Results and practical implications of the first 3 years of the programme

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Executive Summary

Background

This report summarises the results of the first 3 years of the Water Friendly Farming project which was launched in October 2012 by Freshwater Habitats Trust and the Allerton Project of the Game & Wildlife Conservation Trust, supported by a range of partners, including the Environment Agency and Syngenta.

Water Friendly Farming is a research demonstration project designed to test the effectiveness of landscape-wide mitigation measures that are used to reduce the impact of rural land use on streams, ponds, lakes and rivers, without impinging on the profitability of farm businesses. The impacts mitigated include elevated levels of pollutants such as nitrogen, phosphorus, sediments and pesticides, the accelerated runoff of water from the land and the physical modification of freshwater habitats.

To date, despite widespread use of measures such as buffer strips, interception ponds and constructed wetlands across the country, there is little evidence to evaluate how effective these measures are *at the catchment scale*.

Water Friendly Farming aims to provide this evidence.

Approach

Water Friendly Farming is a Before-After-Control-Impact experiment in three directly adjacent catchments, each of about 10 km^2, and drained by the Barkby Brook, Eye Brook and Stonton Brook. The Eye Brook and Stonton Brook catchments are being manipulated experimentally, with the Barkby Brook acting is the control.

An important feature of the project is the establishment of a pre-works baseline varying in length between two and three years for different elements of the project. Baseline data sampling began in 2010 and was fully established at the end of 2011. Mitigation measures were mainly installed in winter/spring 2013/14, becoming active in April 2014, so that we are now 6 months into evaluating their effectiveness.

As part of the experiment design, one catchment (Eye Brook) has had water resource protection measures alone applied (e.g. interception ponds, bunded ditches), with these measures intended to slow flows and intercept or reduce pollution. The second catchment (Stonton Brook) has had water resource protection measures plus habitat creation work applied (e.g. pond creation, debris dam installation), to assess the additional benefit that habitat creation work brings for freshwater biota.

The project has two main approaches to assessing the effectiveness of mitigation measures:

(i) broad scale studies of freshwater biodiversity and ecology across the whole landscape with annual 'snapshot' surveys of wetland plants, freshwater invertebrates and water chemistry in a stratified sample of 250 ponds, streams and ditches (approximately 80 in each catchment);

(ii) more intensive studies of stream water quality based on continuous water sampling at the catchment outfalls and twice monthly sampling within individual catchments. This has involved evaluation of nutrients (nitrogen and phosphorus), sediments, water flows and pesticides.

In addition to the landscape studies, we have collected further biological data on stream invertebrates, wetland plants, diatoms and fish.

Landscape and water environment

The project area is typical of a large part of the UK farmed environment being made up of two Defra Land Classes: Land Class 5, the eutrophic tills, and Land Class 6, pre-Quaternary clays which, together, make up about 35% of the arable land in Britain. In terms of the water environment, the project landscape is typical of the ordinary farmed countryside. Most waterbodies in the project area are small, comprising streams, ponds and ditches. In total, freshwaters occupy about 0.5% of the land surface. Individually, streams comprise the largest part of the water environment, followed by ditches and ponds. There are no lakes (water bodies of 2 ha or more) or rivers (defined as linear watercourses marked by two blue lines on Ordnance Survey 1:25,000 scale maps) in the project area.

Ecology and freshwater biodiversity

Our landscape scale studies of wetland plants in ponds, streams and ditches in the three catchments confirm the now widely observed pattern that, although ponds occupy the smallest physical area, they support the widest variety of freshwater species, followed by streams and ditches. Streams and ditches, however, also support species of ecological importance. Patterns in freshwater biodiversity in the project area have been remarkably consistent over the three baseline years, both year to year in each catchment, and between the catchments.

Assessment of the ecological quality of ponds, using the PSYM system, shows that only about 10% are in Good condition, with the majority either Poor or Very Poor, a pattern which mirrors that seen nationally in the UK Countryside Survey. Uncommon wetland plants occurred only in ponds.

A distinctive feature of ponds in the project landscape is that they are virtually the only areas supporting submerged vascular water plants, which are amongst the most sensitive freshwater species. In the study area, streams and ditches are generally either too shaded or shallow to support many of these species. Interestingly, and of some concern, since the establishment of the baseline period in 2010, there has been a marked decline in the number of submerged plants recorded in each of the catchments, although habitat creation work has offset this decline in the Stonton catchment (see 'Effects of Mitigation' below).

There is, to date, less evidence of change in stream and ditch ecosystems. Long-term stream invertebrate monitoring data, collected from about 2000 onwards by the Environment Agency, are available from a small number of sites downstream of the project catchments. These show evidence of long-term improvement in some locations but deterioration elsewhere.

Figure 1. Combining oilseed rape in the Eye Brook catchment. Oilseed rape is the second most important crop in the project area, after winter wheat.

The majority of streams in the project area are not currently classified under the Water Framework Directive. Within the three project catchments, only the main stem of the Eye Brook is classified along its full length in the project area. Part of the Barkby Brook is also classified under the Directive but none of the Stonton Brook in the study area. Streams in the project area have, therefore, been provisionally classified using data collected by the project, based mainly on invertebrate information so far. Results indicate that all three catchments include some High status waters (also supported by phosphorus analysis - see below), whilst other sites are Moderate or Poor status.

Overall, the results show that streams within the project area vary substantially in biological quality and differ significantly from the statuses shown for catchments on Water Framework Directive maps, which simplify the natural heterogeneity of small streams based on samples often taken further down the catchment.

We have collected baseline datasets on fish across the landscape in two years. There was good agreement in fish species composition and density between these years (2012 and 2013). One catchment, the Eye Brook, is known locally for supporting wild brown trout. Survey work undertaken roughly 10 years previously suggests, when compared to the project datasets, that there may be a long-term decline in the brown trout population. There is support for this observation from Environment Agency fish data collected at other locations in the Eye Brook catchment over the last 10 years.

Water quality, pollution and flows

The project datasets show clear evidence of the distinctive physico-chemical heterogeneity of small waters in lowland landscapes: typically, the standing or slow -flowing waters (ponds and ditches) are chemically more varied than streams, which, because they flow, integrate physico-chemical differences between sites. Studies elsewhere also suggest that ponds, ditches and streams are themselves more heterogeneous than larger rivers: a finding which has important practical and policy implications (see 'Implications for policy and practice' below).

Although all catchments have some patches of 'clean water' (i.e. free from significant impacts due to human pressures), pollution is widespread, affecting around 95% of the waterbodies in the project area. Across the catchments as a whole, ponds and ditches have higher average total phosphorus concentrations than streams, even though some streams are impacted by rural sewage works effluents. This suggests that the smallest water are experiencing the most substantial pollution impacts. Annual 'snapshot' surveys suggest that about 30% of waterbodies (ponds, streams and ditches) have low total phosphorus levels, close to natural background levels. In contrast, total nitrogen levels are generally higher, with very few waterbodies - around 5% - having nitrogen concentrations near natural background levels.

In terms of Water Framework Directive nutrient standards, streams in all three project catchments range from Bad to High status. It is notable that within catchment twice monthly sampling confirms that streams draining predominantly from grassland often have very low soluble reactive phosphorus levels - well within natural background levels. However, many of these streams have high nitrogen levels. Although not currently classified under Water Framework Directive, nitrogen levels are commonly well above levels which are internationally recognised as damaging to freshwater biota.

Water quality monitoring data collected by the Environment Agency from the 1980s onwards provide a longer-term perspective on water quality in two of the project catchments: Barkby Brook (the control) and Eye Brook. In the Barkby Brook, data from a sampling location just downstream of the project area shows there has been a significant downward trend in both orthophosphate and total oxidised nitrogen over this time. In the Eye Brook, based on a sampling location 10 km downstream of the project area, there has been no change in phosphorus levels over the last 20 years, but a clear downward tend in nitrogen concentrations.

These patterns contrast with the very recent water quality trends measured as part of the intensive monitoring programme of the project. All three catchments show a significant upward trend in Total Phosphorus concentrations at the end of catchment monitoring location from spring 2012 onwards. The trend is similar in all catchments, including the control (Barkby).

Suspended sediment concentrations showed significant downward trends in the control catchment (Barkby) and the Eye Brook during the baseline period. The Stonton Brook showed no trend in suspended sediment concentrations suggesting that there may have been over-riding non-climatic factors operating to increase sediment loss from this catchment.

Total oxidised nitrogen concentrations declined over the baseline period in the control (Barkby) and the Stonton Brook, but remained constant in the Eye Brook.

We are currently exploring these data in detail to understand the influence of the extremely wet years 2102 and 2013 on these patterns. The role of mitigation measures on water quality is discussed in the 'Effects of mitigation' section (below).

Pesticides

We monitored end of catchment concentrations of metaldehyde, widely used in slug pellets, and three autumn applied herbicides: carbetamide and propyzamide, which are commonly applied to winter wheat, and chlorotoluron which is used on oilseed rape. Information on metaldehyde was available in both winter 2012/13 and 2013/14. Because much of the oilseed rape crop in the region failed in 2012/13, due to the exceptionally wet conditions, little pesticide was applied at this time. Monitoring data for the three autumn herbicides are therefore

Figure 2. Black Grass (*Alopecurus myosuroides*), an annual weed that can reach heights of 80-90cm, growing amongst wheat. Black Grass is a major problem to UK farmers because infestations can cause substantial loss of yield. Populations of 200-400 plants/m^2 are quite common; densities of just 12 plants/m^2 can reduce yield by 5%. Seed is shed before harvest thereby replenishing the soil seedbed.

only available for 2013/14.

Metaldehyde runoff was clearly seen following rainfall during the main application period from mid-September to early November, with low level contamination into December. The Eye Brook and Stonton Brook showed very similar patterns of metaldehyde runoff. Data for the Barkby Brook (control) were only available in 2013/14. Here peaks matched those seen in Eye Brook and Stonton Brook but concentrations were around 10 times lower reflecting lower metaldehyde application.

Carbetamide was seen in runoff from the control catchment (Barkby) and Stonton in early autumn 2013/14, with losses up to mid -November. Propyzamide, which is applied later in the autumn, was detected in the Eye Brook just before Christmas in 2013/14. The low levels in the Eye Brook, and lack of detection in the control, reflect the lower levels of use of the compound.

Overall, pesticide monitoring provides evidence to suggest that the hydrological response is similar in the three catchments, which is important to help understand trends observed following installation of mitigation measures, and to facilitate development of modelling approaches that can be used to apply the results more widely.

Mitigation measures

Mitigation measures installed so far as part of the project have been concerned with both water resource protection measures (Eye Brook and Stonton Brook) and additional habitat creation measures for freshwater biodiversity (Stonton Brook only). On farmland we have begun changing in-field cultivation practices and used edge of field methods (interception ponds, bunded ditches) to intercept surface runoff and drainflow. We have also tackled point source pollution, through emptying of septic tanks, refurbishment of a rural reed bed treatment works, and reconstruction of the yard drainage of one farm (most farms were assessed as having acceptable waste water management in place already). Most streams, and many ditches, are already buffered (see 'Effects of mitigation', below). There were some stretches of stream which were previously unfenced and accessible to livestock. We have now completed the network of fences in these areas and installed alternative drinking water sources (Papa pumps).

To enhance habitats for freshwater biodiversity, in the Stonton Brook catchment we installed in-stream woody debris at a wide range of locations and created clean water ponds, off-line from the main (contaminated) drainage network. We have also begun management of existing pond habitats.

Effects of mitigation

Mitigation measures to influence water quality and hydrology mainly became operational in spring 2014, with any structures created before this time designed in such a way that they could be 'switched on' once baseline data collection had been completed. New ponds, created to provide additional biodiversity habitat, were mostly created over winter 2013/14, but were off-line and did not directly influence stream water quality. In addition to direct observation of the effectiveness of measures, we have used modelling techniques to provide an early indication of the expected effects of mitigation measures.

Biologically there is clear evidence of a landscape-wide decline of aquatic plants (i.e. specifically submerged species) in all three catchments. These are the most sensitive part of the aquatic flora and are almost entirely restricted to ponds in the project catchments. In the Stonton catchment, where new ponds were added to the landscape for wildlife, this trend has been counteracted, with the mitigation measures preventing landscape scale loss of aquatic plant diversity. We have not yet undertaken 'post-mitigation works' sampling of other biotic groups.

We have begun to use the population viability assessment model Meta-X with our current biological datasets to develop a fuller understanding of the way in which new habitats could help to maintain the persistence of populations of freshwater species. We have initially modelled populations of two aquatic plants: one restricted species, Horned Pondweed (*Zannichellia palustris*), which occurs in only one or two sites in each catchment annually, and a much more widespread species, Common Duckweed (*Lemna minor*), which is present in 50-75% of standing waterbodies annually.

To assess the effects of mitigation measures on the physical and chemical environment, we have used the Soil and Water Assessment Tool (SWAT). The model captures our field-measured flow data effectively, a first pre-requisite for modelling transport of agricultural pollutants and incorporating the effects of mitigation measures. Having established the basic hydrological foundations of the model, we have applied it successfully to the simulation of metaldehyde, with an excellent fit achieved between observed and modelled concentrations in both the Eye Brook and Stonton Brook.

We have used the model to retrospectively assess the effect of buffer strips in the Eye Brook catchment. Most streams and ditches in the catchments already have riparian buffer zones, and we used the model to assess differences in sediment with and without buffers. The model appears to provide a good estimate of current sediment loads with modelled annual losses within 25% of measured losses. A separate simulation indicated that sediment losses would have been more than double (130%) the amount now seen without buffers, suggesting that buffering in the Eye Brook is already having a substantial effect.

We are currently developing further model components to predict sediment and nutrient losses from the catchments to asses the effect of our current measures.

To assess catchment flow retention, we have used simple modelling techniques to compare the amount of water retention capacity we have created in bunded ditches, interception ponds and other features with the amount of storage required to reduce downstream flood risk. This suggests that to reduce peak flows by 15-20% we will need roughly 10 times more storage than we have currently installed in each catchment. At present we have about 3000 m^3 of short-term water storage; to make a significant impact on downstream peak flows we need in the region of 30,000 m^3 storage.

Conclusions & implications for policy and practice

The results so far suggest that the project area is representative of a large part of lowland Britain's cultivated land, that patterns of freshwater biodiversity are very similar in the three project areas and that chemically and hydrologically the catchments behave in similar ways. This indicates that the sites are functioning well as experimental demonstration sites and that the results will be relevant to a large part of the lowland landscape. Importantly we have been able to simulate the catchments hydrology using SWAT and model, with good agreement, key chemical parameters. This suggests that we have a reasonable understanding of the underlying processes which should improve the implementation of practical measures to protect and improve the water environment.

We have seen one of the first practical demonstrations that habitat creation can prevent loss of freshwater biodiversity at a landscape scale. There is often debate about how fast mitigation measures become effective in freshwaters: the current results show that ponds can provide a landscape level mitigation response within one year.

Catchment modelling using the project data has enabled us to retrospectively demonstrate the value of buffer zones in reducing sediment loads. It also shows that we need to increase the amount of storage capacity in the catchment to hold back water in sufficient quantities to reduce flood risk downstream. In the near future we expect to predict the likely effects of our practical work to date on phosphorus, nitrogen and sediment concentrations and loads, and to fine tune further mitigation measures accordingly. This will give us important insights into the effectiveness of measures which can be compared to field observations.

The catchments show the importance of small standing waters for freshwater biodiversity, and the extent of pollution impacts across rural landscapes. As importantly the study shows the heterogeneity of the landscape: there are still patches of clean water in the landscape which, for biodiversity, are important refuges. The results suggest a number of new approaches that will be needed to transition from freshwater mitigation and protection focused on downstream waters: work that will need to encompass all parts of the water environment, both small and large, and the biodiversity and ecosystem services these waters collectively support.

1. Background to the project

1.1 Background to the project

The impact of agriculture on freshwater ecosystems

It is very widely recognised that agriculture has substantial unwanted impacts on freshwaters, and a very wide range of measures have been proposed in an attempt to reduce or eliminate these impacts.

In developing these measures an equally wide range of studies has been undertaken investigating the effectiveness of different mitigation techniques. However, until very recently, virtually all of these studies have been undertaken at a relatively small scale, and have focussed on evaluating the effectiveness of individual measures (e.g. buffer strips, non-inversion tillage, interception wetlands). Most have also lacked comprehensive pre-intervention baseline descriptions of the environments being protected.

A critical gap therefore has been in understanding whether measures introduced into the landscape, often at considerable cost to public funds, are proving effective at catchment scale.

Here we report the results of the baseline characterisation phase of the Water Friendly Farming project, and summarise the first results following the installation of mitigation measures in a typical lowland arable and grassland farming system in the East Midlands of the UK. We also describe the mitigation measures which are being implemented in the landscape for testing.

1.2 The project location

The Water Friendly Faming project is located in Leicestershire, between Leicester and Stamford. The main settlements in the study area are Tilton-on-the Hill and Skeffington (Figure 4).

The project is taking place within the upper reaches of the catchments of the Barkby Brook, Eye Brook and Stonton Brook.

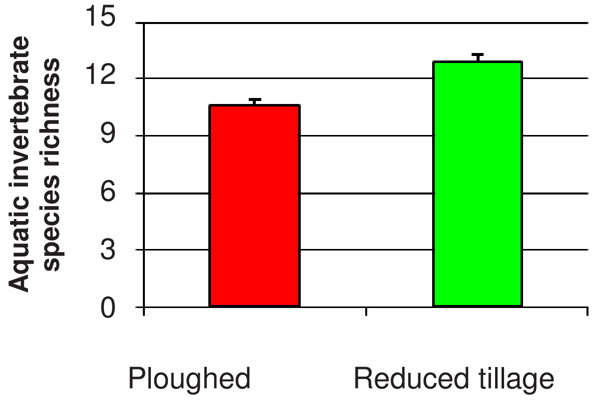


Figure 3. Aquatic invertebrate species richness in streams in ploughed and reduced tillage catchments in the SOWAP project. Results are based on bi-monthly sampling in n = 5 ploughed and n = 5 reduced tillage catchments over 1 year. (Freshwater Habitats Trust, unpublished data).

1.3 The need for evidence on the effectiveness of mitigation measures

There is an abundance of evidence showing the *small scale physical* and *chemical* effects of mitigation measures. Despite this, a number of reviews have cast doubt on the effectiveness of many freshwater protection techniques, both individually and collectively (e.g. Mayer *et al*. 2007, Palmer 2009, Harris and Heathwaite 2011).

There are two main reasons why measures often appear to be ineffective:

- Firstly, most techniques have focused on mitigating pollution, assessed in terms of water chemistry changes. It has generally been assumed that ecological benefits would automatically follow chemical trends. However, where ecological research has been undertaken to confirm this, the results have generally been disappointing.
- Second, even amongst water chemistry studies, the effectiveness of measures is very varied. Recent reviews indicate this is typically either because:

  (i) methods are more variable in their practical effectiveness than originally anticipated.

(ii) measure application is too piecemeal across catchments, or

(iii) the mode of application is not optimal: buffer zones are too narrow or are by-passed by sub-surface drains, minimum tillage is not used on appropriate soil types, etc.

In addition, the poor catchment-level performance of water protection measures may reflect limitations in the type of measure applied. Agriculture has considerable impacts on catchment hydrology through drainage and canalisation. However, interpretation of the Water Framework Directive means that the hydromorpholgy elements (e.g. depth, width, flow, structure) are only considered to be supporting elements of chemical and biological status unless the water body is at high status, where hydromorphology is assessed in its own right, or for artificial or heavily modified water bodies where mitigation measures must be put in place to ensure the hydromorphological quality of the waterbody is achieving at least Good Ecological Potential. In general therefore, measures to protect freshwaters from agricultural impacts are strongly focused towards preventing pollution. Physical habitat work is normally only undertaken on Heavily Modified Waterbodies outside of the standard suite of pollution protection techniques and poorly funded within agri-environment schemes.

The omission of hydro-morphological restoration from the standard array of protection measures is an increasing limitation. Water chemistry and biodiversity are both intimately linked to catchment hydrology. Thus, in biodiversity terms, chemically 'clean' waterbodies may not recolonise to give biological benefits if waterbodies are constrained hydro-morphologically or isolated from sources of colonising organisms. To achieve adequate restoration which achieves multiple benefits for biodiversity, water quality and catchment hydrology may require re-establishment of a more natural physical structure in headwater

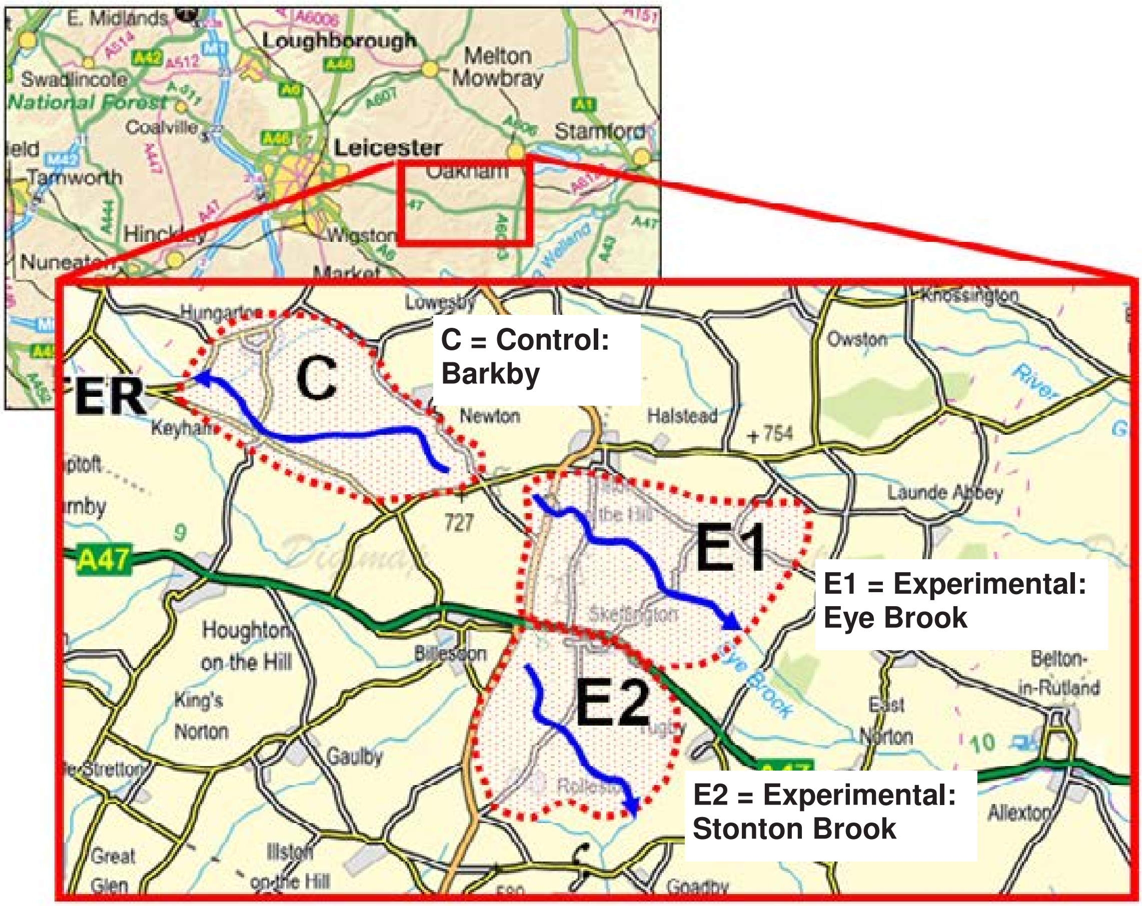


Figure 4 Location of the project area and catchments

streams, increased accessibility of upper catchments to migrating organisms by removing barriers, and increased connectivity between different kinds of freshwater habitat by creating new habitats, such as new ponds and wetlands, to reduce between-waterbody distances.

Given both the current environmental demands and the limited evidence base, there has for some time been an urgent need for "proof of concept": clear evidence that existing measures *can* be applied to give catchment-scale outcomes, and begin to deliver the benefits we require in terms of sustainable catchments and delivery of policy targets.

There are two broad approaches to providing such proof:

- a greater focus on bottom-up approaches which test the efficacy of each individual measure (buffer strips, constructed wetlands, river restoration) under differing environmental conditions,
- a top-down approach which combines the range of optimised measures, to identify whether, given our best efforts and knowledge, ecological, hydrological and water quality gains are achievable within practical timescales.

Ultimately both approaches are necessary. A bottom-up approach helps us to understand and optimise application of individual measures. A top-down approach provides a reality check – enabling us to identify the scale of environmental benefits that are possible when measures are combined, and the temporal scales over which changes are likely to be seen.

Water Friendly Farming takes a top-down approach. It does so for the following reasons:

1. So far, most top-down catchment-scale trials have been limited in application and poorly monitored. As a result, although we broadly understand the extent to which agriculture degrades freshwater environments, we still have little idea of the degee to which mitigations can be combined to restore quality and functioning.

2. The demands for catchment-scale answers are now considerable. "Win-win" scenarios, where biological, hydrological and chemical benefits all accrue through integrated catchment management, are much discussed but little tested. The need to provide answers is increasingly urgent, particularly given the timescales (5-20 years) needed to adequately evaluate performance.

Figure 5. The Eye Brook, which drains one of the three project catchments.

3. Bottom-up approaches have not yet provided satisfactory answers at a catchment scale. Most individual techniques are still in the process of evaluation and for many, assessment has hardly begun. Adequate evaluation is likely to require very considerable research effort: even supposing research funds are available. We cannot wait until each individual mechanism is understood, before putting them together to have a broad idea of efficacy.

1.4 Aims

Overall, the project aims to determine experimentally whether measures intended to protect freshwaters, and the services they provide, from the unintended impacts of agriculture are effective at a catchment scale. Although many studies have demonstrated benefits at plot and field scale (e.g. buffer strips, constructed wetlands, changes in tillage practice), there is remarkably little evidence available on the effectiveness of these measures at a catchment scale.

1.5 Experimental design

The project takes an experimental approach to assess the effects of water protection and habitat creation measures at a catchment scale. A Before-After-Control-Impact (BACI) design is being used: an approach which most previous studies lack. Pre-implementation monitoring is essential to prove change in freshwater systems which are inherently variable, particularly given inevitable limitations finding adequate replicates and control sites.

The project experimentally addresses two key scientific questions:

1. By comprehensively implementing across a landscape the *full* range of measures available for reducing diffuse pollution and controlling runoff, can significant improvements be achieved in waterbody ecological quality and landscape scale aquatic biodiversity, downstream flood risk and waterbody chemical quality?

2. Are there likely to be significant additional benefits from physically restoring habitats (e.g. restoration of headwaters by, for example, adding woody debris to streams, installation of on-line retention ponds, pond creation in areas with clean micro-catchments)?

To answer these questions the BACI design comprises:

1. A control catchment where no changes are made; the control catchment allows background changes in the landscape to be controlled for in the experiment

2. A catchment in which water protection and hydrological management measures alone are implemented

(iii) A catchment in which water protection measures, hydrological measures *and* additional physical habitat enhancements are all implemented allowing the combined effect of both types of measure to be assessed.

We originally planned a baseline of at least 2 years monitoring before introducing any change. A schematic of the experimental design of the demonstration area is shown in Figure 6a.

1.6 Small and large waters make up the aquatic environment

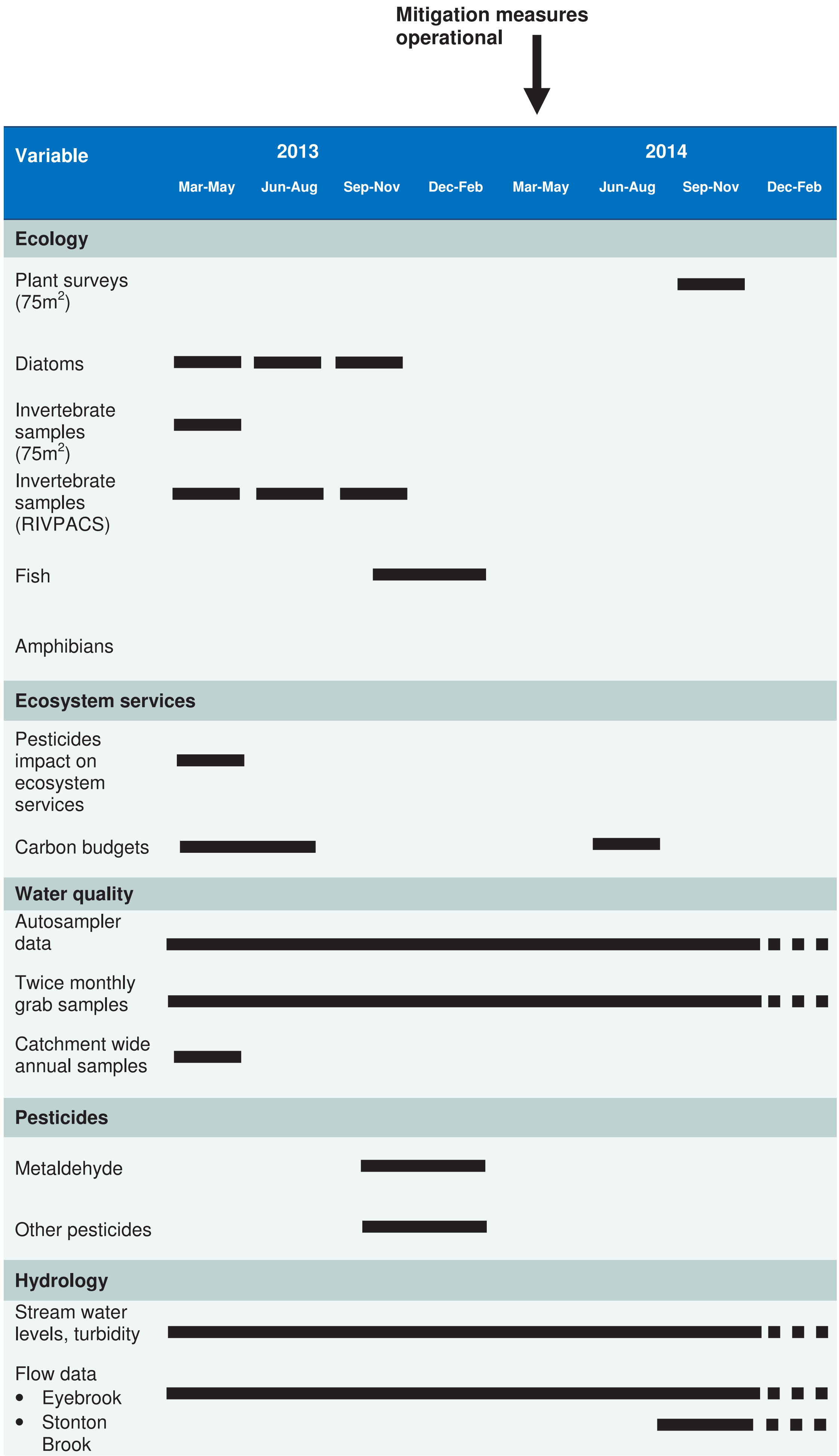
The project is the first catchment study to consider the whole of the freshwater environment including streams, ponds and ditches (there are no waterbodies large enough in the study to be identified as rivers). It builds on a long series of research and practical projects undertaken by Freshwater Habitats Trust and our partners which has evaluated the comparative importance and roles of different waterbody types in the agricultural landscape. This has led to increasing recognition of the importance of smaller waters, both still and running, influencing both policy and practice in the protection of freshwater ecosystems.

1.7 Scope of work and timetable

Planning began in 2006, and the baseline establishment started in 2010 with the first biological catchment surveys. Intensive water quality and hydrological monitoring started at the beginning of 2012 (see Table 1). Installation of mitigation measures began in the second half of 2012 but, with the exception of new offline wildlife ponds, measures were installed in a non-operational state to be ‘switched on’ when the baseline monitoring work was completed in April 2014.

