Investigating the Effectiveness of NVZ Action Programme Measures: Development of a Strategy for England

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Report by CEH and University of Plymouth

The Taw River Catchment and Estuary: A case study for the effects of NVZ measures

Part 1 – The Freshwater Catchment

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Executive Summary

The estuary of the River Taw and its freshwater catchment has been designated as an NVZ on the basis that its estuary is eutrophic. A small part of the catchment drained by the Ashmill Stream has a second designation because it has nitrate concentrations that exceed those set down in the drinking water directive. The Taw estuary catchment covers 1126 km^2 and is drained by seven rivers, the Taw, the Caen, the Venn, the Knowle Water, the Bradiford Water, the Langham and the Yeo (Barnstaple) of which the River Taw is by far the largest draining 77% of this area.

The aim of this work was to use this catchment as a case study to assess the potential effects of NVZ measures on the eutrophic status of the freshwater streams and the loads of nutrient being delivered to the Estuary.

Three main data sources were used for this assessment:

1. Concentrations of nutrients (nitrogen species and ortho-phosphate) and other determinands measured as part of the General Quality Assessment (GQA) programme of the Environment Agency of England and Wales (the Agency).
2. Mean daily flow data provided by the National River Flow Archive (CEH) for four river gauging stations within the freshwater river system of the Taw;
3. Total N loads and total N concentrations derived from the ADAS NEAP-N model run under "prior practice" and under agricultural practice described by the NVZ current action programme measures.

These data were used for several analyses which were designed firstly to estimate loads to the estuary under current practice and under NVZ measures for input to the work of the University of Plymouth. And secondly to assess the eutrophic status of the rivers in the Taw catchment and the effect the NVZ measures might have on this status. The analyses were:

- An assessment of the spatial distribution of nitrate and ortho-phosphorous concentrations across the catchments.
- Estimation of annual and monthly total nitrogen (sum of nitrate, nitrite and ammonium) and ortho-phosphate loads discharged to the estuary through each of the 7 rivers in the catchment.
- Estimation of annual loads of total nitrogen in the headwater catchments of the Taw (those not influenced by sewage treatment works effluents).
- A comparison between the NEAP-N model output run under "prior practice" and the loads calculated from the observed data.
- Estimates of point source loads to the estuary calculated in a previous study were used to estimate the relative importance of point and diffuse source loads.
- The estimated change in nitrate concentrations and annual loads in the seven rivers was estimated based on the outputs of the NEAP-N model run under NVZ ("Action Programme") rules.

In making an assessment of the ecological response of the Taw system to the "action programme", best estimates of limiting nutrient concentrations would be in the order of 5 mg/L N and 0.3 mg/L P; a ratio of 16.67:1 N:P. These are substantially higher than the figures for static waters and are based on the interaction of flow, residence time, nutrient status and ecological variables already in place.

It should be emphasised that, especially in the upper reaches of the Taw, that eutrophication is not obvious from the aquatic macrophyte community. The rapid flow in the very upper catchment even with a mean N of 12.6 mg/L does not permit the development of eutrophic macrophyte species, but a future assessment of the epilithic diatom community may indicate nutrient enrichment. The combination of flow and geology are the dominant factors in determining the plant and diatom community in the lower reaches of the Taw system. Currently, the plant communities observed in the system are not representative of eutrophic conditions.

The predicted 10% reduction in N and 5% reduction in P, while not reaching the limiting nutrient values, will contribute to an increase in ecological stability of the system. Systems that operate near the trigger values for eutrophic ecological responses tend to have episodes of excessive plant biomass, occupation of space and hyper-accumulation of nutrients more often than systems with lower nutrient loadings. The consequences of this for the Taw would only be damaging, if flows were to reduce significantly in future.

In summary, it is unlikely that AP measures will have a significant impact on existing plant and diatom communities present in the river Taw, as the communities probably do not indicate eutrophic conditions at present. However, reductions in nutrient loading will probably contribute to a reduction in estuarine nutrient loadings, and the ecological response in the estuary may be more significant than that in the river.

Contents

1. Introduction

The Nitrates Directive (91/676/EEC) is designed to protect waters against nitrate pollution from agricultural sources. Waters have been identified as being impacted by agricultural activities according to specific criteria established by the Secretary of State for the Department for Environment, Food and Rural Affairs (Defra). These are[1]:

a. Surface freshwaters, including those used or intended for the abstraction of drinking water which contain, or could contain if protective action is not taken, more than the concentration of nitrates laid down in accordance with The Drinking Water Directive (75/440/EEC);
b. Groundwaters which contain, or could contain if protective action is not taken, more than 50 mg/L (11.3 mg/L nitrate-N) of nitrate;
c. Natural freshwater lakes, other freshwater bodies, estuaries, coastal waters and marine waters which are eutrophic or may become so in the near future if protective action is not taken.

Following the identification of these waters, all known areas of land which drain into them have been identified for designation as NVZs. Farmers working land within designated NVZs are required to comply with an action programme to control fertilizer and manure use[2].

The estuary of the River Taw and its freshwater catchment has been designated as an NVZ on the basis that the Estuary is eutrophic (criterion c above). A small part of the catchment drained by the Ashmill Stream has a second designation because it has nitrate concentrations that exceed those set down in the drinking water directive (citerion a). This report used this catchment as a case study to assess the potential effects of NVZ measures on the eutrophic status of the freshwater streams and the loads of nutrient being delivered to the Estuary.

Three main data sources are used for this assessment:

4. Concentrations of nitrogen species (nitrate, nitrite and ammonia) and other determinands measured as part of the General Quality Assessment (GQA) programme of the Environment Agency of England and Wales (the Agency). Data for the period 1990-2000 inclusive were used to provide a measure of the baseline water quality under agricultural practice prior to implementation of the NVZ action plan ("prior practice");
5. Mean daily flow data provided by the National River Flow Archive for four river gauging stations within the freshwater river system of the Taw;
6. Total N loads and Total N concentrations derived from the ADAS NEAP-N model run under "prior practice" and under agricultural practice described by the NVZ current action programme measures. These data were supplied to CEH for a number of selected catchments and sub-catchments (described more fully later).

[1] Taken from: Description of the methodology applied by the Secretary of State in identifying additional Nitrate Vulnerable Zones in England (2002), Defra, Water Quality Division, October 2002.
[2] Guidelines for Farmers in NVZs – England, Defra.http://www.defra.gov.uk/corporate/regulat/forms/agri_env/nvz/nvz4.pdf

2. Description of the Taw River Catchment

The Taw estuary catchment covers 1126 km^2 and is drained by seven rivers, the Taw, the Caen, the Venn, the Knowle Water, the Bradiford Water, the Langham and the Yeo (Barnstaple) of which the River Taw is by far the largest draining 77% of this area (Figure 2.1). The mean annual rainfall in the River Taw catchment (1958 - 2000) above the most downstream gauging station is 1180 mm of which 705 mm leaves the catchment in runoff.

The catchment area land cover is grassland (59%), arable (14%), woodland and forest (12%), rough grassland (9%), urban development (5%) and open water (1%). The main arable crops are winter wheat (21% of arable area), winter barley (20%), spring barley (15%) and maize (9%). The grazed area is stocked with cattle (1.7 animals/ha), sheep (3.2 animals/ha) and lambs (3.2 animals/ha). The main housed animals are chickens and other poultry (15.6 animals/ha)[3].

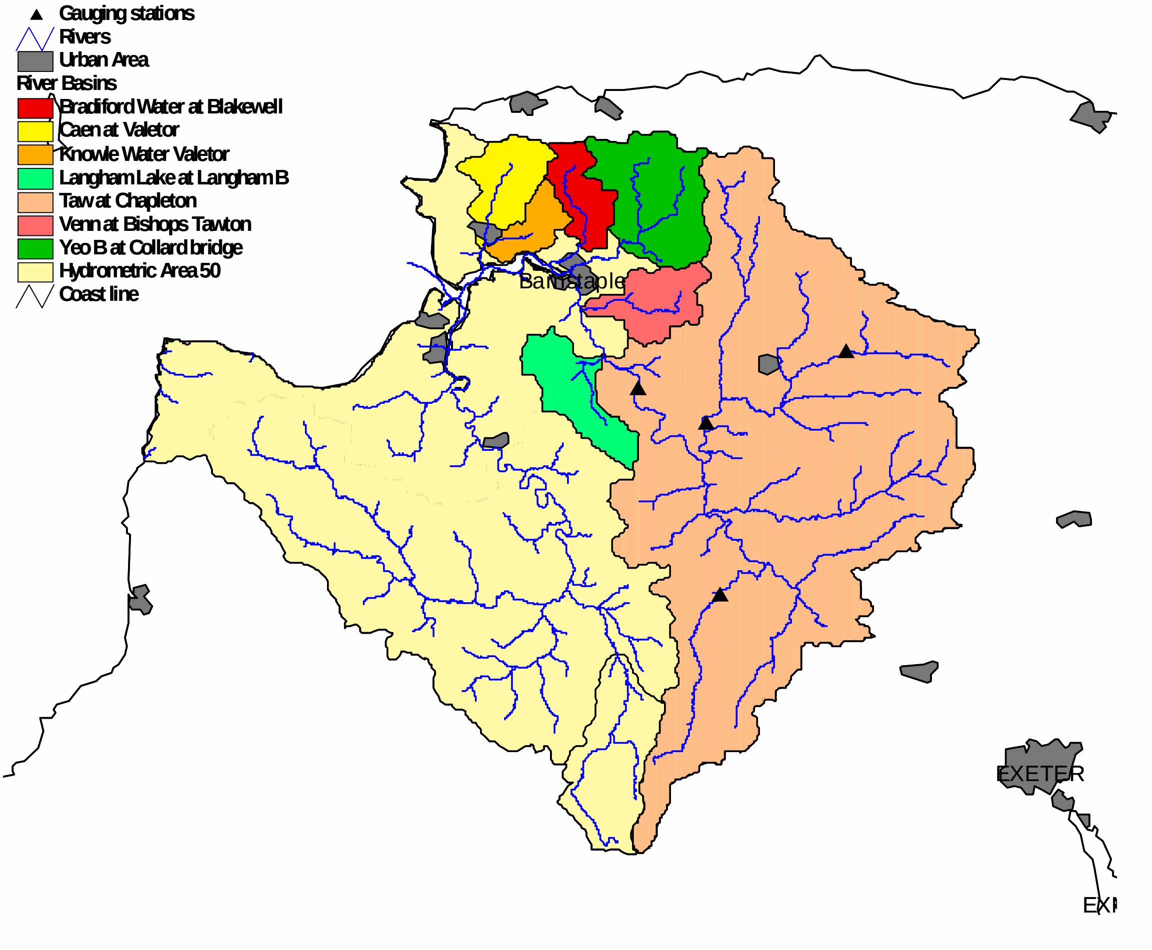

Figure 2.1 **Main rivers and their catchments draining to the Taw Estuary. The River system to the west is the River Torridge**

