EUTROPHICATION IN CONTROLLED WATERS IN THE WARWICKSHIRE AVON CATCHMENT

(Final Report)

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EUTROPHICATION IN CONTROLLED WATERS IN THE WARWICKSHIRE AVON CATCHMENT
(Final Report)

A Research Report Commissioned by the Environment Agency

Volume 1

Report and Executive Summary

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EXECUTIVE SUMMARY

Introduction

The River Avon was designated a Sensitive Area (Eutrophic) under the UWWT Directive in 1994. A major advance in dealing with the problems of eutrophication (increased phytoplanton blooms, excess macrophyte growth etc.) is the removal of significant levels of phosphate from the major sewage works in the Catchment. Following on from designation as a SA(E) this project was initially designed to:

- Identify the present levels of phosphate and nitrate in the Avon catchment.
- Estimate the likely effect of phosphate removal at the major sewage works
- Estimate the possible further improvements possible by extending phosphate treatment to smaller sewage works
- Identify the other major sources of phosphate and nitrate in the catchment.

The project also provides a baseline for assessing the improvements that shall result from phosphate treatment at the major STWs commencing at the end of 1998. It has also identified a number of areas where additional investigative work may be required to improve the understanding of nutrients in the Avon catchment. This will allow targeting of resources to reduce the input of diffuse phosphate and nitrate to the river.

The following points highlight the major issues addressed within this report:

1. The Avon has shown signs of accelerated eutrophication in recent years by the presence of attached and planktonic algae and as a result of the presence of nuisance blue-green algal blooms. Such characteristics are undesirable from both a water quality management and recreation/resource perspective.

2. Phosphorus and nitrogen are essential nutrients which control the productivity of natural waters. In aquatic systems phosphorus is usually considered to be the limiting nutrient and the soluble orthophosphate ion is the form in which it is believed to be most readily available to photosynthesising organisms. At concentrations above 10 µg/l PO_4 accelerated algal growth may occur in lakes. Critical phosphorus concentrations in rivers are more difficult to define but the DoE (1993) assign a limit of 100 µg/l PO_4-P (expressed as an annual average) to designate eutrophic sensitive running freshwaters.

3. This report synthesises the main findings obtained from an analysis of the 22 months (December 1994- September 1996) of data collected for the "Eutrophication in Controlled Waters in the Warwickshire Avon Catchment" project.

4. The project was established to monitor total nitrogen and total phosphorus concentrations and river and effluent discharges in addition to a range of other water quality parameters in the 2200 km^2 drainage basin of the river Avon upstream of Evesham. (Whilst this report considers both N and P, only P removal will be installed at qualifying STWs in the River Avon Catchment under the UWWT Directive). In total, water quality data were collected at 79 monitoring stations which included:

i) Effluent discharges from five qualifying (Urban Waste Water Treatment Directive: EC, 1991) Sewage Treatment Works (STWs).

ii) Thirteen minor STW effluents

iii) Fifty seven river sites in catchments ranging in size from <50 km^2 to 2200 km^2.

iv) Four lakes/reservoirs.

5. Compliance with the programme for the collection of water samples exceeded 86% and compliance with the flow gauging programme exceeded 97%.

6. All water samples were collected in duplicate at each site. One sample was filtered prior to analysis and the other was unfiltered. Both samples were analysed for orthophosphate in order to determine bias and uncertainty in measuring concentrations on unfiltered samples; a method currently used routinely by the Environment Agency.

7. All samples were analysed at the Environment Agency's NAMAS accredited laboratory at Nottingham under private contract.

8. Flow and water quality data were managed and analysed by the research team at Coventry University using an IBM compatible PC supplied by the Environment Agency. Summary water quality statistics, load calculations and inferential statistical analyses were performed using 'Microsoft Excel' and 'SPSS for Windows'. All statistical analysis and nutrient load calculations follow the procedures recommended to the Environment Agency by the WRc.

9. The objectives of the data analysis were to:

i) Evaluate the impact of qualifying discharges and 13 minor STW effleunts on the nutrient concentrations in local rivers and in the river Avon at Evesham.

ii) Identify the potential contribution of diffuse sources to nitrogen and phosphorus loads.

iii) Estimate the potential reduction in nitrogen and phosphorus concentrations and loads based on nutrient removal estimates at the five qualifying STWs. (Qualifying STWs are defined as STWs serving an agglomeration of greater than 10000 population equivalent).

iv) Assess the potential impact of nutrient removal options on eutrophication.

v) Identify areas of uncertainty and make suggestions for further analysis of the 'Eutrophication' data base and of other issues relating to the future health of the river Avon.

10. The report concludes that:

    i) The river Avon at Evesham transports 1551 kg phosphorus/day and 14846 kg nitrogen/day.

    ii) Of the major subcatchments of the river Avon, the river Sowe at Stoneleigh has the highest specific phosphorus and nitrogen loads of 12.98 and 59.46 kg/ha/yr respectively whilst the river Leam at Eathorpe has the lowest nitrogen load of 9.28 kg/ha/yr and the river Dene at Wellesbourne has the lowest phosphorus load of 0.35 kg/ha/yr.

    iii) Of the sewage treatment works (STWs), highest mean total phosphorus concentrations of 13.72 mg/l are recorded at Leamington (Heathcote) whilst lowest mean total phosphorus concentrations of 2.78 mg/l are recorded at Rugby (Newbold) STW. Highest mean total oxidised nitrogen concentrations of 25.15 mg/l are recorded at Tanworth STW and lowest total oxidised nitrogen concentrations of 10.66 mg/l at Stratford (Milcote) STW.

    iv) For the river samples, highest mean total phosphorus concentrations of 4.65 mg/l are recorded on the river Sowe at Stoneleigh and lowest total phosphorus concentrations of 0.07 mg/l are recorded on the Wyken Slough Brook. Highest total oxidised nitrogen concentrations of 14.22 mg/l are recorded on the river Sowe at Stoneleigh and lowest total oxidised nitrogen concentrations of 2.4 mg/l are recorded on the Wyken Slough Brook.

    v) The seasonal patterns of nitrogen behaviour at STWs is complex and site specific. The seasonal patterns of phosphorus behaviour at STWs usually show some increase in concentration between March and September. Over the last 6 months of record at Rugby (Newbold), total phosphorus concentrations appear to be increasing whereas the opposite trend is apparent at Warwick (Longbridge).

    vi) Total oxidised nitrogen concentrations at sites on the river Avon upstream of Rugby reveal a seasonal pattern with highest concentrations in late autumn and spring. The dominance of STW contributions downstream of the Sowe/Avon confluence masks any seasonality in total oxidised nitrogen concentrations.

    vii) Weak seasonality in the total phosphorus record is evidenced at sites on the Avon upstream of Rugby. The seasonality in total phosphorus concentrations on the Sowe at Stoneleigh, at sites downstream of the Sowe/Avon confluence and at sites on the river Arrow downstream of Redditch reflects a lack of effluent dilution between the early summer and autumn. Total phosphorus concentrations on the main river Avon frequently exceed 4 mg/l over the summer and autumn of which the vast majority is present in dissolved form.

viii) Analysis of the impact of implementing the UWWT Directive on river concentrations suggests that total phosphorus concentrations will exceed 0.5 mg/l with an annual average in excess of the DoE (1993) threshold for total P (on average, PO_4(filt) accounts for 95% of the average total P concentration in rivers). Highest concentrations will be evident from March through October, a period when most phytoplankton growth occurs. It is concluded that concentrations of total phosphorus at Evesham will exceed the DoE (1993) criteria for phosphorus even if the UWWTD standards (2 mg/l or 1 mg/l as annual mean) are implemented at all STWs. However, it also apparent that there will be a substantial reduction in the phosphorus concentration at Evesham.

ix) Analysis of nutrient concentrations in all forms at major sites on the river Avon reveals increases downstream of the Rugby STW and downstream of the Sowe confluence with the river Avon at Barford. High concentrations in the river Sowe reflect the dominance of Finham STW discharges. There are statistically significant differences in nutrient concentrations in all forms, (with the exception of PO_4), and in suspended sediment concentrations, between Lawford (higher concentrations) and Stare Bridge (lower concentrations). Between these two monitoring sites is a major wetland (Brandon Marshes) which may play a role in nutrient assimilation.

x) Loads of nitrogen and phosphorus increase most dramatically between Stare Bridge and Barford on the main river Avon, the latter site including the contribution from Finham STW. Nitrogen and phosphorus loads increase very little between Lawford and Stare Bridge.

xi) Particulate-phosphorus makes a major contribution (45%) to the total phosphorus transport at Evesham between January and March 1995. In the remaining period of monitoring, particulate-phosphorus contributes less than 15% of the total phosphorus load at Evesham.

xii) The impact of P removal, assuming minimum compliance with the Urban Waste Water Treatment (UWWT) Directive, will reduce phosphorus loads at Evesham by ca. 50%. After P removal it is estimated that 40% of the total phosphorus will derive from minor STWs. It is also estimated that implementation of the UWWT Directive threshold concentrations at all STWs would result in a further phosphorus load reduction of ca. 15% of the present load at Evesham. If the UWWT Directive was implemented for nitrogen, it is estimated that N loads at Evesham would be reduced by 11%. After N removal it is estimated that 8% of the total nitrogen will derive from minor STWs.

xiii) After nutrient removal, high concentrations of total P are likely to be experienced in the river Sowe.

xiv) It is evident from this study that the introduction of P removal to UWWTD standards will bring significant reductions in P concentrations and loads. It is also apparent that P removal in isolation will not produce P concentrations below the limits cited in the literature as being likely to limit eutrophication. There is uncertainty as to the limiting concentrations of P in rivers and the true 'benfits' of P removal at STWs can only be properly assessed once treatment is introduced at the qualifying STWs from 31st December 1998.

xv) The effects of field filtering on the determination of orthophosphate concentration is significant on 17 of the 18 weekly sampled stations investigated. Only for the river Avon sampling site at Lawford does the analysis of unfiltered samples provide a reliable estimate of orthophosphate concentrations in filtered samples. At 13 of the 18 sites, there is a statistically significant difference between the mean orthophosphate concentration determined on filtered and unfiltered samples.

xvi) Eight areas of further research are recommended. These are:

1. Investigate the impact of P removal in the Avon catchment
2. Calculating nutrient loads
3. Subcatchments generating high loads from diffuse and unaccountable sources
4. Export coefficient modelling and testing.
5. The role of wetlands (Brandon Marsh) as sediment and nutrient sinks and as phytoplankton re-seeding areas.
6. Phytoplankton and eutrophication
7. Rural sewage pollution.
8. Climate change and eutrophication.

1. INTRODUCTION

1. This is the final report on the main findings of the 22 months of data collection in the EA funded project 'Eutrophication in Controlled Waters in the Warwickshire Avon Catchment' (hereafter referred to as the Eutrophication Project)

2. This report updates preliminary research findings presented in the Quality Review Report of October 1995 (Buckland, 1995) and 'Eutrophication In Controlled Waters In Lower Severn Area (Analysis of the first 12 months data)' (Foster *et al.*, 1996a). The terms of reference of the Eutrophication Project are listed below.

3. The project objectives are

- To assess the potential contribution of point source inputs of the nutrients Nitrogen and Phosphorus to watercourses in the Upper Avon catchment (upstream of Evesham).
- To assess the potential impact of nutrient removal options on eutrophication.

4. This report will consider the following issues for the twenty two months sampling period December 1994 to September 1996:

- compliance with the sampling programme
- compliance with analysis programme
- analytical quality control
- maintenance of the data base at Coventry University
- identification of nutrient sources
- calculation of concentrations and loadings for phosphorus and nitrogen
- assess whether nutrient removal from a qualifying discharge will have an impact on eutrophication in the receiving waters
- identify areas of uncertainty
- investigate the link between cause and effect in eutrophication

2. STUDY BACKGROUND

1. Over the past several decades, the River Avon catchment area (**Figure 1**) has seen diverse and intense, urban, rural and agricultural development and growth (**Figure 2**). As a result both water use and nutrient rich waste discharge have increased substantially. Symptoms of accelerated eutrophication, including the growth of attached and planktonic algae, leading to diurnal variations in dissolved oxygen, have characterised the main river and some of its tributaries. During low flows in 1990, nuisance blue-green algal blooms of *Oscillatoria agardhii* occurred in the lower reaches of the River Avon. Such characteristics are undesirable from both a water quality management and recreation/resource perspective.

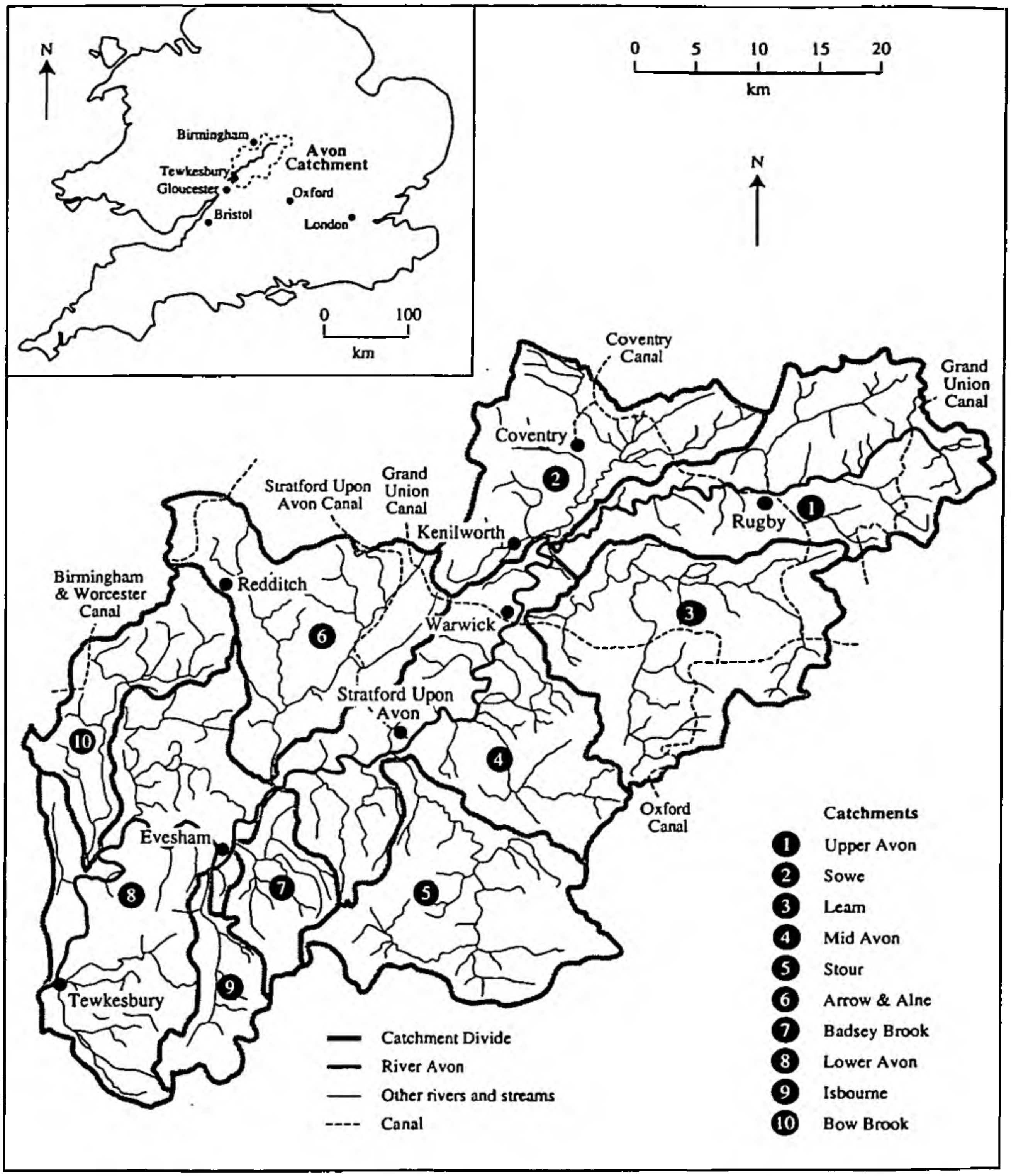
2. The River Avon meets all of the criteria set by the Department of the Environment (DOE) to define Eutrophic (running) waters. In December 1992 the Avon and a major tributary, the River Arrow, were put forward as candidates for designation as 'Sensitive Areas(Eutrophic)' under the EC Urban Waste Water Treatment Directive (UWWTD, 91/271/EEC).

3. For designation as a Sensitive Area (Eutrophic) under the UWWT Directive a watercourse must receive sewage effluent from "a qualifying STW discharge" serving a population of greater than 10000 pe. In addition, the watercourse must meet the necessary chemical and biological criteria defining eutrophication. These criteria are set out in 'The Methodology For Identifying Sensitive Areas (UWWTD)'. Where these criteria are fulfilled, the Environment Agency may require nutrient removal, i.e. phosphorous (P) and/or Nitrogen (N), the causative chemicals of eutrophication, from the qualifying discharge(s), providing that it can be demonstrated that nutrient removal will have an impact on eutrophication. In freshwaters P is usually found to be the limiting nutrient and therefore only P removal is required.

4. Eutrophication processes are well documented for standing water where much is known about the relationship between P and N in the sediments, water and biota. However, very little work has been carried out in running waters. As a consequence there is uncertainty concerning the relative contribution of point sources (STWs) and non-point or diffuse sources (e.g. agricultural runoff) to P and N concentrations and loadings in rivers. This uncertainty also extends to the relationships between nutrient concentrations and loads and the ecological impact of excess P and N.

5. In 1993, the Environmental Quality Section at Lower Severn Area established links with the Geography Department at Coventry University where there is considerable expertise on eutrophication. Both parties agreed to a collaborative study of nutrient sources and dynamics in the upper River Avon catchment in order to improve understanding of the eutrophication processes in running waters.

Figure 1 The river Avon and its sub-catchments



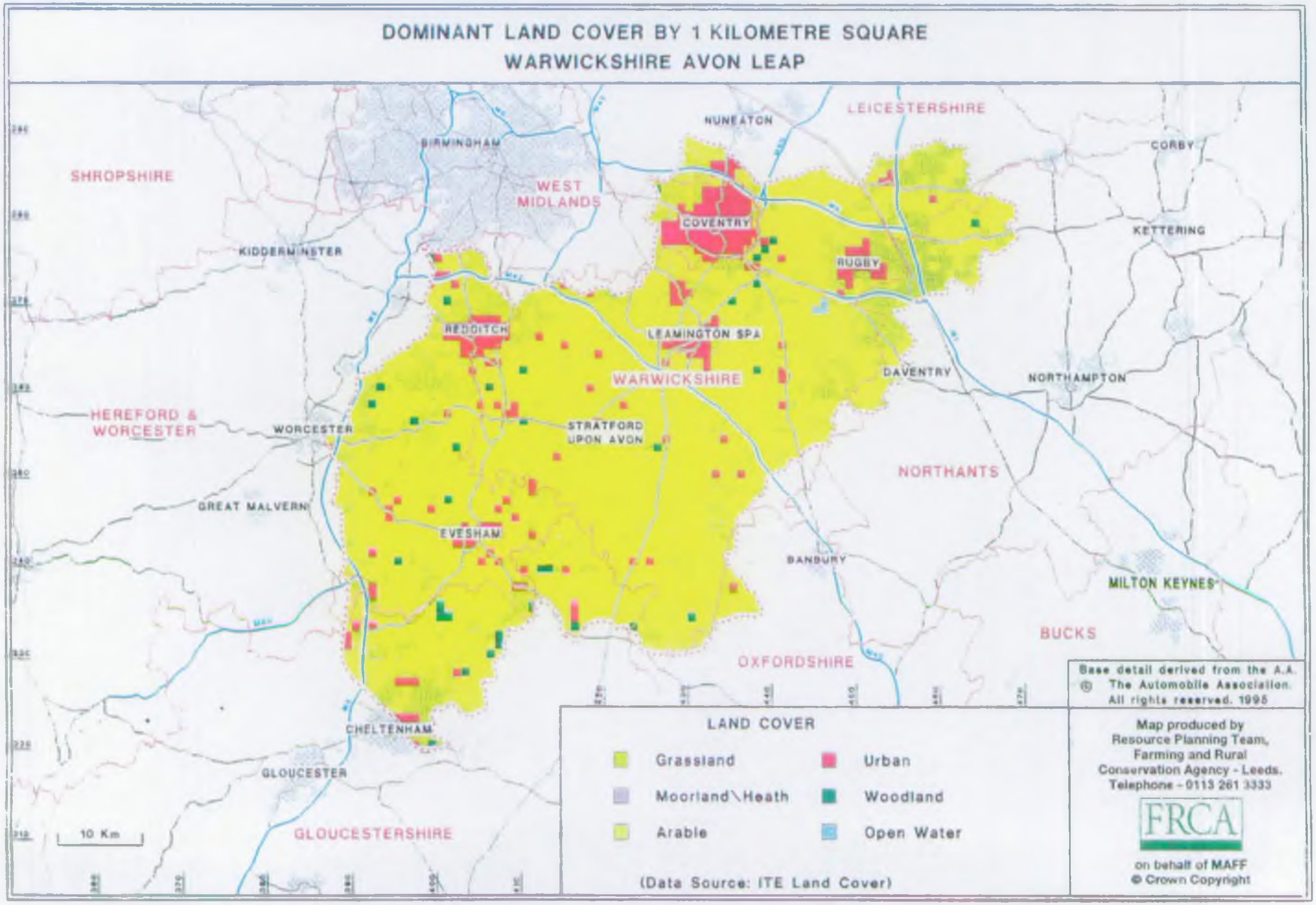


Figure 2 Land use in the Avon catchment

6. In May 1994, Lower Severn Area received confirmation that the River Avon and River Arrow had been designated Sensitive Areas (Eutrophic) by the DOE together with a request for further information and data on trophic status of the Bow Brook, River Leadon, River Severn (d/s Worcester), River Leam and the Gloucester and Sharpness Canal (including the Rivers Frome and Cam), all of which are suspected of being eutrophic.

7. In addition, in April 1994, the National Rivers Authority issued its "Guidance Note on Information Gathering for Future Reviews" (hereafter called the Guidance Note). This document confirms that it is the responsibility of Regions, and therefore Areas, to demonstrate that watercourses meet the criteria for defining eutrophication and show that nutrient removal from point source STWs will have an impact on eutrophication in those watercourses.

8. Eutrophication is described as the priority issue in the River Avon Catchment Management Plan (NRA, 1994) and the Warwickshire Avon LEAP (Environment Agency, 1998).

9. In April 1996 the NRA was incorporated into the Environment Agency.

2.1 Phosphorus and nitrogen in Natural Waters

1. Phosphorus (P) and nitrogen (N) are essential nutrients which control the productivity of natural waters but P is usually considered to be the growth-limiting nutrient in freshwater ecosystems. In consequence, its loss in surface and subsurface runoff from agricultural land and its addition to water bodies from point sources (the most important source) can accelerate the eutrophication of P sensitive waters. Withers (1996) has estimated that the average net surplus of 10 kg P ha^{-1} yr^{-1} (resulting from fertiliser application) could potentially cause the P saturation of many UK soils in the near future.

2. Export coefficients from arable and grassland systems in the UK range from <1 to 3 kg P ha^{-1} yr^{-1}, although the frequency and intensity of storm events results in large annual variations. A major review of P export coefficients for 34 watersheds in Southern Ontario (Dillon and Kirchner, 1975) has shown that the effects of agriculture and urbanisation were to greatly increase the total phosphorus exported. The annual export from forested watersheds draining igneous rocks was 0.048 kg ha^{-1} yr^{-1} whereas this increased to 0.107 kg ha^{-1} yr^{-1} for forested watersheds on sedimentary rocks. Average phosphorus losses from intensive agriculture were 0.46 kg ha^{-1} yr^{-1} whereas urbanised catchments exported between 0.11 and 16.6 kg ha^{-1} yr^{-1}.

3. In aquatic systems, P naturally occurs as simple orthophosphates, as condensed phosphates and as organic phosphates. Of the total P present in stream and river water only certain forms are available for biological utilisation. Dissolved P is generally thought to be immediately available for biological uptake although Logan (1982) found that whereas more than 90% of molybdate reactive P (MRP) was bioavailable, this percentage decreased to below 50% for dissolved organic P (DOP). (Dissolved and fine colloidal organic P will pass through a 0.45μm filter paper and will not be measured by standard analytical procedures for orthophosphate (MRP) as described in section 3.2 of this report. An estimate of the dissolved and fine colloidal P concentration can be made by examining the difference between orthophosphate and total P determined on filtered samples). Particulate P (PP) is not immediately available but in the long term between 10 and 90% of PP becomes bioavailable through naturally occurring physical, chemical and biological processes (Bostrom *et al.*, 1988).

4. Waterbodies can be broadly classified according to their trophic status, the major categories in increasing order of productivity being oligotrophic, mesotrophic, eutrophic and hypereutrophic (OECD, 1982). Total N and P and chlorophyll a concentrations are parameters which are frequently used to set the boundaries between trophic classes. Under natural conditions, biological productivity can be checked by the supply of a specific nutrient relative to demand (the limiting nutrient concept) and in freshwater systems P is usually considered to be the limiting nutrient. The basis of the limiting nutrient concept lies in the photosynthesis reaction where phytoplankton utilise nutrients in the approximate ratio of 106C:16N:1P. Eutrophication in lentic water bodies (e.g. lakes) is fairly well understood. Concentrations of 10 μg P /l for soluble inorganic P have been found to be sufficient

to accelerate algal growth (Vollenweider, 1968). The relative importance of P to the biological productivity of fast flowing (lotic) waters is more complex as hydraulic controls (residence time, sediment-water transfer times) are short (Daniel *et al.*, 1994). A critical P concentration which causes eutrophication in lotic waters has not been established but Baker *et al.* (1978), for example, suggest a range of between 10 and 30 µg/l. Mainstone *et al.* (1995) use a matrix for risk of planktonic growth ranging up to 200 ug SRP/l and for Cladophera growth the matrix ranges up to 500 µg/l. In accordance with procedures laid down by the DoE (1993) an annual average concentration of 100 µg/l PO_4-P is used to designate sensitive (Eutrophic) running freshwaters.

5. Recognition of the greater significance of P in the eutrophication process has led to the implementation of controls by the Environment Agency on P rather than N discharges at qualifying STWs in the Avon catchment.

3. PROJECT TECHNICAL PLAN

3.1 Sampling Programme

1. The River Avon, upstream of Evesham (**Figure 1**) drains a catchment area of 2210 km^2. It is located in a lowland predominantly agricultural catchment (**Figure 2**), rises to the north-east of Rugby and flows for approximately 125 km to its confluence with the River Severn at Tewkesbury. The mean annual flow at Evesham (1963-91) is ca 15.2 m^3/s (1310 Ml/d) (NRA, 1992).

2. Rainfall for the region ranges from 720 mm in the north east to 599 mm in the south (1941-1970) and average effective rainfall ranges from ca 250 mm to less than 150 mm/yr (NRA, 1992).

3. The Avon comprises a number of major subcatchments including, from north to south, the Swift, Sowe, Finham Brook, Leam (and Itchen), Dene, Stour and Arrow (and Alne). Downstream of the confluence with the River Arrow, and upstream of Evesham, smaller tributaries entering the Avon system include the Noleham Brook, Bow Brook and Badsey Brook.

4. Around 900,000 people live within the Avon catchment, with over half occupying the headwaters of the upper Avon and Sowe subcatchments mainly focused on the urban areas of Rugby, Coventry, Kenilworth, Leamington and Warwick.

5. Five major STWs come within the remit of the UWWT Directive. These are Coventry (Finham) which discharges ca. 121 Ml/d, Rugby (Newbold) which discharges ca. 23 Ml/d, Warwick (Longbridge) which discharges ca 32 Ml/day, Stratford (Milcote) which discharges ca. 14 Ml/d and Redditch (Spernal) which discharges ca. 29 Ml/d (Figures based on the 22 month monitoring programme).

6. The project centres on an extensive water sampling programme on the River Avon catchment upstream of Evesham. The programme is designed to measure several forms of phosphorus and nitrogen, in addition to a range of other water quality parameters, both spatially and with respect to flow at selected points within the Avon catchment.

7. The catchment area was subdivided in such a way as to be able to identify the downstream impacts on the river of the five major qualifying STW discharges. Rivers without major point source discharges, such as the Leam, were sampled in order to determine potential diffuse inputs to the Avon system.

8. Wherever practicable, sampling locations were selected in relation to existing National Rivers Authority (now Environment Agency) flow gauging stations equipped with flow recorders.

9. The sampling programme represents a compromise between a high frequency sampling programme, required to determine river loads with some degree of confidence during high runoff events; the need to determine spatial variations in

water quality relating to point and diffuse source inputs from subcatchments as small as 50 km^2; the capacity of the analytical laboratory at Nottingham to process the samples, and the overall cost of the sampling and analytical programme.

10. Wherever possible, sites sampled under existing Area water quality sampling programmes were utilised to reduce the number of additional analyses required and to maximise coverage. It was not possible to integrate the project sampling with the Area programme due to the latters reliance upon random sampling and the project's requirement for simultaneous sampling along a watercourse.

11. The sampling programme was designed such that relatively small (<50 km^2), homogenous catchments could be identified as potential nutrient sources. Five main monitoring points on the River Avon were selected for intensive sampling in order to identify major parts of the catchment from which the nutrient problem was likely to derive.

12. The programme provided for weekly data from the major qualifying discharges at Coventry, Rugby, Warwick and Redditch and fortnightly data at Stratford and for selected minor effluent discharges entering the River Avon and its tributaries

13. Diffuse sources have been isolated by nesting catchments using intensive (weekly) sampling on the main river and key tributary nodes and a monthly sampling strategy on minor tributaries.

14. Data for all stations are given as summary time series plots in Volume 2 of this report. Station locations and sample types are given schematically in **Figure 3**.

15. Two water samples were collected from each field site. One sample was immediately filtered through a 0.45µm filter membrane in the field before return to the laboratory for analysis. A second unfiltered sample was returned untreated to the laboratory for analysis.

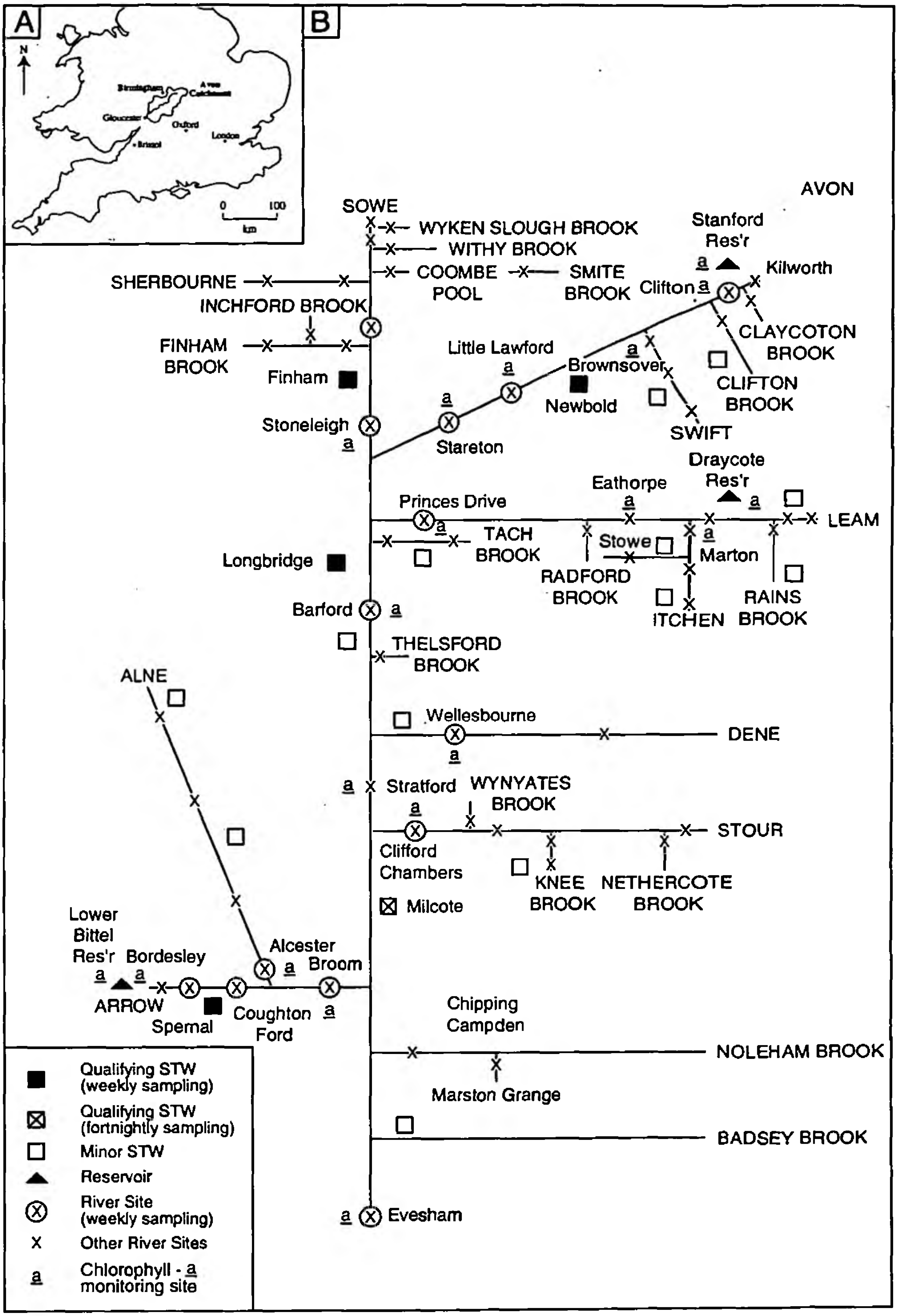
16. The following field determinations were made on all samples.

- pH
- redox potential (mV)
- electrical conductivity (S)
- dissolved oxygen (mg/l & % saturation)

Electrical conductivity was taken as a surrogate measure of the total dissolved solids concentrations in river water samples. Redox potential was measured in order to determine whether suitable conditions might exist in the Avon catchment for the release of phosphorus from sediment to the water column which may occur under reducing conditions when phosphorus species associated with iron and manganese oxides and hydroxides become soluble.

17. River flow was measured by current metering on the day of sampling at each site except where continuous flow records were available. Effluent discharge measurements were supplied by Severn Trent Water plc.

Figure 3 Schematic catchment diagram showing the location of sampling stations



3.2 Analytical Schedule

1. The following laboratory determinations were made on all samples

Determinand Code	Analysis	Units
007	Suspended solids	mg/l
010	BOD (biochemical oxygen demand)	mg/l
070	COD (chemical oxygen demand)	mg/l
05X	Total Nitrogen (kjeldahl; unfiltered)	mg/l
084	Total Phosphorus (unfiltered)	mg/l
0GG	Ammonia (filtered)	mg/l
0GS	Ammonia (filtered)	µg/l
0GM	TON (filtered)	mg/l
0GW	TON (filtered)	µg/l
0GK	Orthophosphate (filtered)	mg/l
0GT	Orthophosphate (filtered)	µg/l
051	Orthophosphate (unfiltered)	mg/l
0GX	Total Phosphorus (filtered)	mg/l
083	Chlorophyll a (After April 1st 1995)	mg/m^3

2. All water quality analysis was performed at the Environment Agency laboratory in Nottingham.

3. Phosphate and TON analysis was carried out at routine and/or low level where appropriate. Data analysis was carried out using the low level detection values when both values were available.

4. PROJECT REVIEW

4.1 Sampling Programme

1. Seventy nine sites were selected for sampling (**see Figure 3**). These included 57 river sites, the five major qualifying STWs, 13 minor STWs and 4 reservoirs/lakes.

2. The qualifying STWs at Coventry, Rugby, Warwick and Redditch, the main River Avon sites and major tributaries were all sampled weekly (w). The qualifying STW at Stratford and the minor STWs and tributaries were sampled fortnightly (f) with the remainder of the sites sampled at monthly (m) intervals.

3. The sampling programme was constructed in such a way as to allow for efficient use of manpower and vehicle mileage. The schedule allowed for a rolling programme of sample collection as follows.

Month 1	week 1	w + f	= 52 samples
	week 2	w	= 19 samples
	week 3	w + f	= 52 samples
	week 4	w + m	= 47 samples
Month 2	week 5	w + f	= 52 samples
	week 6	w	= 19 samples

4. The weekly sampling programme involved sample collection over two days. However, the weekly and fortnightly and the weekly and monthly programme required sampling for all five days of the week. This sampling was intensive and often involved considerable distances.

4.2 Sampling Performance

1. Compliance with the programme for the collection of water samples exceeded 86% as shown in **Table 1**. (Sampling compliance for individual sites is given in **Appendix 1**, Volume 1) The shortfall was due either to illness, holidays or hazardous conditions at the sites.

Table 1 Summary of sampling compliance.

Sampling frequency	Target per site	Number of sites	Target total	Samples taken	Sampling compliance (%)
Weekly	95	18	1710	1511	88.4
Fortnightly	47	33	1551	1308	84.3
Monthly	23	28	644	556	86.3
Total		79	3905	3375	86.4

4.3 Laboratory Analysis

1. All samples were analysed at the Environment Agency's NAMAS accredited laboratory, at Nottingham, under private contract.

2. Sample input, analysis and reporting of results were governed by standard Environment Agency Procedures. Service levels and agreements have been adhered to and Laboratory performance has been very satisfactory.

3. Estimates of analytical errors for the determinands measured in this research project are given in **Table 2**.

Table 2 Analytical errors for laboratory determinands

Determinand	Units	MRV	AQC Data April - June 1997			
			Concentration	%RSD	%Bias	No of Results
Suspended Solids	mg/l	3.0	30	5.6	-0.9	904
BOD + atu	mg/l	1.0	205	6.8	-0.2	2772
pH	-	-	7.6	0.7	-0.2	803
Chlorophyll	µg/l	0.4	-	-	-	-
Conductivity	µS/cm	10	1275 133	1.8 2.2	-1.2 +1.6	794 736
Chloride	mg/l	1.0	10 100	4.5 1.2	-2.1 -0.5	934 936
Ammonia Routine	mg/l	0.03	0.3 4.0	3.8 1.3	-1.2 +0.1	976 972
Ammonia Low Level	µg/l	3.0	20 100	9.5 3.5	-0.6 -2.9	23 20
Phosphate Routine	mg/l	0.02	0.2 1.5	3.1 1.4	+0.4 +0.6	930 933
Phosphate Low Level	µg/l	1.0	20 80	4.6 2.0	-2.0 +0.4	78 64
TON Routine	mg/l	0.2	2.0 24.0	3.5 1.9	+0.6 +1.6	965 955
TON Low Level	µg/l	3	100	4.4	-1.7	16
Total Phosphorus	mg/l	0.02	0.2 0.8	9.4 4.8	+0.3 +3.9	82 82
Total Nitrogen	mg/l	0.1	0.5 4.0	12.4 4.1	+1.4 -3.1	37 37
Silicate	mg/l	0.2	15.0	4.5 4.1	+5.3 +1.8	107 81
Silicate Low Level	µg/l	6.0	100 500	4.4 1.9	+0.6 -0.4	8 5

MRV - Minimum Reporting Value RSD - Relative Standard Deviation

4.4 Flow Gauging

1. Initially, it was expected that flow gauging at the river sites would be carried out by the Hydrometrics section at Tewkesbury. It was soon apparent that additional resources would be required and the decision was taken to appoint external contractors. Following their successful tender, Ewan Associates Ltd were appointed and commenced gauging in December 1994.

2. Compliance with the gauging programme exceeded 97%. The shortfall was due to loss of equipment or hazardous conditions.

3. Flow records for STW discharges were made available by Severn Trent Water plc. Whilst every effort has been made to evaluate the accuracy of these gauging records, it has only been possible to obtain continuously monitored data from Finham STW.

4. Quality control of gauging was carried out by the Hydrometrics sections at Warwick and Tewkesbury. The data were received in typed format from Ewan and this was checked against known flows at the same site for any anomalies which could not be explained by the weather. Any discrepancies were verified by the Hydrometrics section.

4.5 Data Analysis

1. An IBM compatible PC has been supplied to Coventry University in order to develop the data management and analysis system. This PC contains a 75mHz Pentium processor, with 1 gB of hard disk storage and a supplementary optical disk (670 mB)storage system for backup purposes. Peripheral devices include an inkjet printer, scanner and digitiser.

2. Data management and analysis reported in this project have been largely analysed using the Microsoft Excel spreadsheet package which provides sufficient flexibility for reading data derived from the sampling programme. These data have been stored on QUIS (the data archive system used at present in the Midlands region of the Agency) following normal Environment Agency procedures. The data were manually typed into a Lotus spreadsheet and files were transferred to Microsoft Excel for analysis.

3. Summary statistics have been produced using Microsoft Excel. Boxplots and inferential statistical analysis has been performed using the SPSS package for Windows (Kinnear and Gray, 1994).

4. All data have been quality controlled. Initially, summary boxplots were produced for all parameters at each site in order to identify outliers and extreme values.

5. Missing data was identified using SPSS. Field measurements for pH, redox and electrical conductivity began on 8/3/1995. Laboratory analysis produced measurements for over 98% of samples for 9 of the 11 determinands (details are given in **Appendix 2**, Volume 1). The initial database contained flow data for less than 92% of the samples. Details of the additional data subsequently supplied by the Hydrometric Section of the Environment Agency are contained in **Appendix 4**, Volume 1.

6. Using SPSS a large number of samples were identified for which the Phosphorus filtered value exceeded the unfiltered value or for which Orthophosphate was greater than Total Phosphorus. Details were supplied to the Nottingham Laboratories which resulted in some changes to the database (see **Appendix 3**, Volume 1).

7. Before carrying out load calculations missing data for flow, Phosphorus, Kjeldahl Nitrogen and Oxidised Nitrogen was infilled using regression, interpolation or mean

values as appropriate (see **Appendix 4**, Volume 1). This infilled data was ***not*** used for calculating the summary statistics or for the time series plots presented in Volumes 1 and 2 of this report.

4.6 Background and Definitions

1. From the data base constructed at Coventry University, additional water quality parameters were derived from the analytical data provided by the Nottingham Laboratory.

2. In accordance with the UWWTD, (91/271/EEC), Total Nitrogen (TN) is defined as the sum of Kjeldahl-nitrogen + TON. Kjeldahl-N includes organic-N and NH_3. TON (Total Oxidised Nitrogen) includes NO_2 and NO_3.

3. In accordance with the UWWTD, (91/271/EEC), Total Phosphorous conforms to laboratory analysis performed on unfiltered samples. TP includes both organic and inorganic forms of phosphorus.

4. For practical purposes, the particulate-P (PP) concentration was defined as

$$PP\ (mg/g) = \frac{TP_{(unfiltered)} - TP_{(filtered)}}{(SS / 1000)}$$ **Equation 1**

where:

PP = particulate-P concentration in mg/l.
TP = Total phosphorus concentration in mg/l
SS = suspended solids concentration in mg/l

5. Where STW loads are expressed as population equivalents (pe), this is in accordance with the Urban Waste Water Treatment Directive (EC, 1991). 1 pe means the organic biodegradable load having a five day biochemical oxygen demand of 60g of oxygen per day.

5. NUTRIENT CONCENTRATIONS

5.1 STW Data

1. Summary statistics (mean and standard deviation) for nutrient concentrations, BOD and COD are given in **Table 3**.

2. Highest mean TP concentrations (13.72 mg/l) are recorded at Leamington (Heathcote) STW whilst lowest mean concentrations (2.78 mg/l) are recorded at Rugby (Newbold).

3. Highest mean PO_4 (filt) concentrations (13.19 mg/l) are recorded at Leamington (Heathcote) and lowest mean concentrations (2.46 mg/l) at Rugby (Newbold).

4. The difference between average TP and average PO_4 (filt) P for all sites is 0.47 mg/l suggesting that on average, some 93% of total P is discharged in dissolved form from sewage treatment works. Comparisons between qualifying and monitored minor STWs give PO_4 (filt) P as 91% and 94% of the TP concentration respectively. However, average total P and PO_4 (filt) P concentrations for the monitored minor works are over 2 mg/l higher than the average of the qualifying STWs.

5. Highest mean TON concentrations (25.15 mg/l N) are recorded at Tanworth in Arden whilst lowest mean concentrations (10.66) are recorded at Stratford (Milcote).

6. Highest mean TN concentrations (28.97 mg/l) are recorded at Tanworth and the lowest at Snitterfield (14.86 mg/l). On average, 79% of TN in sewage effluent is TON. Comparisons between qualifying and monitored minor STWs give TON as 81% and 78 % of the TN concentration respectively. There is little difference between the TON and TN concentrations in qualifying and monitored minor STWs.

7. Highest mean BOD concentrations (16.57 mg/l) are recorded at Stratford (Milcote) whilst lowest mean concentrations (1.54 mg/l) are recorded at Snitterfield. On average BOD concentrations are 6.16 and 6.82 mg/l for qualifying and monitored minor works respectively.

8. Highest mean COD concentrations (82.85 mg/l)are recorded at Stratford (Milcote) whilst lowest mean concentrations (37.86 mg/l) are recorded at Snitterfield. Average COD concentrations are 54.53 and 56.02 mg/l for qualifying and monitored STWs respectively.

Table 3 Summary (a) N (b) P and (c) BOD and COD concentration data for Qualifying and minor STWs

(a) STW name	n	Mean TON mg/l	Std.Dev.	Mean TN mg/l	Std.Dev.
Minor works					
Blackminster STW	38	14.24	3.52	16.91	3.85
Braunston STW	40	16.36	5.58	22.78	5.31
Chipping Campden STW	39	13.82	2.43	17.65	2.41
Crick (final effluent) STW	35	19.27	4.72	23.37	5.05
Harbury STW (Deppers Bridge)	41	11.22	3.22	20.16	4.84
Kilsby STW	39	17.84	5.59	24.00	6.24
Leamington Heathcote STW	39	21.92	6.73	28.48	5.51
Lutterworth STW(final effluent)	37	22.94	5.11	26.93	5.88
Snitterfield STW	37	13.19	3.53	14.86	3.86
Southam STW(final effluent)	40	18.82	3.91	25.79	5.18
Tanworth in Arden STW(final effluent)	21	25.15	10.27	28.97	10.12
Wellesbourne STW	36	17.73	4.72	20.44	4.13
Wootton Wawen STW	37	11.34	5.88	15.10	6.68
All minor sites	*479*	*16.90*	*6.45*	*21.74*	*6.99*
Qualifying discharges					
Coventry (Finham) STW	86	16.89	3.05	23.92	3.45
Redditch STW final effluent (old grass)	83	20.51	6.58	22.44	6.74
Rugby STW (Newbold)	82	13.20	6.45	16.16	6.71
Stratford STW(Milcote)	42	10.66	4.94	15.91	5.21
Warwick STW(Longbridge)	82	20.59	4.01	24.22	4.32
All qualifying sites	*375*	*17.00*	*6.33*	*21.06*	*6.49*
All sites	***854***	***16.94***	***6.39***	***21.44***	***6.78***

(b) STW	n	Mean Total P mg/l	Std.Dev.	Mean PO_4 (filt.)mg/l	Std.Dev.
Minor works					
Blackminster STW	38	6.48	1.60	6.06	1.55
Braunston STW	40	7.48	2.51	6.97	2.39
Chipping Campden STW	39	4.77	1.42	4.34	1.32
Crick (final effluent) STW	35	8.74	2.24	8.27	1.99
Harbury STW (Deppers Bridge)	41	5.95	1.78	5.61	1.93
Kilsby STW	39	9.55	2.82	8.61	2.57
Leamington Heathcote STW	39	13.72	1.96	13.19	1.78
Lutterworth STW(final effluent)	37	7.25	1.61	6.55	1.44
Snitterfield STW	37	6.20	2.41	6.11	2.36
Southam STW(final effluent)	40	7.92	2.05	7.46	2.13
Tanworth in Arden STW(final effluent)	21	7.33	1.94	6.80	1.85
Wellesbourne STW	36	6.47	1.21	6.12	1.18
Wootton Wawen STW	37	4.76	1.99	4.28	1.90
All minor sites	*479*	*7.43*	*3.03*	*6.96*	*2.94*
Qualifying discharges					
Coventry (Finham) STW	86	6.79	1.53	6.21	1.41
Redditch STW final effluent (old grass)	83	6.89	2.18	6.47	2.12
Rugby STW (Newbold)	82	2.78	1.57	2.46	1.52
Stratford STW(Milcote)	42	5.58	1.99	4.89	2.04
Warwick STW(Longbridge)	82	4.12	1.75	3.76	1.59
All qualifying sites	*375*	*5.21*	*2.44*	*4.76*	*2.33*
All sites	***854***	***6.46***	***3.00***	***5.99***	***2.90***

(c) STW	n	Mean BOD mg/l	Std.Dev.	Mean COD mg/l	Std.Dev.
Minor Works					
Blackminster STW	38	4.71	3.20	57.68	26.32
Braunston STW	40	8.30	3.06	60.41	16.69
Chipping Campden STW	39	6.82	2.72	49.69	33.02
Crick (final effluent) STW	35	5.60	2.56	54.24	11.61
Harbury STW (Deppers Bridge)	41	6.75	4.06	48.37	17.74
Kilsby STW	39	9.95	5.01	66.54	28.56
Leamington Heathcote STW	39	5.19	2.12	57.00	12.44
Lutterworth STW(final effluent)	37	6.74	2.77	61.04	18.87
Snitterfield STW	37	1.54	1.24	37.86	34.09
Southam STW(final effluent)	40	10.05	4.41	66.96	25.21
Tanworth in Arden STW(final effluent)	21	6.93	3.69	58.43	17.64
Wellesbourne STW	36	2.63	2.17	38.29	29.52
Wootton Wawen STW	37	12.86	4.91	70.49	34.19
All minor sites	*479*	*6.82*	*4.49*	*56.02*	*26.51*
Qualifying discharges					
Coventry (Finham) STW	86	7.82	2.82	63.44	17.44
Redditch STW final effluent (old grass)	83	2.59	1.35	38.57	17.16
Rugby STW (Newbold)	82	3.86	2.60	51.50	31.18
Stratford STW(Milcote)	42	16.57	6.39	82.85	30.07
Warwick STW(Longbridge)	82	4.99	3.20	50.20	28.77
All qualifying sites	*375*	*6.16*	*5.24*	*54.53*	*28.13*
All sites	***854***	***6.53***	***4.84***	***55.36***	***27.23***

5.2 River Data

1. Summary statistics of concentration and flow data for Rivers is given in **Table 4.** The following points have been extracted from this table.

2. Highest mean TON concentrations (14.22 mg/l) are recorded at Stoneleigh, whilst lowest mean TON concentrations (2.40 mg/l) are recorded at the Wyken Slough Brook (Overflow from the Oxford Canal). On average, TON concentrations are 8.14 mg/l.

3. Highest mean KN concentrations (4.69 mg/l) are recorded at Stoneleigh and the lowest mean concentration (0.74 mg/l) on the Leam at the A425 road bridge. On average, KN concentrations are 1.3 mg/l.

4. Highest mean PO_4 (filt) concentrations (4.45 mg/l) are recorded at Stoneleigh with lowest mean concentrations (0.02 mg/l) at the Wyken Slough Brook (Overflow from the Oxford Canal). On average, PO_4 (filt) concentrations are 0.99 mg/l.

5. Highest mean TP concentrations (4.65 mg/l) are recorded at Stoneleigh with lowest mean concentrations (0.07 mg/l) on the Wyken Slough Brook. On average TP concentrations are 1.05 mg/l. On average PO_4 (filt) P accounts for 95% of the average total P concentration in rivers.

6. Highest mean BOD concentrations (5.9 mg/l) are recorded at Stoneleigh and lowest mean concentrations (1.35 mg/l) on the Radford Brook. On average, the mean BOD concentration for all rivers is 2.29 mg/l.

7. Highest mean COD concentrations (65.0 mg/l) are recorded on the Sowe at Astley Hall with lowest concentrations (15.45 mg/l) on the Knee Brook (at Paxford); a tributary of the Stour. On average, COD concentrations for all rivers is 31.79 mg/l.

Table 4 Summary concentration data for river monitoring sites

Sub-catchment	Site name	n	Mean Q Ml/d	Mean PO4(filt) mg/l	Std.Dev.	Mean Total P mg/l	Std.Dev.
Upper Avon	Avon (Clifton)	82	55.34	0.14	0.08	0.19	0.11
	Avon (Kilworth)	18	24.27	0.19	0.11	0.27	0.11
	Avon (Lawford)	83	123.80	1.35	1.15	1.49	1.17
	Avon (Stare Bridge)	87	155.38	1.00	0.62	1.04	0.61
	Claycoton/Yelvertoft Brook (Lilbourne)	17	19.36	0.50	0.35	0.55	0.35
	Clifton Brook (Rugby) conf. Avon	19	15.76	1.35	1.40	1.53	1.63
	Swift (Bransford Bridge)	19	41.71	1.24	0.64	1.37	0.62
	Swift (Brownsover Hall)	41	25.25	0.85	0.45	0.88	0.44
	Swift (Lutterworth)	20	29.35	0.22	0.15	0.33	0.20
	All sites	386	n/a	0.81	0.87	0.88	0.90
Sowe	Coombe Pool (outflow)	17	33.17	0.28	0.24	0.39	0.24
	Finham Brook (Finham Bridge, conf. Sowe)	40	22.67	0.08	0.05	0.10	0.06
	Finham Brook (Chase Lane, Kenilworth)	19	6.34	0.04	0.02	0.09	0.10
	Inchford Brook (Kenilworth Castle)	16	4.40	0.12	0.05	0.14	0.06
	Sherbourne (Allesley, Kingsbury Rd)	40	3.55	0.32	0.24	0.39	0.20
	Sherbourne (conf. Sowe)	40	14.01	0.10	0.03	0.16	0.06
	Smite Brook (Coombe Abbey)	19	25.87	0.72	0.60	0.85	0.60
	Sowe (Astley Hall)	12	4.57	0.22	0.15	0.35	0.20
	Sowe (Baginton)	86	86.57	0.13	0.07	0.18	0.07
	Sowe (Stoneleigh)	87	247.27	4.45	1.78	4.65	1.87
	Sowe (Walsgrave)	39	26.58	0.14	0.05	0.20	0.08
	Withy Brook (Walsgrave/High Bridge)	17	16.69	0.07	0.06	0.13	0.15
	Wyken Slough Brook (Overflow Oxford Canal)	12	0.00	0.02	0.01	0.07	0.04
	All sites	444	n/a	1.02	1.89	1.09	1.95
Leam	Itchen (A425) Thorpe Bridge	23	39.43	1.23	1.29	1.45	1.33
	Itchen (Deppers Bridge)	41	37.76	0.19	0.10	0.20	0.09
	Itchen (Marton, conf. Leam)	41	54.42	1.36	0.94	1.42	0.93
	Leam (A425 Road Bridge)	40	9.07	0.09	0.08	0.09	0.15
	Leam (Birdingbury)	41	67.40	1.04	0.69	1.09	0.65
	Leam (Eathorpe)	41	68.89	0.90	0.52	0.87	0.46
	Leam (Princes Drive)	81	101.75	0.42	0.21	0.47	0.19
	Leam (Sawbridge)	41	21.77	0.94	0.79	1.01	0.76
	Radford Brook (A425)	23	8.59	0.11	0.06	0.17	0.19
	Rains Brook (Barby Lodge)	20	4.34	2.94	1.74	3.13	1.79
	Stowe (Southam, Brown's Bridge)	23	16.86	0.98	0.71	1.14	0.70
	All sites	415	n/a	0.84	0.96	0.86	0.97
Mid Avon	Avon (Barford)	86	597.59	2.54	1.13	2.69	1.14
	Avon (Stratford)	43	767.97	2.21	1.08	2.34	1.09
	Dene (Fosse Way)	23	36.49	1.20	1.15	1.37	1.13
	Dene (Wellesbourne)	83	32.58	0.39	0.22	0.44	0.22
	Marston Grange (trib. Noleham Brook)	19	0.73	0.14	0.07	0.29	0.17
	Noleham Brook (Welford Pastures)	42	9.25	0.68	0.49	0.70	0.44
	Tach Brook (A41 Road Bridge)	38	12.00	1.07	0.54	1.13	0.51
	Tach Brook (A452 Road Bridge)	23	10.26	0.26	0.12	0.34	0.26
	Thelsford Brook (Hampton Lucy)	23	12.05	0.29	0.17	0.48	0.58
	All sites	380	n/a	1.23	1.20	1.31	1.22
Stour	Knee Brook (High Furze)	20	49.72	0.33	0.18	0.39	0.17
	Knee Brook (Paxford)	22	34.41	0.40	0.28	0.48	0.28
	Nethercote Brook (Mitford Bridge, Conf. Stour)	21	26.58	0.26	0.18	0.32	0.18
	Stour (Cherington)	23	24.35	0.12	0.07	0.20	0.10
	Stour (Clifford Chambers)	85	142.74	0.41	0.25	0.48	0.25
	Stour (Shipston)	40	76.46	0.34	0.21	0.39	0.19
	Wynyates Brook (conf. Stour)	23	21.22	0.61	0.49	0.67	0.46
	All sites	234	n/a	0.37	0.28	0.43	0.27
Arrow & Alne	Alne (Alcester)	82	71.80	0.51	0.23	0.59	0.22
	Alne (Danzey Green)	22	5.64	0.61	0.34	0.69	0.33
	Alne (Little Alne)	22	71.02	0.55	0.24	0.63	0.24
	Alne (Wootton Wawen)	42	61.18	0.36	0.14	0.41	0.14
	Arrow (Bordesley) A441 Road Bridge	42	37.65	1.47	0.82	1.54	0.81
	Arrow (Broom)	84	175.86	1.75	1.00	1.87	0.98
	Arrow (Coughton Ford)	83	97.80	2.32	1.01	2.48	0.98
	Arrow (Studley)	83	47.67	0.70	0.29	0.73	0.27
	All sites	460	n/a	1.19	1.00	1.26	1.00
Lower Avon	Avon (Evesham)	86	1143.88	1.80	0.92	1.98	0.92
Grand Total		2405	137.67	0.99	1.22	1.05	1.25

Sub-catchment	Site name	n	Mean Q Ml/d	Mean TON mg/l	Std.Dev.	Mean N Kjeld mg/l	Std.Dev.
Upper Avon	Avon (Clifton)	82	55.34	4.71	4.28	0.86	0.46
	Avon (Kilworth)	18	24.27	6.32	4.37	0.99	0.76
	Avon (Lawford)	83	123.80	9.34	3.90	1.56	0.70
	Avon (Stare Bridge)	87	155.38	8.17	3.91	1.28	0.57
	Claycoton/Yelvertoft Brook (Lilbourne)	17	19.36	5.84	4.41	0.91	0.41
	Clifton Brook (Rugby) conf. Avon	19	15.76	7.40	5.81	1.56	0.86
	Swift (Bransford Bridge)	19	41.71	9.59	4.25	1.25	0.74
	Swift (Brownsover Hall)	41	25.25	8.10	4.19	1.06	0.62
	Swift (Lutterworth)	20	29.35	8.02	4.42	0.95	0.64
	All sites	386	82.41	7.52	4.50	1.19	0.67
Sowe	Coombe Pool (outflow)	17	33.17	5.92	5.93	1.40	0.56
	Finham Brook (Finham Bridge, conf. Sowe)	40	22.67	8.01	2.28	0.99	0.71
	Finham Brook (Chase Lane, Kenilworth)	19	6.34	5.89	2.97	0.80	0.38
	Inchford Brook (Kenilworth Castle)	16	4.40	9.42	3.49	1.12	0.46
	Sherbourne (Allesley, Kingsbury Rd)	40	3.55	6.12	3.65	1.14	0.80
	Sherbourne (conf. Sowe)	40	14.01	7.29	1.54	0.97	0.63
	Smite Brook (Coombe Abbey)	19	25.87	8.84	4.36	1.10	0.64
	Sowe (Astley Hall)	12	4.57	6.52	8.11	2.66	2.34
	Sowe (Baginton)	86	86.57	5.97	3.33	1.02	0.80
	Sowe (Stoneleigh)	87	247.27	14.22	3.19	4.69	1.77
	Sowe (Walsgrave)	39	26.58	5.42	2.32	1.02	0.71
	Withy Brook (Walsgrave/High Bridge)	17	16.69	3.96	3.73	0.97	0.66
	Wyken Slough Brook (Overflow Oxford Canal)	12	0.00	2.40	2.89	0.82	0.20
	All sites	444	75.77	7.94	4.78	1.75	1.76
Leam	Itchen (A425) Thorpe Bridge	23	39.43	8.87	7.93	1.51	0.53
	Itchen (Deppers Bridge)	41	37.76	6.17	7.30	1.03	0.52
	Itchen (Marton, conf. Leam)	41	54.42	8.77	5.01	1.22	0.52
	Leam (A425 Road Bridge)	40	9.07	4.22	4.00	0.74	0.56
	Leam (Birdingbury)	41	67.40	7.11	4.43	1.19	0.65
	Leam (Eathorpe)	41	68.89	7.98	4.51	1.12	0.51
	Leam (Princes Drive)	81	101.75	6.51	4.11	1.15	1.05
	Leam (Sawbridge)	41	21.77	6.57	3.22	1.10	0.49
	Radford Brook (A425)	23	8.59	9.05	2.77	0.91	0.80
	Rains Brook (Barby Lodge)	20	4.34	8.01	3.50	1.26	0.73
	Stowe (Southam, Brown's Bridge)	23	16.86	6.70	5.37	1.42	0.53
	All sites	415	49.26	7.04	4.98	1.13	0.71
Mid Avon	Avon (Barford)	86	597.59	12.48	2.31	1.86	0.88
	Avon (Stratford)	43	767.97	12.19	2.14	1.54	0.87
	Dene (Fosse Way)	23	36.49	8.59	4.68	1.17	0.61
	Dene (Wellesbourne)	83	32.58	9.33	3.50	1.11	0.73
	Marston Grange (trib. Noleham Brook)	19	0.73	8.22	4.06	1.22	0.90
	Noleham Brook (Welford Pastures)	42	9.25	12.00	9.76	1.14	0.54
	Tach Brook (A41 Road Bridge)	38	12.00	12.48	1.84	1.26	0.94
	Tach Brook (A452 Road Bridge)	23	10.26	9.62	1.98	1.01	0.86
	Thelsford Brook (Hampton Lucy)	23	12.05	7.60	1.93	0.98	0.66
	All sites	380	235.08	10.78	4.55	1.34	0.85
Stour	Knee Brook (High Furze)	20	49.72	9.08	1.89	0.91	0.82
	Knee Brook (Paxford)	22	34.41	9.76	1.34	0.97	0.62
	Nethercote Brook (Mitford Bridge, Conf. Stour)	21	26.58	9.09	4.76	0.81	0.63
	Stour (Cherington)	23	24.35	11.22	2.72	0.81	0.51
	Stour (Clifford Chambers)	85	142.74	8.40	3.99	1.00	0.57
	Stour (Shipston)	40	76.46	9.20	2.40	0.80	0.51
	Wynyates Brook (conf. Stour)	23	21.22	6.82	8.20	1.12	0.53
	All sites	234	79.27	8.91	4.13	0.93	0.59
Arrow & Alne	Alne (Alcester)	82	71.80	5.35	2.34	1.07	0.63
	Alne (Danzey Green)	22	5.64	7.80	2.81	1.63	1.11
	Alne (Little Alne)	22	71.02	5.18	2.42	1.25	0.83
	Alne (Wootton Wawen)	42	61.18	4.57	2.18	1.19	0.76
	Arrow (Bordesley) A441 Road Bridge	42	37.65	6.88	1.82	1.20	0.63
	Arrow (Broom)	84	175.86	8.23	1.47	1.42	0.74
	Arrow (Coughton Ford)	83	97.80	9.65	2.11	1.40	0.71
	Arrow (Studley)	83	47.67	4.94	2.32	0.98	0.51
	All sites	460	83.85	6.76	2.82	1.23	0.72
Lower Avon	Avon (Evesham)	86	1143.88	11.08	2.23	1.45	0.93
Grand Total		2405	137.67	8.14	4.52	1.30	1.03

Sub-catchment	Site name	n	Mean Q Ml/d	Mean BOD mg/l	Std.Dev.	Mean COD mg/l	Std.Dev.
Upper Avon	Avon (Clifton)	62	55.34	1.50	0.76	24.42	15.62
	Avon (Kilworth)	18	24.27	1.56	0.94	29.25	23.91
	Avon (Lawford)	83	123.80	2.21	0.85	37.30	27.01
	Avon (Stare Bridge)	87	155.38	1.82	0.66	39.50	61.60
	Claycoton/Yelvertoft Brook (Lilbourne)	17	19.36	1.88	0.74	22.00	13.03
	Clifton Brook (Rugby) conf. Avon	19	15.76	2.21	1.42	34.82	15.88
	Swift (Bransford Bridge)	19	41.71	2.58	2.15	30.13	17.39
	Swift (Brownsover Hall)	41	25.25	2.22	1.44	24.76	11.95
	Swift (Lutterworth)	20	29.35	1.78	1.34	19.83	11.13
	All sites	386	n/a	1.92	1.07	31.30	34.39
Sowe	Coombe Pool (outflow)	17	33.17	3.12	2.31	36.06	10.38
	Finham Brook (Finham Bridge, conf. Sowe)	40	22.67	1.78	0.95	21.98	14.41
	Finham Brook (Chase Lane, Kenilworth)	19	6.34	2.00	2.36	16.61	13.14
	Inchford Brook (Kenilworth Castle)	16	4.40	2.31	1.99	23.69	14.91
	Sherbourne (Allesley, Kingsbury Rd)	40	3.55	2.49	1.68	28.34	18.63
	Sherbourne (conf. Sowe)	40	14.01	2.11	1.66	21.58	14.74
	Smite Brook (Coombe Abbey)	19	25.87	1.56	0.82	23.84	11.53
	Sowe (Astley Hall)	12	4.57	4.75	3.60	65.00	48.65
	Sowe (Baginton)	86	86.57	2.66	3.59	40.48	35.64
	Sowe (Stoneleigh)	87	247.27	5.90	3.50	55.30	28.07
	Sowe (Walsgrave)	39	26.58	2.27	0.95	59.90	39.50
	Withy Brook (Walsgrave/High Bridge)	17	16.69	2.04	1.04	39.79	53.34
	Wyken Slough Brook (Overflow Oxford Canal)	12	0.00	2.96	1.72	39.58	35.39
	All sites	444	n/a	3.08	2.95	38.73	32.07
Leam	Itchen (A425) Thorpe Bridge	23	39.43	1.46	0.66	33.52	17.69
	Itchen (Deppers Bridge)	41	37.76	1.43	1.23	29.88	13.30
	Itchen (Marton, conf. Leam)	41	54.42	1.72	0.91	29.05	11.65
	Leam (A425 Road Bridge)	40	9.07	1.55	0.87	19.84	13.05
	Leam (Birdingbury)	41	67.40	1.76	0.86	29.54	14.59
	Leam (Eathorpe)	41	68.89	1.68	0.84	28.15	16.93
	Leam (Princes Drive)	81	101.75	2.07	1.23	34.20	39.46
	Leam (Sawbridge)	41	21.77	1.61	0.78	24.35	12.32
	Radford Brook (A425)	23	8.59	1.35	0.82	22.13	18.68
	Rains Brook (Barby Lodge)	20	4.34	1.71	0.86	34.75	20.30
	Stowe (Southam, Brown's Bridge)	23	16.86	2.13	1.00	35.63	14.42
	All sites	415	n/a	1.72	1.00	29.25	22.33
Mid Avon	Avon (Barford)	86	597.59	2.93	1.01	40.02	33.46
	Avon (Stratford)	43	767.97	2.73	1.16	38.72	25.80
	Dene (Fosse Way)	23	36.49	1.67	0.58	27.04	18.94
	Dene (Wellesbourne)	83	32.58	2.16	1.33	24.14	17.29
	Marston Grange (trib. Noleham Brook)	19	0.73	2.35	1.72	36.71	26.15
	Noleham Brook (Welford Pastures)	42	9.25	1.84	1.02	40.02	44.98
	Tach Brook (A41 Road Bridge)	38	12.00	1.61	1.37	29.12	30.84
	Tach Brook (A452 Road Bridge)	23	10.26	1.98	1.93	22.59	17.79
	Thelsford Brook (Hampton Lucy)	23	12.05	1.50	0.69	28.78	47.73
	All sites	380	n/a	2.24	1.31	32.63	30.90
Stour	Knee Brook (High Furze)	20	49.72	1.38	0.56	48.00	123.62
	Knee Brook (Paxford)	22	34.41	1.57	0.44	15.45	11.58
	Nethercote Brook (Mitford Bridge, Conf. Stour)	21	26.58	1.58	0.56	19.74	12.49
	Stour (Cherington)	23	24.35	1.41	0.62	21.11	20.20
	Stour (Clifford Chambers)	85	142.74	1.72	0.85	20.45	25.78
	Stour (Shipston)	40	76.46	1.70	0.85	23.54	34.84
	Wynyates Brook (conf. Stour)	23	21.22	1.72	0.60	34.52	26.13
	All sites	234	n/a	1.63	0.73	24.25	43.49
Arrow & Alne	Alne (Alcester)	82	71.80	2.52	1.53	29.80	24.15
	Alne (Danzey Green)	22	5.64	2.40	1.18	34.14	34.83
	Alne (Little Alne)	22	71.02	2.78	1.11	27.34	18.42
	Alne (Wootton Wawen)	42	61.18	2.63	1.21	33.69	28.81
	Arrow (Bordesley) A441 Road Bridge	42	37.65	2.77	1.34	33.65	25.07
	Arrow (Broom)	84	175.86	2.81	1.51	30.01	18.16
	Arrow (Coughton Ford)	83	97.80	2.64	1.01	29.55	16.36
	Arrow (Studley)	83	47.67	2.78	1.46	29.86	29.96
	All sites	460	n/a	2.68	1.35	30.60	24.00
Lower Avon	Avon (Evesham)	86	1143.88	2.64	1.39	33.67	28.55
Grand Total		2405	137.67	2.29	1.72	31.79	30.88

5.3 Seasonal trends in water quality

1. Time series plots for all river, lake and STW sampling stations are given in Volume 2 of this report.

2. This section will consider water quality trends on the Avon main river gauging stations and the qualifying and minor STWs. Data for DO, temperature, electrical conductivity, suspended solids, BOD, COD, N, P, pH and flow are given for all sites.