Table 1. Project monitoring timetable: 2010-2014

Variable	2010		2011				2012			
	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb
Ecology										
Plant surveys ($75m^2$)					■				■	
Diatoms										
Invertebrate samples ($75m^2$)			■				■			
Invertebrate samples (RIVPACS)			■				■			
Fish									■	■
Amphibians							■			
Ecosystem services										
Pesticides impact on ecosystem services										
Carbon budgets										
Water quality										
Autosampler data							■	■	■	■
Twice monthly grab samples							■	■	■	■
Catchment wide annual samples	■						■			
Pesticides										
Metaldehyde									■	■
Other pesticides										
Hydrology										
Stream water levels, turbidity							■	■	■	■
Flow data • Eyebrook • Stonton Brook										


Mitigation measures operational
Variable
2013
2014
Mar-May
Jun-Aug
Sep-Nov
Dec-Feb
Mar-May
Jun-Aug
Sep-Nov
Dec-Feb
Ecology
Plant surveys (75m2)
Diatoms
Invertebrate samples (75m2)
Invertebrate samples (RIVPACS)
Fish
Amphibians
Ecosystem services
Pesticides impact on ecosystem services
Carbon budgets
Water quality
Autosampler data
Twice monthly grab samples
Catchment wide annual samples
Pesticides
Metaldehyde
Other pesticides
Hydrology
Stream water levels, turbidity
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• Stonton Brook

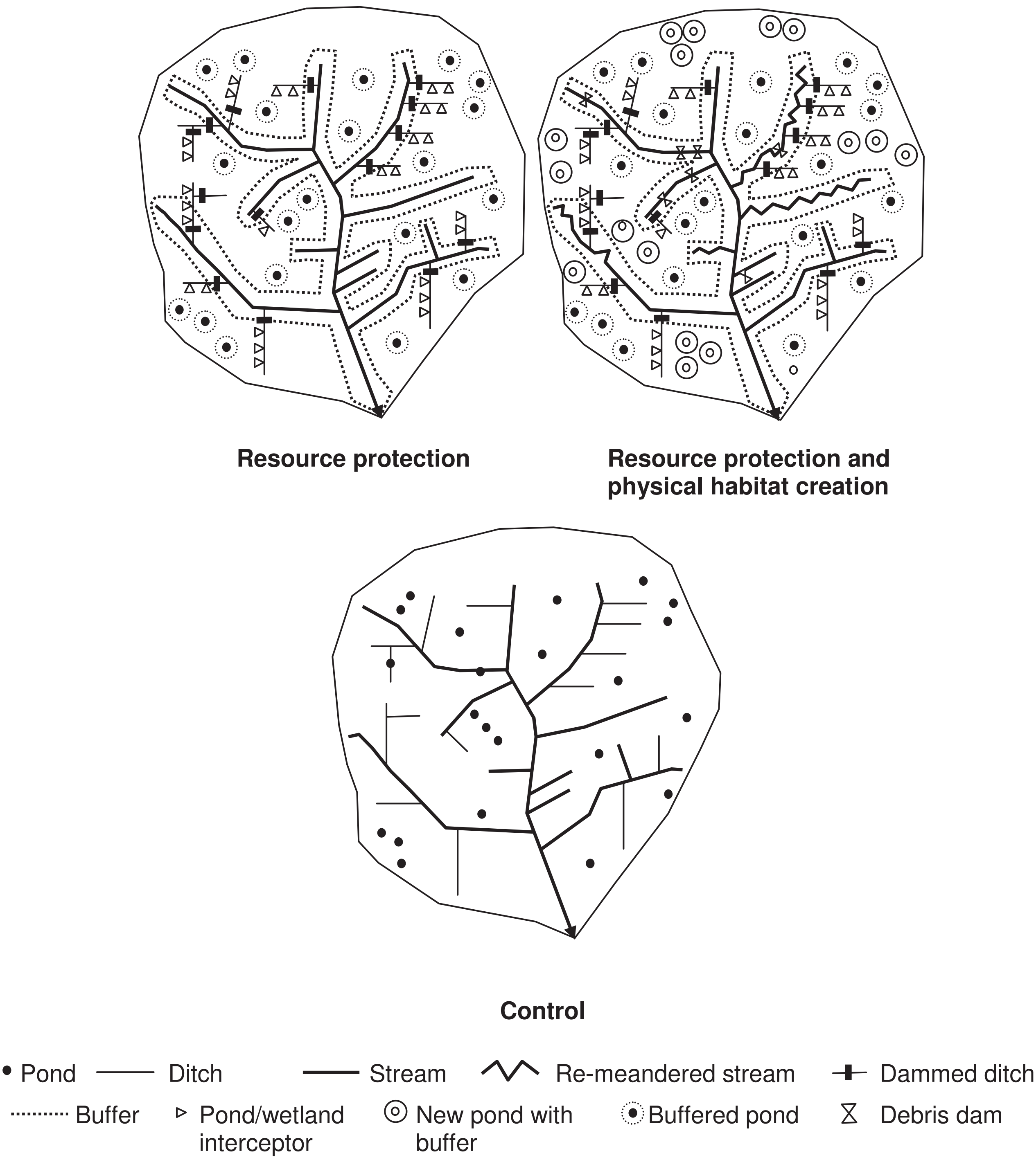


Figure 6a. Schematic layout of each demonstration site in the Water Friendly Farming Landscapes project. Examples of the types of measures are not comprehensive.

Figure 6b. The Stonton Brook catchment where both resource protection and habitat creation measures are being investigated.

2. Landscape and water environment

2.1 How typical of the lowland farmed landscape is the project area?

The Water Friendly Farming project area is made up of two of the most extensive of the cultivated land classes of the British agricultural landscape: Land Class 4, eutrophic tills, and Land Class 6, pre-Quaternary clay. Originally defined by Brown *et al.* (2006), the land class classification was developed for Defra and divided the landscape of Great Britain into 13 land-classes based on hydrogeology, soils, topography and cropping patterns (Figure 7 and Table 2). Together, Land Classes 4 and

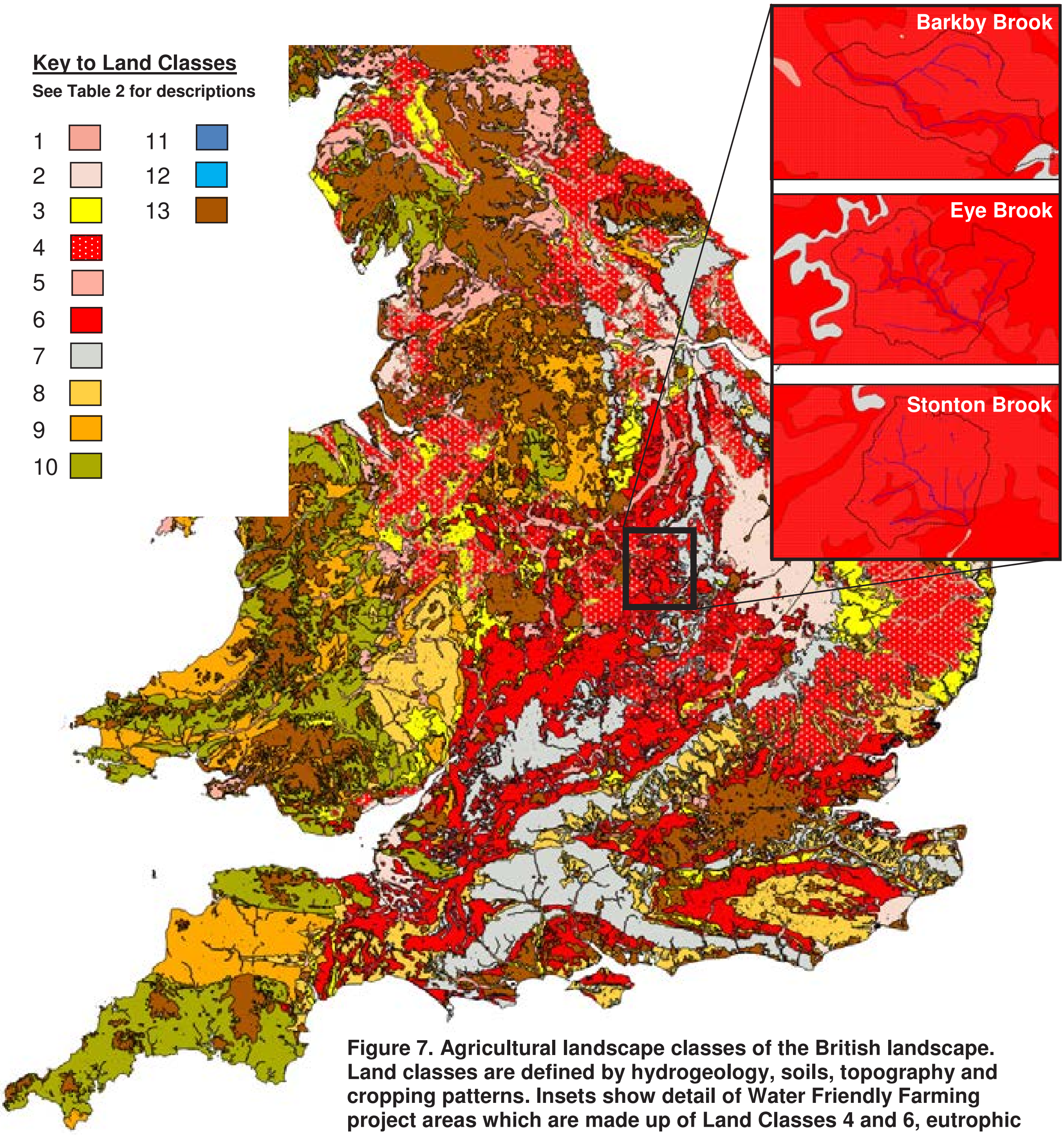


Figure 7. Agricultural landscape classes of the British landscape. Land classes are defined by hydrogeology, soils, topography and cropping patterns. Insets show detail of Water Friendly Farming project areas which are made up of Land Classes 4 and 6, eutrophic tills and pre-Quaternary clays

Table 2. Agricultural landscape classes in Great Britain

Land class	Description	Total area (km^2)	Groundwater	Dominant water flow
1. River floodplains and low terraces	Level to very gently sloping river floodplains and low terraces	7781	Normally present at <2 m depth	Vertical
2. Warplands, fenlands and low terraces	Level, broad 'flats' with alluvial very fine sands, silts, clays and peat	9017	Normally present at <2 m depth	Vertical or saturated lateral
3. Sandlands	Level to moderately sloping, rolling hills and broad terraces. Sands and light loam	10871	Normally present at <2 m depth	Vertical
4. Till landscapes (eutrophic)	Level to gently sloping glacial till plains. Medium loams and clays with low base status (oligotrophic). Some lighter textured soils on outwash	22151	Generally none present	Predominantly saturated lateral
5. Till landscapes (oligotrophic)	Level to gently sloping glacial till plains. Medium loams and clays with low base status (oligotrophic). Some lighter textured soils on outwash	15449	Generally none present	Predominantly saturated lateral
6.Pre-quaternary clay landscapes	Level to gently sloping vales. Slowly permeable, clays (often calcareous) and heavy loams. High base status (eutrophic)	19706	None present	Saturated lateral
7. Chalk and limestone plateaux and coombe valleys	Rolling 'wolds' and plateaux with 'dry' valleys. Shallow to moderately deep loams over chalk and limestone	14197	Present at >2 m depth	Vertical
8. Pre-quaternary loam landscapes	Gently to moderately sloping ridges and vales and plateaux. Deep, free-draining and moderately permeable silts and loams	10072	None present	Saturated lateral
9. Mixed, hard, fissured rock and clay landscapes	Gently to moderately sloping hills, ridges and vales. Moderately deep free-draining loams mixed with heavy loams and clays in vales	12259	Either none or present at >2 m	Saturated lateral; some vertical over groundwater
10. Hard rock landscapes	Gently to moderately sloping hills and valleys. Moderately deep free-raining loams over hard rocks. Some slowly permeable heavy loams on lower slopes and valleys	23342	None	Lateral along rock boundaries
11. Scotland only: moundy morainic and fluvio-glacial deposits	Gently and moderately sloping mounds, some terraces. Free-raining moraines, gravels and sands on mounds, poorly draining gleys in hollows	2270	Variable	Vertical over groundwater; some saturated lateral
12. Scotland only: footslopes with loamy drift	Concave slopes or depressional sites, often with springlines	1081	Variable	Variable
13. Non-agricultural	All areas not cultivated with arable (including orchards, soft fruit and horticultural) or maintained grassland	79690	Variable	Variable

6 make up 35% of the arable land in Great Britain. The project area is therefore representative of a substantial proportion of the UK's cultivated land.

Eutrophic tills (Land Class 4) are characterised by level to gently sloping glacial till plains with medium loam, clay and chalky clay soils, with high base status (eutrophic). The pre-Quaternary clays (Land Class 6) are characterised by level to gently sloping vales, slowly permeable clay (often calcareous) and heavy loam soils, with high base status (also eutrophic).

2.2 The freshwater environment

The water environment in the Water Friendly Farming study area is made up of three waterbody types: ponds, streams and ditches (Table 3). These freshwater habitats make up about 0.5% of the land surface area in the study catchments (Figure 8). Streams are the most extensive waterbody type, and ponds the least extensive. Pre-project pond densities were typical of the current UK landscape average of 1.8 / km^2.

This pattern is typical of a large part of the farmland landscape and has been seen elsewhere when similar landscape scale studies of all freshwater habitat have been made. The total water area (Figure 8a) is slightly lower than the national average for the extent of freshwaters, which is approximately 2% of the land surface. This is because the study area lacks larger areas of open water, particularly lakes and reservoir's. There are no rivers in the study area.

Table 3. Definitions of waterbody types used in the project

Brown *et al.* (2006) defined in a Defra funded study the main freshwater habitat types in the UK landscape: ponds, lakes, stream, rivers and ditches. In the Water Friendly Farming project area there are ponds, streams and ditches. None of the linear watercourses are large enough to be classified as rivers. There are no lakes in the study area. The types are:

Ponds	Waterbodies between 25 m2 and 2 ha in area which may be permanent or seasonal (Collinson et al., 1995). Includes both man-made and natural waterbodies.
Streams	Small lotic waterbodies created mainly by natural processes. Marked as a single blue line on 1:25,000 Ordnance Survey (OS) maps and defined by the OS as being <8.25 m in width. Stream differ from ditches by (1) usually having a sinuous planform, (2) not following field boundaries, or if they do, pre-dating boundary creation, and (3) showing a relationship with natural landscape contours e.g. running down valleys.
Ditches	Man-made channels created primarily for agricultural purposes, and which usually: (i) have a linear planform, (ii) follow linear field boundaries, often turning at right angles, and (iii) show little relationship with natural landscape contours.
Rivers	Larger lotic waterbodies, created mainly by natural processes. Marked as a double blue line on 1:25,000 OS maps and defined by the OS as >8.25 m in width.
Lakes	A body of water >2 ha in area. Includes reservoirs and gravel pits.

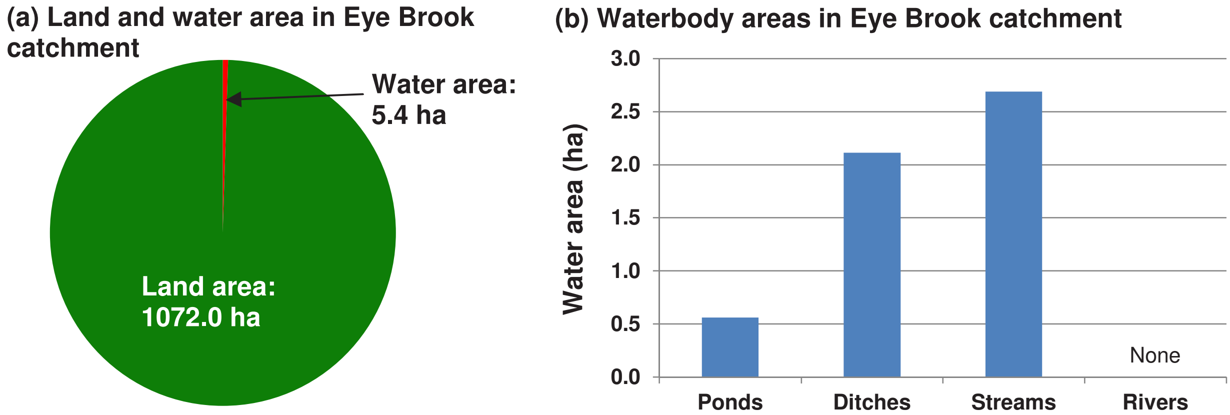


Figure 8. Area of water in the Eye Brook catchment (ha): (a) as proportion of whole catchment and (b) proportions of the three waterbody types

Figure 9. Freshwater habitats in the three project catchments: (a) Barkby Brook (b) Eye Brook (c) Stonton Brook. Maps show all surface waterbodies in each landscape. Gaps in the stream network (blue lines) occur where streams are piped underground (culverted).

2.3 Landuse and topography

Landuse

Landuse in the project area is roughly equally divided between arable and grassland, although the control catchment, Barkby Brook, has a slightly higher proportion of grass than the two experimental catchments. Between 7% and 10% of each of the project catchments comprises woodland. Settlements and other minor landuse categories make up the remainder of the land surface. Water occupies about 0.5% of the study area.

The main crop types are oilseed rape, winter wheat, field beans and winter barley.

Table 4. Landuse in the three project catchments

	Barkby Brook	Eye Brook	Stonton Brook
Arable	36%	45%	44%
Grass	52%	42%	41%
Woodland	7%	9%	10%
Other	4%	4%	5%

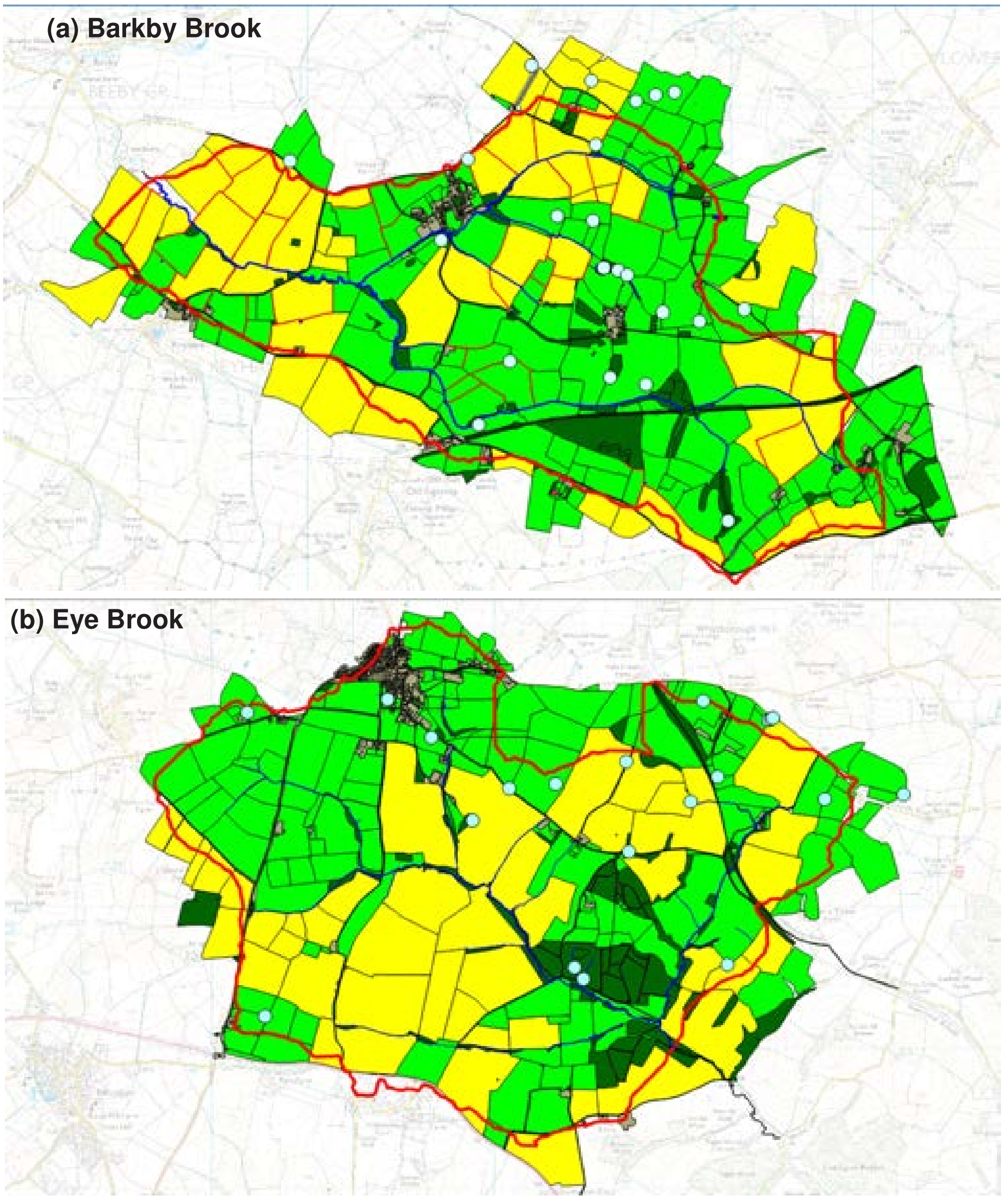
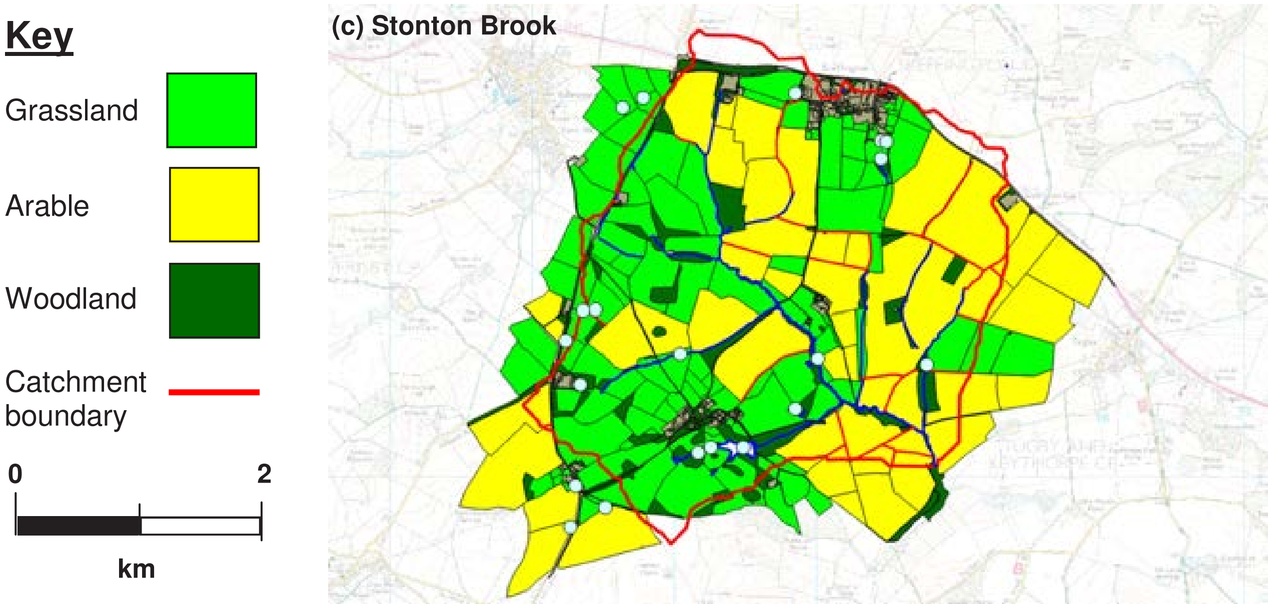


Figure 10. Landuse in the project area: (a) Barkby Brook (b) Eye Brook (c) Stonton Brook..



Soils in the study area are mainly heavy to medium clays, with some sandy outcrops, and are predominantly poorly draining. They generate significant surface runoff and are extensively under-drained for arable agriculture.

The landscape in the study area is moderately sloping and creates substantial runoff risks for the water environment (Figure 11).

Figure 11. Many parts of the project area are at risk from surface runoff. In the upper part of the Eye Brook substantial overland flow occurred during January 2013.

Examples of the three main freshwater habitat types in the project area

Figure 12a. Pond 2 in the Stonton Brook catchment is one of a small number of sites that support Great Crested Newts. Spring total phosphorus concentrations were moderately high with an average over three years of 205 µg/L.

Figure 12b. Ditch draining into the Stonton Brook in wet weather in January 2013 transporting substantial quantities of sediment and associated pollutants to the stream network. Field drains are an essential part of the agricultural environment maintaining soils in a condition suitable for crop growth.

Figure 12c. The Eye Brook, shown above, fluctuates between High and Good status, in terms of the Water Framework Directive freshwater invertebrate assemblage. In terms of phosphorus, the status of the waterbody is only Moderate because of sewage works effluents. However, this section is officially classified as High status for phosphorus because, at the monitoring point, which is about 10 km downstream, enough dilution has taken place to reduce the phosphorus concentration to that required to meet the High status criterion.

3. Methods

3.1 Design of the landscape scale study

For the landscape-wide study of all freshwater habitats, for assessing freshwater biodiversity and water quality, we created a stratified random sample of streams, ponds and ditches which have been sampled annually (Figure 14a). A total of 180 sites was selected initially (60 each of the habitat types: ponds, stream and ditches). A new set of stream and ditch sites were selected each year to maintain a random sampling structure so that the total dataset now comprises 240 sites. In addition, a further 50 ponds have been added to the sampling network in the Eye Brook and Stonton Brook experimental catchments as a result of mitigation measure construction (e.g. drainage interception ponds in both catchments, wildlife ponds in the Stonton catchment).

Figure 13. Automated water sampling equipment is installed at the downstream end of each stream catchment. We are using this equipment to near-continuously monitor nutrient and sediment concentrations. In the autumn when surface runoff and drainflow normally restarts, we are using this equipment to samples for pesticides. The photograph shows an Isco sampler on the right with a solar powered data logger .

3.2 Water quality characterisation methods

Landscape-scale water quality analysis

Nutrient concentrations were recorded at the landscape-wide sites in spring in each year from 2011-2013. In 2013 we also collected a full suite of data on all common water quality anions, cations and heavy metals as a result of additional support provided by the Environment Agency. Analyses were conducted either in the laboratories of Oxford Brookes University or the Environment Agency National Laboratory Service.

3.3 Catchment study

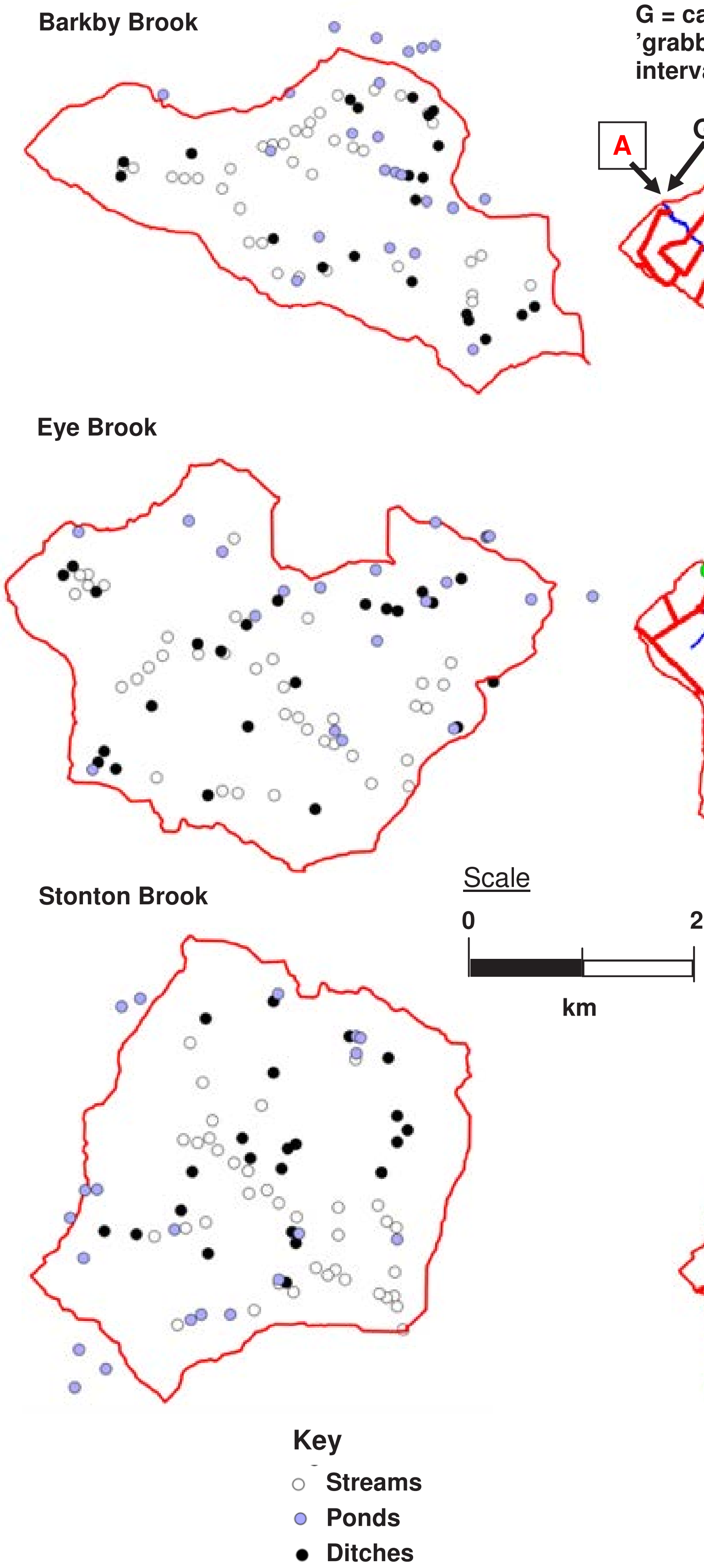
Nutrients and sediments

Samples were collected near continuously at the catchment outfalls (Figures 13, 14b). We ran Isco water samples at a 7 hour sampling frequency, except for interruptions due to serious flooding. Over each 7 hour cycle water was sampled hourly into the same sample bottle giving a reasonable compromise between continuity of recording and time needed for sample analysis. We analysed total phosphorus, total oxidised nitrogen and suspended sediments in the ‘continuous’ samples.

To provide additional understanding of water quality within the catchments twice monthly nutrient and sediment samples were collected at four to six locations in each catchment (Figure 14b). In this case, because the samples were quickly returned to the laboratory, soluble reactive phosphorus was also analysed, in addition to the determinands noted above. This was also useful in enabling us to make direct comparisons with Environment Agency reporting of phosphorus concentrations in the Water Framework Directive with are based on the closely analogous measure of settled orthophosphate phosphorus.

(a) Landscape wide freshwater biodiversity and water quality annual sampling points. Each spot indicates the location of a sampling point on a waterbody.

(b) Location of (i) near continuous catchment outfall water sampling points and (ii) within-catchment twice monthly water sampling locations. Sampling points are indicated by the arrows: A = Autosampler at catchment outfall; G = catchment 'grab' sample, a sample taken by 'grabbing a water sample at twice monthly intervals. STW = Sewage Treatment Works.



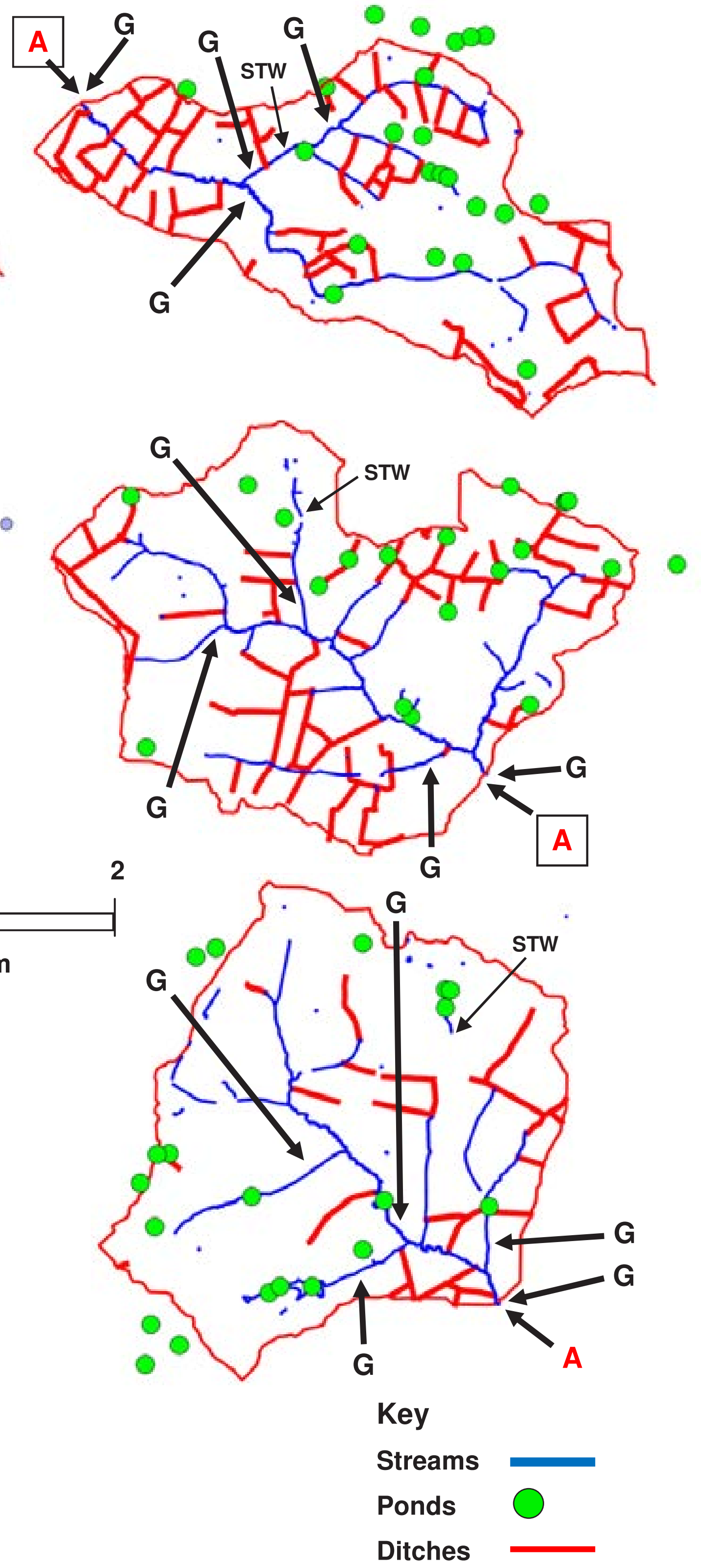


Figure 14. Sampling locations for: (a) landscape wide studies of freshwater biodiversity and water quality and (b) detailed flow, nutrient, sediment and pesticide analysis. Note that some ponds are located outside the catchment boundaries because there were too few ponds strictly within the catchments to obtain a balanced sample of 20 waterbodies of each type.

3.4 Hydrology

Flows were measured at the outfall of each catchment from January 2012 onwards (Figure 14b) at the same location as the autosampler ('A' in Figure 14b). Flows were initially calculated using continuous measures of depth and manual gauging of flow. Equipment continuously measuring flow was installed during 2013 and 2014.

3.5 Pesticides

Samples were collected at the catchment outfalls (Figure 14b) in the autumn flow season from 2012 onwards. For the first year data are only shown for metaldehyde because bad weather and crop failures resulted in very little pesticide usage. In the second year metaldehyde and three autumn herbicides associated with oilseed rape and winter wheat were measured: carbetamide, propyzamide and chlorotoluron.

The three herbicides selected for monitoring were chosen from the nine compounds included in the Environment Agency indicator for pesticides in surface water. Carbetamide and propyzamide are applied to winter wheat, whilst chlorotoluron is used on winter cereals. Metaldehyde, the active ingredient in many slug pellets, was included as it has been shown to have widespread presence in UK surface waters and is the subject of stewardship campaigns as well as a number of derogations imposed on the water industry.

Integrated water samples were collected on a daily basis from the outlets of the three catchments. Samples were extracted and concentrated using solid-phase extraction methods and then analysed with either liquid or gas chromatography coupled with mass spectroscopy. Limits of detection using these methods were c.a. 0.01 µg/L.

3.6 Describing catchment freshwater biodiversity

Assessing freshwater biodiversity at the landscape level

We undertook standardised surveys of vascular wetland plants and macroinvertebrates at approximately 250 locations across the three catchments in ponds, streams and ditches following the approach developed by Williams *et al*. (2004) (Figure 14a). We used the data to assess the landscape level richness of the three waterbody types in the landscape (see section 5).