The majority of the urban development is concentrated around the Taw/Torridge Estuary with only small towns and villages scatter through the catchment. The number of and size of major sewage treatment works (STW) in the Taw catchment is therefore small (Table 2.1) and

[3] Land use and stocking data provided by ADAS

on an annual basis the contribution of STW effluent to nutrient loads in the catchment would be expected to be small.

Table 2.1 Main Sewage Treatment works in the River Taw Catchment

Sewage Treatment Works Name	National Grid Reference	Population Equivalent
High Bickington	SS5910020200	151
Chittlehampton	SS6350025200	110
Burrington	SS6350016700	No data
Belstone And South Tawton	SX6470094800	404
North Tawton	SS6567001880	220
Bow	SS7160002100	272
Lapford	SS7400007900	260
Morchard Bishop	SS7650007600	110
Chulmleigh	SS6872013870	136
Witheridge	SS7940014800	245
South Molton	SS7230025600	1299
North Molton	SS7450029600	132
Bishops Nympton	SS7590023500	162

A previous study using data from 1994 to 1996 showed this to be the case for most of the year, but concluded that point source discharges were an important part of the load in the summer months (Jonas, 1997). Table 2.2 shows the figure calculated by Jonas (1997) by season for the rivers discharging into the Taw estuary (Jonas grouped some of the rivers that are treated separately in the rest of this report).

Table 2.2 Estimated percentage contribution of point source to total inorganic nitrogen loads to the Taw estuary (data from Jonas, 1997).

River Name	Winter	Spring	Summer	Autumn[1]
River Taw	0.7 – 0.9	2.9 – 7.1	82 – 100	2.6 – 93
Bradiford Water	0.7 – 1.2	1.9 – 3.6	18 – 36	1.9 – 32
Knowle Water and River Caen	0.2 – 0.5	0.8 – 2.4	14 – 29	1.0 – 25
River Yeo	0.8 – 1.4	2.1 – 4.1	28 – 44	6.5 – 48
River Venn	0.5 – 0.8	1.4 – 3.2	26 – 53	1.3 – 70

[1] Calculated for 1996 using September data only

Point sources were found to be most significant for the River Taw and much less so for the other rivers. However, it is worth noting that summer flows were particularly low during 1994-1995 compared to the longer period 1990-2000 considered in this report (Figure 2.2). Under low flow condition diffuse pollution loads are at their lowest and point sources will therefore increase in importance.

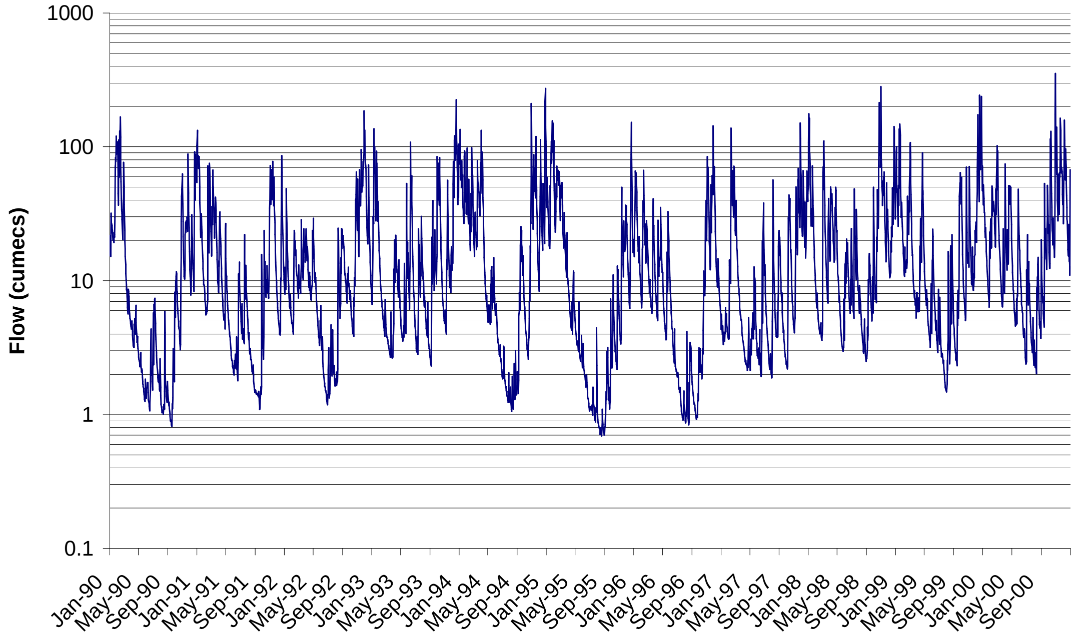

Figure 2.2 Gauged daily flows (log scale) for the River Taw at Umberleigh (most down stream flow gauge)

3. Methods

3.1 LOAD ESTIMATION

Loads were calculated from the routine agency chemistry data and the daily flow data using the method 5 from Littlewood *et al.* (1998). The annual load of the chemical of interest, L is given by:

$$L = L_2 \left(\frac{n}{\sum_{i=1}^{n} Q_i} \right) \left(\frac{\sum_{k=1}^{N} Q_k}{N} \right)$$

Equation 1

where n is the number of samples, Q_i represents the flow on the day of sampling, N is the number of daily mean flows, Q_k is the mean daily flow on the kth day of the year and L_2 (the mean of the instantaneous loads on each sampling day) is given by:

$$L_2 = K \left(\frac{\sum_{i=1}^{n} (Q_i C_i)}{n} \right)$$

Equation 2

where C_i is the concentration of the sample on the ith day and K is a factor which converts the mass load into appropriate units. Usually C_i is in mg/L and Q is in m^3/s in which case K takes the value 24 x 3600 x N (the number seconds in an N day year).

In most cases the flow data were not available at the water quality sampling point at which the load estimation was to be made. The flow data from the nearest most appropriate gauging station was therefore scaled using the ratio of the mean natural flow at the sampling site of interest to the mean natural flow at the gauging site. The mean flows at the two sites were estimated using the LowFlow2000 software.

Load estimations were made separately for ammonium, nitrite and nitrate and summed to give total inorganic nitrogen. In most cases the concentrations of these three nitrogen species were above the detection limit for the analytical methods used. However, where the values were reported at less than the detection limit a value of half the detection limit was used in the load calculation.

3.2 LOCATIONS FOR LOAD ESTIMATES

Loads were estimated at two types of sites (1) At the most downstream sampling site within each river basin discharging to the Taw Estuary (see figure 2.1) and (2) At the most upstream sampling point on minor tributaries of the these rivers (see figure 3.1). This allowed estimates to be made of nitrogen losses from the most rural areas monitored by the Agency, which was assumed to represent losses from agricultural land. Load estimates from the tidal limits allowed an estimate of nutrient loads from all sources for each river catchment including sewage treatment works (STW) effluents.

