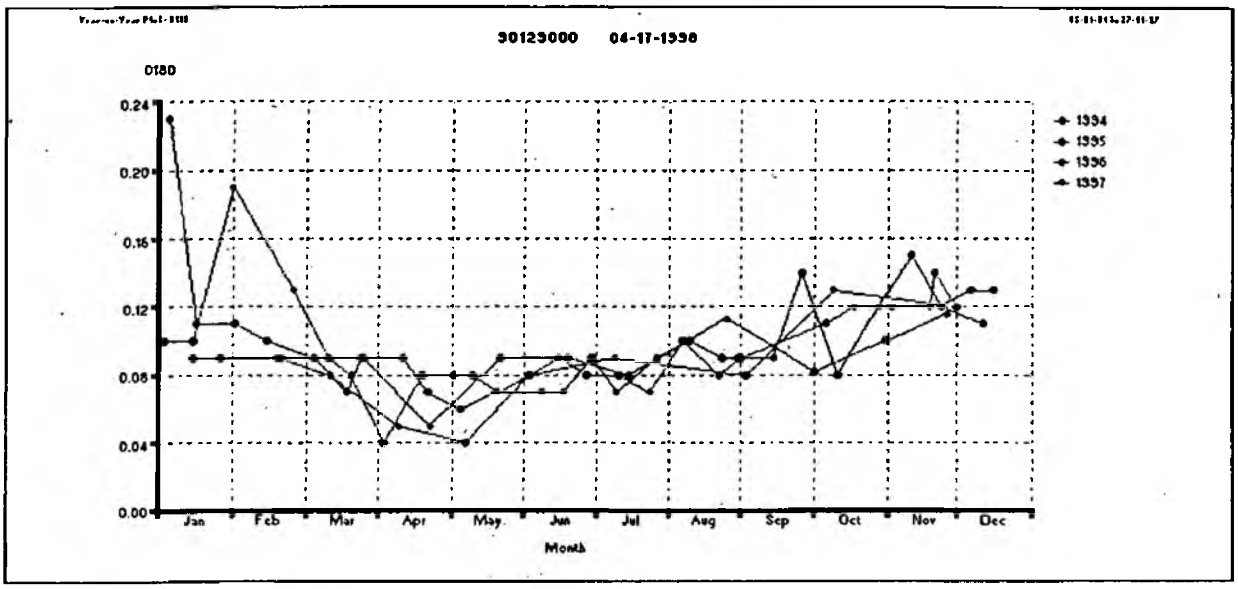


Figure 5 Ortho-Phosphate Concentrations in mg/l upstream of Warminster STW

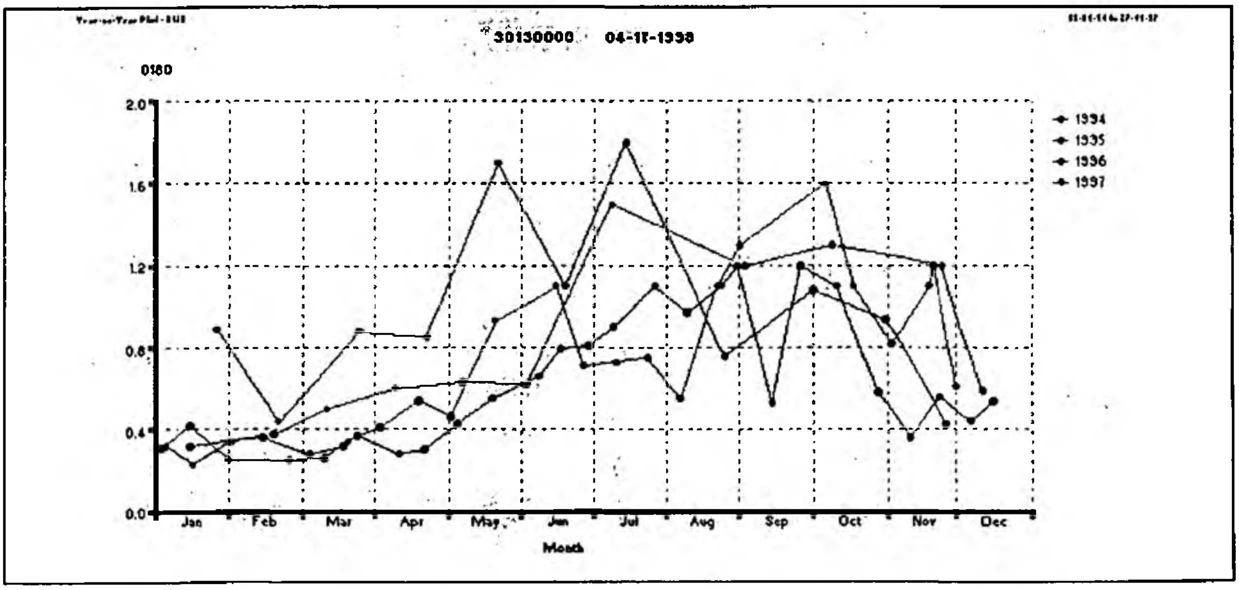


Figure 6 Ortho-Phosphate Concentrations in mg/l downstream of Warminster STW

3.3 Concentrations and Loads - Annual and Summer

The figures on the following pages show the following:

- average *annual* ortho-phosphate *concentrations* and *loads* for *discharges* and for *in-stream monitoring points* 1994-96
- average *summer* ortho-phosphate *concentrations* and *loads* for *discharges* and for *in-stream monitoring points* 1994-96

Also shown in these figures are the number of samples at each point discharge or river monitoring point. As already mentioned on p.5 very little monitoring of ortho-phosphate in discharges was done during 1997, and this year has been excluded from the analysis in this section.

Summer was deemed to be the months of June, July and August.

3.3.1 Concentrations

Discharges

Average annual point source concentrations vary considerably, ranging from about 5 to 20 mg/l. I should be borne in mind that the flows of some of these are negligible, and a more realistic idea of their impact can be derived from consideration of the loads figures. The discharge of most concern - Warminster STW has an average annual concentration of about 6mg/l.

Average summer point source concentrations are about the same as the annual values, as would be expected.

In-stream river monitoring points

Average annual in-stream concentrations at the upstream end of the Wylye are of the order of 0.1 mg/l, and about double that at the downstream end where the river joins the Nadder. The highest concentrations are immediately downstream of Warminster STW, where they range from approximately 0.6 to 0.8 mg/l. What is interesting to note is that the high concentrations downstream of Warminster STW persist for a distance of some 4 km or more.

The average summer concentrations in the river are generally about .2 mg/l higher than the average annual concentrations.

KEY TO ACCOMPANY FIGURES 7 TO30

The following list gives the full name and URN for the points plotted along the x-axis.

Discharges

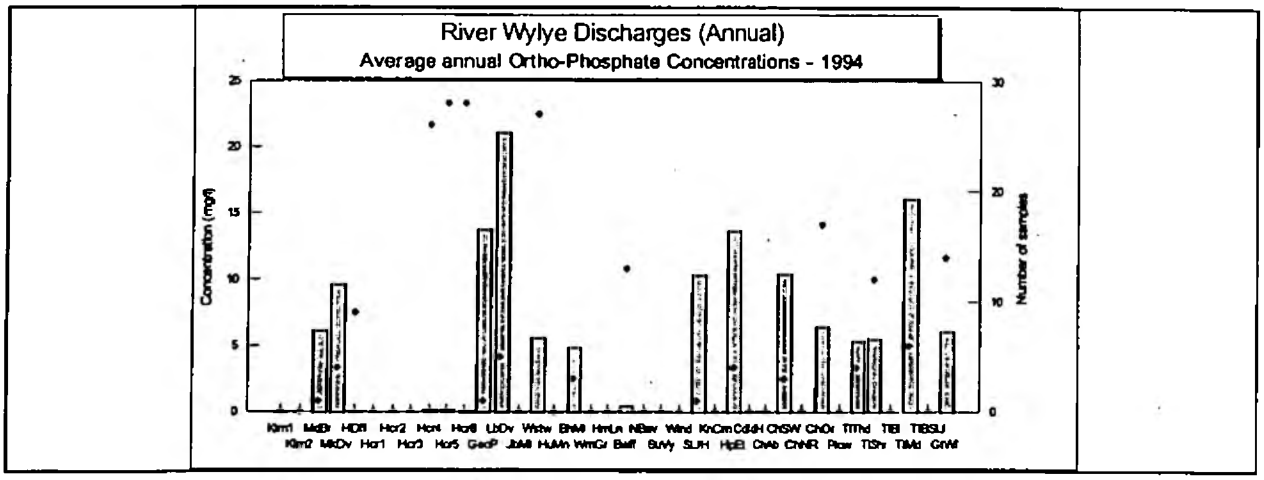
Abbreviation/Full Name/URN

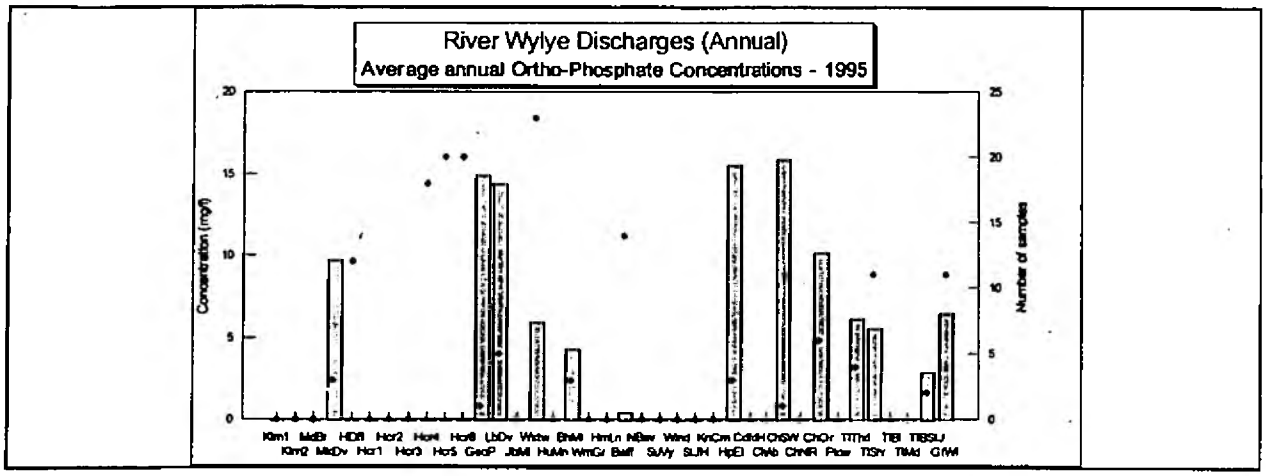
Klm1/Kilmington The Street/31524900
Klm2/Kilmington Old Sawmills/31491900
MdBr/MaidenBradley/41429900
MkDv/MonktonDeverill/31526900
Hdff/HillDeverillFishFarm/30117000
Hcr1 to 6/Hurds CressBeds/37040/1/2000
and 301452/4/600
GeoP/George PH/3153900
LbDv/L'bridgeDev'llHoSTW/31591900
JbMl/JobsMill/31546900
Wstw/WarminsterSTW/41406900
HuMn/HuntersMoon/31979900
BhMl/BorehamMill/31535900
WmGr/WarminsterGarr/31475900
HmLn/HarmanLines/31980900
Bwff/BishopstrowFishFarm/30135000
Nbav/NortonBavantFishFarm/30125200
SuVy/WWDCSuttonVeny/31528900
Wlnd/WWDCWestlands/31523901
StJH/StJohnsHosp/31538900
KnCm/KnookCamp/31476900
HpEt/HappyEater/31579900
CdfdH/CodfordHall&Ho/31474900
ChAb/ChitterneAbdonClo/31481900
ChSW/Chitterne/41434900
ChNR/CodfordNewRoad/31510900
ChOr/Codford/CherryOrchard/31501900
Plow/Plough Stockton/31976900
TlTlhd/Tilshead/41428900
TlShr/Shrewton/41412900
TlBl/Bell Inn/31978900
TlMd/SDCMeadowView/31529900
TlBStJ/BerwickStJames/41420900
GtWf/GtWishfordSTW/41415900

