Rivers Nene and Great Ouse Eutrophication Studies

Final Report

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Summary

- The aim of the project has been to assess the impact of phosphorus stripping at major sewage treatment works (STWs) on the Rivers Nene and Great Ouse. Particular emphasis has been placed on sites at Wansford and Offord, where water is pumped from the rivers into Rutland and Grafham Waters, respectively.

- Phosphorus (soluble reactive phosphorus - SRP and total phosphorus - TP), dissolved iron, chlorophyll *a*, dissolved oxygen, temperature, secchi depth, phytoplankton, diatom and macrophyte data have been collected between June 1993 and December 1996, at sites along both rivers.

- The water concentrations of phosphorus and nitrogen have remained high throughout the project, and are therefore, unlikely to have been limiting to primary production.

- Indices derived from the diatom and macrophyte communities suggested that both rivers are eutrophic. MTRs (from the macrophyte community) generally indicate greater nutrient enrichment downstream of STWs.

- Phosphorus stripping was successful in reducing SRP levels in STW effluents and river water in the Great Ouse. At Bedford and Cotton Valley STWs the effluent SRP concentrations fell from 3.9 to 0.7mg/l and 4.2 to 0.95mg/l, respectively. These are below the limit of 1mg/l set out for each, under the Urban Waste Water Treatment (UWWT) Directive. SRP loads in the main river fell by an estimated 28%, during phosphorus stripping.

- Phosphorus stripping was less successful on the River Nene. Effluent SRP concentrations at Billing, Broadholme and Corby STWs fell 36%, 38% and 49% respectively, remaining well above the limit of 1mg/l, set out for each under the UWWT Directive. The SRP load in the main river only fell by an estimated 17.4% during the initial phase of phosphorus stripping

- Small STWs, other point sources, diffuse sources and internal loading have been identified as other possible sources of phosphorus to the rivers.

- An annual cycle of river phytoplankton growth has been suggested for both rivers. This involves a spring bloom, initially dominated by pennate diatoms. As the bloom progresses centric diatoms and green algae become more abundant. A clear phase follows the spring bloom which is either prolonged or interspersed with periods of elevated phytoplankton growth.

- Recommendations have been made for areas requiring further work, including, the modelling of diffuse inputs of phosphorus and the role of sediments in the rivers.

- A set of guidelines for future monitoring programmes has been proposed.

Chapter One - Introduction

1.1 Introduction:

Eutrophication is the enrichment of waters by inorganic plant nutrients, which results in the stimulation of an array of symptomatic changes. These include the increased production of algae and/or other aquatic plants, affecting the quality of the water, and disturbing the balance of organisms present within it. Such changes may be undesirable and interfere with water uses (Environment Agency,1996a). The process is viewed as being natural, but is accelerated by human activity. Moss (1988) goes as far as to suggest that natural eutrophication is rare and that artificial eutrophication (also known as cultural eutrophication) is primarily responsible. For the purpose of this report, the term eutrophication will be used to mean artificially induced nutrient enrichment.

A prerequisite for eutrophication is that, nutrients essential for plant growth, are present in high enough concentrations not to limit plant growth (Abel,1989). The two principal nutrients that cause eutrophication are nitrogen and phosphorus (Harper,1992). Nitrogen comes primarily from diffuse sources (agricultural - especially in fertilisers), with phosphorus inputs mainly from point sources (domestic and industrial effluents) - (Moss,1988). Historically diffuse and small point sources of phosphorus have not been regarded as important (Mason,1996). However, these can provide a significant input of phosphorus depending on land use and the proportion of the population in smaller settlements in a catchment (Mainstone et al,1996). Studies have shown considerable variation in the contribution of non-point phosphorus inputs, varying between 20% (MacDonald *et al*,1995) and 44% (Mainstone *et al*,1996) of total phosphorus input, depending on the relative extent of urban and agricultural land in the catchment. Phosphorus, in particular, is considered to be limiting to plant growth in freshwaters due to its low natural abundance and availability (Mason,1996). Nitrogen is much more abundant and is highly soluble in its more common forms (Mason,1996). Nitrogen is, therefore, readily available, and unlikely to be limiting to plant growth. The combination of point source origins, and its role in limiting plant growth, has consequently made phosphorus control of primary importance in the management of eutrophication.

The effects of eutrophication are well documented (for a full account see Harper,1992). This includes an increase in overall plant biomass, as the growth of tolerant species is no longer limited by nutrient availability. These taxa often out-compete other species. As a result, eutrophication can lead to a reduction in diversity, a situation often seen with phytoplankton where, a few blue-green species can come to dominate (Harper,1992). This is a direct effect, but there are also indirect effects of eutrophication. For example, the bacterial breakdown of extra detritus, produced from increased biomass, can lead to a drop in dissolved oxygen concentrations (Mehner & Benndorf,1995). There are human as well as other biological consequences of eutrophication. For example increased nutrient levels in sources for drinking water supply (e.g. nitrogen) can take concentrations above health limits (as defined in the Surface Water Abstraction Directive), and so require further treatment or blending before use; algal blooms block water filters, have toxic effects on animals and, lower dissolved oxygen levels can cause fish kills, affecting the amenity value of angling waters (Mehner & Benndorf,1995).

Whilst the effects of nutrient enrichment are reasonably well understood in lakes, the situation is less straightforward and has been much less studied in rivers. In rivers the process appears to be slower, and the effects are not as obvious, so that measurement of eutrophication is generally more onerous (Harper, pers comm).

1.2 Background to Project:

In the summer of 1989 algal blooms (particularly of blue-green algae) formed at many standing waters in Great Britain including Rutland and Grafham Waters. Anglian Water Services (AWS) subsequently embarked on an agreed programme to reduce phosphorus levels in these two reservoirs. The programme involved direct dosing of ferric salts in an attempt to precipitate phosphorus from the water column to the sediments, making the nutrient unavailable to phytoplankton and in turn reducing the potential for algal blooms. After a period of dosing, the National Rivers Authority (NRA) monitoring identified a deterioration in the benthic invertebrate community of the reservoirs caused by the iron precipitate and/or associated impurities. To help resolve this problem AWS diverted their efforts more towards the removal of phosphorus at point source (sewage treatment works - STWs), ceasing direct dosing altogether, at Grafham Water, in 1992. Direct dosing continued in Rutland Water until April 1996.

Phosphorus control commenced during 1993/4 at a number of STWs on the rivers Nene, Great Ouse and some of their tributaries (see Table 1.2). Water is pumped from these rivers to Rutland (from the Nene) and Grafham (from the Great Ouse). The technique used has been phosphate stripping using ferric and ferrous salts (for procedure see Strickland,1996). There will be a need for phosphorus control at Grafham Water, Rutland Water and the River Nene, downstream of Northampton, as all have been designated as Sensitive Areas (Eutrophic) under the Urban Waste Water Treatment (UWWT) Directive. The River Great Ouse is not designated (it is a potential candidate for designation in 1997 review). Certain discharges into the River Great Ouse and its tributaries are, indirect qualifying discharges, affecting Grafham Water, so are also identified for phosphorus removal measures. The phosphate stripping programme must, therefore, be fully operational by the end of 1998 at these STWs..

Phosphate stripping in the River Nene catchment has continued intermittently since 1993. Dosing ceased at Great Ouse sites in December 1994 and is unlikely to recommence until the UWWT Directive requirements become effective at the end of 1998.

As nutrient stripping is taking place at the STWs it is hoped that this will reduce or eliminate the need for any further direct dosing at Grafham and Rutland Waters. Standards must still be met for the levels of dissolved iron and sulphates in the rivers / effluents however. The limits are set for specific sites on the river, such as at abstraction points to water treatment works. These limits are currently:

- Iron = 1mg/l as an annual average (from Dangerous Substances Directive, List II).
- Sulphate = 250mg/l for 95% of samples (from Surface Water Abstraction Directive).

The limits for effluent are set by consent for the individual discharge.

Table 1.2: Summary of AWS Phosphorus Control at STWs on the Nene and Great Ouse.

River	STW	P Control Measures	Start Date
Nene	Broadholme	Crude sewage and Activated Sludge (AS) plants (50%) dosed with ferric sulphate.	July 1993
	Corby	Oxidation ditch dosed with ferrous sulphate.	Dec 1993
	Great Billing	Crude sewage and AS lanes (50%) dosed with ferric sulphate.	July 1993
		R&D: Return Activated Sludge (RAS) and Filter Bed dosed with ferrous sulphate.	May 1993
		R&D: Biological removal of P from AS lanes.	1993/4
Great Ouse	Bedford	Crude Sewage and AS1 & AS2 plants (76%) dosed with ferric sulphate.	July 1993
	Chalton	RAS and filters dosed with ferric sulphate.	March 1994
	Cotton Valley	RAS and AS plant (100%) dosed with ferric sulphate.	Aug 1993
	Dunstable	Oxidation ditch dosed with ferrous sulphate.	March 1994

1.3 Project Objectives:

- To monitor changes in concentrations and loads of phosphorus and suspended nutrients in the rivers and STW effluents.
- To monitor changes in phytoplankton, macrophytes and diatoms.
- To interpret these results in relation to eutrophication.

Phosphorus is considered to be of primary importance in the eutrophication process (Harper,1992). Throughout this project it has therefore been the measurement and influence of phosphorus that has received most attention.

1.4 Phosphorus:

Phosphorus is accepted as being the principal nutrient that controls the trophic status of a water course (Fox & Malati,1985; Harper,1992). The speciation of phosphorus is particularly important, determining whether it is in a form that is biologically available for plant growth or not (Holtan et al,1988). Soluble reactive phosphorus (SRP - also known as orthophosphate) is the most readily available form, (Fox & Malati, 1985) and is generally used as a measure of biologically available phosphorus. Total phosphorus (TP) analysis gives the cumulative level of phosphorus in a sample. A measure of particulate phosphorus (PP) can be derived by subtracting SRP from TP. Bio-availability of PP is either by algal assimilation involving phosphatase enzymes or after desorption of certain fractions into solution (Fox & Malati,1985).

The speciation of sediment phosphorus is fairly complicated with clay, aluminium, iron and calcium-bound; organic and inert forms. The biological availability of each fraction is uncertain (Goltermann *et al*,1992) which means that dry weight TP is the most reliable measure of sediment phosphorus.

Phosphorus cycles through the water, sediment and biota. In a lake this principally occurs *in situ*. In a river the phosphorus moves downstream as it passes through the cycle, a process called spiralling (Newbold,1994). The cyclical aspect of the phosphorus spiral is displayed in Figure 1.4. The movement of phosphorus between sediment and water is particularly significant to this project. The process is a two way mechanism of particulate settling and sorption (binding of dissolved phosphates to sediment particles) to the sediments or the suspension and desorption (return of sediment bound phosphate to the dissolved fraction) of phosphorus to the water. The net direction of movement is determined by relative water to sediment concentrations, which attempts to move towards an equilibrium (zero net sorption or desorption) - (Forsberg,1989). It is the net direction of phosphorus movement that may be of critical importance in determining phosphorus levels in the water column. Where phosphorus loads from STWs are high and, therefore, those in the water column are high, there is likely to be a net movement from the water to accumulate in sediments. Reduced phosphorus inputs as a result of stripping at STWs could mean that there are proportionally higher levels of phosphorus in a sediment than the overlying water. This will result in a shift to net desorption, a process called internal loading (Krieritz *et al*,1996). If phosphorus has become accumulated in a sediment then internal loading can keep water phosphorus levels elevated for a period of time after the reduction of external inputs (Harper,1992).

Throughout the project phosphorus levels have not been considered in isolation. An integral part of the work has been the response of primary producers to changing phosphorus levels.

1.5 Phytoplankton:

In comparison with our understanding of lake phytoplankton, our knowledge of river phytoplankton is poor. The main controls of phytoplankton growth in lakes are nutrients (particularly phosphorus and silicate), grazing, temperature, residence time and light (Cloot *et al*,1992). In rivers, flow is of major importance (Canter-Lund & Lund,1995). In faster flowing rivers phytoplankton establishment is less likely (Canter-Lund & Lund,1995).

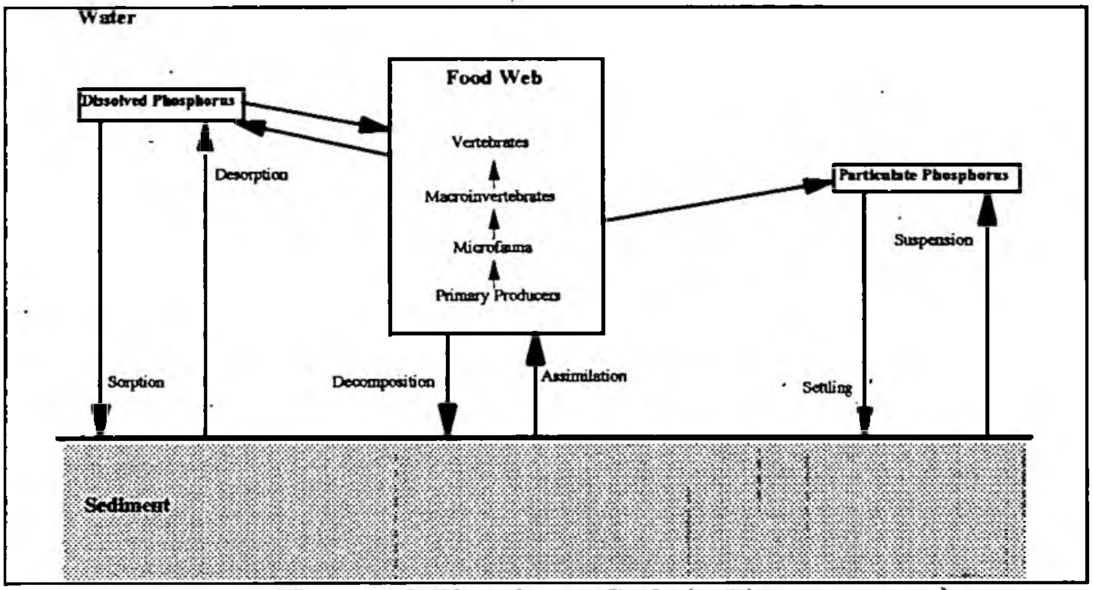


Figure 1.4: Phosphorus Cycle in Rivers

In lakes a cycle of phytoplankton exists, starting with initial growth and a bloom in spring which is dominated by diatoms and some green algae. The spring growth is often followed by a clear phase with less phytoplankton. During the summer, blue-green algae tend to become more dominant. Algal growth is reduced in winter with lower temperatures (Harper,1992). Phytoplankton growth tends to increase with increasing enrichment and this is reflected in increased chlorophyll *a* concentrations (OECD,1982). The community structure of phytoplankton may also change with blue-green taxa becoming more prevalent throughout the year. Large blooms of blue-green algae may be seen in late summer (Mason,1996). Changes in phytoplankton community can occur fairly rapidly in response to changing environmental conditions .

Although knowledge of phytoplankton growth in rivers is limited, a cycle of phytoplankton succession has been identified in the Rivers Nene (Environment Agency,1997) and Great Ouse (Reynolds & Gaister,1992). There is a spring bloom, initially of centric and pennate diatoms, and, as the bloom progresses, green algae become more abundant. The bloom may be short lived or extend into the summer. Conditions in rivers are generally hostile to the development of blue-green algae. In low flow periods, some rivers can sustain blooms of blue-green algae, although the algae is likely to originate from an external source such as enriched lakes, within the catchment. The UWWT regulations have set an annual mean chlorophyll *a* concentration of greater than 25ug/l or a bloom chlorophyll *a* measurement of greater than 100ug/l as a threshold for indicating eutrophication in flowing waters.

Changes resulting from eutrophication can cause several problems. There may be difficulties affecting the extraction and treatment of drinking water, with filters becoming clogged, water becoming discoloured and sometimes taste and odour problems associated with phytoplankton.

There may also be reciprocal effects in the food chain associated with a variable primary food source, so that changes occur within the whole aquatic community.

Health implications also exist, in that some blue-green algae species release toxic substances to the water which can cause illness in humans and are believed to have killed animals, such as sheep and dogs, that have been in contact with the water (NRA,1990)

Interpretation of phytoplankton data should be carried out with care. It is important, for example,to know whether a species grows and reproduces naturally within rivers, or whether it exists mainly in lakes or other waterbodies in the catchment. It would clearly be wrong to derive an indication of trophic status from algae which are not a normal part of the phytoplankton community of the river, although the trophic status and flow regime of the river will of course determine whether algae actively grow in the river.

1.6 Benthic Diatoms:

Benthic diatom growth, as with phytoplankton growth, is controlled by light, flow, grazing and nutrient concentrations. As benthic organisms, light penetration through the water column is very important for growth (Haslam,1978). The frustule (cell wall) of a diatom is formed from silica which makes this nutrient essential for growth and, therefore, potentially limiting (Barber & Haworth,1981). The benthic diatom community responds to changes in the nutrient status of the river, with a shift in taxa present or dominant. Certain indicator species or taxa can be used to characterise this change. (Kelly,1996) . As with phytoplankton, the response is fairly rapid, potentially occurring within a single season. Benthic diatoms are, therefore, a useful biological tool, along with phytoplankton and macrophytes, for monitoring eutrophication.

1.7 Macrophytes:

The factors controlling macrophyte growth are flow (including frequency and severity of spates), nutrients, light, substrate characteristics and human activities, most notably boats, channel engineering and weed-cutting. Flow is often considered to be of primary importance (Haslam,1978). Unlike phytoplankton, macrophytes can grow in higher flows. Well rooted or attached taxa are suited to survival in these conditions.

Nutrients for macrophytes originate both from the water and sediment. Sediments are believed to be the biggest source of phosphorus for rooted plants (Chambers *et al*,1989). Nutrient enrichment of a river causes macrophyte communities to respond by increased biomass and a change in the taxa that are present or dominate (Mason,1996). The responses from the macrophyte community are slower than those of the diatom community (Kelly,1996), possibly taking several years to become apparent. Macrophytes, therefore, require longer-term monitoring to identify changes in trophic status or environmental quality.

These aspects will be summarised in this report for the whole of the three year study period.

Chapter Two - Methods and Data

2.1 Sample Sites:

River Nene sample sites are shown in Figure 2.1.1. Initially a further site, White Mills, which lies between Billing and Hardwater was sampled, but this was dropped in 1993, following a rationalisation of the sampling programme. The two Willow Brook sample sites (Weldon and Fotheringhay), and Corby STW, were added in November 1993 in response to the commencement of ferric dosing at Corby STW. Duston Mill, St Andrews and the River Ise were added in July 1994. A short survey to assess the influence of Chettles (Ditchford Mill) was conducted in late 1994 to early 1995, and the sampling of Ditchford Mill Stream switched from fortnightly to monthly when this survey ceased. During 1996 a short term study of extra sites upstream of Billing Marina, in Billing Marina itself and at Thrapston, Summer Leys and Kinewell Lakes was carried out to investigate, potential non-lotic sources of phytoplankton.

Sample sites for the River Great Ouse are shown in Figure 2.1.2. The site at Stanbridgeford on the River Ouzel was added to the sample run in November 1993. It was dropped along with the site at Cranford Bridge on Fancott Brook in October 1995 following a rationalisation of the sampling programme. A short term study of extra sites was carried out in 1996 at Willen Lake, Caldecotte Lake and Neck Pit to investigate, potential non-lotic sources of phytoplankton.

Problems have occurred in terms of the spatial distribution of sample sites on both rivers. For example Elton to Wansford is 7km, whilst Thrapston to Elton is over 20km (see Figure 2.1.1). Also, the River Ouzel/Ouse confluence and Cotton Valley STW, are both situated between Newport Pagnell and Tyringham (see Figure 2.1.2), and the individual impact of each is consequently lost (Appendix 1).

2.2 Sampling Strategy:

2.2.1 General

Tables 2.2.1 & 2.2.2 shows the strategy and frequency for sampling undertaken for 1996. This differs a little from previous years (see Appendix Two).

2.2.2 Chemical Sampling

TP and SRP have been measured at all sites. Chlorophyll *a* has been sampled at most sites, apart from a few minor tributaries. Chlorophyll *a* samples have also been taken at extra sites, involved in the short term study in 1996 (Billing Marina, Willen Lake etc.). Throughout the project chlorophyll *a* at Wansford has been taken more frequently during the summer months as part of the monitoring programme for another project.

Table 2.2.1: Rivers Nene and Great Ouse Sampling Program (for 1996).

F = Fortnightly M = Monthly A = Annually * = April to October only + = more often in summer	CHL A	SRP	TP	SO4	TOT FE	DIS FE	SI	PHYTO	DIATOM
Will Bk - GtWeldon		F	F	M	M	M			A
Will Bk - Fotheringhay	F	F	F					F	A
Nene - Wansford	F+	F	F				F+	F+	
Nene - Elton	F	F	F						
Nene - Thrapston	F	F	F					F	
Nene - Irthlingborough	F	F	F	M	M	M			A
Nene - Ditchford Lock	F	F	F	M	M	M			A
Nene - Ditchford Stream	F	F	F						
Nene - Wellingborough	F	F	F					F	
Nene - Hardwater Mill	F	F	F	M	M	M			A
Nene - Billing	F	F	F	M	M	M		F	A
Nene - Duston	F	F	F						
Nene - St Andrews	F	F	F						
Ise - Wellingborough	F	F	F					F	
u/s Billing Marina	F*							F*	
Billing Marina	F*							F*	
Thrapston Lake	F*							F*	
Summer Leys Lake	F*							F*	
Kinewell Lake	F*							F*	
Ouse - Offord	F	F	F				F	F	
Ivel - Tempsford	F	F	F					F	A
Ouse - Roxton	F	F	F					F	
Ouse - Castle Mills	F	F	F	M	M	M			A
Ouse - Newnham	F	F	F	M	M	M			
Ouse - Sharnbrook Mill	F	F	F					F	A
Ouse - Tyringham	F	F	F	M	M	M			
Ouse - Newport Pagnell	F	F	F	M	M	M		F	A
Ouzel - Lovat Bank	F	F	F					F	A
Ivel - Navigation	F	F	F						
Ivel - Langford	F	F	F						
Willen Lake	F*							F*	
Caldecotte	F*							F*	
Cotton Valley - Neck Pit	F*							F*	

It should be acknowledged that some problems may also exist with the temporal resolution of this sampling strategy. Periodic, spot sampling of phosphorus from sample sites, STWs and Chettles Ltd, for example, may miss high concentration phosphorus discharges (consented or illegal).

The sampling of silicon, sulphate, and total and dissolved iron has been targeted at a few main river and tributary sites. Sediment sampling has occurred intermittently at Bedford, Hardwater Mill and Billing, ceasing on the Great Ouse in 1993, and on the Nene in 1995.

Routine sampling, successively by, the Anglian Water Authority, NRA and Environment Agency, at Offord and Wansford provides long term data stretching back as far as 1981 for some determinands. Examples of data sets are chlorophyll *a* (1981 onwards), BOD (1981 onwards at Wansford only) and TP (1985 onwards at Wansford and 1989 onwards at Offord).

Field measurements (see Table 2.2.2) of Secchi depth (to an accuracy of 0.1m), were carried out at all the main river sites on the Nene and Great Ouse throughout the project, but due to the high flow and shallow nature of the tributaries, such measurements were not made at these points. At selected main river sites sampled for phytoplankton, dissolved oxygen levels and temperature were also measured (using a YSI 55 meter).

Surface water samples and field measurements have been taken from bridges or the banks of the rivers, always from flowing surface waters and as near to the centre of the channel as possible. During warmer seasons samples have been stored in cool boxes while being transported. Sediment samples were taken initially using a pipe corer and later using a pole mounted Ekman Grab from a boat (see Elliott & Drake,1981). Chemical analysis of samples was carried out at the regional laboratory at Peterborough until the end of 1993. Since January 1994 analysis has been carried out by the National Laboratory Service.

Sampling of the effluent from the STWs has been carried out as part of Environment Agency (and NRA) routine sampling programmes, on a weekly basis for TP, SRP, total iron, dissolved iron, and sulphate since 1993.

2.2.3 Biological Sampling

Sampling of phytoplankton has been targeted at selected main river and tributary sites. Phytoplankton samples were analyzed in-house at Brampton and Spalding.

Surveys were taken of epiphytic and epilithic diatoms on an annual basis, initially being sampled at all sites, but from 1994 only selected sites were sampled (see Table 2.2.1). Diatom identification was carried out by the Natural History Museum.

Table 2.2.2: Rivers Nene and Great Ouse Field Measurements.

F = Fortnightly + = in Summer more often	Secchi Depth	Dissolved Oxygen	Temperature
Nene - Wansford	F+	F	F+
Nene - Elton	F		
Nene - Thrapston	F	F	F
Nene - Irthlingborough	F		
Nene - Ditchford Lock	F		
Nene - Wellingborough	F	F	F
Nene - Hardwater Mill	F		
Nene - Billing	F	F	
Ouse - Offord	F	F	F
Ouse - Roxton Lock	F	F	F
Ouse - Castle Mills	F		
Ouse - Newnham	F		
Ouse - Sharnbrook Mill	F	F	F
Ouse - Tyringham	F		
Ouse - Newport Pagnell	F	F	F

One macrophyte survey of the main river sample sites on the Nene and Great Ouse was carried out in 1993 (see Cranston & Ayres,1994). Subsequent surveys have been carried out by the Environment Agency, either once or twice a year as part of the monitoring programme for the UWWT directive. This work has concentrated on sites associated with upstream and downstream of STWs which do not correspond with the project sample sites. These have included STWs not involved in the project, such as Hitchin STW. These additional sites provide useful additional information about the trophic status of the rivers.

2.3 Phosphorus Data:

(The results have been calculated for each sample and on a quarterly basis).

Samples were filtered in the field to remove the particulate fraction, before analysis for SRP concentration, using a new, pre-washed 0.45um cellulose nitrate filter - (determinand code - dc:74972). Samples from STW discharges have been unfiltered and are stated as measuring dissolved SRP (dc:01916). The long term SRP data for Wansford, and Offord prior to 1989, are also from unfiltered samples (dc:01806).

TP concentrations have been determined from unfiltered water samples and the discharges from STWs to provide a measure of all the phosphorus present in a sample (dc:75301). PP concentrations have subsequently been calculated by subtracting SRP from TP for samples and STW discharges. Long term TP data for Wansford and Offord also exist (also dc:75301).

There have been some analytical problems throughout the project. Chemical analysis has frequently shown SRP concentrations to exceed TP concentrations. In these cases is has been assumed that the SRP result is correct and the TP value is therefore, rejected. Also, there are no PP concentrations recorded for these samples.

Phosphorus concentration is greatly influenced by flow (the same input of phosphorus will be at a lower concentration in higher flow). This means that the interpretation of concentrations alone will not provide an accurate picture of phosphorus levels and inputs (such as those from the tributaries, STWs and Chettles) to a river. This problem can be overcome by using flow and concentrations to calculate phosphorus loads (mass per unit time):

ie: Load (kg/day) = P Concn (mg/l) * Flow (Cumecs) * 863 (time constant)

The load reflects the amount of phosphorus in the river or a discharge independent of flow, so that the relative impacts of different inputs, internal loading and flow can be assessed.

Problems of temporal resolution exist for load calculations. A significant proportion of the annual phosphorus load is transported during a few high rainfall/flow events. Loads will fluctuate considerably over a short period during these events. Fortnightly sampling, largely fails to account for the impact of these periods. The implication is that the use fortnightly load calculations is not a very accurate method for tracing the annual pattern of loads in the Rivers Nene and Great Ouse. The alternative is to use relationships between known loads and flows to extrapolate or interpolate loads from more frequently recorded flow data (Wade & Harrison, 1996).

Flows have been taken, where available, from gauged flows at the sample sites. At sites on the Nene where gauged flows were unavailable, a flow model based on gauged flows up- or downstream of the sample site has been used. The model takes into account abstractions, discharges and the difference in catchment area between the gauged site and the sample site. The abstractions and discharges are taken to be constant, which is unlikely. Also, the model assumes an instantaneous relationship between flows at the gauging stations (upstream of Billing or on tributaries) and at study sites, ignoring any time lag (Hill, pers comm).

A flow model does not exist for the Great Ouse, so at ungauged sites an estimation of flow has been made, wherever possible. The estimate is achieved by scaling back flow from gauged sites in relation to catchment area. Differences and allowances are made for major abstractions and discharges where possible. Such estimations have been carried out for Newnham, Castle Mills and Sharnbrook Mill. These produce fairly rough estimates so should be treated with caution. The complex situation at Langford and Clifton (geology, catchment area etc.) means that there is no flow data, and hence no loads, available for these sites (Whiteman, pers comm).

All daily mean effluent discharge flows were provided by AWS.

2.4 Other Chemical Data:

Total iron (dc:04217) and sulphate (dc:01833) concentrations have been measured from unfiltered samples, and dissolved iron (dc:04197) levels have been measured from filtered samples using a 0.45um cellulose filter.

Chlorophyll *a* samples (dc:07921) were stored in light tight bags prior to analysis, to prevent further photosynthesis after collection. The results have been calculated on a fortnightly and quarterly basis.

Other chemical data has been provided through the routine sampling of the study sites by the Environment Agency (and its predecessor, the NRA). Relevant determinands include total oxidised nitrogen (TON, dc:01165), ammonium (dc:01113) and silicate (dc:01823).

Sediments samples were analyzed for dry weight (mg per kg of sediment) of phosphorus and iron.

2.5 Biological Data:

Phytoplankton samples have been fixed on collection using Lugol's iodine solution. The samples have been selectively analyzed to identify the taxa present and their abundance (see NRA Standard Methodologies, 1993). The samples were selected based on the chlorophyll *a* analysis (ug/l), those exhibiting high chlorophyll *a* levels being analyzed.

Macrophyte data for each site has been collected during late spring and summer. The information obtained is of species presence and percentage cover (see Environment Agency Methodology, 1996). This raw data also has been converted into a Mean Trophic Ranking (MTR), derived from the trophic score of the individual species and the total cover for that species (for a full explanation see Holmes, 1995; Environment Agency, 1996). The lower the MTR for a site then the more eutrophic the site. A site upstream of a sewage works should have a higher MTR than the downstream site if the STW discharge is having a significant impact on the trophic state of the river.

Diatom samples were collected in early autumn (1993) or summer (1994/5) . Samples were taken from plants, boulders or cobbles at each site and were fixed on collection with Lugol's iodine solution. Diatoms were identified and counted (300 cells) for each sample (for a full explanation of the collection and counting methods see Cox & Reid, 1994 & 1996; Cox, 1995). The raw data has been analyzed through a number of water quality assessment techniques including MEWAM (Methods for the Examination of Waters and Associated Materials - Round,1993), IPS (specific pollution index - Coste,1982), GEN (generic index - Rumeau & Coste, 1988), Steinberg & Schielfe (1988) Zone system and from 1995 onwards the TDI (Trophic Diatom Index - Kelly & Whitton,1995; Kelly,1995) - (For a full explanation of how these were applied see Cox & Reid,1994 & 1996; Cox,1995).

Figure 2.1.1: River Nene

Figure 2.1.2: River Great Ouse

Chapter Three - River Great Ouse

3.1 Flow:

Figure 3.1 shows the quarterly flows for the main river sites. The absence of flow data for Sharnbrook Mill during parts of 1994 and 1995 was due to gauging problems at Harrold Mill, from where the Sharnbrook Mill flow is derived.

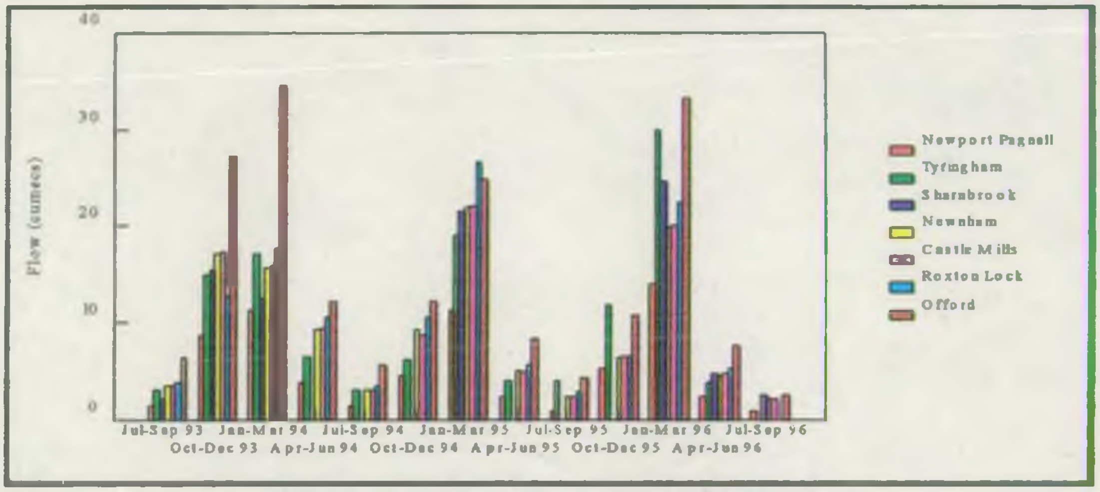


Figure 3.1: Great Ouse Quarterly Flow

There is some variability in the pattern of flow downstream due to the estimation of flows at ungauged sites, which is less accurate than gauged flow. It has, nevertheless, been possible to make an estimate of flow, so that an estimate of load can be calculated for each site. Accurate assessment of flows is critical for reliable load calculations. Improvements in load calculations could be made through the development of a model (as used for the River Nene) or, more widespread gauging.

