Water Friendly Farming

Autumn 2016 Update

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Headwater stream in the Stonton Brook catchment – small water bodies like this make up the majority of the running water network
Cover image: Landscape of the Eye Brook catchment

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1. Summary

Water Friendly Farming is a research demonstration project assessing the effectiveness of measures to protect freshwater habitats and the ecosystem services they provide in the rural environment, whilst maintaining the profitability of farm businesses. The project, which began in 2010, is intended to provide answers to three key water and land management questions:

- Can we protect and increase freshwater biodiversity without impinging on farm profitability?
- Can we reduce diffuse water pollution?
- Can we hold back water to help reduce downstream flooding?

From 2011 to 2013 the project created a detailed physical, chemical and biological baseline description of the water environment – ponds, streams and ditches – in three catchments, work which was described in Biggs et al. (2014). From spring 2014 onwards mitigation measures were installed in two experimental catchments to hold back sediments, nutrients and water, and increase the variety of freshwater wildlife (biodiversity) across the landscape. A third catchment is used as a control where no changes are being made.

The project shows that, as in most of England, clean water is scarce in the landscape with only a small proportion of the study area's streams, ponds and ditches remaining unpolluted. These areas of clean water are important for protecting freshwater biodiversity. To test whether the condition of ponds, streams and ditches could be improved for freshwater wildlife a range of mitigation measures were installed in the two experimental catchments. These included on-line measures to reduce sediment and nutrient loss with earth bunds on ditches to trap sediment, interception ponds on field drains and off-line ponds to trap flood water. We also created new habitat, particularly new clean water ponds. These off-line waterbodies are located in parts of the landscape where, as far as possible, they are filled by unpolluted water. Using wetland plants as an indicator of freshwater biodiversity, the project has shown that these waterbodies rapidly colonised with new species not present elsewhere in the project area, which has led to a consistent, landscape wide, increase in freshwater biodiversity. Further monitoring will determine whether the increase is short-lived or permanent. This is one of the first demonstrations of a landscape-wide increase in freshwater biodiversity as a result of land management measures, and is also notable for its rapidity, occurring immediately (i.e. in the first year after the installation of the new habitats). It further emphasises the unexpectedly large role of ponds and small wetlands in maintaining freshwater biodiversity at a landscape scale.

Modelling indicates that buffer strips, typically about 10m wide and already extensively installed in the landscape at the beginning of the project, mainly under Stewardship agreements, have reduced sediment losses by around 30% compared to minimum statutory 2m buffer strips. We have used modelling techniques to evaluate further changes to cultivation practices which show that conversion to reduced tillage, or more advanced zero tillage, solutions could reduce sediment loss by 35-40%, close to the level theoretically achievable by completely converting the landscape to woodland. In practice, sediment levels have gone down slightly in the control catchment over the course of the project, and shown inconsistent trends in the experimental catchments. These short-term changes are probably related to the pattern of wet weather.

For nitrogen and phosphorus, further work is in progress combining modelling and field data to assess the effects of mitigation measures on the levels of these two pollutants. In practice, phosphorus levels have increased in both control and experimental landscapes during the course of the project, probably because of reduced dilution of sewage effluents as a result of drier weather in recent years. In contrast, nitrate levels have generally declined across the study area, including in the control catchment. Computer modelling will be used to distinguish the short-term changes in pollutant levels caused by the wet weather, and the variation in flows, from the underlying benefits of the mitigation measures, work which is in progress.

Intensive monitoring of the slug control chemical metaldehyde has shown that it is regularly present at levels which must be reduced by water companies for drinking water supply. The monitoring of this chemical has provided an important benefit for the project in refining the reliability of catchment hydrological models used to assess the mitigation measures installed. However, metaldehyde cannot be removed by mitigation measures intended to intercept nutrients and sediments so a 'risk reduction' programme was carried out by Anglian Water in autumn 2015 using the alternative molluscicide ferric phosphate. Applications were targeted on land thought to be most at risk of metaldehyde runoff, based on runoff-risk mapping. Concentrations in water were not reduced, emphasising the need for complete product substitution, replacing metaldehyde with ferric phosphate for slug control in catchments used for drinking water supply that have heavy clay soils and subsurface drains.

In the project study area propyzamide is a key pesticide for control of blackgrass through application to winter oilseed rape and field beans in the arable rotation. Our monitoring again shows regular contamination of stream water from November onwards. Product substitution is not a viable option for propyzamide, so we are currently working with farmers on soil management strategies and rotations that reduce losses, and encouraging application of propyzamide at different times over the winter to reduce peaks in runoff.

In the north and west of Britain several projects (e.g. Slowing the Flow projects at Pickering, North Yorkshire and at Holnicote, Somerset) have demonstrated that water can be held back in upland marginal landscapes where water is draining off moorland and can be stored on river floodplains. This helps to reduce at least small scale floods. To hold back water in lowland farmed clay-dominated landscapes with extensive networks of field drains, like those in the project area, requires substantial volumes of water to be temporarily stored in the landscape. The storage for flood water so far created by the installation of interception features, c. 3000 cubic metres in each experimental catchment, has had only a very slight effect on peak flows during wet weather. However, modelling has indicated that by installing more of these features, particularly so-called 'permeable dams' which hold back flood water for a few days in stream valleys and then allow it to drain slowly, could reduce the 1 in 100 year flood peak by 20%. We are now installing a network of these dams, with associated detailed modelling work, to evaluate the potential of this technique in the lowland farmed landscape, where there is limited space for interventions to store water without impinging on the cropped area. This work will be implemented and evaluated over the next 5 years with the support of the Environment Agency.

Soil management is central to many of our objectives for aquatic biodiversity, drinking water supply, and flood risk management. We are therefore working increasingly closely with farmers within the study area to support soil management practices that deliver these benefits, while also improving conditions for arable cropping. Compaction, organic matter and earthworm surveys contribute to this process, and this work is linked to major soil research projects at the Allerton Project farm nearby at Loddington. Throughout, we attempt to identify synergies between environmental and farm business objectives.

The project, in conjunction with information from other investigations, provides a number of new conclusions for land managers and policy makers concerned with protecting the water environment. We have undertaken extensive programmes of dissemination and training with farmers, as well as learning from them, and are making results available to policy makers and others.

2. The first 6 years of the Water Friendly Farming project

About the Project

Water Friendly Farming is a long-term research demonstration project designed to test the effectiveness of landscape-wide mitigation measures intended to reduce the impact of rural land use on freshwaters—ponds, streams, lakes, rivers and ditches—and the services they provide, whilst maintaining profitable farming. Although these mitigation measures are widely applied, and often shown to have some effect at a field or ditch scale, there is still remarkably little evidence that they work to control pollution or protect freshwater life at the scale of whole streams, rivers or ponds.

The aim of the project is to provide a reality check on the extent to which, by introducing landscape-wide mitigation measures, we can reduce rural water pollution, hold back flood water and protect freshwater biodiversity.

Water Friendly Farming has two experimental catchments, with a three year 'before' baseline, and a control catchment where we are making no changes. This approach has required substantial financial support and requires a lot of effort by many people to organise and fund, but the costs are a fraction of the money that could be wasted on ineffective practical land management schemes.

The Problem

Globally, freshwater ecosystems in rural landscapes are under pressure from a wide range of pollutants, including diffuse pollution caused by sediments, nutrients and pesticides, sewage effluents from country towns and villages, the engineering of rivers to make them more efficient drains and the abstraction of water for drinking and irrigation. Some people now speak of a 'global pandemic' of threats to freshwater, particularly from pollution and from modifications to hydrology[1]. In lowland Britain 90% of all waterbodies experience damaging levels of pollution[2] which mostly goes unnoticed because it is not caused by obvious sewage or litter. Added to this, climate change is probably exacerbating some of these problems. Many specialists now believe that freshwaters are more threatened than any other kind of habitat. These threats also have implications for the supply of water: in most parts of Britain the provision of clean water for drinking and other uses requires immense technical and financial investment to maintain the quality expected by consumers.

Since we launched Water Friendly Farming in 2010 the need to understand which measures help to protect freshwater ecosystems has become ever clearer. An immense amount of practical and research work is in progress around the world as policy makers struggle to find solutions to the effect of diffuse pollution.

The Location

The Water Friendly Farming project is taking place in Leicestershire in the catchments of the R. Welland and the R. Soar (Figure 1). The project comprises a control catchment (C) and two experimental catchments (E1, E2). It is a mixed farming landscape on clay soils with wheat and rape as the main arable crops, and beef and sheep as the main livestock. Farms range considerably in size and tenure but all are managed as businesses. The farming community, system and soils are therefore broadly representative of a large part of lowland England. We are testing the effectiveness of measures in a landscape where commercial farming is the main land use.

The Partners

The project partners are Freshwater Habitats Trust, Game and Wildlife Conservation Trust, Environment Agency, University of York, Syngenta, Anglian Water, University of Sheffield, The Welland Rivers Trust and Oxford Brookes University.

1. Vörösmarty, C.J., Pahl-Wostl, C., Bunn, S.E., Lawford, R., 2013. Global water, the anthropocene and the transformation of science. Current opinion in environmental sustainability, 5: 539–550.
2. Data from the Water Friendly Farming project show that 90% of the waterbodies across the study area had levels of nitrogen, phosphorus or both that were damaging.

