Improvement Programme for England's Natura 2000 Sites (IPENS) – Planning for the Future IPENS008c

Pollution Risk Assessment and Source Apportionment: River Axe

River Axe Special Area of Conservation (SAC)

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Foreword

The **Improvement Programme for England's Natura 2000 sites (IPENS)**, supported by European Union LIFE+ funding, is a new strategic approach to managing England's Natura 2000 sites. It is enabling Natural England, the Environment Agency, and other key partners to plan what, how, where and when they will target their efforts on Natura 2000 sites and areas surrounding them.

As part of the IPENS programme, we are identifying gaps in our knowledge and, where possible, addressing these through a range of evidence projects. The project findings are being used to help develop our Theme Plans and Site Improvement Plans. This report is one of the evidence project studies we commissioned.

Water pollution has been identified as one of the top three issues in all Natura 2000 rivers. It also affects many terrestrial and some marine and coastal Natura 2000 sites.

Diffuse water pollution is the release of potential pollutants from a range of activities that individually may have little or no discernable effect on the water environment, but at the scale of a catchment can have a significant cumulative impact. The sources of diffuse water pollution are varied and include sediment run-off from agricultural land.

The mid to lower reaches of the River Axe have been designated as both a Special Area of Conservation (SAC) and a Special Protection Area (SPA) due to the diverse assemblages of in-stream aquatic and marginal flora and fauna. The River Axe SAC/SSSI is currently classified as being in unfavourable declining condition. The findings of this report have been used to develop a Diffuse Water Pollution Plan for the catchment to help improve the water quality and thus the condition of the designated site.

Diffuse Water Pollution Plans are a joint Natural England and Environment Agency tool used to plan and agree strategic action in relation to diffuse pollution at the catchment-scale. They are the most frequently identified mechanism for improving water quality on Natura 2000 sites.

This study is one of four produced by the IPENS project "Meeting local evidence needs to enable Natura 2000 Diffuse Water Pollution Plan Delivery".

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Executive Summary

The mid to lower reaches of the River Axe have been designated as both a ***Special Area of Conservation*** (SAC) and ***Site of Special Scientific Interest*** (SSSI) due to its diverse assemblages of in-stream aquatic and marginal flora and fauna. As such, the River Axe SAC/SSSI must meet certain biological, physical and chemical standards, to maintain and where necessary improve its ecological integrity and prevent any deterioration.

The River Axe SAC/SSSI is currently classified as 'unfavourable declining' (Natural England, 2012). Consequently, a 'diffuse water pollution plan' (DWPP) has been developed to assess pressures and management options for the River Axe SAC/ SSSI. The outputs from this parallel report will feed into the DWPP for the River Axe.

As the River Axe SAC/SSSI receives water drained from the wider catchment, we have carried-out a full catchment scale investigation. Our investigation incorporates detailed water quality analysis and presents a suite of model outputs, including SCIMAP, SAGIS, SIMCAT and FARMSCOPER.

This report and previous investigations have identified specific pressures from suspended sediments (SS) and phosphorus (P) within the Axe catchment.

1. Introduction

Special Areas of Conservation (***SACs***) and ***Special Protection Areas*** (***SPAs***), collectively known as ***Natura 2000*** sites, are protected under European legislation for their wildlife and habitats. Under the Water Framework Directive (WFD), SACs and SPAs are required to be in favourable or improving condition by 2015. However, due to the high percentages of SACs and SPAs affected by diffuse pollution, the ***Improvement Programme for England's Natura 2000 Sites*** (***IPENS***) has identified and prioritised the need for ***Diffuse Water Pollution Plans*** (***DWPPs***) to be devised on a site-by-site basis, where ***Natura 2000*** sites are failing to meet conservation objectives and where pollution represents a threat to their long term integrity.

In August 2013, 43 Natura 2000 sites were identified as requiring DWPPs. DWPPs are to provide starting points for a sequential approach to integrated diffuse water pollution management in identified sites.

Natural England has engaged the Westcountry Rivers Limited to develop a catchment wide pollution risk and source apportionment assessments, in support of the River Axe DWPP. The objective of these assessments is to undertake a detail review of the available evidence and using visualisation techniques present this information so it is more accessible and thus better able to inform the DWPP and any potential future catchment management initiatives.

Specific objectives of these assessments are to provide: (1) a targeted and fully costed catchment intervention strategy designed to achieve the most significant improvements in water quality using the most cost-effective and resource-efficient approach; (2) an assessment of potential implications of future housing and employment growth in the catchment, in terms of deterioration and the ability to meet conservation objectives; and (3) clear spatial visualisations and representation of all data and evidence collected.

The mid to lower reaches of the River Axe has been designated as both an SAC and SSSI due to its diverse assemblages of in-stream aquatic and marginal flora and fauna. In particular, the site hosts Annex II and V species (Salmon, Bullhead, Otter and Medicinal Leach) which are protected under the European Commission (EC) Directive on the Conservation of Habitats and Wild Flora and Fauna; Kingfishers, which are listed on Annex 1 under EC Directive on the Conservation of Wild Birds; and ranunculus, which is a UK Biodiversity Action Plan (UKBAP) species. In addition, the River Axe SSSI features diverse invertebrate communities and meander features which are of national geomorphological interest.

The River Axe SAC/SSSI includes the mid and lower reaches of the River Axe and has a length of around 13 km, starting at the confluence with the Blackwater River and ending at its tidal limit near Colyford. The River Axe SSSI meanders through predominately lowland agricultural land use, and is located within the East Devon Area of Outstanding Natural Beauty (ANOB).

2. Methodology

Our approach has been tailored to the Axe Catchment taking into consideration its size, the data available and the nature of the diffuse pollution challenges upstream of River Axe SAC/ SSSI.

Presentation of existing information regarding current natural habitats, SAC and WFD classifications provides an initial starting point of this assessment. These catchment classifications provide background information to our detailed analysis of empirical data and evidence. Existing standards and requirements for SACs and WFD objectives have been detailed, along with an examination of the methods used to derive existing classifications.

2.1. Pollutant source apportionment

In order to develop tailored and targeted catchment management interventions, we have, through the integration of data and modelling outputs, developed a programme of catchment investigations to diagnose possible causes for any degradation or failure to meet conservation targets within the SAC.

2.1.1. Pollution risk modelling

There are a variety of approaches available to model land-use and other human-derived pollution risks and estimate pollutant loads across each of the study catchments. These approaches include SCIMAP a fine sediment erosion risk model, SIMCAT and SAGIS to estimate the contribution of consented and un-consented sewage discharges, as well as inputs from diffuse sources, and PSYCHIC (Davison et al., 2008) to estimate phosphate and sediment loads delivered to receiving waters.

The outputs of these risk assessment tools and models have been combined with additional spatial data and evidence to identify potentially high risk areas for each pollutant in each catchment or sub-catchment.

2.1.2. Monitoring data review

Having assessed pollution risk a comprehensive review of historical and spatial evidence was undertaken encompassing data collated from the Environment Agency and where available variety of additional 3rd party sources. This review examines the observed / measured pollutant concentration trends and loads across the catchment.

2.2. Intervention strategy development

2.2.1. Assessment of current mitigation measures in the catchment

Before a full catchment management plan can be developed it is necessary to have a clear understanding of what mitigation measures are already in place or are in the process of being implemented. We have therefore attempted to summarise the previous and on-going approaches adopted in the Axe catchment to mitigate the risks and impacts of pollution derived from a variety of sources.

The measures assessed include the presence of naturally occurring mitigation in the landscape, the protection of the landscape through the designation of protected areas, the uptake of Environmental Stewardship Schemes (ESS), interventions delivered through Catchment Sensitive Farming and any other environmental work being done in the catchment.

2.2.2. Proposal for delivery of future intervention

FARMSCOPER modelling has been carried out to assess the potential reductions for diffuse agricultural pollutant loads within the catchment. Mitigation method scenarios have been created using FARMSCOPER outputs, and informed methods lists have been detailed based on local knowledge.

Based on all of our findings, we have, for the catchment, developed a detailed and costed intervention strategy, which we believe could remediate the problems found and mitigate the risk to the SAC/ SSSI. These plans will outline which areas and activities represent the greatest pollution risk in the catchment and what interventions and resource allocation would be required to mitigate those risks. Furthermore, consideration has been given to future growth risk within the catchment, with estimates of the likelihood of resultant increases in pollution risk, and associated mitigation suggestions.

2.3. Assessment of potential outcomes

It is vital that we collect sufficient evidence to provide an objective, evidenced and thus scientifically robust assessment of the effectiveness of our interventions. This evidence approach is essential to engage stakeholders and enable targeting and uptake of measures on land across the catchment.

3. Catchment overview

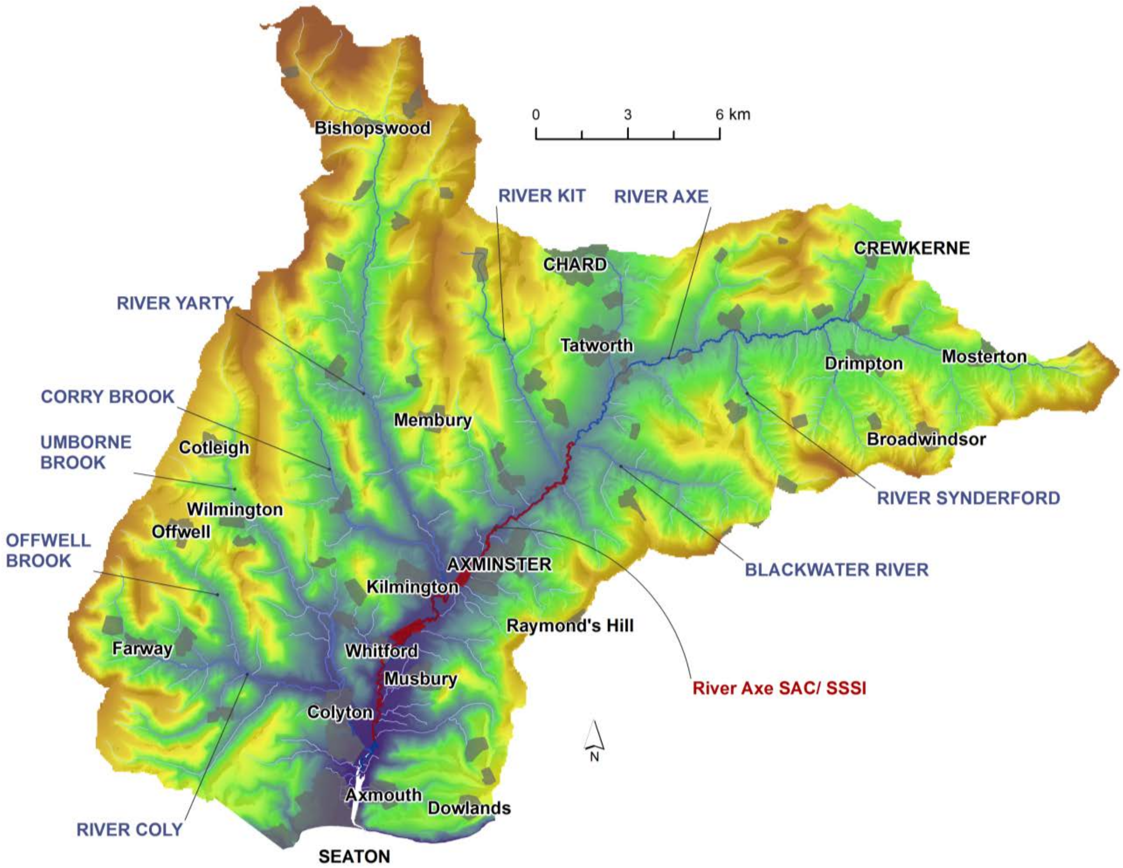
3.1. Morphology & hydrology

The catchment of the River Axe covers a total land area of around 300 km^2 in the counties of Dorset, Somerset and Devon, South West England. The River Axe is around 35 km long, rising near Beaminster in Dorset to Axmouth near Seaton, where is flows into the English Channel at Lyme Bay. The River Yarty, which is also fed by the Corry Brook, is the main tributary of the River Axe. The confluence of the River Yarty and Axe lies in the middle of the River Axe SAC/ SSSI. The main tributaries in the upper reaches of the Axe are the River Synderford and Blackwater River on the East and River Kit or Kit Brook on the West. In the lower reaches of the catchment, significant tributaries include the River Coly, Offwell Brook and Umborne Brook, on the Western side of the Axe.

The headwaters of the River Axe flow from Greensand and Chalk geologies. The mid and lower reaches of the River Axe are underlain by low permeability Mercia Mudstone, Lias Clays and Greensand. The River Yarty and Corry Brook are predominantly underlain by Greensand geology with mixed permeability.

The length of the Axe and its tributaries total approximately 418 km, and data from the Environment Agency hydrometric gauging station at Weycroft Bridge near Axminster reveal that the average daily discharge from the river is 5.4 cumecs and that the flow exceeds this 30% of the time and is below this level 70% of the time. Base flow generally provides around 47% if the flow to the River Axe.

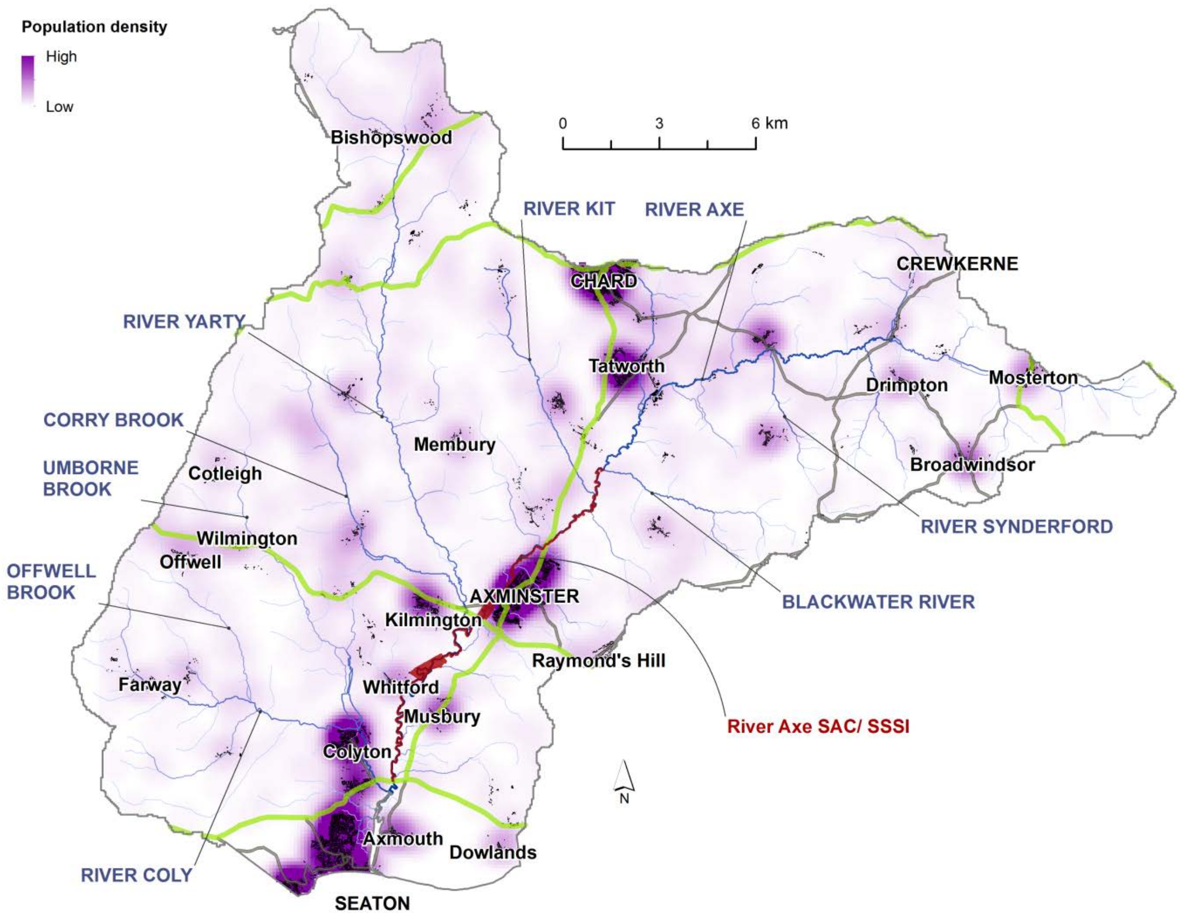
Figure 1: *Morphology of the River Axe catchment showing key hydrological features and the location of the River Axe SAC/ SSSI.*



3.2. Social & economic

The Axe catchment has a population of approximately 76,000 (at an average density of 0.2/km^2) (see: Figure 2). The two major towns in the south of the catchment are Seaton (~6,800 residents) and Axminster (~6,100 residents). The main towns in the north of the catchment are Chard (~9,300 residents) and Crewkerne (~7,500 residents). Major roads dissect the catchment including the A303 which runs along the upper reaches of the River Axe, and the A35, which runs across the lower reaches of the River Axe. Social and economic data indicate that the economy of the catchment is particularly dominated by the agriculture, forestry and fishing industries. Tourism and retail also provide major sources of income within the Axe catchment.

Figure 2: *Population density and infrastructure in the River Axe catchment.*

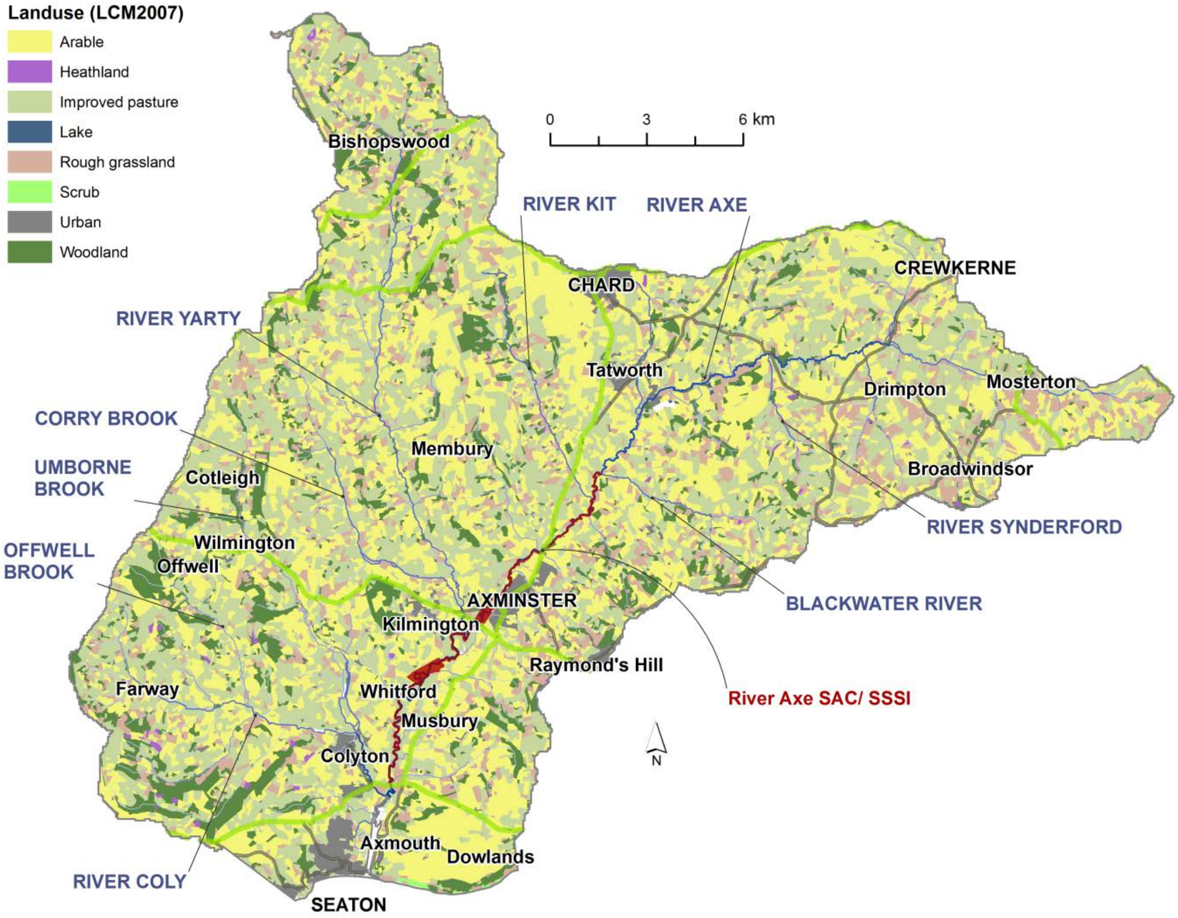


3.3. Farming & land-use

Agricultural practice and land-use data derived from the Rural Land Register in 2013 and the Agricultural Census of 2010 indicate that there are around 1,000 individual farm holdings in the catchment which cover around 36,300 Ha (88 %) of the catchment area (Figure 4). These farm holdings include fragmented patches of coniferous and broadleaf woodland and occasional scrub and heathland throughout the catchment (see Figure 3).

Of the mapped farmland in the catchment; ~15,000 Ha (38 % of the farmed area) are under temporary or improved grassland and ~15,800 Ha (41 % of the farmed area) have been used to grow any form of crops. The remainder, which totals 8, 0960 Ha (21 % of the farmed area) in the catchment, is under rough/permanent pasture or woodland/forestry. The total area of woodland/forestry in the catchment is 3,890 Ha (9 % of the catchment area).

Figure 3: *Land-use data from Land Cover Map 2007 (CEH, 2010).*



The Rural Land Register data (Figure 4) indicates that ~370 of the farm holdings within the Axe catchment are over 30 Ha in size. Whilst only offering a coarse indication of numbers, as farm boundaries are rarely coincident with catchment boundaries, the 2010 Agricultural Census indicates that there are 87 pig/poultry, 101 dairy and 109 beef and 200 arable (predominantly maize and wheat) farms in the catchment area.

A comparison between AgCensus returns between 2000 and 2010 clearly illustrate intensification across the catchment for cattle, sheep, maize and temporary grassland (Figure 5). The AgCensus data indicates that total sheep and cattle numbers and density have increased throughout much of the Axe catchment between 2000 and 2010. The amount of land used for temporary grassland has decreased in the northeast of the Axe catchment, and increased in the northwest between 2000 and 2010. In addition, land used for maize cropping has also increased in the northeast of the catchment around the upper Axe and Blackwater sub-catchment. Both livestock intensification and maize cropping can present numerous risks to pollutant loads in the catchment. For instance, compaction of soil resulting from livestock trampling can increase runoff carrying diffuse agricultural pollution. The impacts of agricultural land-use in the catchment are discussed further in section 5.