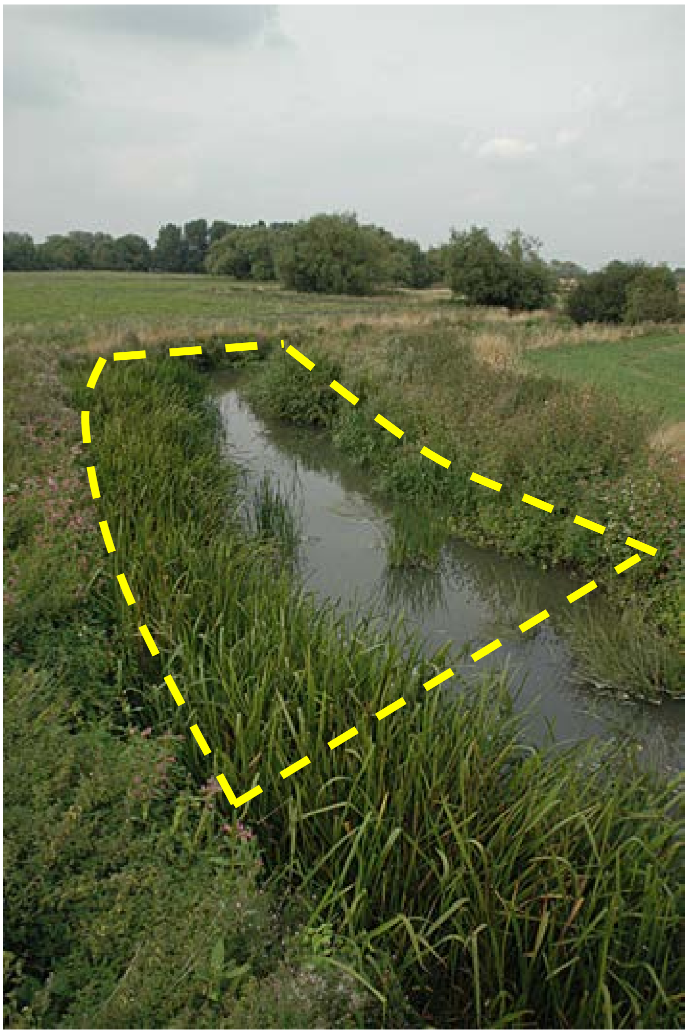


Figure 15. In ponds, a wedge of 75 m^2 was surveyed, from the edge to the centre of the pond. In ditches and streams a linear length, varying depending on stream width and totalling 75 m^2, was surveyed.

Plants were surveyed annually in autumn from 2010 onwards. 'Wetland macrophytes' were defined as those plants listed as wetland plants in the National Pond Survey methods guide (Pond Action, 1998) which comprises a standard list of ca.300 submerged, floating-leaved and emergent wetland plants.

To assess wetland plant richness at the landscape scale we sampled 75 m^2 sections of each waterbody type to ensure that the results were not influenced by the size of the habitat sampled. For example, for a 1 m wide ditch, each survey section was 75 m in length; for a 3 m wide stream, a 25 m length was surveyed. For ponds we surveyed a triangular section of the pond of 75 m^2, with the apex in the centre, as shown in Figure 15. For ponds with a total area of 75 m^2 or less we surveyed the whole waterbody.

Ecological quality of ponds

To assess the overall condition of ponds in the landscape we used the Predictive System for Multimetrics (PSYM) (Biggs *et al.* 2000). PSYM assesses the overall condition of ponds by determining the extent to which their condition deviates from the undamaged baseline state. The method uses the same approach as is adopted for the Water Framework Directive assessments of streams and rivers

Macroinvertebrates from the landscape study

Results from the macroinvertebrate monitoring are still being analysed and will be reported in future outputs from the project. Previous landscape studies (Biggs *et al*. 2004, Davies *et al.* 2007) have shown that freshwater invertebrate biodiversity patterns closely match those of wetland plants at the landscape scale. For this reason we expect that the patterns reported for plants will generally reflect the biodiversity patterns for freshwater invertebrates.

Assessment of running waters

The biological condition of streams and rivers (and also lakes of 50 ha or more) is now commonly assessed using the techniques of the Water Framework Directive. This involves assessments of freshwater invertebrates, wetland plants, microscopic algae and fish, as well as measurements of water quality.

We have collected data on these groups to assess stream condition. Ten stream sites in each catchment were selected for survey from the network of sites shown in Figure 13a. Aquatic macroinvertebrates and wetland plants were surveyed three times during the baseline period. Fish were surveyed in 2012 and 2013. A single set of diatom samples was collected in 2013 (three seasons). Initial results from this work are presented here covering macroinvertebrate and fish. To date, not all samples have been processed: these results will be reported in future outputs.

At present the assessment of ditches using Water Framework Directive compliant assessment methods is not well-developed, although there have been some experimental applications of the methods (see results of the Countryside Survey 2007 in Dunbar *et al*. 2010). Ditches have been assessed using the main landscape level biodiversity dataset.

3.7 Modelling

We used modelling techniques to assess the likely long-term impact of the measures being installed by the project. Modelling of the effectiveness of water quality mitigation measures was evaluated using the Soil and Water Assessment Tool (SWAT). Further information on modelling techniques is given in Section 8.

The long term impact of habitat creation measures on freshwater biodiversity was assessed using the metapopulation modelling tool Meta-X (Grimm *et al*. 2004).

4. Ecology and freshwater biodiversity

4.1 Landscape level freshwater biodiversity: wetland plants

Wetland plant diversity

Alpha diversity (individual site richness)

In all three catchments, the average number of wetland plant species was greatest in ponds, followed by streams and ditches (Figure 16). This is a pattern seen in other landscape studies, reflecting the inherent richness of pond habitats and, in the present study area, the high degree of shading of linear running waters.

Gamma diversity: landscape level richness

Across the landscape *as a whole* most wetland plant species were found in ponds with a smaller proportion in stream and ditches.

The patterns observed in both site and catchment richness were consistent over three years of the baseline phase (Figure 16).

Table 5. Proportion of wetland plant species found in each water-body type in the three catchment areas

	Barkby Brook	Eye Brook	Stonton Brook
Ponds	36%	45%	44%
Streams	52%	42%	41%
Ditches	7%	9%	10%

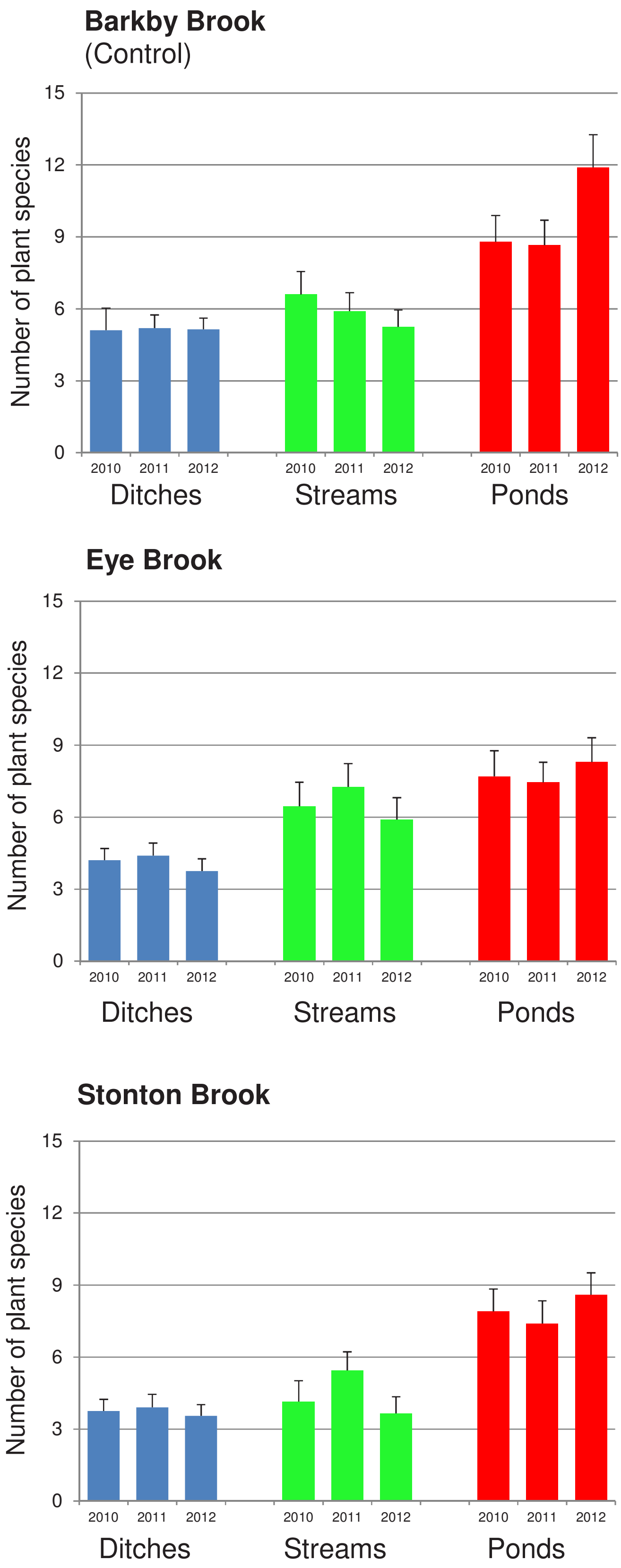


Figure 16. Average wetland plant species richness in different waterbody types.

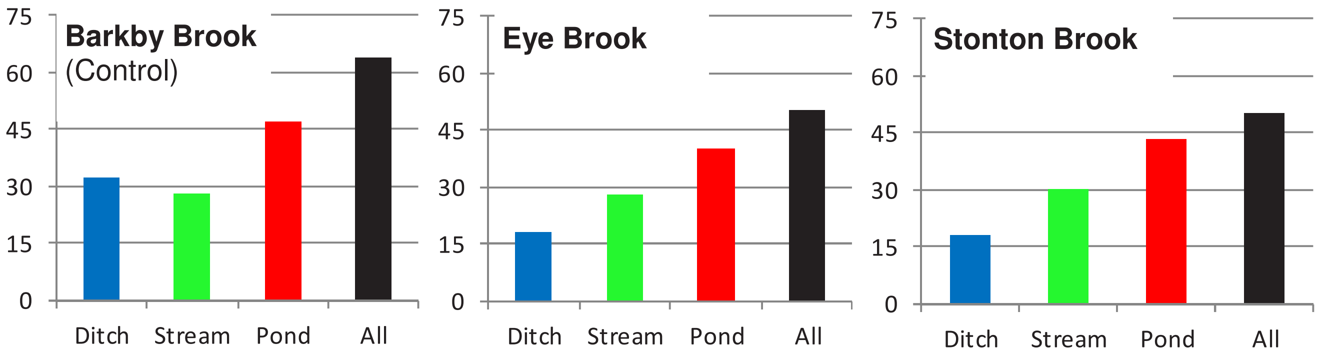


Figure 16. Total number of wetland plants in each waterbody type and in all waterbodies in each catchment.

4.2 Uncommon wetland plants: which freshwater habitats support species of conservation concern?

Uncommon wetland plant species (defined here as species occurring in fewer than a quarter of all UK 10 x 10 km squares) were only found in ponds, with none in streams or ditches in the project study area.

This pattern was consistent over all three years of the baseline study.

The alpha diversity of ponds, streams and ditches in the Water Friendly Farming project area was very similar to that seen in the catchment of the R. Cole in central southern England (Williams *et al* 2004) (Table 6). The patterns first seen in the Cole catchment has since been widely repeated in other landscapes, with the Water Friendly Farming landscape providing the most detailed support for this pattern so far seen.

Table 6. Individual site wetland plant species richness (alpha diversity) in ponds, rivers, streams and ditches in the R. Cole landscape

	Number of wetland plant species(range in parentheses)
Ponds	10.1 (2-17)
Streams	7.3 (1–17)
Ditches	6.1 (1-14)
Rivers	10.7 (6-19)

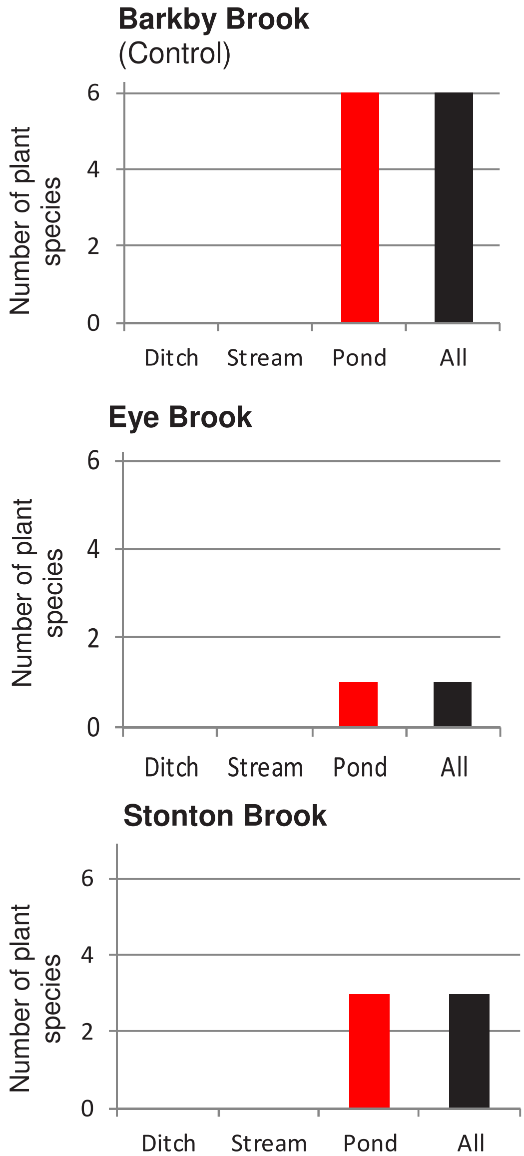


Figure 17. Total number of uncommon wetland plant species in each waterbody type and in all waterbodies in each catchment. Note that only ponds supported uncommon species.

4.3 Association of wetland plants with still and flowing water habitats

Background

The landscape analysis allows us to identify the proportion of wetland plants species associated with still and flowing waters, respectively ponds and streams. This shows that the majority of the species in the project landscapes are associated with still water habitats.

The analysis is based on four years survey (2010-12, 2014) and includes 20 ponds and 20 streams for each year from each catchment (i.e. 240 sampling locations for each year). Because the survey covers all existing ponds in each catchment ponds, it is effectively a census of ponds. To ensure a fair comparison with streams, a random sample of 20 streams from each catchment was drawn from the data set for each year.

Results

45% of species are only associated with ponds, 45% can be found in both ponds and stream and 5% only in streams (Figure 18).

The association of species with still and flowing water habitats is shown in Table 7 which shows the percentage of sites where the species occurs which are ponds. The percentage occurrence in rivers is simply 100% minus the value in the table. Thus, Marsh Thistle (*Cirsium palusre*) is mainly associated with streams being found in 100-33% of stream sites i.e. 67% of its occurrences were streams.

In this landscape, aquatic plants are almost entirely associated with standing water habitats. Surprisingly, only one species of aquatic plant, Common Starwort (*Callitriche stagnalis*) is found in the streams. Aquatic species are otherwise only found in ponds. Note that the survey does not include lower plants (mosses and liverworts) where more species do occur in running water..

In contrast, marginal plants are more widely spread amongst both habitats types.

Five species were exclusively associated with running water habitats: Lesser Pond Sedge (*Carex acutiormis*), Pendulous Sedge (*Carex pendula*) and three non-native species: *Gunnera tinctoria*, Orange Balsam (*Impatiens capensis*) and Himalayan Balsam (*Impatiens glandulifera*).

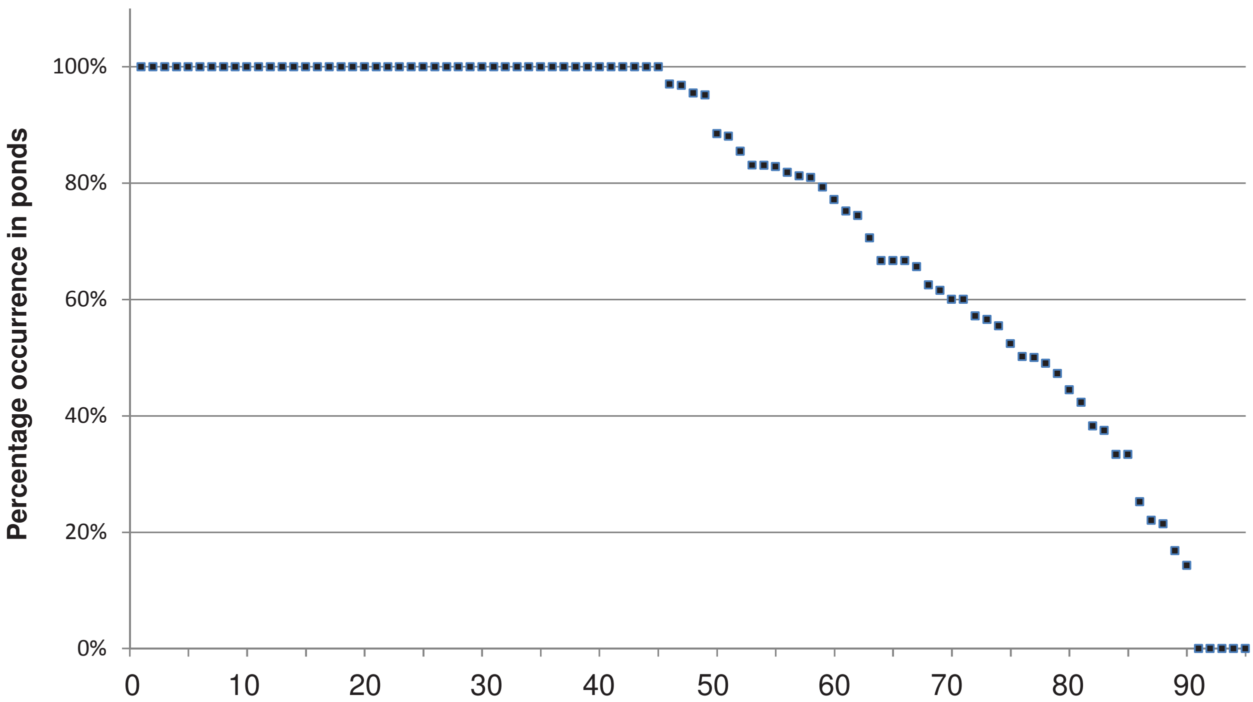


Figure 18. Association of wetland plant species in the Water Friendly Farming landscape with ponds only, ponds and streams and streams only. X-axis numbers refer to plant number in Table X. Thus the first species not to occur with 100% frequency in ponds is species 46. Lemna minor which has 97% of its occurrences in ponds.

Table 7. Occurrence of wetland plants in ponds and stream

No.	Species	% in ponds	No.	Speicies	% in ponds
1	Callitriche hamulata (s.l.)	100%	50	Iris pseudacorus	88%
2	Ceratophyllum demersum	100%	51	Carex riparia	88%
3	Chara globularis	100%	52	Glyceria fluitans	85%
4	Chara hispida	100%	53	Rorippa nasturtium-aquaticum (s.l.)	83%
5	Chara vulgaris	100%	54	Juncus articulatus	83%
6	Elodea nuttallii	100%	55	Sparganium erectum	83%
7	Fontinalis antipyretica	100%	56	Epilobium sp	82%
8	Hippuris vulgaris	100%	57	Cardamine pratensis	81%
9	Potamogeton berchtoldii	100%	58	Juncus bufonius (s.l.)	81%
10	Potamogeton crispus	100%	59	Epilobium parviflourm	79%
11	Potamogeton pectinatus	100%	60	Galium palustre	77%
12	Potamogeton pusilus	100%	61	Deschampsia caespitosa	75%
13	Ranunculus species	100%	62	Juncus inflexus	74%
14	Sparganium emersum	100%	63	Equisetum palustre and hybrid	71%
15	Stratiotes aloides	100%	64	Lotus pedunculatus	67%
16	Zannichellia palustris	100%	65	Lycopus europaeus	67%
17	Lemna minuta	100%	66	Stellaria uliginosa	67%
18	Lemna trisulca	100%	67	Juncus effusus	66%
19	Menyanthes trifoliata	100%	68	Eupatorium cannabinum	63%
20	Nuphar lutea	100%	69	Carex otrubae	62%
21	Nymphaea alba	100%	70	Callitriche obtusangula	60%
22	Nymphaea exotic	100%	71	Berula erecta	60%
23	Nymphoides peltata	100%	72	Callitriche platycarpa	57%
24	Persicaria amphibia	100%	73	Epilobium cilliatum	57%
25	Potamogeton natans	100%	74	Veronica beccabunga	55%
26	Acorus calamus	100%	75	Glyceria declinata	52%
27	Alisma plantago-aquatica	100%	76	Epilobium hirsutum	50%
28	Alopecurus aequalis	100%	77	Solanum dulcamara	50%
29	Alopecurus geniculatus	100%	78	Agrostis stolonifera	49%
30	Carex flacca	100%	79	Mentha aquatica and hybrids	47%
31	Crassula helmsii	100%	80	Petasites hybridus	44%
32	Eleocharis palustris	100%	81	Apium nodiflorum	42%
33	Epilobium tetragonum	100%	82	Glyceria notata and x pedunculata	38%
34	Glyceria maxima	100%	83	Hypericum tetrapterum	38%
35	Gnaphalium uliginosum	100%	84	Cirsium palustre	33%
36	Lythrum salicaria	100%	85	Luzula sylvatica	33%
37	Mimulus guttatus	100%	86	Angelica sylvestris	25%
38	Myosoton aquaticum	100%	87	Phalaris arundinacea	22%
39	Persicaria hydropiper	100%	88	Chrysosplenium oppositifolium	21%
40	Ranunculus flammula	100%	89	Filipendula ulmaria	17%
41	Scoenoplectus lacustris	100%	90	Scrophularia auriculata	14%
42	Triglochin palustris	100%	91	Carex acutiformis	0%
43	Typha agustifolia	100%	92	Carex pendula	0%
44	Typha latifolia	100%	93	Gunnera tinctoria	0%
45	Veronica catenata	100%	94	Impatiens capensis	0%
46	Lemna minor	97%	95	Impatiens glandulifera	0%
47	Ranunculus sceleratus	97%			
48	Callitriche stagnalis (s.l.)	95%			
49	Myosotis laxa	95%			

4.4 Pond ecological quality

Wetland plant diversity

Alpha diversity (site richness)

Across England and Wales wetland plant richness averages around 7 species per pond. In the three project catchment areas, average richness was slightly higher at between 9 and 12 species per pond (Figure 19). These values are all substantially lower than the 23 plant species which can typically be found in ponds located in semi-natural landscapes (Williams *et al.* 2010).

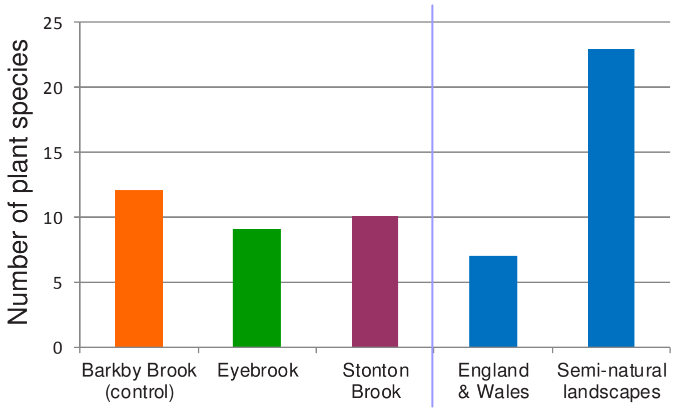


Figure 19. Number of wetland plant species in ponds in the three project catchments, and comparison with national data

Pond quality using PSYM

PSYM (Box 1) was used to assess the ecological quality of ponds in each catchment based on their wetland plant communities, and to place ponds in one four quality bands: Good, Moderate, Poor or Very Poor.

The three catchments showed similar trends (Figure 20), with the majority of ponds in all catchments Poor quality. In the first year of survey (2010) 15% of ponds in each catchment classified as Good quality and therefore qualify as Priority Ponds.

Comparison with 2007 Countryside Survey data shows that the pond quality in our three catchments was slightly better than the wider countryside across all of England and Wales where, on average, only 8% of ponds qualify as Good quality on the basis of PSYM plant data.

Declines in pond quality

An interesting finding was that between 2010 and 2014 the number of Good quality ponds declined across all three catchments (Figure 20). Decline was strongest in the Eye Brook, where none of the pre-existing ponds classified as Priority Ponds in 2014.

This decline mirrors the worrying loss of pond quality observed in the Countryside Survey between 1998 and 2007 in England and Wales (Williams *et al*. 2010).

Between 2010 and 2014 the number of Good quality (Priority) ponds declined across all three catchments

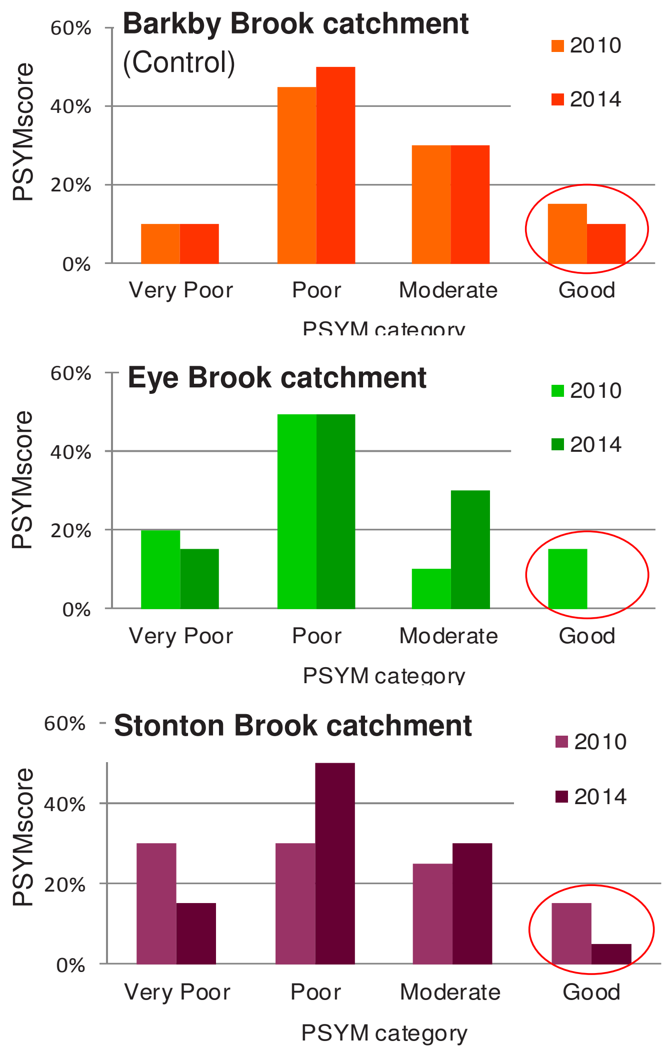


Figure 20. Pond quality trends in the three

Box 1. What is PSYM?

PSYM, the Predictive SYstem for Multimetrics, is a Water Framework Directive compatible method for assessing pond quality (Biggs *et al.* 2000). PSYM uses a range of metrics shown to vary predictably with degradation to measure quality. The values from individual metrics are then combined to give a single measure which represents the overall ecological quality of the waterbody. Conceptually, the method is similar to the stream bioassessment tool RIVPACS, but PSYM assesses overall pond quality, rather than specifically water pollution status.

PSYM scores are ideally calculated using both wetland plant and aquatic macroinvertebrate data. However where invertebrate data are not available, a partial assessment can be made using plant data alone.

Plant PSYM uses three metrics, each of which has been shown to vary strongly with pond degradation. These metrics are: (i) number of submerged and emergent plant species (ii) trophic ranking score (a measure of nutrient enrichment) and (iii) the number of uncommon plant species. The PSYM programme works by comparing the value of each metric observed at a pond, with the value that would be expected if the pond was pristine (i.e. in the "reference state"). Comparing the two scores provides an overall measure of how degraded each pond is relative to its expected pristine state.

The observed metric values are expressed as a percentage of the expected value. In high quality ponds the similarity with a pristine site is high (75%-100% similarity). As degradation increases, the percentage similarity between the observed and expected values falls. For reporting purposes percentage similarity is divided into four grades of ecological condition:

0%- 24%	Very Poor
25% - 49%	Poor
50% - 74%	Moderate
75% or above	Good

4.5 Stream ecological quality: long-term trends

Data available

Medium to longer-term information on the ecological quality of two of the project's main streams, based on invertebrate data collected by the Environment Agency, are available for the Eye Brook and Stonton Brook. In the Eye Brook, there is information from Tugby Wood (Figure 21), which is immediately downstream (0.5 km) of the project area, and also approximately 10 km further downstream at Stockerston. In the Stonton Brook there is information available from 2008 onwards at Stonton Wyville (Figure 21) which is approximately 6 km below the project area. Long term data are not currently available for the Barkby Brook.

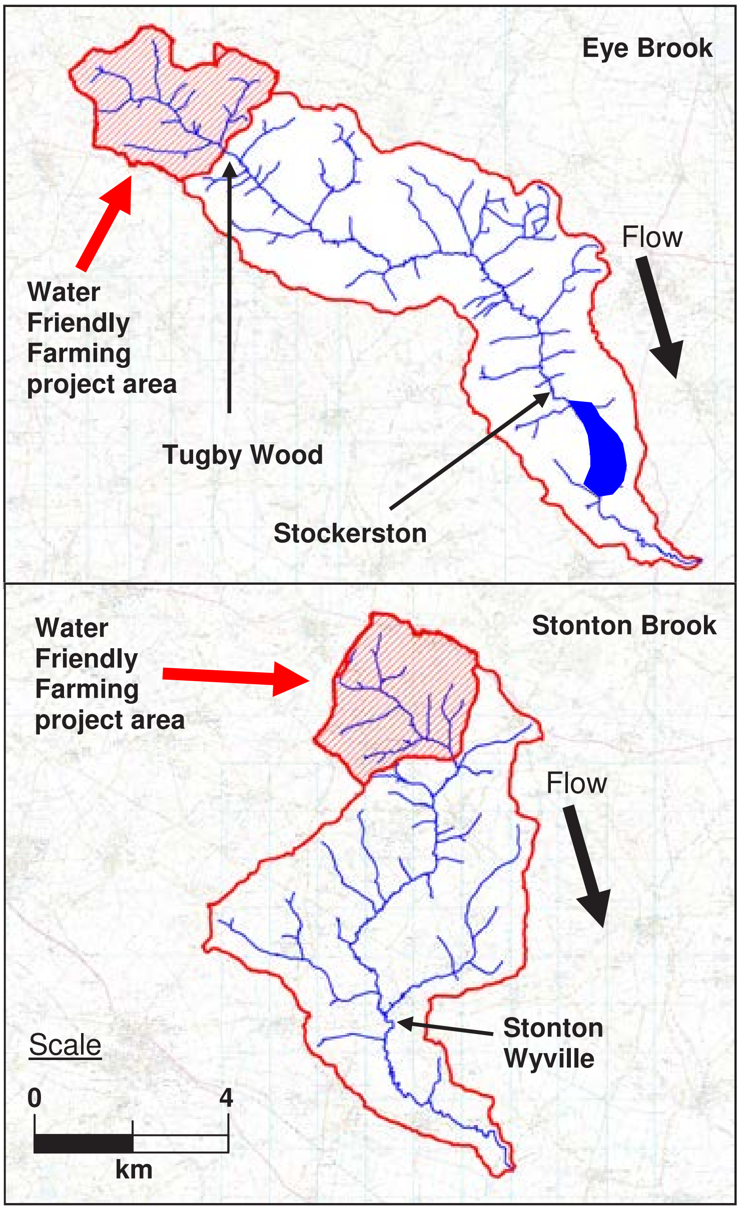


Figure 21. Location of sampling sites on the Eye Brook and Stonton Brook which have long-term freshwater invertebrate data

Stonton Brook: Stonton Wyville

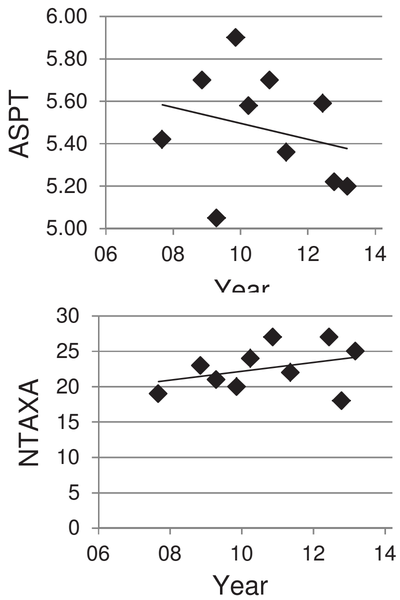


Figure 22. Macroinvertebrate scores for the period 2007-2013 at Stonton Wyville on the Stonton Brook. Although there is a suggestion of trends, with declining Average Score per Taxon (ASPT) and increasing Number of Taxa (NTAXA), they are not statistically significant (p=0.168, Mann-Kendall trend test

Results

There are suggestions of improvements over time in the quality of stream invertebrate assemblages which are most apparent some way downstream of the project area. In the Stonton Brook, this occurred over a relatively short time from 2007 to 2013. Although there is a suggestion that ASPT scores declined and NTAXA increased, neither trend is statistically significant.