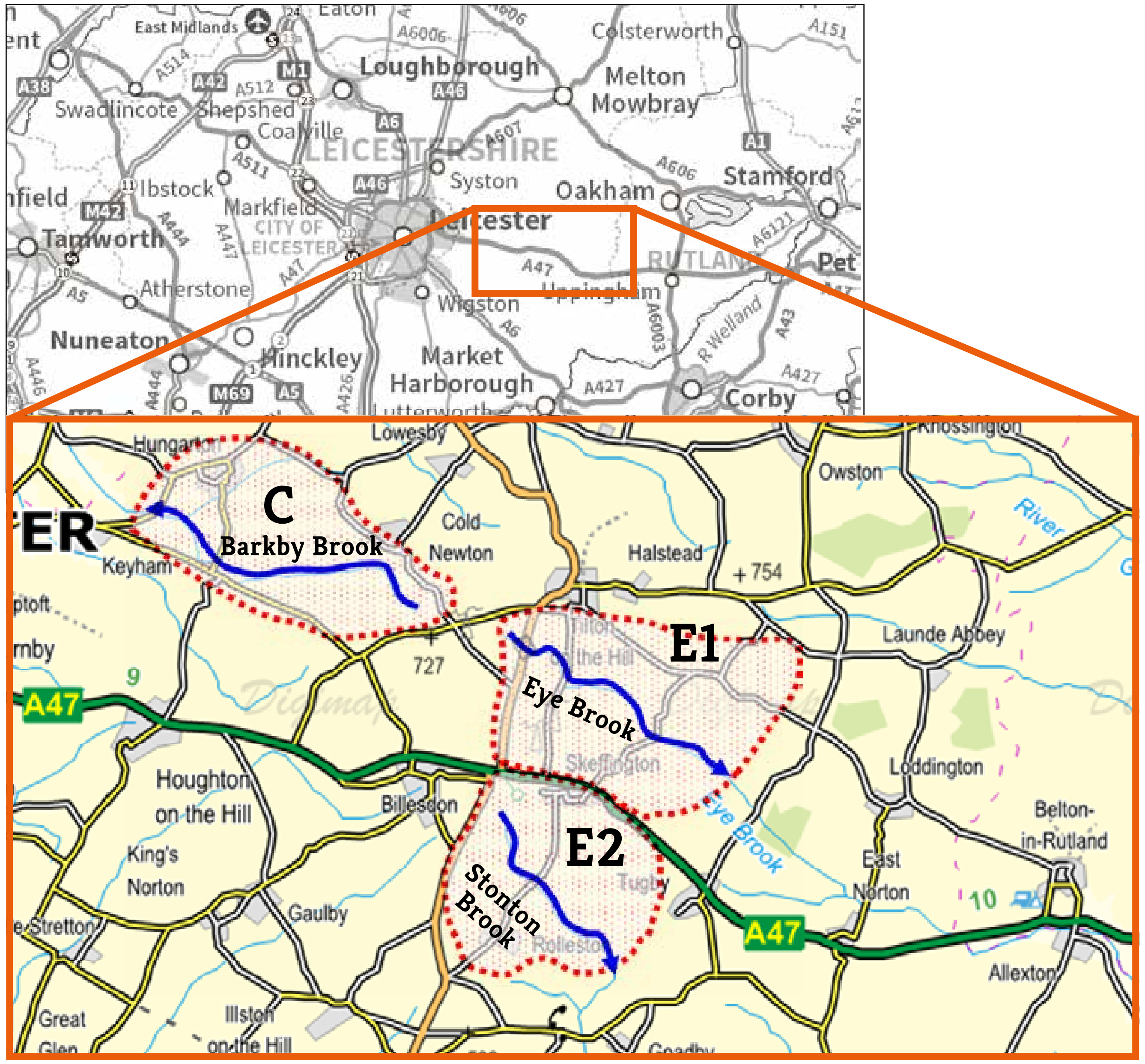

Figure 1: The location of the Water Friendly Farming project study area.

Can we control diffuse pollution?

Estimates of the effectiveness of measures to control diffuse pollution are worrying. For example, in the Hampshire Avon catchment, models indicate that current measures reduce the amount phosphorus lost by 10%, sediment by 7% and nitrate by 4%. The theoretical maxima if all technically feasible measures were installed are, respectively, 47%, 66% and 22%. So even in the most optimistic scenarios there would remain substantial pollutant losses (Zhang et al. 2012). A similar situation is predicted on the R. Wensum in Norfolk where mitigation measures could reduce nitrate losses by up to 20% and phosphorus by up to 17%. In both examples, reduced loads do not necessarily lead to reduced concentrations which, in freshwaters, are critical in determining pollutant impacts (Taylor et al., 2016).

Changes in agricultural context (economic, agronomic and policy)

Since the start of the project there have been substantial changes which have started to affect the way land is managed locally, as well as more widely across the country. We have seen further examples of intense winter storm events which have implications for food production, water quality and flood risk management. From a farming perspective, these conditions have accentuated compaction, water-logging and populations of the competitive arable weed, blackgrass, increasing the cost of soil management, drainage and herbicide use. Combined with a reduction in global commodity prices, these factors have contributed to a reduction in farm profitability, as well as increasing the risk of runoff, with all the implications that has for erosion, and loss of nutrients and pesticides to water.

In part because of the blackgrass problem, there has been an increase in the area of pasture that has been brought into arable production, increasing the area of land that is susceptible to runoff and erosion. While some local farms are putting arable land into grass leys for blackgrass control, this has not yet been the case within the project study area.

Greening of the Common Agricultural Policy (CAP) has introduced Ecological Focus Areas and a requirement for increased crop diversity. This has limited implications for water per se, but is compatible with cultural means of grass weed control, and potentially reduces the crop area receiving individual pesticides. The UK's forthcoming departure from the EU may have more substantial implications for the way land is managed, most immediately adding uncertainty to the economic challenges farmers face. The level of support for farmers' environmental management in future will depend on the outcome of current trade negotiations and national priorities.

Increasing abundance of the competitive weed, blackgrass, combined with soil compaction and loss of soil organic matter, creates challenges for both farm businesses and the environment.

Changing knowledge of freshwater ecosystems

Since the Water Friendly Farming project began a number of studies have further emphasised the practical problems of protecting the water environment:

- Nutrient pollution is proving difficult to control. There are large stores of nitrogen and phosphate in soils and aquifers. It will take many decades to draw down these stores, even if N and P fertilizers were no longer applied[3].
- Although there are some positive trends, the effects of mitigation measures to control diffuse chemical pollution are varied, with some recent positive results and some negative[4].
- Globally, there is so far very limited evidence that land management measures lead to biological recovery in freshwaters. One North American study has shown positive evidence of diatoms responding to mitigation measures intended to reduce diffuse farmland pollution in North America, but not freshwater invertebrates[5].
- The state of freshwaters generally in England is not improving: for example, the 2016 update of the England natural environment indicators[6] indicates a short-term (2010-2015) deterioration in water quality (longer-term trends were not assessed).
- In 2016 a new mechanism was identified linking increased nutrient levels in streams to accelerated breakdown of leaves and twigs, an important food source and shelter for invertebrates, which is likely to be causing completely unnoticed damage to freshwater habitats[7]. The work is important because it shows that both nitrogen, the biologically damaging effects of which are increasingly recognised, and phosphorus, are responsible for prompting increased losses of carbon from streams, reducing the capacity of agricultural landscapes to contribute to climate change mitigation.

Since Water Friendly Farming began in 2010, there have also been positive developments in understanding the effects of practical management of the water environment:

- Improvements in sewage treatment works have been clearly shown to reduce impacts from large urban point source pollutions leading to improvements in freshwater biota, with the evidence clearest for well-monitored invertebrates[8].
- Although diffuse pollution is extensive, there are patches of clean water out there. New citizen science-based survey methods suggest that, in both rural and urban landscapes, about 20% of waterbodies (ponds, lakes, streams, rivers and ditches) have low, near natural, background nutrient concentrations (Figure 2, page 8). These surveys also show that, in the rural environment, nature reserves often help maintain patches of clean water[9].
- There is currently rapid development in understanding of the importance of small waterbodies. Ponds and small lakes, small streams, ditches and springs are the most numerous freshwater environments globally, are critical for freshwater biodiversity and increasingly recognised for their role in ecosystem service delivery (Biggs et al. in press).

3. Withers, P.J.A., Neal, C., Jarvie, H.P., Donnacha, G. & Doody, D.G., 2014. Agriculture and eutrophication: where do we go from here? Sustainability 6: 5853-5875.
4. Pearce, N.J. & Yates, A.G., 2015. Agricultural best management practice abundance and location does not influence stream ecosystem function or water quality in the summer season. Water, 7: 6861–6876.
5. Gabel, K.W., Wehr, J.D., & Kam Truhn, K.M., 2012. Assessment of the effectiveness of best management practices for streams draining agricultural landscapes using diatoms and macroinvertebrates. Hydrobiologia, 680: 247–264.
6. Defra, 2016. England Natural Environment Indicators 25 August 2016. Department for Environment, Food & Rural Affairs, London.
7. Rosemond, A.D., Benstead, J.P., Bumpers, P.M., Gulis, V., Kominoski, J.S., Manning, D.W.P., Suberkropp, K. & Wallace, J.B., 2015. Experimental nutrient additions accelerate terrestrial carbon loss from stream ecosystems. Science, 347: 1142-1145.
8. Vaughan, I.P. & Ormerod, S.J., 2012. Large-scale, long-term trends in British river macroinvertebrates. Global Change Biology, 18: 2184–2194.
9. Clean Water for Wildlife project: http://freshwaterhabitats.org.uk/projects/clean-water/clean-water-results