<u>STW monitoring sites</u>

3. Locations of the 18 STW monitoring stations are given in **Figure 4**, with time series plots for the five qualifying and three selected monitored minor STWs in **Figures 5-12.** The three minor works at Braunston, Harbury and Wootton Wawen were selected as sites which represent high, intermediate and low mean total P concentrations respectively in comparison with minor works averages (**Table 3**).

4. Temperatures at qualifying and monitored STWs show strong seasonality. Maximum temperatures approach 25°C in water discharged during the late summer months. At all qualifying STWs, DO levels have fallen below 40% on at least one occasion during the sampling period. Lowest DO concentrations are recorded in the wetter winter of 1994-95 at all qualifying STWs.

5. Suspended sediment concentrations for the qualifying discharges show little seasonality and are generally below 15 mg/l although on occasions, concentrations have exceeded 30 mg/l at Rugby Newbold and Coventry Finham. In contrast, suspended sediment concentrations for the non-qualifying effluents at Braunston, Harbury and Wootton Wawen are generally higher than the qualifying STWs. Consent limits will depend on flow, quality and river objectives.

6 At all stations, conductivity peaks between March and June and falls significantly during late autumn and winter months.

7. Redox potential shows little seasonality at most sites. With the exception of Warwick Longbridge, redox potential values for the qualifying STWs usually lie between ca. +150 and +250 mV. Warwick Longbridge is a significant exception, with redox potential values on at least two occasions falling below +50mV, a level at which there may be some potential for the liberation of heavy metals and phosphorous from sediments if they are retained in the sediment as iron and/or manganese oxides and hydroxides. Redox potential values fall below +100 mV on at least one occasion at Redditch Spernal and Braunston STWs.

8. BOD and COD concentrations show weak seasonality at most sites, with levels declining slightly in Spring and Summer. This pattern is not reflected in the outflow from Coventry Finham where BOD and COD levels remain fairly uniform at an average of 6.8 and 59 mg/l respectively. There is some evidence to suggest that both BOD and COD have increased over the last 6 months of record at Coventry Finham in association with a decrease in flow.

9. With the exception of Coventry Finham, pH shows a decrease at all sites by between 0.4 and 0.6 pH units from the beginning to the end of the record; a trend often superimposed on a seasonal pattern. On one occasion at Coventry Finham, pH levels approach 10.

10. The pattern of N response in effluents is complex and site specific. Rugby effluent has lower TON and TKN concentrations between April and August, whilst both species in Finham effluent increase in concentration gradually over the period of record. TON and TKN concentrations at Leamington Heathcote decline throughout the period of record and at Warwick (Longbridge) show similar trends to those at Finham. With the exception of five major periods of dilution and one extremely high concentration, TN and TKN concentrations at Redditch Spernal remain fairly constant throughout the sampling period. The smaller effluent discharges at Braunston, Harbury and Wootton Wawen show strongly seasonal patterns of concentration, with high concentrations occurring in spring and/or summer. TON and TN concentrations at Wootton Wawen appear to increase in concentration over the last six months of the sampling period

11. P concentrations at Rugby Newbold are low but, like all other qualifying discharges, show some slight increase in concentration between March and September. At all qualifying STWs, particulate-P makes a small but measurable contribution to total P concentration. Effluents from Braunston, Harbury and Wootton Wawen have a strong seasonality in P concentration, with peak concentrations recorded in mid to late summer. Over the last 6 months of record at Rugby Newbold, TP concentrations appear to be increasing whereas the opposite trend is apparent at Warwick Longbridge.

Figure 4 Location of STW monitoring sites

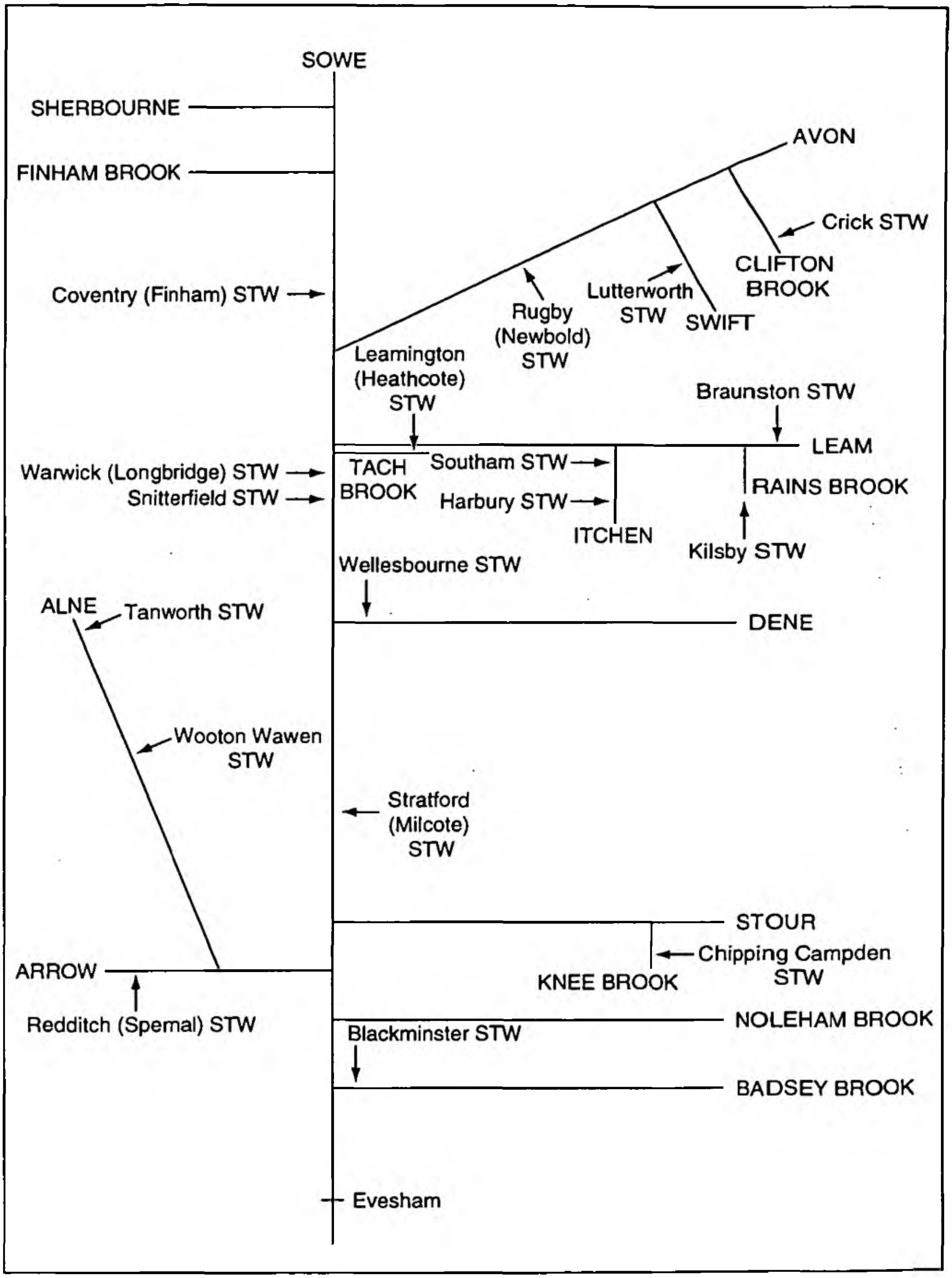
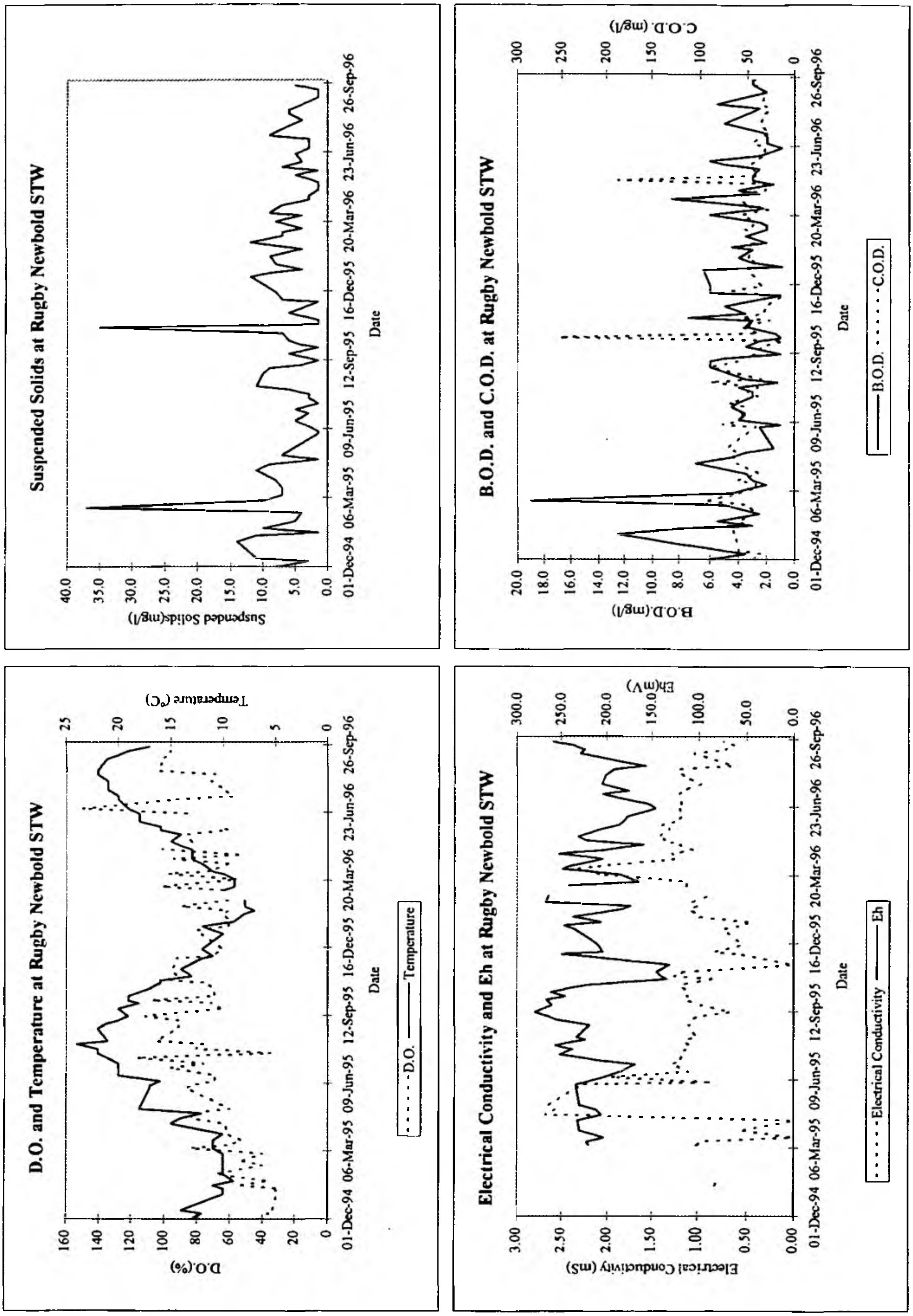
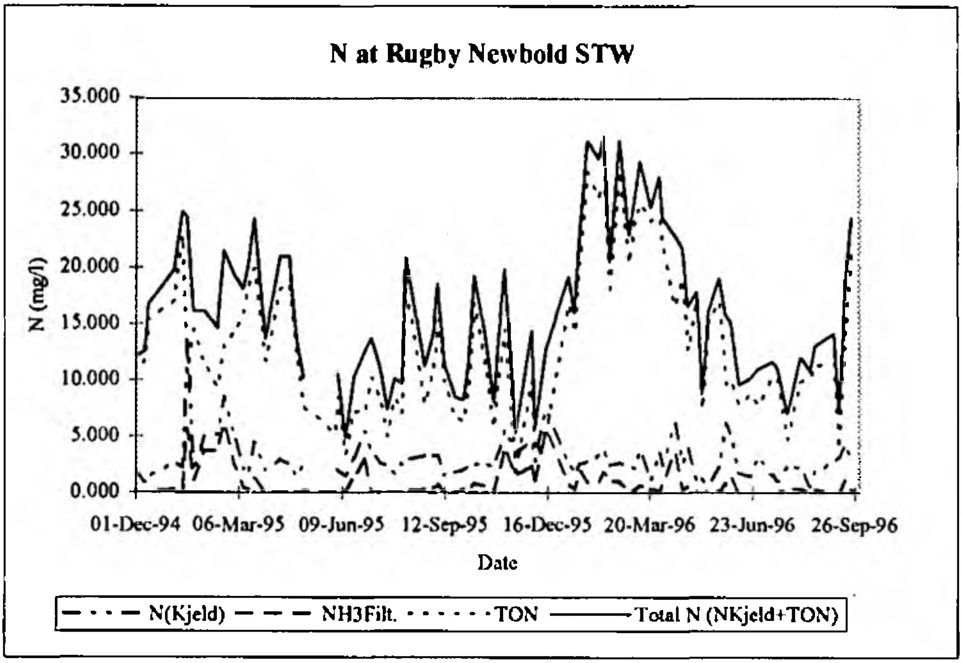


Figure 5 Seasonal trends in water quality at Rugby (Newbold) STW




N at Rugby Newbold STW
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)

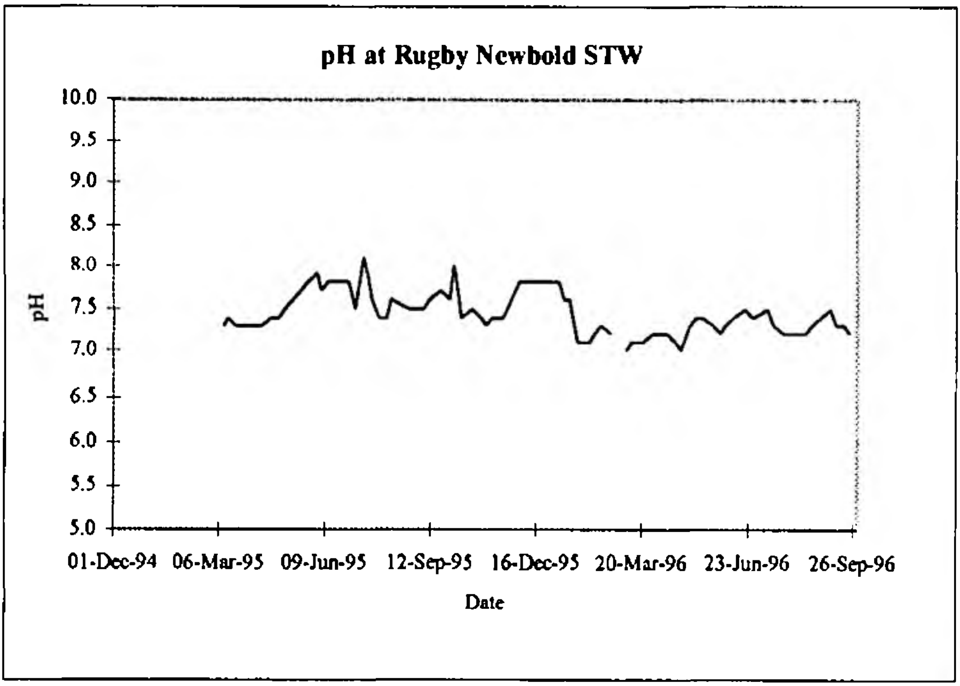
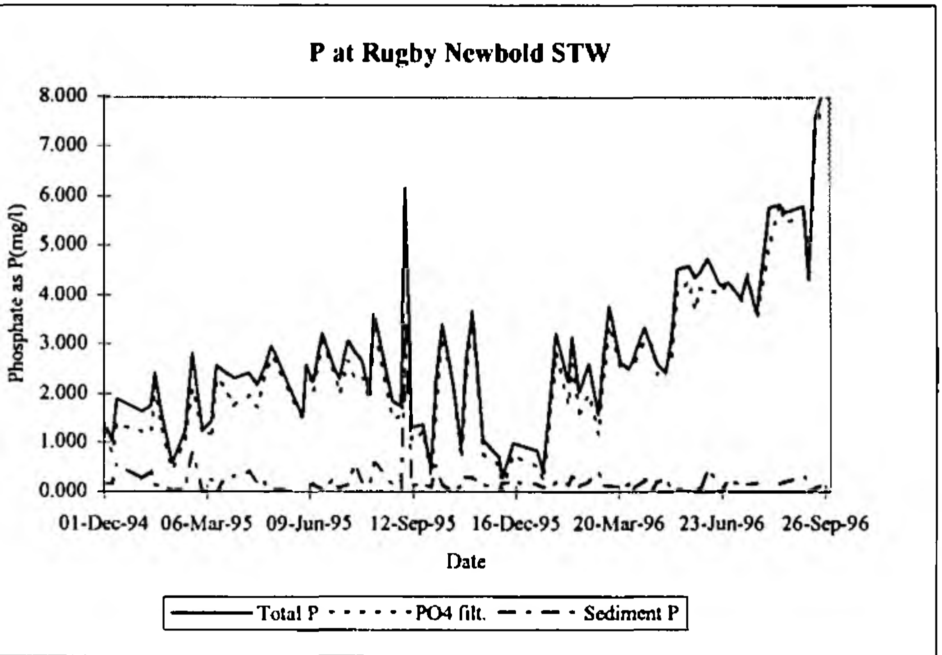

pH at Rugby Newbold STW
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date

Figure 5 cont.



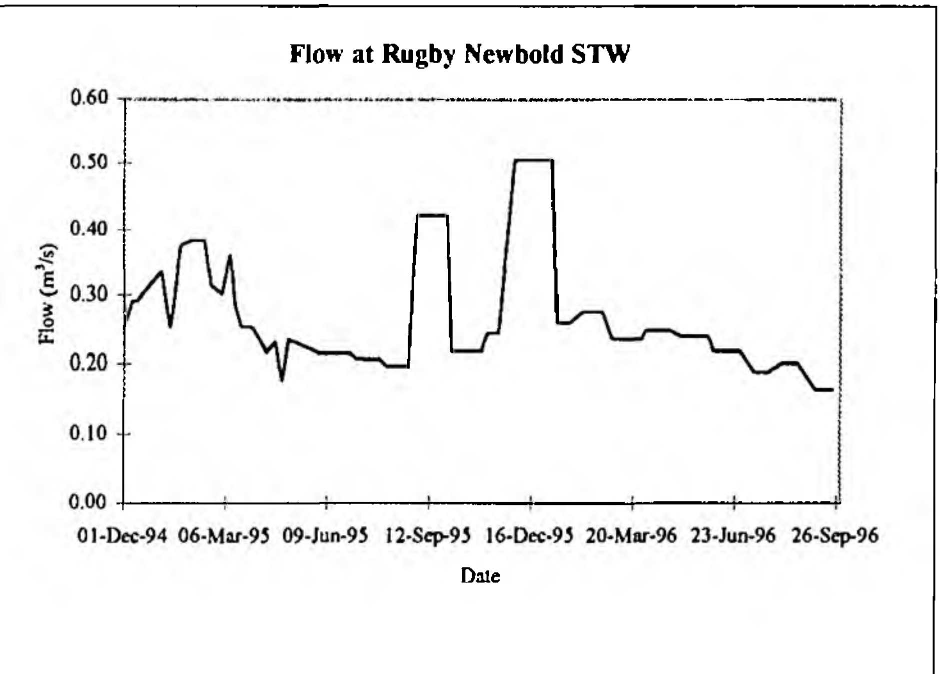
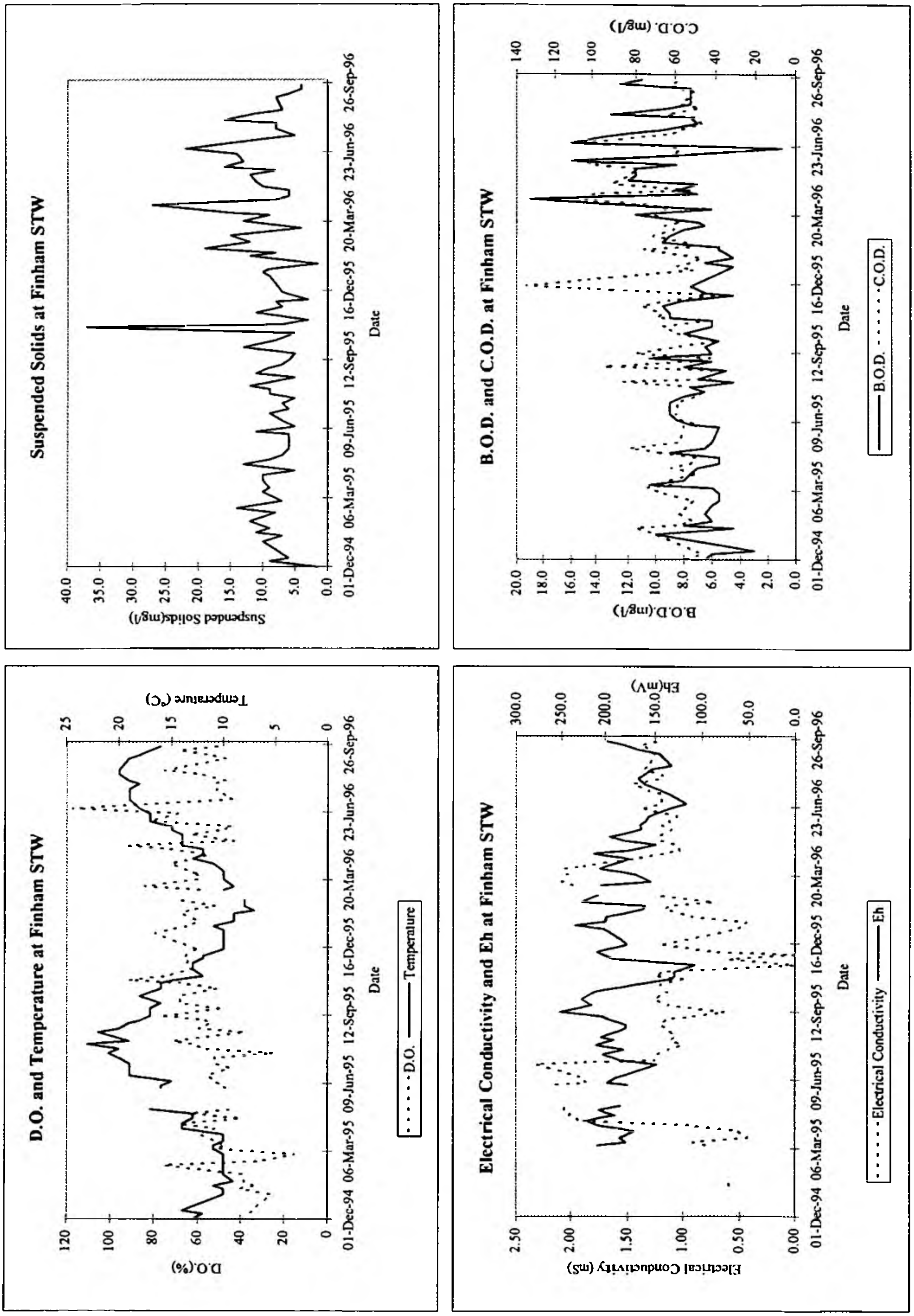
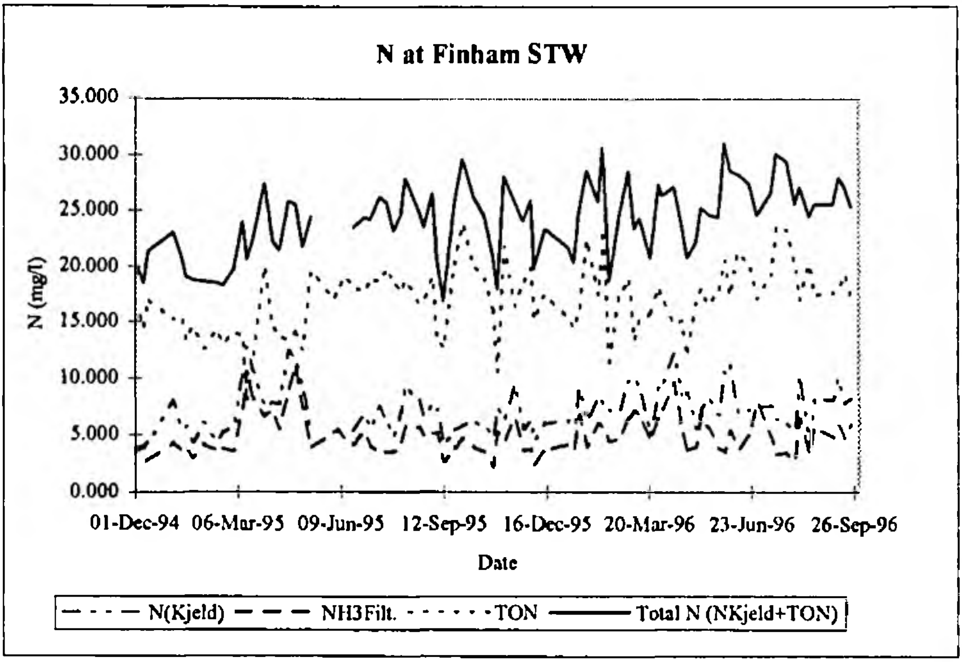
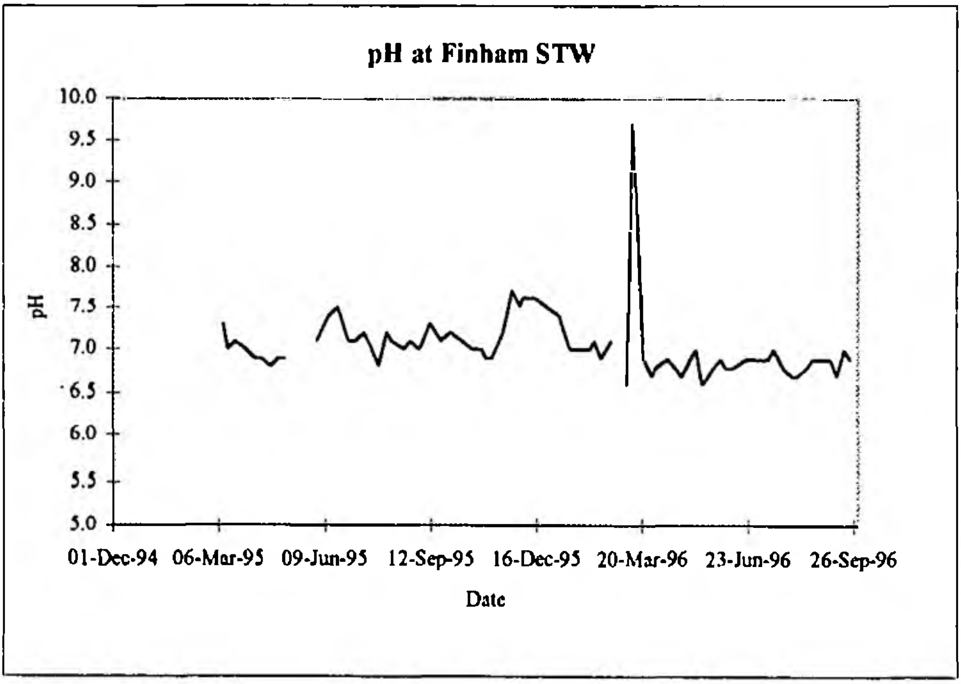


Figure 6 Seasonal trends in water quality at Coventry (Finham) STW



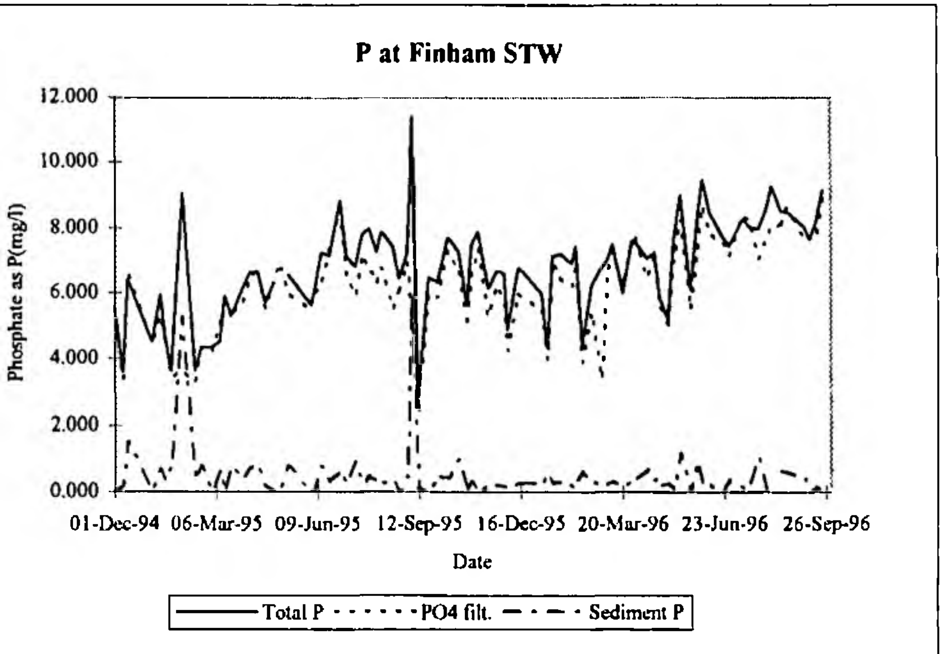


N at Finham STW
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)



pH at Finham STW
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date

Figure 6 cont.



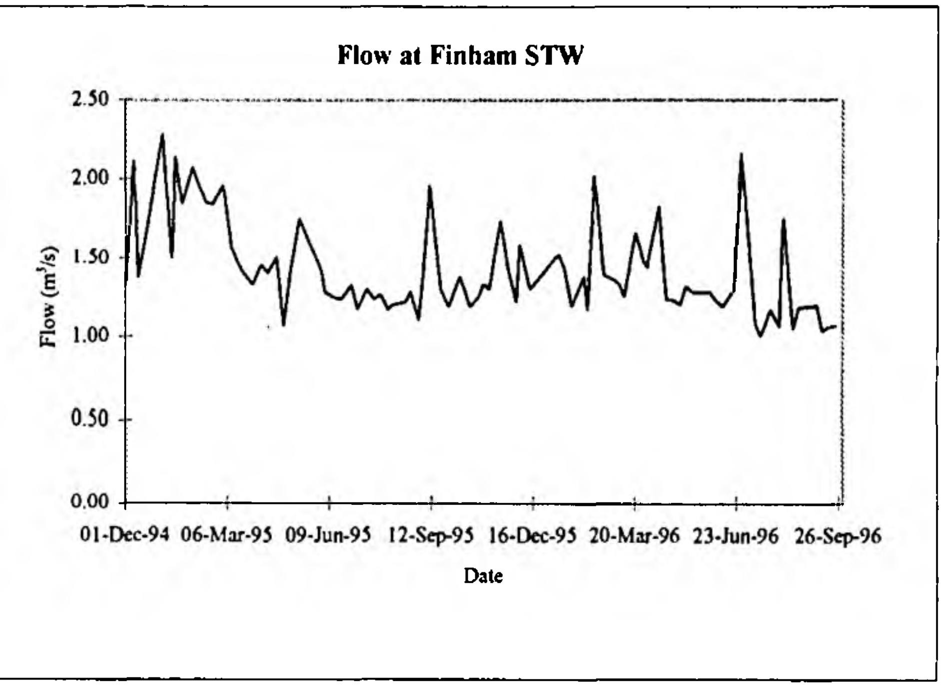
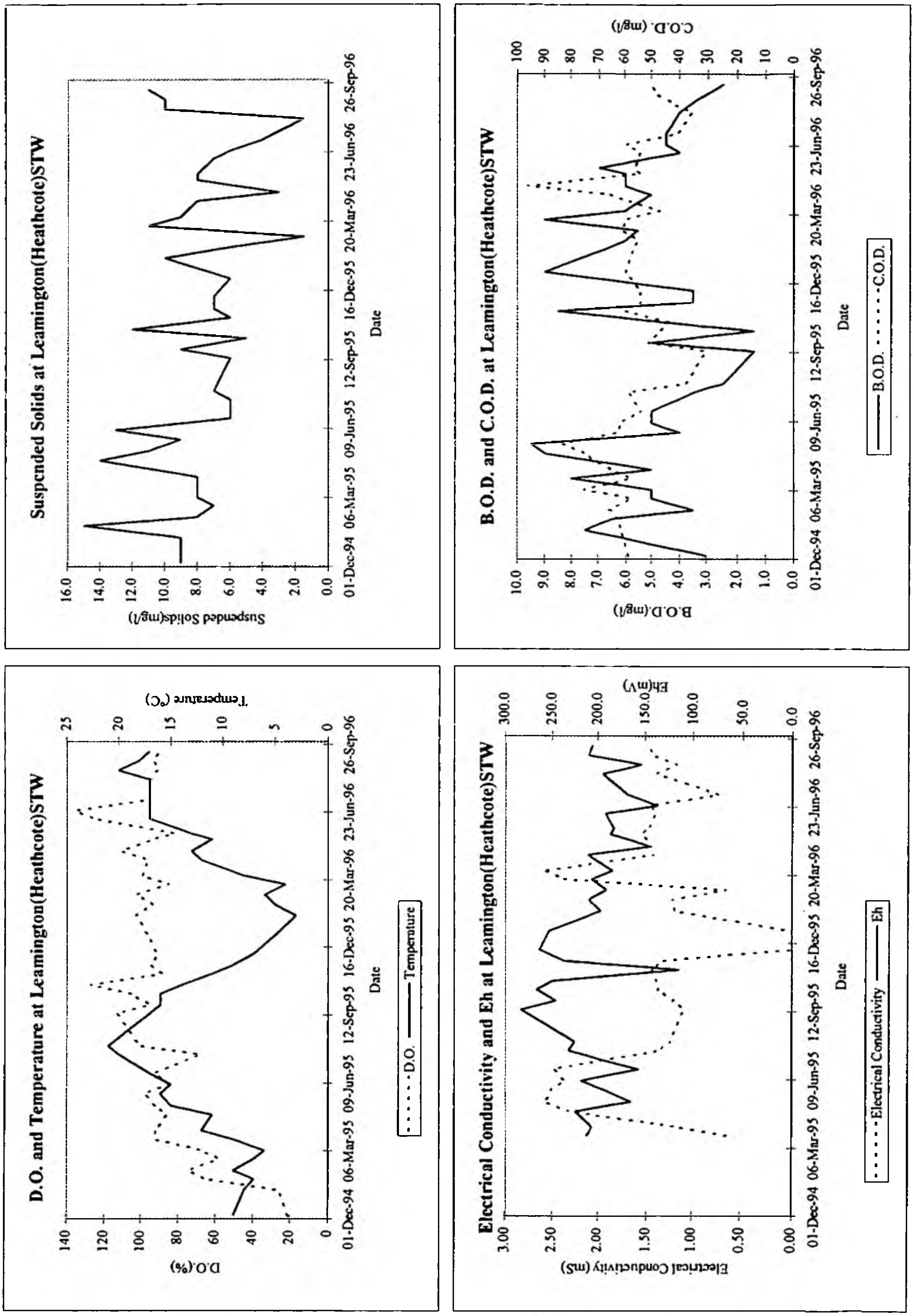
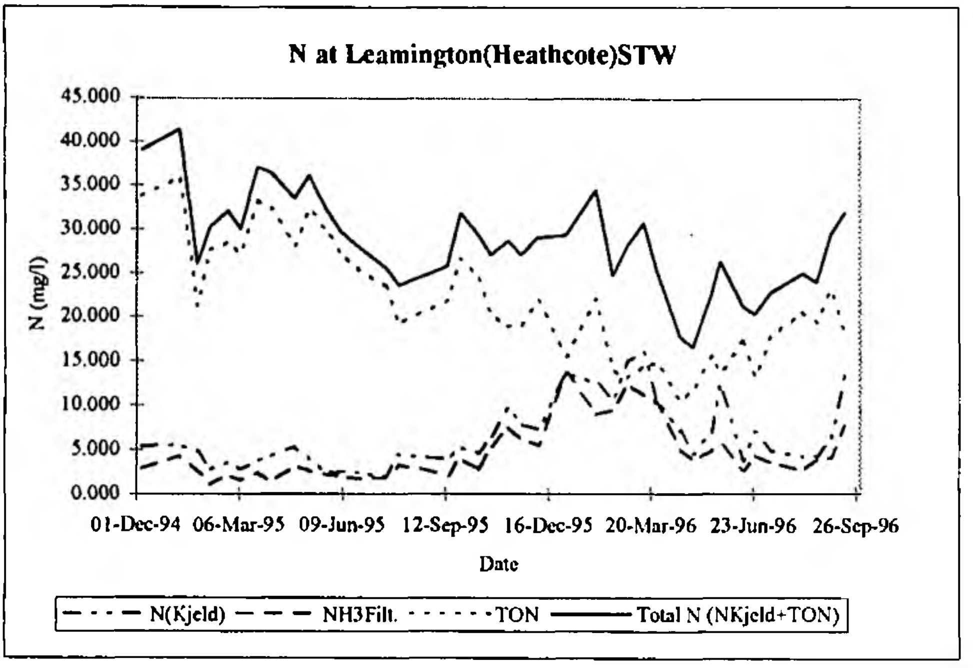
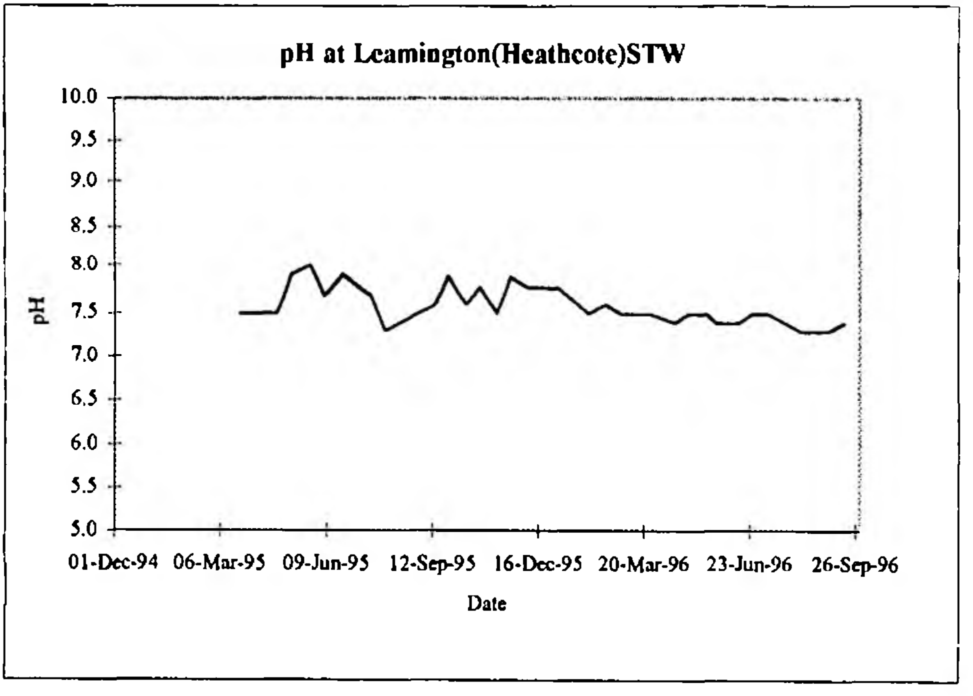


Figure 7 Seasonal trends in water quality at Leamington (Heathcote) STW

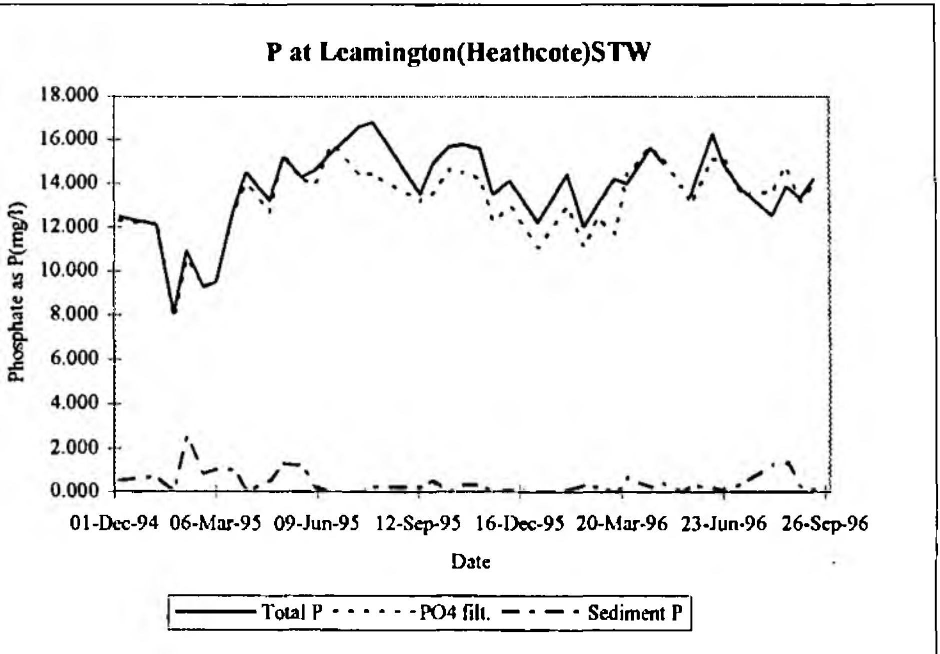




N at Leamington(Heathcote)STW
45.000
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)



pH at Leamington(Heathcote)STW
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date


P at Leamington(Heathcote)STW
Phosphate as P(mg/l)
18.000
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
Total P
PO4 filt.
Sediment P

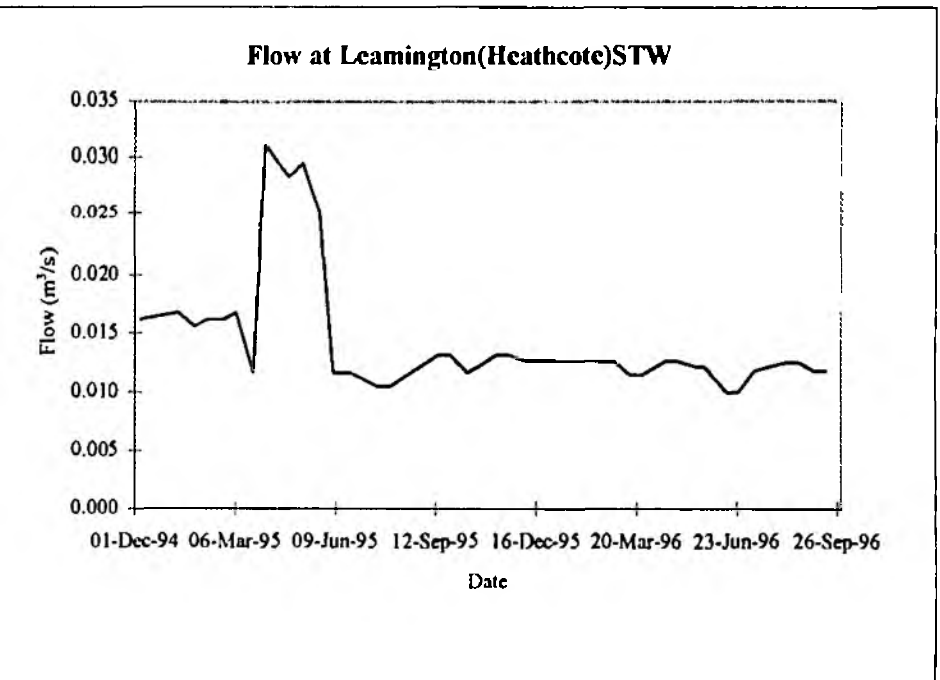
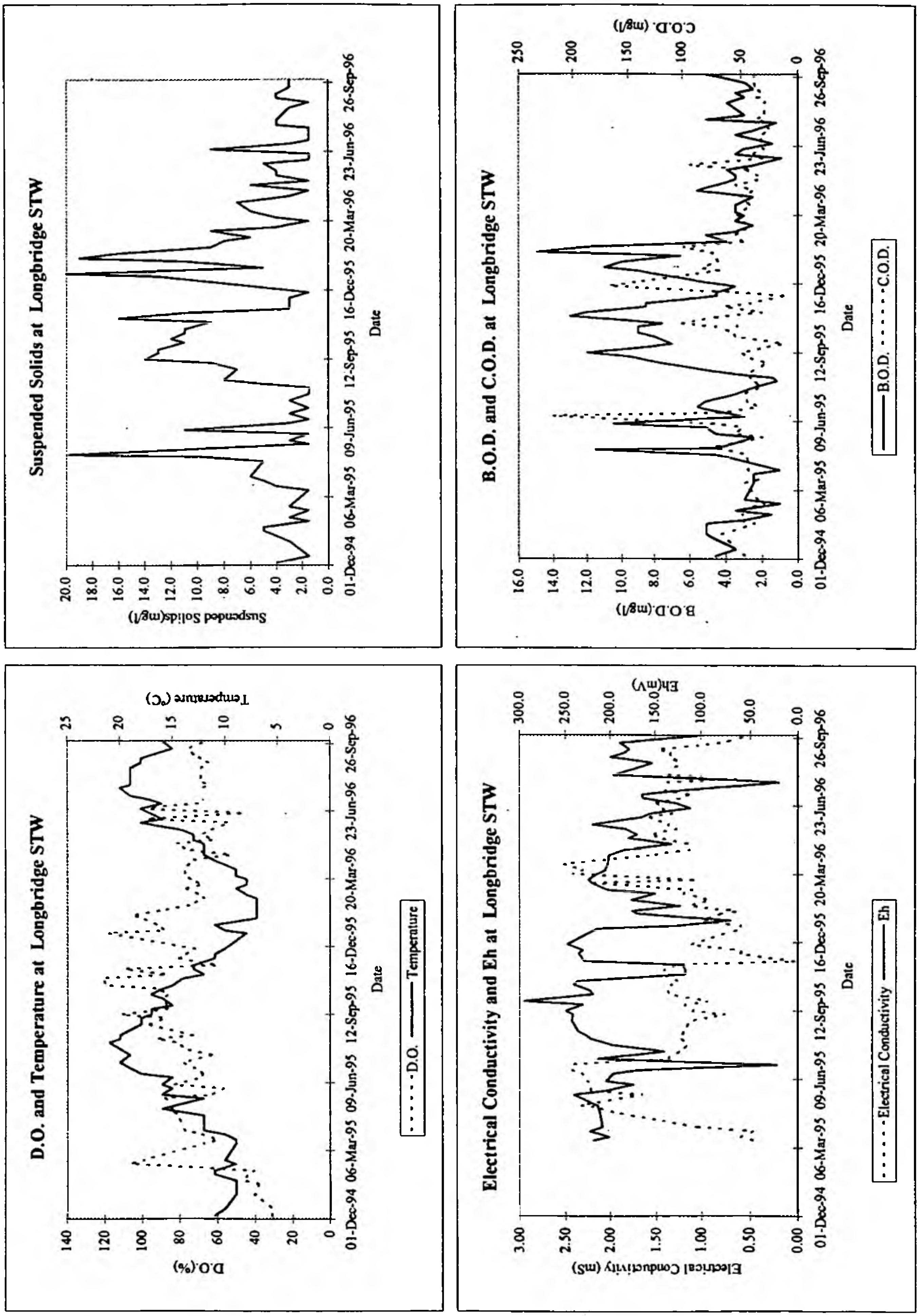
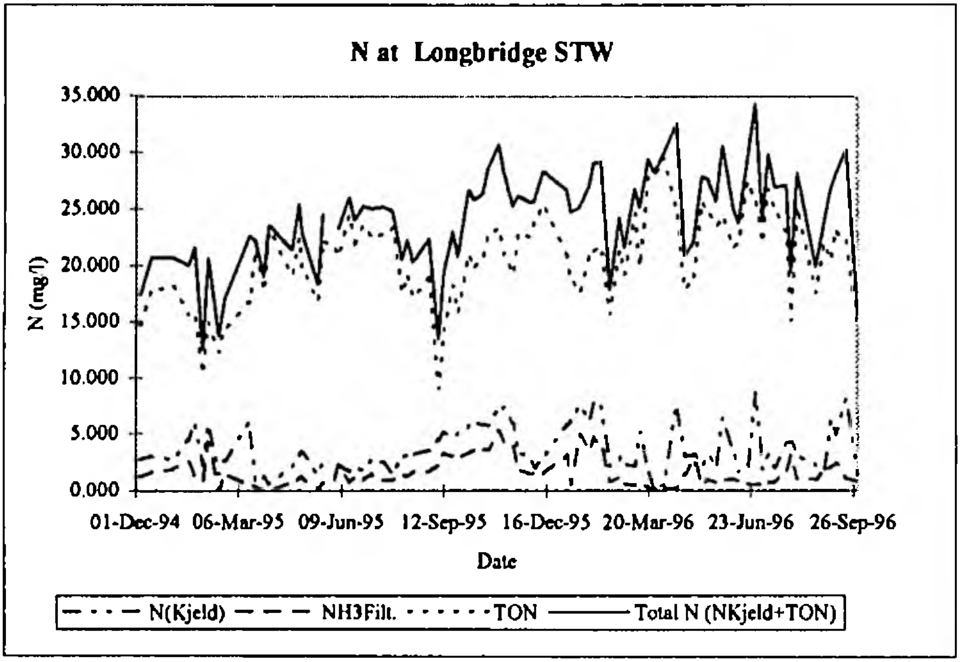
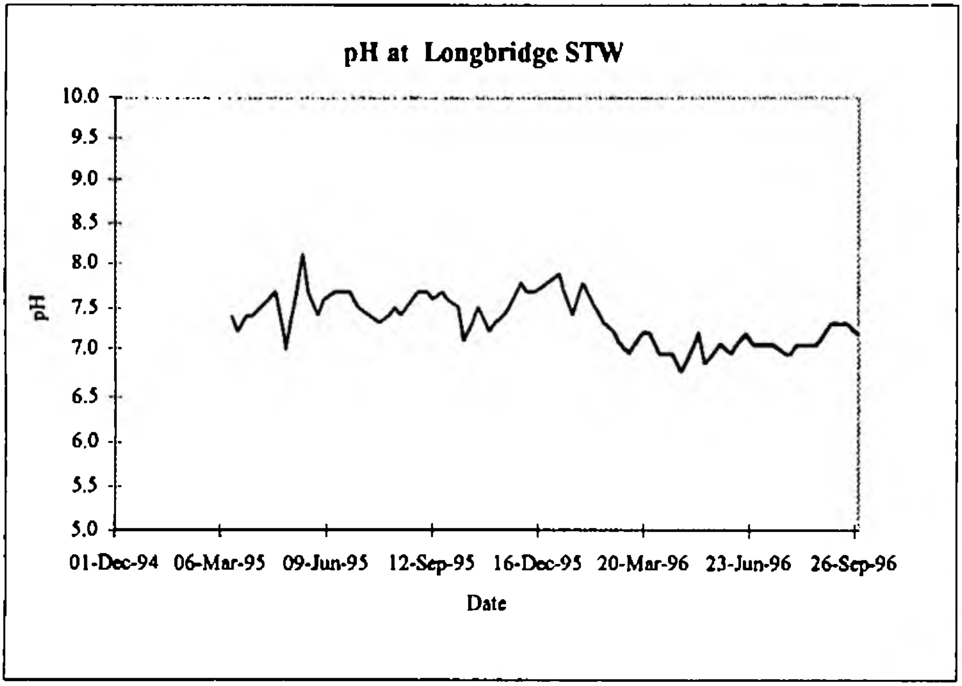

Flow at Leamington(Heathcote)STW
Flow (m³/s)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date

Figure 8 Seasonal trends in water quality at Warwick (Longbridge) STW

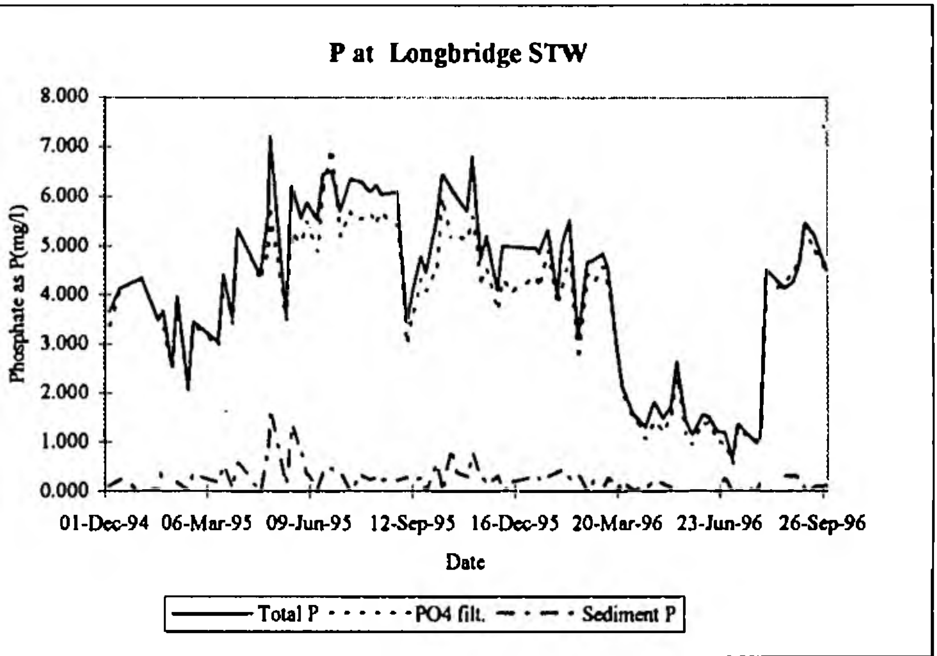




N at Longbridge STW
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)



pH at Longbridge STW
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date



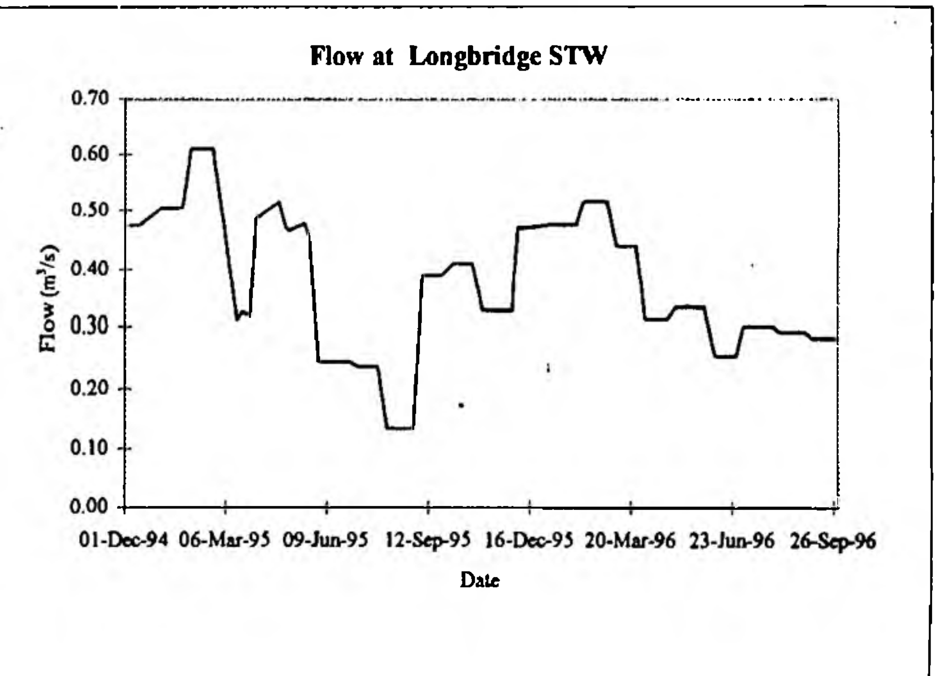
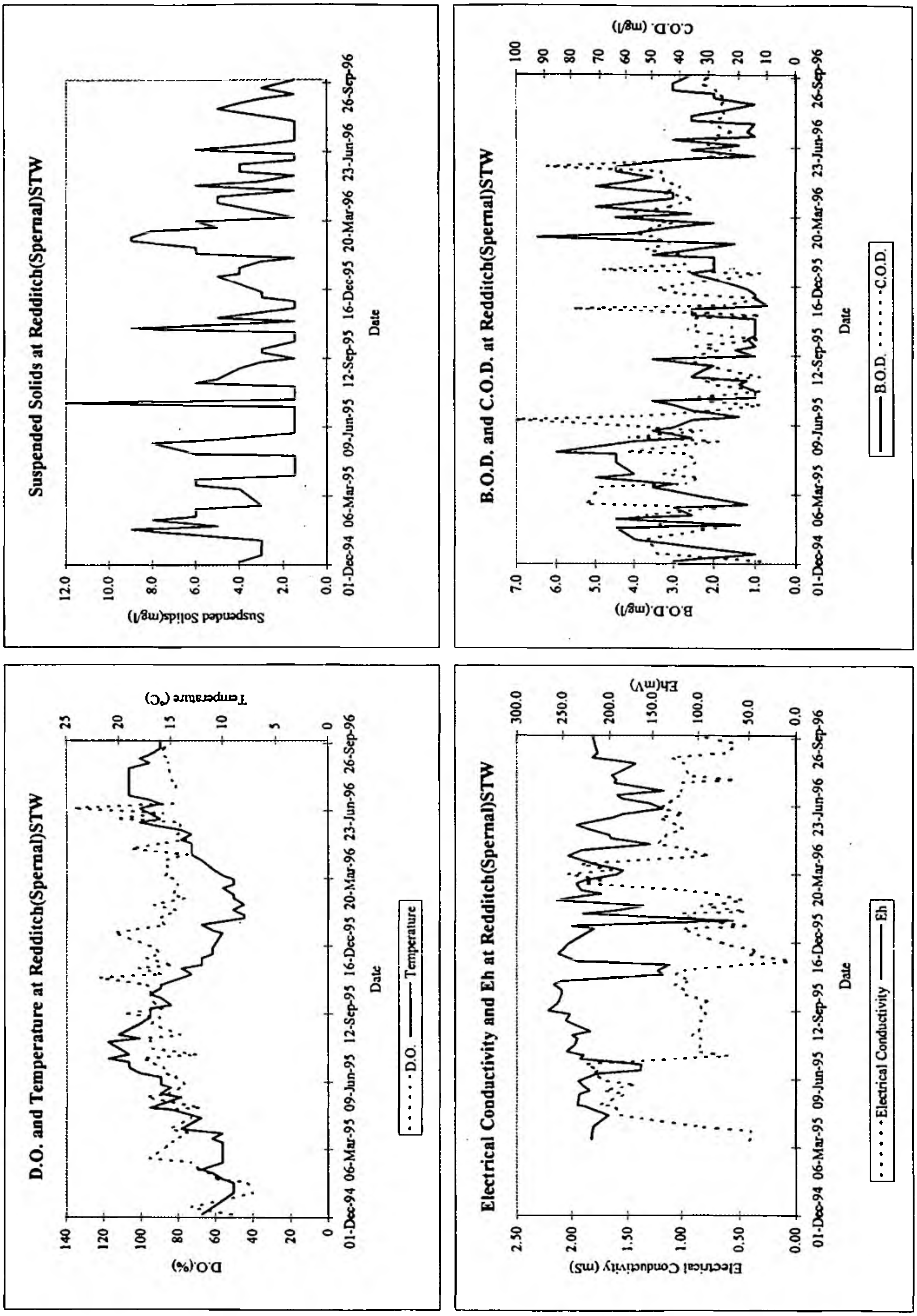
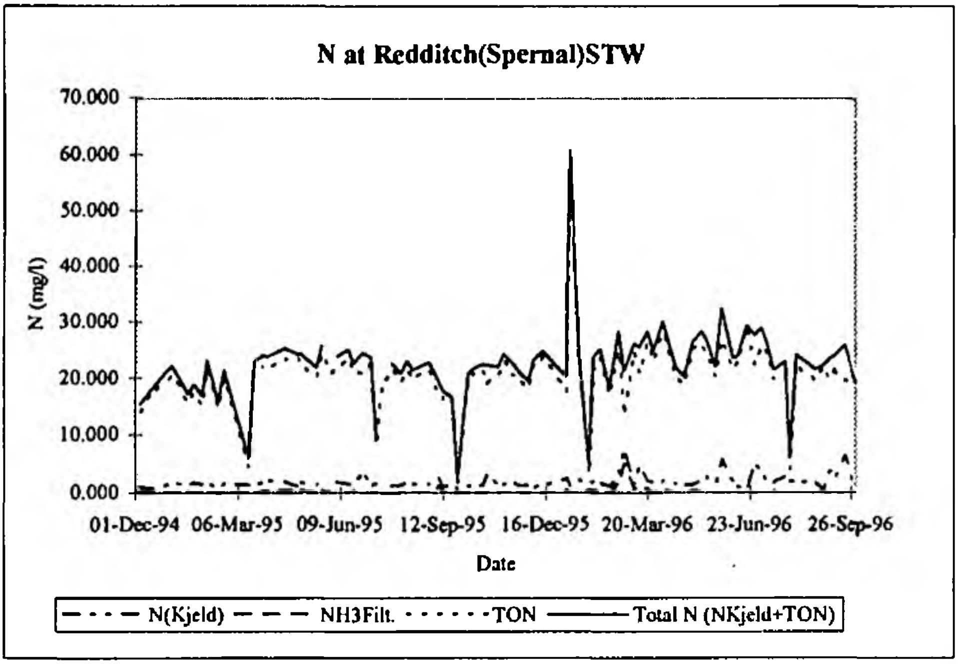
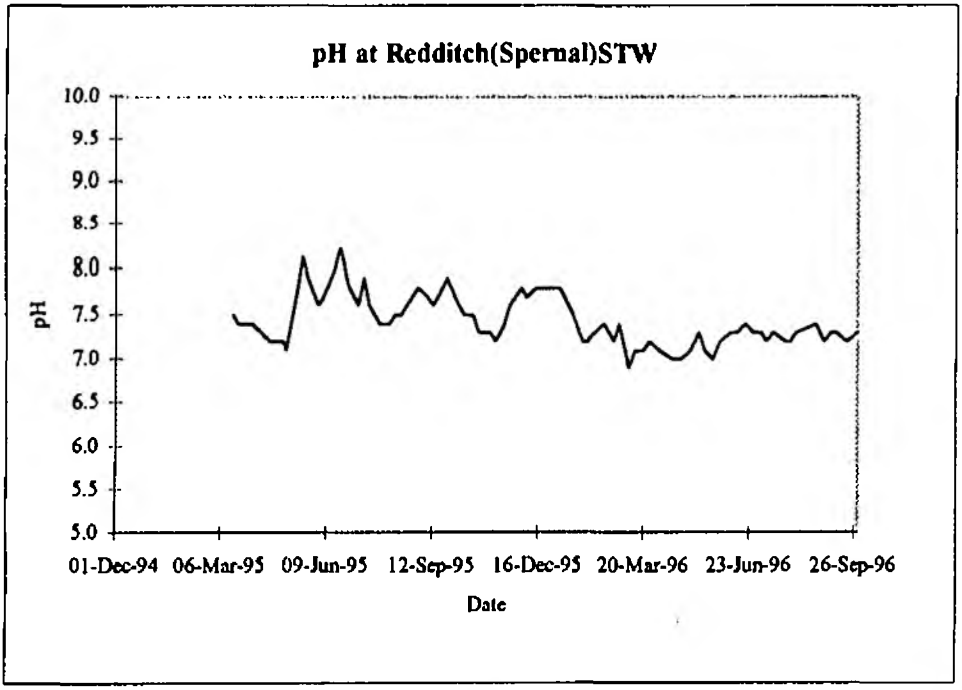


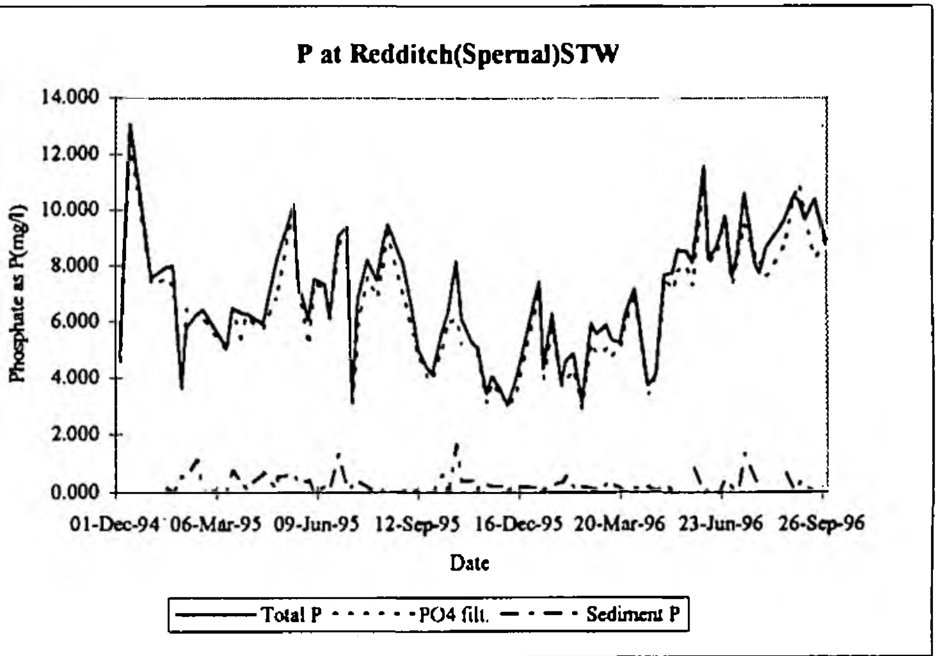
Figure 8 cont.