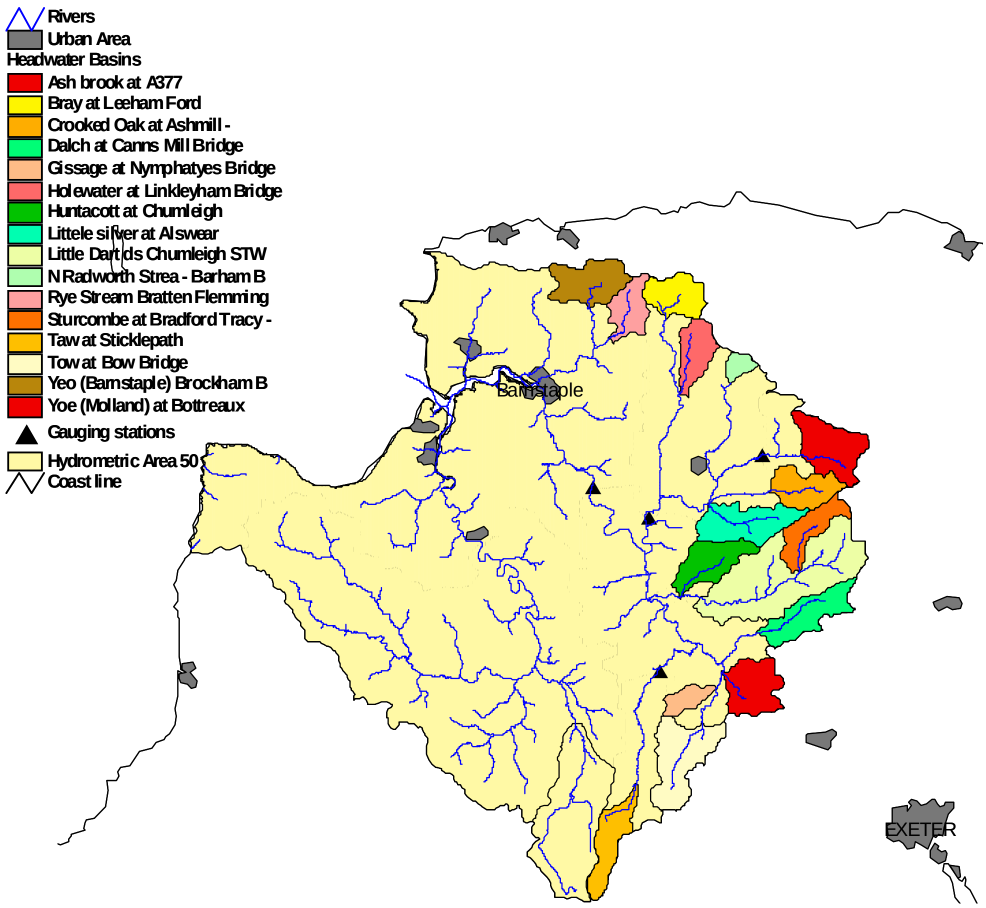

Figure 3.1 **Location of the headwater basins for which load estimates of nitrogen species have been made from observed data and model output (NEAP-N).**

4. Results and Discussion

4.1 NITRATE AND PHOSPHORUS CONCENTRATIONS FROM AGENCY DATA 1990-2000

The key nutrients that determine eutrophication in rivers and Estuaries are nitrogen and phosphorus (see reviews of eutrophication in Rivers and Estuaries for details). For surface waters to be classified as NVZs the 95th percentile nitrate concentration must exceed 11.3 mg as NO_3^--N/L (50 mg NO_3^-/L). Figure 4.1 shows the distribution of the 95th percentile nitrate concentrations through selected river stretches in the Taw catchment.

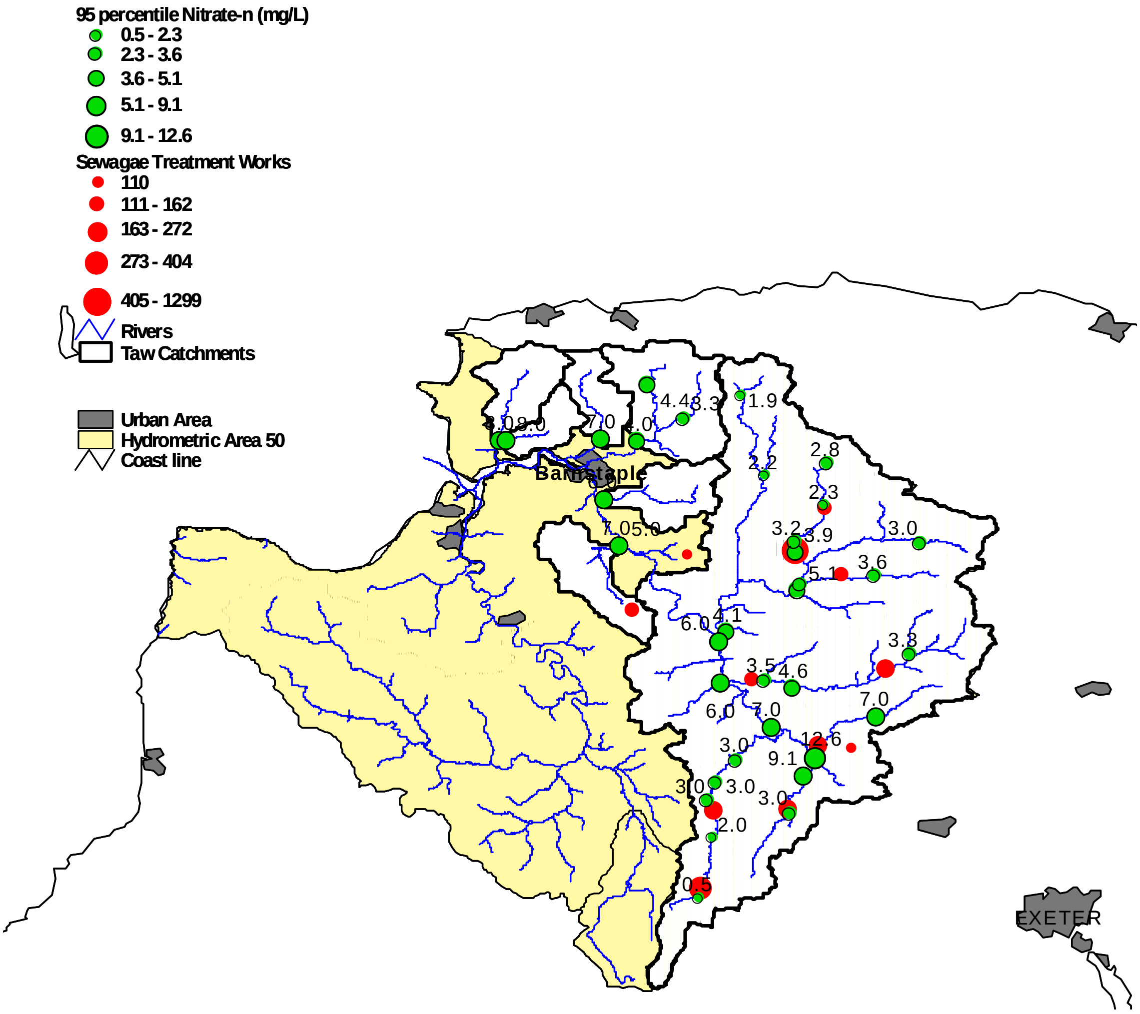

Figure 4.1 95th percentile nitrate-N concentrations (mg/L) derived from the Environment Agency data for the period 1990-2000

As expected, only at one sampling location did the 95th percentile nitrate (as N) concentration exceed 11.3 mg/L. This location is the Ashmill stream just below the A377, which coincides with the downstream limit of the small surface water NVZ (as described above).

Phosphorus exists in several different forms. Ortho-phosphate (ortho-P) is measured by the Environment Agency and is a measure of the biologically available dissolved phosphorus, the form that will contribute to eutrophication. Figure 4.2 shows the 95th percentile concentrations of ortho-phosphate in the River Taw and it tributaries.

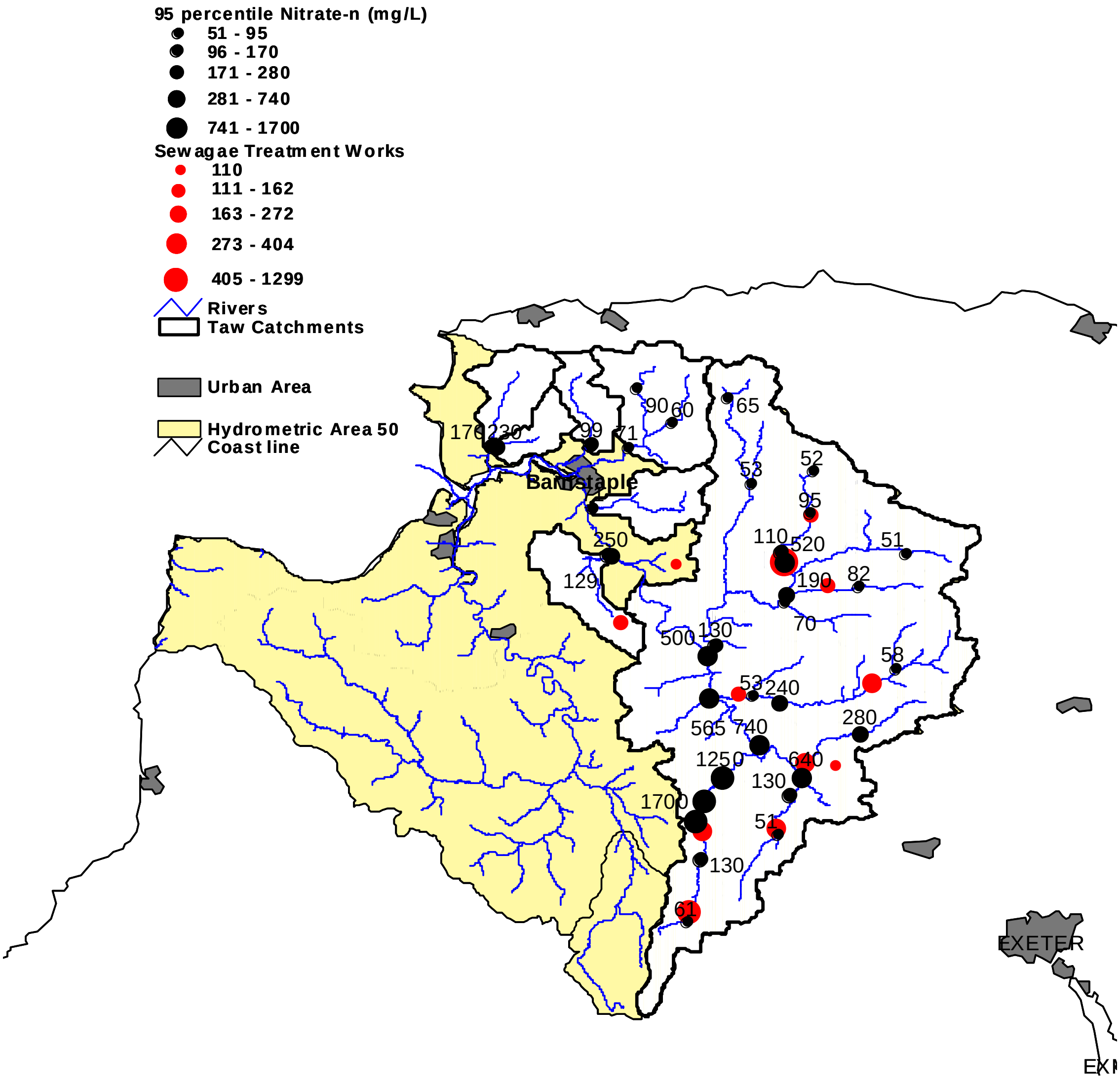

Figure 4.2. **95th percentile ortho-P concentrations (mg/L) derived from the Environment Agency data for the period 1990-2000**