In the Eye Brook there is an apparently stronger signal suggestive of long-term trends. At Tugby Wood, immediately downstream of the project area, there is a suggestion that ASPT scores increased over the last 10 years, and the NTAXA declined, although, neither trend is statistically significant. 10 km downstream, at Stockerston, there is a more consistent pattern with both ASPT score and NTAXA

Eye Brook: Tugby Wood

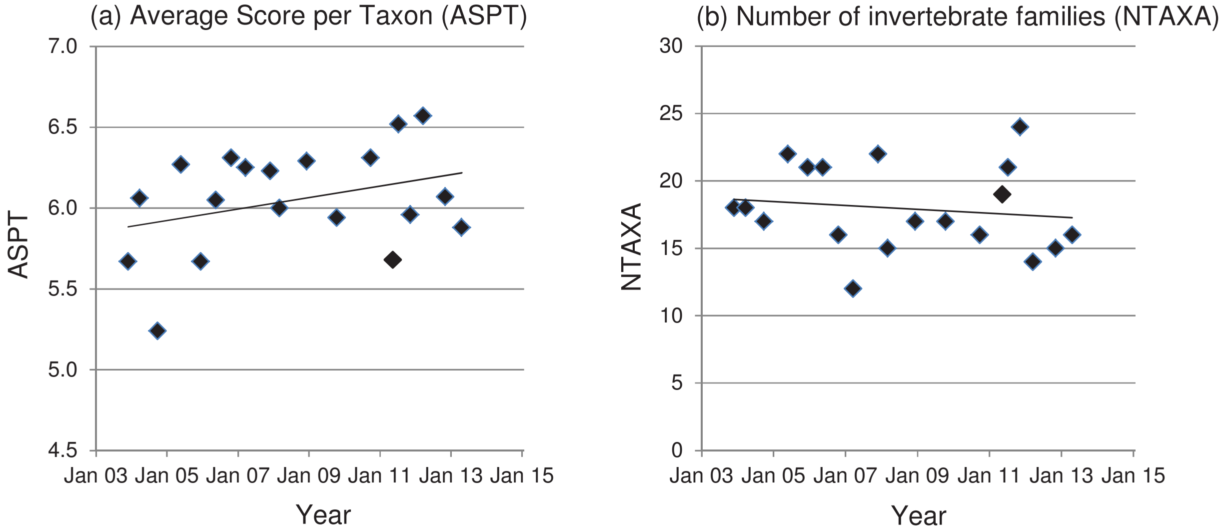
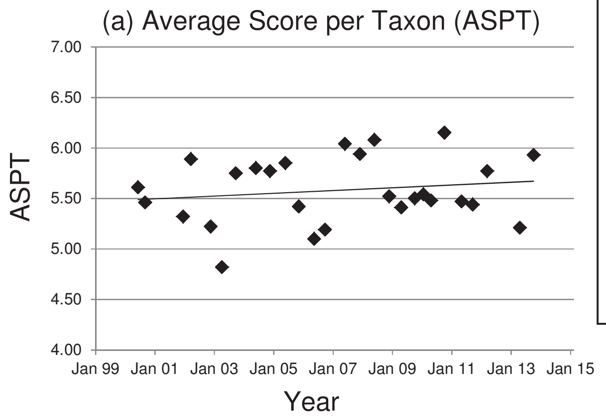


Figure 23. Long-term freshwater invertebrate biological quality scores at Tugby Wood, Eye Brook. (a) Average Score per Taxon (ASPT); (b) Number of invertebrate families (NTAXA). The trend in ASPT score is not statistically significant (Mann-Kendall trend test p=0.545) but is significant for NTAXA (Mann Kendall trend test p = 0.045).

Eye Brook: Stockerston



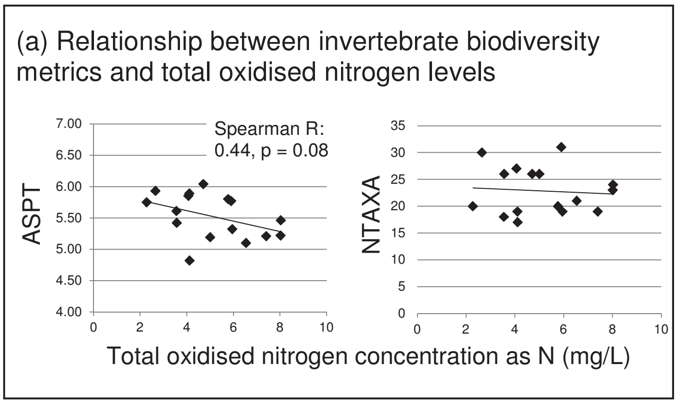
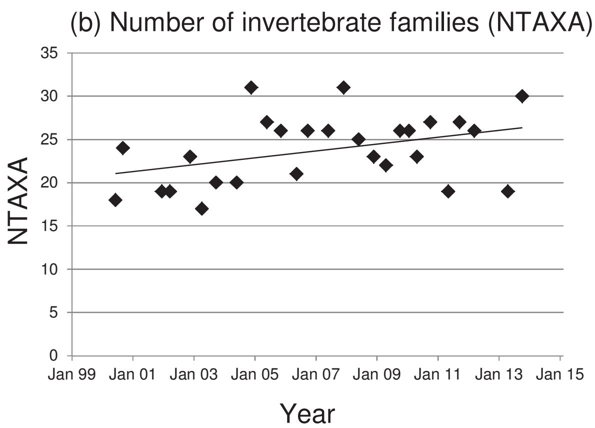


Figure 24. Long-term freshwater invertebrate biological quality scores at Tugby Wood, Eye Brook. (a) Average Score per Taxon (ASPT); (b) Number of invertebrate families (NTAXA). The trend in ASPT score is not statistically significant (Mann-Kendall trend test p=0.545) but is significant for NTAXA (Mann Kendall trend test p = 0.045. The insets show the relationship between ASPT and NTAXA and the Total Oxidised Nitrogen concentration over the last 13 years.



apparently increasing over the last 10 years, although only the increase in the number of invertebrate families (NTAXA) is significant at p<0.05 (Mann-Kendall trend test).

It is worth noting that ASPT scores and nitrate concentrations are correlated at this site. There has been a long-term trend in nitrate levels in the Eye Brook (see section 4.6), and higher ASPT scores (better water quality as judged by invertebrates) were associated with lower nitrate concentrations. There was no relationship between number of invertebrate families and nitrate concentrations (see Inset (a), Figure 23)..

4.6 Stream chemical quality: long-term trends over the last 25-30 years

Background

Environment Agency monitoring provides long-term chemical data stretching back 30 years for areas downstream of the three project catchments. For each catchment data are available from one sampling station between 2 and 10 km downstream of the project area. No long-term data are available describing the chemical quality of still waters in the study area.

Long-term data are available for the Eye Brook and Barkby Brook (Figure 25). Both show long slow declines in total oxidised nitrogen concentrations over 30 years. Phosphate concentrations have remained constant in the Eye Brook and have declined significantly in the Barkby Brook. Water quality monitoring has been undertaken in detail for a much shorter period on the Stonton Brook, beginning in 2010, shortly before the Water Friendly Farming project.

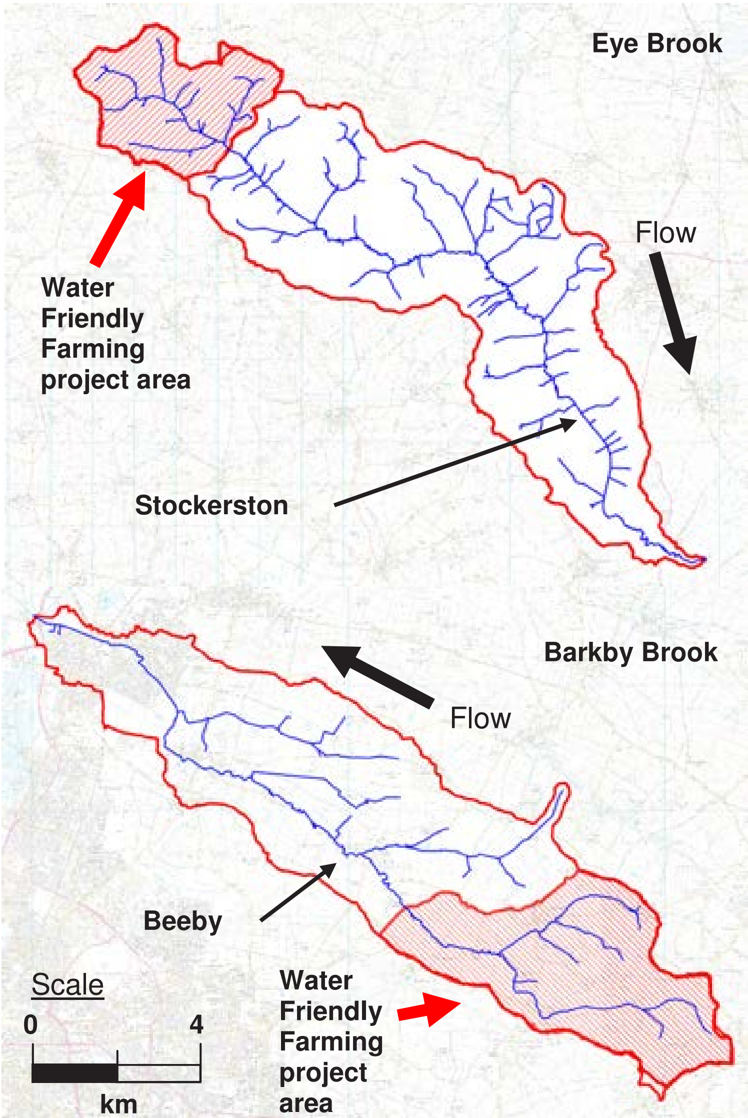


Figure 25. Location of sampling sites on the Eye Brook and Stonton Brook which have long-term freshwater invertebrate data

Eye Brook

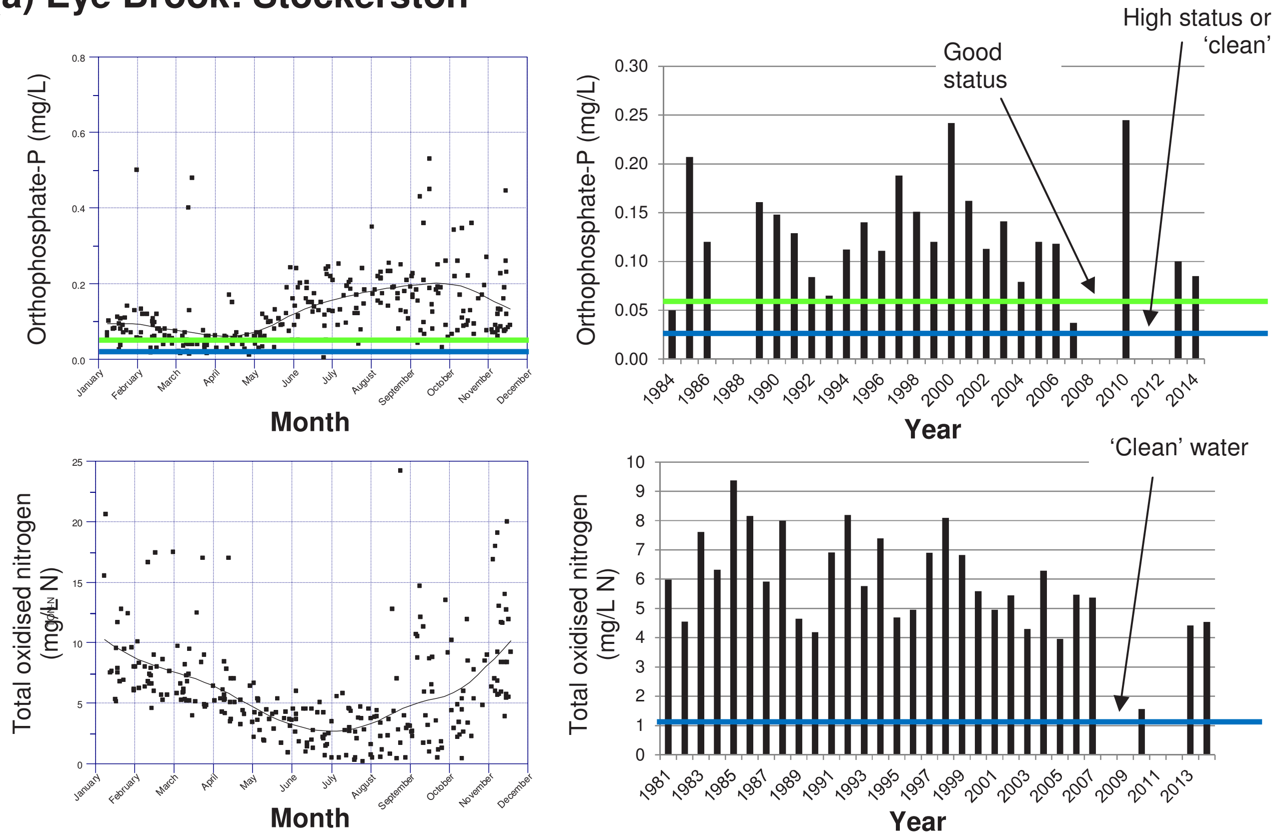
Phosphorus: There is a distinct long-term seasonal pattern, with orthophosphate higher in summer and autumn than in winter and spring (Figure 26). This is a normal pattern for sites where the phosphorus load is dominated by sewage treatment works effluents. Over the 25 years of the Environment Agency data set there has been no overall change in phosphorus concentrations in the Eye Brook.

Throughout this time annual concentrations have been generally above the level now adopted as 'Good' status for Water Framework Directive and always above the concentration needed to achieve High status.

Nitrogen: In contrast to phosphorus there has been a statistically significant, long-term decline in total oxidised nitrogen concentrations since the 1980s in the Eye Brook ($p<0.001$, Seasonal Kendall test).

Reductions in nitrogen concentration in streams fed largely by runoff are well-known, presumably reflecting a general reduction in agricultural inputs and the absence of long-time lags associated with predominantly groundwater-fed streams and rivers. There are no official biologically relevant nitrate limits but, even following the slow decline in nitrogen levels seen in the Eye Brook at Stockerston, concentrations are still substantially above the levels that are likely to damage freshwater ecosystems.

(a) Eye Brook: Stockerston



(b) Barkby Brook: Beeby

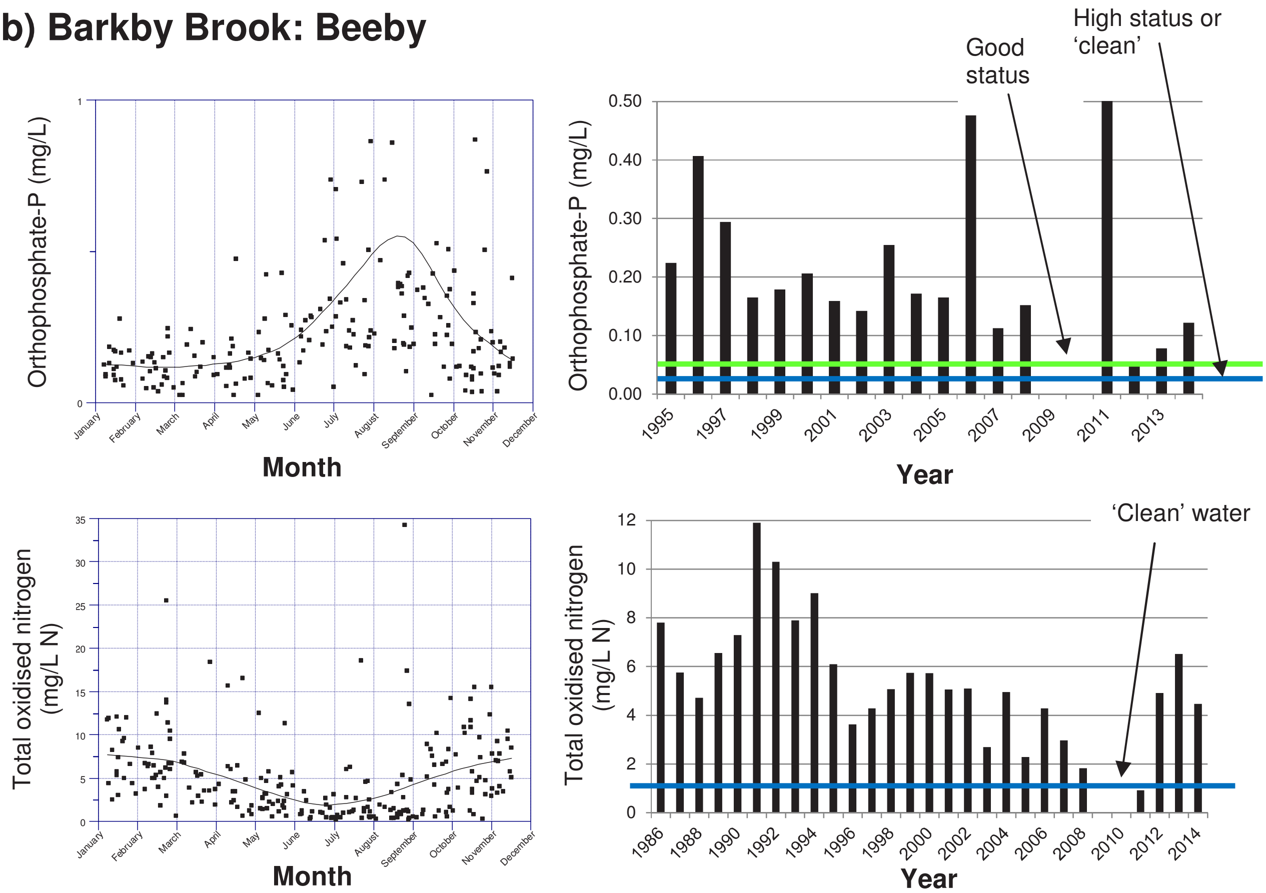


Figure 26. Long-term (20-30 year) trends in Environment Agency collected orthophosphate and total oxidised nitrogen data in (a) the Eye Brook at Stockerston and (b) the Barkby Brook at Beeby.

Barkby Brook

The Beeby site is close to the downstream end of the Water Friendly Farming project study area (2 km downstream). It therefore provides an indication of long-term background trends that largely reflect conditions in the project area.

Phosphorus: As in the Eye Brook, the Barkby Brook shows clear seasonal patterns in orthophosphate concentrations in long-term water quality data, with levels highest in summer and declining with dilution during winter (Figure 26b). This is a common pattern in streams and rivers where phosphorus levels are heavily influenced by sewage effluents.

Unlike the Eye Brook, the Barkby Brook shows a long term trend in its phosphorus concentrations, with a statistically significant reduction since the 1995 (Figure 27; $p<0.001$, Mann-Kendall test). Despite this reduction, levels in the stream at the Beeby site are still well above the standard needed for Good status in the Water Framework Directive, and substantially above levels likely to cause biological impacts.

Nitrogen: Levels of nitrogen also show a distinctive long-term pattern with levels generally lower in summer than in winter, reflecting the influence of autumn and winter runoff on nitrogen levels, and summer denitrification. The Barkby Brook also shows a long-term reduction in total oxidised nitrogen concentrations ($p<0.001$, Mann-Kendall test), although the trend is rather noisy.

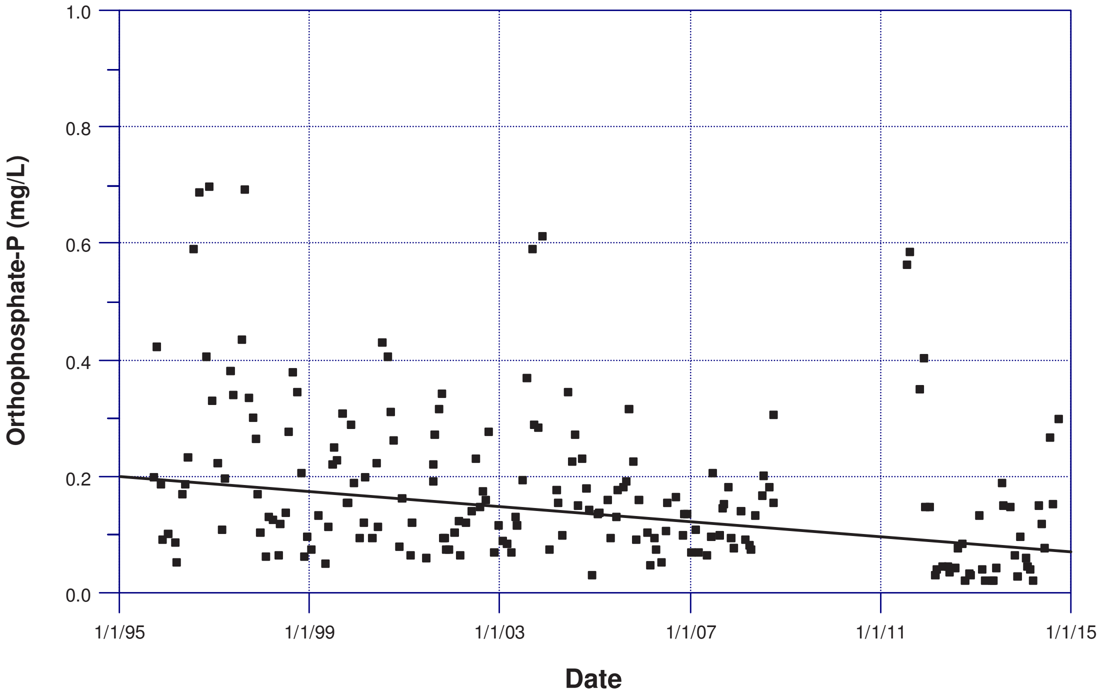


Figure 27. Long-term (20-30 year) trends in orthophosphate concentrations in the Barkby Brook at Beeby, about 2 km downstream of the Water Friendly Farming project area. Although the trend looks encouraging it may have been particularly emphasised during 2011/12 by exceptionally wet weather. Intensive monitoring undertaken during the Water Friendly farming project shows that Total Phosphorus concentrations in the Barkby Brook have increased significantly since 2012 (see Section 5).

Figure 28 This tributary stream of the Stonton Brook typifies the impacts experienced in headwater systems in the rural environment. The stream receives treated sewage effluent from septic tanks and a small rural reed bed sewage treatment system, surface water and drainflow from cultivated land (which probably includes intermittent herbicide and other biocide runoff), runoff from rural roads and occasionally drainage from manure heaps. It has been channelized, deepened and, in places, piped to increase its ability to remove water from the fields.

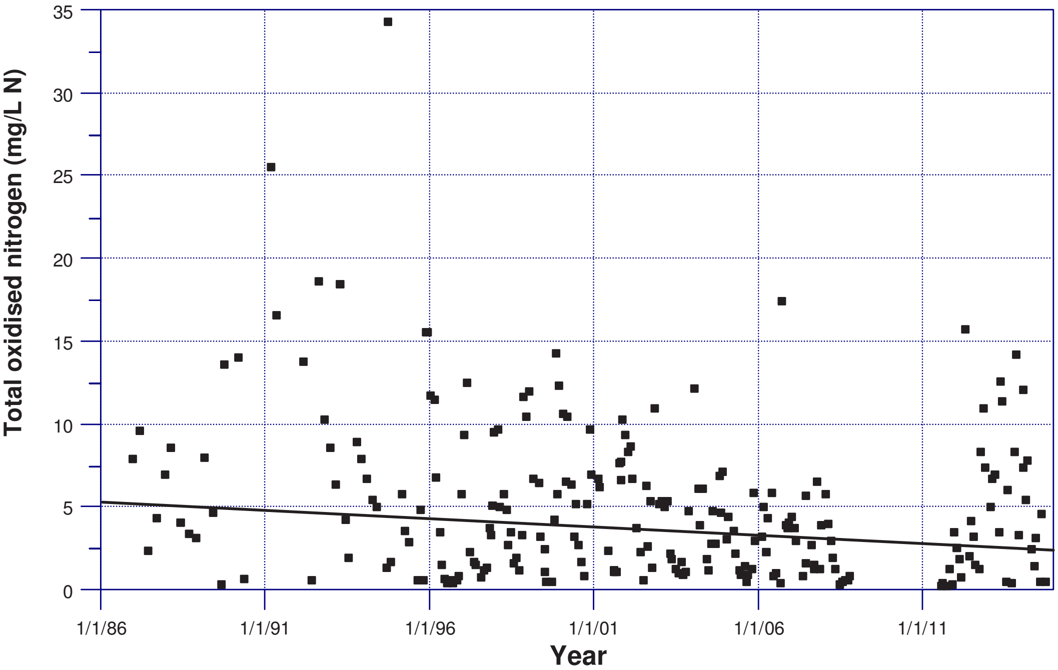


Figure 29. Long-term (20-30 year) trends in total oxidised nitrogen concentrations in the Barkby Brook at Beeby, about 2 km downstream of the Water Friendly Farming study area. The observed decline is significant (p=0.001, Mann-Kendal trend test).

4.7 Stream ecological quality: Water Framework Directive classification compared to Water Friendly Farming results

Environment Agency classification of streams under Water Framework Directive

Under the provision of the Water Framework Directive, the Environment Agency classifies streams, rivers and lakes into five ecological quality classes: High, Good, Moderate, Poor and Bad. The overall status is determined by the lowest of the biological, chemical and hydromorphological 'quality elements', including mitigation measures for artificial and heavily modified waterbodies)

Biologically the Eye Brook is currently classified as Moderate status for fish and High for invertebrates. No data are available for phytobenthos. Chemically, the stream is at High status for dissolved oxygen, ammonia and phosphate. Overall the stream is therefore at Moderate status. The Stonton Brook is not classified in the project area but lower reaches are Bad for fish and Poor for Phytobenthos (Figure 30). Neither the Eye Brook or Stonton Brook are classified as heavily modified waterbodies and therefore hydro-morphology is considered where it may account for failures in either the biological or chemical quality elements.

In the Water Friendly Farming project area the Water Framework Directive classification presents a simplified overview of the stream network and its ecological conditions. Specifically:

- Most 1st and 2nd order headwater streams, which make up about 2/3rds of the running water network in the project area, are omitted (Table 8)
- On the Stonton and Barkby brooks, the classified length begins several kilometres below the headwaters of the streams (Figure 30 and 31).
- Water quality and biological classifications are typically based on a small number of sampling points (usually only one at the bottom end of the catchment) and do not allow differences in stream quality up and down the catchment, or in smaller tributaries, to be described

Using detailed catchment data to present a finer-scale description of the water environment

Because of the simplified presentation of the Water Framework Directive classification we used the datasets from the Water Friendly Farming Project to describe the finer scale variations in water chemistry and biological quality in the stream networks in the study area. We were able to make this fine-scale

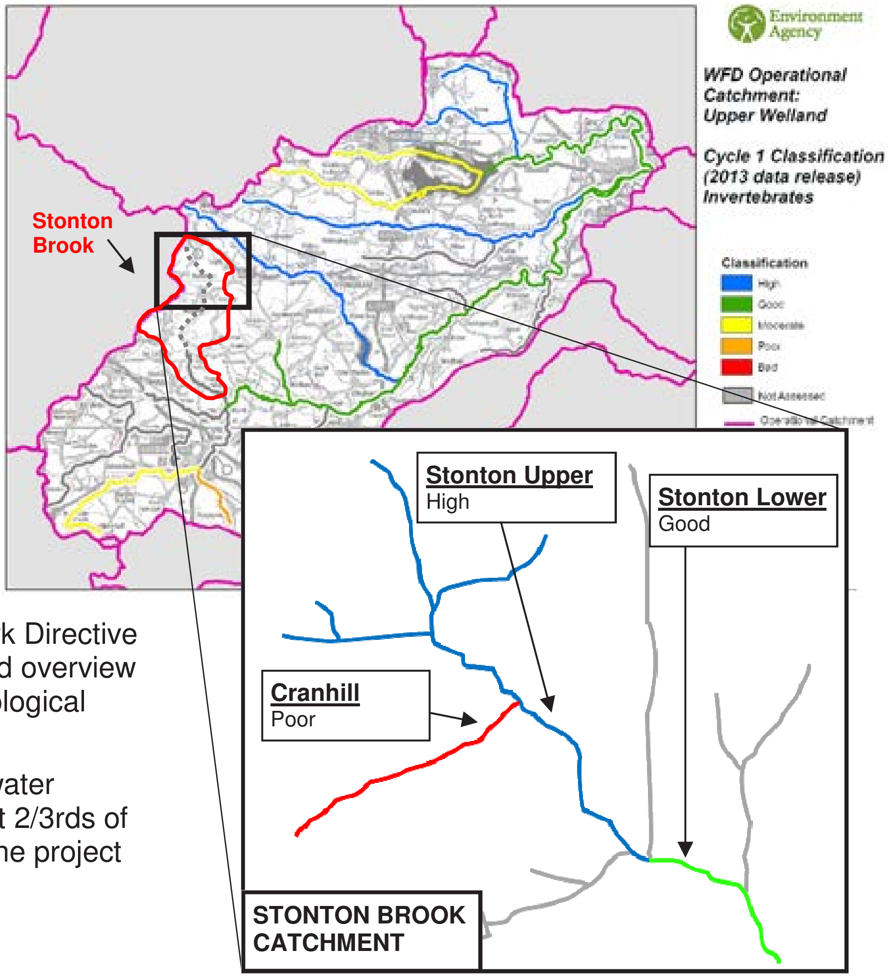
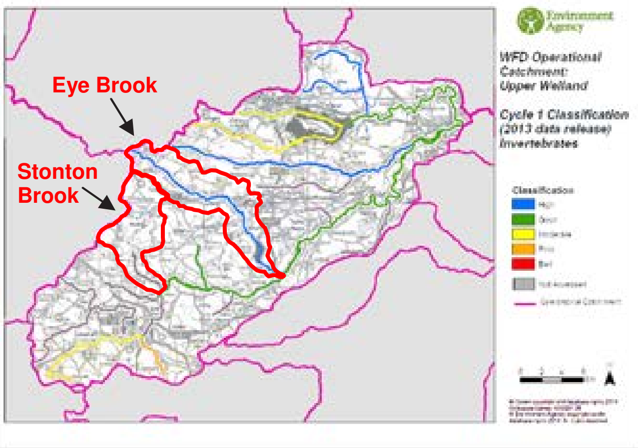
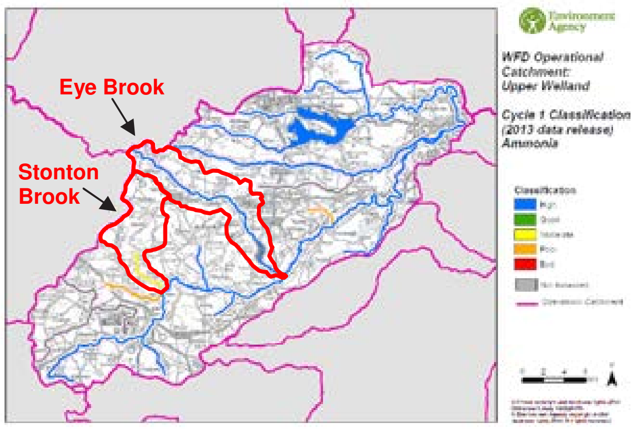


Figure 30. Water Framework Directive classification of tributaries in the Stonton Brook project area based on aquatic invertebrates. Different branches of the stream network vary from Poor to High status within the project area.

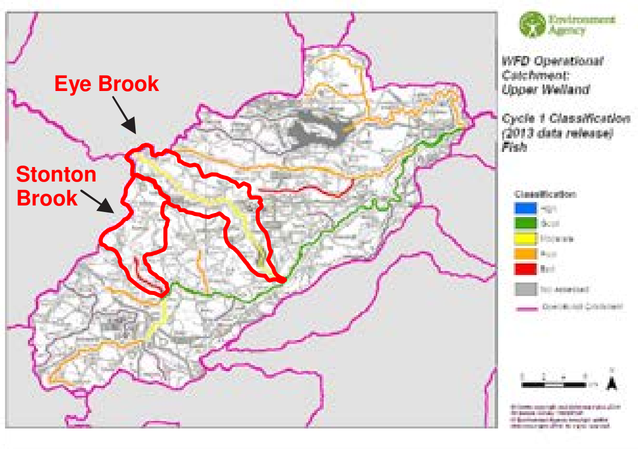
Invertebrates: High status



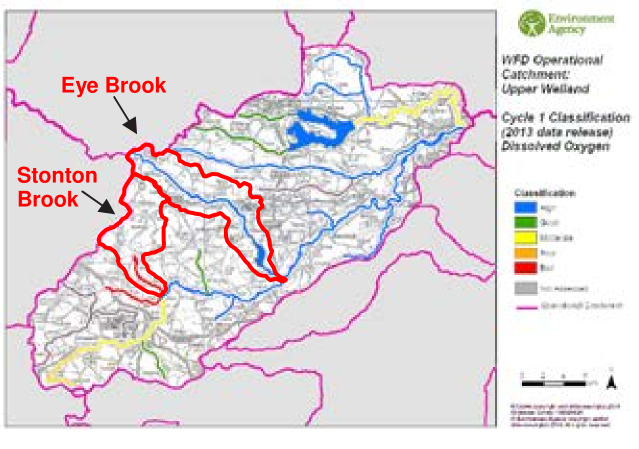
Ammonia: High status



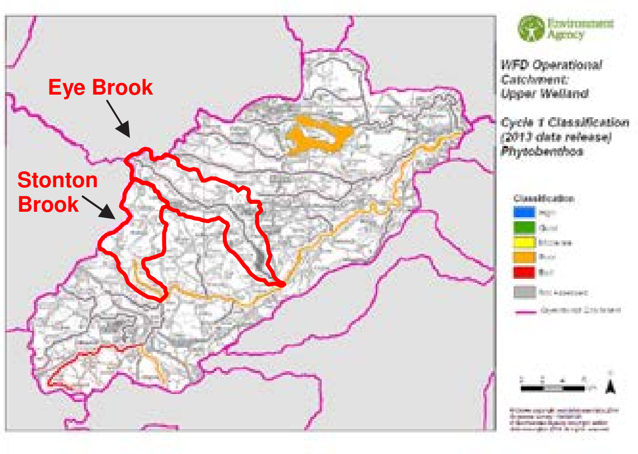
Fish: Moderate status



Dissolved oxygen: High status



Phytobenthos: not classified



Phosphate: High status

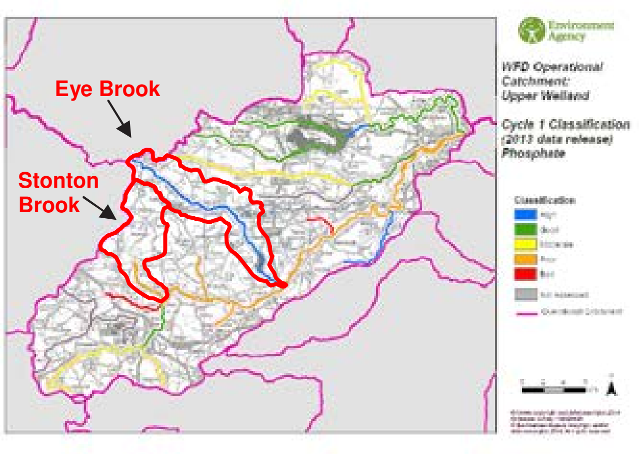


Figure 31. Classification of the Eye Brook in the Water Framework Directive in terms of different 'biological quality elements' (Invertebrates, Fish, Phytobenthos) and 'water quality elements' (Ammonia, Dissolved Oxygen and Phosphate). The overall ecological quality of the Eye Brook is determined by the lowest individual element, Fish, which leads to the waterbody being assessed as being at Moderate status. A single status is given to the whole length as it is identified as a single waterbody within the Water Framework Directive. The Stonton Brook in the project area is not classified under the Water Framework Directive.

comparison using macroinvertebrate and phosphorus data.