Figure 4: *Farm boundary data from the Rural Land Register (2013) for the Axe catchment.*

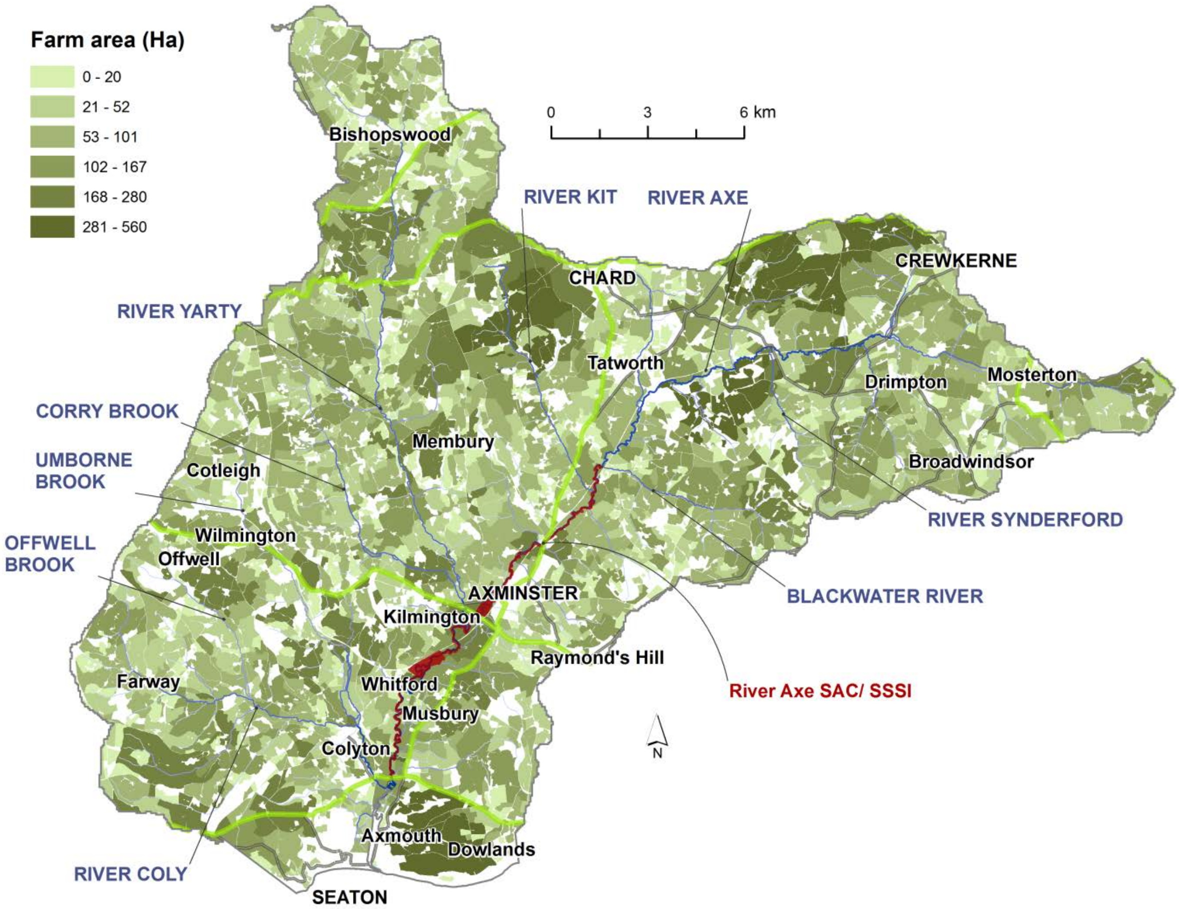


Figure 5 (continues over page): *Agricultural Census data from 2000 and 2010 showing the changes in the total area of land being cultivated for maize or temporary grassland and for the numbers of sheep and cattle.*

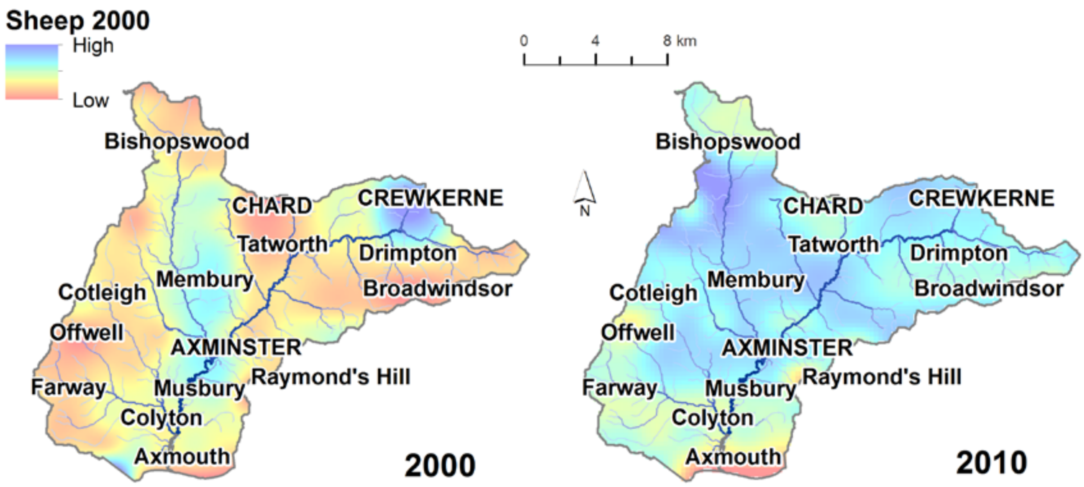


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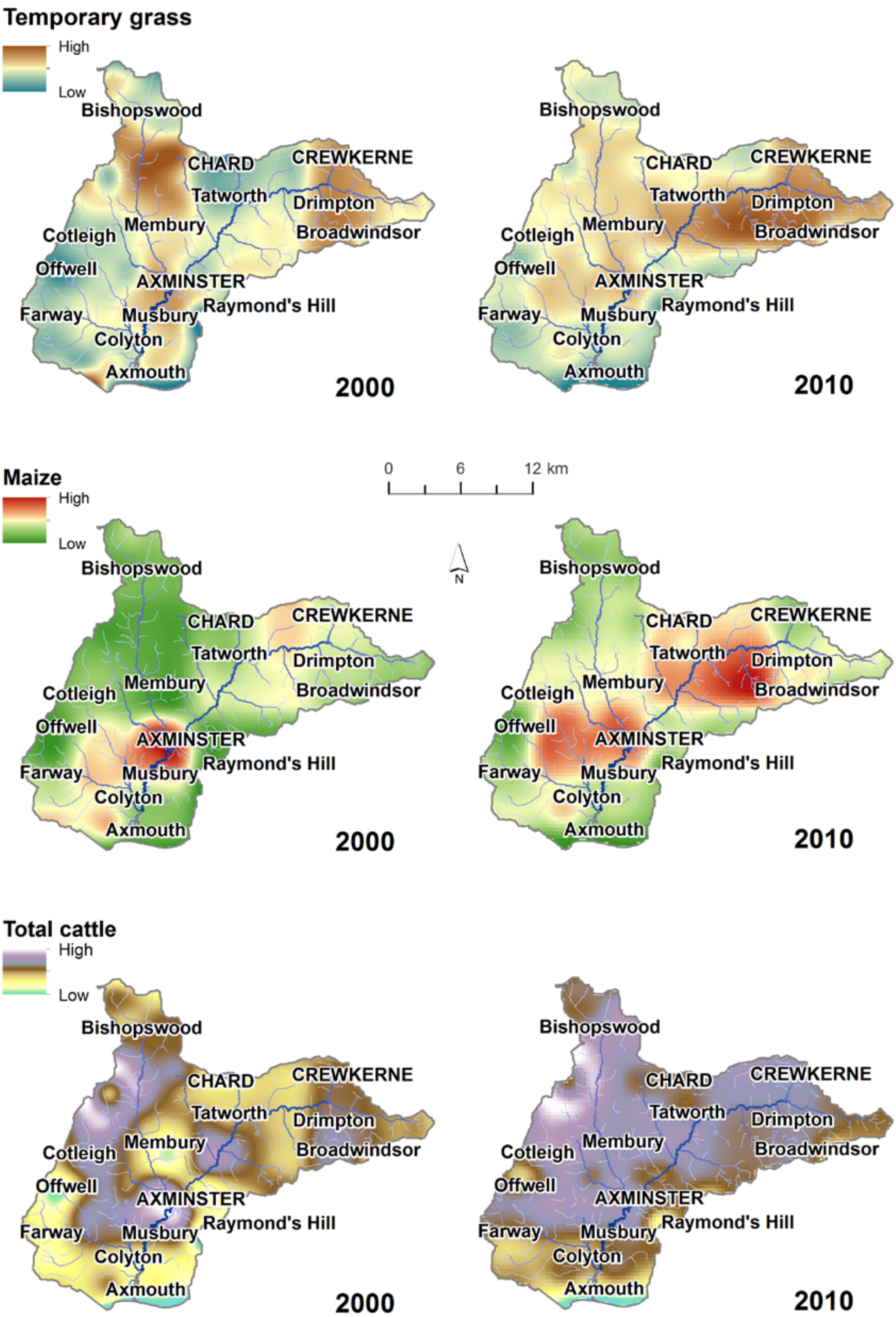
Figure 5 (cont.): *Agricultural Census data from 2000 and 2010 showing the changes in the total area of land being cultivated for maize or temporary grassland and for the numbers of sheep and cattle.*



4. Catchment classifications and challenges

There are two methods for ecological condition assessment (status classifications) that help us to identify pressures acting on the River Axe SAC/SSSI. These are condition assessments for the SAC/SSSI itself and the Water Framework Directive classification of waterbodies within the catchment.

While Natural England are responsible for monitoring the condition of sites designated as SAC/SSSIs, the Environment Agency carry out water quality monitoring for statutory and water management purposes. A brief description of SAC/SSSI and WFD assessment methods, standards and targets are provided below, followed by information on the current status of the River Axe SAC/SSSI and the WFD waterbodies within the catchment.

4.1. River Axe SAC/SSSI status

In order to protect the species and biological integrity in the River Axe SAC/SSSI condition assessment targets must be met. The method for assessment of SAC/SSSIs includes methods and measures, such as, River Habitat Surveys (RHS), water quality assessment, and calculation of biological indexes. Environment Agency monitoring data covering the three years preceding assessment are used to assess water quality and biological indices. The results of the assessment, in particular, status of the protected habitats and species, are used to define a condition for the site/ unit (JNNC, 2014).

The condition for the River Axe SAC/SSSI is currently classified as 'unfavourable declining', meaning that, *"the unit/feature is not being conserved and will not reach favorable condition unless there are changes to site management or external pressures. The site condition is becoming progressively worse, and this is reflected in the results of monitoring over time, with at least one of the designated features mandatory attributes not meeting its target with the results moving further away from the desired state. The longer the SSSI unit remains in this poor condition, the more difficult it will be, in general, to achieve recovery"* (Natural England, 2012).

The main reasons for the adverse condition in the River Axe SAC/SSSI have been attributed to: inappropriate, weirs dams and other structures, overgrazing, siltation, and water pollution; especially from agricultural run-off and effluent discharges. Additional comments have also attributed the 'unfavorable declining' conditions in the Axe SAC/SSSI relate to: invasive Himalayan Balsam; heavily grazed riparian zones; failures in Bullhead population structures and invertebrate assemblages (Natural England, 2012).

We have carried out an assessment of the chemical status of the River Axe SAC/SSSI using Environment Agency monitoring data from 2010 – 2013. Figure 6 illustrates the chemical status of the SAC/SSSI across 7 locations within the River Axe SAC/ SSSI.

It should be noted that the Common Standards Guidance (2014) no longer uses a specific numeric target concentration for SSs to assess condition. In this report, a former condition assessment target of no more than 10 mg/ L as an annual mean for SSs in river and stream SAC/SSSI units, defined by Natural England, is used as a benchmark against which to compare measured water quality.

Figure 6: *Chemical condition assessment report card for the River Axe SAC/SSSI (EA data: 2010 – 2013). River Axe site names are provided followed by EA water quality monitoring reference codes.*

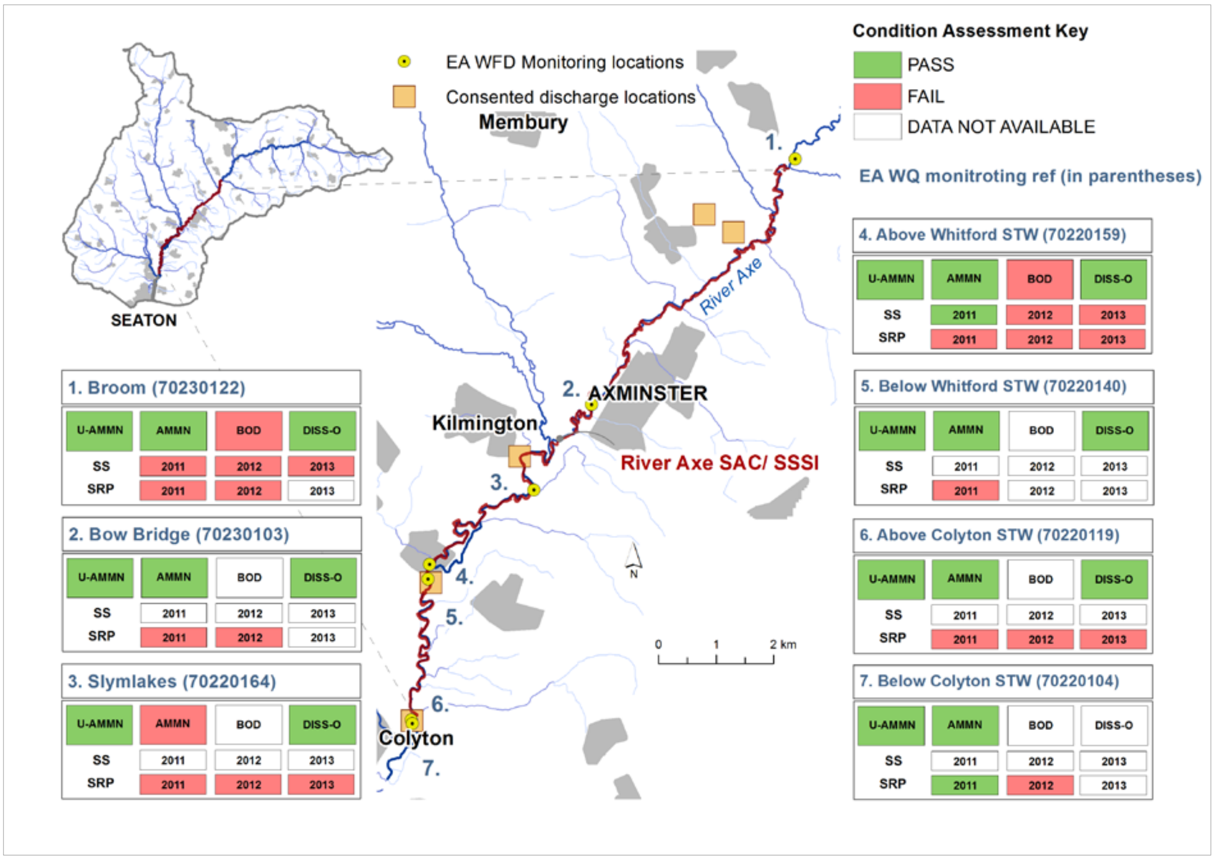


Table 1: *River Axe SAC/SSSI condition assessment target statistics compared with actual concentrations using EA monitoring data from 2010 – 2013. Site number locations and names are shown in Figure 6.*

				Site number						
				1	2	3	4	5	6	7
Chemical parameter		**Statistic**	**Target**				**Actual**			
Un-ionised Ammonia (mg/l)		95^{th} %ile	0.025	0.003	0.002	0.008	0.003	0.002	0.003	0.004
Total Ammonia (mg/l)		90^{th} %ile	0.25	0.16	0.15	0.27	0.15	0.14	0.14	0.17
DO % Saturation		10^{th} %ile	>85	89.6	91.0	92.0	91.7	94.0	88.6	-
BOD (mg/l)		Mean	1.5	1.67	-	-	1.59	-	-	-
SRP (mg/l)	2011	Annual mean	0.04	0.122	0.122	0.114	0.094	0.090	0.104	-
	2012			0.113	0.113	0.092	0.093	-	0.106	-
	2013			-		0.092	0.090	-	0.097	-
Suspended Solids (mg/l)	2011	Annual mean	10	55.8	-	-	5.0	-	-	4.7
	2012			13.9	-	-	12.6	-	-	14.2
	2013			13.0	-	-	22.4	-	-	

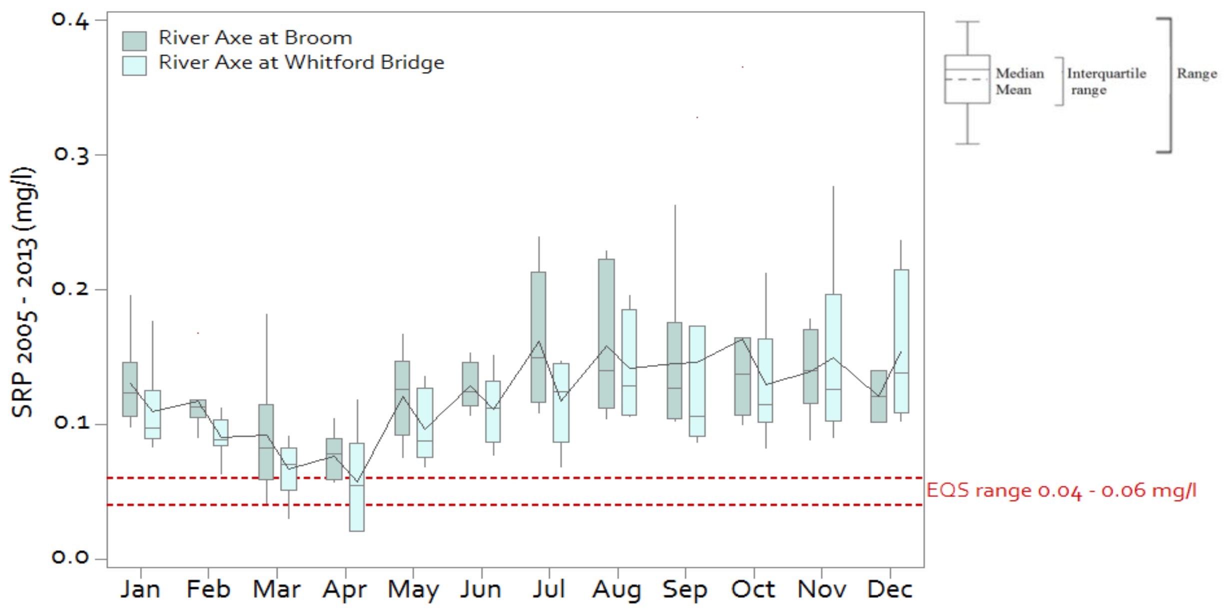
The condition assessment indicates that soluble reactive phosphorous (SRP) and suspended solids (SS) are the main water quality drivers for failure in the River Axe SAC/ SSSI. Dissolved oxygen (DO) concentrations are shown to be within condition assessment targets where data was available. Biological oxygen demand (BOD) failed the target measures in both sites where data was available.

An analysis of long-term Environment Agency data found that both total phosphorous (TP) and BOD had a significant positive correlation (R^2= 0.76; *P*-value <0.05). However, BOD was not correlated with SRP or SS, indicating that organic P may be the main pressure relating to BOD. Ammonia and un-ionised ammonia do not appear to pose as significant pressures in the River Axe SAC/ SSSI. However, one failure for total ammonia was found at site 3, River Axe at Slymlakes. Likely sources of ammonia pollution are agricultural run-off, effluent from sewage treatment works (STW) and other industrial discharges as well as septic tanks. Site 3 is directly downstream of an STW, which may be contributing ammonia load to the watercourse.

As SRP appears to be a key driver for water quality failures in the River Axe SAC/ SSSI, a more detailed assessment of the data has been carried out. An analysis of long-term (2005 – 2013) Environment Agency data highlights continued pressures from SRP within the River Axe SAC/ SSSI. Elevated SRP concentrations can prove a particular risk specifically for native flora assemblages, where scientific research suggests that there may be a critical threshold above which assemblages change, and less tolerant species may be difficult to regain. SRP also poses a major threat to fauna via eutrophication.

Assessment of long-term (2005 – 2013) monthly SRP averages at two sites within the River Axe SAC/SSSI was carried-out to identify months where SRP pressures are greatest, see Figure 7. Both sites show similar variations in SRP concentrations throughout the year, and are greater than SAC/SSSI target measures throughout the year. The reasons for monthly variations in SRP can be caused by a combination of factors relating to sources, dilution, and chemical/ biological processes. For instance, decreases in SRP concentrations in March and April may relate to plant uptake during spring growth or an increase in flow acting to dilute pollutants from continuous point sources.

Figure 7: *Box plot and means motion plot showing monthly variations in SRP concentrations using 2005-2013 EA monitoring data from two sites in the River Axe SAC/ SSSI.*



4.2. WFD classifications

The statuses and reasons for failure within Axe catchment WFD waterbodies are detailed in this section to provide information relation to pressures and potential risks which have been identified.

It should be noted, however, that while WFD monitoring data and classifications can provide some insight into pollution issues, the low sampling resolution rarely allows for identification of high risk areas and provision of targeted interventions. For instance, many waterbodies only have one monitoring location, which may not always capture changes in water quality as pollution loads are added, diluted, sequestered and transformed via natural processes as they are transported downstream. Both the SAC/SSSI condition assessments and WFD classifications do not have a target measure for SS in their assessment.

In line with the designated site condition assessments within the Axe SAC/ SSSI, SRP was also a main driver for Environmental Quality Standard (EQS) failures in the Axe catchment. SRP or orthophosphate (ortho-P) concentrations were above EQS in the five waterbodies where SRP was measured.

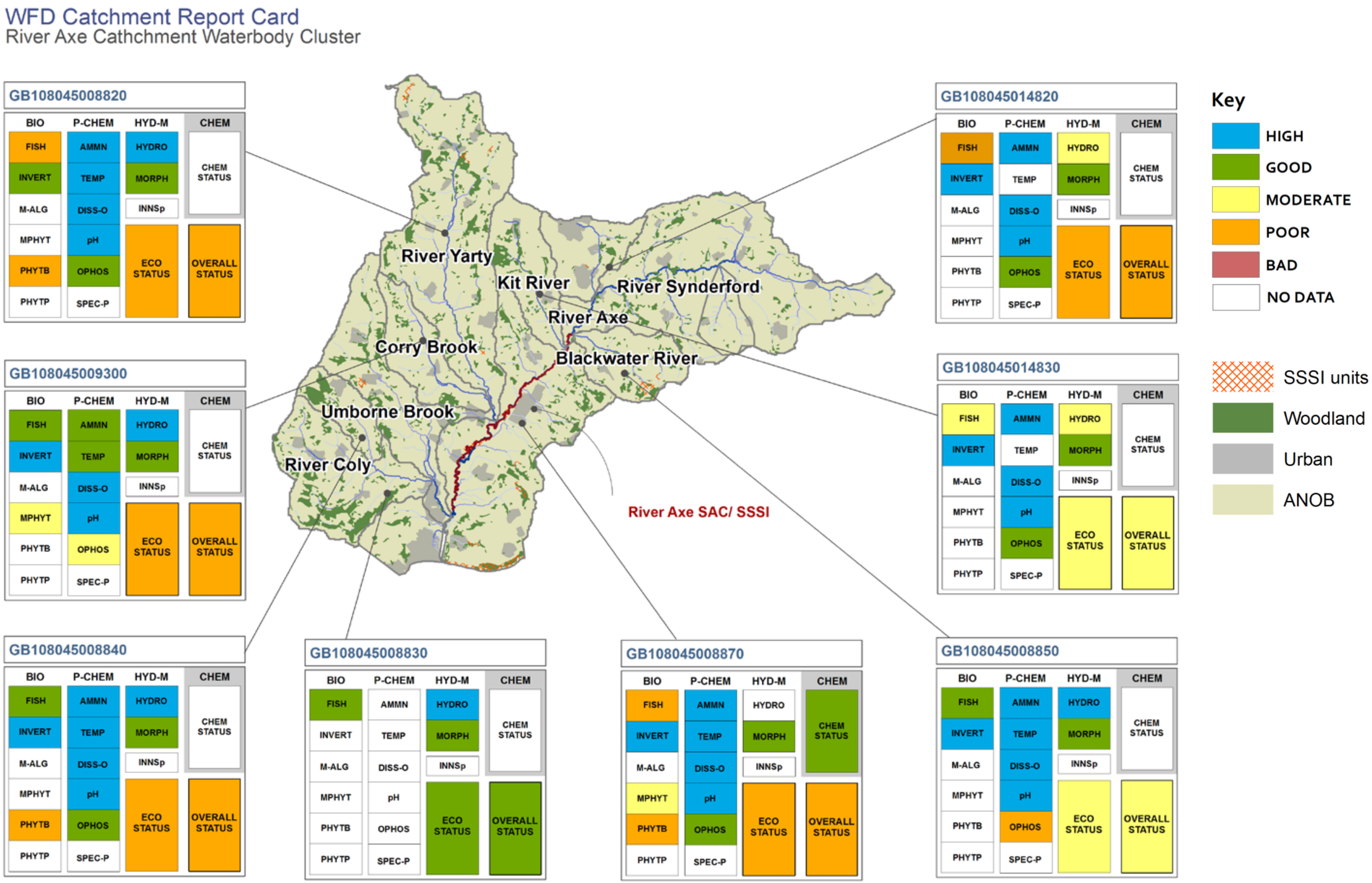
While the WFD monitoring site, which is located within in the Axe SAC/ SSSI, has a 'good overall status' classification, it has 'poor' SRP and phytoplankton (phytp) classifications. Classifications of 'poor' for phytoplankton along with SRP may be an indication of eutrophication within the SAC/ SSSI. A 'health card' showing WFD classifications for 2014 is shown in Figure 8.

It should be noted that the WFD EQS for phosphate classification may be updated in 2014 as part of the overhaul of WFD classification being undertaken for the 2nd Cycle of River Basin Management Planning by the Environment Agency.

These proposed changes, recently set out in a provisional report, will see the phosphate standard standards defined by river type in a manner more similar to the current SAC/ SSSI standards used for the Axe catchment.

Under this proposed change, the 'good status' standard for the River Axe would to change from 0.12 to 0.06 – 0.08 mg/l, and 'high status' to change from 0.05 to 0.035 – 0.045 mg/l (UKTAG, 2012). This change would mean that all of the 'good and high status' classifications from 2012 would change to moderate or poor under the new EQSs.

Figure 8: *Water Framework Directive 'Health Card' for the Axe catchment (data source EA, 2014).*



5. Pollutant source identification & risk assessment

Having assessed WFD and SAC/SSSI classifications, along with issues highlighted in existing literature it is clear, as already recognised by Natural England that SSs and P pose the greatest risk to the River Axe SAC/ SSSI.

In this section we present an integrated assessment of both observed and derived (modelled data) to identify potential sources of these pollutants in the catchment, and their relative contribution to in river-concentrations / loads within the SAC/ SSSI. This desk-based assessment is undertaken in accordance with the ‘source-pathway-receptor’ principle of pollution.

SOURCE		PATHWAY	RECEPTOR
Pollutant Availability +	Mobilisation +	Connectivity =	Pollution risk

5.1. Suspended solids

Numerous methods have been developed to identify the sources of suspended solids and the dynamics of sediment transport in rivers. Overall these studies reveal that the sediment load in rivers is primarily derived from point or diffuse sources in three principal locations: material from the river channel and banks, soil and other organic material from the surface of surrounding land and particulate material from anthropogenic sources (e.g. roads, industry and urban areas).