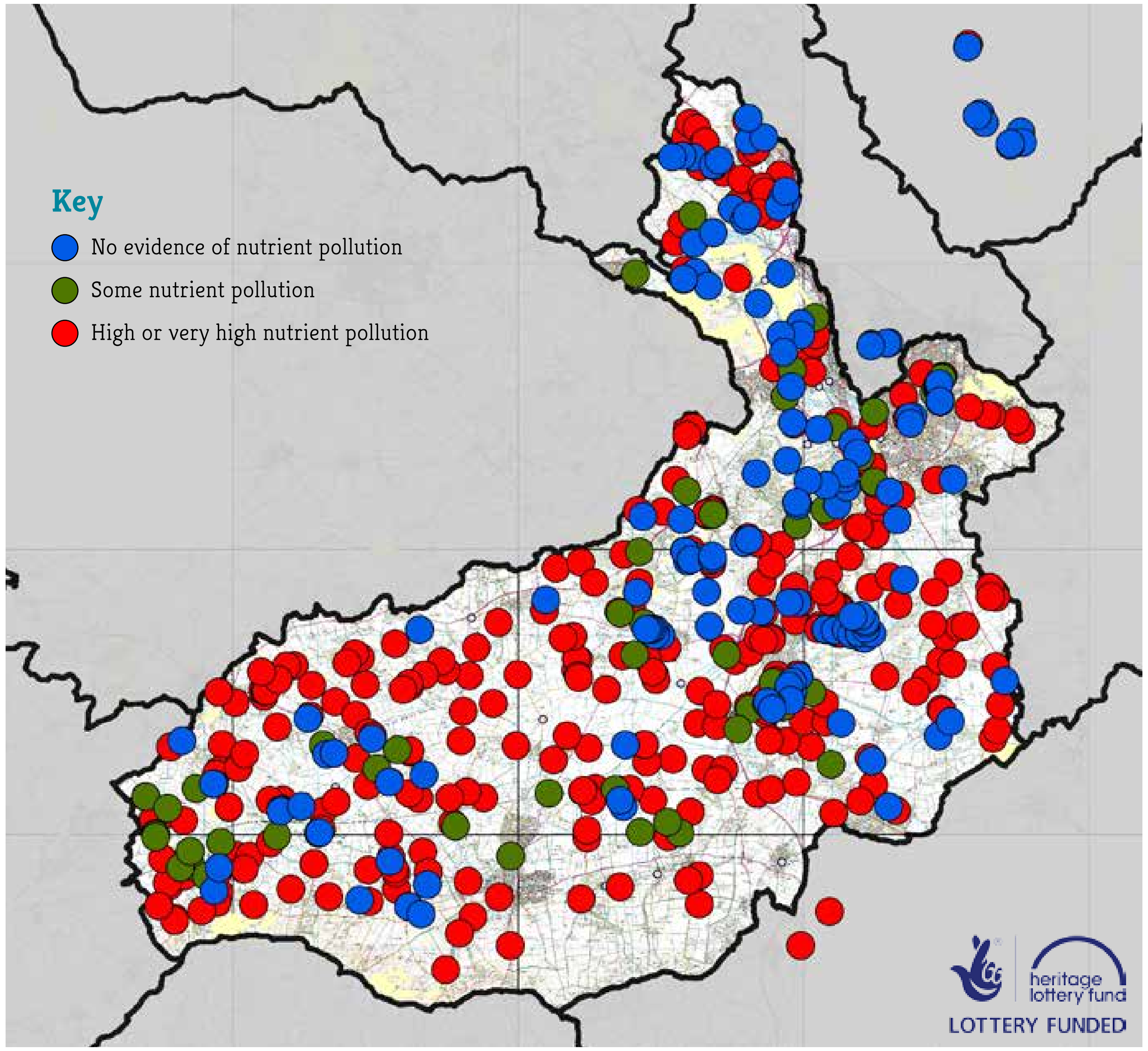

Figure 2: In Oxfordshire, in typical lowland English countryside, surveys of nutrient pollution in ponds, streams, rivers, lakes and ditches in the catchment of the River Ock, using rapid, low-cost, test kits, show frequent patches of clean water where nitrate and phosphate concentrations are close to natural background levels. Clean water is found in ponds, some lakes, headwater streams and some ditches. It also occurs in fen nature reserves. Surveys were undertaken as part of the Clean Water for Wildlife project supported by the Heritage Lottery Fund.

Figure 3: One of the most popular freshwater habitat management measures - making new ponds - is looking increasingly effective as more data on the effects of clean water pond creation become available, both within the Water Friendly Farming project and elsewhere. The pond above, created in unimproved grassland in Oxfordshire following the principles of the Million Ponds Project[10], is now one of Britain's most important ponds for wildlife and supports that county's only population of the declining Red Data Book water plant, Lesser Water-plantain. Water Friendly Farming has provided important new evidence of the surprising significance of new pond creation for the protection of freshwater biodiversity (Section 7).

10. There is an extensive range of information about the design of new clean water ponds for wildlife in the Million Ponds Project toolkit: http://freshwaterhabitats.org.uk/projects/million-ponds/pond-creation-toolkit

3. Controlling diffuse pollution

Nutrients and sediments

Since the Water Friendly Farming project started the scale of diffuse pollution problems both in Britain and globally, has become ever clearer.

Our baseline data shows that water bodies in the project landscapes are substantially impacted by nutrients as is quite typical of lowland England. In the baseline years, about 90% of water bodies (ponds, streams, ditches) had nutrients at levels which are biologically damaging. We only measured nutrients so this is a minimum estimate of the extent of rural water pollution (Figure 4).

In the Water Friendly Farming project we have installed edge of field measures to attempt to control runoff from the largely clay dominated landscape. We are also attempting to reduce pollutant losses from the cropped area through advice on soil management. Our results, like those of others, suggest that the measures applied so far are having a modest effect. Continuous monitoring of water quality at the downstream end of each catchment shows that phosphorus levels have increased since the start of the project, probably because of reduced dilution of sewage effluents, nitrogen levels have fallen slightly, probably because of reduced runoff, and sediment levels have so far shown no consistent pattern.

Proportion of ponds, streams and ditches in the project area with clean water in the baseline survey years

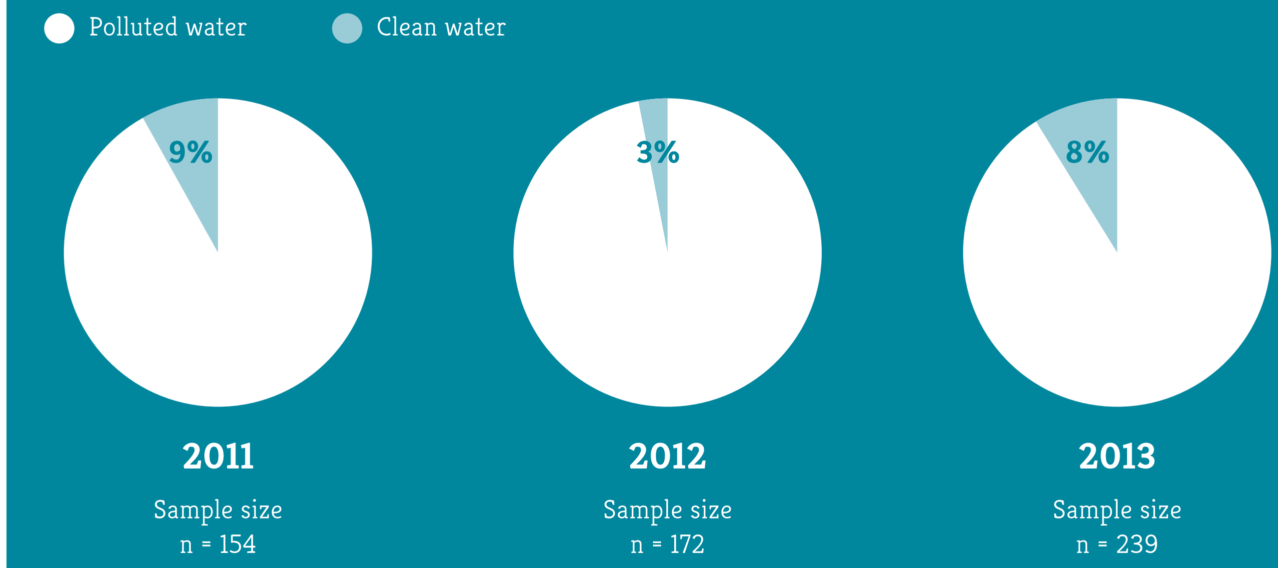

Figure 4. 'Clean water' analysis in the Water Friendly Farming landscape. Between 3% and 9% of sites had water unpolluted by both nitrogen and phosphorus in the baseline years 2011-13.

'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 or 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).

Phosphorus in the project streams

Phosphorus is derived mainly from runoff during storms and from sewage works effluents. In the Water Friendly Farming end-of-catchment continuous monitoring locations, phosphorus levels are dominated by sewage effluents. Concentrations rise during the summer when flows are lower, with additional spikes at times when flood flows occur. There has been a significant increase in phosphorus in all three catchments perhaps because of the exceptionally high summer flows in 2012 causing an unusual degree of dilution in the first year of the project. In subsequent years, summer flows have been lower, leading to higher total phosphorus concentrations. Further analysis is in progress to model nutrient losses from the catchments.