In the Eye Brook, the Water Framework Directive classification suggests that the whole length of the stream is High status (Figure 32) for macroinvertebrates. There is no classification of tributary streams. Finer scale data from the project indicates that sections of the stream network in the project study area vary in ecological quality from Moderate to High (Figure 32).

Stream status in terms of phosphorus

Phosphorus levels vary in the Eye Brook catchment waterbodies, with some streams having very low (near background) phosphorus concentrations (i.e. High status) and other areas experiencing significant impacts from sewage works and other point sources (Figure 33). Currently the full length of the Eye Brook is described as High status for phosphorus. In practice, the data indicate that around 30% of the length of the Eye Brook is probably at Moderate status for phosphorus. However, dilution of phosphorus downstream leads to the waterbody switching to High status at some point above the Stockerston monitoring point.

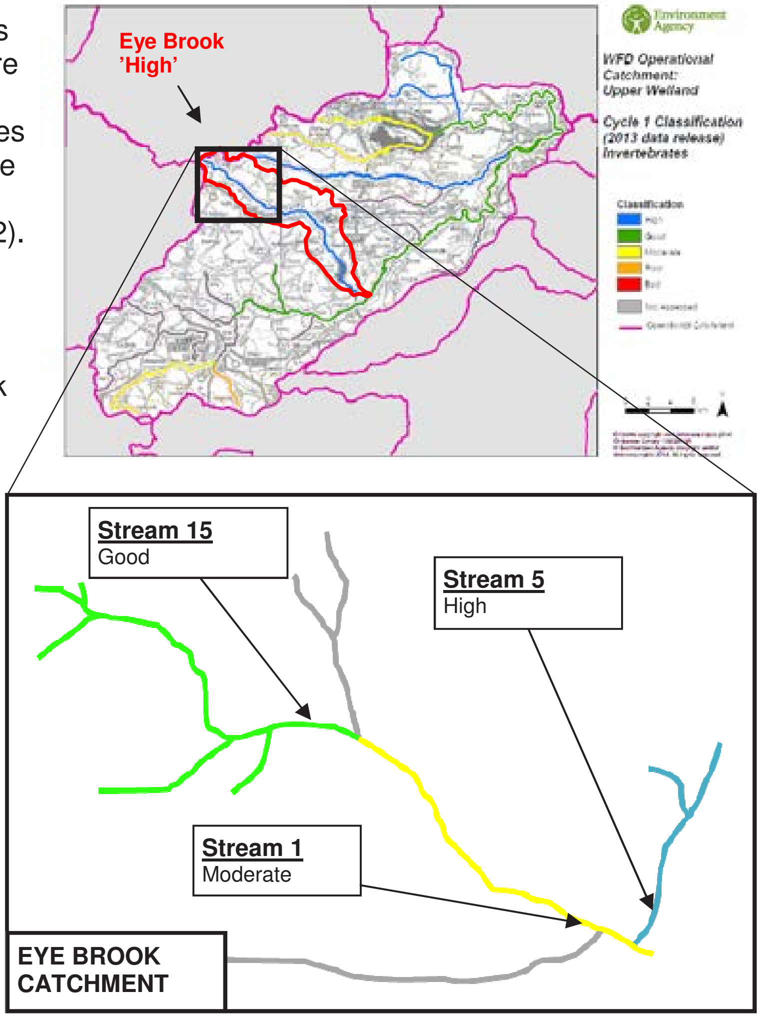


Figure 32. Classification of the Eye Brook streams in terms of Water Framework Directive invertebrate assemblage data, using Water Friendly Farming project data. The official Water Framework Directive classification (see upper panel) describes the main stem of the Eye Brook as High status, based on a sampling point c20 km downstream.

Table 8. Water Framework Directive classified stream length compared to whole stream network in the Water Friendly Farming catchments.
Note this analysis describes the *whole* catchments of the Barkby Brook, Eye Brook and Stonton Brook from source to respective confluences with the R. Soar and R. Welland. The stream networks analysed are shown in Figure 25 (Barkby Brook and Eye Brook) and Figure 21 (Stonton Brook)

	Length of stream classified for Water Framework Directive, km (%)	Length of tributaries and headwaters km (%)	Total stream network length km (%)
Eye Brook	26 (27%)	70 (63%)	96 (100%)
Stonton Brook	8 (13%)	55 (87%)	63 (100%)
Barkby Brook	9 (22%)	29 (78%)	38 (100%)

Practical implications

The implication of these data is that there are substantial variations in the quality of the headwater and upper catchment networks in the project area which are not well-described by current Water Framework Directive approaches. Experience in the Water Friendly Farming project area suggests that, more generally, there are likely to be extensive areas of undetected High and Good quality stream habitat in upper catchments, as well as poorer quality streams that would be classified as Moderate, Poor or Bad.

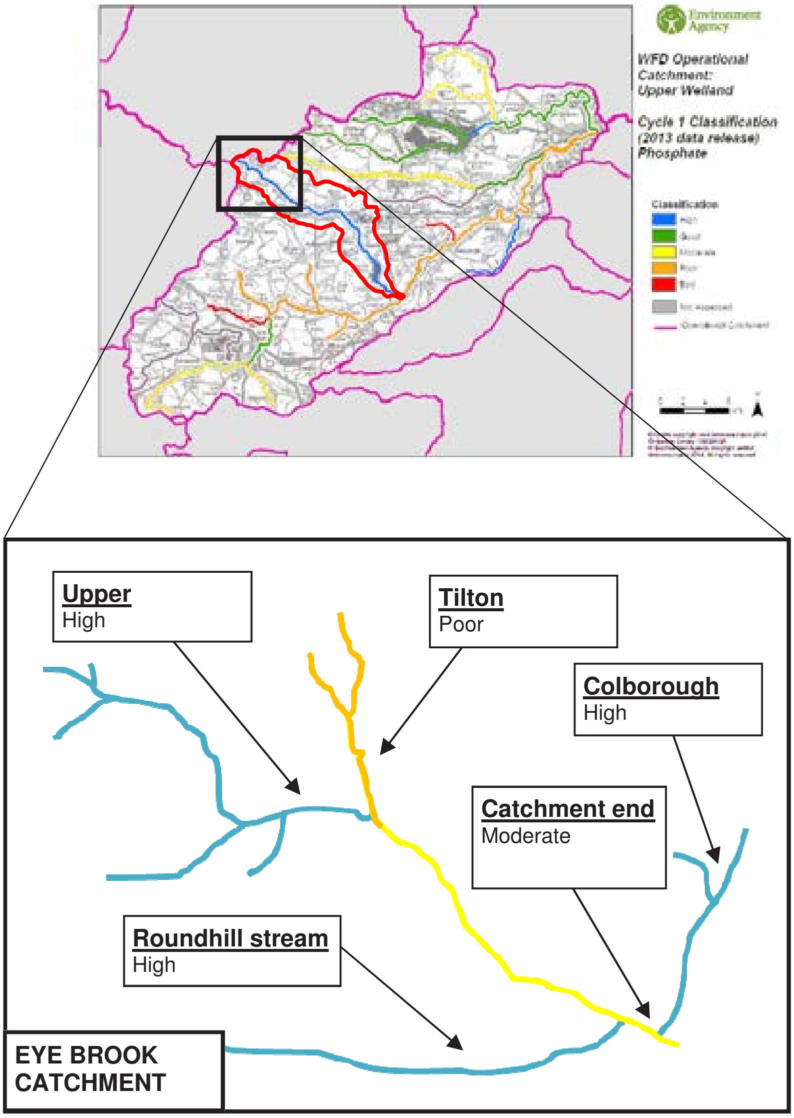


Figure 33a. Classification of the Eye Brook streams in terms of Water Framework Directive compatible soluble reactive phosphorus data collected in the twice monthly Water Friendly Farming water quality monitoring programme. The official Water Framework Directive classification (see upper panel) describes the main stem of the Eye Brook as High status in terms of phosphorus throughout its length, based on a sampling point c20 km downstream.

Figure 33b. Site 22 Stream in the Eye Brook catchment is typical of headwater streams which are not classified under the Water Framework Directive

4.8 Fish

Baseline surveys of fish populations were undertaken in 2012 and 2013 with electro-fishing surveys running from late autumn to early winter in both years. Overall, there was good agreement in species composition and density measurements between the two survey years (Figure 34 and 36).

Eye Brook

There is some evidence of long-term declines in the quality of the fish community in the Eye Brook, although the fish fauna is notable for retaining a wild brown trout (*Salmo trutta*) population. Surveys of brown trout undertaken by Game & Wildlife Conservation Trust in the early 2000s suggest that densities at that time were higher than are now observed. Environment Agency data also suggest long term declines in fish populations in the Eye Brook. In the Eye Brook the fish fauna is dominated by bullheads (*Cottus gobio*) with smaller numbers of brown trout and occasional three-spined stickleback (*Gasterosteus aculeatus*) (Figure 34). Fish are only absent from the smallest

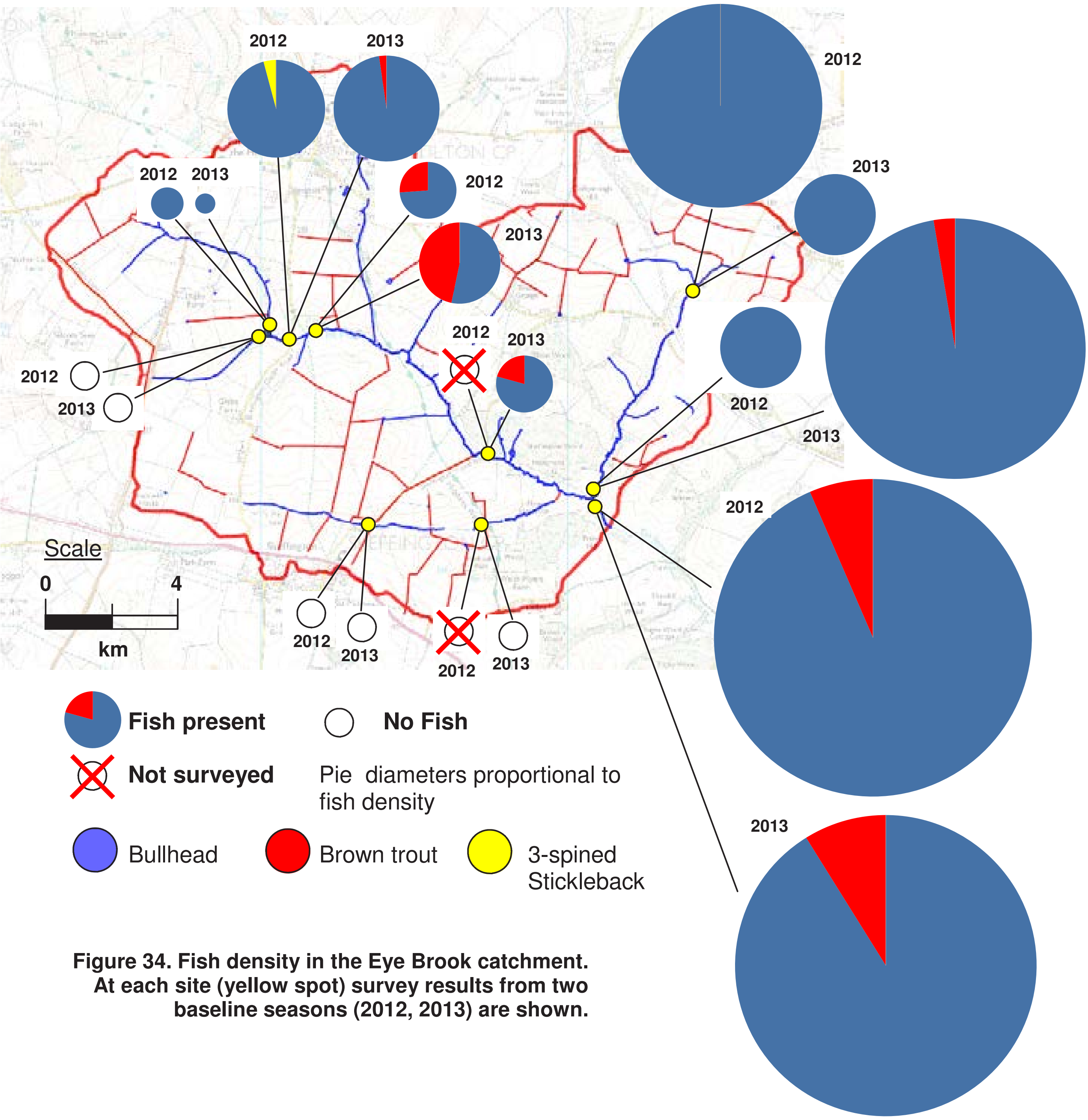


Figure 34. Fish density in the Eye Brook catchment. At each site (yellow spot) survey results from two baseline seasons (2012, 2013) are shown.

headwaters, with a clear relationship between waterbody size and fish density.

Stonton Brook

In the Stonton Brook, Environment Agency data indicate that in the lower reaches, downstream of the Water Friendly Farming project area, fish communities are in poor condition. Within the project area the fish fauna of the Stonton Brook is dominated by bullheads with densities similar to those seen in the Eye Brook (Figure 36). Stone loach (*Barbatula barbatula*) were found at one location. There are no brown trout in the Stonton Brook system.

Barkby Brook

The fish fauna of the Barkby Brook is dominated by three-spined sticklebacks, with bullheads present in smaller numbers. Stone loach were found at several sites. There were no brown trout recorded. Overall fish densities were similar to those seen in the Eye Brook and Stonton Brook, except for one site with very large stickleback populations (Figure 36). Data on the fish populations in the lower catchment of the Barkby Brook are not currently available,

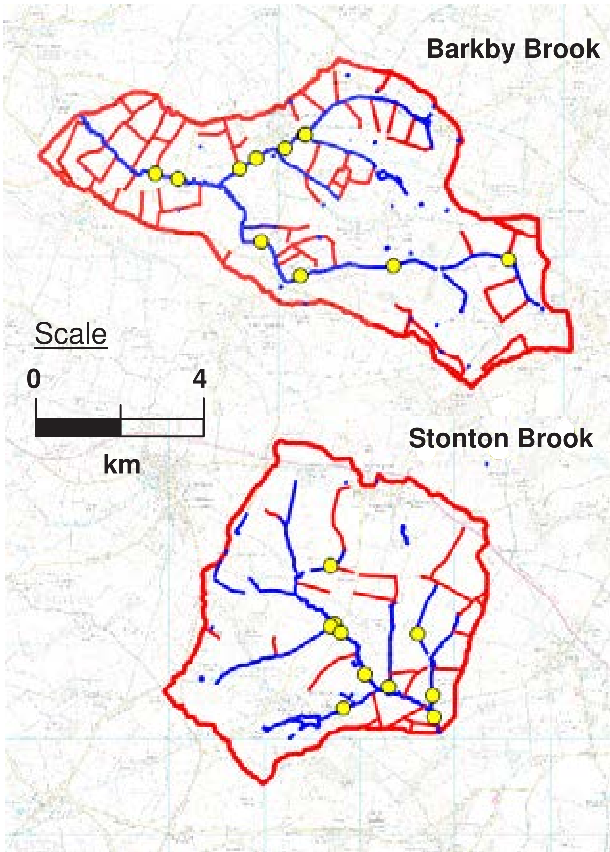
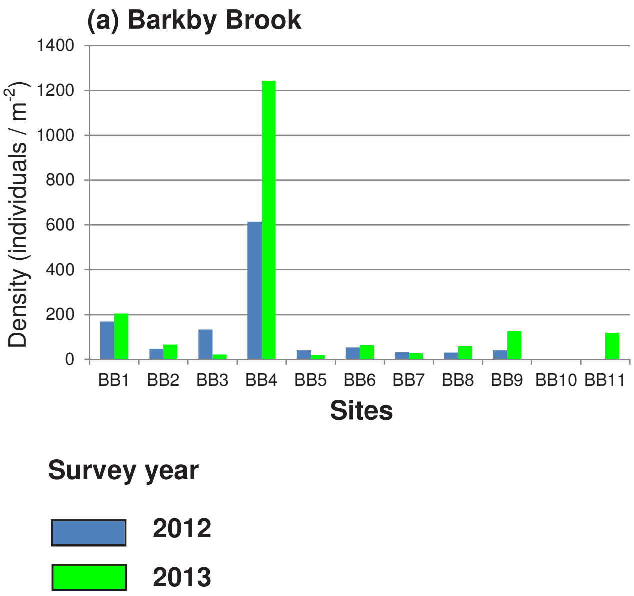


Figure 35. Fish survey sites in the Barkby Brook and Stonton Brook catchments. At each site (yellow spot) baseline surveys were undertaken in 2012 and 2013.



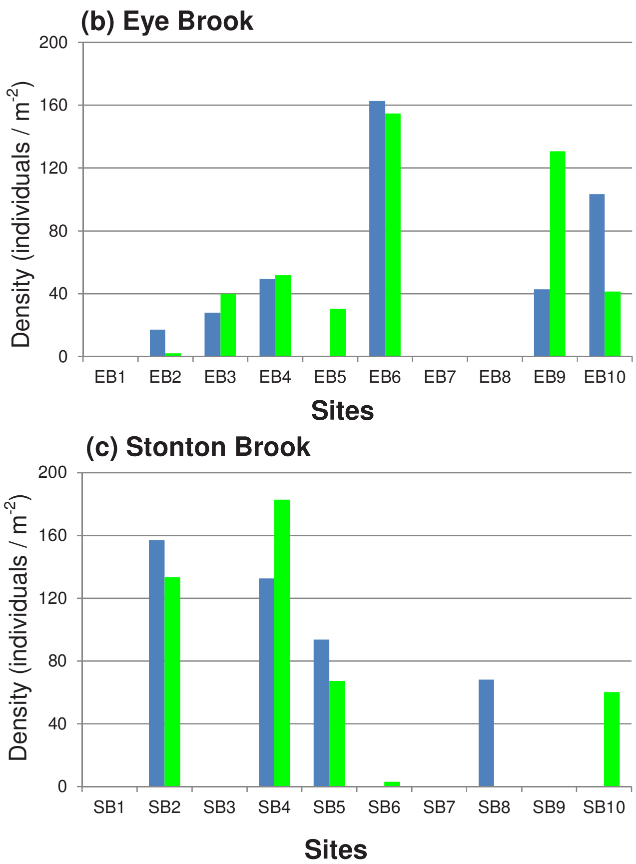


Figure 36. Comparison of total fish densities in the three project catchments: 2012 and 2013. (a) Barkby Brook; (b) Eye Brook and (c) Stonton Brook.

5. Water quality, pollution and flows

5.1 Water quality at the landscape level: chemical variability

Water quality

Landscape level water quality analysis normally shows that small waterbodies have a greater range of water chemistry than larger waters (Biggs *et al*. 2004; Demars and Edwards 2007). The Water Friendly Farming landscape broadly conforms to this pattern: typically, ditches and ponds are more chemically heterogeneous than streams (Figure 37). We described this pattern in Water the Friendly Farming project area using the 2013 landscape sample dataset, collected in spring from ponds, streams and ditches (Figure 14). Of the 24 determinands analysed, 20 out of 24 showed greater heterogeneity in ditches and ponds than in streams (Figure 38)

Although this pattern is unsurprising, it has important practical implications. It shows that there are more likely to be clean water refuges in smaller waters and, conversely, that some of the worst pollution problems will be seen in the smallest waters. This pattern reflects the local influence of small catchments, and also highlights the practical issue that smaller waters experience a wider range of impacts than larger waters. These impacts may not be addressed by broad policies intended to reduce pollutant burdens affecting larger waters.

Figure 37. Ponds and ditches normally show the biggest variation in water quality parameters, with both the cleanest water and the dirtiest.

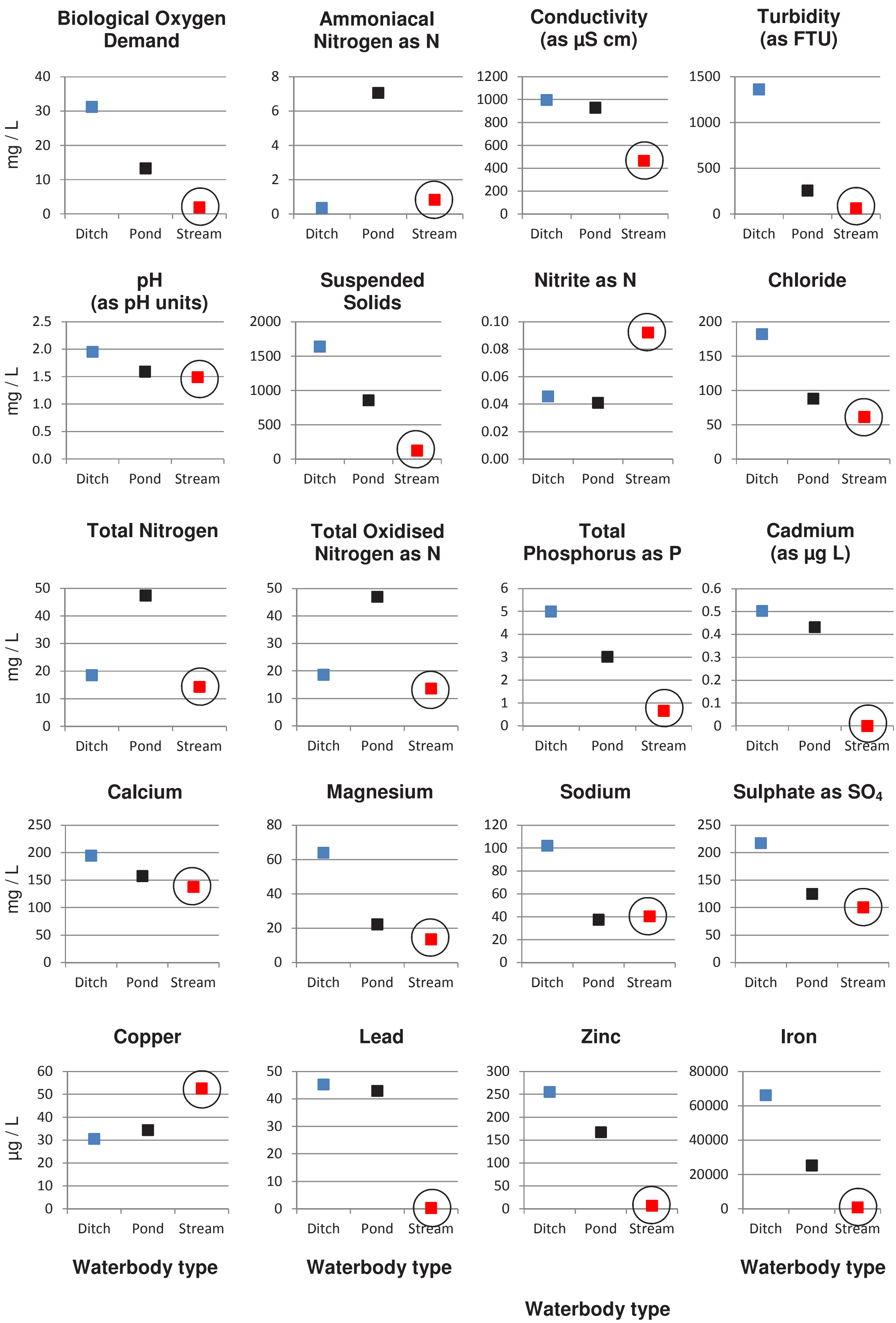


Figure 38. Chemical variability of freshwater habitats (ponds, ditches and streams) at the landscape scale. Graphs show range from minimum to maximum values for each determinand in the three waterbody types present in the Water Friendly Farming Landscape: ponds, ditches and streams. Data from all three catchment combined; n=60 for each habitat in all figures. Values are mg/L, unless stated in caption above graph, except metals which are µg/L. Streams are circled for clarity.

5.2 Spatial pattern of nutrient pollution

Phosphorus

Water quality in the Water Friendly Farming landscapes varies widely in terms of nutrients. Phosphorus analysis identifies significant numbers of waterbodies with both very low (close to the natural background) and very high total phosphorus levels (respectively, 'Low Risk' and 'Very High risk' sites in Figure 39a-c).

Considering the landscape data, which are based on a single annual 'grab' sample in three years (2011-2013), phosphorus concentration were, perhaps surprisingly, lowest in streams, and higher in ponds and ditches. Despite the wide influence of sewage sources on streams (sewage works, septic tanks) *individually* the highest phosphorus concentrations were usually seen in ponds and ditches (Figure 39).

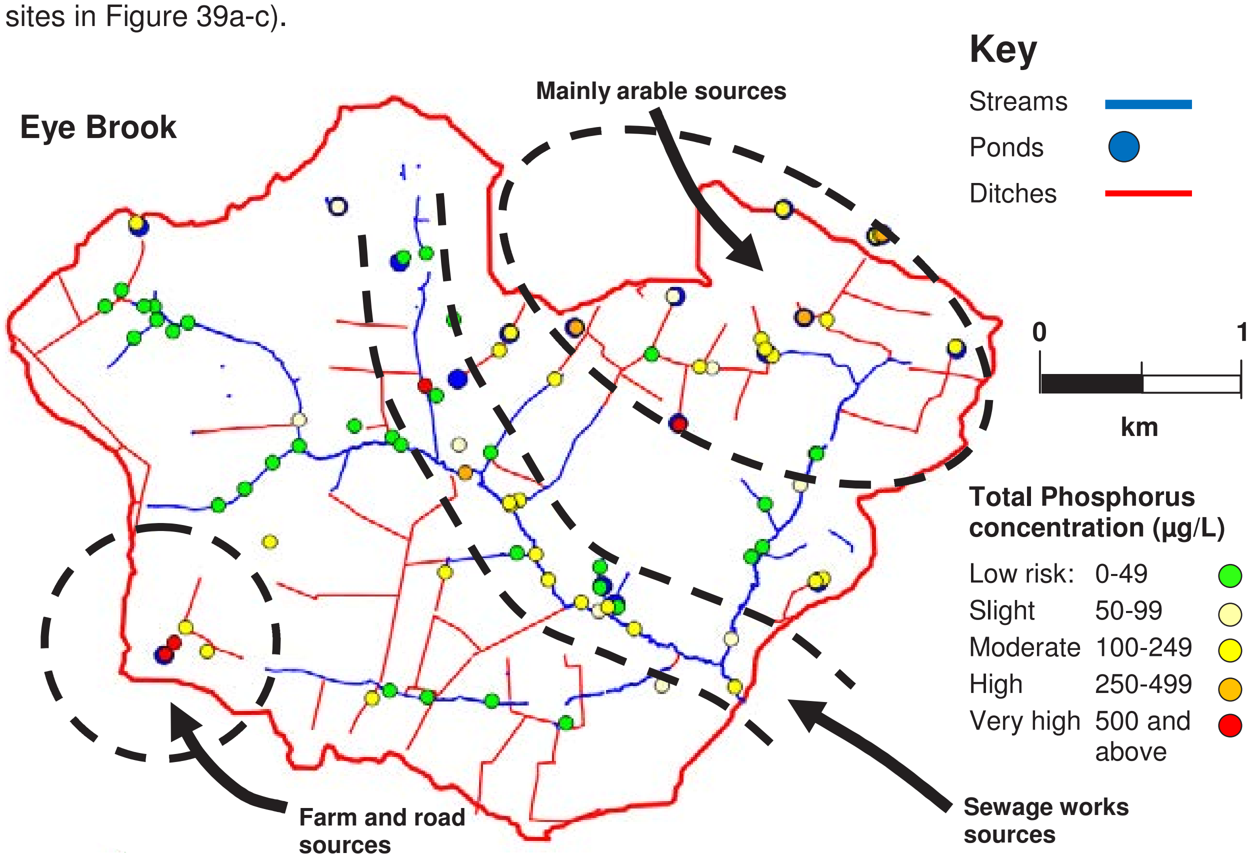
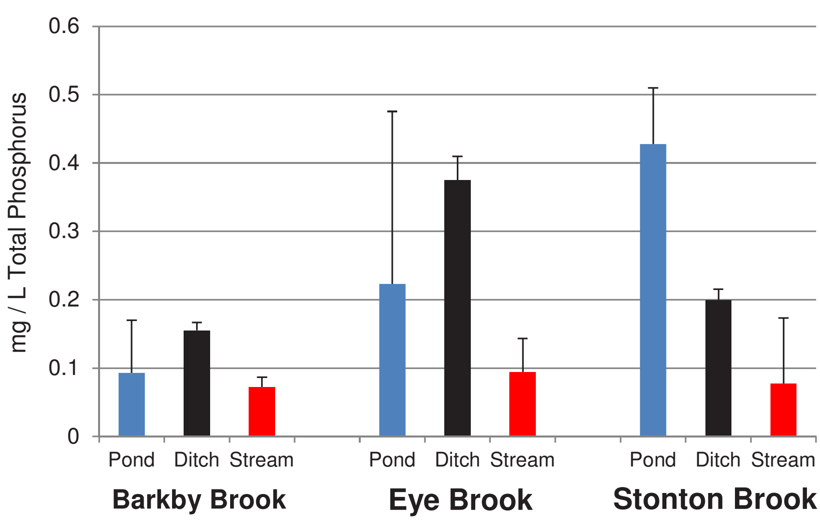


Figure 39a. Phosphorus distribution and sources in Eye Brook catchment waterbodies

Figure 40. Average Total Phosphorus concentrations in the three waterbodies in the Water Friendly Farming landscapes. Concentrations are on average lowest in streams and substantially higher in ponds and ditches. The practical implication of this is that more effort is needed to control nutrient excesses in ditches and ponds; with their comparatively small catchments this should be cheaply and easily achieved at a substantial proportion of sites.



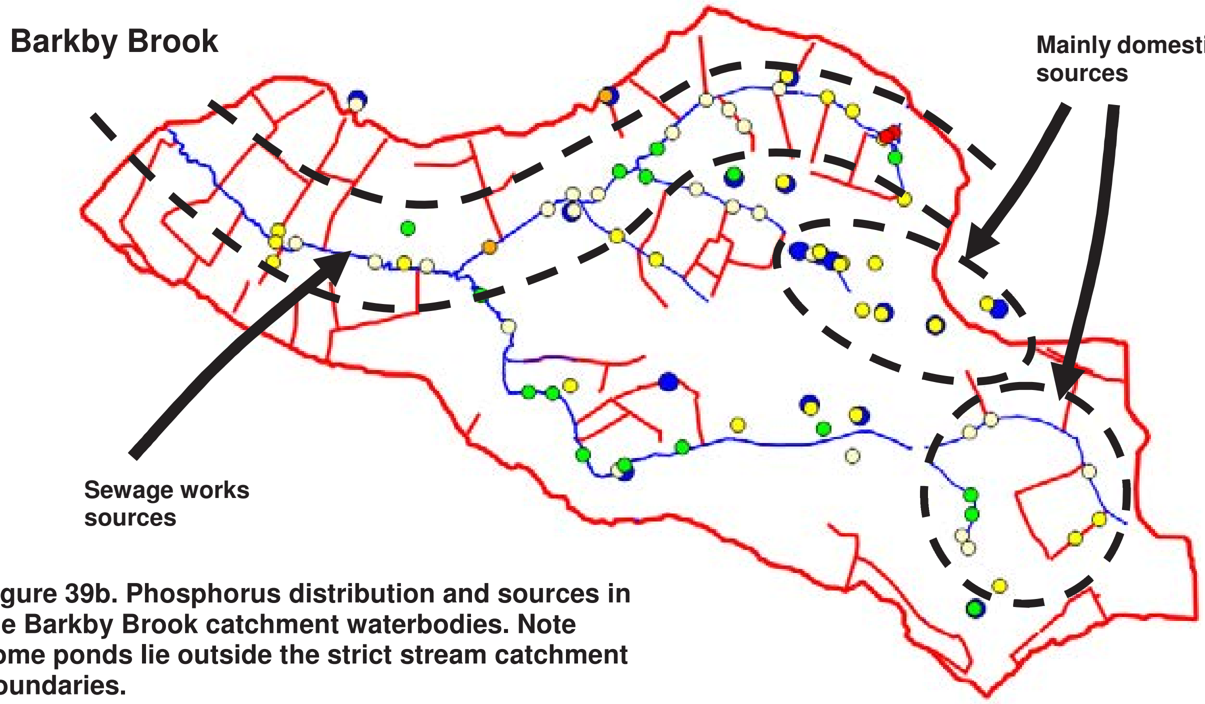
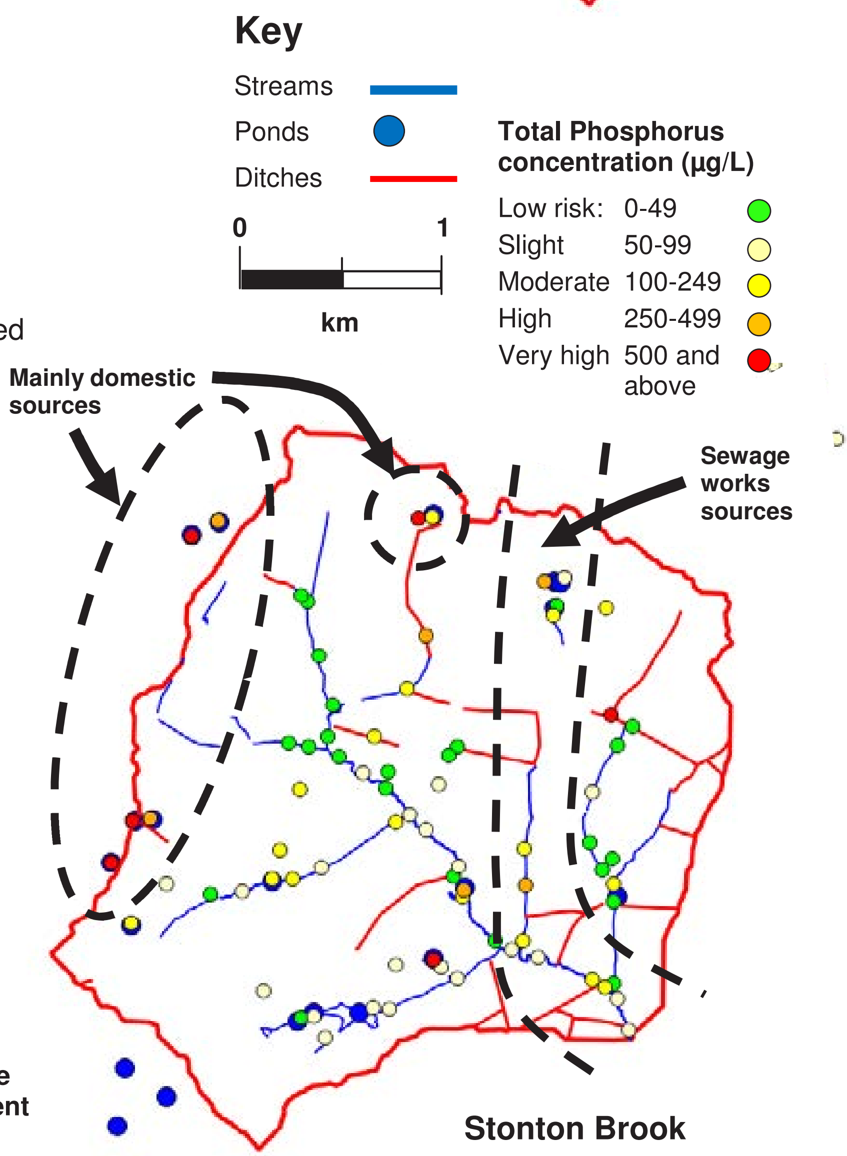


Figure 39b. Phosphorus distribution and sources in the Barkby Brook catchment waterbodies. Note some ponds lie outside the strict stream catchment boundaries.



