

# Evidence

## Evaluating the benefits of catchment management for multiple ecosystem services

Report – SC120042

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Miranda Kavanagh  
**Director of Evidence**

# Executive summary

## Background

The Water Framework Directive placed a new emphasis on the management of freshwaters by establishing ecologically based water quality targets that are to be achieved through holistic, catchment-scale, ecosystem management approaches. However, significant knowledge gaps still exist in our understanding of the cumulative effectiveness of multiple mitigation measures on a number of pollutants at catchment scales. This research contributes to improved understanding of the effectiveness of an ecosystem management approach to deliver catchment-scale water quality improvements on the National Trust Holnicote Estate on Exmoor, UK.

## Main objectives

The research was part of a larger multi-objective project funded by the Department for Environment, Food and Rural Affairs (Defra) to demonstrate the benefits of land use interventions for the management of flood risk. The report evaluates the effects of upland ditch blocking on physicochemical and biological parameters of water quality in the upland Horner Water catchment one year after habitat restoration, and establishes a solid baseline for the monitoring of the effects of current and future land management changes in the contrasting lowland, intensively managed, agricultural Aller catchment.

## Results

The spatial variability of soil physical and chemical properties – bulk density (BD), total carbon (TN), total nitrogen (TN), C:N ratio, stable isotope  $\delta^{15}\text{N}$ , total phosphorus (TP), inorganic phosphorus (IP), organic phosphorus (OP) – was characterised in the two study catchments to identify the likely critical source areas of diffuse water pollution. Results suggested that agricultural land use resulted in extensive homogenisation of soil properties. The lowest soil carbon content, lowest C:N ratio and highest soil BD, nitrogen, phosphorus and  $\delta^{15}\text{N}$  coincided with the most intensively managed land (arable and short-term ley) in the middle reaches of the agricultural Aller catchment. The alteration of soil physical and chemical properties in the agricultural catchment is likely to have long-term implications for the restoration of ecosystem functioning and achieving water quality improvements.

Intensive land use seems to have resulted in an altered ‘catchment metabolism’, manifested in a proportionally greater total fluvial carbon export from the agricultural Aller catchment compared with the semi-natural Horner Water catchment. During an eight-month period for which a comparable continuous turbidity record was available, the agricultural Aller catchment exported proportionally more total particulate carbon (TPC) ( $0.51\text{--}2.59\text{ kg mm}^{-1}$ ) than the semi-natural Horner catchment ( $0.36\text{--}0.97\text{ kg mm}^{-1}$ ) when normalised by catchment area and total discharge. The export of DOC from the semi-natural Horner Water catchment ( $0.24\text{--}0.32\text{ kg mm}^{-1}$ ) was not significantly higher than from the agricultural Aller catchment ( $0.26\text{--}0.52\text{ kg mm}^{-1}$ ), despite the higher soil percentage carbon content and higher soil carbon storage in Horner Water. For the eight month period, the estimated suspended sediment (SS) yields from the agricultural catchment ( $25.5\text{--}116.2\text{ t km}^{-2}$ ) were higher than from the semi-natural catchment ( $21.7\text{--}57.8\text{ t km}^{-2}$ ). This is likely to be due to enhanced rates of soil erosion.

Although detection of catchment-scale effects of mitigation measures typically requires high resolution, resource-intensive, long term datasets, this study found that simple approaches can be effective in bridging the gap between fine scale ecosystem functioning and catchment-scale processes. A new macro-invertebrate index, Proportion of Sediment-sensitive Invertebrates (PSI), has been shown to be more closely related to a physical measure of sedimentation (visual estimate of percentage

fine bed sediment cover) than existing non-pressure specific macro-invertebrate metrics such as the Lotic Index for Flow Evaluation (LIFE) and percentage Ephemeroptera, Plecoptera and Trichoptera (EPT) abundance. Further testing of PSI along a pronounced environmental gradient is recommended as PSI and percentage fine bed sediment cover (including silt and clay fractions) have the potential to become a sensitive tool for the setting and monitoring of twin sedimentation targets.

Upland ditch management did not have any discernible effect on water quality in the semi-natural upland catchment one year after restoration. This may be due to the short-term post-restoration monitoring period but may also reflect benign effects of large-scale earthmoving works on this high quality environment. The conceptual understanding of catchment processes developed in the thesis on which this report is based suggests that, cumulatively, the recently completed mitigation works in the lowland agricultural catchment are likely to result in reduced sediment and nutrient input into the aquatic environment. However, further research is needed to build on this detailed baseline characterisation and inform the understanding of the effectiveness of combined mitigation measures to reduce the flux of multiple contaminants at the catchment scale.

## **Conclusions**

This study found a profound influence of agricultural land use on soil properties and the enhanced export of sediment and carbon from the terrestrial to the aquatic ecosystem. These extensive alterations to ecosystem processes may have important implications for the timescales over which improvements in water quality can be achieved at a catchment scale. However, the study also found that a relatively simple approach such as the new invertebrate index PSI has the potential to be developed into a sensitive tool for setting and measuring of ecologically meaningful water quality targets in relation to sedimentation impacts. In addition, the established macro-invertebrate index LIFE was a more sensitive integrated metric for the detection of the potential impact of upland ditch blocking on water resources than monthly monitoring of discharge and physicochemical water quality parameters. Finally, while this study established a solid baseline for the monitoring of the impact of land management interventions on water quality in the lowland agricultural catchment, further monitoring is needed to evaluate the effectiveness of the recent and soon to be implemented land management changes on achieving water quality improvements at a catchment scale over the next few years.

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Parts of the Executive Summary, Sections 1 and 4, figures and tables in this report are reproduced from a PhD thesis by Miriam Glendell, *Evaluating an Ecosystem Management Approach for Improving Water Quality on the Holnicote Estate, Exmoor*, submitted to the University of Exeter in 2013.

Table 3.1 and Figures 2.8, 3.1 and 3.3 are reproduced from Glendell (2014a, 2014b) with the publisher's permission.

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# 1 Introduction

Both our well-being as individuals and the material wealth of human society depend critically upon the environment (UK NEA 2011), yet increasing human population, rising expectations and changing diets are compromising the ability of global ecosystems to sustain the needs of humans as well as those of other species (MEA 2005). The rate of anthropogenic change to natural systems over the past 50 years is unparalleled in human history and it is estimated that approximately 60% of ecosystem services are now being degraded or used unsustainably including soils, freshwater and water purification (MEA 2005). With the projected increase in human population, it is estimated that the global demand for food will rise by 70% by 2050 (FAO 2011). Satisfying this growing demand in a sustainable way in a changing climate is a major challenge for the governance of the world's natural resources. The vast majority of global food production occurs under intensive agricultural regimes. As such, agriculture covers approximately 40% of the land area of Organisation for Economic Co-operation and Development (OECD) countries and thus has a significant effect on the environment. While agricultural nutrient surpluses in OECD countries have declined and soil erosion has stabilised since the early 1990s, agriculture is still a significant source of diffuse water pollution (OECD 2013). In the UK, agriculture covers approximately 70% of the land area and agricultural intensification was a major driver of enhanced soil erosion, reduced soil quality, loss of biodiversity (UK NEA 2011) and ecological impairment of water bodies (McGonigle et al. 2012) over the past 60 years.

In the UK, 30% of ecosystem services are declining (UK NEA 2011). While biodiversity underpins the functioning of all ecosystems (UK NEA 2011), it continues to decline both nationally and globally (Lawton et al. 2010). Focussing biodiversity conservation efforts on management of small designated areas has not been successful in stemming the continued loss of species and habitats (Lawton et al. 2010) and a broader holistic approach to the management of multi-functional landscapes, with the involvement of local stakeholders, is needed to deliver the full range of ecosystem services (UK NEA 2011).

Global awareness and development of a holistic 'ecosystem management' approach that combines understanding of both natural and social factors to address environmental problems can be traced back to the Earth Summits of 1992 and 2002, and the Convention on Biological Diversity 1992 (Hering et al. 2010). Water is a critical resource that underpins all ecosystem functions and social and economic activities (WWAP 2012) and catchments provide a natural focus for the new integrated 'ecosystem management' approach to provide the full range of ecosystem services. European Union environmental legislation has been a major driver behind the development of national environmental policies and environmental improvement (UK NEA 2011). As an ambitious piece of environmental legislation, the Water Framework Directive (WFD) 2000 brought a new emphasis on holistic landscape-scale management of freshwater systems by including ecologically based water quality outcomes, coupled with a requirement for the involvement of all stakeholders and the consideration of economic costs in the development of integrated solutions.

But while intuitively correct and conceptually clear, practical implementation of the WFD's goals represents a major challenge (Page et al. 2012). The emphasis on ecologically relevant, basin-scale assessment of water quality poses a significant challenge to the scientific community and the legislative bodies that enforce the WFD in terms of translating detailed process-based understanding of single pollutants at often small scales to an integrated understanding of multiple pollutant responses to a combination of mitigation measures at a catchment scale (Haygarth et al. 2013). This

upscaling requires a multi-disciplinary approach, involving natural and social scientists as well as the policy community (Neal and Heathwaite 2005, McGonigle et al. 2012).

Catchments are complex systems, not readily conducive to the requirements of rigorous experimental design and replication (Haygarth et al. 2013), with many unknown and 'un-knowable' uncertainties (Harris and Heathwaite 2012, Page et al. 2012). While acknowledging this uncertainty, policy demands practical 'no-regret' solutions to complex problems, often in a short timescale (Jordan et al. 2012, McGonigle et al. 2012). For example, while linking nutrient impact with ecological status in a quantitative manner is a huge challenge (Neal and Heathwaite 2005), farmers and regulators need simple and easy metrics to monitor and assess the environmental impact of agriculture on soil and water quality (McGonigle et al. 2012).

Neal and Heathwaite (2005) identified many fundamental questions that need to be answered to secure sustainable management of freshwaters. These include:

- How do freshwater systems function on a catchment and basin scale?
- How do small-scale measures scale-up in large systems?
- How do we define 'good ecological status'?
- What do we need to do to improve our detection, understanding and mitigation of diffuse pollution and its impact on ecosystem function?
- What are the impacts from anthropogenic activities on ecosystem health?

This research addressed some of these questions. It takes a multi-pollutant approach to the evaluation of the cumulative effectiveness of mitigation measures to deliver water quality improvements. As part of a national Defra-funded, catchment-scale, multi-objective flood management demonstration project on the National Trust's Holnicote Estate on Exmoor, this research seeks to contribute to the emerging understanding of the effectiveness of multiple ecosystem management measures to achieve water quality improvements at a catchment scale. This research complements existing hydrological monitoring by Penny Anderson Associates and JBA Consulting, commissioned by the National Trust, with biological, physical and chemical water quality monitoring. In addition, it presents a comprehensive characterisation of the status of soils and land management across two catchment scales so as to elucidate the controls and sources of pollutants found in-stream.

Specifically, this report addresses the following research questions:

- How does the spatial variability of key soil properties vary between the two contrasting study catchments and what are the implications for water quality and mitigation of poor water quality?
- What are the current rates of fluvial carbon export in terms of dissolved organic and particulate carbon from the two catchments and how do they relate to soils, prevailing land use and habitat mitigation?
- Can the new macro-invertebrate index, Proportion of Sediment-sensitive Invertebrates (PSI), act as a tool for determining ecologically relevant water quality sedimentation targets?
- How does upland ditch restoration impact on the chemical and biological indicators of water quality in three headwater tributaries of Horner Water?
- Are the proposed mitigation measures in the lowland Aller catchment likely to deliver water quality improvements at a catchment scale?
- How effective can an ecosystem management approach to deliver water quality objectives be?

## 2 The project

This project contributes significantly to the current research agenda examining the cumulative impact of land use mitigation measures on multiple pollutants in freshwater systems, using catchments as real world research platforms. This report offers a concise summary of the main research findings (Glendell 2013) with some suggestions for further research.