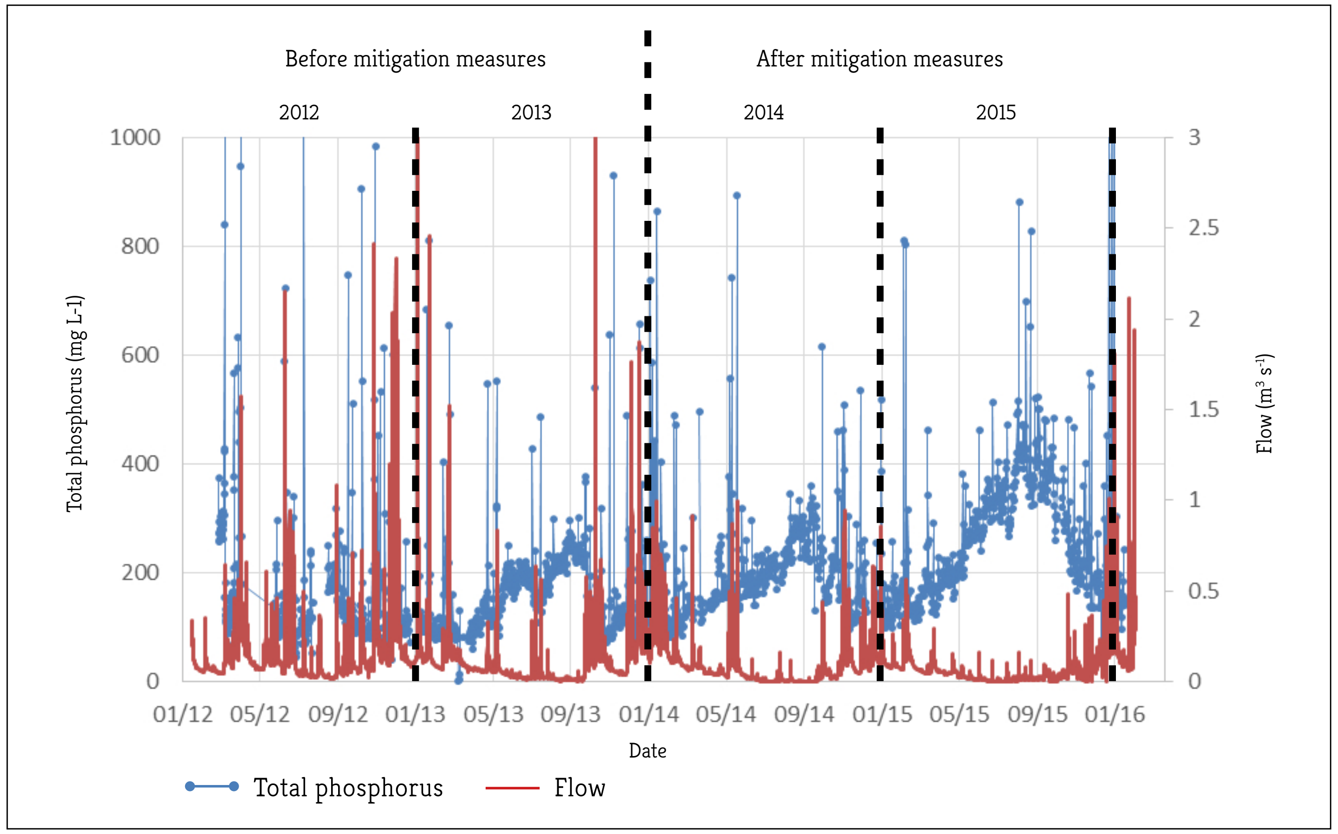

Figure 5: Trends in total phosphorus concentrations (blue line and points) in the Eye Brook experimental catchment from 2012 to 2016. Flow is shown (maroon line) superimposed. The high, and increasing, summer concentrations in both catchments reflect the very wet summer of 2012, followed by subsequent drier years reducing the dilution of sewage effluents.

The impact of sewage works on streams

There are a total of 9000 sewage works in the UK, but only about 1900 (21%) are large enough (serving >2000 person equivalents) to warrant secondary or tertiary treatment to reduce organic and phosphorus discharges. A large proportion of small and medium-sized sewage works (with or without secondary treatment) are still discharging high concentrations (up to 10 $mg{\cdot}P{\cdot}L^{-1}$) of highly bioavailable phosphorus into rural headwaters and rivers. There are also a large number of pumping stations that discharge raw effluent into nearby watercourses to overcome issues of overflow at sewage works during storm events. The high phosphorus concentrations discharged, relative to dilution within the receiving waters, are not only a key determinant of eutrophication risk in streams and rivers, but also become adsorbed onto eroded agricultural sediments leading to overestimation of diffuse P loadings when these sediments are suspended during storm events (Withers et al. 2014).

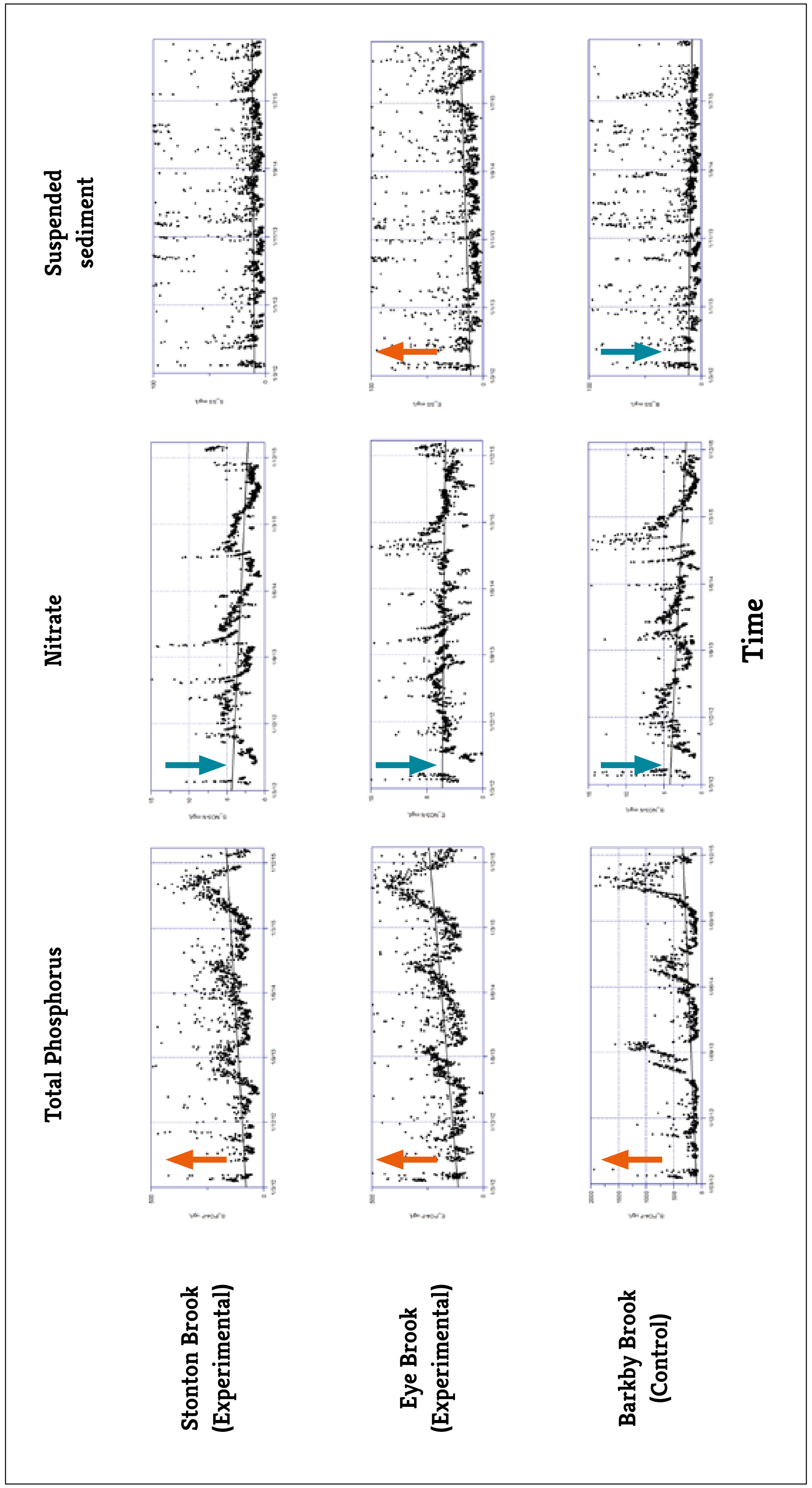

Figure 6: Trends in total phosphorus, nitrate and suspended sediment over the first five years of the project (2012-2016). All trends marked by arrows are significant, with red indicating increasing concentrations and blue declining concentrations (p<0.001, Mann-Kendall trend test).

Nitrogen and sediments in the project streams

The concentrations of nitrate in the project study area have gone down modestly over the last 30 years (Biggs et al. 2014) but remain well above the levels likely to be biologically damaging, as in many other parts of the country. During the course of the project's intensive monitoring programme, nitrate levels have declined modestly in the control catchment and in the Stonton (experimental) catchment, with a smaller, but statistically significant, downward trend in the Eye Brook (Figure 7). The decline in the experimental catchments is similar to that seen in the control.

More detailed modelling of sediment losses from the landscape (see Section 8), and the role of buffer strips, suggests that, as expected, the pre-existing extensive buffering of the watercourse in the landscape contributes to a significant reduction of sediments reaching streams.

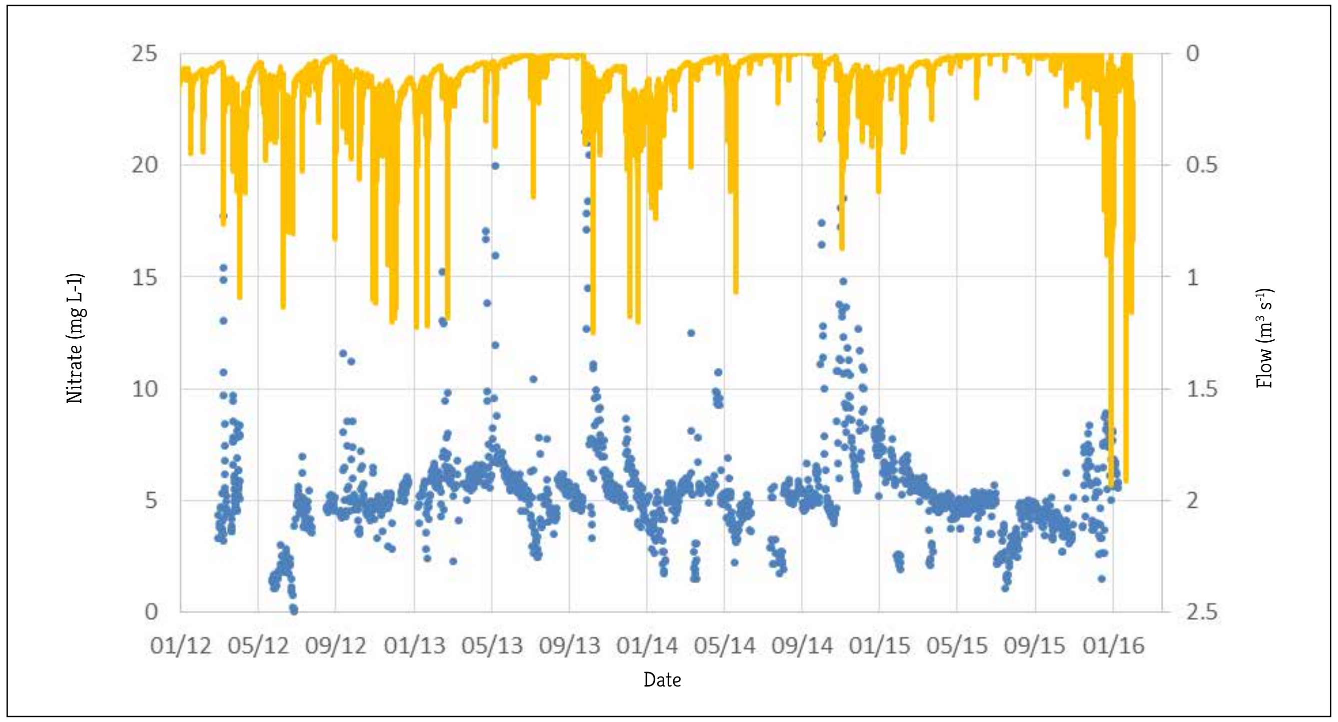

Figure 7: Nitrate concentrations are generally high in the project catchments, rising during periods of high rainfall. The Stonton Brook and the control catchment, Barkby Brook, showed statistically significant declines in nitrate concentrations. The Eye Brook (this figure) also showed a slight significant decline in nitrate levels.