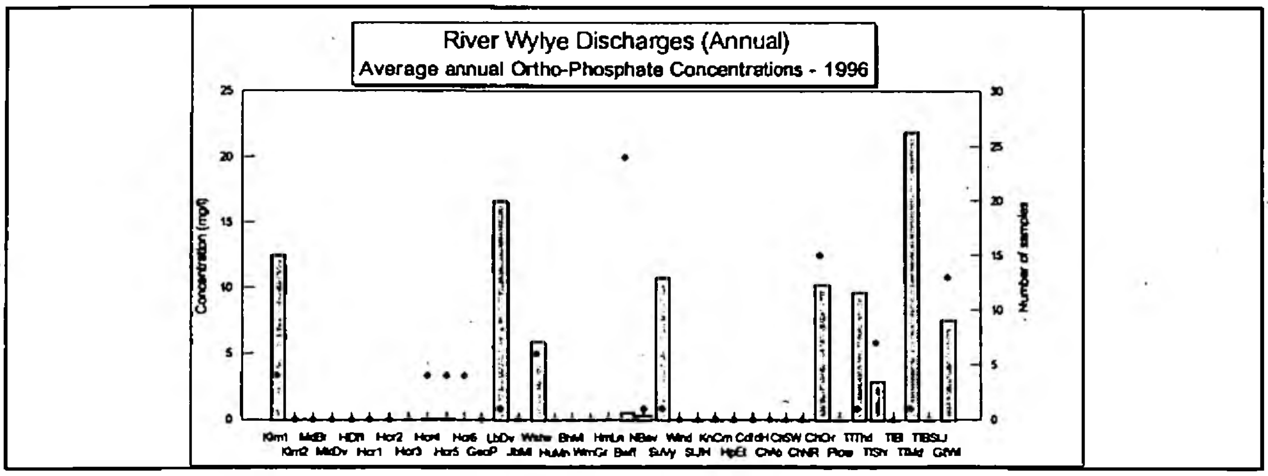
In-Stream Monitoring

Abbreviation/Full Name/URN

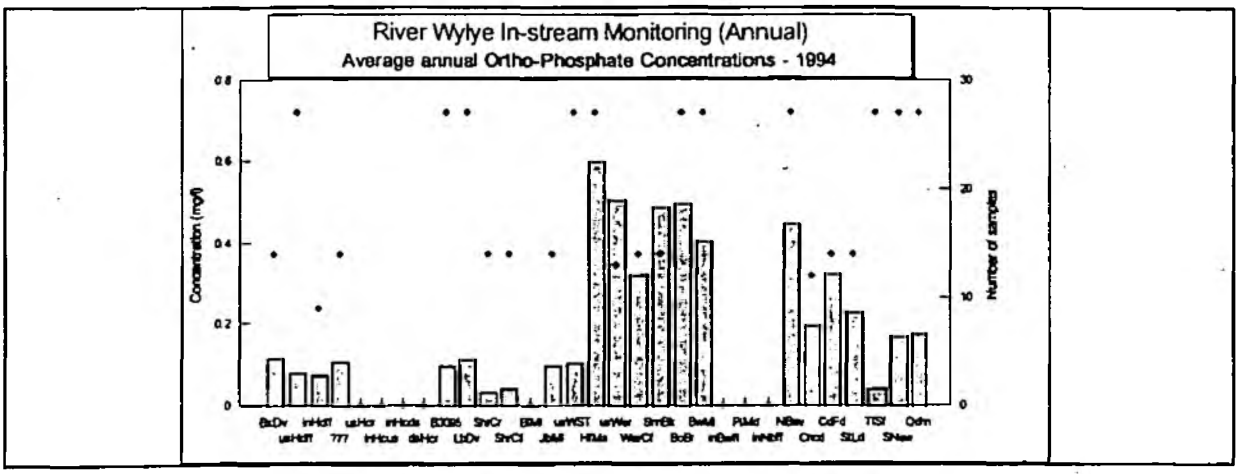
BxDv/BrixtonDeverill/3018800
usHdff/upstreamHillDeverillFishFarm/30116000
inHdff/InletHillDeverillFishFarm/30143000
??? /Oldsampling point-DoubtfulPos/30145000
usHcr/upstreamHurdsCressBeds/30121000
inHcus)Inlet to Hurds Cress Beds
)upstream Settlement Tank/30144100
inHcds)downstream Settlement Tank/30144200
dsHcr/downstreamHurdsCressBeds/30120200
B3095/B3095Bridge/30121000
LbDv/LongbridgeDeverill/30122000
ShrCr/ShearWaterCrockerton/30178000
ShrCf/ShearWater at Confluence/30179000
BlMl/BullMill/30126000
JbMl/JobsMill/30127000
usWST/upstreamWarminsterSTW/30129000
HfMa/HenfordMarsh/30130000
usWer/upstreamWereConfluence/30149000
WerCf/WereCalveswaterPS/30131000
SmBk/Smallbrook/30150000
BoBr/BorehamBridge/30133000
BwMl/BishopstrowMill/30134000
inBwff/InletFishFarm/30135100
PtMd/PitMeadsFB/30136000
inNbff/InletFishFarm/30125100
NBav/NortonBavant/30125000
Chcd/CodfordChitterne/30138000
Cdfd/CodfordStMary/30127100
StLd/SteepleLangford/30127200
TlSf/Stapleford/30146000
SNew/SouthNewton/30128000
Qdhn/Quidhampton/30245000