Sources of phosphorus contamination were often grouped together. In Figures 38a-c these are indicated by the arrowed concentrations of high Total Phosphorus values. However there were also areas with patches of clean water which are indicated by the groups of green spots (see also Box 2 over page for definition of 'clean water').

Figure 39c. Phosphorus distribution and sources in the Stonton Brook catchment waterbodies. Note some ponds lie outside the strict stream catchment boundaries.

Nitrogen

Total Nitrogen concentrations across the catchment show a different pattern to those seen for phosphorus. Unlike phosphorus, nitrogen is more widely, and uniformly, present (Figure 41). It is also present at relatively high concentrations in most locations, with a much smaller number of 'clean' patches than for phosphorus.

In the landscape scale annual snapshot survey, about 32% of sites had phosphorus concentrations at background level. In contrast only 3% of sites were at natural background levels for nitrogen.

Nitrogen concentrations are substantially elevated downstream of sewage works and other domestic sources. Unlike phosphorus there is also significant elevation of nitrogen in the waterbodies draining farmland.

Practical implications

It has long been assumed that nitrogen was the less important nutrient than phosphorus in freshwaters. However, there is a range of evidence now suggesting that nitrogen is more important than was originally thought (see, for example, Moss *et al.* 2005 and Lambert and Davy 2011). Although the effects of reduced fertiliser inputs can be seen in the long-term nitrogen trends in the Water Friendly Farming landscape (see Section 4.6), a step change in concentrations is likely to be needed to adequately protect freshwater biodiversity. Continued innovation in landscape management will be needed to achieve this aim.

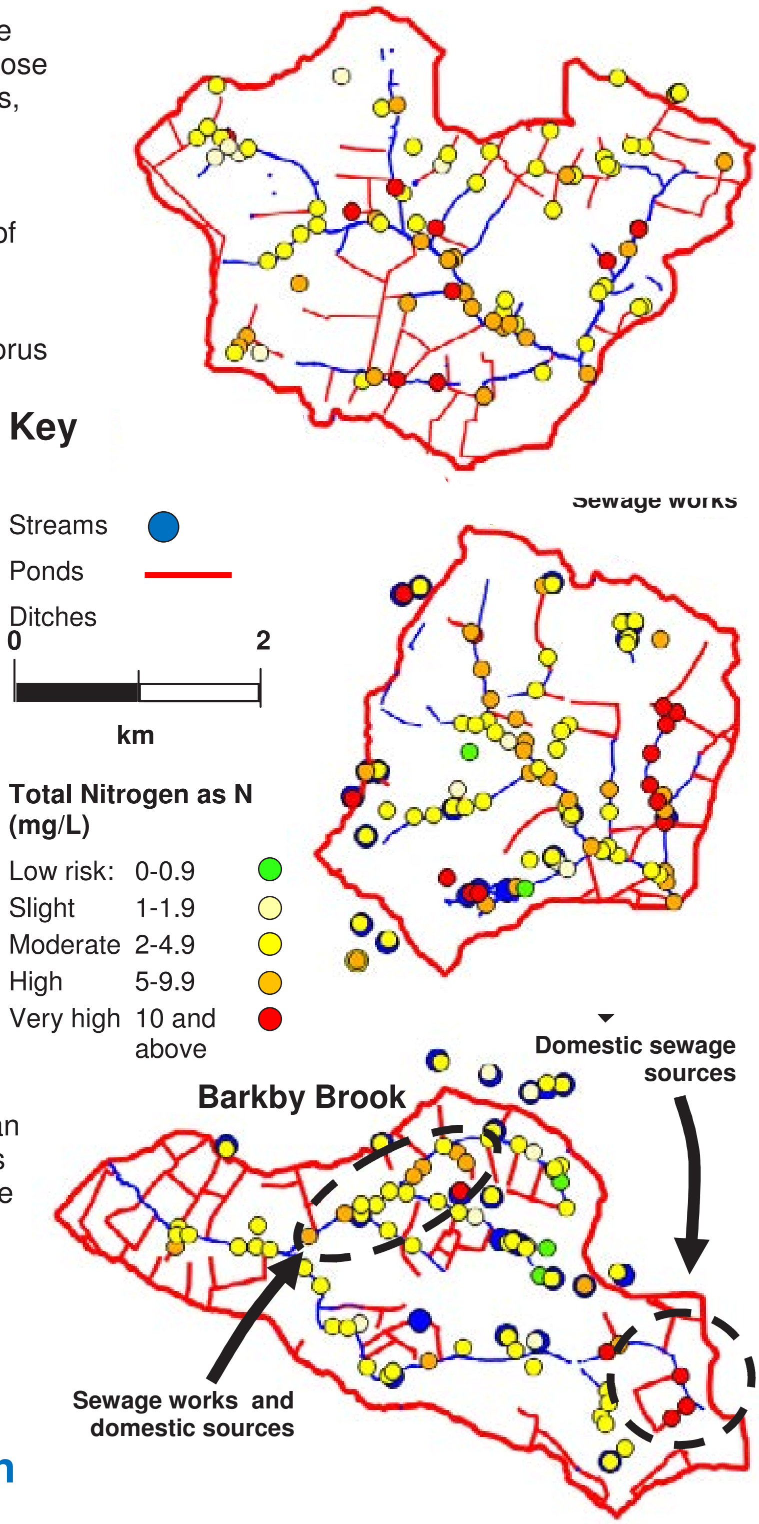
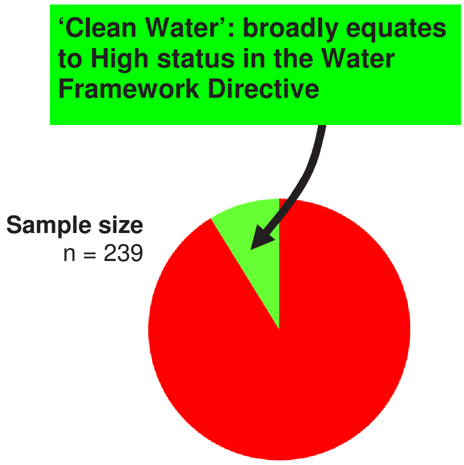


Figure 41. Nitrogen distribution and sources (measured as Total Nitrogen) in the Water Friendly Farming project catchments. Note that levels are at least moderately high (yellow circles) over most of the areas of the three catchments.

5.3 How common is 'clean water'?

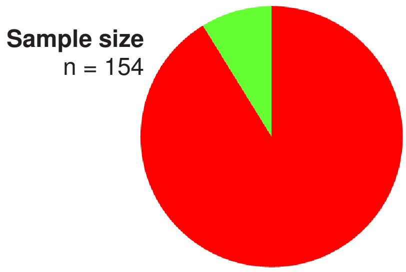
'Clean water' in the project area

There are areas of clean water in all three of the project catchments, although these represent a small proportion of the whole water environment (Figure 42a). Over the three years of the baseline study (2011-2013) the proportion of sites which had 'clean water' concentrations of both nitrogen and phosphorus varied from 3% - 8%. The proportion was a little lower in 2012, perhaps because of the exceptionally wet weather that year leading to additional polluting runoff. Thus, on average 93% of waterbodies in the catchment were affected by levels of nutrient pollution which are known to have biologically detrimental impacts. As we did not assess the prevalence of other pollutants the true position may be worse than this.



(a) Proportion of clean water stes: 2013

(b) Proportion of clean water sites: 2012



(c) Proportion of clean water sites: 2011

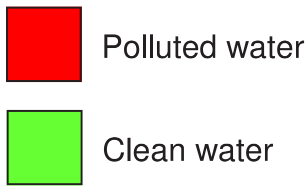


Figure 42a. The proportion of waterbodies in the three Water Friendly Farming catchments with 'clean' and polluted water in single annual snapshot surveys in 2011, 2012 and 2013. The sample size has increased with time as larger numbers of survey sites have been incorporated into the survey.

Box 2. What is 'clean water'?

'Clean water' has a chemistry and biology that would be normal for its area in the absence of significant human pressure. It is sometimes called 'the natural background', 'minimally impaired water quality' or 'the reference condition'.

In terms of legislation it is water categorised as 'High' on the five point Water Framework Directive water quality classification of High, Good, Moderate, Poor and Bad.

In this analysis clean water refers to waterbodies with Total Nitrogen concentrations below 1 mg/L and Total Phosphorus concentrations below 50 µg/L. This broadly equates to Water Framework Directive 'High' status (or its equivalent for ponds and ditches).

Figure 42b. This headwater stream in the Eye Brook has natural background phosphorus levels, but nitrogen is High.

5.3 Intensive water quality monitoring programme

Background

Runoff from farmland and other parts of the rural landscape washes substantial quantities of nutrients, sediment and pesticides into streams, ditches and ponds. This has a direct impact on these waterbodies which, although individually small, collectively are a large and significant part of the water environment. Runoff in the upper catchment also feeds pollutants to receiving waterbodies downstream, and adds to the pollutant burden reaching the sea. During wet weather, runoff from farmland is often greater than from natural vegetation, leading to flooding of built infrastructure downstream. Various rural land management practices make the runoff of pollutants, sediment and water worse than under more natural landscapes.

The Water Friendly Farming programme incorporates a range of measures aimed at reducing contamination of surface waters by pollutants, and intended to reduce the rate of runoff from the land. To check the impact of these measures, high frequency monitoring of concentrations and amounts of nutrients and sediment has been is undertaken at the end of each catchment and, at a lower frequency, at selected locations within the catchments. Flows are also being continuously monitored.

Water quality

To establish pre-intervention conditions intensive, near continuous, monitoring was undertaken over two years from spring 2012 to spring 2014. High frequency monitoring is important because a large proportion of all pollutants are transported during storm events which are poorly sampled with standard monthly or weekly sampling programmes. Initial analyses of the pre-works background conditions are presented here: mitigation measures were made operational in April 2014 and there has not yet been a substantial flow period (which normally begins with autumn rainfall as soils wet up) with which to begin evaluating their effect. We have also examined some of the expected effects of the mitigation measures on water quality using modelling techniques (see Section 8).

Phosphorus

All three catchments have shown statistically significant increasing trends in Total Phosphorus concentrations over the two years of the pre-works baseline. In each case this trend appears to be continuing during 2014. Both the experimental catchments are showing the same trend as the control (Barkby). Evaluating trends in phosphorus is complicated by the impact of sewage treatment works and may reflect periods of reduced flows following exceptional rainfall that occurred in 2013 and 2013. A general weather related cause of the pattern is suggested by the fact that all three catchments are behaving in the same way.

Nitrogen

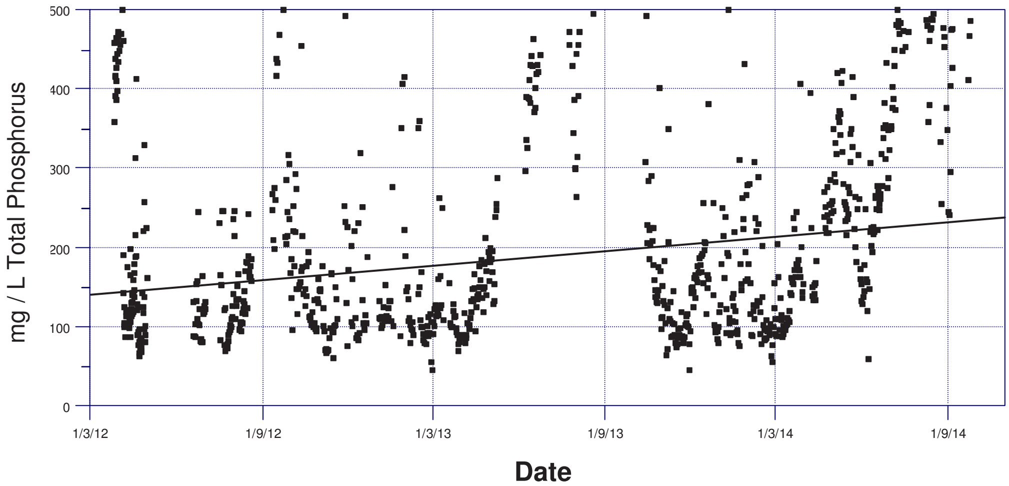
In the Barkby Brook (control) and Stonton Brook, nitrate concentrations at the catchment outfall show a statistically significant declining trend. In contrast, nitrate levels in the Eye Brook have not changed. This suggests that the pattern seen is not simply weather related (i.e. less nitrogen being lost during the drier weather of 2014). The trend in the Eye Brook suggests that losses of nitrogen rose in that catchment, compensating for the period of drier weather. Our next step will be to investigate these patterns further, particularly through detailed analysis of flow patterns and comparison with within-catchment water quality measurements.

Suspended sediments

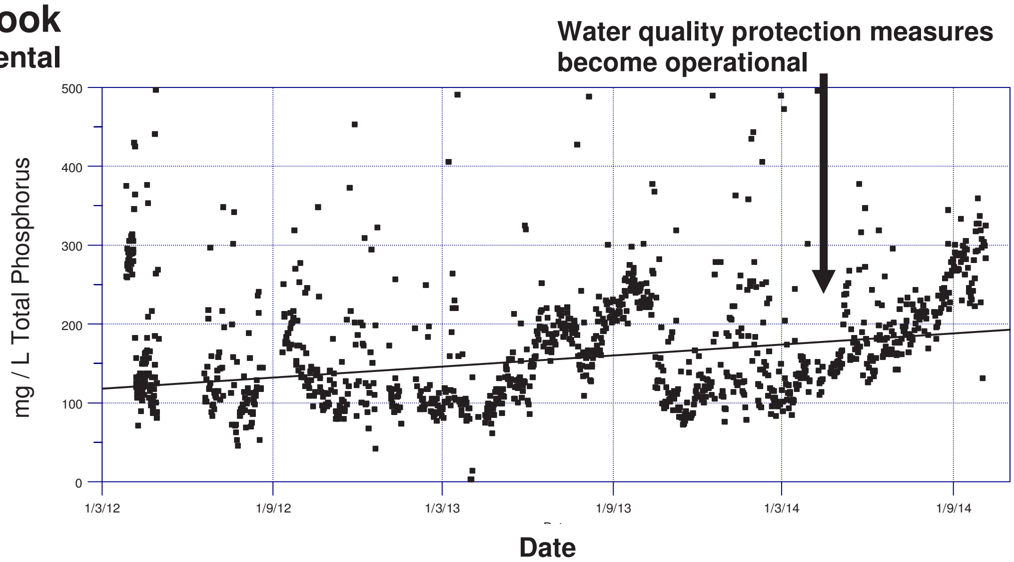
For suspended sediment, two catchments showed declining trends over the last three years: the control (Barkby) and Eye Brook. The drier weather after 2013 might be expected to contribute to reduced sediment losses. However, the results suggest that, in the Stonton Brook, other factors worked against this general trend as suspended sediment concentrations remained constant through the monitoring period.

Total Phosphorus

(a) Barkby Brook
Control



(b) Eye Brook
Experimental



(c) Stonton Brook
Experimental

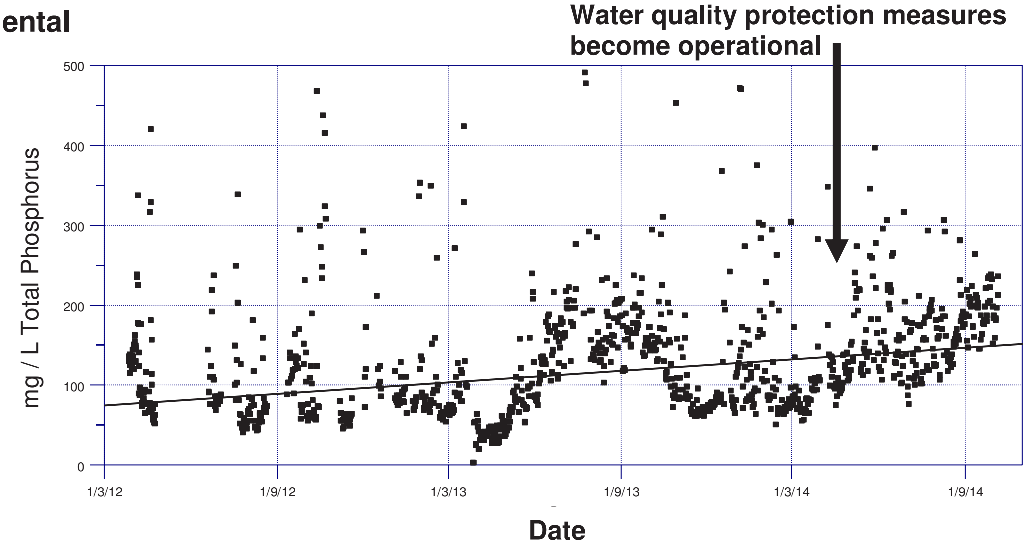
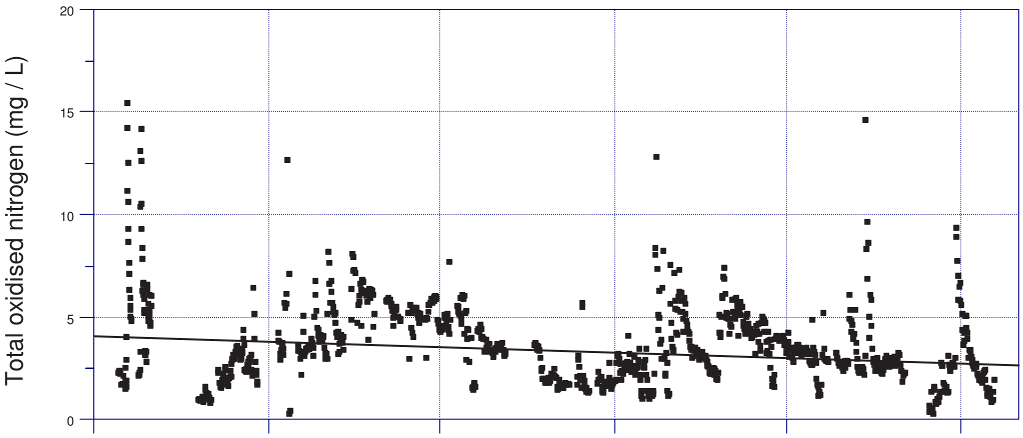


Figure 43. Continuously monitored Total Phosphorus concentrations in: (a) Barkby Brook (b) Eye Brook and (c) Stonton Brook. All trends are statistically significant (Mann-Kendall test, P<0.001).

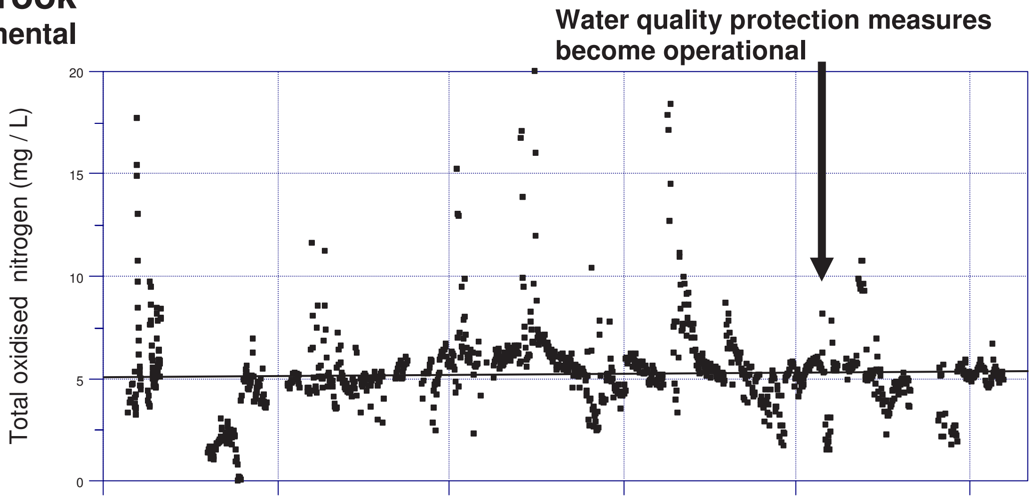
Total oxidised nitrogen

(a) Barkby Brook
Control



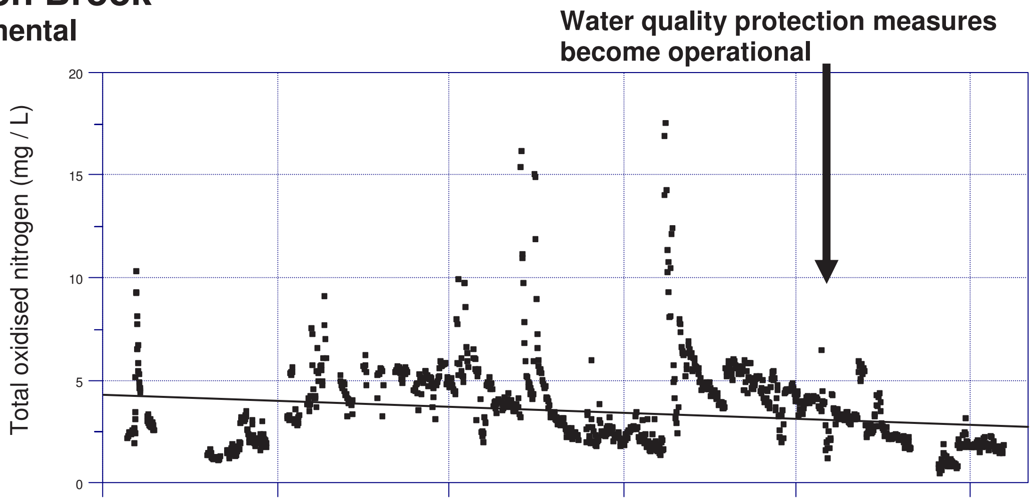
Date

(b) Eye Brook
Experimental



Date

(c) Stonton Brook
Experimental

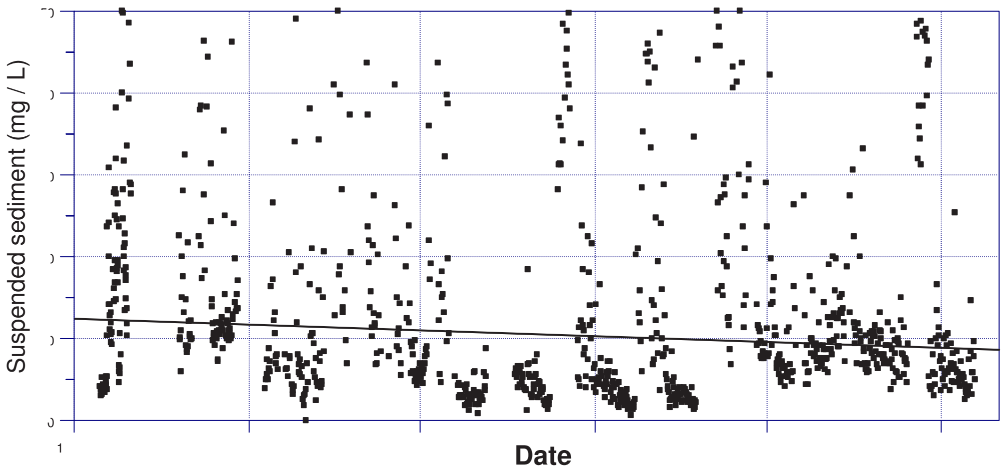


Date

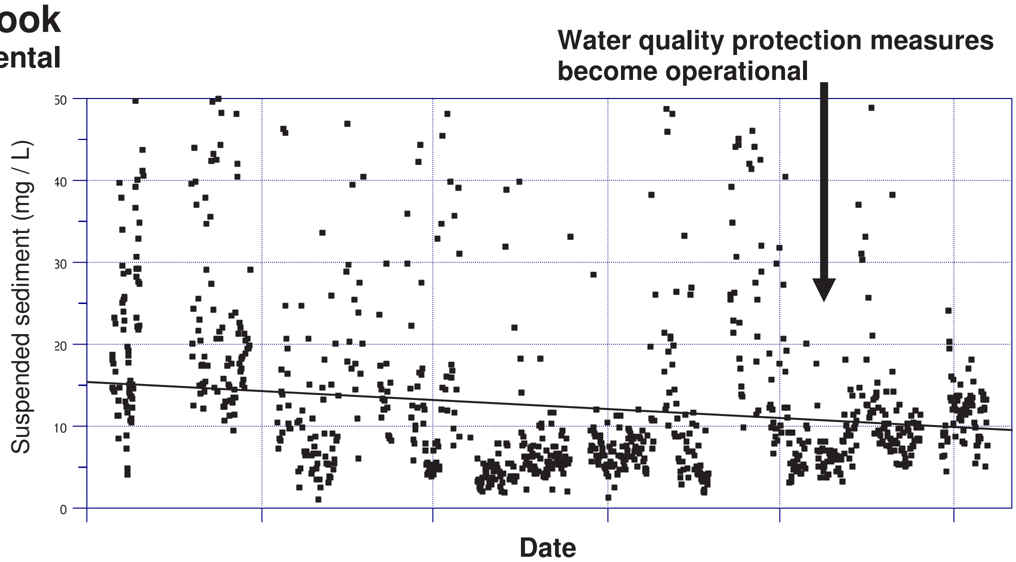
Figure 44. Total oxidised nitrogen concentrations continuously monitored in: (a) Barkby Brook (b) Eye Brook and (c) Stonton Brook. Trends in the Barkby Brook and Stonton Brook are statistically significant. There is no change over tie in the Eye Brook.

Suspended sediment

(a) Barkby Brook
Control



(b) Eye Brook
Experimental



(c) Stonton Brook
Experimental

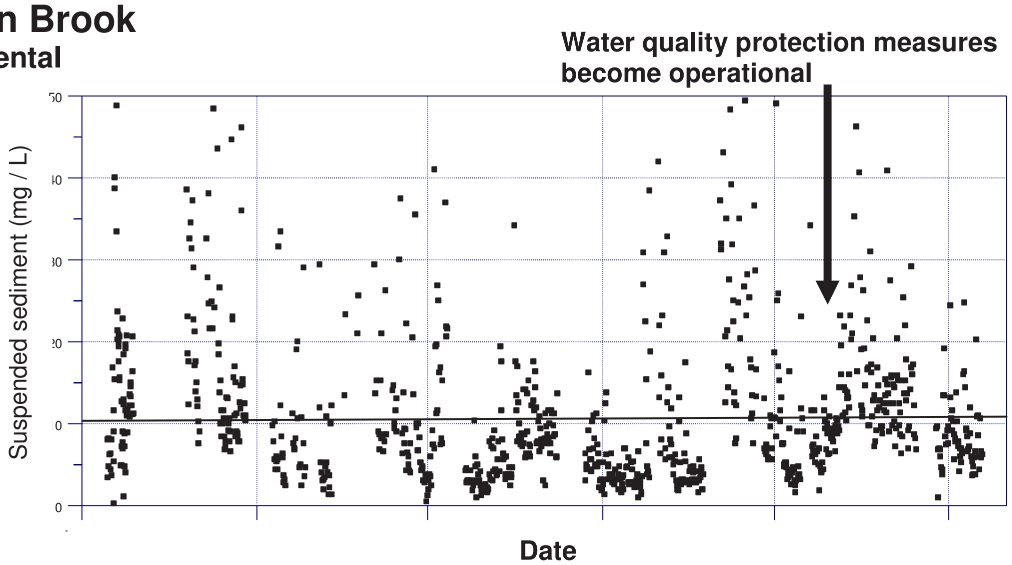


Figure 45. Suspended sediment concentrations continuously monitored in: (a) Barkby Brook (b) Eye Brook and (c) Stonton Brook. There are statistically significant trends in the Barkby Brook and Eye Brook. There is no long-term trend in suspended sediment concentration in the Stonton Brook

6. Pesticides

6.1 Pesticides: pre-works baseline

Background

Environment Agency monitoring data demonstrate an intransigent problem associated with the presence of pesticides in river systems. This presents issues for treatment and supply of water against the 0.1 µg/L standard for pesticides in drinking water. It also means that many drinking water protection areas (DrWPAs) are either failing or at risk of failing Article 7.3 of the Water Framework Directive which stipulates that there must be no increase in the requirements for treatment of drinking water.

The Water Friendly Farming programme incorporates a range of measures aimed at reducing contamination of pesticides by surface waters. To check the impact of these measures, catchment monitoring for pesticides has been undertaken during the baseline period and going forwards now that measures are operational.

The programme of pesticide baseline monitoring focussed on three autumn herbicides: carbetamide and propyzamide, which are applied to oilseed rape, and chlorotoluron which is used on winter cereals. We also assessed metaldehyde, the active ingredient in many slug pellets.

Integrated water samples were collected on a daily basis from the outlets of the three catchments.

Results: Metaldehyde 2012/13 and 2013/14

We collected data on metaldehyde in the Eye Brook and Stonton Brook in winter 2012/13 and in all three catchments in winter 2013/14.

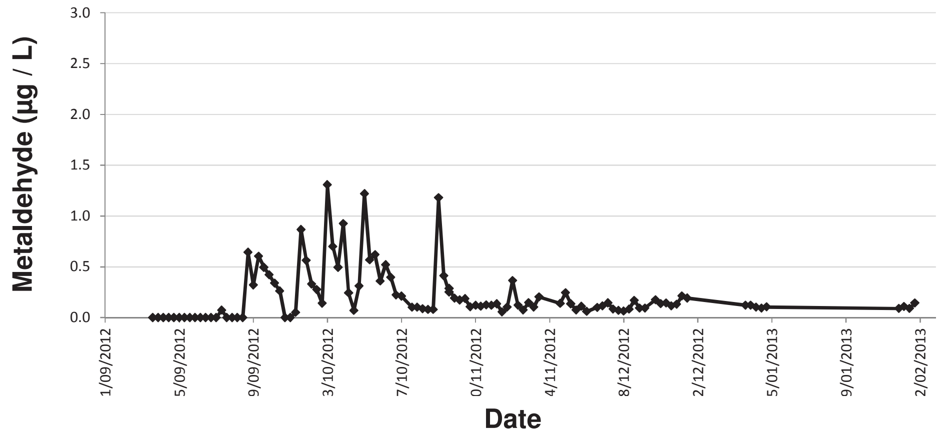
The main uses of metaldehyde in the catchments are applications to winter cereals and oilseed rape from mid-September to early November. Monitoring data show regular presence of metaldehyde in streamwater throughout the usage period and low-level contamination into December. Peaks in concentration are associated with rainfall events that transport the compound via overland flow and subsurface drainage. Concentrations are highest at the start of these events and decline over the course of the event.

There is very close correspondence between patterns of metaldehyde contamination in the Stonton and Eye Brook catchments for both 2012/13 and 2013/14 (Figure 46 and 47). This indicates both similar levels of usage and that hydrological processes operating in the two catchments are similar. Maximum concentrations over two seasons are in the range 1-3 µg/L.

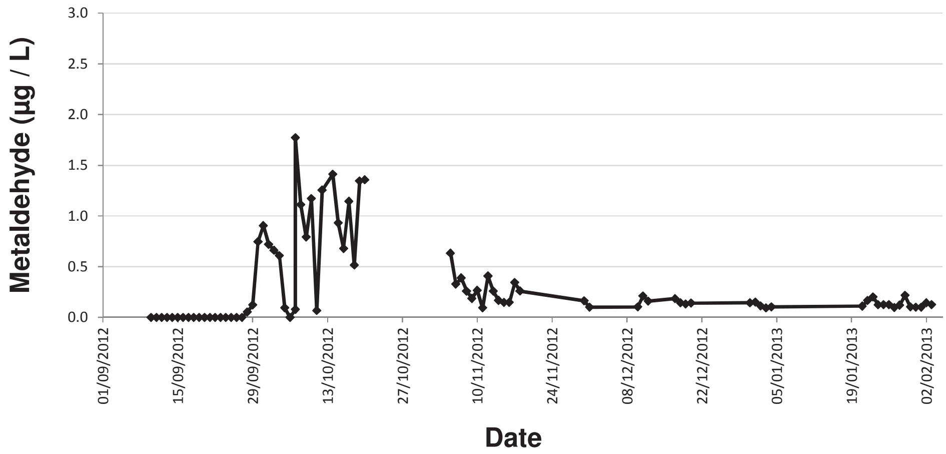
In 2013/14 the timing of peak concentrations was also similar for Barkby, but the concentrations detected were almost ten times smaller. This suggests much lower levels of use for metaldehyde in the Barkby catchment.