The role of sewage works

All three of the project catchments have small rural sewage works, typical of the thousands of rural sewage works which currently have only simple treatment processes. These contribute substantially to phosphorus pollution, outweighing the effects of land management in streams with a sewage works. Elsewhere land management is more significant, with phosphorus spikes during wet weather.

4. Pesticides and drinking water

Concerns about pesticide concentrations in drinking water sources exceeding the 0.1ug/l^{-1} limit set by the EU Drinking Water Directive continue to be dominated by the molluscicide metaldehyde, and Anglian Water is active in some parts of the Welland river basin promoting the use of an alternative product, ferric phosphate. However, there is increasing concern about some herbicide concentrations, most notably those used in oilseed rape to control blackgrass.

We have monitored the concentrations of the molluscicide metaldehyde, and the grassweed herbicides propyzamide and carbetamide for three years and, along with other water courses in lowland England, recorded concentrations that exceed the 0.1ug/l^{-1} legal limit on several occasions. Given the importance of these products to the control of grassweeds, and the risk of their withdrawal from the market because of drinking water targets, we are working with farmers in one of the two experimental catchments to explore ways of reducing concentrations of propyzamide in water. Potential measures include reduced cultivations to create more stable soil conditions, alternative crops to oilseed rape in order to reduce the area sprayed by pesticides, and spreading the timing of applications across the catchment in order to reduce the amount able to run off at any one time.

Metaldehyde

Metaldehyde is an active ingredient of slug pellets which is the most widespread threat to water quality from pesticides under the Water Framework Directive. The compound is widely applied to winter cereals and winter oilseed rape in the project area and monitoring demonstrates a consistent presence in the streams each autumn with maximum concentrations in the range 1-3 µg L^{-1} (Figure 8).

The monitoring for metaldehyde has advanced our characterisation of the catchments, demonstrating that the three catchments have very similar hydrological responses, with subsurface drains a dominant route for transfer of pesticides to the stream network. The data have also allowed us to validate the catchment model that we have developed using SWAT (the US EPA Soil and Water Assessment Tool), enabling us to explore future interventions from a sound understanding of the processes operating in the catchments.

In 2015/16 we worked in partnership with Anglian Water to mitigate metaldehyde transport to the streams using a runoff risk mapping approach. Concentrations in water were not reduced (Figure 8, 2015/16 data), emphasising the need for complete product substitution for slug control with ferric phosphate on the heavy clay soils with subsurface drains that dominate the catchments.

Propyzamide

Propyzamide is a key pesticide for control of blackgrass through application to winter oilseed rape and field beans within the arable rotation. Our monitoring again shows regular contamination of stream water from November onwards, with maximum concentrations in the range 0.5-2.5 µg L^{-1} (Figure 9). Product substitution is not a viable option for propyzamide, so we are currently working with farmers on soil management strategies to reduce transport and to ensure that propyzamide applications across the catchment are made at different times over the winter.

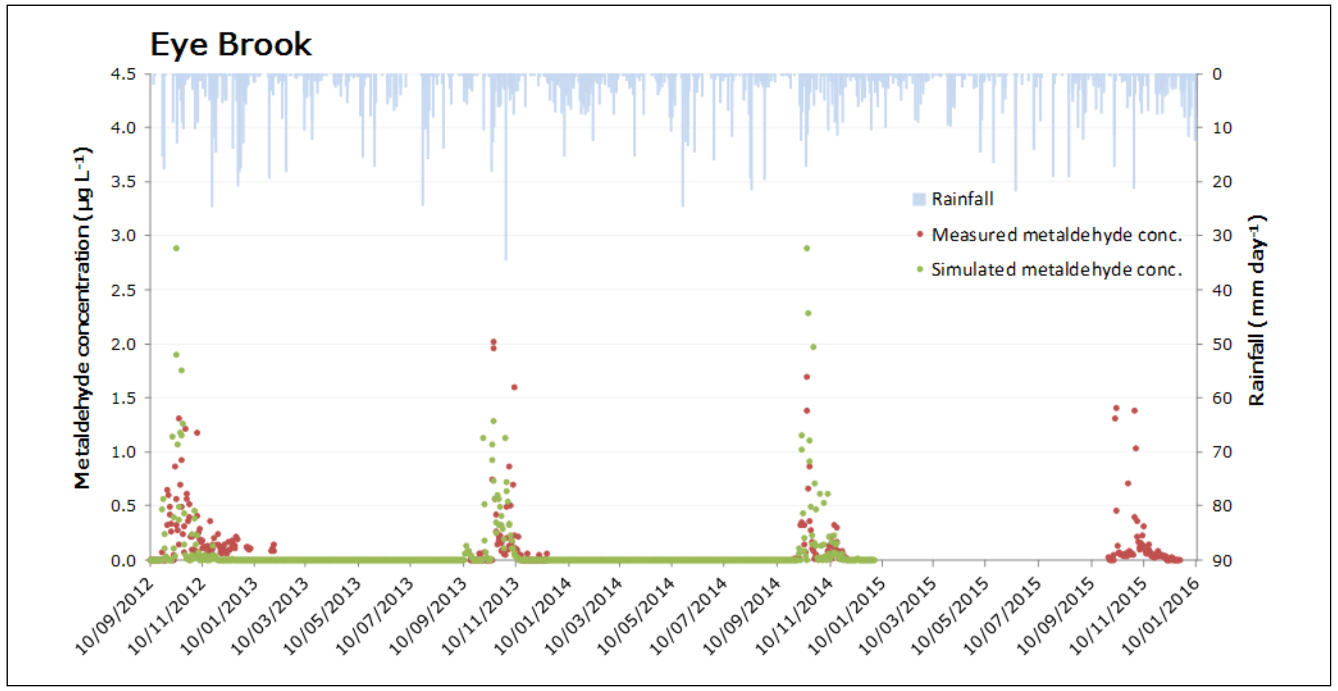

Figure 8: Measured concentrations of metaldehyde (red dots) at the outlet of the Eye Brook catchment for 2012/13 to 2015/16 and comparison with simulations (green dots) with the catchment model SWAT (2012/13 to 2014/15; simulations not yet completed from 2015/16).

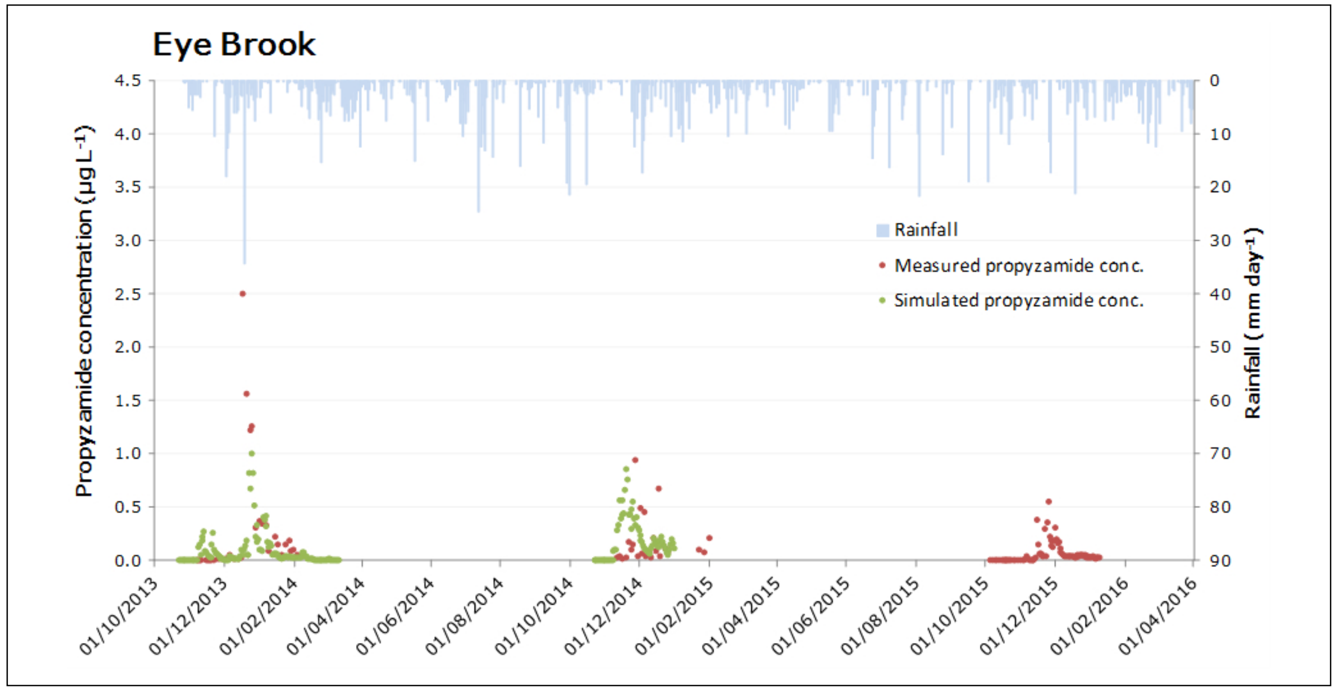

Figure 9: Measured concentrations of propyzamide (red dots) at the outlet of the Eye Brook catchment for 2013/14 to 2015/16 and comparison with simulations (green dots) with the catchment model SWAT (2013/14 to 2014/15). There were no applications of propyzamide in 2012/13 due to exceptionally wet conditions and consequent crop failure.

5. Flood risk management policy agenda

Since the beginning of Water Friendly Farming in 2010, three of the six years have seen exceptional hydrological events with major storms and floods. In that time the Environment Agency has also adopted new flood management policies, particularly towards the application of 'natural flood management', using the land to hold back water.