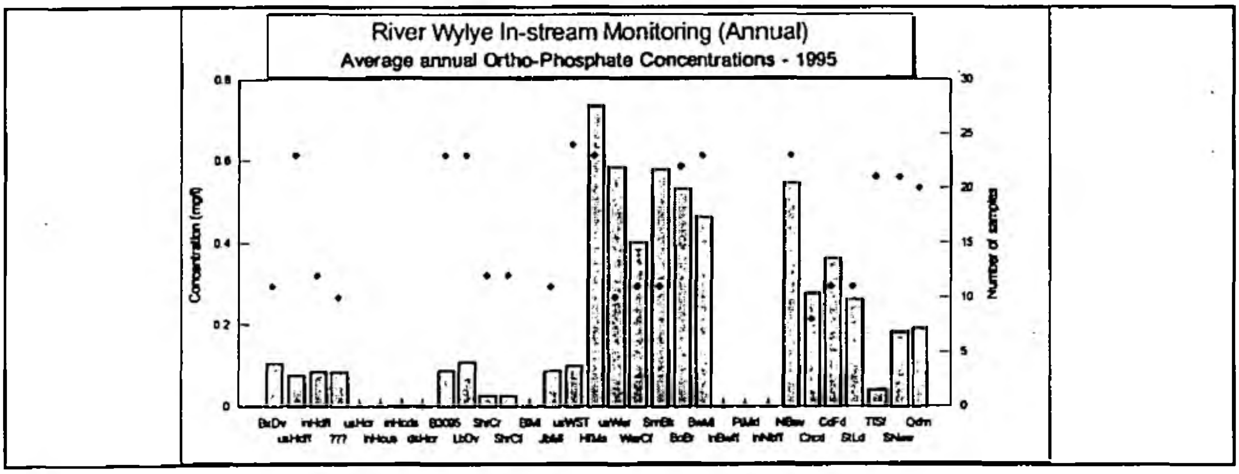


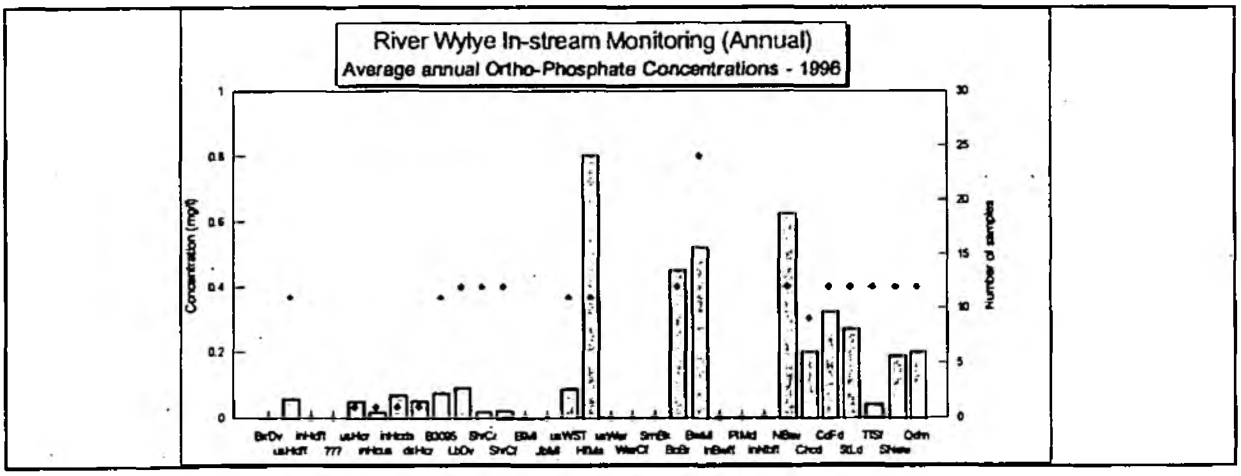




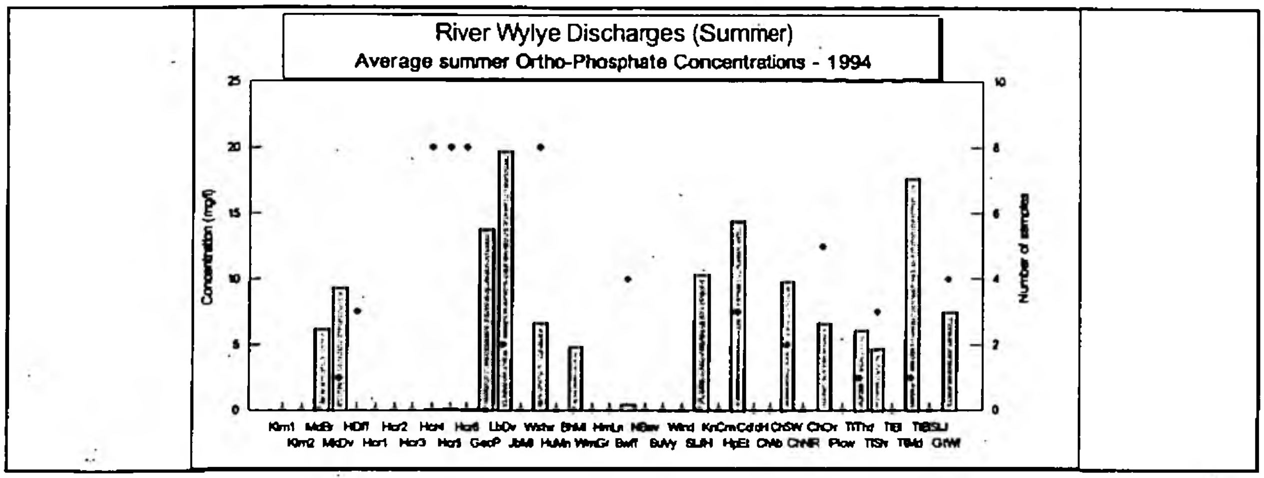
Figures 7 to 9 Average Annual Discharge Ortho-Phosphate Concentrations 1994-6

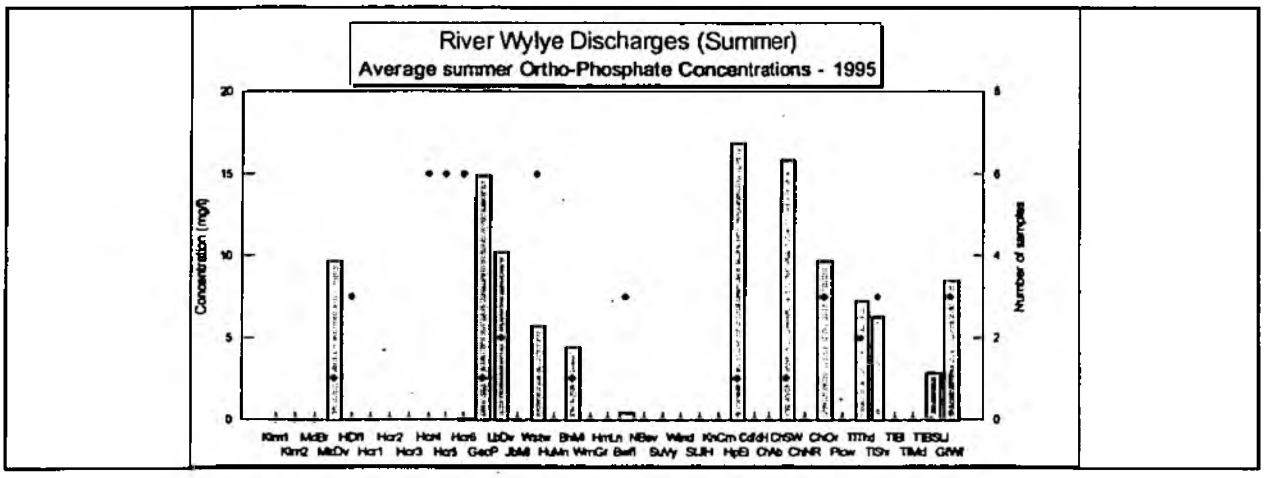


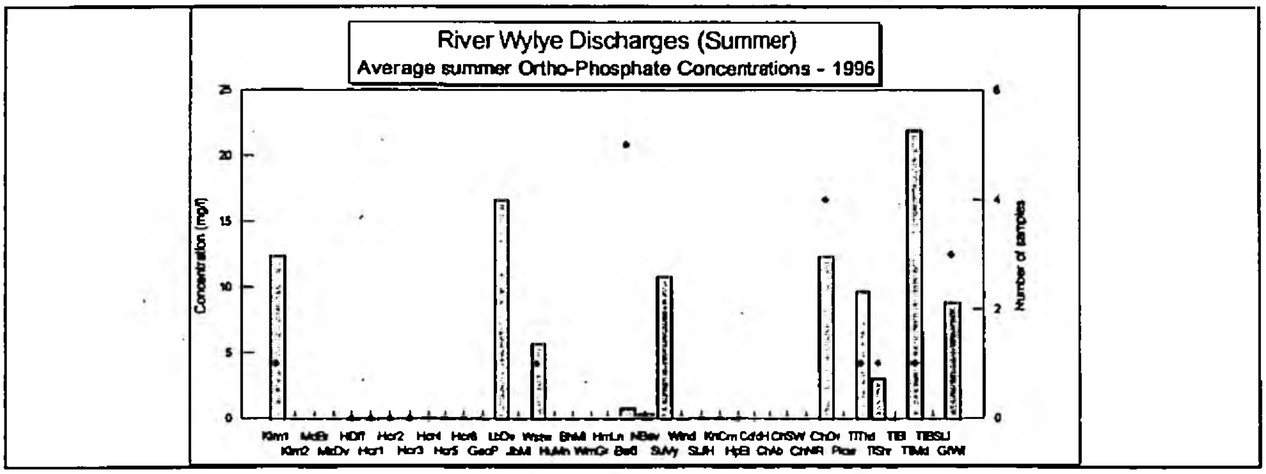




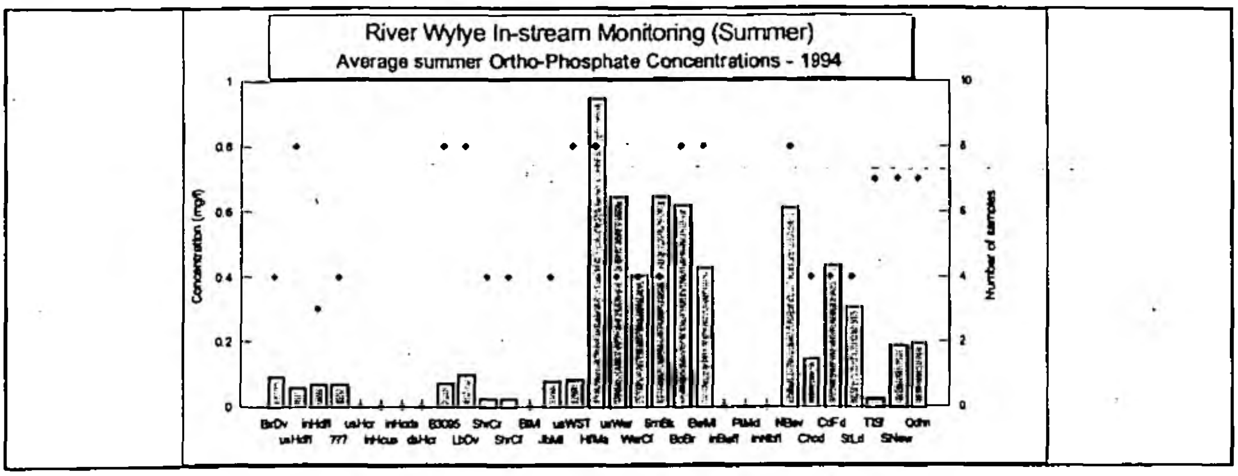
Figures 10 to 12: Average Annual In-stream Ortho-Phosphate Concentrations 1994-6

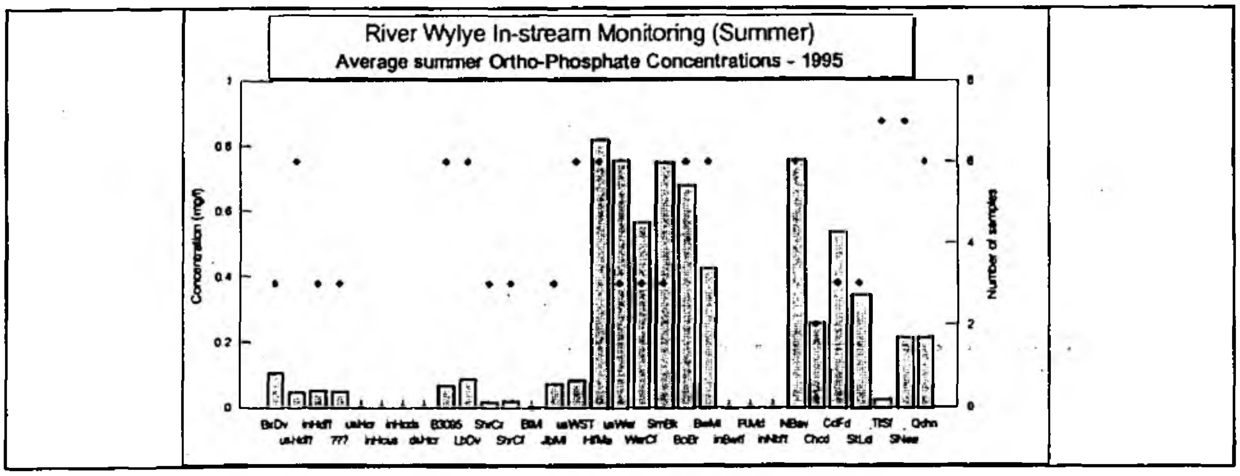


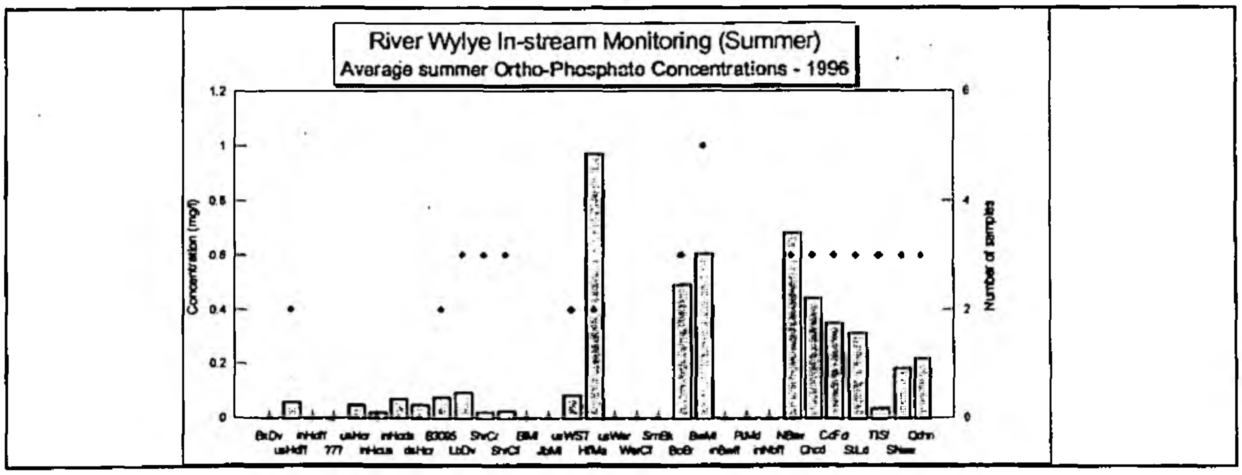




Figures 13 to 15: Average Summer Discharge Ortho-Phosphate Concentrations 1994-6







Figures 16 to 18: Average Summer In-stream Ortho-Phosphate Concentrations 1994-6

3.3.2 Loads

Discharges

Constant flow rates were used for the entire year - these were either the DWF or the Maximum value shown on the consent. Warminster STW has the highest average annual discharge load at approximately 0.3 g/s. Gt Wishford and Tillshead both have loads of about 0.1 g/s, but the latter is a soakaway so does not have a direct effect on the river loads. Bishopstrow fish farm contributes a load of approximately 0.05 g/s.