The aims of this research were to:

- monitor the pre- and post-mitigation water quality impacts of the Defra-funded catchment-scale multi-objective flood management demonstration project on the National Trust Holnicote Estate on Exmoor between 2009 and 2013
- contribute information towards the assessment of overall ecosystem services benefits of this multi-objective project

### 2.1 Research site

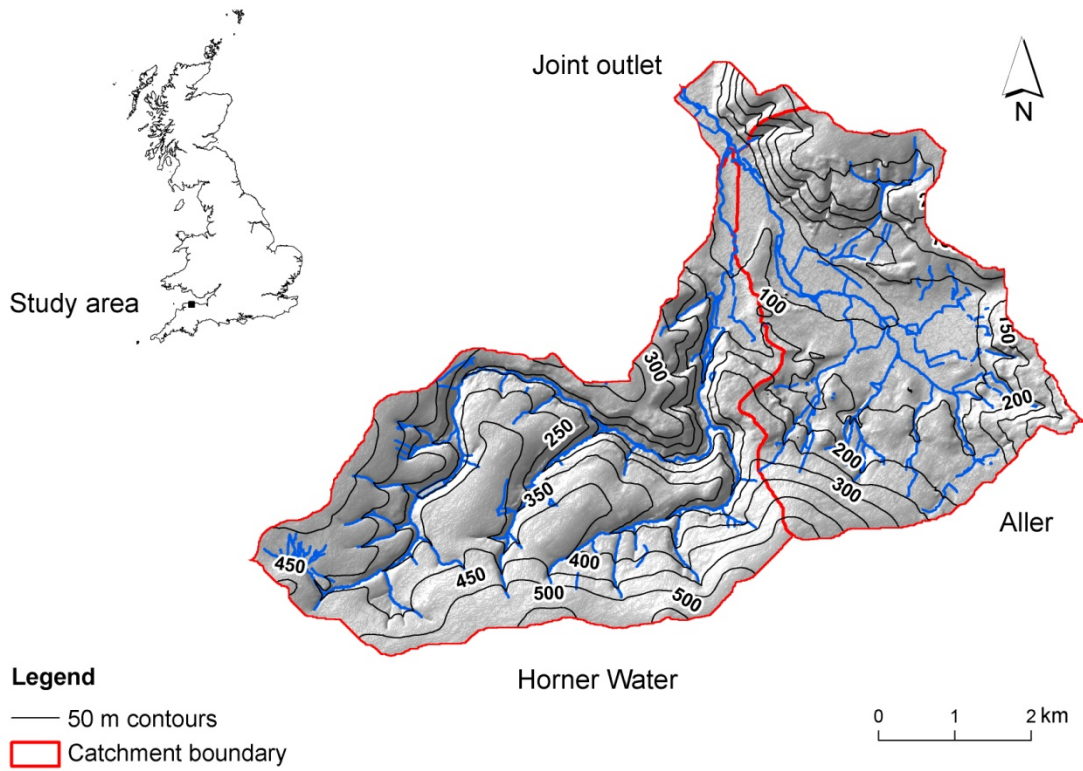
The two research catchments, Aller and Horner Water, are located in south-west England on the north-east edge of Exmoor National Park.

The geology of south-west England represents almost the whole geological timescale found in Britain, from primary igneous and metamorphic rocks to more recent sediments (Findlay et al. 1984). The underlying geology shapes the landscape, with the highest ground in the west coinciding with the hard rocks of older formations (Met Office 2011).

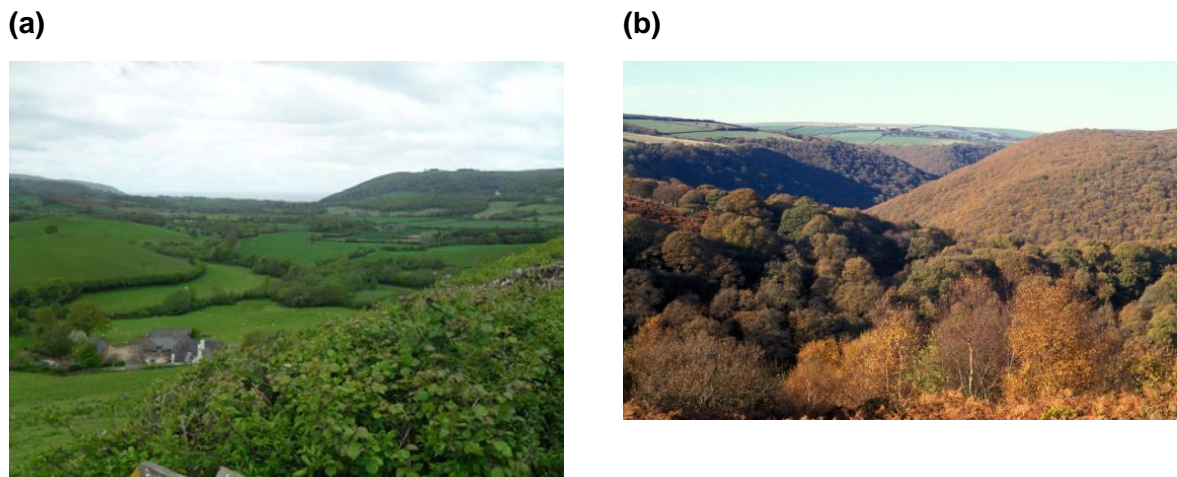
The mild and wet maritime climate of the south-west peninsula is influenced by the surrounding sea (Met Office 2011). The 9°C range between the mean monthly temperature of the warmest and coldest months is narrower than in most of the UK and the mean annual rainfall is higher than in the east of the country, ranging between 644 and 2,584 mm/year, being influenced by altitude, aspect and the proximity to the sea (Findlay 1984, Met Office 2011).

Agriculture accounts for over 70% of rural land use within the region, with the rest covered by semi-natural vegetation such as woodland, moorland and coastal habitats (Findlay 1984). The high average rainfall facilitates grass growth, and dairy farming is well established within the region, particularly in lower lying areas (Findlay 1984). On higher ground, sheep and beef rearing is prevalent.

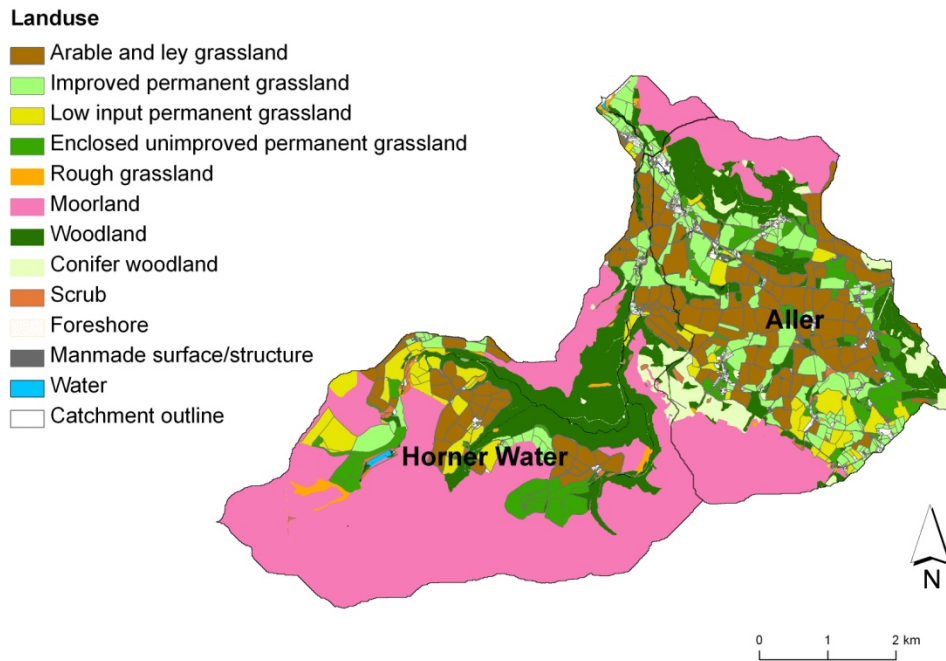
The two contrasting research catchments, Aller and Horner Water (Figures 2.1 and 2.2), represent a geological, climatic and land use gradient typical of south-west England, from semi-natural vegetation on the high ground in Horner Water to intensive agricultural land use near sea level in the Aller Vale. The close proximity of these two study catchments allows a comparison of the effects of contrasting land use (Figure 2.3) and an evaluation of a range of land use mitigation measures on water quality.



**Figure 2.1 Study site showing the Aller and Horner Water catchments and the joint catchment outlet**



**Figure 2.2 (a) Aller and (b) Horner Water catchments on the National Trust Holnicote Estate**



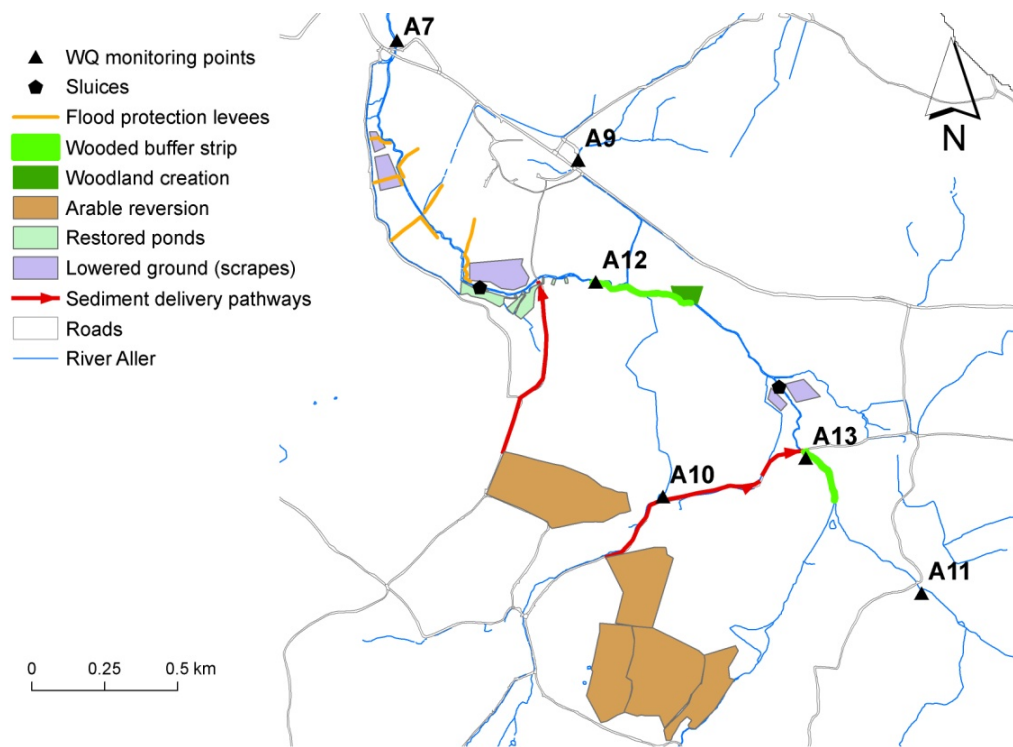
**Figure 2.3 Land use map of the study catchments compiled from Natural England agri-environment scheme information, Ordnance Survey Mastermap and interviews with farmers**

## 2.2 Land management interventions

Figure 2.4 shows the location of the various interventions.

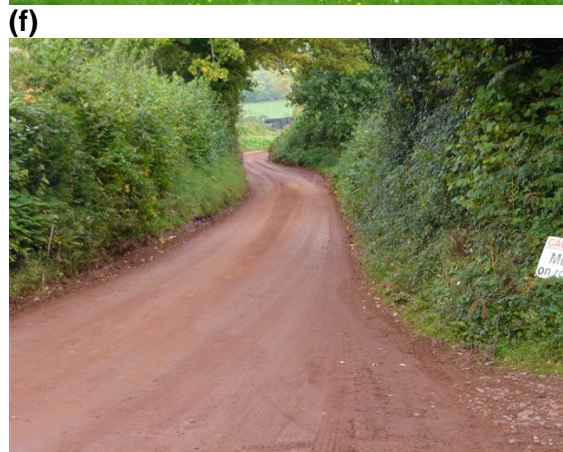
In the Aller catchment, old mill ponds were cleared and restored for increased flood water storage between 2 and 18 November 2011 (Figure 2.5a,b) and a small area of floodplain woodland was planted in spring 2012. The flood alleviation works in the Aller catchment, including construction of levées and lowering of ground, were carried out between 6 May and 26 July 2013 (Figure 2.5c,d).

Two tenant farmers agreed to enter into a Higher Level Stewardship scheme from 1 June 2013, whereby four arable fields on the steepest ground in the central part of the catchment will be converted to permanent pasture. The aim is to reduce the loss of topsoil from these fields (Figure 2.5e, f). Also, 6 m wide woodland buffer strips will be created in the upper reaches of the river Aller in 2014.



**Figure 2.4 Location of land management interventions in the Aller catchment, including restoration of old ponds (November 2011), woodland planting (spring 2012) and construction of flood alleviation levées and shallow habitat scrapes (May to June 2013)**

Notes: Preferential sediment delivery pathways from arable fields to the watercourse were observed along paved roads and are highlighted in red. Conversion of arable land to permanent pasture and 6 m wide wooded riparian buffer strips will be implemented in 2014.