3.2 Phosphorus in STW Effluent:

SRP concentrations in the effluents of Bedford and Cotton Valley STWs (Figures 3.2.1 & 3.2.2) fell dramatically during the stripping period (June 1993 - December 1994). This is further illustrated by the mean SRP concentrations pre- and during stripping (Table 3.2). At Bedford STW the SRP concentration fell to 0.685 mg/l and at Cotton Valley to 0.95 mg/l during stripping, equivalent to reductions of 82.5 and 77.5% respectively, compared to the pre-stripping period. Stripping at Dunstable and Chalton STWs (Figures 3.2.3 & 3.2.4) occurred over a shorter period, and the reduction in SRP concentrations, whilst marked, were less than at Bedford or Cotton Valley STWs.

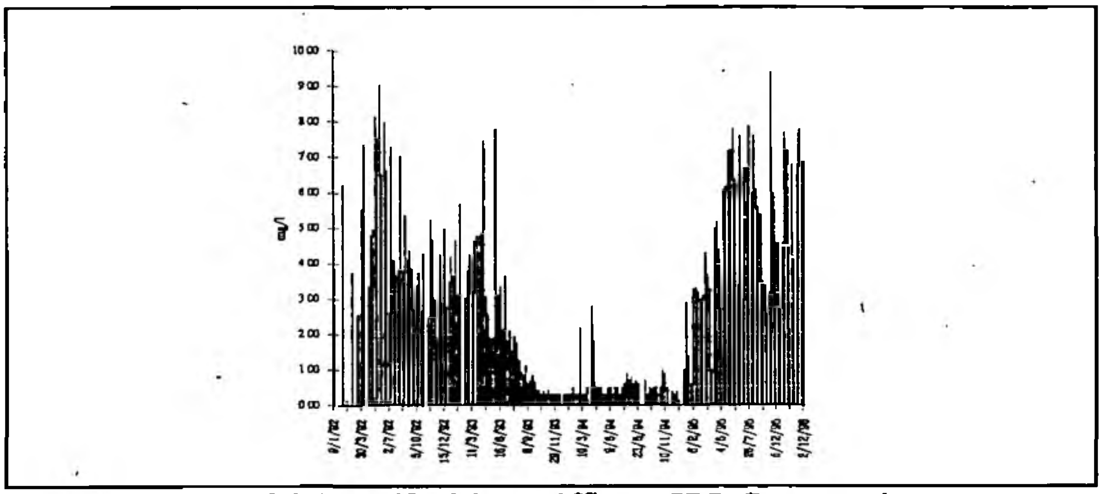


Figure 3.2.1: Bedford STW Effluent SRP Concentration

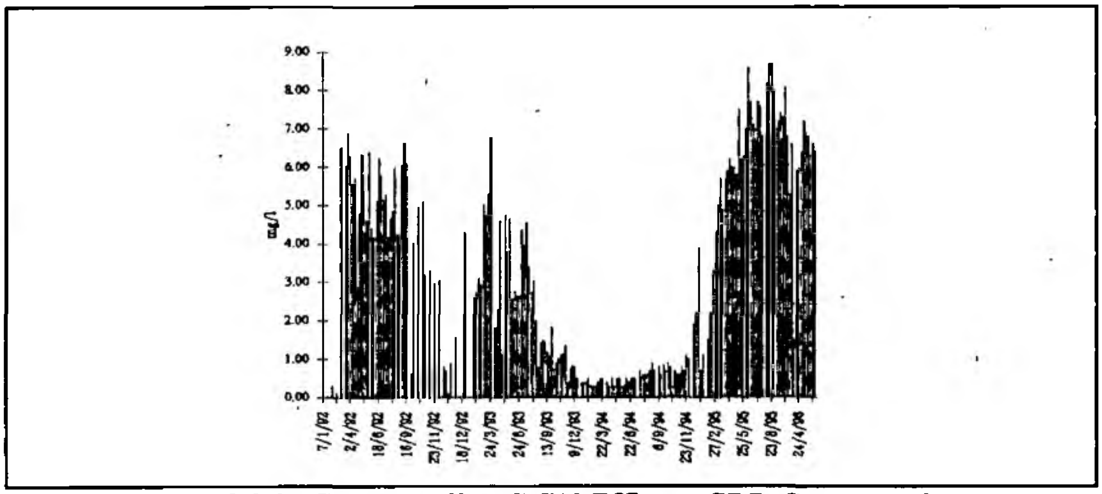


Figure 3.2.2: Cotton Valley STW Effluent SRP Concentration

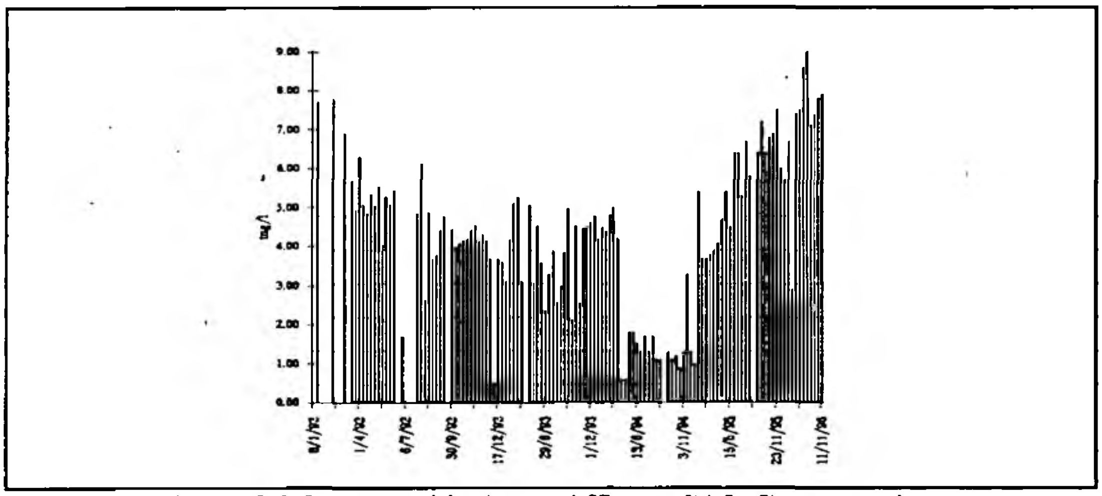


Figure 3.2.3: Dunstable STW Effluent SRP Concentration

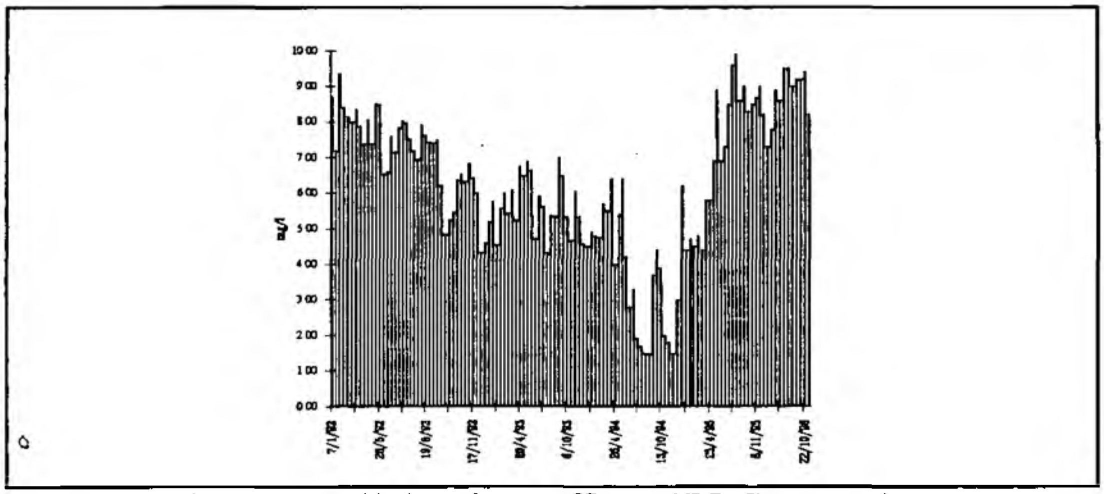


Figure 3.2.4: Chalton STW Effluent SRP Concentration

Following the cessation of stripping at all four STWs in December 1994, the effluent SRP concentrations began to rise, reaching pre-stripping levels by May 1995.

STW	Jan '92 -June '93	July '93 - Dec '94	Jan '95 - Sep '96
Bedford	3.92	0.685	4.732
Chalton	6.828	4.323	7.444
Cotton Valley	4.218	0.95	5.686
Dunstable	4.339	1.383	5.746

Table 3.2: Mean SRP Concentrations in Great Ouse STW Effluents

3.3 Phosphorus in Rivers

Figure 3.3.1 illustrates how SRP is typically the dominant form of phosphorus in the River Great Ouse. The proportion of both PP, and TP tend to increase in winter, with the associated higher flows (Figure 3.3.1) This suggests that particulate matter is being flushed out of the system. The source of the PP is likely to be from either sediment bound phosphorus, or organic material, such as sedimented phytoplankton. The exceptionally high PP in January - March 1996, may be due to the flushing of organic matter, that collected as a result of the blue-green algal bloom, that occurred during the summer of 1995, or due to low flows in previous years. There is also a pattern of, April - June PP levels, being consistently higher than July - September PP levels, in each year. This may reflect greater phytoplankton activity during the early summer period.

A plot of Load vs Flow shows the expected pattern of higher loads with increasing flow (Figure 3.3.2). It should be noted that since flow makes up a component of the load calculation no correlation between load and flow can be inferred.

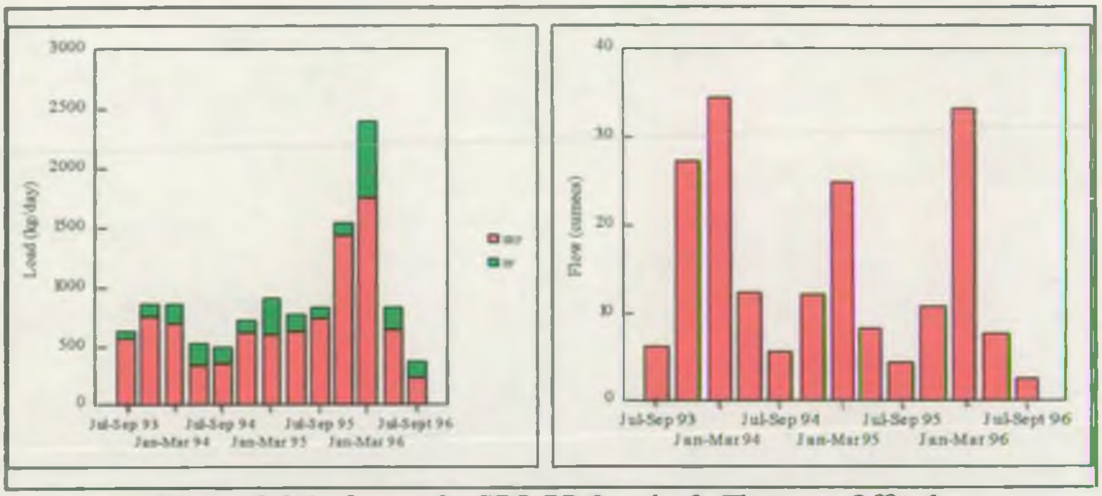


Figure 3.3.1: Quarterly SRP:PP Loads & Flows at Offord

TP levels were fairly stable over the study period until September 1995 (Figure 3.3.1). Subsequent fluctuations can be attributed to variations in flow, except for the quarter, October - December 1995. The high TP load during this period can be attributed to a large concurrent increase in SRP load input from the River Ivel (Figure 3.4.3). TP levels were lower during stripping (April - December 1994) than in the corresponding quarters of 1993, and 1995, pre- and post stripping (Figure 3.3.1). This pattern is emphasised by the plot of load vs flow, where pre-stripping and during stripping data points do not overlap (Figure 3.3.2). The small data set for the during dosing period means, however, that the findings have to be treated with some caution.

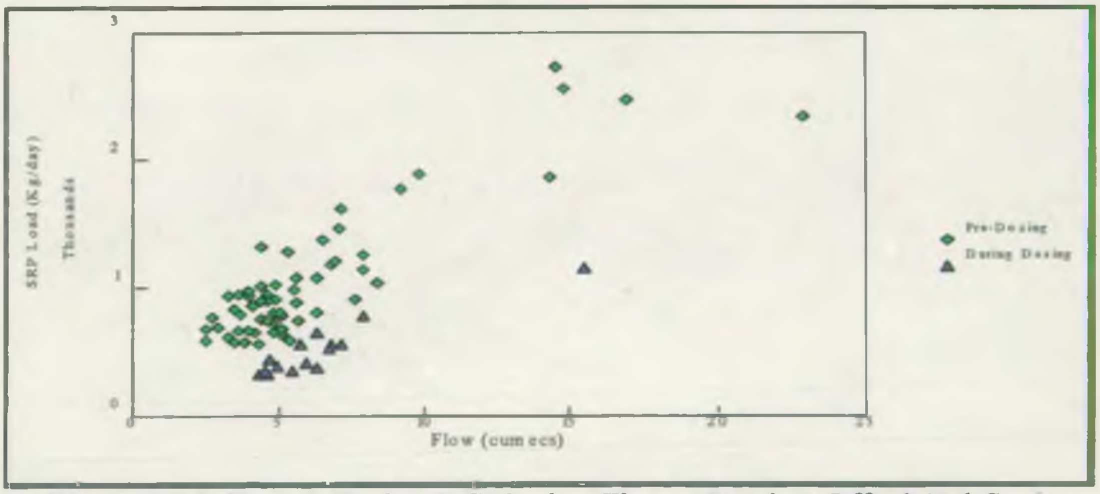


Figure 3.3.2: Pre- & During P-Stripping Flow v Load at Offord (Jul-Sep)

Long term data for Offord (Figure 3.3.3) shows a gradual decline in SRP loads since the mid-1980's, irrespective of flow (Figure 3.3.4). There was a slight increase in loads, after stripping ceased, in 1995. This decline is part of a long-term downward trend, with various causes, notably, improvements in the sewage treatment process, a larger proportion of the population being connected to STWs, and reductions in the phosphate content of detergents (Balmer & Hultman,1988).

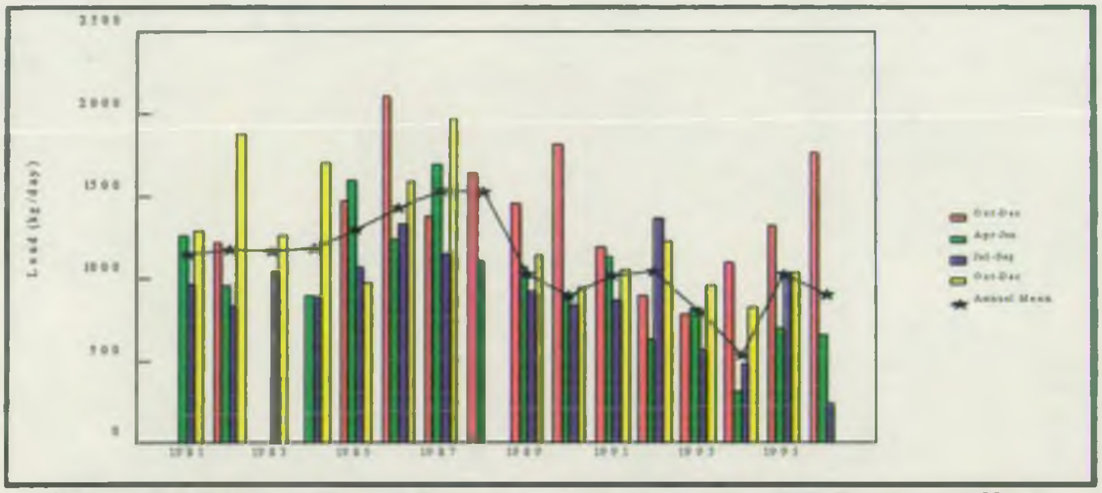


Figure 3.3.3: Long Term Mean Annual & Quarterly SRP Load at Offord

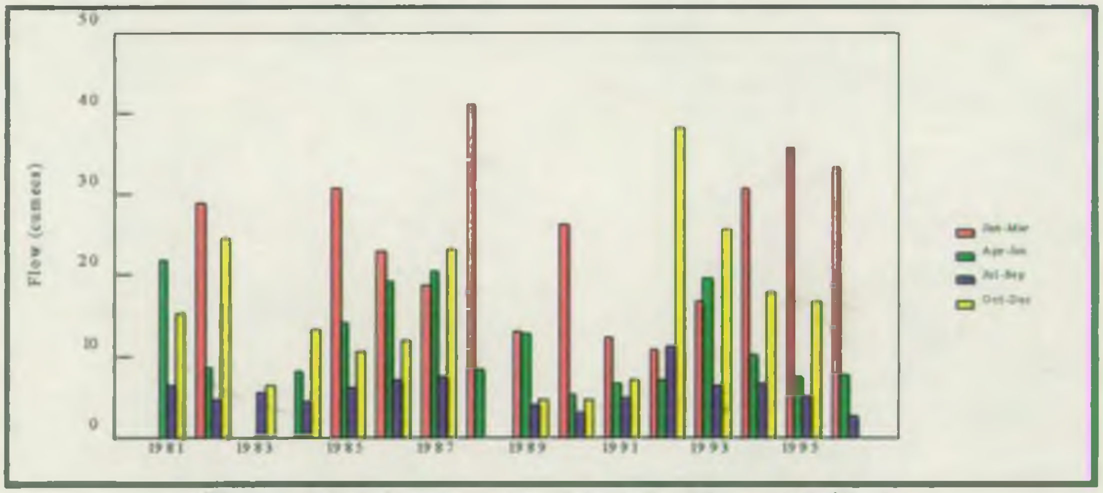


Figure 3.3.4: Long Term Quarterly Flow at Offord

Figure 3.3.5 shows that a fall in nitrogen levels has occurred over the same period. As a result the N:P ratio has remained fairly constant (Figure 3.3.6), with a lower ratio in the summer than in winter . The summer ratio is higher during the stripping period (1993 & 1994) - (between 6-10:1) than in the pre-or post stripping periods (normally between 2-5:1) , indicating a fall in the level of phosphorus relative to nitrogen during stripping.

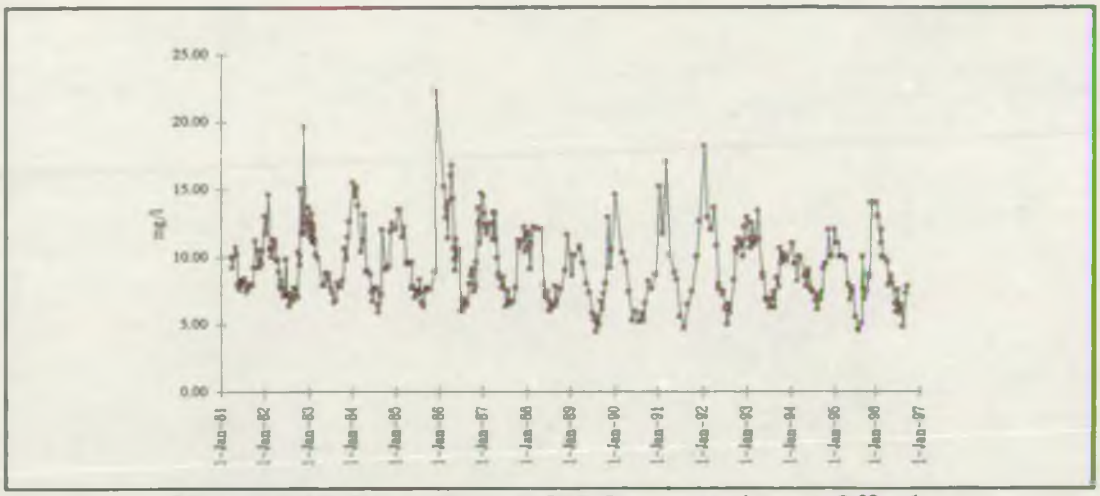


Figure 3.3.5: Long Term TON Concentration at Offord

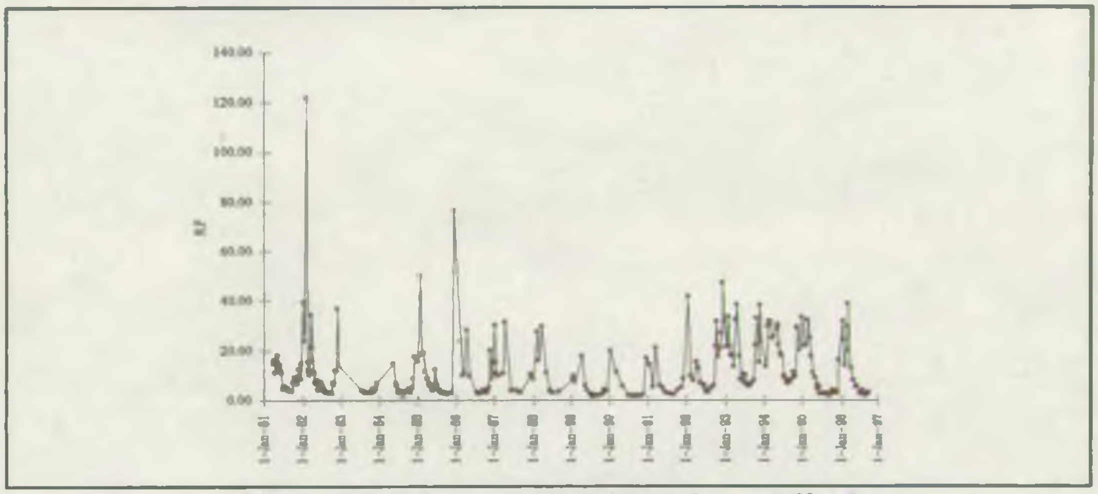


Figure 3.3.6: Long Term N:P Ratio at Offord

	Phosphorus (mg/kg)		Iron (mg/kg)	
Date	Newnham	Castle Mills	Newnham	Castle Mills
06.07.93	7860	1490	59300	34400
03.08.93	2080	1910	46900	57700
17.08.93	2770	2640	47000	64300
31.08.93	2390	2240	44600	45400
28.09.93	1190	850	34800	54100
26.10.93	1920	1400	39900	33000
23.11.93	2360	3510	39400	36700
20.12.93	1160	1960	49500	48900

Table 3.3: Phosphorus & Iron in Sediments Up & Downstream of Bedford STW.

Sediment phosphorus levels upstream (Newnham) and downstream (Castle Mills) of Bedford STW (Table 3.3) show no particular pattern. The frequency and extent of sediment sampling makes this data of limited use.

3.4 Sources of Phosphorus:

3.4.1 Major STWs

The evidence suggests that effluent from the large STWs is a major source of phosphorus in the River Great Ouse. There is a noticeable fall in SRP and TP loads in the river, that correspond with periods of reduced phosphorus loads from STWs in 1994 (see sections 3.2 & 3.3).

Figures 3.4.1a & 3.4.1b emphasise this point. There is a general trend of increased SRP and TP loads downstream. The largest increases occur between Newport Pagnell and Tyringham (up and downstream of Cotton Valley STW) and to some extent between Newnham and Castle Mills (up and downstream of Bedford STW).

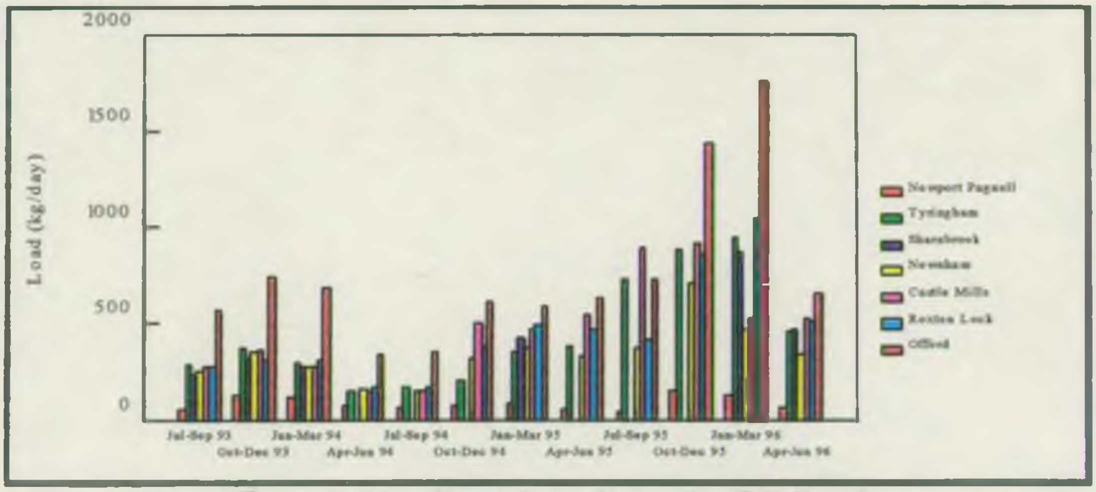


Figure 3.4.1a: Great Ouse Quarterly SRP Load

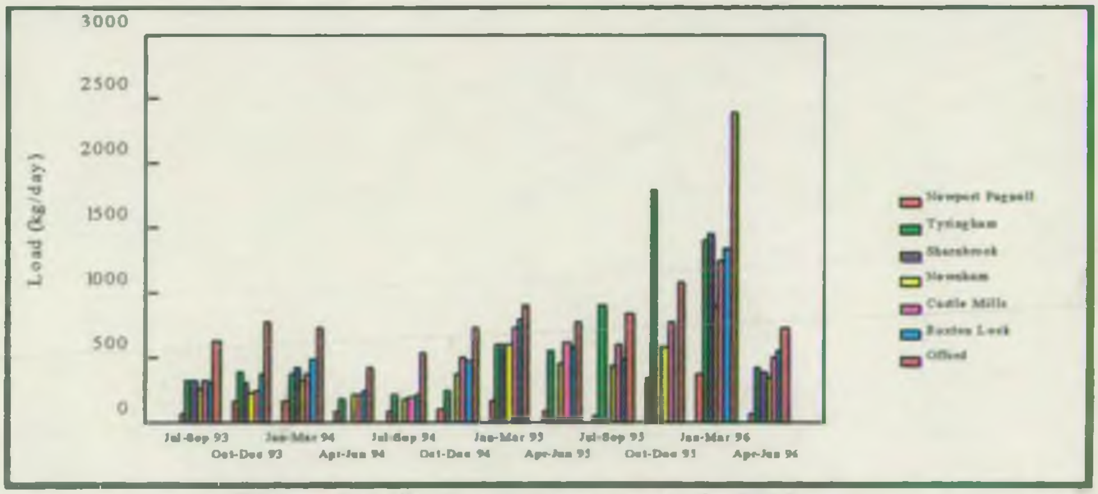


Figure 3.4.1b: Great Ouse Quarterly TP Load

3.4.2 Small STWs

A study of the River Ivel has estimated the contribution of smaller STWs in this catchment (Table 3.4.2). Loads have been calculated by multiplying the mean annual SRP concentrations at each STW by the dry weather flow, multiplied by 1.25. This is believed to best reflect the annual flow situation. It can be seen that Chalton, whilst being the largest STW in the catchment, contributes less than 25% of the overall SRP load to the River Ivel, at 106.5 kg/day. Other STWs do not account for more than 17% of the total individually, but combine to produce a load of 347.8 kg/day. The combined SRP load from Ivel catchment STWs is 454.2 kg/day. This clearly exceeds the load of 329 kg/day entering the River Great Ouse from the River Ivel at Tempsford. The reason for this may be an over-estimation of loads from the STWs. Alternatively, in-channel processes could have caused a downstream fall in SRP loads between the STWs and the confluence of the River Ivel and the River Great Ouse. It is clear that in order to significantly reduce the SRP load in the River Ivel, it will be necessary to remove phosphorus at additional STWs.

STW	Load (kg/day)	% of Total Load
Biggleswade	28.1	6.19
Chalton	106.5	23.45
Clifton	11.7	2.58
Clop Hill	17.4	3.83
Flitwick	60.1	13.23
Hitchin	64.5	14.2
Letchworth	75.6	16.64
Poppy Hill	31.0	6.83
Potton	16.9	3.72
Sandy	8.2	1.81
Shillington	9.9	2.18
Others	24.3	5.35
Total	454.2	100

Table 3.4.2: Estimated SRP Load Contribution of STWs in the River Ivel Catchment

3.4.3 Tributaries

Figure 3.4.3 shows that the SRP loads entering the River Great Ouse from the River Ivel and River Ouzel are significant (up to 329 kg/day at Tempsford on the River Ivel, and up to 230.3 kg/day at Lovat Bank on the River Ouzel). The input of phosphorus to the tributaries is, as noted, predominantly from STWs, notably Chalton STW (River Ivel) and Dunstable STW (River Ouzel).

The River Ouzel enters the River Great Ouse, downstream of Newport Pagnell, and upstream of Tyringham, which appears to combine with the Cotton Valley STW, to cause the large increase in SRP load between the two sample sites (Figure 3.4.1a). The confluence of the Rivers Ivel and Great Ouse is downstream of Roxton Lock, and upstream of

Offord, which probably accounts for the large increases in SRP loads between the sites (Figure 3.4.1a).

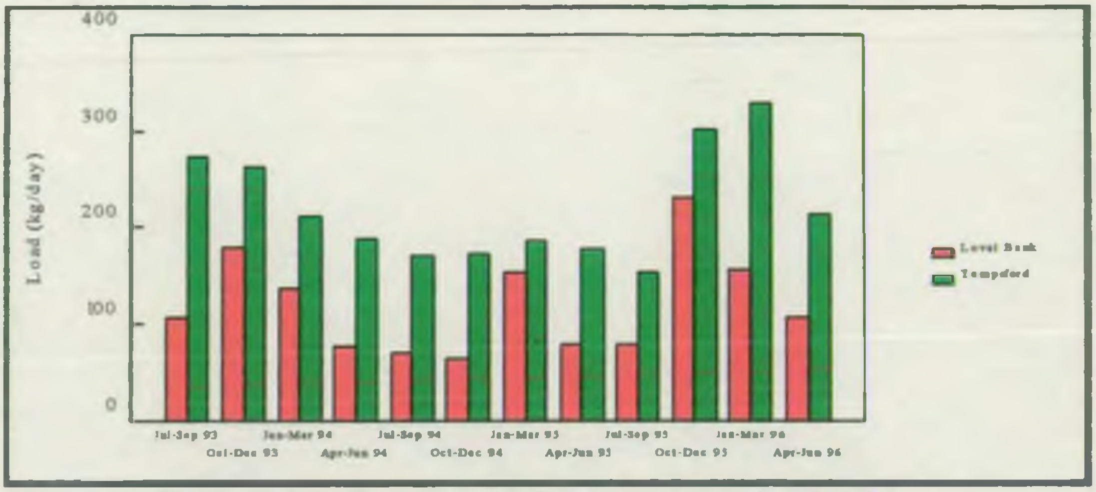


Figure 3.4.3: Great Ouse Tributaries Quarterly SRP Load

3.5 The Impact of P-Stripping on the River:

The SRP and TP concentrations at selected sites are shown in Figures 3.5.1 & 3.5.2. All graphs are to the same scale with the x-axis running from July 1993 to December 1996, and the y-axis representing SRP or TP concentrations (scale 0-5 mg/l). Both SRP and TP concentrations fluctuate according to seasonal conditions, concentrations being greater in the summer.

Concentrations were low at all sites during the stripping period, even during reduced flows in the summer. After stripping ceased concentrations increased. The pattern is picked up at Offord with SRP loads being estimated as 28% lower during stripping, compared to the post stripping period.

The decreasing relative contribution of STWs to the SRP load during the period July 1993 - December 1994 is also seen in Figure 3.4.1a. The increase in phosphorus loads, downstream of Cotton Valley and Bedford STWs, was smaller during the stripping period (June 1994 - December 1994), compared with the load increases during the post stripping period (January 1995 to December 1996). Table 3.5 shows the estimated proportion of the SRP load at Offord from different sources. This emphasises the reduced relative contribution of STWs during stripping. Cotton Valley and Bedford STWs account for only 7.5 and 4.1% respectively during stripping, increasing to 32.7 and 12.5% post stripping.

There is a similar pattern on the River Ouzel, where the SRP load fell considerably, whilst phosphorus stripping was taking place at Dunstable STW (Figure 3.4.3). The SRP load returned to pre-stripping levels when phosphorus stripping ceased at Dunstable STW in December 1994.

On the River Ivel the limited success of stripping at Chalton STW, and large load from smaller STWs, meant that, the load input to the River Great Ouse from this tributary was comparatively high during stripping, representing 31.1% of the SRP load at Offord, whilst in the post stripping period this was only 23.4% (Table 3.5).

Source	During Stripping	Post Stripping
Offord - Mean SRP Ld (kg/day)	688.1	960.9
Bedford STW (%)	4.1	12.5
Cotton Valley STW (%)	7.5	32.7
River Ivel (%)	31.1	23.4
River Ouzel (%)	15.3	13.8
Other Sources (%)	42.0	17.6

Table 3.5: Estimated Proportion from Different Sources of Mean, During & Post Stripping SRP Loads at Offord.

Levels of iron and sulphate show no particular trends upstream and downstream of STWs; and pre-, during and post stripping levels fall within the prescribed legal limits (section 1.2).

Sediments analyzed for iron (Table 3.3.1) do not show any pattern between the sample sites upstream and downstream of Bedford STW.