The average summer discharge loads are much the same as the annual loads, as would be expected, given that the same discharge flow rates were used for both annual and summer loads.

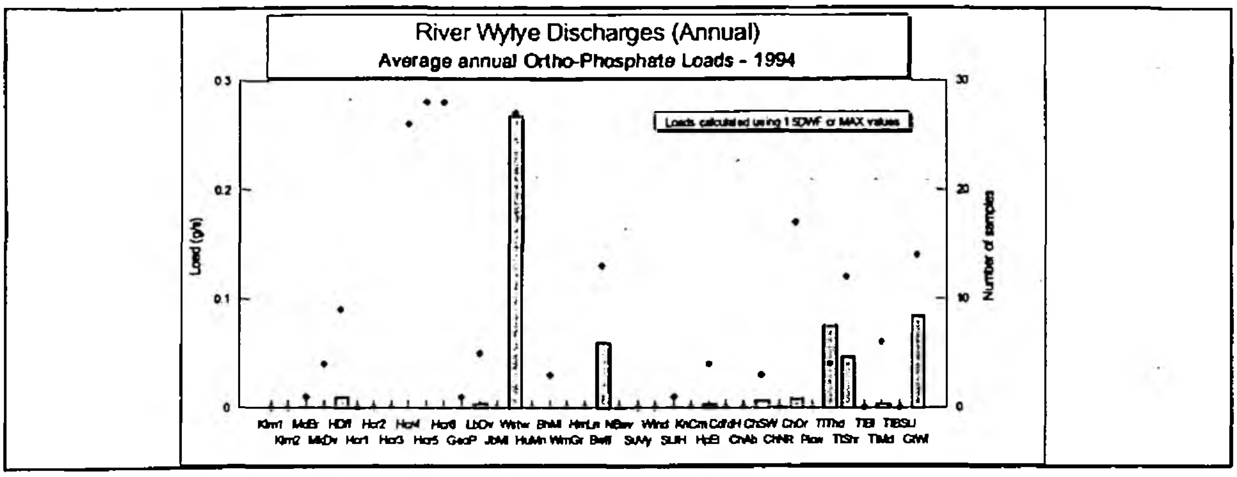
Figures 31 and 32 show a comparison of in-stream and discharge loads for the years 1994-6 both as annual averages and as summer averages. Also given on these figures are the average annual and summer flows at the downstream end of the system. These figures clearly show that on an annual basis, the discharge load is less than the downstream load during the wetter years, but is equal to it in 1996. In the case of summer loads, the discharge load is consistently higher than that downstream.

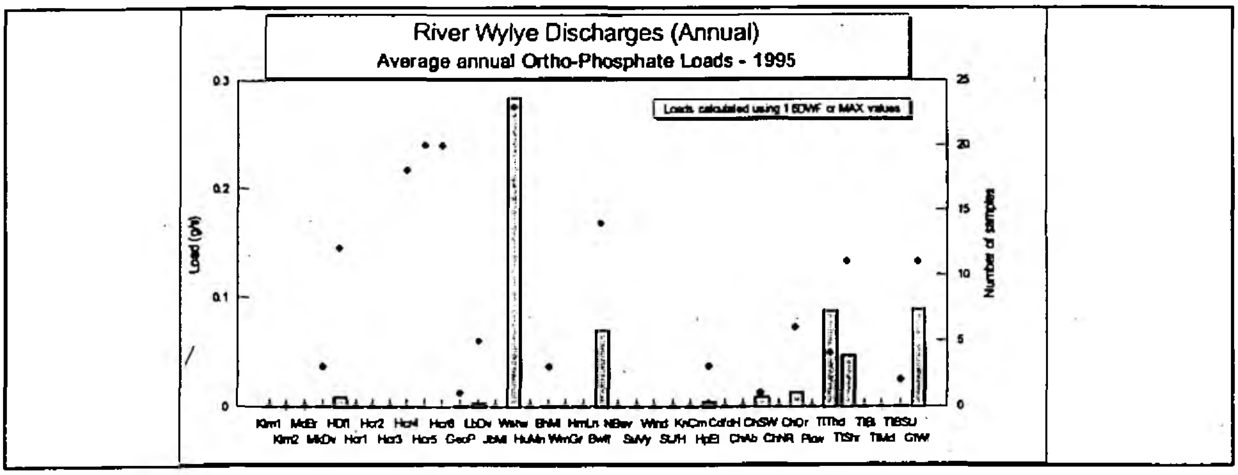
In-stream River Monitoring Points

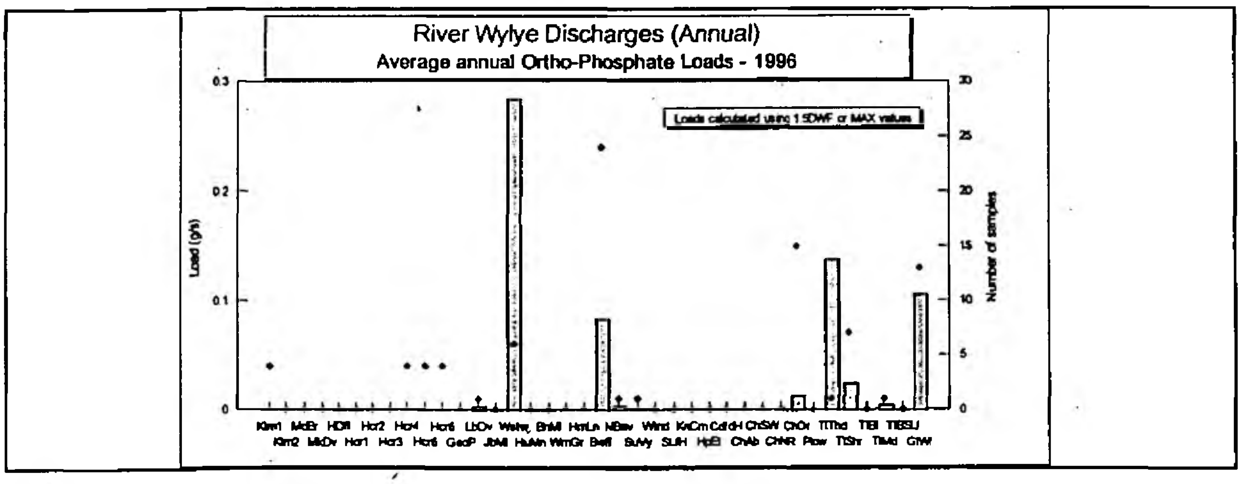
Monthly loads were calculated by multiplying the mean monthly flow (evaluated as described on p.5) and mean monthly sample concentration values. Annual mean loads were found by taking the mean of the monthly loads.

There is a buildup of the average annual in-stream load on proceeding downstream, reflecting the increasing flows. The load exported from the system is given by the load at the downstream end, which is approximately 0.8 g/s in 1994 and 1995 and 0.6 g/s in 1996, a drier year. The sum of the discharge loads is roughly 0.6 g/s, so that during the two wetter years there is a net export of phosphate from the system, whereas in the drier year, 1996, there is no export, and, possibly, even an accumulation of phosphate.

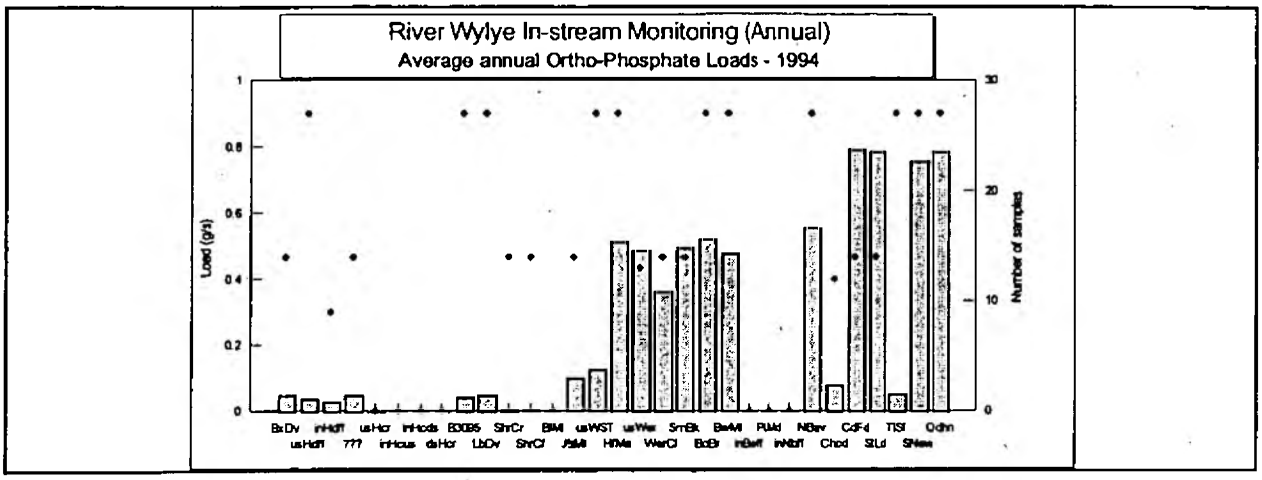
In summer, the load at the downstream end (approximately 0.4 g/s) is always less than the sum of discharge loads, indicating that during these summer months there is a buildup of phosphates; probably bound up within the river sediments. Export of the accumulated phosphate relies on their being sufficient winter rain to flush out the phosphate bearing sediment.