Figure 9 Seasonal trends in water quality at Redditch (Spernal) STW




N at Redditch(Spernal)STW
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)


pH at Redditch(Spernal)STW
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date



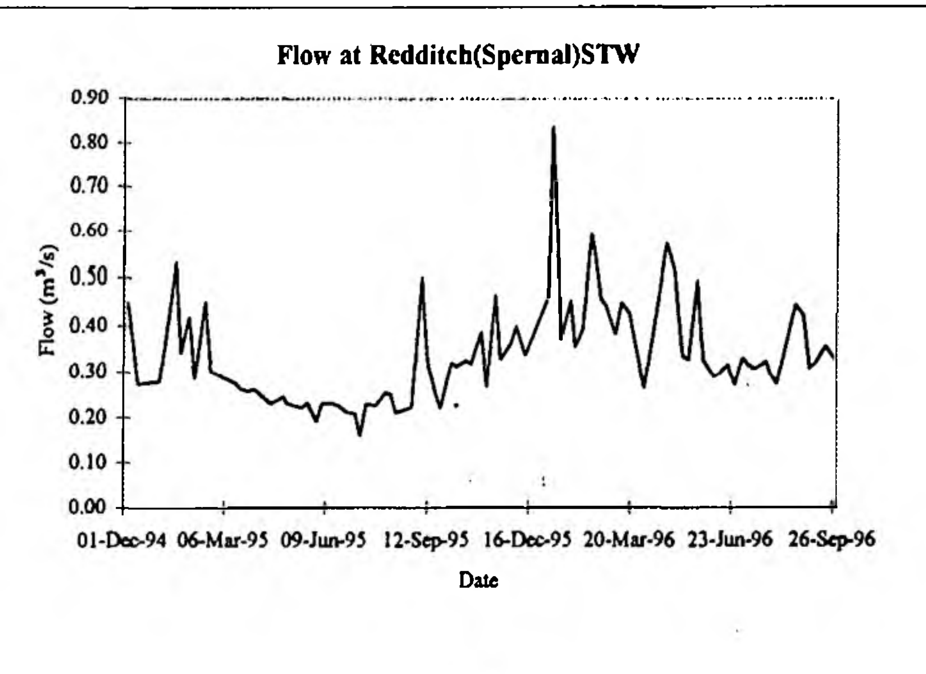
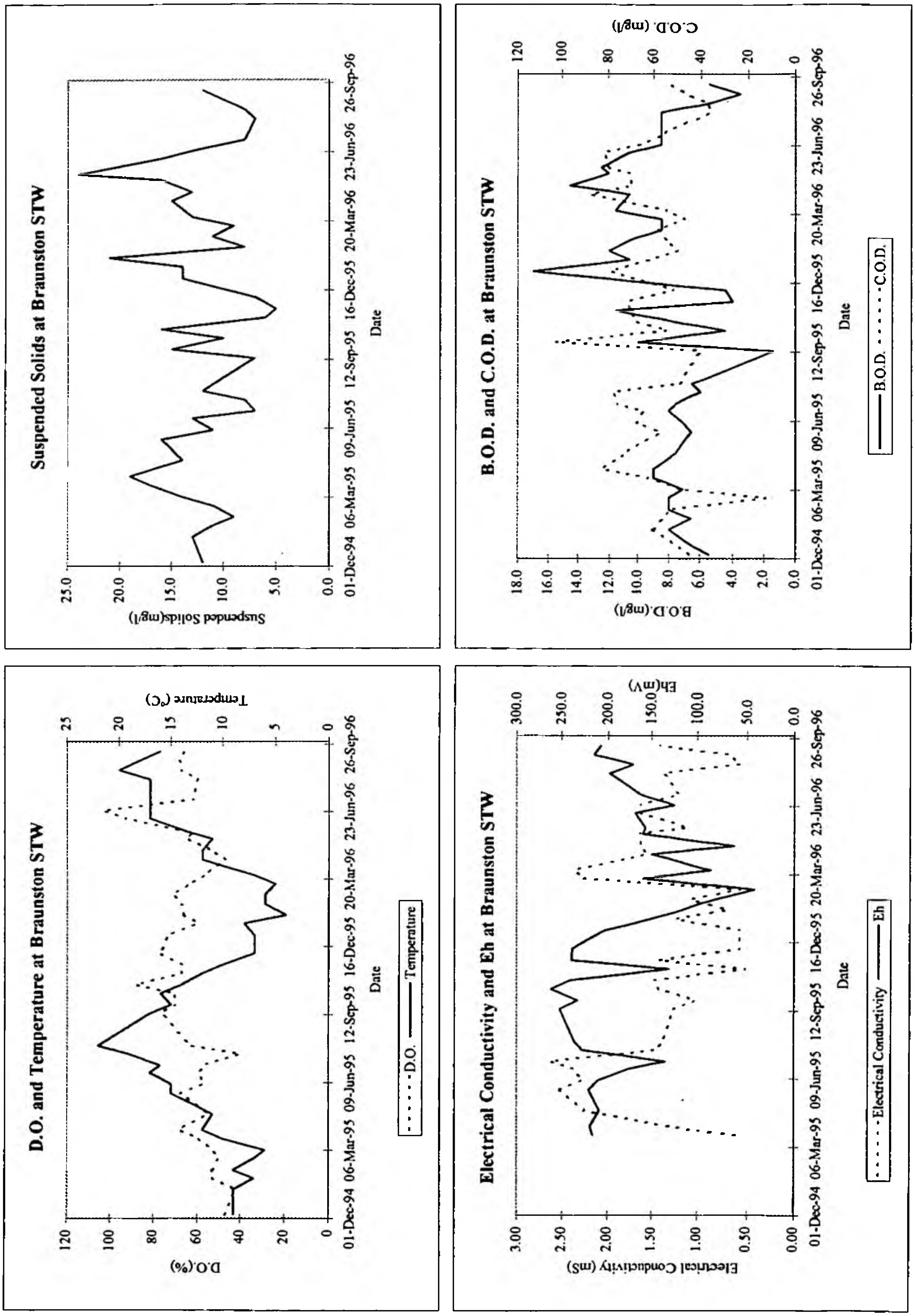
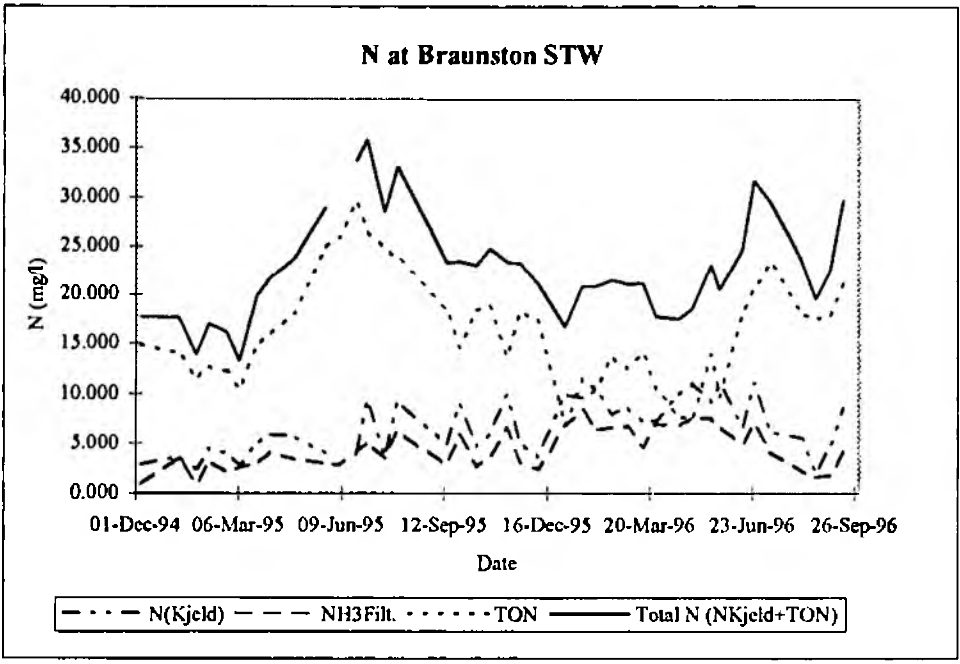
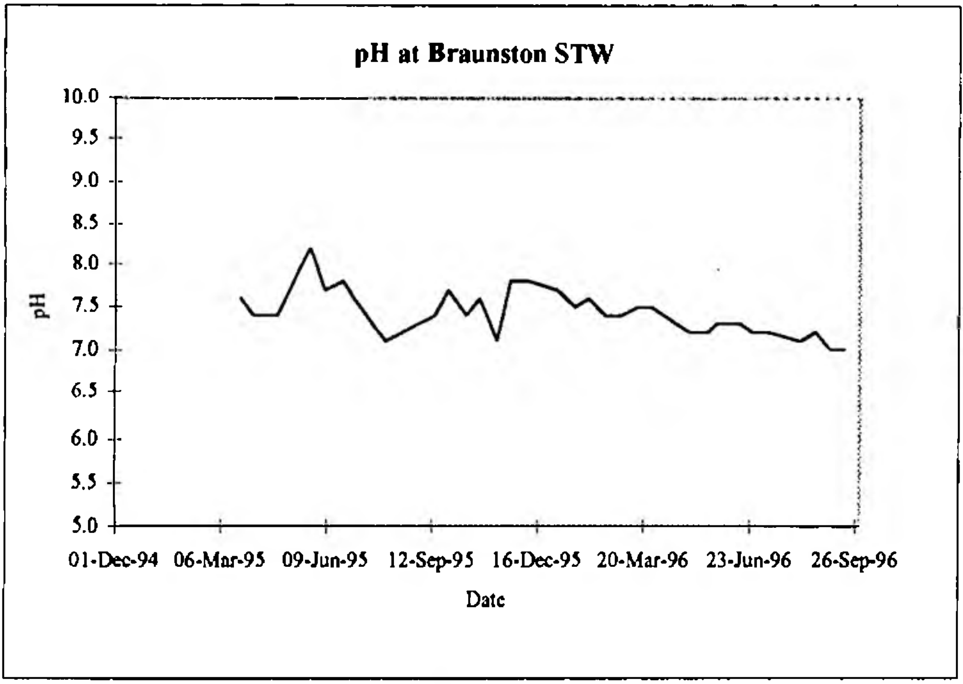


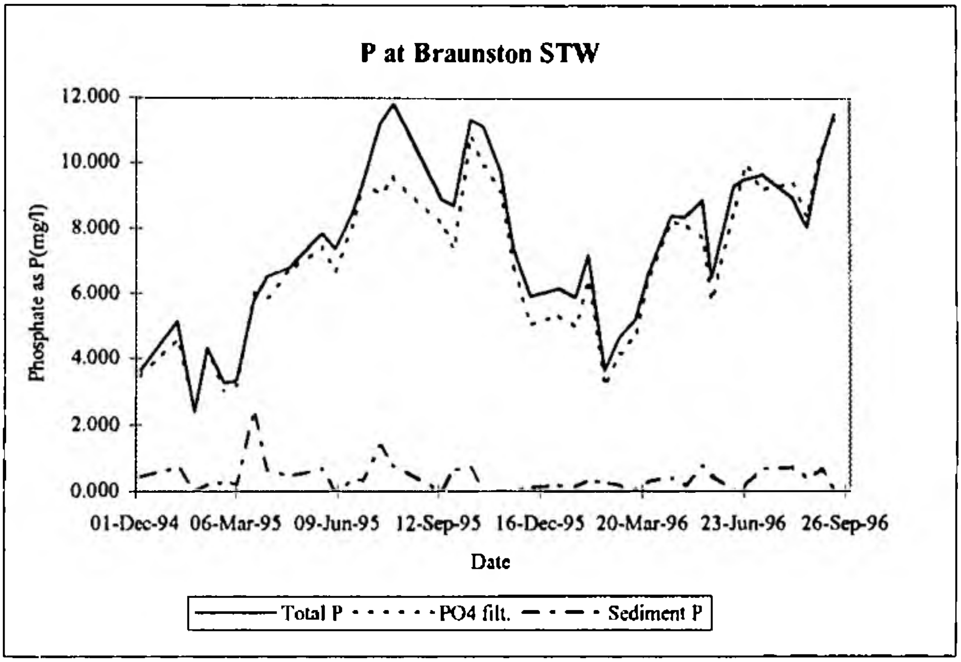
Figure 9 cont.

Figure 10 Seasonal trends in water quality at Braunston STW




N at Braunston STW
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)


pH at Braunston STW
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date



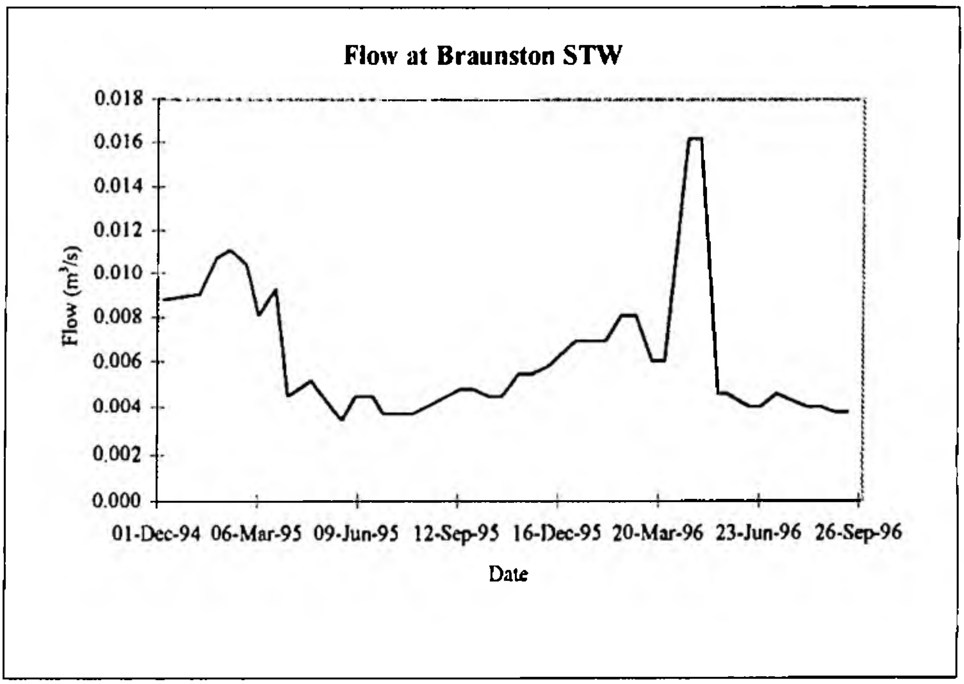
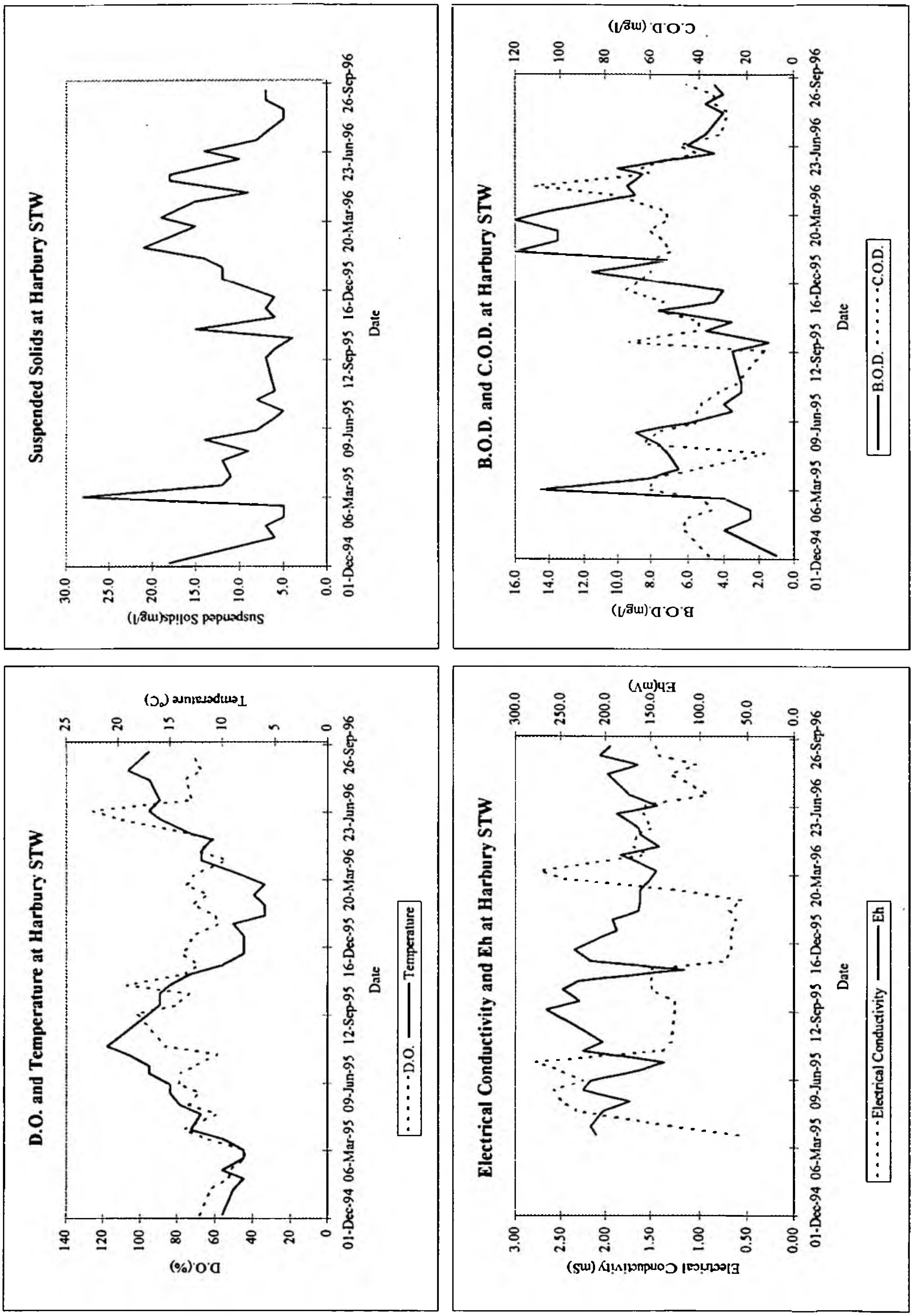
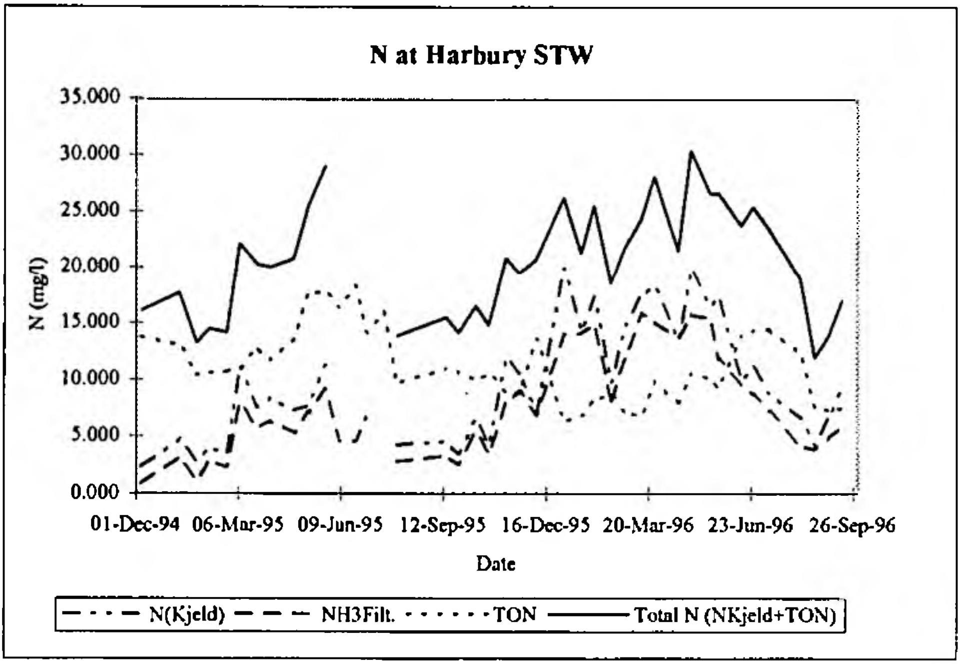
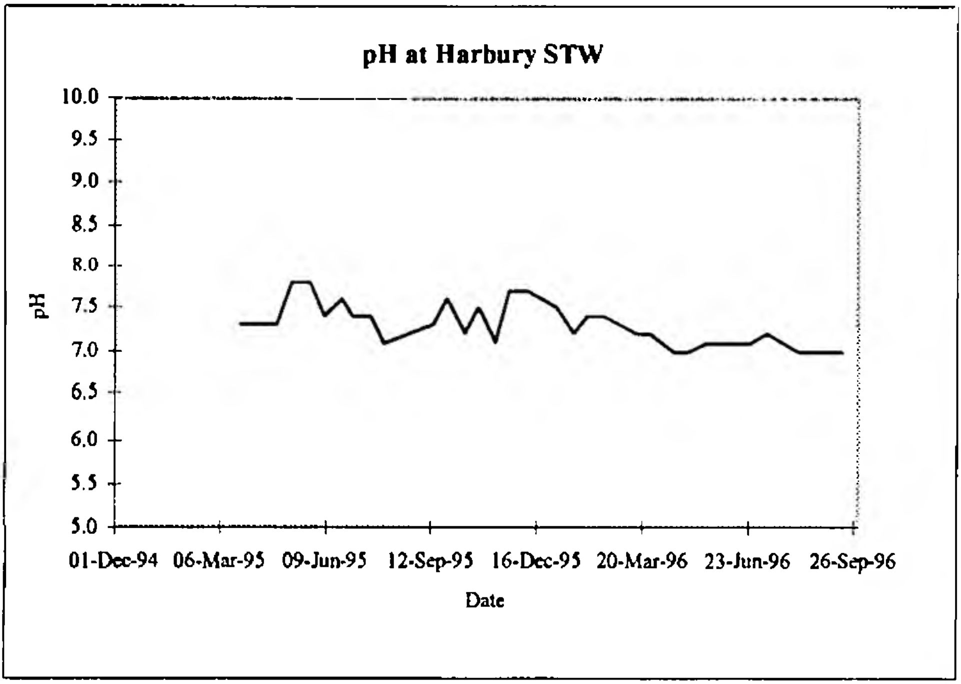


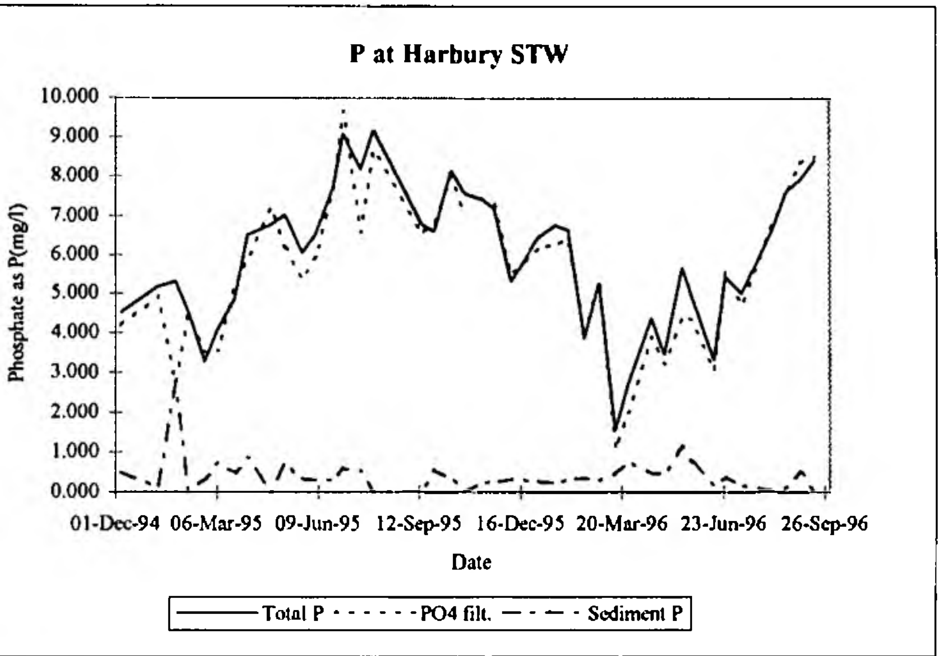
Figure 10 cont.

Figure 11 Seasonal trends in water quality at Harbury STW




N at Harbury STW
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)


pH at Harbury STW
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date



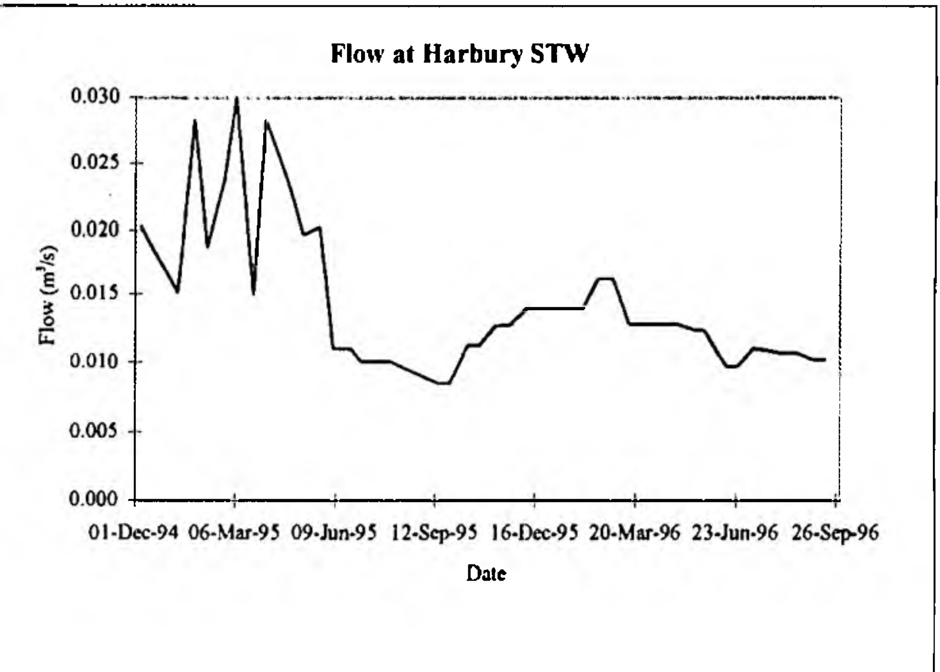
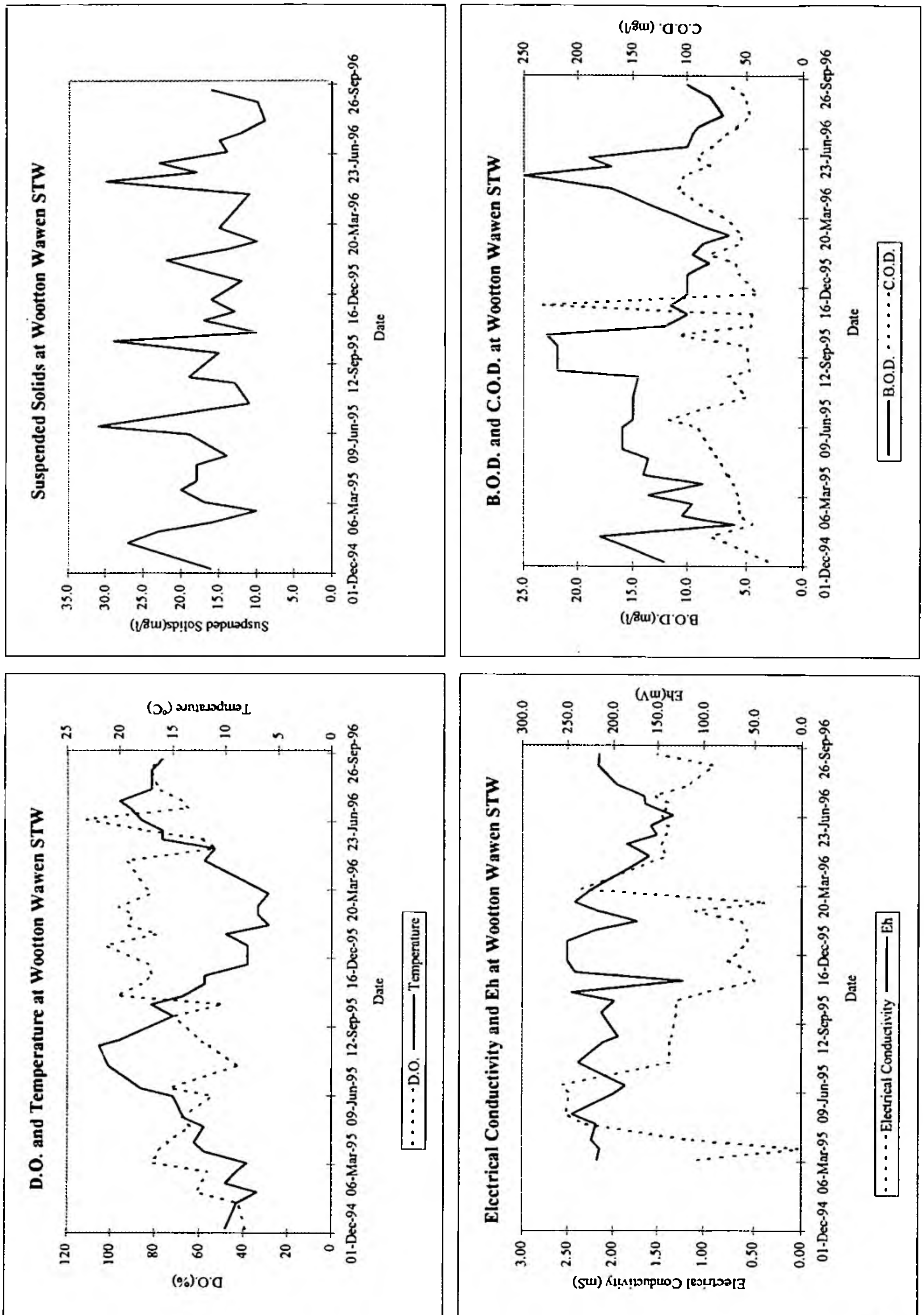
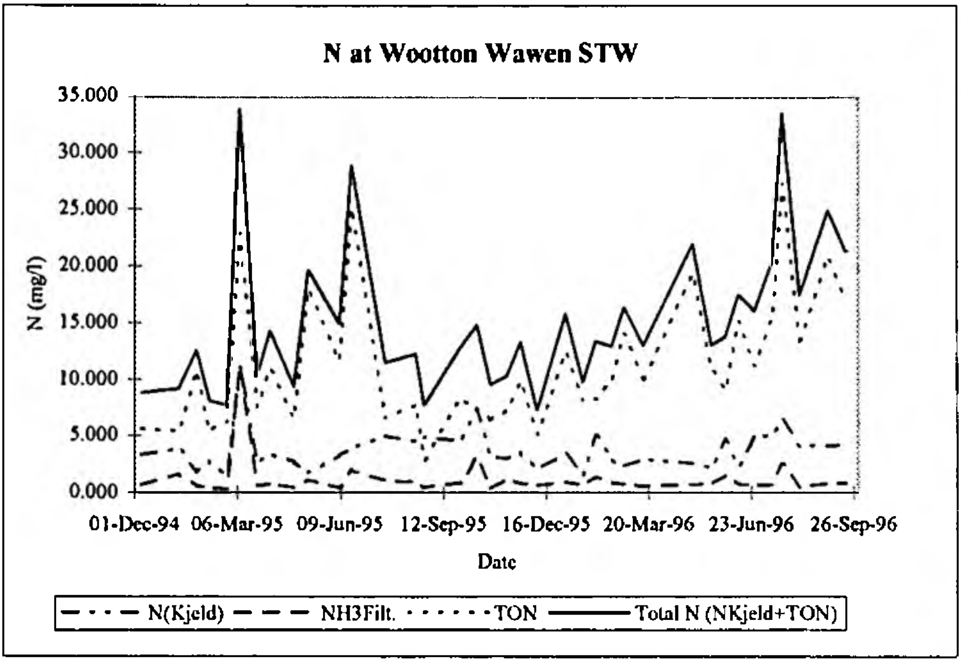
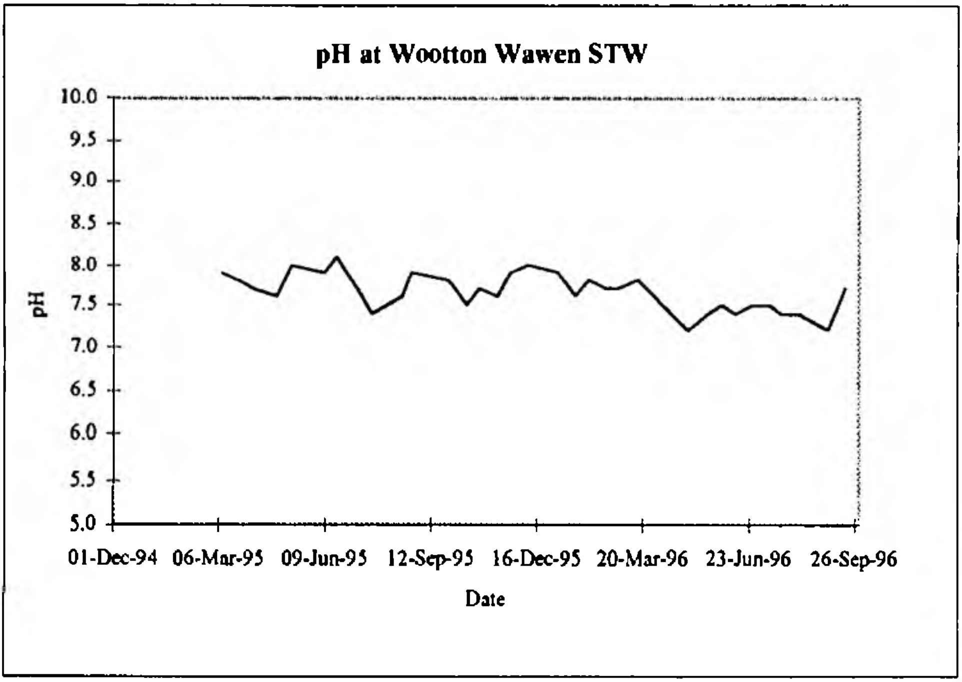


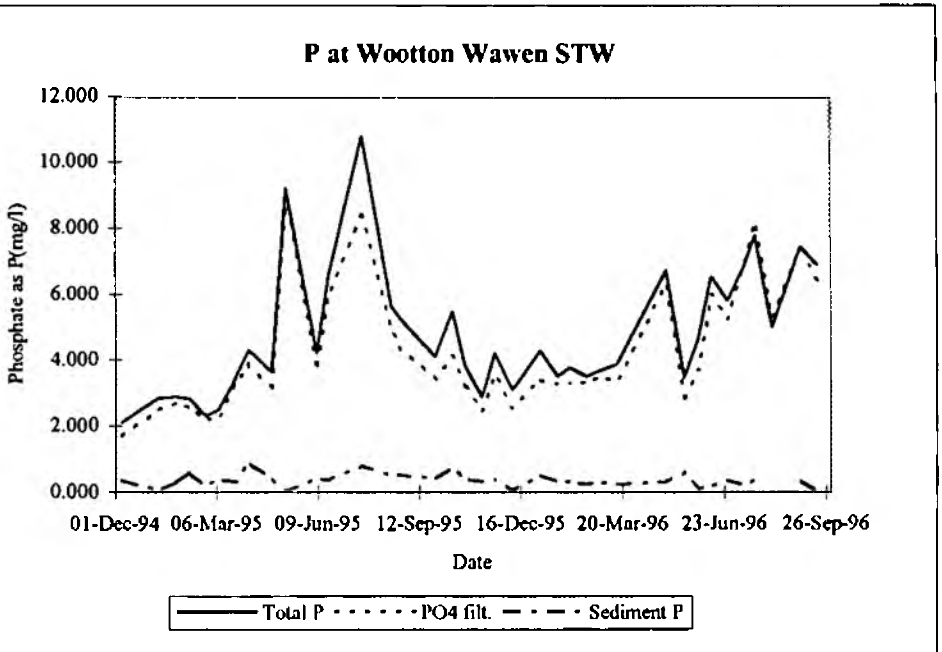
Figure 11 cont.

Figure 12 Seasonal trends in water quality at Wootton Wawen STW




N at Wootton Wawen STW
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)


pH at Wootton Wawen STW
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date



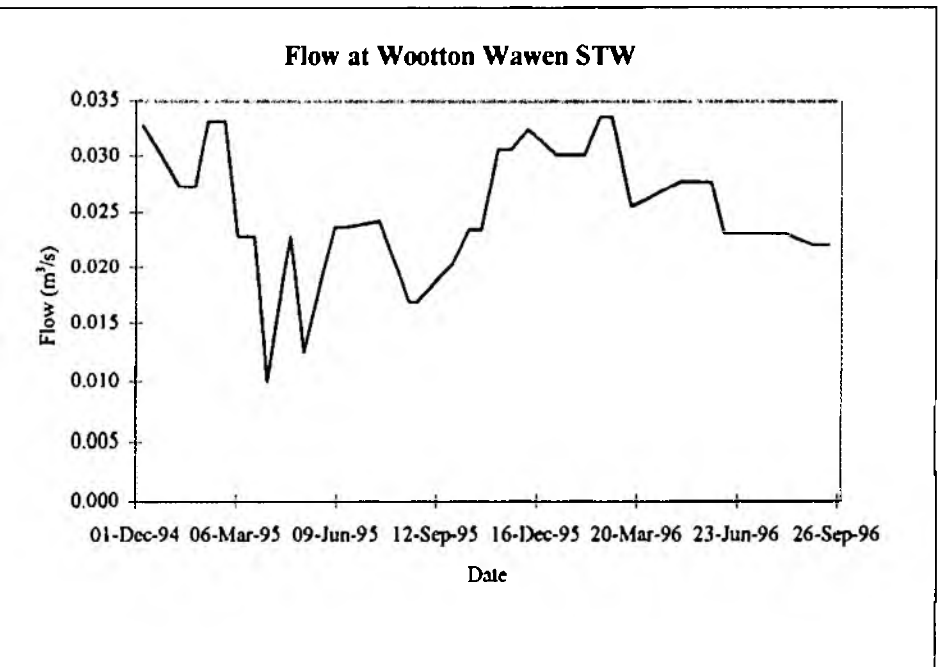


Figure 12 cont.

River monitoring stations

12. Locations of the 8 main river water quality monitoring stations on the river Avon are given in **Figure 13**, with time series plots for Temperature, DO, conductivity, Redox Potential, BOD, COD, N, P, pH and flow in **Figures 14-21**.

13. Temperature shows strong seasonality at Kilworth but, for most of the record, DO remains at or close to 100% saturation. At Clifton, the seasonal behaviour of DO and temperature is strong, with maximum temperatures recorded in late summer. DO values often fall below 60% saturation. In general, the strong seasonality in temperature and periodic decreases in DO to below 60% saturation is recorded at all sites downstream of Kilworth.

14. Periodically high suspended solids concentrations are recorded at all sites. High concentrations are associated with individual samples collected at high river flows. Maximum recorded concentrations exceed 80 mg/l at Kilworth, 90 mg/l at Stare Bridge, 140 mg/l at Barford and Stratford, 230 mg/l at Clifton and Little Lawford, 300 mg/l at Stoneleigh and 500 mg/l at Evesham.

15. Conductivity is generally higher at all sites between the months of March and July. As a measure of total dissolved solids concentration it reflects the dilution by higher effective rainfalls over the catchment in the winter months. Conductivity increases downstream from headwater sites towards the main downstream sampling station at Evesham. Redox Potential remains fairly constant throughout the year at all sites, but drops significantly at most stations in November 1995. At all times Redox Potential remains above +100 mV in river water samples.

16. River monitoring stations on the Avon upstream of the Sowe confluence generally have BODs of less than 4 mg/l although there is some seasonality, especially at Clifton and Stare Bridge, with highest levels recorded in the spring. Downstream of the Sowe confluence, the impact of Coventry Finham STW dominates the BOD record. There is little seasonality in the BOD record at Stoneleigh but a seasonal trend reappears at, and downstream, of Stratford. Seasonal peaks in these stations occur slightly later in the year than those at stations upstream of the Sowe/Avon confluence.

17. River water pH lies between 7.5 and 9.0 and is higher by as much as one pH unit over the year at sites upstream of the Sowe confluence. There is a seasonal trend at most sites but at Kilworth, pH decreases by ca. 0.5 units between the beginning and end of the sampling period. Seasonal maxima appear to be associated with periods of maximum phytoplankton growth as recorded in the chlorophyll a record.

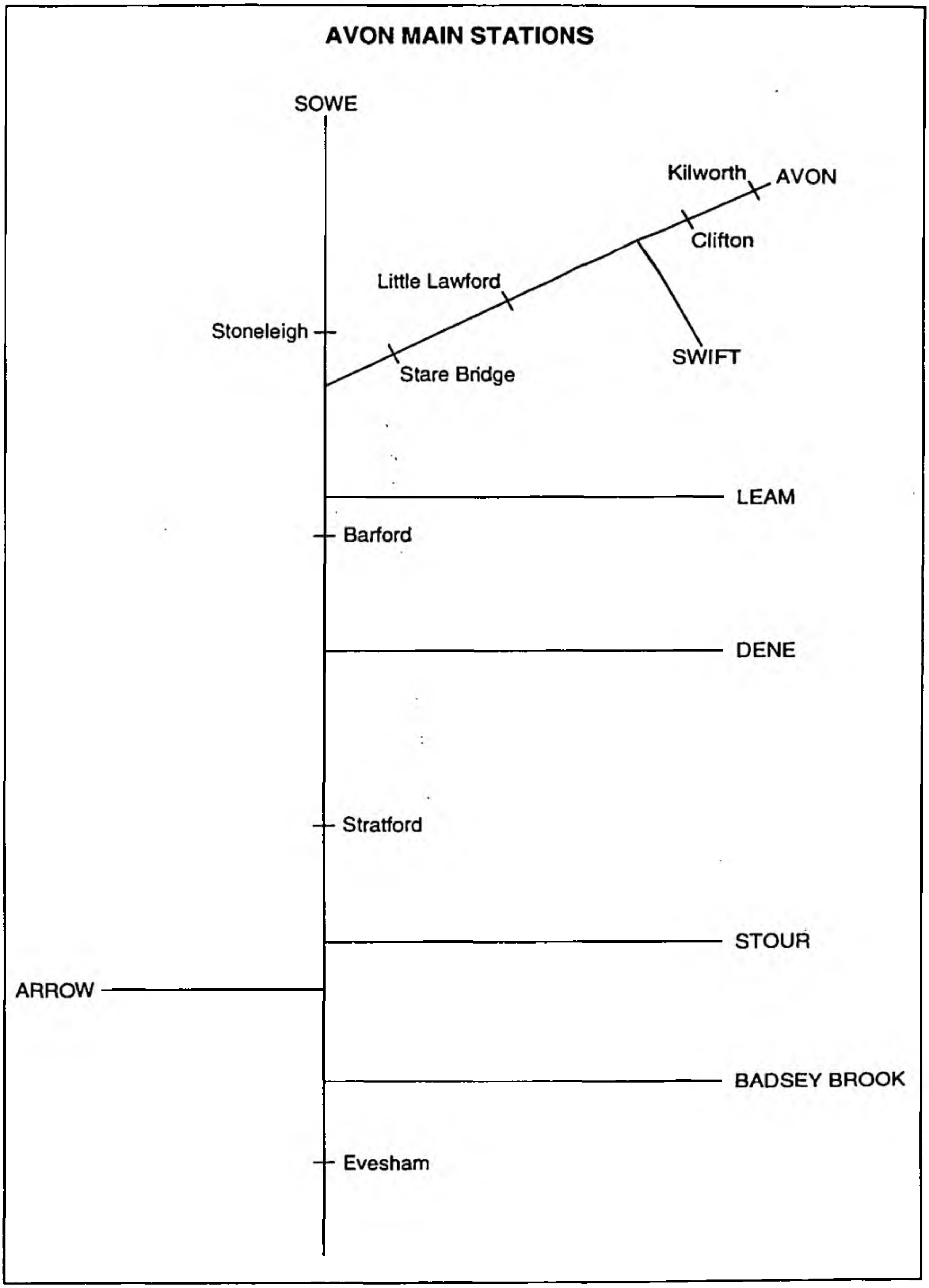
18. Chlorophyll a concentrations have been recorded at 19 monitoring stations and time series plots are given in Figures 15-21. Samples were not collected and measured over the winter period. The DOE (1993) define the occurrence of planktonic algal blooms in running waters in relation to chlorophyll a. A planktonic bloom occurs either where the annual mean chlorophyll a concentration exceeds 25 mg/m^3 or where the maximum concentration exceeds 100 mg/m^3. The average concentrations cannot be calculated since a full years chlorophyll a data are not available. However, the 100

mg/m^3 limit defined by the DOE (1993) can be used as a guide to the occurrence of significant blooms. Chlorophyll a concentrations exceeding 100 mg/m3 are recorded at Stoneleigh, Barford, Stratford and Evesham, i.e. at all main stream river monitoring sites downstream of the Finham STW input.

19. TP concentrations are below 0.5 mg/l at Kilworth and Clifton (with the exception of a high total P in a single sample at Clifton in September 1995). Weak seasonality is shown by the Clifton record with a winter peak in concentration; a pattern repeated at Little Lawford with stronger seasonality and a notable increase in the last 6 months of the record. The influence of sewage effluent discharges on the seasonality of P concentrations becomes evident at Little Lawford and at all sites downstream. At stations downstream of the Sowe/Avon confluence, total P concentrations frequently exceed 4 mg/l of which most is present in dissolved form.

20. N concentrations at Kilworth and Clifton are dominated by diffuse agricultural inputs, with high concentrations occurring between late autumn and spring. Whilst there remains some evidence of seasonality in nitrate concentrations at Little Lawford and Stare Bridge, the initial increases typically occur in autumn and early winter indicating a predominantly agricultural influence. By contrast, N concentrations at Stoneleigh show little seasonal pattern due to the dominance of Finham STW effluents. The lack of seasonality can be detected in all records downstream of the Sowe/Avon confluence.

Figure 13 Location of the main Avon quality monitoring stations.



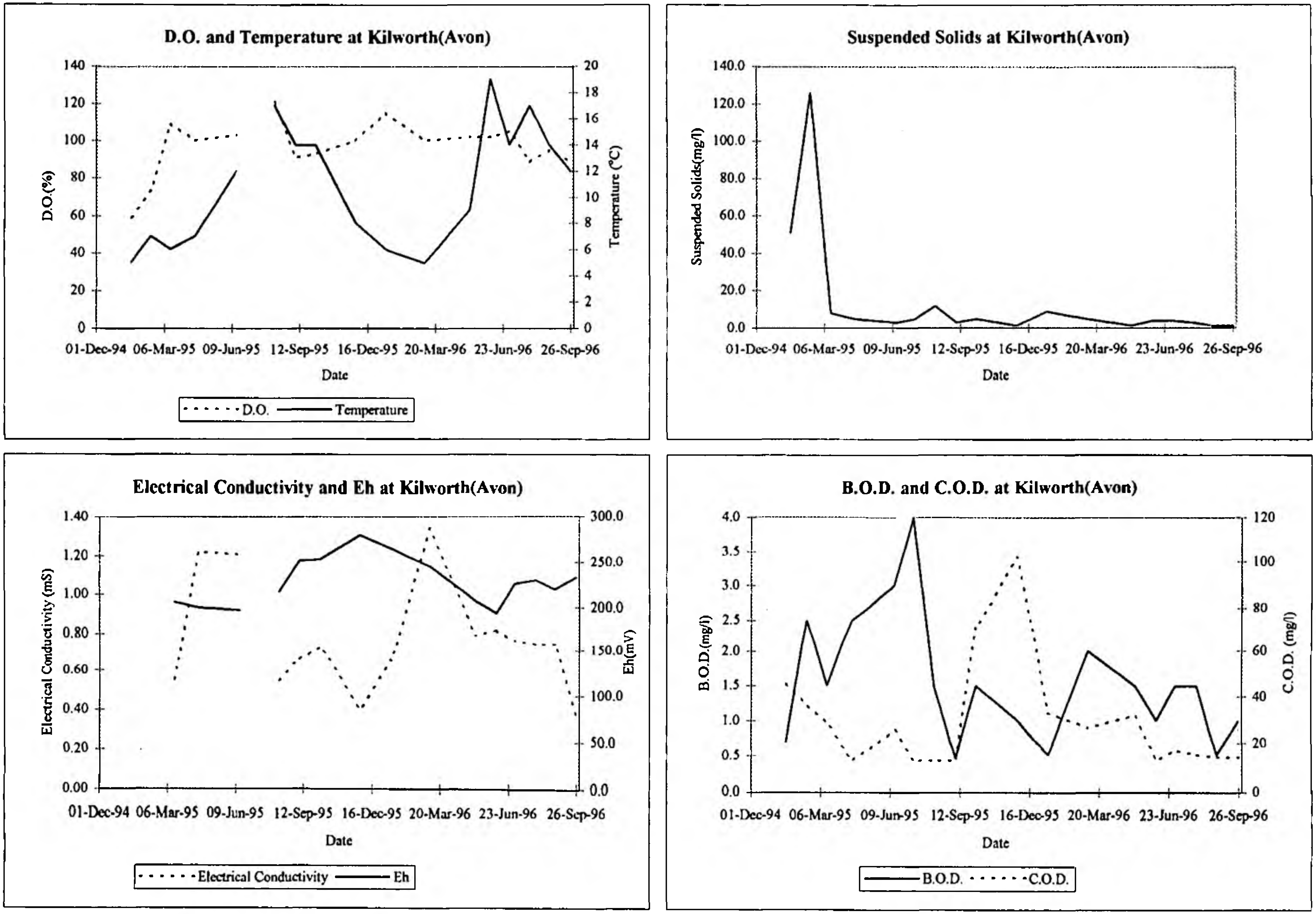
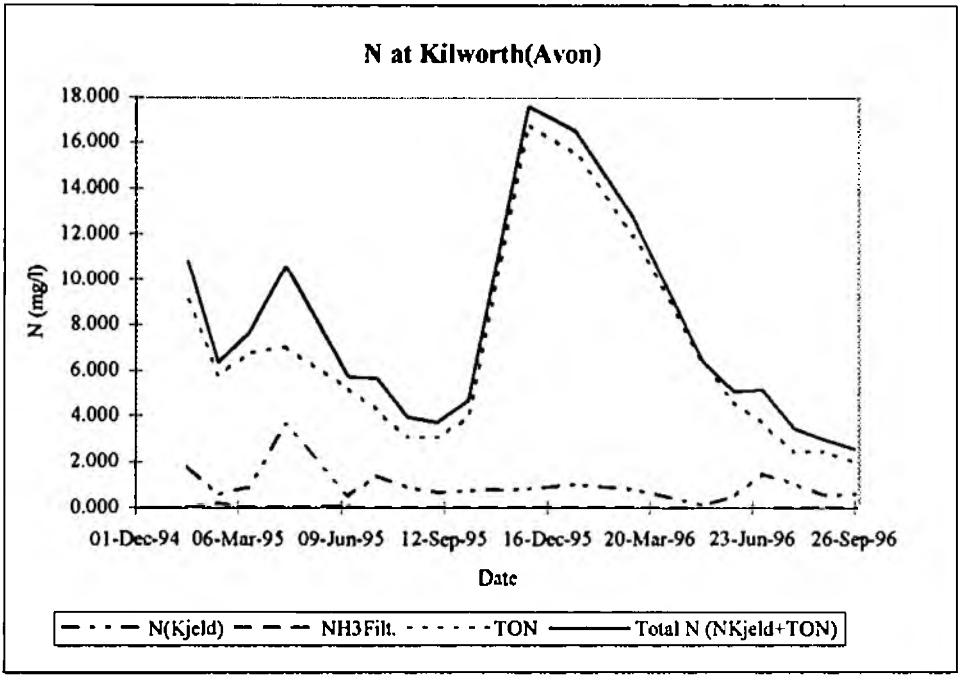
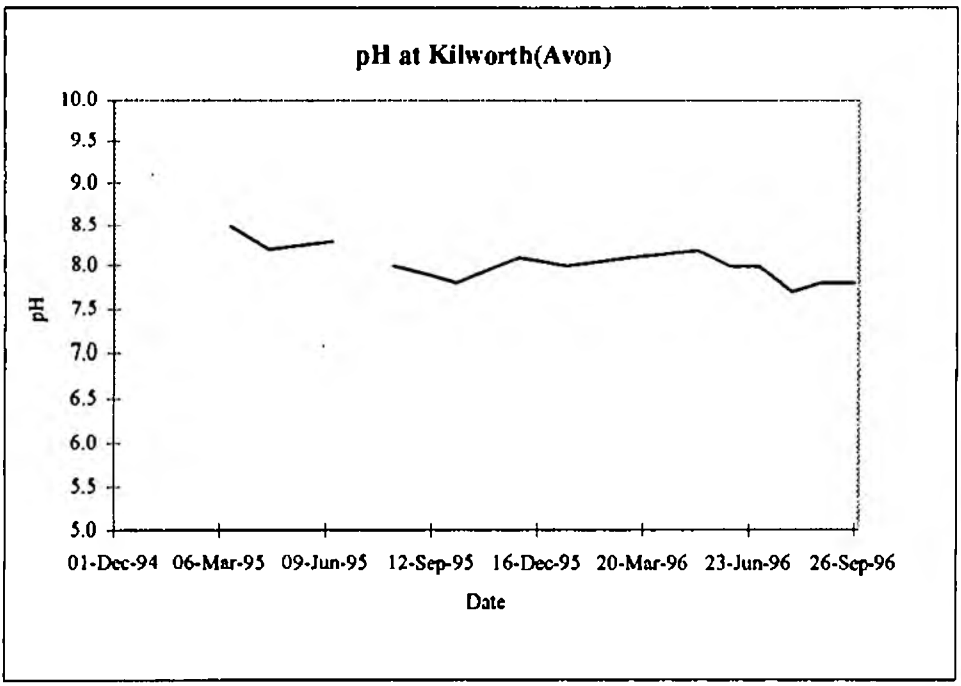
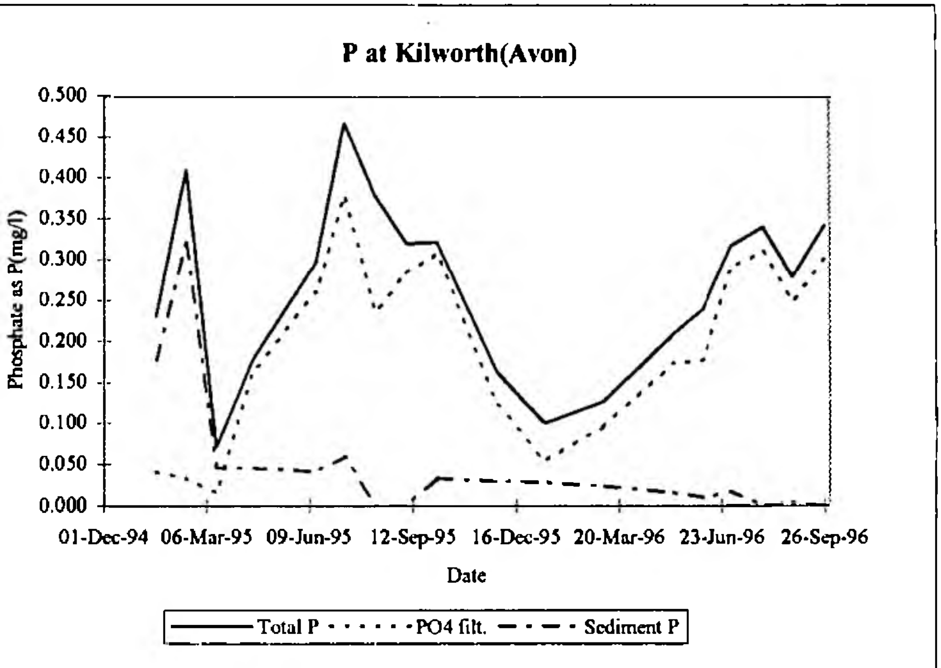


Figure 14 Seasonal trends in water quality at Kilworth


N at Kilworth(Avon)
18.000
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)


pH at Kilworth(Avon)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date



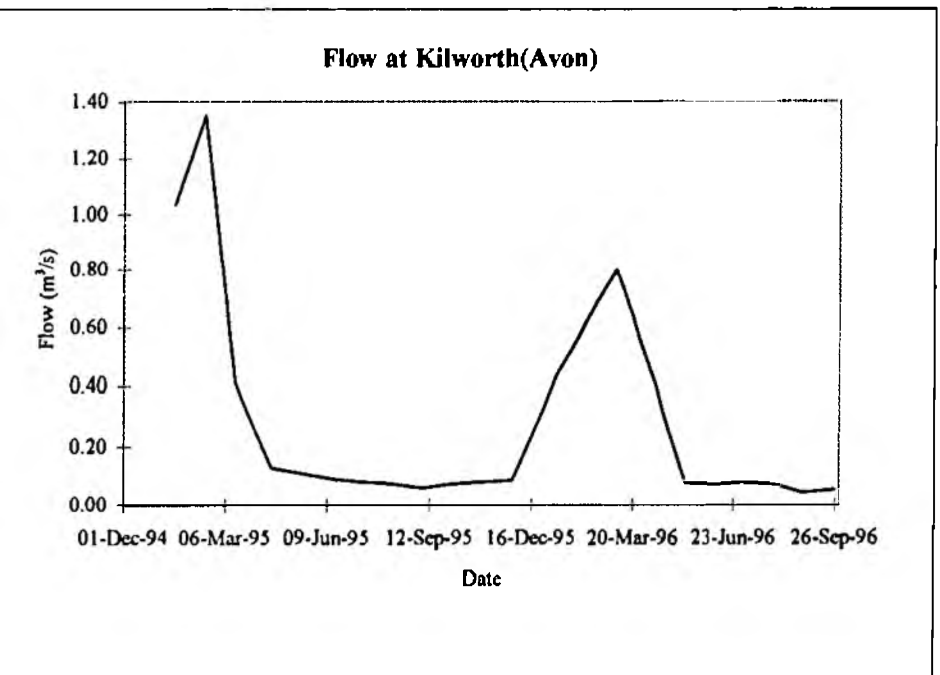


Figure 14 cont.