For the Environment Agency, sediment management, and its on-going costs, are also an integral part of flood risk management. For example, each year approximately £2.2 million is spent de-silting rivers within the area covered by the Lincolnshire & Northamptonshire Regional Flood & Coastal Committee, which includes the Water Friendly Farming project area.

2012 The year began in drought, broken by flows in late April and early May which were the highest in the 62-yr national record[11]. The 6th and 7th July were particularly stormy. The year culminated in the wettest nine-month period for England and Wales since 1766.

2013 The period from mid-December 2013 to mid-February 2014 saw at least 12 major winter storms, the stormiest period of weather in the UK for at least 20 years[12]. Extensive long-lasting flooding occurred in the Thames Valley and Somerset Levels, and elsewhere.

2014 The warmest year on record for the UK and, because of January and February rain, the fourth wettest year in the UK since 1910, behind 2012, 2000 and 1954.

2015 December 2015 was an 'extraordinary month'[13] with some of the most widespread and severe flooding witnessed in the UK. Effects were most pronounced in northern England but the Water Friendly Farming project area also experienced high winter flows.

11. Marsh, T.J., Parry, S., Kendon, M.C. Hannaford, J., 2013. The 2010-12 drought and subsequent extensive flooding. Centre for Ecology & Hydrology, Wallingford.
12. Met Office: http://www.metoffice.gov.uk/climate/uk/interesting/2014-janwind
13. CEH, 2016. Briefing Note: Severity of the December 2015 floods – preliminary analysis. Centre for Ecology & Hydrology, Wallingford.

Flood water on the floodplain of the River Welland in 2014.

In the north and west of England several projects have successfully demonstrated the ability of water retention measures to hold back water draining from moorland down to lower-lying river valleys, where water can be held on the floodplain, such as at Pickering in North Yorkshire[14] and Holnicote in Somerset.

Assessing the extent to which water can be held back in the lowland farmland environment water is one of the core objectives of Water Friendly Farming.

In 2015 we modelled the effect of changing land use and holding back water in the Water Friendly Farming landscape. This showed that the maximum land use change, including the most extreme hypothetical option of converting the whole of the landscape to woodland, caused only limited changes to peak flows. Complete conversion to forest would reduce peak flow by 14-18% (Figure 10). Changes to tillage (e.g. reduced tillage, zero tillage) were examined and had modest benefits. Earlier work had shown that buffer strips had little effect and so they were not modelled further.

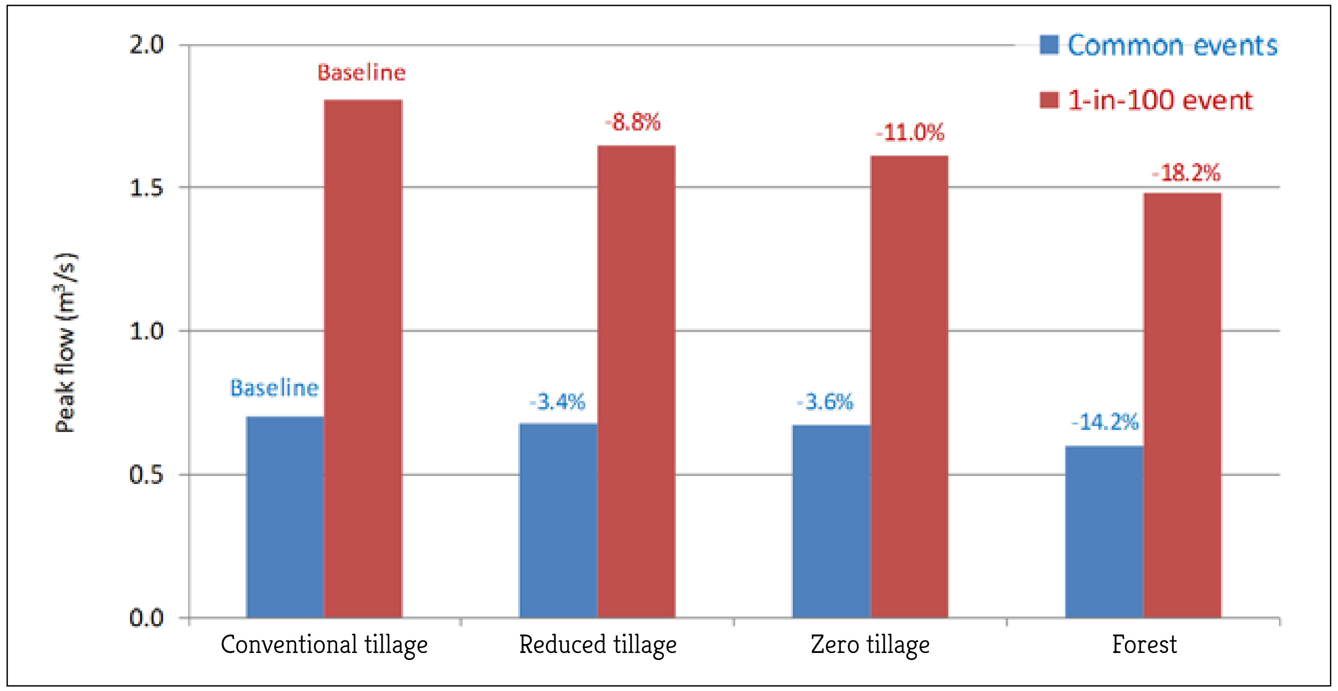

Figure 10: The modelled effect of changing tillage techniques and land use on the peak flow during storms. Blue bars show common flood events; maroon bars show the effect on unusual, 1 in 100 year, events.

We also modelled the effect of the storage we had already created which was about 3000m^3 in each of the Stonton and Eye Brook catchments (no storage was created in the control). Mitigation measures installed to date (e.g. Figure 11) are predominantly storage features. However, evaluation of the effect of this storage on flows indicated that it was too limited to have any substantial effect on peak flows. Further modelling indicated that installation of a network of permeable dams across the Eye Brook catchment could reduce peak flows by as much as 20%, a potentially substantial benefit for downstream flood protection. In the light of these modelling studies, we have now developed a new 5-year programme to test in detail, with the Environment Agency, the effect of on-stream permeable dams for flood mitigation linking land-use models to the standard hydraulic models used by flood defence engineers (Figures 11 and 12).

Although property flooding in the Welland catchment is minimal (due mainly to the floodplain being free of housing or development), property flooding is a major concern in the neighbouring Nene catchment, where in 1998 some 2500 properties were flooded at an estimated cost of £350 million.

14. Slowing the Flow Partnership Briefing: Boxing Day 2015 Flood Event. This paper analyses the effect of 'slowing the flow' measures at Pickering concluding that about half of the benefit was caused by woody debris, permeable dams and other land management measures, and half by the conventionally engineered flood storage reservoir created on the floodplain of the Pickering Beck. See: http://www.forestry.gov.uk/pdf/160329_PBeck_Boxing_Day_2015_Final.pdf/$FILE/160329_PBeck_Boxing_Day_2015_Final.pdf

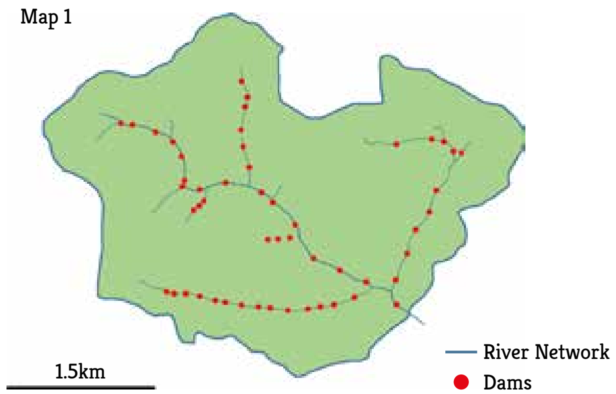

Figure 11: An earth dam under construction. Dams like these have created about 3000m3 of water storage in each catchment. In practice, approximately 10 times this amount of temporary water storage is needed to have a significant impact on peak flows. We are now implementing a programme of permeable dam installation (Map 1, above) which models predict reduce 1:100 year flood peaks by 20%.

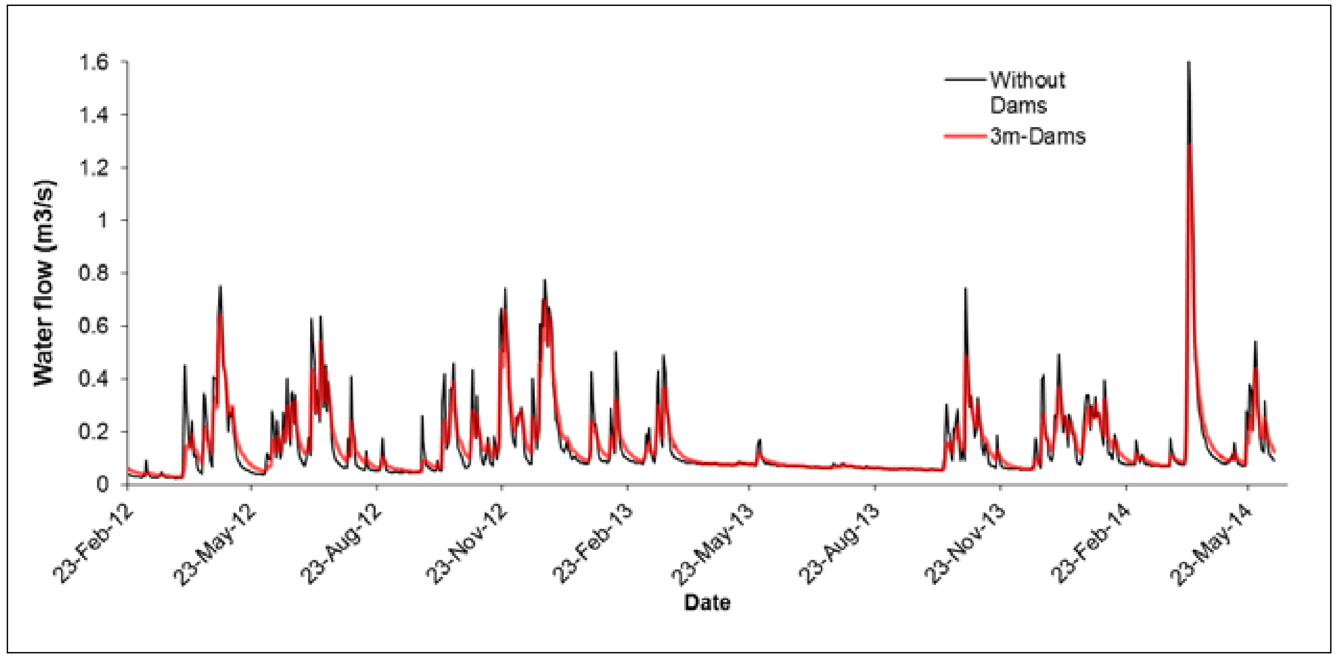

Figure 12: A combined modelling technique was used to link a drainflow model (SPIDER) to groundwater and storage basin models to predict the effect of installing multiple small permeable dams across the landscape (see picture above). This showed that the peak flows could be reduced by up to 20%.

