

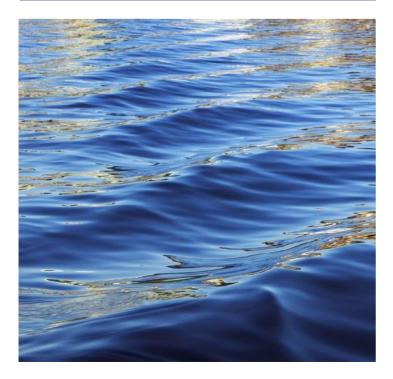


Demonstration Test Catchments

Improving Water Quality in Rural Areas



Demonstration **T**est **C**atchments















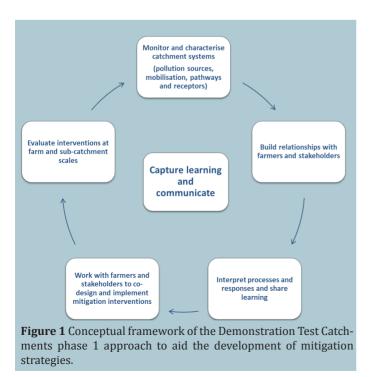


Welcome - An Introduction to the Defra Demonstration Test Catchments (DTC) Programme



The Demonstration Test Catchments (DTC) programme was established in December 2009 to inform the mitigation of agricultural water pollution across farmed landscapes in England. We have taken a 'learning by doing' approach to develop, test and demonstrate suites of measures at landscape scale that are practical within commercial farming systems. Our approach recognises the river catchment as an appropriate spatial unit for understanding and managing water quality, whilst balancing the demands of food production and environmental protection. The diffuse, and often sporadic, weather-driven nature of agricultural pollution means that understanding the effectiveness of mitigation measures requires a long-term monitoring approach, both pre- and post-implementation of on-farm interventions. Applying this at a catchment scale in the DTCs has required interaction between broad communities of stakeholders, regulators and scientists. We are now working on upscaling our findings from case-study sub-catchments to generate best practice for wider catchment management.

This summary document guides readers through the conceptual framework (Figure 1) that we are using to develop bespoke on-farm mitigation strategies, by illustrating each of the steps through example case studies. It also sets out emerging findings from phase 1 and describes the ongoing programme of work (phase 2) to 2017.



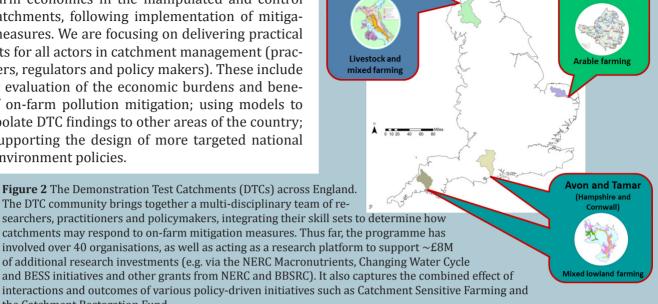
Demonstration Test Catchments in Practice

The DTC focuses on four river catchments representative of the major English agricultural practices and landscapes: the River Wensum in Norfolk, the River Eden in Cumbria, the Hampshire Avon and the River Tamar on the Cornwall/Devon border (Figure 2).

In phase 1 of DTC (2009-2014) we have tried to understand the complexities of the interactions between the farmed landscape, the river system and the factors influencing farmers' decision making. Using existing information, and through our intensive monitoring, we have been able to characterise each study sub-catchment, identifying pollutant sources, dynamics and pathways to groundwater and streams. We have worked with farmers, Catchment Sensitive Farming (CSF) and Environment Agency (EA) officers, Rivers Trust staff, farm advisors and others to develop mitigation strategies that address critical sources and pathways without unduly affecting individual farm performance.

In phase 2 of DTC (2015-2017) we are continuing to monitor changes in water quality, aquatic ecology and farm economics in the manipulated and control sub-catchments, following implementation of mitigation measures. We are focusing on delivering practical outputs for all actors in catchment management (practitioners, regulators and policy makers). These include better evaluation of the economic burdens and benefits of on-farm pollution mitigation; using models to extrapolate DTC findings to other areas of the country; and supporting the design of more targeted national agri-environment policies.

the Catchment Restoration Fund.