**Figure 2.5 (a) Restoration of former mill ponds for flood water storage in November 2011 (b) Restored ponds in May 2013 (c) and (d) Construction of flood alleviation levées in the Aller Vale in May 2013 (e) and (f) Preferential overland sediment pathways along paved roads delivering eroded topsoil to the river Aller from the fields targeted for arable conversion. Photos (e) and (f) © Nigel Hester, The National Trust**

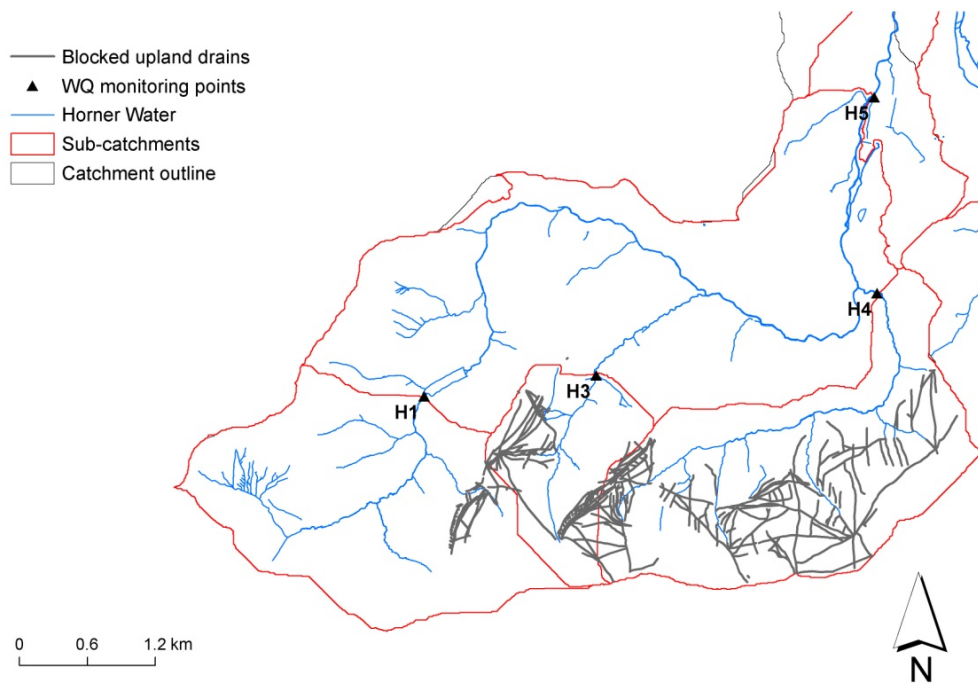
In the Horner Water catchment, upland ditch blocking was undertaken between 8 September and 14 October 2011 (Figure 2.6). The works affected 5% of sub-catchment H1, 35% of sub-catchment H3 and 80% of sub-catchment H4 (Figure 2.7).

Originally, all the works were scheduled to take place between summer 2010 and 2011, allowing one year for pre- and one year for post-restoration monitoring. However, there were delays due to difficulties obtaining statutory consents and agreement of tenant farmers. This meant that the present study can only report on the **potential** of the ecosystem management approach to produce water quality improvements in the Aller catchment and offer an assessment of the short-term impacts of upland ditch blocking on water quality and biodiversity of upland streams in Horner Water catchment.



**Figure 2.6 Upland ditch blocking undertaken by the National Trust in the upper reaches of the Horner Water catchment in October to November 2011 with the aim of increasing water storage and reducing the velocity and magnitude of discharge response to rainfall events**





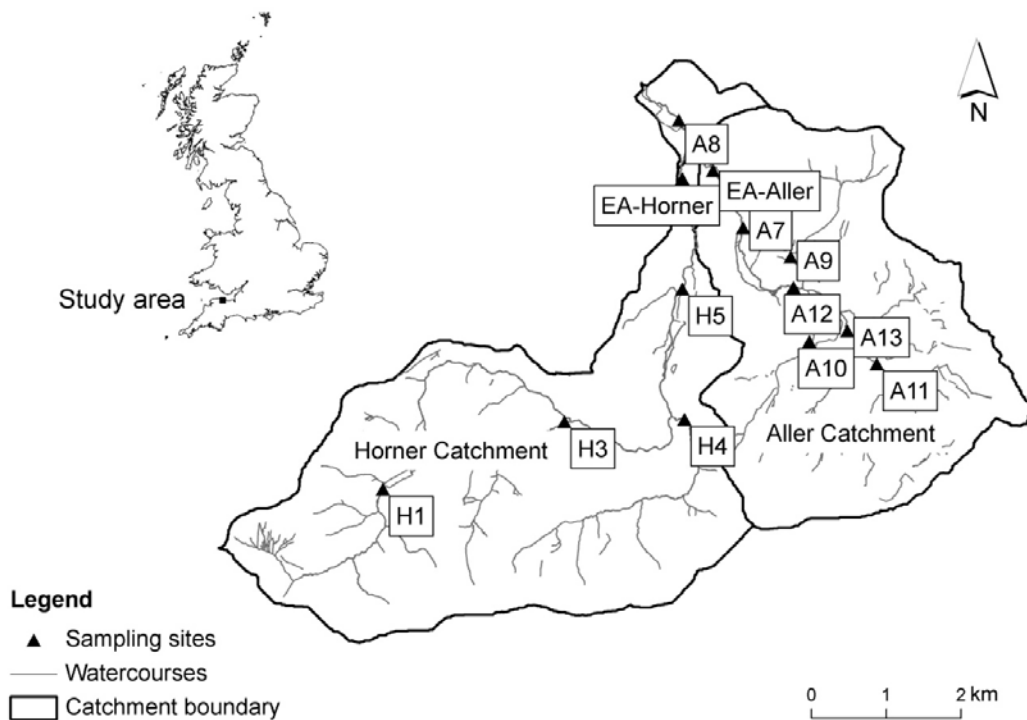
**Figure 2.7** Extent of upland ditch blocking in sub-catchments H1 to H3 carried out in the autumn 2011

## 2.3 Water quality monitoring

As part of this research project, chemical and biological water quality was monitored at nested locations throughout the two study catchments between February 2010 and November 2012 (Figure 2.8). Monthly grab samples were taken at 11 sites (H1 to A13) and analysed for suspended sediment (SS), total oxidised nitrogen (TON), dissolved organic carbon (DOC) and dissolved reactive phosphorus (DRP). Storm-integrated monitoring for the above determinands + total particulate carbon (TPC) was undertaken at five locations (H5, A7, A8, A11, A12), with a total of 1,971 individual samples analysed.

Freshwater macro-invertebrates were sampled at all 13 locations (Figure 2.3) using standard UK Technical Advisory Group (UK TAG) sampling methodology (Environment Agency 2009) on four occasions (spring and autumn 2010 and 2011), with additional samples taken in Horner Water catchment (H1 to H3) in spring and autumn 2012.

Sampling, laboratory and data analysis protocols are described in detail in Glendell (2013), Glendell and Brazier (2014) and Glendell et al. (2014a, 2014b).



**Figure 2.8 Aller and Horner Water catchments and the location of 11 regular monthly water quality monitoring sites (H1–A13), five stormflow monitoring sites (H5, A7, A8, A11, A12) and two Environment Agency biological monitoring sites (EA-Aller and EA-Horner).**

Notes: Reproduced from Glendell et al. (2014a)

Environment Agency monthly water quality data for the years 2000 to 2010 (Table 2.1) show concentrations below the current drinking water quality standard for TON of  $50 \text{ mg L}^{-1}$  (Leeson et al. 2003) but above levels of  $0.5\text{--}1 \text{ mg N L}^{-1}$  ( $2.21\text{--}4.43 \text{ mg L}^{-1}$  as TON) associated with eutrophication in rivers (Pierzynski et al. 2000, Hilton et al. 2006). Long-term mean monthly orthophosphate levels in both rivers are below the current good ecological status standard of  $40 \text{ } \mu\text{g L}^{-1}$  for Horner Water and  $120 \text{ } \mu\text{g L}^{-1}$  for Aller (UK TAG 2012). The suspended sediment concentrations in both rivers are below the Freshwater Fish Directive Guideline Standard for suspended solids of annual mean of  $25 \text{ mg L}^{-1}$  (UK TAG 2008).

Under the Water Framework Directive, the Environment Agency has classified the ecological status of the river Aller as 'moderate' on account of its macrophyte status, while Horner Water has been classified as 'good' (P. Grigorey, Environment Agency, personal communication, 22 July 2013).

**Table 2.1 Environment Agency mean monthly values and standard deviation (in brackets) for key water quality variables in rivers Aller and Horner Water, 2000 to 2010**

	SS (mg L <sup>-1</sup> ) <sup>1</sup>	DRP (mg L <sup>-1</sup> )	TON (mg L <sup>-1</sup> )	pH	TON in groundwater (mg L <sup>-1</sup> ) <sup>2</sup>
Aller	20.08 (3–1,290)	0.05 (0.01)	11.73 (1.95)	7.98 (0.26)	2.68 (0.90)
Horner Water	11.67 (3–726)	0.03 (0.01)	5.09 (3.23)	7.77 (0.30)	– –

Notes: <sup>1</sup> SS data were not normally distributed, therefore minimum and maximum values are given instead of standard deviation.

<sup>2</sup> Groundwater data measured twice per year for 2003 to 2009 are available from a private borehole in the upper reaches of the Aller catchment.

SS = suspended solids; DRP = reactive soluble phosphorus; TON = total oxidised nitrogen.

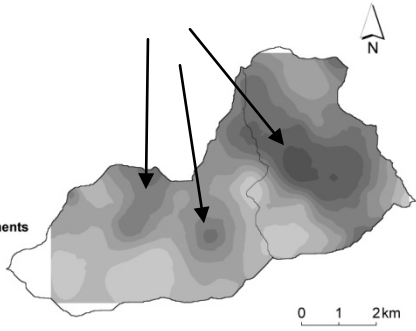
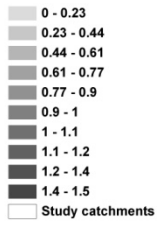
# 3 Results

## 3.1 Soil characterisation

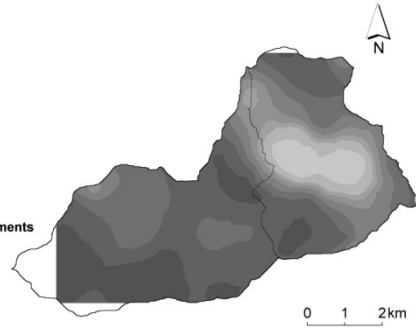
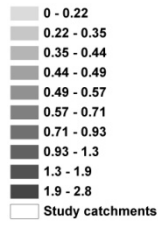
Detailed results of this work are published in Glendell (2013) and Glendell et al. (2014b). The spatial variability of key soil properties – bulk density (BD), total soil carbon, nitrogen and phosphorus, C:N ratio and stable N isotope  $\delta^{15}\text{N}$  – in the two contrasting study catchments was characterised to establish a baseline against which future land use changes can be monitored and to identify likely critical source areas for targeting of land management interventions to improve water quality (Figure 3.1). BD was quantified as it influences soil hydrological properties such as infiltration rates and the generation of overland flow, while the C:N ratio and  $\delta^{15}\text{N}$  enrichment ratio help to understand the rates of soil organic matter (SOM) turnover (higher SOM turnover rate is linked to a lower C:N ratio and a higher  $\delta^{15}\text{N}$  enrichment ratio) (Brady and Weil 1999, Kuzyakov et al. 2000).

Geostatistical analysis identified reduced spatial variability (homogenisation) of soil properties in the agricultural Aller catchment (data not shown). The lowest soil carbon content, lowest C:N ratio and highest soil BD, nitrogen, phosphorus and  $\delta^{15}\text{N}$  coincided with the most intensively managed land (arable and short-term ley) in the middle reaches of the Aller catchment. Similarly, human impact on soil properties is apparent on enclosed farmland in the Horner Water catchment in areas with most intensively managed arable and short term grass ley land use (Figure 2.3). These areas have the highest soil BD, reduced total soil percentage carbon content, lower C:N ratio and increased  $\delta^{15}\text{N}$  enrichment ratio. These patterns indicate a faster rate of soil organic matter turnover and greater loss of inorganic nitrogen from the soils in areas with intensive agricultural land use, which are likely to be a result of inorganic fertiliser applications and therefore a greater 'leakiness' of the system (Bol et al. 2008). In addition, the stable nitrogen isotope  $\delta^{15}\text{N}$  enrichment may also reflect the regular application of farmyard manures.