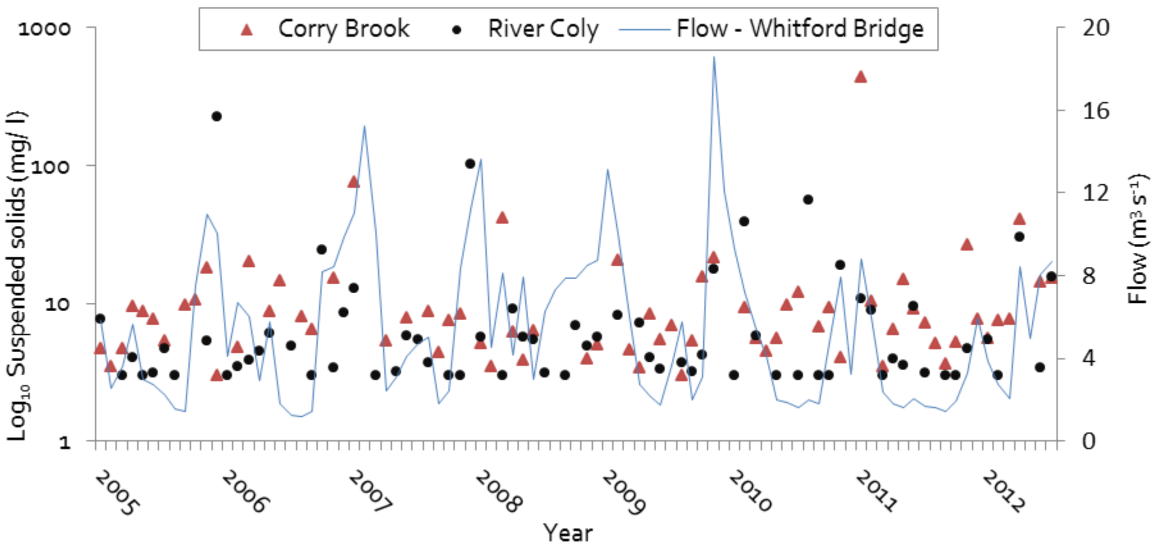
In the following sections, we present water quality monitoring data, SCIMAP risk modelling, sediment fingerprinting data and walk-over data to attempt to quantify, identify areas of high risk and apportion sediment pollution in the Axe catchment.

5.1.1. Water quality assessment

Statutory monitoring data and past research indicate that elevated SS concentrations within the River Axe are likely to be contributing towards deterioration of its SAC/SSSI status. WFD monitoring data from 5 sites, either within or at a confluence with the River Axe SSSI indicate that, between 2010 and 2012, suspended solid concentration exceed the former annual condition assessment targets 60% of the time, with these elevated concentrations ranging from 10.5 to 55.8 mg/ L.

Figure 9 shows monthly averaged Environment Agency SS data, at sites which had long-term data sets (i.e. Corry Brook and River Coly). The flow hydrograph shows monthly averaged flow data (CEH, 2014) from the River Axe – Whitford Bridge flow gauging station (NGR: SY2620895324). Significant correlations were not found between flow and SS; and there was no clear temporal trend in the SS data. This suggests variability in SS solid pollution levels are controlled by multiple of factors including rainfall, soil characteristics, riparian vegetation and landuse practices.

Figure 9: *Graph showing monthly averaged long-term flow data for the River Axe at Whitford Bridge (CEH, 2014) and suspended sediment data for the Rivers Corry and Coly (EA, 2014) for Jan 2005 – June 2012.*



It may be useful to assess relationships between changes in landuse practices and SS concentrations within the Axe catchment. For instance, maize cropping which can promote sediment run-off (Figure 10) increased by 16% between 2000 and 2010, in the Axe catchment.

However, much of the increase in maize cropping occurred in the upper reaches of the catchment, where there are no available long-term SS datasets.

Figure 10: *Photo showing run-off from maize stubble in the Axe catchment (source J. Hickey, 2012).*

5.1.2. Sediment source apportionment

The chemical composition of sediment samples can be analysed to identify their sources. Methods which apportion sediment sources based on characteristic signatures are often referred to as sediment fingerprinting studies.

A sediment fingerprinting study was carried out by ADAS in January and February 2009, to assess contributions from selected source types for sediments collected from floodplain surfaces within the Axe catchment. Between 24 and 80 samples were collected with a trowel from the floodplains of each sub-catchment. It should be noted that the results from this study are do not consider temporal variability, only providing a snapshot of sediment apportionment within the catchment.

Figure 11 displays the results of the sediment fingerprinting study. Damaged road verges (Figure 12) were the greatest source of floodplain sediment in the Rivers Blackwater (67%) and Coly (69%) sites. Damaged road verges were also found to be the main source of sediments sampled in the Rivers Kit (39%) and Axe at Whitford Bridge (38%).

In contrast, pasture topsoils provided the greatest source of sampled sediments in the Upper Axe sites, including: Upper Axe (68%), River Synderford (39%) and Temple Brook (60%). Cultivated topsoils were found to be a relatively small source of sampled sediments, ranging from 0 – 16% across the Axe catchment (Figure 13). Channel banks and sub-surface sources provided relatively high percentages of floodplain sediments in the Kit River (37%) and River Yarty (43%) sites.

Figure 11: *Sediment fingerprinting: sediment type source apportionment map for the Axe catchment (Data source: ADAS, 2009).*

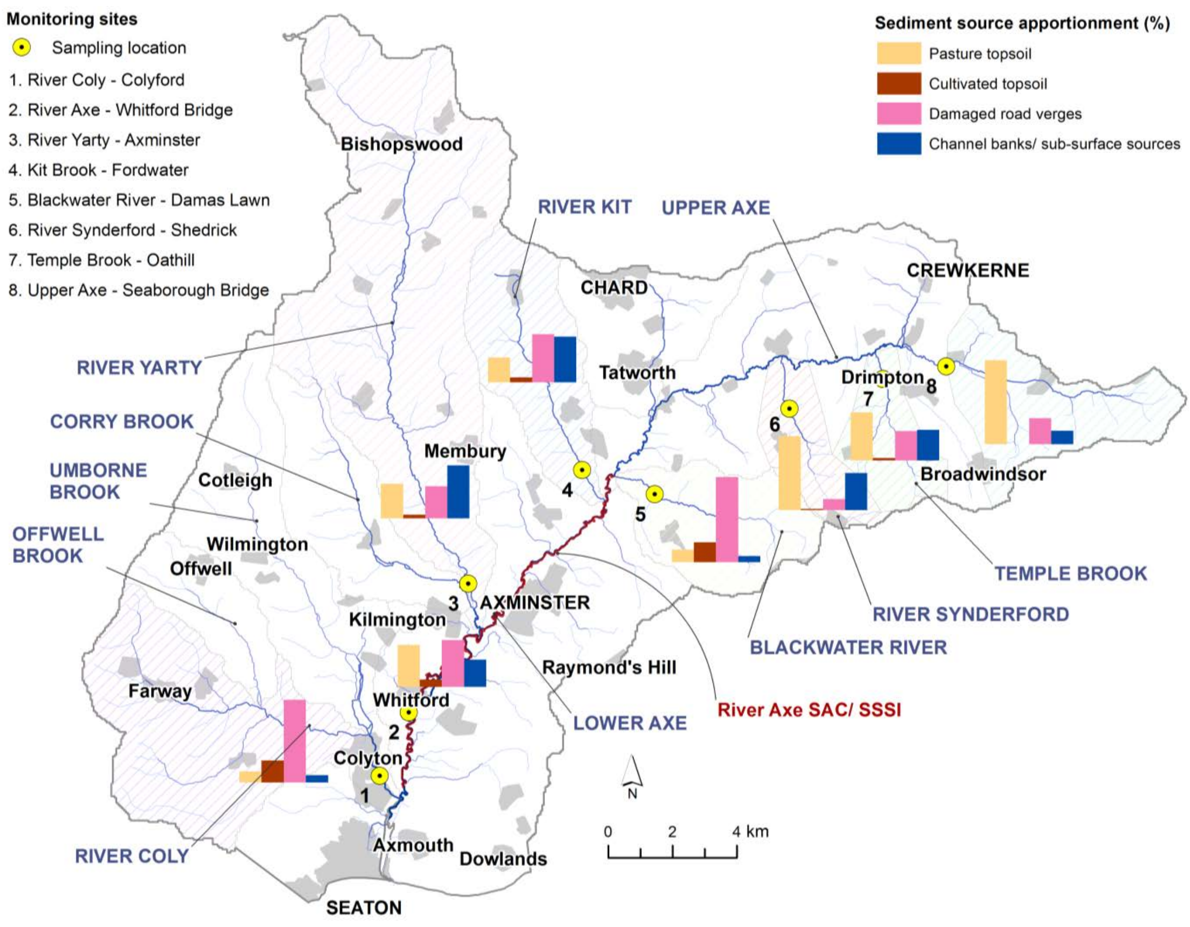
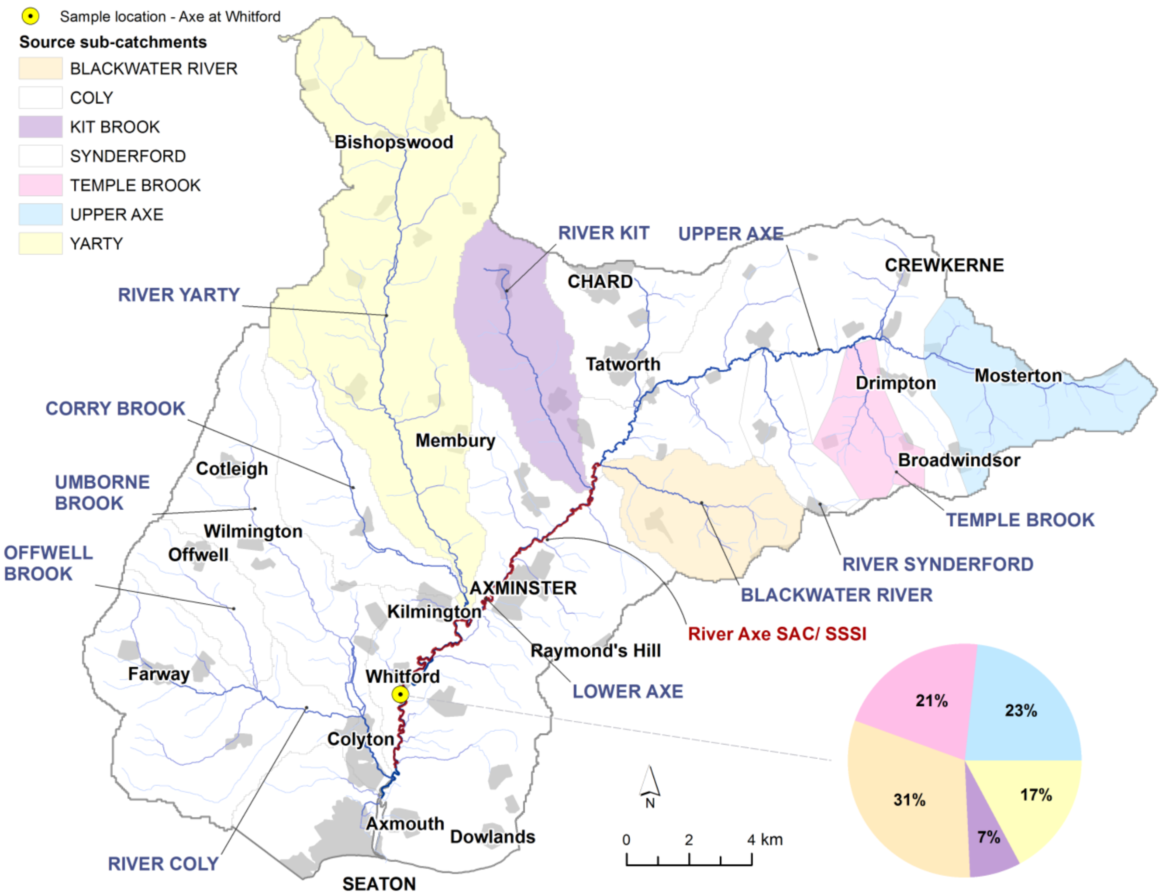


Figure 12: *Photo showing damaged road verges and roads acting as a sediment pollution pathway in the Axe catchment (source J. Hickey, 2012).*

Figure 13: *Photo showing cultivated topsoil sediment run-off in the Axe catchment (source J. Hickey, 2012).*

Figure 14: *Sediment fingerprinting: sediment location source apportionment map for the Axe catchment (Data source: ADAS, 2009).*



The sediment fingerprinting study identified the Blackwater River sub-catchment as the main source of sediments (31%) in the River Axe SAC/SSSI at Whitford (Figure 11).

While the sediment fingerprinting study can provide valuable sediment source apportionment information, it should be noted that this study was carried-out in 2009. Therefore, changing landuse practices and infrastructure may have altered the relative sources of sediment pollution in the Axe catchment. Furthermore, the report authors have stated that road verge run-off contributions may have been over estimates, particularly in the Blackwater catchment as road works were taking place at the time if the study.

Previous studies have found that the elevated suspended solids within the River Axe originate from both diffuse and point sources, being mobilised and transferred from a number of sources across the catchment. We have undertaken a risk assessment to identify the source areas with an elevated risk of fine sediment erosion.

5.1.3. Fine sediment risk analysis

In addition to the mobilisation of sediment and other suspended material from within the riparian corridor, fine sediment can also be mobilised from land-surface sources by overland flow. We can identify potential sources of this kind through field surveys (see section 5.1.4). A spatial modelling approach can be used to assess the fine sediment erosion and mobilisation risk across the River Axe catchment.

A catchment scale assessment of erosion risk is beneficial in helping to target and tailor both further monitoring, advice and catchment management interventions.

The SCIMAP fine sediment risk model, developed through a collaborative project between Durham and Lancaster Universities (Reaney, 2006) was used for this purpose. The development of this risk modelling framework was also supported by the UK Natural Environment Research Council, the Eden Rivers Trust, the Department of the Environment, Food and Rural Affairs and the Environment Agency.

SCIMAP provides an indication of where the highest risk of sediment erosion risk occurs in the catchment by (1) identifying locations where, due to land-use, sediment is available for mobilisation (pollutant source mapping) and (2) combining this information with a map of hydrological connectivity (likelihood of fine sediment, and associated pollutants mobilisation and transfer).

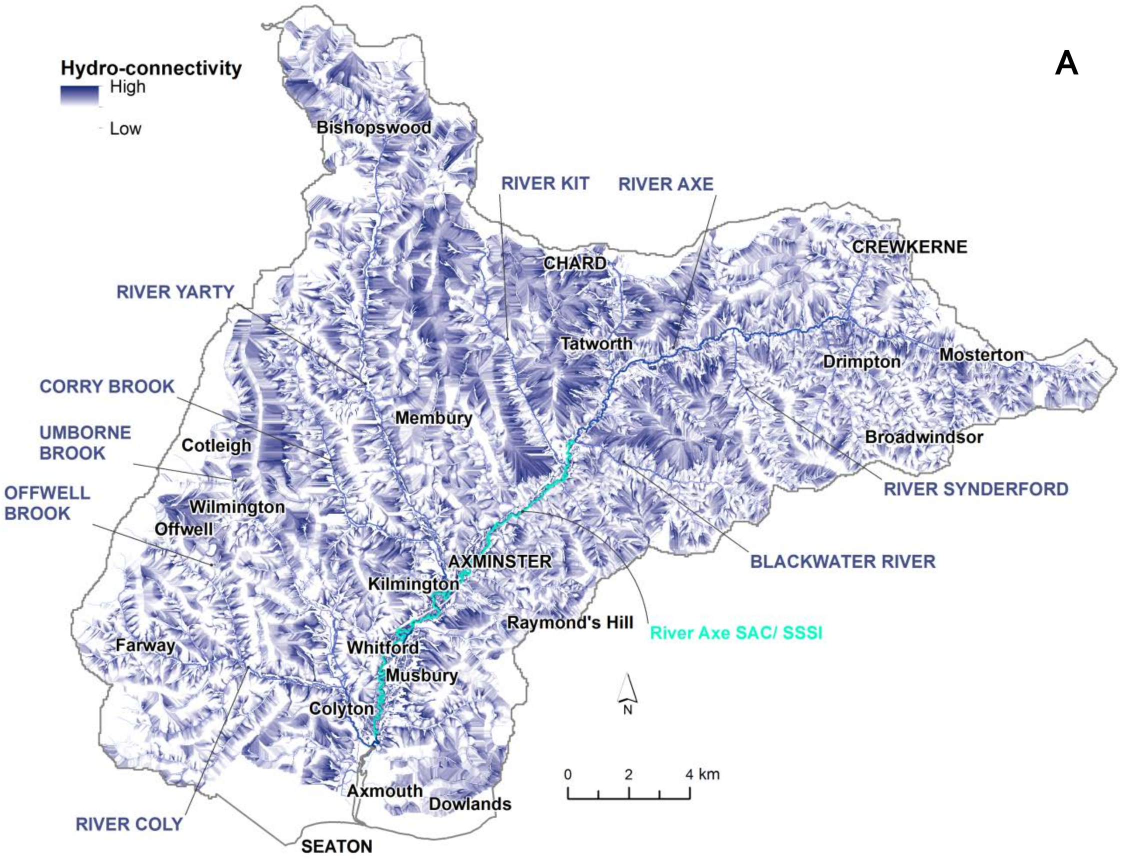
The SCIMAP risk modelling framework produces a map of hydrological connectivity based on the analysis of the potential pattern of soil moisture and saturation across a landscape. For each point in the landscape, the probability of continuous flow to the river channel network is assessed. This is achieved through the spatial prediction of soil moisture and hence the susceptibly of each point in the landscape to generate saturation excess overland flow.

The Axe catchment has been analysed at 10, 5 and 2m resolutions. The 5m resolution has been split into three representative sub-catchments, to allow SCIMAP analysis to be carried out with higher resolution data (see Appendix 2). As the SCIMAP outputs are relative, each modelled sub-catchment has been analysed independently. The hydrological connectivity map resulting from this analysis is shown in Figure 15 A, whilst the resulting fine sediment erosion risk and estimated in-channel concentration maps created from this analysis are shown in Figure 15 B and C, respectively.

The SCIMAP output in Figure 15 clearly illustrates that there are a number of areas where there may be a fine sediment mobilisation risk in the River Axe catchment. These are areas of land where cultivation or improvement of grassland and/or the action of livestock may increase the availability of sediment for erosion. There are a number of areas where there is an elevated likelihood of run-off occurring during periods of high rainfall.

The areas with greatest risk of in-channel sediment are where landuse practices contribute to sediment erosion and where there is high connectivity to watercourses. In the Axe catchment, areas with a high risk of sediment run-off are concentrated in Blackwater River, River Yarty, and a number of small streams which flow directly into the River Axe SAC/ SSSI.

Figure 15 (continues over page): *Fine sediment erosion risk maps of the Axe catchment, derived using the SCIMAP modelling approach, 10m DEM resolution.* ***(A)*** *Surface Flow Index model derived from rainfall and topographic data in the SCIMAP modelling framework,* ***(B)*** *Fine sediment erosion risk model, and* ***(C)*** *Estimated in-channel sediment concentration model.*



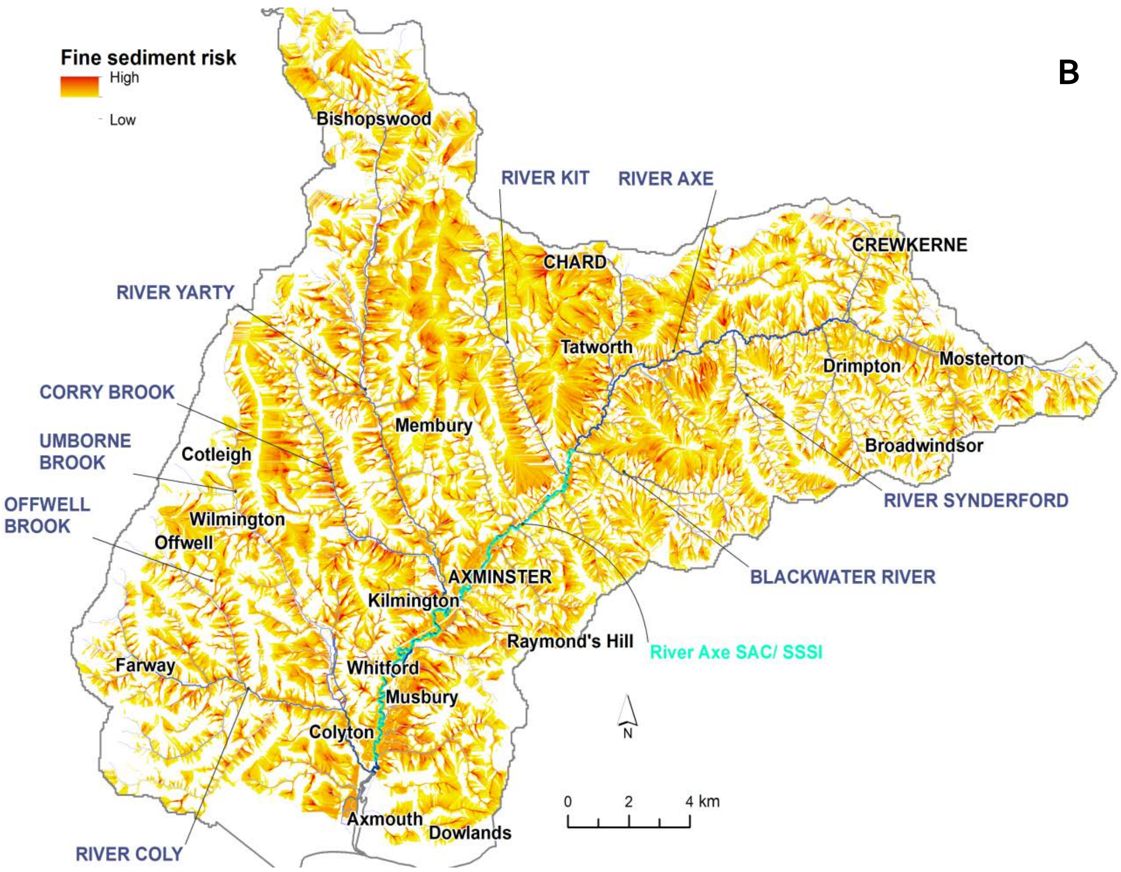
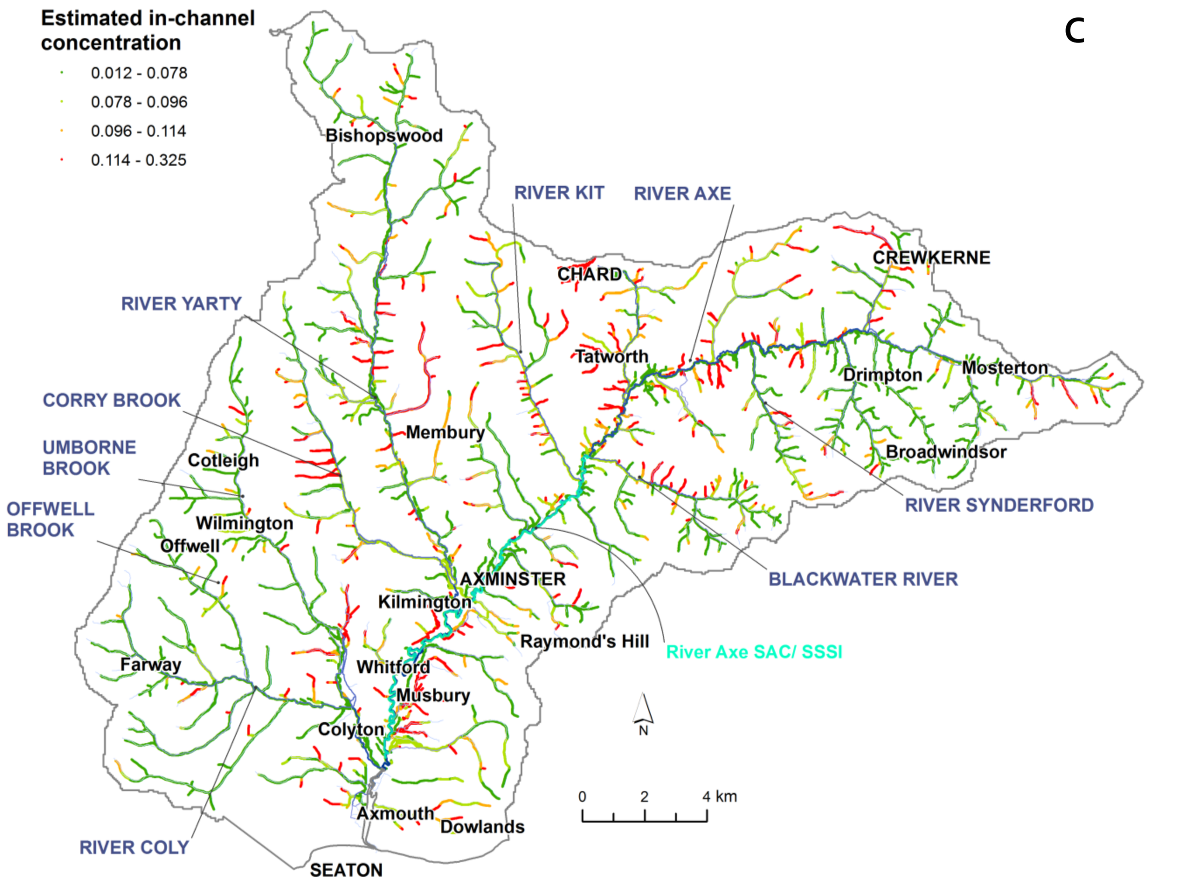


Figure 15 (continued)...



SCIMAP modelling indicates a risk of fine sediment pollution throughout the Axe catchment. In combining the areas with highest fine sediment erosion risk and the estimated in-channel concentration, discrete high risk areas can be identified (Figure 16). Figure 18 also provides an example of the SCIMAP analysis at 5m resolution, of one source area.

The high resolution SCIMAP analysis in Figure 17 clearly shows that there are a number of areas with high sediment erosion risk which have high connectivity with river channels. Furthermore, 2007 CEH landcover data indicates that high risk sediment erosion areas often occur on arable or improved grassland.

Such areas could be significant sources of sediment pollution to receiving waterbodies, where agricultural 'Best Management Practices' BMP's are not applied.

In addition, agricultural land with high sediment erosion risk is also likely to be a source of phosphorus (P) to receiving waters as is often physically and chemically bound to sediment. Phosphorus concentrations/ loads in the Axe catchment is explored in the section 5.2.