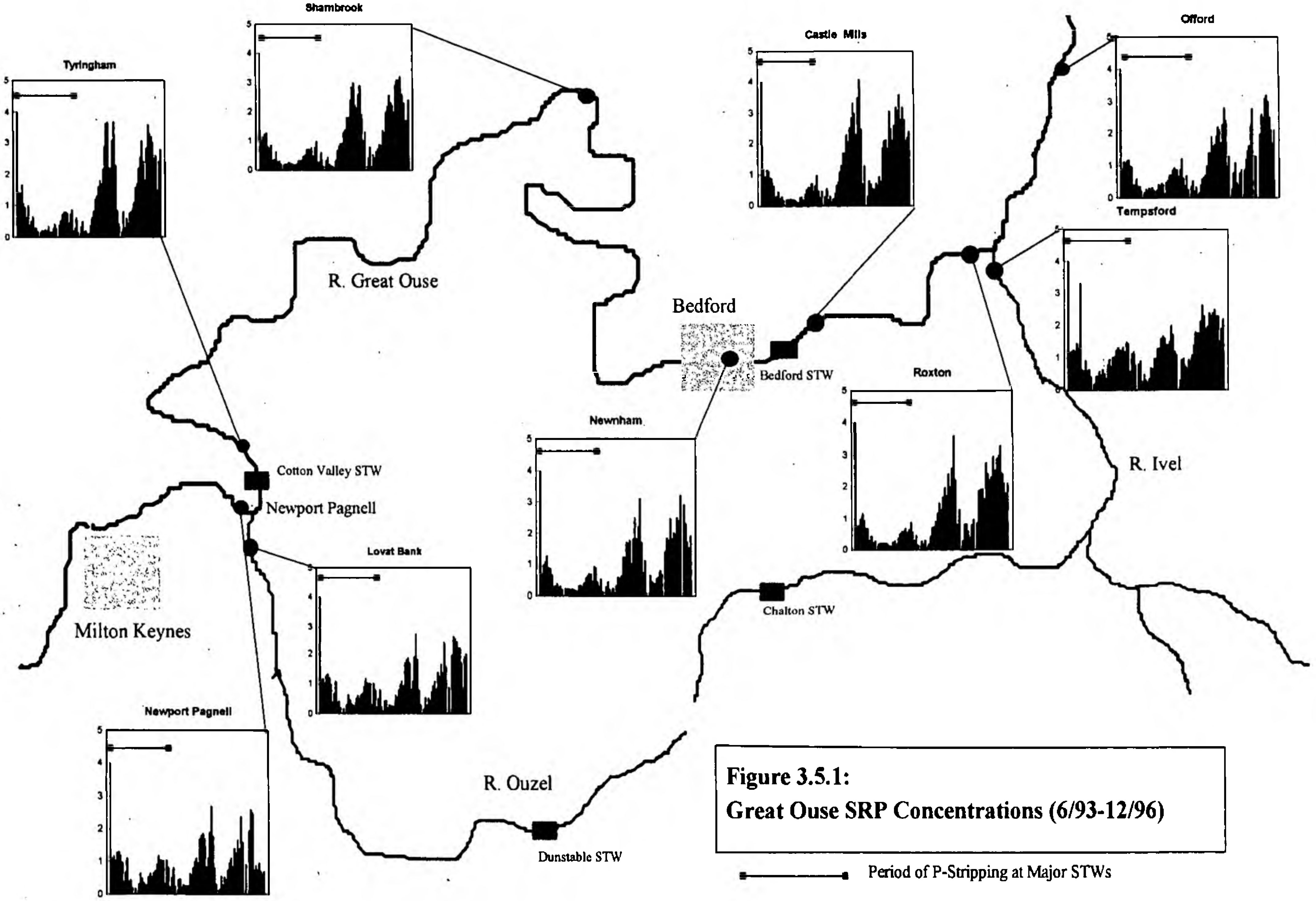
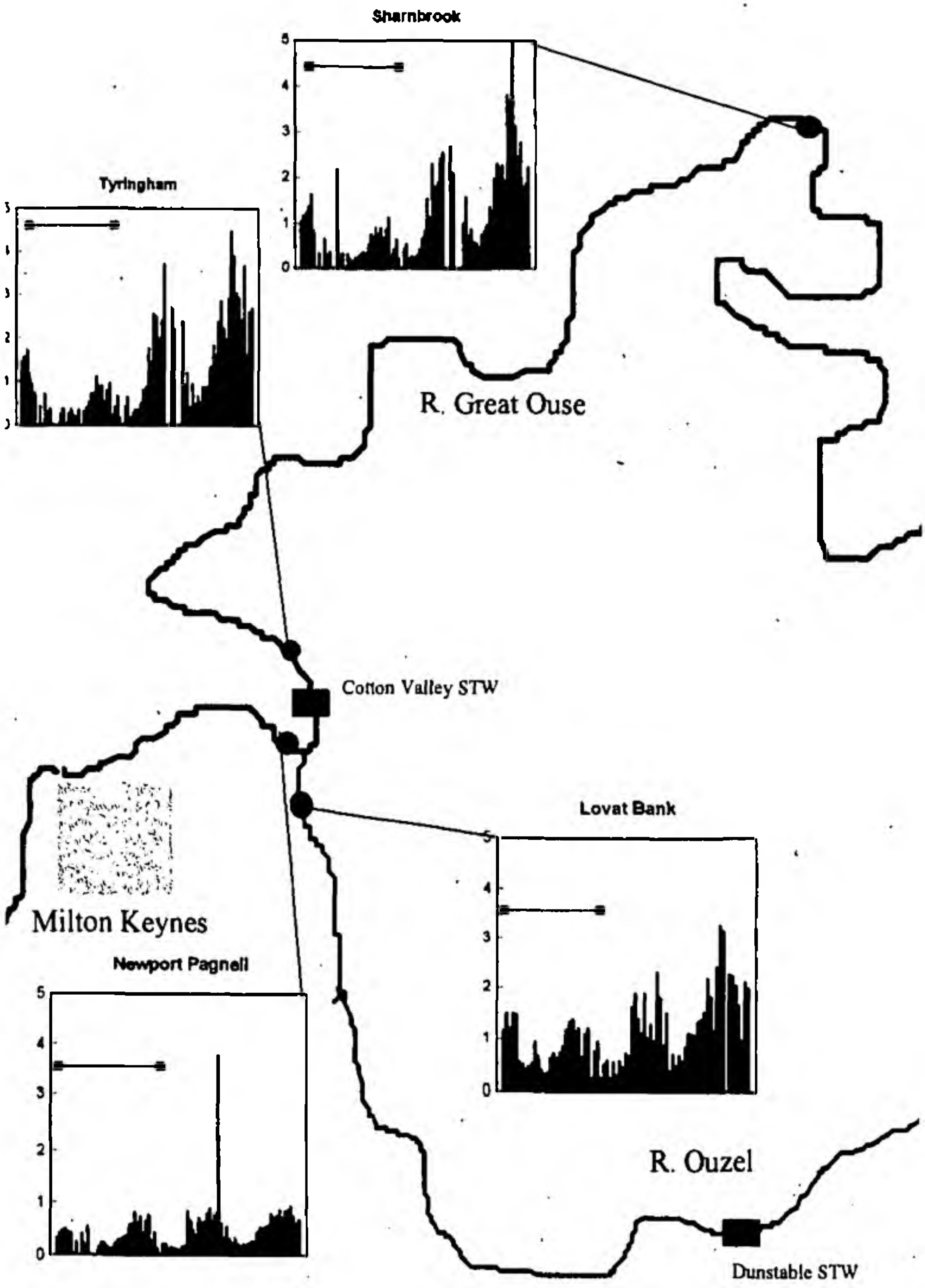


Figure 3.5.1:
Great Ouse SRP Concentrations (6/93-12/96)



Sharnbrook
Tyringham
R. Great Ouse
Cotton Valley STW
Milton Keynes
Newport Pagnell
Lovat Bank
R. Ouzel
Dunstable STW

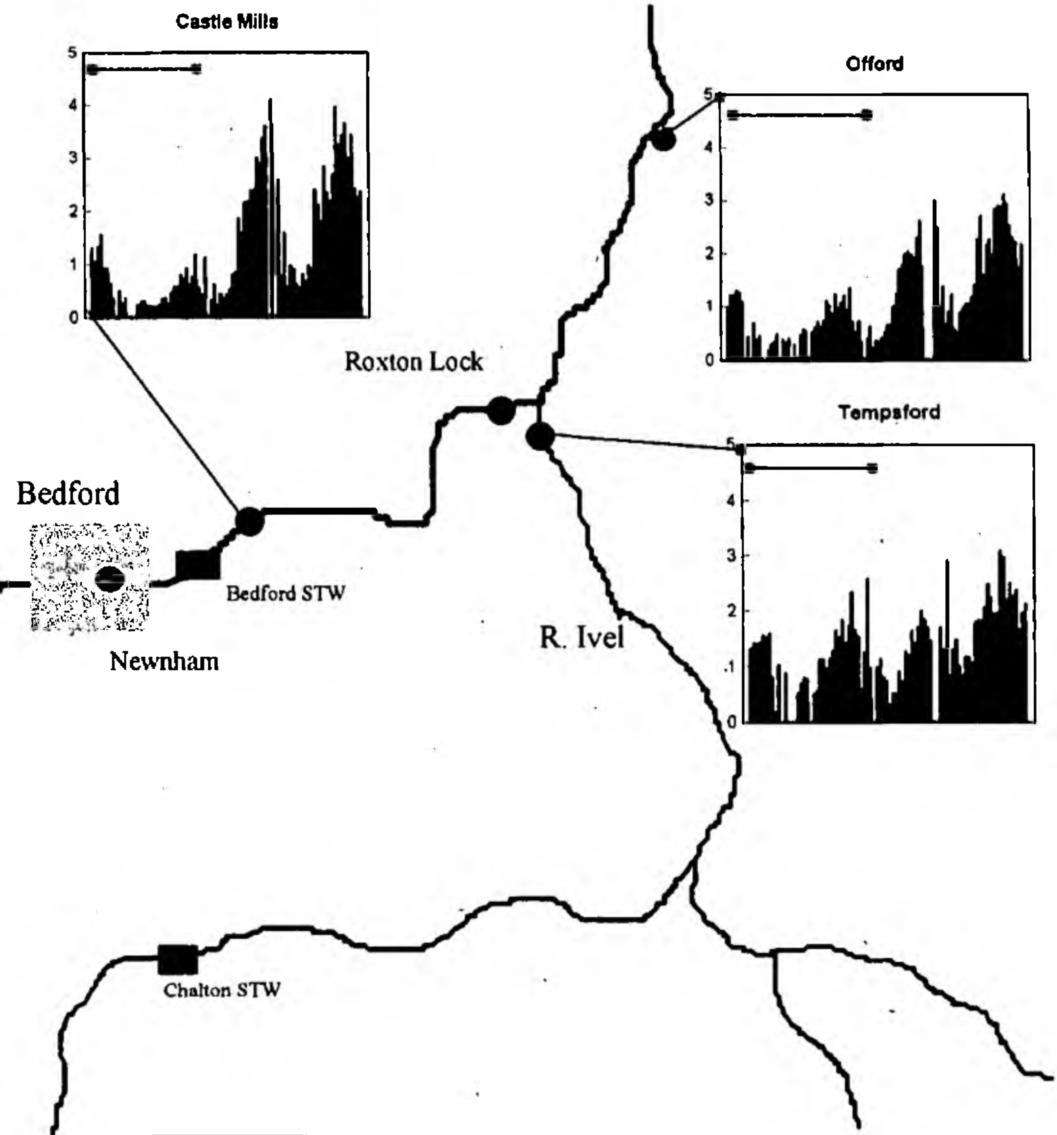


Figure 3.5.2:
Great Ouse TP Concentrations (6/93-12/96)

Period of P-Stripping at Major STWs

3.6 Biological Data:

3.6.1 Diatoms

The complete results for the diatom indices are reported in Cox and Reid (1996). The MEWAM and GCN scores were typical of all the indices used. They indicate that all sites were eutrophic throughout the project (Figures 3.6.1a & 3.6.1b). This even included Newport Pagnell, which is upstream of the major STWs, where water phosphorus levels were at their lowest (Figure 3.4.1a). Cox and Reid (1996) found no correlation between diatom communities and physical or chemical factors.

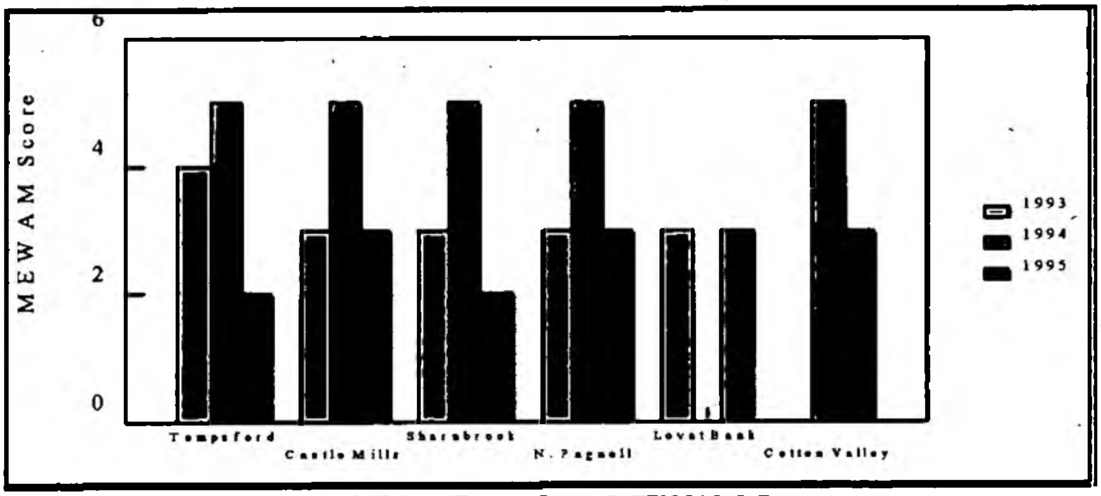


Figure 3.6.1a: Great Ouse MEWAM Scores

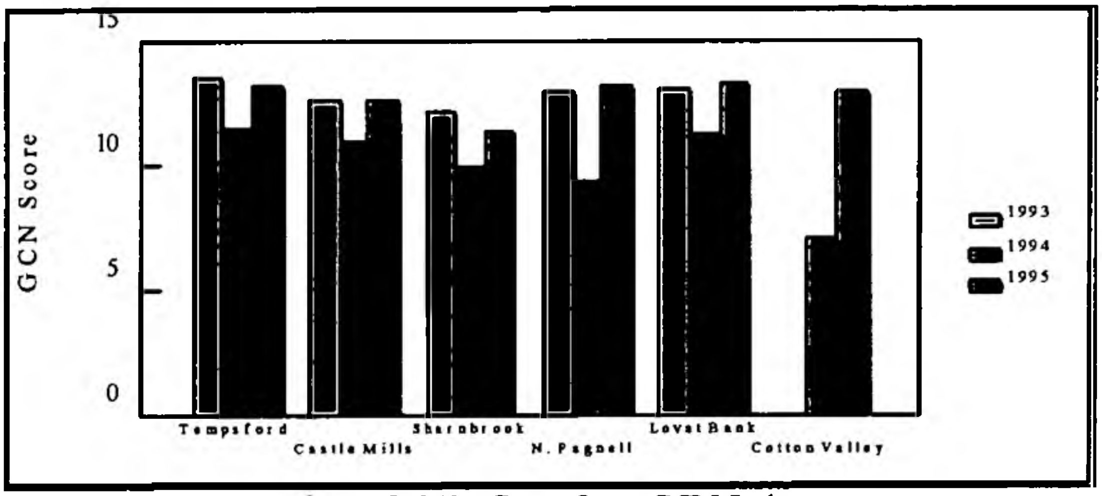


Figure 3.6.1b: Great Ouse GCN Index

3.6.2 Macrophytes

The MTR results are in agreement with the diatom indices. MTRs for the survey sites all fall between 25 and 35 (Figure 3.6.2a), indicating the River Great Ouse to be eutrophic.

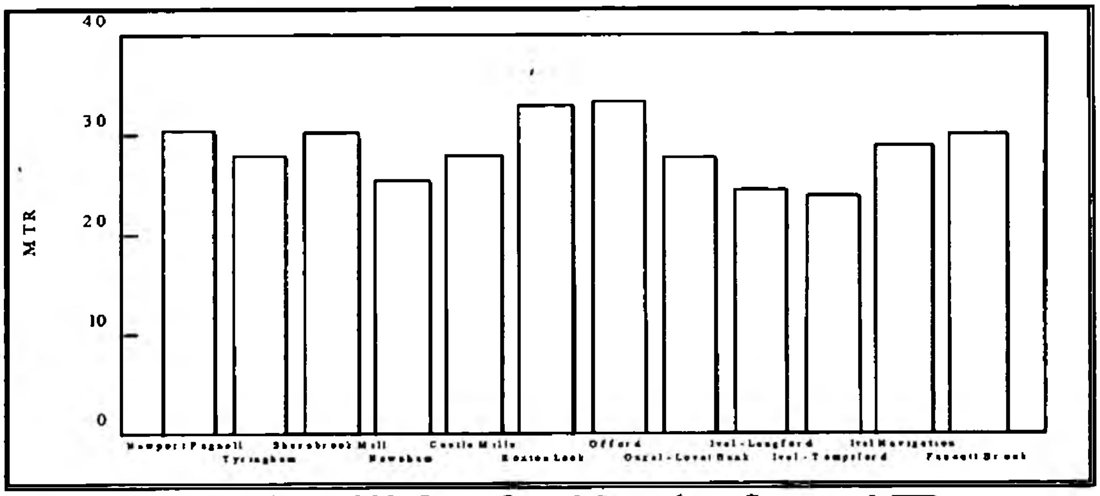


Figure 3.6.2a: 1993 Great Ouse Macrophyte Survey - MTRs

MTRs derived from the UWWT directive monitoring programme show a fall between the upstream and downstream of STWs throughout the study period (Figure 3.6.2b). This does mirror increases in phosphorus loads downstream of STWs (Figure 3.4.1a). Greater declines in the MTR score between up and downstream sites tend to be exhibited higher up in the catchment. This is illustrated in Figure 3.6.2b, which shows the contrast between Hitchin STW, higher up the catchment and Cotton Valley STW, located well downstream.

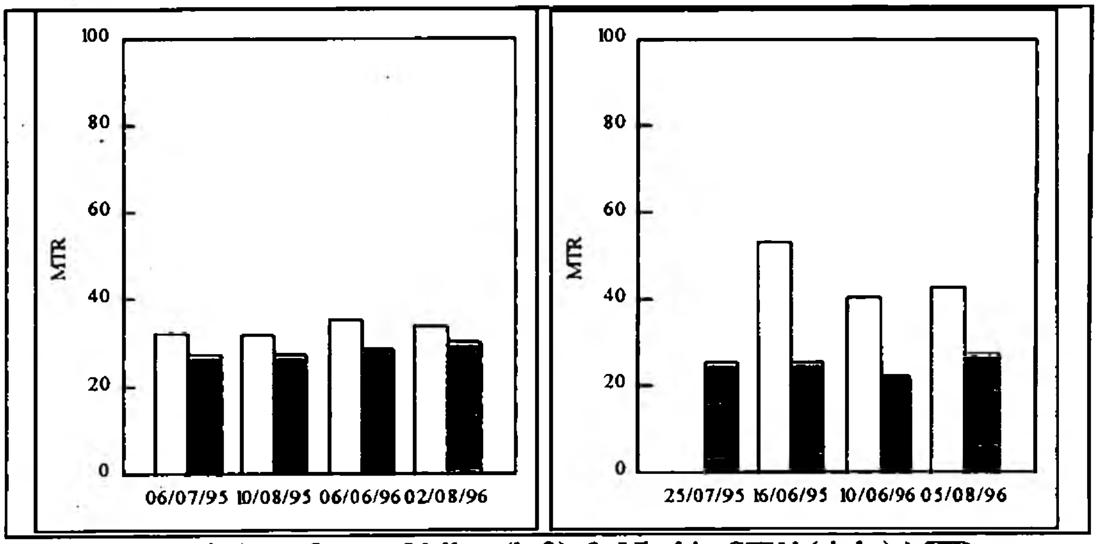


Figure 3.6.2b: Cotton Valley (left) & Hitchin STW (right) MTRs
red = u/s, green = d/s

3.6.3 Phytoplankton

Long-term chlorophyll a data (Figure 3.6.3a) indicates, the occurrence of annual phytoplankton biomass cycles in the River Great Ouse at Offord. Initial growth of phytoplankton occurs in early spring as temperatures start to rise (Figure 3.6.3b). The peak chlorophyll *a* concentrations normally occur during the late spring. These periods of algal activity (spring blooms) are of varying durations and amplitude, but normally last for two to three months and usually have peak chlorophyll *a* concentrations which exceed 100μg/l. The spring blooms are either followed by, a period of little activity, as during the summers of 1994, or by a period of intermittent activity, such as the summer and autumn of 1995.

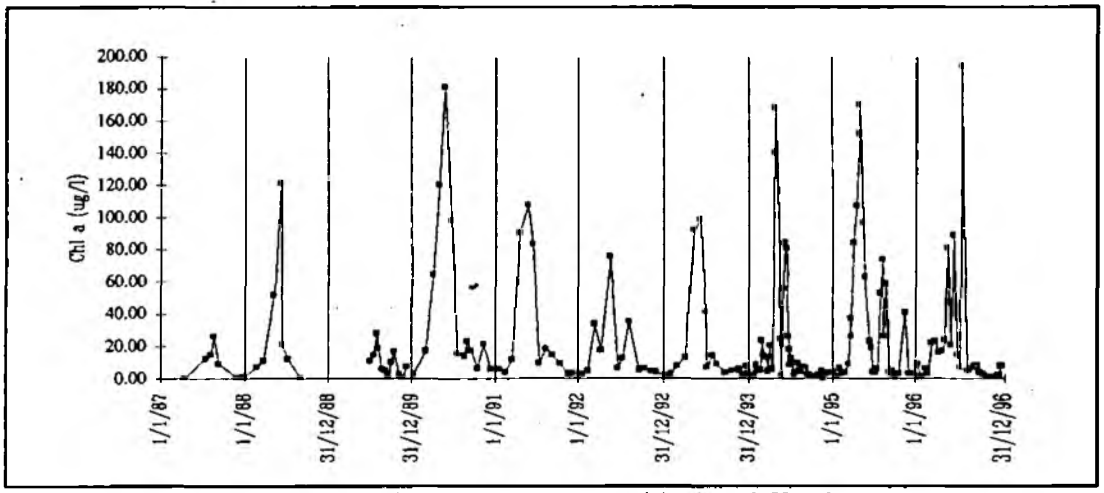


Figure 3.6.3a: Long Term Chl *a* at Offord

An inverse relationship exists between flow and chlorophyll *a* concentrations (Figure 3.6.3b). High or erratic flows can suppress, or delay the development of chlorophyll *a* in the river. Flows during the spring of 1994 were generally above 20 m3/s, interspersed with discharges that were two or three times this value. This resulted in delayed phytoplankton activity. Stable flows, through the spring and summer of 1995, permitted phytoplankton density to develop sooner and, persist for a longer period, than in 1994. Increased flow, during a phytoplankton bloom, can reduce the chlorophyll *a* concentration to a very low level. Several days of high flow, during the summer of 1993 when flows exceeded 30 m3/s, resulted in the chlorophyll *a* concentration being reduced from 100 μg/l to about 10 μg/l. The 1996 spring bloom was unusually unproductive, with chlorophyll *a* concentrations remaining around 20 μg/l until the end of April.

The spring blooms, in the River Great Ouse are made up of a mixture of centric and pennate diatoms (*Stephanodiscus*, *Cyclotella* and *Cyclostephanos*), with green algae (*Scenedesmus* spp., *Pediastrum* spp., and *Actinastrum hantzschii* etc.) becoming increasingly abundant as the bloom progresses (Figure 3.6.3c). Blue-green algae, such as *Oscillatoria redekei* and *O. agardhii* are present, sometimes becoming very abundant, as during the summer of 1995 (Figure 3.6.3c). The duration of the 1995 spring diatom bloom was greater, than during 1994, and this again could have been related to flow.

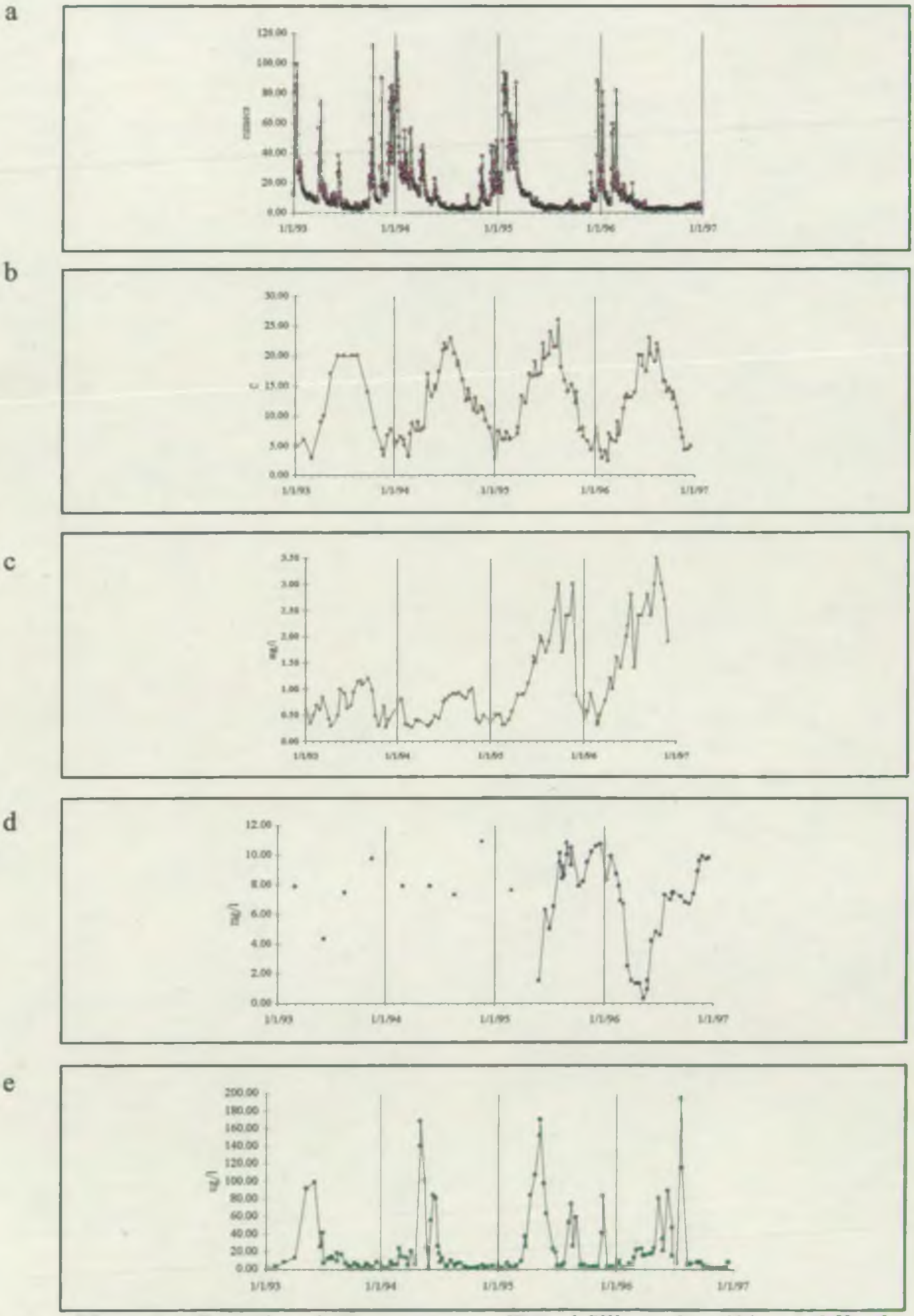
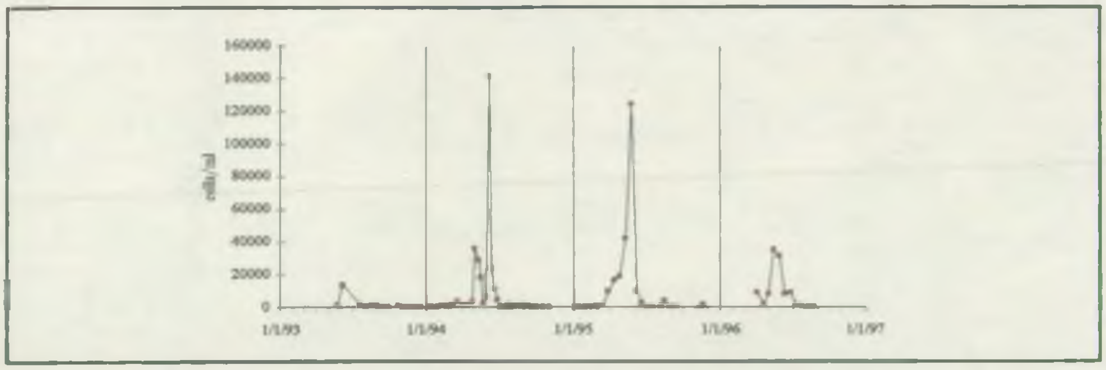
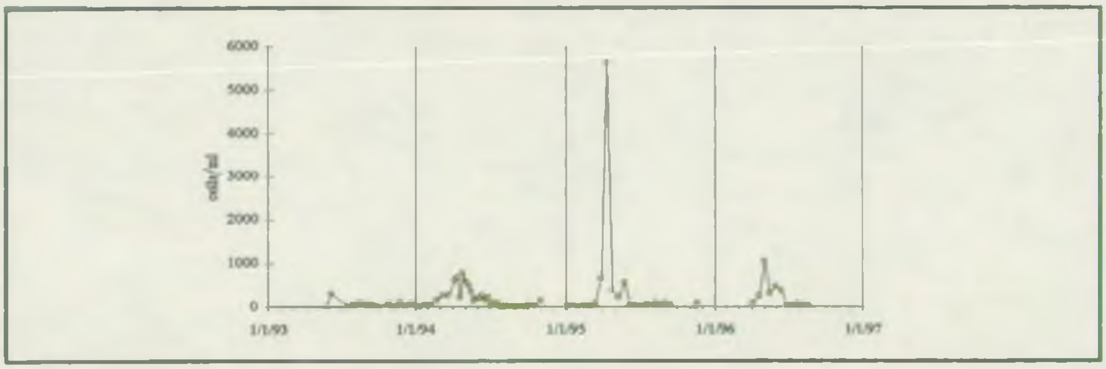


Figure 3.6.3b: a-Flow, b-Temperature, c-SRP, d-Silicate & e-Chl *a* at Offord

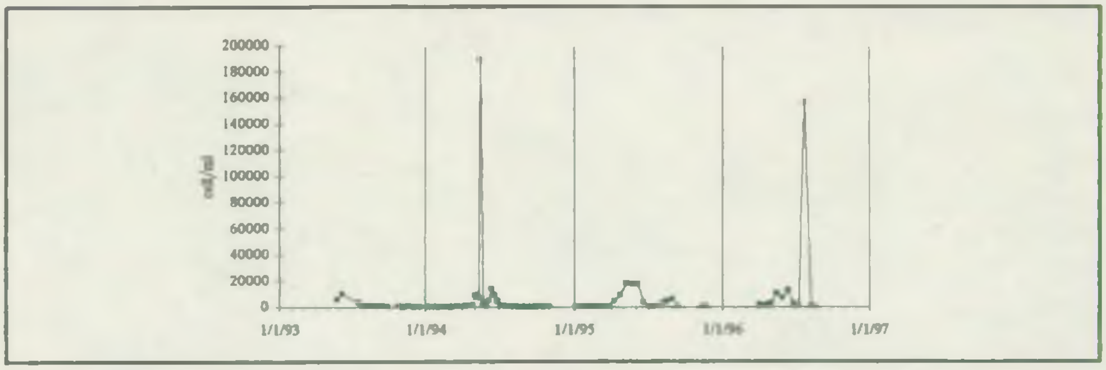
a



b



c



d

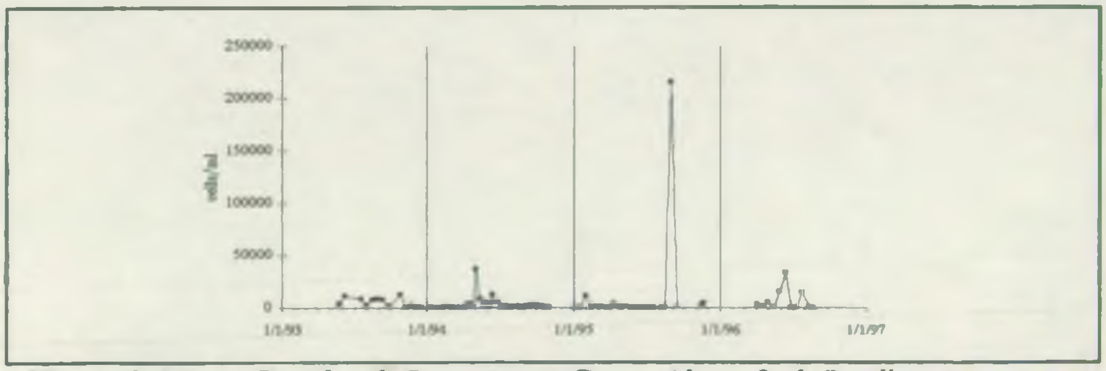


Figure 3.6.3c: a-Centrics, b-Pennates, c-Green Algae & d-*Oscillatoria* spp. at Offord

During the summer months, phytoplankton activity in the rivers was generally low, with green algae (mainly *Scenedesmus* spp.) and *Cryptomonas* spp., being present in low abundance. This was particularly the case, during the summer of 1994, when the river was very clear. Unusually, there was a large peak of activity, during the summer of 1995, which was the result of the *Oscillatoria agardhii* bloom, which passed down the river during this period (Figure 3.6.3c). A large chlorophyll *a* peak also occurred during the summer of 1996, the highest recorded value to date (Figure 3.6.3b). This peak of chlorophyll *a* activity was the result of abundant 'green' algae and some *Oscillatoria redekei*, and could have been the result of consistently low flows, during the summer of 1996. Analysis of phytoplankton from the River Ivel and main river sites, upstream of Offord, may help to clarify this.