6. The mitigation measures being used in the Water Friendly Farming project

The objective of Water Friendly Farming is to test the combined effects of multiple measures to control water pollution, runoff and protect freshwater life. We are not attempting to assess the effectiveness of individual measures as there is an immense amount of information already available about how well individual measures do, or do not, work. Very much less is known about the combined effectiveness of the different measures when applied across whole landscapes, the scale at which effects must be observed to make a real difference.

In 2013 and 2014, after three years of baseline measurement, a range of mitigation measures were introduced to the Water Friendly Farming landscape. We have described these previously in our 2014 report and only briefly refer to them here (Figure 11, Figure 13, Figure 16, Figure 19; Biggs et al., 2014).

Figure 13: Some measures to control undesirable water-movements may use conventional techniques. (a) In winter 2012/13 a block of arable land in the Eye Brook developed a large overland flow causing extensive soil erosion. This was due to an under-capacity field drain. (b) The old field drain was replaced by a new larger capacity field drain which eliminated the overland flow. The drain discharges into a sediment interception basin before entering the Eye Brook.

7. Freshwater biodiversity

Globally, freshwater wildlife is in retreat, a major threat being the decline in water quality (Vörösmarty, 2012). Diffuse pollution from farmland is a major contributor, and although efforts to improve chemical water quality have shown some positive effects, these programmes have led to limited gains in freshwater biodiversity.

To date, projects to protect freshwater biodiversity have focused on the improvement of individual streams, rivers or lakes. In Water Friendly Farming we are assessing the effect on freshwater biodiversity as a whole, in all freshwaters across the landscape, taken together. No previous projects have taken such an approach.

A number of projects have now shown that in farmed landscapes a large proportion of all freshwater species, typically about two-thirds, are found in the smallest waters, the ponds. In contrast, in Britain about 35% of large macroinvertebrate species and perhaps 10% of vascular wetland plants, are exclusively found in streams or rivers (Biggs et al., in press). In Water Friendly Farming we are taking account of this fact, managing both ponds and streams to achieve the greatest benefit for freshwater life. As well as looking at the benefits for streams, Water Friendly Farming is specifically testing the hypothesis that adding new clean water ponds to the landscape can increase landscape-scale freshwater biodiversity.

Data are so far available for wetland plants. Invertebrate samples have also been collected from the three waterbody types across the landscape and sample processing is currently in progress. We anticipate similar results to those seen for plants as in other studies of landscape scale freshwater biodiversity, invertebrates have reflected patterns shown by wetland plants[15]. In the Eye Brook catchment a range of interceptor waterbodies have been created at field edges (e.g. Figure 11). In the Stonton catchment, in addition to the water resource protection measures which intercept contaminated water, additional clean water ponds were also created specifically to provide high quality habitat, roughly doubling the existing pond density.

In the Water Friendly Farming study area, landscape-wide freshwater biodiversity measured in terms of wetland and aquatic plants remained constant over the 6 years of the project in the **pre-existing** freshwater habitats (streams, ponds, ditches). The pattern was the same in the control and experimental catchments. In all areas, these confirmed a now well-known pattern: that the majority of freshwater species are seen in ponds, and taken collectively they support more species than the other freshwater habitats in the landscape (Figure 14).

15. Williams, P., Whitfield, M., Biggs, J., Bray, S., Fox, G., Nicolet, P. & Sear, D., 2004. Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. Biological Conservation 115: 329-341.

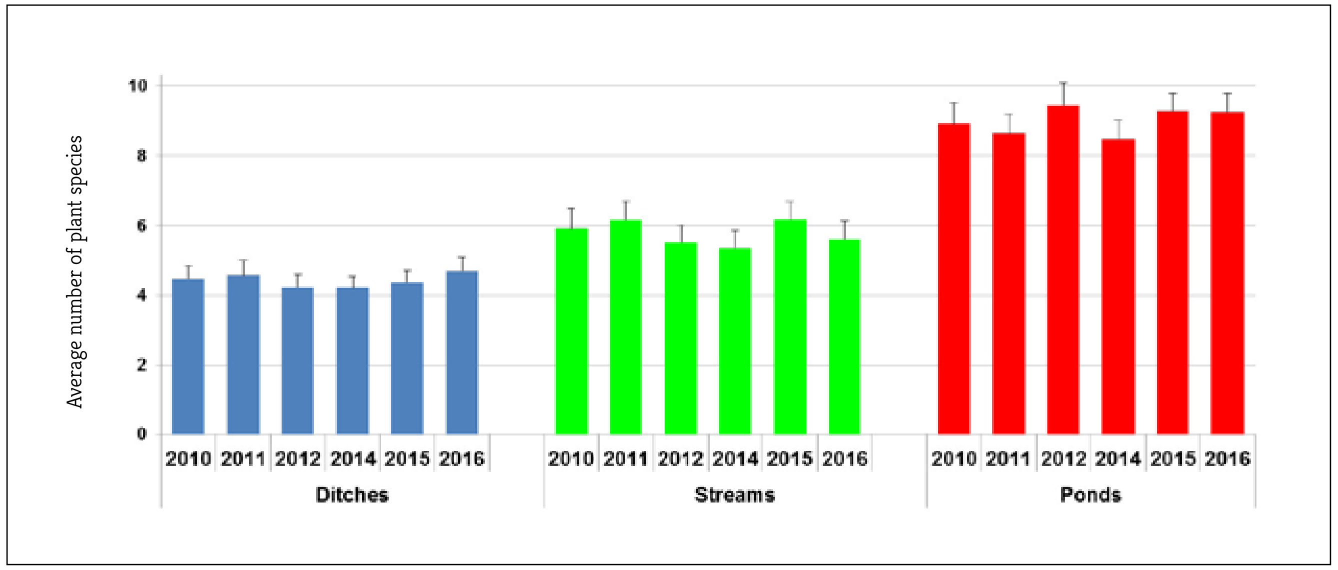

Figure 14: Comparative biodiversity of the three freshwater habitat types found in the project area. Ponds consistently support more species per site (alpha diversity) than streams or ditches. They also support more species in total (gamma diversity, not shown). There are no waterbodies large enough to be described as rivers or lakes *sensu* Brown et al. 2006.

In the Stonton Brook catchment, the new ponds have rapidly colonised, and considering the most sensitive group, the submerged aquatic plants, have now led to a consistent, landscape wide, increase in freshwater biodiversity. This is the first unequivocal demonstration of this process (Figure 15). Further monitoring will determine whether the increase is permanent. Elsewhere, new ponds have maintained their high biological interest for over 20 years, so depending on good water quality being maintained, this increase in freshwater biodiversity could be permanent.

Ponds and pollinators

We also surveyed pollinating insects associated with four of the newly created ponds and at nearby control sites where no management had been carried out. Although we have sown the disturbed ground with flowering plants to attract pollinating insects, we have discovered that naturally regenerating plant species such as rosebay willowherb and spear thistle are at least as important to these insects for much of their foraging period. Creating small field edge or field corner wetlands may therefore have a role in the conservation of pollinating insects such as bumblebees and solitary bees.

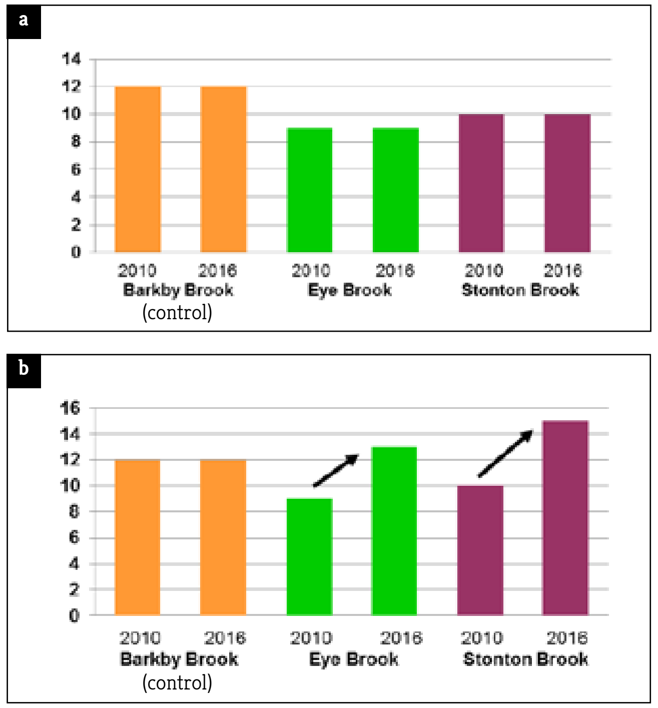

Figure 15: The effect of adding new clean water ponds to the landscape. (a) Upper inset graph shows aquatic plant richness (gamma diversity) in all existing waterbodies (ponds, streams, ditches) across the three landscapes. There is no change between 2010 and 2016. (b) All waterbodies + new ponds from 2014 onwards, showing an increase in both experimental catchments and no change in the control, where no new ponds were created.

Figure 16: A new clean water pond, intended to provide high quality, unpolluted freshwater habitat in the Stonton Brook catchment. New ponds also provide nectar sources for pollinators, such as the thistles in the left foreground of this picture.