Figure 16: *Fine sediment risk and estimated in-channel concentration modelled at 10m resolution in SCIMAP. Areas with risk > 70% fine sediment risk are shown. Selected areas have been modelled at 2m resolution Figure 17.*

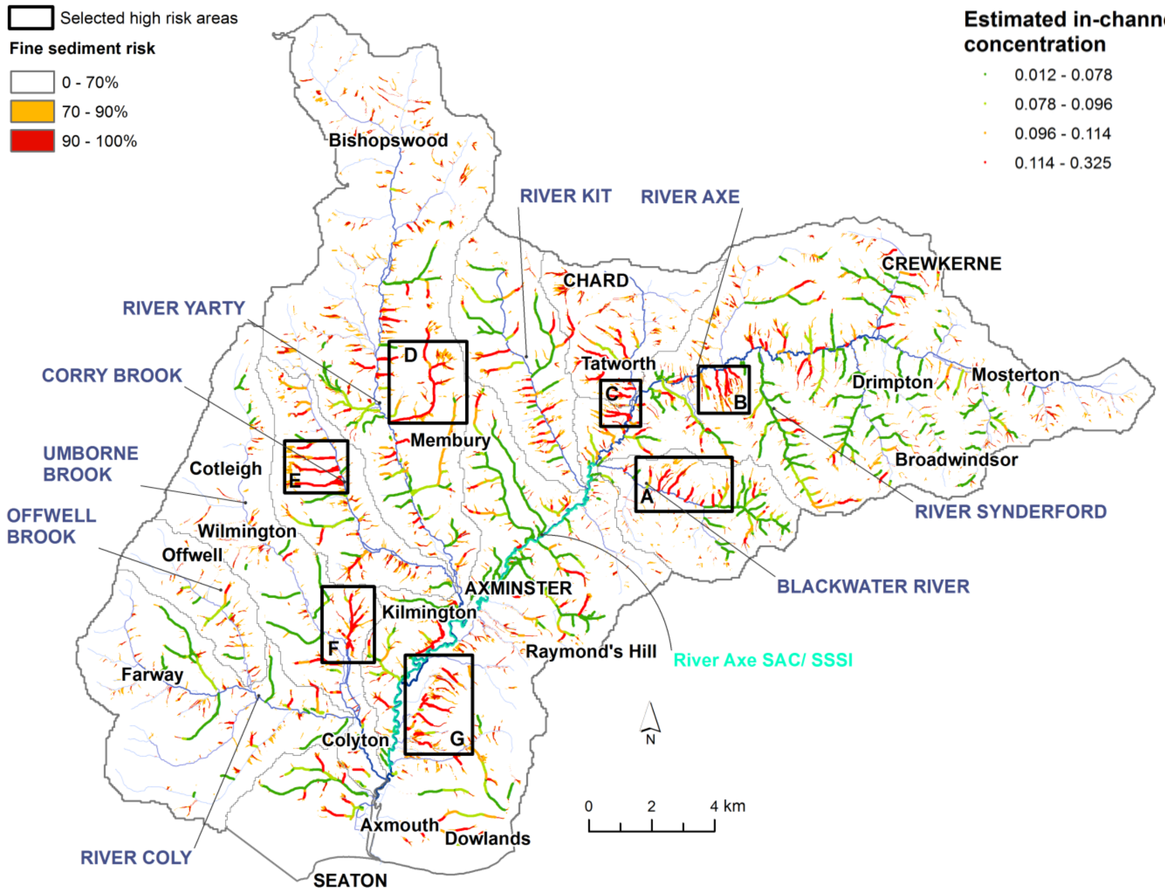


Figure 17: *SCIMAP fine sediment risk maps modelled at 2m resolution for areas identified as having high fine sediment erodability risk at 10m resolution.*

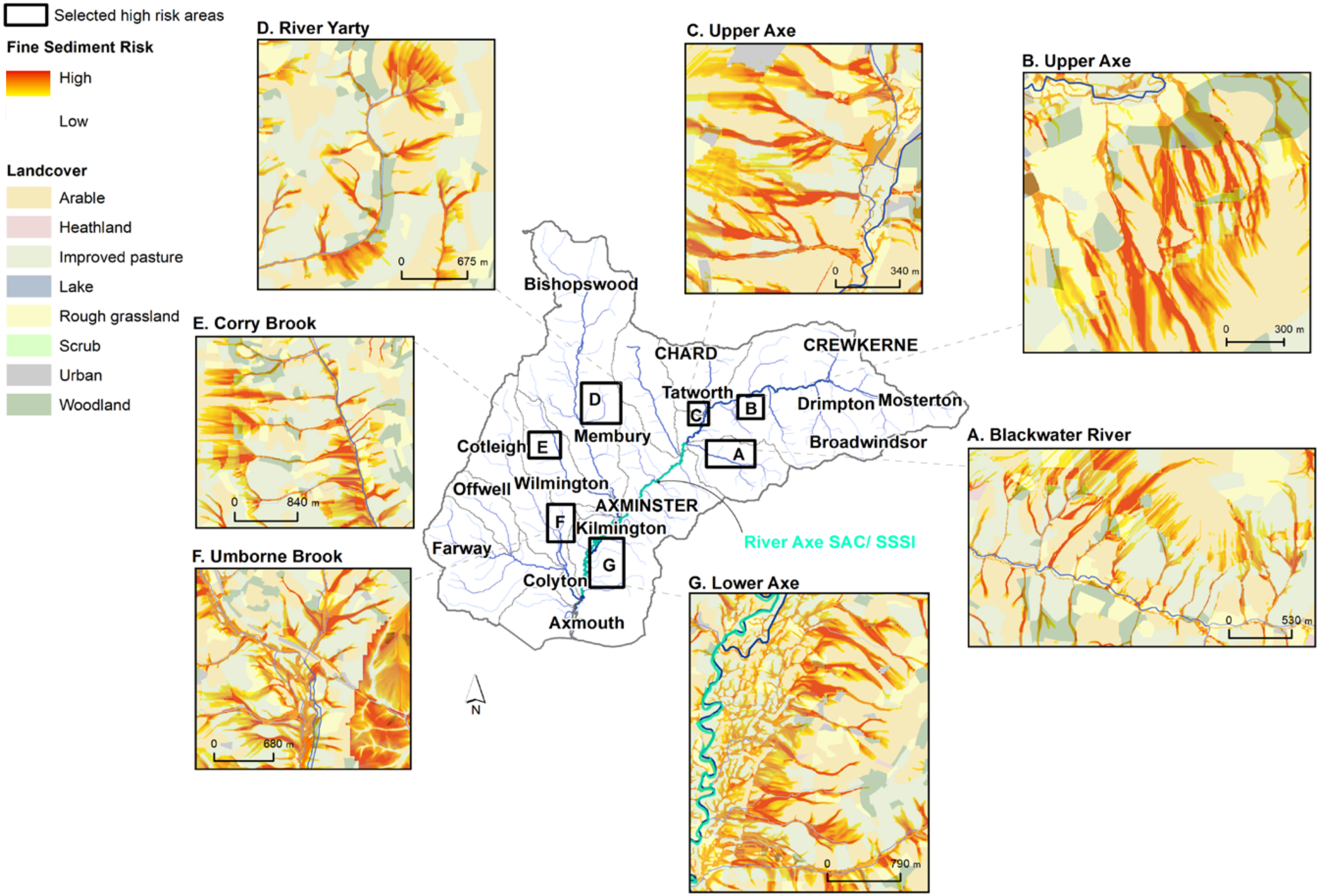
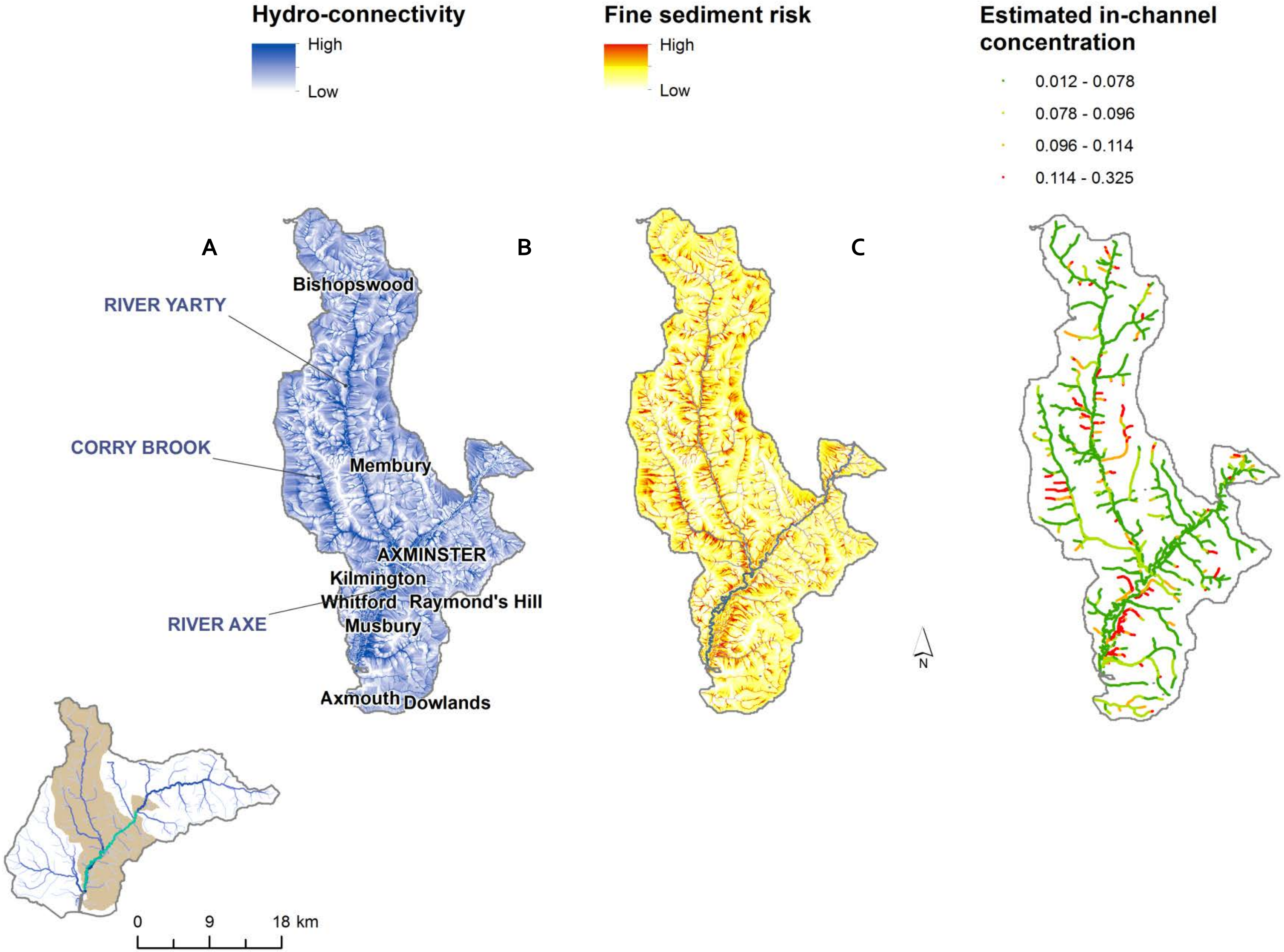


Figure 18: *Example fine sediment erosion risk maps of an Axe sub-catchment, derived using the SCIMAP modelling approach, 5m DEM resolution.* ***(A)*** *Surface Flow Index model derived from rainfall and topographic data in the SCIMAP modelling framework* ***(B)*** *Fine sediment erosion risk model.* ***(C)*** *Estimated in-channel sediment concentration model.*



5.1.4. Sediment load analysis

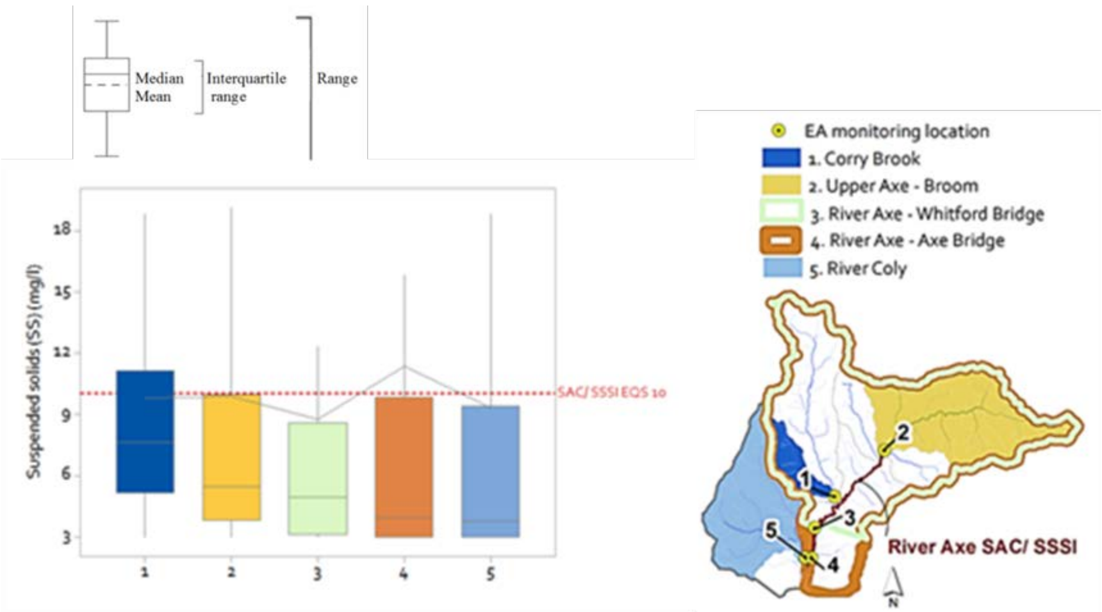
Having identified where the greatest fine sediment erosion risk may be present in the River Axe catchment, we next interrogated the water quality monitoring data collected at strategic locations in the catchment to identify which areas were contributing the greatest amount of suspended solids. **For this study we examined 3 years of Environment Agency water quality monitoring data at 5 key locations across the catchment (shown in Figure 19; *inset*).**

Figure 19 shows the average suspended solids concentration recorded by the Environment Agency over a 3 year period between 2010 and 2012. Samples were taken at the outflow of each of the River Corry and the Coly Brook and at 3 locations along the main River Axe with a sampling frequency of once a month. There are no suspended solids data available in the other sub-catchments.

The data shown in Figure 19 indicates that there were similar average SS levels recorded at WFD monitoring sites between 2010 and 2012. Due to large diffuse pollution source areas and low sampling resolution in the water quality data for SS, it is difficult to use water quality data to identify specific sources of SS in the Axe catchment.

These data do, however, indicate that, as identified in the SCIMAP modelling, SS pollution is widespread in the Axe catchment. The Corry Brook was found to have the highest average SS concentrations. The high sediment risk areas, which have a short pathway between the source and receptor, in Figure 17 – E, show likely source areas of sediment pollution in the Corry Brook. The highest SS levels may be occurring during spate conditions when large amounts of sediment are washed down thorough the catchment.

Figure 19: *Boxplots showing variation in suspended sediment concentrations across 5 locations in the Axe catchment.*



5.1.5. River corridor & landscape sediment risk assessments

Fine sediment or suspended solids pollution in rivers can be derived from natural geomorphological processes, such as bank and channel erosion, and through erosion of the soil and materials from the land surface during run-off events.

These inputs can be significantly increased if river banks and channels become damaged or excessively disturbed due to the actions of livestock when given unrestricted access to the watercourse or if soil condition is degraded due to the farming practices being undertaken upon it.

Walkover surveys can provide detailed fine scale information about sediment source areas. Figure 20 and Figure 21 summarise findings from an Environment Agency commissioned walkover survey of the Axe catchment undertaken in 2009.

High, moderate and low risk sediment pollution sources were identified throughout the catchment (Figure 21), with a particularly high density of high risk cases found in the sub-catchments of the Upper Axe and River Coly.

A summary of site descriptions (Figure 20) highlighted road run-off as the most frequently occurring high priority case in the walkover survey. Maize and arable run-off tended to occur only as high priority cases, this result could be expected as maize is known to represent a higher risk of soil loss.

Overall the walkover survey indicated that road run-off, maize, arable run-off, livestock poaching and tile/ gully and/or track drainage were the main sources of sediment pollution in the Axe catchment at the time of the survey.

Figure 20: *Summary of sediment sources identified in the Axe catchment in a 2009 walkover survey (EA, 2009).*

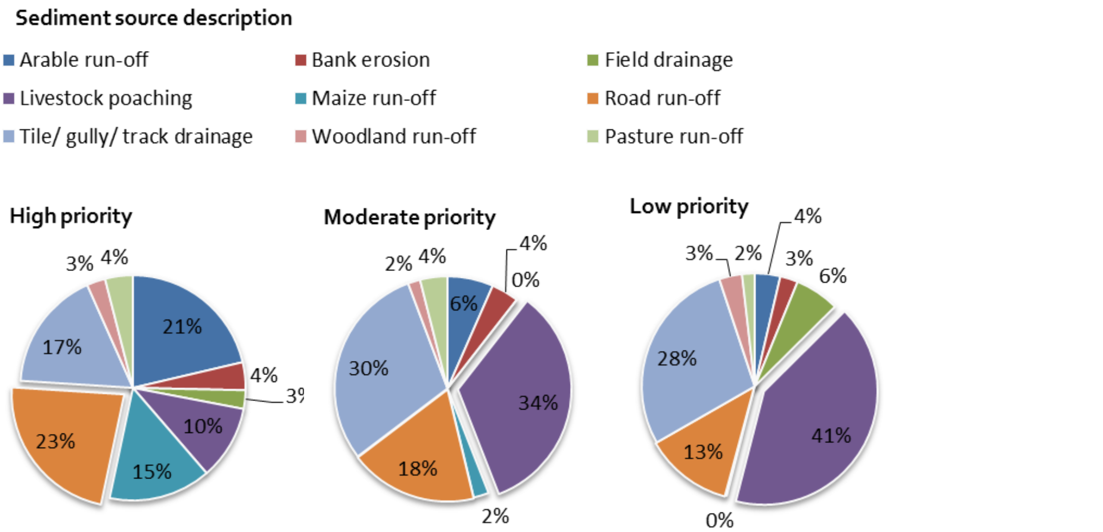
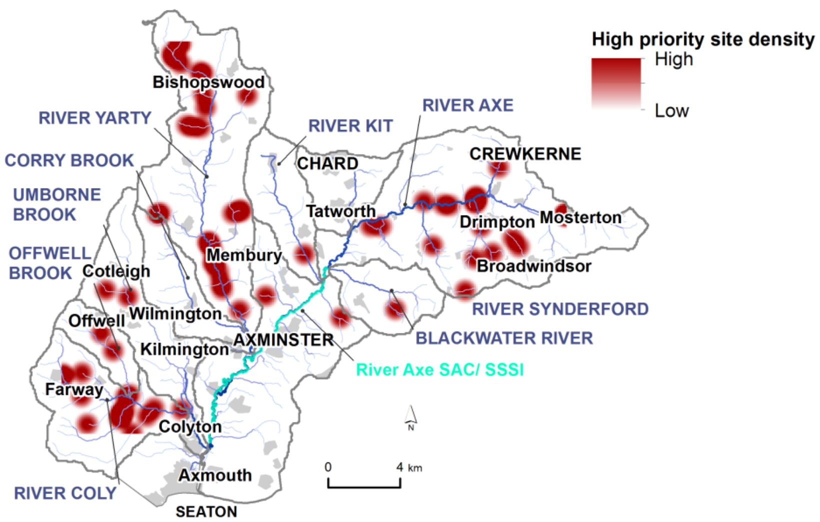
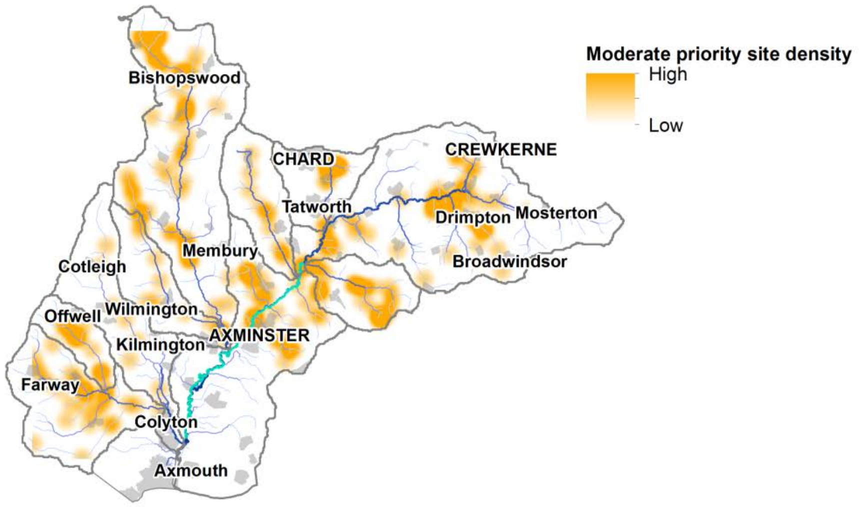
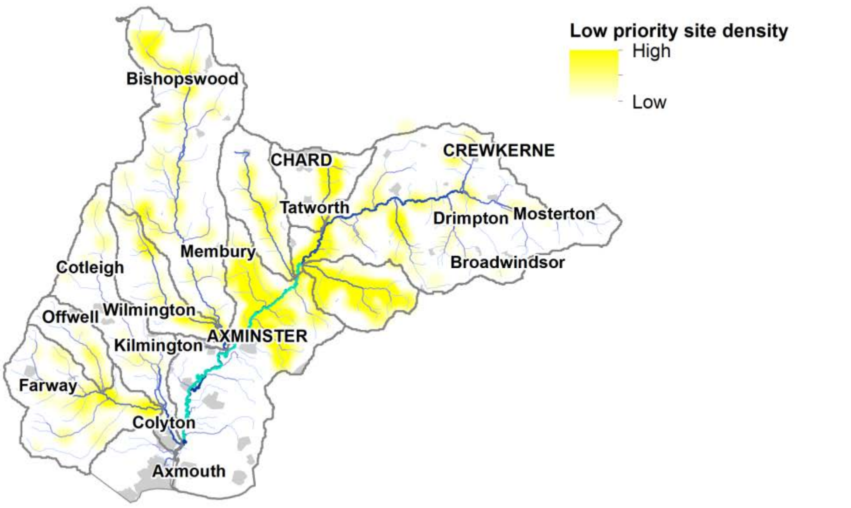


Figure 21: *Density of high risk sediment run-off areas, identified via walkover surveys (EA, 2009).*







5.2. Nutrients

For the purposes of this study we have focused our modelling and assessment of nutrients on phosphorus (P) containing compounds, which are having a deleterious impact on the status of the SAC/ SSSI.

There are two principal measures of phosphorus; these are soluble reactive phosphate (SRP), also referred to as orthophosphate, and total phosphorus (TP). The soluble reactive form is regarded as being biologically available and is the limiting nutrient that facilitates the growth of plants and algae. The insoluble fraction of total phosphorus is often associated with suspended solids in the water and is often ignored, but it can rapidly become biologically active through decomposition or solubilisation and there are many who believe that total phosphorus is the better or more complete measure of phosphorus load in rivers.

There are three principal sources of phosphorus compounds in a river catchment: (1) point agricultural sources, (2) diffuse agricultural sources and (3) point anthropogenic sources. The potential for these sources to generate nutrient pollution in the Axe catchment are described in the following sections.

5.2.1. Water quality analysis

Within the Axe River SAC/ SSSI, phosphorous can have an impact on water quality and biological integrity via enhancement of algal and plant growth. Excess phosphorus can have a significant impact on the general ecological health of the aquatic ecosystem of the river (especially at a localised scale). In particular, phosphorus pollution has been linked with eutrophication, which depletes oxygen and light availability within the water column as a result of excessive production of algae. In some instances continued pressures from phosphorus associated nutrient enrichment can reach a critical point where the composition, richness and abundance of floral and faunal communities can be altered. In the United Kingdom, phosphorus is the limiting nutrient in freshwater environments, thus, aquatic systems are thought to be more sensitive to relatively small changes in phosphorous concentrations.

Water quality monitoring data obtained from the Environment Agency indicate that the SRP concentrations exceed the annual average current WFD Environmental Quality Standard (EQS) of 0.12 mg/L as well as the tighter standards set within the River Axe SAC/SSSI itself.

We have looked at long-term Environment Agency monitoring data to identify trends in SRP concentrations (Figure 23). Interestingly, annual SRP averages across the assessed monitoring sites have generally been decreasing between 2005 and 2013. Despite the decreasing SRP trends, concentrations are still significantly higher than SAC/SSSI ESSs as shown in Figure 23.