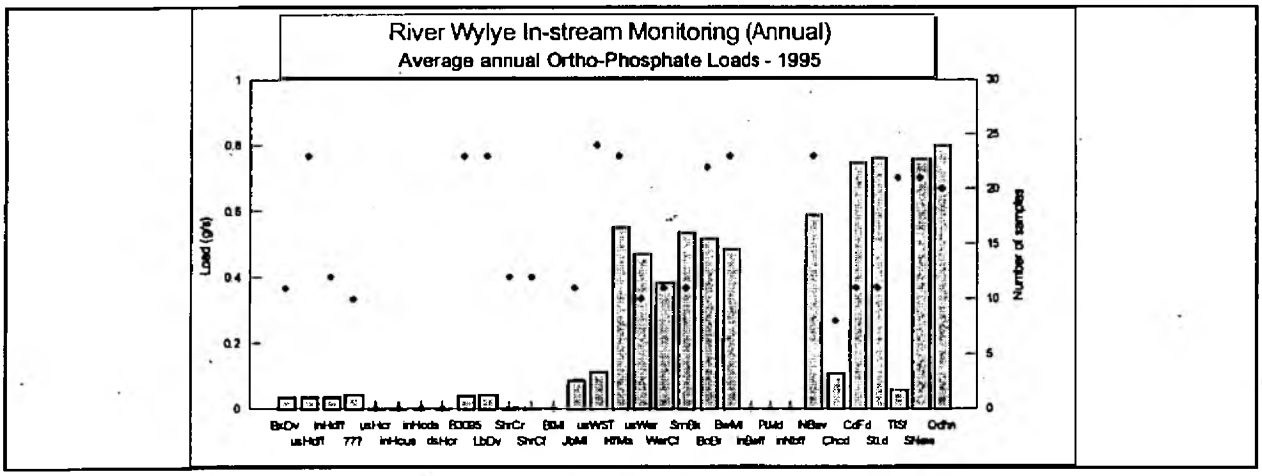


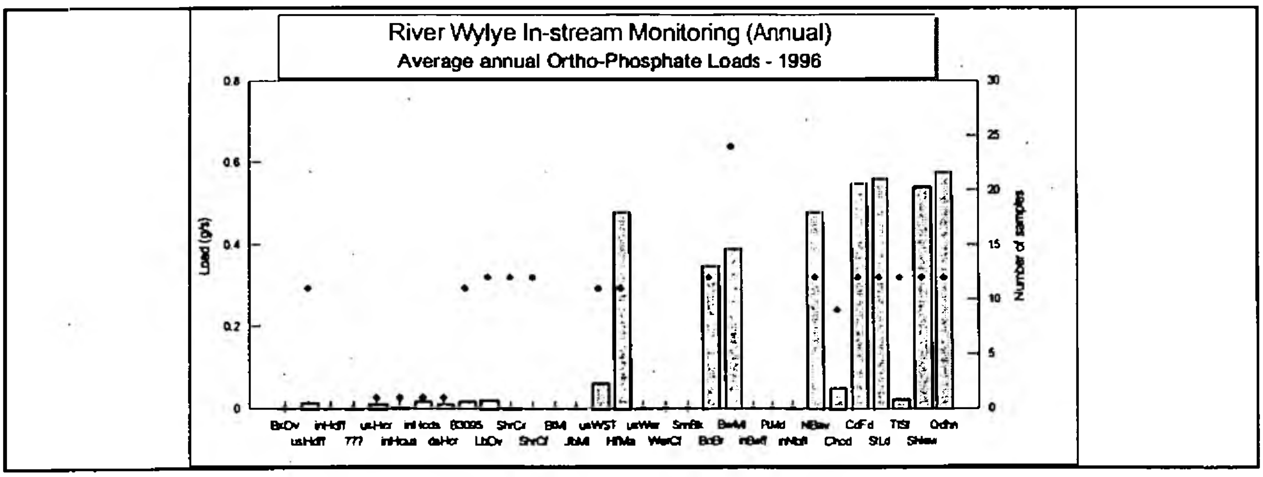




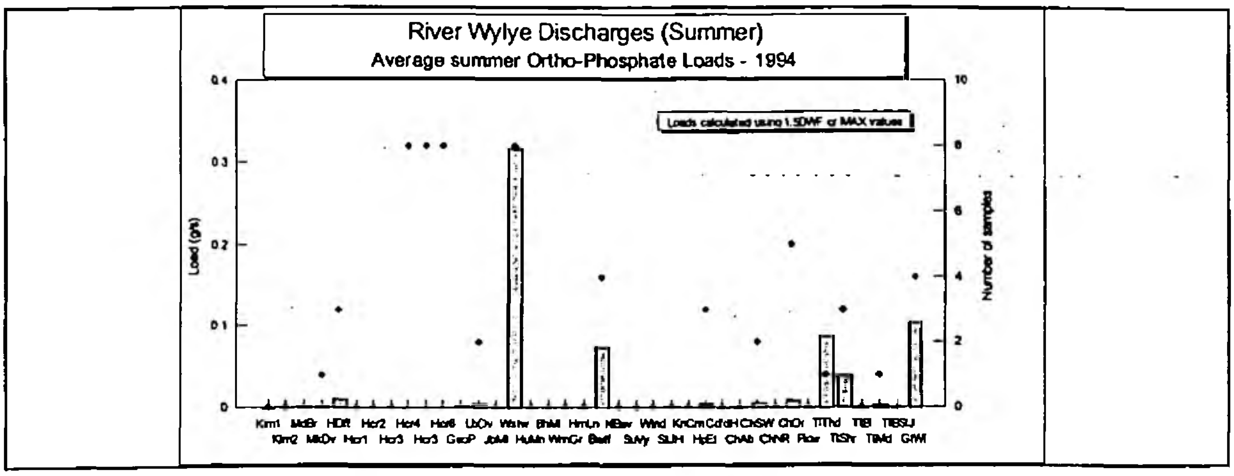
Figures 19 to 21: Average Annual Discharge Ortho-Phosphate Loads 1994-6

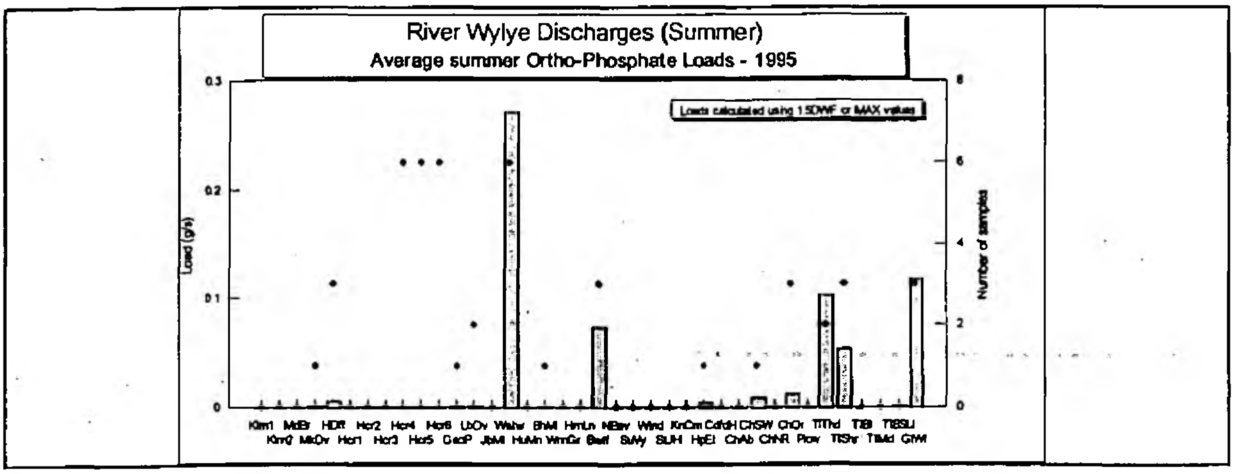


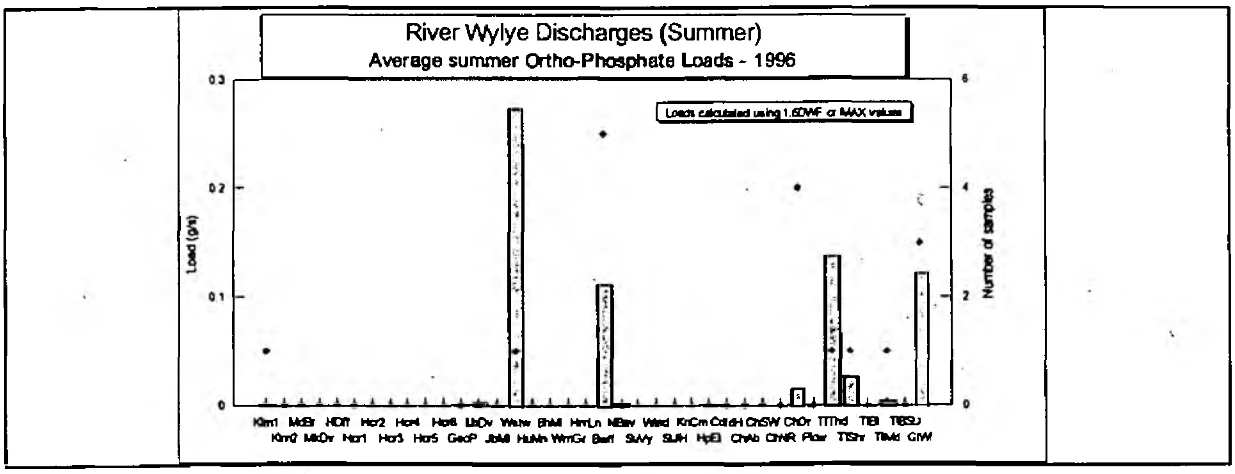




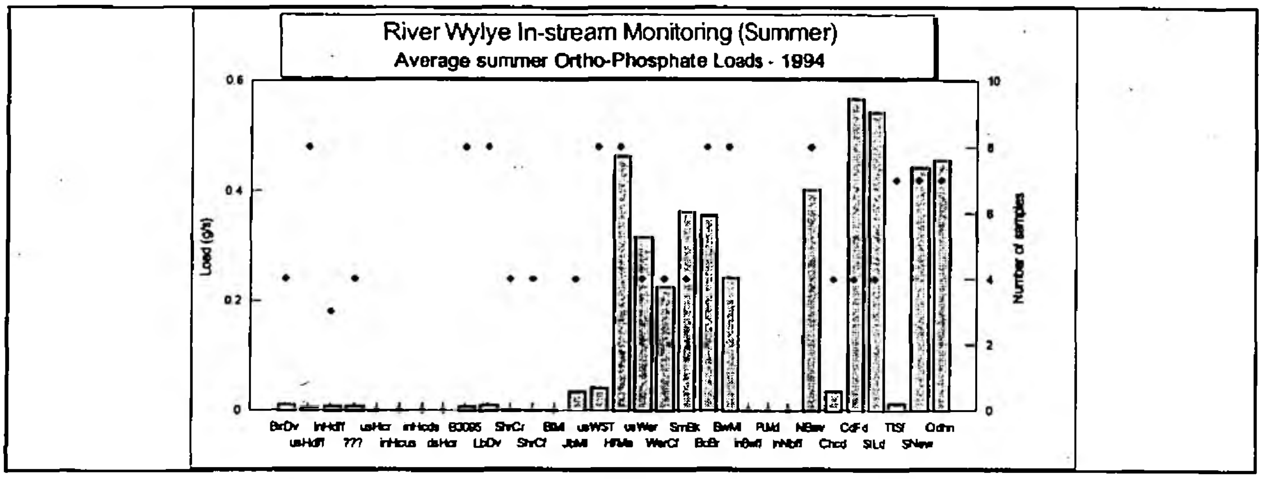
Figures 22 to 24: Average Annual In-stream Ortho-Phosphate Loads 1994-6