(Norfolk)

Eden

(Cumbria)

Understanding the Problem

We undertook detailed water quality and aquatic biology monitoring and carried out social research within each of the DTC study catchments in order to build up an understanding of the main drivers of agricultural pollution and the barriers to its mitigation. This included an assessment of the major pollutant sources, causes of mobilisation, together with pathways to, and impact on, the receiving watercourses (receptors). Farm baseline surveys carried out using detailed questionnaires built up an understanding of farm business structures and practices in each catchment. Case studies 1-3 illustrate some of the approaches we developed in the DTCs to interpret water quality monitoring data to identify the dominant pollution sources within river catchments using ecological and chemical metrics. Case study 4 illustrates the differences in the ways in which water quality responds to storms in river catchments with different geologies and land uses.

Case Study 1: How do we easily understand the ecological responses of aquatic organisms to changes in pollutant fluxes and flows?

The challenge: How to determine whether the ecological health of our streams and rivers will respond to mitigation measures.

The study system: Flow in the headwater streams of the Eden responds rapidly to rainfall, which mobilises and transports sediment and nutrients to downstream ecosystems. These headwaters contain relatively simple ecological assemblages of algae, invertebrates, higher plants and fish. Diatoms are a type of freshwater algae found within the slimy brown biofilm that covers cobbles on the stream bed. They respond directly and sensitively to physical, chemical and biological changes in their environment, so can serve as a valuable indicator of the recent environmental conditions they have experienced (antecedent period). We explored the relationship between land-use, physical and chemical

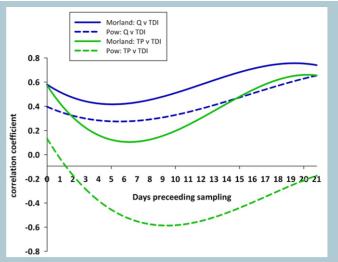
changes in streams and the impact on diatom communities by collecting diatom samples in the Eden study sub-catchments, and then calculated the 'critical antecedent period' using the continuous water chemistry, rainfall and flow data. The Trophic Diatom Index (TDI), a water quality measure, was used to represent the diatom communities.

What we found: At both Pow Beck and Newby Beck we found that community composition at individual sites (Figure 3) was a product of flow rates and total phosphorus (TP) concentrations over the preceding 7-21 days.

So what? This study confirms that the benthic diatom community reflects the cumulative impact of water quality and flow conditions over a three-week peri-

Figure 3 Critical antecedent response period of diatom communities to the cumulative impact of preceding flow-nutrient conditions. The continuously sampled flow (Q) and water chemistry data was average over time periods of zero to 21 days. The Trophic Diatom Index (TDI) was collected monthly over 25 months for Newby Beck (n=25) and 18 months for Pow Beck (n=18).

od, even in dynamic headwater streams. Diatoms are therefore an appropriate indicator that can provide a measure of rapid ecological response to mitigation strategies, and will be used in phase 2 to assess changes due to the new measures we have introduced. This understanding will serve to better inform and critique methods, to assist catchment managers assessing ecological health.



Case Study 2: In what form are nutrients transported to the river, and does it matter?

The challenge: Nutrient flux to water from diffuse sources comprises both organic and inorganic forms. Inorganic nutrient flux is more commonly measured in routine monitoring programmes in the UK and is typically highest in arable catchments. Organic nutrient concentrations are typically higher in catchments with intensive livestock agriculture. These are delivered to streams as particulate organic N or P (PON, POP) and dissolved organic N or P (DON, DOP). POP is a component of particulate P (PP) which also includes inorganic phosphorus compounds bound to mineral sediment particles. Sources include animal manures and urine

Nitrogen fractions (2012-2013) (kg/ha) 15.0 15.0 ■ PON Annual load DON 10.0 Ammonium 5.0 KIRESON DEVERILLANDE Bixen Desem, whie Upstream, tithe Cools Cottage, 3.5 Phosphorus fractions (2012-2013) 3.0 Annual load (kg/ha) 2.5 2.0 ■ PP 1.5 1.0 DOP 0.5 ■ SRP Brikton Deverilli