Figure 22: *Locations of Environment Agency SRP monitoring sites analysed in Figure 23.EA water quality reference code (in parentheses).*

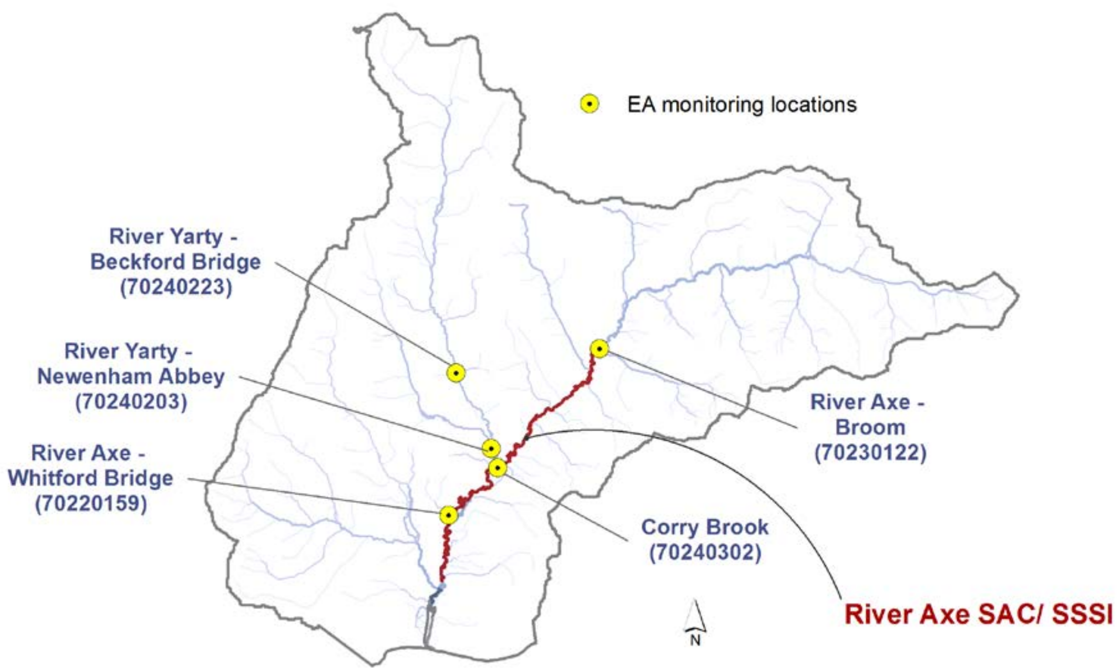
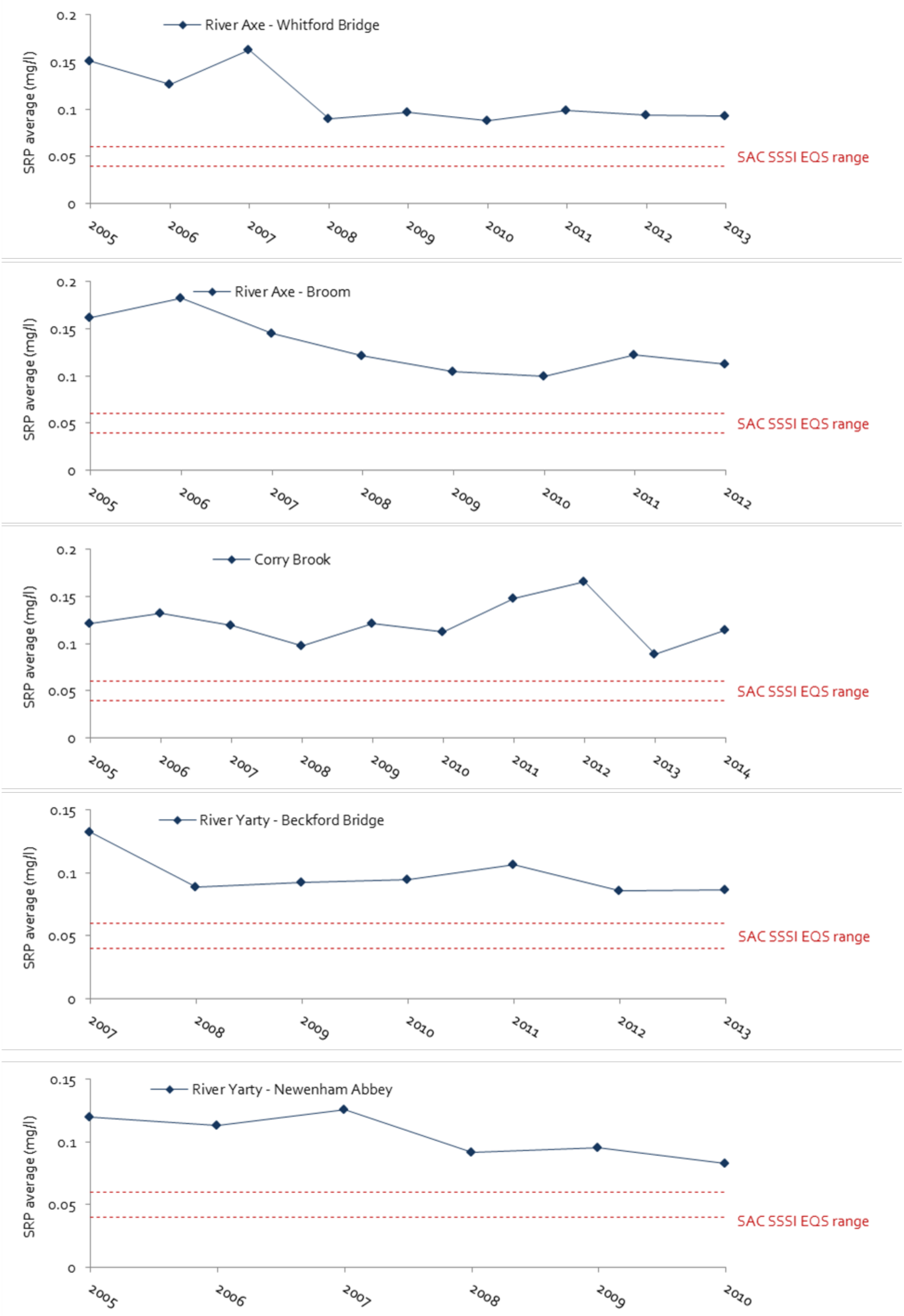


Figure 23: *Long-term SRP annual average trends in relation to WFD and SAC/SSSI Environmental Quality Standards (EQS) in the Axe catchment.*



5.2.2. Phosphorus risk analysis

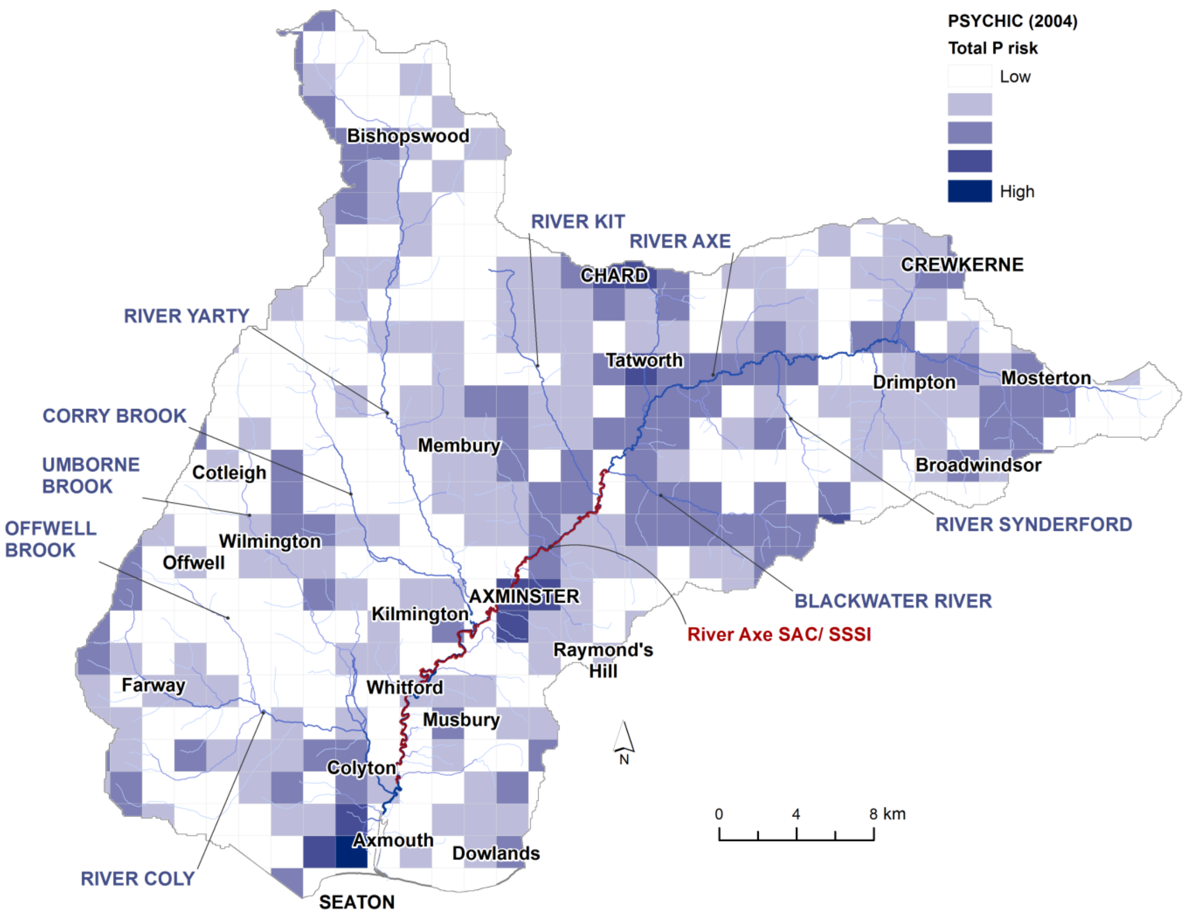
To assess the distribution of phosphorus pollution risk across the River Axe catchment, we have used the **P**hosphorus and **S**ediment **Y**ield **CH**aracterisation **I**n **C**atchments (**PSYCHIC**) model developed by a consortium of academic and government organisations led by ADAS (Davison et al., 2008).

PSYCHIC is a process-based model of phosphorus and suspended sediment mobilisation in land run-off and subsequent delivery to watercourses. Modelled transfer pathways include release of desirable soil phosphorus, detachment of suspended solids and associated particulate phosphorus, incidental losses from manure and fertiliser applications, losses from hard standings, the transport of all the above to watercourses in under-drainage (where present) and via surface pathways, and losses of dissolved phosphorus from point sources.

The model can be used at two spatial scales: the catchment scale, where it uses easily available national scale datasets to infer all necessary input data, and at the field scale, where the user is required to supply all necessary data. The model is sensitive to a number of crop and animal husbandry decisions, as well as to environmental factors such as soil type and field slope angle. The catchment-scale model, output from which has been used here, is designed to provide the first tier of a catchment characterisation study, and is intended to be used as a screening tool to identify areas within the catchment which may present elevated risk of phosphorus loss.

The PSYCHIC output in Figure 24 serves as an illustration rather than a tool in this report, as the data is from 2004.

Figure 24: *Total P risk maps derived from the PSYCHIC phosphorus risk model.*



5.2.3. Point sources – agriculture

Point sources of nutrient pollution from agricultural sources include farm infrastructure designed to store and manage animal waste and other materials such as animal food. Key infrastructure includes dung heaps, slurry pits, silage clamps, uncovered yards, feeding troughs and gateways. Animal access points to the watercourse can also lead to the direct delivery of P compounds to the water and to their mobilisation following channel substrate disturbance.

We have consulted farm advisors, who have reported that lack of slurry storage is a major problem in the Axe catchment, particularly in the Blackwater sub-catchment. In addition, livestock poaching and watercourse access maybe contributing to point sources of P within the Axe catchment.

Efforts have been made to fence off rivers to discourage poaching and voiding. However, due to the cost of infrastructure such as bridges, pathways and access to rivers is still a problem in the catchment.

5.2.4. Diffuse sources – agriculture

When manure, slurry or chemical phosphorus-containing fertiliser are applied to land prior to or following rainfall it can run-off into a watercourse. Intensive farming of heavy soils or the absence of a cover crop during wet periods increases the likelihood of fine sediment and associated phosphorus mobilisation and transfer.

The intensive farming practices undertaken throughout the Axe catchment result in a potential risk of P transfer to the receiving waters. The land-use data shown previously indicate that there are significant areas of improved/temporary grassland and arable production throughout the catchment which present a potential source risk. Small scale slurry injection interventions have taken place on the Axe to reduce P run-off from slurry. However, there are still a large number of farms which apply slurry directly on to fields, leading to increased risk of P run-off.

Along with diffuse agricultural sources, release of P which has build-up in river bed sediments can be a source of in-stream P pollution. It should also be noted in the Axe catchment that the Greensand bedrock which underlies river channels can be rich in P compounds, which can increase background P levels. Little research has been carried-out to assess P release from Greensand bedrocks. However, greensand bed rock has recently been identified as a potentially significant source of P in the headwaters of the River Avon, Wiltshire. Natural levels of SRP have been measured as around 0.025 mg P L^{-1} (Meybeck (1982), with overall contributions of around 0.1 kg P ha−1 yr^{-1} in a review of rivers around the UK (Withers and Jarvie, 2008).

5.2.5. Point sources – consented & unconsented discharges

Treated sewage effluent presents another significant source of readily bioavailable phosphorus delivered directly to the receiving water via an end-of-pipe discharge.

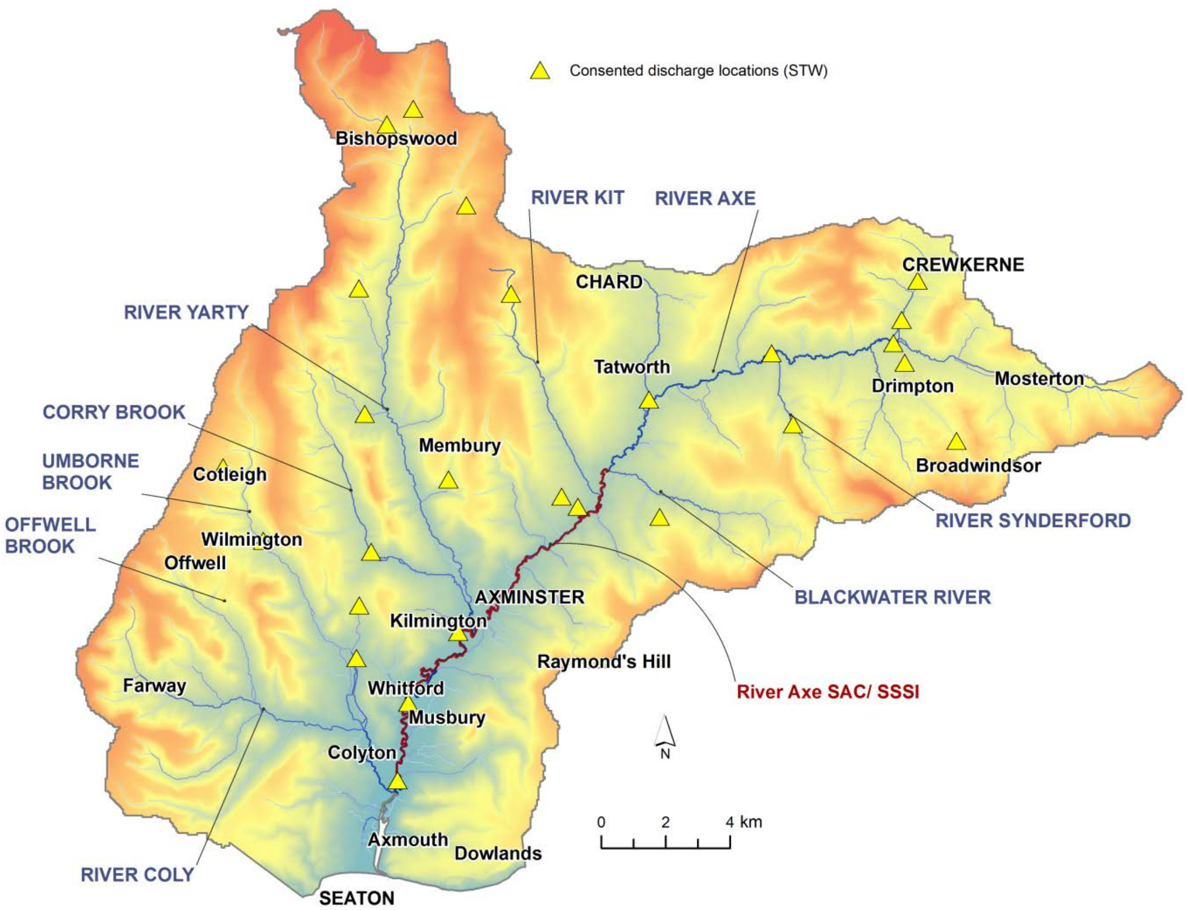
The principal sources of phosphates in sewage are human faeces, urine, food waste, detergents and industrial effluent which enter the sewer system and are conveyed to a sewage treatment works (STW).

Typical sewage treatment processes generally remove 15-40% of the phosphorus compounds present in raw sewage. Advanced / tertiary treatment, usually in the form of chemical dosing with a precipitant (e.g. Iron or Aluminium Sulphate), can remove up to 95% of phosphorus compounds.

In rural catchments like the Axe with a relatively small and dispersed population there are many smaller sewage treatment facilities (sewage treatment works or septic tanks). Both in isolation and combined these can make a significant contribution to in river phosphorus loads and concentrations, both locally and to the overall catchment budget. As continuous point discharges the relative contribution of these sources tend to increase during base / low flow periods as the dilution ratio lowers.

The effluent discharge points of many sewage treatment facilities now have an environmental permit or discharge consent associated with them, but there are still many small STWs and septic tanks which are not registered and which do not have numerical discharge consents.

Figure 25: *Distribution of consented discharges in the Axe catchment.*

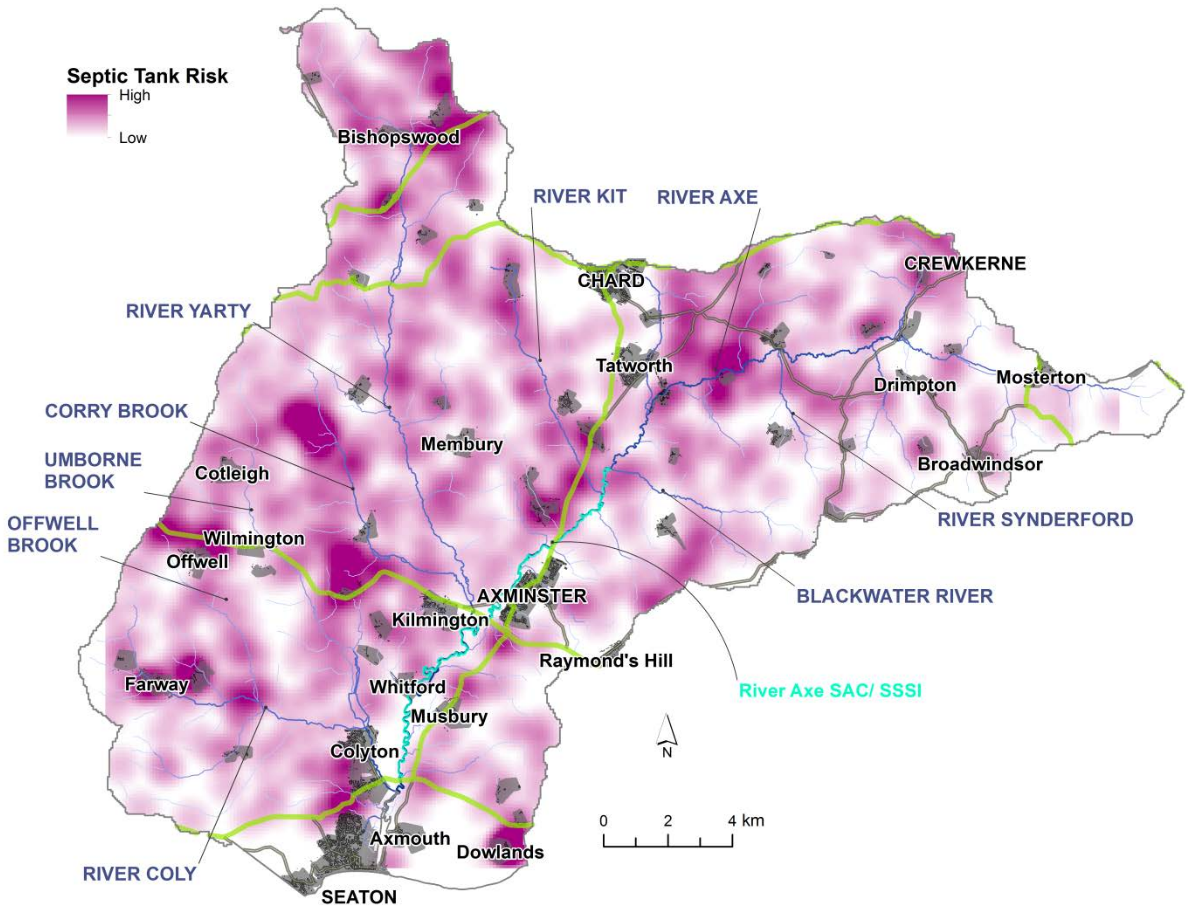


As Figure 26 illustrates, there are a number of additional potential discrete point sources which could be making significant nutrient contributions to the watercourses in the catchment and having some impact on their ecological health and, potentially, contributing to degradation in the Axe SAC/ SSSI.

Among these point sources are a number of properties which may have unconsented septic tank discharges. An analysis of property locations compared to the South West Water sewerage network and the Environment Agency Consented Discharges datasets reveals that there are ~500 properties further than 250m from both a sewer network and that ~50 of these are within 50m of a watercourse. These potentially higher risk properties need to be investigated and checked to ensure any septic tanks are being operated optimally and that they are not polluting the receiving water. The distribution of these potential un-consented discharges is shown in Figure 26. A more detailed map could be produced to show the precise location of properties which are not within 250m of the sewage network.

A similar approach to this mapping, with post code locations, could be used to identify specific properties for targeting visits.

Figure 26: *Distribution of properties with and without consented discharges, which are not on the sewer network.*



5.2.6. Pollutant load analysis

Having characterised where the greatest phosphorus export risk may be present in the Axe catchment, Environment Agency water quality monitoring data collected at 18 locations in the catchment between 2009 and 2012 was assessed to identify which areas were making the greatest contribution to in-stream phosphorus concentrations / loads (monitoring location shown in Figure 27b).

Figure 27 shows the average SRP concentration (the measure used by the Environment Agency for their WFD assessment of nutrient load) recorded between 2009 and 2012. Figure 28 shows average TP concentrations measured by the Environment Agency at two locations. The Environment Agency does not routinely measure total phosphorus in their statutory monitoring programme.

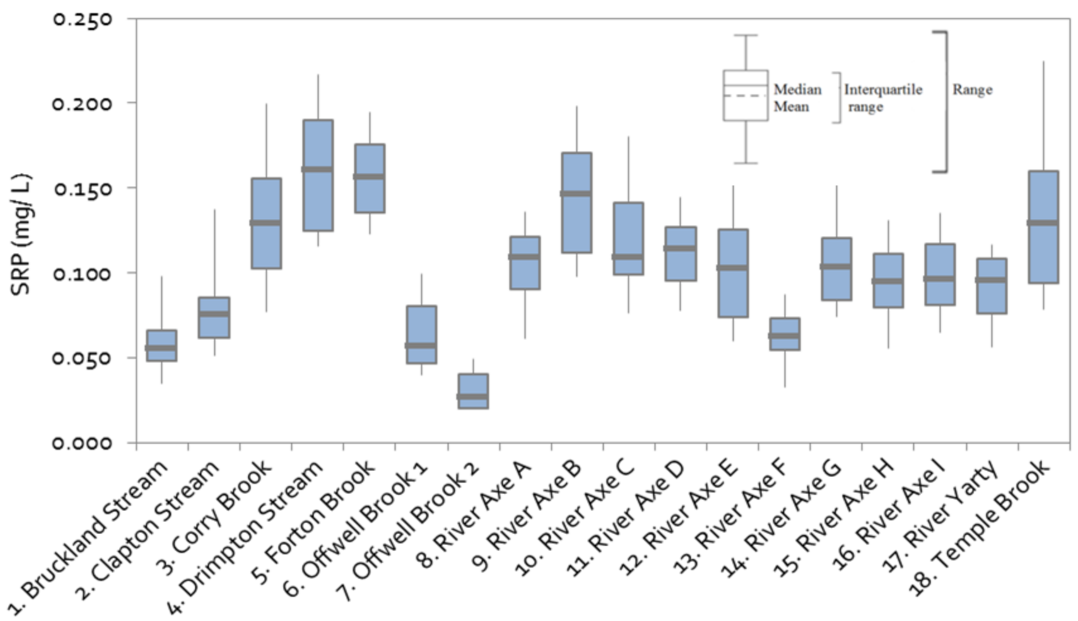
This data clearly confirms that the average levels of SRP exceed SAC/SSSI (0.05 – 0.06 mg/L) and WFD targets (0.12mg/L) across all but five of the monitoring locations in the catchment. SRP concentrations >0.08 mg/ L have been show to lead to algal blooms (Mainstone et al., 2000).

From the modelling data available for this analysis, the highest recorded average SRP concentrations were found in Drimpton Stream, Temple Brook, Corry Brook and River Axe A. Sediment fingerprinting and SCIMAP targeted delivery of intervention measures in these sub-catchments therefore has the greatest potential to reduce elevated phosphorus concentrations in the River Axe SAC/ SSSI.

Not all water quality monitoring points had comparable long-term SRP data. Thus, only those which had data between 2005 and 2012 were included in Figure 23. The water quality monitoring points used in Figure 23 are not all the same as those in Figure 27, which includes sites with SRP data for 2009 – 2013.