The ortho-P concentrations show a wide range of values from a few tens of micro-grammes per litre to several thousand. The highest concentrations occur in the headwaters of the River Taw gradually reducing along its length from 1700 µg/L down to 250 µg/L at the tidal limit. The reduction in concentration is likely to be caused by mixing with tributaries of low ortho-P concentrations (see Figure 4.2) and perhaps through sorption to the river bed sediments (Jarvie *et al.*, 2005).

The 95th percentile does not show the temporal nature of the concentrations measured at the sampling point. Figure 4.3 shows the time course of nitrate-N and ortho-P concentrations at the lowest sampling point on the River Taw at Chapletown. It is clear that there is a seasonal signal for both Nitrate and ortho-P. Nitrate shows peak concentrations in the winter as summer mineralized nitrate is flushed from the soils during re-wetting and runoff processes and drainage flow paths are re-established. The ortho-P on the other hand shows peak values in summer, which is consistent with low summer flows providing less volume for dilution of point source discharges.

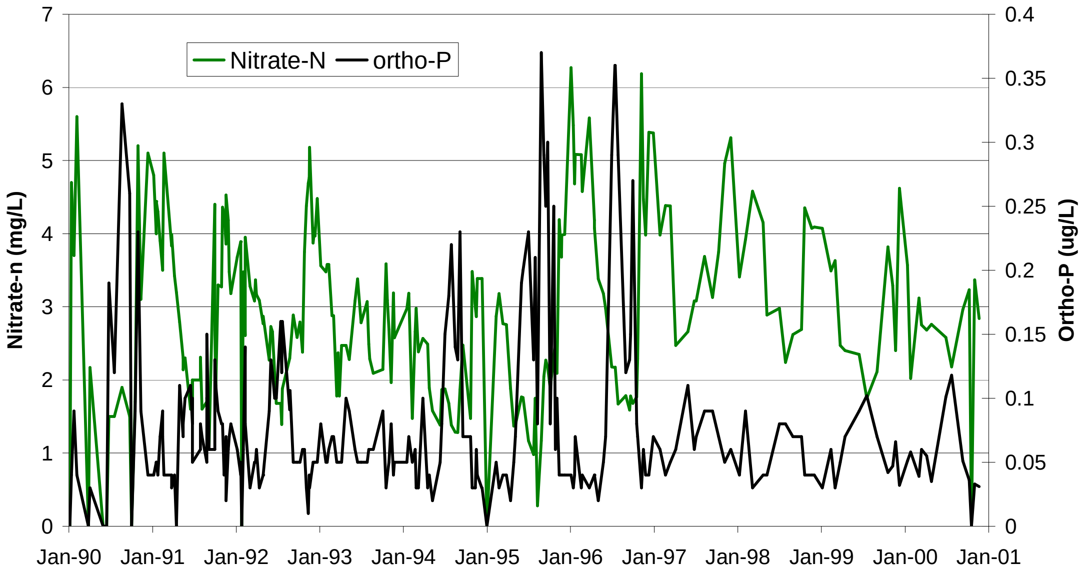

Figure 4.3 **Time course of nitrate-N and ortho-P concentrations for the River Taw at Chalpleton Foot Bridge**

The plot of nitrate-N concentration against flow for the River Taw at Chapleton shows nitrate-N generally increasing with flow, although there is a great deal of scatter (Figure 4.4). The same plot for ortho-P (Figure 4.5) shows the opposite trend with the highest concentrations occurring at the lowest flows. This confirms the different sources of nitrate-N and ortho-P within the catchment. Nitrate-N is clearly dominated by diffuse, agricultural runoff whereas ortho-P is likely to be from both diffuse and point sources, with point source loads dominating in the summer months. Recent research has shown that even in rural catchments ortho-Phosphate concentrations under low flow conditions (those critical for eutrophication to occur) are mainly sourced from point sources (Jarvie *et al.*, 2006). It is therefore not surprising that the River Taw should conform to this pattern.

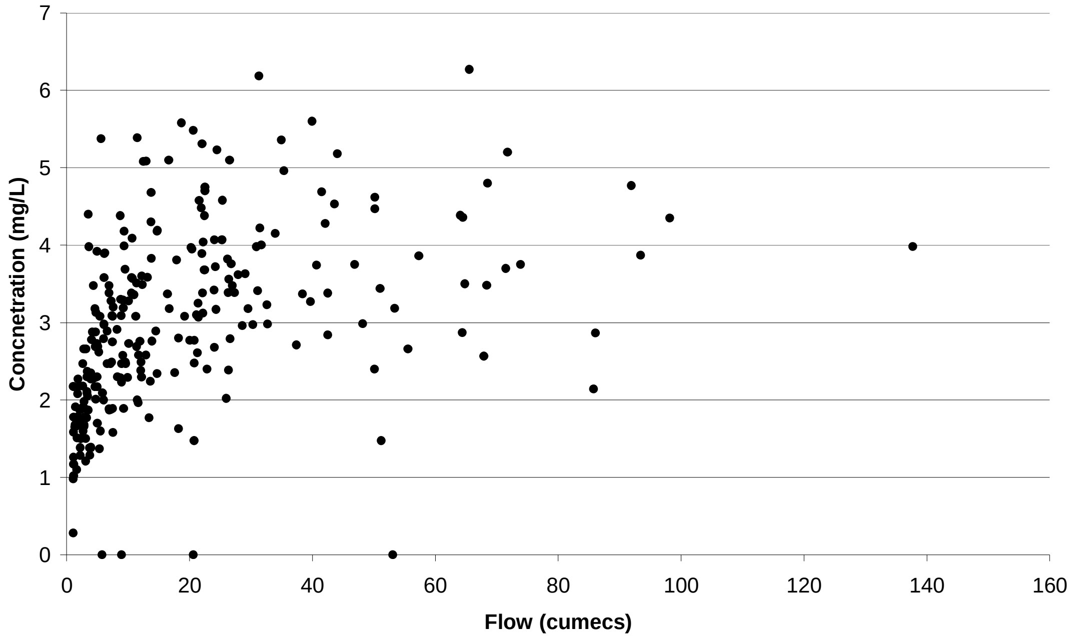

Figure 4.4 **Nitrate-N concentrations against flow for the River Taw at Chapleton Footbridge**

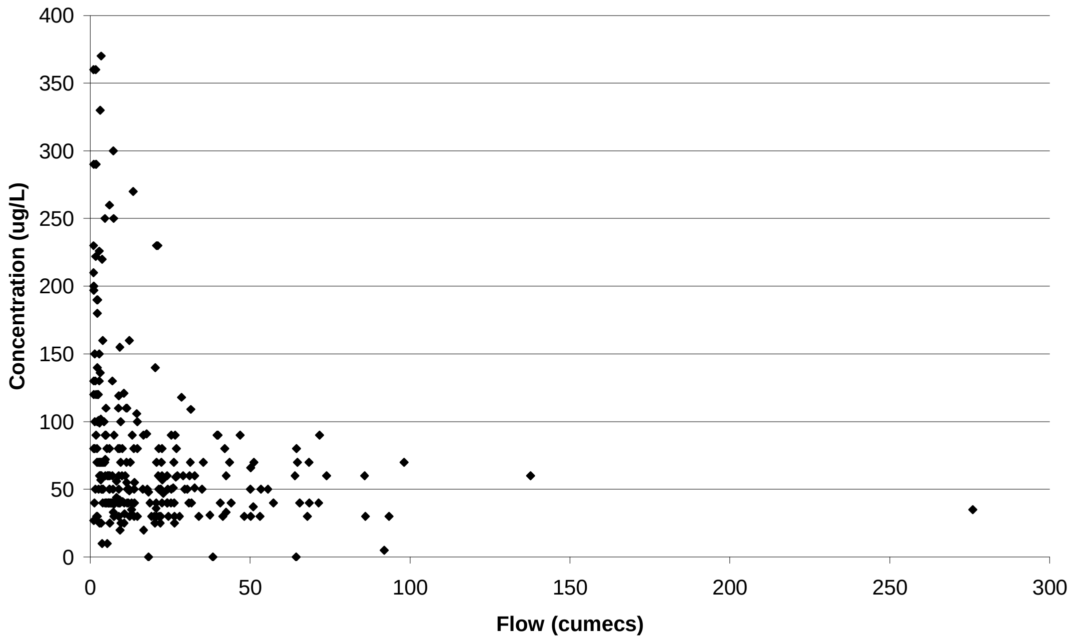

Figure 4.5 **ortho-P concentrations against flow for the River Taw at Chapleton Footbridge**

4.2 LOAD ESTIMATIONS FROM AGENCY DATA 1990-2000

4.2.1 Annual Loads Nitrogen

Annual loads were estimated for total inorganic nitrogen (TN) for the 7 rivers that discharged into the Taw Estuary using the methods described above. These annual loads were then combined to give an estimate of the annual average load over the period 1990-2000 (Table 4.1). The River Taw contributed around 73% of the average load of TN but had the lowest load per hectare (24.7 kg/ha). The highest load per hectare was for the River Caen which lost 38.3 kg/ha.