Figure 4 Nutrient fractions contributing to total nutrient flux in livestock dominated (Sem, Tamar) versus mixed farming (Ebble) and arable dominated (Wylye) catchments. PON = particulate organic nitrogen; DON/DOP = dissolved organic nitrogen/phosphorus, respectively; PP = particulate phosphorus; SRP = soluble reactive phosphorus.

voided in fields, in poached areas of fields, directly voided in-stream at watering sites, in farm yards and on tracks, or applied as a slurry dressing to fields. Although catchment mitigation measures for livestock production systems are well developed compared with arable, ignoring the contribution of organic nutrients, particularly in livestock-dominated catchments, could lead to an incomplete understanding of the relationship between diffuse pollution and ecological responses. Therefore we may fail to select the most appropriate mitigation measures for the type of pollution occurring.

The study system: We gathered evidence in the Hampshire Avon and Tamar DTC study sub-catchments on the balance between inorganic and organic nutrient fractions. Daily water samples were collected and analysed for inorganic and organic nutrient fraction concentrations, and these were combined with river flow data to calculate annual loads. This has provided us with valuable information on the likely balance of the various contributing sources of nutrient enrichment.

What we found: Examples of the trends observed are shown in Figure 4. In the clay catchments of the Sem (Hampshire Avon) and in the Tamar catchment, intensive cattle production contributes 50% of the total N load and 65-80% of the total P load, in organic and particulate form. In the chalk catchments of the Hampshire Avon, over 75% of the total N and 60% of the total P contribution stems from fertiliser applications to crops, and arrives in-stream largely in the inorganic form. These findings have helped us to target on-farm mitigation measures effectively at source, along mobilisation pathways and in-stream. Measures include the separation of clean rainwater from dirty water in yards; improved manure management on livestock farms; and fencing of watercourses to prevent direct stream access by livestock. In mixed farming and arable areas efforts have focused on repairs to tracks linking source areas to streams; reversion of arable land to grassland;

installation of settling ponds to intercept overland flow in vulnerable areas; and integrated manure and fertiliser planning.

So what? It is possible to use the ratio of organic and inorganic sources to help understand the dominant

pollution sources in a catchment, and to use this to help guide the targeting of on-farm mitigation measures. We will continue to research this concept in phase 2 to develop guidance for regulators and catchment managers in order to better target mitigation.

Case Study 3: Where does the sediment come from?

The challenge: The River Wensum experiences high suspended sediment concentrations which cause an array of detrimental impacts threatening ecosystem functioning. Mitigation measures are therefore required to reduce the amount of land-to-river sediment transfer, but for these to be targeted effectively it is essential to first understand sediment provenance.

The study system: Employing a novel automated water quality monitoring procedure we have been able to quickly, accurately and cost-effectively derive high-temporal resolution (1-2 hour) sediment source apportionment estimates throughout the progression of 15 individual storm events since 2012. Sediment contributions have been apportioned, with uncertainty, to eroding arable topsoils, damaged road verges and a combined subsurface stream channel bank and agricultural field drain source.

What we found: The results revealed that arable topsoils and road verges are major contributors of fine suspended sediment, during and after heavy precipitation events following the initiation of surface runoff (Figure 5), with metalled roads found to significantly enhance field-to-river connectivity.

So what? The results we found in the Wensum highlight the importance of identifying the various sources of sediment in intensively farmed arable catchments (and other areas where siltation of the river bed is an issue). Applying such an analytical approach to other

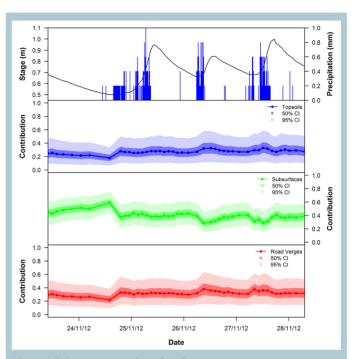


Figure 5 Time-series plots for three consecutive precipitation events in November 2012, showing changing sediment source contributions at 120-minute intervals over a 118-hour period. Light and dark shading around median source apportionment estimates represents the 95% and 50% Bayesian credible intervals (CI), respectively.

catchments provides a way to target sediment mitigation efforts (e.g. roadside sediment traps) to the dominant sources, enabling a more efficient deployment of mitigation measures.