8. Flow and sediment modelling

Watercourses in the Water Friendly Farming project are already extensively buffered, often with broad wooded strips between arable land, streams and ponds. We used the SWAT model to evaluate retrospectively the effect of these buffer strips, and other hypothetical land management options, on sediment runoff to watercourses (Figure 17).

The analysis showed that with 20m buffer strips and reduced or zero tillage it was predicted that sediment losses would only be slightly greater than would occur if the landscape was fully forested. In the study area complete woodland cover would be present naturally so this provides the baseline or 'reference condition' target for sediment losses to water in the project area. At present we estimate that soil losses are about 0.5 tonnes/hectare/year (range 0.3-0.6).

Modelled effects of buffer strips and tillage on sediment losses from the Eye Brook catchment

With no buffers	**407.8 tonnes**
Current buffers (c10m average)	**288.3 tonnes (-29%)**
20m buffers on all arable + reduced tillage	**177.7 tonnes (-56%)**
All forest	**152.0 tonnes**

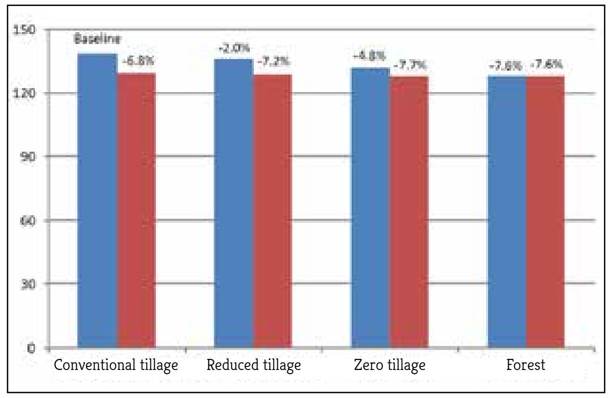

Figure 17b: The effects of land use on sediment loss are very modest in a simulated 1 in 100 year flood event. As much sediment may be lost from the catchment in a single storm as in the rest of the year.

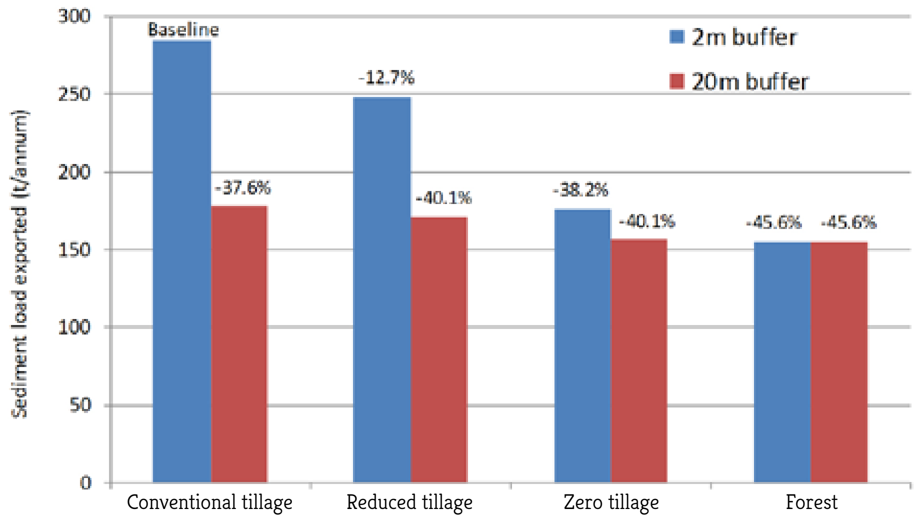

Figure 17: Modelled effects of alternative tillage and land-use methods on the loss of sediments from the Eye Brook catchment during typical flood events. The inset (upper graph) shows the effect of land use change on a 1 in 100 year flood event, simulated from an event in the neighbouring county of Northamptonshire (there were none in the study area during the course of the project).

9. Working with farmers

The immediate post-baseline period was dominated by the introduction of a range of mitigation outside the productive area, including fencing livestock out of ditches and streams, and the creation of various detention ponds to capture silt lost from arable land. However, previous research with Lancaster University has revealed that such wetlands have limited capacity to capture sediment in clay catchments unless they are fed by surface runoff, rather than field drains. This is because the fine material associated with clay soils is held in suspension and passes through the pond systems.

We have therefore been working more closely with farmers to address the issue of soil erosion and loss to water at source, in the fields themselves. We have provided electrical conductivity maps of some fields to illustrate changes in soil type within them, and bought in specialist advice on soil management, specifically matching farmers' existing equipment to the issues present in their fields. Changes in soil management require a substantial shift in mindset and knowledge base, and often substantial and costly changes in farm machinery. The latter is particularly difficult to address given the existing economic challenges and political uncertainty. The Welland Valley Partnership has bought a Dale no-till drill which is made freely available to local farmers to trial when they are comfortable that conditions are right for them (Figure 18).

We have carried out compaction surveys of the most severely affected fields and shared that information with farmers. The results provide information on the depth of compaction layers in the soil profile, as well as the distribution of compaction across the field. In response to interest and requests from local farmers, we have also carried out surveys of soil organic matter and earthworms across some fields given the increasing recognition of the role of these in soil function for both farming and water management (Figure 19). In the spirit of knowledge exchange, rather than traditional knowledge transfer, we are actively engaging local farmers in setting our future soil research agenda so as to ensure practical relevance and applicability as well as policy relevance and environmental benefit.

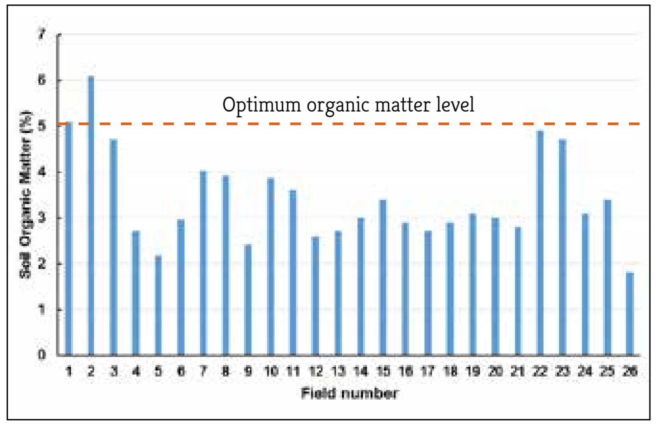

Figure 19: A survey of soil organic matter in fields within and around the study area revealed that levels are variable but generally well below the 5% regarded as optimal for cropping and environmental objectives.

Figure 18: A Dale seed drill purchased by the Welland Valley Partnership to encourage farmers to adopt direct drilling in the study area.

10. Dissemination

The results arising from the Water Friendly Farming project, and the lessons learnt from our engagement with participating farmers, are shared with a wide range of practitioners, policy makers and regulators through the Allerton Project's ongoing programme of knowledge exchange activities at its research and demonstration farm nearby at Loddington. The information is also fed into the Catchment Sensitive Farming programme through the Nene and Welland CSF Partnership, ensuring that the emerging knowledge is disseminated and applied locally and further afield.

Figure 20: Farmers visit the Allerton Project farm to discuss management practices that could have economic and environmental benefits within their businesses.

11. What's next?

Flood risk management

Our current focus is on the management of the headwater catchment to reduce downstream flood risk. This includes continuing our work with farmers to encourage improved soil management that will increase water infiltration and retention and reduce soil loss and sedimentation, while also improving crop rooting capacity and nutrient uptake. We are also putting in place a series of permeable log dams which do not impede base flow but hold water back as flow increases in response to storm events (Figure 21), modelling the effectiveness of these dams and assessing the performance in practice.

Satellite data

Sentinel satellite data became freely available in 2016 and we are working with the Environment Agency and Geomatics to explore the potential of these data and images to inform land management that will benefit both cropping and catchment management. We will be collecting soil compaction data in some fields, and using the combination of remote and ground sourced data as a focus for discussion with farmers about the management of their land.

Food and dietary choices

A new PhD study with Nottingham University will enable us to explore the role of dietary choice in influencing phosphorus discharges from rural sewage treatment works. Choice of diet is influenced by a wide range of considerations including price, health, animal welfare, biodiversity, food miles and fair trade, but as far as we are aware, this is the first time that the impact on water quality has been investigated in this broader context.

Soil research

We will be linking major new soil research projects funded by the EU and AHDB to our landscape scale research within the Water Friendly Farming project.

Freshwater biodiversity and ecosystem services

The project's core activity is to assess the effects of mitigation measures on freshwater biodiversity and water quality which will be continuing for the next 5 years.

Figure 21: A newly installed (September 2016) permeable dam in the Eye Brook catchment. It is of simple construction using low-cost, easily available, materials.

12. Policy implications of the Water Friendly Farming project results

Some key message for land managers and others are beginning to emerge from the results of Water Friendly Farming, and other projects.

Whole landscape, not just rivers: to protect freshwater biodiversity it is necessary to manage the whole of the water environment, both small and larger waters.

Focus more rigorously on what works: there is growing evidence of what works and, conversely, what is less successful. At all times it is important to spend time and money on what works best. Many water management schemes are rolled out with a limited evidence base.

Focus on management that meets farm business objectives as well as environmental ones. Encourage the generation of ideas and approaches from within the farming community.

Focus more on maintaining what we have and rigorously, systematically, 'building out': it is increasingly clear that for freshwater biological systems to recover, nearby sources of colonists are crucial, as well as clean water. This makes protection of existing freshwater biodiversity hotspots, whether the cleanest streams or isolated groups of unpolluted ponds and wetlands, all the more critical as the basis for a network of 'source habitats'.

Stop focusing on a single pollutant, phosphorus: A lot of effort is focused on managing phosphorus but all pollutants are likely to be important and probably interact in their effects. Regulators and legislators should aim more for 'clean water' rather than precisely measured degrees of pollution by individual chemicals.

Models save time and money: many large scale catchment management initiatives could benefit from more routine modelling of likely impacts, especially in the control of nutrients and sediments.

What should landowners and managers do? Think small in order to think big: land managers are most likely to be able to interact with small waters. Try to get some clean water on every farm by making, or better managing, small waterbodies.

Be joined up. Clusters of collaborating, motivated farmers can deliver ecological connectivity.

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