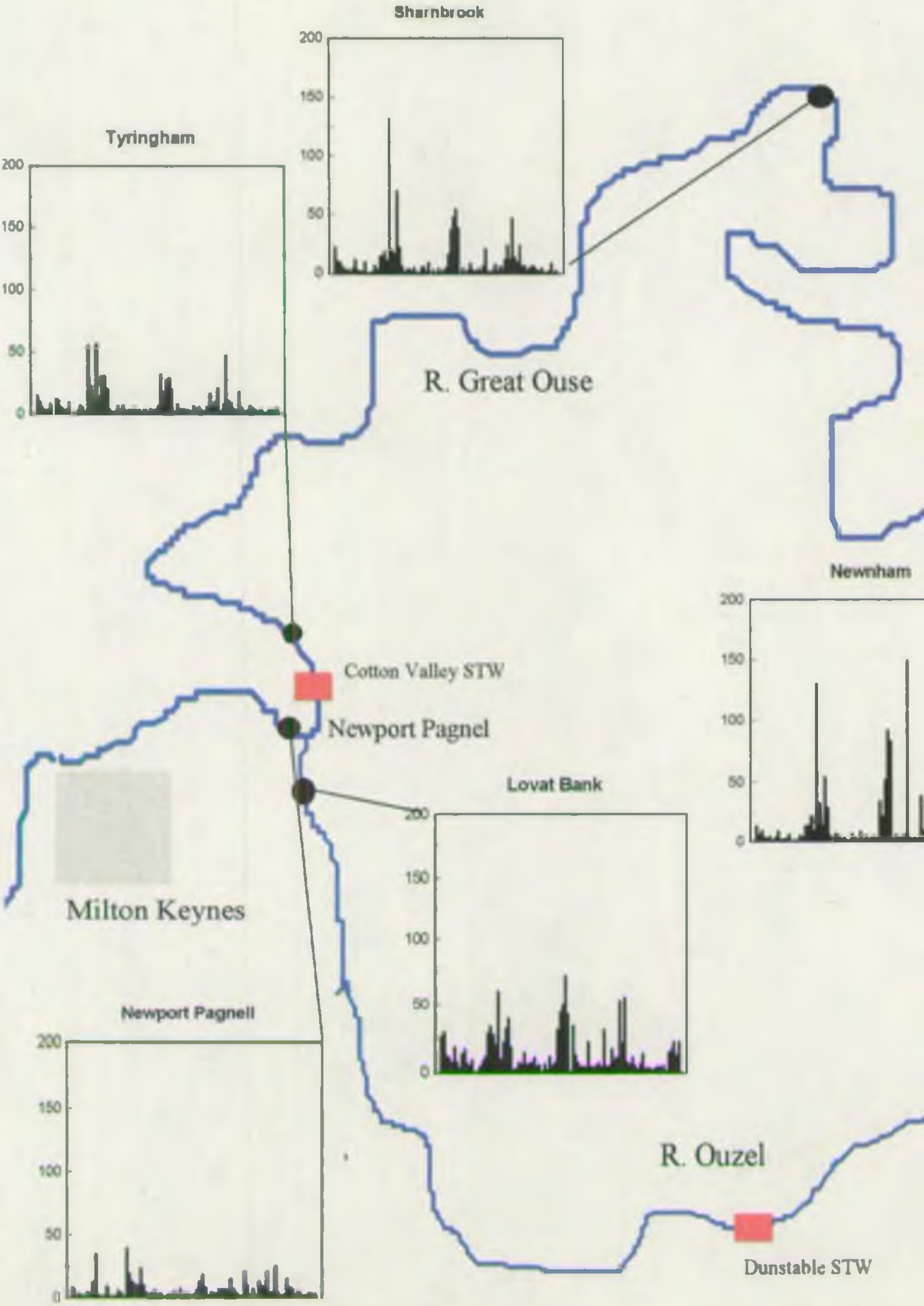
The River Great Ouse also experienced a chlorophyll *a* peak during November 1995, and this was the result of a bloom of a *Euglena* sp. *Euglena* is known to be associated with the breakdown of organic matter, and is thought to feed on the bacteria, which are involved in decomposition (West & Fritsch,1932 Round,1981). This unprecedented bloom of *Euglena* sp. could have been a secondary effect of the summer blue-green algal bloom, resulting from the decomposition of algal filaments, which were deposited as the bloom declined.

SRP concentrations fluctuate with changing flow conditions (Figure 3.6.3c). Both chlorophyll *a* and phosphorus concentrations increase with decreasing river flows, indicating that phosphorus is abundant and not limiting algal growth. Nitrogen concentrations rarely fall below 5 mg/l (Figure 3.3.5), and are also not likely to be limiting algal growth. Silicate concentrations decline in relation to an increase in diatom abundance (Figure 3.6.3c), but do not fall to a level which is thought to be limiting to growth (Reynolds, 1981).

Spatial chlorophyll *a* and phytoplankton investigations have revealed that spring peaks of algal activity, as described above, occur simultaneously along the deeper sections of the river (Figure 3.6.3d). Therefore phytoplankton are most abundant at sites downstream of Bedford.

Some tributaries appear to be more important as sources of phytoplankton, to the main river, than others. The River Ouzel exhibits higher chlorophyll *a* activity than other tributaries, within the Great Ouse catchment (Figure 3.6.3d), and a high concentration relative to the main river at Newport Pagnell (Figure 3.6.3f). The high chlorophyll *a* concentrations in the River Ouzel are almost certainly the result of algae which originates from the flood balancing lakes (Willen and Caldecotte) in the Milton Keynes area. High winter chlorophyll *a* concentrations, at Lovat bank, positively correlate with flows at Willen (Figure 3.6.3e), indicating that algae, which has accumulated during the summer, is being flushed from the balancing lakes. The influence of elevated chlorophyll *a*, originating from the River Ouzel, on the main river, are evident at Tyringham, several kilometres downstream (Figure 3.6.3f).

The River Ivel, at Tempsford does not, normally exhibit much phytoplankton activity. During the summer of 1995, however, there was a large bloom of the unicellular green alga *Chlamydomonas* sp. This bloom may have formed in the impounded waters upstream of Langford Mill, and is probably the result of a dry, sunny summer (Figure 3.6.3d).



Sharnbrook
Tyringham
R. Great Ouse
Newnham
Cotton Valley STW
Newport Pagnel
Lovat Bank
Milton Keynes
Newport Pagnell
R. Ouzel
Dunstable STW

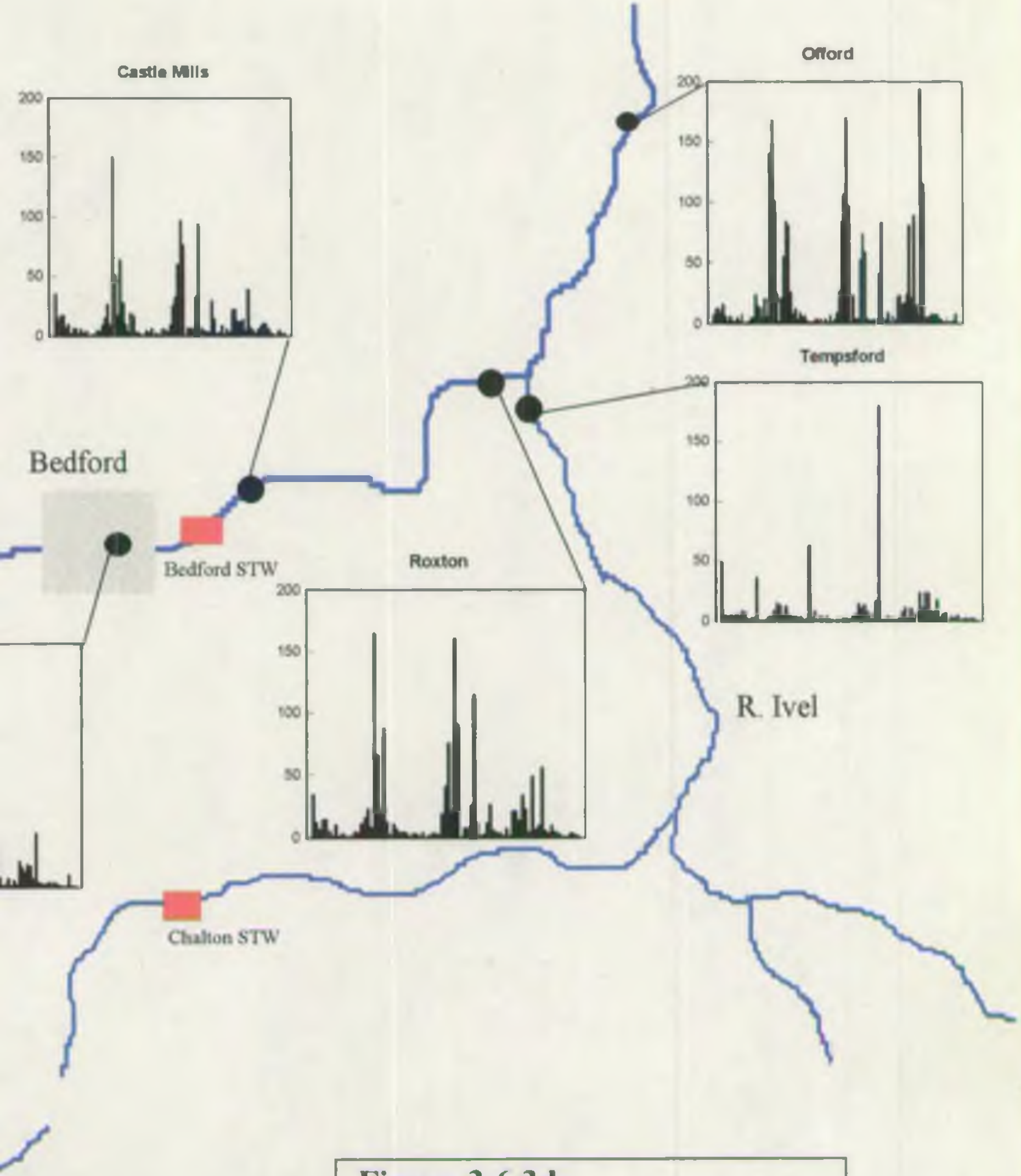


Figure 3.6.3d:
Great Ouse Chl a (6/93-12/96)

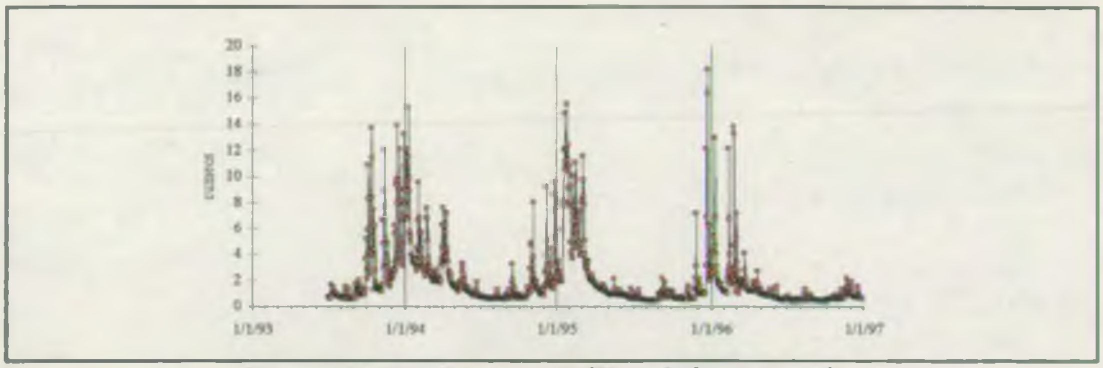


Figure 3.6.3e: Flow at Willen (River Ouzel)

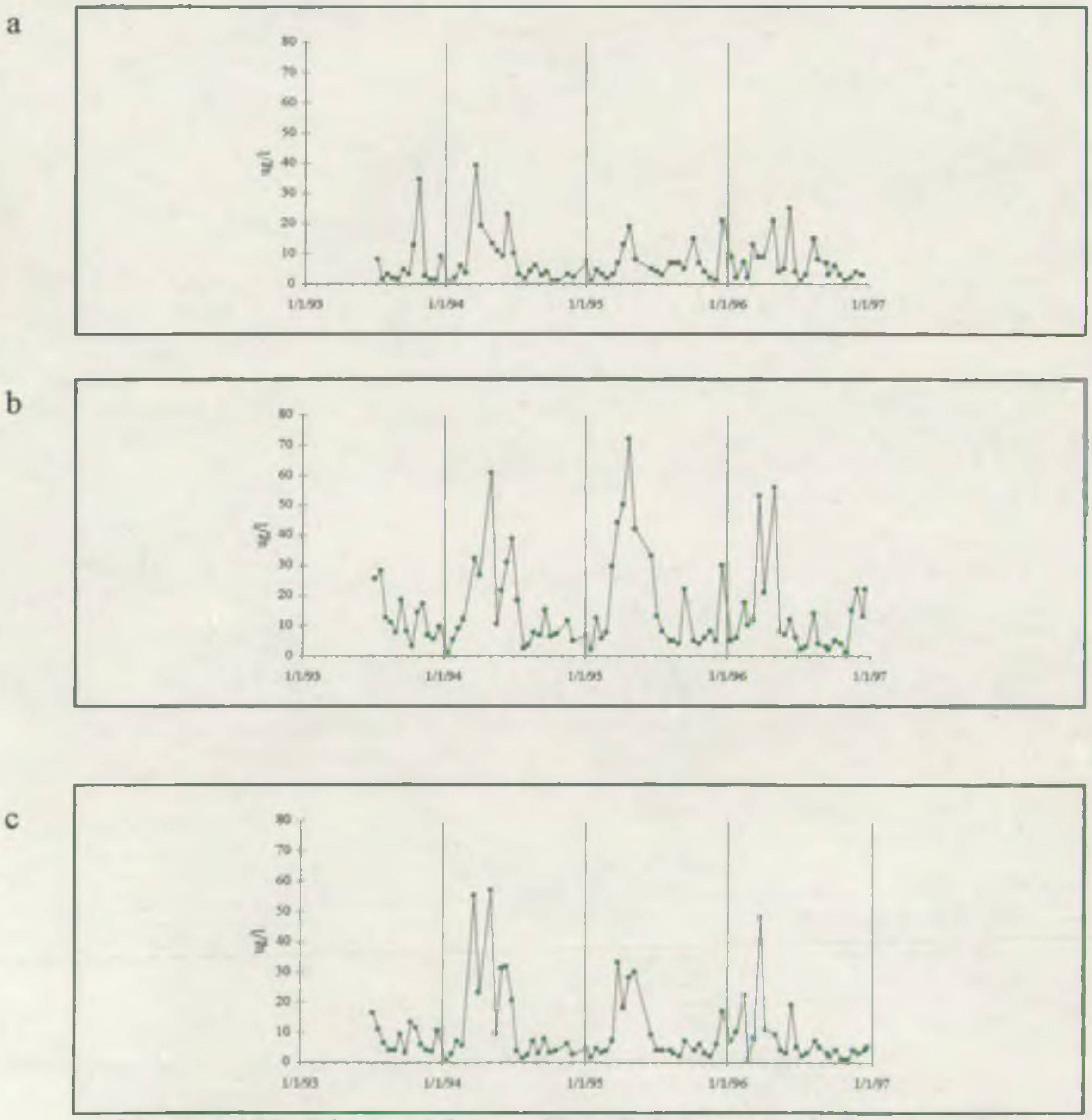


Figure 3.6.3f: Chl *a* at a-Newport Pagnell, b-Lovat Bank & c-Tyringham

The River Ouzel has been identified as a source of blue-green algae to the River Great Ouse system for several years (Balbi,1994 & 1995 NRA,1994). Spatial surveys carried out along the River Ouzel, in the Milton Keynes area, during 1994, implicated Willen and Caldecotte Lakes as a major source of blue-green algae to the Great Ouse system. Special investigations during 1994 and 1995 have shown Willen Lake, Milton Keynes, to contain very high concentrations of the blue-green alga *Oscillatoria agardhii* (Balbi et al, 1996). High chlorophyll *a* concentrations were recorded from Willen Lake (Figure 3.6.3g) throughout 1996, and the dominant taxa during August (samples not yet fully analyzed) was found to be *Oscillatoria agardhii*.

Oscillatoria agardhii was found to be the principal alga responsible for the bloom which occurred in the River Great Ouse, during the summer of 1995 (Williams,1996). Investigations during December 1995, revealed that a large quantity of water (about 13900 m^3) was released from Willen Lake, into the River Ouzel, on the 21st July 1995. The increase in flow, in the River Ouzel, was clearly recorded at Willen Gauging Station on the same day. The algal rich water, released from Willen Lake, appears to have been initially diluted as it entered the main river and moved relatively quickly downstream to Bedford. At Bedford, where the river characteristics favour the formation of phytoplankton, the bloom appears to have become established, and slowly moved downstream from this point. The average number of cells per filament, in the *Oscillatoria agardhii* bloom, increased markedly downstream of Bedford), thus indicating that the bloom was growing in the river, and not just floating downstream en masse.

Investigations into the phytoplankton of Caldecotte Lake and Neck Pit (Figure 3.6.3g) indicate that both are a potential source of phytoplankton to the main river. The importance of Caldecotte Lake and Neck Pit may be clarified when the phytoplankton analysis is complete.

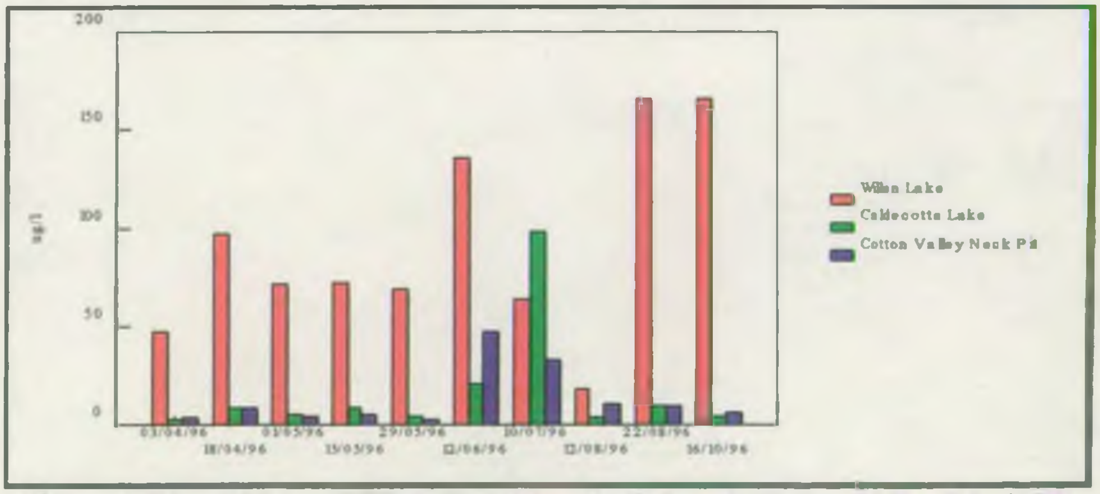


Figure 3.6.3g: Chl *a* at Willen & Caldecotte Lakes & Cotton Valley Neck Pit

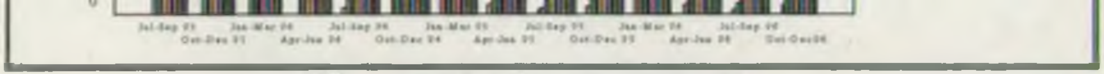


Figure 4.1.1: Nene Quarterly Flow

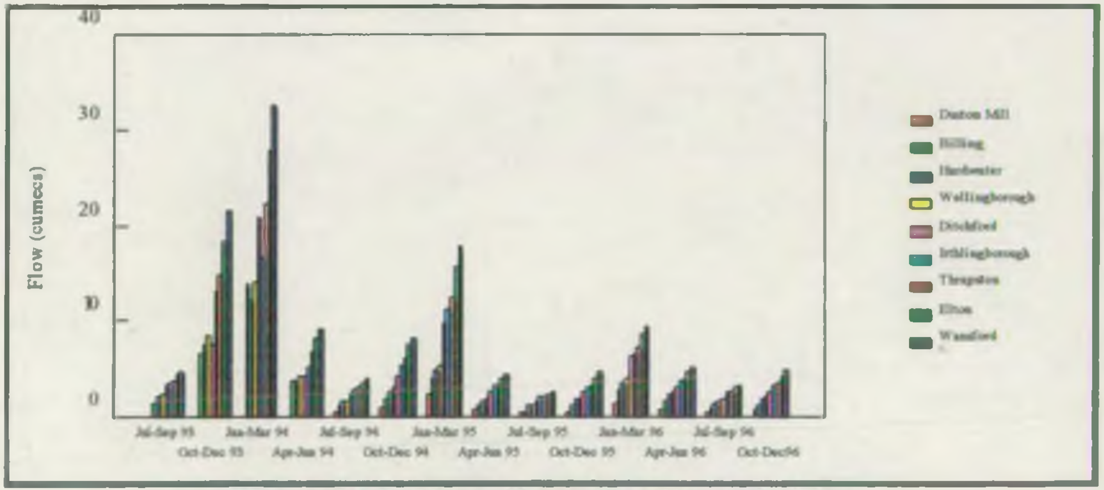


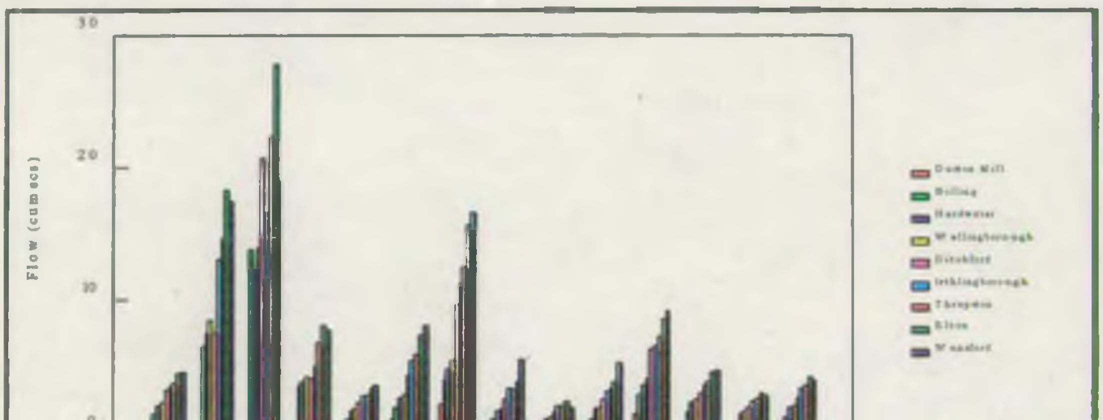
Figure 4.1.2: Nene Alternative Quarterly Flow

Chapter Four - River Nene

Phosphorus stripping at the River Nene STWs has been somewhat intermittent throughout the study, particularly after September 1995. The evaluation of the success of the stripping programme on the River Nene, is not, therefore, straightforward.

4.1 Flow:

Figure 4.1.1 shows the flows for the main river sites. There has been a consistent pattern of increased flow downstream, a reflection of the effectiveness of the flow model. It may be possible to improve the model further by using actual abstraction and discharge data, rather than constant values.



Wansford flow is not covered by the model, and estimations based on Orton flow have tended to be only a little higher, or, even lower than the flow at Elton (upstream of Wansford). An alternative is to estimate Wansford flow scaled forwards from Elton (Figure 4.1.2), but the accuracy of this is uncertain. For the purpose of load calculations at Wansford, estimates based on Orton flow have been used, which provides a long term data set. The recent introduction of a gauging station at Wansford should dispense with the need for estimations of flow in the future.

4.2 Phosphorus in STW Effluent:

Phosphorus stripping at the STWs in the River Nene catchment has not been effective throughout. At Billing and Broadholme STWs there was an immediate fall in effluent SRP concentrations, when stripping commenced in July 1993 (Figures 4.2.1 & 4.2.2). The initial reduction in SRP concentrations (July 1993 to May 1995), compared to pre-stripping levels (January 1992 - June 1993) were 35.6 and 37.6% at Billing STW and Broadholme, STW respectively (Table 4.2). Following the initial decrease, the SRP concentrations at both

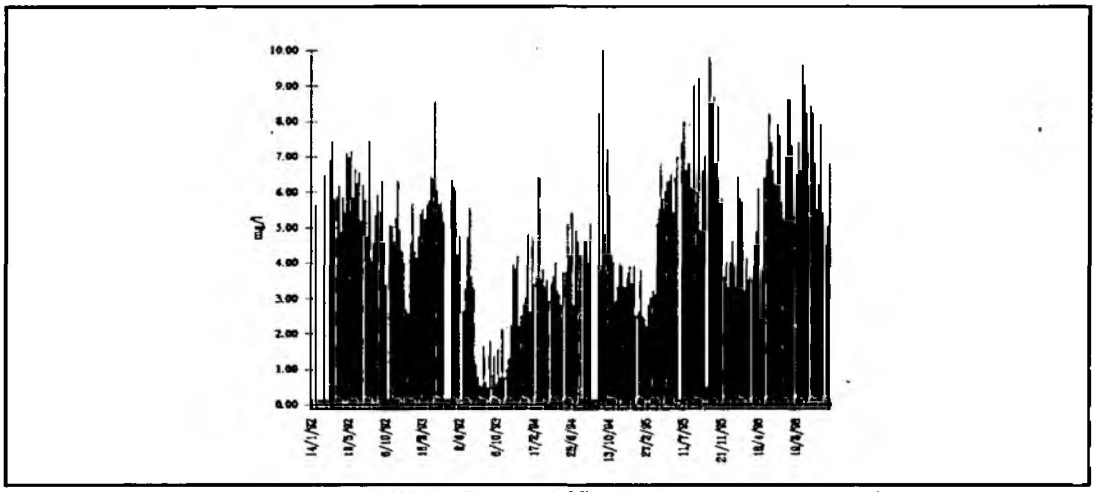


Figure 4.2.1: Billing STW Effluent SRP Concentration

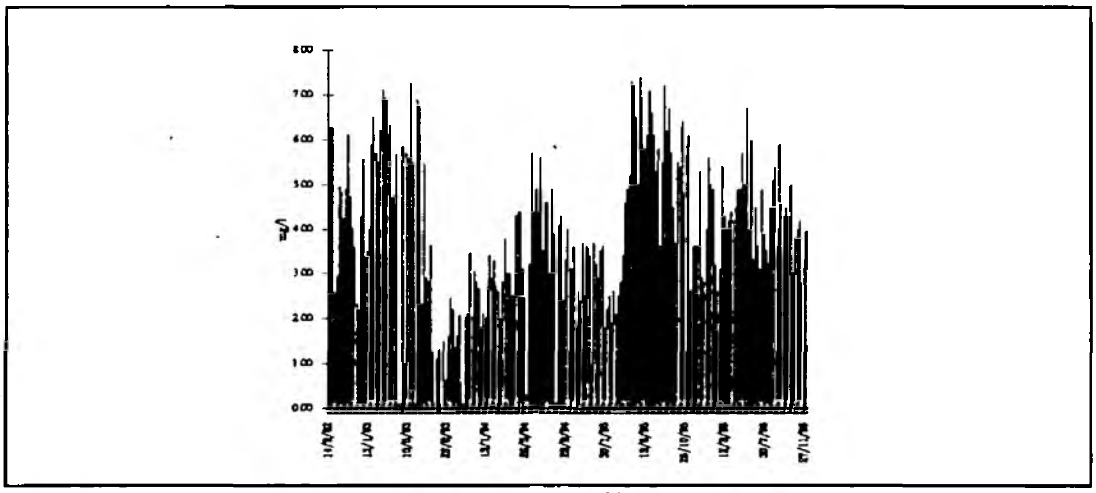


Figure 4.2.2: Broadholme STW Effluent SRP Concentration

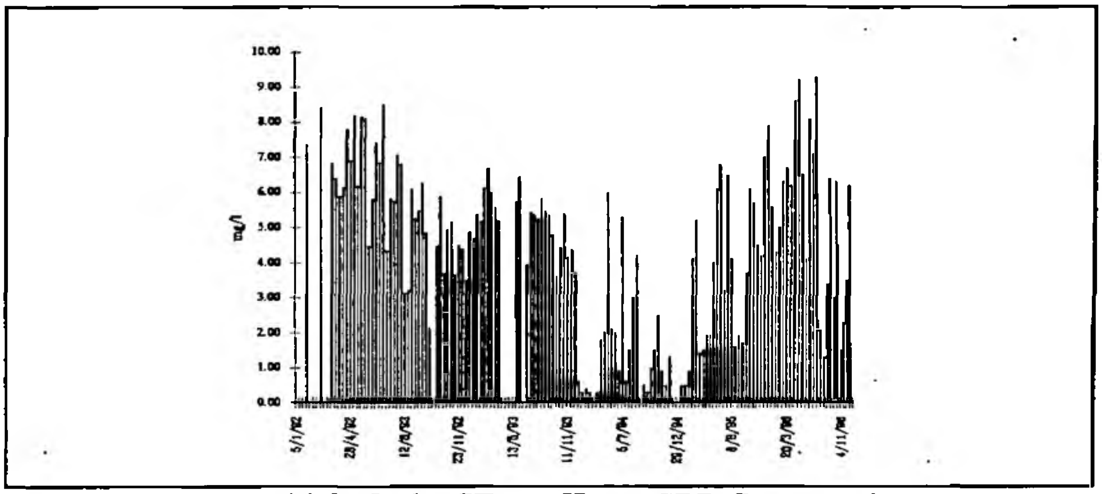


Figure 4.2.3: Corby STW Effluent SRP Concentration

STWs increased, and by June 1995 had returned to pre-stripping levels, even though stripping was still being carried out, intermittently.

At Corby STW stripping occurred over a shorter period, but was more effective than at Billing or Broadholme STWs (Figure 4.2.3). The reduction in SRP concentration between the pre-stripping period and the period, July 1993 to May 1995, was 49%. Since May 1995, SRP has returned to pre-stripping levels (Table 4.2).

STW	Jan '92- Jun '93	Jul '93 - May '95	Jun '95 - Dec '96
Billing	5.434	3.502	6.212
Broadholme	5.007	3.126	4.697
Corby	4.718	2.388	5.103

Table 4.2: Mean SRP Concentrations in Nene STW Effluents

4.3 Phosphorus in Rivers:

Figure 4.3.1 shows SRP to be the dominant form of phosphorus in the River Nene (using Wansford as an example). The proportion of both PP and TP, have tended to increase in the winter, with the associated higher flows (Figure 4.3.1). This is evident for the periods, October - December 1993 and January - March 1995. This pattern supports the concept of, the flushing of particulate matter in high flows, previously outlined in section 3.3.

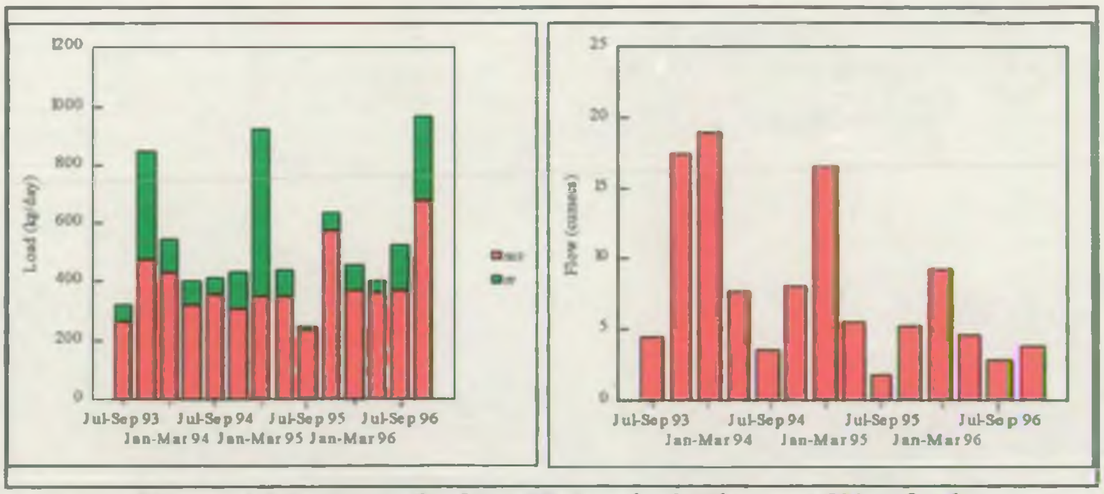


Figure 4.3.1: Quarterly SRP:PP Loads & Flows at Wansford

The absence of elevated PP loads during the high flows of January - March 1994, may be a consequence of particulate matter having been previously flushed out of the system during the high flows of the previous quarter (there was no period in between for the accumulation of particulate matter to occur). Flows were not particularly high in the winter of 1995/6, so caused less flushing of particulate matter. The low phosphorus load during the quarter July - September 1995 is most likely to be due to very low flows during this period.

TP Levels were relatively stable throughout the study period, at Wansford, with any variation being accounted for by changes in the flow regime (Figure 4.3.1). The stripping programme does not appear to have had much effect on phosphorus loads. This is borne out by the plot of load vs flow, where there is considerable overlap of pre- and during stripping data points (Figure 4.3.2).