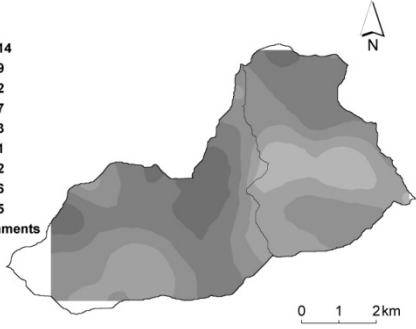
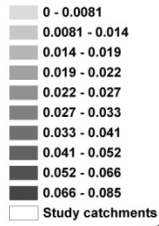
Bulk density  $\text{g cm}^{-3}$



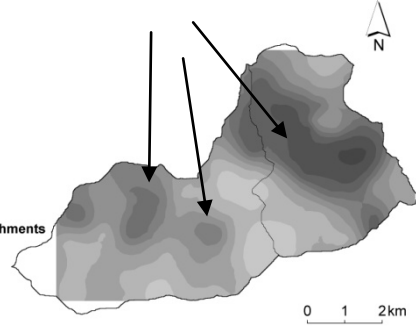
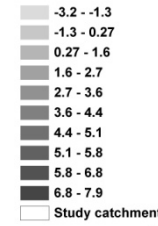
TN %



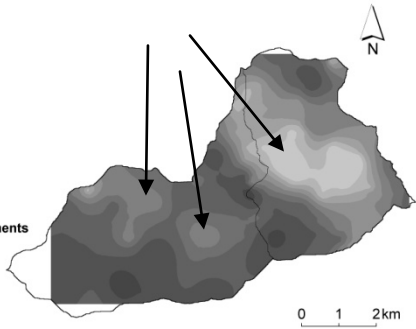
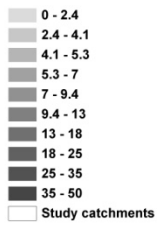
N storage  $\text{g cm}^{-2}$



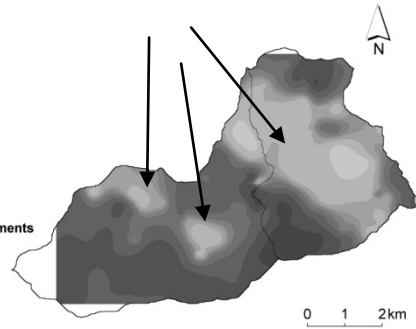
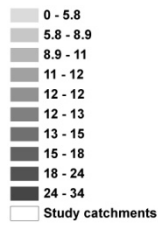
$\delta^{15}\text{N}$



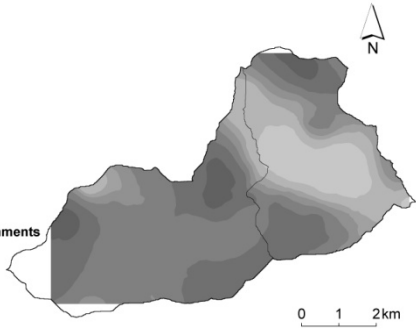
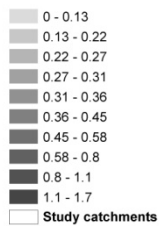
TC %



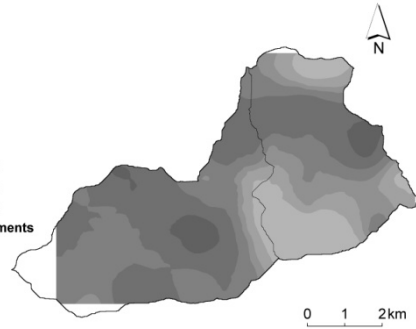
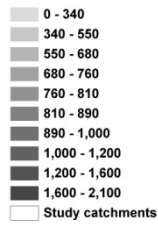
C:N ratio

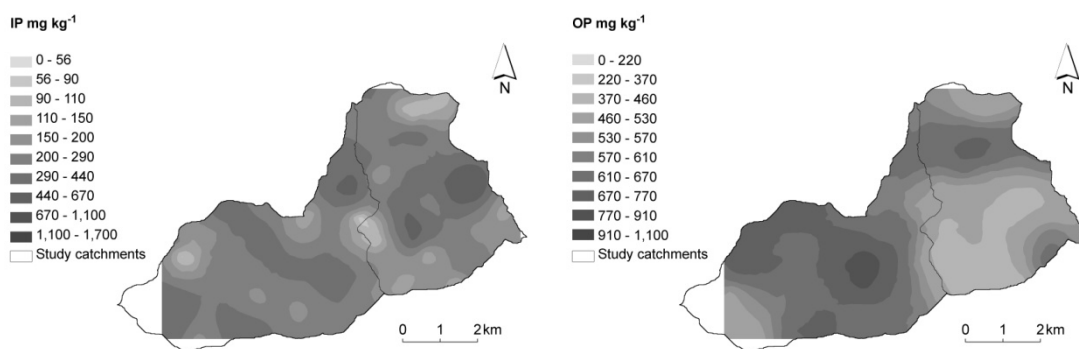


C storage  $\text{g cm}^{-2}$



TP  $\text{mg kg}^{-1}$





**Figure 3.1** Kriged surfaces for soil properties broadly reflect the land use and soil types in the two study catchments and highlight potential critical source areas of diffuse pollution

Notes: Arrows highlight areas where highest soil bulk density and increased soil organic matter turnover coincide with the most intensively managed arable and short term grass ley land use.

Source: Reprinted from *Geoderma* (Glendell et al. 2014b) with permission from Elsevier

## 3.2 Soil nutrient stocks

Comparison of soil nutrient stock calculations (carbon and phosphorus) using the detailed geostatistical sampling and the National Soil Research Institute (NSRI) dataset (Soils Data @ Cranfield University (NSRI) and for the Controller of HMSO 2013) showed comparable results, indicating that higher resolution soil sampling does not necessarily improve the estimation of soil nutrient stocks in the top 5 cm of the soil profile (Table 3.1). This finding supports the use of coarse-resolution national datasets for the estimation of soil nutrient stocks at a range of scales.

**Table 3.1** Comparison of estimated carbon and total phosphorus stocks in the top 5 cm of the soil profile within the study area, using NSRI data and the high resolution geostatistical survey approach

	Carbon storage (tonnes)			Phosphorus storage (kg)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
NSRI	146.51	–	–	1.12	0.50	2.40
Geostatistical survey	–	132.35	168.01	–	1.13	1.48

Source: Reprinted from *Geoderma* (Glendell et al. 2014b) with permission from Elsevier

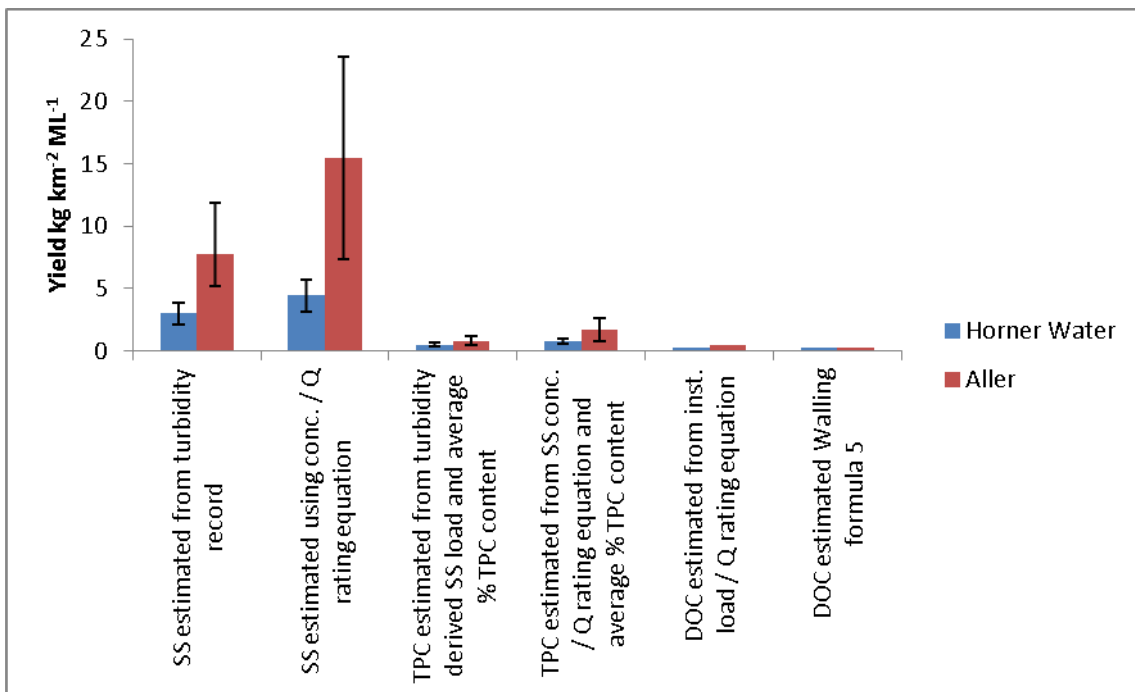
## 3.3 Fluvial sediment and carbon fluxes

Detailed results of this work are published in Glendell and Brazier (2014). The total fluvial fluxes of DOC, SS and TPC in the two study catchments were quantified over an eight-month period. Agriculture altered both the quality and quantity of the fluvial carbon export. The prevalence of more humic, higher molecular weight compounds in

the agricultural catchment and simpler, lower molecular weight compounds in the semi-natural catchment indicated enhanced microbial turnover of fluvial DOC in the agricultural catchment and additional DOC input from terrestrial sources.

The Aller catchment yielded proportionally greater fluxes of TPC ( $0.51 - 2.59 \text{ kg mm}^{-1}$ ) than the Horner Water catchment ( $0.36 - 0.97 \text{ kg mm}^{-1}$ ), when normalised by catchment area and total discharge (Figure 3.2). The export of DOC from the semi-natural Horner Water catchment ( $0.24-0.32 \text{ kg mm}^{-1}$ ) was not significantly higher than from the agricultural Aller catchment ( $0.26-0.52 \text{ kg mm}^{-1}$ ), despite the higher soil percentage carbon content and higher soil carbon storage in Horner Water. This may be due to the faster turnover of soil organic matter in the agricultural catchment. Enhanced DOC production and transformation of particulate carbon into DOC in the aquatic environment, as a result of anthropogenic sediment and nutrient input, may also play a part. Furthermore, the alteration of hydrological pathways as a result of land drainage may also contribute to enhanced DOC fluxes. The implications of enhanced fluvial carbon fluxes on the cycling of other nutrients in the aquatic environment are currently poorly understood but are likely to be significant, as DOC plays an important role in aquatic metabolism. Further research in replicated catchments with contrasting land use but similar climatic and topographic controls would help to understand the significance of enhanced fluvial carbon fluxes in agricultural catchments for the global carbon cycle, while qualitative analysis of DOC and TPC in catchments with contrasting land uses would elucidate the sources, pathways and ecological significance of the altered carbon cycling.

The estimated SS yields from the agricultural Aller catchment ( $25.5-116.2 \text{ t km}^{-2}$ ) were higher than from the semi-natural Horner Water catchment ( $21.7-57.8 \text{ t km}^{-2}$ ). The Aller catchment also yielded proportionally greater fluxes of SS ( $5.16-23.52 \text{ kg mm}^{-1}$ ) than the Horner Water catchment ( $2.14-5.70 \text{ kg mm}^{-1}$ ), when normalised by catchment area and total discharge (Figure 3.2). This is likely to be due to enhanced rates of soil erosion.



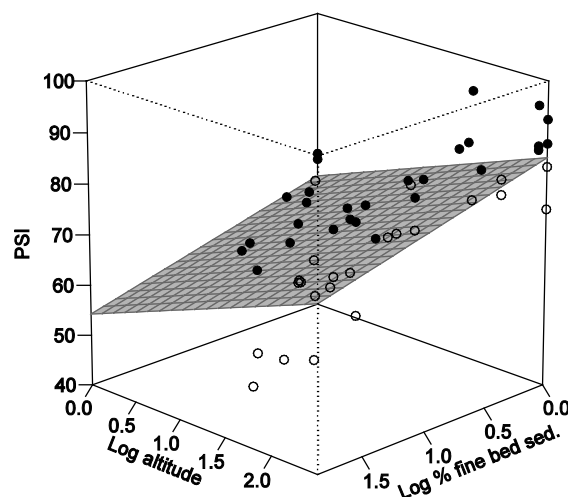
**Figure 3.2** Estimated suspended sediment (SS), total particulate carbon (TPC) and dissolved organic carbon (DOC) yields for the period between 26/1/2012 and 22/9/2012 show a proportionally greater SS and TPC flux from the Aller catchment, when normalised by the total discharge for the study period.

Notes: DOC yield normalised by the total discharge shows no clear difference between the two catchments, despite the greater percentage soil carbon content in the Horner Water catchment. The error bars show 95% confidence intervals. ML = megalitres ( $10^6$  litres); Q = discharge.