Figure 27: (a) Variation in soluble reactive phosphorus (SRP) concentrations at 18 locations in the Axe catchment. **(b)** *EA SRP monitoring locations.*

(a)



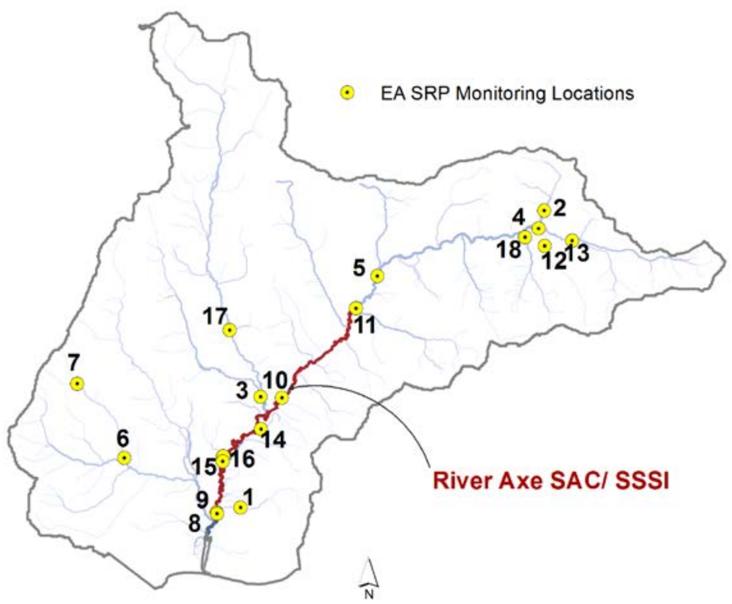
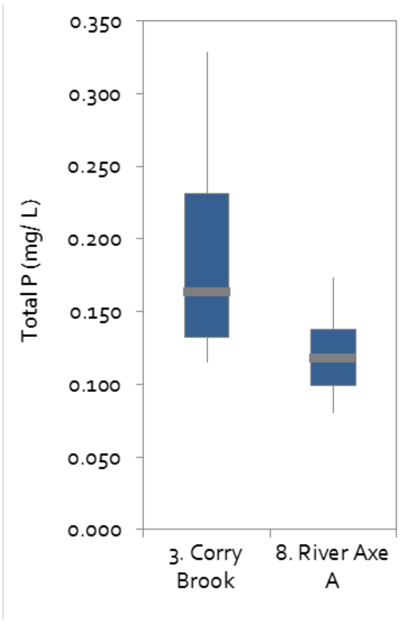


Figure 28: Variation in total phosphorus (TP) concentrations at 2 locations in the Axe catchment.



5.2.6. Source Apportionment

There a number of models available that can be used to estimate the relative contribution to in river phosphorus loads and concentrations from different sources / sectors. These estimates help to put the diffuse source contribution in context with that of other sector sources and are thus useful in targeting measures at the dominant sources / sectors. In many cases it may be that a combination of measures applied across multiple sources is required to meet a conservation objective.

The output from two such models has been made available to inform this project, these are:

- Source Apportionment GIS (SAGIS) – A high level modelling framework based on the best available datasets with National coverage. SAGIS has predominantly been used for strategic planning; for example, to inform policy decisions or run scenarios at the National or regional scale. The model has been refined using 'localised' data in some regions / catchments but this has not yet been undertaken in the South West of England, which means that the outputs made available for this study are based on default data and have only been calibrated at the National scale.
- SIMCAT – Setup on the Axe catchment by local Environment Agency staff with specific knowledge of the catchment, water industry assets and industry discharges. The initial driver for developing this model was to support the Habitats Review of Consents process, though the model has since been updated in 2010 to inform river basin planning.

Outputs from both models provide a comparative assessment of the contribution from point versus diffuse sources and thus are useful in informing the extent of the measures required across these sectors and where these are best targeted. However, outputs do not provide a direct comparison as SAGIS and SIMCAT are calibrated at different scales (national vs catchment) and time periods (2005 – 2009 and 2006 – 2008, respectively). Figures 29 (a) and (b) show the predicted verses observed SRP concentrations for the periods modelled in SAGIS and SIMCAT.

Figure 29 (a): *Predicted verses observed SRP concentrations from SAGIS modelling for the Axe catchment for 2005 - 2009. * Observed SRP monitoring data not available.*

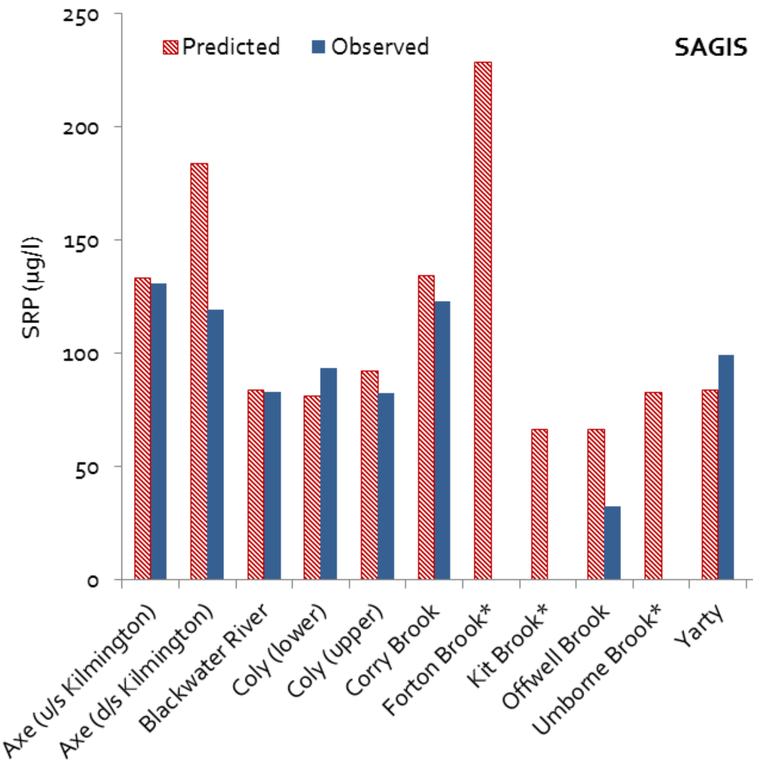
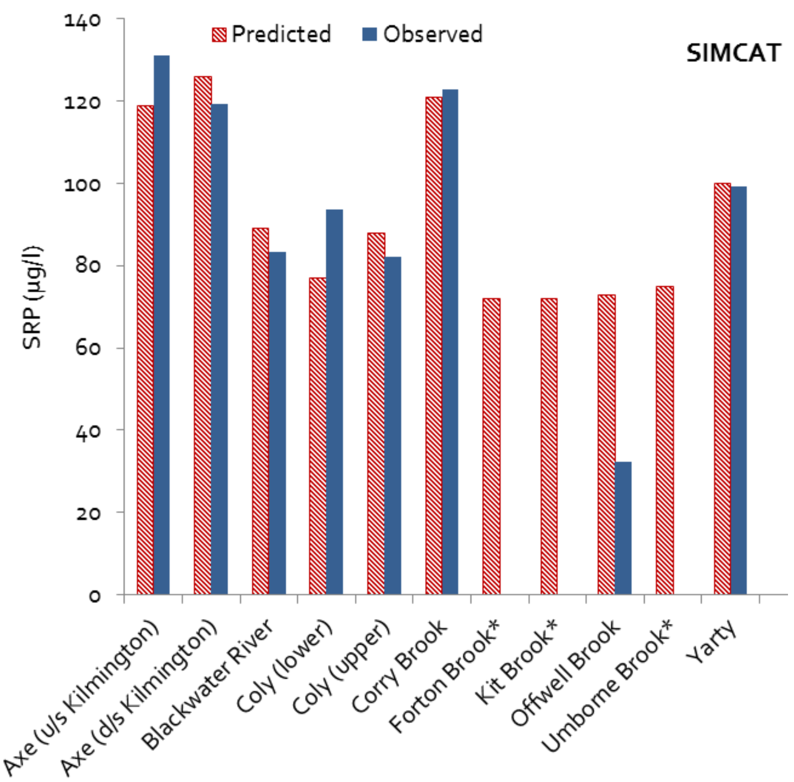


Figure 29 (b): *Predicted verses observed SRP concentrations from SIMCAT modelling for the Axe catchment for 2006 - 2008. * Observed SRP monitoring data not available.*



SAGIS

SAGIS implicitly estimates the contributions from different sector sources based on observed / modelled data, rather than by difference. However, in the National phosphorus calibration, made available for this study by the Environment Agency, point sources are treated as known and diffuse inputs amended. Whilst the relative contribution between different sectors is preserved, outputs are lumped together and thus provide only the total diffuse contribution, which includes agriculture and urban sources. However, agricultural sources in a rural catchment like the Axe are considered to make the main contribution to the total diffuse P load. The output is calibrated against observed in-stream annual average concentrations between 2005 and 2009.

SAGIS (see Figure 30) illustrates the Upper Axe catchment has the highest overall SRP inputs, specifically near Chard and Drimpton. SAGIS indicates that diffuse sources (agriculture and urban combined) make a significant (>50%) contribution from to the annual average SRP concentration. Figure 30 also provides an indication of the extent of the improvement required, in percentage terms, to meet WFD EQS along with an indication of the accuracy of the calibration against observed Environment Agency monitoring data for 2005 – 2009.

STW locations are shown with symbols proportional to the population equivalents they serve. Following the Review of Consents under the Habitats Directive, remedial works at Kilmington STW were carried out in March 2008 to reduce phosphorus output. This improvement is not included within the SAGIS where a default value of 3.425 mg/l is used for the total phosphorus concentration in the effluent, well above the existing 1 mg/l consent. As a result the current point source contribution will be over-estimated by SAGIS in the Lower Axe catchment.

Figure 30: *SAGIS modelled source apportionment data for the period 2005 – 2009. Monitoring points are located at the exit of each waterbody. Map includes STW and industrial discharge locations sized by population equivalents. Sub-catchments are shaded according to percentage reduction required to bring SRP concentrations within SAC/ SSSI EQSs.*

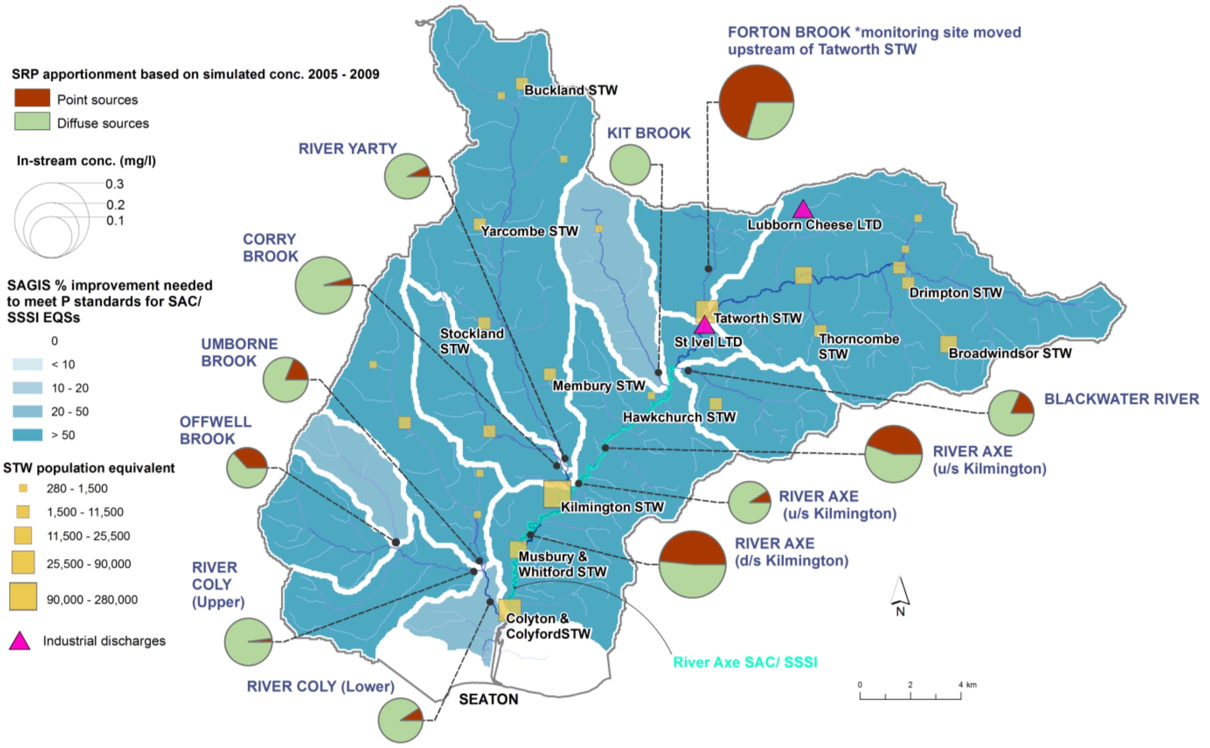


__Figure 31:__ SAGIS P mitigation opportunity map, based on SAGIS modelled source apportionment data for the Axe catchment, 2005 – 2009, including an indication of model accuracy.

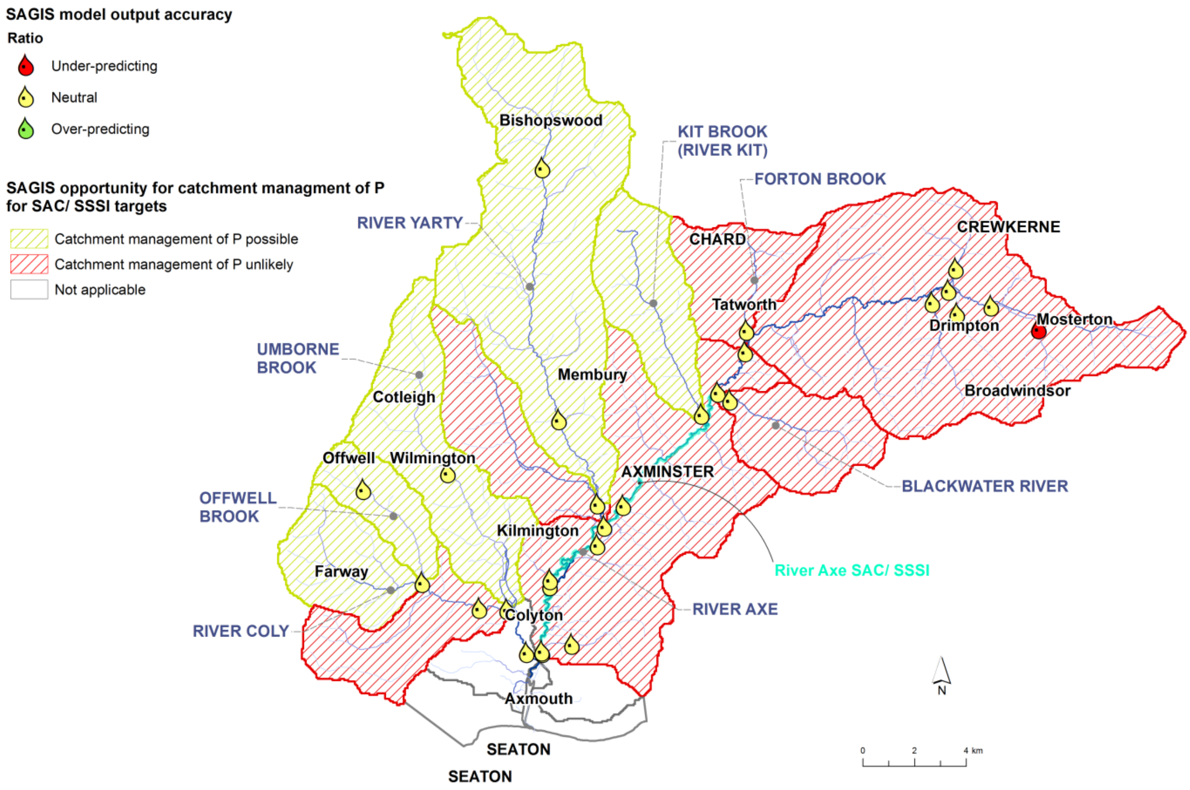


Figure 31 provides an indication of where catchment management may be a viable alternative or even complement end of pipe treatment. This is a high level assessment based on both: the modelled P inputs from diffuse agricultural and urban sources; and the average modelled P concentrations relative to SAC/ SSSI EQS standards. If the percentage improvement needed to meet SAC/ SSSI EQS's for P is less than 50 % and the diffuse source contribution is greater than 50 % then catchment management of P is deemed to be a viable option. Sub-catchments where P concentrations are within SAC/ SSSI EQSs are not highlighted, although it is important to note some level of management may still be required to help prevent deterioration.

The model output highlights that a number of sites require large >50% reductions in SRP to bring concentrations within EQSs for the SAC/ SSSI. SAGIS outputs indicate that SRP concentrations in the Blackwell River, River Yarty, Offwell Brook and River Coly exceed SAC/SSSI EQSs by around 20%, and therefore in these areas catchment management may be possible. The model output suggests that reductions in diffuse sources alone are unlikely to bring in-stream SRP concentrations within SAC/ SSSI EQSs for the Upper Axe and the Corry Brook sub-catchments and in these catchments further reductions in the point source loads are also likely to be required to meet the EQS.

Figure 31 also gives an indication of the accuracy of the calibration by providing a comparison against observed Environment Agency monitoring data for 2006 - 2009.

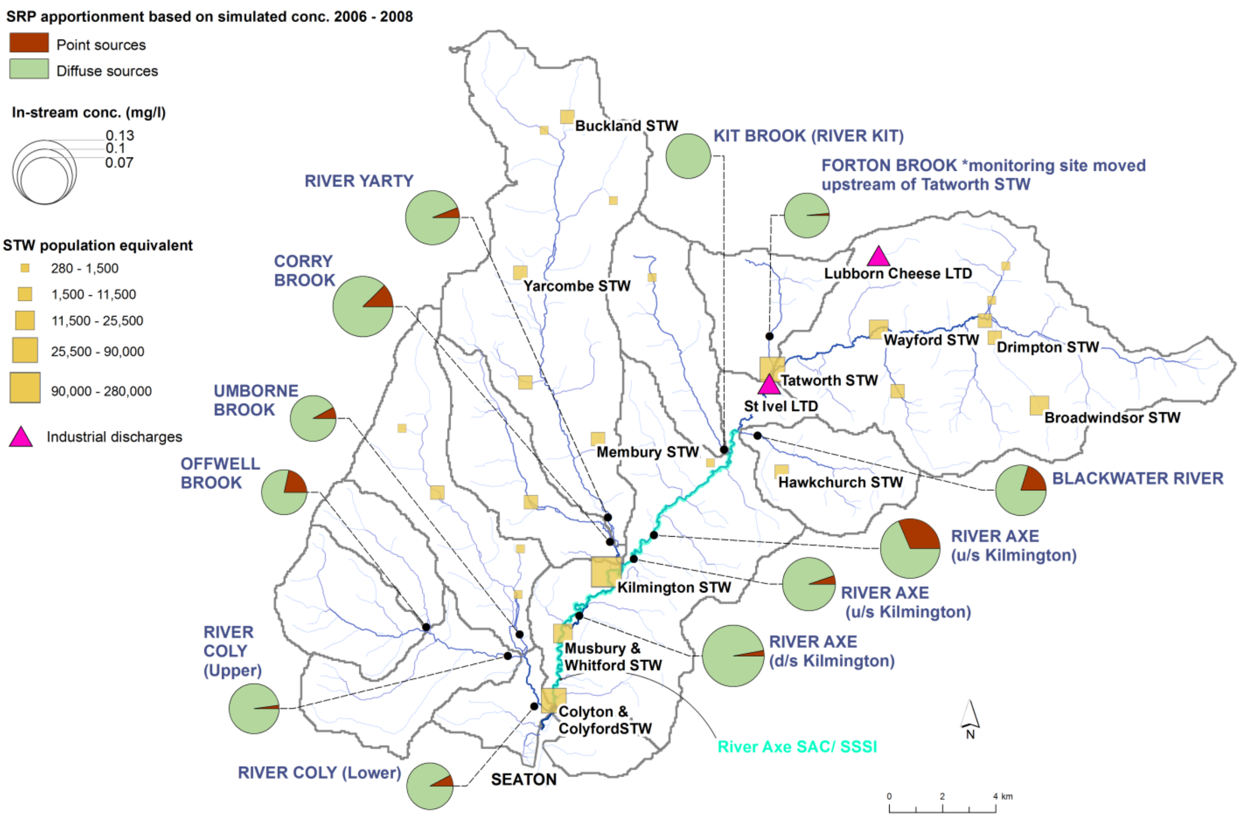
SIMCAT

Based on SIMCAT modelling for the period between 2006 and 2008, agricultural diffuse pollution makes the dominant contribution to the elevated SRP concentrations across all waterbodies in the Axe catchment.

Scenario modelling indicates that even by removing all point source discharges the diffuse contribution alone causes water quality concentrations to exceed the EQS (0.05 – 0.06 mg/L) in the SAC/ SSSI.

This finding is not particularly surprising as diffuse concentrations used by SIMCAT range from 0.06 to 0.140 mg/L, with a default value of 0.11 mg/L, all well above the EQS. The diffuse component estimated using SIMCAT is effectively derived by difference and so incorporates all non-point sources, including urban diffuse and septic tanks. Septic tank contributions are estimated to be in the order of 2%, based on data from the Hampshire Avon.

Figure 32: *SIMCAT modelled source apportionment data for the Axe catchment, based on 2006 – 2008 EA monitoring data. Monitoring points are located at the exit of each waterbody.*



It is important to note that outputs from SAGIS and SIMCAT are not directly comparable as models are calibrated against different model and scales (i.e. National for SAGIS versus local for SIMCAT) and use different base data and underlying assumptions. These differences do, however, provide an indication of the uncertainty associated with catchment scale models. Due to the local calibration of SIMCAT, outputs from this model are perceived, by local EA staff, to be more accurate.

Despite these issues, the outputs from both models are broadly in agreement for most waterbodies and indicate that agricultural diffuse sources represent the dominant contribution to nutrient loads across the Axe Catchment (Figures 30 and 32).

Point source contributions tend to be a little higher using SAGIS, ranging from 37% in Ofwell Brook to 45-49 % in the main channel of the Axe itself, compared to around 20 – 30 % using SIMCAT. Since in both models the diffuse loads are effectively determined by difference this is likely to reflect a difference in point effluent load themselves.

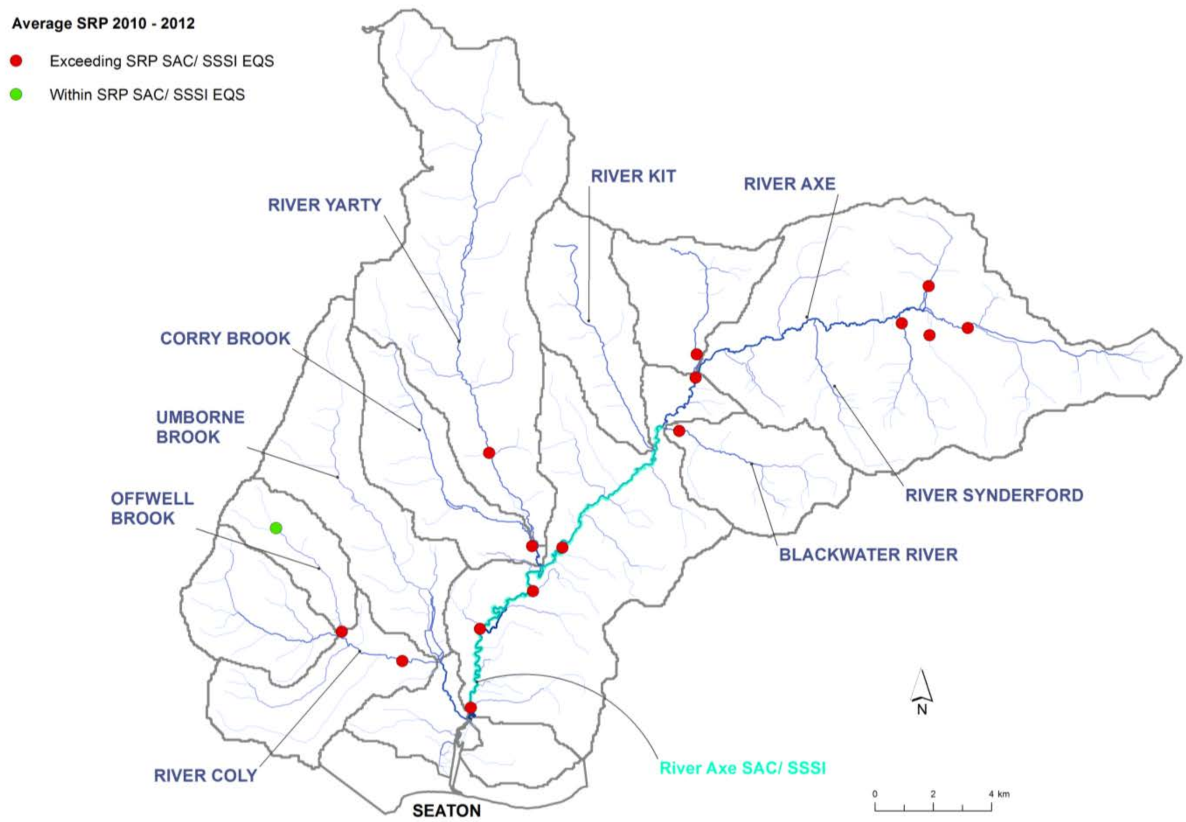
Effluent concentrations and flows behind SAGIS are based on continuous flow monitoring for the Environment Agency's quality controlled monitoring certification scheme (MCERTS) and where available spot water quality samples. In the absence of a local calibration it is not possible to ensure that SAGIS captures the latest consent conditions and that all discharge points are correct. SIMCAT also uses observed data to derive summary statistics for effluent concentrations, whilst flows reflect those in the consent (Dry Weather Flow x 1.25).

In the absence of access to the models themselves or the data that underpins them it is difficult to identify the definitive reason behind all the differences. The most marked difference in the estimate of the point source contribution is in Forton Brook, 70% using SAGIS versus 2% in the local SIMCAT model. This is due to the contribution from Tadworth STW which discharges immediately upstream of the waterbody outlet and thus makes a significant contribution to the concentration at the waterbody outlet in SAGIS. In the local SIMCAT model the load from Tadworth STW is added to the downstream reach to ensure the in-stream concentrations are more representative of waterbody as a whole.

Both models also incorporate the contribution from the St Ivel Creamery in the Forton Brook catchment. However, this is likely to be more accurate in the local calibrated SIMCAT model, since it is based on observed data following a reduction in both effluent flows and concentrations.

It is important to note that both the SAGIS and SIMCAT modelling outputs used in this report are a number of years out of date. A more recent reflection of the current statuses is displayed in Figure 33 based on more recent monitoring data (2010-2012).