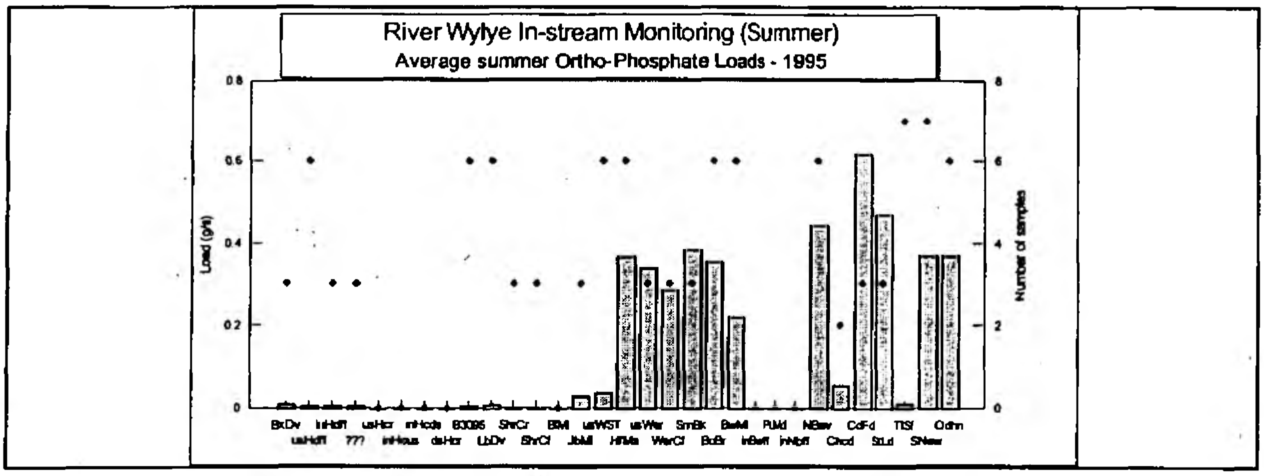


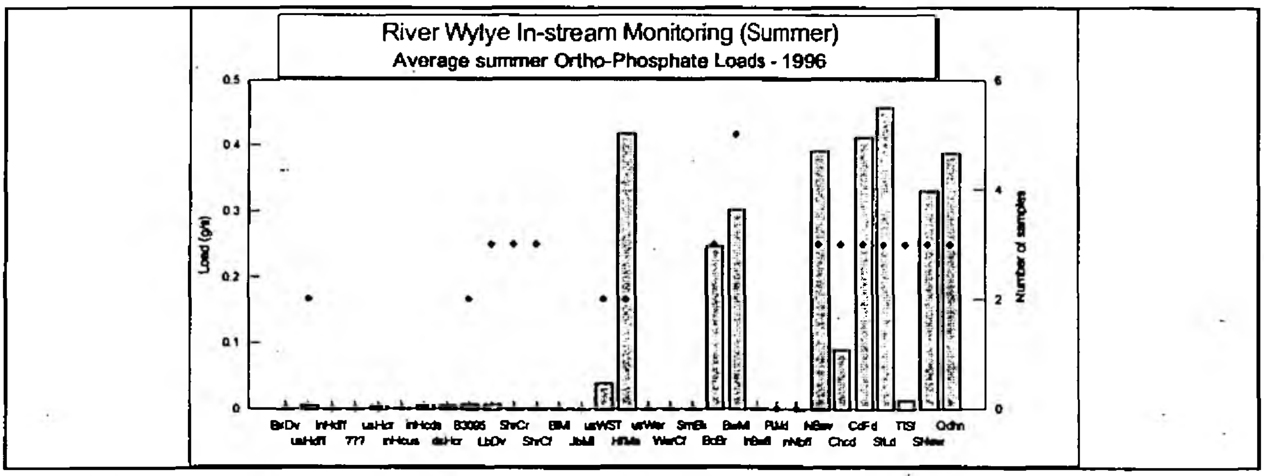




Figures 25 to 27: Average Summer Discharge Ortho-Phosphate Loads 1994-6







Figures 28 to 30: Average Summer In-stream Ortho-Phosphate Loads 1994-6

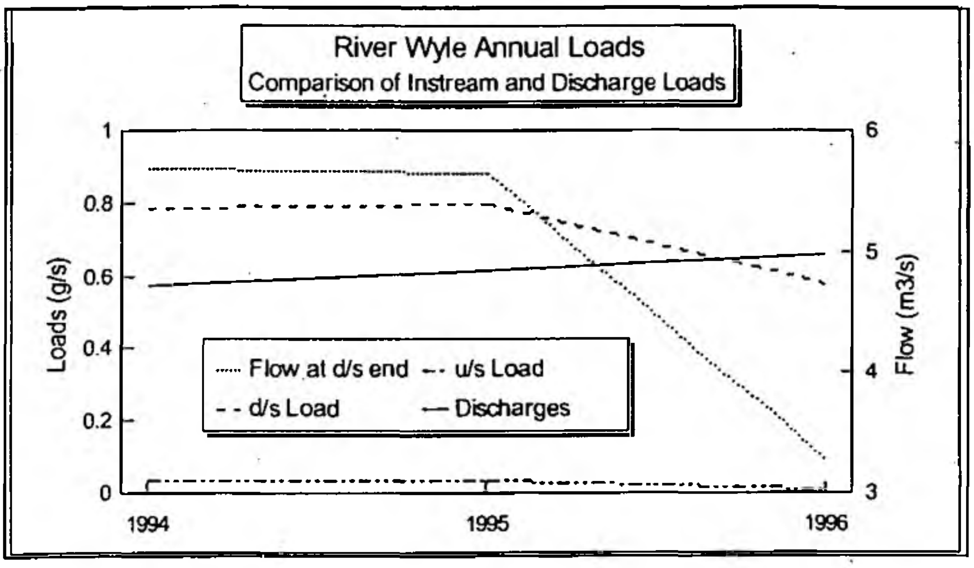


Figure 31: Comparison of Annual Discharge and Downstream Loads

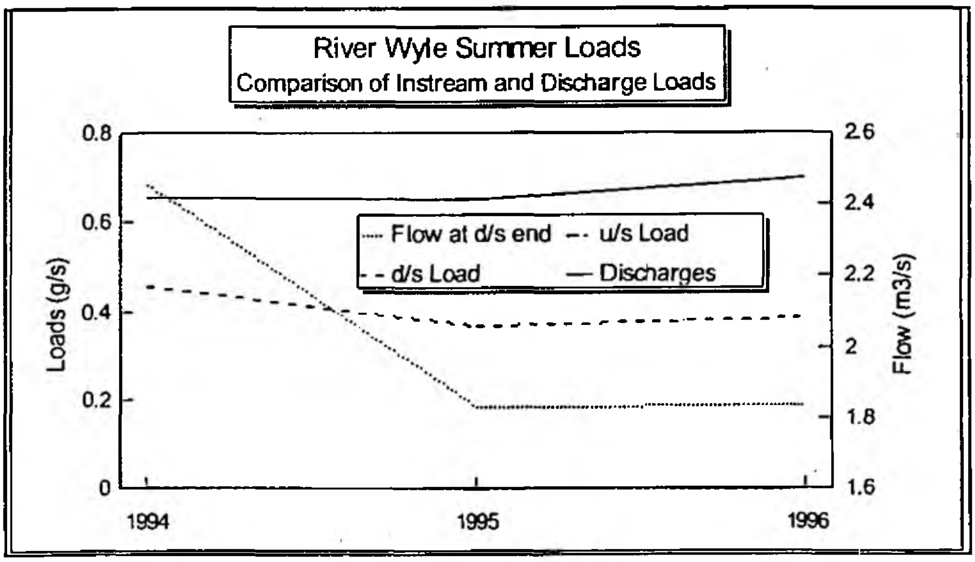


Figure 32: Comparison of Summer Discharge and Downstream Loads

4 MODELLING

4.1 Aims

The aims are:

a. To improve our understanding of the behaviour of phosphates in rivers, so as to improve the modelling
b. Estimate the effect of nutrient stripping for the Warminster STW discharge.

4.2 Model Components

Whilst load analysis provides a succinct summary of the catchment features, modelling gives a better insight into the impact of individual point sources, and the consequences of modifying a discharge, through nutrient stripping.

4.2.1 Discharges

All the smaller discharges were excluded from the model as these have a very small impact on the system. The discharges which were included are as follows:

- Hill Deverill Fish Farm
- Warminster
- Bishopstrow Fish Farm
- Gt Wishford

4.2.2 Tributaries

One of the main problems encountered in the modelling was that of water accretion along the river. The Wylye runs through a chalk landscape and there is considerable seepage of water from the ground via springs and channels. This seepage was allowed for in the QUASAR model by the introduction of artificial tributaries at points along the river.

Actual tributaries were as follows:

- Shear Water
- Were
- Chitterne Brook
- Till River

The flows for these tributaries were derived using MLF and the monthly flow records for the nearest gauging station in the same way as already described on p.5

Two additional tributaries were introduced near Norton Bavant and near Knook Camp to allow for water accretion.

4.2.3 Gauging Stations

There were three fairly equally spaced gauging stations along the river, at Brixton Deverill, Norton Bavant and South Newton, and data from these was used in conjunction with MLF to derive monthly flows at the upstream limit of the model and for the tributaries.

A schematic figure of the model structure is shown below.