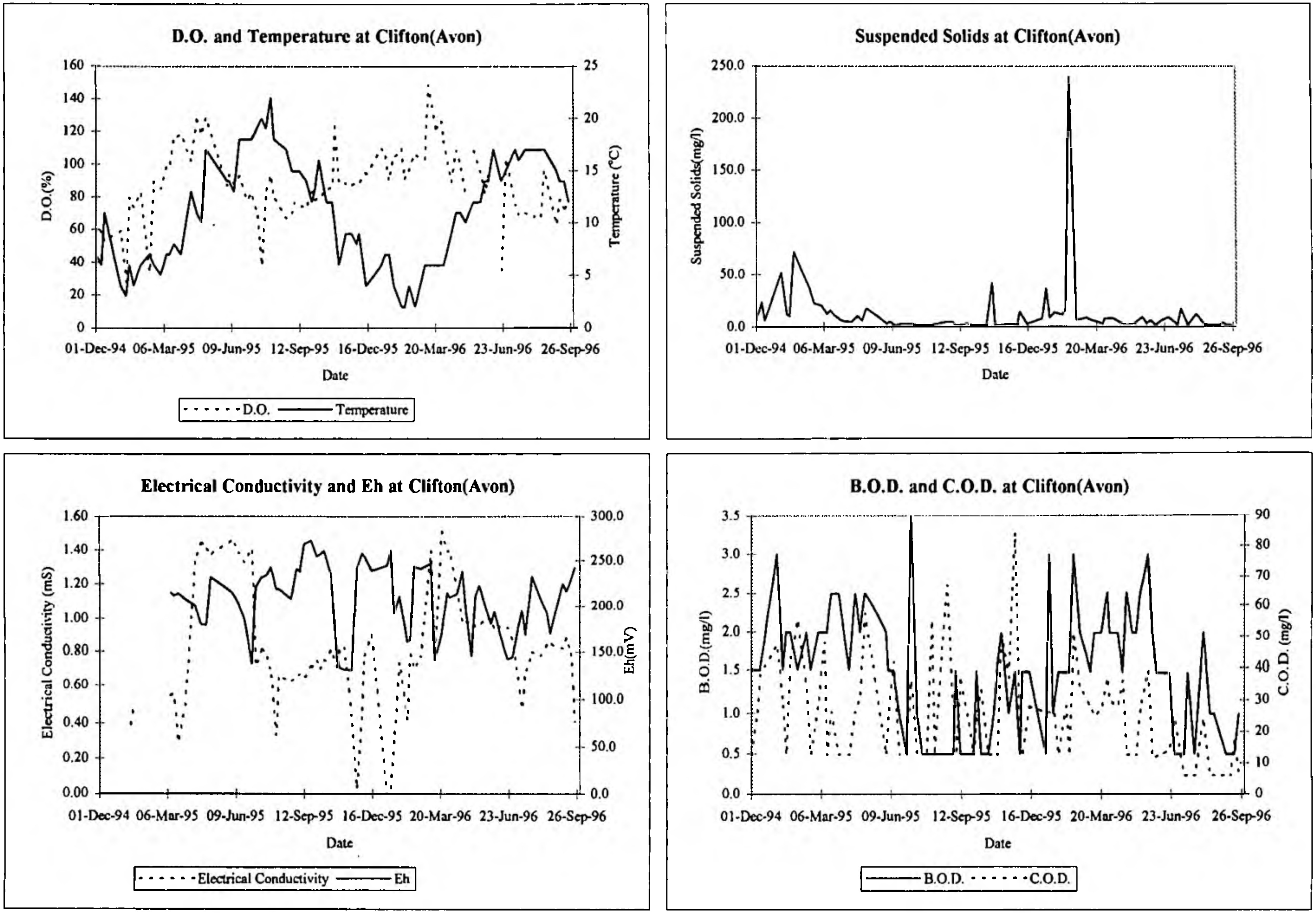
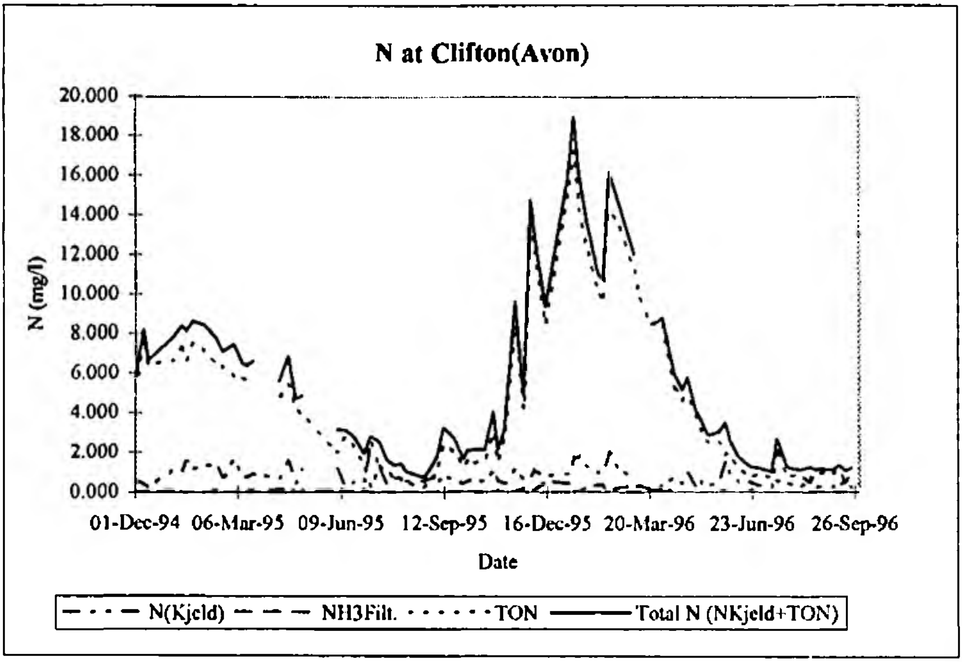
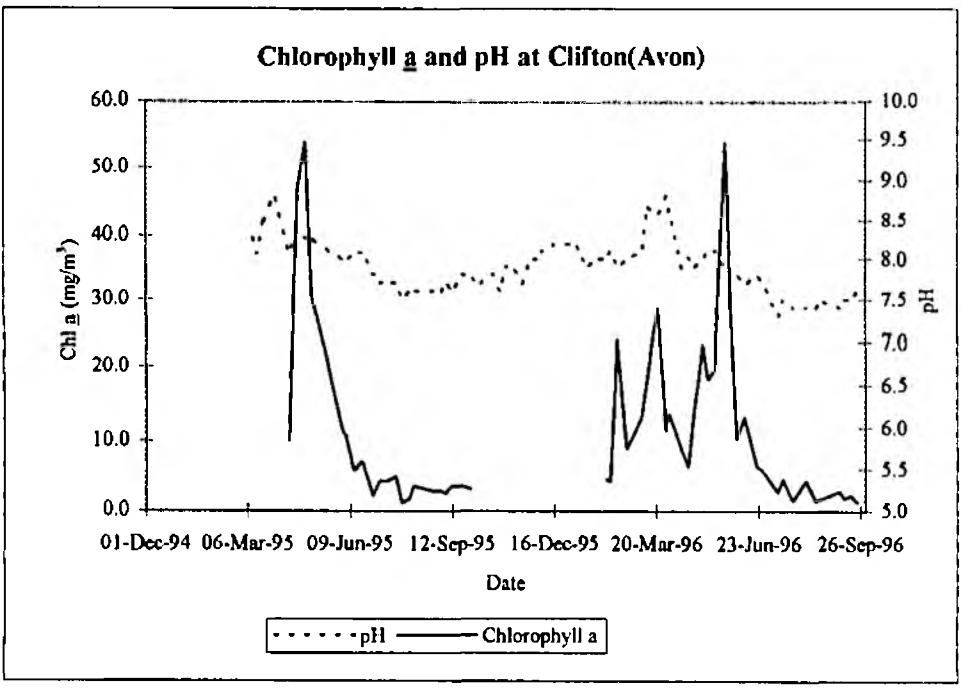
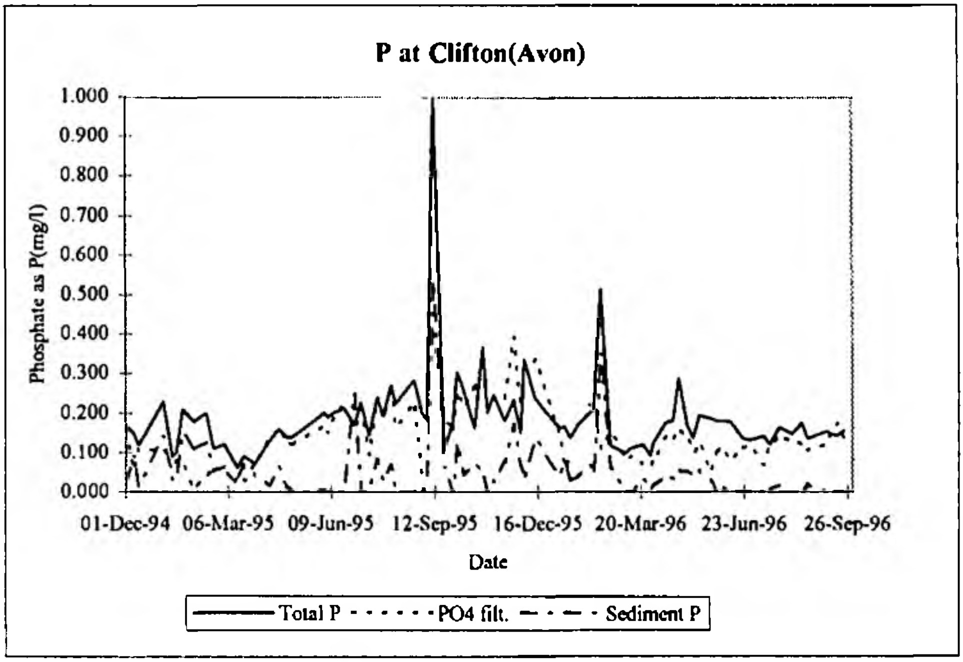


Figure 15 Seasonal trends in water quality at Clifton


N at Clifton(Avon)
20.000
18.000
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)


Chlorophyll a and pH at Clifton(Avon)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Chl a (mg/m³)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
pH
Chlorophyll a



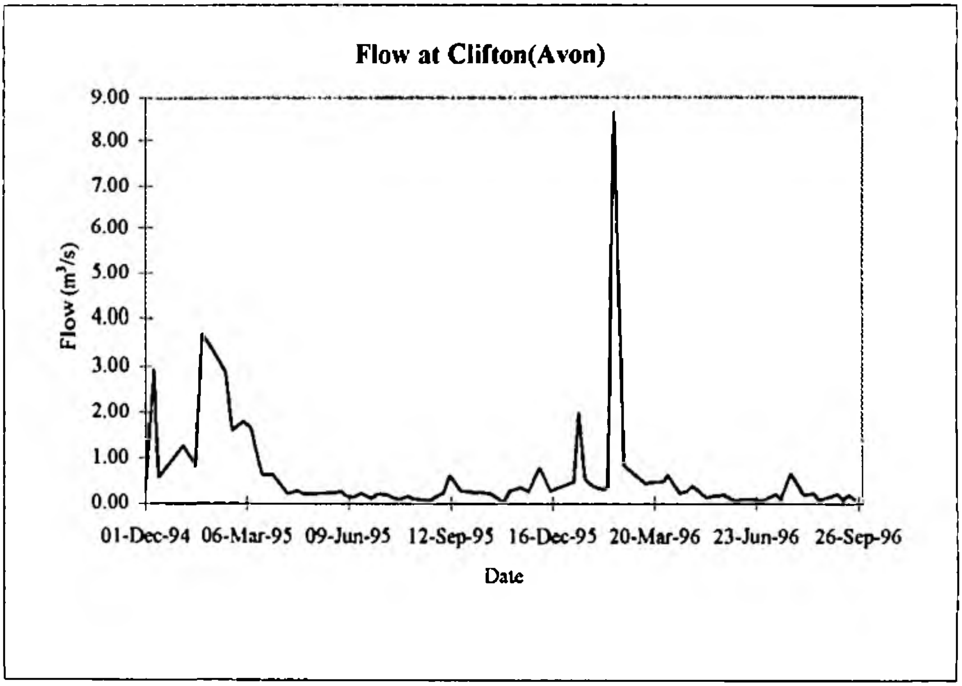
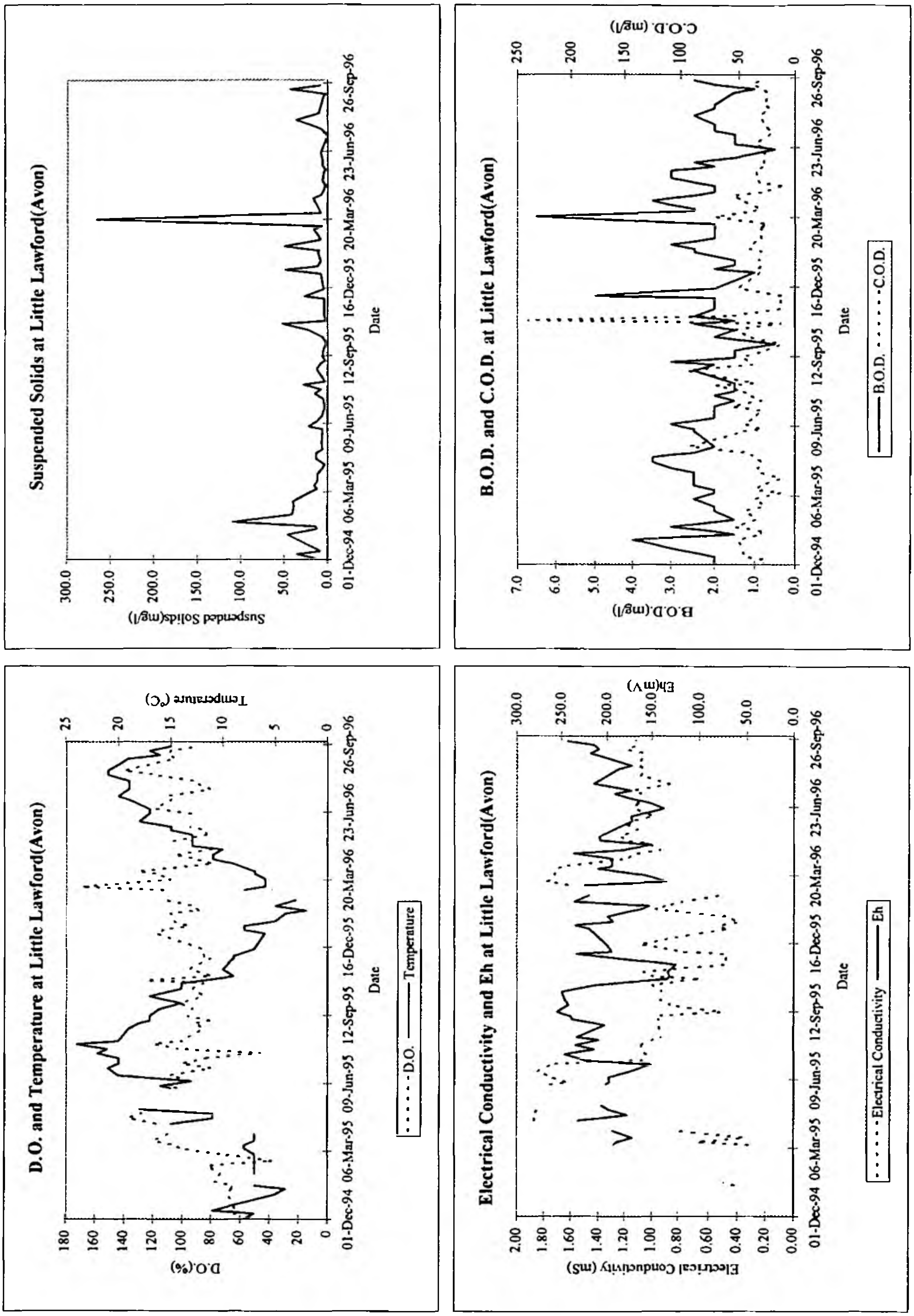
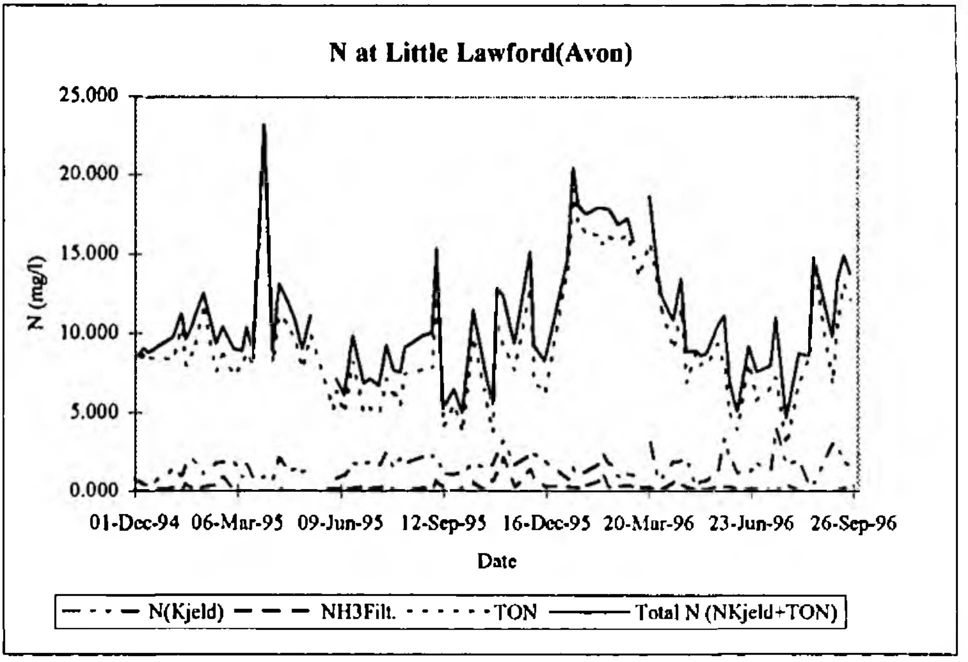


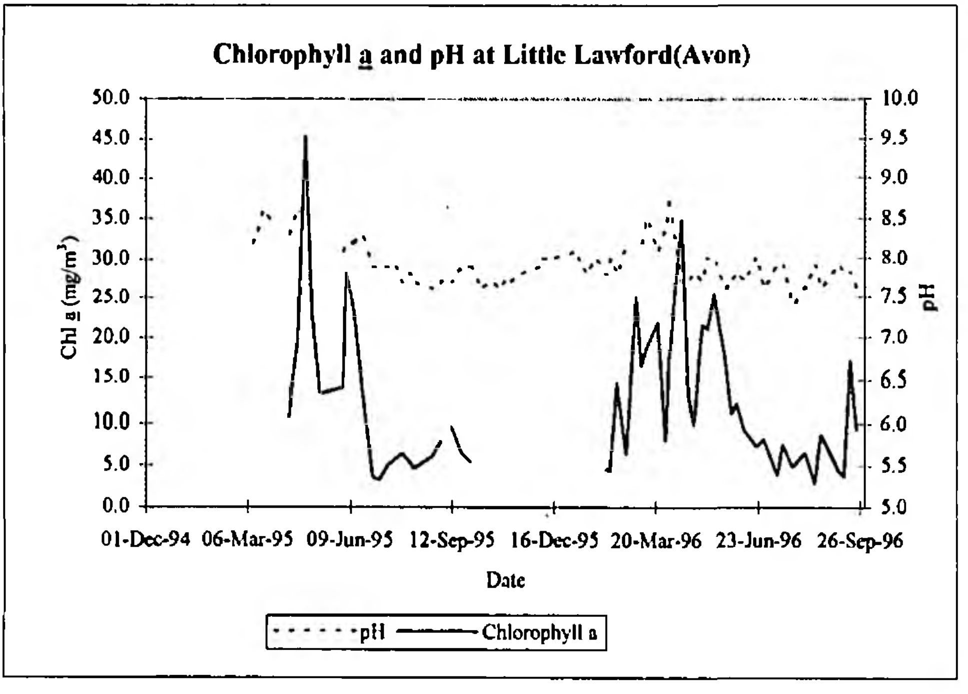
Figure 15 cont.

Figure 16 Seasonal trends in water quality at Little Lawford

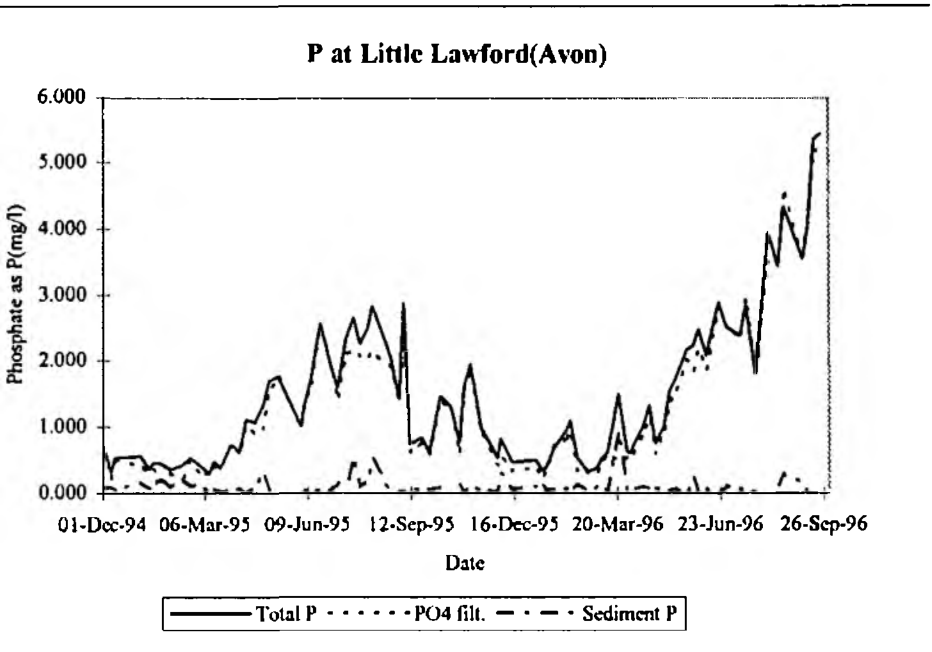




N at Little Lawford(Avon)
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)



Chlorophyll a and pH at Little Lawford(Avon)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Chl a (mg/m3)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
pH
Chlorophyll a



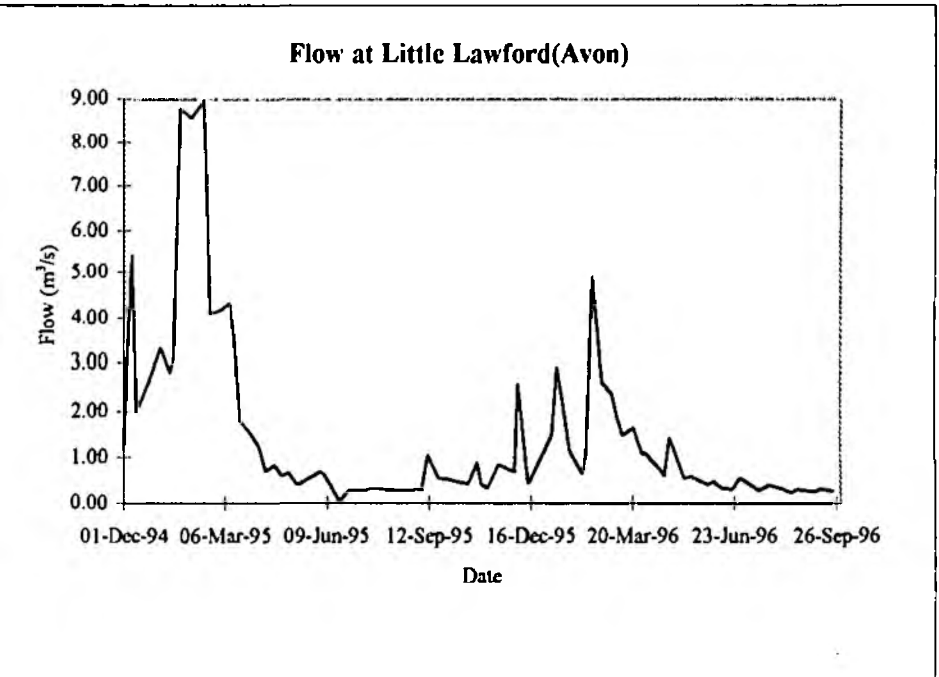
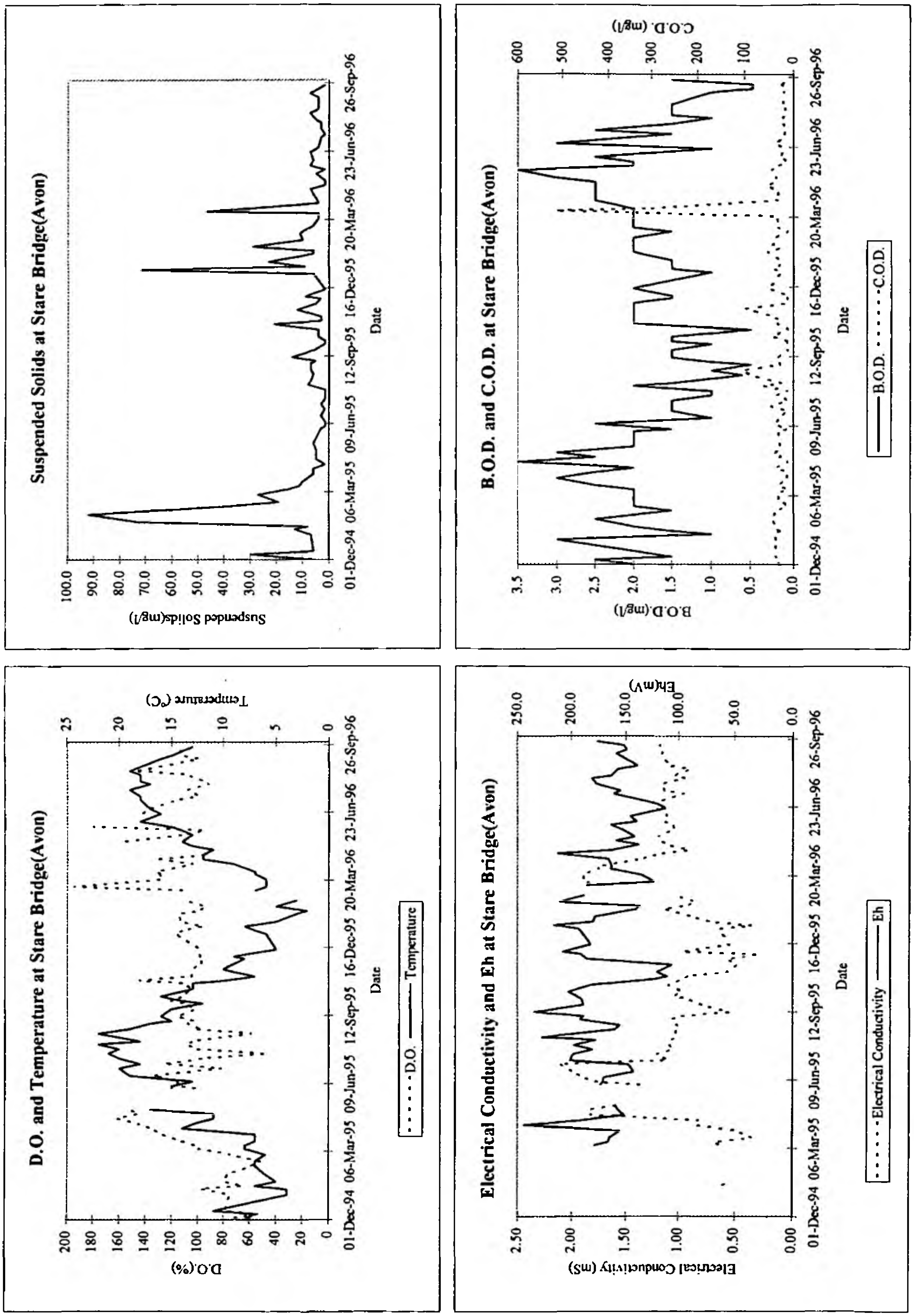
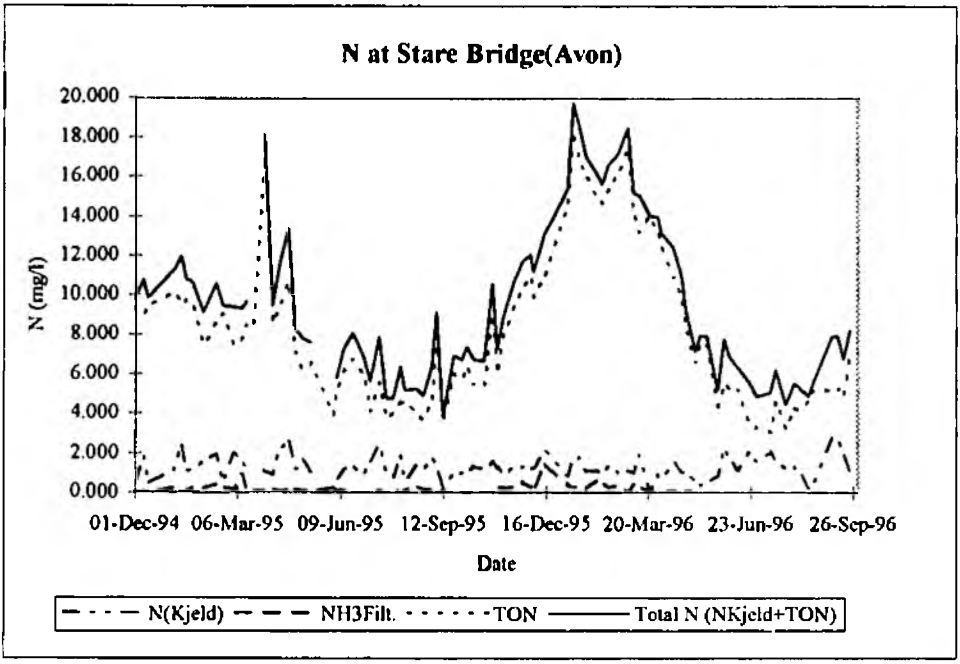


Figure 16 cont.

Figure 17 Seasonal trends in water quality at Stare Bridge




N at Stare Bridge(Avon)
20.000
18.000
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
N (mg/l)
01-Dec-94 06-Mar-95 09-Jun-95 12-Sep-95 16-Dec-95 20-Mar-96 23-Jun-96 26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)

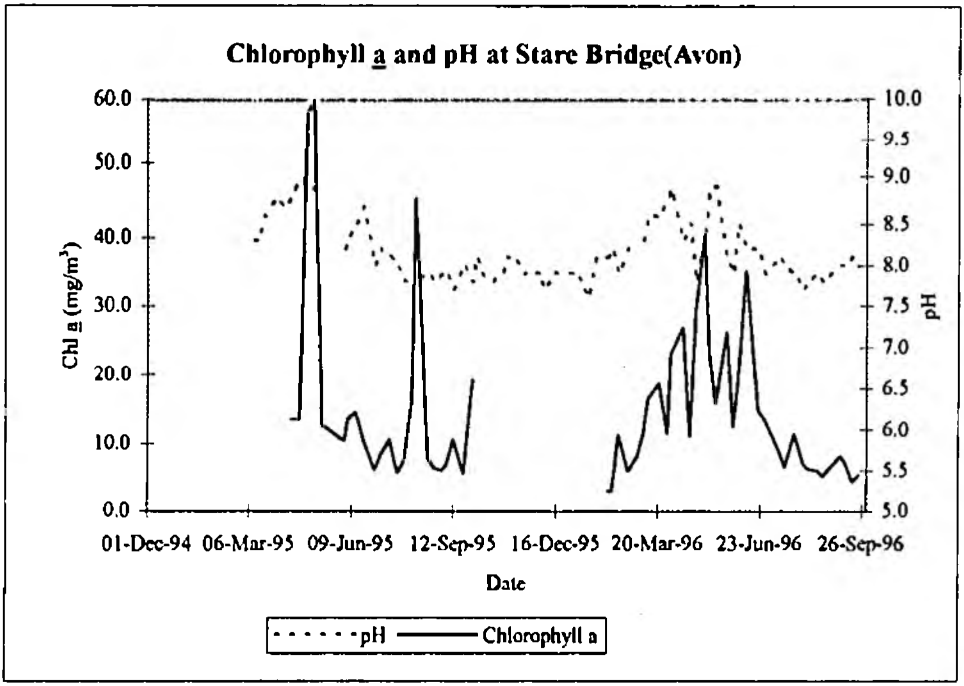
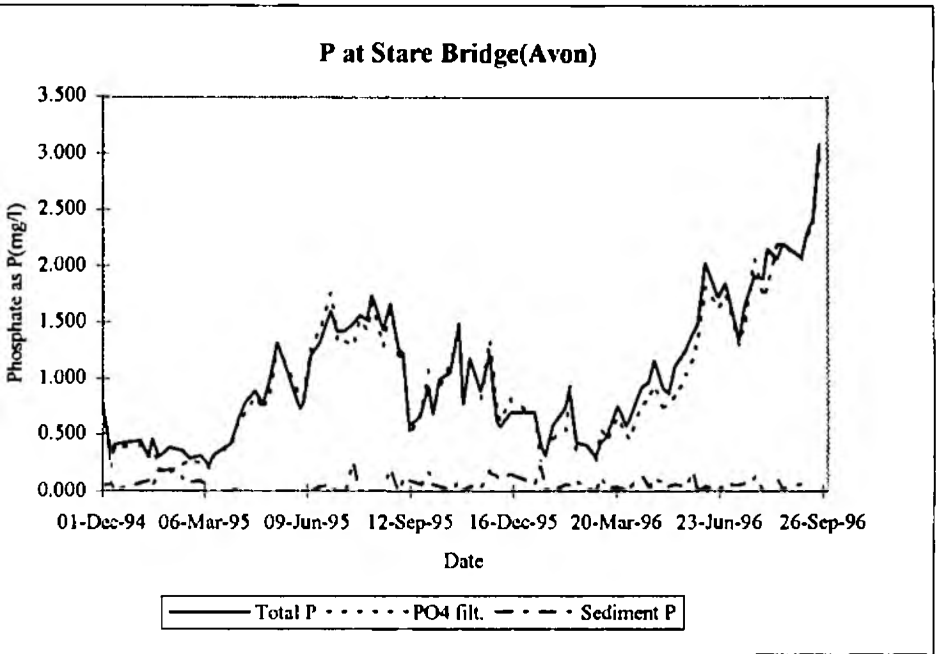

Chlorophyll a and pH at Stare Bridge(Avon)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Chl a (mg/m³)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94 06-Mar-95 09-Jun-95 12-Sep-95 16-Dec-95 20-Mar-96 23-Jun-96 26-Sep-96
Date
pH
Chlorophyll a

Figure 17 cont.



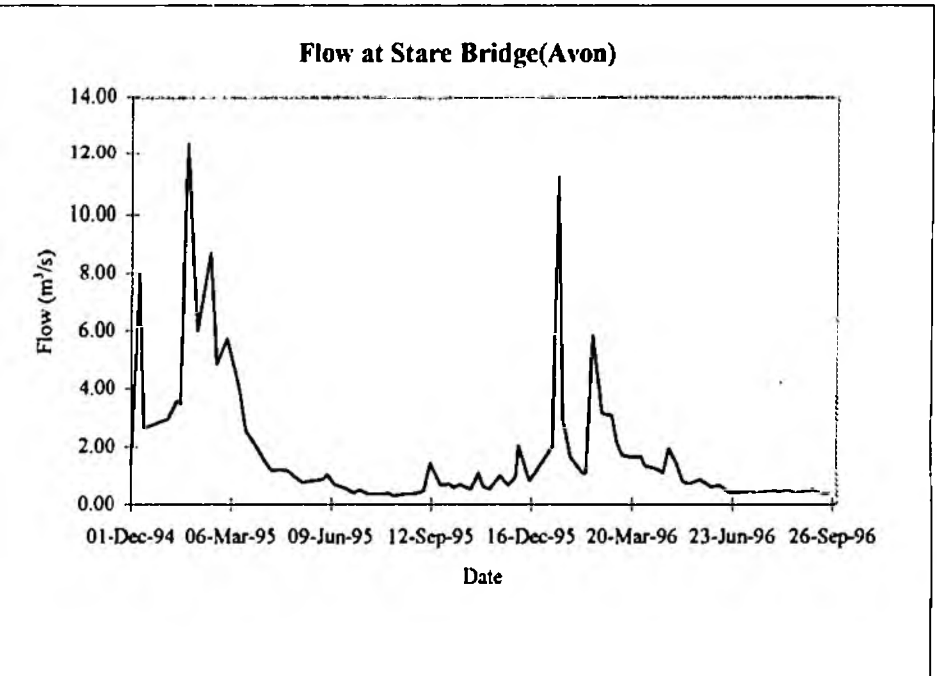
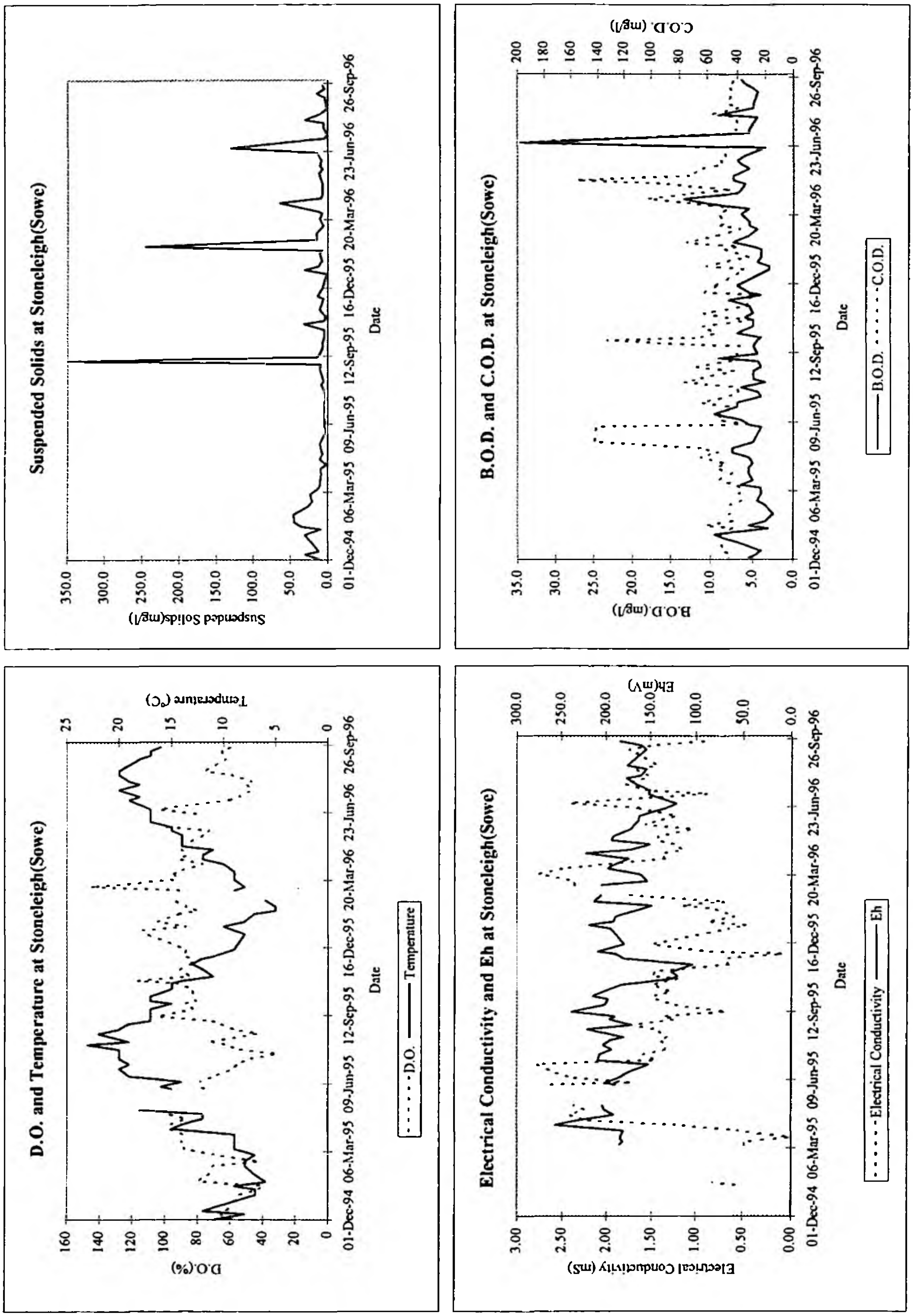
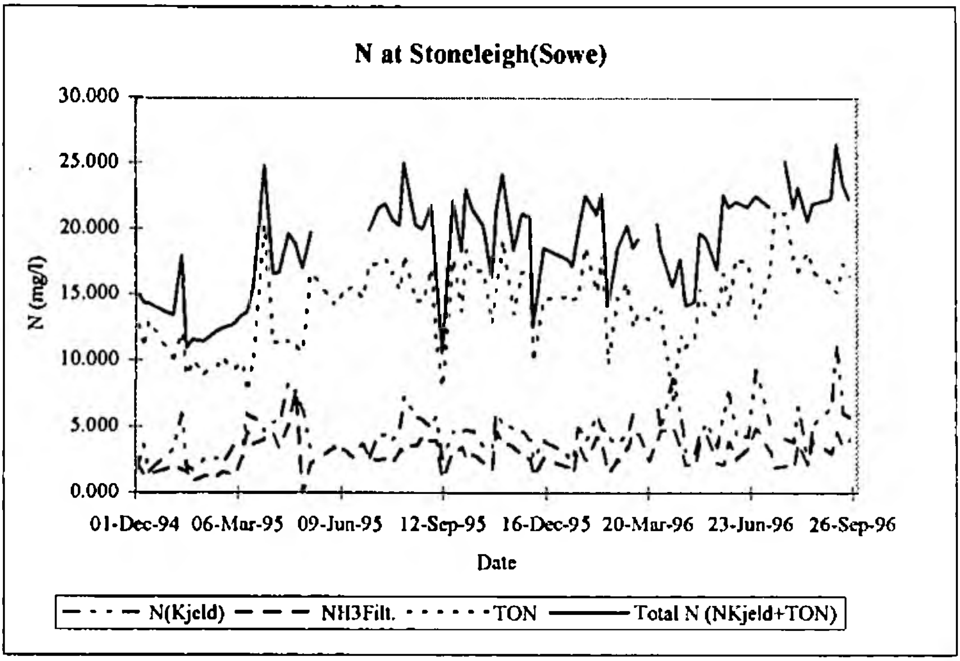


Figure 18 Seasonal trends in water quality at Stoneleigh




N at Stoneleigh(Sowe)
30.000
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)

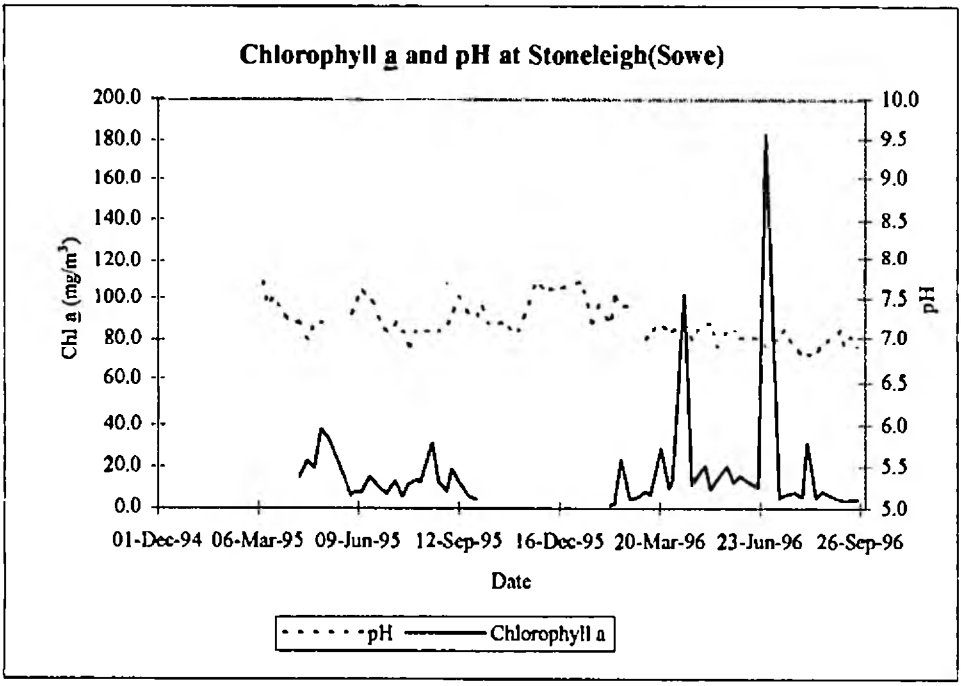
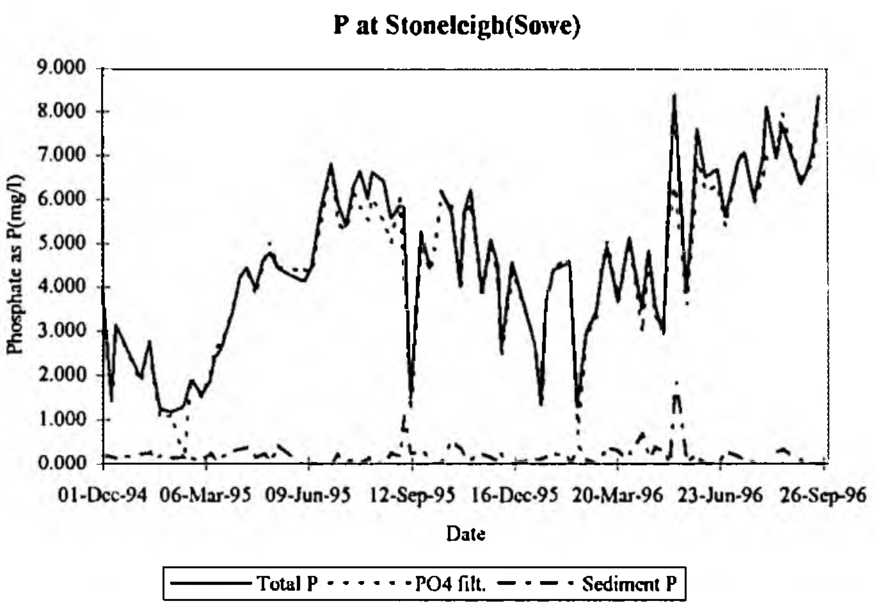
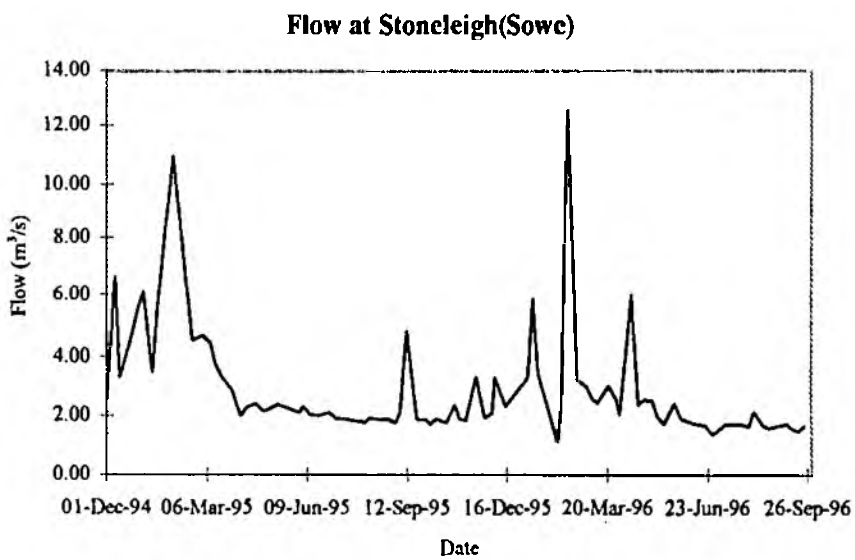

Chlorophyll a and pH at Stoneleigh(Sowe)
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Chl a (mg/m³)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
pH
Chlorophyll a

Figure 18 cont.





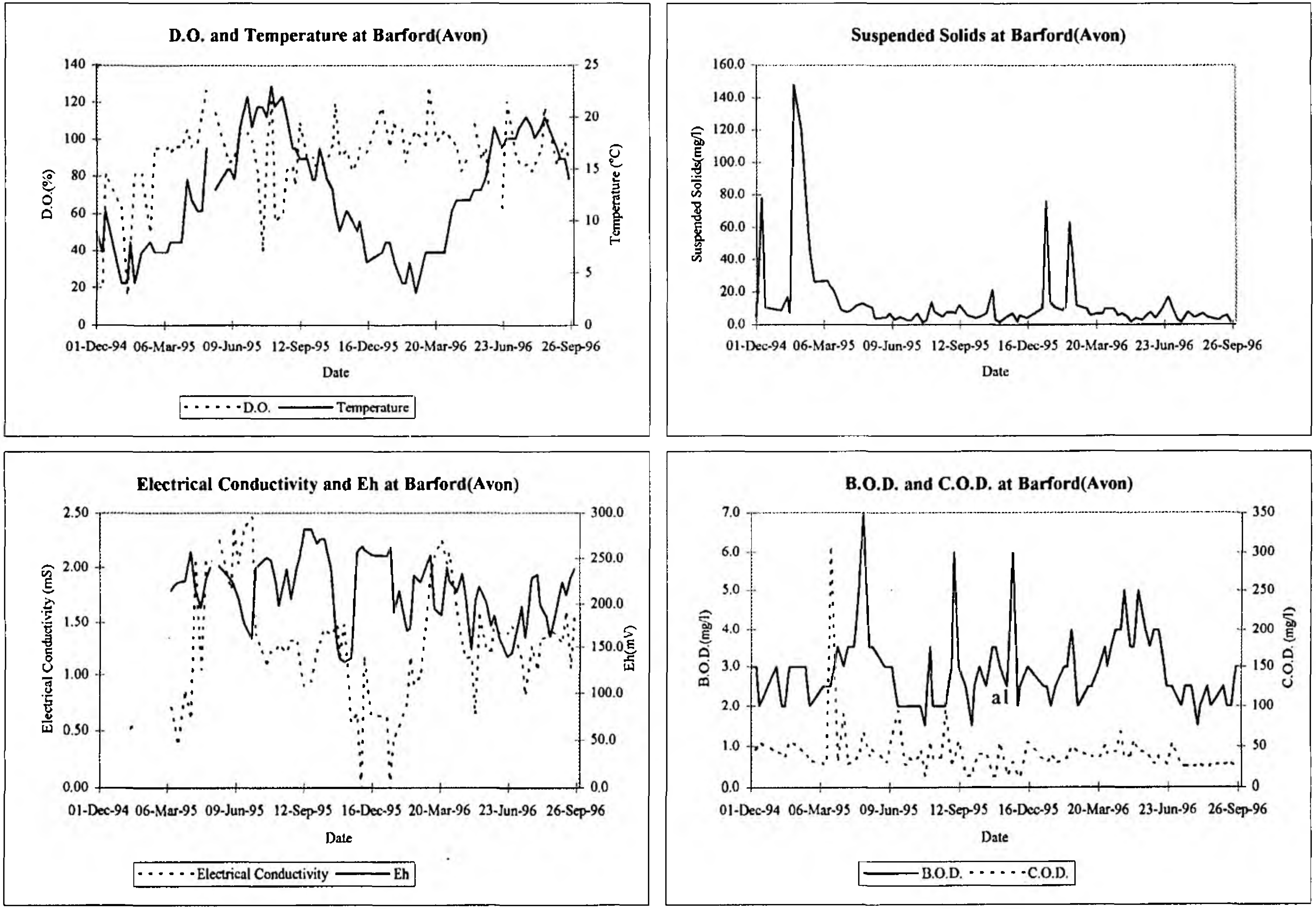
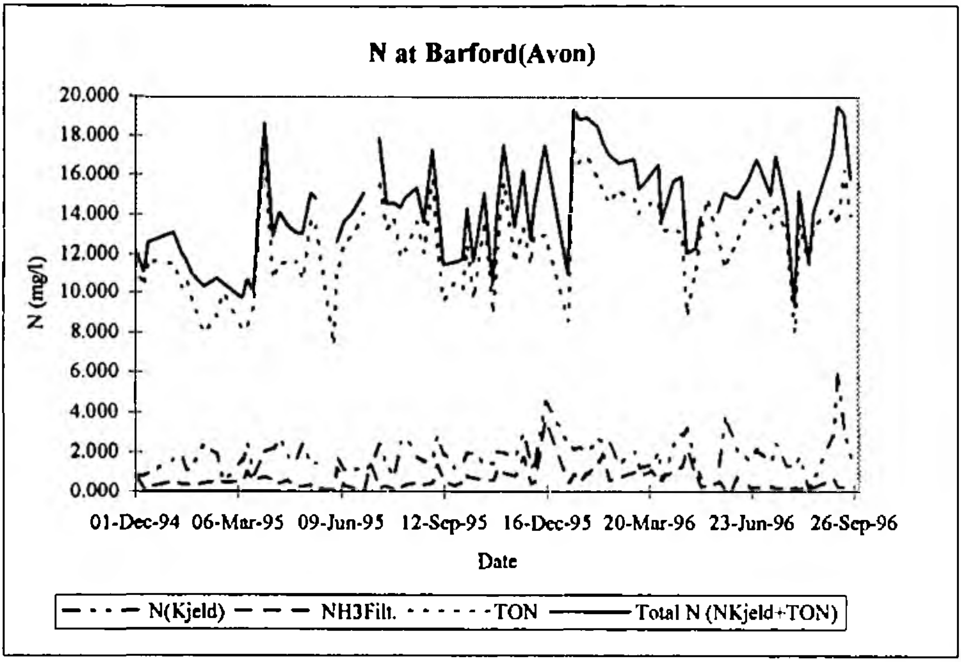
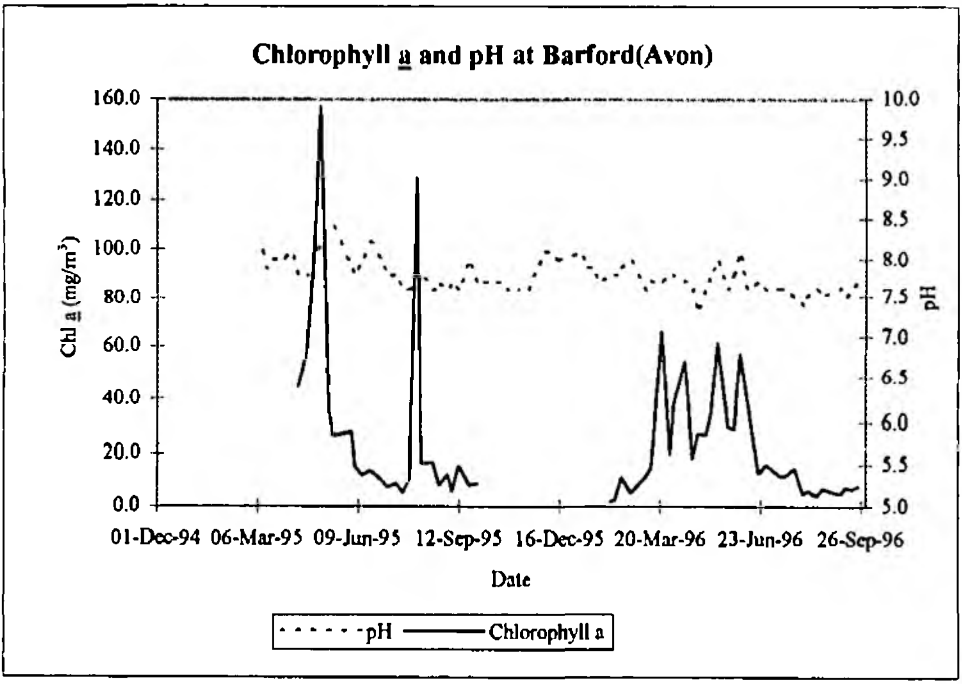


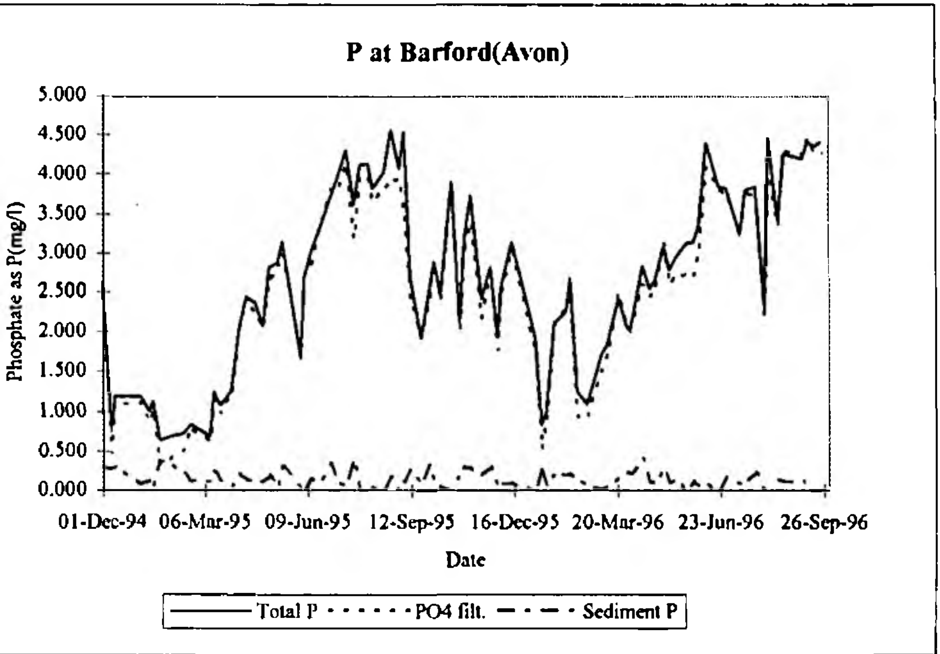
Figure 19 Seasonal trends in water quality at Barford



N at Barford(Avon)
20.000
18.000
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)



Chlorophyll a and pH at Barford(Avon)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Chl a (mg/m3)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
pH
Chlorophyll a



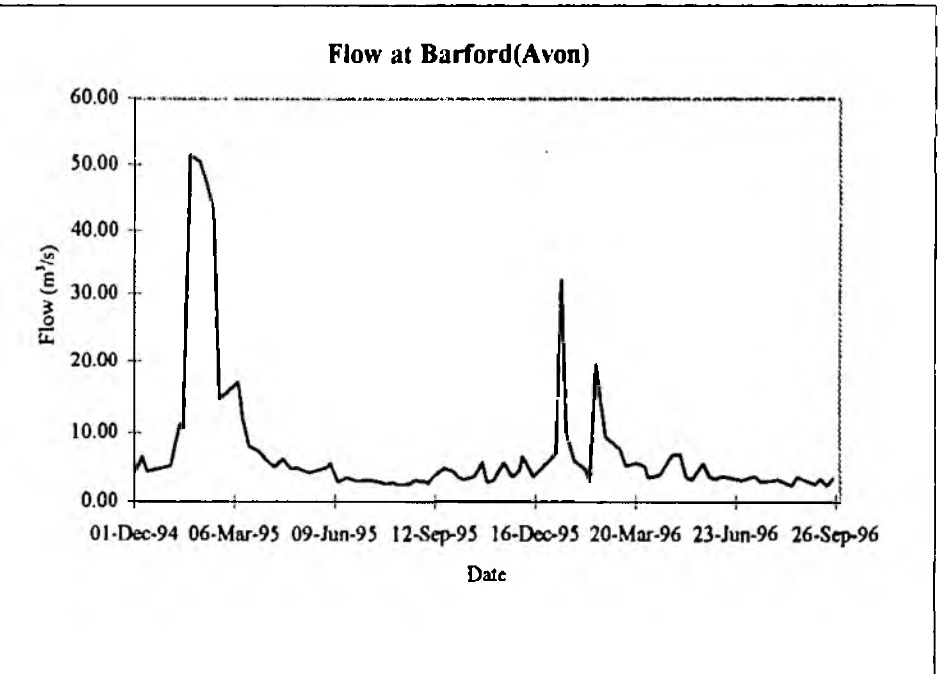


Figure 19 cont.

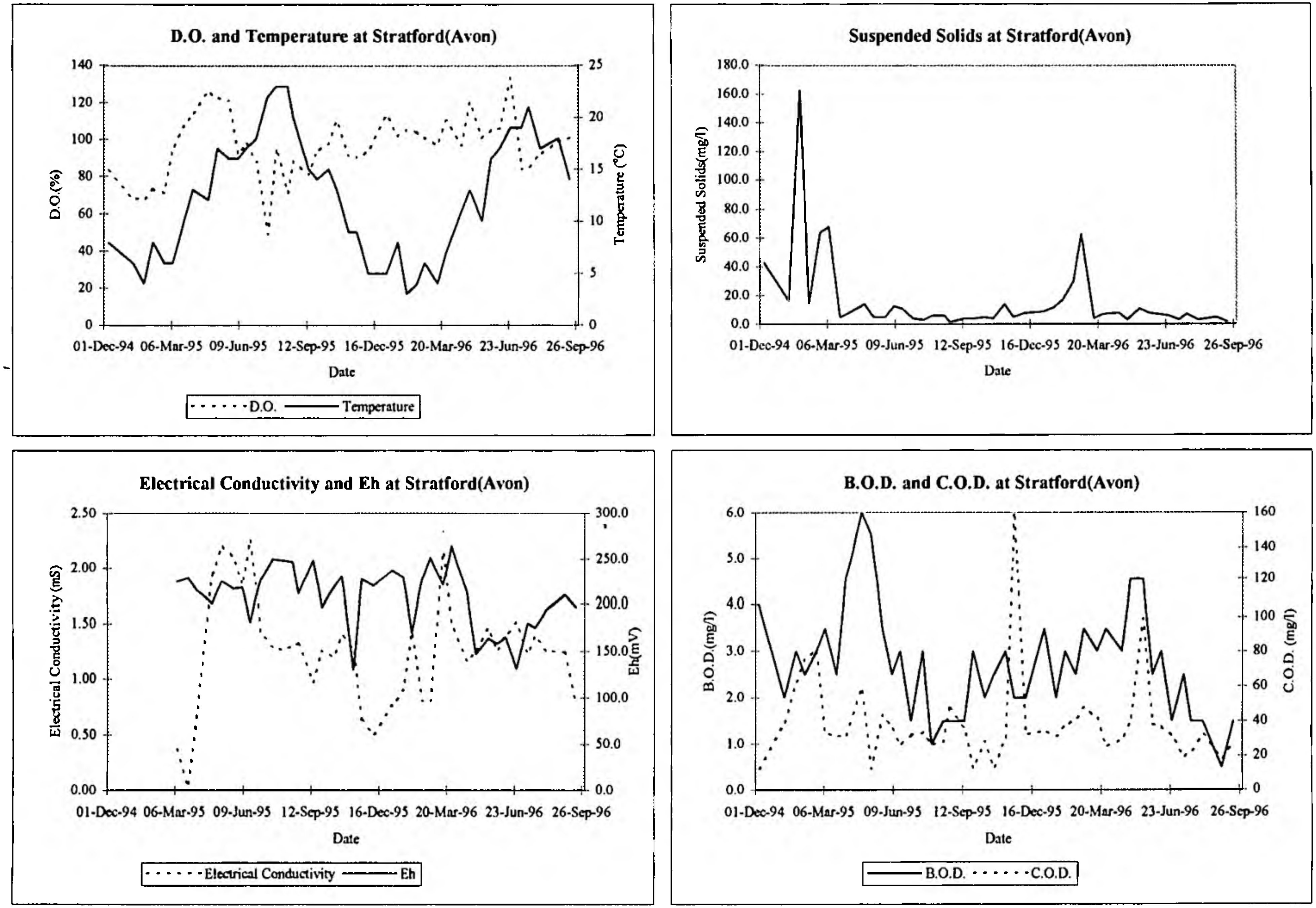
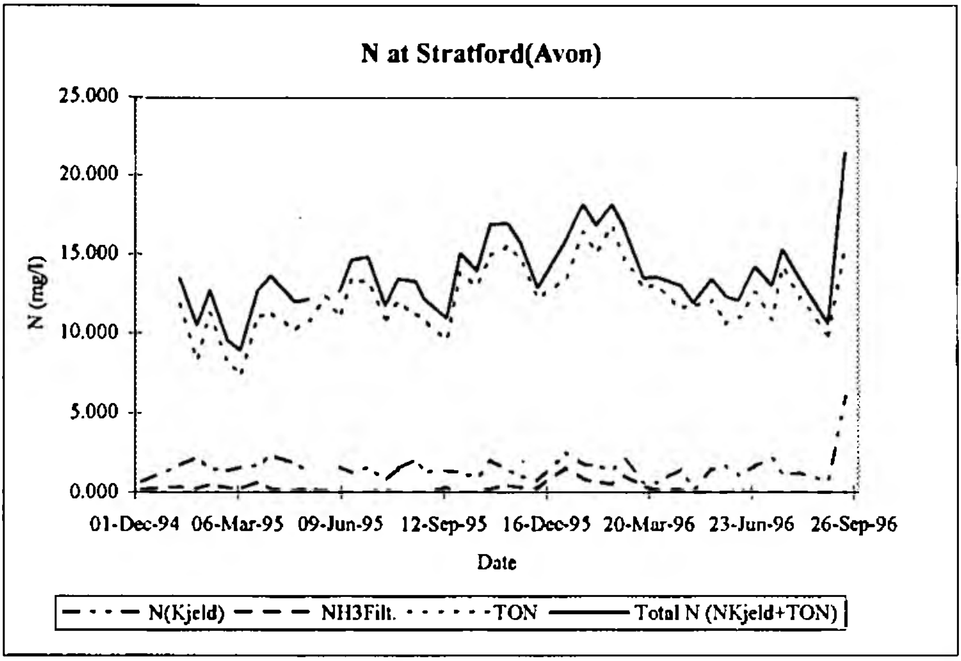
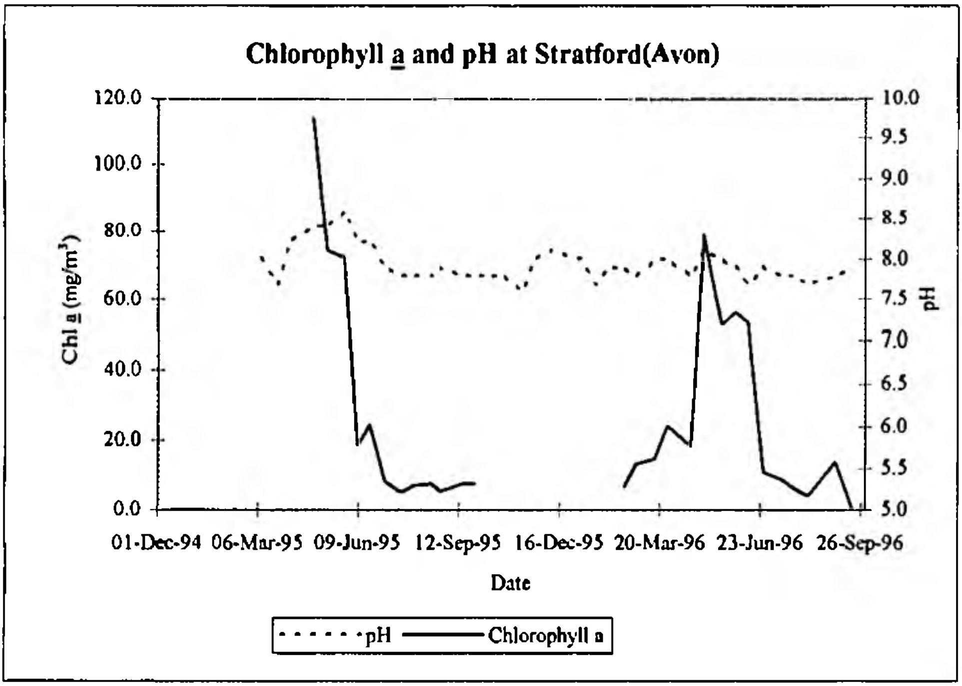
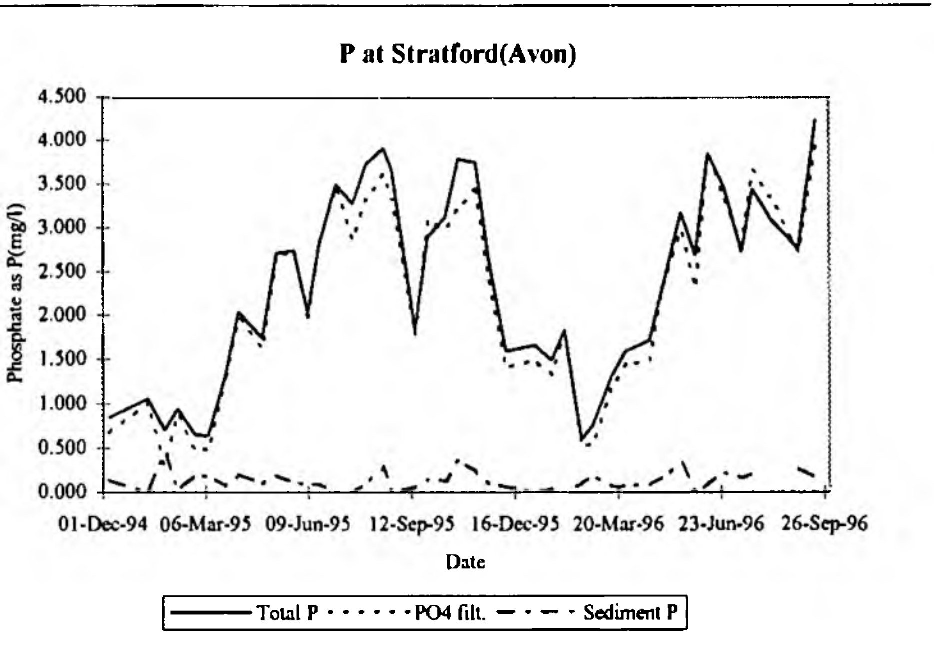


Figure 20 Seasonal trends in water quality at Stratford


N at Stratford(Avon)
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)


Chlorophyll a and pH at Stratford(Avon)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Chl a (mg/m³)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
pH
Chlorophyll a



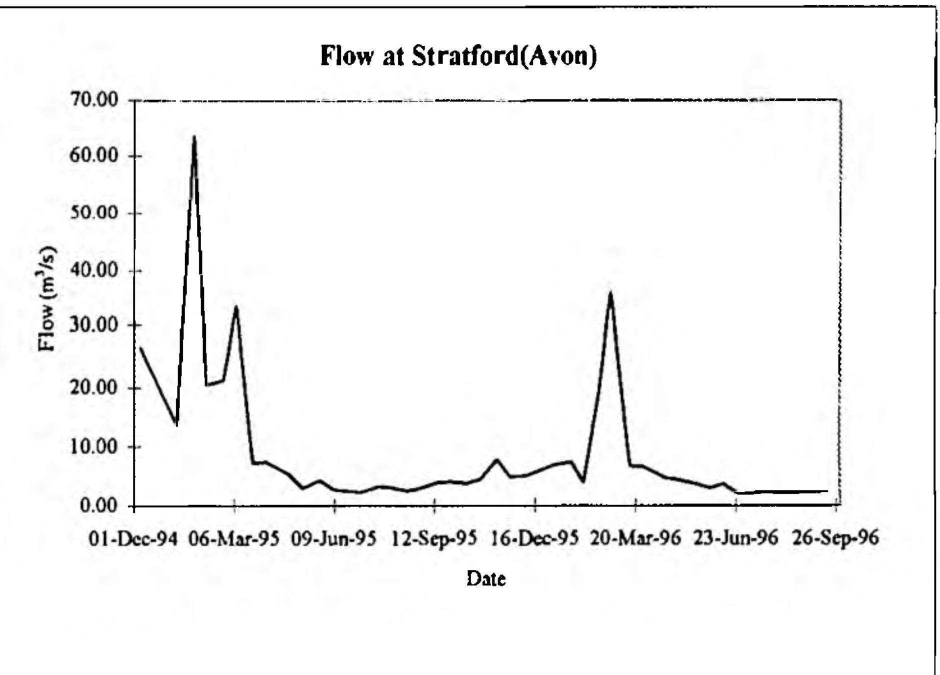
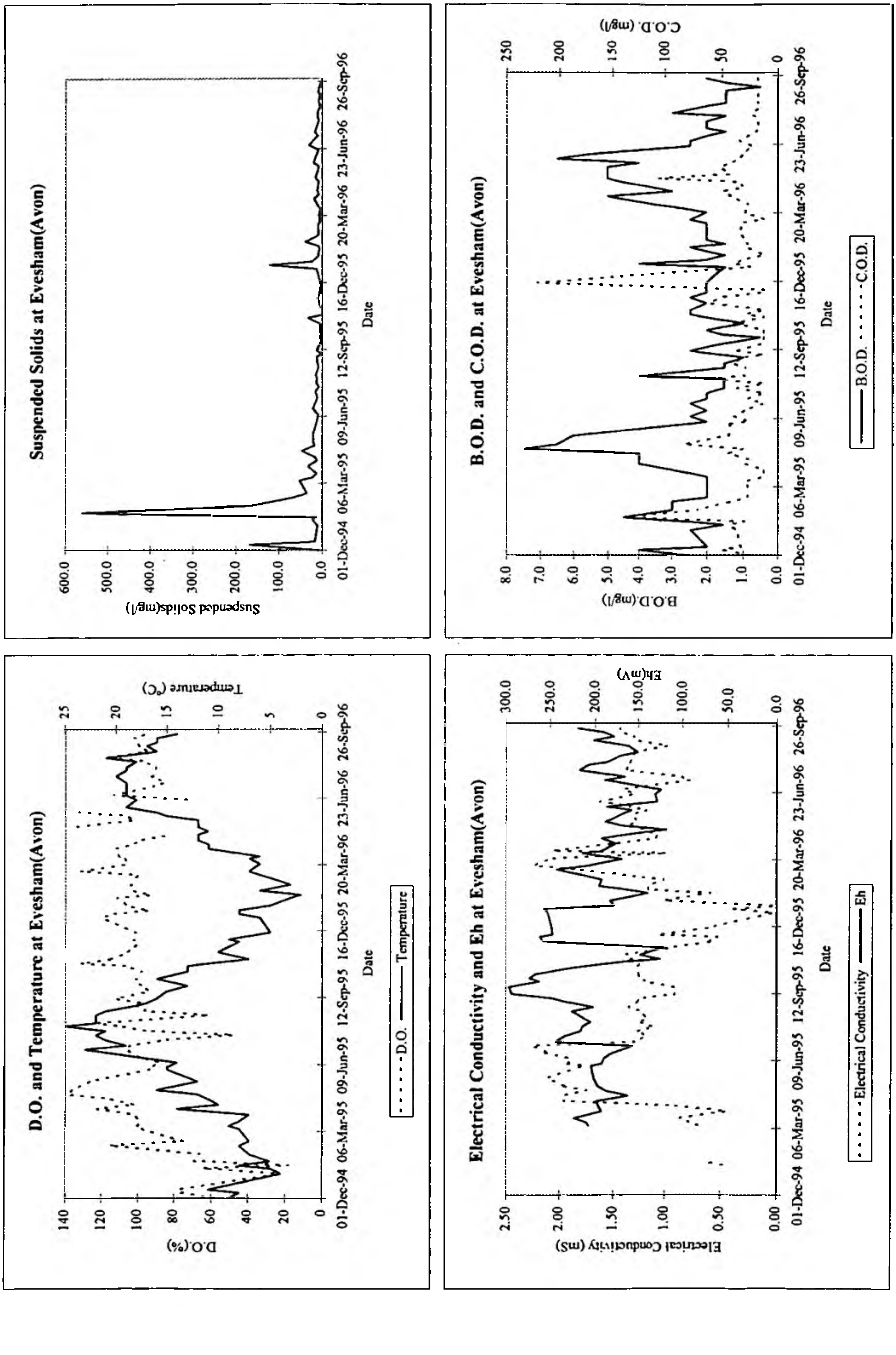
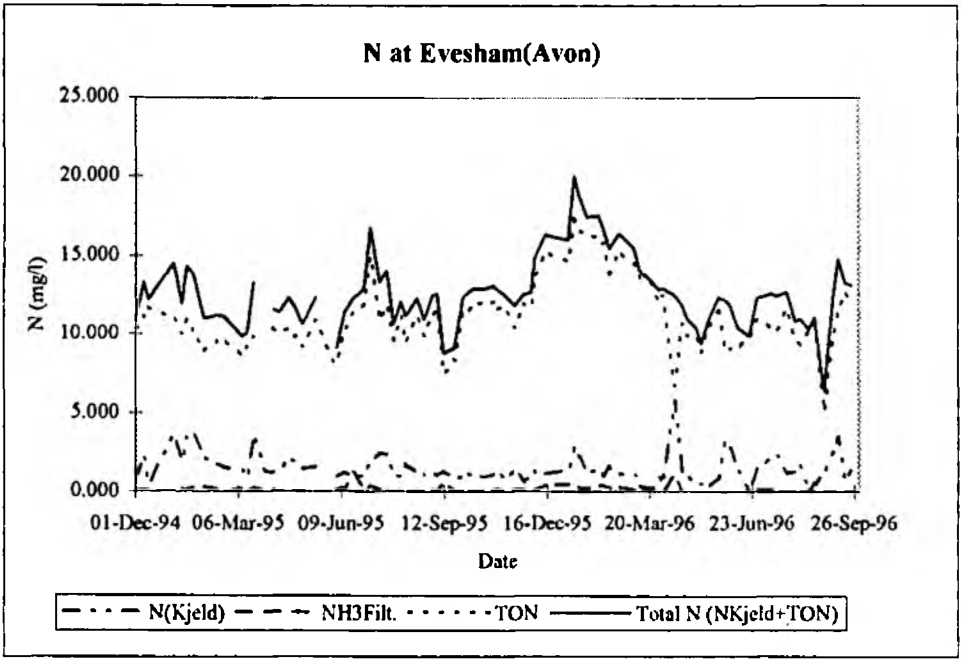


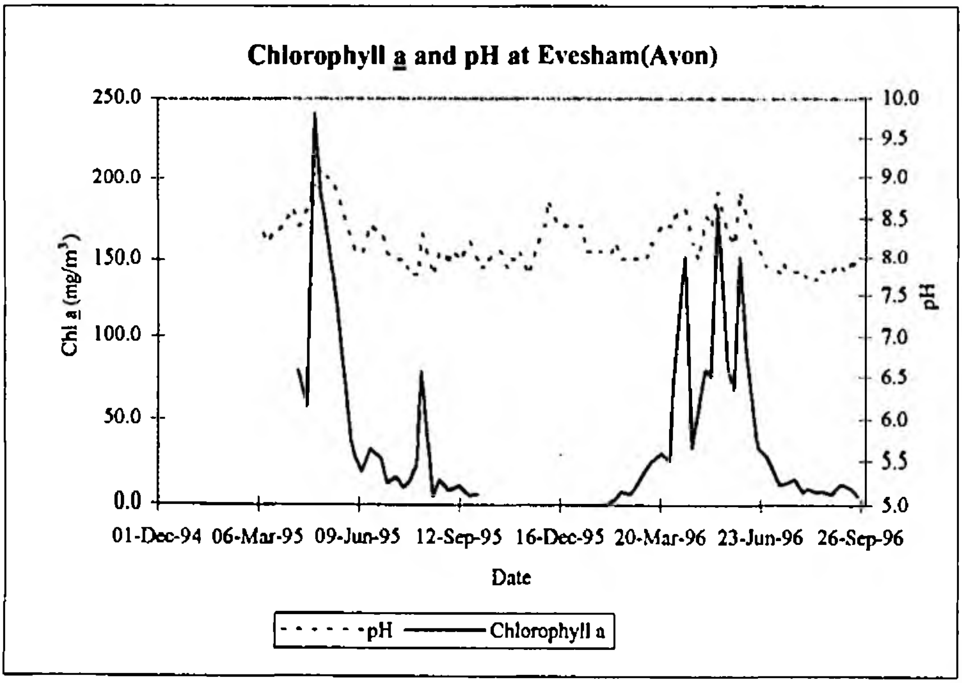
Figure 20 cont.