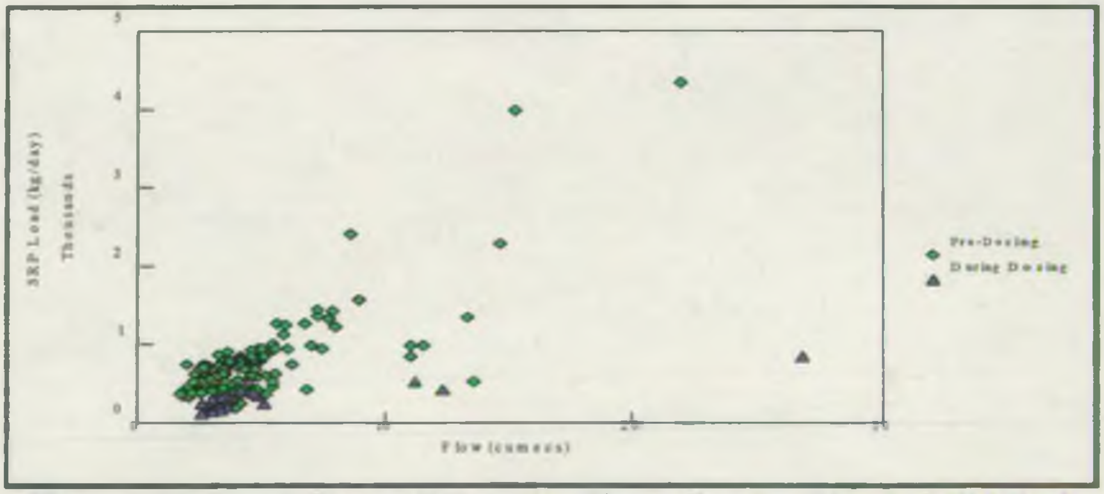


Figure 4.3.2: Pre- & During P-Stripping Flow v Load at Wansford (Jul-Sep)

As at Offord, the long term data for Wansford (Figure 4.3.3) shows a gradual fall in SRP loads since the mid 1980's, irrelevant of flow (Figure 4.3.4). This decline is part of a long-term annual downward trend, also noted for the River Great Ouse (see section 3.3).

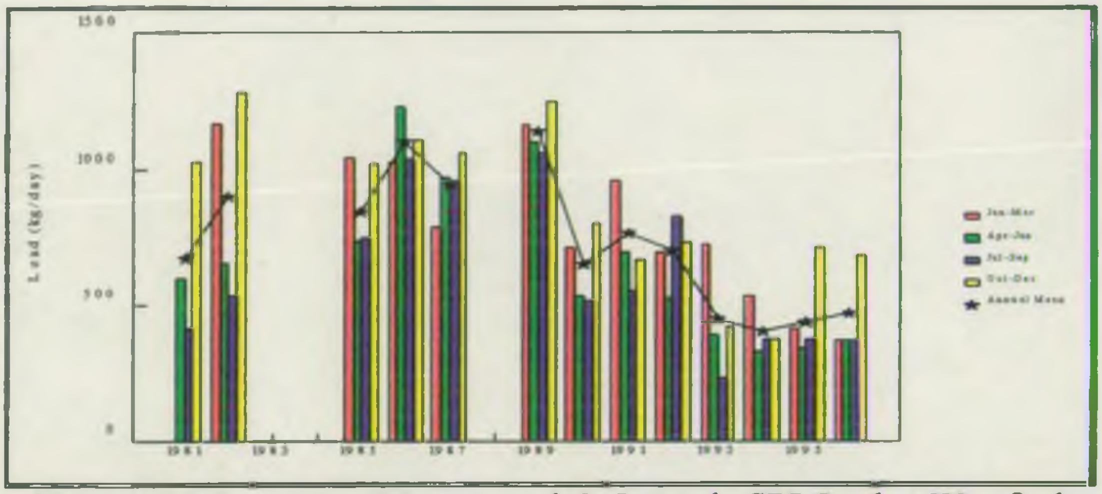


Figure 4.3.3: Long Term Mean Annual & Quarterly SRP Load at Wansford

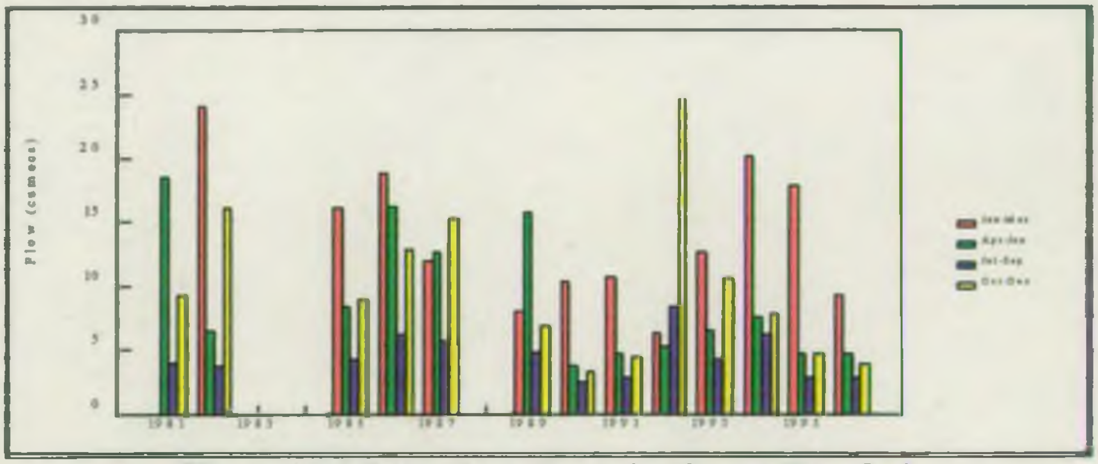


Figure 4.3.4: Long Term Quarterly Flow at Wansford

Over this same period, nitrogen levels have exhibited a slight decline (Figure 4.3.5). The N:P ratio has, therefore remained fairly constant, with a lower ratio in summer than in winter (Figure 4.3.6) . The ratio in the summer of 1993 is higher than in preceding and subsequent years. This indicates a fall in phosphorus, relative to nitrogen, during the period when stripping has been identified as most effective.

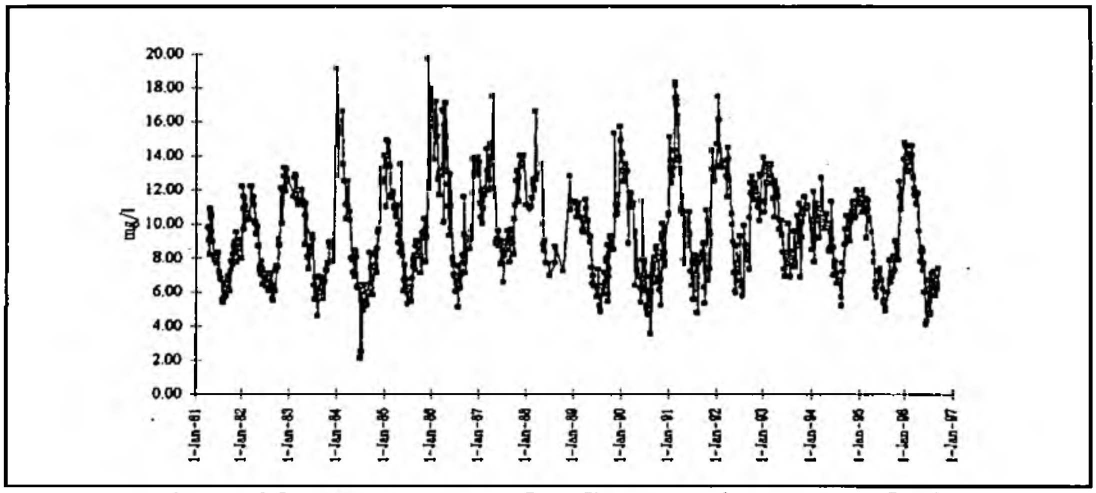


Figure 4.3.5: Long Term TON Concentration at Wansford

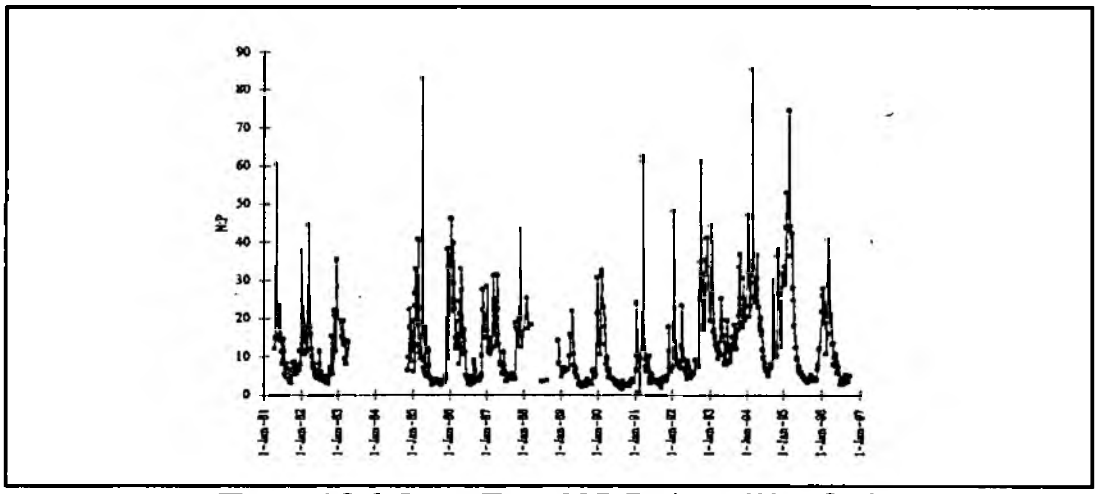


Figure 4.3.6: Long Term N:P Ratio at Wansford

Sediment phosphorus concentrations up and downstream of Billing STW show no particular pattern (Table 4.3). The frequency and extent of sampling makes all the sediment data of limited use.

	Phosphorus (mg/kg)		Iron (mg/kg)	
Date	**Billing**	**Hardwater**	**Billing**	**Hardwater**
13.07.93	5490 3080	1020 24400	70000 74600	58600 123000
11.08.93	5400 1350	5010 4500	70700 72200	138000 58700
07.09.93	2690 2810	2510 3920	73200 48800	70600 58700
06.10.93	3000 2690	4130 4030	85900 78800	53900 60700
02.11.93	2710 2520	5560 6710	64000 62500	58700 67100
30.11.93	2890 2590	5470	72300 68800	68700
21.06.94	2250 2920 3760 4070 2360	4860 3830 1930 5050 1470 7450	52300 50600 103000 93100 69600 67100	51700 80100 31900 111000 80100 56200
13.09.95	7200 3700 4300 3600 2700	3900 7300 5200 5600 1500 9400	46200 45500 46100 45000 44500	46900 49900 49700 50600 47500 47100

Table 4.3: Phosphorus & Iron in Sediments Up & Downstream of Billing STW.

4.4 Sources of Phosphorus:

4.4.1 Major STWs

Large STWs appear to be a major source of phosphorus in the River Nene. Figures 4.4.1a & 4.4.1b show a general trend of increasing SRP and TP loads downstream. The exception is at Ditchford Mill Lock, which frequently exhibits a fall in load, from the site upstream (Hardwater Mill). There are particularly large increases downstream of Billing STW (between Billing and Hardwater), and downstream of Broadholme STW (between Ditchford and Irthlingborough), emphasising the significance of phosphorus inputs from the major STWs, on phosphorus loads in the river.

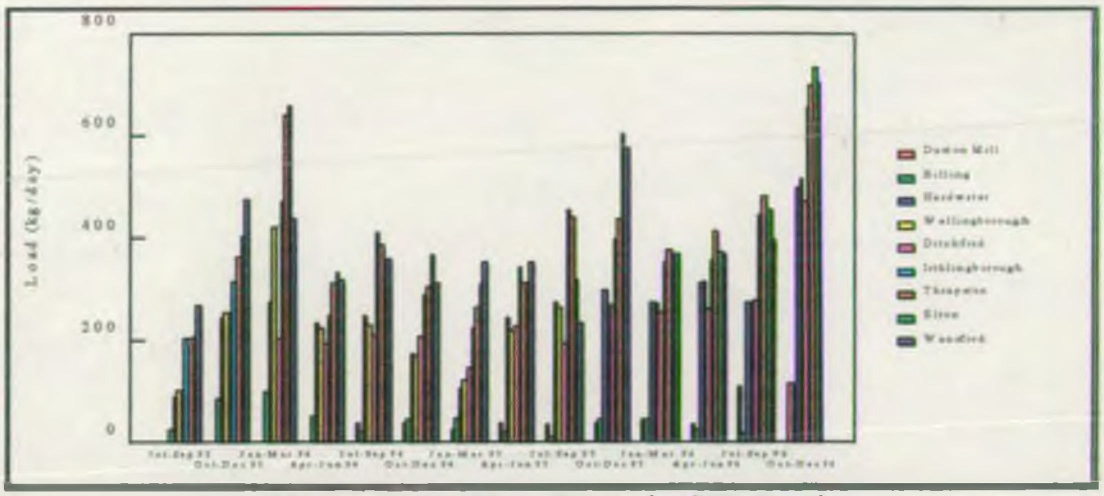


Figure 4.4.1a: Nene Quarterly SRP Load

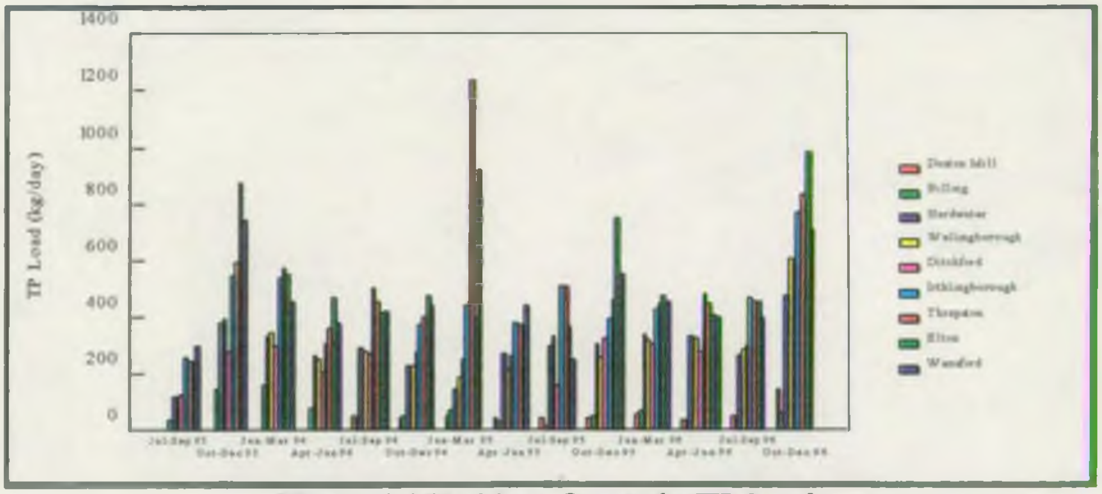


Figure 4.4.1b: Nene Quarterly TP Load

4.4.2 Small STWs

A limited study of the Upper Nene catchment (upstream of Billing STW) has estimated the phosphorus contribution of smaller STWs (Table 4.4.2). The impact of these is individually and collectively very minor, with an overall SRP load of 1.51kg/day, 41% of which comes from Whilton. This compares with a mean annual SRP Load of 319.2kg/day from Billing. The smaller STWs, therefore, appear to have very little impact on the load in the main river. They may of course become more important when dosing becomes effective at major STWs. Also, in the context of the smaller headwaters of the River Nene, these loads may be significant but, a more detailed investigation would be required to quantify this. It should be noted that, a number of other small STWs enter the River Nene, downstream of Billing (usually via tributaries), and these too will increase overall loads.

STW	Load (kg/day)	%of Total Load
Brixworth	0.169	14.70
Bugbrooke	0.156	13.56
Doddington	0.005	0.45
Hackleton	0.071	6.24
Hollowell	0.061	5.33
Long Buckby	0.138	12.03
Newnham	0.028	2.43
Weedon	0.051	4.40
Whilton	0.470	40.86
Total	1.151	100.00

Table 4.4.2: Estimated SRP Load Contribution of STWs in the Upper Nene Catchment

4.4.3 Chettles Ltd (Ditchford Mill)

Figure 4.4.3 shows that there is very little difference between the SRP or TP concentrations in the Lock Channel and Mill Stream at Ditchford Mill. This indicates that Chettles Ltd is not a significant source of phosphorus to the River Nene.

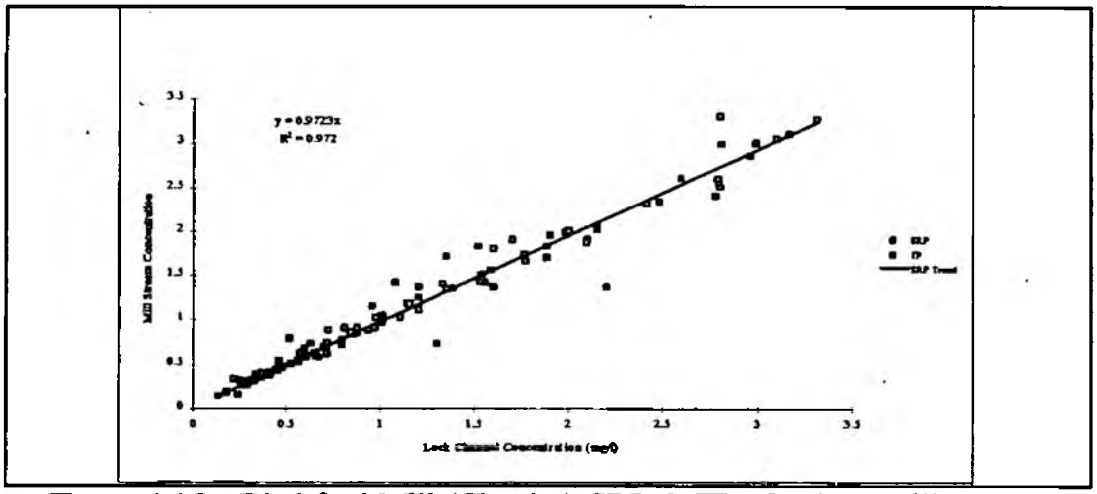


Figure 4.4.3: Ditchford Mill (Chettles) SRP. & TP - Lock vs Mill Stream

4.4.4 Tributaries

Figure 4.4.4 shows the SRP loads in major River Nene tributaries. The amount of phosphorus in the Willow Brook is clearly significant, with up to 50 kg/day entering the River Nene at Fotheringhay. The high loads, further upstream, at Great Weldon, suggest that it is the effluent from Corby STW, that results in the large phosphorus load entering the River Nene, from Willow Brook. This further supports the contention that, large STWs are the main source of phosphorus to the River Nene.

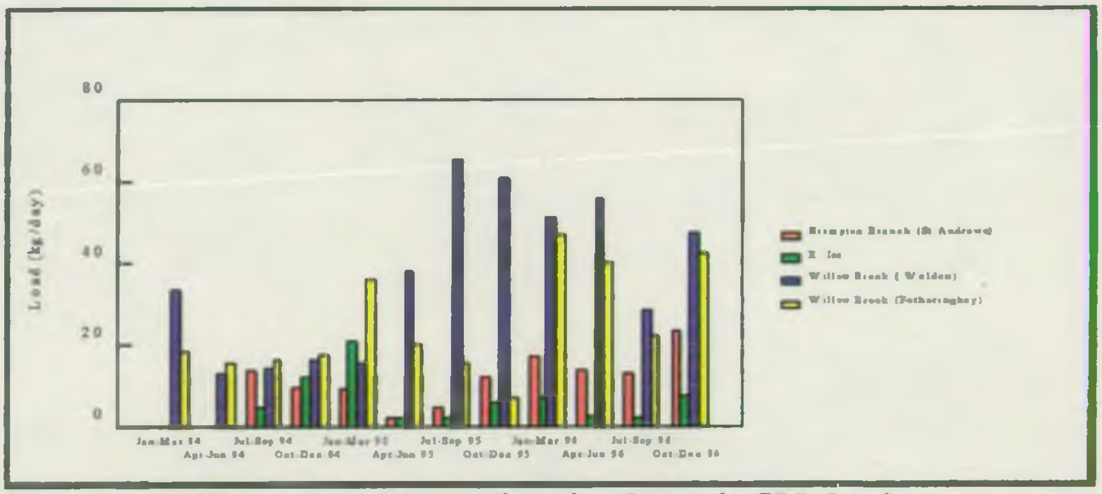


Figure 4.4.4: Nene Tributaries Quarterly SRP Load

The absence of a significant rise in SRP loads between Elton and Wansford (up and downstream of the confluence of the Willow Brook and the River Nene) - (Figure 4.4.1a), is probably due to flow gauging problems, and the resultant difficulties in accurately calculating loads at Wansford.

SRP loads at St Andrews on the Brampton Branch and from the River Ise are relatively low (Figure 4.4.4) and at no time is a load of 20 kg/day exceeded. These tributaries are, therefore, fairly minor sources of phosphorus to the main river, but they again, could become proportionally more important, after the onset of permanent phosphorus stripping at large STWs.

4.5 The Impact of P-Stripping on the River:

SRP and TP concentrations at selected sites are shown in Figures 4.5.1 & 4.5.2. All graphs are to the same scale, with the x-axis running from July 1993 to December 1996, and the y-axis representing SRP or TP Concentrations (scale 0-5mg/l). Both SRP and TP concentrations fluctuate according to seasonal conditions, with concentrations being higher in summer.

SRP and TP concentrations were lower at all sites during 1993, even during the summer. In subsequent years concentrations were higher, probably as a result of lower flows (Figure 4.1.1) and less effective phosphorus stripping (Figures 4.2.1, 4.2.2 & 4.2.3). This is clearly shown at Wansford where SRP loads for the early stripping period (June 1993 - December 94) were 17.4% lower than in the period January 1995 - December 1996.

The reduced relative contribution of STWs early on in the stripping programme, can be identified for Billing STW (Figure 4.4.1a) and Corby STW (Figure 4.4.4). Phosphorus loads downstream of Billing and Corby STWs are initially smaller, compared with the increases experienced downstream of the STWs, after stripping has been in operation for a while. This is much less marked, however, than for STWs on the River Great Ouse. The initial reduction in SRP Load is not evident downstream of Broadholme STW (Figure 4.4.1a). This may be due to the limited success of phosphorus stripping at Broadholme STW. Alternatively it may be an indication of other influences, upstream of Irthlingborough, such as, in-channel processes or non STW discharges / inputs. Table 4.5 finally emphasises the (estimated) relative contribution of STWs to SRP load at Wansford during stripping. At Billing and Corby STWs the contribution increases from 51.1 and 8.9% respectively in the early stage of stripping to 58.8 and 11.1% post 1994. Broadholme, however, remains fairly constant contributing 30.4% early on and 28.6% after 1994.

Source	Jun '93 - Dec '94	Jan '95 - Dec '96
Wansford - SRP Ld (kg/day)	374.9	453.6
Billing STW (%)	51.1	58.8
Broadholme STW (%)	30.4	28.6
Corby STW (%)	8.9	11.1
Other Sources (%)	9.6	1.5

Table 4.5: Estimated Proportion from Different Sources of Mean, During & Post Stripping SRP Loads at Wansford.

Levels of iron and sulphate show no general pattern upstream and downstream of STWs. Pre-, during and post stripping levels fall within the prescribed legal limits (see section 1.2).

Sediments analyzed for iron (Table 4.3.1) do not show any pattern between the sites upstream and downstream of Billing STW during 1993 and 1994. However, samples taken in 1995 show a definite increase in sediment bound iron, downstream of the STW. Whether or not this is because of iron from dosed effluent, settling out in the sediment, is uncertain. Further investigation would be necessary to determine this.

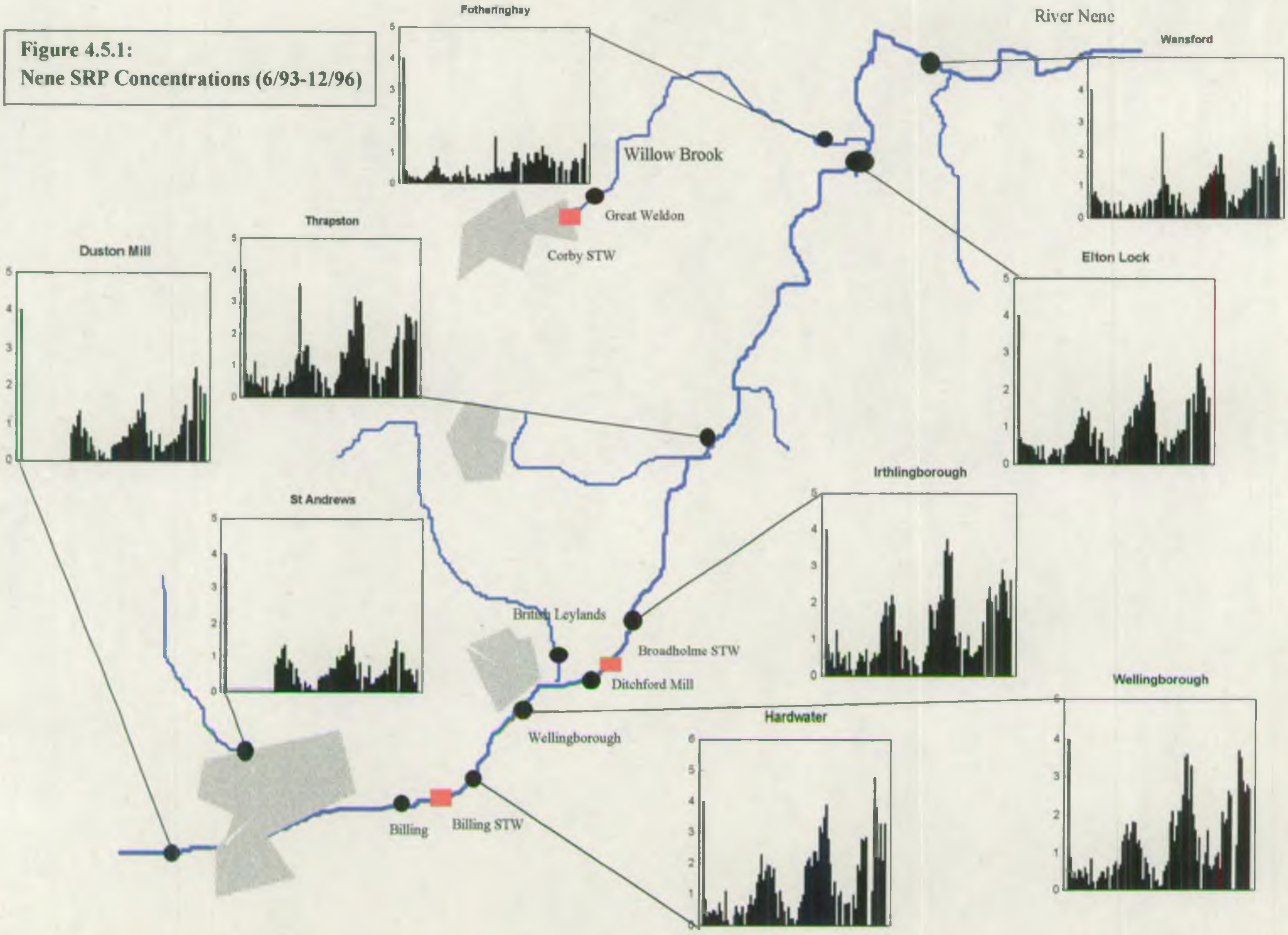


Figure 4.5.1:
Nene SRP Concentrations (6/93-12/96)

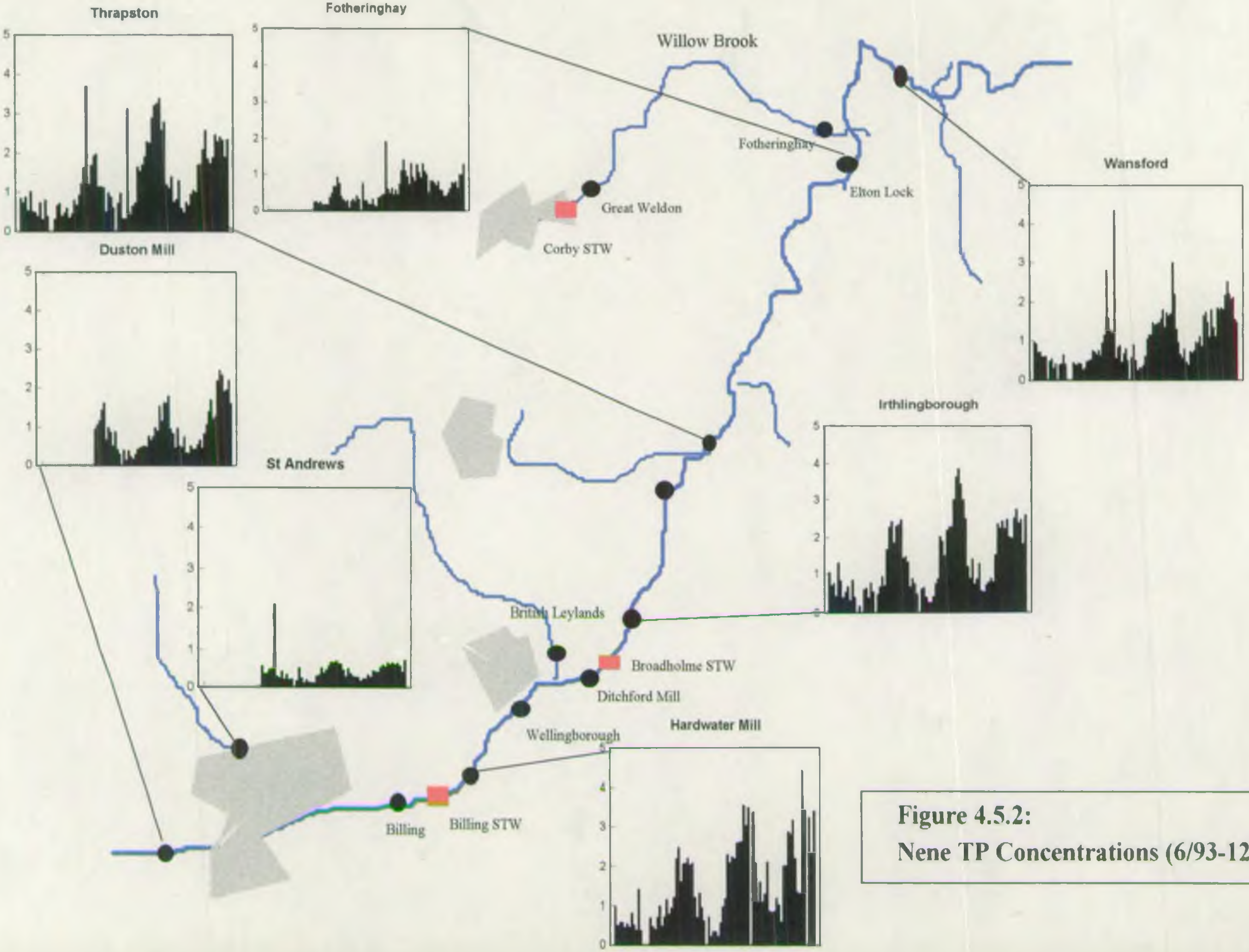


Figure 4.5.2:
Nene TP Concentrations (6/93-12/96)

4.6 Biological Data:

4.6.1 Diatoms

The results for the diatom indices are reported in Cox and Reid (1996). The MEWAM and GCN scores (Figure 4.6.1a & 4.6.2b) were typical of the other indices used. The indications are that all sites are eutrophic irrespective of the phosphorus loads measured during the project (Figure 4.4.1a). This is supported by Cox and Reid (1996).

The GCN score (Figure 4.6.1b) appeared to highlight a pollution incident at Ditchford Mill during 1995 (also picked up by IPS and TDI - see Cox & Reid,1996). Further investigation, however, suggest that this was due to sampling error, rather than pollution.