Figure 33: *SRP EQS statuses in the Axe catchment, based in averages for 2010 – 2012 EA monitoring data.*



5.2.6. Population Growth

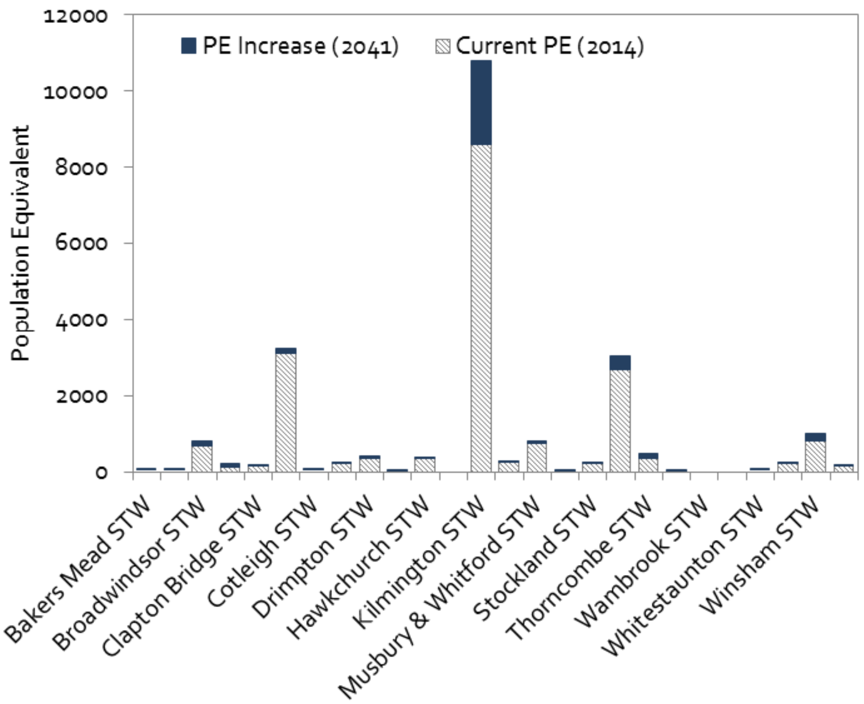
Population growth in the catchment has the potential to affect the relative contribution of point and diffuse sources to nutrient pollution of the watercourses in the catchment.

Both models rely on observed data summary statistics that best reflect the current effluent concentrations. SIMCAT uses the consented flow conditions and thus presents the worst case scenario. SAGIS uses actual MCERTS flow monitoring data, which for some STW has been found to be higher than consented flows, though it is not clear whether this is the case in the Axe catchment.

There are currently no planned changes to existing or new phosphorus consents in the Axe catchment and therefore it is not anticipated that the current consented point source load will change prior to 2020 (the duration of AMP6). This already accounts for the predicted population increase across the catchment since the Environment Agency are likely to require a tightening of the effluent quality in order to achieve load standstill, where effluent flows do exceed the current consent.

Unfortunately data on flow or water quality headroom at individual STW has been requested but has not been provided for this study. However, discussions with SWW do indicate that they do not envisage any difficulties in accommodating growth in the catchment based on known developments and historic population trend data.

Figure 34: *Summary of SWW projected growth in population equivalent within each sewerage catchment.*



6. Intervention strategy development

Before we can proceed with the development of a management programme for diffuse pollution within the Axe catchment, we must first gather precise and detailed evidence of what plans are in place and what interventions have already been delivered across the catchment.

6.1 Prior interventions

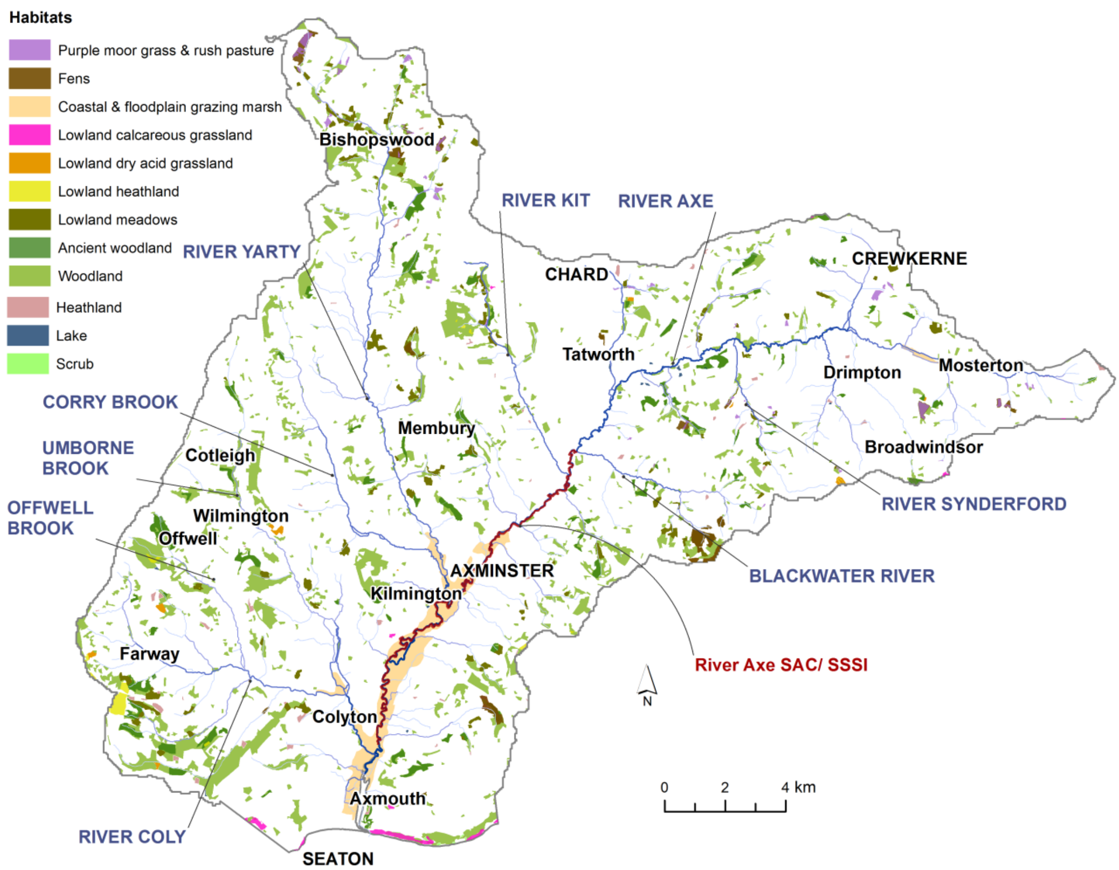
6.1.1. Natural mitigation & designated sites

Natural habitats play a key structural and functional role in the ability of our natural ecosystems to provide the services on which we all depend; including the protection of clean, fresh water in our rivers and streams, the mitigation of flood risk and the prevention of erosion.

Extending and increasing the connectivity of existing natural habitats across catchments, in addition to the creation of new riparian wetlands to disconnect hydrological pollution pathways, are some of the key methods used in catchment management and natural resource protection.

Data obtained from the Natural England habitat inventory (Figure 35a), indicate that there are ~111 Ha of heathland and ~5,065 Ha rough/moorland grazing habitat in the Axe catchment.

Figure 35a: *Distribution of important natural habitats in the Axe catchment.*



Under the Conservation (Natural Habitats) Regulations 1994, the UK is committed to the designation and protection of three types of internationally important conservation sites: Special Areas of Conservation (SACs), Special Protection Areas (SPAs) and Ramsar Sites. No SPAs or

Ramsar sites exist within the Axe catchment. The designated stretch of the River Axe is the only SAC within the catchment.

The designation and protection of land that is important for nature conservation has historically been one of the key methods used to protect and conserve the natural environment in the UK.

In an attempt to increase the benefits obtained from the protection and expansion of the designated site network in the Westcountry, Biodiversity South West are adopting a more integrated landscape-scale approach to nature conservation. They have identified a series of Strategic Nature Areas that are being prioritised for conservation action through active partnership within and beyond the environmental sector. Their objective is to achieve the best environmental return for the optimum investment of resources.

Figure 35b shows the distribution of designated land across the Axe catchment. The entire catchment is designated as an Area of Outstanding Natural Beauty (ANOB). Including the River Axe itself, there are 20 designated SSSI sites within the catchment. The Exmouth to Lyme Regis undercliff site is the largest SSSI within the catchment ~125 Ha, followed by the River Axe SSSI which covers an area of 70 Ha. The River Axe is the only designated aquatic site within the catchment. The Dorset and East Devon coastline which the River Axe drains into is designated as a World Heritage Site.

Figure 35b: Distribution of sites designated for their conservation or heritage value in the Axe catchment.

6.1.2. Previous on-farm interventions: Environmental Stewardship

The Environmental Stewardship Scheme (ESS), incorporating the Entry Level Scheme (ELS), Organic Entry Level Scheme (OELS), the Uplands Entry Level Scheme (UELS) and Higher Level

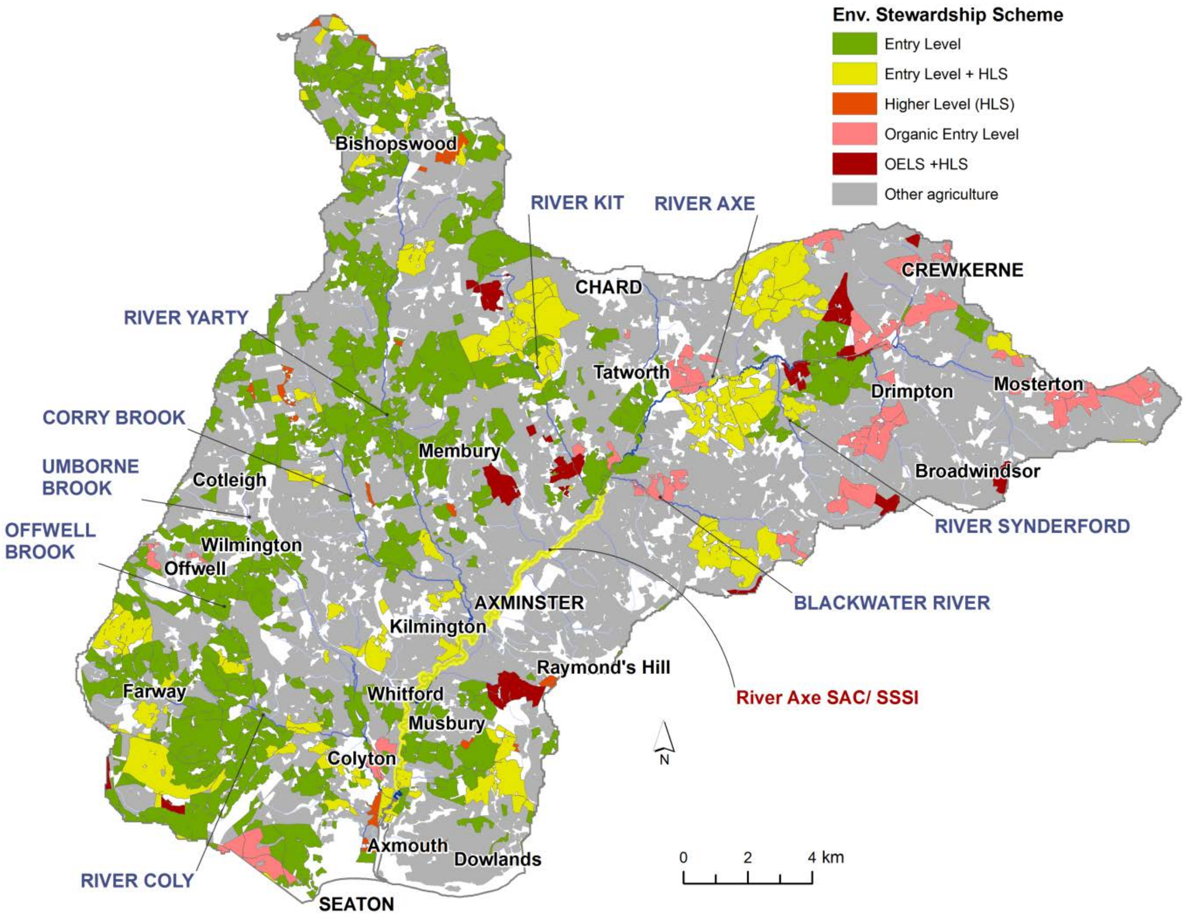
Scheme (HLS), provides payments to farmers to undertake specific management practices or capital works that protect and enhance the environment and wildlife.

The ESS is offered to farmers on a voluntary basis and is promoted as multi-objective scheme covering a range of biodiversity, heritage and natural resource protection objectives, including soil and water protection.

The ELS, OELS and UELS are non-competitive schemes and are open to all farmers whilst the HLS is a competitive scheme within which farmers must effectively bid for a share of a limited budget. According to Natural England personnel engaged with the project, HLS currently covers 10% of agricultural land across England and is increasingly focusing on SSSI sites and Habitats Directive designated areas.

Figure 36 shows the distribution of farm holdings currently in ESS across the Axe catchment. These data indicate that there are 30 farms in the catchment that are in Organic Entry Level or Organic Higher Level Environmental Stewardship schemes, around 6 that are in Higher Level Stewardship and the majority in Entry Level Schemes.

Figure 36: *Distribution of Environmental Stewardship schemes taken up by farmers in the Axe catchment.*



6.2. Diffuse pollution management

Diffuse nutrient and sediment pollution can result from various urban and rural sources. The catchment characterisation, water quality monitoring and SIMCAT/SAGIS modelling outputs presented in this report indicate that diffuse agricultural pollution makes a significant contribution to the ecologically damaging P and SS pollution in the Axe Catchment.

Therefore, implementation of a targeted diffuse agricultural pollution management plan would most likely provide the greatest water quality benefits to the Axe Catchment and, more specifically, the SAC/ SSSI. It should be noted, however, that while we are referring to all agricultural pollution as a diffuse, other literature sometimes refers to agricultural sources with discrete pathways, e.g. tile drainage and slurry spills, as point sources.

In order to manage agricultural pollution a now well established 'toolbox' of Best Farming Practices (BFPs) has been developed, which can be used to target P and SS pollution. When effectively implemented, BFPs can have a wide range of additional secondary environmental, social and economic benefits. For instance, a number of interventions used to tackle P and SS involve creation and enhancement of natural features, such as riparian buffer strips, which can provide habitats along with reducing pollution transport to water courses.

Habitat creation and subsequent biodiversity improvements in the wider catchment can also improve biodiversity in the SAC/ SSSI by reducing fragmentation and increasing genetic diversity and species networks. Furthermore, reduction of pollutants such as nitrogen, specifically nitrate, which is often associated with P sources, is a common secondary benefit of BFPs.

In designing BFP scenarios for P pollution, it is important to consider the form or species of P that is being targeted. Whilst the monitoring and modelling data in this report focus on SRP (dissolved P) concentrations in water, most of the total P load from agricultural practices is transferred to watercourses associated with particulate material. Once in the watercourse, particulate P can be chemically and biologically mobilised into a readily bioavailable form (i.e. SRP). Therefore, our interventions aim to reduce both particulate and dissolved P. As particulate P is often associated with sediment, BFPs aimed at reducing particulate P pollution may also have high potential to reduce SS pollution and vice versa.

Some of the main BFP 'toolbox' interventions are presented in Figure 37, where 'bad' farming practices are illustrated on the left, and 'good' farming practices on the right. Figure 38 provides a series of before and after photographic examples of on-farm interventions of this type, which have previously been delivered in catchments across the South West of England.

Figure 37: *Illustration of Best Farming Practices (BFPs) that can minimise loss of pollutants to watercourses as a result of agricultural activity.*

Soil management

- (A) Cultivate and drill across the slope
- (B) Avoid over-winter tramlines
- (C) Establish in-field grass buffer strips
- (D) Adopt minimal cultivation systems
- (E) Avoid high risk crops next to river

Livestock management

- (A) Reduce overall stocking rates on livestock farms
- (B) Reduce field stocking rates when soils are wet
- (C) Move feeders and water troughs at regular intervals
- (D) Construct troughs with a firm but permeable base
- Reduce dietary N and P intakes

Fertiliser management

- (A) Do not apply fertiliser to high-risk areas
  Avoid spreading fertiliser to fields at high risk time
- (B) Use clover in place of grass

Farm infrastructure

- (A) Fence off rivers & streams from livestock
- (B) Construct bridges for livestock crossing streams
- (C) Re-site gateways away from high-risk areas
- (D) Farm track management
- (E) Establish new hedges
- (F) Establish Riparian buffer strips
  Establish & maintain artificial wetlands

Manure management

- (A) Increase the capacity of farm manure (slurry) storage
  Install covers on slurry stores
- (B) Site manure heaps away from watercourses
  Site manure heaps on concrete and collect effluent
- (C) Minimise volume of dirty water and slurry produced

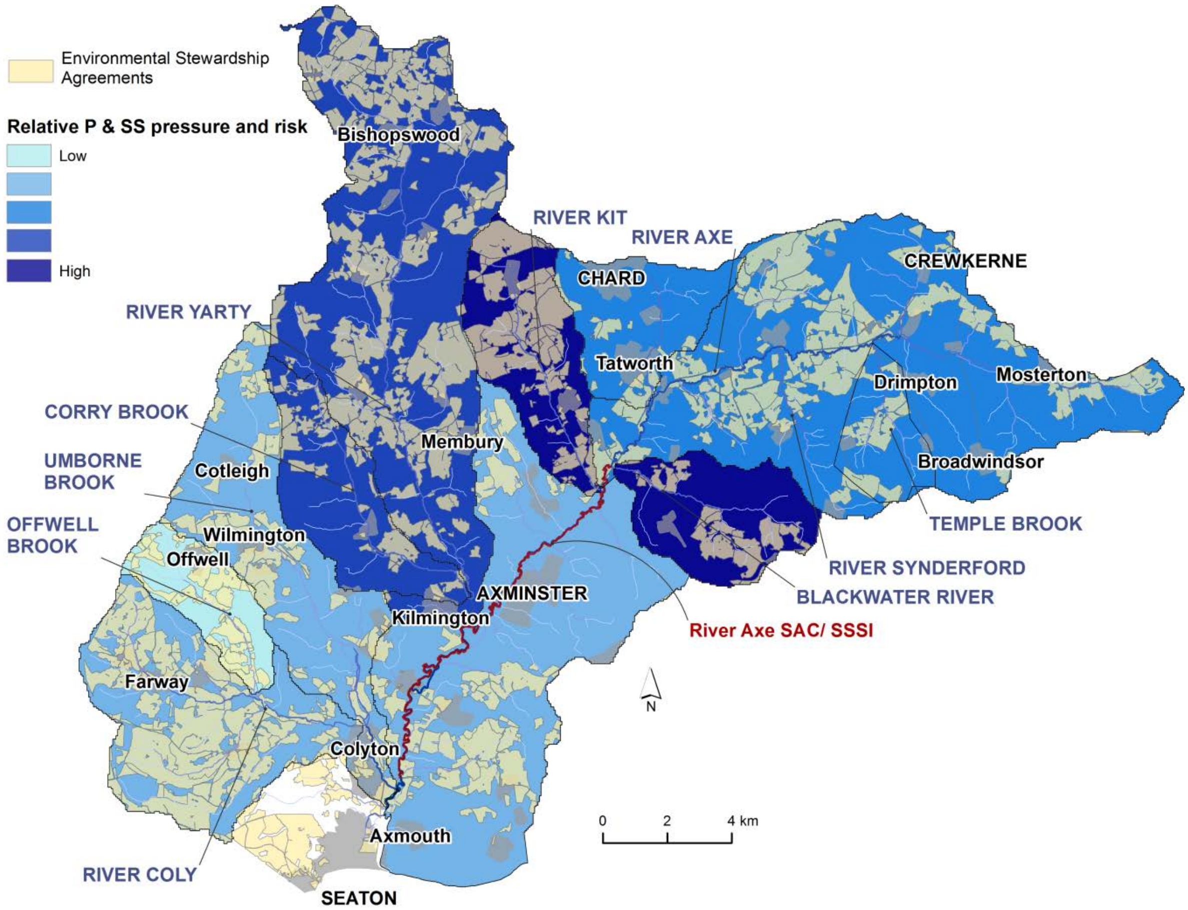
Figure 38: *Actual examples of Best Farming Practices (BFPs) that can minimise loss of pollutants to watercourses as a result of agricultural activity.*

The mapping, modelling and water quality analyses set out in this report have highlighted that diffuse P and SS pollution occur throughout the Axe catchment. Thus, application of BFPs could be carried-out across the catchment to achieve necessary P and SS reductions, particularly in SRP, which was found to be well above SAC/ SSSI EQSs in many locations. We have carried-out a GIS analysis of P and SS monitoring and modelling, along with current interventions to identify areas in the catchment where application of BFPs may result in greatest, and possibly more cost effective, reductions P and SS. The results of our analysis are presented in Figure 39.

To develop a map of high BFP impact locations involved firstly identifying areas with the greatest P and SS pressures and risks. Sites were then identified with the highest: (1) empirical SRP and SS concentrations from averaged EA monitoring data (2011 – 2013); (2) fine sediment erosion risk (top 10% risk from 10m SCIMAP); and (3) diffuse SRP inputs modelled in SAGIS (2005 – 2009) and SIMCAT (2006 – 2008). High P and SS risk areas have been identified on a sub-catchment basis to align the sampling and modelling resolutions of the underlying data.

To illustrate how this data could be used to target interventions across the whole catchment, the farms currently engaged in an Environmental Stewardship Scheme (ESS) have been overlaid on these areas of high P and SS pressures. These farms may be considered to represent an opportunity for the delivery of resource protection measures (either now or in the future) and the remaining areas could become priorities for ESS or other catchment management schemes in the future.

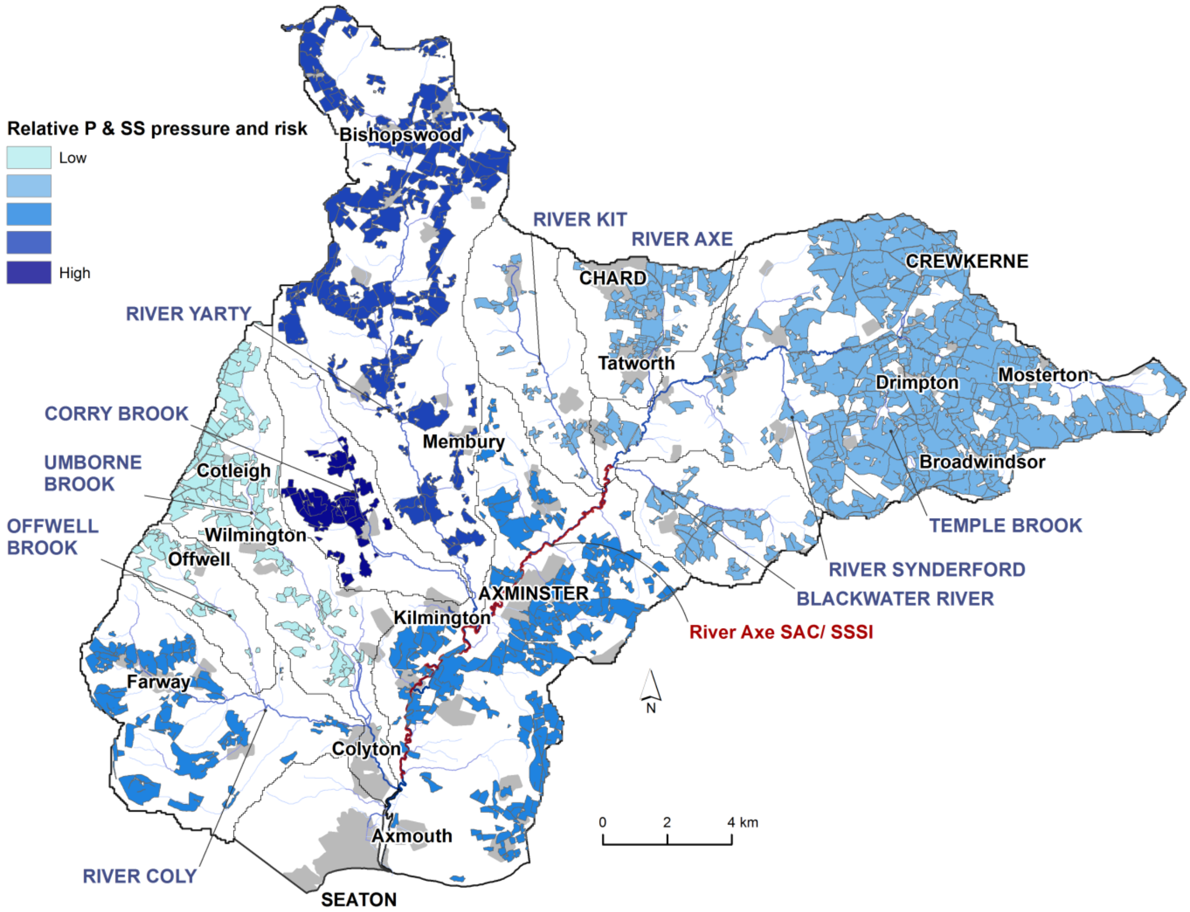
Figure 39: *Relative sub-catchment P and SS pollution risk based on EA water quality monitoring, SAGIS, SIMCAT and SCIMAP outputs with ELS uptake.*



The intervention target map in Figure 40 highlights a small cluster of farms in the Corry Brook sub-cachment with high diffuse P and SS pressures, which are not currently signed up to any ELS schemes.

Modelling suggests the Upper Axe sub-catchment has a medium relative P and SS risk, but the large area and number of farms here mean that P and SS loads may be more significant. The ADAS fingerprinting study presented in section 5 incidated that a majority of sediments found in the River Axe SAC/SSSI originated from the Blackwater and Temple Brook sub-cathcments, although this is only a snapshot. Therefore, whilst this analysis has not highlighted the Blackwater and Temple Brook as having the highest P and SS presures, they should be targeted in for management interventions.