Figure 21 Seasonal trends in water quality at Evesham

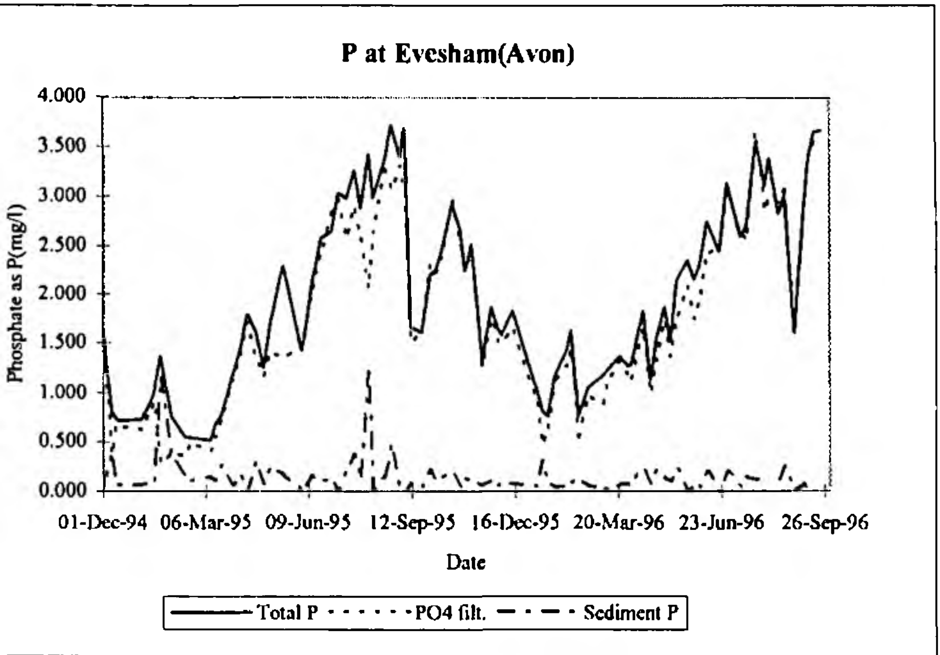




N at Evesham(Avon)
25.000
20.000
15.000
10.000
5.000
0.000
N (mg/l)
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
N(Kjeld)
NH3Filt.
TON
Total N (NKjeld+TON)



Chlorophyll a and pH at Evesham(Avon)
250.0
200.0
150.0
100.0
50.0
0.0
Chl a (mg/m³)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
01-Dec-94
06-Mar-95
09-Jun-95
12-Sep-95
16-Dec-95
20-Mar-96
23-Jun-96
26-Sep-96
Date
pH
Chlorophyll a



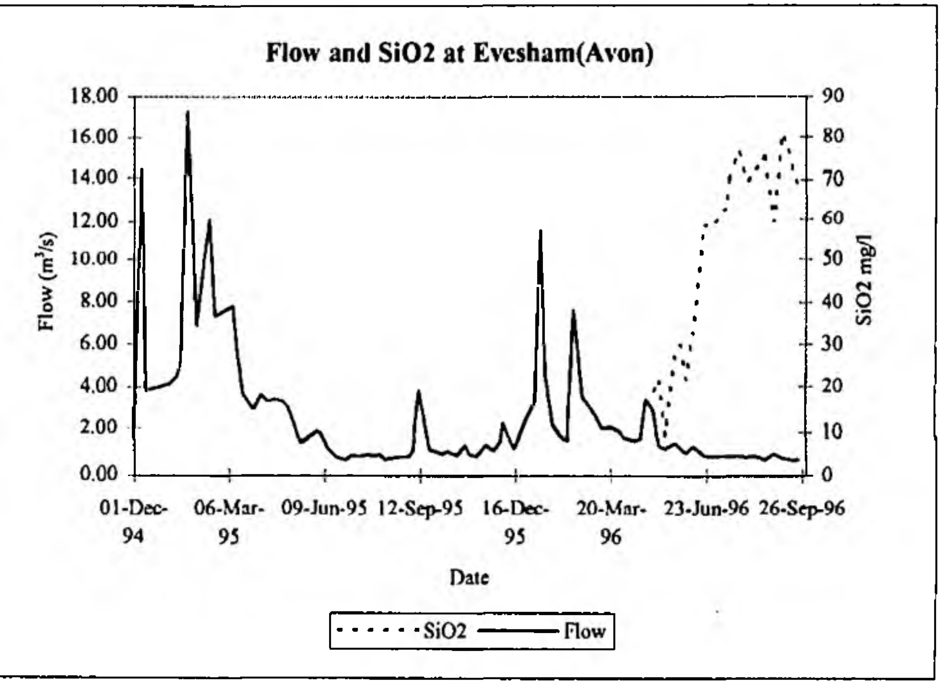


Figure 21 cont.

5.4 Downstream trends in concentration

1. Whilst the downstream river load calculations presented in section 7.5 below are dependent on the volume of water discharged, concentration data will more clearly reflect the general quality of the river Avon and the impact of STW effluents.

2. **Figures 22-34** summarise downstream trends in water quality at the 7 main gauging stations on the river Avon as boxplots. (Since most water quality data are not normally distributed, these plots are based on $\log_{10}$ transformations). The boxes contain 50% of the values between the 75th and 25th percentiles of the frequency distribution, whilst the whiskers extend to the maximum and minimum values excluding outliers and extremes. An outlier (o) is defined as a value more than 1.5 box lengths away from the box and an extreme value (*) as more than 3 box lengths away from the box. The line across the box indicates the median value of the data set.

3. Trends in N and P loads through the Avon system (see section 7) are generally mirrored by changes in concentration data. **Figures 22-27** show downstream trends in N and P concentrations in different forms.

4. TON and PO_4 concentrations appear to decrease slightly between Kilworth and Clifton although the TON data at Clifton show greater variability than at Kilworth.

5. TON and PO_4 concentrations decrease slightly between Lawford and Stare Bridge although the differences are only statistically significant ($p < 0.05$, Mann-Whitney test on medians) for TON concentrations.

6. Major increases in TON and PO_4 concentrations are observed between Clifton and Lawford as a result of inputs from Rugby STW and again between Stare Bridge and Barford as a result of inputs from the Finham STW via the river Sowe. Both parameters decrease in concentration towards Evesham either as a result of dilution from cleaner tributaries or as a result of instream uptake and adsorption of nutrients.

7. Median TON concentrations exceed 11.3 mg/l ($\log_{10}$ value of 1.05) at Barford, Stratford and Evesham. The value of 11.3 mg/l is equivalent to 50 mg/l when N is expressed as nitrate(NO_3).

8. Similar downstream patterns are observed in NH_3 and kjeldahl N (KN) concentrations **(Figures 24 and 25)** and in Total N (TN) and Total P (TP) concentrations **(Figure 26 and 27)**. (Note that TP is determined on unfiltered samples (det code 084) and includes organic as well as inorganic phosphorus). There are statistically significant differences ($p < 0.05$, Mann-Whitney test on medians) between TN, TP, KN and NH_3 concentrations at Lawford and Stare Bridge showing that concentrations decrease downstream between these sampling sites. (The possible significance of these decreases in nutrient concentrations between Lawford and Stare Bridge are further discussed in section 10).

9. For the mainstream Avon gauging stations, median redox potential exceeds 150 mV ($\log_{10}$ value of 2.2) **(Figure 28)** and no single value falls below 100 mV. Lowest median values are recorded at the river monitoring station at Stare Bridge, median

values are ca 180 mV and minimum values approach 100 mV. Despite the influx of sewage effluent downstream of Lawford and Stare Bridge, median values indicate strong oxidation. There is no evidence from the available data to suggest that the river becomes subject to reducing conditions.

10. Median electrical conductivity values lie between 1.2 and 1.7 mS (1200 to 1700 µS) and generally increase in a downstream direction (**Figure 29**). Extreme values approach 3 mS (3000 µS) at Barford. As an index of total dissolved (ionised) salts, conductivities are relatively high in comparison with unpolluted rivers in the UK. The increase in conductivity downstream is a reflection of an overall increase in total dissolved solids which may in part be attributed to the effects of evaporation and in part to the input of dissolved salts from STW inputs and weathering processes.

11. Median BOD concentrations for all seven sites ranges from ca. 1.5 to 3.0 mg/l (**Figure 30**). Highest extreme values, approaching 8 mg/l, are to be found in mainstream sites below the confluence with the Sowe at Barford, Stratford and Evesham. Median BOD levels decrease between Barford and Evesham.

12. Median COD levels remain fairly constant throughout the Avon catchment (**Figure 31**). Three extreme values exceed 300 mg/l at Stare Bridge and Barford.

13. Suspended solids concentrations generally increase downstream, a pattern which is apparently reversed between Lawford and Stare Bridge (**Figure 32**). There is a statistically significant difference between the suspended sediment concentrations recorded at these two sites($p<0.05$, Mann-Whitney test on medians).

14. **Figure 33** plots the downstream trends in chlorophyll a concentration and follow a pattern of increasing concentration downstream as reported for other UK rivers (c.f. Reynolds, 1995 and section 10).

15. Particulate-P (PP) concentrations at 6 river gauging stations are given as boxplots in **Figure 34** (Occasions where suspended sediment concentration lies below the minimum detection limit of 3 mg/l have been excluded from the data set). These are presented in rank order from highest to lowest median concentration. It is apparent from these plots that the highest median PP is found in the river Sowe and the lowest in the rivers Leam and Stour. Rivers with no statistically significant difference in PP concentration are regrouped in **Figure 35** for further analysis. There is a statistically significant difference ($p<0.05$) in concentration between all paired values with the exception of that between the Arrow and Avon (Lawford plus Evesham). These data suggest that, in rivers with a high dissolved P input, there is some transfer of dissolved P from the water to the actively transported sediment.

16. Median values of PP at all sites exceed 3000 µg/g. By comparison, most of the major soil groups in the Avon catchment have PP concentrations in the sub 63µm particle size fraction of below 1800 µg/g with the exception of typical stagnogley soils where the concentration lies between 2000 and 2300 µg/g (Foster *et al.*, 1996). The significantly higher PP concentrations in river sediments in comparison with

catchment soils may reflect some transfer of dissolved P to actively transported sediment at all six sites.

Figure 22 Downstream trends in TON concentration (log scale)

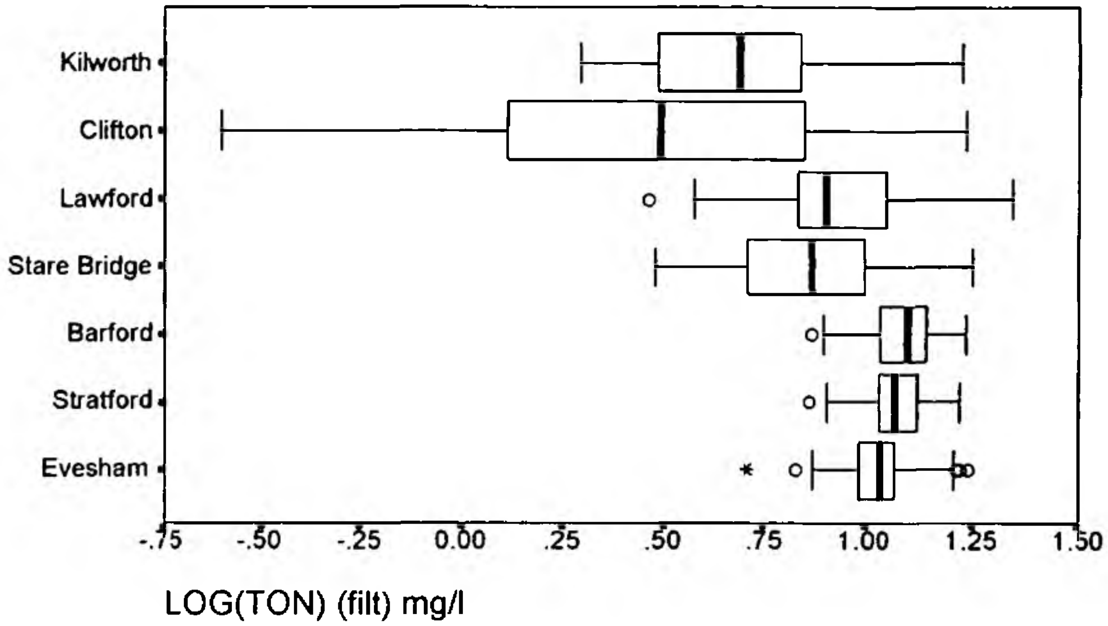


Figure 23 Downstream trends in PO_4 concentration (log scale)

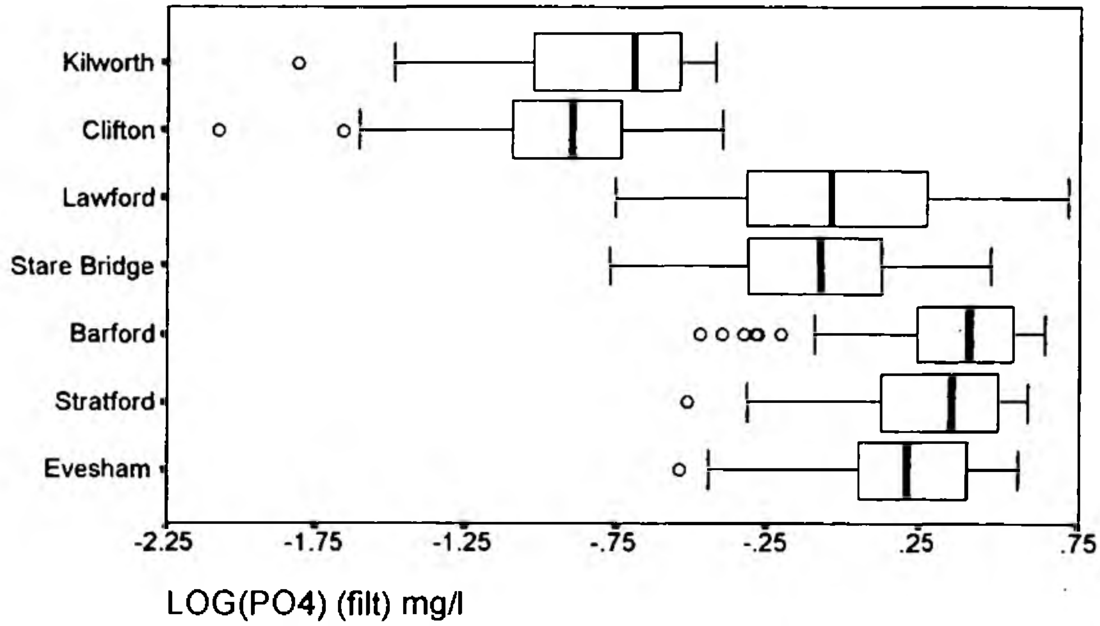


Figure 24 Downstream trends in NH_3 concentration (log scale)

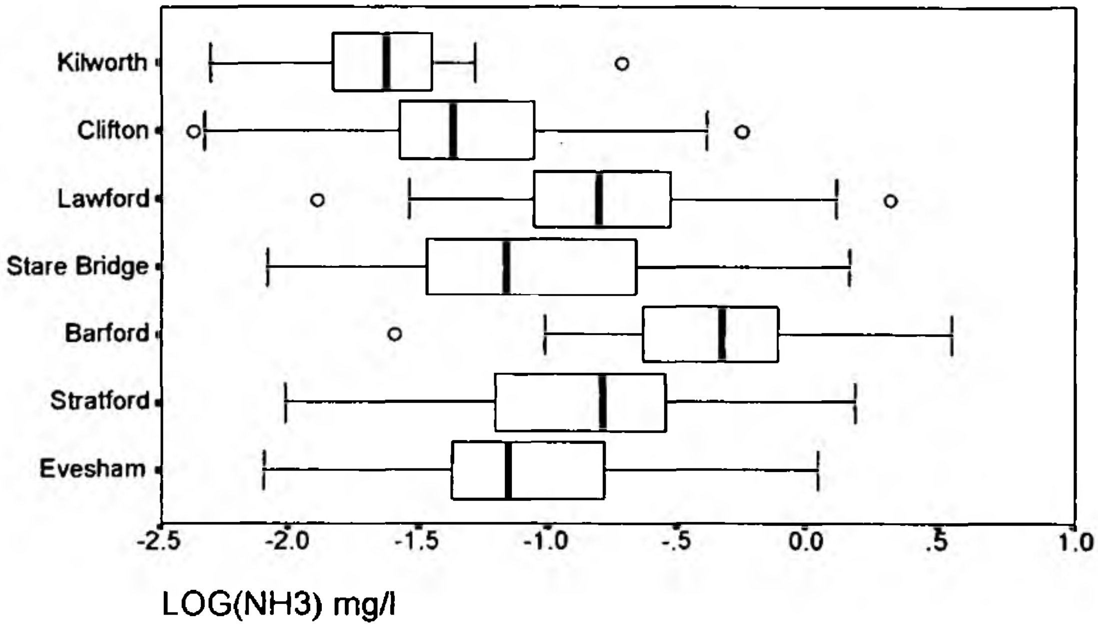


Figure 25 Downstream trends in Kjeldahl Nitrogen (KN) concentration (log scale)

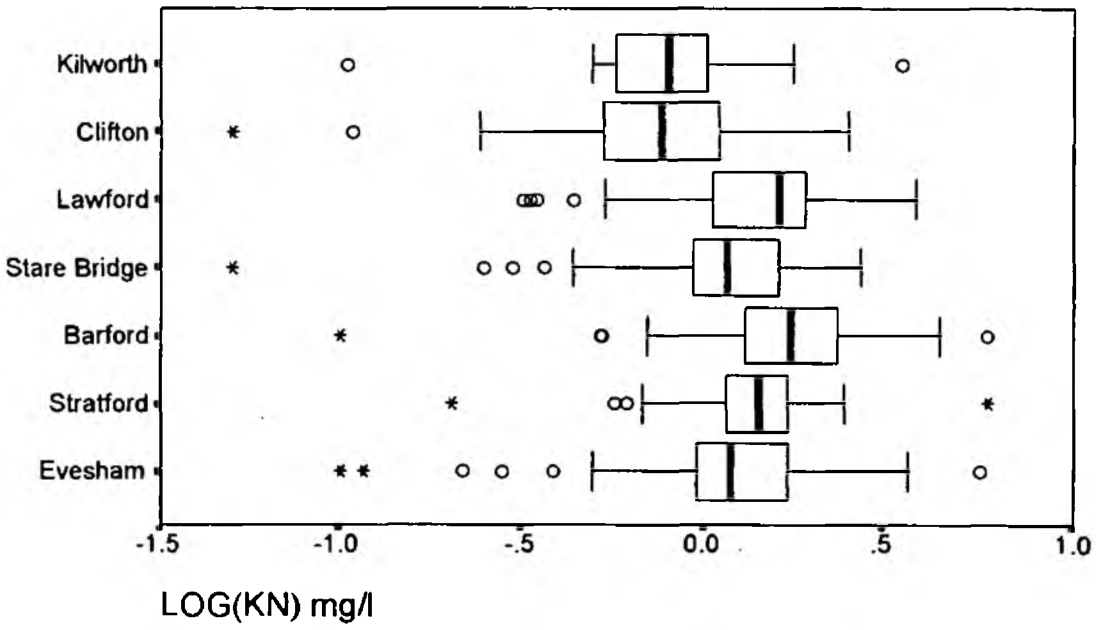


Figure 26 Downstream trends in total N concentration (log scale)

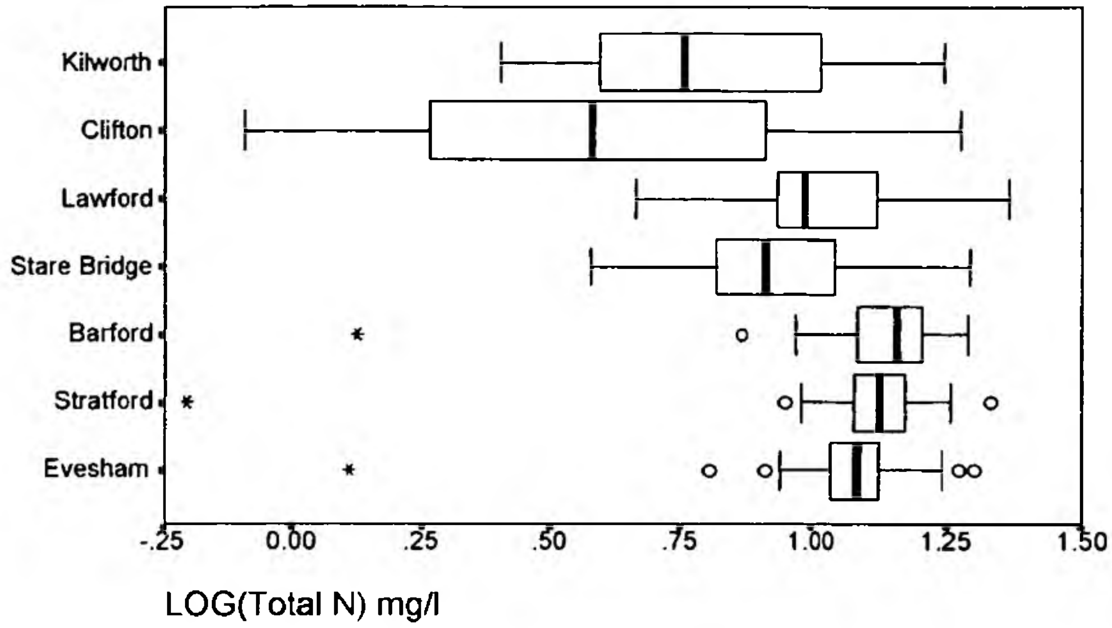


Figure 27 Downstream trends in total P concentration (log scale)

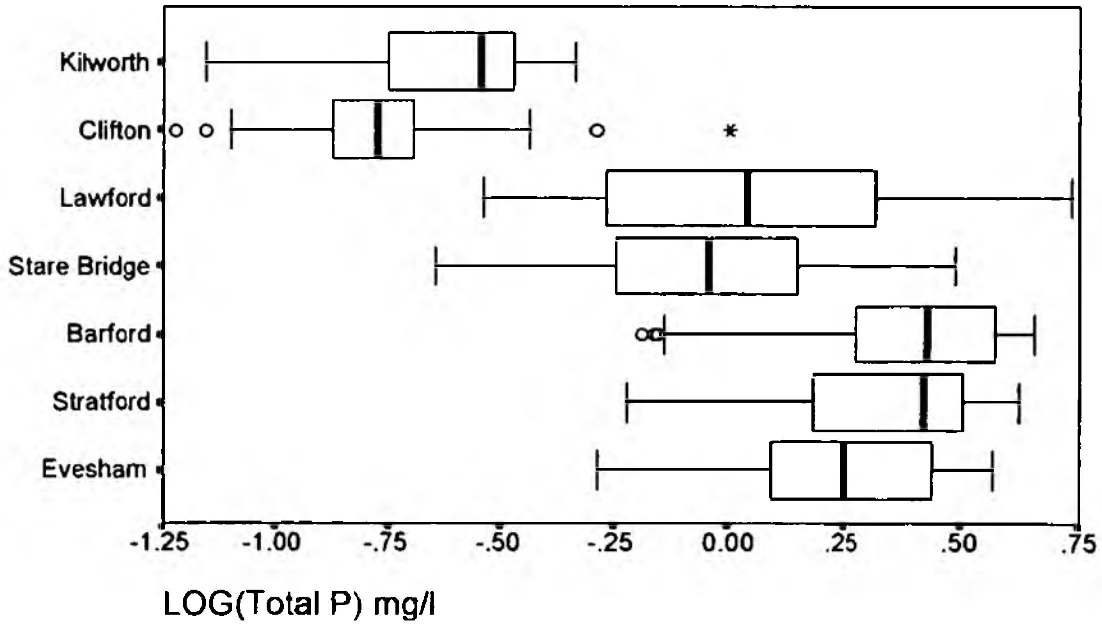


Figure 28 Downstream trends in redox potential (log scale)

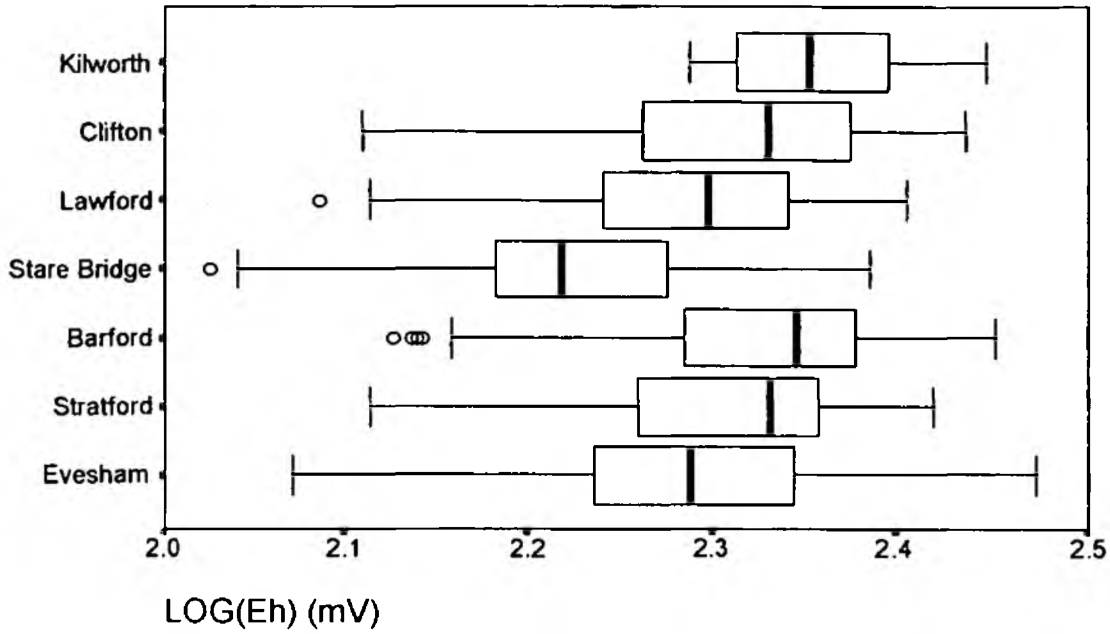


Figure 29 Downstream trends in electrical conductivity (log scale)

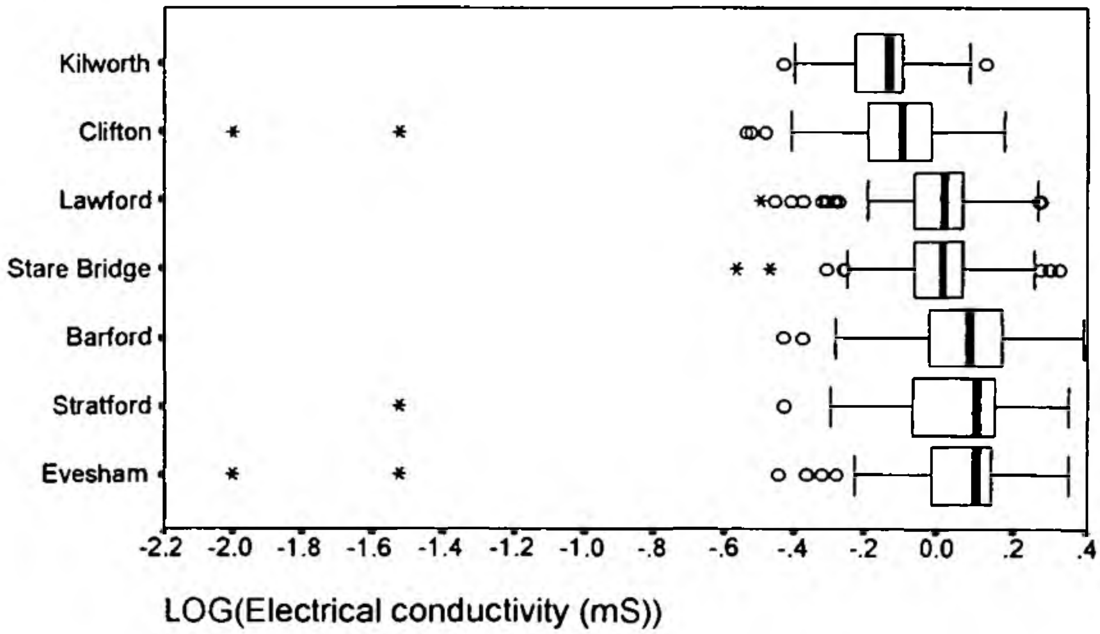


Figure 30 Downstream trends in BOD (log scale)

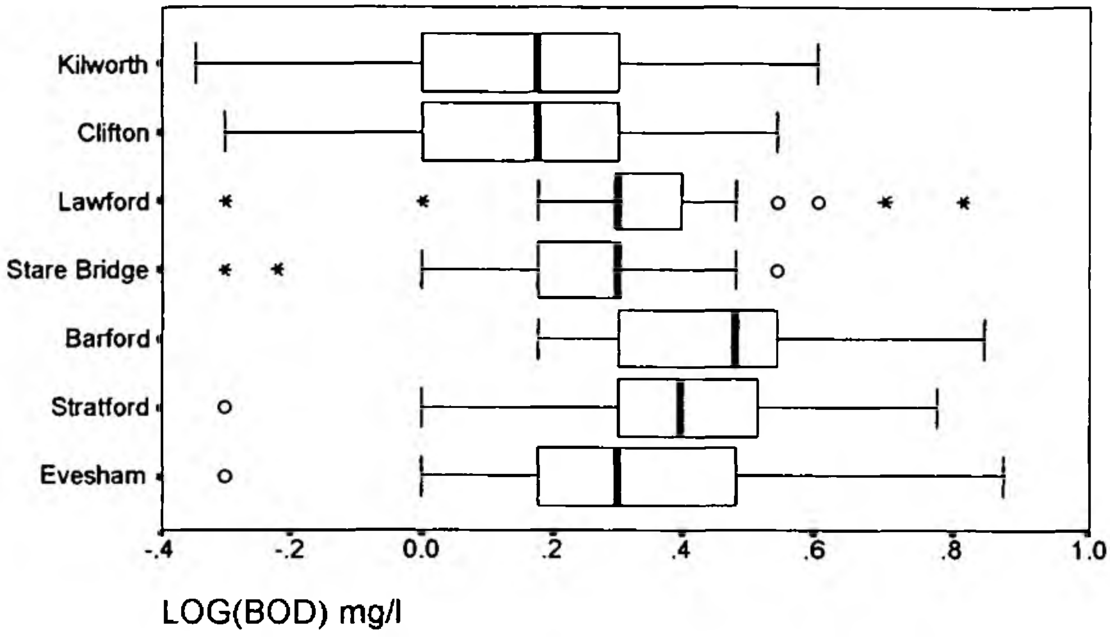


Figure 31 Downstream trends in COD (log scale)

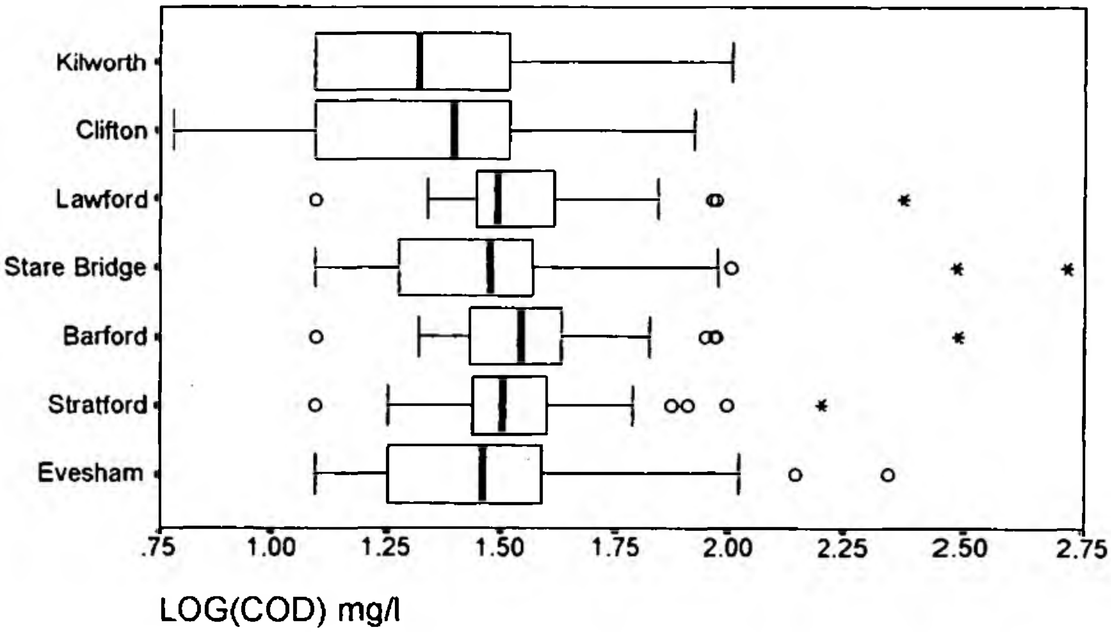


Figure 32 Downstream trends in suspended solids concentration (log scale)

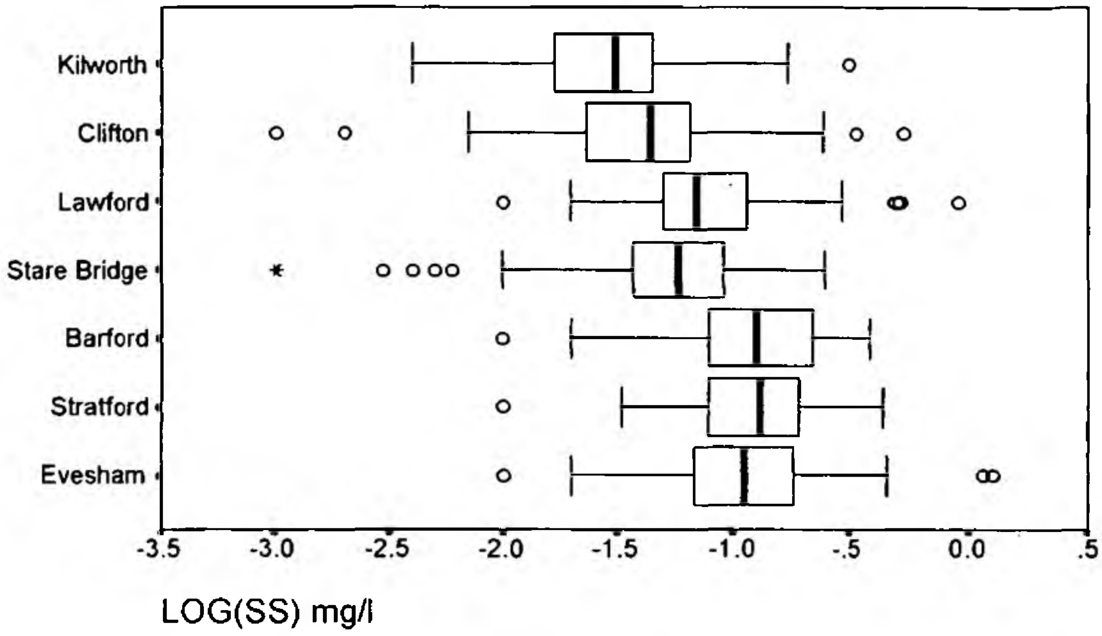


Figure 33 Downstream trends in chlorophyll a concentration (log scale)

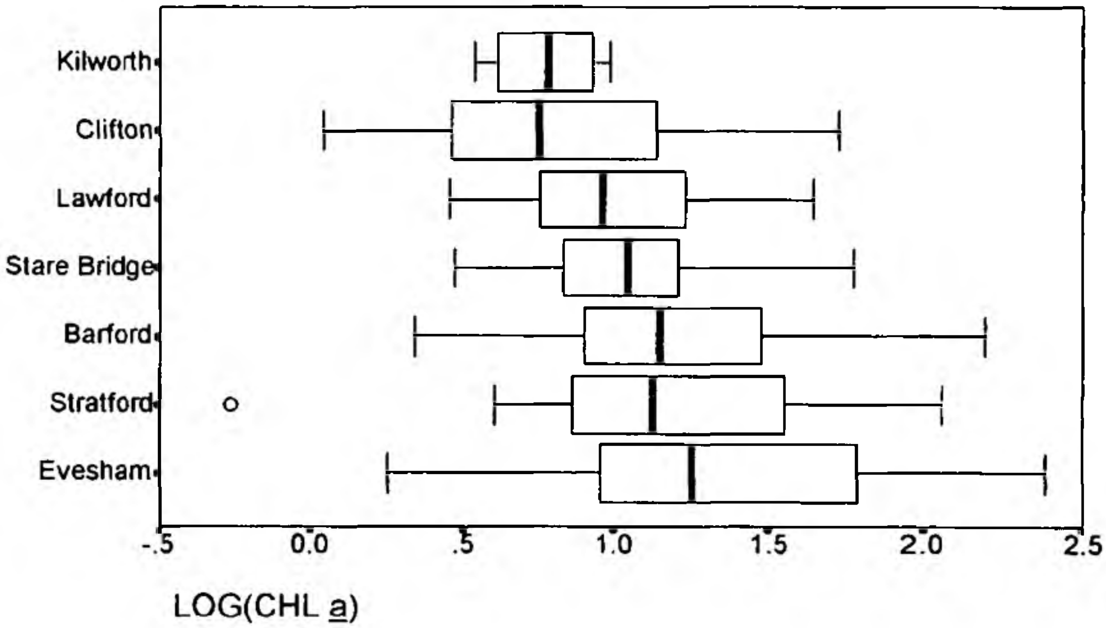


Figure 34 Particulate-P concentrations in selected rivers (log scale)

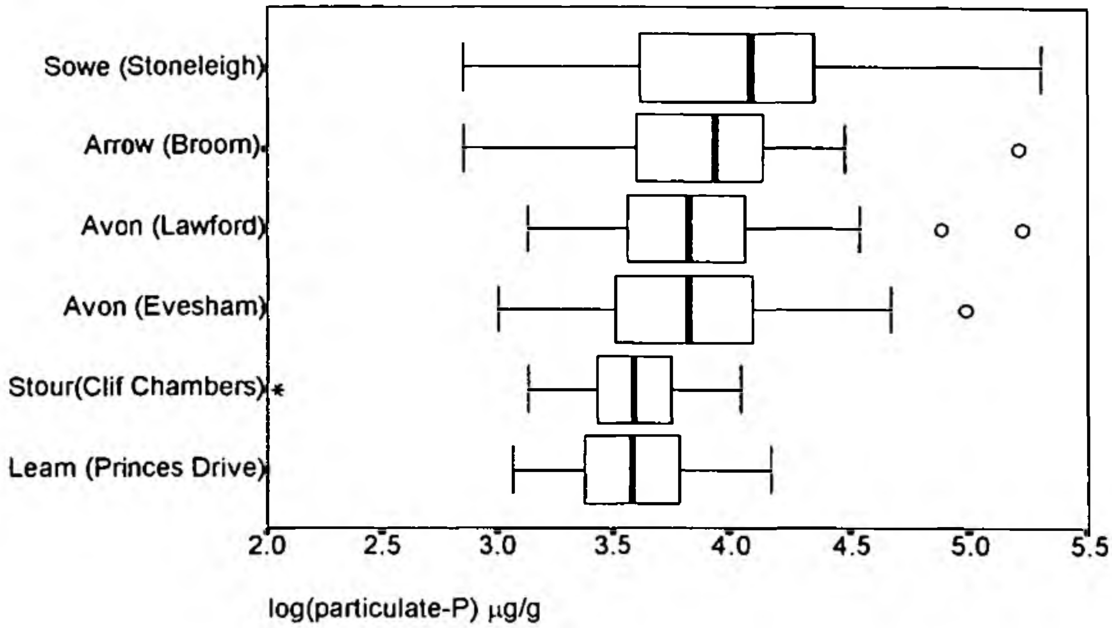
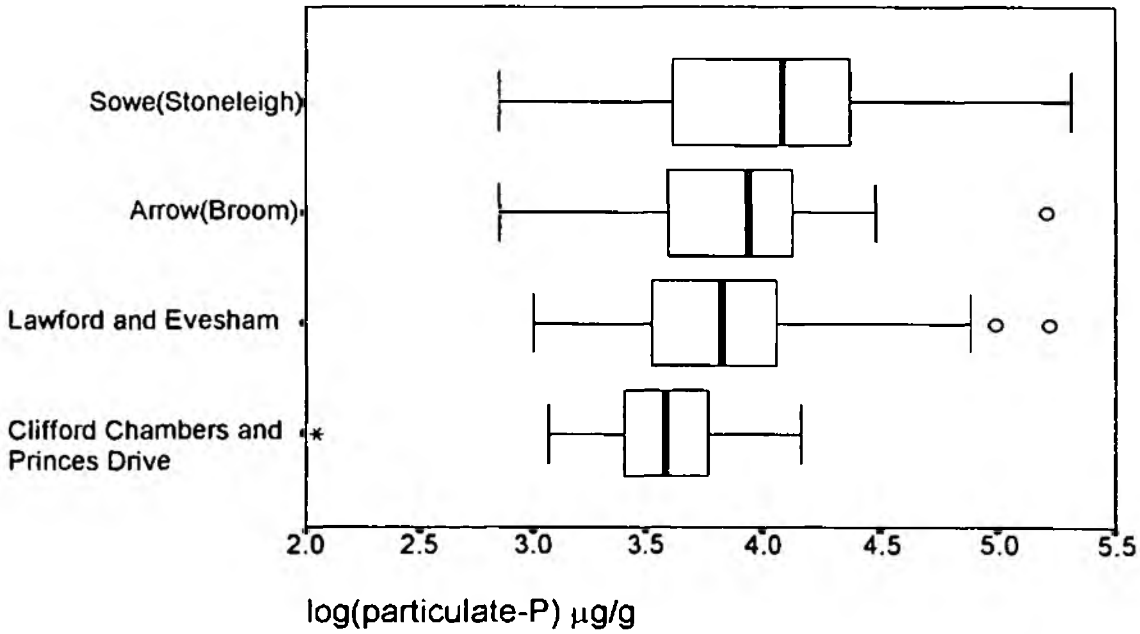


Figure 35 Regrouped data of Figure 34 (log scale)



6. The impact of the Urban Waste Water Treatment Directive On STW Discharges and River Concentrations.

1. The Environment Agency uses the DOE(1993) criteria from 'Methodology For Identifying Sensitive Areas (UWWTD) March 1993' to determine if a watercourse would qualify for designation as a SA(E). These criteria include chlorophyll a, dissolved oxygen, algal biomass/blooms and macrophytes. All of these criteria are used to define a SA(E). The criterion for phosphorus concentration is an annual average orthophosphate level in excess of 100μg/l P.

2. The Council Directive (91/271/EEC) defines nutrient removal for two classes of effluent.

a) For a pe of greater than 100000, maximum total N and P concentrations are set at 10 and 1 mg/l (as annual mean) respectively.

b) For a pe of between 10000 and 100000, maximum total N and P concentrations are set at 15 and 2 mg/l (as annual mean) respectively.

The UWWT Directive allows an alternative compliance of an 80% reduction from the influent load to the STW. However, influent P load data were not available from the monitoring programme or from Severn Trent Water and subsequent scenario testing assumed compliance with class a) or class b) concentrations under the UWWT Directive.

3. For the qualifying discharges, it is assumed that class a) is applicable to Finham and class b) is applicable to Rugby (Newbold), Redditch and Stratford (Milcote). Since Warwick (Longbridge) was not sampled on the same day as local rivers, this site was not included in the analysis of local river impacts. However, the impact of this input to concentrations at Evesham was assessed by using mean concentrations and flow over the appropriate sampling period.

4. For the purposes of the following calculations complying with class a) and class b) discharges given above it is assumed that the maximum permissible concentrations (as annual means) are discharged throughout the year. Additional scenarios have been tested. At all stations except Finham, the class a) scenario has been tested and at all stations the impact of a zero concentration in sewage effluent has been examined to estimate residual impacts associated with diffuse and minor STWs on local rivers. Since STWs and local rivers were sampled on the same day, calculations were based on instantaneous flow and concentration data. Here, instantaneous loads were calculated for STWs under each scenario separately and a mixing model used to compute estimated concentration. For Evesham, four scenarios have been evaluated, assuming initial implementation of the UWWT Directive, assuming additional implementation of class b) for minor STWs, assuming 0 mg/l P at all qualifying works and class b) at minor STWs and, finally, assuming 0 mg/l at all STWs.

5. The Directive stipulates maximum concentrations for both N and P. However, since it is generally accepted that P is the limiting nutrient in running freshwaters, only P

removal will be put in at qualifying discharges in the UK. The impact of nutrient removal from qualifying STWs under the UWWT Directive and other scenarios for P concentrations have been calculated for local impacts on rivers downstream of Rugby STW, Finham STW, Stratford STW and Redditch STW. This is shown in **Figures 36-39**. The overall impact at Evesham is given in **Figure 40**.

6. The most significant impacts of implementing the UWWT Directive are recorded at Stoneleigh, downstream of Finham STW, at Broom, downstream of Redditch STW and in the Avon at Evesham. The least significant impact is recorded at Stratford since the input from the STW contributes a small amount to the total flow of the Avon at this point in the system. Whilst in the majority of cases discharges meeting the minimum requirements of the UWWT Directive will result in a significant decrease in P concentration, at most sites it is predicted that total P concentrations will exceed 0.5 mg/l. It was suggested in the introduction that the accelerated algal productivity in flowing waters could be detected at concentrations exceeding 30 µg/l which suggests that river water concentrations will remain at least an order of magnitude higher than this level within the river Avon even after implementation of the Council Directive of 1991. Comparison with the DoE (1993) annual average concentration in running freshwaters (100 µg/l PO_4-P) suggests that this limit will also be exceeded since 90% of the total P in rivers is present as PO_4. Further reductions in sewage effluent concentration could have a significant impact on P concentrations in rivers but it is unlikely that substantial improvements would be achieved without further reductions in the concentration of effluent discharges from all STWs within the Avon catchment.

7. Under the local scenarios tested in **Figures 36-39**, reducing P concentrations to zero from qualifying STWs leaves concentrations well in excess of the 30 µg/l threshold discussed above. Even after P removal from all monitored and unmonitored STWs, P concentrations are likely to exceed 0.1 mg/l throughout the year at Evesham (**Figure 40**) suggesting that other unidentified point sources or diffuse agricultural sources will maintain concentrations of P well in excess of the 30 µg/l threshold.

8. At the four river sites where local impacts were investigated, predicted concentrations occasionally fell to 0 mg/l, especially in the summer months. It is believed that this outcome is, in part, related to instream nutrient assimilation by phytoplankton and macrophytes.

9. Of particular significance to the eutrophication problem is the seasonal pattern of concentration. From the chlorophyll a data summarised in **Figures 15-21**, it is evident that high rates of phytoplankton productivity occur between April and September in both sampling years. It is clear from the time series plots of **Figures 36- 40** that P concentrations rise significantly over the period March-September under present conditions and for future scenarios following the implementation of the UWWT Directive. It appears that a major component of the algal flora are diatoms which are limited by silica concentrations. It would seem that there is sufficient P to maintain phytoplankton populations throughout the summer. A more detailed analysis of the relationship between nutrient concentrations and chlorophyll a is required. (see section 10).

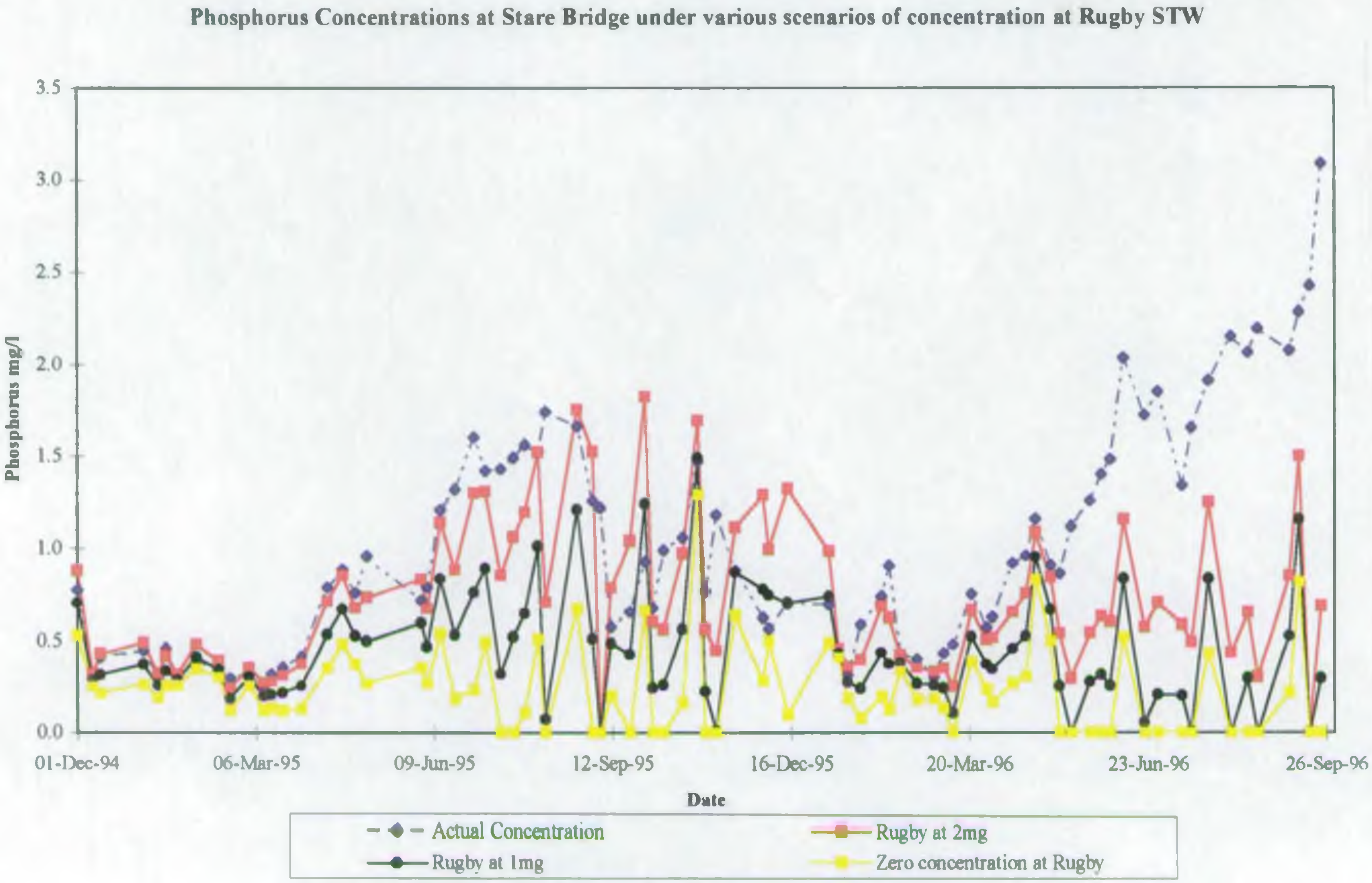
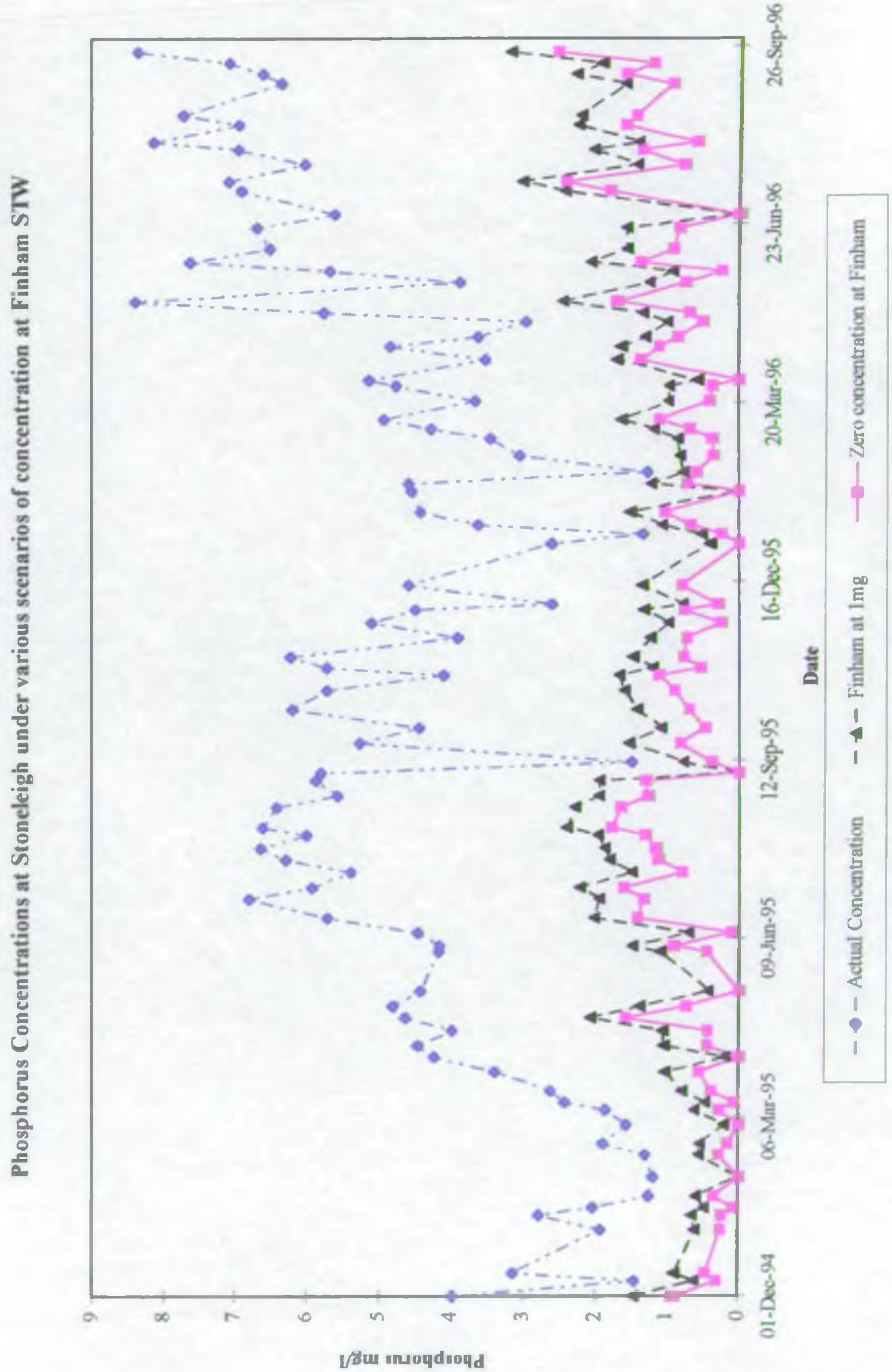


Figure 36 Phosphorus concentrations at Stare Bridge under various scenarios of concentration at Rugby STW

Figure 37 Phosphorus concentrations at Stoneleigh under various scenarios of concentration at Finham STW



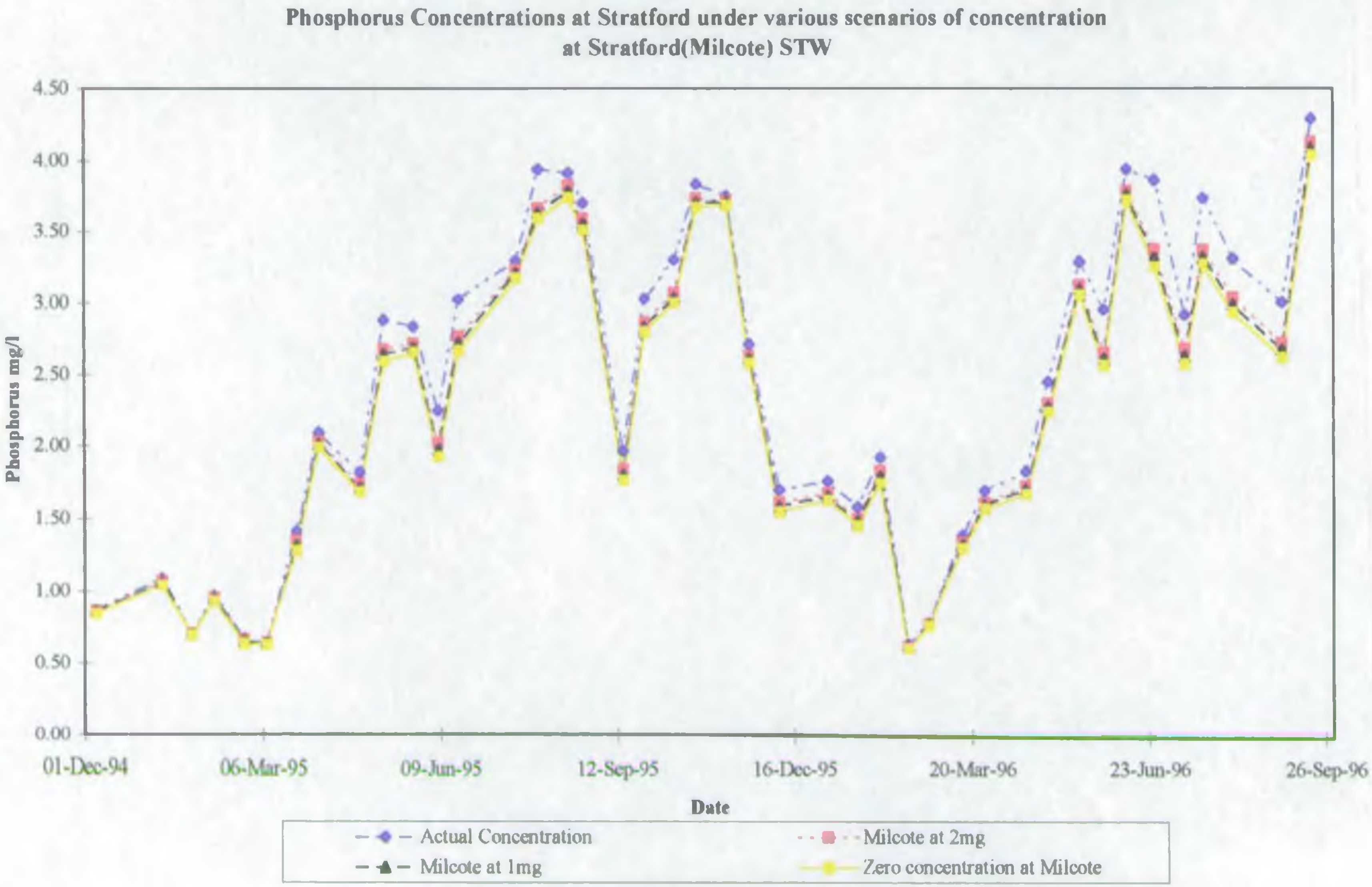


Figure 38 Phosphorus concentrations at Stratford under various scenarios of concentration at Stratford (Milcote) STW

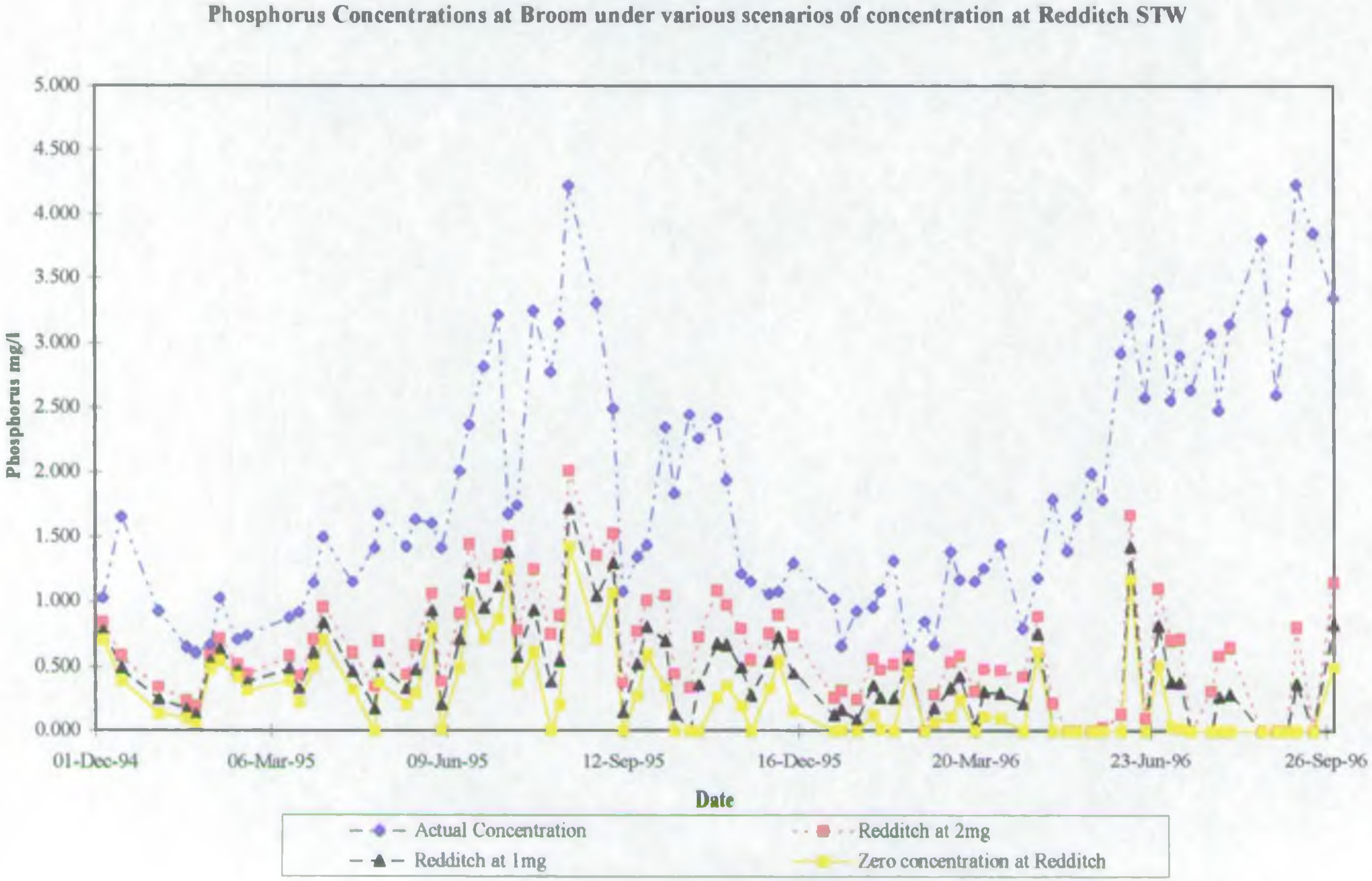


Figure 39 Phosphorus concentrations at Broom under various scenarios of concentration at Redditch STW

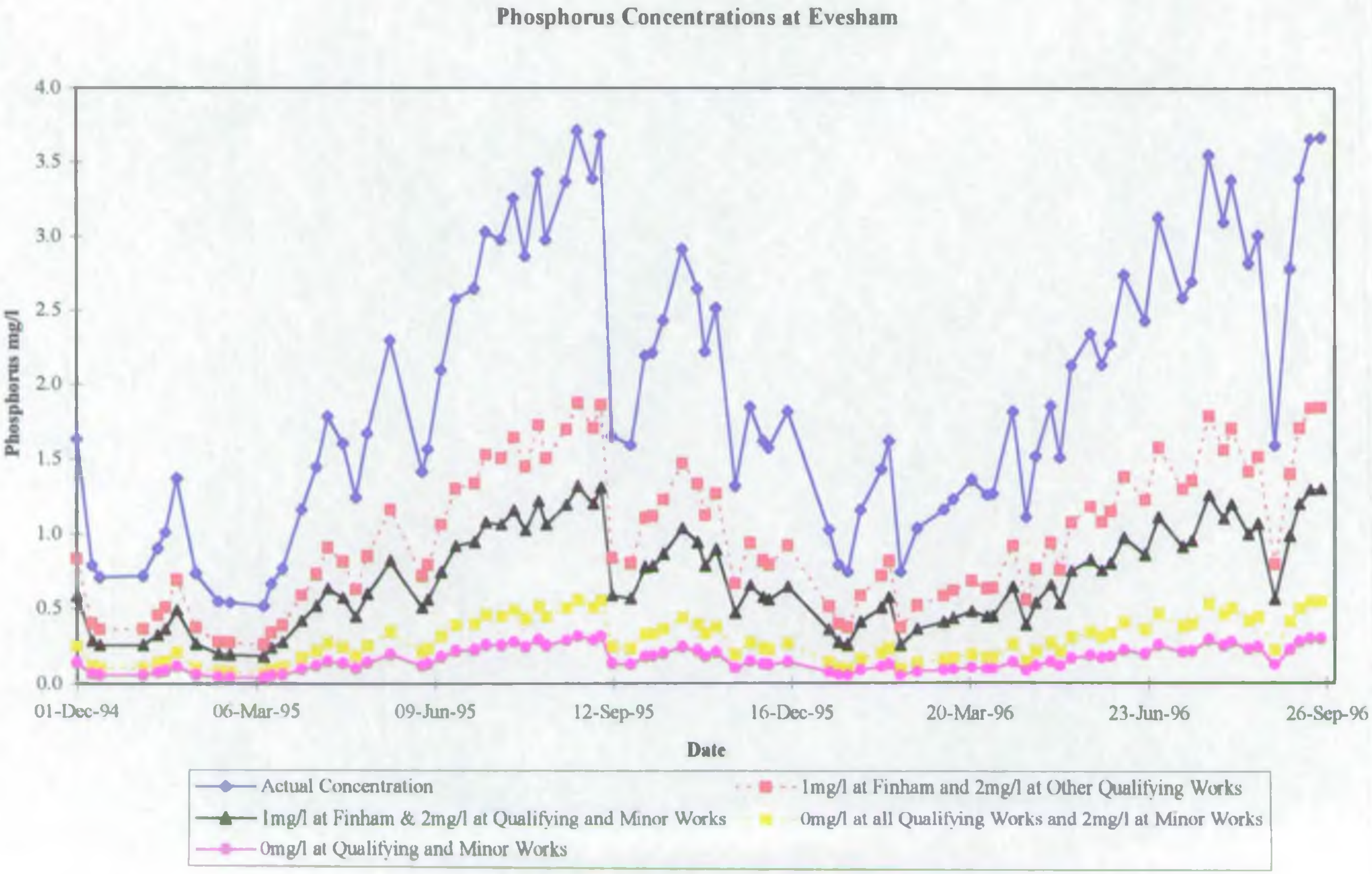


Figure 40 Phosphorus concentrations at Evesham under various scenarios of concentration at all qualifying STWs

7. CALCULATION OF NUTRIENT LOADS

7.1 Background

1. Calculation of nutrient loads in effluent discharges and rivers is complicated by a number of unknown or unquantifiable factors.