Case Study 4: How do different river catchments transport pollutants in response to rainfall?

The challenge: Heavy rainfall events are a key instigator of nitrate, sediment and phosphate transfer from wider catchments into river networks. During the initial four years of DTC monitoring, weather conditions ranging from drought to flood conditions were observed. We wanted to know how the catchments responded to a transition from dry to wet conditions in April 2012, and what these responses could tell us about the conceptual understanding of each catchment in terms of hydrology and diffuse pollution transport.

The study system: In the first part of 2012, flows in the Eden, Wensum and Avon catchments were relatively low, particularly the latter two, as they were still in recovery from a drought in 2011. A broad weather front passed over the UK in April 2012, causing heavy rainfall and large runoff events in all three catchments.

We gathered data from storm events which occurred between 25 April to 1 May 2012, comprising rainfall, discharge and high frequency measurements of nitrate-N, total phosphorus (TP) and total reactive phosphorus (TRP; Figure 6).

What we found: Delays between rainfall and flow peaks in the hydrographs for both the Wylye tributary (Avon) and the Blackwater tributary (Wensum) shows how significant groundwater flows are to those systems. However, the much shorter time between peak rainfall and peak discharge in the Newby Beck tributary (Eden) confirms its more 'flashy' response.

Despite both the Avon and Wensum tributaries being dominated by groundwater inputs, we found that the nitrate concentration changes in response to rainfall in these two catchments were completely different. Nitrate dilution of nitrate-rich groundwater base-flow occurred in the Wylye, whereas nitrate flushing occurred in the Blackwater due to rapid movement of soil nitrate through the extensive drain network. Sharp TP concentration peaks in the Newby Beck and Blackwater tributaries were observed due to the rapid delivery in association with sediment, whereas a more attenuated response was observed in the Wylye, showing the influence of slower flow pathways. In the Blackwater the responses of TP and TRP were very similar, indicating that both soluble and particulate forms of P were mobilised from similar sources and pathways. In contrast, the TRP peak in Newby Beck was more delayed than the TP peak, suggesting particulate P transport occurred at the beginning of the event, followed by slower sub-surface movement of dissolved P towards the end of the event.

So what? This work illustrates the need to understand the hydrology of any particular catchment and the way pollutants are transported to streams and rivers in different ways, before implementing an overall catchment plan for mitigation measures. The importance of a relatively few storm events in transporting the majority of sediment and associated adsorbed pollutants has profound implications for the design of mitigation features and catchment management planning. We will be taking this forward in phase 2 of DTC.

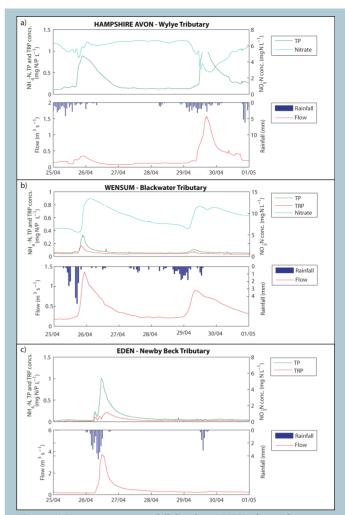


Figure 6 Responses to rainfall for three DTC sub-catchments for an event which occurred across all DTC focus catchments in April 2012. TP/TRP = Total phosphorus/total reactive phosphorus, respectively

Building Stakeholder Consensus

Tackling agricultural pollution requires cooperation from farmers and landowners. By building relationships with the farmers on whose land we are working, we have been able to devise mitigation approaches that are practical, acceptable to those working the land and compatible with farming systems in each of the catchments. Social research in the DTC catchments has assessed farmers' attitudes to diffuse pollution, the acceptability of measures and the main barriers to uptake. It has also investigated the influence that regulators, advisers and other stakeholders have on farm practices. We have experimented with farm diaries and water quality self-monitoring to engage farmers to act. The knowledge gained from this work can inform management approaches and policy interventions at catchment to national scales.