Table 4.1 Annual average loads (1990-2000) of total inorganic nitrogen entering the Taw Estuary from each of the seven major tributaries

Site Name	Area (km^2)	Mass load (tonnes/year)	SE[1]	kg/ha	SE[1]
River Caen at Valetor Bridge	39.9	153.0	12.7	38.3	3.2
Knowle Water at Velator	21.5	77.4	6.5	36.0	3.0
Bradiford Water at Blakewell	30.5	115.0	9.0	37.7	2.9
Venn at Bishops Tawton	39.2	96.9	6.8	24.7	1.7
River Taw at Chapleton	869.7	2146.0	118.0	24.7	1.4
Langham Lake at Langham Bridge	45.7	125.0	9.0	27.4	2.0
River Yeo Barnstaple at Collard Bridge	79.4	238.0	15.3	30.0	1.9

[1] Standard Error

TN loads were also calculated for a number of headwater catchments (Table 4.2). Theses catchments are mostly about a few tens of kilometres square although the biggest is 100 km^2 and the smallest only 3.3 km^2. The specific loads were also generally around a few kg/ha, but Ash Brook was notably high at 211.8 kg/ha. This catchment is the only part of the Taw that is designated as a surface water NVZ, so this observation is not that surprising. The headwaters of the River Taw at stickle path had a notably low specific load of only 5.9 kg/ha.

Table 4.2 Annual average loads (1990-2000) of total inorganic nitrogen leaving selected headwaters in the Taw Estuary freshwater catchment (see figure 3.1 for catchment locations).

Site Name	Area (km2)	Mass load (tonnes/year)	SE[1]	kg/ha	SE[1]
River Taw - Sticklepath	21.8	12.8	2.1	5.9	1.0
River Yeo - Bow Bridge	35.9	81.5	4.7	22.7	1.3
River Dalch - Canns Mill Bridge	24.5	62.3	4.2	25.4	1.7
Gissage lake - Nymphayes Bridge	8.7	21.8	1.4	25.1	1.6
Little Dart - d/s Chawleigh STW	100.0	177.0	12.0	17.7	1.2
Huntacott Water - Chumleigh	22.4	29.6	1.6	13.2	0.7
Sturcombe River - Bradford Tracy	18.7	25.2	1.6	13.5	0.9
Little Silver Stream - Alswear	28.8	58.3	5.0	20.2	1.7
Crooked Oak - Ashmill	19.9	36.7	2.9	18.4	1.5
River Yeo (Molland) - Bottreaux Bridge	28.7	60.1	3.4	20.9	1.2
River Bray - Leeham Ford	19.2	32.3	2.3	16.8	1.2
River Holewater - Linkleyham Bridge	17.6	35.6	2.2	20.2	1.3
River Yeo (Barnstaple) - Brockham Bridge	25.1	85.4	6.2	34.0	2.5
Rye Stream - Bratten Flemming	16.7	39.6	2.7	23.7	1.6

Ash Brook - A377	24.5	519.0	21.6	211.8	8.8
North Radworthy Stream – Barham Bridge	3.3	16.1	1.1	48.8	3.3

[1] Standard Error

4.2.2 Annual Loads ortho-Phosphate

Annual loads were estimated for ortho-P for the seven rivers that discharged into the Taw Estuary using the methods described above. These annual loads were then combined to give an estimate of the annual average load over the period 1990-2000 (Table 4.3). The river Taw contributed around 82% of the average load of ortho-P and had the highest load per hectare (2 kg/ha).

Table 4.3 Annual average loads (1990-2000) of ortho-P entering the Taw Estuary from each of the seven major tributaries

Site Name	Area (km^2)	Mass load (tonnes/year)	SE[1]	kg/ha	SE[1]
River Caen at Valetor Bridge	39.9	1.45	2.71	0.36	0.68
Knowle Water at Velator	21.5	0.85	0.06	0.40	0.03
Bradiford Water at Blakewell	30.5	1.15	0.12	0.38	0.04
Venn at Bishops Tawton	39.2	0.95	0.09	0.24	0.02
River Taw at Chapleton	869.7	39.40	2.71	0.45	0.03
Langham Lake at Langham Bridge	45.7	1.57	0.12	0.34	0.03
River Yeo Barnstaple at Collard Bridge	79.4	2.62	0.25	0.33	0.03

[1] Standard Error

As for TN, loads were also calculated for headwater catchments in order to try to assess the loss from areas not expected to contain significant point source loads (Table 4.4). With the notable exception of Ashmill stream the specific ortho-P loads are generally smaller for the headwater sites. The mean of the headwater sites (without Ashmill) is 0.28 kg/ha and 0.36 kg/ha for the most downstream points (significantly different, t-test: $p<0.03$).

Table 4.4 Annual average loads (1990-2000) of ortho-P leaving selected headwaters in the Taw catchment (see figure 3.1 for catchment locations).

Site Name	Area (km2)	Mass load (tonnes/year)	SE[1]	kg/ha	SE[1]
River Taw - Sticklepath	21.8	0.45	0.10	0.21	0.05
River Yeo - Bow Bridge	35.9	1.08	0.14	0.30	0.04
River Dalch - Canns Mill Bridge	24.5	1.40	0.11	0.57	0.04
Gissage lake - Nymphayes Bridge	8.7	0.27	0.05	0.31	0.06
Little Dart - d/s Chawleigh STW	100.0	3.55	0.23	0.36	0.02
Huntacott Water - Chumleigh	22.4	0.32	0.04	0.14	0.02
Sturcombe River - Bradford Tracy	18.7	0.32	0.03	0.17	0.02
Little Silver Stream - Alswear	28.8	0.70	0.08	0.24	0.03
Crooked Oak - Ashmill	19.9	0.52	0.07	0.26	0.04
River Yeo (Molland) - Bottreaux Bridge	28.7	0.58	0.05	0.20	0.02
River Bray - Leeham Ford	19.2	0.32	0.03	0.17	0.02
River Holewater - Linkleyham Bridge	17.6	0.37	0.04	0.21	0.02
River Yeo (Barnstaple) - Brockham Bridge	25.1	1.08	0.14	0.43	0.06
Rye Stream - Bratten Flemming	16.7	0.31	0.03	0.19	0.02

Ash Brook - A377	24.5	14.48	1.45	5.91	0.59
North Radworthy Stream – Barham Bridge	3.3	0.16	0.01	0.48	0.03

[1] Standard Error

Ashmill Stream shows high values of ortho-P load and also of TN load and it must be assumed that there is some unusually intense agricultural activity within this sub-catchment to account for these values.

4.2.3 Monthly Loads Nitrogen

Monthly average loads of TN were calculated for the rivers flowing into the Taw estuary in order to assess seasonal variability. All of the rivers showed strong seasonality with large loads transported during high flow periods through autumn, winter and spring and small loads in summer. Typically the lowest loads transported in July/August were and order of magnitude lower than the highest loads transported in winter (Figure 4.6).

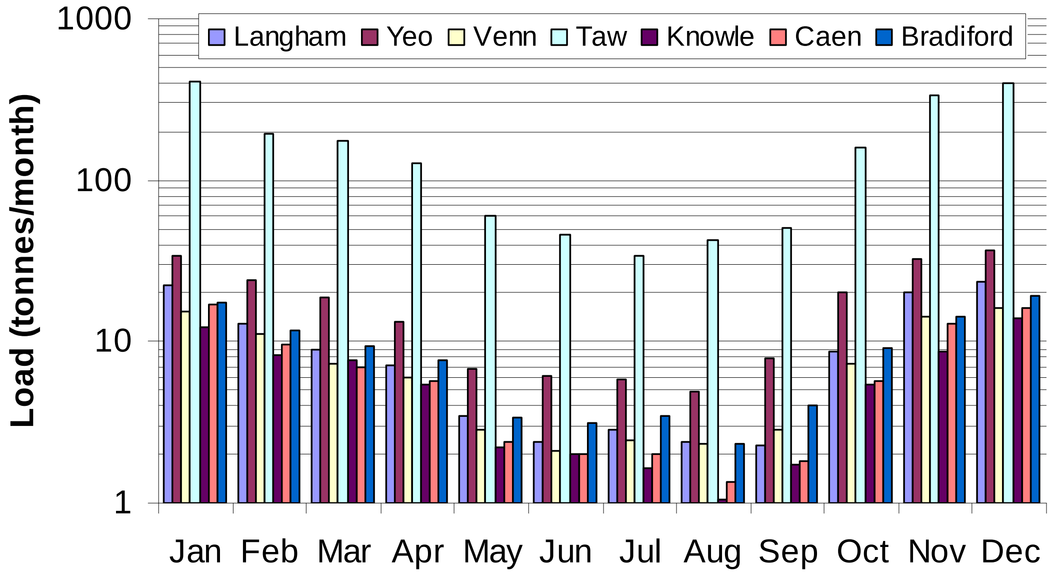

Figure 4.6 Monthly average total inorganic nitrogen loads (1990-2000) for the rivers discharging to the Taw Estuary

The consistency of the seasonal pattern of TN loads entering the Taw estuary becomes more evident when specific loads (kg/ha) are plotted (Figure 4.7). As the loads of TN decrease in the spring and summer, so the importance of point source discharges is likely to increase as has been observed previous and discussed above in Section 2.