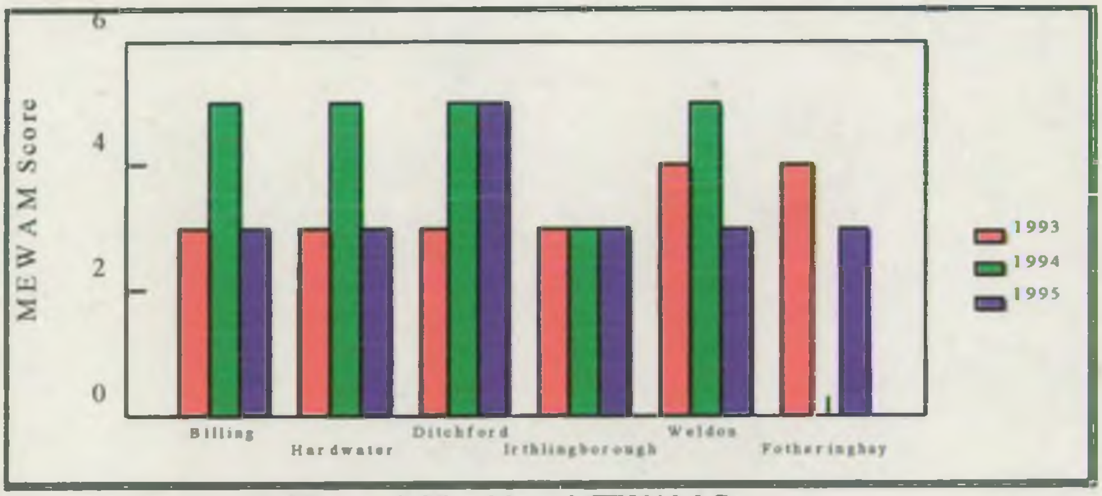


Figure 4.6.1a: Nene MEWAM Scores

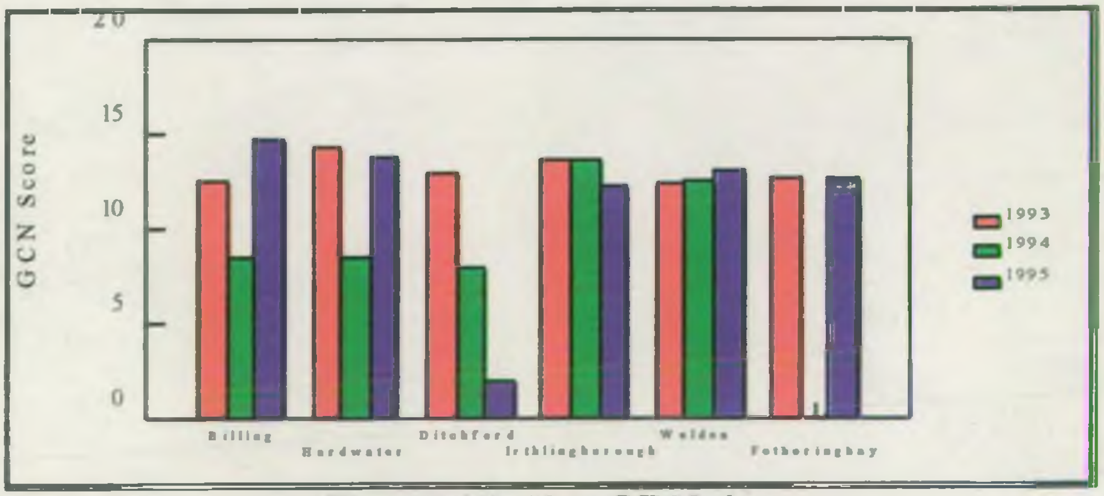


Figure 4.6.1b: Nene GCN Index

4.6.2 Macrophytes

The MTRs for sample sites in the River Nene Catchment indicate that they are eutrophic, with all MTR scores falling between 27 and 32 (Figure 4.6.2a). As with the diatom indices this does not directly relate to measured phosphorus levels (Figure 4.4.1a).

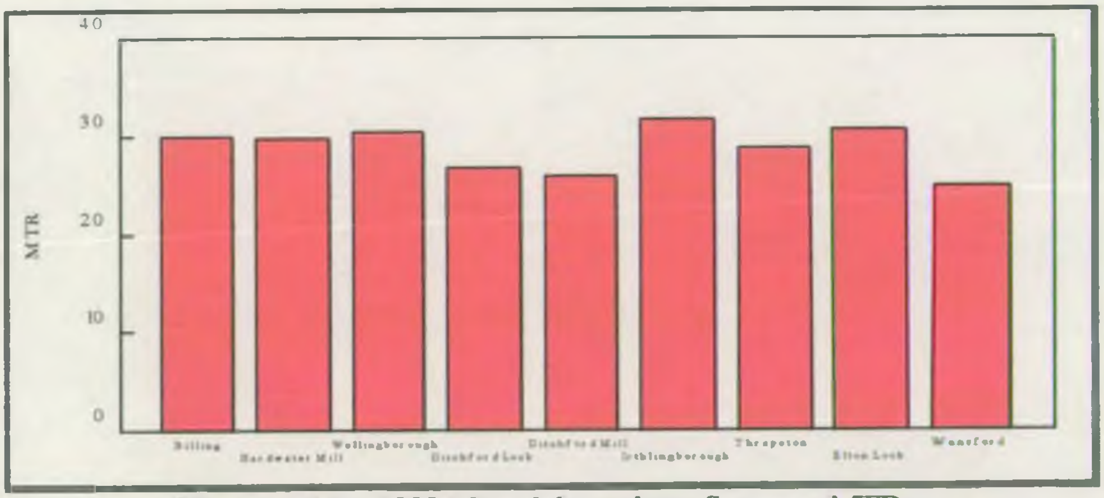


Figure 4.6.2a: 1993 Nene Macrophyte Survey - MTRs

Monitoring under the UWWT directive generally shows a fall in MTR downstream of STWs (examples in Figure 4.6.2b). This does correspond with the pattern of significant increases in phosphorus loads downstream of STWs (Figure 4.4.1a). The sites upstream of STWs are mainly eutrophic (MTR <40). The fall in MTR at downstream sites was variable being greater, for example, at Corby than at Billing (Figure 4.6.2b).

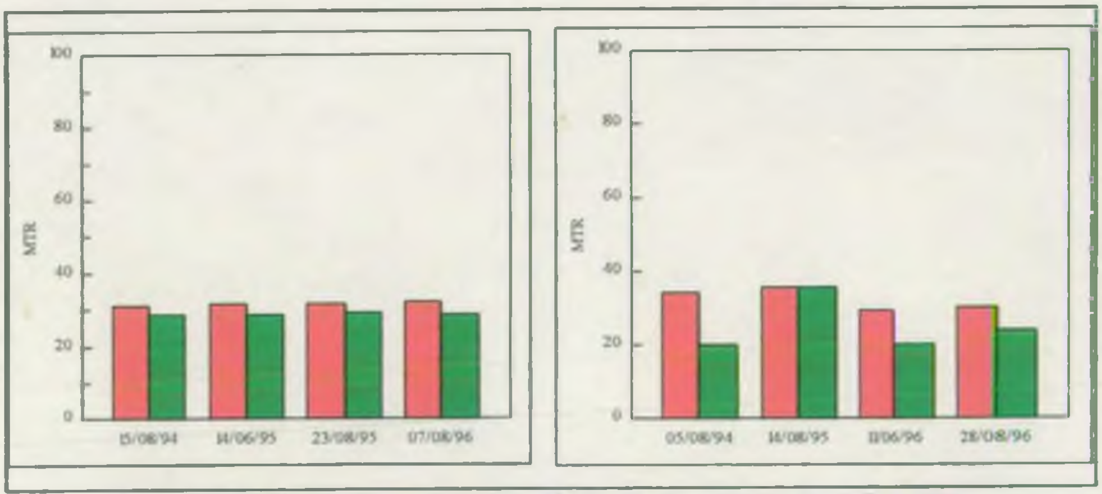


Figure 4.6.2b: Billing STW (left) & Corby STW (right) MTRs
red = u/s, green = d/s

4.6.3 Phytoplankton

Long-term chlorophyll *a* data (Figure 4.6.3a) indicate the occurrence of annual phytoplankton biomass cycles, in the River Nene. Initial growth of phytoplankton occurs in early spring as temperatures start to rise (Figure 4.6.3b). The peak chlorophyll *a* concentrations always occur during the spring months, April to June inclusive. These periods of algal activity (spring blooms) are of varying durations and amplitude, but normally last for two to three months, and always have a maximum chlorophyll *a* concentration in excess of 100µg/l. The spring blooms are either, followed by a period of little activity, as during the summer of 1994, or by a period of prolonged activity, such as in the summer of 1996.

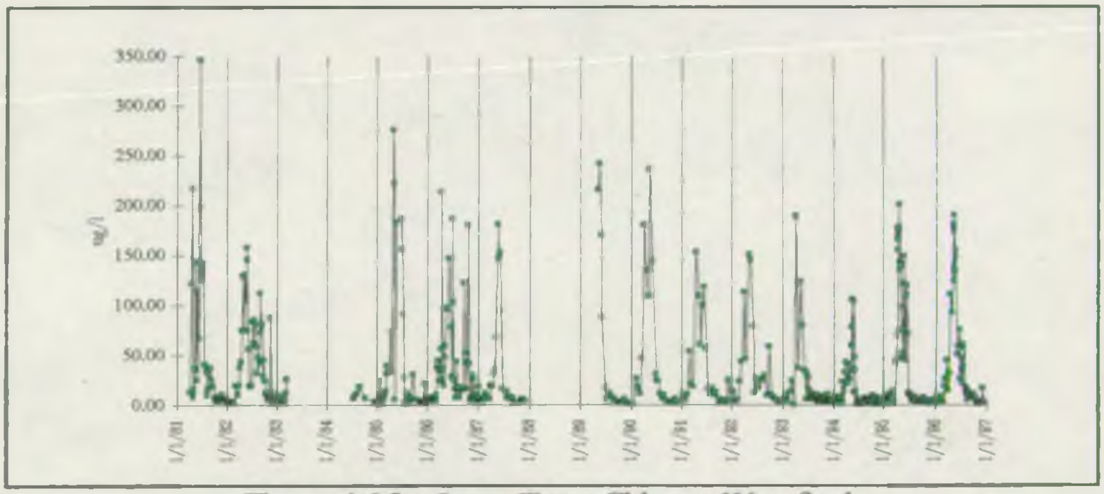


Figure 4.6.3a: Long Term Chl *a* at Wansford

An inverse relationship exists between flow and chlorophyll *a* concentrations (Figure 4.6.3b). High or erratic flows can suppress or delay the development of chlorophyll *a* in the river. Flows during the spring of 1994 were generally above 10 m3/s, interspersed with discharges that were two or three times this value. This resulted in delayed phytoplankton activity and an unusually low chlorophyll *a* peak. Low flows, through the spring of 1995, permitted phytoplankton density to develop sooner, and to a greater extent, than in 1994. Increased flow, during a phytoplankton bloom, can reduce the chlorophyll *a* concentration to a very low level. Two days of high flow, during the spring of 1996 when flows exceeded 40 m3/s, resulted in the chlorophyll *a* concentration being reduced from 100 µg/l to less than 10 µg/l.

Spring blooms have been made up of a mix of centric and pennate diatoms, with green algae (*Scenedesmus* spp., *Pediastrum* spp., and *Actinastrum hantzschii* etc.) becoming increasingly important as the bloom progresses (Figure 4.6.3c). Blue-green algae, such as *Oscillatoria redekei*, are often present in low numbers during the spring, particularly in periods of low flow. Unicellular pennate diatoms (mainly *Nitzschia acicularis)* tend to be dominant early in the bloom. During low flow summers colonial pennate diatoms, mainly *Nitzschia fruticosa*, became abundant. This shift is presumably a function of falling turbulence within the river.

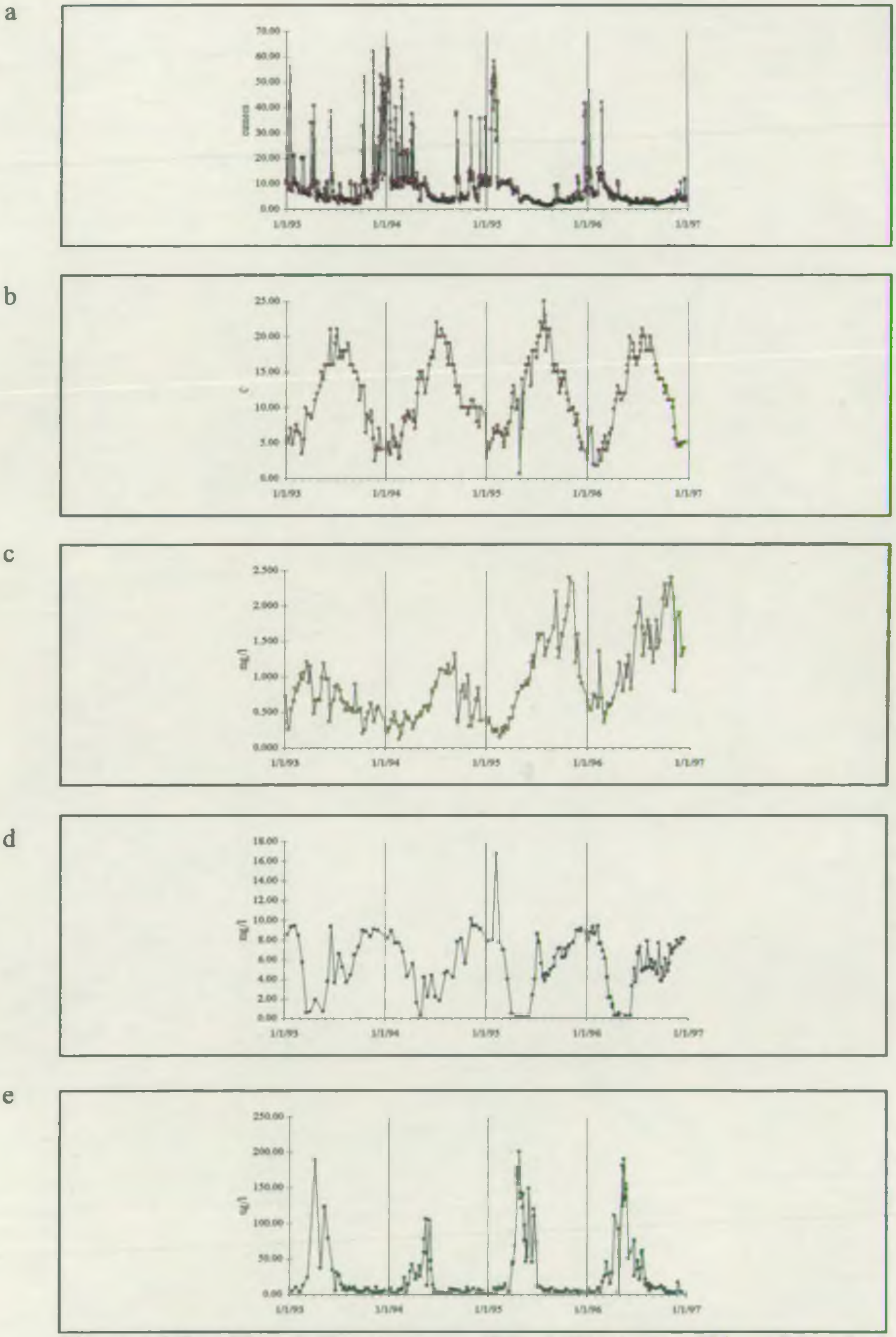


Figure 4.6.3b: a-Flow, b-Temperature, c-SRP, d-Silicate & e-Chl *a* at Wansford

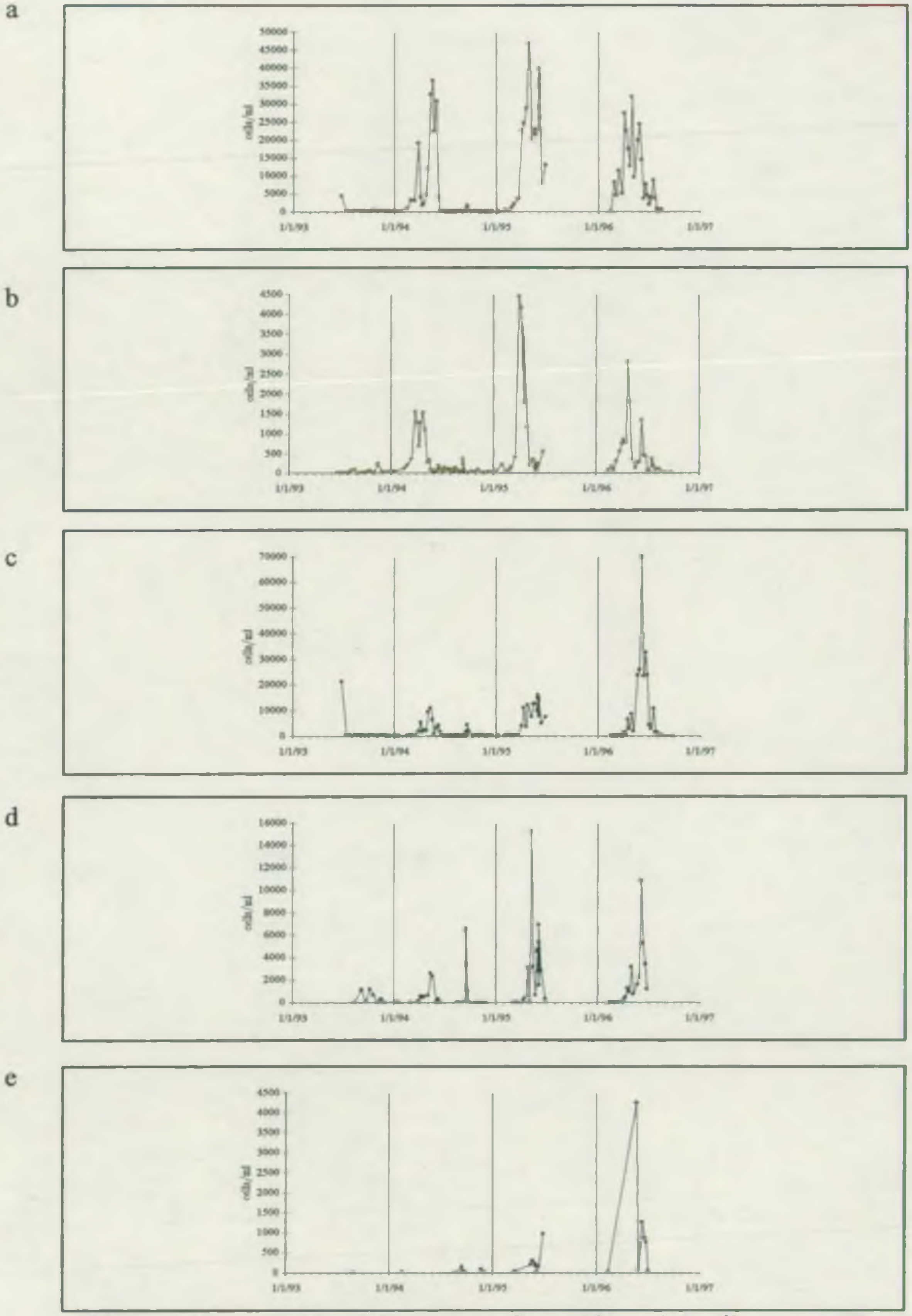


Figure 4.6.3c: a-Centrics, b-Pennates, c-Green Algae, d-*Oscillatoria* spp. & e-*Anaebaena* sp./*Aphanizomenon* sp.

Centric diatoms, mainly of the genera *Stephanodiscus*, *Cyclotella* and *Cyclostephanos*, formed the main part of the spring bloom, and are present in the water column over a greater time period than other forms. The duration of the 1995 and 1996 spring blooms, was greater than during 1994, and this was probably a function of flow.

During the summer months phytoplankton activity in the rivers is generally lower, with green algae (mainly *Scenedesmus* spp.) and *Cryptomonas* spp. being present in low abundance. This was particularly the case during the summer of 1994, when the River Nene was very clear. The increase in algal abundance during September 1994 (Figure 4.6.3c) was due to high rainfall and the subsequent flushing of algae both from lakes within the catchment, and the river itself.

SRP concentrations fluctuate with changing flow conditions (Figure 4.6.3b). Both chlorophyll *a* and SRP concentrations increase with decreasing river flows, indicating that phosphorus is abundant, and not limiting algal growth. Nitrogen concentrations rarely fall below 4 mg/l (Figure 4.3.5), and are also unlikely to be limiting algal growth.

Silicate concentrations (Figure 4.6.3b) have in inverse relationship to centric diatom abundance. Centric diatoms blooms, during 1995 and 1996, reduced the silicate concentrations in the river at Wansford, to a very low level. Diatom frustule development, in samples taken in 1995, was very poor, and this could indicate either, that there is silicate limitation, or that cells were dividing so quickly that they did not have time to fully develop their frustules (Haworth, pers comm).

Spatial chlorophyll *a* and phytoplankton investigations have revealed that spring peaks of algal activity, as described above, occur simultaneously along the deeper sections of the River Nene (Figure 4.6.3d). Therefore phytoplankton are most abundant at sites downstream of Northampton.

Some tributaries appear to be more important, as sources of phytoplankton, to the main rivers, than others. For example, Willow Brook (Fotheringhay), exhibits higher chlorophyll *a* activity than the River Ise (British Leyland) - (Figure 4.6.3d). Elevated chlorophyll *a* concentrations, in the Willow Brook, are probably the result of algal growth in the numerous on channel lakes and impoundments, that occur along its length.

Chlorophyll *a* concentrations, at Fotheringhay, have exceeded 100 µg/l each spring, since the study began, and were more extensive during, the low flow years of, 1995 and 1996 (Figure 4.6.3f). There is also some evidence of 'flushing' from the Willow Brook. High flows during September 1994 were followed by an increase in chlorophyll *a* at Fotheringhay (Figure 4.6.3e). A similar situation occurred during 1995 and 1996. Consistently low flows, during the summer of 1996, resulted in prolonged chlorophyll *a* activity.

The first chlorophyll *a* peak, at Fotheringhay, in 1995 (early April) was dominated by centric diatoms which became decreasingly abundant through May and June. In June a large bloom of the green alga *Scenedesmus quadricauda* was detected, and this resulted in the second large chlorophyll *a* peak of the year. Other phytoplankton samples have yet to be analysed.

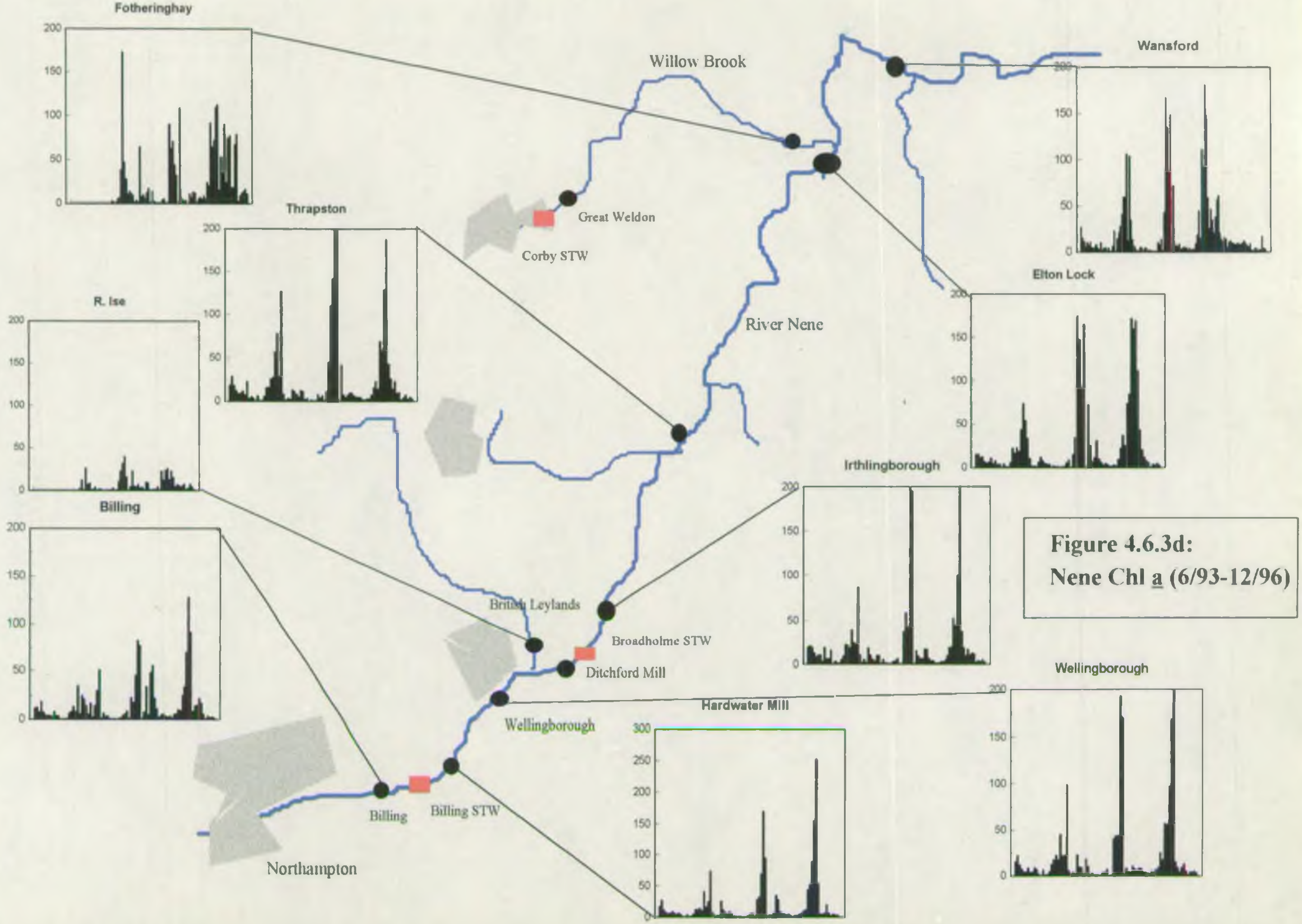
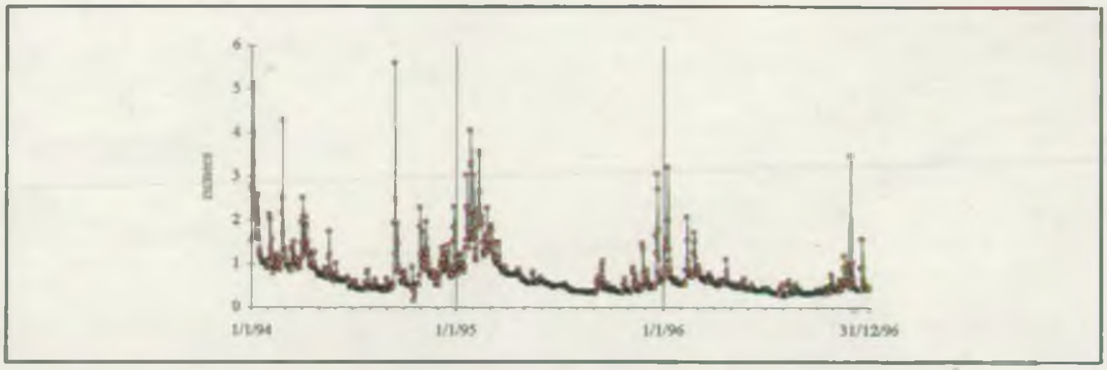


Figure 4.6.3d: Nene Chl a (6/93-12/96)

a



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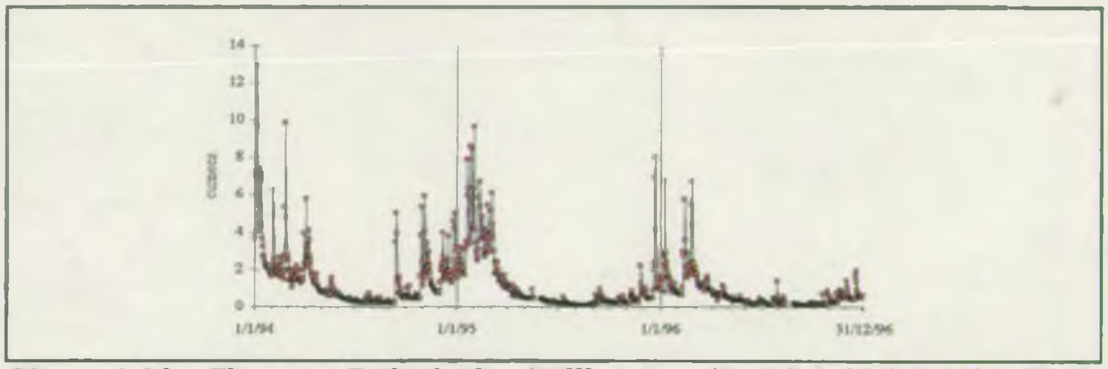
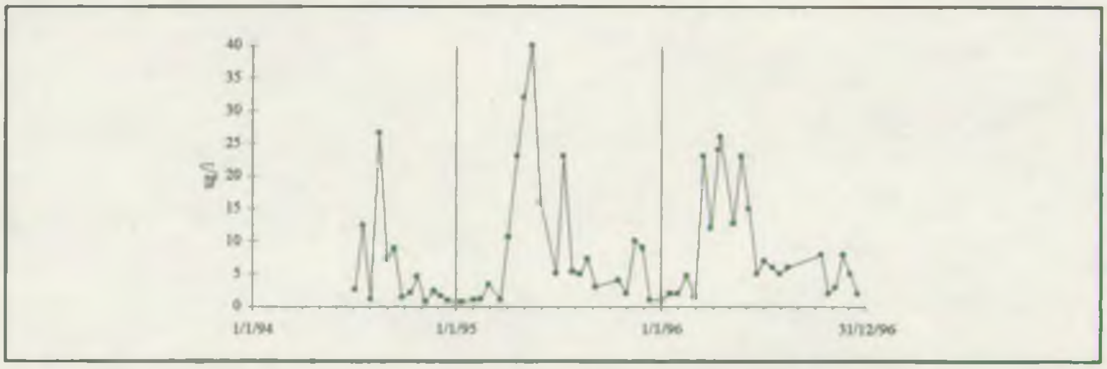


Figure 4.6.3e: Flow at a-Fotheringhay(Willow Brook) & b-British Leyland(Ise)

a



b

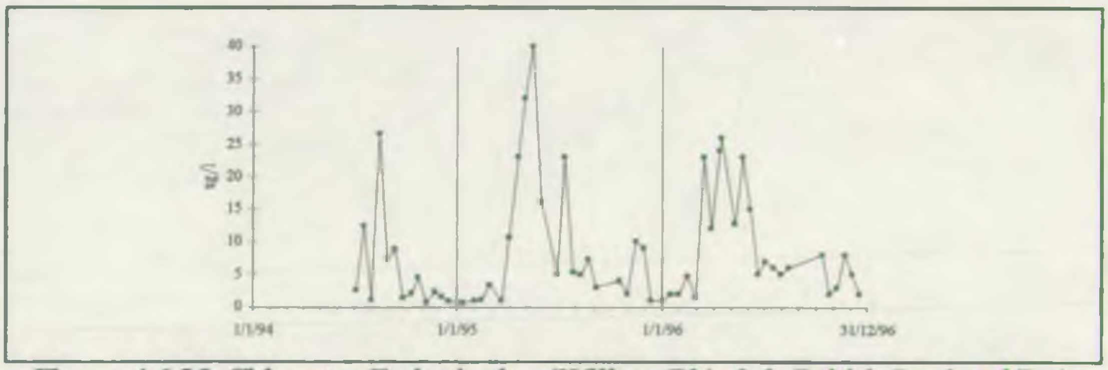


Figure 4.6.3f: Chl *a* at a-Fotheringhay(Willow Bk) & b-British Leyland(Ise)

Chlorophyll *a* concentrations in the River Ise (British Leyland) were generally low, never exceeding 40 µg/l (Figure 4.6.3f), and may have resulted in part, from the scouring of benthic algae. There is some evidence of increased chlorophyll *a* values, following increased flows (Figure 4.6.3e). These too are probably the result of scouring of benthic algae, rather than flushing (phytoplankton samples not yet analyzed).

Thrapston sailing lake, Kinewell Lake, Summer Leys Lake and Billing Marina, have all been identified as potential sources of algae to the River Nene system. These sites are all flooded gravel extractions, some of which were established over thirty years ago.

Thrapston Lake, receives water from, and discharges back into the main river Nene. This lake experienced blooms of blue-green algae during 1995 and 1996. In 1995 a severe bloom of *Anaebaena* and toxic *Aphanizomenon flos-aqua* , was found to be discharging into the river. Although large quantities of algae entered the river very little was detected in samples taken at Wansford (Figure 4.6.3c). A severe bloom of *Aphanizomenon flos-aqua*, along with *Microcystis aeruginosa* (which was found to be toxic by bioassay), reoccurred during 1996. The extent to which the river was affected is uncertain, as flow from the lake was intermittent, due to a lowering of the water levels to permit maintenance work. A large bloom of *Chlamydomonas* sp. and *Ankistrodesmus* sp. occurred in late March (chlorophyll *a* = 177 µg/l), and persisted for several weeks. Chlorophyll *a* levels were lower during April and May and began to build up again in June, as populations of blue-green algae became abundant (Figure 4.6.3g).

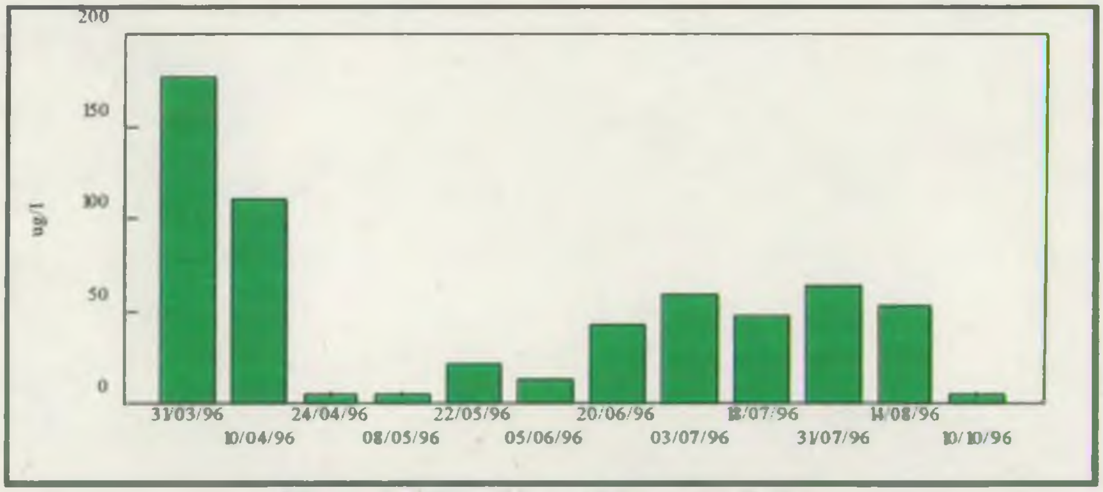


Figure 4.6.3g: Chl *a* at Thrapston Lake

Kinewell Lake, near Ringstead, discharges directly into the River Nene, and a large quantity of *Anabaena* sp. was found to be flowing into the river, during June 1996 (chlorophyll *a* = 118 µg/l).