- There are statistical problems associated with the selection of the most suitable calculation procedure (see below and section 10).
- Calculation of nutrient budgets and potential export coefficients (section 8) in large rivers is confounded by instream nutrient uptake and release and the possible exchange of P between dissolved and particulate transport phases.
- An underestimate of non-point source loads will result from calculations based on downstream monitoring and estimates of point source load if a significant proportion of the loads from non-point sources sediment out prior to reaching the bottom of the catchment where monitoring takes place (Mainstone *et al.*, 1995: NRA Research and Development note No. 470).
- P from non-point sources tends to enter the river under high flow conditions which may not be picked up by the monitoring point at the lower end of a catchment. This has been found by Mainstone *et al.* (1995) to be particularly true for low energy rivers such as the river Avon. In consequence, no attempt has been made to estimate export coefficients from diffuse sources.

The calculated nutrient loads will therefore only provide an approximate guide as to the relative significance of point sources contributing to local rivers and to the overall P output at Evesham. The data and analysis reported in section 6 will provide a more rigorous guide as to the implications of phosphorus removal at qualifying STWs than the budgets calculated in this section. However, these data are presented for debate and discussion and is provided in order to demonstrate the potential for a reduction in P loads.

7.2 Load Calculation Procedures

1. The methods currently recommended to the Environment Agency by the WRc have been adopted in calculating annual nutrient budgets. These methods are discussed in detail by Ellis *et al.*, 1993.

2. Four methods were recommended in the WRc report. The first two methods assume that sampling is proportional to flow and are not relevant to the data collection protocol established for the Avon eutrophication project. Methods 3 and 4, described by Ellis *et al.* (1993), are interpolation procedures (Walling *et al.*, 1992).

3. Interpolation techniques essentially assume that the values of flow and concentration associated with individual samples are representative of the periods between samples.

4. For all the load calculation in this report, a single load calculation procedure, based on WRc recommended interpolation techniques, was used:

WRc Method 3

Observed mean load $\bar{l}$ **Equation 2**

where $\bar{l}$ is the arithmetic mean of the observed instantaneous loads calculated as the product of concentration and flow.

It was decided that it would be best to only use one load method for the study. This was because a combination of data was being analysed i.e. P and N in river and effluent samples. Continuous flow data were not available for all sites and it is recognised that the correlation between flow and N and flow and P are different. The Code of Practice states that method 3 gives the true result whatever combination of data arises. The other 3 methods in the Code of Practice are sensitive to the number of samples taken at high flows and so tend to have a positive bias. It is therefore recognised that method 3 may, if anything, give an underestimate of the true mean load because it may miss these high flow events.

5. Alternative methods have frequently been used to calculate river loads using extrapolation procedures which utilise a different approach and make use of a concentration/flow relationship or rating curve established using the available samples (Walling and Webb, 1985; Littlewood, 1992). Flow is usually related to concentration by means of a power function relationship of the form:

$Ci = a.Qi^b$ **Equation 3**

where Ci is instantaneous concentration

Qi is instantaneous flow

a and b are constants derived from a least squares regression analysis on $\log_{10}$ transformed flow and concentration data.

6. From the regression equations derived from the total instantaneous chemical and flow data sets, hourly concentrations are predicted for each flow from **Equation 3**. Predicted hourly concentration is multiplied by hourly flow and summed for the period.

7. There are a variety of different methods for calculating loads and there is currently much debate over which method is the most appropriate. The load method chosen will obviously depend on data availability and what determinands are being calculated. Work has been done by Walling and Webb (1985), Littlewood (1992) and Horowitz (1995) and Foster *et al.*, (1996) and this has highlighted the known statistical errors associated with these methods. (This is summarised in section 10 of the report). It is therefore recommended that further work is done and guidance produced on the procedures to follow when calculating loads under varying scenarios.

7.3 The magnitude of nutrient loads in the Avon Catchment

1. From WRc method 3 described above, it is estimated that daily mean N loads range from 14846 to 411 kg/d and daily mean P loads in the River Avon catchment range from 1551 to 10 kg/d (**Table 5**).

Table 5 Nutrient loads for selected river Avon sites (kg/d)

	Total N kg/d			Total P kg/d		
Site	90%-	Mean	90%+	90%-	Mean	90%+
Sowe (Stoneleigh)	3946.5	4267.9	4615.6	897.8	931.5	966.6
Avon(Stare Bridge)	1398.5	1797.4	2310.0	83.5	93.4	104.4
Leam(Eathorpe)	500.9	762.6	1161.0	28.8	39.2	53.3
Leam(Princes Drive)	831.5	1216.9	1781.1	31.0	44.3	63.3
Dene(Wellesbourne)	298.8	411.4	566.4	7.7	9.7	12.3
Stour(Clifford Chambers)	1386.8	1795.1	2363.7	35.5	45.9	59.3
Arrow(Broom)	1411.3	1713.0	2079.3	214.7	232.9	252.6
Avon(Evesham)	12000.5	14845.7	18365.7	1358.4	1550.6	1770.0

2. From the above data, and respective catchment area statistics, budgets have been recomputed and expressed in units of kg/ha/yr (**Table 6**).

Table 6 Nutrient loads for:

a. Selected river Avon sites

Site	Area[1] km^2	N load kg/ha/yr	P load kg/ha/yr
Sowe (Stoneleigh)	262.0	59.46	12.98
Avon (Stare Bridge)	347.0	18.91	0.98
Leam (Eathorpe)	300.0	9.28	0.48
Leam (Princes Drive)	362.0	12.27	0.45
Dene (Wellesbourne)	102.0	14.72	0.35
Stour (Clifford Chambers)	326.0	20.10	0.51
Arrow (Broom)	319.0	19.60	2.66
Avon (Evesham)	2210.0	24.52	2.56

b. Other recent estimates for UK rivers[2]

Avon (Bredon)	2674.0	23.63	2.10
Severn (Upton)	6850.0	18.71	1.62
Exe (Thorverton)	601.0	24.38	1.64
Dart (Bickleigh)	46.0	35.03	1.87

(1) Data from NRA (1992)
(2) Data from Walling *et al.* (1997) for 1995 only

3. Total N loads range from 59.5 to 9.3 kg/ha/yr and total P loads from 12.98 to 0.35 kg/ha/yr. These data are compared with other available published N and P data in **Table 6** and are considered subsequently in further detail.

4. Total N yields for UK rivers are sparse. However, recent summaries of NO_3-N loads, published by Walling and Webb (1981) and Betton *et al.* (1991), provide a useful comparison. For small Midland England rivers (<100 km^2), Walling and Webb (1981) and Betton *et al.* (1991) estimate that nitrate nitrogen loads range from 10 to 30 kg/ha/yr. The monitored data of **Table 6a** are mostly within the range of nitrate-nitrogen loads estimated by Betton *et al.* (1991), although the load at Eathorpe is slightly lower than the minimum reported range. (From the summary of water quality statistics presented below, it should be noted that, on average, ca. 85 % of total N is present in rivers as TON). Recent estimates of total N loads for 4 UK rivers given in **Table 6b**. The data for the Avon at Bredon is remarkably similar to that estimated for the Avon at Evesham in this study.

5. Reliable UK data for total P transport are only available for four major river systems for a single year and are summarised in **Table 6b**. Numerous studies have measured orthophosphate concentrations and/or loads and attempts have also been made to estimate export coefficients from available land use and land management data as summarised in Section 2.1 above. **Table 7** gives estimated total P yields from the published literature for a range of land uses.

Table 7 Estimated P loads from catchments (kg/ha/yr)

Catchment Location	P export (kg/ha/yr)	Source
Agriculture		
Denmark	1.03 - 1.69	Kronvang, 1990
USA (Oklahoma/Texas)	0.15 - 10.42	Sharply & Smith, 1990
USA	0.08 - 18.6	Reckhow *et al.*, 1980
Forest		
USA	0.01 - 0.88	Loehr *et al.*, 1989

6. Comparison of **Tables 6a** and **7** would suggest that, with the exception of the River Sowe at Stoneleigh, most P yields lie well within the range of those published for agricultural catchments although they are generally higher than those estimated for forested environments. The estimate of total P load for the Avon at Bredon lies close to that estimated for the Avon at Evesham for this study.

7. Those rivers with yields of less than 1 kg/ha/yr probably reflect more closely conditions where the dominant yields are derived from diffuse agricultural sources.

8. NUTRIENT BUDGETS

8.1 Calculating Budgets

The loads reported in section 7 are subject to a number of errors associated with the load calculation methods employed and the lack of information regarding instream nutrient transformations. Furthermore, nutrient loads from unmonitored works are not derived from measured data but from averages computed from the mean pe loads at monitored works. In consequence, whilst nutrient budgets have been calculated and attempts have been made to estimate the impact of nutrient removal on N and P loads at Evesham, these data should be taken as guides rather than definitive estimates of the impact of nutrient removal on river loads.

8.2 Sewage Treatment Works

<u>Qualifying STWs</u>

1. Total N and P loads have been estimated by WRc Method 3 for the 5 qualifying Sewage Treatment Works in the Avon catchment and for the 13 minor Sewage Treatment Works (of ca. 10000 pe or less) (**Table 8**).

2. N and P are expressed both as population equivalents (pe) and as a proportion of actual population (ap).

3. N loads range from nearly 2900 kg/d at Finham STW to just over 200 kg/d at Stratford STW.

4. P loads range from just over 800 kg/d at Finham STW to just under 60 kg/d at Rugby STW.

5. Highest pe loads of N derive from Warwick STW and highest pe loads of P from Redditch STW.

6. Lowest pe loads of N and P derive from Rugby STW.

<u>Minor STWs</u>

7. Total N and P loads for 13 minor sewage treatment works have been calculated by method 3.

8. N and P loads, expressed as population equivalents, are particularly high at Crick and Southam.

9. On average pe loadings of N and P in the smaller STWs are ca. 10% and 43% higher for N and P respectively than the average for the five qualifying STWs if the Crick and Southam STW loads are included; and ca. 4 % lower and 24% higher respectively if the Crick and Southam STW loads are excluded from the calculation of average minor STW load.

10. The average N and P load data for the 13 minor STWs, in combination with pe information, were used to estimate the contribution of all of the smaller STWs within the Avon catchment upstream of Evesham.

Table 8 Estimated N and P loads for qualifying and minor STWs

Site	Actual Population	Population Equivalent	Mean P load kg/d	Mean N load kg/d	P load g/ap/d	P load g/pe/d	N load g/ap/d	N load g/pe/d
Finham STW	348390	390257	801.73	2882.10	2.30	2.05	8.27	7.39
Redditch STW	61497	89772	193.45	671.05	3.15	2.15	10.91	7.48
Rugby STW (Newbold)	61480	88860	57.28	368.70	0.93	0.64	6.00	4.15
Stratford (Milcote)	26945	48707	70.80	209.41	2.63	1.45	7.77	4.30
Warwick (Longbridge)	79517	92066	131.21	766.12	1.65	1.43	9.63	8.32
Mean	115566	141932	250.89	979.48	2.13	1.55	8.52	6.33

Site	Actual Population	Population Equivalent	Mean P load kg/d	Mean N load kg/d	P load g/ap/d	P load g/pe/d	N load g/ap/d	N load g/pe/d
Blackminster	8290	10230	19.69	51.79	2.38	1.92	6.25	5.06
Braunston	1647	1647	3.78	11.71	2.30	2.30	7.11	7.11
Chipping Campden	2308	2308	4.88	19.28	2.11	2.11	8.35	8.35
Crick	1610	1853	7.97	22.15	4.95	4.30	13.76	11.95
Harbury	4395	4395	7.20	25.80	1.64	1.64	5.87	5.87
Kilsby STW	2579	2579	4.79	11.68	1.86	1.86	4.53	4.53
Leamington Heathcote	9895	9895	16.97	36.75	1.72	1.72	3.71	3.71
Lutterworth	8525	9771	19.60	73.03	2.30	2.01	8.57	7.47
Snitterfield	1172	1172	2.23	6.23	1.90	1.90	5.32	5.32
Southam	5629	5687	19.16	64.45	3.40	3.37	11.45	11.33
Tanworth in Arden	410	411	0.72	2.84	1.75	1.75	6.93	6.91
Wellesbourne	6096	6544	15.27	50.05	2.51	2.33	8.21	7.65
Wootton Wawen	4292	6675	9.94	32.15	2.32	1.49	7.49	4.82
Mean	4373	4859	10.17	31.38	2.39	2.21	7.50	6.93
Mean(exc. Crick and Southam)	4510	5057	9.55	29.21	2.07	1.91	6.58	6.07

8.3 Rivers

1. WRc Method 3 was used to determine the average daily load of N and P transported at each of the major river gauging stations.

2. For the subcatchment data presented in **Table 9**, the contribution derived from non-point and non-monitored point sources are referred to as the balance. The balance is calculated as a daily load and as an export coefficient (kg/ha/yr) for comparison with **Tables 6 and 7**.

3. No account is taken in these budget calculations of in-stream nutrient adsorption and release processes or of possible transmission losses. The budgets therefore indicate the possible contribution of point N and P inputs to total N and P loads passing through the gauging stations on the Avon at Lawford and Evesham, the Sowe

at Stoneleigh, the Arrow at Broom, the Leam at Princes Drive and the Stour at Clifford Chambers (**Table 9**). Whilst it is tempting to ascribe a negative budget to transmission losses or biological uptake of N and P, it is stressed that negative budgets could simply be a function of the errors associated with estimates of nutrient loads at individual stations.

4. Nutrient balances for the Upper Avon, Sowe, Arrow, Leam and Stour (**Table 9**) indicate that N export coefficients range from ca. 19 kg/ha/yr (Sowe) to 9 kg/ha/yr (Arrow) and that P export coefficients range from ca 1.7 kg/ha/yr (Sowe) to 0 kg/ha/yr (Arrow, Avon and Leam) (c.f. **Tables 6 and 7**).

Table 9 Total P and N budgets for major subcatchments (a-e) and the Avon at Evesham (f).

(a) UPPER AVON Site	kg d^{-1} Total P	kg d^{-1} Total N	% Total P	% Total N
Avon(Stare Bridge)	93.38	1797.37	100.00	100.00
Rugby STW	57.28	368.70	61.34	20.51
Other minor works(21)	53.12	168.77	56.89	9.39
Balance	-17.02	1259.90	-18.23	70.10
Balance kg ha^{-1} a^{-1}	-0.18	13.25		

(b) Sowe Site	kg d^{-1} Total P	kg d^{-1} Total N	% Total P	% Total N
Sowe (Stoneleigh)	931.54	4267.93	100.00	100.00
Coventry(Finham) STW	801.73	2882.10	86.06	67.53
Other minor works(3)	7.53	23.92	0.81	0.56
Balance	122.29	1361.91	13.13	31.91
Balance kg ha^{-1} a^{-1}	1.70	18.97		

(c) Arrow & Alne Site	kg d^{-1} Total P	kg d^{-1} Total N	% Total P	% Total N
Arrow (Broom)	232.89	1713.04	100.00	100.00
Redditch STW	193.45	671.05	83.06	39.17
Wootton Wawen STW	9.94	32.15	4.27	1.88
Other minor works(12)	69.39	220.43	29.79	12.87
Balance	-39.89	789.41	-17.13	46.08
Balance kg ha^{-1} a^{-1}	-0.46	9.03		

(d) LEAM Site	kg d^{-1} Total P	kg d^{-1} Total N	% Total P	% Total N
Leam (Princes Drive)	44.31	1216.91	100.00	100.00
Braunston STW	3.78	11.71	8.54	0.96
Harbury STW	7.20	25.80	16.26	2.12
Kilsby STW	4.79	11.68	10.82	0.96
Southam STW	19.16	64.45	43.23	5.30
Other minor works(12)	22.27	70.76	50.27	5.81
Balance	-12.90	1032.51	-29.13	84.85
Balance kg ha^{-1} a^{-1}	-0.16	12.56		

(e) STOUR Site	kg d^{-1} Total P	kg d^{-1} Total N	% Total P	% Total N
Stour (Clifford Chambers)	45.87	1795.14	100.00	100.00
Chipping Campden STW	4.88	19.28	10.63	1.07
Other minor works(15)	29.00	92.12	63.21	5.13
Balance	12.00	1683.74	26.16	93.79
Balance kg ha^{-1} a^{-1}	0.13	18.55		

(f) Avon at EVESHAM Source	kg d^{-1} Total P	kg d^{-1} Total N	% Total P	% Total N
Avon (Evesham)	1550.63	14845.74	100.00	100.00
Coventry (Finham) STW	801.73	2882.10	51.70	19.41
Redditch STW	193.45	671.05	12.48	4.52
Rugby STW	57.28	368.70	3.69	2.48
Stratford STW	70.80	209.41	4.57	1.41
Warwick STW	131.21	766.12	8.46	5.16
Minor works (monitored)	136.25	407.91	8.79	2.75
Other minor works	202.44	643.13	13.06	4.33
Diffuse (Arrow)	0.00	789.41	0.00	5.32
Diffuse (Stour)	12.00	1683.74	0.77	11.34
Diffuse (Leam)	0.00	1032.51	0.00	6.95
Diffuse (Sowe)	122.29	1361.91	7.89	9.17
Diffuse (U. Avon)	0.00	1259.90	0.00	8.49
Sub-total	1727.44	12075.89	111.40	81.34
Balance (Mid Avon)	-176.81	2769.85	-11.40	18.66
Balance kg ha^{-1} a^{-1}	-0.29	4.57		

5. On average, the Avon at Evesham transports 1551 kg P/day and 14846 kg N/day (**Table 9**). The negative budget for the Avon at Evesham is within known errors in the budget calculations (see below).

6. Results would indicate for the period December 1994 to September 1996 that

- P removal from the five qualifying STWs within the Avon catchment could make a substantial impact on the annual P load at Evesham

- N removal from the 5 qualifying STWs would make a significant impact on the annual N load at Evesham

8.4 Local impacts of STWs

1. **Figures 41 and 42** shows the impact of N and P inputs to receiving rivers from the 5 major STWs. Effluent flows are calculated as a proportion of total annual flow for the nearest downstream river gauging station.

2. Local effluent inputs contribute between 49% of the annual flow at Stoneleigh to less than 1% of the annual flow at Evesham. In consequence, those rivers which have a dominant effluent contribution to annual flow have a significant local impact on N and P loads.

3. The impact of qualifying STWs on receiving waters is not simply a function of flow contributions. Whilst Finham STW contributes 49% to the annual discharge at Stoneleigh, it contributes some 86% of total P load and some 68% of total N load. Rugby (Newbold) contributes only 18% of the flow at Lawford but contributes over

63% of the P load and approximately 26% of the N load. Stratford STW makes little contribution to the overall N and P loads at Evesham.

Figure 41 Local impact of qualifying STWs on flow and nitrogen loads

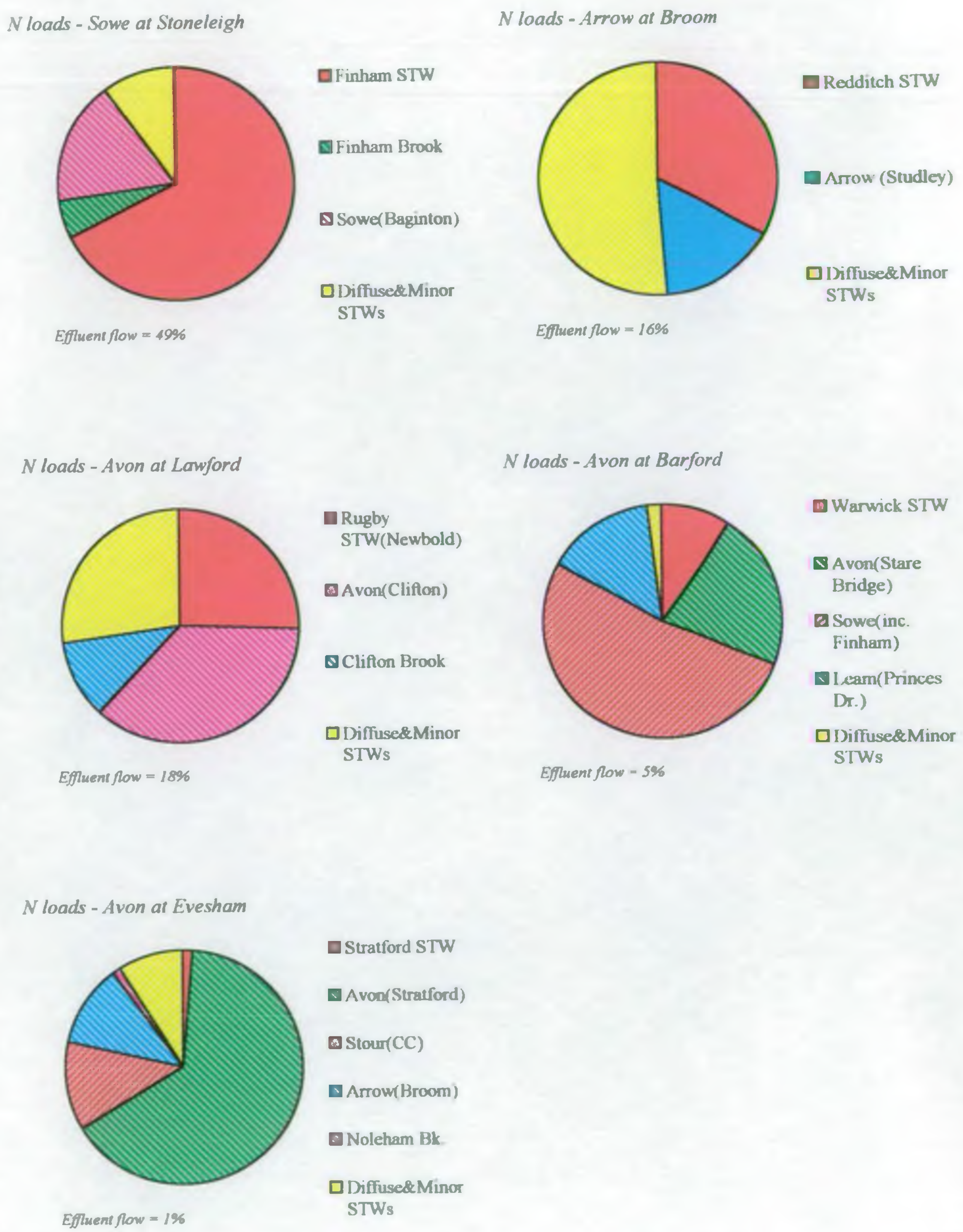
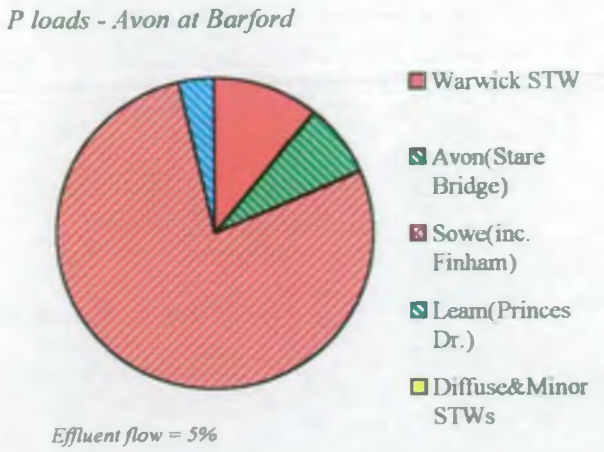


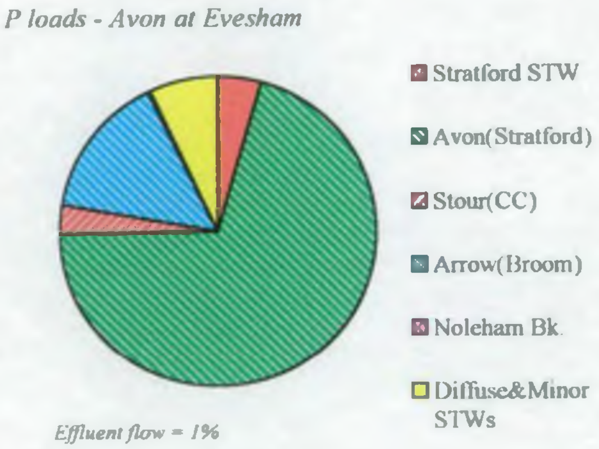
Figure 42 Local impact of qualifying STWs on flow and phosphorus loads including an estimate of the impact of P removal at qualifying STWs

BEFORE P REMOVAL **AFTER P REMOVAL**

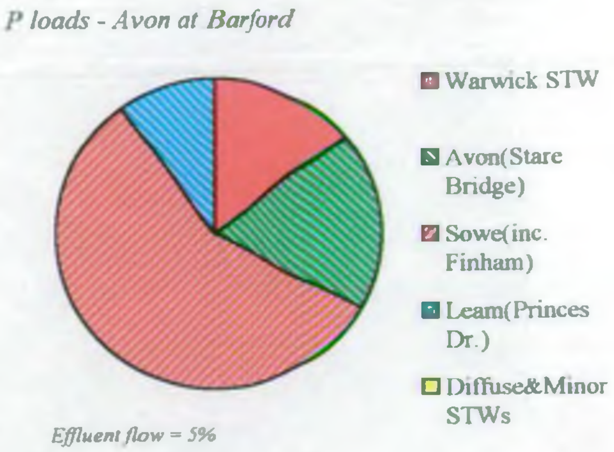
Figure 42 cont

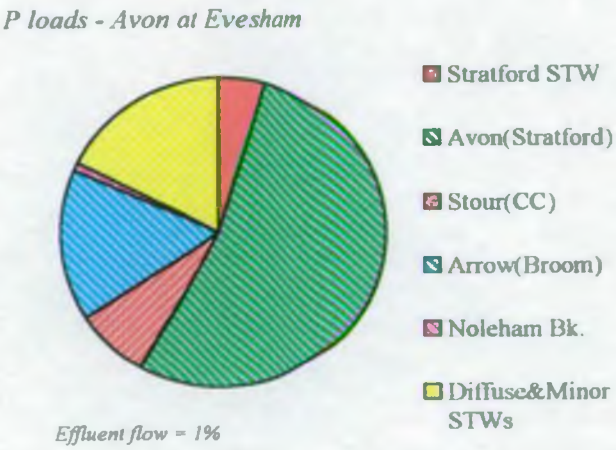
BEFORE P REMOVAL





AFTER P REMOVAL





8.5 Downstream trends in River Loads

1. Mean daily loads of N and P, calculated by WRc method 3 for the 7 major gauging stations on the river Avon between Kilworth and Evesham, are given in **Table 10**. The following observations have been made from these data.

2. Loads of N and P generally increase downstream. However, the rate of increase, calculated as a function of downstream distance, is highly variable.

3. Of particular note is the small rate of increase in both N and P loads between Lawford and Stare Bridge. (Section 5.4 highlighted statistically significant decreases in all nutrients except TON between these two sites). This could be related to the presence of a major wetland (Brandon Marshes) located between the two monitoring sites and, whilst the results are not conclusive, suggest that this area could be an important focus for further investigation (see section 10 below).

4. Loads of N and P increase most dramatically between Stare Bridge and Barford, downstream of the confluence of the Avon and Sowe. The latter includes the contribution from Finham STW.

5. Whilst both N and P loads increase downstream between Barford and Evesham, the rate of increase between Barford and Stratford is lower than that between Stratford and Evesham. Whilst no specific mechanism has been identified to account for this apparent anomaly, it has been suggested (EA Hydrometric section, Solihull pers. comm.) that the flow gauging station at Stratford may be significantly underestimating river flow. No further comment can be made in relation to these data until the accuracy and precision of flow gauging at Stratford has been fully investigated.

Table 10 Downstream trends in river P and N loads

Site	Mean Q Ml/d	P Load kg/d	N Load kg/d	Increase in P load kg/d	Increase in N load kg/d	Increase in P load kg/d/km	Increase in N load kg/d/km
Kilworth	24.27	6.05	226.09	6.05	226.09	0.22	8.37
Clifton	55.34	12.71	524.36	6.66	298.27	0.56	24.86
Lawford	123.80	90.63	1440.28	77.92	915.92	7.79	91.59
Stare Bridge	155.38	93.38	1797.37	2.75	357.09	0.11	14.88
Barford	597.59	1098.84	8204.31	1005.46	6406.94	45.70	291.22
Stratford	767.97	1089.27	9659.86	-9.57	1455.55	-0.58	88.22
Evesham	1143.88	1550.63	14845.74	461.36	5185.88	16.19	181.96

8.6 Seasonal trends in river loads and the contribution of STWs to N and P loads at Evesham

1. Monthly river loads for N and P have been calculated for STWs and river sites where weekly quality and flow data were available. This allows a +/-90% error estimate on the load to be derived using the WRc recommended methods (Ellis *et al.*, 1993).

2. Monthly total N loads are given in **Figure 43**. From the qualifying STWs, there is evidence for a seasonally variable input, with highest loads being discharged in late winter and spring. A similar seasonality is apparent at all river gauging stations. These trends undoubtedly reflect the seasonality of effective rainfall in the river Avon catchment. The maximum daily load by month transported by the river Avon at Evesham approaches 50000 kg/d (50 t/d). The maximum daily load by month derived from STW inputs is ca. 3500 kg/d (3.5 t/d) from Coventry Finham STW.

3. Monthly total P loads are given in **Figure 44**. From the qualifying STWs there is only weak seasonality in the data. The seasonal trends reported in section 5 would suggest that P concentration is inversely related to flow (i.e. high flows are associated with periods of low concentration), a trend confirmed by the analysis undertaken by Foster *et al.* (1996a). In consequence loads remain relatively uniform throughout the year since load is the product of flow and concentration. However, monthly loads at Redditch and Rugby STWs appear to increase over the last 5 to six months of monitoring whilst at Warwick STW there is a major decrease in load between April and July 1996. River loads evidence some seasonality, again reflecting the effective rainfall over the catchment with highest loads being transported in late winter and spring months. The maximum daily load by month transported by the river Avon at Evesham approaches 4000 kg/d (4 t/d). The maximum daily load by month derived from STW inputs is ca. 1000 kg/d (1 t/d) from Coventry Finham STW.

4. Estimates of the seasonal contribution of particulate P and qualifying STW effluent to the Total P transported at Evesham are given in **Figure 45** from which the following points are noted.

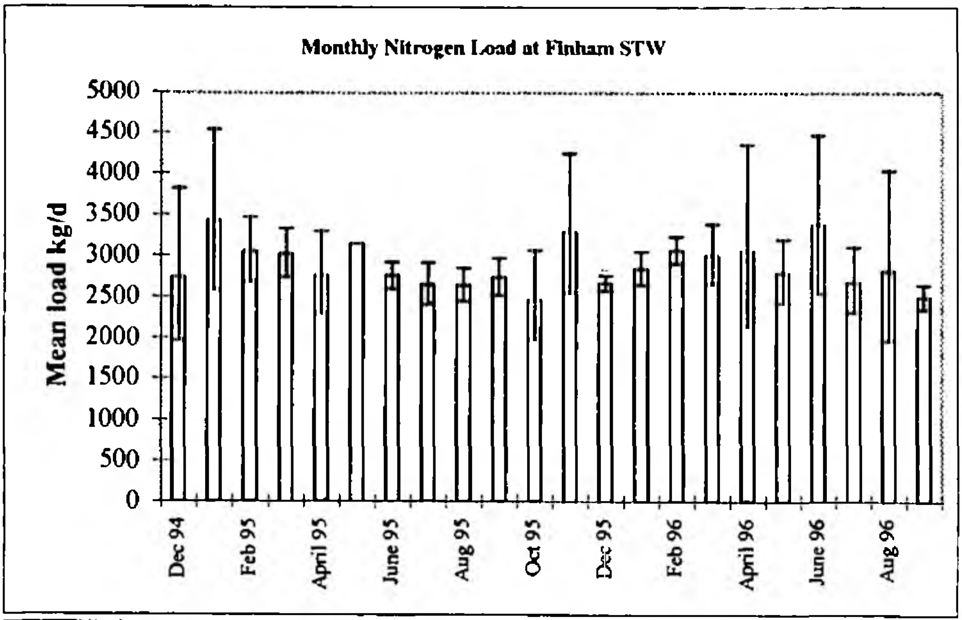
5. Highest mean daily loads of P, exceeding 2000 kg/d, are recorded in the period January-March 1995. As a result of the drier winter in 1995-96, in comparison with 1994-95, loads are some 500 kg/d lower for the January-March period in the second year.

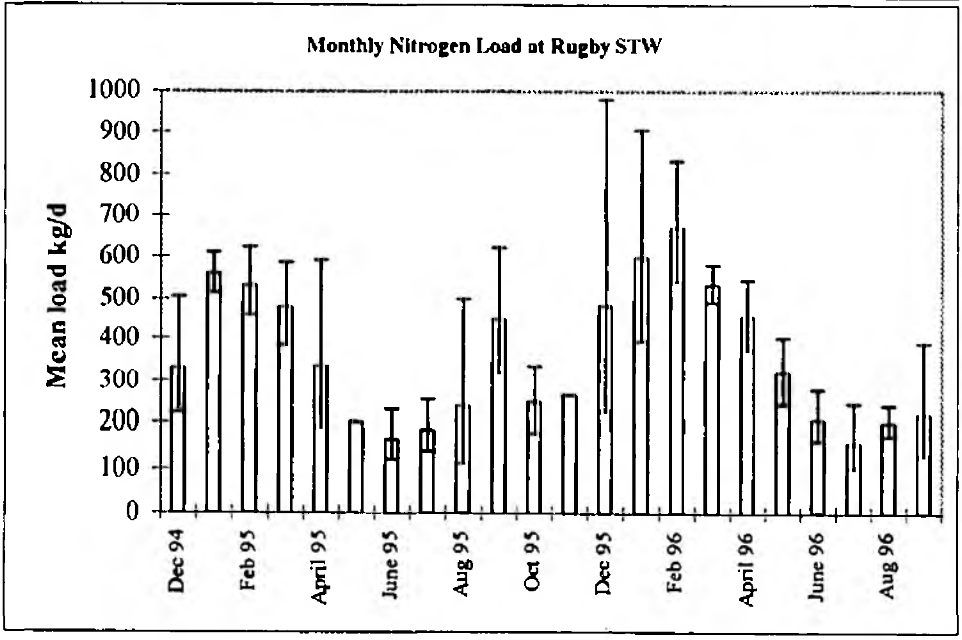
6. The absolute contribution from the 5 qualifying STWs to the total P load at Evesham remains relatively constant throughout the year for the whole period of record.

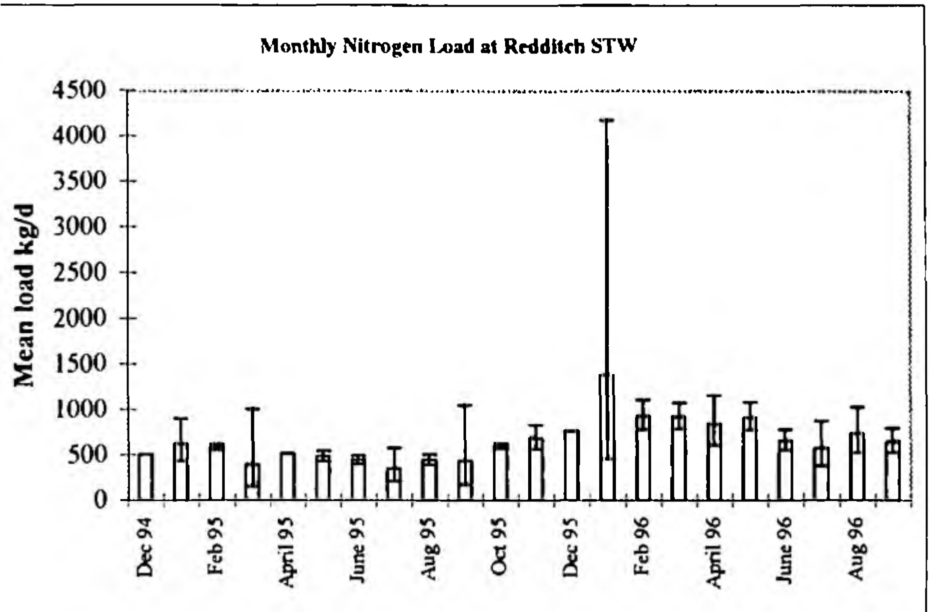
7. Particulate-P makes a major contribution to total P transport between January and March 1995 where it accounts for ca. 45% of the total load transported. For the remaining 6 periods particulate-P contributes only ca. 8%, 7%, 5%, 14%, 7% and 2.2% of the total P load at Evesham

8. Estimates of the seasonal contribution of qualifying STW effluent to the Total N load transported at Evesham are given in **Figure 46** from which the following points are noted.

9. Quarterly N loads range from 36849 to 4308 kg/d. As a result of the drier winter of 1996, average loads from January to March 1996 are ca. 10,000 kg/d lower than for the same period in 1995. Whilst effluent discharges could account for all of the total N transported at Evesham between July and September 1996, the pattern is highly variable with as little as 14% of the total N load at Evesham being accounted for by qualifying STW discharges in the period January to March 1995.


Monthly Nitrogen Load at Finham STW
Mean load kg/d
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96


Monthly Nitrogen Load at Rugby STW
Mean load kg/d
1000
900
800
700
600
500
400
300
200
100
0
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96



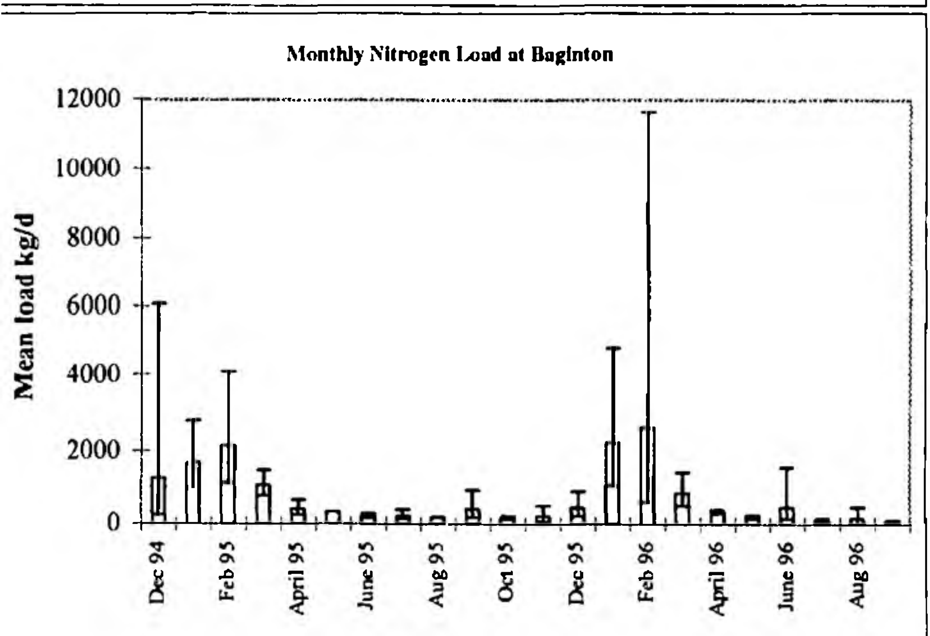
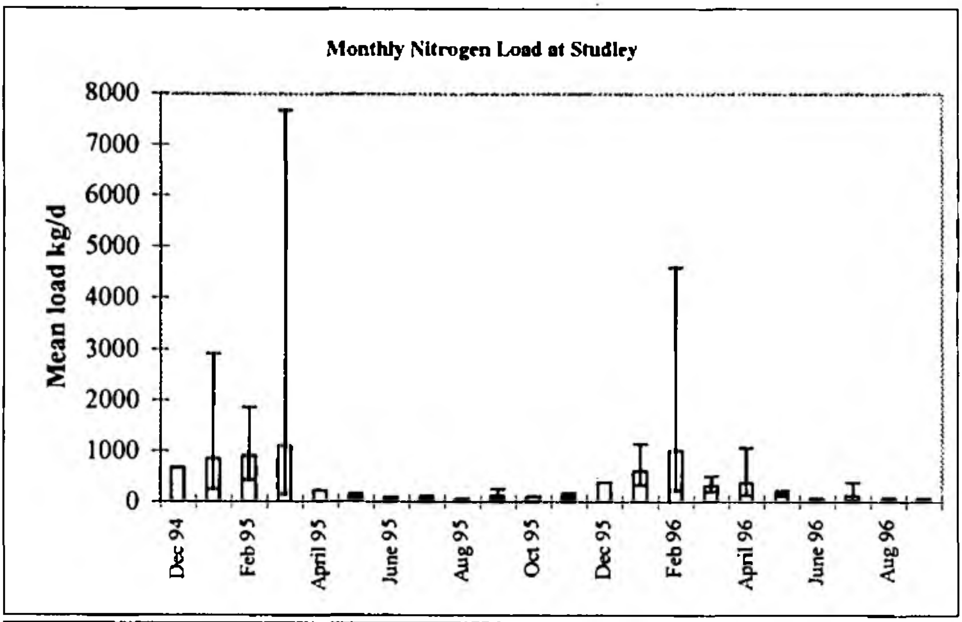
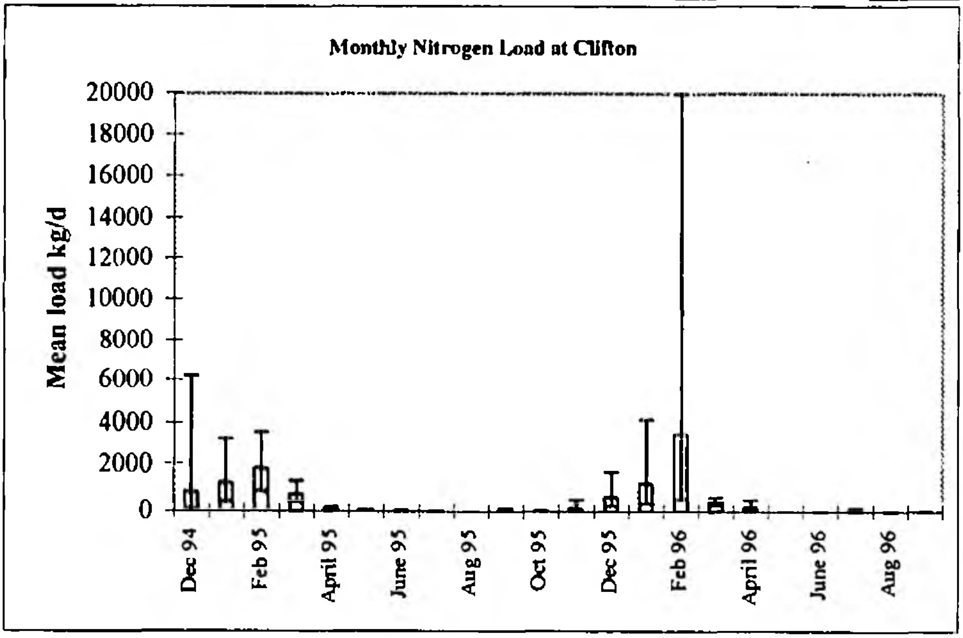
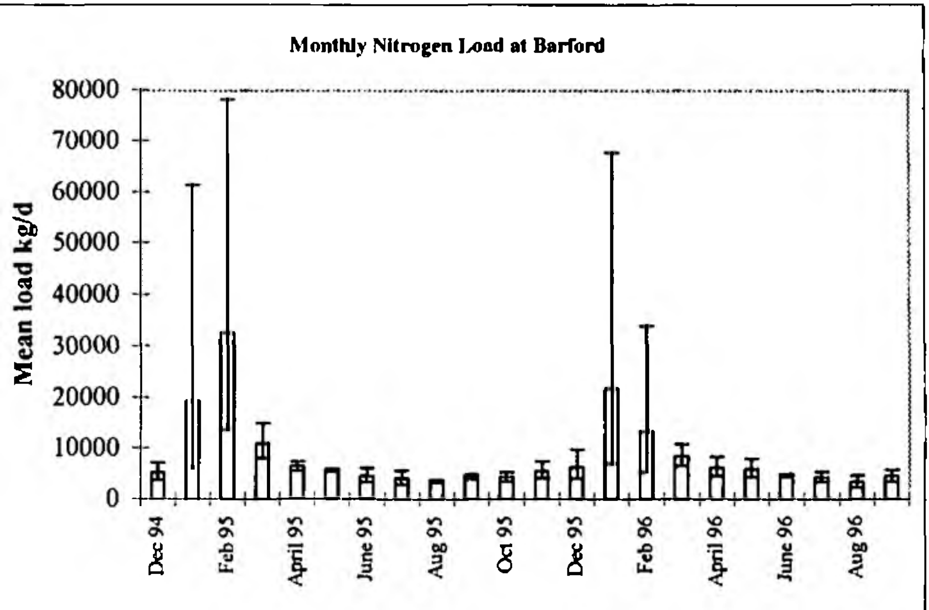


Figure 43 Monthly TN loads at all weekly monitoring sites


Monthly Nitrogen Load at Studley
Mean load kg/d
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96


Monthly Nitrogen Load at Clifton
Mean load kg/d
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96



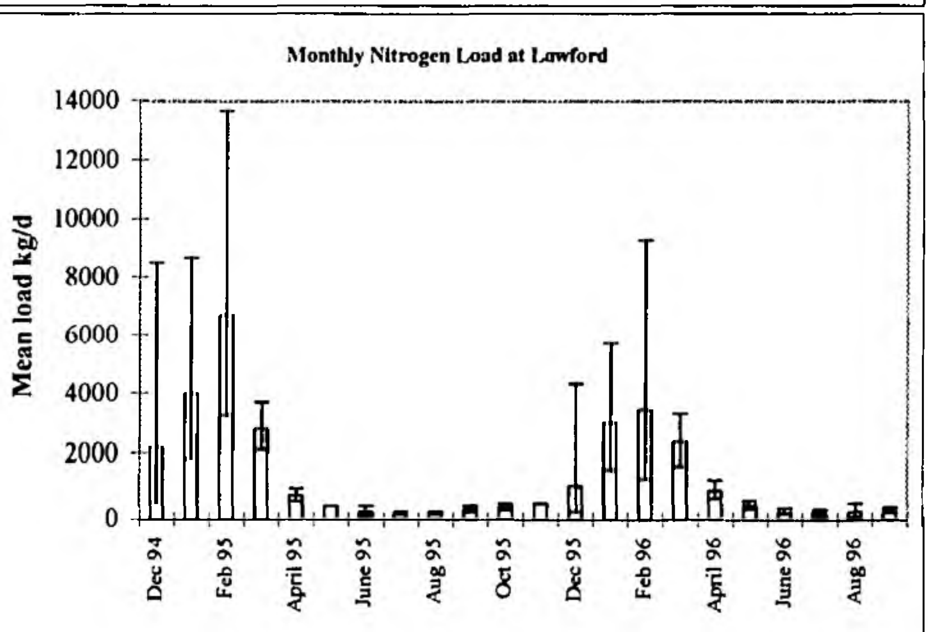
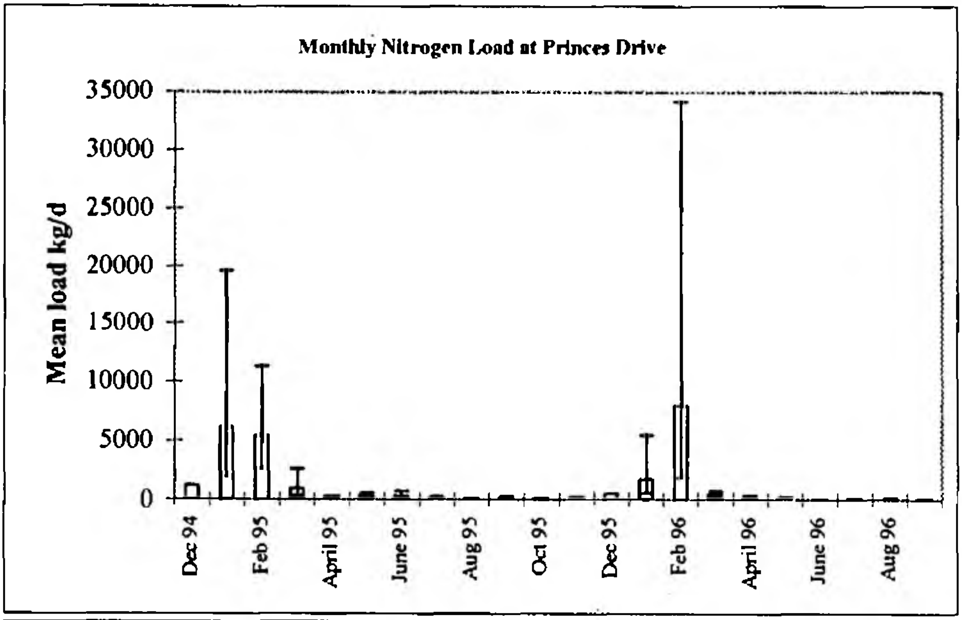
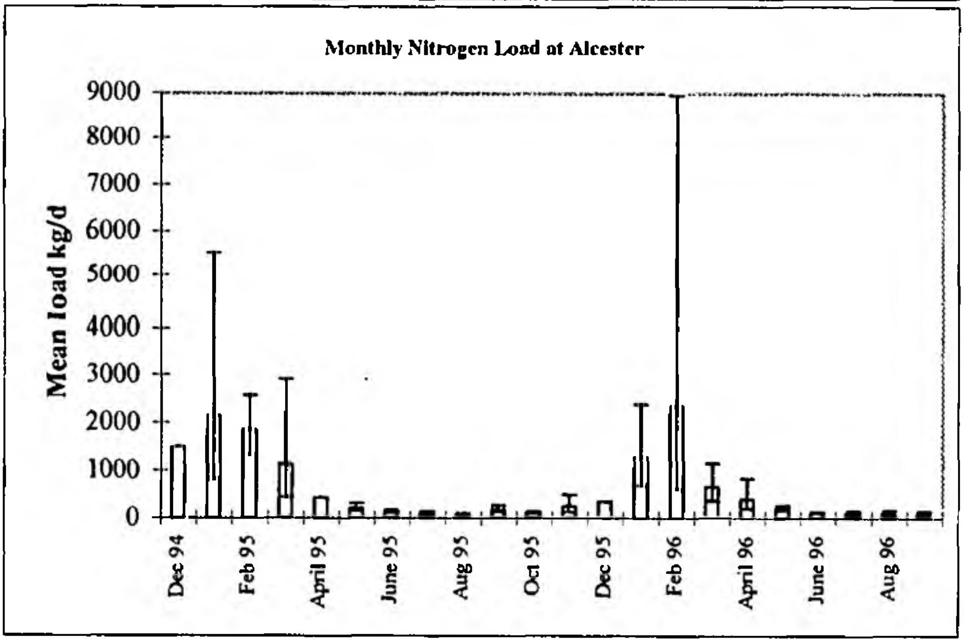
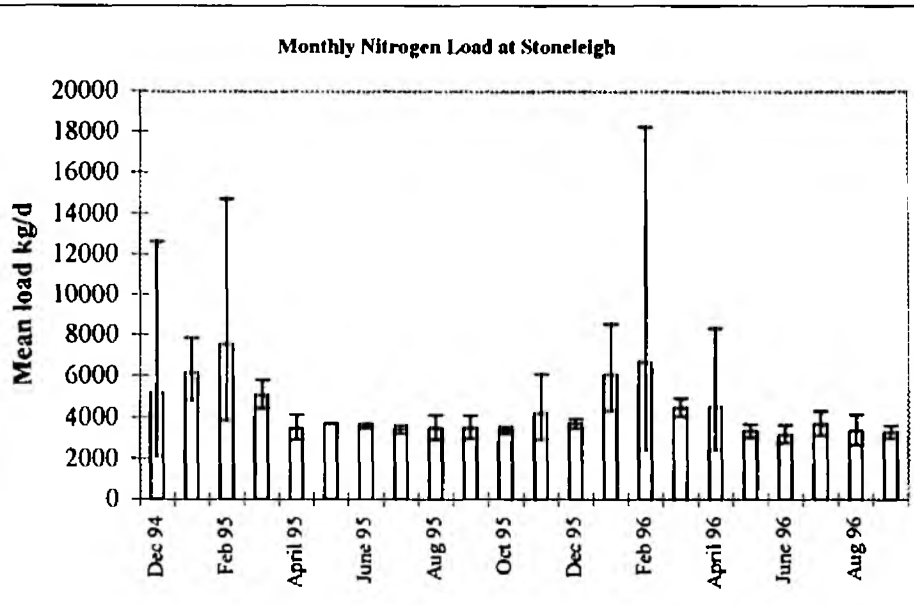


Figure 43 cont.


Monthly Nitrogen Load at Princes Drive
Mean load kg/d
35000
30000
25000
20000
15000
10000
5000
0
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96


Monthly Nitrogen Load at Alcester
Mean load kg/d
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96



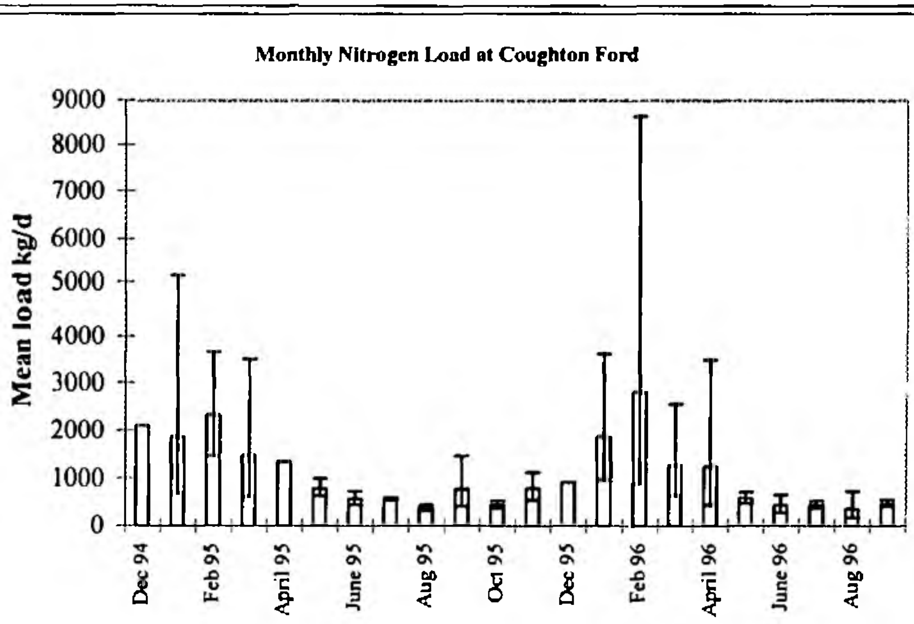
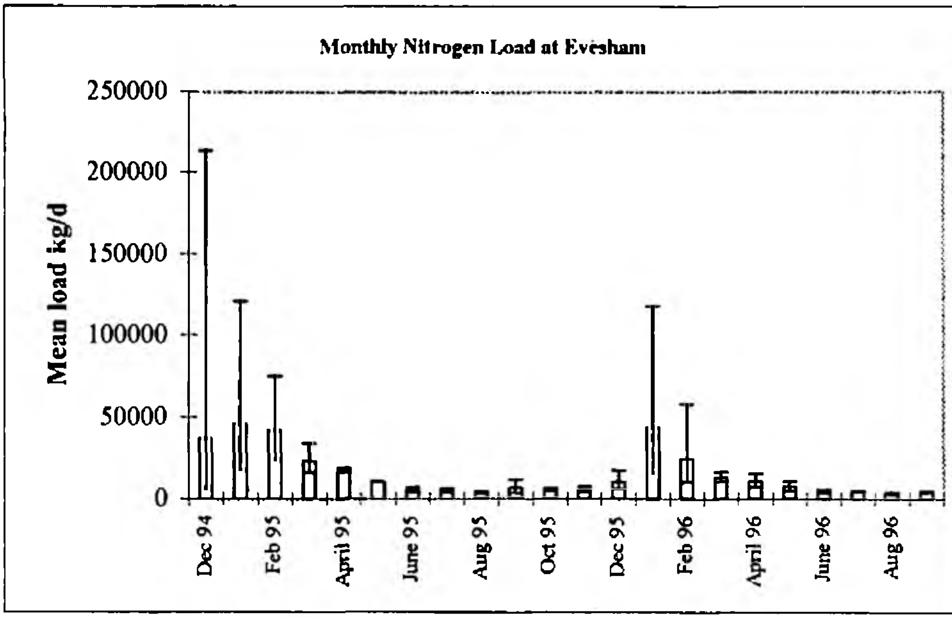
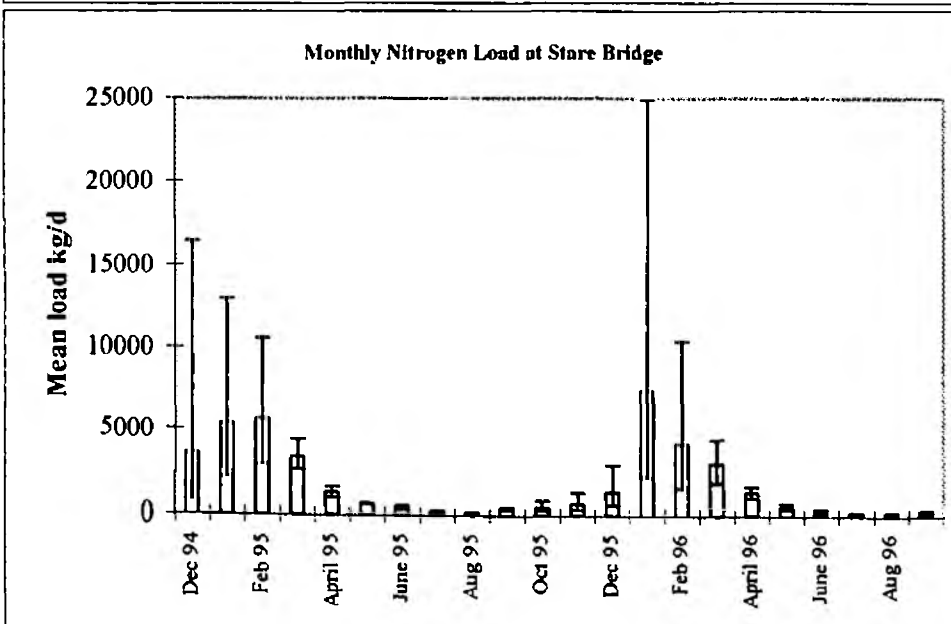


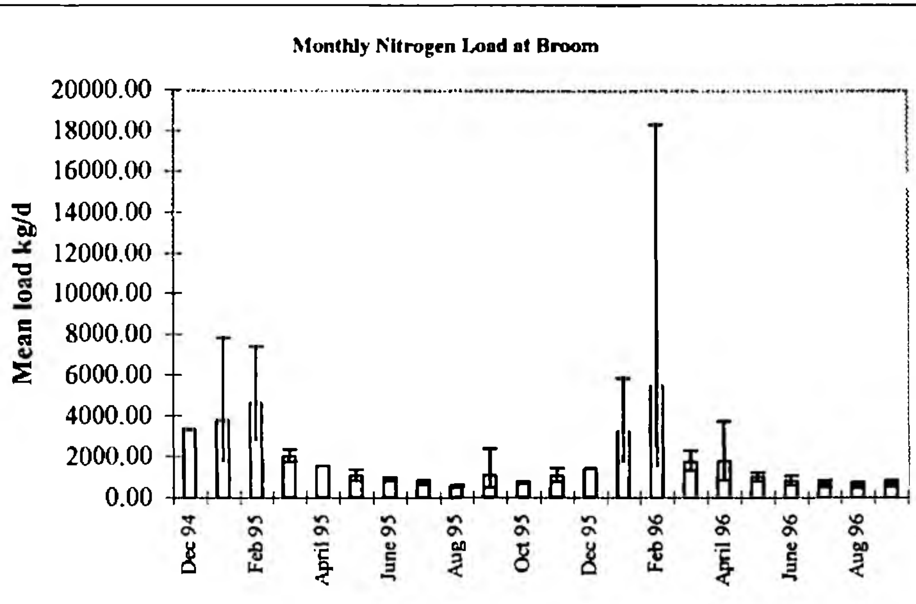
Figure 43 cont.



Monthly Nitrogen Load at Evesham
Mean load kg/d
250000
200000
150000
100000
50000
0
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96



Monthly Nitrogen Load at Stare Bridge
Mean load kg/d
25000
20000
15000
10000
5000
0
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96



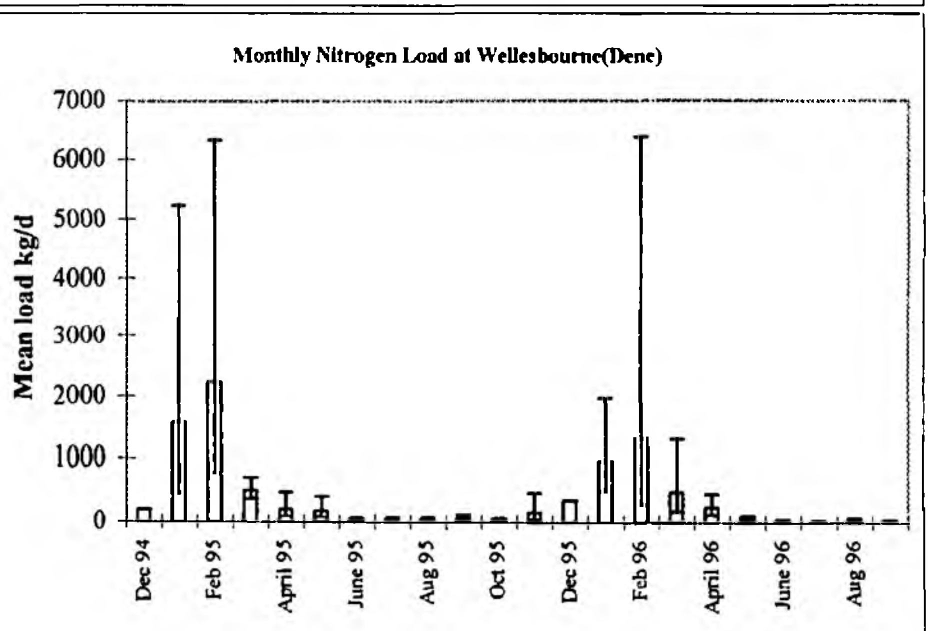
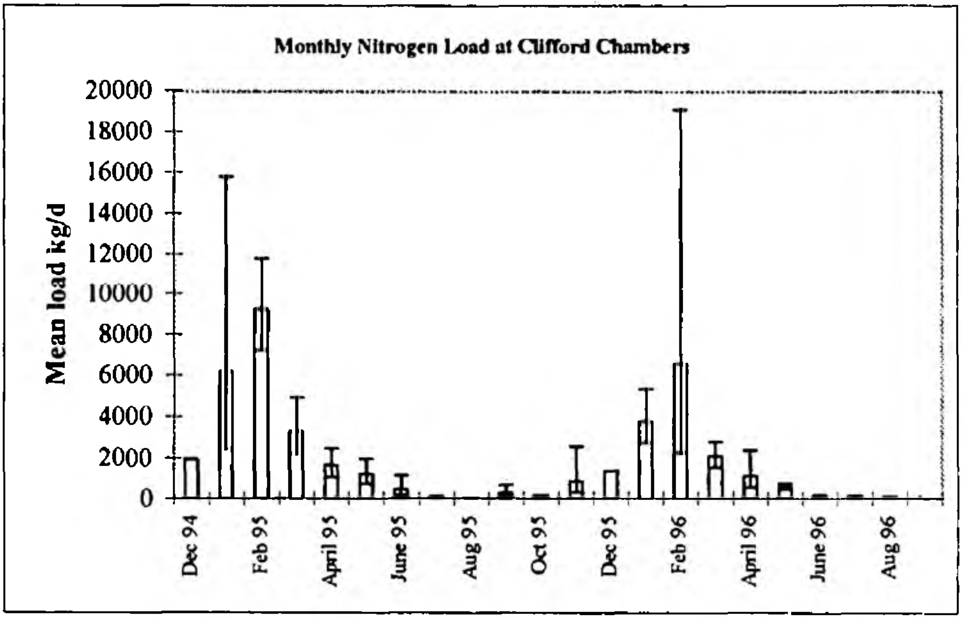


Figure 43 cont.