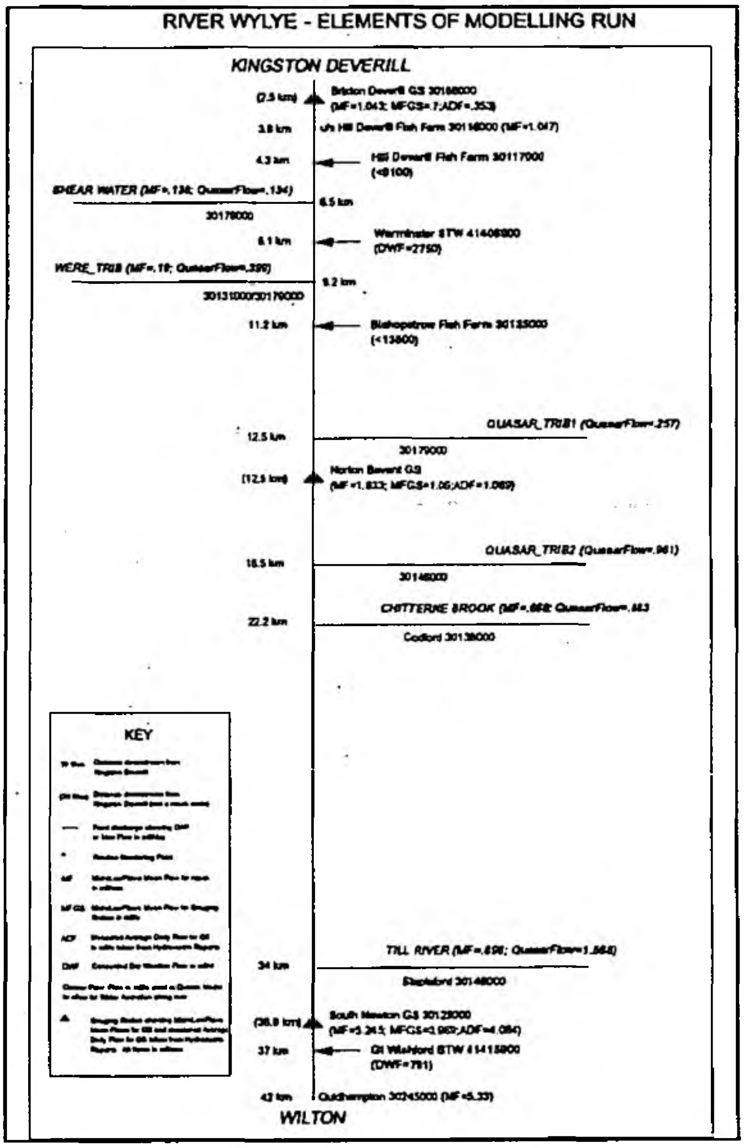


Figure 33: Schematic View of Components of River Wylye Model

4.2.4 Calibration and Validation

Only the years 1994 and 1995 were modelled as only for these two years is there a full set of sample ortho-phosphate data. Outputs for the model reaches were compared against observed concentrations at routine monitoring points within these reaches. The results are shown in figures 34 to 39. These figures show monthly values of modelled and observed ortho-phosphate for each reach throughout the year. The data for 1994 was used to calibrate the model and 1995 data used for validation.

Phosphate treated as Conservative
The initial modelling run was done treating ortho-phosphate as conservative. Suprisingly, this gave quite good agreement with observations for reaches as far downstream as Knook, but modelled concentrations further downstream of this were persistently higher than those observed, as would be expected, given that phosphates are generally perceived to be subject to decay processes.

Phosphate treated as subject to Decay
The phosphate decay process was modelled by an equation of the form:

$$d\frac{C}{dt} = -k(C - C_0)$$

Here 'C_0 ' is some equilibrium/saturation concentration value. This equation has been used in previous modelling work on the Upper Hampshire Avon. The value chosen for k was .08 and for C_0 0.02. These same decay parameters were used for all reaches.

The results obtained from the modelling runs using these parameters were rather disappointing. Although there was a reasonable fit with observations at the downstream end, the fit was worse for the middle reaches of the river.

General Comments
The 'spikiness' of the 1995 results can be attributed to the rather low sample values recorded for Warminster STW phosphate discharges during July and August of that year. The resulting drop in modelled concentrations downstream of Warminster persists to at least Norton Bavant, a distance of 4km, again indicating the strong influence of the STW discharge. The sudden increase in concentrations in December 1995 downstream of the Chitterne tributary is a result of the very high (1.5 mg/l) sample value recorded in the tributary at URN 30138000 for that month.

The consistent under prediction of phosphate levels during the winter may result from the fact that the model has no mechanism to represent flushing effects on sediments. The fact that it under predicts implies that there is an unmodelled source of phosphates, which could be due to winter flushing.