Summer Leys Lake, near Earls Barton, is another flooded gravel pit which was established in 1993. The lake is on-channel with Grendon Brook, and discharges directly into Wollaston Mill by-pass channel. In April 1996, water discharging from the lake had a chlorophyll *a* concentration of 74 µg/l and contained a high concentration of *Cryptomonas* sp., pennate diatoms and mixed 'green' phytoplankton. In May, waters flowing from the lake were very clear (chlorophyll *a* = 5 µg/l). The lake discharge was visited again in late June and a very high concentration of *Aphanizomenon flos-aqua* was flowing from the lake into the river (chlorophyll *a* = 337 µg/l). The concentration of algae, was such that approximately a third of the river channel was discoloured, and the bloom was evident in the river several kilometres downstream, at Wellingborough. Anecdotal evidence suggested that discolouration in the main river, near the lake discharge, had been occurring for some time.

Aphanizomenon flos-aqua and *Anabaena* sp. were found regularly in samples taken at Wansford (Figure 3.6.3c), during 1996, and these taxa could well have originated some distance upstream at Summer Leys and Kinewell Lakes.

Billing marina does not flow continuously into the main river, however boat movements, diffusion and surface water run-off could all result in algae entering the river. Investigations during 1996, when samples were taken up and downstream of the marina and in the mouth of the marina itself, indicate that the marina may be having an influence on chlorophyll *a* levels in the main river, particularly during June and July (Figure 3.6.3h). As the downstream sample site (for this investigation) is the routine Billing site, these finding have relevance to data interpretation here. The relevant phytoplankton samples have not yet been analysed.

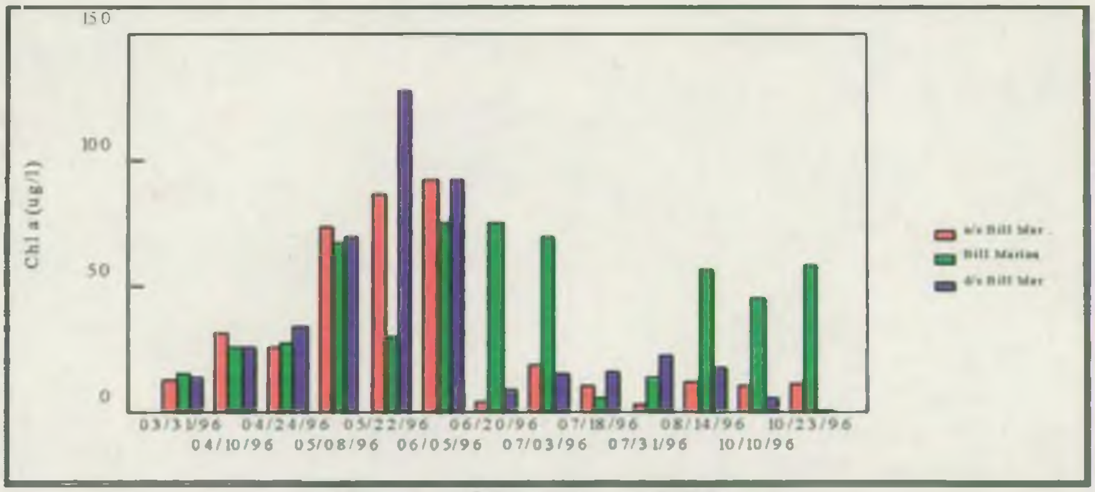


Figure 4.6.3h: Chl *a* at Billing

Chapter Five - Discussion

5.1 Phosphorus at the STWs:

The phosphorus stripping programme has achieved varying degrees of success at the different STWs. There was a general trend of more efficient phosphorus removal from effluent at River Great Ouse STWs than at River Nene STWs. Removal efficiencies range from 82.5% at Bedford STW (Great Ouse) to 35.6% at Billing STW (Nene). This is also highlighted by the proportion of the SRP load at Offord, accounted for by the major STWs. During stripping, the relative contribution of SRP from Bedford and Cotton Valley STWs was a fraction (approximately a third and a quarter respectively) of that for the post stripping period (Table 3.5). Table 4.5 illustrates the estimated contribution from major STWs on the SRP load of the River Nene. This remains high, even in periods of fairly effective stripping. Billing for example is estimated as being responsible for between 50-60% of the SRP load at Wansford.

The success of phosphorus stripping can be partly explained by the effluent treatment techniques at each STW (see Table 1.2). Bedford and Cotton Valley STW use activated sludge (AS) plants for over 80 and 100% of effluent treatment respectively. Dosing of this type of STW has been very successful, with mean annual effluent SRP concentrations falling below the UWWT directive standard of 1 mg/l.

Chalton STW fails to meet the UWWT directive standard of 2mg/l imposed on smaller STWs. This is because treatment at Chalton STW is mainly by filtration (65%). Phosphorus stripping from filter plants is much less effective than from AS plants.

Dunstable and Corby STWs rely on AS treatment, but phosphorus stripping was not as effective there as at Bedford or Cotton Valley STWs. It is possible that the reduced efficiency was because dosing at Dunstable and Corby STWs was into the oxidation pits, whilst at Bedford and Cotton Valley STWs dosing was into the AS lanes. Trials at Billing STW investigating dosing at different stages of the treatment process, however, discovered that this had little impact on the efficiency of phosphorus stripping (Strickland,1996).

A more likely explanation is the different forms of iron sulphate used in phosphorus stripping, at each STWs. Ferrous sulphate was used at Dunstable and Corby STWs, whilst ferric sulphate was used at Bedford and Cotton Valley STWs. Results from experiments carried out at Letchworth STWs show that ferric salts are more reactive, and are therefore, more efficient at phosphorus removal than ferrous salts (Strickland,1996). The lower reactivity of ferrous sulphate may not have been taken into account at Dunstable and Corby STWs, but could be overcome by dosing at a higher level than if ferric sulphate were being used. This is less of a problem for Dunstable STW, which is not a qualifying discharge under the UWWT directive.

A failure at Billing and Broadholme STWs to meet the UWWT directive standard of 1mg/l imposed there, can initially (in 1993) be attributed to similar reasons to Chalton, with 50 - 50% AS and filter treatment systems at both STWs. The proportion of AS treatment increased significantly after 1993, so that other factors have become important. Dosing has been intermittent at Billing and Broadholme STWs, so that a sustained reduction in effluent phosphorus levels has not been achieved. The reasons for this include the introduction of an

AS lane at Billing in 1995, and a new oxidisation ditch at Broadholme, neither of which could be fitted with phosphorus removal equipment, as they have been under warranty (Bland, pers comm). A significant proportion of the final effluent from both STWs has therefore not been dosed.

At Broadholme STW there have been ongoing difficulties with the dosing of primary sedimentation tanks, often causing the cessation of dosing altogether.

Billing STW has been used for various experiments in dosing and biological phosphorus removal. These experiments have taken at least one AS lane out of the stripping programme for extended periods.

Most recently there has been a total cessation of dosing at Billing and Broadholme STWs whilst new equipment is being fitted to enable dosing with ferric chloride. A continuous period of dosing is now required to allow an assessment of whether or not the phosphorus concentration of final effluents from Billing and Broadholme STWs can meet the required UWWT directive standard.

5.2 Point Sources of Phosphorus:

The main form of phosphorus in the rivers is SRP as shown in Figures 3.3.1 & 4.3.1. The STWs included in the stripping programme are the main source of SRP to the rivers. The potential for reducing SRP loads from phosphorus stripping is displayed most strikingly on the River Great Ouse. There were small increases downstream of the STWs whilst dosing was carried out (Figure 3.4.1a) and the SRP load at Offord, and therefore the potential load to Grafham Water, were lower by an estimated 28%. The influence of flow can be ruled out when the N:P ratio at Offord is considered (Figure 3.3.6). Flow variations had little effect on the N:P ratio, pre- or post dosing, with the same seasonal pattern existing. During dosing however, the summer N:P ratios were much higher than in previous or subsequent years, illustrating a reduction in relative phosphorus levels.

Similar, but less marked patterns can be identified from data for the River Nene, and at Wansford, with an estimated 17.4% reduction in SRP loads during the early stripping period. This emphasises the limited success of the stripping programme at Billing and Broadholme.

Whilst the achievement and potential reduction in SRP load are significant, it cannot be assumed that phosphorus removal at the major STWs alone will alleviate the effect of eutrophication. There are a myriad of sources and factors influencing nutrient supply (Foy *et al*,1995).

Along with the major STWs there are numerous smaller STWs in both catchments. The example of the River Ivel catchment shows that the combined load of all smaller STWs can be significant, representing an estimated 31.1% of the SRP load at Offord during stripping. A study of the Warwickshire River Avon catchment showed that 20% of the SRP load in the river can derive from smaller STWs (Wade & Harrison,1996). Treatment efficiency of small STWs is often poorer than for larger STWs so that the phosphorus load per capita is greater, for example, 56% higher in the River Avon catchment (Wade & Harrison,1996). In the River Nene catchment, less of the population is served by small STWs. Successful phosphorus stripping at major Nene STWs could, therefore result in, a large improvement in water phosphorus levels. Even so, if the STW is situated in headwaters or a tributary, a small input of SRP may affect trophic status locally, and thus contribute to eutrophication downstream.

In the River Great Ouse catchment a much larger population is served by small STWs. Improvements in effluent treatment may be necessary at more STWs to produce a beneficial reduction in the level of phosphorus in the river.

Inputs of phosphorus from industry were investigated for the River Nene at Chettles Ltd (Ditchford Mill). The evidence indicated that there has been no impact on water phosphorus levels from the effluent discharged by Chettles Ltd. The timing and frequency of sampling at Chettles would not, however, identify periodic discharges with high phosphorus concentration. Similarly, other industrial effluents cannot be ruled out as having no influence on water phosphorus levels in either catchment.

Another influence is small point source discharges of phosphorus such as from septic tanks serving the unsewered population, and from farmyard waste. It has not been possible to identify these sources for the Nene or Great Ouse catchments. In rural areas, where much of the population is not connected to the sewerage system, there can be a large cumulative effect on phosphorus levels. Good farmyard management practises are also important. Much material that collects or is stored around the farm, such as manure, fertilisers and silage, have a very high phosphorus content. Leakage can have severe effects both locally and cumulatively on a river (Lewis,1996).

The impact of tributaries on the main river is determined by the same factors controlling phosphorus levels in the main river. Significant inputs of phosphorus are evident to the River Nene from Willow Brook (contributing an estimated 8.9-11.1% of SRP loads at Wansford) and to the River Great Ouse from the Rivers Ivel and Ouzel (contributing an estimated 23.4-31.1 and 13.8-15.4% respectively of SRP loads at Offord). This is likely to be because they receive effluents from large STWs, at Corby, Chalton and Dunstable respectively. In contrast the River Ise and Brampton Branch do not have large STWs discharging into them, and consequently the load these tributaries contribute to the River Nene is minor.

The removal of phosphorus from major STWs would mean that a higher proportion of the phosphorus load in the rivers will originate from other sources. On the River Great Ouse this could rise from an estimated 17.6 to 42%, and on the River Nene from 1.5 to 9.6% (Tables 3.5 & 4.5). Individual smaller point sources or tributaries may have negligible or only a local effect on water quality. They may, however, combine to influence the trophic status of the whole river (Foy *et al*,1995). An evaluation of the contribution of all point sources will still fail to provide an accurate assessment of phosphorus inputs to the Rivers Nene and Great Ouse. The non-point source component of the phosphorus load plays an important role, and will become more significant, with greater control of point sources (Everard,1996).

5.3 Other Factors Controlling Phosphorus Loads:

The non-point phosphorus load to the rivers will almost totally consist of PP in surface run-off (MacDonald *et al*,1995). This makes the load a function of land use, livestock and human density, fertiliser application, topography, soil characteristics and rainfall (Burt *et* *al*,1996; Johnes *et al*, 1996). There are two mains lines of thought in calculating non-point source phosphorus load. First, are the physically based models that consider the processes and routes of run-off. The alternatives are export coefficient models that yield estimates of load for different land uses per unit area of land. Export coefficient models require much less data for validation and are easier to scale up to catchment level than physical models (Johnes,1996). Export coefficient models, however, do not estimate the different phosphorus fractions, but only TP export, and do not elucidate any information on the processes occurring (Abbot & Refgaard,1996).

The relative importance of the non-point phosphorus load depends on the load from point sources, and land use within the catchment. In agricultural catchments, non-point sources can account for over 90% of the total phosphorus load (Frost,1996). In the Great Ouse and Nene catchments the large impact of point sources mean that the non-point source contribution would be well below this figure. Calculations in the Warwickshire River Avon, catchment show that 20% of TP in the river can be accounted for by non-point sources (Wade & Harrison,1996). This figure would rise sharply if phosphorus removal were to be carried out at major STWs in the River Avon catchment. The implication for the Rivers Nene and Great Ouse is that run-off from land may be significant in terms of riverine eutrophication.

The seasonal nature of the non-point source load is worth noting. The dominant form of phosphorus in run-off is PP. PP tends to be transported to rivers during periods of high rainfall (storm events), normally in the winter. Over 70% of the annual non-point source phosphorus load can occur in less than 5% of the year (Kronvang,1995). This point is supported by high PP loads in the Rivers Nene (Figure 4.3.1) and Great Ouse (Figure 3.3.1) during winter quarters (January-March). Another factor contributing to high water PP loads during winter is that the high flows lead to re-suspension and flushing of particulate organic and inorganic matter from the bed of the main river, backwaters and on line lakes. It is possible that, because there is little demand for phosphorus, and the throughput of loads is so high during the winter flows, that the non-point source phosphorus load will have little influence on the trophic status of the rivers (Leeds-Harrison,1996).

SRP also displays a positive correlation with flow throughout the year in the Nene and Great Ouse. An element of this may be dissolved fractions in surface run-off, and throughflow from the land. Another possibility is that exceptionally fine PP of less than 0.45um, becomes suspended with increasing flow. These particles will be analyzed as part of the SRP fraction. Also, the potential for the solution or desorption of phosphorus, that is bound to particulate matter, can increase during particulate suspension in higher flows (Cooke & Williams,1973).

Desorption of phosphorus is the principal mechanism of internal loading (Krieritz *et al*,1996). Internal loading may have occurred in the Nene and Great Ouse whilst phosphorus stripping was occurring at the STWs. The net movement between water and sediments will have shifted from adsorption to desorption due to lower water SRP concentrations in this period (Forsberg,1989). This could have cancelled out the impact of reduced phosphorus in STW effluents, so that improvements in water quality, particularly those evident for the River Great Ouse, were not reaching their full potential.

Sediments can act as a sink as well as a source for phosphorus, even during periods of reduced water SRP concentrations. This process of settling and adsorption will occur in very sluggish stretches of the river and on line lakes. This is because flow is insufficient to maintain even the smallest particles in suspension, thus dissolved phosphorus is resident for longer so has greater potential to become adsorped to the sediments. There are lakes along the route of both rivers. Findings from the Warwickshire River Avon show a fall in phosphorus loads downstream of on line lakes and marsh areas (Wade & Harrison,1996). The evidence (Figures 3.4.1a & 4.4.1a) does not indicate any obvious impact of lakes on downstream phosphorus loads in the main rivers. Figure 4.4.4 does show a fall in SRP loads downstream between Weldon and Fotheringhay (in Willow Brook), where there are a number of on line lakes. The presence of lakes may, therefore, go some way to explain the inconsistency in the pattern of increasing loads downstream, in the Nene and Great Ouse. The process may also serve to explain the frequently lower phosphorus loads at Ditchford Mill (Lock Channel) than upstream at Wellingborough (Figure 4.1.1). At Ditchford Mill, water becomes backed up behind the lock and flow is often imperceptible at the site. There is, therefore, greater potential for settling of PP and adsorption of SRP. Also, the slow flow may be less limiting on phytoplankton growth, than at other sites. This may enable greater biological uptake of phosphorus at Ditchford Mill.

The premise of the above discussion is that SRP is an accurate measurement of the bio-available phosphorus fraction (Fox & Malati,1985), and is therefore most important in terms of eutrophication. This would suggest that there would be little or no impact on the trophic state of the river from predominantly particulate, non-point source inputs. In fact, little is known of the movements and transformations within the phosphorus spiral (Heathwaite & Johnes,1996; Fabre *et al*,1996). There may be other inorganic or organic phosphorus fractions in the water and sediments that are available or can rapidly become available.

The assumption has also been made that phosphorus is the nutrient that limits primary production and controls trophic status. This has become the established view for lakes and rivers (Mason,1996). There is increasing conjecture that this is not the case, and that nitrogen is limiting in some waterbodies (Suttle *et al*,1991) or that phosphorus and nitrogen may limit primary production at different times of year within the same water body (Ryding & Rast,1989). The implication for macrophytes and phytoplankton will be in terms of which nutrient is limiting during the different stages of the growing season.

5.4 Biological Responses:

The macrophyte and diatom communities provide further evidence that primary production is not limited by nutrient levels alone (phosphorus or nitrogen), in either, the River Great Ouse or River Nene. MEWAM, GCN and MTR scores indicated that all sites were eutrophic. This includes Billing (on the River Nene) and Newport Pagnell (on the River Great Ouse) which are both upstream of the major STWs involved in the stripping programme. Investigations during 1995, revealed that sites upstream of Whilton STW, high up in the River Nene catchment, were eutrophic (Balbi,1996). Major STWs are shown to be one of many nutrient sources affecting the trophic status of the rivers. The UWWTD phosphorus stripping programme alone might, therefore, not significantly lessen or reverse eutrophication in either river.

Only a few sites in, the headwaters of the Rivers Nene and Great Ouse, exhibit plant communities of a lower trophic status. An example is the River lvel, upstream of Hitchin STW (Figure 3.6.2b). Once there has been an initial input of effluent from Hitchin STW the MTR falls sharply, indicating that the River Ivel has become much more eutrophic. This emphasises the importance of other sources of nutrients, particularly small STWs, in contributing to the eutrophication of the Rivers Great Ouse and Nene.

The decrease in MTR scores downstream of STWs (Figures 4.6.2b), indicates a deterioration in trophic status. Phosphorus stripping may help to eliminate or reduce this downstream effect.

At present the interpretation of the MTR and diatom indices in isolation should be viewed with some caution, as the relationship between plant communities, nutrient conditions and other physical factors is not fully understood (Holmes, pers comm; Kelly,1996).

5.5 The River Phytoplankton Community:

The results from this project provide evidence of a true river phytoplankton community, in both the River Nene and River Great Ouse, the occurrence of which loosely follows a predictable pattern. This project has also highlighted the importance of tributaries and lakes, within the catchments, as a source of algae to these river systems.

Both the Rivers Nene and Great Ouse clearly support rich and varied phytoplankton communities, which are controlled principally by flow, light and temperature. The duration and intensity of the spring blooms, appears to be mainly dependant on the flow regime during that period. High and/or spate flows, such as those which occurred during the spring of 1994, reduce the potential for high and sustained chlorophyll *a* peaks. Flows during the spring of 1995 were lower and more consistent, than those of spring 1994. This resulted in a more prolonged period of algal activity, with chlorophyll *a* peaks of much greater magnitude.

The lower intensity and shorter duration of the 1994 spring bloom on the River Nene corresponded with greater growth of benthic algae and submerged macrophytes (Environment Agency,1997). This implies that phytoplankton can reduce light penetration, and therefore, play a role in the limitation of submerged and benthic communities .

During the spring of 1995, flow decreased gradually, resulting in a steady reduction in turbulence within the water column, and a clear picture of phytoplankton succession was evident. The early stages of the spring blooms were dominated by a mix of pennate and centric diatoms. As flow decreased, further the larger pennate diatoms disappeared from the water column, presumably lost through sedimentation, in reduced turbulence. As flow reduced further still, centric diatoms become very abundant, and it is during this period that the chlorophyll *a* peaks were produced. The peak of pennate diatoms, which occurred in the River Nene during June 1995 and 1996, was mainly the result of an abundance of the colonial diatom *Nitzschia fruticosa* The stellate form of this taxa results in a reduced sinking rate, permitting it to maintain itself within the water column in reduced turbulence (Reynolds, 1984). The appearance of the stellate form could also be a result of grazing pressure. Green algae became progressively more abundant as the bloom progressed, and probably played a significant role in the main chlorophyll *a* peaks.

There is no evidence of phosphorus limitation of the phytoplankton communities in either river. In both rivers SRP concentrations, even during phosphorus removal, remained high relative to the very small quantities necessary for growth (see below). Algae have evolved over many thousands of years, often in phosphorus poor environments. They are very efficient at actively taking up phosphorus against huge concentration gradients, and storing sufficient phosphorus for several divisions (Harris,1986). They can also, utilise phosphorus in many different forms, but probably, preferentially use SRP (Round,1981). The concentration of SRP thought necessary to limit algal growth varies greatly. Reynolds (1984) cites 5 -10μg l^{-1} as a concentration which is likely to limit algae growth. However, Reynolds (pers comm) now believes that the SRP concentration would have to fall below 5 μg l^{-1} before limitation could take place. Others think that ecological change could take place in benthic algae populations at much greater SRP concentration, 100 - 200μg l^{-1} (Kelly & Whitton,1995). Regardless of these discrepancies phosphorus concentrations actually increase during the algal blooms (Figure 3.6.3b & 4.6.3b) and the opposite would be expected if any kind of limitation was taking place.

TON remained high, in both rivers, throughout the spring and summer of 1995. The TON concentrations rarely fell below 4 μg l^{-1}, in either river. This concentration is many times that which is thought to limit freshwater phytoplankton growth (Reynolds 1984). As both phosphorus and nitrogen are in such abundance in both rivers, the N:P ratio becomes largely irrelevant (Reynolds,1995).

Although phosphorus and nitrogen are not limiting algal growth, there is some indication of silicate limitation. Silicate concentrations fell below 0.2 μg l^{-1}, in the River Nene, during the spring and early summer of 1995 and 1996. The centric diatom *Stephanodiscus tenuis* was abundant in both rivers during the spring of 1995, and this taxa has recently been recognised as a thinly silicified form of *Stephanodiscus hantzschii*. There is also evidence of fungal attack on the centric diatom communities, occurring during the spring blooms. Fungal parasites can have a significant impact on diatom abundance and viability (Reynolds,1984).

The 'clear phases', (periods of low phytoplankton abundance), which occur during the summer, are not, at present, readily explained. During these periods flow is low, nutrients are abundant, temperature and, sunlight hours are high. All these factors contribute to high phytoplankton production in lakes, but rivers can remain clear for long periods under these conditions. Some possible explanations for these clear phases, in the rivers, are, grazing by rotifers and fish fry, fungal attack, filtering by mussels and lastly, sedimentation through reduced turbulence. Which of these factors are important is, as yet, uncertain. Turbulence, created by flow, is probably a key factor. Phytoplankton productivity was very low in the River Great Ouse during spring 1996. This corresponded with a period of very low flow, for the time of year. This is unlikely to be due to low temperatures during this period, because there was not a bloom on the River Nene, where temperatures were the same but flows were higher. It was not until flows returned to a more characteristic levels, in early March, that the abundance of phytoplankton began to increase. This may indicate that a certain level of flow is necessary to produce a sufficiently turbulent environment for diatoms to remain in the water column. River Nene diatom communities are more constant and this may relate to the narrower channel of the River Nene, which may create more turbulence.

An understanding of tributaries and lakes, as a source of phytoplankton, to the river systems, is developing. These sources of inoculum can have a significant impact on the phytoplankton species composition in the rivers they discharge to. The blue-green algae *Oscillatoria agardhii* and *O. redekei* are a common feature of the plankton of the River Great Ouse (Reynolds et al,1992, NRA,1994 Balbi,1995). The main source of inoculum to the river appears to be the balancing lakes at Milton Keynes. Little blue-green algae is found in the main River Great Ouse, at Newport Pagnell, but *Oscillatoria agardhii* and *O. redekei* are often present in the River Ouzel, and at sites downstream of the confluence of the two rivers. The contribution from other tributaries is less clear.

If spring and summer river flows continue to be low, then the importance of tributaries, canals, lakes and water transfer schemes, as a source of algal inoculum to rivers, may become increasingly significant. There is evidence to support the hypothesis that the blue-green algal bloom which occurred in the River Great Ouse, during the summer of 1995, originated from Willen Lake, Milton Keynes. The timing, quantities and taxa involved all support this. *Oscillatoria agardhii* appears to grow well in shallow, turbid, nutrient rich lakes and as this environment is not dissimilar to a slow flowing river, it is not impossible that the bloom established itself in the deeper, slower flowing sections of the River Great Ouse.

During 1996 *Oscillatoria agardhii* and *O. redekei* were present in the River Great Ouse, at a similar concentration as found in 1994, but not to the same extent as during 1995. Nutrients, flow and water temperature were all similar in the summers of 1995 and 1996. The fact that a massive bloom of blue-green algae did not occur during 1996, therefore; further suggests a large inoculum from Willen Lake, as the principal cause of the 1995 bloom, and not just the trigger, as suggested by Williams (1996).

Chlorophyll *a* at Lovat Bank, and Willen flow data, indicate that large quantities of algae are being flushed from the balancing lakes, presumably when flood waters are being released from the lakes.

There are numerous flooded gravel workings along both the Nene and Great Ouse valleys. Although many of these are not connected to the river, some may be, and these should be identified, along with the type of algae they contain. On-line lakes, along Willow Brook, Wootton Brook and Grendon Brook are also potential sources of algae to the River Nene.

Special investigations of several potential sources of algae, during 1996, highlighted the serious impact that lakes can have on the river plankton. Summer Leys Lake and Kinewell Lake, in the Nene catchment, were both identified as sources of algae to the main river. Blue-green algae entering the River Nene, from these water bodies, was detectable many miles downstream.

The differing contribution of algae from the Willow Brook and River Ise highlights the contribution of on line lakes (of which there are many in the Nene Catchment). Willow Brook has several on line lakes. The most downstream of these, at Apethorpe, is about five kilometres from its confluence with the main river. This means that phytoplankton growth in Apethorpe Lake is subject to flushing with increased flows. The River Ise also has lakes along its course. The most downstream of these, at Wicksteed Park, Kettering, is about ten kilometres from the River Ise / River Nene confluence, but more importantly is not on-channel. Water does flow through Wicksteed Park Lake, to maintain the level, but in periods of high discharge the bulk of the flow goes through the original river channel. Therefore the location and arrangement of lakes can have a significant impact on the quantity of algae which is carried. This factor should be considered when lakes are constructed, and where possible the on line design should be rejected.

Inevitably there have been sampling and analysis difficulties associated with this work, and certain assumptions have had to be made. This does not, however, detract from the key patterns, trends and conclusions discussed in this document.

This report has highlighted a number of crucial features driving the eutrophication process in rivers, and these must be accounted for in any future monitoring, assessment or remediation programme.

Chapter Six - Conclusions

The findings of the project can be summarised as:

- Phosphorus loads increased downstream on the River Nene and River Great Ouse.

- The highest increases in phosphorus loads were downstream of STWs.

- Phosphorus stripping was successful on the River Great Ouse at Bedford, Cotton Valley and Dunstable STWs, but less so at Chalton STW. The phosphorus load in the river was lower during the stripping period, by an estimated 28%.

- Phosphorus stripping achieved limited, short-term success at the STWs on the River Nene. There was only a slight reduction in the river phosphorus loads, at the beginning of the stripping programme (estimated at 17.4%).

- Small STWs were identified as a major source of phosphorus to the rivers, particularly in the Great Ouse catchment where an estimated 23-31% of the SRP load in the main river was from STWs on the River Ivel.

- The importance of other small point sources and non-point sources (surface runoff and internal loading) is uncertain, but could potentially be large.

- Phosphorus and nitrogen concentrations are currently high, so that neither is likely to be limiting to primary production.

- The River Nene and River Great Ouse possess complex phytoplankton communities, which exhibit blooms in the early spring. The blooms initially consist of pennate diatoms, with centric diatoms and green algae becoming dominant later in the year.

- Blue-green algae in the rivers generally appear to have originated from non-lotic sources. Conditions in the River Great Ouse, were on occasion, sufficient to maintain and allow the development of a bloom of blue-green algae.

- The macrophyte and diatom communities of the River Nene and River Great Ouse are indicative of eutrophic conditions. The MTR scores indicate greater nutrient enrichment downstream of STWs.

- There are limitations with the project and the potential exists to improve and broaden the scope of study.

Chapter Seven - Recommendations

Improvements and expansion of the project could be in a number of areas:

7.1 Research:

- Quantification of the role of sediments, in particular internal loading.
- Establish the contribution of small point sources (industry, septic tanks and farmyards) and non-point sources of phosphorus to the rivers.
- Define the link between diatom / macrophyte communities and trophic status.
- Assess the role of zooplankton to provide an insight into the movement of phosphorus through food webs.
- The use of bioassays to monitor trophic status.

7.2 Monitoring:

- Re-evaluation of determinands used, monitoring and analysis techniques, sampling frequency and sample sites.
- Improve the River Nene flow model.
- Develop a flow model for the River Great Ouse.
- Monitor nitrogen and silicate to ascertain their role in the eutrophication of the rivers.

7.3 Monitoring Programme Guidelines:

- Future monitoring could be incorporated into existing routine sample runs.
- Sampling of STW effluents.
- Sample river sites, up- and downstream of STWs.
- Sample river sites up- and downstream of tributaries and on tributaries, upstream of the confluence with the main river.
- Sample at Wansford and Offord. The current Offord sample site is not ideal so it is worth trying to find a site just upstream.

- Sample for SRP, TP at all (STW effluent and river) sites.
- Sample for metals and sulphates (chloride on River Nene) in STW effluents.
- Sample chlorophyll *a* at river sites to provide some indication of biological activity.
- Sample phytoplankton depending on resources (time and expertise) and carry out identification based on chlorophyll *a* results.
- Sample at least fortnightly (weekly at Wansford and Offord).

References

Abbott, M.B. & Refsgaard, J.C. (1996) *Distributed Hydrological Monitoring*. Kluwers Academic.

Abel, P.D. (1989) *Water Pollution Biology*. Ellis Horwood.

Balbi, D.M. (1994) Presentation, *Eutrophication Control Seminar*, NRA Brampton - 11/5/94.

Balbi, D. (1995) *Rivers Nene and Great Ouse Eutrophication Studies - First Year Report*. NRA.

Balbi, D.M. (1996) Evaluation of the TDI in the Welland and Nene catchments (Anglian Region). In M.G. Kelly *Use of Diatoms to Monitor Nutrients in Rivers*. Environment Agency.

Balmer, P. & Hultman, B. (1988) Control of phosphorus discharges: present situation and trends, *Hydrobiologia*. **170**, 305-319.

Barber, H.G. & Haworth, E.Y. (1981) *A Guide to the Morphology of the Diatom Frustule*. Freshwater Biology Association.

Burt, T.P. Heathwaite, A.L. & Johnes, P.J. (1996) Stream water quality and nutrient export in the Slapton catchment, *Field Studies*. **8**, 613-627.

Canter-Lund, H.C. & Lund, J.W.G. (1995) *Freshwater Algae: their Microscopic World Explored*. Biopress.

Chambers, P.A. Prepas, E.E. Hamilton, H.R. & Bothwell, M.L. (1991) Current velocity and its effects on aquatic macrophytes in flowing waters, *Ecological Applications*. **1(3)**, 249-257.

Cloot, A. Schoombie, S.W. Pieterse, A.J.H. & Roos, J.C. (1992) A note on a light-temperature dependent model for algal blooms in the Vaal River, *Water South Africa*. **18**, 299-302.

Cooke, G.W. & Williams, R.J.B. (1973) Significance of man-made sources of phosphorus: fertilisers and farming, *Water Research*. 7, 19-33.

Coste, M. (1982) *Etude des methodes biologiques quantitatives d'appreciation de la qualite des eaux*. CEMAGREF.

Cox, E.J. (1995) *River Great Ouse and River Nene Eutrophication Studies. Diatoms* (2). Natural History Museum.

Cox, E.J. & Reid, G. (1994) *River Great Ouse and River Nene Eutrophication Studies. Diatoms.* Natural History Museum.

Cox, E.J. & Reid, G. (1996) *River Great Ouse and River Nene Eutrophication Studies. Diatoms(3).* Natural History Museum.

Cranston, L.E. & Ayres, A. (1994) *River Great Ouse and River Nene Eutrophication Studies - Macrophyte Report 1993.* ICOLE.

Elliott, J.M. & Drake, C.M. (1981) A comparative study of seven grabs used for sampling benthic macro-invertebrates in rivers, *Freshwater Biology.* **11**, 99-120.

Environment Agency (1996) *Methodology for the Assessment of Freshwater Riverine Macrophytes for the purposes of the Urban Waste Water treatment Directive.* Environment Agency.

Environment Agency (1996a) *The Environment Agency's Strategy on Eutrophication.* 2nd Draft, Environment Agency.

Environment Agency (1997) *Sensitive Areas (Eutrophication) - River Nene.* Environment Agency.

Everard, M. (1996) Concluding remarks, *Conference on Measuring Nutrient Run-Off from Land to Water.* University of Leicester - 6/12/96.

Fabre, A. Qottsi, A. Dauta, A. & Baldy, V. (1996) Relation between algal available phosphate in sediments of the River Garonne and chemically determined phosphate fraction, *Hydrobiologia,* **335**, 43-48.