Metaldehyde 2012/13

(a) Eye Brook



(b) Stonton Brook



(c) Combined

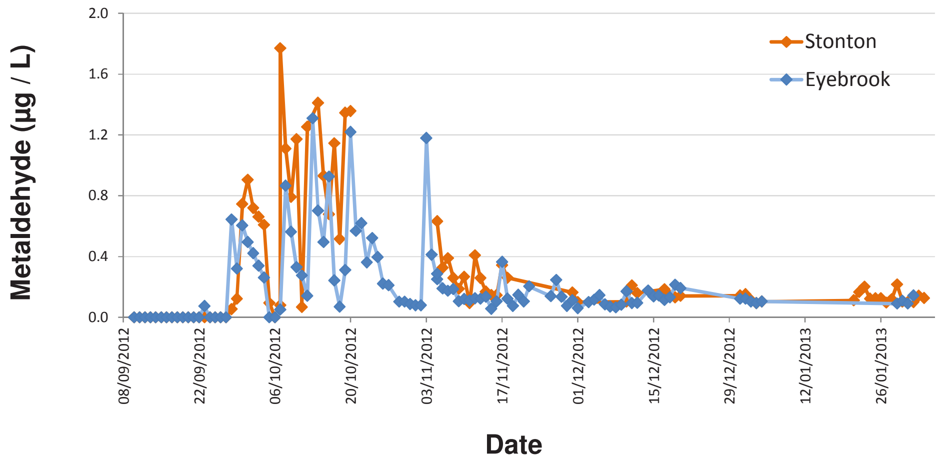
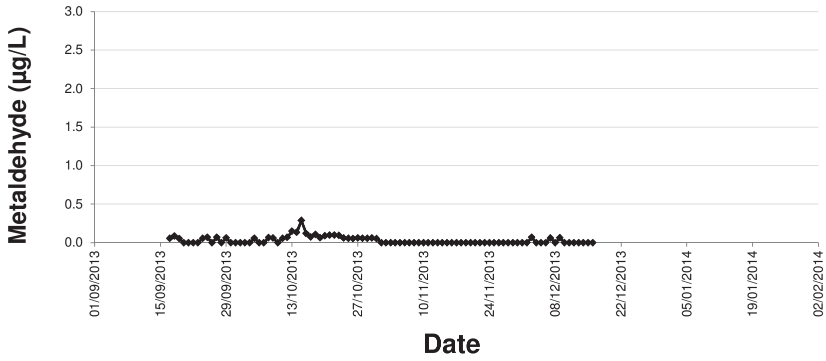


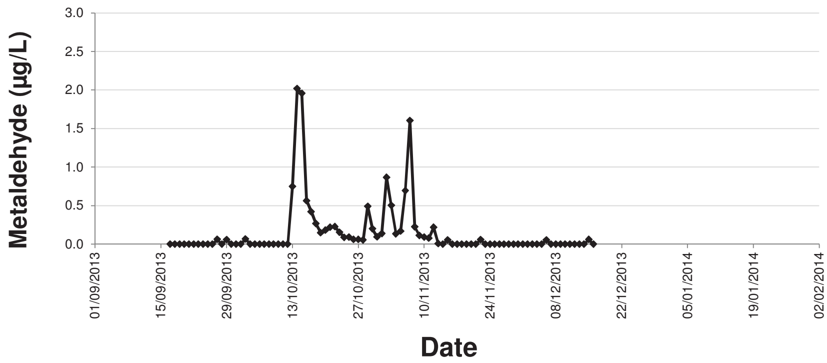
Figure 46. Metaldehyde runoff in winter 2012/13. (a) Eye Brook (b) Stonton Brook (c) combined, to show similarity of trends in the two catchments.

Metaldehyde 2013/14

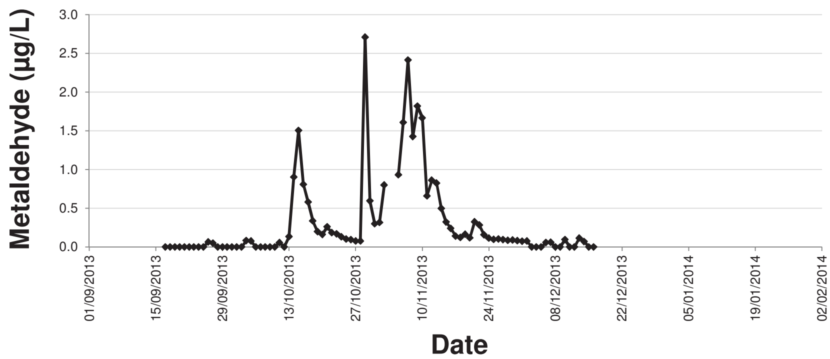
(a) Barkby Brook



(b) Eye Brook Brook



(c) Stonton Brook



(d) Combined

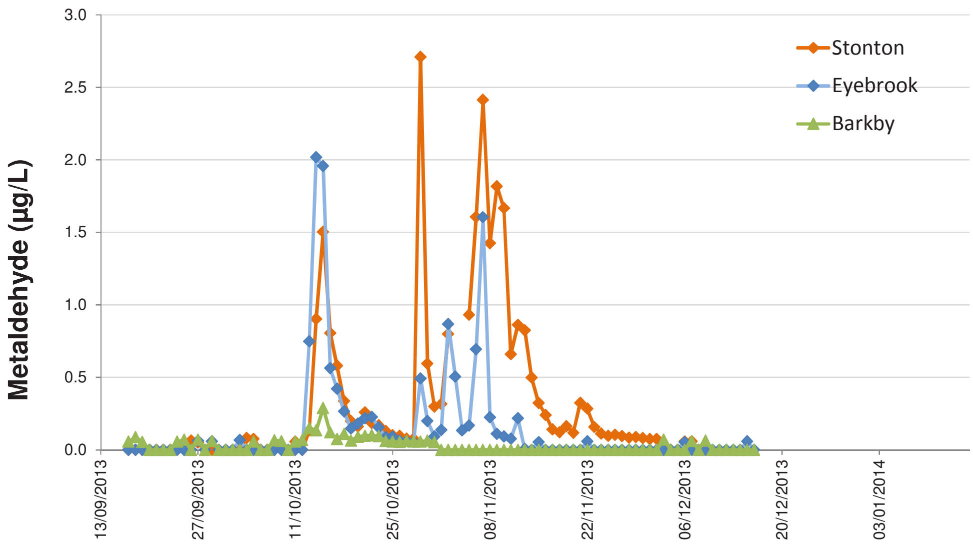


Figure 47. Metaldehyde runoff in winter 2013/14. (a) Barkby Brook, (b) Eye Brook, (c) Stonton Brook and (d) combined to show similarity of trends in the two catchments

Results: carbetamide, propyzamide and chlorotoluron 2013/14

Much of the oilseed rape crop in the Upper Welland failed in 2012/13 due to exceptionally wet autumn conditions. As a result, there was very little use of autumn herbicides.

Monitoring data for 2013/14 showed presence of carbetamide in streamwater from the Stonton and Barkby catchments. The maximum concentrations occurred in the first significant flow with maxima of 0.2 and 0.7 µg/L in Stonton and Barkby, respectively (Figure 48). Carbetamide is often applied fairly early in autumn and the compound degrades fairly rapidly in soil. Presence in water was negligible from mid-November onwards.

Propyzamide works best when applied to cold soil, so treatments often occur in late autumn. Propyzamide had much greater use in the Eye Brook catchment. Here, a peak concentration in streamwater of 2.5 µg/L was detected just before Christmas 2013, with elevated concentrations persisting through to early January and lower level presence through to the end of monitoring in February 2014 (Figure 49). Smaller concentrations of propyzamide detected in Stonton Brook and lack of presence in Barkby suggest much lower levels of use of the compound in these catchments.

Analysis for chlorotoluron revealed very little presence of this compound in surface water. We attributed this to the very limited use, within the study catchments, of the compound over the 2-year baseline period.

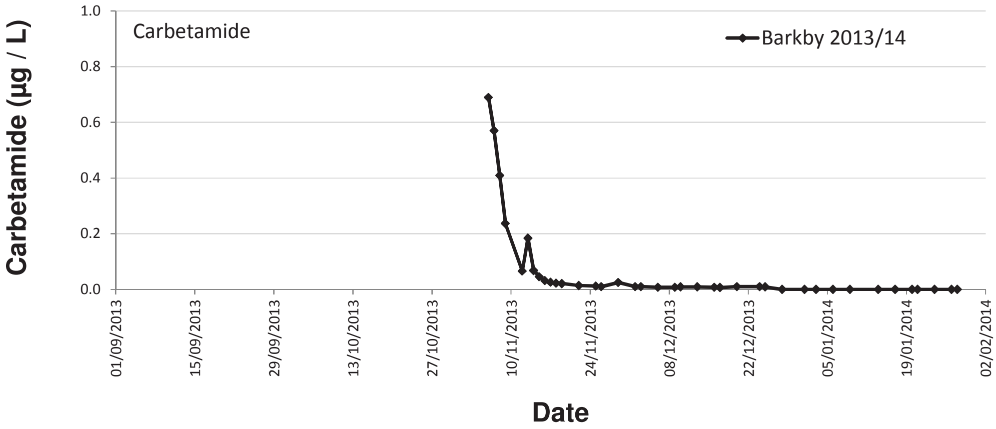
Practical implications

Results of pesticide monitoring suggest that hydrological conditions are similar in the three catchments, providing a good basis for comparison across the different treatments that have been applied to Stonton, Eye Brook and Barkby (control). The catchments are typical of large areas of lowland agriculture in central and eastern England with hydrology dominated by slowly-draining soils formed from glacial tills and clays; arable rotations are dominated by winter cereals and winter oilseed rape.

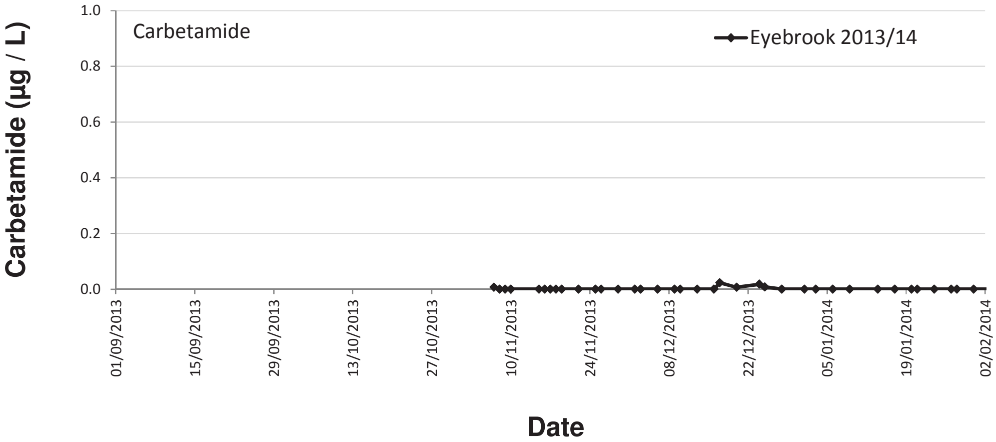
Patterns of contamination of streamwater by pesticides are consistent with measurements made in field-scale experiments and also fit with Environment Agency monitoring that targets larger rivers and sites of drinking water abstraction. The design of measures in Water Friendly Farming mainly targets preventing pesticides from reaching the stream network by changing practices such as cultivation in-field and intercepting flows with edge-of-field measures including vegetated filter strips and constructed wetlands. As the programme moves into the post-measures phase, we will be assessing the impact of these measures on pesticide contamination so that results can be fed into national policy discussions.

Carbetamide 2013/14

(a) Barkby



(b) Eye Brook



(c) Stonton Brook

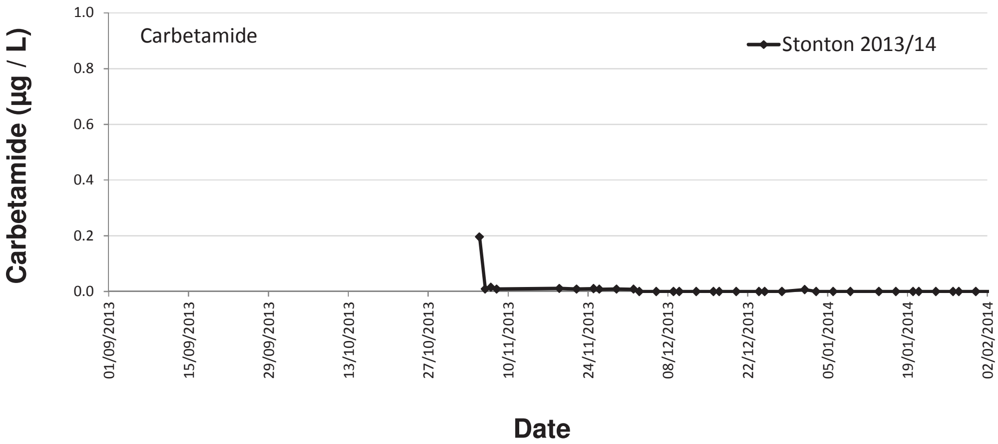
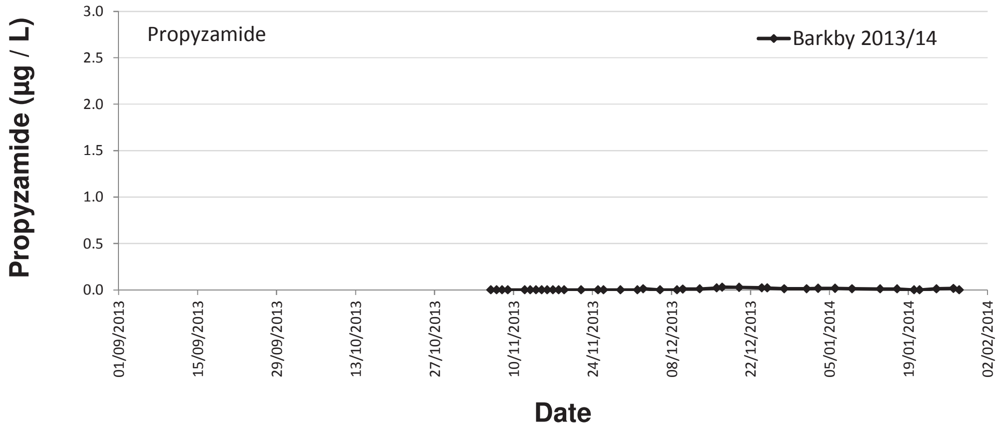


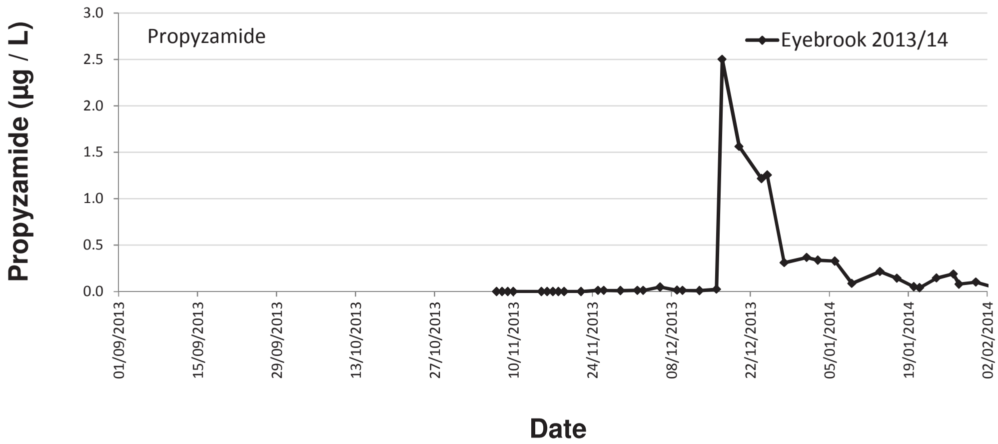
Figure 48. Carbetamide runoff in winter 2013/14. (a) Barkby Brook (b) Eye Brook (c) Stonton Brook.

Propyzamide 2013/14

(a) Barkby



(b) Eye Brook



(c) Stonton Brook

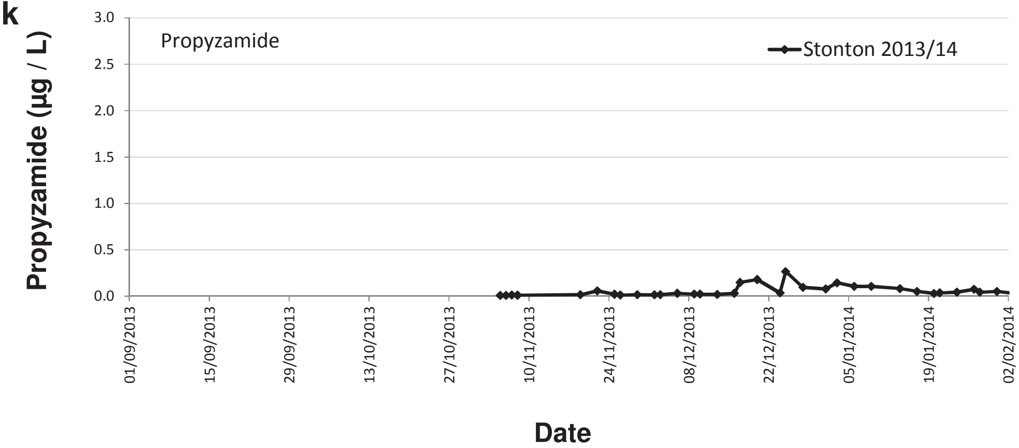


Figure 49. Propyzamide runoff in winter 2013/14. (a) Barkby Brook (b) Eye Brook (c) Stonton Brook.

7. Mitigation measures

7.1 Background to mitigation measures installed

As part of the Water Friendly Farming project we have installed five main types of mitigation measure to reduce diffuse pollution from farmland in order to assess their effectiveness in producing landscape level reductions in water pollution (Table 9, measures 1-5). A further four types of measure have been added or refurbished to reduce rural point source pollution. In the Stonton Brook catchment only, to increase the extent of high quality freshwater habitats, we have installed woody debris widely in streams and created clean water ponds. Note that virtually all fields in the Eye Brook and Stonton Brook catchments already have 6 m buffer strips, or wider. The number of features, and where relevant, the length of linear waterbodies (ditches, streams) influenced, is shown.

To date diffuse pollution mitigation features have been installed over about 25% of the

Table 9. Mitigation measures installed in the Eye Brook and Stonton Brook catchments to reduce impact on water resources and provide additional habitats

Mitigation measure	Purpose	Number or length of linear features covered
1. Earth bunded ditches	Retain flow and sediment in smaller ditches and headwater streams	750 m at 13 separate sites
2. Log-bunded ditch	Retain flow and sediment in larger ditches and small streams	450 m at two sites
3. Field drain interception ponds	Intercept nutrients and sediments from field drains	14 ponds
4. Flood storage basins	Reduce flood-peak by off-line water storage	2 basins
5. Sluice dams	Retain flow in in headwater streams during floods whilst not blocking low flows	4 dams covering 500 m
6. Septic tank emptying	Reduce rural house point source sewage pollution	17 septic tanks emptied
7. Reedbed sewage treatment plant refurbishment	Reduce point source rural housing sewage pollution	One site serving 6 properties
8. Farm yard dirty water mitigation measures	Reduce dirty water farmyard runoff	One site
9. Stream fencing	Eliminate livestock trampling of stream margin and bed	1300 m (note most grass fields already fenced)
10. Woody debris dams	Create habitat diversity (also traps sediment)	Total: 2.7 km of stream modified
11. Clean water pond creation	Create high quality new waterbodies to increase quality of freshwater habitat network	22 ponds created

total length of the network of ditches and small streams directly draining arable land (Figure 50). Examples of the mitigation measures are shown in Figures 51-56.

Further measures are planned for 2014-15 including cultivation changes and further physical interventions.

Note that specifically in the context of the Water Framework Directive, the Environment Agency defines mitigation measures as practicable steps used to mitigate anthropogenic impacts, interpreted to mean physical modifications of watercourses, coasts and estuaries. A list of mitigation measures has been prepared by the Environment Agency which, if implemented, could allow heavily modified waterbodies to achieve at least Good Ecological Potential. In addition to these prioritised measures there are other operations which could achieve water pollution and hydromorphological gains within the catchment

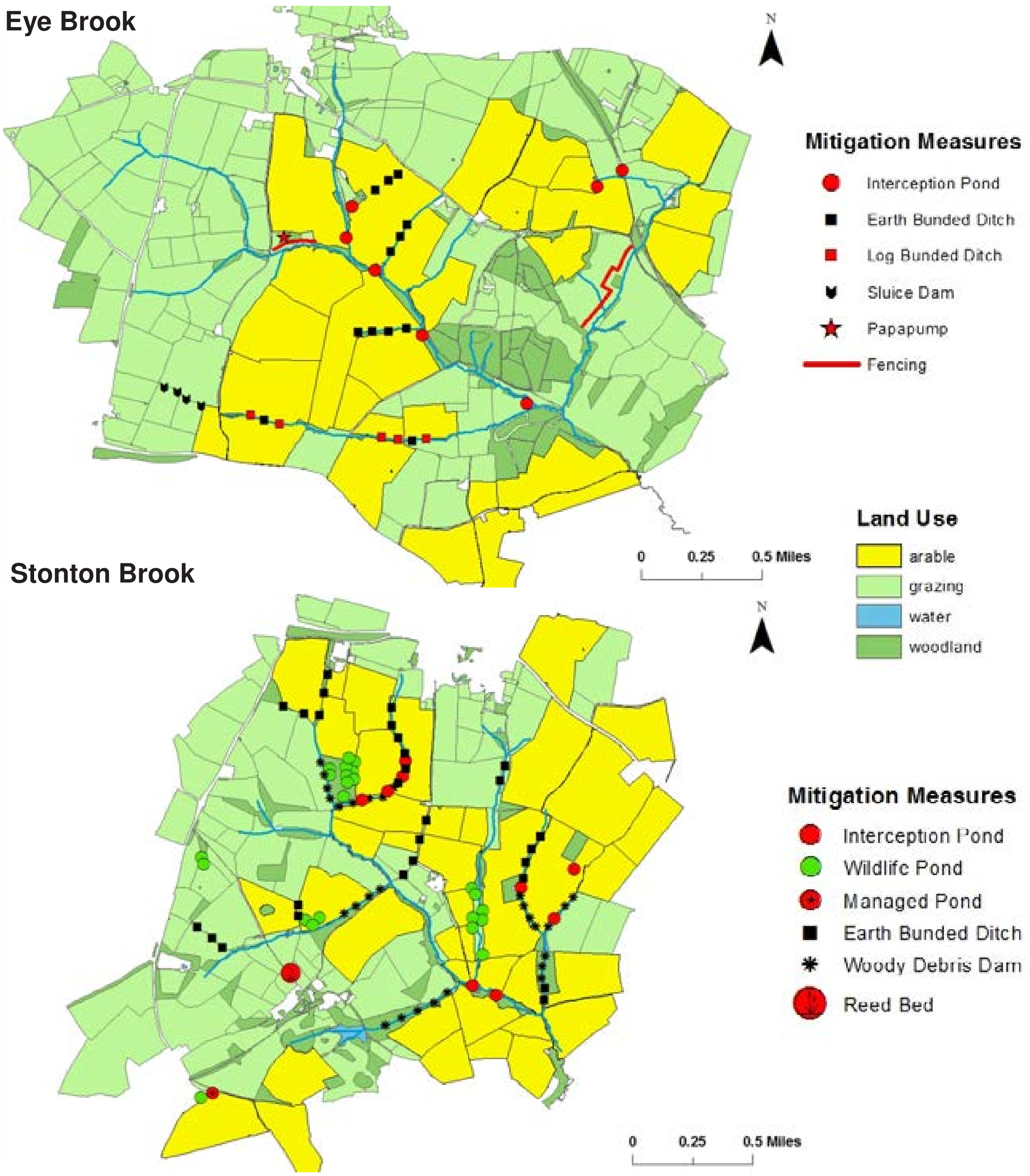


Figure 50. Locations of mitigation measures in (a) Eye Brook and (b) Stonton Brook catchments. Measures are mainly concentrated in the arable farmed environment.

Figure 51. Large earth-bunded ditch. **The picture shows the bund before being 'switched on', with bottom pipe still open. This pipe is now closed and the bund retains water and sediment during high flows.**

Figure 52. Small earth-bunded ditch: the picture shows bund in winter 2013 before being made operational. In spring 2014, lower pipe was blocked to make feature operational.

Figure 53. Field drain interception ponds. Pond intercepting field drain that discharges directly into the Eye Brook (behind photographer). This drain collects water from a field which represents about 5% of the arable area in Eye Brook catchment within the project area. Note that there was overland flow and gullying along the line of field drain because the pipe was under capacity at the time of the photograph in January 2013. This field drain has now been replaced with a larger diameter pipe in autumn 2014.

Figure 54. Flood storage basins. This flood storage basin detains water temporarily from the ditch draining the arable area behind the site, including the land upslope to the woodland. Figure 55 below shows detail of a second, adjacent, flow detention pond.

Figure 55. Detail of inlet pipe in a flood detention pond on the Eye Brook (downstream of detention pond in Figure 4). The outlet pipe is visible at the top right of the photograph.

Figure 56. Large earth-bunded ditch interceptor under construction.

8. Effects of mitigation

8.1 Modelling the effects of mitigation measures on hydrology and water quality

Background

Many physical, chemical and biological mitigation measures inevitably take time to come into effect. For this reason we are using modelling approaches to assess the likely longer term and large scale impacts of measures. Modelling also allows us to check and refine our understanding of the underlying processes that determine how well measures work; this is a crucial step that allows practices developed and demonstrated within the Water Friendly Farming programme to be applied in managing other catchments.

Methods

For water quality and hydrological modelling we selected the Soil and Water Assessment Tool (SWAT). SWAT is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds. The model is physically-based and has been extensively used around the world.

ArcSWAT 10.1 SP1 was used along with the ArcGIS-ArcView extension which provides the graphical user input interface for SWAT. Modelling is initiated by using a digital elevation model to define sub-basins within each catchment (Figure 57). Then, hydrological response units are defined as areas with homogeneous soils, cropping and slope. There are 25 sub-basins and more than 200 hydrological response units in the Eye Brook catchment. Detailed process descriptions are then incorporated to describe in-field processes of crop growth, management and water balance, transport of water and agricultural pollutants to ground- and surface water, and transfer of water and pollutants within the surface water network.

Modelling for the baseline period

The model captures flow conditions within the catchments (Figure 58). This is a first pre-requisite for modelling transport of agricultural pollutants and incorporating the effects of mitigation measures.

Next, the model was applied to simulating contamination of the streams with metaldehyde, one of the key agricultural pollutants incorporated into baseline monitoring. Again, the model gives an excellent simulation of the observed behaviour, both in terms of the time during which contamination is present and the pattern of contamination observed (Figure 59, page 72).

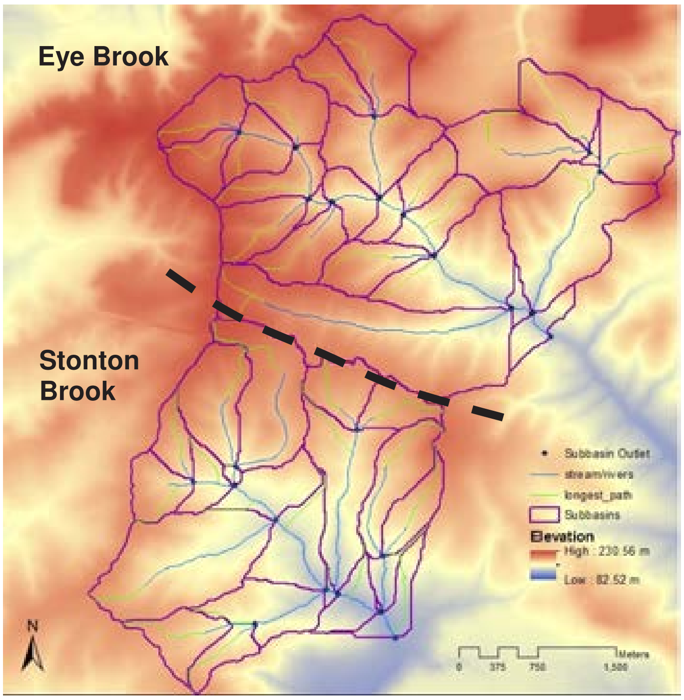
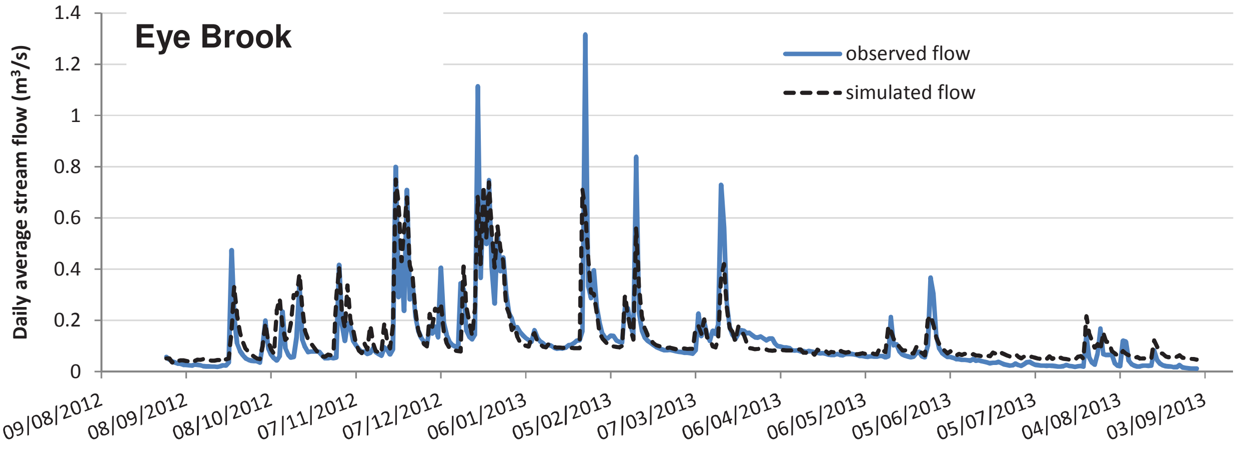


Figure 57. GIS project of the sub-basins and surface water network within the SWAT model projected onto a digital elevation model

SWAT model simulation of measured flows



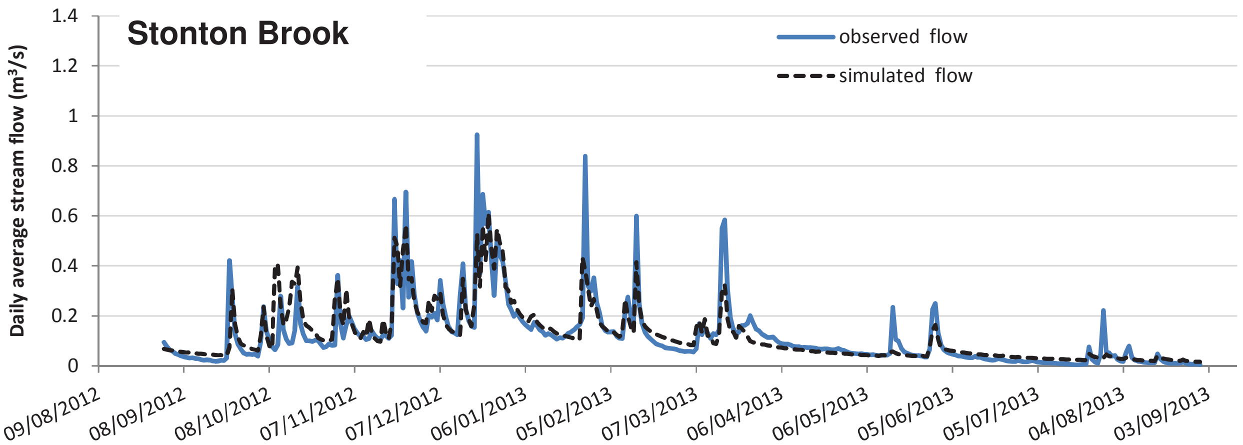
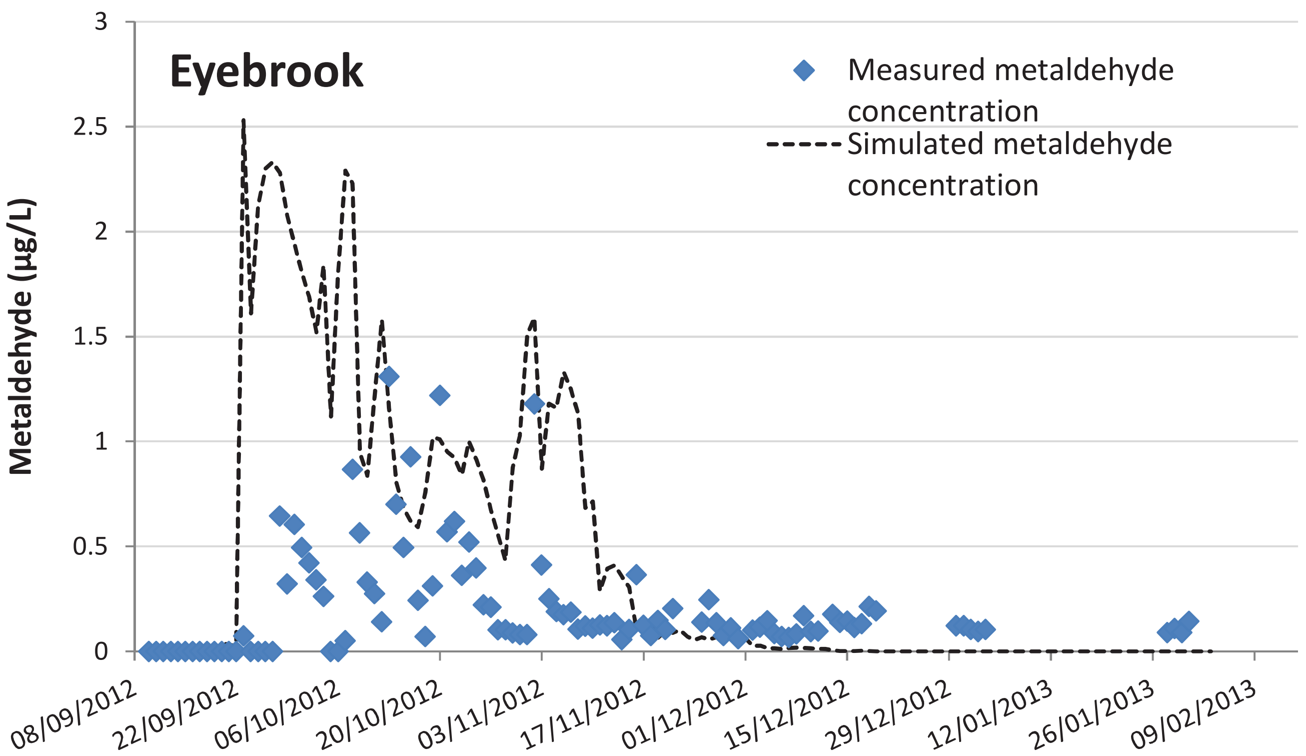


Figure 58. Comparison between observed daily flow and that predicted by SWAT (r^2 = 0.74 for Stonton and 0.71 for Eye Brook; Nash-Sutcliffe model error = 0.74 for Stonton and 0.70 for Eye bBrook).