### 3.4 Testing the macro-invertebrate Proportion of Sediment-sensitive Invertebrates (PSI) index

Full details of this work package are published in Glendell (2014a). This research tested the relationship between a new pressure-specific macro-invertebrate index (Extence et al. 2013) and physical measures of sedimentation. The PSI index (Extence et al., 2013) has been shown to relate to the percentage of fine bed sediment cover (silt and clay) at a reach scale sampling resolution across a narrow gradient of impact ( $p = 0.009$ , deviance = 10.7%) (Figure 3.3). The highest PSI values were found at the least sediment sites at higher altitude. PSI was not related to mean suspended sediment concentration or the percentage of time for which the current guideline SS threshold of  $25 \text{ mg L}^{-1}$  had been exceeded. Two existing macro-invertebrate metrics – Lotic Index for Flow Evaluation (LIFE) and percentage EPT (Ephemeroptera, Plecoptera and Trichoptera) abundance – were also related to the percent fine bed sediment cover. However, this relationship was statistically less significant and accounted for a smaller proportion of model deviance ( $p = 0.012$ , deviance = 7 and 6.1% respectively). While PSI was correlated with the existing macro-invertebrate LIFE metric, the relationship was weaker in the absence of hydrological stress (Table 3.2). Furthermore, PSI and percentage EPT abundance were not correlated, suggesting that they were responding differently to multiple environmental pressures.

This study indicates that PSI and visual assessment of percentage fine bed sediment cover (silt and clay), as used in the UK TAG macro-invertebrate sampling methodology, have the potential to act as simple tools for the monitoring and setting of twin sedimentation targets. However, further testing along a pronounced gradient of multiple stressors is recommended.



**Figure 3.3 Relationship between percentage fine bed sediment cover, altitude and PSI, with highest PSI scores predicted for sites with lowest percentage fine bed sediment cover at high altitude**



Notes: Dots represent observed data while the plane shows the model predicted values.  
 Observed data (for the 13 sampling locations, with 3–4 repeated measures per site) that lie above the surface are solid and those below are open.  
 $p = 0.009$ , accounted deviance = 10.7%

Source: Reproduced from Glendell et al. (2014a)

**Table 3.2 Correlation between PSI, O:E PSI and other macro-invertebrate indices over the sampling period**

	Season		LIFE	ASPT	NTAXA	EPT % abundance
PSI	Spring 2010	↓	0.630*	ns	ns	ns
	Autumn 2010		0.771**	0.744**	ns	ns
	Spring 2011		0.799**	0.731**	ns	ns
	Autumn 2011		0.899**	0.843**	ns	ns
			O:E LIFE	O:E ASPT	O:E	
O:E PSI	Spring 2010	↓	0.578*	ns	ns	
	Autumn 2010		0.781**	0.664*	ns	
	Spring 2011		0.822**	0.646*	ns	
	Autumn 2011		0.911**	0.840**	ns	

Notes: \*  $p < 0.05$ , \*\*  $p < 0.01$ , ns = not significant  
 The arrow indicates increasing hydrological stress due to an onset of a drought period.  
 O:E = observed: expected ratio

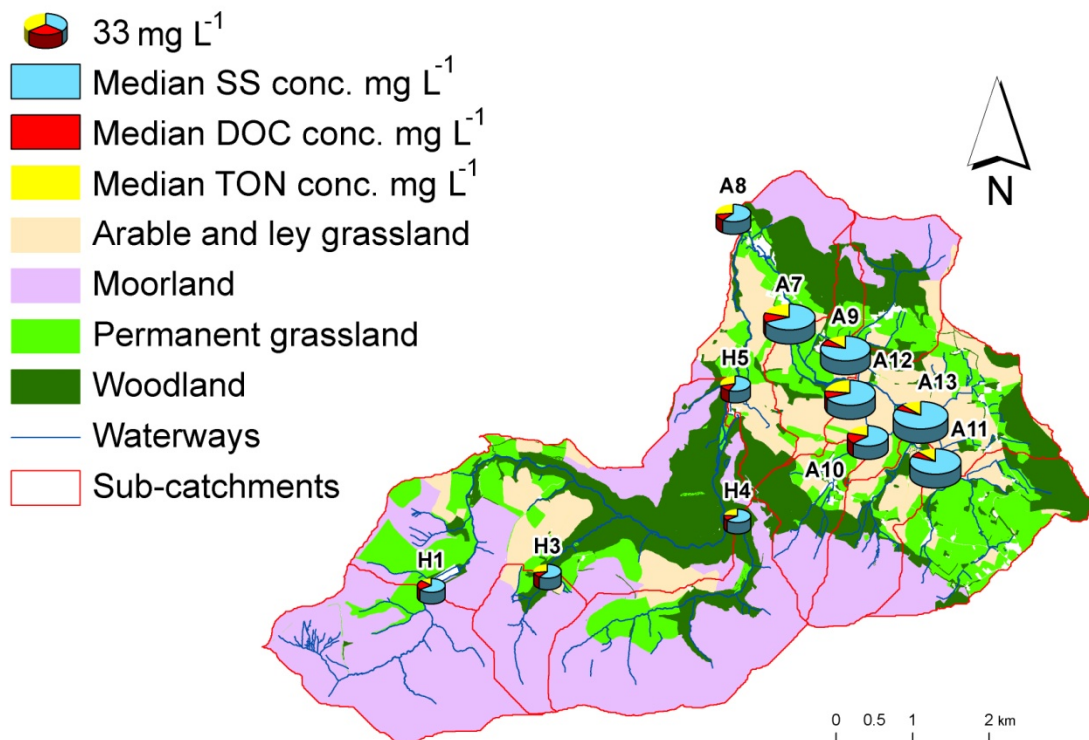
## 3.5 Effectiveness of land management mitigation measures to deliver water quality improvements

### 3.5.1 Aller catchment

The research established a firm baseline against which the effects of future land use changes on water quality in the Aller catchment can be evaluated. A summary of the monthly base flow water quality monitoring results is published in Glendell et al. (2013b). A summary of the stormflow monitoring results is published in Glendell (2013).

#### *Pollutant concentrations*

Field observations identified a number of direct preferential overland delivery pathways of sediment from arable fields along paved roads (Figures 2.4 and 2.5). The most impaired sampling sites were located in the most intensively farmed central part of the Aller catchment, associated with arable cropping and short-term leys (Figure 3.4).



**Figure 3.4 Map showing ranking of water quality determinands across the two study catchments in relation to land use**

Notes: The greatest water quality impairment can be observed in the most intensively farmed central part of the Aller catchment associated with arable land use. The size of the circles represents a sum of median values of the monthly SS, DOC and TON concentrations.

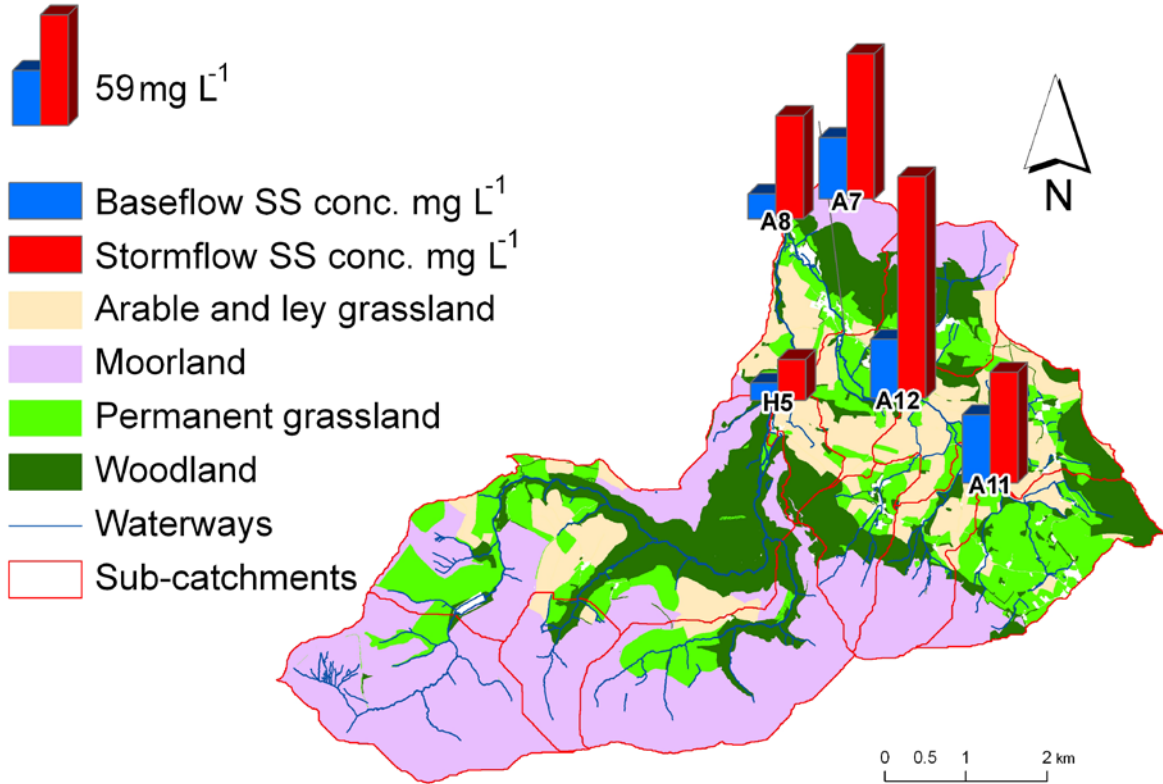
The greatest concentrations of SS, DRP and TON were recorded in the middle reaches of the Aller catchment, reflecting an enhanced input of sediment and nutrients from the intensively farmed arable and grassland land uses (Figure 3.5).

Median baseflow DOC concentrations increased in a downstream direction from the upper reaches of the Aller at A11 to the outlet at A7 and were greater than median baseflow DOC concentrations at the Horner Water outlet at H5 and the joint outlet at A8. In stormflow, the highest median DOC concentration was recorded at the joint outlet at A8, followed by the Horner Water outlet at H5, while the ranking of sites within the Aller catchment remained the same.

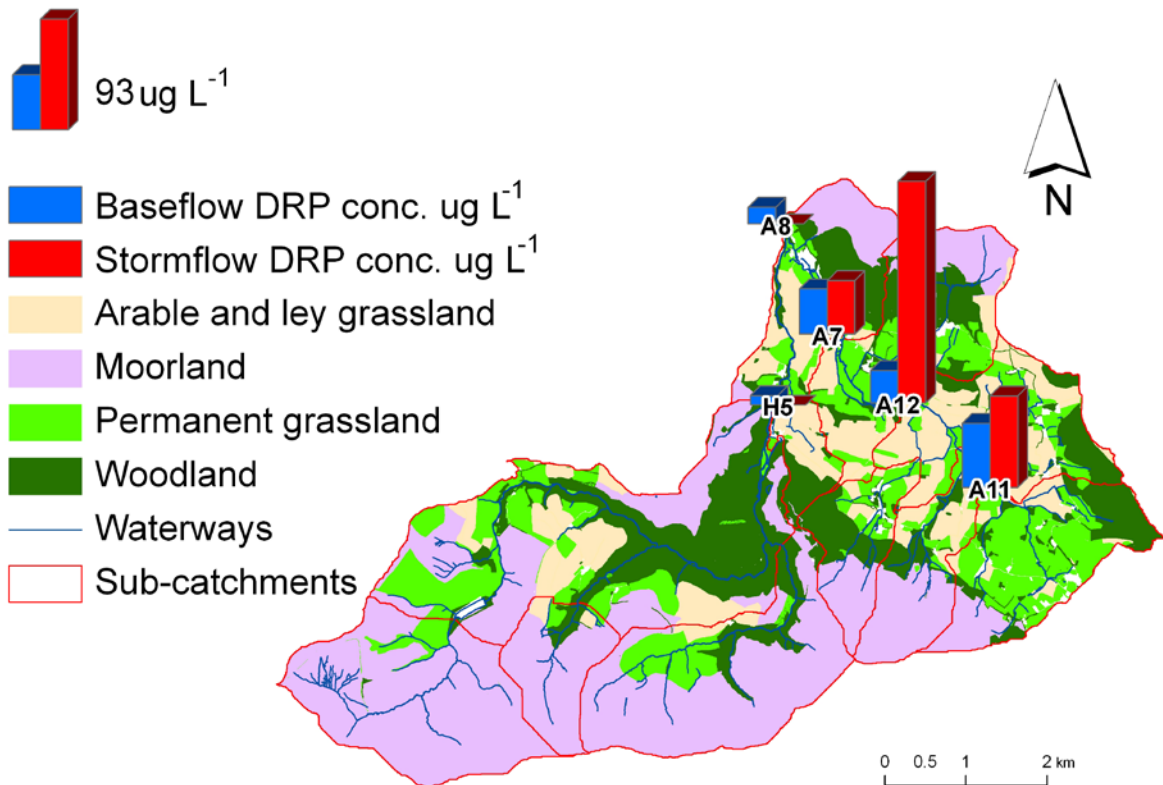
### *Pollutant yields*

The highest yields of SS, DRP, DOC, TPC and TON were recorded in the upper reaches of the Aller catchment in the A11 sub-catchment, with soil erosion rates of 1.9 tonnes (t) ha<sup>-1</sup>, in excess of the mean estimated soil formation rate of 1 t ha<sup>-1</sup> year<sup>-1</sup> (Figure 3.6). Although for SS and TPC the reducing yields may be related to increasing downstream sediment storage with increasing catchment size, this is not the case with solute loads. Greater hydrological connectivity (steeper slopes) and a high water yield (runoff per unit area) are likely to contribute to higher efficiency of nutrient delivery to the watercourse from intensive land use and from rural point sources (for example, septic tanks) upstream of the A11 sampling locations.