Monthly Nitrogen Load at Clifford Chambers
Mean load kg/d
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96

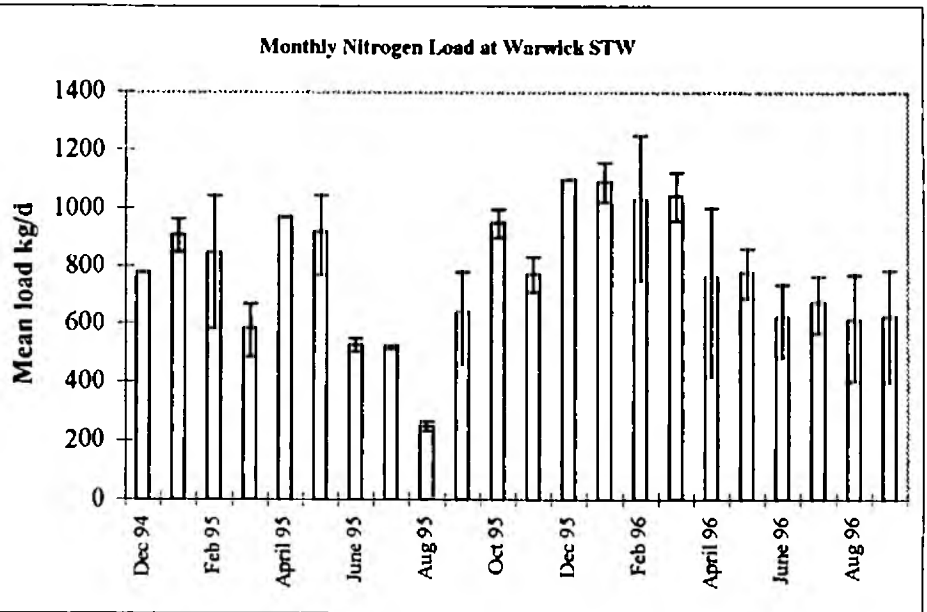
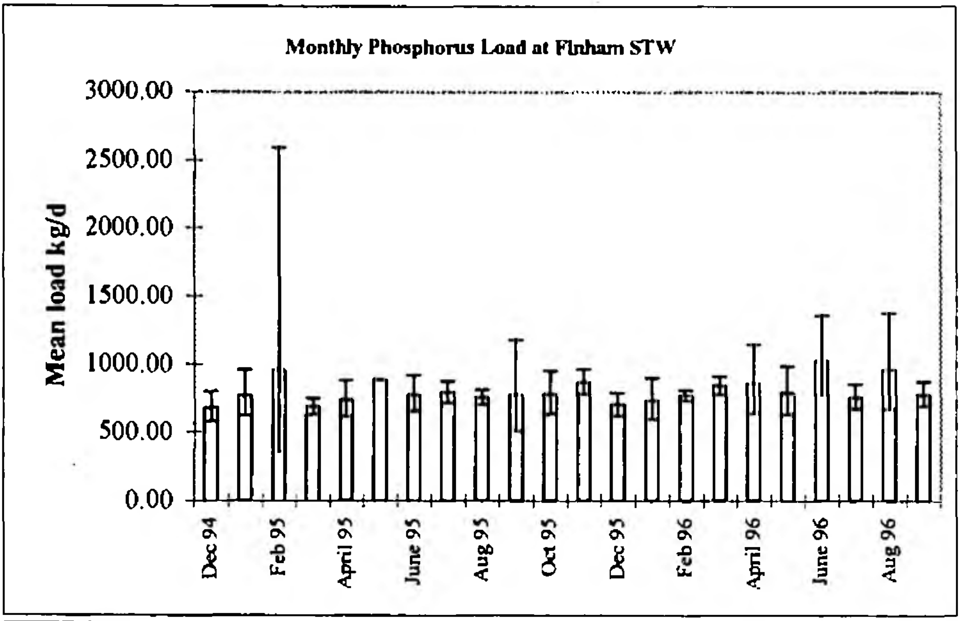
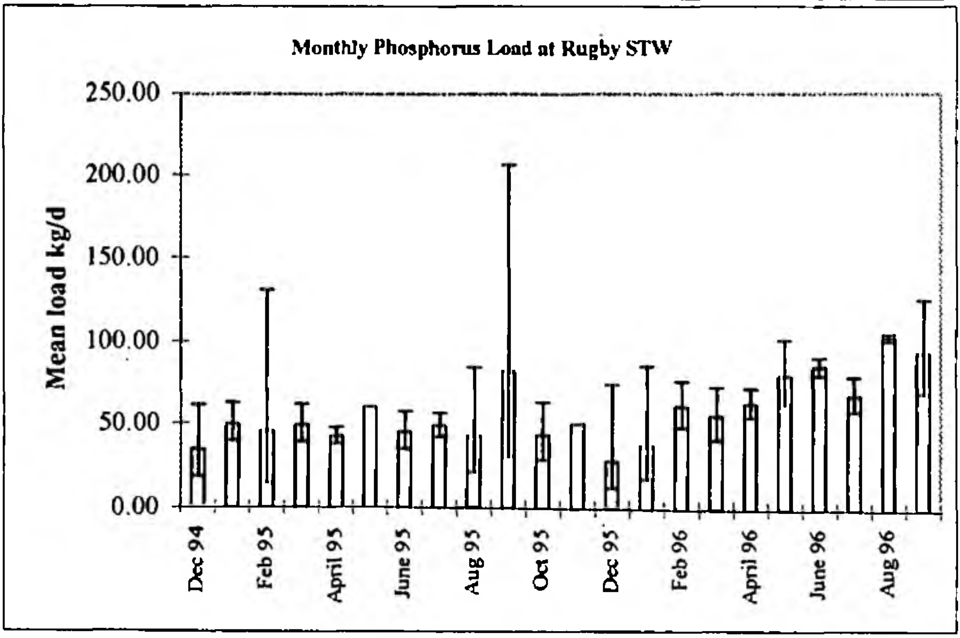
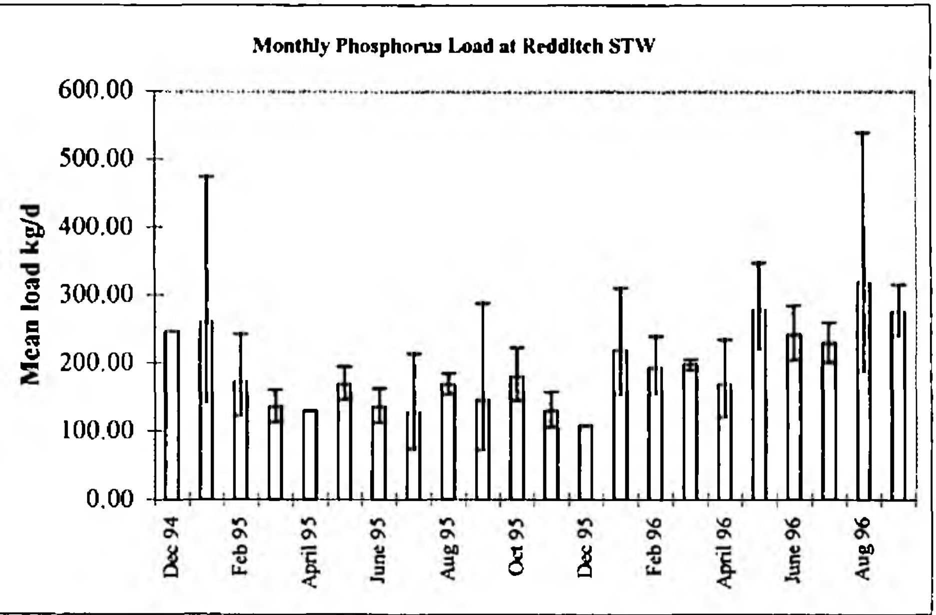


Figure 43 cont.


Monthly Phosphorus Load at Finham STW
Mean load kg/d
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96


Monthly Phosphorus Load at Rugby STW
Mean load kg/d
250.00
200.00
150.00
100.00
50.00
0.00
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96



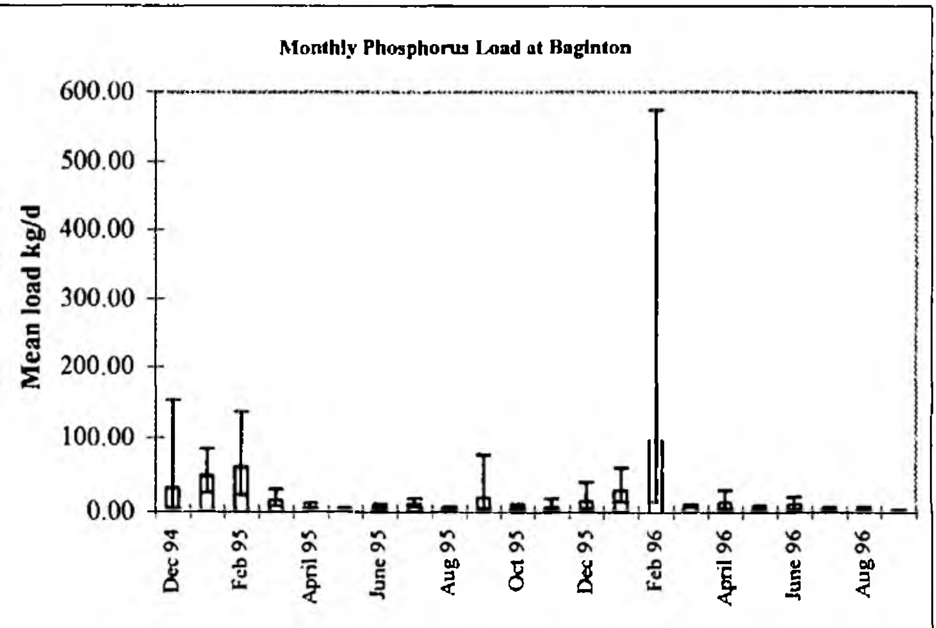
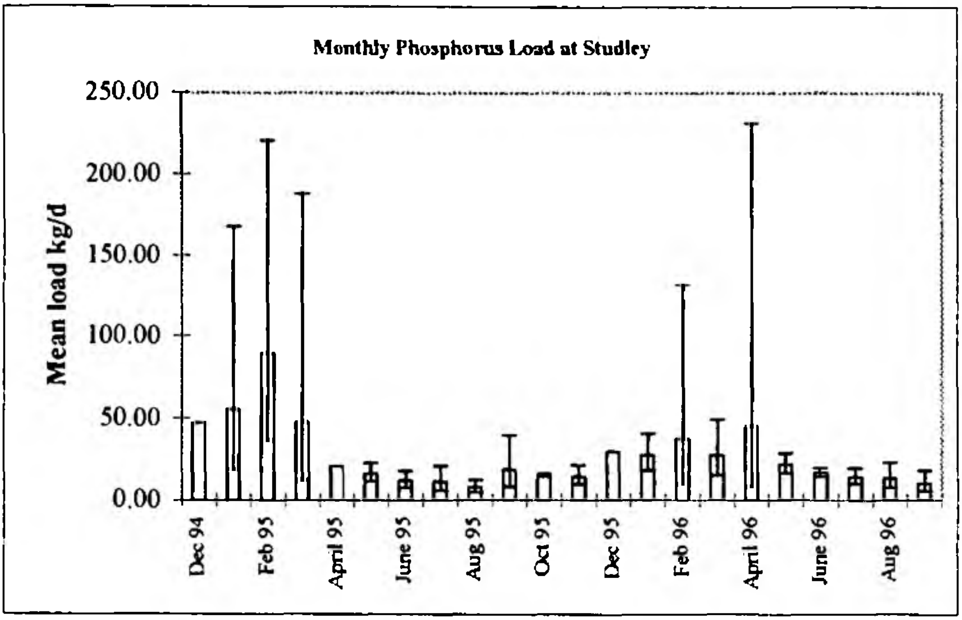
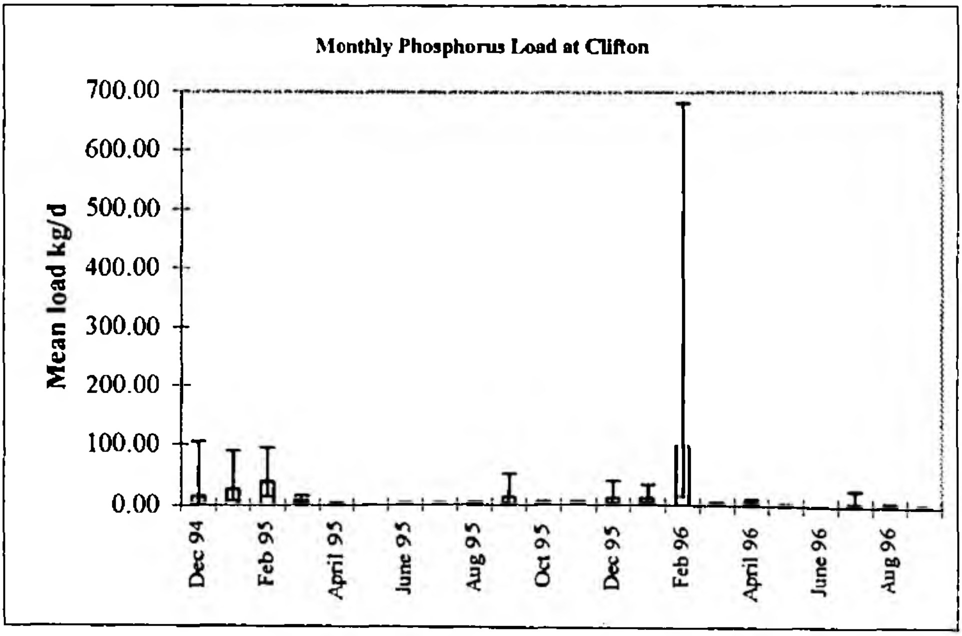
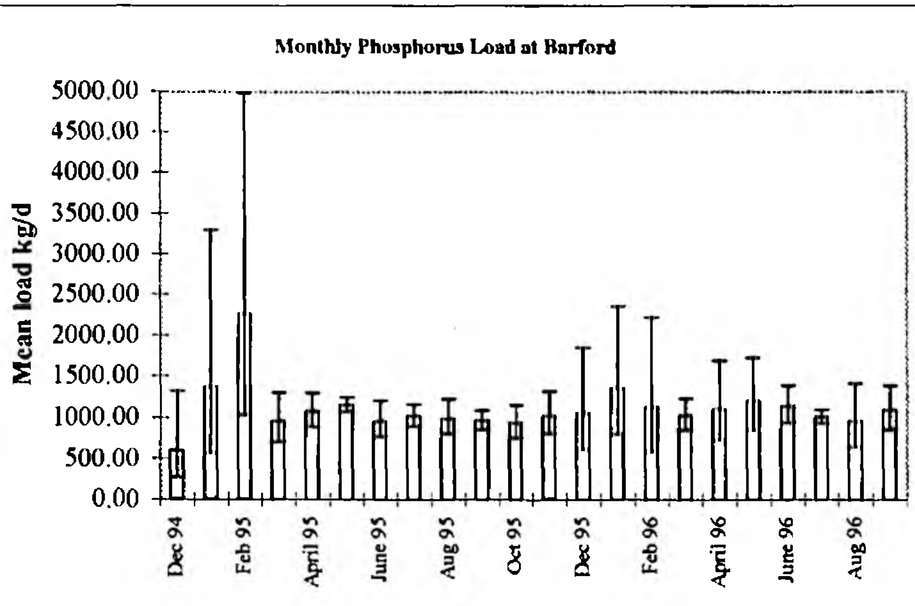


Figure 44 Monthly TP loads at all weekly monitoring sites


Monthly Phosphorus Load at Studley
Mean load kg/d
250.00
200.00
150.00
100.00
50.00
0.00
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96


Monthly Phosphorus Load at Clifton
Mean load kg/d
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96



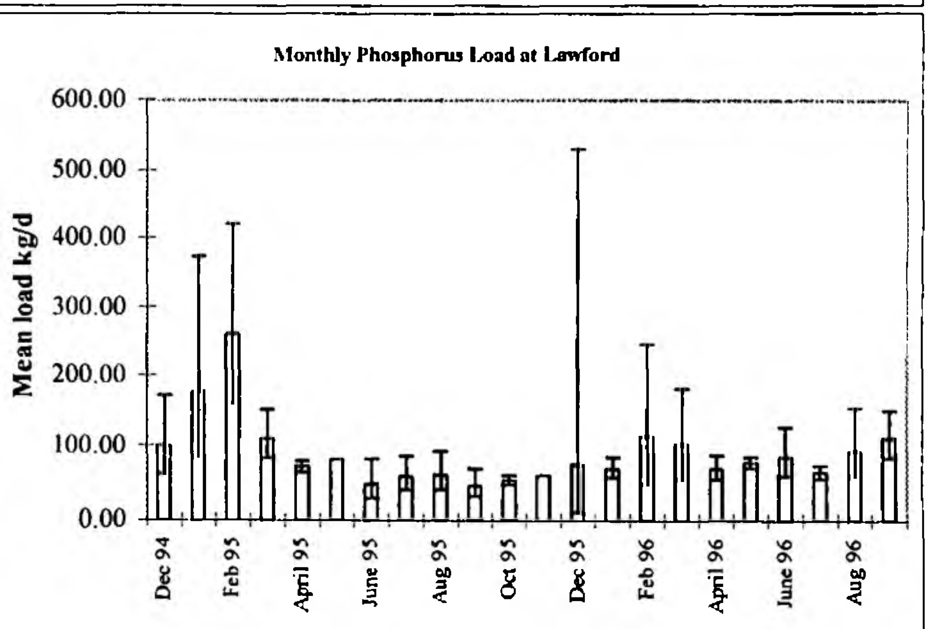
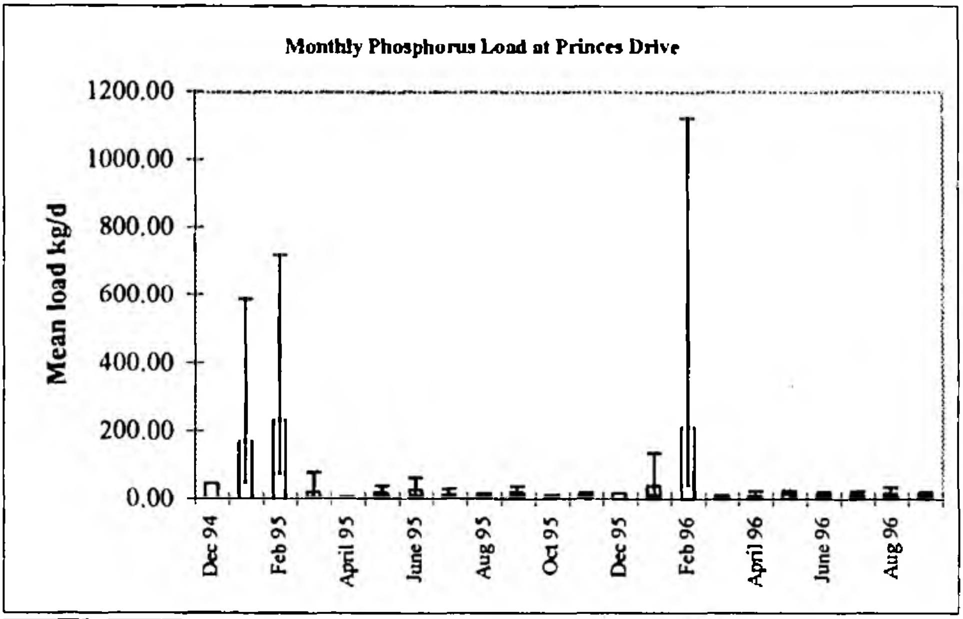
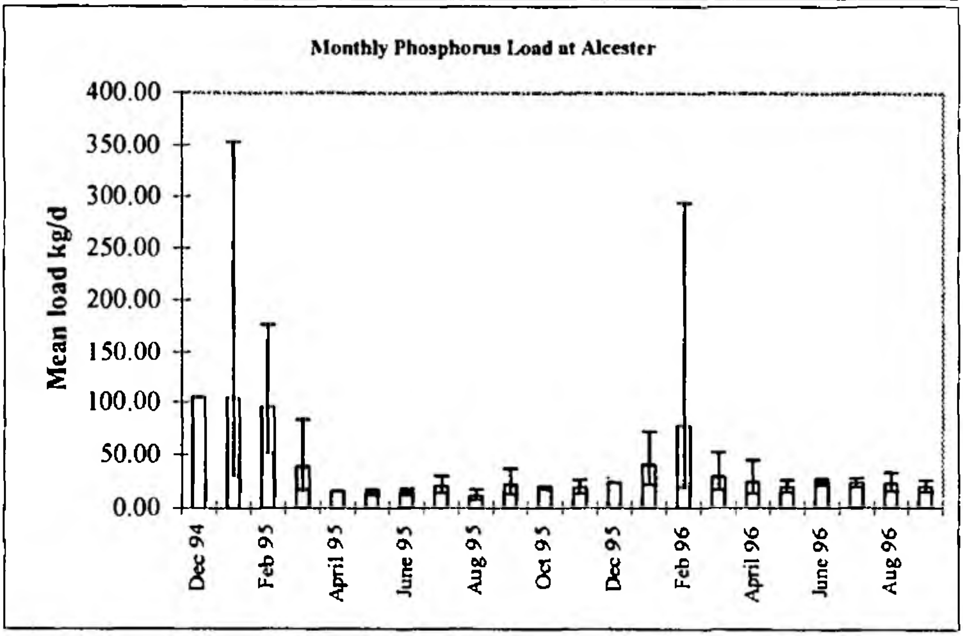
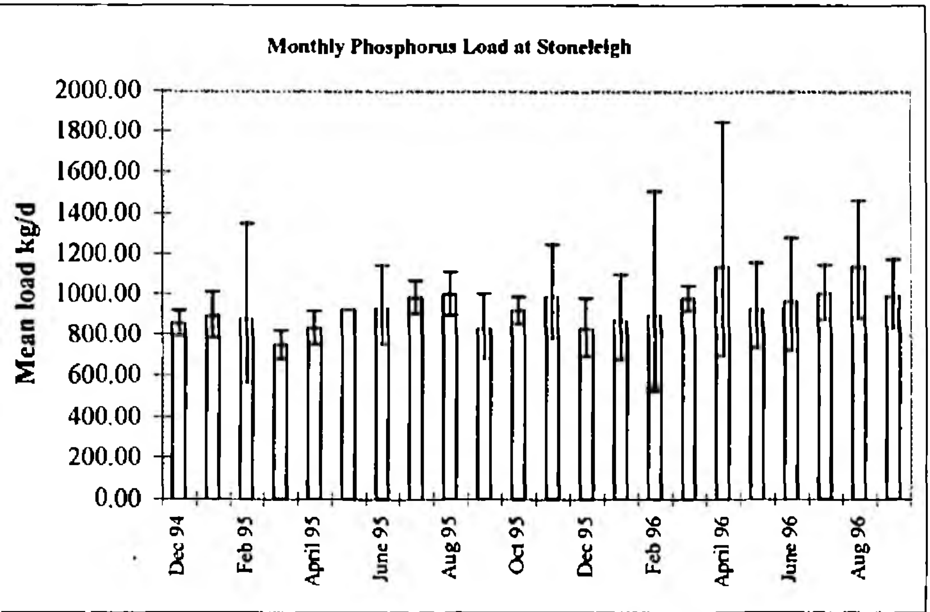


Figure 44 cont.


Monthly Phosphorus Load at Princes Drive
Mean load kg/d
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96


Monthly Phosphorus Load at Alcester
Mean load kg/d
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96



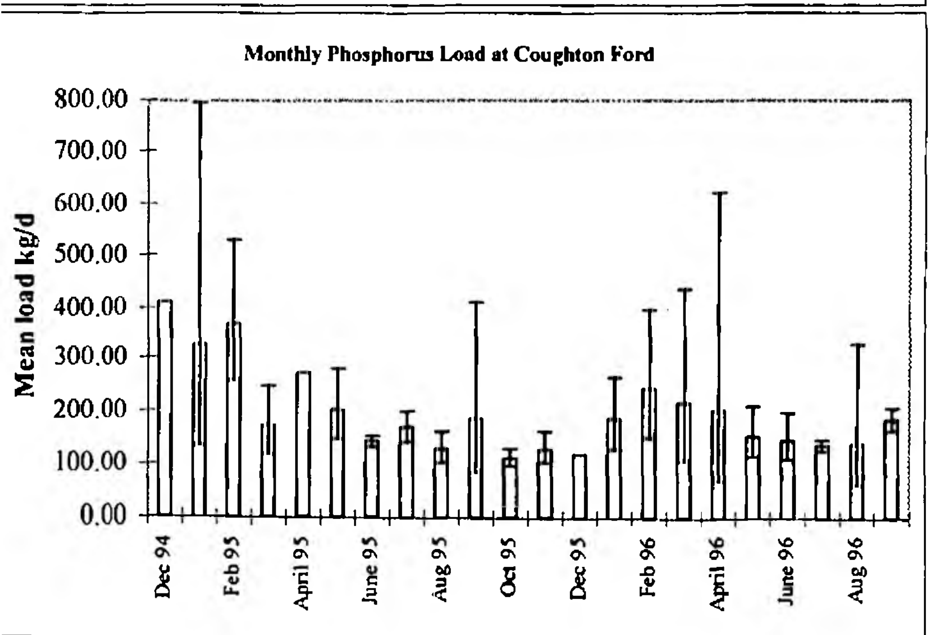
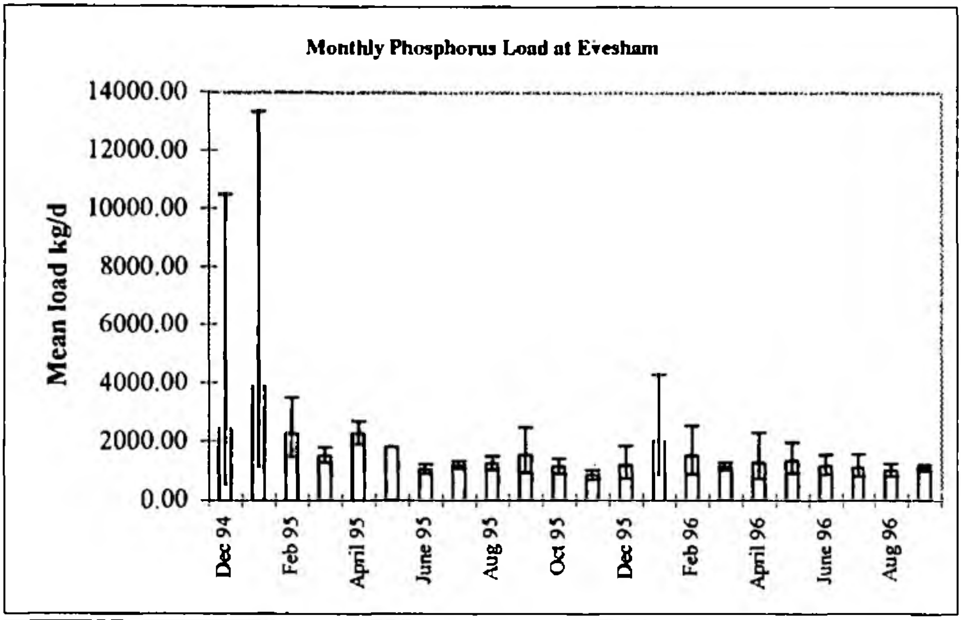


Figure 44 cont.


Monthly Phosphorus Load at Evesham
Mean load kg/d
14000.00
12000.00
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96

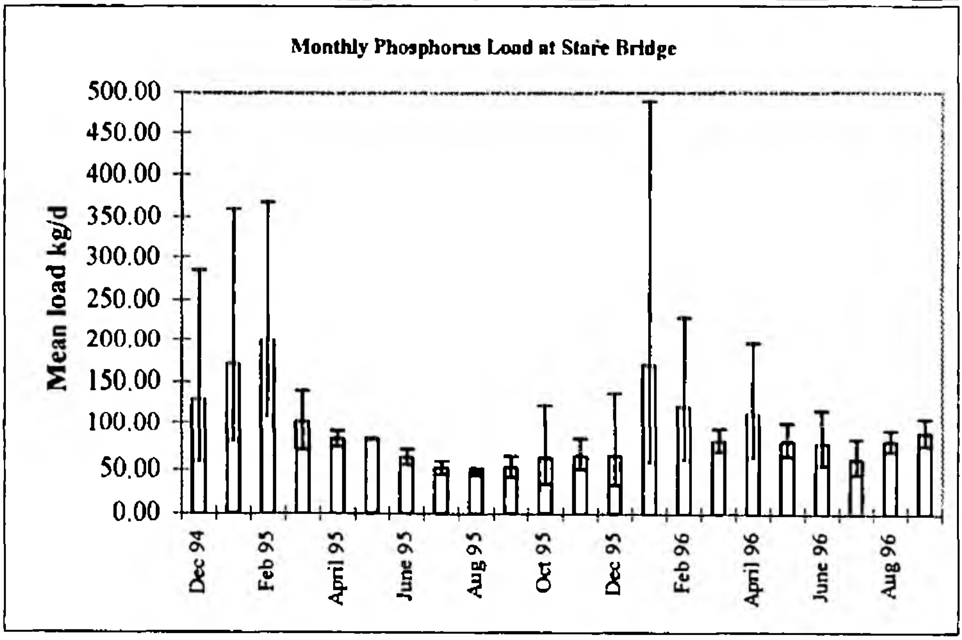
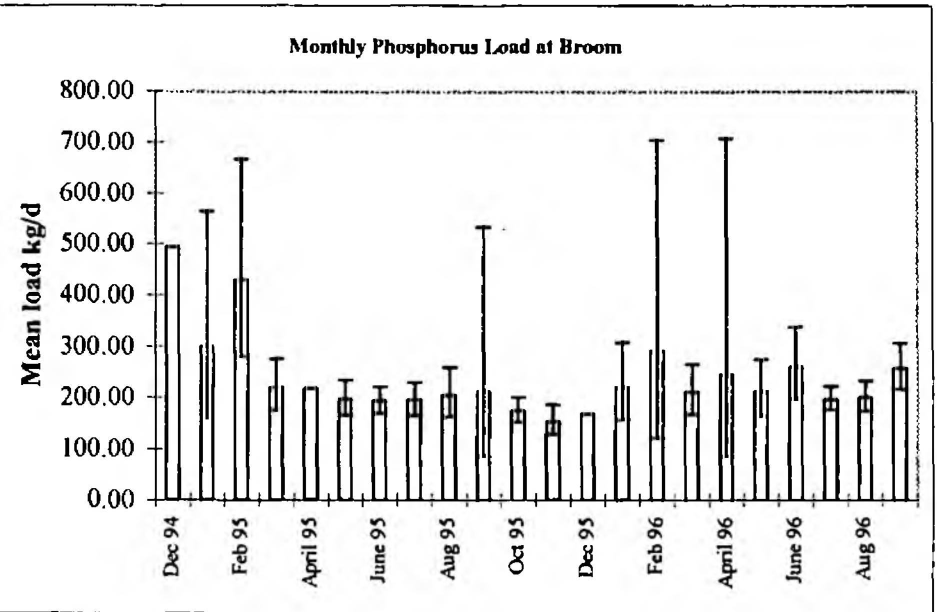
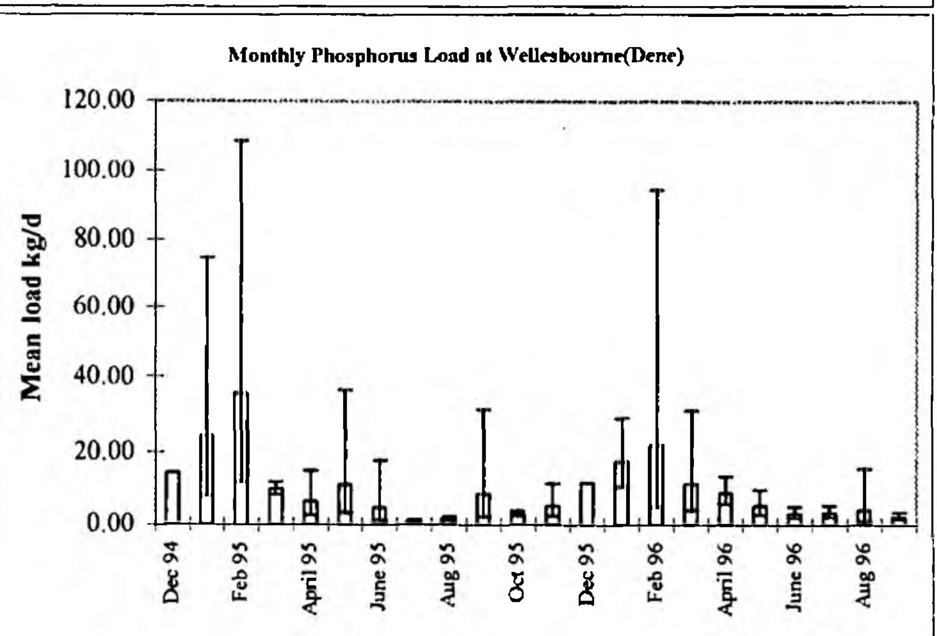
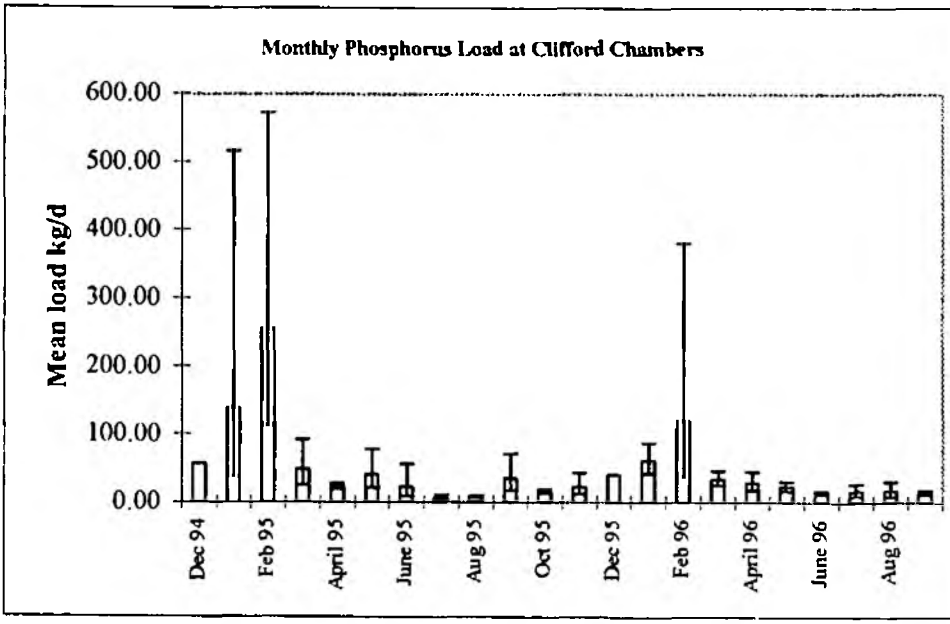

Monthly Phosphorus Load at Stare Bridge
Mean load kg/d
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96

Figure 44 cont.






Monthly Phosphorus Load at Clifford Chambers
Mean load kg/d
600.00
500.00
400.00
300.00
200.00
100.00
0.00
Dec 94
Feb 95
April 95
June 95
Aug 95
Oct 95
Dec 95
Feb 96
April 96
June 96
Aug 96

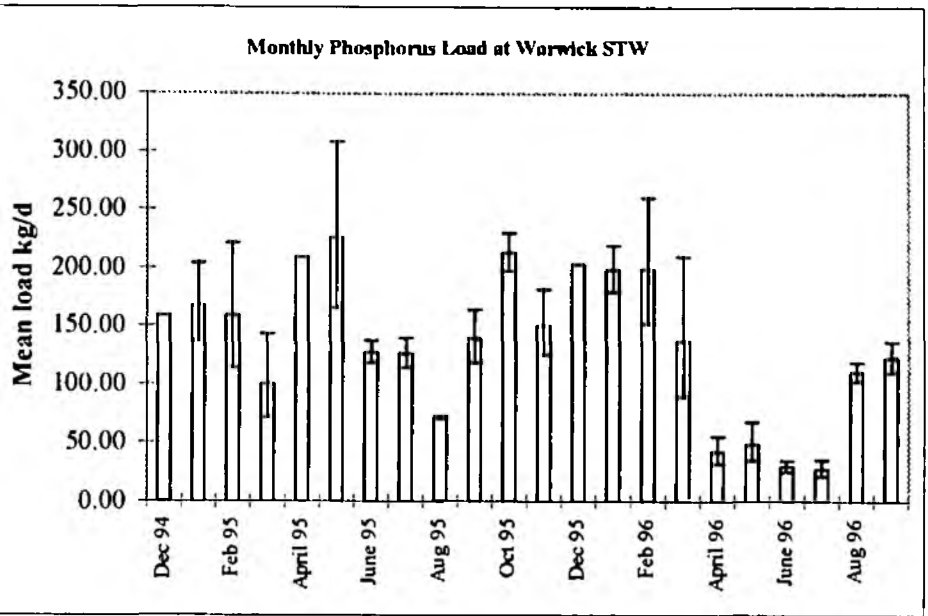


Figure 44 cont.

Figure 45 Seasonal contribution of Qualifying STW effluent loads to P transport at Evesham

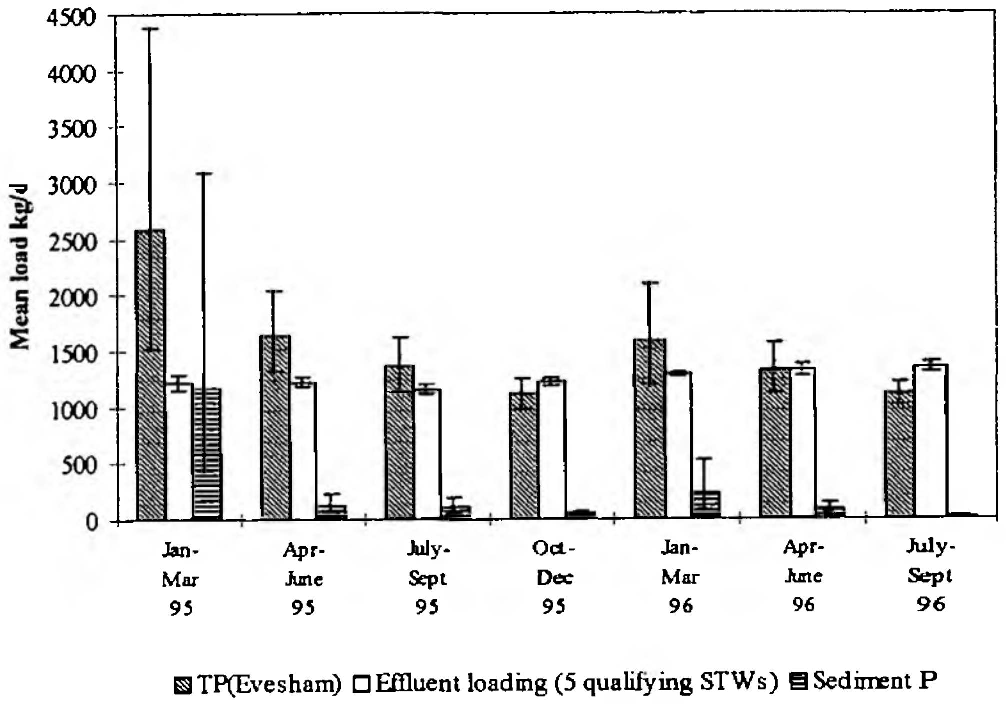
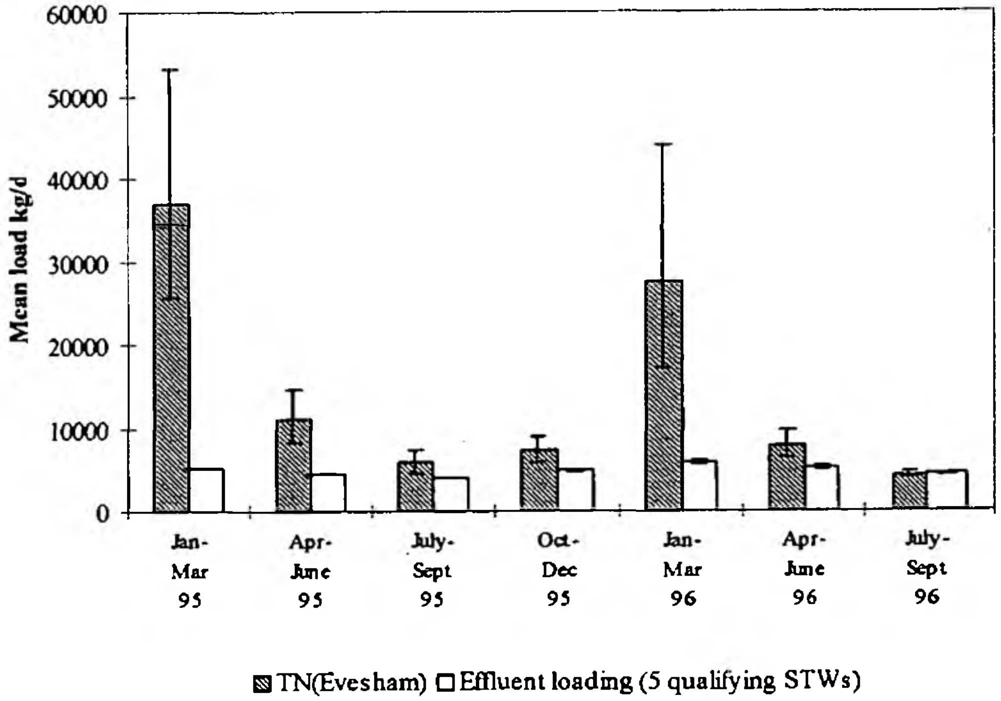


Figure 46 Seasonal contribution of Qualifying STW effluent loads to N transport at Evesham



8.7 The impact of the Urban Waste Water Treatment Directive on River Loads.

1. The Council Directive (91/271/EEC) defines nutrient removal for two classes of effluent.

a) For a pe of greater than 100000, maximum total N and P concentrations are set at 10 and 1 mg/l (as annual means) respectively.

b) For a pe of between 10000 and 100000, maximum total N and P concentrations are set at 15 and 2 mg/l (as annual means) respectively.

2. For the qualifying discharges, it is assumed that class a) is applicable to Finham and class b) is applicable to Rugby (Newbold), Redditch, Stratford (Milcote) and Warwick (Longbridge). Although N removal will not be undertaken at qualifying STWs, selective calculations are presented for information.

3. For the purposes of the following calculations, it is assumed that the maximum permissible concentrations (ass annual means) are discharged throughout the year.

4. The impact of nutrient removal from qualifying STWs on N and P loads at Evesham, assuming minimum compliance with the Urban Waste Water Treatment Directive, is given in **Figure 47**. It is calculated that the total P load reduction approaches 1000 kg/d (over 50%) and that the total N load reduction is ca. 1800 kg/d (11%). The most significant impact is achieved by nutrient removal at Finham, Redditch and Warwick with a relatively insignificant impact at Rugby and Stratford. Following nutrient removal it is estimated that total N yields would be ca. 21 kg N/ha/yr and total P yields would be ca. 1.29 kg P/ha/yr.

5. After nutrient removal, it is estimated that the minor STWs contribute over 40% of total P and around 8% of total N to nutrient loads at Evesham.

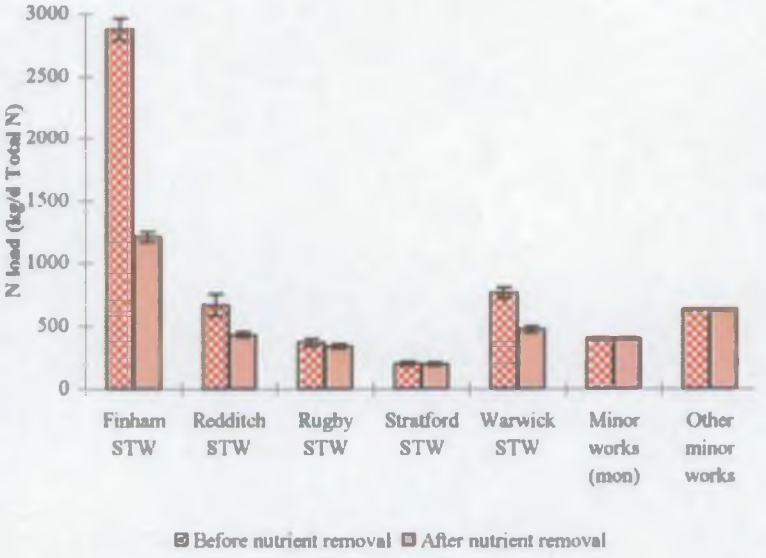
6. After nutrient removal, the major diffuse and/or unaccounted P load derives from the Rivers Sowe (16%) and Stour (1.5%) and the diffuse and/or unaccounted N load derives from the Rivers Sowe (11%), Stour (13%) and the upper Avon (10%).

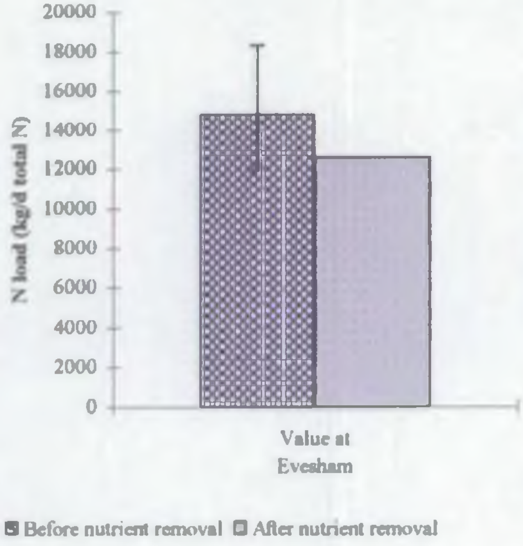
7. Further scenarios in relation to P removal have been examined in **Figure 48**. **Figure 48a** examines the impact of reducing all minor STWs to a 2 mg/l total P threshold. It is estimated that compliance with this maximum threshold at all STWs would result in a reduction in total P load at Evesham by an additional 233 kg/d, or 15% of the total P load currently transported.

8. **Figure 48b** examines the impact of reducing total P concentrations to zero at the qualifying works and to 2 mg/l total P at other sites. This is predicted to reduce loads at Evesham to around 15% of the current load. Such a reduction would give an export coefficient of ca. 0.39 kg P/ha/yr for the Avon at Evesham.

a) N loads before and after N removal based on a consent of 10mg/l at Finham and 15mg/l Total N at other Qualifying Works

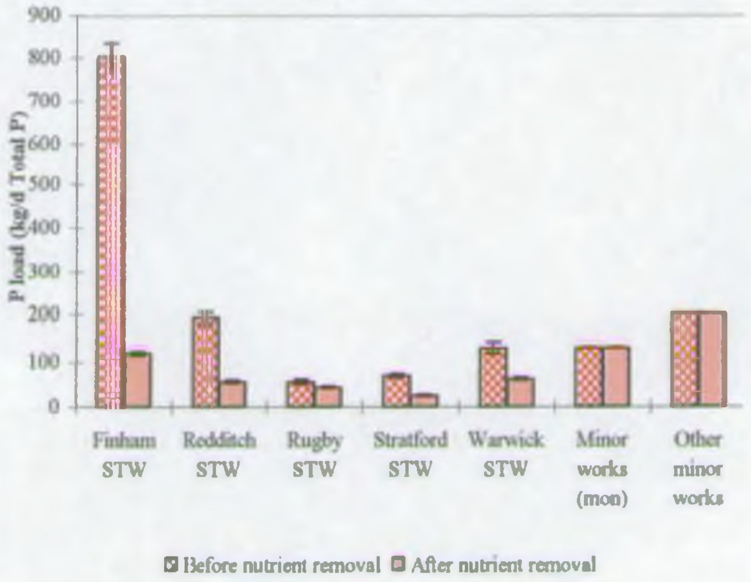
WHOLE AVON	BEFORE		AFTER	
	kg/d Total N	% Total N	kg/d Total N	% Total N
Measured Value at Evesham	14845.74	100.00	12619.82	100.00
Source				
Finham STW	2882.10	19.41	1211.10	9.60
Redditch STW	671.05	4.52	435.38	3.45
Rugby STW	368.70	2.48	341.25	2.70
Stratford STW	209.41	1.41	202.93	1.61
Warwick STW	766.12	5.16	480.80	3.81
Minor works (mon)	407.91	2.75	407.91	3.23
Other minor works	643.13	4.33	643.13	5.10





b) P loads before and after P removal based on a consent of 1mg/l at Finham and 2mg/l Total P at other Qualifying Works

WHOLE AVON	BEFORE		AFTER	
	kg/d Total P	% Total P	kg/d Total P	% Total P
Measured Value at Evesham	1550.63	100.00	611.99	100.00
Source				
Finham STW	801.73	51.70	121.11	19.79
Redditch STW	193.45	12.48	58.05	9.49
Rugby STW	57.28	3.69	45.50	7.43
Stratford STW	70.80	4.57	27.06	4.42
Warwick STW	131.21	8.46	64.11	10.48
Minor works (mon)	132.22	8.53	132.22	21.61
Other minor works	202.44	13.06	202.44	33.08



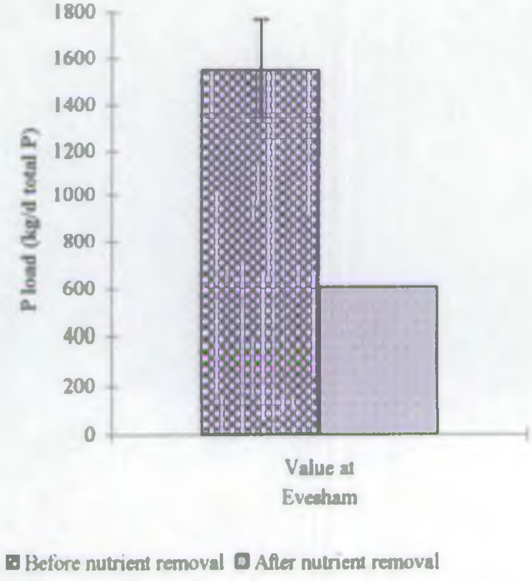
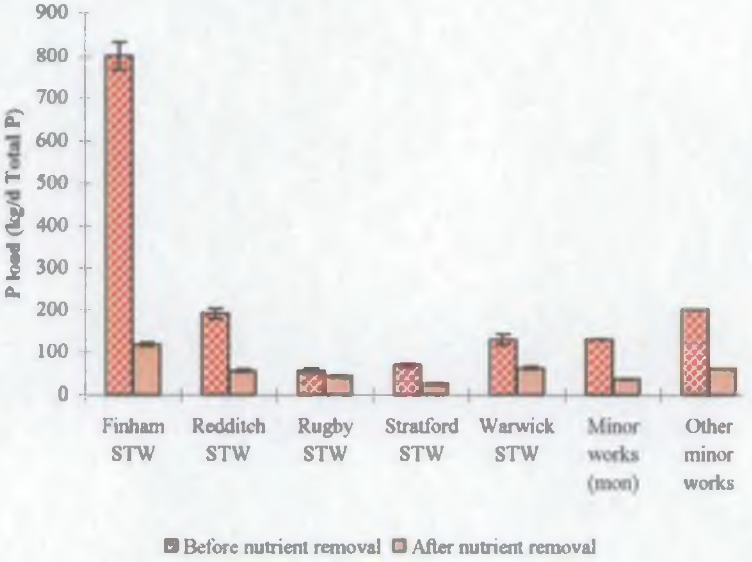
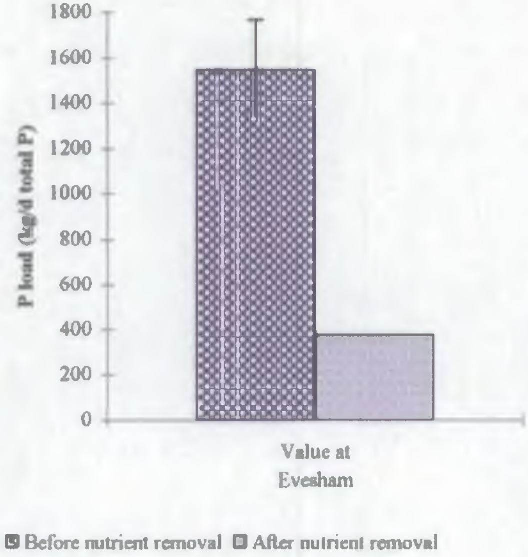


Figure 47 The potential impact of meeting the UWWT Directive on N and P loads at Evesham

a) P loads before and after P removal based on a consent of 1mg/l at Finham and 2mg/l Total P at other Qualifying and Minor Works

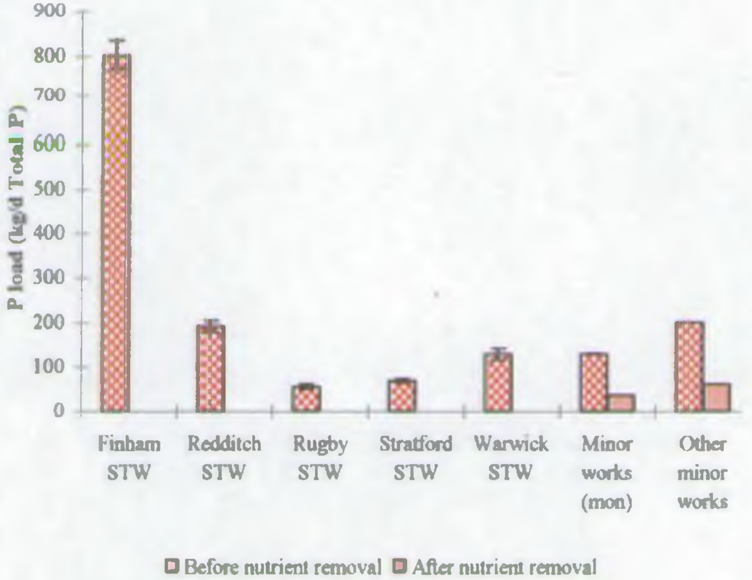
WHOLE AVON	BEFORE		AFTER	
	kg/d Total P	% Total P	kg/d Total P	% Total P
Measured Value at Evesham	1550.63	100.00	378.71	100.00
Source				
Finham STW	801.73	51.70	121.11	31.98
Redditch STW	193.45	12.48	58.05	15.33
Rugby STW	57.28	3.69	45.50	12.01
Stratford STW	70.80	4.57	27.06	7.14
Warwick STW	131.21	8.46	64.11	16.93
Minor works (mon)	132.22	8.53	38.07	10.05
Other minor works	202.44	13.06	63.31	16.72





b) P loads before and after P removal based on a consent of 0mg/l at Qualifying works and 2mg/l Total P at all Minor Works

WHOLE AVON	BEFORE		AFTER	
	kg/d Total P	% Total P	kg/d Total P	% Total P
Measured Value at Evesham	1550.63	100.00	62.88	100.00
Source				
Finham STW	801.73	51.70	0.00	0.00
Redditch STW	193.45	12.48	0.00	0.00
Rugby STW	57.28	3.69	0.00	0.00
Stratford STW	70.80	4.57	0.00	0.00
Warwick STW	131.21	8.46	0.00	0.00
Minor works (mon)	132.22	8.53	38.07	60.54
Other minor works	202.44	13.06	63.31	100.69



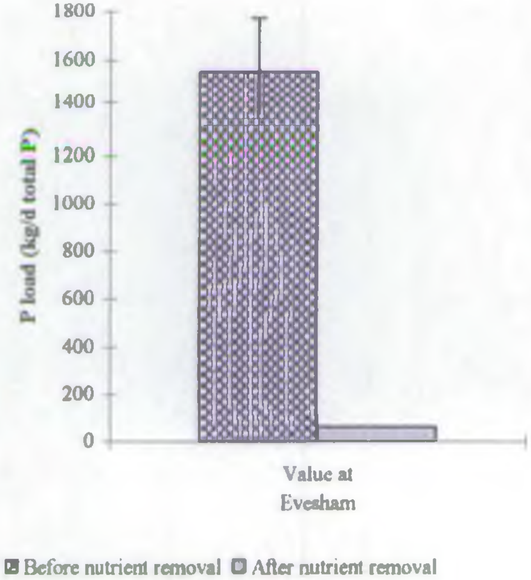


Figure 48 The potential impact of further reductions in P concentrations from STW discharges on P loads at Evesham.

9. EFFECTS OF FIELD FILTERING ON ORTHOPHOSPHATE ANALYSIS

1. As part of the monitoring strategy, samples of water were field filtered and analysed for orthophosphate in addition to the same analysis being performed on unfiltered samples. These data have been compared to establish the impact of filtering on the preservation of orthophosphate during transport and storage in unfiltered conditions.

2. **Figure 49** plots the relationship between filtered and unfiltered data for all sites at which weekly sampling was undertaken. (At each site, between 73 and 87 samples were collected and analysed).

3. Two sets of statistical analysis have been undertaken on the filtered and unfiltered samples at each of the 18 sites and is summarised in **Table 11**. A t test was used to compare the mean concentrations determined on filtered and unfiltered samples. The table includes the computed t value (t^a value) and its significance (t^a sig) using a two-tailed significance test at the 5% confidence level. An F test was used to compare the variances of the filtered and unfiltered data sets following the procedure recommended by the WRc where:

F-value = variance of PO_4 difference/$\sqrt{s_1^2 + s_2^2}$
s_1 is the reported AQC standard deviation for PO_4 unfiltered (**Table 2**)
s_2 is the reported AQC standard deviation for PO_4 filtered (**Table 2**)

Table 11 Comparison between filtered and unfiltered orthophosphate determinations on paired samples from 18 weekly monitoring sites in the Avon catchment.

	PO_4 filt Mean	PO_4 unfilt Mean	PO_4 diff Mean	PO_4 diff Stdev	t^a value	t^a sig	f^b value
Alne (Alcester)	0.506	0.514	0.012	0.041	2.59	0.011	3.31
Arrow (Broom)	1.753	1.771	0.034	0.062	5.03	0.000	3.15
Arrow (Coughton Ford)	2.322	2.400	0.094	0.223	3.81	0.000	22.74
Arrow (Studley)	0.696	0.643	-0.042	0.077	-4.79	0.000	6.90
Avon (Barford)	2.544	2.595	0.051	0.068	6.89	0.000	1.81
Avon (Clifton)	0.142	0.136	-0.008	0.052	-1.31	0.196	74.04
Avon (Evesham)	1.805	1.862	0.058	0.157	3.40	0.001	18.63
Avon (Lawford)	1.352	1.374	0.021	0.057	3.37	0.001	0.91
Avon (Stare Bridge)	1.000	0.963	-0.015	0.074	-1.80	0.076	2.99
Coventry (Finham) STW	6.207	6.381	0.174	0.345	4.68	0.000	7.66
Dene (Wellesbourne)	0.390	0.378	-0.024	0.081	-2.50	0.015	23.37
Leam (Princes Drive)	0.419	0.407	-0.008	0.089	-0.77	0.443	24.28
Redditch STW final effluent	6.468	6.640	0.188	0.292	5.83	0.000	5.07
Rugby STW (Newbold)	2.458	2.531	0.073	0.084	7.85	0.000	2.90
Sowe (Baginton)	0.134	0.144	0.010	0.077	1.20	0.232	158.22
Sowe (Stoneleigh)	4.452	4.471	0.018	0.155	1.11	0.272	3.08
Stour (Clifford Chambers)	0.407	0.421	0.015	0.035	4.01	0.000	3.62
Warwick STW(Longbridge)	3.762	3.844	0.103	0.111	8.36	0.000	2.19

at the 5% significance level, the critical F-value (f^b, **Table 11**) is 1.29
at the 1% significance level, the critical F-value (f^b, **Table 11**) is 1.43

Example calculation.

Avon (Evesham)

$s_1 = 1.4 * 1.862/100 = 0.026068$
$s_2 = 1.4 * 1.805/100 = 0.025270$

$F = (0.1567)^2 / (0.026068^2 + 0.025270^2) = 18.6$

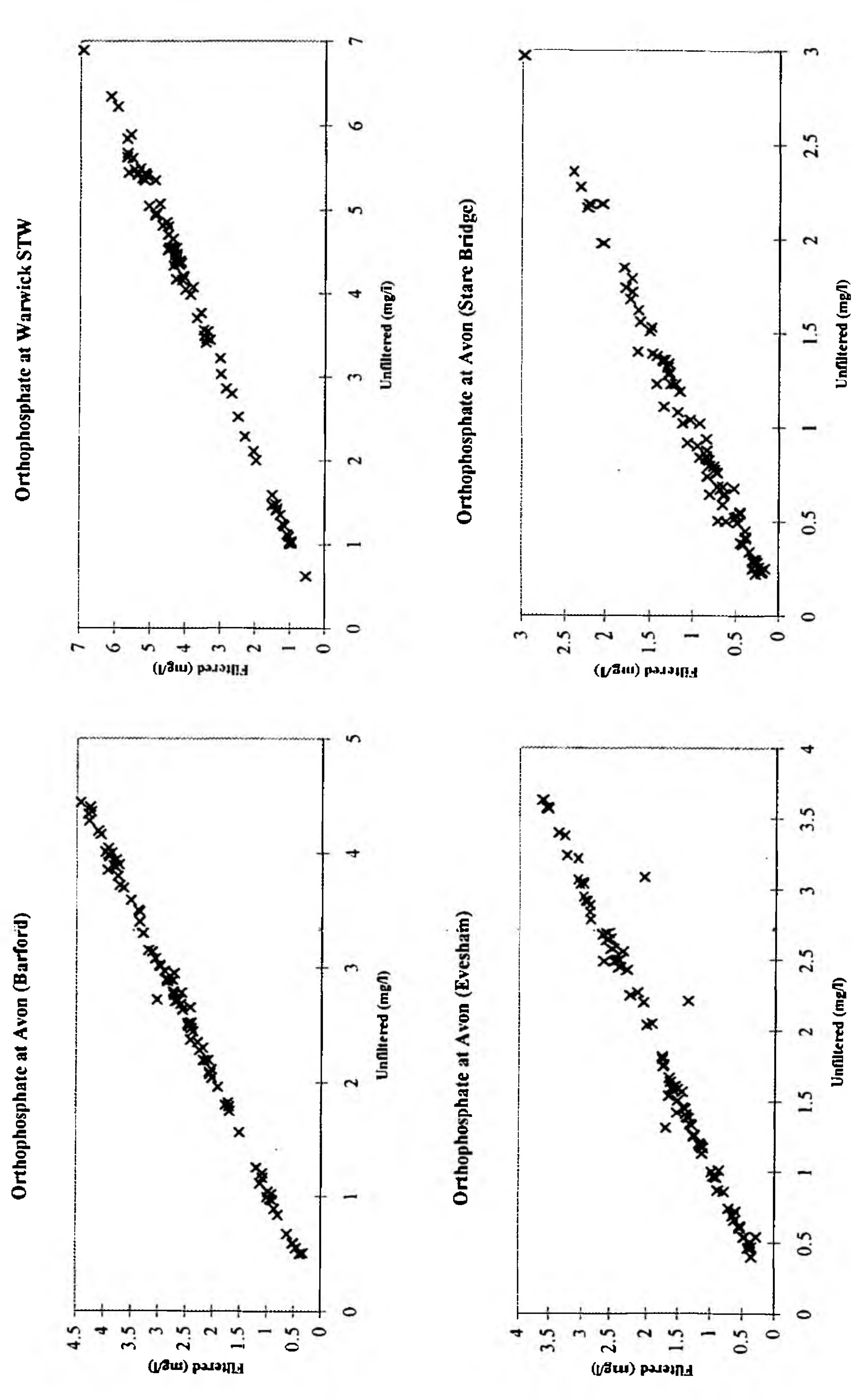
$\text{T-value} = (1.862-1.805)/(0.1567/\sqrt{85}) = 3.4$

4. Of the 18 sites analysed, 13 show a statistically significant difference in the mean concentrations between filtered and unfiltered samples. Of the 13 significant differences, 11 means are higher for unfiltered samples and 2 means are lower for unfiltered samples. The latter occurs on samples collected from the river Arrow at Studley and the river Dene at Wellesbourne. Higher mean orthophosphate concentrations on unfiltered samples suggests some exchange of P between the sediment and water column during transport and storage prior to analysis.

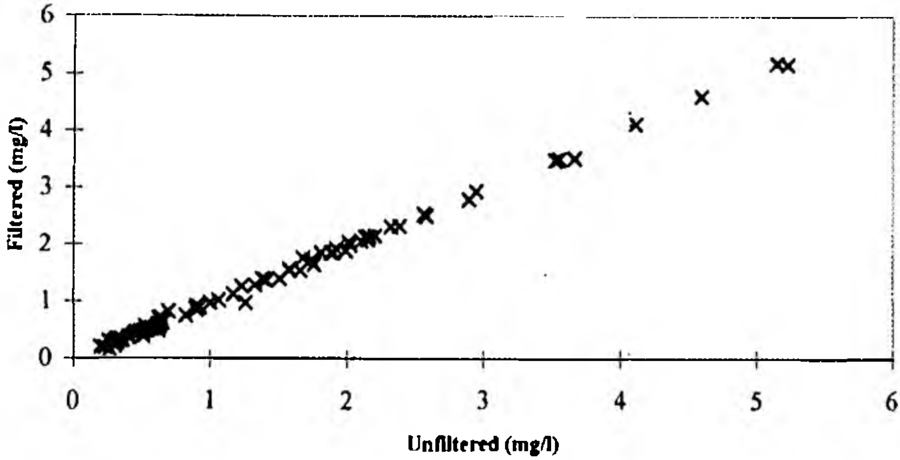
5. Comparison of the paired differences (f^b value, **Table 11**) with critical F-values suggests that there are significant differences between the orthophosphate determinations undertaken on filtered and unfiltered samples at all stations with the exception of the river Avon at Lawford.

6. The evidence from this detailed study of the Warwickshire Avon catchment shows that filtered orthophosphate concentrations provide a more accurate estimate of the orthophosphate concentrations in the river and effluent samples..

Figure 49 The relationship between orthophosphate concentrations determined on filtered and unfiltered samples for sites where weekly sampling was undertaken.



Orthophosphate at Avon (Lawford)



Orthophosphate at Rugby STW

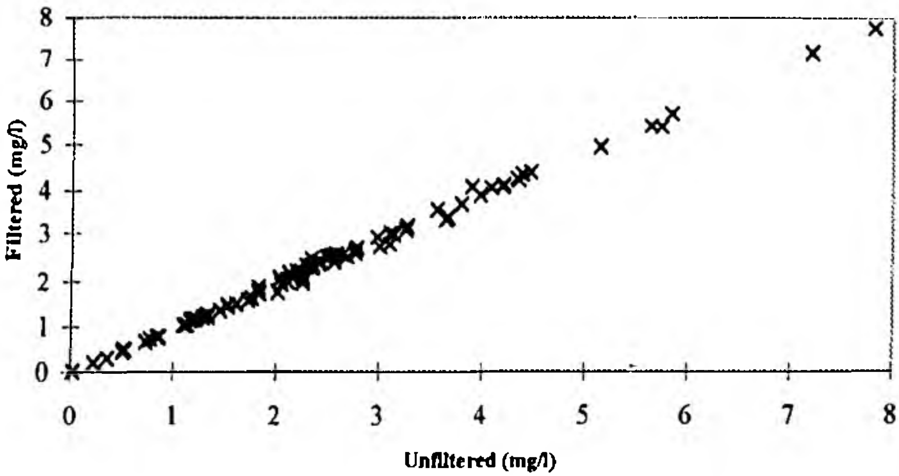
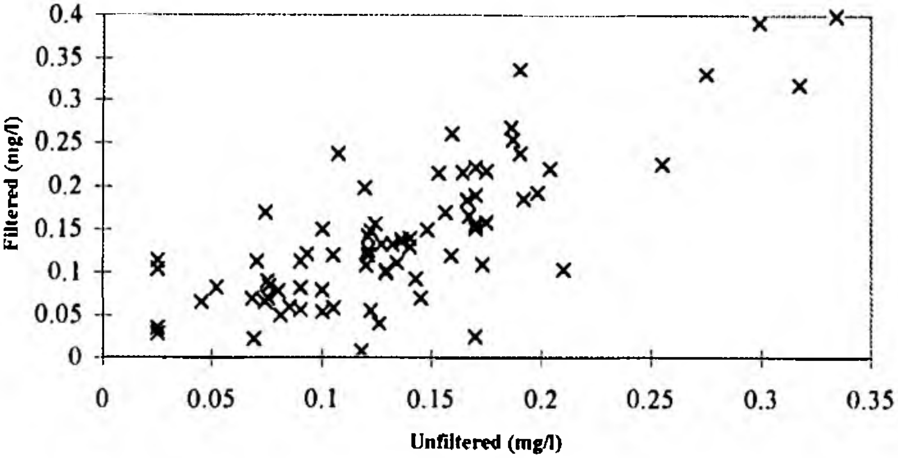
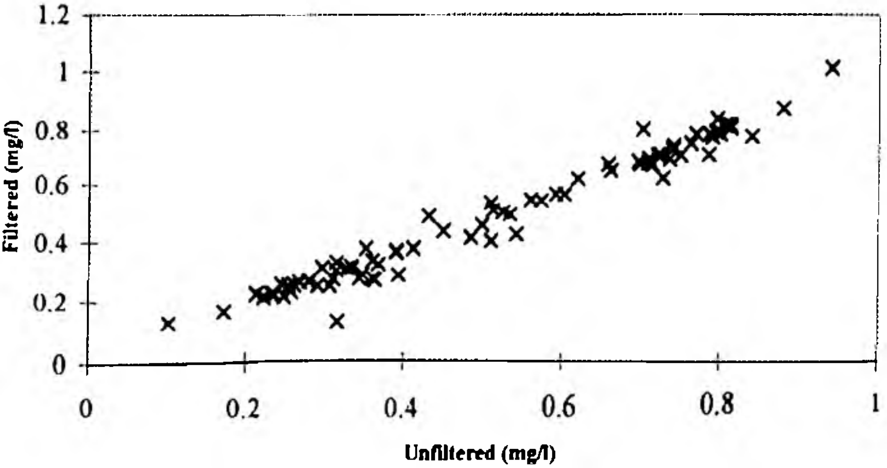


Figure 49 cont.