The role of vegetated buffers

Most water bodies within the catchments have pre-existing riparian buffer zones (e.g. Figure 60). These range in width from 6 m to >20 m and are vegetated with maintained grassland, rough grassland or scrub. Modelling for export of suspended sediment from the catchments during the baseline period included these buffers into the simulations (Figure 63). A separate simulation for the Eye Brook catchment predicted that sediment loss would have been 130% greater if the buffers had not been present (890 rather than 390 tonnes for the hydrological year from September 2012 to August 2013).

SWAT model simulation of measured metaldehyde levels



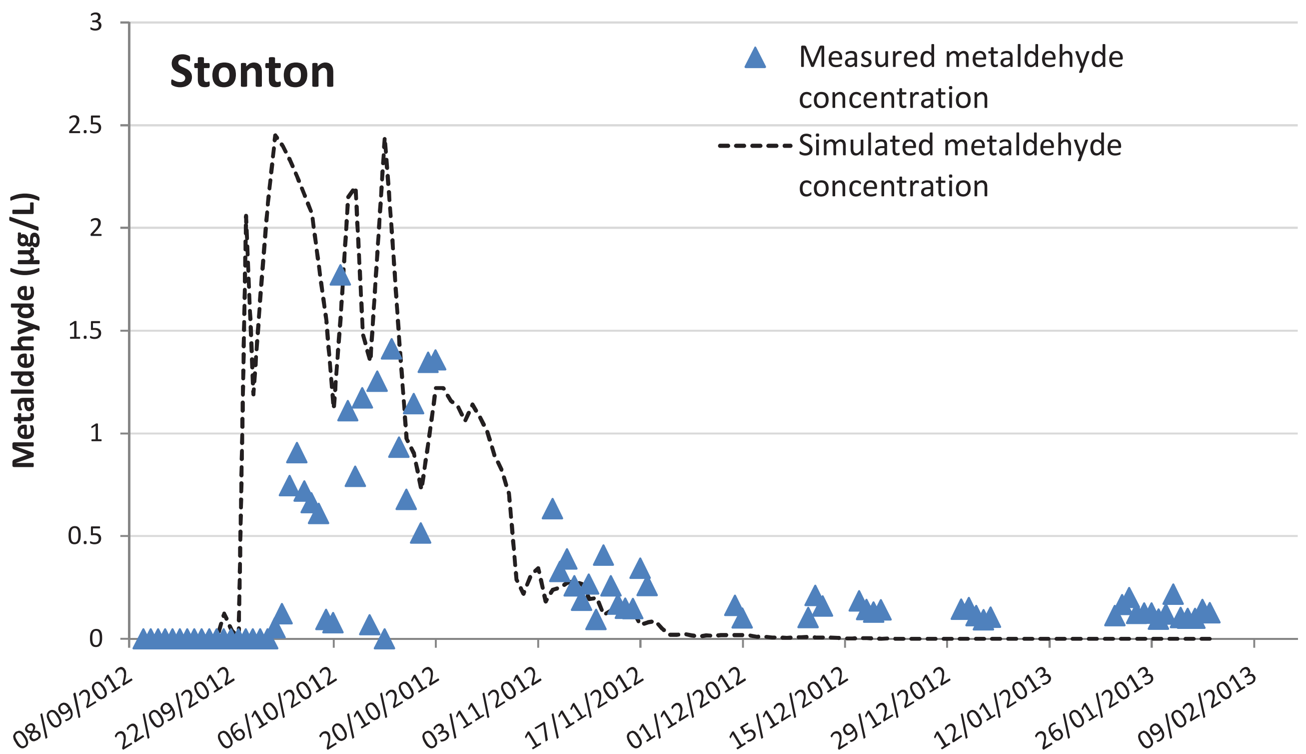


Figure 59. Comparison between observed concentrations of metaldehyde at the catchment outlet of Stonton and Eyebrook and concentrations predicted by SWAT.

Figure 60. Most watercourses in the project area, like this ditch, have buffer strips.

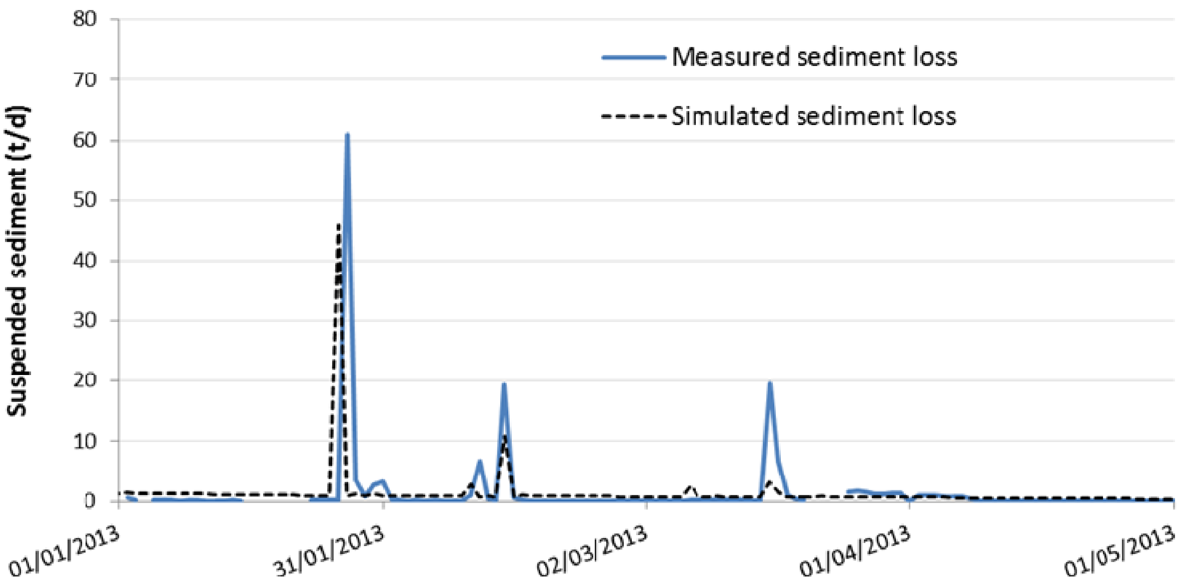


Figure 61. Comparison between measured and simulated losses of sediment from the Eyebrook catchment; the simulated loss includes the effect of pre-existing riparian buffers within the catchment

Effects of water storage within the catchments on peak flows

There is potential for management interventions in headwater catchments to influence flood risk much further downstream. The Water Friendly Farming project has installed a number of water retention measures including interception ponds, sluices, bunded ditches and debris dams. Simple modelling was undertaken to assess the impact of different storage strategies on peak flows at the catchment outlet (Figure 62 and Table 10). As the total storage increases from 25,000 to 50,000 m^3, the reduction in peak daily flows increases from 10 to 29%. Such storage capacities are exceptionally challenging. We estimate that a total of around 3,000 m^3 additional storage has been installed within the Eye Brook catchment to date.

Table 10. Impact of different in-catchment storage strategies on peak flows from the Eye Brook catchment

Reductions in peak flow are averages for the three events in Figure 64 where daily average flow exceeds 1 m^3/s

Total storage (m^3)	Average reduction in peak flow (%)
25,000	9.8
37,500	18.4
50,000	29.4

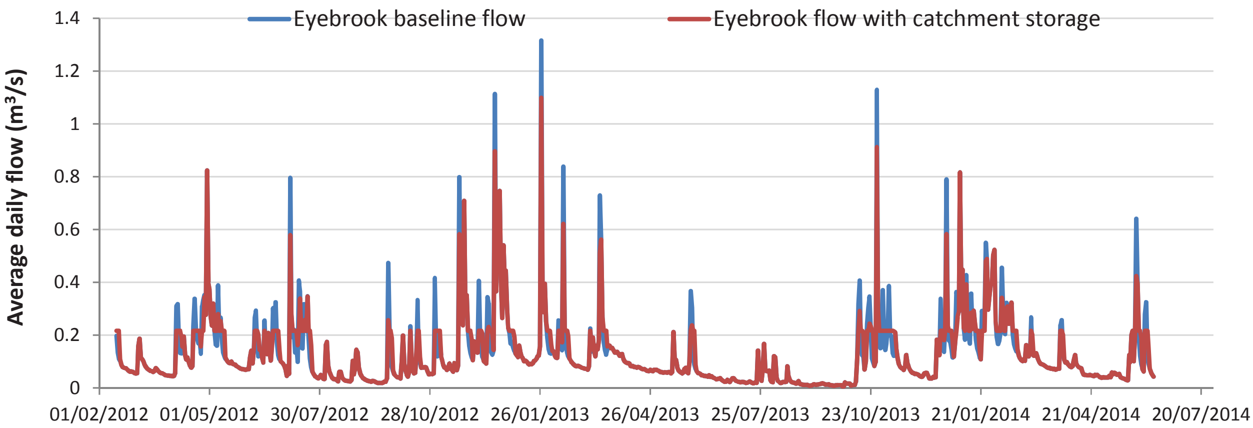


Figure 62. (a) Measured flow for the Eyebrook catchment and impact on flow of installing 37,500 m^3 of in-catchment water storage; data are expressed at a daily resolution as this is considered most relevant to downstream impacts on flood potential.

8.2 What is the value of the mitigation ponds after 1 year?

Following the introduction of measures in 2013, two catchments, Eye Brook and Stonton Brook, had 21 new ecosystem services ponds (interception ponds and on-line bunded ponds) created in their catchments.

In the Stonton Brook, an additional 19 new clean-water wildlife ponds were also created.

The quality of all new ponds was assessed using PSYM (see Section 4.4, Box 1), and compared to the value of the pre-existing ponds.

After one year of colonisation, most ecosystem services mitigation ponds were Very Poor or Poor in quality, with the exception of two Good quality ponds in the Stonton Brook (Figure 63a).

In contrast, the new wildlife ponds, created in places where they would receive a clean water source, were generally higher quality than both the pre-exiting ponds and ecosystem service ponds (Figure 63b,c). After just one year's colonisation, 26% of the wildlife ponds were Good quality (i.e. close to the pristine reference state).

One year after they were created, the new clean-water wildlife ponds (created only in the Stonton Brook catchment) were typically better quality than the catchments' pre-existing ponds.

Ecosystem services ponds (intercepting water from streams and ditches) were similar quality to pre-existing ponds.

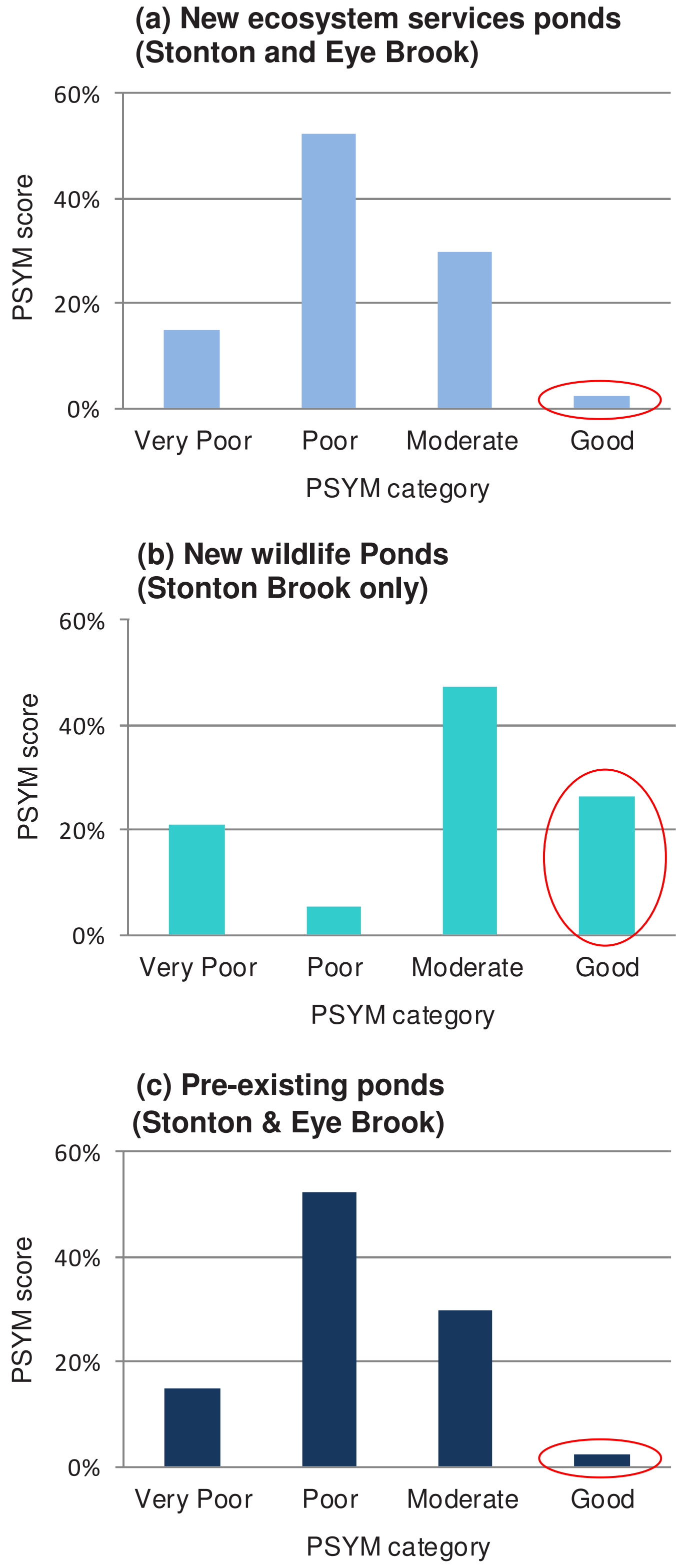


Figure 63. The quality of (a) new ecosystem services ponds (b) new wildlife ponds and (c) and pre-existing ponds in 2014.

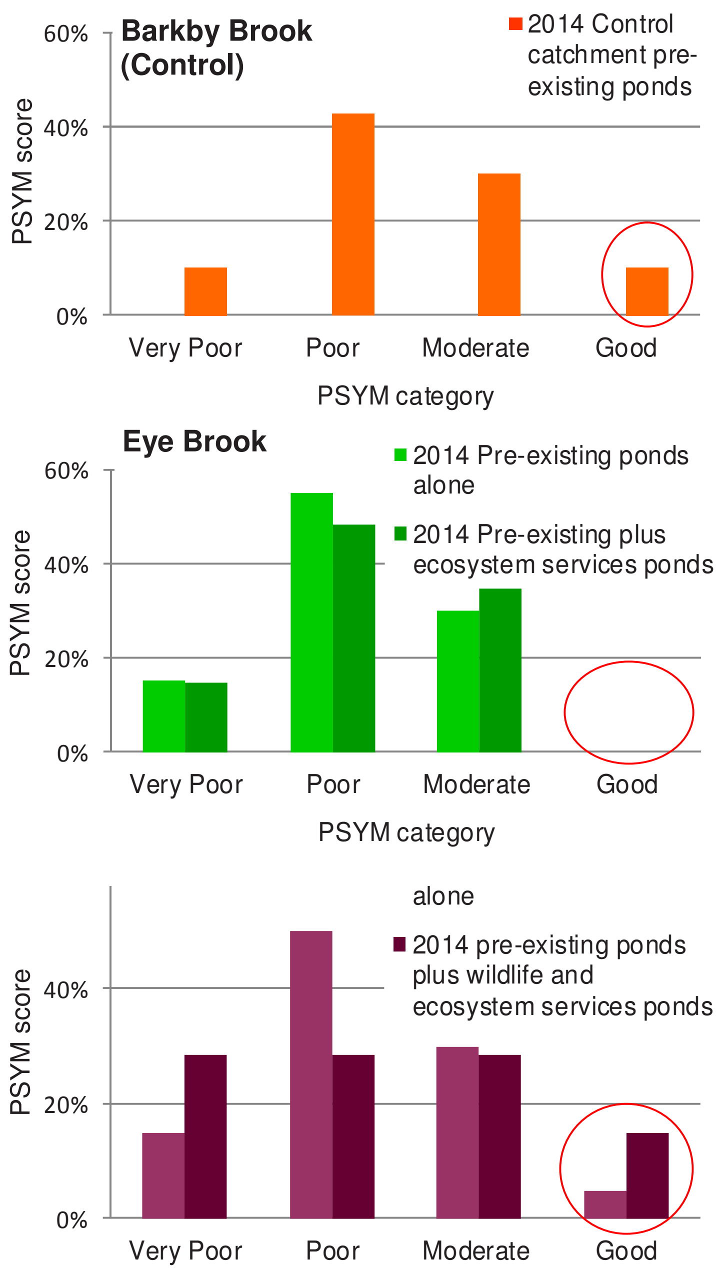


Figure 64. The effect on pond quality of adding new ponds to the Eye Brook and Stonton Brook catchments in 2014

Have new ponds added to species diversity in the landscape so far?

In Section 4.4 we saw that the quality of pre-exiting ponds declined in all three catchments between 2010 and 2014. Did the creation of new ponds in 2013 in two of the catchments have an impact on pond quality and biodiversity?

In the Eye Brook, the creation of ecosystem services ponds had a minor positive effect: increasing the number of Moderate but not Good quality ponds (Figure 64).

In the Stonton Brook, however, where both ecosystem services and wildlife ponds were created, the number of Good quality ponds increased to 15%, returning pond quality to the 2010 baseline level.

One of the most significant effects of the new wildlife ponds was on the richness of submerged aquatic plant species. These plants are particularly sensitive to water quality, and were declining in all three catchments prior to 2014 (Figure 65). In the Stonton Brook the effect of creating new wildlife ponds was to increase the number of aquatic plants across the whole of the project area (i.e. over all three catchments) to 2010 levels.

The addition of clean water wildlife ponds increased landscape-scale biodiversity: in the Stonton Brook, where they were created, these new ponds restored both the number of Priority Ponds and the number of aquatic plant species across all waterbody types, to 2010 levels.

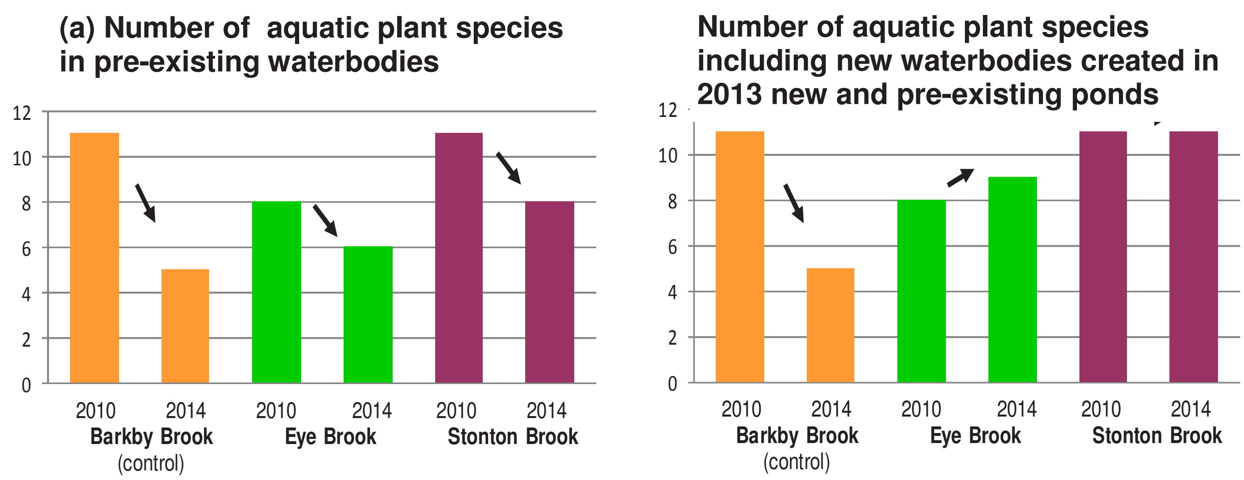


Figure 65. The effect on submerged aquatic plant richness across all waterbody types of creating new ponds

8.3 Modelling effects of habitat creation on freshwater species populations?

Background

In the Water Friendly Farming project we are testing the additional benefit of habitat creation for freshwater biodiversity, particularly by making clean water ponds across the landscape. We are also adding new habitats to stream ecosystems (initially by creating debris dams and, later, by physical restoration of in-stream habitat structure) to investigate whether this brings further biological improvements, above those we anticipate from the expected from water quality improvements.

We expect creation of ponds to be especially beneficial for landscape level freshwater biodiversity as ponds are generally the richest part of the freshwater environment, support a large proportion of the more sensitive and scarce freshwater species in most landscapes and are comparatively easily established with high quality clean and unpolluted water, and good physical structure.

New ponds were created in the second and third years of the project (see Section 7) and are already beginning to colonise with aquatic plants. Typically new ponds fairly rapidly accumulate new species over the first 5-6 years after creation, after which colonisation slows in following years. There is evidence that this slow colonisation continues for at least the first 20 years of the life of a new pond. Depending on the management, populations may then remain stable for a substantial time after that; studies of ponds from the 1970s suggest that at high quality and well-managed sites, species richness of plants assemblages can broadly persist without loss of species.

Modelling population persistence with Meta-X

Longer term monitoring is required in order to asses the extent to which new ponds allow species to persist for longer in the landscape, avoiding the risk of extinction and, if possible, spreading to re-occupy parts of their ranges from which they have been lost.

To assess whether pond creation is likely to help species persist and spread in the landscape we modelled the effect of adding new ponds to the landscape using Meta-X, a software programme for Population Viability Assessment (Figure 66).

In Meta-X we simulated the Water Friendly Farming landscape focussing on pond specific aquatic plants: specifically we evaluated the population persistence of two representative aquatic species which are essentially confined in the Water Friendly Farming landscape to ponds, and extremely rarely, or never, recorded in streams and ditches (although they can use these habitats lower down in catchments where flows are

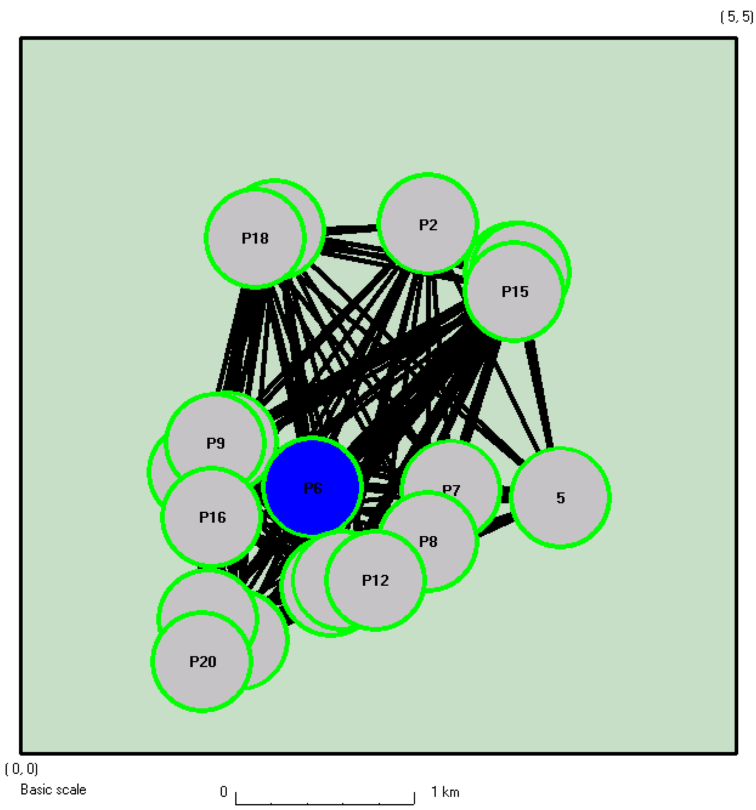


Figure 66. The pond network in the Stonton Brook catchment represented in Meta-X

slower and water deeper).

The species modelled were Horned Pondweed (*Zanichellia palustis*) and Common Duckweed (*Lemna minor*). Horned Pondweed is moderately sensitive to pollution, being naturally associated with eutrophic waters but not able to stand severe eutrophication. Common Duckweed is a robust and widespread species tolerant of severe pollution.

Meta-X requires a relatively simple set of parameters to describe the landscape it tests, which makes it useful as an exploratory tool for this kind of work. The model was initially created with animals and, in adapting it to plants we have made a number of assumptions about the ecology of the wetland plants we are interested in to allow them to be tested using the model (Figure 67). Initial results indicate that the models are able to effectively discriminate the differences in time to extinction in widespread and less common species.

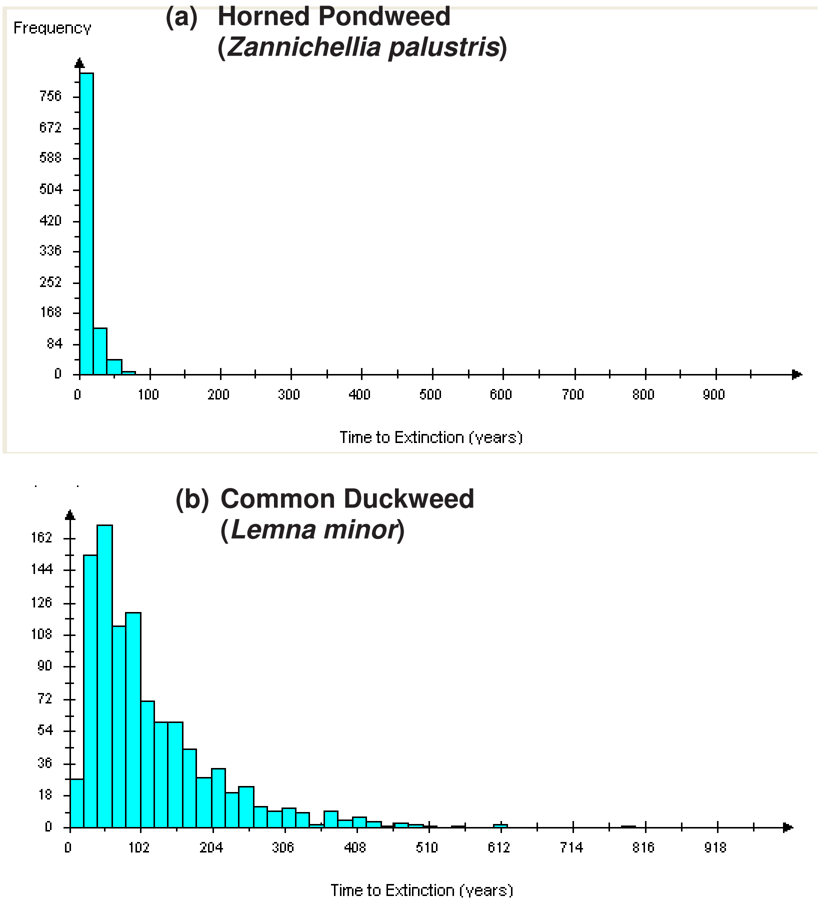


Figure 67. Time to extinction of (a) Horned Pondweed (*Zannichellia palustris*) and (b) Common Duckweed (*Lemna minor*) in the present 20 pond landscape of the Stonton Brook simulated using the Meta-X model.

9. Policy and practical implications

9.1 Introduction

The interim results of the project provide a range of information and practical outcomes that can help to increase protection for the freshwater environment and the services it provides.

Overall the key results so far suggest that:

- The project catchments are typical of a large part of lowland Britain's cultivated land, are similar biologically and chemically, and respond in similar ways hydrologically and chemically. The responses observed in the project are therefore likely to be widely applicable to large parts of the English landscape.
- Aquatic plants have declined across the landscape during the four years of plant monitoring so far undertaken. There is good evidence that, in the Stonton Brook catchment, even after one year, habitat creation mitigation measures have maintained the species richness of aquatic plant communities, at landscape scale, compared to the other two catchments.
- A catchment model created using SWAT is able to capture flow conditions and give an excellent simulation of one of the key agricultural pollutants being monitored, metaldehyde, simulating both the time during which contamination is present, and the pattern of contamination observed in field-collected samples.
- Parameterising the SWAT model to retrospectively predict the effect of adding buffer strips to the landscape, the model:
  - (a) generates a good approximation of the observed sediment losses from the Eye Brook catchment: first indications are that it gets within 20% of measured actual losses from the catchment
  - (b) allows the effect of buffering of the catchment to be 'back-calculated' suggesting that installation of buffer strips has halved sediment losses in the Eye Brook catchment. Although there have been many plot and field scale studies of buffers, fewer have demonstrated significant buffer effects at catchment scale.
- We have installed a range of small scale features (bunded ditches, interception basins, flood storage ponds) in the Eye Brook and Stonton Brook catchments, providing in each around 3000 m^3 of temporary water storage. Simple modelling of the effects of this storage on flow peaks suggests that, to reduce peak flows by about 20%, which would provide downstream flood risk management benefits, would require around 30,000 m^3 of storage in each catchment, roughly 10x that so far installed. It will be challenging to install this much storage, given the space limitations in the catchment.

We are currently undertaking further refinement of the SWAT model to model the nitrogen and phosphorus losses from the catchment.

9.2 Results of catchment baseline modelling

Intensive water quality monitoring in the three project catchments shows that total phosphorus concentrations have risen since 2012. Although it is early in the post-works phase, initial comparisons of the experimental and control catchments do not suggest that mitigation measures have constrained this increase, which is probably related to broad weather patterns,

Both total oxidised nitrogen and sediment concentrations declined over the same period in the control catchment (Barkby). Responses differed in the two experimental catchments: the Eye Brook did not follow the control catchment trend, suggesting an effective increase in nitrogen levels. However the sediment load dropped in the Eye Brook, reflecting the control catchment trend.

In the Stonton Brook the pattern was reversed: Total Nitrogen levels declined, matching the control. Sediment levels however, did not, suggesting that in the Stonton Brook there was an effective increase in sediment runoff.

These patterns require further investigation (we are currently undertaking these more detailed analyses) but they suggest that those involved in managing catchments will need to understand in reasonable detail the specific features of each catchment, rather than relying on general trends. Given that it will not be possible, or desirable, to investigate every catchment in the same level of technical detail as the Water Friendly Farming project area, new techniques for making rapid assessments of local conditions will be needed. In water quality analysis, imaginative use will need to be made of 'quick' test kits which are improving in quality, allow large numbers of waterbodies to be assessed quickly, and are much cheaper than laboratory tests. It is likely that new statistical techniques will also be needed to manage the less precise data generated by such methods and their relationship to 'proper' laboratory chemistry.

9.3 Protecting freshwater biodiversity

At a catchment level evidence from the project confirms that the greatest variety of wetland plants, a good surrogate for freshwater biodiversity more generally, is found in ponds. 30% of species were found only in streams or ditches. This confirms patterns that increasingly show that, to protect freshwater biodiversity, equal emphasis should be given to the protection and management of all kinds of freshwater habitats. Ponds are especially important because they are often the richest freshwater habitats biologically and, in all areas which have so far been examined, also supported the widest range of uncommon and protected freshwater species. However, attention also needs to be paid to the species occurring in running waters.

The project datasets provide a clear indication of the physical and chemical heterogeneity of small waters. Although a reasonably well-known observation it has important practical implications. First, small waters are more vulnerable than large waters: they can be completely and quickly degraded. For example, the evidence suggests that ponds are in a worse condition than lakes in Britain. It is possible, though by no means clear, that headwaters are in a similar situation. However, there is also a positive and important converse to this problem: small waters, both still and running, are also probably more likely to contain high quality refuges because they drain smaller areas of land, and are more likely to be positively influenced by less intensively managed parts of the landscape, such as woodland, lower or no input grassland and uncultivated land.

Practically, this means that we also need to think at a different and more detailed scale when it comes to managing freshwaters. At present, many of the measures designed to protect freshwaters are implemented at very large scale, across large catchments. For example, sewage works mitigation programme focus on the biggest works affecting the largest downstream waters; small works in rural landscape are often all but ignored because, by the time their effluents reach downstream monitoring points they have been diluted to acceptable levels. However, during this process of dilution, they have a considerable impact on the small waters they discharge into, as can be seen in the Water Friendly Farming landscape (and many other rural locations). Large scale programmes may not, therefore, be able to protect small waters effectively because they do not capture this fine scale pattern in the landscape.

9.4 Effectiveness of mitigation measures and ecosystem services

The mitigation measures applied in the Water Friendly Farming landscape focus on surface water and drain pollutants, and on hydrological control. They also aim to strengthen habitat networks. As noted, the first results, and modelling studies, suggest that newly created ponds are bringing benefits for freshwater biodiversity and buffer strips are probably reducing the sediment loads entering stream considerably at the landscape scale.

In contrast, recent research reveals that, while effective on sandy and silty soils, interception basins on clay soils may be much less effective at capturing fine particulate matter. We are currently evaluating the collective water quality impacts of the Water Friendly Farming interception basins.

From hydrological modelling it is clear that, whilst interception basins for storing water to reduce flood peaks are perfectly practical, the difficulties of creating enough storage are considerable. Even though the Eye Brook and Stonton Brook landscapes now have roughly four time the national density of water storage habitats (roughly half are off-line clean water ponds, with the other half water and sediment traps) the practical implication of the modelling studies is that considerably more storage space is still needed.

It is clear from the intensive programme of pesticide monitoring described here, as well as the results of other projects, that there is substantial movement of pesticides, sediment and phosphorus from farmland to water. The results suggest both a need to hold back more water physically, as well as renewed attention to manage soils so as to reduce initial movement of soil and nutrients from arable land. Given that a large part of the rural environment is necessarily influenced by farming, the need to focus on soil management to improve the aquatic environment provides opportunities for farmers through improved soil structure and function. Identifying relevant opportunities for farm businesses is key to improved water quality and ecology.

Although the project clearly shows the widespread extent of water pollution in the rural landscape, it is important to recognise that even now there remain a significant fraction of areas where contaminant levels are lower and approach the natural background (‘High’ status), or the less stringent ‘Good’ standard of the Water Framework Directive.

Clearly, given the level of stress on the water environment, there is a strong imperative to identify these areas and build out from them, particularly because of the benefits this can bring in strengthening biotic networks.
The streams and ditches in the study area are affected by elevated levels of nitrogen, phosphorus and sediments; nutrient levels are also elevated in some of the ponds.

9.4 Implications for monitoring and managing freshwater ecosystems

As the present study highlights, a very large proportion of the water environment lies outside current approaches to classification of freshwater used for the Water Framework Directive. Clearly this suggests a more refined approach is needed, but this must be consistent with reasonable use of resources: it is not possible to roll-out the Water Framework Directive approach to every single waterbody. However, there is no doubt that current interest in the management of small waters, including ever greater public involvement, has potential to encourage a new approach to monitoring and management of freshwaters that includes small and big waters.

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