Forsberg, C. (1989) Importance of sediments in understanding nutrient cycling in lakes, *Hydrobiologia.* **176/177**, 263-277.

Fox, I. & Malati, M.A. (1985) *Cycling of Phosphorus in Rivers: Final Report of the Department of the Environment.* DoE.

Foy, R.H. Smith, R.V. Jordan, C. & Lennox, S.D. (1995) Upward trend in soluble phosphorus loadings to Lough Neagh despite phosphorus reduction at sewage treatment works, *Water Resources.* **29(4)**, 1051-1063.

Frost, A. (1996) A catchment scale study to identify particulate P sources, *Conference on Measuring Nutrient Run-Off from Land to Water.* University of Leicester - 6/12/96.

Goltermann, A. Bosrom, B. Jansson, M. & Forsberg, C. (1982) Phosphorus release from sediments, *Polskie Archiwum Hydrobiologh.* **18**, 5-59.

Harper, D. (1992) *Eutrophication of Freshwaters: Principles, Problems and Restorations.* Chapman & Hall.

Haslam, S.M. (1978) *River Plants.* Cambridge University Press.

Heathwaite, A.L. & Johnes, P.L. (1996) Contribution of nitrogen species and phosphorus fractions to stream water quality in agricultural catchments, *Hydrological Processes,* **10**, 971-983.

Holmes, N.T.H. (1995) *Macrophyte for Water Quality and other River Quality Assessment.* NRA.

Johnes, P.J. (1996) Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to surface waters: the export coefficient modelling approach, *Journal of Hydrology.* **183**, 323-349.

Johnes, P.J. Moss, B. & Phillips, G. (1996) The determination of total nitrogen and total phosphorus concentrations in freshwaters from land use, stock headage and population data: testing of a model for use in conservation and water quality management, *Freshwater Biology.* **36**, 451-473.

Kelly, M.G. (1995) *The Trophic Diatom Index: A Users Manual.* NRA.

Kelly, M. (1996) *The Trophic Diatom Index.* Presentation for Managers and Biologists in the Environment Agency.

Kelly, M.G. & Whitton, B.A. (1995) The Trophic Diatom Index: a new index for monitoring eutrophication in moving waters, *Journal of Applied Phycology.* **7**, 433-444.

Krieritz, L. Krasprzak, P & Koschel, R. (1996) Long-term study on the influence of eutrophication, restoration and bio-manipulation on the structure and development of phytoplankton communities in Feldberger Haussee (Baltic Lake District, Germany), *Hydrobiologia.* **330**, 89-110.

Leeds-Harrison, P. (1996) Buffer zones studies of nutrient interception, *Conference on Measuring Nutrient Run-Off from Land to Water.* University of Leicester - 6/12/96.

Lewis, D. (1996) A model for risk assessment of slurry and nutrient loss, *Conference on Measuring Nutrient Run-Off from Land to Water*. University of Leicester - 6/12/96.

MacDonald A.M. Edwards, A.C. Pugh, K.B. & Balls, P.W. (1995) Soluble nitrogen and Phosphorus in the River Ythan system, UK: Annual and seasonal trends, *Water Resources.* **29(3)**, 837-846.

Mainstone, C.P. Davies, R.D. & Parr, W. (1996) *A Review of Methods for Assessing and Controlling Non-Point Source of Pollution.* NRA.

Mason, C.F. (1996) *Biology of Freshwater Pollution, 3rd Edition.* Longman.

Mehner, T. & Benndorf, J. (1995) Eutrophication - a summary of observed effects and possible solutions, *Journal of Water Science Research & Technology.* **44**, 35-44.

Moss, B. (1988) *Ecology of Fresh Waters.* Blackwell Scientific.

Newbold, J.D. (1994) Cycles and spirals of nutrients. In G. Petts & P. Calow *The Rivers Handbook - Volume One.* Blackwell Science.

NRA (1990) *Blue-Green Algae.* NRA.

NRA (1993) *Standard Methodologies: Freshwater Phytoplankton.* NRA.

NRA (1994) *Rivers Nene and Great Ouse Eutrophication Project Interim Report.* not published.

OECD (1982) *Eutrophication of Waters: Monitoring, Assessment and Control.* OECD.

Reynolds, C.S. (1981) *The Ecology of Freshwater Phytoplankton.* Cambridge University Press.

Reynolds, C.S. & Gaister, M.S. (1992) *The Environments of Large Rivers.* IFE.

Round, F.E. (1981) *The Ecology of Algae.* Cambridge University Press.

Round, F.E. (1993) *A Review and Methods for the use of Epilithic Diatoms for Detecting and Monitoring Changes in River Water Quality, 1993.* MEWAM, HMSO.

Rumeau, A. & Coste, M. (1988) Initiation a la systematique des diatomees d'eau douce pour l'utilisation pratique d'un indice diatomique generique, *Bulletin Francais de la Peche at de la Pisciculture.* no. **109**.

Ryding, S.O. & Rast, W. (1989) *The Control of Eutrophication of Lakes and Reservoirs.* UNESCO.

Steinberg, C. & Schielfe, S. (1988) Biological indication of trophy and pollution of running waters, *Wasser-Abwasser-Forsch.* **21**, 227-234.

Strickland, J. (1996) *Development in Wastewater Nutrient Removal: Paper presented to East Anglian Branch of the Chartered Institution of Water and Environmental Management.* AWS.

Suttle, C.A. Cochlan, W.P. & Stockner, J.G. (1991) Size dependant ammonium and phosphorus uptake and N:P supply ratios in an oligotrophic lake, *Canadian Journal of Fisheries and Aquatic Sciences.* **48**, 1226-1234.

Wade, S. & Harrison, S. (1996) *Eutrophication in Controlled Waters in Lower Severn Area.* Coventry University.

West, G.S. & Fritsch, F.E. (1932) *A Treatise on the British Freshwater Algae.* Cambridge University Press.

Williams, E.M. (1996) *Report into the Blue-Green Algal Bloom - River Great Ouse, Summer 1995.* NRA.

Wray, J. & Balbi, D. (1996) *Rivers Nene and Great Ouse Eutrophication Studies - Second Year Report.* Environment Agency.

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Appendix One

River Nene Sample Sites:

Site	LIMS Code	NGR
River Nene: Duston Mill	R05BFNENE080D	SP 729 596
River Nene: Billing Road Bridge	R05BFNENE170B	SP 814 611
River Nene: Hardwater Mill	R05BFNENE220H	SP 876 637
River Nene: Wellingborough Road Bridge	R05BFNENE240W	SP 902 665
River Nene: Ditchford Mill Stream	R05BFNENE250D	SP 930 683
River Nene: Ditchford Mill Lock Channel	R05BFNENE260D	SP 930 682
River Nene: Irthlingborough Old Road Bridge	R05BFNENE300I	SP 957 706
River Nene: Thrapston Road Bridge	R05BFNENE370T	SP 991 787
River Nene: Elton Lock	R05BFNENE500E	TL 083 939
River Nene Wansford Old Road Bridge	R05BFNENE550W	TL 075 991
River Nene - Brampton Branch: St Andrews Gauging Station	R05BFBRAM140S	SP 749 615
River Ise: British Leyland B571 Road Bridge	R05BFRISE310B	SP 907 674
Willow Brook South: A427 Great Weldon	R05BFWILS040W	TL 930 895
Willow Brook: Fotheringhay Road Bridge	R05BFWILL170F	SP 063 935

River Great Ouse Sample Sites:

Site	LIMS Code	NGR
River Ouse: B526 Road Bridge Newport Pagnell	R05BF05M03	SP 878 442
River Ouse: Tyringham Bridge	R02BF11M02	SP 857 465
River Ouse: Sharnbrook Mill	R02BF11M12	TL 011 590
River Ouse: Newnham Foot Bridge	R02BF12M03	TL 063 493
River Ouse: Castle Mills	R02BF12M05	TL 092 509
River Ouse: Roxton Lock	R02BF12M08	TL 160 535
River Ouse: Offord Intake	R02BF22M03	TL 214 662
River Ouzel: Lovat Bank	R02BF10M01	SP 878 439
Ivel Navigation: Twin Bridge Clifton	R02BF18M01	TL 163 398
River Ivel: A6001 Road Bridge Langford	R02BF15M01	TL 183 402
River Ivel: Tempsford Depot Foot Bridge	R02BF19M07	TL 161 533

Appendix Two

Rivers Nene and Great Ouse Sampling Program (for 1993/4):

F = Fortnightly M = Monthly A = Annually * = April to October only + = more often in summer	CHL A	SRP	TP	SO4	TOT FE	DIS FE	PHYTO	DIATOM
Will Bk - Gt Weldon		F	F	M	M	M		A
Will Bk - Fotheringhay	F	F	F				F	A
Nene - Wansford	F+	F	F				F+	A
Nene - Elton	F	F	F					A
Nene - Thrapston	F	F	F				F	A
Nene - Irthlingborough	F	F	F	M	M	M		A
Nene - Ditchford Lock	F	F	F	M	M	M		A
Nene - Ditchford Stream		F	F					A
Nene - Wellingborough	F	F	F				F	A
Nene - Hardwater Mill	F	F	F	M	M	M		A
Nene - Billing	F	F	F	M	M	M	F	A
Nene - Duston	F	F	F				F	
Nene - St Andrews	F	F	F				F	
Ise - Wellingborough	F	F	F				F	
Ouse - Offord	F	F	F				F+	A
Ivel - Tempsford	F	F	F				F	A
Ouse - Roxton	F	F	F				F	A
Ouse - Castle Mills	F	F	F	M	M	M		A
Ouse - Newnham	F	F	F	M	M	M		A
Ouse - Sharnbrook Mill	F	F	F				F	A
Ouse - Tyringham	F	F	F	M	M	M		A
Ouse - Newport Pagnell	F	F	F	M	M	M	F	A
Ouzel - Lovat Bank	F	F	F				F	A
Ouzel - Stanbridgeford		F	F	M	M	M		A
Fancott Brook		F	F	M	M	M		A
Ivel - Navigation	F	F	F					A
Ivel - Langford	F	F	F					A

Rivers Nene and Great Ouse Sampling Program (for 1995):

F = Fortnightly M = Monthly A = Annually	CHL *A*	SRP	TP	SO4	TOT FE	DIS FE	SI	PHYTO	DIATOM
Will Bk - Gt Weldon		F	F	M	M	M			A
Will Bk - Fotheringhay	F	F	F					F	A
Nene - Wansford	F	F	F				F	F	
Nene - Elton	F	F	F						
Nene - Thrapston	F	F	F					F	
Nene - Irthlingborough	F	F	F	M	M	M			A
Nene - Ditchford Lock	F	F	F	M	M	M			A
Nene - Ditchford Stream		M	M						
Nene - Wellingborough	F	F	F					F	
Nene - Hardwater Mill	F	F	F	M	M	M			A
Nene - Billing	F	F	F	M	M	M		F	A
Nene - Duston	F	F	F						
Nene - St Andrews	F	F	F						
Ise - Wellingborough	F	F	F					F	
Ouse - Offord	F	F	F				F	F	
Ivel - Tempsford	F	F	F					F	A
Ouse - Roxton	F	F	F					F	
Ouse - Castle Mills	F	F	F	M	M	M			A
Ouse - Newnham	F	F	F	M	M	M			
Ouse - Sharnbrook Mill	F	F	F					F	A
Ouse - Tyringham	F	F	F	M	M	M			
Ouse - Newport Pagnell	F	F	F	M	M	M		F	A
Ouzel - Lovat Bank	F	F	F					F	A
Ivel - Navigation	F	F	F						
Ivel - Langford	F	F	F						

Appendix Three

Available Data:

Determinand	Units	Source	D.C.	Wansford*	Offord*
Filtered SRP	mg/l	LIMS	74972	-	-
Unfiltered SRP	mg/l	LIMS	01806	1981	1981
STWs SRP	mg/l	LIMS	01912	-	-
TP	mg/l	LIMS	75301	1985	1989
Chl *a*	ug/l	LIMS (&on paper)	07291	1981 (1975)	1987
Total Iron	mg/l	LIMS	04217	1981	-
Dissolved Iron	mg/l	LIMS	04197	-	-
Sulphate	mg/l	LIMS	01833	1981	-
TON	mg/l	LIMS	01165	1981	1981
Nitrite	mg/l	-	-	1981	1981
Ammonia	mg/l	LIMS	01113	1981	1984
Silicate	mg/l	LIMS	01823	1981	-
BOD	mg/l	LIMS	00851	1981	-
Conductivity	uS/cm	LIMS	00772	1985	-
DO	% Saturation	LIMS	92191	1981	1990
Temperature	C	LIMS	00761	1981	-
pH	-	LIMS	00613	1981	-
Secci Depth	m	LIMS	91051	-	-
Turbidity	-	LIMS	00683	1988	-
River Flow	cumecs	EA	-	1981	1981
Effluent Flow	cumecs	AWS	-	-	-

* - Year long-term data is first available.

Appendix Four

River Nene Sites - Quarterly Phosphorus Concentrations:

Quarterly SRP Concentrations

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Duston Mill					0.97	0.53	0.12	0.57	1.08	1.01	0.41	0.62	3.24	1.92
Billing	0.20	0.19	0.18	0.19	2.36	0.28	0.13	0.21	0.20	0.45	0.19	0.17	0.25	0.66
Hardwater	0.47	0.48	0.45	0.81	1.79	0.90	0.30	1.75	2.84	2.21	0.83	1.80	1.98	3.25
Wellingborough	0.50	0.42	0.40	0.71	1.56	0.79	0.30	1.39	2.94	1.81	0.85	1.65	1.86	3.03
Ditchford	0.35	0.30	0.23	0.59	1.11	0.71	0.20	1.10	1.44	1.85	0.51	1.13	1.61	2.17
Irthlingborough	0.65	0.35	0.44	0.65	1.76	0.75	0.25	1.46	2.95	1.71	0.67	1.53	2.01	2.42
Thrapston	0.63	0.36	0.40	0.65	1.63	0.70	0.29	1.25	2.61	1.72	0.68	1.31	2.03	2.35
Elton	0.54	0.30	0.30	0.56	1.18	0.64	0.26	1.02	1.80	1.88	0.53	1.00	1.69	2.15
Wansford	0.57	0.32	0.31	0.52	1.19	0.55	0.24	0.83	1.39	1.66	0.51	0.98	1.52	1.98
Tributaries:														
St Andrews					0.28	0.18	0.86	0.22	0.47	0.38	0.18	0.31	0.45	0.53
R .Ise					0.20	0.10	0.07	0.58	171.00	0.17	0.07	0.08	0.13	0.20
Willow Brk. (Weldon)			1.55	0.76	0.92	1.08	0.64	2.60	3.39	3.23	3.34	4.10	1.90	2.34
Willow Brk. (Foth)			0.17	0.23	0.41	0.23	0.26	0.41	0.44	0.62	0.80	0.87	0.61	0.80

Quarterly TP Concentrations

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Arp-Jun	Jul-Sep	Oct-Dec
Main River:														
Duston Mill					1.26	0.68	0.28	0.63	1.37	1.02	0.49	0.68	1.44	2.14
Billing	0.28	0.27	0.27	0.32	0.32	0.33	0.20	0.30	0.34	0.52	0.29	0.22	0.26	0.70
Hardwater	0.60	0.66	0.65	0.88	2.10	1.15	0.41	1.95	3.07	2.05	1.18	1.90	2.01	2.88
Wellingborough	0.59	0.59	0.56	0.80	1.88	1.03	0.44	1.55	3.63	1.40	0.97	1.68	2.06	3.06
Ditchford	0.45	0.46	0.34	0.62	1.44	0.89	0.32	1.26	1.33	1.65	0.61	1.21	1.82	2.36
Irthlingborough	0.83	0.53	0.52	0.89	2.16	0.93	0.45	1.65	3.24	1.50	0.80	1.72	2.24	2.38
Thrapston	0.76	0.52	0.54	0.75	1.91	0.88	1.00	1.50	3.01	1.63	0.77	1.43	2.02	2.29
Elton	0.62	0.41	0.44	0.78	1.42	0.83	0.32	1.23	1.96	2.13	0.66	1.09	1.78	2.05
Wansford	0.70	0.45	0.42	0.59	1.47	0.69	0.48	1.03	1.57	1.60	0.62	1.05	1.54	2.10
Tributaries:														
St Andrews					0.63	0.25	0.21	0.29	0.60	0.45	0.23	0.36	0.54	0.53
R .Ise					0.26	0.13	0.10	0.51	0.25	0.21	0.13	0.31	0.21	0.19
Willow Brk. (Weldon)			2.03	1.37	1.79	1.31	0.83	2.94	4.04	3.71	3.73	4.04	2.56	1.96
Willow Brk. (Foth)			0.22	0.34	0.51	0.28	0.34	0.55	0.51	0.71	1.00	0.95	0.66	0.82

Quarterly PP Concentrations

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Duston Mill					0.19	0.15	0.15	0.06	0.29	0.01	0.08	0.10	0.66	1.37
Billing	0.09	0.08	0.08	0.13	0.08	0.05	0.06	0.09	0.15	0.07	0.11	0.09	0.01	0.08
Hardwater	0.16	0.18	0.08	0.11	0.31	0.25	0.11	0.19	0.24	0.27	0.16	0.10	1.02	0.18
Wellingborough	0.10	0.17	0.09	0.09	0.31	0.24	0.14	0.16	0.69	0.14	0.12	0.12	1.13	0.16
Ditchford	0.09	0.16	0.01	0.03	0.33	0.18	0.11	0.15	0.23	0.52	0.10	0.10	0.64	0.21
Irthlingborough	0.19	0.18	0.06	0.17	0.40	0.18	0.20	0.19	0.29	0.21	0.14	0.06	0.73	0.13
Thrapston	0.17	0.16	0.09	0.10	0.28	0.18	0.71	0.25	0.40	0.23	0.14	0.11	1.01	0.04
Elton	0.08	0.20	0.09	0.22	0.25	0.19	0.06	0.21	0.24	0.39	0.13	0.12	0.28	0.12
Wansford		0.08	0.08	0.13	0.20	0.15	0.24	0.20	0.11	0.19	0.11	0.12	0.40	0.67
Tributaries:														
St Andrews					0.15	0.06	0.12	0.07	0.13	0.07	0.05	0.12	0.09	0.04
R .Ise					0.06	0.03	0.04	0.45	0.08	0.04	0.64	0.28	0.11	0.02
Willow Brk. (Weldon)			0.47	0.60	0.87	0.23	0.19	0.34	0.66	0.48	0.54	0.28	1.74	0.55
Willow Brk. (Foth)			0.64	0.11	0.10	0.04	0.08	0.14	0.10	0.09	0.20	0.12	0.31	0.23

River Great Ouse Site - Quarterly Phosphorus Concentrations:

Quarterly SRP Concentrations

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Newport Pagnell	0.38	0.22	0.12	0.25	0.49	0.39	0.08	0.28	0.56	0.55	0.14	0.34	0.64	0.76
Tyringham	1.15	0.38	0.23	0.28	0.55	0.48	0.26	1.23	2.71	0.52	1.55	2.84	1.06	2.57
Sharnbrook	0.99	0.35	0.20	0.28	0.54	0.50	0.22	1.00	2.34	0.52	1.55	2.84	2.51	2.43
Newnham	0.90	0.28	0.20		0.55	0.52	0.23	0.82	1.73	1.77	0.47	1.16	2.19	2.25
Castle Mills	0.98	0.30	0.21		0.55	0.58	0.30	1.21	2.69	2.40	0.61	1.48	2.77	2.73
Roxton	0.85	0.30	0.20	0.18	0.54	0.49	0.24	1.06	1.95	2.10	0.57	1.53	2.52	2.51
Offord	1.05	0.39	0.20		0.18	0.83	0.67	0.29	0.96	2.11	0.64	1.38	2.23	2.53
Tributaries:														
Lovat Bank	1.16	0.53	0.39	0.51	0.91	0.60	0.31	0.82	1.48	1.43	0.45	1.23	1.99	1.90
Tempsford	1.55	0.64	0.47	0.78	1.26	1.11	0.49	1.00	1.57	1.48	0.78	1.55	2.25	2.16
Clifton	0.81	0.26	0.32	0.44	0.61	0.52	0.18	0.67	0.91	0.64	0.33	0.82	1.47	1.48
Langford	1.54	0.99	0.65	1.21	1.55	1.80	0.87	1.50	2.03	2.25	0.99	2.12	2.83	2.84

Quarterly TP Concentrations

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Newport Pagnell	0.43	0.36	0.19	0.29	0.63	0.46	0.16	0.47	0.68	1.22	0.26	0.36	0.71	0.74
Tyringham	1.28	0.47	0.32	0.34	0.82	0.54	0.40	1.66	2.71	1.69	0.66	1.49	3.06	2.72
Sharnbrook	1.23	0.43	0.67	0.33	0.80	0.60	0.36	1.39	2.40	1.57	0.68	1.20	2.71	2.40
Newnham	1.04	0.38	0.24		0.69	0.60	0.34	1.15	2.05	1.38	0.54	1.04	2.42	2.35
Castle Mills	1.11	0.38	0.26		0.71	0.82	0.42	1.58	2.95	2.27	0.75	1.50	2.89	2.95
Roxton	0.95	0.35	0.30	0.28	0.69	0.59	0.39	1.31	2.01	1.59	0.69	1.43	2.74	2.50
Offord	1.19	0.50	0.34	0.57	1.07	0.78	0.42	1.18	2.14	1.63	0.80	1.33	2.37	2.20
Tributaries:														
Lovat Bank	1.36	0.45	0.56	0.57	1.14	0.74	0.43	1.24	1.33	1.36	0.59	1.24	2.32	1.76
Tempsford	1.46	0.72	0.71	0.97	1.75	1.43	0.72	1.19	1.81	1.84	1.11	1.62	2.45	2.16
Clifton	1.06	0.57	0.51	0.75	1.02	0.72	0.39	1.11	1.64	1.12	0.99	1.24	1.86	3.11
Langford	1.89	1.17	0.85	1.34	2.25	2.31	1.07	1.72	2.42	1.97	1.26	2.21	3.18	2.87

Quarterly PP Concentrations

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Newport Pagnell	0.06	0.13	0.07	0.04	0.14	0.07	0.07	0.19	0.14	0.58	0.12	0.03	0.09	0.05
Tyringham	0.10	0.07	0.08	0.07	0.15	0.06	0.14	0.43	0.47	0.24	0.14	0.19	0.44	0.35
Sharnbrook	0.21	0.05	0.47	0.05	0.16	0.10	0.14	0.39	0.34	0.11	0.14	0.05	0.53	0.20
Newnham	0.08	0.08	0.03	0.06	0.14	0.08	0.11	0.32	0.32	0.05	0.15	0.29	0.33	0.31
Castle Mills	0.14	0.05	0.05		0.15	0.24	0.12	0.38	0.27	0.04	0.14	0.16	0.28	0.47
Roxton	0.10	0.05	0.10	0.10	0.15	0.10	0.15	0.25	0.20	0.16	0.12	0.29	0.56	0.17
Offord	0.13	0.08	0.08	0.21	0.27	0.11	0.13	0.23	0.25	0.08	0.16	0.34	0.69	0.52
Tributaries:														
Lovat Bank	0.18	0.11	0.15	0.06	0.23	0.14	0.12	0.42	0.13	0.02	0.14	0.15	0.27	0.10
Tempsford	0.18	0.16	0.21	0.19	0.49	0.33	0.22	0.19	0.24	0.49	0.33	0.19	0.47	0.06
Clifton	0.25	0.29	0.29	0.31	0.42	0.20	0.22	0.45	0.72	0.58	0.56	0.41	0.49	1.62
Langford	0.20	0.11	0.12	0.13	0.70	0.51	0.19	0.22	0.39	0.21	0.27	0.27	0.29	0.27

River Nene Sites - Quarterly Phosphorus Loads:

Quarterly SRP Loadings

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Duston Mill					37.1	36.3	22.6	38.5	33.6	37.4	44.6	33.6	108.9	113.9
Billing	25.1	83.7	98.4	50.6	21.0	45.1	48.8	19.1	9.2	42.9	42.4	23.5	18.6	68.2
Hardwater	87.8	244.7	273.1	235.5	247.0	173.8	106.3	242.8	273.5	297.2	275.0	311.4	273.0	499.3
Wellingborough	101.4	255.7	421.1	223.9	231.5	171.1	120.9	220.7	264.7	267.8	272.8	317.2	272.7	515.6
Ditchford	90.3	156.2	204.7	193.8	211.0	205.3	144.7	227.5	194.7	268.5	252.8	260.6	279.3	470.5
Irthlingborough	202.6	314.4	471.0	246.3	409.9	289.7	222.5	341.8	454.7	396.4	353.4	355.4	444.6	655.7
Thrapston	202.6	362.0	640.8	313.2	386.2	305.9	263.2	311.7	441.3	437.5	377.6	412.7	482.9	697.6
Elton	207.8	403.2	657.4	332.8	337.2	366.0	309.3	310.7	319.4	603.2	366.7	373.5	453.4	733.3
Wansford	267.7	476.4	436.6	319.4	359.5	312.1	354.3	353.5	233.5	575.1	369.4	369.0	395.6	706.4
Tributaries:														
St Andrews					13.9	9.8	9.2	2.0	4.4	12.2	17.1	13.8	13.1	23.1
R .Ise					4.6	12.1	20.8	2.0	2.1	6.0	7.1	2.4	2.3	7.5
Willow Brk. (Weldon)			33.2	12.9	14.2	16.2	15.5	38.0	65.4	60.9	51.0	55.8	28.2	47.5
Willow Brk. (Foth)			18.4	15.3	16.3	17.4	35.6	19.9	15.3	7.0	47.0	39.7	21.9	42.4

Quarterly TP Loadings

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Duston Mill					47.1	44.6	48.3	43.1	42.4	39.9	55.0	36.5	52.7	146.9
Billing	35.0	148.0	157.1	76.8	27.9	53.3	73.6	26.6	15.8	50.2	69.5	32.5	19.5	62.7
Hardwater	115.5	377.9	332.8	263.7	291.2	230.3	149.6	271.6	295.0	301.6	337.8	329.7	261.8	472.2
Wellingborough	121.6	392.8	347.5	249.8	278.9	231.2	189.5	213.2	328.6	255.9	314.9	323.4	285.6	609.1
Ditchford	127.3	275.2	294.5	208.2	273.1	277.5	247.7	263.0	157.0	326.6	301.6	278.9	296.2	582.5
Irthlingborough	259.5	542.0	534.0	300.7	506.2	376.2	440.5	378.4	508.8	391.2	425.5	484.8	471.7	773.1
Thrapston	244.5	589.4	572.3	361.2	455.6	401.4	1234.6	373.0	508.0	461.3	451.2	448.1	458.0	832.1
Elton	243.4	870.0	548.7	466.3	410.5	474.5	394.1	374.1	369.0	752.6	473.6	408.7	453.4	982.8
Wansford	296.8	745.7	454.5	378.0	423.5	442.7	921.4	442.7	249.7	552.4	455.6	400.7	398.4	850.0
Tributaries:														
St Andrews					18.3	13.5	24.0	2.6	8.0	14.4	22.8	18.1	15.7	28.7
R .Ise					6.4	15.5	30.8	9.5	3.1	7.8	13.3	9.1	3.6	10.8
Willow Brk. (Weldon)			39.5	22.7	27.2	19.4	20.7	42.9	77.5	70.8	66.1	53.8	37.9	42.6
Willow Brk. (Foth)			23.0	22.3	20.6	20.5	46.2	26.1	18.4	7.4	58.6	43.3	22.7	36.6

Quarterly PP Loadings

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Duston Mill					7.2	12.8	25.7	4.5	8.8	5.5	10.4	3.3	9.7	85.0
Billing	9.9	96.5	58.7	26.2	7.0	8.2	24.8	7.5	6.6	7.3	27.1	10.5	1.2	7.1
Hardwater	28.8	133.3	48.3	42.6	44.2	57.1	43.6	28.7	21.5	38.2	55.1	18.2	125.3	32.9
Wellingborough	22.9	137.0	55.8	26.0	47.5	60.0	68.6	24.1	64.0	27.3	42.1	11.5	149.3	39.3
Ditchford	37.0	119.0	89.8	14.4	62.1	72.1	103.0	35.5	24.7	92.4	48.8	18.8	62.4	44.1
Irthlingborough	56.9	227.6	118.4	63.5	96.3	86.5	217.9	36.6	54.1	53.5	72.1	14.1	138.3	53.8
Thrapston	56.7	227.4	79.7	48.0	69.4	95.4	971.3	61.3	66.8	61.7	83.8	35.4	52.3	39.2
Elton	30.9	422.6	122.3	133.5	73.3	108.5	84.8	63.4	49.6	137.9	106.9	37.7	75.5	69.7
Wansford	55.6	374.6	111.3	81.2	58.6	121.2	567.1	88.7	16.2	63.0	86.2	35.3	161.7	292.4
Tributaries:														
St Andrews					4.4	3.7	14.8	0.6	2.1	2.2	5.7	4.4	2.6	3.8
R .Ise					1.8	3.4	10.0	7.5	1.0	1.8	6.2	6.6	1.9	1.2
Willow Brk. (Weldon)			9.2	9.8	12.9	3.3	5.2	5.0	12.2	10.0	8.2	0.3	2.6	11.6
Willow Brk. (Foth)			6.9	6.9	4.3	3.6	10.6	6.8	3.5	0.6	11.6	3.7	10.2	12.5

River Great Ouse Sites - Quarterly Phosphorus Loads:

Quarterly SRP Loadings

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Newport Pagnell	46.4	127.4	111.8	67.1	55.1	75.5	80.4	49.7	38.1	143.4	129.0	59.0	51.9	75.66
Tyringham	283.8	368.7	300.0	149.9	165.0	205.9	347.3	388.6	733.0	884.8	950.4	459.7		
Sharnbrook	235.2	316.1	275.4				427.0				876.1	473.9	537.2	
Newnham	259.3	349.0	277.8	161.1	142.2	316.8	375.6	327.2	370.6	709.6	473.9	345.0	415.1	619.64
Castle Mills	281.7	361.4	281.0	150.5	146.1	498.4	469.3	542.4	898.2	916.6	528.4	522.0	522.0	723.41
Roxton Lock	272.8	312.6	310.4	163.6	164.4	390.0	496.9	472.1	417.9	860.5	1043.4	512.3	541.3	751.93
Offord	565.2	745.2	682.4	342.1	353.9	608.3	595.5	634.0	727.8	1432.4	1757.3	651.1	428.1	617.24
Tributaries:														
Lovat Bank	106.8	179.8	137.0	75.7	69.6	64.0	153.6	77.9	78.8	230.3	155.7	107.2	107.2	
Tempsford	272.7	263.0	211.1	186.6	171.3	172.2	184.5	176.9	152.5	301.8	329.0	213.0	195.6	226.75
Clifton														
Langford														

Quarterly TP Loadings

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Newport Pagnell	53.1	158.5	147.3	76.0	71.5	95.2	147.3	81.0	47.8	332.3	368.9	62.8	57.5	80.32
Tyringham	310.9	383.9	366.2	167.2	200.1	229.2	597.2	543.8	896.3	1795.5	1398.1	408.6		
Sharnbrook	320.2	302.3	411.1				585.5				1452.0	389.8	576.3	
Newnham	256.2	221.9	322.2	202.3	178.2	359.5	586.3	441.6	429.8	582.5	907.8	335.2	460.1	659.54
Castle Mills	316.5	231.7	363.1	196.7	188.2	500.5	726.8	606.0	599.7	768.3	1246.5	488.1	548.9	844.88
Roxton Lock	303.1	368.2	478.0	231.6	208.3	464.3	779.9	570.1	472.5		1331.6	547.3	591.0	828.08
Offord	630.1	777.3	730.0	411.3	525.1	720.5	908.7	769.2	832.8	1083.6	2390.0	717.8	471.5	690.99
Tributaries:														
Lovat Bank	0.0	0.0	164.0	84.1	90.6	79.0	205.4	114.1	79.4	792.9	228.5	99.8	116.5	
Tempsford	226.5	265.6	283.2	232.2	240.5	220.5	288.5	211.9	175.2	703.2	499.0	204.7	310.8	232.10
Clifton														
Langford														

Quarterly PP Loadings

	1993		1994				1995				1996			
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Main River:														
Newport Pagnell	8.7	63.8	56.3	8.9	16.4	19.8	66.9	31.3	9.4	175.0	239.9	4.3	7.3	7.67
Tyringham	28.5	60.9	112.3	37.4	35.1	20.8	231.4	146.9	153.1	843.2	497.7	30.8		
Sharnbrook	64.4	40.2	104.2				158.5				43.6		103.0	
Newnham	21.5	39.2	44.5	41.2	36.0	42.7	210.7	114.4	59.3	34.6	433.9	64.2	52.0	94.18
Castle Mills	34.8	38.9	82.0	46.2	42.1	134.2	228.5	136.8	57.4	112.5	329.9	45.9	36.8	121.74
Roxton Lock	34.0	53.6	167.6	68.0	43.9	74.3	283.1	98.0	39.9	214.1	288.3	127.7	61.4	133.54
Offord	66.9	117.7	177.7	182.8	145.3	112.4	313.3	135.2	104.9	130.9	632.7	177.1	195.7	218.33
Tributaries:														
Lovat Bank	0.0	0.0	44.2	8.4	21.0	15.1	51.7	36.2	8.9	736.3	72.8	8.5	14.9	
Tempsford	29.0	51.9	83.7	45.7	69.2	48.3	104.1	34.9	22.7	350.6	170.0	19.0	36.9	11.77
Clifton														
Langford														