Figure 40: *Intervention target farm locations and relative P and SS pollution.*



6.3. Deliverables and costs for proposed plan

In light of all of the findings of this investigation we have developed a high-level, costed intervention plan as an illustration of what level of intervention may be required (Table 2). These estimates are purely based on the number of farms. Through further investigation and farm visits, these numbers could be adjusted and any additional elements easily added to this structure as required. Locations for interventions should be targeted using the outputs from this report, specifically fine scale SCIMAP analysis, combined with walkover surveys and further field and in stream monitoring where necessary.

Table 2: *Approximate deliverables and costs for management in the Axe catchment. These are estimated numbers of deliverables based on the number of farms engaged, the uptake and average uptake. Costs are approximate and for guidance only as are based on the average cost of implementing these measures in similar catchments.*

Advice & testing	**Output**	**Unit Cost (£000)**	**Total Cost (£000)**
- Farm planning/advisory visits including full farm survey, farm advisory plan & capital grant offer / negotiations	200		
- Septic tank management plans survey and advice programme for septic tank best practice and management	75		
- Soil tests including full soil assessment on each farm according to EA standard, documentation and follow-up	200	0.5	**100**
- Water chemistry monitoring weekly or bi-weekly samples at 6 locations for 2 years (yrs. 1 & 5)	624	0.125	**78**
Total			**178**

Investments	**Output**	**Unit Cost (£000)**	**Total Cost (£000)**
- Fencing riparian corridor fencing (kms)	100	5	**500**
- Farm infrastructure slurry storage, tracks and crossing points, major clean & dirty water separation, roofing etc.	200	25	**5,000**
- Minor infrastructure alternative drinking, troughs, pumps, clean and dirty water separation etc.	150	1.0	**150**
Total			**5,650**

*** HR, delivery costs and overheads are not included here and all costs are rough estimates based on previous delivery

7. Assessment of outcomes

It is vital to collect sufficient evidence to provide an objective and scientifically robust assessment of the effectiveness of interventions. Ultimately, the weight of evidence should be sufficient to be able to justify that the money we have spent and the interventions made across the landscape have either delivered significant improvements in water quality (and have therefore made significant contributions to the conservation status) and have generated significant secondary financial, ecological and social benefits.

A range of approaches can be used that will allow a detailed assessment of the effectiveness of various outcomes delivered through catchment management work. This approach is designed to achieve the following objectives;

- ***Quantification of intervention delivery.*** Gather precise and detailed evidence of what has to be delivered, where it has been delivered, what it has cost and, perhaps most importantly, whether the intended outcome is for each.

- ***Monitor and evaluate environmental outcomes.*** Collect a comprehensive and robust set of data and evidence which demonstrates qualitatively and quantitatively that genuine improvements in water quality, and thus conservation status, have been achieved. In order to demonstrate the effectiveness of catchment management interventions, it is vital to collect baseline data (of the type presented in this report) and, in addition to temporal (before intervention) controls also explore the potential for some catchments/sub-catchments to form spatial controls. This approach should include a comprehensive evaluation of the current scientific literature relating to the likely outcomes achieved through the delivery of on-farm measures and the use of the most advanced modelling techniques which can be used to estimate the improvements in water quality that have been achieved.

- ***Monitor and evaluate secondary outcomes.*** In addition to demonstrating real improvements in water quality, an array of other outcomes can make considerable contributions to the conservation status of protected sites or towards other environmental or nature conservation targets. A number of monitoring and modelling approaches can be used to assess how catchment management can enhanced the provision of other ecosystem services across the catchment and to quantify the economic gains achieved by those engaged in the process.

7.1 Predicting outcomes: Farmscoper

Introduction

While the collection and collation of evidence for the environmental outcomes that can achieved through the delivery of catchment management interventions continues there are also a number of mathematical water quality models that we can use to predict the cumulative effects of implementing on-farm BFP measures at a catchment scale.

This section describes the results of the FARM Scale Optimisation of Pollutant Emission Reductions (FARMSCOPER) model, which has been used to assess potential P and SS reduction scenarios in the Axe catchment, along with guidelines for post implementation assessments.

The FARMSCOPER model is a decision support tool that can assess diffuse agricultural pollutant loads on a farm and quantify the impacts of on-farm measures on these pollutants (Zhang et al., 2012). FARMSCOPER allows for the creation of unique farming systems, based on combinations of livestock, cropping and manure management practices. The pollutants losses and impacts of mitigation measures can then be assessed for different farming system scenarios.

FARMSCOPER uses input farm data and representative farm types to provide a baseline for diffuse agricultural pollutant emissions. The effect of potential mitigation methods are expressed as a percentage reduction in the pollutant loss from specific sources, areas or pathways.

The effectiveness of mitigation methods are characterised as a percentage reduction against the pollutant loss from this baseline. The effectiveness values were based on a number of existing literature reviews, field data and expert judgement and are assumed to incorporate and an assumed level of uptake.

The effectiveness values for mitigation were allowed to take negative values, which represent 'pollutant swapping', where a reduction in one pollutant is associated with an increase in another. The tool also estimates potential consequences of mitigation implementation on biodiversity, water use and energy use.

Method

In this report, FARMSCOPER has been used to identify optimal mitigation scenarios to quantify the potential reductions for agricultural P and SS pollution within the Axe catchment and selected sub-catchments. Agricultural Census returns for the Axe catchment in 2010 were used to develop a typical farm for the Axe catchment. We have also run finer scale FARMSCOPER analyses on the Blackwater, Yarty, Corry Brook and Upper Axe sub-catchments, as these are areas which have been identified as having relatively high diffuse P and SS loads.

Other studies, such as Zhang et al. (2012), created a series of typical farm types within a catchment and multiplied the results by the number of farms for each type. As the Axe catchment is predominantly dairy farms, and dairy farms can produce high P loads, we have created a typical dairy farm for the whole of the Axe catchment. A dairy farm was selected as the base farm because the reductions associated which reduce P, which is a problem for the Axe, were more in-line with what would be expected when compared to a mixed farming base farm. For instance, under a mixed farm, increased slurry storage did not show any reductions in P, however, these interventions would be important for catchment management of P in the Axe.

FARMSCOPER has been used to test 3 different scenarios and estimate SS and P loads. The scenarios tested were:

- **Scenario 1:** Current emissions based on an estimate of the existing level of mitigation measures implemented. Current uptake was estimated based on local knowledge, ELS uptake and CSF interventions.
- **Scenario 2:** Maximum 100% uptake through implementation of optimised measures selected by FARMSCOPER.
- **Scenario 3:** 'Realistic' implementation measures based on local knowledge and 50% uptake of measures.

It should be noted that FARMSCOPER modelled costs detailed in this section, refer to the overall cost required to achieve the modelled reductions in pollutants, rather than a cost per area or time.

Results

Scenario 1

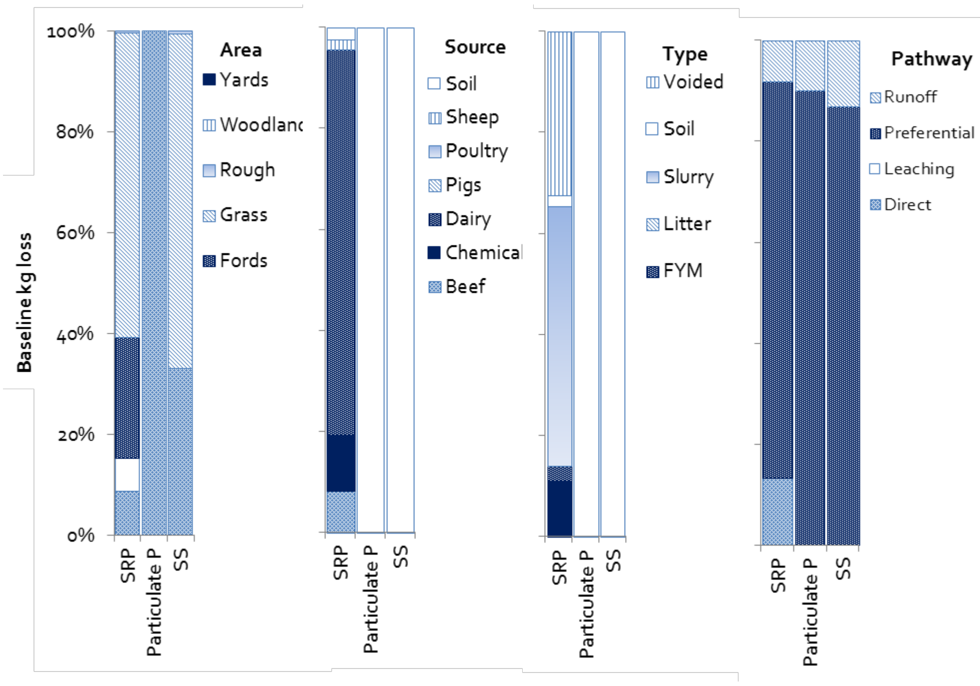
According to the FARMSCOPER baseline-emission apportionments; grassland (temporary grazing) and arable land supply a majority of P and SS pollution. In particular, dairy is a main source of P pollution via farm yard manure and voiding; while soil erosion and transport are the main sources of the SS load. The main pathway for all pollutants has been apportioned to preferential flow paths (i.e. tracks and tramlines), followed by runoff (see Figure 41).

FARMSCOPER predicts baseline pollutant loadings in kg per hectare per year (kg ha^{-1} yr^{-1}) (Table 3).

Table 3: *FARMSCOPER modelled baseline P and SS loses (kg ha^{-1} yr^{-1}).*

		Axe Catchment	Blackwater	Upper Axe	Corry Brook
Area (ha)		41205	1823	9249	1948
Reduction kg ha^{-1} yr^{-1}	**SRP**	311	275	1144	2257
	Particulate P	66	23	96	256
	SS	53145	29246	121663	257362

Figure 41: *FARMSCOPER baseline P and SS source apportionment for the Axe catchment.*



Scenario 2

The maximum potential reduction scenario for SRP, particulate P and SS were modelled as 54 and 13, and 59 % respectively for the Axe catchment. Higher potential reductions were found for sub-catchments, as has been show in previous research (Table 4) (Zhang et al., 2012).

The total cost for these mitigation methods for the Axe catchment has been estimated as £31,615,000 within FARMSCOPER. It is unrealistic that these maximum reductions could be achieved as the FARMSCOPER analysis was carried-out at catchment scale, using 71 methods, all set to 100% maximum implementation.

Whilst it may be possible to achieve greater reductions in P concentrations with higher intervention up-take rates, research suggests that around 15% reductions are realistic for P at the catchment scale, and 30% at a sub-catchment scale.

Descriptions of each intervention used in this FARMSCOPER optimised model are summarised in Appendix 1.

Table 4: *FARMSCOPER modelled maximum mitigation methods and scenario outputs defined by FARMSCOPER. Methods were set to 100% implementation.*

		Axe Catchment	Blackwater	Upper Axe	Corry Brook
Area (ha)		41205	1823	9249	1948
Reduction kg ha^{-1} yr^{-1} (%)	**SRP**	169 (54%)	175 (63%)	728 (63%)	1684 (65%)
	Particulate P	9 (13%)	5 (14%)	21 (22%)	89 (5%)
	SS	31615 (59%)	18160 (62%)	75546 (62%)	101717 (39.5%)

Scenario 3

A more realistic but still intensive scenario implies that SRP, particulate P and SS could be reduced by up to 24, 5 and 20% respectively for a cost of £9,519,000 for the Axe catchment (Table 5). FARMSCOPER predicts that these reductions would be possible if intervention methods were carried out in 50% of farms within the catchment. This scenario includes method scenarios and prior interventions which incorporated local knowledge to select methods which would best address diffuse agricultural P and SS pollution in the Axe catchment, Blackwater and Upper Axe sub-catchments.

Selected implementation methods and the modelled % P and SS reduction and cost associated with each implementation method are detailed in Table 6. P has not been divided into particulate and dissolved in Table 6 because FARMSCOPER does not differentiate between these in the output. However, methods which contribute to particulate P reduction are usually those which contribute to SS reductions.

Along with P and SS reductions, the selected implementation methods can also benefit a number of other environmental factors. FARMSCOPER modelling has shown that the implementation of these methods would likely provide benefits for Ammonium, Nitrous Oxide (a greenhouse gas) and pesticide pollution, along with Biodiversity benefits. Increased energy use has been predicted for implemented methods (Table 7) and for some measures do illustrate a trade off with energy use increasing to reduce P and SS loads.

Table 5: *FARMSCOPER modelled realistic mitigation methods and scenario outputs defined by FARMSCOPER.*

		Axe Catchment	Blackwater	Upper Axe	Corry Brook
Area (ha)		41205	1823	9249	1948
Reduction kg ha^{-1} yr^{-1} (%)	**SRP**	84 (24%)	69 (25%)	287 (25%)	619 (95%)
	Particulate P	3 (5%)	2 (5%)	8 (9%)	33 (5%)
	SS	10,654 (20%)	6275 (21%)	26104 (21%)	34860 (13.5%)

Table 6: *FARMSCOPER modelled 'realistic' mitigation methods and % reduction and FARMSCOPER cost estimate outputs.*

Mitigation method description	Axe catchment			Blackwater			Upper Axe			Corry Brook		
	P % reduction	SS % reduction	Cost £000*	P % reduction	SS % reduction	Cost £000*	P % reduction	SS % reduction	Cost £000*	P % reduction	SS % reduction	Cost £000*
Establish cover crops in the autumn	2	11	315	1	12	0	0	30	0	0.4	3.6	55.5
Early harvesting and establishment of crops in the autumn	1	4	1425	1	4	315	6	11	1310	-	-	-
Establish in-field grass buffer strips	0	0	39	0	0	1425	2	3	5928	0.2	1.6	27.838
Loosen compacted soil layers in grassland fields	0	0	475	0	0	39	0	3	161	0.3	1.6	798.5
Increase the capacity of farm slurry stores to improve timing of slurry applications	2	0	1076	2	0	475	0	0	1976	0.4	0.0	1389.542
Store solid manure heaps on an impermeable base and collect effluent	0	0	64	0	0	1076	8	0	4476	1.4	0.0	178.0759
Do not spread slurry or poultry manure at high-risk times	4	0	81	5	0	64	1	0	266	1.0	0.0	82.92697
Use slurry injection application techniques	9	0	1624	10	0	81	21	0	338	2.0	0.0	1658.539
Fence off rivers and streams from livestock	2	0	475	3	0	1624	41	0	6755	6.8	0.0	798.5
Re-site gateways away from high-risk areas	0	1	108	0	1	475	12	1	1976	1.2	3.3	168.68
Establish and maintain artificial wetlands - steading runoff	3	0	841	3	0	107	1	0	447	6.9	0.0	1335.82
Plant areas of farm with wild bird seed / nectar flower mixtures	0	2	1373	0	2	841	13	9	3499	1.7	8.3	2174.88
Beetle banks	0	0	39	0	0	1373	2	0	5710	0.1	0.6	28.287
Take field corners out of management	0	0	188	0	0	39	0	0	164	0.1	0.6	134.7
Leave over winter stubbles	1	1	683	0	2	188	0	4	780	0.1	0.5	120.25
Capture of dirty water in a dirty water store	5	0	715	5	0	682	2	0	2839	11.1	0.0	8952.039
TOTAL	29	20	9519	32	21	715	21	0	2975	**33.5**	**20.2**	55.5

***overall cost for modelled pollutant reductions.**

Table 7: *Impact of modelled 'realistic' mitigation methods and on other environmental components, values shown as % change per % in reduction in either SRP or SS. Negative values indicate and increase (highlighted in red) while positive values indicate a decrease, or positive effect (highlighted in green).*

	Ammonia (%)		Nitrous Oxide (%)		Pesticides (%)		Biodiversity (Score)		Energy Use (Score)	
% change per 1 % reduction in:	**SRP**	**SS**	**SRP**	**SS**	**SRP**	**SS**	**SRP**	**SS**	**SRP**	**SS**
Mitigation method description:										
Establish cover crops in the autumn	0.000	0.000	0.167	0.025	0.777	0.118	0.059	0.009	-0.739	-0.112
Early harvesting and establishment of crops in the autumn	0.000	0.000	0.133	0.020	0.249	0.038	0.000	0.000	0.000	0.000
Establish in-field grass buffer strips	0.000	0.000	0.013	0.002	3.614	0.467	40.518	5.234	0.000	0.000
Loosen compacted soil layers in grassland fields	0.000	0.000	1.005	0.154	9.132	1.401	0.000	0.000	-34.128	-5.234
Increase the capacity of farm slurry stores to improve timing of slurry applications	-0.239	0.000	0.061	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Store solid manure heaps on an impermeable base and collect effluent	0.000	0.000	1.060	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Do not spread slurry or poultry manure at high-risk times	0.000	0.000	0.389	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Use slurry injection application techniques	1.280	0.000	0.070	0.000	0.000	0.000	0.000	0.000	-0.057	0.000
Fence off rivers and streams from livestock	0.000	0.000	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Re-site gateways away from high-risk areas	0.000	0.000	0.099	0.048	0.000	0.000	0.000	0.000	0.000	0.000
Establish and maintain artificial wetlands - steading runoff	0.000	0.000	0.037	0.000	0.000	0.000	0.166	0.000	0.000	0.000
Plant areas of farm with wild bird seed / nectar flower mixtures	0.000	0.000	0.017	0.004	0.543	0.145	5.934	1.581	0.237	0.063
Beetle banks	0.000	0.000	0.035	0.004	5.782	0.700	108.037	13.085	-4.321	-0.523
Take field corners out of management	0.000	0.000	0.035	0.004	5.782	0.700	54.019	6.543	21.607	2.617
Leave over winter stubbles	0.000	0.000	0.107	0.041	0.497	0.189	2.364	0.898	-0.189	-0.072
Capture of dirty water in a dirty water store	0.000	0.000	0.072	0.000	0.000	0.000	0.000	0.000	-0.021	0.000
TOTAL Change	1.041	0.000	3.370	0.303	26.375	3.758	211.097	27.351	-17.610	-3.261

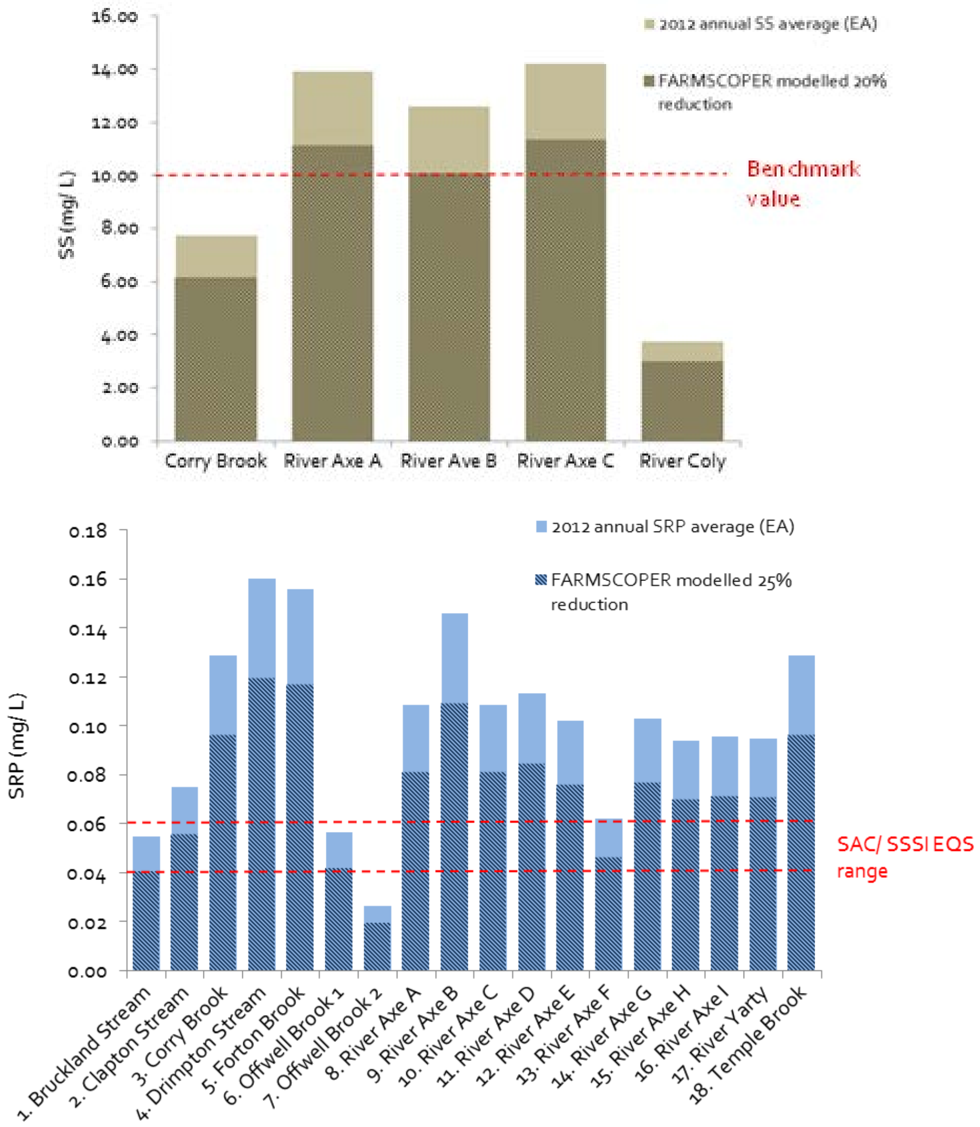
Conclusion

FARMSCOPER modelling results suggest that with intensive application of on-farm measures across the Axe catchment could dramatically reduce P and SS concentrations.

The modelled 'realistic' reduction of 20% for SSs would be sufficient to bring overall concentrations within the 10 mg/l benchmark used in this report (see Figure 42; top). However, environmental factors such as dry summers followed by heavy rainfall may still produce spikes in SS concentrations which are relatively high. For instance, in 2010, the average SS concentration at a site in the Axe SAC/ SSSI was five times the SS benchmark used in this report, as a result of peak, rainfall driven concentrations. This again highlights the need for measures are required to further reduce the point source load.

SRP would still exceed the EQS (0.04 – 0.06 mg/L) in the SAC/ SSSI as concentrations here need to be reduced by up to 67%, whereas FARMSCOPER predicts maximum reductions of 25% for SRP (Figure 42; lower).

Figure 42: *Predicted reductions in SS and P concentrations from FARMSCOPER analysis.*



Limitations & assumptions

There are a number of limitations to the FARMSCOPER analysis used within this study which must be considered, summarised below:

- Cost estimates in FARMSCOPER are derived from a wide range of sources, specifically previous research projects, resulting in a number of assumptions that may not be directly applicable in the Axe catchment.
- The AgCensus data was collected 4 years ago, livestock and cropping statistics for the Axe may have changed significantly during this time.
- AgCensus data is provided at an averaged 2km resolution. At this resolution it is difficult to assess farm scale land-use variability cannot be assessed.
- Prior implementation of mitigation methods has been estimated in the absence of detailed data on the uptake of specific measures.
- Selected overall farm type, rainfall and soil characterisations at catchment and sub-catchment scale, overlooks smaller scale variations, leading to potential over and under estimations of pollutant emissions.

Due to limitations detailed above, the FARMSCOPER outputs within this study should be used to provide a coarse indication of potential SRP and SS reduction within the Axe catchment. Furthermore, the selected mitigation methods can be used to provide a guideline for the most effective on-farm management options for P and SS, in-terms of cost and emission reductions.

Appendix 1: Optimised FARMSCOPER measures

Measure
Increase the capacity of farm slurry stores to improve timing of slurry applications
Minimise the volume of dirty water produced (sent to dirty water store)
Site solid manure heaps away from watercourses/field drains
Store solid manure heaps on an impermeable base and collect effluent
Cover solid manure stores with sheeting
Use liquid/solid manure separation techniques
Do not apply manure to high-risk areas
Do not spread slurry or poultry manure at high-risk times
Use slurry injection application techniques
Do not spread FYM to fields at high-risk times
Incorporate manure into the soil
Fence off rivers and streams from livestock
Construct bridges for livestock crossing rivers/streams
Re-site gateways away from high-risk areas
Farm track management
Establish new hedges
Protection of in-field trees
Management of in-field ponds
Unintensive hedge and ditch management on arable land
Unintensive hedge and ditch management on grassland
Management of field corners
Plant areas of farm with wild bird seed / nectar flower mixtures
Beetle banks
Uncropped cultivated margins
Uncropped cultivated areas
Unfertilised cereal headlands
Unharvested cereal headlands
Undersown spring cereals
Take field corners out of management
Leave over winter stubbles
Use correctly-inflated low ground pressure tyres on machinery
Locate out-wintered stock away from watercourses
Use dry-cleaning techniques to remove solid waste from yards prior to cleaning

References

ADAS, 2009. Quantification of recent fine sediment sources in the River Axe ECSFDI priority catchment using a revised numerical mixing model framework. Natural England.

JNCC, 2014. Common Standards Monitoring Guidance.

Meybeck M., (1982). 'Carbon, nitrogen and phosphorus transport by world rivers'. American Journal of Science, 282, 401-450.

Withers, P. J. A & Jarvie, H. P. (2008). 'Delivery and cycling of phosphorus in rivers: a review'. The Science of the Total Environment, 400, 379–95.

UKTAG, 2012. A revised approach to setting Water Framework Directive phosphorus standards.

Zhang, Y., Collins, A. L., & Gooday, R. D. (2012). Application of the FARMSCOPER tool for assessing agricultural diffuse pollution mitigation methods across the Hampshire Avon Demonstration Test Catchment , UK. Environmental Science and Policy, 24, 120–131.

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