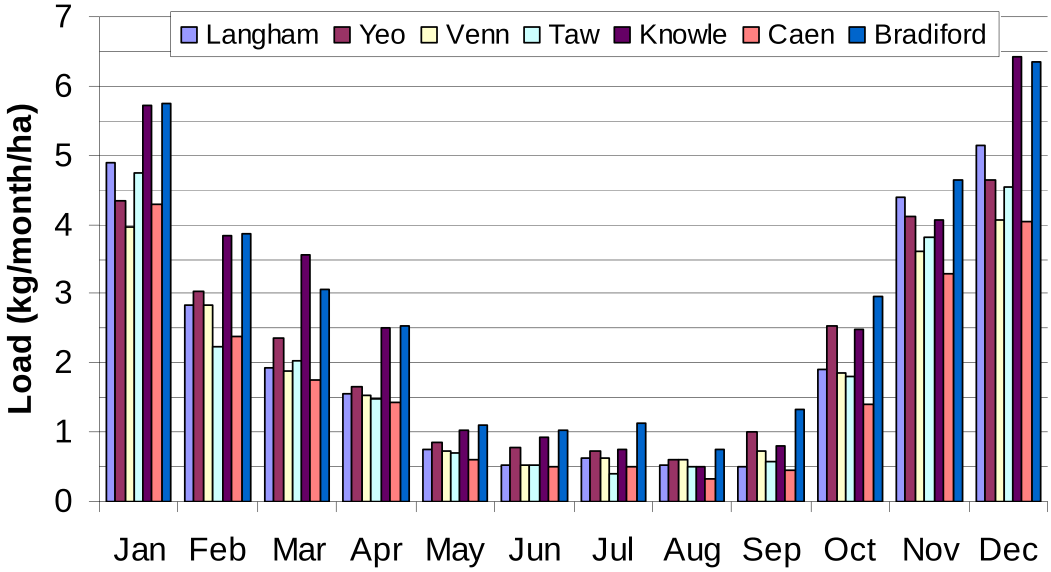

Figure 4.7 **Monthly average specific total inorganic nitrogen loads (1990-2000) for the rivers discharging to the Taw Estuary**

4.2.4 Monthly ortho-P loads

Monthly ortho-P loads show a similar pattern to TN loads reflecting the volumes of water running of the catchment through the year (Figure 4.8). Overall the loads are about an order of magnitude smaller than for TN and the minimum load is discharged slightly earlier, in May. The contrast between winter and summer loads is less pronounced especially for the River Taw, which may reflect a greater significance of point source loads.

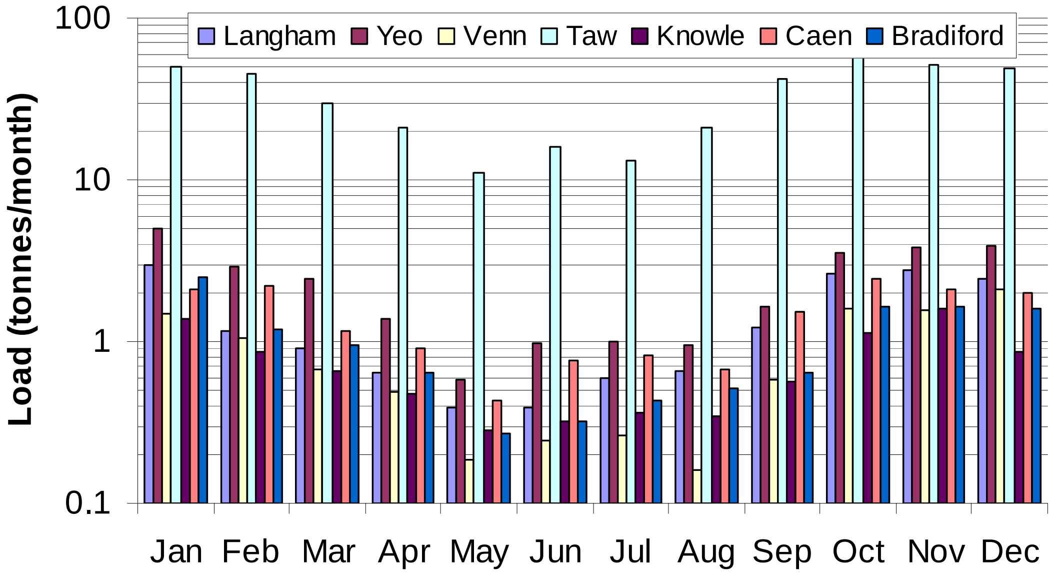

Figure 4.8 **Monthly average total inorganic nitrogen loads (1990-2000) for the rivers discharging to the Taw Estuary**

The specifc ortho-P loads show that the amounts lost per hectare are generally similar across the seven rivers, although the Taw is generally the highest and the Venn the lowest (Figure 4.9).

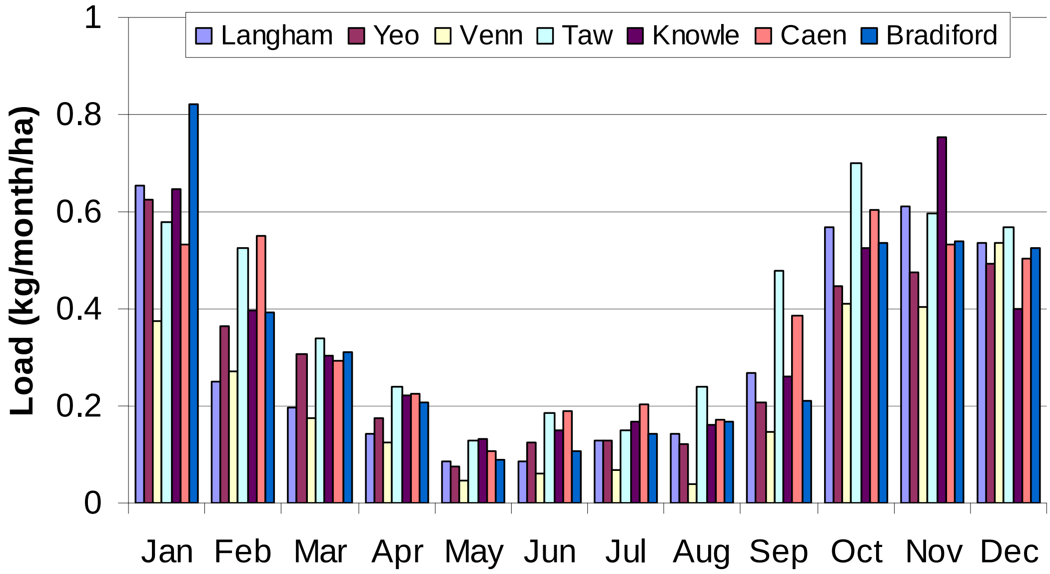

Figure 4.9 **Monthly average specific ortho-phosphate loads (1990-2000) for the rivers discharging to the Taw Estuary**

4.3 NITROGEN LOADS FROM THE ADAS NEAP-N MODEL

4.3.1 Prior Practice

Model output was available for all of the locations for which loads were calculated using the Environment Agency monitoring data and described in the previous section. Figure 4.10 compares the calculated loads with the modelled loads. The loads calculated from the Agency data will be referred to as the observed load. It should be remembered that this observed load is only an estimate of the real load and is limited by the frequency of sampling for chemical analysis, which is typically only monthly.

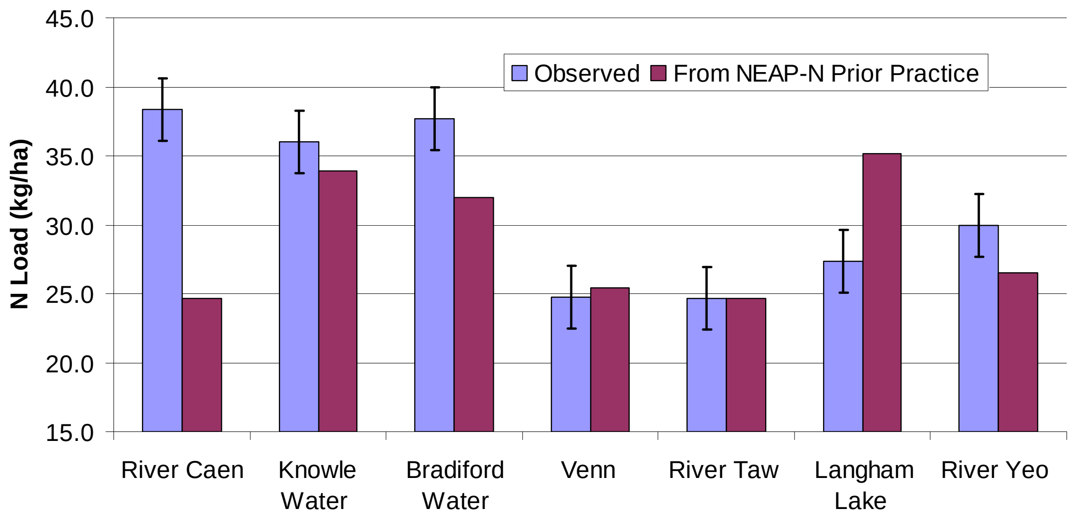

Figure 4.10 **Comparison of observed and modelled specific loads for the rivers discharging into the Taw Estuary (error bars are 95% confidence limits, these show the confidence based on the inter annual variability and not in the confidence associated with the method of load estimation)**

The modelled TN data are derived solely from diffuse sources and would be expected to show loads less than those estimated from the Agency data which will also include point source inputs. In fact, the modelled outputs are either larger or about equal to the observed loads in all but one case – Langham Lake. If the differences in loads are all attributed to point sources then this would suggest that such sources are a small component of the total load and is consistent with previous work. This would also suggest that the NEAP-N model is making reasonable predictions at this scale. Against this argument is that the results in Figure 4.8 imply a high point source load for the River Caen, which is not consistent with previous work (see Table 2.2).