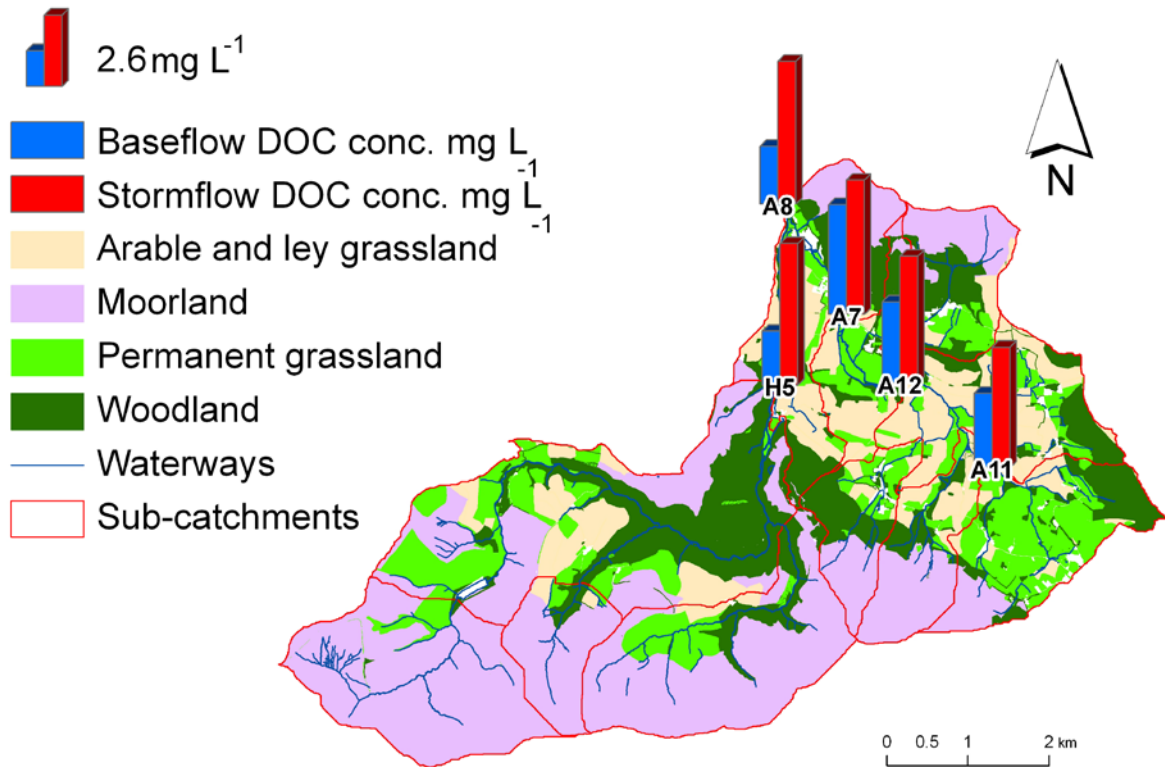
(a)



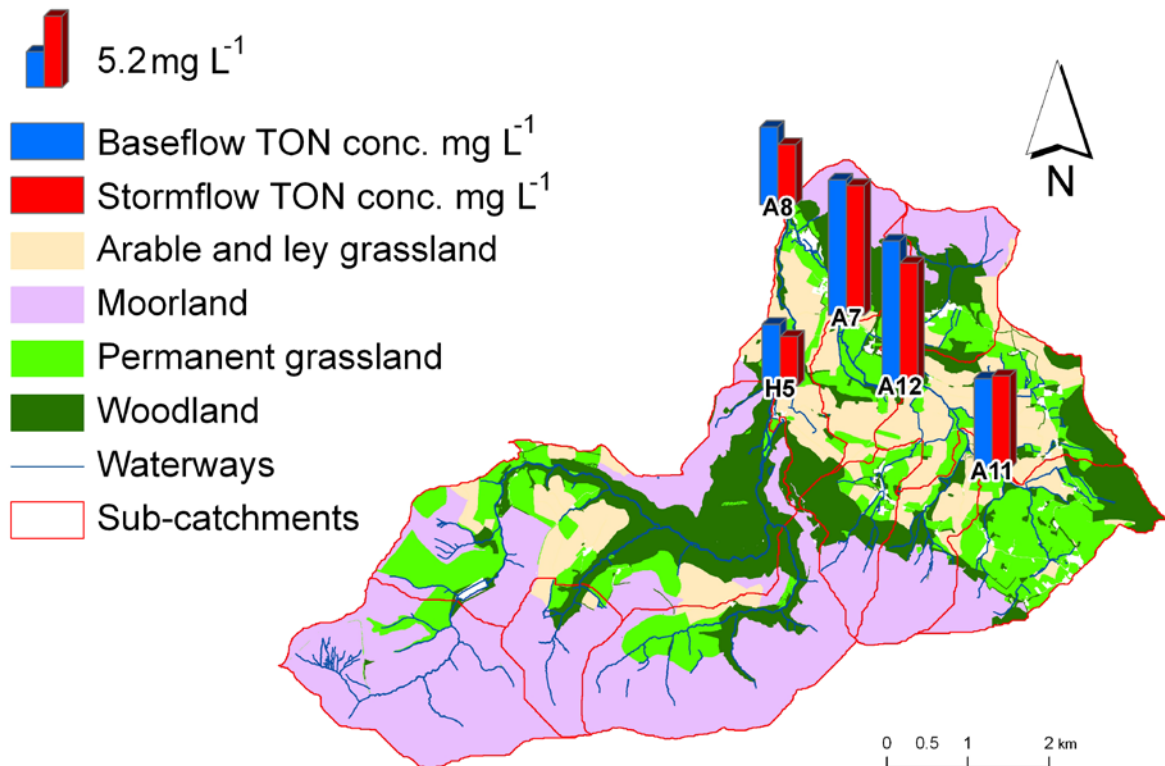
(b)



(c)

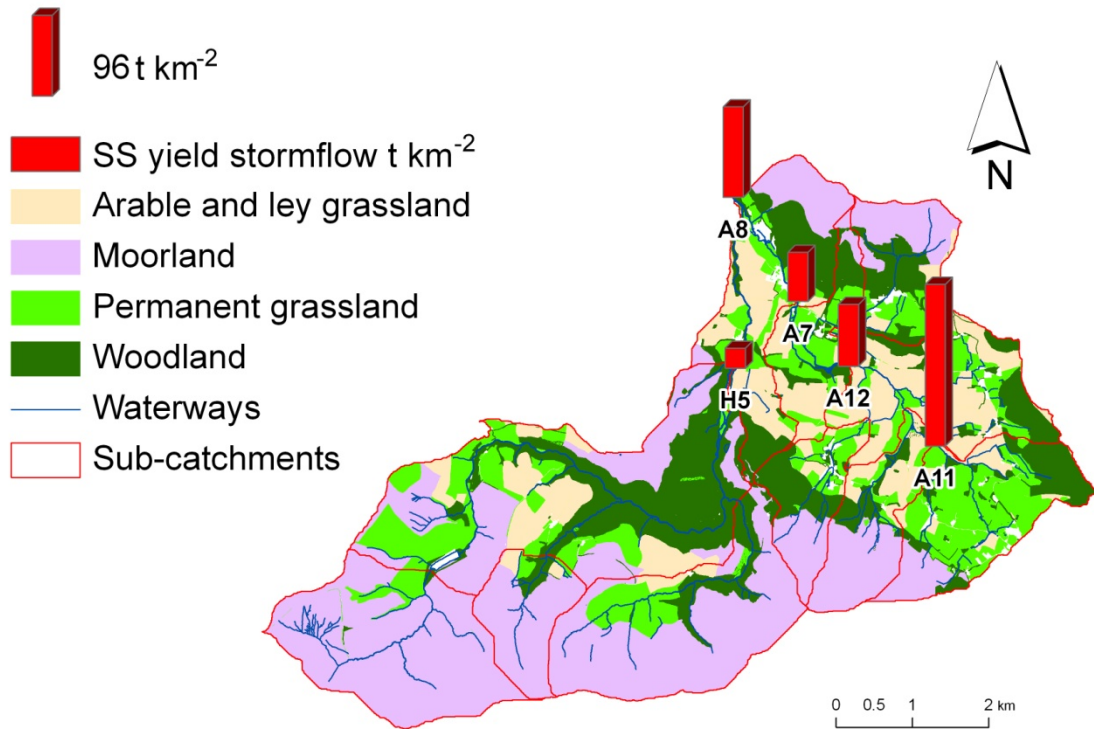


(d)

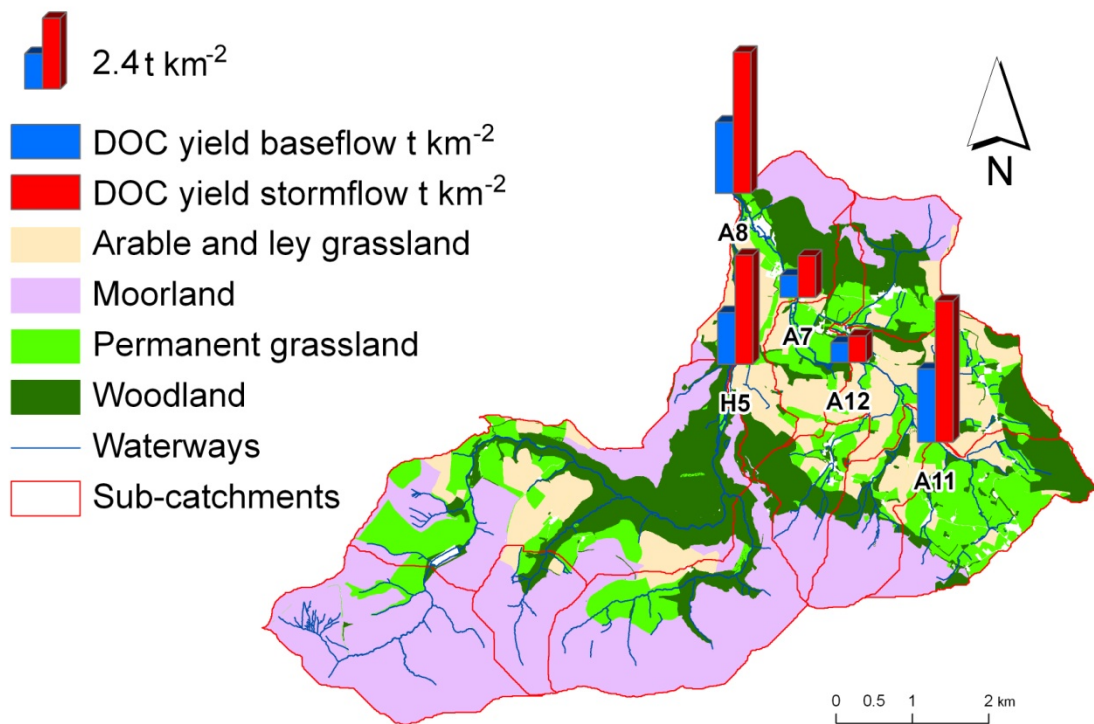


**Figure 3.5** Median concentrations of (a) SS, (b) DRP, (c) DOC and (d) TON in baseflow and stormflow at the five stormflow monitoring sites, showing the spatial distribution of water quality determinands and the ranking of sites both in baseflow and stormflow conditions (all units mg L<sup>-1</sup>, DRP units  $\mu\text{g L}^{-1}$ )