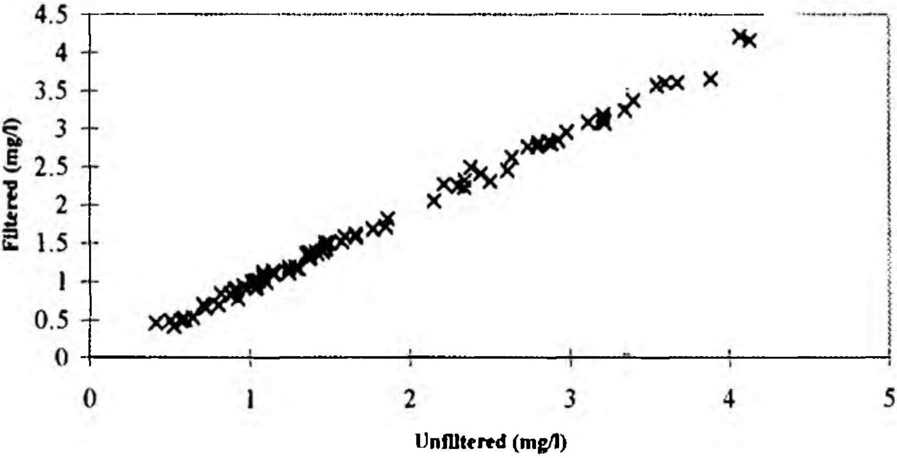
Orthophosphate at Avon (Clifton)



Orthophosphate at Alne (Alcester)



Orthophosphate at Arrow (Broom)



Orthophosphate at Arrow (Coughton Ford)

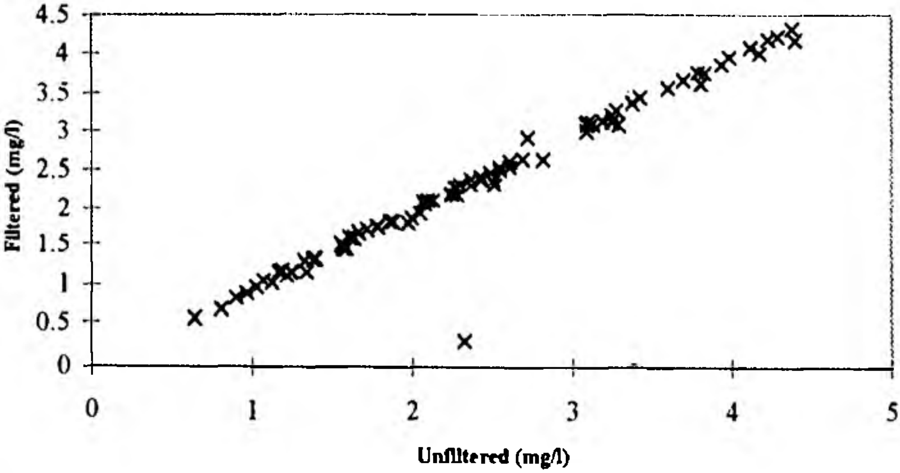
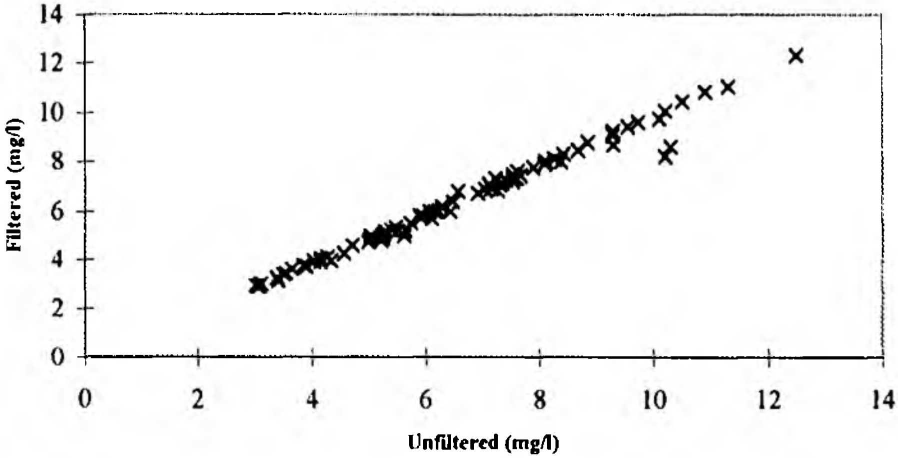
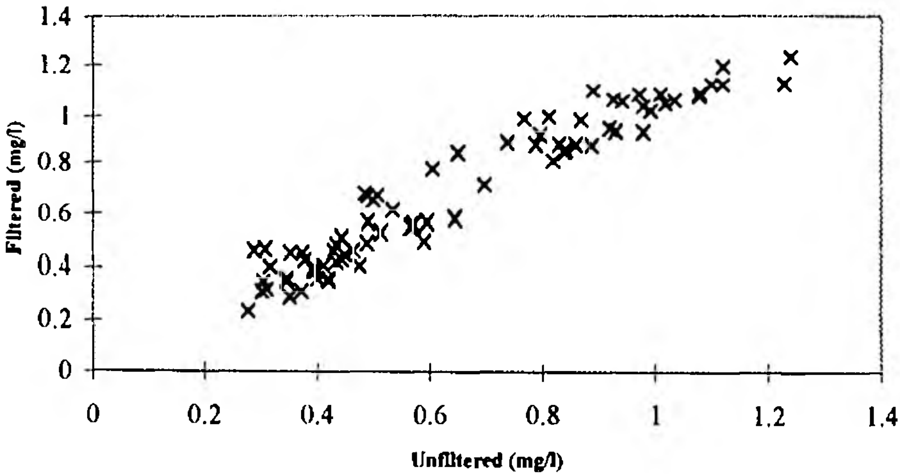


Figure 49 cont.

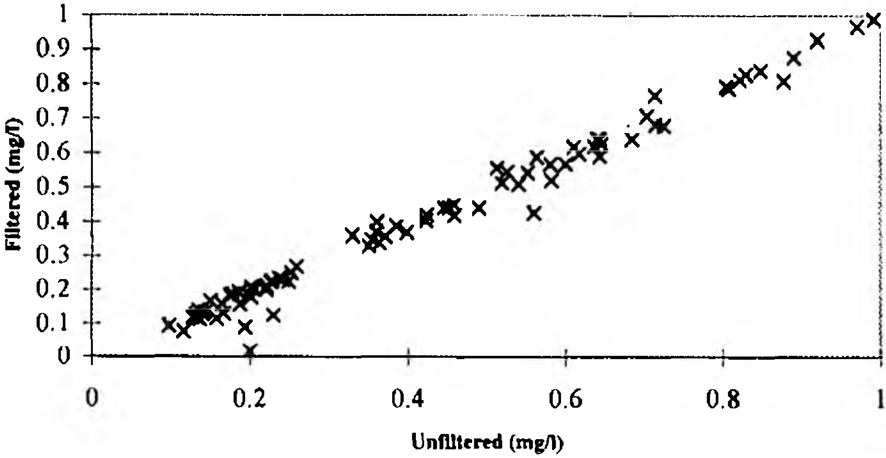
Orthophosphate at Redditch STW



Orthophosphate at Arrow (Studley)



Orthophosphate at Stour (Clifford Chambers)



Orthophosphate at Dene (Wellesbourne)

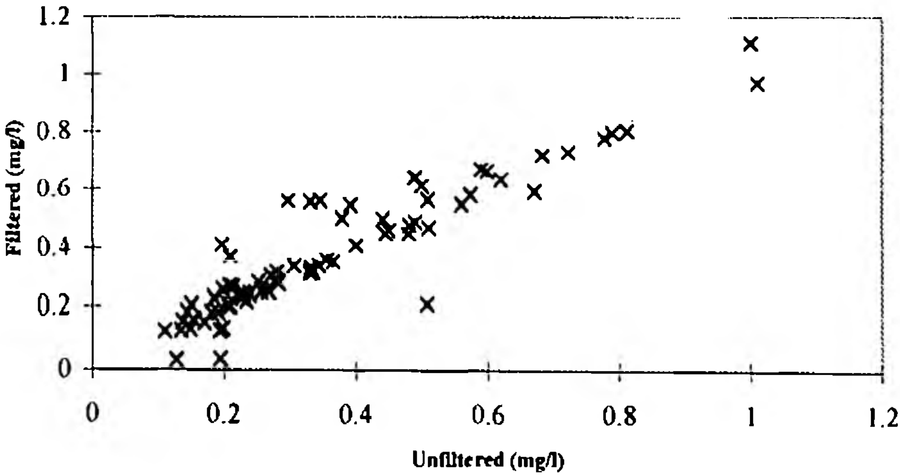
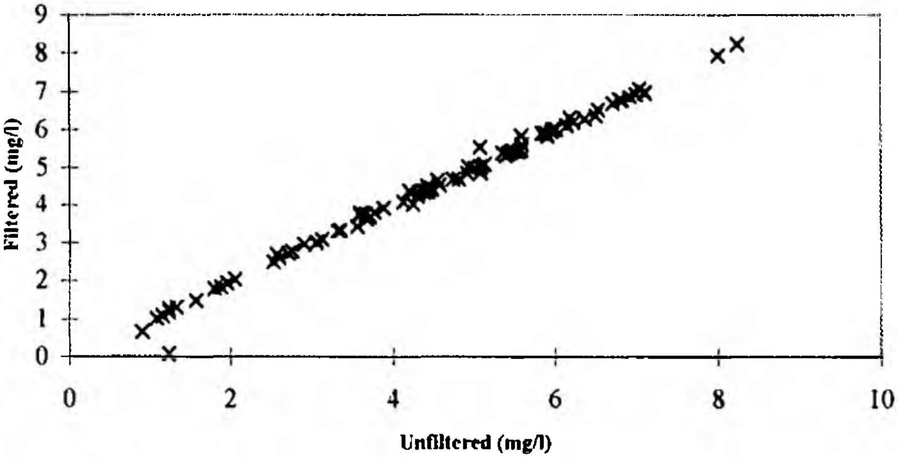
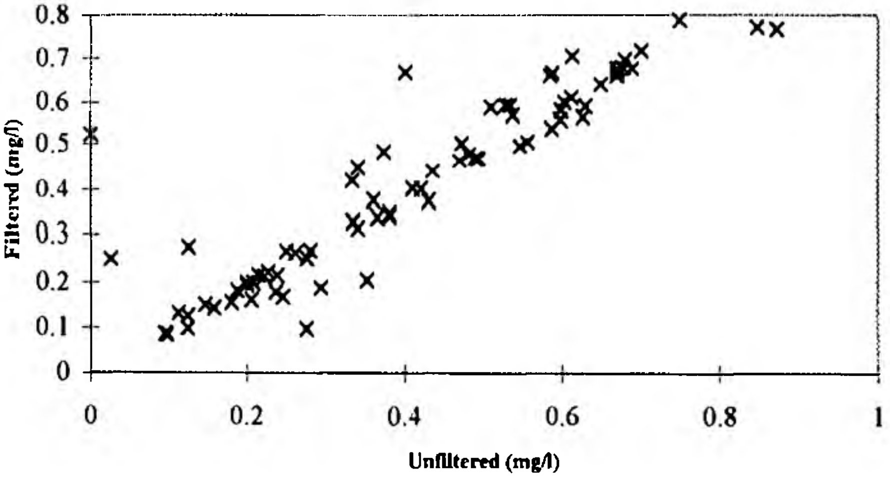


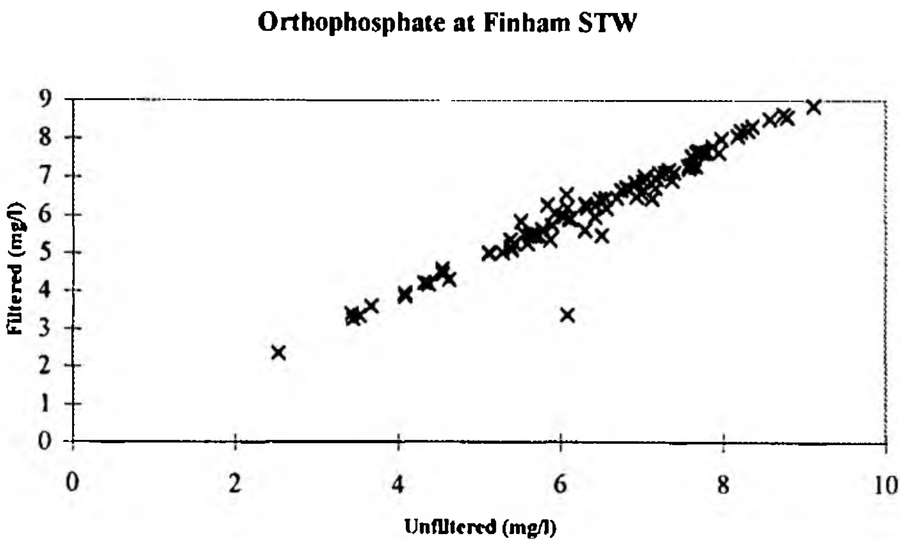
Figure 49 cont.

Orthophosphate at Sowe (Stoneleigh)



Orthophosphate at Leam (Princes Drive)





Orthophosphate at Sowe (Baginton)

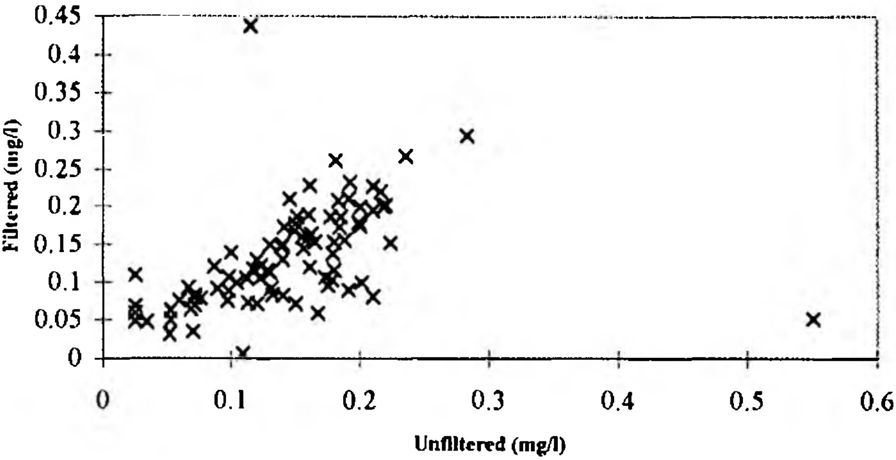


Figure 49 cont.

10. FUTURE INVESTIGATIONS

The project has attempted to answer a number of objectives. One of these was to identify areas of uncertainty. Consequently, there are a number of areas where additional investigative work may be required to improve the understanding of nutrients in the Warwickshire Avon catchment. Some of these are discussed below.

10.1 Investigate the Impact of P Removal in the Avon Catchment

As already stated P removal will be installed at the five qualifying discharges in the River Avon and River Arrow catchment by the end of 1998. A much reduced chemical sampling programme was set up in April 1997 in order to help establish what the impact of P removal will actually be. This programme is based upon paired sampling sites upstream and downstream of the qualifying discharges and sites at the bottom of the major tributaries. The discharges are also monitored on the same day as the river sites. The determinands analysed include: pH, DO, TON, Orthophosphate, BOD, NH_3, Silica, Chlorophyll a and conductivity. Flow data are no longer collected specifically for nutrient monitoring purposes.

10.2 Calculating nutrient loads

The methods used in this study to calculate river and STW nutrient loads are based upon those recommended to the Environment Agency by the WRc (Ellis *et al.*, 1993). The academic literature contains numerous references (Littlewood (1992) and Horowitz (1995)) to the problem of estimating river loads based upon these methods and, as suggested in section 7 above, it is therefore recommended that further work is carried out and a guidance note produced on the most appropriate load methods to use under various scenarios.

10.3 Subcatchments generating high P loads from diffuse and unaccountable sources

The nutrient budgets presented in **Figures 47 and 48** highlight the Sowe and Stour as two subcatchments generating high diffuse and/or unaccountable P loads. It is suggested that further more detailed investigation is required in both of these sub-catchments in order first to determine the accuracy of the budget estimates and secondly to identify other potential point and diffuse sources of P.

10.4 Export coefficient modelling and testing

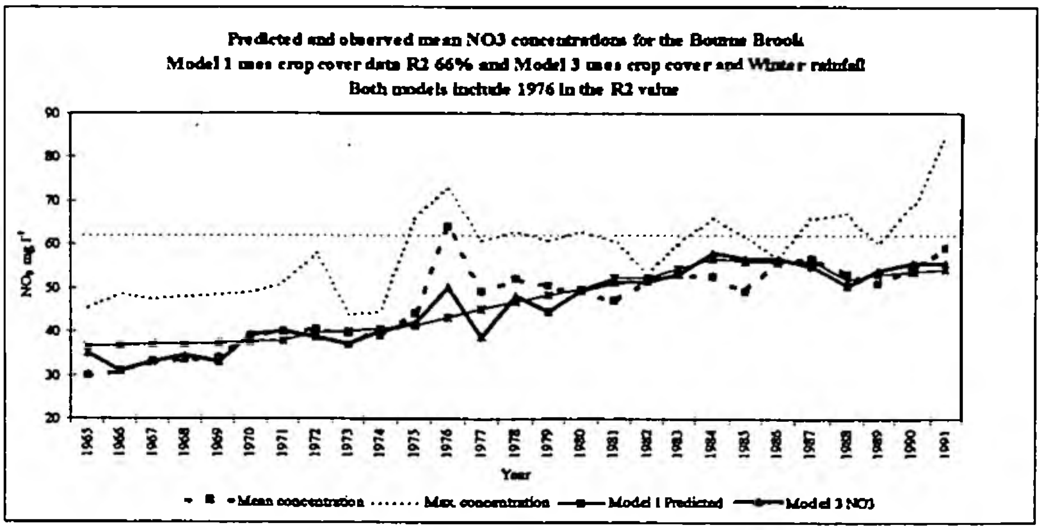
1. Export coefficient models have been applied to a large number of catchments (c.f. Johnes, 1996). These models are based on a crop specific leaching coefficient which estimates the percentage of applied fertiliser (N and/or P) which is "lost" annually to

2. Models of this type vary in their sophistication from lumped approaches to those which attempt to 'weight' particular land use types depending on their proximity to stream channels. More sophisticated models, taking account of seasonal and annual variations in rainfall, could be used with detailed land use information to provide better estimates of the potential diffuse source inputs of both N and P to the Avon catchment for comparison with estimates of total catchment and subcatchment load derived from an analysis of the eutrophication data base.

3. An example of the potential for such models to predict diffuse source inputs and their impact on river water quality is given in **Figure 50**. Based on the research undertaken by Wade (1996) on the Bourne Brook, North Warwickshire, two export coefficient models are used to predict NO_3 concentrations from 1965-1991 and are compared with mean and maximum nitrate concentrations observed in the river. Model 1 uses historical crop cover data and model 3 uses both crop cover and winter rainfall data which improves the estimate of concentration. The approach successfully models the long term trend in increased nitrate concentration in the catchment and, with calibration, could be used to predict both concentrations and loads of N and or P derived from diffuse agricultural sources.

4. Such a modelling approach may be extremely valuable in estimating the diffuse N and P inputs to the main River Avon from its subcatchments as a first stage in examining the impact on non-point sources on N and P concentrations and loadings.

Figure 50 A nitrogen export coefficient model for the Bourne Brook, North Warwickshire 1965-1991.



10.5 The role of Wetlands (Brandon Marsh) as sediment and nutrient sinks and as phytoplankton re-seeding areas.

From the data presented in **Figures 22-33** and in **Table 10**, it was suggested that changes in water quality could be detected between the monitoring sites at Lawford and Stare Bridge in the upper Avon catchment upstream of the Sowe/Avon

10.5 The role of Wetlands (Brandon Marsh) as sediment and nutrient sinks and as phytoplankton re-seeding areas.

From the data presented in **Figures 22-33** and in **Table 10**, it was suggested that changes in water quality could be detected between the monitoring sites at Lawford and Stare Bridge in the upper Avon catchment upstream of the Sowe/Avon confluence. Between these two sites is a major wetland system (Brandon Marshes) which may have an impact on sediment and nutrient storage and assimilation. Whilst the analysis reported here is inconclusive, further research is required to provide a more detailed investigation of the possible impact of this wetland on downstream nutrient transfer and on the possible role of the wetland as a source for phytoplankton seeding in the upper Avon (c.f. Reynolds, 1995; Foster *et al.*, 1997a).

10.6 Phytoplankton and eutrophication

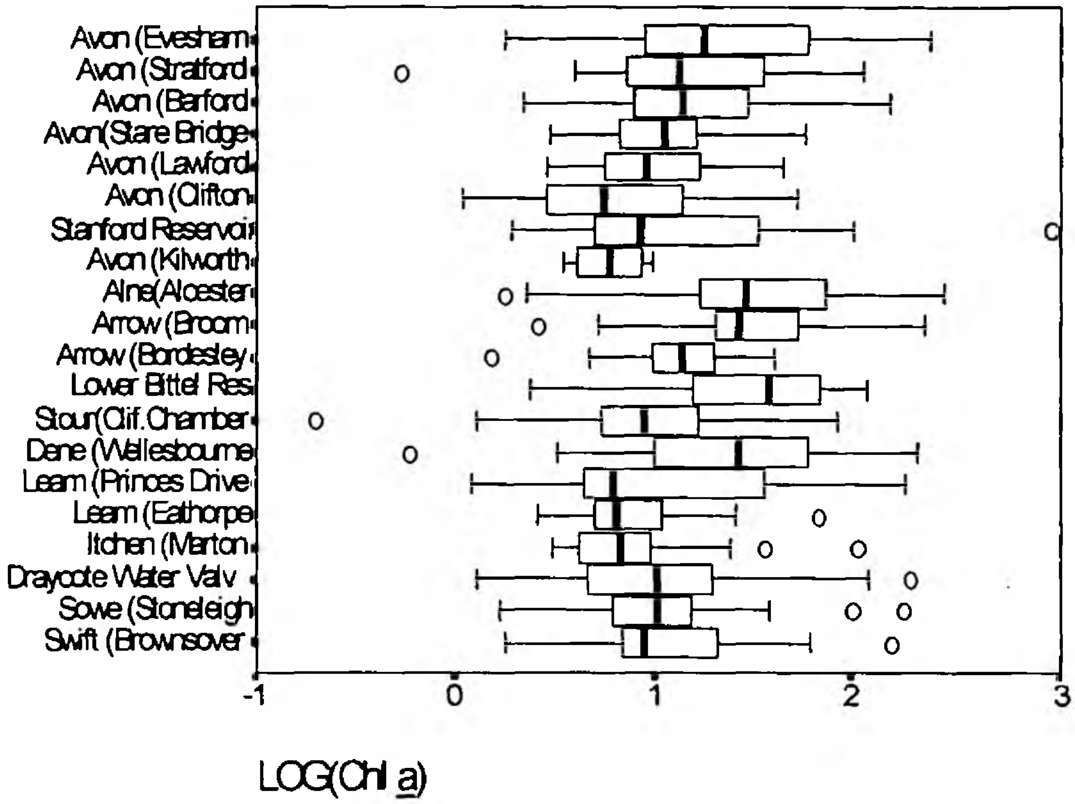
1. Chlorophyll a concentrations have been recorded at 20 monitoring stations and SiO_2 concentrations have also been determined at these sites for the second year of the investigation. The spatial distribution of chlorophyll a monitoring stations and time series plots are given in volume 2 of this report. Downstream trends on the main Avon gauging stations are summarised as boxplots in **Figure 51**.

2. The DOE (1993) define the occurrence of planktonic algal blooms in running waters in relation to chlorophyll a. A planktonic bloom occurs either where the annual mean chlorophyll a concentration exceeds 25 mg/m^3 or where the maximum concentration exceeds 100 mg/m^3. The average concentrations cannot be calculated since a full years chlorophyll a data are not available.

3. **Figure 51** shows the trends in chlorophyll a concentrations at the 20 monitoring stations and also shows that concentrations exceed 100 mg/m^3 over the sampling period at 13 of the 20 sites. There is some evidence to suggest that chlorophyll a concentrations are high in all three reservoirs and that concentrations increase in the lower reaches of the Avon; a pattern observed in many UK rivers (c.f. Reynolds, 1995). Controls on phytoplankton concentration have yet to be explored in detail. Preliminary results published by Foster *et al.* (1997a) suggest that silica is probably the most important limiting nutrient in relation to the spring diatom bloom. However, further preliminary research on the significance of water velocity suggests that over 50% of the variation in the spring chlorophyll a peak can be explained by a combined index representing silica availability and water velocity as predicted from reach gradient.

4. The current data base will provide an important opportunity to examine controls on, and effects of, high phytoplankton productivity. These data could be subjected to more rigorous statistical analysis and further research effort should be directed towards a biological assessment aimed at identifying the relative contribution of green and blue-green algae and diatoms to the chlorophyll a record.

Figure 51 Boxplots of chlorophyll a concentrations for all sites (log scale)



10.7 Rural Sewage Pollution

1. The research undertaken for the eutrophication project identified major point source inputs associated with sewage treatment works which will comply with the UWWT directive and over 80 minor works serving less than 10,000 pe which were included in the analysis in order to estimate their potential contribution to P loads. Nationally, some 96% of households are connected to a public sewerage system leaving 4% of households, largely in rural areas, which are not connected to sewers. The recent survey published by Tucker and Kimber (1994) suggest that up to 500,000 people in England and Wales may be served by inadequate sewerage systems.

2. The data of **Table 12** are taken from the study of Tucker and Kimber (1994) and relate to all measurements taken during their survey of discharges to water courses within the Avon catchment upstream of Evesham. Whilst nutrient data were not obtained from the analysis suite, the overall quality of water in the receiving water course at the sampled sites is usually poor and it is likely that these discharges also contain high total N and especially P concentrations. Of particular concern is the high suspended sediment concentration in some of the receiving watercourses.

Table 12 The quality of streams receiving sewage effluent in rural areas

Site	Ammoniacal N (mg/l)	BOD (ATU) (mg/l)	Susp. Solids. (mg/l)	Dissolved Oxygen (%)	NWC Class
Corley	3.4	12.5	36.0	73	3
Hawkes End	2.0	7.0	7.0	69	2
Allesley	27.4	58.0	115.0	53	4
Keresley	24.5	62.0	117.0	43	4
Catthorpe	87.0	254.0	205.0	13	4
Flecknoe	70.5	208.0	119.0	39	4
Wasperton	36.7	26.0	36.0	32	4
Barton	0.04	6.0	21.0	83	2
Kineton	0.11	1.5	2.0	81	1a
Winderton	30.3	22.0	115.0	58	4

3. There are two reasons for identifying these potential sources. First, because there are no available estimates of N and P loading for rural sewage and, whilst dispersed and volumetrically rather small, they may have significant local impacts on nutrient loadings to small streams. Secondly, because the first 4 sites listed in **Table 12** lie within the Sowe catchment area which has a high residual P load after removing the impact of the Finham STW (see 10.1 above). It is suggested that any further research into nutrient sources conducted in the Sowe basin should include a review of the number of sites and potential nutrient loading from rural sewage inputs.

10.8 Climate change and eutrophication

1. In a recent report commissioned by the Environment Agency, Foster *et al.* (1997) analysed two long term rainfall series for England and Wales and Coventry. The former was based on the data of Wigley *et al.* (1982) and extended by cross correlation with other Midland rainfall stations to 1996. Both data sets showed no statistically significant trend in long term rainfall. The summary data of **Table 13** are derived from this analysis and indicate a slight decrease in mean annual rainfall in Coventry over the last decade by around 18 mm (2.6%) in comparison with the 1867-1996 average. Over the same decade, there is evidence for a reduction in the Standard Deviation (i.e. less variability) than in the other two accounting periods.

2. Despite increased concern over reductions in rainfall, there is little evidence from an analysis of these data to demonstrate a major sustained decrease in annual rainfall over the last ten years which might make a significant impact in diluting the contaminant loads derived from point sources.

Table 13 Summary Statistics for the Coventry and the England and Wales Annual Rainfall Series

	Coventry		England and Wales	
	Mean	St. Dev.	Mean	St. Dev
1766-1996			912.2	115.6
1867-1996	676.1	114.3	920.6	110.8
1964-1996	673.1	112.8	916.8	90.2
1987-1996	658.3	90.1	905.1	79.4

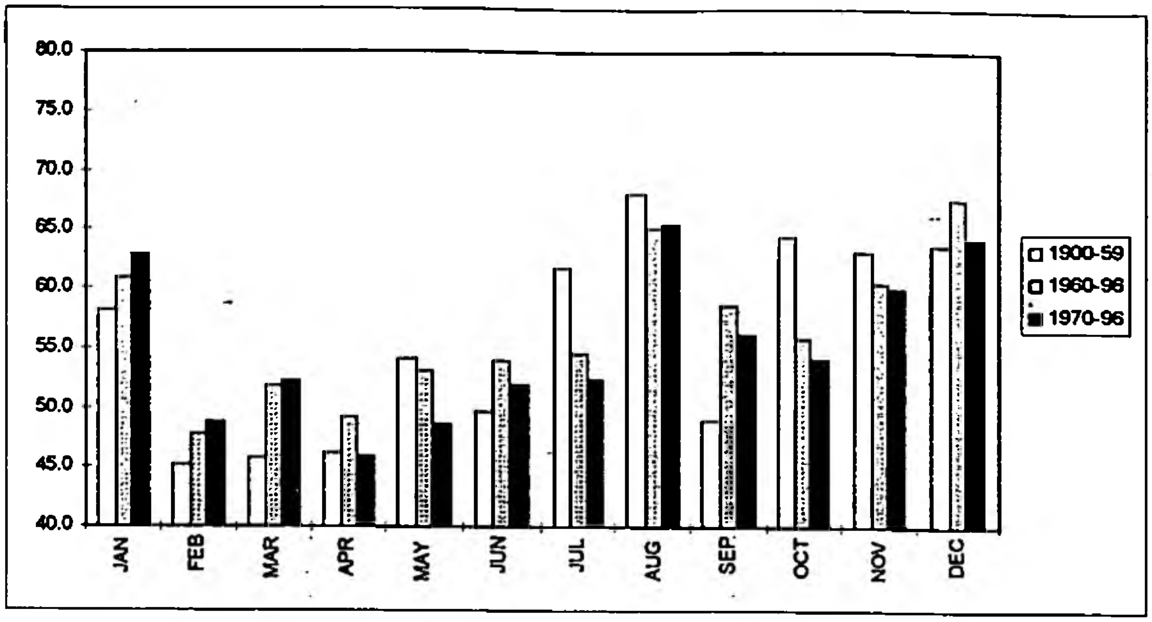
3. Two other features of the Coventry rainfall record, however, may be significant and require further more detailed consideration.

3a. First, Foster (1995) and Foster *et al.* (1997) analysed a data base of daily rainfall events in Coventry of greater than 25 mm compiled by Sheard (1994). A major change in the frequency of daily rainfalls is observed after 1964. Seven of these years have 3 or more days with rainfalls exceeding 25 mm, four of these years have 4 or more days with rainfalls exceeding 25 mm and two of these years have 5 or more days with rainfalls exceeding 25 mm. In comparison, in the period 1892-1964, only seven years had 3 days with rainfall exceeding 25 mm. This pattern demonstrates a significant shift in the magnitude and frequency of rainfall delivery. On only two occasions in the pre 1964 period does the percentage of annual rainfall delivered in daily events of over 25 mm exceed 15% and, for the majority of the record, this proportion is less than 10%. In five years of the post 1964 period, over 15% of the annual rainfall is delivered in daily events of over 25 mm and in two years, this figure exceeded 25%. This analysis highlights a significant shift in the magnitude and frequency of rainfall delivery suggesting that the record is becoming dominated by infrequent high intensity events. Such a pattern is likely to have significant implications for a reduction in groundwater recharge and the long term availability of uncontaminated water to dilute the pollutant loads from point sources between rainfall events.

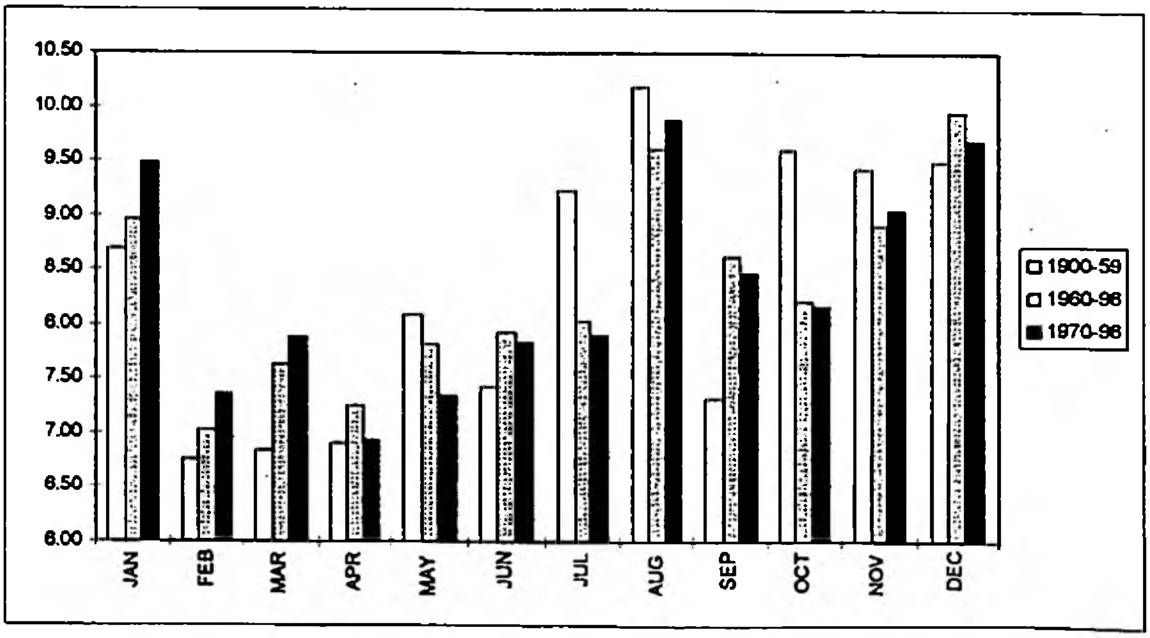
3b. Secondly, analysis of available monthly data for Coventry from 1900 to 1996 reveals some significant trends. These data have been sub-divided into three time periods 1900-1959; 1960-1996 and 1970-1996 and are plotted in **Figure 52**. **Figure 52a** plots rainfall volume by month for the three time periods. The data show little seasonal variability although the months of February through June have slightly lower totals than the period July through January. The differences between the three time periods and the significance of the seasonal variability in monthly rainfall is highlighted in **Figure 52b** where monthly rainfall totals are plotted as a percentage of the annual total. This plot emphasises the lower contribution of monthly rainfall to the annual total from February through June - a period of significance to the rise in phytoplankton productivity in the Avon. Lower rainfalls over these months reduce the

Figure 52 Coventry monthly rainfall 1900-1996

a) Rainfall volume by month (mm)



b) Monthly Rainfall as a percentage of the annual total



potential dilution effect (independently of evaporation rates). Long term changes in monthly rainfall since 1960 may be of significance to contemporary and future eutrophication issues. Of importance here is the decrease in the May and July monthly rainfall totals over the period 1960-96 and 1970-96. Whilst this is in part compensated by the increases in monthly rainfall from January through March and also in September, such a decrease may have significant implications under summer low flow conditions for reducing further the dilution potential in the Avon system. The reduction in May rainfall could be particularly significant in relation to the onset of phytoplankton productivity which usually occurs in April and in the maintenance of high nutrient concentrations well into the late autumn.

4. From the above review it is evident that changes in weather patterns and climatic conditions may have a significant impact on dilution potential within the Avon system and it is recommended that the Environment Agency undertake a detailed analysis of long term annual, monthly and daily weather statistics in order to more fully understand the potential implications for dilution potential in relation to nutrient and other contaminant concentrations.

11. ACKNOWLEDGEMENTS

Suzanne Howarth, Michael Wooldridge and Jonathan Hall (EA placement students) for sample collection. Sarah Harrison for database maintenance and the day to day running of the project. The Hydrology and Hydrometric sections at Tewkesbury, Warwick and Solihull offices of the Environment Agency for supplying rainfall, flow data and QA of the data. The National Laboratory Service for analysis and QA of the data.

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Appendix 1 Sampling compliance for individual sites

Table (i) Number of samples taken at weekly sampled sites.(Target - 95)

Alne(Alcester)	82
Arrow (Broom)	84
Arrow (Coughton Ford)	83
Arrow (Studley)	83
Avon (Barford)	86
Avon (Clifton)	82
Avon (Evesham)	86
Avon (Lawford)	83
Avon(Stare Bridge)	87
Dene (Wellesbourne)	83
Coventry (Finham) STW	86
Leam (Princes Drive)	81
Redditch STW final effluent	83
Rugby STW (Newbold)	82
Sowe (Baginton)	86
Sowe (Stoneleigh)	87
Stour (Clifford Chambers)	85
Warwick STW (Longbridge)	82

Table (ii) Number of samples taken at fortnightly sampled sites.(Target - 47)

Alne (Wootton Wawen)	42
Arrow (Bordesley) A441 Road B	42
Avon (Stratford)	43
Blackminster STW	38
Braunston STW	40
Chipping Campden STW	39
Crick (final effluent) STW	35
Draycote Water Valve Tower	40
Finham Brook (Finham Bridge)	40
Harbury STW (Deppers Bridge)	41
Itchen (Deppers Bridge)	41
Itchen (Marton, conf. Leam)	41
Kilsby STW	39
Leam (A425 Road Bridge)	40
Leam (Birdingbury)	41
Leam (Eathorpe)	41
Leam (Sawbridge)	41
Leamington Heathcote STW	39
Lower Bittel Reservoir Outlet	39
Lutterworth STW (final effluent)	37
Noleham Brook (Welford Pastures)	42
Sherbourne (Allesley, Kingsbury)	40
Sherbourne (conf. Sowe)	40
Snitterfield STW	37
Southam STW (final effluent)	40
Sowe (Walsgrave)	39
Stanford Reservoir	37
Stour (Shipston)	40
Stratford STW (Milcote)	42
Swift (Brownsover Hall)	41
Tach Brook (A41 Road Bridge)	38
Wellesbourne STW	36
Wootton Wawen STW	37

Table (iii) Number of samples taken at monthly sampled sites.(Target - 23)

Alne(Danzey Green)	22
Alne (Little Alne)	22
Avon (Kilworth)	18
Claycoton/Yelvertoft Brook	17
Clifton Brook (Rugby) conf. Avon	19
Coombe Pool (outflow)	17
Dene (Fosse Way)	23
Finham Brook (Chase Lane, Ken)	19
Inchford Brook (Kenilworth Castle)	16
Itchen (A425) Thorpe Bridge	23
Knee Brook (High Furze)	20
Knee Brook (Paxford)	22
Marston Grange (trib. Noleham)	19
Nethercote Brook (Mitford Bridge)	21
Radford Brook (A425)	23
Rains Brook (Barby Lodge)	20
Smite Brook (Coombe Abbey)	19
Sowe (Astley Hall)	12
Stour (Cherington)	23
Stowe (Southam, Brown's Bridge)	23
Swift (Bransford Bridge)	19
Swift (Lutterworth)	20
Tach Brook (A452 Road Bridge)	23
Tanworth in Arden STW (final eff)	21
Thelsford Brook (Hampton Lucy)	23
Withy Brook (Walsgrave/High B)	17
Wyken Slough Brook (Overflow)	12
Wynyates Brook (conf. Stour)	23

Appendix 2 Analytical compliance for water Quality Data

2.1 Table (iv) Missing Data

Det. Code	VARIABLE	NO. OF MISSING VALUES	% OF MISSING VALUES
	Oxidative Redox potential (ORP) in units of mV	442 (47[a])	13.1% (1.6%)
	Specific Electrical Conductivity in mS field measurement	372 (37[a])	11.0% (1.2%)
	Electrical Conductivity in mS (Calculated from Specific elec cond. before 14/3/96- directly measured from 15/3/96)	372 (37[a])	11.0% (1.2%)
106	Dissolved oxygen as %, field measurement	83	2.5%
DF5	Dissolved oxygen as mg/l, lab calculation based on D	159	4.7%
007	Suspended Solids mg/l	1	0.03%
010	Biochemical oxygen demand (BOD), mg/l	1	0.03%
070	Chemical oxygen demand (COD), mg/l	8	0.24%
05X	Total Nitrogen (kjeldahl; unfiltered), mg/l	53	1.6%
084	Total Phosphorus (unfiltered), mg/l	11	0.3%
0GG	Ammonia (filtered), mg/l	-	-
0GS	Ammonia (filtered) μg/l	-	-
	0GG and 0GS combined[b]	11	0.33%
0GM	TON (filtered), mg/l	9	0.27%
0GW	TON (filtered), μg/l	No data collected	-
	0GM and 0GW combined	9	0.27%
0GK	Orthophosphate (filtered) mg/l	-	-
0GT	Orthophosphate (filtered), μg/l	-	-
	0GK and 0GT combined[c]	109	3.2%
051	Orthophosphate (unfiltered) mg/l	34	1.0%
0GX	Total Phosphorus (filtered), mg/l	61	1.8%
083	Chlorophyll a mg/m^3 [d]	32	3.8%
101	Temperature °C	40	1.2%
	Flow [e]	285 [f]	8.6%
	pH, field measurement	432 (37[a])	12.8% (1.2%)

a Samples collected on or after 8/3/95.

b The OGS value has been used for the 1124 samples where OGS and OGG values are available.
c The OGT value has been used for the 296 samples where 0GK and 0GT values are available.

d Chlorophyll measurements were taken at 20 sites from 1st April 1995 until 30th September 1995 and between 1st February 1996 and 30th September 1996. 835 samples were taken during the period. Of the 32 missing values, 18 are from samples taken during the first week of April 1995 and a further 8 are from Avon (Kilworth).

e Includes 3298 samples collected from non-reservoir sites and Lower Bittel Reservoir Outlet.

f 275 of the missing flow values were supplied and entered into the database. Details of these are included in appendix 4

2.2 Data Reliability

2.2.1 Notes Contained in Database

Notes included in the database concerning the reliability of some of the data are listed in table (v)

Table (v) Unreliable data.

Variable	Site Name	Comments	Cell Row Number
Dissolved Oxygen	Avon (Evesham)	D.O meter faulty	36
Dissolved Oxygen	Avon (Barford)	D.O meter faulty	223
Dissolved Oxygen	Avon (Stare Bridge)	D.O meter faulty	406
Dissolved Oxygen	Avon (Lawford)	D.O meter faulty	499
Dissolved Oxygen	Rugby STW (Newbold)	D.O. meter faulty	586
Dissolved Oxygen	Rugby STW (Newbold)	Reading taken 3 hours later	596
Dissolved Oxygen	Avon (Clifton)	D.O. meter faulty	674
Dissolved Oxygen	Stour (Clifford Chambers)	Suspect data-too low?	1617
Dissolved Oxygen	Chipping Campden	Suspect data-too low?	1835
Dissolved Oxygen	Sowe (Stoneleigh)	D.O. meter faulty	2936
Dissolved Oxygen	Coventry (Finham) STW	D.O. meter faulty	3029
Dissolved Oxygen	Sowe (Baginton)	D.O. meter faulty	3121
Dissolved Oxygen	Withybrook (Walsgrave)	Suspect data-too high?	3447
Temperature	Rugby STW (Newbold)	Reading taken 3 hours later	596
pH.	Rugby STW (Newbold)	Reading taken 3 hours later	596
Electrical Cond.	Rugby STW (Newbold)	Reading taken 3 hours later	596
Electrical Cond.	Leam (Princes Drive)	Faulty ORP probe	2279
Suspended Solids	Sowe (Stoneleigh)	Construction work upstream, river brown due to soil disturbance	2943

2.3 Comparison of the Four Determinands for P

A large number of samples were identified for which a filtered value exceeds the unfiltered value or orthophosphate is greater than total phosphorus as shown in table (vi).

Table (vi) Phosphorus data.

A	B	Number (%) of samples with A>B	Number (%) of samples with A>1.1*B	Number (%) of samples with A > 1.1*B and B >0.2mg	No. Valid Samples (i.e. values present for both A and B)
0GK and 0GT combined	051	968 (29.8%)	376 (11.6%)	163 (5.0%)	3243
0GK and 0GT combined	084	534 (16.4%)	165 (5.1%)	90 (2.8%)	3258
0GK and 0GT combined	0GX	1088 (33.4%)	341 (10.6%)	182 (5.7%)	3217
051	084	516 (16.0%)	61 (1.9%)	22 (0.7%)	3331
051	0GX	1386 (42.3%)	473 (14.4%)	197 (6.0%)	3280
0GX	084	573 (17.3%)	163 (4.9%)	64 (1.9%)	3307

084 Total Phosphorus (unfiltered) 0GX Total Phosphorus (filtered)
051 Orthophosphate (unfiltered) 0GK and 0GT combined Orthophosphate (filtered)

Details were supplied to the Nottingham Laboratories which resulted in instructions from them to make the following changes and deletions to the database.

Variable: Total P Filtered (0GX)

Values removed from rows 671, 1287, 2253, 2260, 2425, 2742, 2744, 3255

Value in row 2247 changed from 1.180 to 0.188

Value in row 1363 changed from 0.710 to 0.755

Variable: PO4 filtered (0GK and 0GT combined)

Values removed from rows 671, 2253, 2260, 2425, 2742, 2744, 3255

Variable: Total P unfiltered (084)

Value removed from row 3677

A number of values were identified in the database which were less than the Minimum Recording Value. Details were supplied to the Nottingham Laboratories which resulted in instructions from them to make the following changes to the database.

Total P (0GX)

Value in row 3294 changed from 0.018 to 0.01

Kjeldahl Nitrogen (05X)

Value in row 2004 changed from 0.03 to 0.05

Suspended Solids (007)

Value in row 291 changed from 1.0 to 1.5
Value in row 577 changed from 1.0 to 1.5
Value in row 3001 changed from 1.0 to 1.5

Appendix 3 Methods used for infilling 'missing' water quality data for load calculations

3.1 Extra Data Inserted in a separate Database

Before carrying out load calculations missing flow data and nutrient concentration data was infilled as described in sections 3.1.1 - 3.1.3.

3.1.1 Total Phosphorus (Unfiltered) (084)

Linear regression was used to infill the missing values where there was a significant correlation (at the 1% level) between $\log_{10}$(Phosphorus) and $\log_{10}$(flow) at the site concerned.(Part A) Where the correlation was insignificant at the 1% level the missing value was replaced by a value based on the Phosphorus readings before and after the missing values at the site concerned.(See part B)

Part A

Estimates based on linear regression of Log_{10} (Total Phosphorus) and Log_{10} (Flow ml/d)
(Total Phosphorus = 10^a * flow ^{b} (where a is the intercept and b the slope of the linear regression)

Site	Date	Estimate	Flow	a	b	Sig. F
Arrow (Broom)	16/6/1995	2.011	97.0	1.621024	-0.663190	0.000
	15/7/1996	2.639	64.39			
Stour (Shipston)	8/12/1995	0.365	21.0	-0.188655	-0.188545	0.0003
Sowe (Stoneleigh)	3/10/1995	6.151	147.97	2.938638	-0.990575	0.0000
Coventry (Finham STW)	4/5/1995	6.562	119.74	2.415799	-0.769272	0.0000
Claycoton Brook	6/6/1996	0.678	1.39	-0.122022	-0.327957	0.0000

Part B

Estimates based on linear interpolation of the Total Phosphorus values immediately preceding and succeeding the missing value.

Site	Date	Estimate
Leamington (Heathcote STW)	16/5/1996	13.718
Sherbourne (conf. Sowe)	22/2/1995	0.156

3.1.2 TOTAL NITROGEN (KJELDAHL: UNFILTERED) (05X)

Linear regression was used to infill the missing values where there was a significant correlation (at the 1% level) between $\log_{10}$(Nitrogen) and another variable at the site concerned. (See parts A, B & C) Where there was no significant correlation at the 1% level the missing value was replaced by the mean of the measured kjeld nitrogen values at the site concerned.(See part D)

Part A

Estimates based on linear regression of Log_{10} (Kjeld Nitrogen) and Log_{10} (Ammonia mg/l)
(Kjeld Nitrogen = 10^a * Ammonia ^{b} (where a is the intercept and b the slope of the linear regression)

Site	Date	Estimate	NH_3	a	b	Sig. F
Warwick STW	1/6/1995	2.716	0.8270	0.468195	0.415711	0.0000
Avon (Lawford)	2/6/1995	1.338	0.1430	0.321682	0.231231	0.0001
	11/3/1996	1.484	0.2240			
Rugby STW	2/6/1995	2.116	0.1270	0.523774	0.221244	0.0000

Blackminster STW	26/5/1995	2.395	0.5410	0.456726	0.290236	0.0000
Chipping Campden STW	26/5/1995 8/6/1995	3.909 3.801	2.460 2.340	0.372488	0.561813	0.0000
Braunston STW	7/6/1995	4.664	2.770	0.345344	0.730920	0.0000
Harbury STW	7/6/1995 23/6/1995	6.401 6.368	4.550 4.520	0.287674	0.788116	0.0000
Kilsby STW	22/6/1995	4.439	2.170	0.435639	0.629070	0.0000
Coventry (Finham) STW	2/6/1995 5/6/1995 12/6/1995	7.445 7.703 6.961	5.170 5.420 4.710	0.356616	0.722160	0.0000

Part B

Estimates based on linear regression of Log_{10} (Kjeld Nitrogen) and Log_{10} (Suspended Solids mg/l) (Kjeld Nitrogen = 10^a * suspended solids ^{b} (where a is the intercept and b the slope of the linear regression)

Site	Date	Estimate	SS	a	b	Sig. F
Avon (Evesham)	2/6/1995	1.206	13.0	-0.197275	0.250052	0.0010

Part C

Estimates based on linear regression of Log_{10} (Kjeld Nitrogen) and Log_{10} (flow ml/d) (Kjeld Nitrogen = 10^a * flow ^{b} (where a is the intercept and b the slope of the linear regression)

Site	Date	Estimate	Flow	a	b	Sig. F
Sowe (Stoneleigh)	2/6/1995 5/6/1995 12/6/1995 20/6/1995 30/6/1995 21/3/1996 16/7/1996	4.661 4.493 4.710 4.730 4.652 4.073 5.031	183.00 202.00 178.00 176.00 184.00 262.78 149.11	1.512365	-0.372981	0.000

Part D

Estimate calculated as the mean of the measured Kjeld Nitrogen over 22 month period.(1/12/1994 - 30/9/1996) at the site concerned.

Site	Date	Estimated Value*
Avon (Stare Bridge)	20/3/1995 2/6/1995	1.282 1.282
Arrow (Broom)	1/6/1995 16/6/1995 15/7/1996	1.415 1.415 1.415
Leam (Princes Drive)	1/6/1995	1.154
Stratford STW (Milcote)	24/3/1995 26/5/1995	5.510 5.510
Southam STW	19/7/1995	7.147
Redditch STW	1/6/1995 17/7/1995	1.977 1.977
Stour (Clifford Chambers)	1/6/1995	0.996
Harbury STW	19/7/1995	9.642

3.1.3 TOTAL OXIDISED NITROGEN

Estimates based on linear regression of Log_{10} (Oxidised Nitrogen) and Log_{10} (Ammonia mg/l) (Oxidised Nitrogen = 10^a * Ammonia ^{b} (where a is the intercept and b the slope of the linear regression)

Site	Date	Estimate	NH_3	a	b	Sig. F
Avon (Evesham)	30/03/1995	10.739	0.0640	1.094359	0.053098	0.0099

3.1.4 FLOW ML/D

Estimated value was calculated as the mean of the measured flows over 22 month period.(1/12/1994 - 30/9/1996) at the site concerned.

Site	Date	Estimated Value
Wyken Slough Brook	4/10/1995, 29/11/1995	0.00
	11/1/1996, 5/3/1996	0.00
	8/5/1996, 6/6/1996	0.00
Lutterworth STW	2/8/1995	2.75
	13/9/1995	2.75

Appendix 4 Additional Hydrometric Data supplied by EA Hydrometric Section, Solihull

4.1 Flow data supplied by EA Hydrometric Section, Solihull was inserted in the original database.

4.1.1 Additional STW Flow Data

Additional flow data supplied for the STW sites came from 3 sources.

1) Actual Flows(a/f) 2) Estimated flow readings - daily average(erda) 3) Monthly Mean Flow(mmf)

Table (v) Additional STW Flow Data

Site	Date	Flow Ml/d	Source
Stratford STW (Milcote)	05/04/1995	15.350	a/f
	27/04/1995	12.600	a/f
Warwick STW (Longbridge)	16/03/1995	27.000	erda
	21/03/1995	28.000	erda
	29/03/1995	27.500	erda
Blackminster STW	26/02/1996	3.220	mmf
	18/04/1996	3.537	mmf
	30/04/1996	3.537	mmf
	17/05/1996	3.360	mmf
Redditch STW	07/11/1995	22.990	mmf
	03/04/1996	22.600	mmf
Tanworth in Arden STW	12/12/1994	0.100	erda
	16/01/1995	0.100	erda
	13/03/1995	0.100	erda
	10/04/1995	0.100	erda
	15/05/1995	0.100	erda
	13/06/1995	0.100	erda
	10/07/1995	0.100	erda
	11/08/1995	0.100	erda
	02/10/1995	0.100	erda
	30/10/1995	0.100	erda
	27/11/1995	0.100	erda
	09/01/1996	0.100	erda
	08/02/1996	0.100	erda
	04/03/1996	0.100	erda
	02/04/1996	0.100	erda
	03/05/1996	0.100	erda
	04/06/1996	0.100	erda
	01/07/1996	0.100	erda
	01/08/1996	0.100	erda
Chipping Campden STW	07/12/1994	1.350	a/f
	24/03/1995	1.337	erda
Wellesbourne STW	26/01/1995	2.300	erda
	26/04/1995	2.250	erda
Leamington Heathcote STW	06/12/1994	1.400	erda
	10/01/1995	1.450	erda
	26/01/1995	1.350	erda
	07/02/1995	1.400	erda
	23/02/1995	1.400	erda
	07/03/1995	1.450	erda

Table (v) cont.

Site	Date	Flow Ml/d	Source
Braunston STW	10/01/1995	0.780	erda
	23/02/1995	0.900	erda
	23/03/1995	0.800	erda
Southam STW	23/03/1995	2.875	a/f
	16/05/1996	2.800	erda
	24/05/1996	2.700	erda
	14/06/1996	2.700	erda
	25/06/1996	2.700	erda
Harbury STW	23/03/1995	1.290	a/f
Lutterworth	28/09/1995	3.044	a/f
Crick STW	22/03/1995	1.069	a/f
	13/06/1996	0.430	a/f
	24/06/1996	0.400	erda
	08/07/1996	0.268	a/f
	09/08/1996	0.400	erda
	19/08/1996	0.450	erda

4.1.2 Additional Flow Data for River Sites

Missing flow data supplied for the River sites came from 3 sources.

1) If the site is a gauging station - the mean daily flow for the required day.
2) If there was a gauging done at the site on the day. - the instantaneous 'spot' flow.
3) A correlation set up between gaugings at site and nearby station. (Tagged depending on how good the regression fit was.)

Table (vi) Extra River Flow Data

River	Site	Date	Flow Ml/d	Calculation Method	Quality
Avon	Stratford	24/02/95	1847	correlation with Stareton	good
		27/04/95	470	gauging	
		10/05/95	266	correlation with Stareton	good
		08/06/95	244	correlation with Stareton	good
		19/06/95	224.4	correlation with Stareton	good
		04/07/95	203.7	gauging	
		01/08/95	270.5	gauging	
		25/08/95	241.6	correlation with Stareton	good
		15/09/95	343.4	correlation with Stareton	good
		27/03/96	591.1	correlation with Stareton	good
		26/06/96	170.7	correlation with Stareton	good
		12/07/96	194.2	correlation with Stareton	good
		02/09/96	200	correlation with Stareton	good
Avon	Barford	09/12/94	567.5	correlation with Stareton	good
		13/12/94	380.1	correlation with Stareton	good
		05/01/95	456.1	correlation with Stareton	good
		06/07/95	271.2	correlation with Stareton	good
		14/07/95	268.8	correlation with Stareton	good
		01/09/95	266.0	correlation with Stareton	good
		11/09/95	331.2	correlation with Stareton	good
		13/05/96	280.4	correlation with Stareton	good
Avon	Stare Bridge	01/03/96	267.5	gauging station	
		25/07/96	40.3	gauging station	
Avon	Lawford	20/06/95	3.2	gauging	
		06/07/95	24.4	gauging	
		14/07/95	24.5	gauging	
		03/08/95	26.2	correlation with Stareton	good
Avon	Clifton	20/06/95	20.2	correlation with Stareton	good
		06/07/95	18.3	correlation with Stareton	good
		14/07/95	16.9	correlation with Stareton	good
		03/08/95	14.9	correlation with Stareton	good
		01/09/95	16.4	correlation with Stareton	good
		05/09/95	19.2	correlation with Stareton	good
		11/09/95	53.2	correlation with Stareton	good
		21/09/95	23.1	correlation with Stareton	good
		29/09/95	23.4	correlation with Stareton	good
		03/10/95	20.8	correlation with Stareton	good
		09/10/95	22.4	correlation with Stareton	good
		19/10/95	19	correlation with Stareton	good
		16/11/95	31	correlation with Stareton	good
		24/11/95	23	correlation with Stareton	good
		11/07/96	18.2	correlation with Stareton	good
		25/07/96	57.2	correlation with Stareton	good
		06/08/96	17.6	correlation with Stareton	good
		15/08/96	19.3	correlation with Stareton	good
		06/09/96	18.8	correlation with Stareton	good
		17/09/96	15.3	correlation with Stareton	good
Avon	Kilworth	04/10/95	6.6	gauging	

Table (vi) cont.

River	Site	Date	Flow Ml/d	Calculation Method	Quality
Alne	Alcester	16/06/95	31.2	correlation with Broom	good
		21/06/95	28.6	correlation with Broom	good
		29/06/95	19.5	correlation with Broom	good
		07/07/95	17.6	correlation with Broom	good
		12/07/95	32.8	correlation with Broom	good
		17/07/95	28.7	correlation with Broom	good
		04/08/95	8	correlation with Broom	good
		14/08/95	12.1	correlation with Broom	good
Arrow	Broom	30/07/96	76.5	gauging station	
Arrow	Coughton Ford	16/06/95	51.4	correlation with Broom	good
		21/06/95	49.3	correlation with Broom	good
		29/06/95	42.1	correlation with Broom	good
		07/07/95	40.5	correlation with Broom	good
		12/07/95	52.7	correlation with Broom	good
		17/07/95	49.4	correlation with Broom	good
		04/08/95	33	correlation with Broom	good
		14/08/95	36.2	correlation with Broom	good
Arrow	Bordesley A441	19/06/95	7.0	correlation with Stareton	good
		04/07/95	5.7	correlation with Stareton	good
		20/07/95	5.3	correlation with Stareton	good
		01/08/95	5.0	correlation with Stareton	good
		17/08/95	4.7	correlation with Stareton	good
	Lower Bittel Reservoir	19/06/95	0.59	gauging	
		04/07/95	0.6	gauging	
		20/07/95	0.62	gauging	
		01/08/95	1.89	correlation with Broom	good
		17/08/95	1.56	gauging	
Alne	Little Alne	10/07/95	39.2	correlation with Broom	good
		09/01/96	334.8	correlation with Broom	good
Alne	Wootton Wawen	19/06/95	18.9	correlation with Broom	good
		04/07/95	12.1	correlation with Broom	good
		20/07/95	13.4	correlation with Broom	good
		01/08/95	18.4	correlation with Broom	good
Alne	Danzey Green	10/07/95	0.37	gauging	
Nolcham Bk	Welford	19/06/95	1.4	correlation with Broom	good
		04/07/95	dry	correlation with Broom	good
		20/07/95	dry	correlation with Broom	good
		01/08/95	1.2	correlation with Broom	good
		17/08/95	dry	correlation with Broom	good
		25/08/95	dry	correlation with Broom	good
		22/07/96	dry	correlation with Broom	good
		07/08/96	0.3	correlation with Broom	good
	Marston Grange	10/07/95	dry	gauging	
		04/09/95	dry	gauging	
		02/10/95	dry	gauging	
		30/10/95	dry	gauging	
		27/11/95	dry	gauging	
		09/01/96	dry	gauging	
		08/02/96	dry	gauging	
		04/03/96	dry	gauging	
		02/04/96	0.4	correlation with Broom	good
		03/05/96	0.5	correlation with Broom	good
		04/06/96	dry	gauging	
		01/07/96	0.02	gauging	

Table (vi) cont.

River	Site	Date	Flow Ml/d	Calculation Method	Quality
Stour	Clifford	16/06/95	19.3	gauging	
	Chambers	21/06/95	16.8	gauging	
		29/06/95	9.8	gauging	
		07/07/95	8	gauging	
		12/07/95	8.5	gauging	
		17/07/95	8.6	gauging	
		04/08/95	15.9	gauging	
		14/08/95	14.5	gauging	
Stour	Shipston	27/04/95	60.4	correlation with	good
				Wellesbourne	
		17/08/95	18.2	correlation with	good
				Wellesbourne	
Stour	Cherington	13/07/95	3.8	gauging	
Wynyates Bk		20/01/95	160	correlation with	med/poor
		13/07/95	0.6	Wellesbourne	
		10/08/95	dry	gauging	
		06/10/95	dry	gauging	
		09/02/96	24.6	gauging	med/poor
		27/09/96	dry	correlation with	
				Wellesbourne	
				gauging	
Knee Bk	High Furze	10/07/95	1.3	gauging	
Knee Bk	Paxford	10/07/95	1.5	gauging	
Nethercote Bk		10/07/95	0.7	gauging	
		04/09/95	3.9	gauging	
Dene	Fosse Way	13/07/95	2.1	gauging	
Thelsford Bk		13/07/95	0.6	gauging	
Tach Bk	A41 Road Bdge	07/12/95	dry	gauging	
		16/05/96	8	correlation with	med/poor
		10/07/96	dry	Wellesbourne	
				gauging	
Leam	Birdingbury	06/12/94	217.5	correlation with Eathorpe	good
		23/06/95	3.7	gauging	
		03/07/95	3.4	gauging	
		19/07/95	2.8	gauging	
Leam	Sawbridge	23/06/95	0.9	gauging	
		03/07/95	0.6	gauging	
		19/07/95	0.6	gauging	
Leam	A425 Road Br	23/06/95	2.3	correlation with Eathorpe	good
		03/07/95	1.9	correlation with Eathorpe	good
		19/07/95	1.7	correlation with Eathorpe	good
Itchen	Marton	23/06/95	25	correlation with Eathorpe	medium
		03/07/95	23.6	correlation with Eathorpe	medium
		19/07/95	22.6	correlation with Eathorpe	medium
Itchen	Deppers Bridge	23/06/95	0.8	gauging	
		03/07/95	0.5	gauging	
		31/07/95	dry	gauging	
Stowe	Southam	19/05/95	1.7	correlation with Eathorpe	poor
Rains Bk	Barby	02/07/96	dry	gauging	
		31/07/96	dry	gauging	
		27/08/96	dry	gauging	
		26/09/96	dry	gauging	
Sowe	Stoneleigh	01/03/96	258	gauging station	

Table (vi) cont.

River	Site	Date	Flow Ml/d	Calculation Method	Quality
Sowe	Baginton	09/12/94	275.4	correlation with Stoneleigh	good
		23/01/95	316.6	correlation with Stoneleigh	good
		02/02/95	309.3	correlation with Stoneleigh	good
		14/02/95	326	correlation with Stoneleigh	good
		20/06/95	52	correlation with Stoneleigh	good
		30/06/95	44.6	correlation with Stoneleigh	good
		06/07/95	45.6	correlation with Stoneleigh	good
		14/07/95	81.2	correlation with Stoneleigh	good
		21/07/95	37.6	correlation with Stoneleigh	good
		03/08/95	33.6	correlation with Stoneleigh	good
		07/08/95	34	correlation with Stoneleigh	good
		10/01/96	250	correlation with Stoneleigh	good
		12/02/96	626.5	correlation with Stoneleigh	good
Sowe	Walsgrave	09/06/95	14.2	gauging	
		22/06/95	18.2	correlation with Stareton	medium
		05/07/95	1.8	gauging	
		18/07/95	1.7	gauging	
		02/08/95	16.4	correlation with Stareton	medium
		15/08/95	13.6	correlation with Stareton	medium
Sowe	Astley Hall	06/09/95	dry	gauging	
		27/08/96	dry	gauging	
Finham Bk	Finham	22/06/95	0.62	gauging	
		05/07/95	0.75	gauging	
		18/07/95	0.8	gauging	
		02/08/95	7.1	correlation with Stoneleigh	good
		15/08/95	5.2	correlation with Stoneleigh	good
Finham Bk	Chase Lane	15/06/95	1.3	gauging	
		08/08/95	0.6	correlation with Stoneleigh	good
		07/02/96	3.0	correlation with Stoneleigh	good
Inchford Bk	Kenilworth	15/06/95	1.6	gauging	
		08/08/95	0.6	correlation with Stoneleigh	good
		01/11/95	dry	gauging	
		07/02/96	13.5	correlation with Stoneleigh	good
Sherbourne	Sowe confluence	09/06/95	8.2	gauging	
		22/06/95	0.82	gauging	
		05/07/95	0.74	gauging	
		18/07/95	0.87	gauging	
		02/08/95	7.2	correlation with Stoneleigh	med/poor
		15/08/95	6.5	correlation with Stoneleigh	
Sherbourne	Allesley	22/06/95	0.27	gauging	
		05/07/95	0.24	gauging	
		18/07/95	0.31	gauging	
		02/08/95	0.65	correlation with Stoneleigh	good
		15/08/95	0.22	correlation with Stoneleigh	good
		13/09/95	dry	gauging	
		28/09/95	dry	gauging	
		11/10/95	dry	gauging	
		26/10/95	dry	gauging	
		08/11/95	dry	gauging	
Coombe Pool	outflow	15/06/95	7.8	correlation with Stoneleigh	good
		07/02/96	15.2	correlation with Stoneleigh	good
Smite Bk	Coombe	15/06/95	1.5	gauging	
		08/08/95	dry	gauging	
		07/02/96	7.1	correlation with Stoneleigh	good

Table (vi) cont.

River	Site	Date	Flow Ml/d	Calculation Method	Quality
Withy	Walsgrave	15/06/95	1.4	gauging	
		07/02/96	7.3	correlation with Stoneleigh	medium
Wyken Slough		15/06/95	dry	gauging	
		06/09/95	dry	gauging	
		04/10/95		no data	
		29/11/95		no data	
		11/01/96		no data	
		05/03/96		no data	
		08/05/96		no data	
		06/06/96		no data	
		02/07/96	dry	gauging	
		31/07/96	dry	gauging	
		27/08/96	dry	gauging	
		26/09/96	dry	gauging	
Swift	Brownsover Hall	22/06/95	1.7	correlation with Stareton	good
		05/07/95	2	correlation with Stareton	good
		18/07/95	1.2	correlation with Stareton	good
		02/08/95	dry	gauging	
		15/08/95	0.25	correlation with Stareton	good
Swift	Lutterworth	15/02/95	150	correlation with Starcton	medium

N.B. dry has been entered in the database as 0.0