The point source estimates made by Jonas (1997) were used to develop seasonal percentage estimates of point source contributions for each of the rivers draining into the Taw estuary (except for the Langham Lake river which was not included by Jonas). These values were then applied to the monthly loads for each river and summed to give an estimate of the annual point source loads. Figure 4.11 shows the same data as in Figure 4.10 with an extra column added which is the sum of the estimated point source load and the output from the NEAP-N model. The annual point source loads are small ranging from around 2 to 7% of the total observed load. However, this small addition does, for the most part, account for the difference between the observed and modelled TN loads given the uncertainty in the estimation of former.

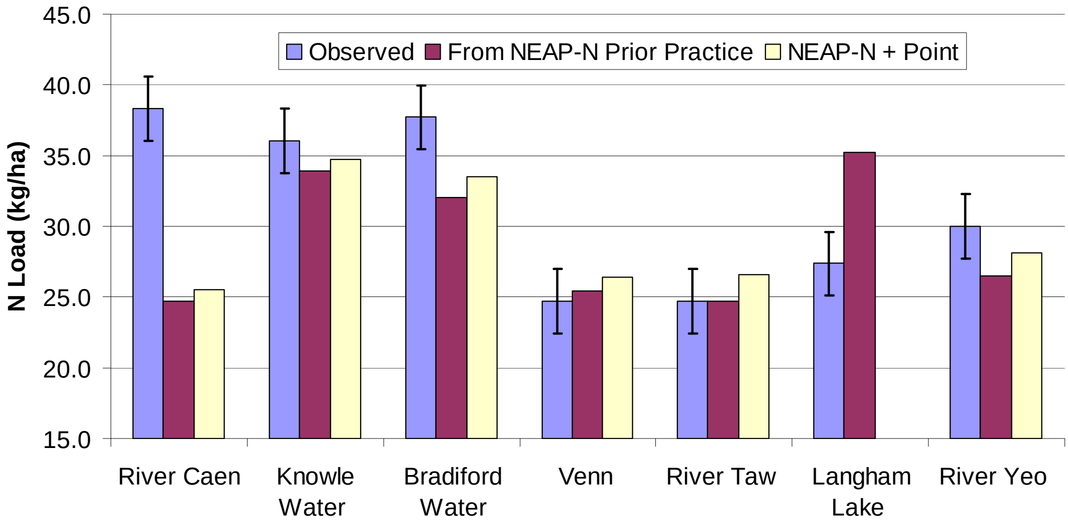

Figure 4.11 Specific nitrate loads comparing observed data, modelled output data and modelled data plus point source loads (estimated from Jonas et al, 1997)

The NEAP-N model was also run for the headwater catchments and the outputs from these catchments have been compared with the observed data for the same catchments (Figure 4.12). There is one clear outlier which is for Ashmill Stream where the observed TN load is around six times greater than the model output. Ashmill showed much higher concentrations of nitrate that the other headwater catchments and is also a designated NVZ surface water site. It is not clear why the model underestimates the load to such an extent.

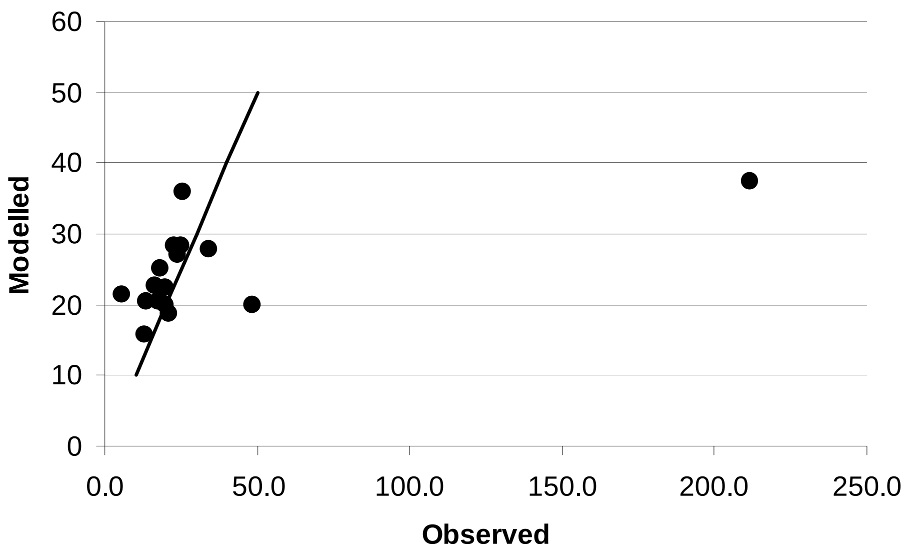

Figure 4.12 Comparison of observed and modelled specific nitrogen loads (kg N/ha) for the headwater sampling points. The solid line is the 1:1 ratio.

If the Ashmill Stream data point is removed a reasonable agreement is seen between the modelled and observed loads, although the model generally overestimates the loads compared to the observed values (Figure 4.13).

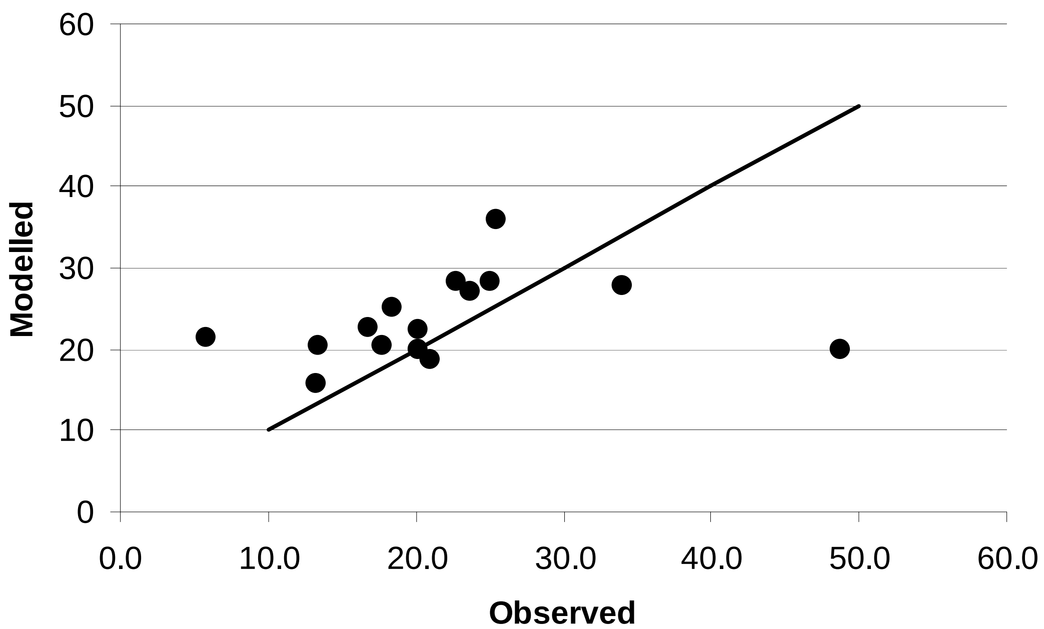

Figure 4.13 Comparison of observed and modelled specific nitrogen loads (kg N/ha) for the headwater sampling points with the Ashmill Stream point removed. The solid line is the 1:1 ratio.

4.3.2 NVZ Current Action Programme

The NEAP-N model predicts an average decrease of about 10% in TN loads from catchments in the Taw under the current NVZ Action Programme measures. Figure 4.13 shows the specific runoff loads modelled for prior practice and the NVZ action plan measures. The 10% reduction anticipated was factored into the observed loads calculated from the Agency data assuming the point loadings remained the same (Table 4.5). The 10% reduction in diffuse load gives an approximately 10% reduction in total load in all moths except June, July and August when point source loads become important. In the summer the loads will be reduced by between about 2 and 8%. Perhaps most notable is that the Taw which contributes around 73% of the loads is only reduced by 2% in summer. These reductions in load will be reflected in similarly lower river concentrations (because the flow will not change). The 95th percentile concentration which occurs at high flow, usually in late autumn would be expected to be reduced by 10%. Summer concentrations, which are more relevant to the process of eutrophication, will be reduced by a lesser amount particularly for the River Taw.