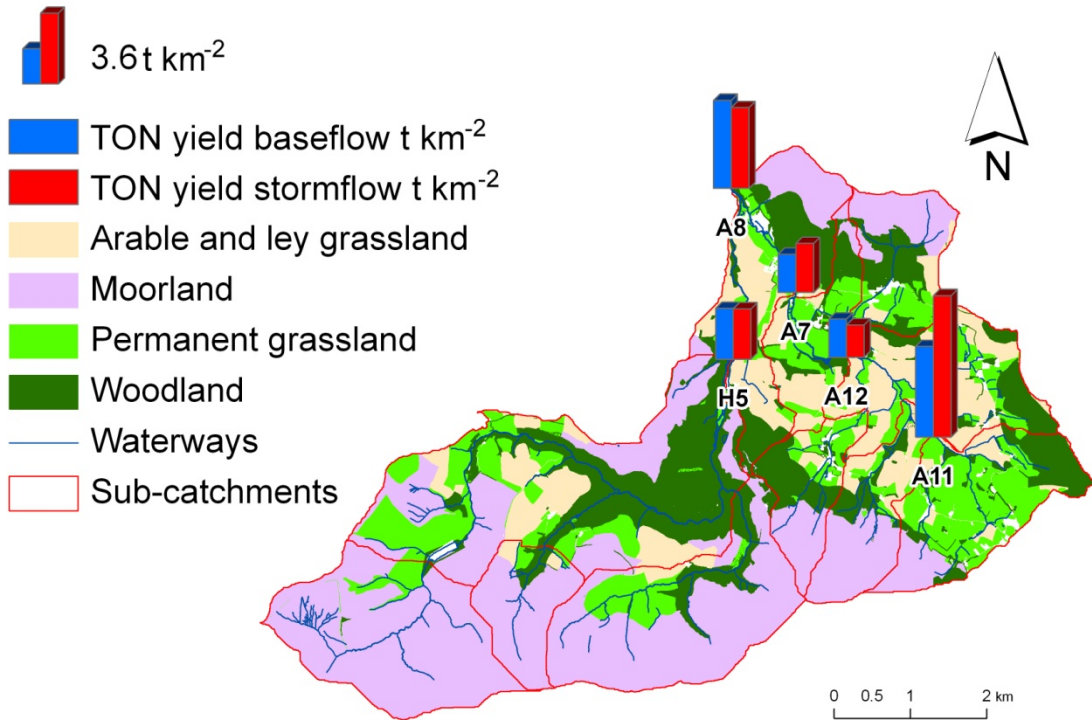
(a)



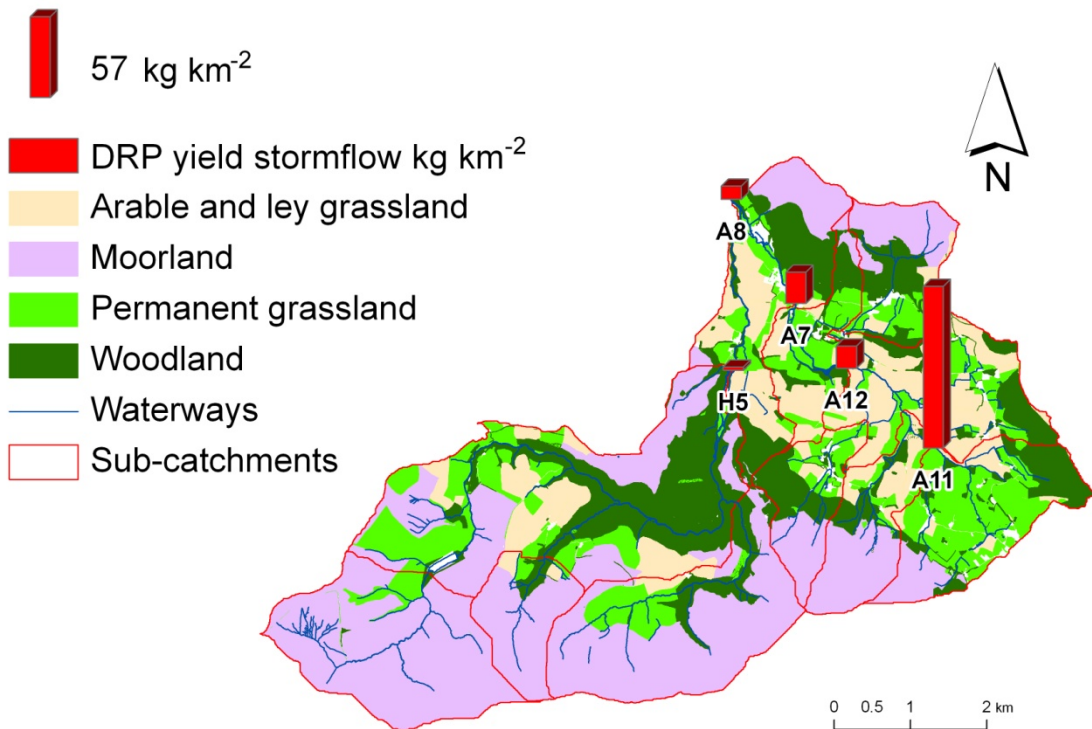
(b)

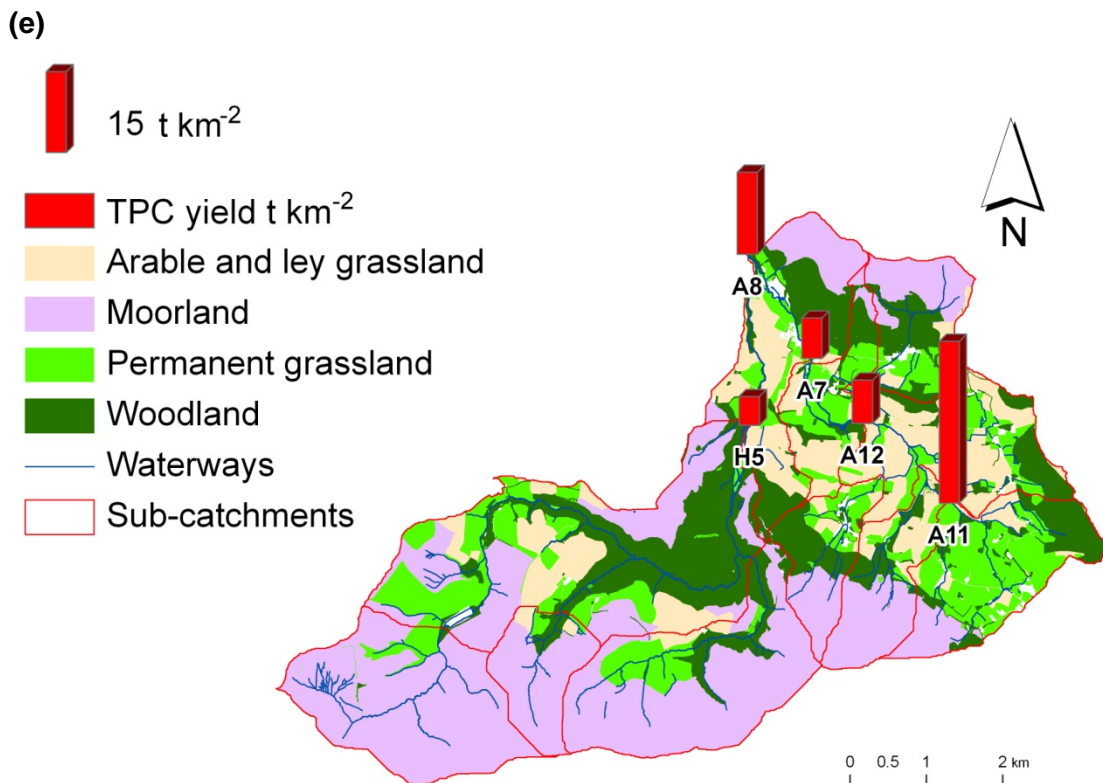


(c)



(d)





**Figure 3.6** Yields of (a) SS, (b) DOC and (c) TON calculated from baseflow data and from all data at the five stormflow monitoring sites; (d) DRP and (e) TPC yield calculation was based on stormflow data alone

### *Mitigation measures*

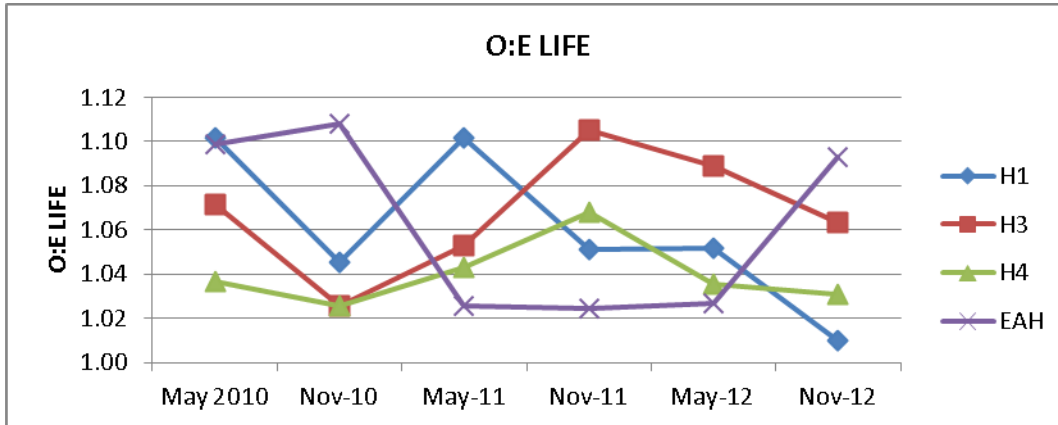
The proposed conversion of arable land on steep slopes within the Aller catchment is likely to reduce the enhanced sediment flux into the watercourse, as are the flood management alleviation levées. However, the greater extent of intensively managed grassland and prolonged anaerobic conditions in the floodplain may lead to an enhanced flux of DRP unless low-input management of these permanent grasslands can be secured. As most of the A11 sub-catchment is outside National Trust ownership, the current mitigation measures will not address the higher pollution risk in this sub-catchment.

Although the observed TON concentrations in the Aller catchment are below the current freshwater drinking standard of 50 mg L<sup>-1</sup>, the extended period of soil saturation in the floodplain and the introduction of wooded buffer strips may lead to an increased removal of TON in the middle reaches of the Aller catchment through enhanced denitrification. Additional wooded buffers along the tributaries in the middle reaches of the catchment (A7 and A12 sub-catchments) would help to stabilise the river banks and thus further reduce the sedimentation impact.

### **3.5.2 Horner Water catchment**

No significant positive or negative physicochemical or biological signal can be detected as a result of the upland ditch blocking in the Horner Water catchment one year after restoration. This may in part be due to the limited period of post-restoration monitoring, but may also indicate that the extensive earth-moving works had no adverse effect on

the water quality in this high quality semi-natural environment. However, a near-significant response of the macro-invertebrate LIFE index ( $p < 0.08$ ) suggests that the ditch blocking may have increased the resilience of freshwater biota by delaying a drop in the LIFE index in the H3 and H4 sub-catchments following a period of drought, as compared with a control (H1) and the Environment Agency long-term monitoring site (EAH) (Figure 3.7). Further data analysis will be undertaken to explore these relationships in more detail.



**Figure 3.7** Time series plot of LIFE shows a potentially delayed response of macro-invertebrate fauna to drought in the restored H3 and H4 sub-catchments compared with the control (H1) and the Environment Agency long-term monitoring site at the Horner Water outlet (EAH) ( $p < 0.08$ ).

Notes: Pre-restoration: May 2010 to May 2011  
 Post-restoration: November 2011 to November 2012.



# 4 Conclusions

This study contributes significantly to the current research agenda examining the cumulative impact of land use mitigation measures on multiple pollutants in freshwater systems, using catchments as real world research platforms. Detailed baseline characterisation of water quality at nested scales in this catchment-scale research platform represents a valuable resource that will help to inform the effectiveness of future land use changes and provide high quality empirical observations for modelling studies that could help to further the understanding of the complex interactions and controls on water quality at a catchment scale. The large-scale alteration of soil physical and chemical properties found in this study is further evidence of extensive anthropogenic impact on catchment processes from the most fundamental microbial level to large-scale hydrological response.

The enhanced fluvial carbon export from the agricultural catchment observed in this study is just one sign of an ecosystem-level response to these cumulative anthropogenic catchment-scale alterations. Restoration of such extensive anthropogenic impact to a more natural state will take time, while the detection of positive change will require commitment to collection of long-term observation time series.

The main research findings are summarised below together with suggestions for further research.

## **Research question 1: How does spatial variability of key soil properties vary between the two contrasting study catchments and what are the implications for mitigation of poor water quality?**

The spatial variability of soil bulk density, total soil C, N, P and  $\delta^{15}\text{N}$  in the two contrasting study catchments was characterised to provide a firm baseline for the monitoring of future land use changes and to identify likely critical source areas of diffuse water pollution. The kriged surfaces of soil variables identified likely critical source areas for targeting of land management interventions to improve water quality and highlighted the large spatial extent of the alterations of soil properties, with implications for the rates of soil organic matter turnover, nutrient retention and prolonged restoration timescales. While extensive alteration of soil properties is likely to have a direct impact on above- and below-ground terrestrial biodiversity, the links between these alterations and the ecological status of water bodies are less clear and deserve further attention.