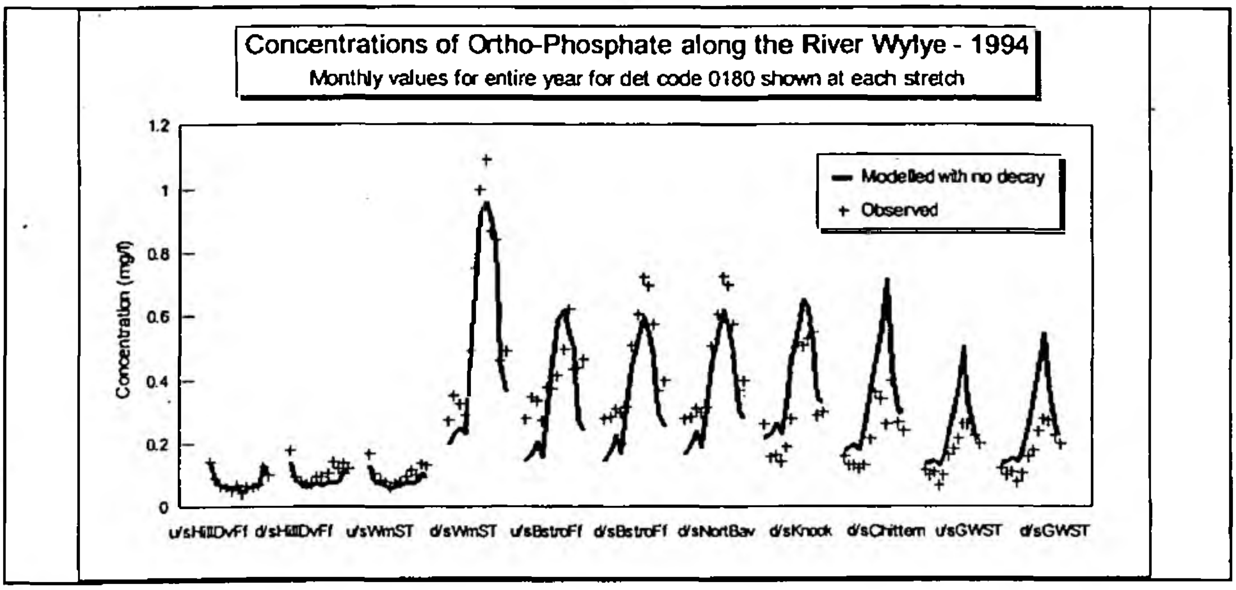


Figure 34: 1994 Ortho-Phosphate Concentrations Modelled (no decay) and Observed

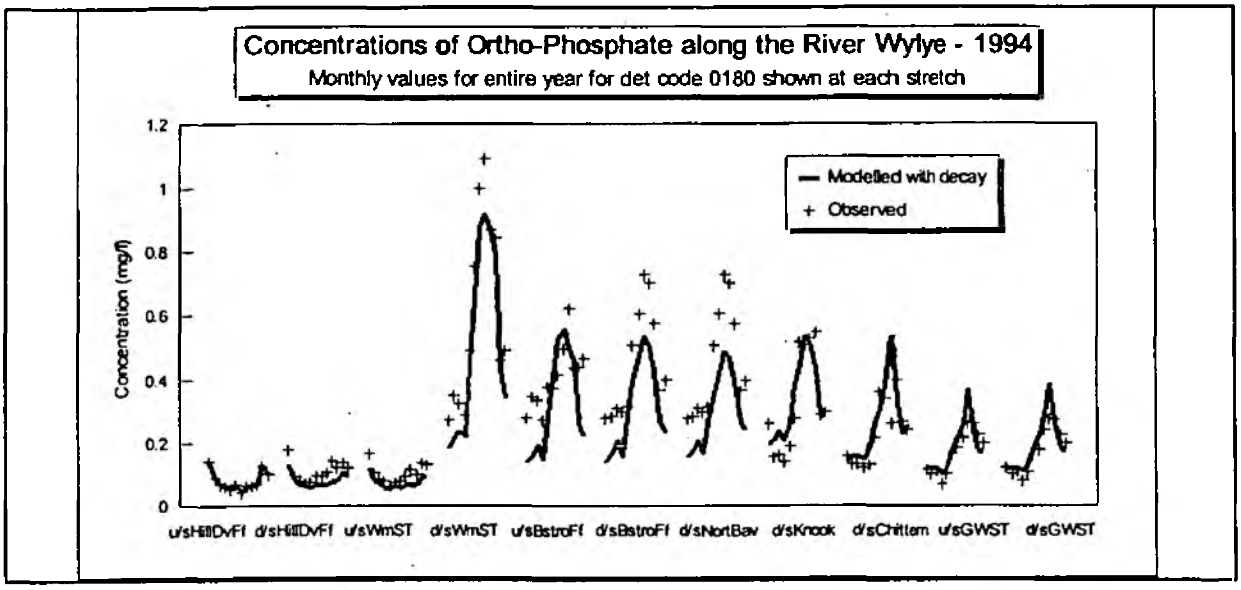


Figure 35: 1994 Ortho-Phosphate Concentrations Modelled with decay and Observed

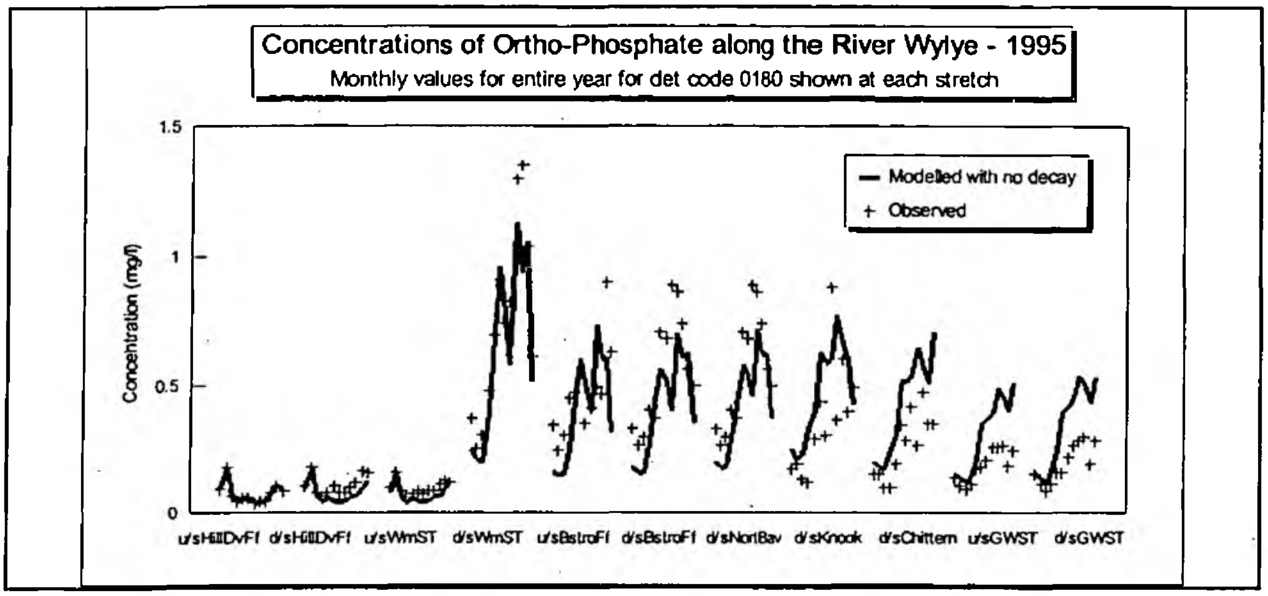


Figure 36: 1995 Ortho-Phosphate Concentrations Modelled (no decay) and Observed

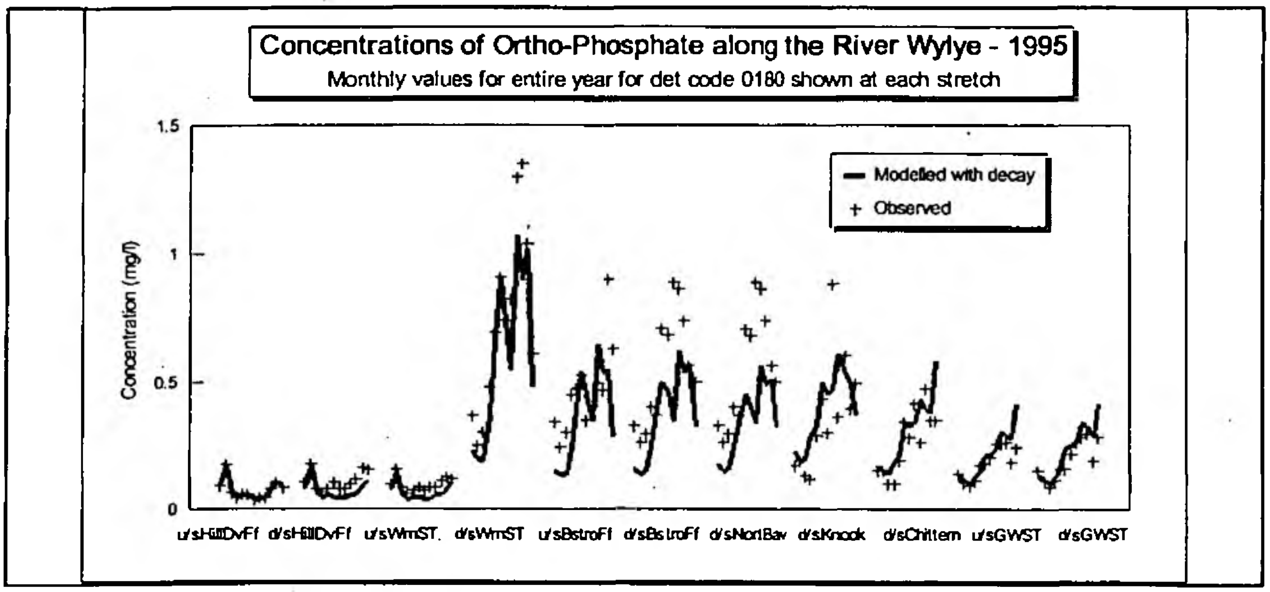


Figure 37: 1995 Ortho-Phosphate Concentrations Modelled with decay and Observed

4.2.5 Modelling Scenarios

One scenario run was done to assess the effect of reducing STW ortho-phosphates to a level which represents the realistic minimum which could be imposed - this was taken as 2 mg/l. The phosphate concentrations were modelled using the decay parameters mentioned above, although as stated already, these did not result in a very good model fit, which limits the reliance which can be placed on the modelled predictions.

As can be seen from the figure, reducing the Warminster STW ortho-phosphate discharge levels to 2 mg/l certainly effects a significant reduction in concentrations for a considerable distance (approximately 10km) downstream of Warminster, but concentrations at the downstream end are only slightly reduced.

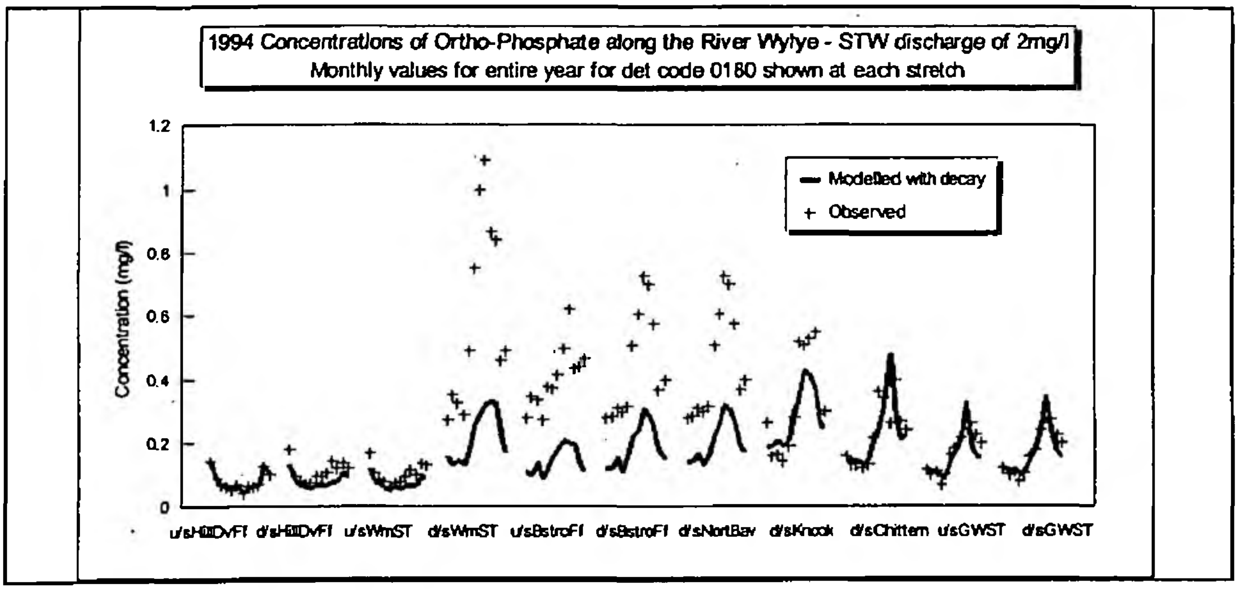


Figure 38: 1994 Ortho-Phosphate Concs Modelled with decay (STW 2 mg/l) and Observed

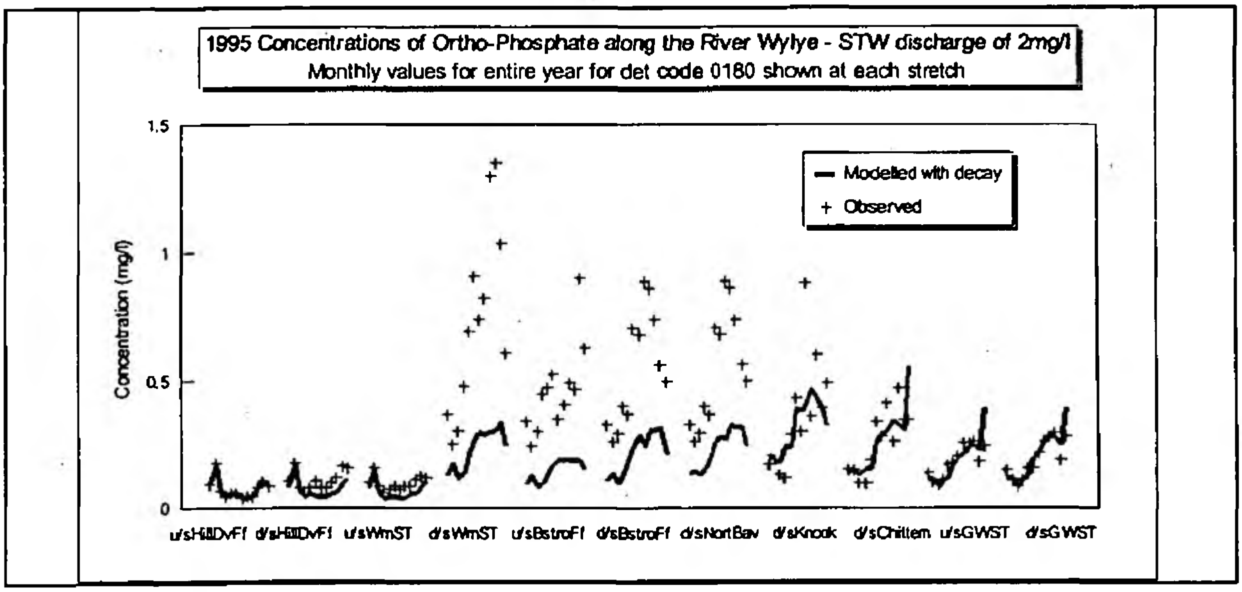


Figure 39: 1995 Ortho-Phosphate Concs Modelled with decay (STW 2mg/l) and Observed

5 SUMMARY and CONCLUSIONS

1 Phosphate concentrations in the River Wylye exhibit a strong seasonal cycle, with peak values of over 1.0 mg/l in August downstream of Warminster STW and minimum values of around 0.08 mg/l in May in reaches upstream of Warminster.

2 Warminster STW has a major impact on the longitudinal downstream phosphate profiles. The small, non PLC discharges have negligible impact on in-situ concentrations.

3 In wetter years the discharge loads are approximately three quarters of the load carried by the river and phosphate is exported from the system. During dry years the discharge loads may exceed the load carrying capacity of the river and phosphate accumulates in the system.

4 In the summer months, the discharge loads always exceed the downstream load and there is a buildup of phosphate in the system.

5 The attempt to model the concentration of ortho-phosphate was unsatisfactory, although the results generally supported the conclusions reached by the analysis of loads and concentrations - see 1 to 4 above.

6 Trying to simulate the accretion of water along the river when undertaking the modelling caused some problems, and 'lumping' this accretion together into artificial tributaries is not a very satisfactory solution.

7 The main problem in trying to calibrate the model was that high in-stream concentrations in the middle reaches could only be adequately simulated by assuming that phosphate behaved in a conservative manner, whereas lower downstream concentrations could only be simulated by imposing some decay on the phosphate. More modelling work needs to be undertaken to resolve this.

8 The problems outlined above may be explained by their being other sources of ortho-phosphate in the reaches of the Wylye between Bishopstrow and Codford - these could be either point discharges, groundwater infiltration or runoff from the land - no attempt has been made to model the latter.