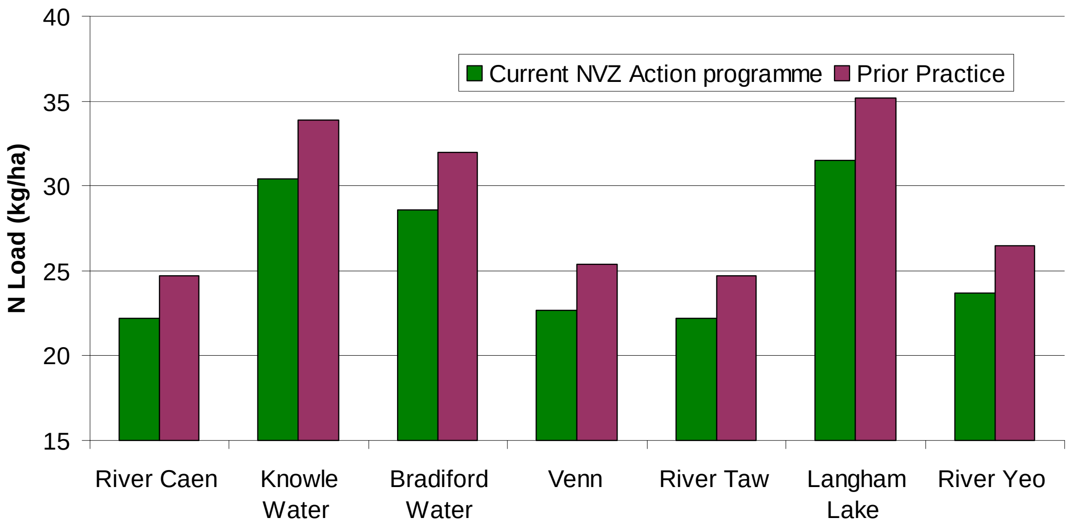

Figure 4.13 Modelled nutrient loads for the rivers draining to the Taw estuary for agricultural practice prior to NVZ designation and assuming application of the current NVZ action programme of measures

Table 4.5 Seasonal Percentage reduction in total nitrogen loads delivered by the major rivers to the Taw Estuary.

Month	Yeo	Venn	Taw	Knowle	Caen	Bradford	Langham
Jan	9.9	9.9	9.9	10.0	10.0	9.9	No data
Feb	9.9	9.9	9.9	10.0	10.0	9.9	No data
Mar	9.7	9.8	9.5	9.8	9.8	9.7	No data
Apr	9.7	9.8	9.5	9.8	9.8	9.7	No data
May	9.7	9.8	9.5	9.8	9.8	9.7	No data
Jun	6.3	6.4	1.9	8.1	8.1	7.4	No data
Jul	6.3	6.4	1.9	8.1	8.1	7.4	No data
Aug	6.3	6.4	1.9	8.1	8.1	7.4	No data
Sep	9.6	9.8	9.5	9.8	9.8	9.6	No data
Oct	9.6	9.8	9.5	9.8	9.8	9.6	No data
Nov	9.6	9.8	9.5	9.8	9.8	9.6	No data
Dec	9.9	9.9	9.9	10.0	10.0	9.9	No data

4.4 IMPLICATIONS OF NVZ MEASURES FOR ORTHO-PHOSPHATE CONCENTRATIONS AND LOADS

The NEAP-N model does not make estimates of ortho-Phosphate loads delivered to rivers, however, the application of the NVZ action programme is likely to have implications for this nutrient as well. The NEAP modellers made this assessment of ortho-P loss –

"Defra project PE0114, Assessment of the implications of NVZ designations for P loss from agriculture to surface waters, concluded that these measures would have modest relative impacts on P losses in catchments dominated by clay soils, since the majority of P transfer within these catchments is via drains, and the measures will have little impact on this pathway. They concluded very tentatively that these measures might reduce P losses by up to 6% in the Wye catchment, which contains a mixture of permeable and impermeable soils,. The corresponding estimate for the Taw, which is dominated by clay soils, would be 0 – 5% reduction".

As with nitrate a 5% loss in ortho-P loads would imply a 5% change in concentrations, although this would not be uniform through the year. Because ortho-P loads from point sources are generally greater than for TN this reduction is likely to be nearer 0% in summer and therefore the 95th percentile concentrations are unlikely to be reduced. Spring and summer concentrations of nutrients are very important for ecological response within the rivers and in determining eutrophic status.

5. Assessment of Eutrophication in the River Taw Catchment and the effects of NVZ measures

Eutrophication is a process not a state, requiring factors external to a system to act in order to bring about change within the system. This is especially so in rivers where plant communities respond to flow, sediment type, and underlying geology more than any transient changes in dissolved nutrient status derived from external inputs. Flushing in flowing systems tends to reduce exposure times to enhanced nutrient loads, thereby reducing the scale of any change.

Increases in both N and P cause changes in plant communities similar to those observed for P-enrichment only. It can be deduced that P, or the change in N:P ratio detected by plants, is the main driver for change in aquatic plant communities, rather than N.

The majority of observable effects of eutrophication are due to enrichment of running waters by P, or a combination of N and P. Enrichment by N tends to be associated with dissolved nutrients in the water column, whereas enrichment by P is associated with both sediment-bound and water column nutrients. It is therefore theoretically possible to reduce the effects of N-enrichment relatively easily over a relatively short timeframe if inputs are controlled, while the effects of P will be less easily resolved over short timescales. Assuming that the major observable effects are P-driven, and exacerbated by N enrichment, then the observable effects of a reduction in N may not be detectable until P is also reduced.

Eutrophication of rivers is best managed by reducing inputs to the river system, rather than any *in situ* remedial action. Point source pollutants are easily managed, but diffuse pollution from agriculture, industry, urbanisation and others is less easily controlled. Diffuse pollution may be caused by leaching of nutrients from soil over a long period, and even by reducing inputs as a consequence of Nitrate Vulnerable Zone (NVZ) initiatives, the rate of effective leaching may result in periods of between 50 and 100 years before significant nutrient reductions are detected in river systems dominated by groundwater recharge. Significant reductions in nutrients are those that have the capacity to alter plant community and population structure.

There are generally accepted nutrient levels predicted to limit vegetation cover to about 30% of the available surface area. These are 1 $mg.L^{-1}$ N and 0.1 $mg.L^{-1}$P (US EPA and others). These figures are valid for static waters (lakes etc.) and are probably higher for flowing waters as exposure / uptake ratios will be altered, perhaps by a factor of 3 for P and perhaps up to a factor of 5 – 6 times higher for N.

The intermittent nature of inputs driven by storm events and field runoff events makes prediction of ecological effects difficult. Different plant communities will respond differently to these nutrient spikes. Existing established, non-eutrophic community types, characterised by a diverse macrophyte community and stable diatom community would be expected to respond by increasing uptake of nutrients when available.

These responses, or the extent of the response, may not be associated with excessive increase in biomass as this could be limited by the availability of other critical nutrients such as carbon.

Established communities characteristic of eutrophic conditions (filamentous algae and duckweeds) in slow flowing waters would be expected to respond by increasing nutrient uptake and increasing biomass. This will result in excessive biomass in some cases, and resulting in reduced species diversity. Prolonged eutrophic conditions would tend to limit the ability of the (pre-existing) non-eutrophic plant community to recover, as seed bank viability declines with time.

Reductions in N-loading to all communities has value as recovery will be evident in all communities with time, with established eutrophic communities taking longer to recover than borderline communities or un-impacted communities. Reduction of nutrients in un-impacted communities will have the benefit of making that community more resistant to change from future external environmental factors.

It should be noted that reductions in P loading will have more effect on ecological indicators, than a reduction in N-loading. Unless reductions of P-loading are made at the same time as the AP measures, changes in ecological quality indicators may not be detected within the timeframe of the AP reductions.

The significance of altering the timing of applications is unlikely to have any significant impact on plant communities. If spring manure applications were adopted then both crop and macrophyte plant uptake of N and P would probably compensate for increased loading at this time. It is difficult to assess how much P is stored within the aquatic system and recycled, compared with direct and indirect inputs of P to the aquatic system. It may be that the aquatic plant community is saturated with existing P, in which case additional P added at different times of the year would either enhance the growth of eutrophic indicator species (at periods of low flow), or be washed out into the estuary at periods of higher or normal flows.

In making an assessment of the ecological response of the Taw system to the AP measures, best estimates limiting nutrient concentrations would be in the order of 5 $mg.L^{-1}$ N and 0.3 $mg.L^{-1}$ P, a ratio of 16.67:1 N:P. These are substantially higher than the figures for static waters and are based on the interaction of flow, residence time, nutrient status and ecological variables already in place.

It should be emphasised that, especially in the upper reaches of the Taw, that eutrophication is not obvious from the aquatic macrophyte community. The rapid flow in the very upper catchment with a mean N of 12.6 mg/L does not permit the development of eutrophic macrophyte species, but a future assessment of the epilithic diatom community may indicate nutrient enrichment. The combination of flow and geology are the dominant factors in determining the plant and diatom community in the lower reaches of the Taw system. Currently, the plant communities observed in the system are not representative of eutrophic conditions. If flow declines substantially in future, then it is likely that eutrophic plant communities dominated by filamentous algae will develop more often in the lower reaches of the system.

The predicted 10% reduction in N and 5% reduction in P, while not reaching the limiting nutrient values, will contribute to an increase in ecological stability of the system. Systems that operate at or near the trigger values for eutrophic ecological responses tend to have episodes of excessive plant biomass, occupation of space and hyper-accumulation of nutrients more often than systems with lower nutrient loadings. The consequences of this for the Taw would only be damaging, with development of patches of eutrophic indicator species, if flows were to reduce significantly in future.

Any reduction in nutrient loading, as predicted by the AP, would be valuable. A delay in the time taken to reach the establishment point for eutrophic plant communities would be achieved by reducing the overall loading. Conversely, it is not clear how long reductions in nutrient loading achieved by the AP would take to limit existing plant communities characteristic of eutrophic conditions in other rivers. Plant communities and diatom communities have not been assessed as part of this project.

In summary, it is unlikely that AP measures will have a significant impact on existing plant and diatom communities present in the river Taw, as the communities probably do not indicate eutrophic conditions at present. However, reductions in nutrient loading will probably contribute to a reduction in estuarine nutrient loadings, and the ecological response in the estuary may be more significant than that in the river.

6. References

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