Comparison of nutrient stocks (carbon and phosphorus) using the detailed geostatistical sampling and the national NSRI dataset showed comparable results, indicating that higher resolution soil sampling does not necessarily improve the estimation of nutrient stocks at the scale of these two study catchments. This finding supports the use of coarse-resolution national datasets for the estimation of soil nutrient stocks at a range of scales.

## **Research question 2: What are the current rates of fluvial carbon export in terms of dissolved organic and total particulate carbon from the two catchments and how do they relate to soils, prevailing land use and habitat mitigation?**

The study quantified the total fluvial fluxes of dissolved organic and particulate carbon in two study catchments with contrasting land uses. The agricultural Aller catchment yielded proportionally greater fluxes of suspended sediment and particulate carbon than the semi-natural catchment; this is likely to be due to enhanced rates of soil erosion. The proportionally greater flux of dissolved organic carbon from the agricultural catchment may be due to a number of factors. First, it is likely to reflect the

faster turnover of soil organic matter as a result of anthropogenic nutrient addition. Secondly, addition of nutrients may promote autochthonous autotrophic DOC production and transformation of particulate carbon into DOC in the fluvial environment. Finally, alteration of hydrological pathways as a result of land drainage may also contribute to enhanced DOC fluxes along preferential pathways. The implications of enhanced fluvial carbon fluxes on the cycling of other nutrients in the aquatic environment are poorly understood, as are the implications of the enhanced fluvial DOC flux from agricultural catchments for the ecological status of freshwaters and the global carbon cycle. Further research in replicated catchments with contrasting land use but similar climatic and topographic controls would help to understand the significance of enhanced fluvial carbon fluxes in agricultural catchments for the global carbon cycle. Qualitative analysis of dissolved organic carbon and total particulate carbon in catchments with contrasting land uses would elucidate the sources, pathways and ecological significance of the altered carbon cycling.

**Research question 3: Can the new pressure-specific invertebrate index PSI act as a tool for determining ecologically relevant water quality sedimentation targets?**

In this study the PSI index has been shown to relate to the percentage of fine bed sediment cover (silt and clay) across a narrow gradient of impact. PSI was not related to mean suspended sediment concentration. In addition, PSI was not related to the percentage of time for which the current guideline suspended solids threshold of  $25 \text{ mg L}^{-1}$  has not been exceeded, although the sample size for this analysis was limited. Two existing macro-invertebrate metrics – LIFE and percentage EPT abundance – were also related to the percentage fine bed sediment cover, though this relationship was statistically less significant than for PSI. Furthermore, while PSI was correlated with the existing macro-invertebrate LIFE metric, the relationship was weaker in the absence of hydrological stress. PSI and percentage EPT were not correlated, suggesting that they were responding differently to multiple environmental pressures. The study's findings suggest that PSI and percentage fine bed sediment cover have the potential to act as simple tools for the monitoring and setting of twin sedimentation targets. However, further testing along a pronounced gradient of multiple stressors is recommended.

**Research question 4: Are the proposed mitigation measures in the lowland Aller catchment likely to deliver water quality improvements at a catchment scale?**

The study established a firm baseline against which the effects of future land use changes on water quality in the Aller catchment can be evaluated. Greatest concentrations of suspended solids, dissolved reactive phosphorus and total oxidised nitrogen were recorded in the middle reaches of the Aller catchment at sampling locations A12 and A7, reflecting the enhanced input of sediment and nutrients from the intensively farmed arable and grassland land uses. Field observations identified a number of direct preferential overland delivery pathways of sediment from arable fields along paved roads. The proposed conversion of arable land on steep slopes within the Aller catchment is likely to reduce this source of enhanced flux of sediment into the watercourse, as are the proposed flood management alleviation levées. But while both these measures are likely to reduce the sedimentation impact in the Aller, a greater extent of intensively managed grassland and prolonged anaerobic conditions in the floodplain may lead to an enhanced flux of dissolved reactive phosphorus unless low-input management of these permanent grasslands can be secured. A number of suitable management prescriptions are outlined in the Higher Level Environmental Stewardship Scheme, including those relating to (Natural England 2013):

- arable reversion to unfertilised grassland to prevent erosion or run-off (HJ3)

- preventing erosion or runoff from intensively managed improved grassland (HJ6)
- seasonal livestock removal on grassland with no input restriction (HJ7)
- nil fertiliser supplement (HJ8)
- restoration of species rich semi-natural grassland (HK7)
- restoration of wet grassland for wintering waders and wildfowl (HK12)

Some of the permanent grassland fields in the floodplain, managed in-hand by the National Trust or the tenant farmer, already receive no input. To reduce the risk of phosphorus leaching this kind of management should be extended to all fields that will be subject to enhanced flooding due to the construction of flood alleviation levées.

Although the observed median total oxidised nitrogen concentrations in the Aller catchment of between 6.5 and 10.4 mg TON L<sup>-1</sup> are low compared with the current freshwater drinking standard of 50 mg TON L<sup>-1</sup>, they are above the perceived eutrophication level of 2.2–4.4 mg TON L<sup>-1</sup> for running waters. The extended period of soil saturation in the floodplain and the introduction of wooded buffer strips are likely to lead to enhanced denitrification. This will help to reduce TON concentrations in the middle reaches of the Aller catchment.

The relationship between the percentage of woodland within a 10 m buffer and SS stormflow concentrations found in this study suggests that bank instability is an important source of sediment in the freshwater environment. Therefore, it is recommended that additional wooded buffers along the tributaries in the A7 and A12 sub-catchments would help to stabilise the river banks and reduce the sedimentation impact.

Highest yields of suspended solids, dissolved reactive phosphorus, dissolved organic carbon, total particulate carbon and total oxidised nitrogen were recorded in the upper parts of the Aller catchment at the A11 monitoring site. Although for suspended solids and total particulate carbon this may be related to increasing sediment storage with the increasing catchment size, this is not the case with solute loads. Therefore, high solute yields reflect proportionally greater nutrient input in the Aller headwaters in the A11 sub-catchment and will not be addressed by the proposed mitigation measures in the middle reaches of the catchment.

#### **Research question 5: How does upland ditch restoration impact on the chemical and biological indicators of water quality in three headwater tributaries of Horner Water?**

No clear positive or negative physicochemical or biological signal can be detected as a result of the upland ditch blocking in the Horner Water catchment one year after restoration. While this may in part be due to the limited period of post-restoration monitoring, it may also indicate that the extensive earthmoving works had no adverse effect on water quality in this high quality semi-natural environment. However, the statistically near significant results indicate that macro-invertebrate monitoring could potentially act as a sensitive tool in detecting a signal from the upland ditch blocking in terms of maintenance of baseflow and a delayed response to drought. Data collected in this study could be subjected to further analysis to understand the detailed macro-invertebrate community response and to examine whether bio-monitoring could provide a simpler time-integrated solution to the evaluation of restoration schemes compared with long-term hydrological and physicochemical monitoring.

#### **Research question 6: How effective can ecosystem management be in delivering water quality objectives?**

Long-term monitoring of the national action plans in Denmark and the Netherlands has demonstrated that significant water quality improvements of a single contaminant (nitrate) are possible through large-scale implementation of a range of mitigation measures that target both sources and delivery pathways (Windolf et al. 2012). Recent modelling of anticipated response times of Irish aquifers has also shown that improvements in the nitrate status of groundwater bodies in response to extensive mitigation measures can be expected within two decades. Similarly, recent modelling has shown that depletion of soil phosphorus status can also be anticipated within similar timescales (Schulte et al. 2010, Wall et al. 2013). These findings indicate that, despite the complexity of the hydrological, physical, biological and land use controls within catchments, improvements in the ecological status of water bodies can be expected, albeit over longer timescales than originally envisaged by policymakers. Detailed baseline characterisation of water quality at nested scales in catchment-scale research platforms represents a transferable monitoring approach. It is also a valuable resource that will help to inform the effectiveness of future land use changes and provide high quality empirical observations for modelling studies that could help to further the understanding of the complex interactions and controls on water quality at a catchment scale.

The large-scale alteration of soil physical and chemical properties at a catchment scale found in this study is further evidence of extensive anthropogenic impact on catchment processes from the most fundamental microbial level to large-scale hydrological response. The enhanced fluvial carbon export from the agricultural catchment observed in this study is just one sign of an ecosystem-level response to these cumulative anthropogenic catchment-scale alterations. Restoration of such extensive anthropogenic impact to a more natural state will take time, while the detection of positive change will require commitment to collection of long-term observation time series.

While long-term collection of high resolution data is resource-intensive, testing of the PSI index shows that the development of simple effective indicator approaches to identification and monitoring of environmental pressures which utilise existing datasets and monitoring techniques represents a cost-effective solution, thus providing a tool that 'adequately represents small scale process complexity ... at a catchment scale' (Soulsby et al. 2006). Similarly, the near-significant signal from upland restoration detected by the macro-invertebrate LIFE index indicates that bio-monitoring may offer an ecologically meaningful, time-integrated solution to the monitoring of landscape-scale restoration schemes.

Collection of high-quality hydrological and physicochemical water quality data is demanding due to technological and logistical challenges. A clear emerging learning point from catchment-scale evaluation projects relates to the need for a sufficient pre-restoration monitoring period, allowing for the installation and testing of field monitoring equipment and almost inevitable initial difficulties with collection of reliable data. An ongoing need for continuous data quality control, field equipment maintenance and high labour input necessary for the collection of flow rating data during high flow events also need to be acknowledged at the start of any monitoring scheme. Further challenges relate to the delays in obtaining statutory consents and the feasibility of effecting actual land management change on farmed land that is subject to business considerations.

Although the extent of nitrate vulnerable zones in England was recently reduced, there is little evidence that the current restrictions within the zones had a significant effect on the improvement of drinking water status compared with non-designated areas (Worrall et al. 2009). Conversely, the initial evaluation of the effectiveness of the Catchment Sensitive Farming (CSF) initiative in England indicates that this approach may be successful in reducing the effects of diffuse water pollution by a number of

contaminants on recipient water courses (CSF Evidence Team 2011). An observed challenge in the lowland catchment in this study related to a ‘pollution swapping’ scenario, whereby although a voluntary agreement for arable conversion was secured from one landowner using an agri-environment scheme agreement, an unforeseen simultaneous conversion of permanent grassland to arable land occurred on a neighbouring holding on similarly ‘high risk’ ground. This illustrates the challenge of securing lasting land management and land use change at a sufficient scale in a commercial environment.

A number of recent research initiatives investigating the effects of land management and land use change on ecosystem services such as flood risk management, water resource management and management of diffuse water pollution have been instigated, including the Defra-funded Demonstration Test Catchments platform and the Multi-objective Flood Management Demonstration Projects. From a policy perspective, it would be efficient to assemble the lessons from all these schemes to inform further scheme implementation and to secure continued scientific monitoring that is integrated between projects set up with different policy objectives in mind.

In summary, a number of learning points emerge from this work:

- Agriculture results in an extensive alteration of soil physical and chemical properties, with implications for ecosystem functioning and restoration timescales.
- Agricultural land use leads to enhanced fluvial export of sediment, particulate and dissolved organic carbon with poorly understood consequences for the health of the aquatic ecosystems and the global carbon cycle.
- The new macro-invertebrate bio-monitoring index PSI appears to be a promising simple integrated tool for the detection of sedimentation impacts and setting of twin sedimentation targets, in conjunction with the monitoring of percentage fine bed sediment cover.
- The potential of macro-invertebrate monitoring to act as a sensitive time-integrated tool for the monitoring of the effects of upland ditch blocking on baseflow maintenance should be investigated further.
- The proposed mitigation measures in the lowland catchment may deliver water quality improvements, though there is likely to be a need for additional wooded buffers in the most extensively managed sub-catchments and implementation of no-input grassland management, especially on newly flooded areas. An ongoing challenge relates to unforeseen future land management changes driven by commercial considerations that may obscure the signal from the implementation of individual mitigation measures at a catchment scale.
- Integration of learning and coordination of research from different research platforms and demonstration projects set up to measure the impact of land management and land use change on different ecosystem services would be beneficial.

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# List of abbreviations

$\delta^{15}\text{N}$	stable nitrogen isotope
BD	soil bulk density
C	carbon
C:N ratio	carbon to nitrogen ratio
Defra	Department for Environment, Food and Rural Affairs
DOC	dissolved organic carbon
DRP	dissolved reactive phosphorus
EPT	Ephemeroptera, Plecoptera and Trichoptera
LIFE	Lotic Index for Flow Evaluation
N	nitrogen
NSRI	National Soil Research Institute
OECD	Organisation for Economic Co-operation and Development
P	phosphorus
PSI	proportion of sediment-sensitive invertebrates
SOM	soil organic matter
SS	total suspended sediment
TON	total oxidised nitrogen
TPC	total particulate carbon
UK TAG	United Kingdom Technical Advisory Group [WFD]
WFD	Water Framework Directive

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