Case Study 5: What drives the attitudes of farmers towards adoption of diffuse pollution mitigation measures?

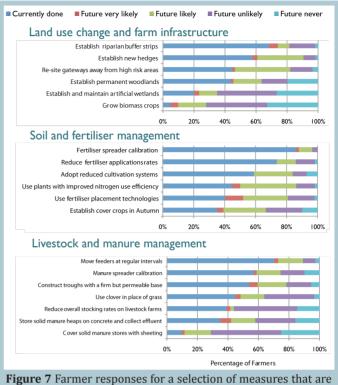
The challenge: Research continues to evaluate the best agricultural practices for water pollution control. However, the implementation of such measures on a voluntary basis depends on the attitudes and responses of farmers and land managers. There is consequently a need for more information on the uptake and acceptability of different measures to assess the scope for pollution mitigation.

The approach: We conducted a survey to create a baseline of current agricultural practices and to give an insight into farmers' attitudes to the adoption of various mitigation measures in the future. Seventy-three farmers were interviewed between February 2012-2013 in the Hampshire Avon, Eden and Wensum catchments. As part of the survey, opinions were obtained on adoption of 70 diffuse pollution measures taken from the Defra Mitigation Methods User Guide. Farm-

ers were asked: "Do you currently practice X mitigation measure? If not, would you be likely or unlikely to consider adopting it in the future?" Survey participants currently not practicing a particular mitigation measure were also asked 'how likely' they would be to adopt the measure in the future.

What we found: Responses for a selection of measures, which are considered to provide wider environmental benefits, are summarised in Figure 7. Overall, measures requiring land use change were less likely to be adopted than those improving farm infrastructure. The measures most likely to be adopted in the future were those that decreased the use of fertiliser and fuel, thereby reducing costs to the farmer. The results also highlighted several measures with relatively low current uptake, but where there were positive attitudes to future adoption, such as re-siting gateways, establishing cover crops and reduced cultivation systems. which could merit inclusion in agri-environmental programmes. The findings also indicate that improvements in farmyard infrastructure are a priority for many farmers, and suggest that radical changes in activities will not occur without substantial financial incentives or regulatory requirements.

So what? As long as voluntary measures and incentives remain the main policy mechanism to combat diffuse pollution, it is as essential to understand the motives and challenges for farmers in any given catchment. We already know that the most palatable measures are often those that are relatively easy to implement, attract grants and incentive funding, or provide economic or



likely to provide environmental benefits.

practical benefits to farm operations. We intend to continue to examine motivational factors for farmers and the barriers/drivers to measure uptake in phase 2. Issues to address include the potential for greater uptake through advice provision; the reasons why apparently effective measures are sometimes not palatable; and the relative importance of factors internal and external to the farm business.

Case Study 6: What technical support tools can we provide to help with planning effective mitigation measures?

The challenge: Farm advisors are in a position to influence decision making on individual farms, but they may not have the necessary tools to deliver advice regarding reducing soil and nutrient losses and how such mitigation measures impact on farm profitability.

The approach: We held a farmer-scientist workshop in December 2011 in the Avon DTC, during which the suggestion was made that FARMSCOPER* could be useful as part of the professional advice provided to farmers. This had not previously been done. A subsequent workshop in May 2012 involved the participation of farm advisors and farmers, generated many reactions to FARMSCOPER and provided opportunities for advisors and scientists to share insights in ways that can inform ongoing model development. The facilitating knowledge exchange team captured views primarily in a qualitative format, although some of the reactions were also expressed quantitatively (see Table 1, p. 7).

What we found: Generally, participants felt that the tool was well placed to provide information on risks and opportunities at both the strategic catchment and sub-catchment levels. They told us that it could highlight key measures that might be employed in an area given its general landscape attributes (such as soil types) and types of farming. Some also suggested that the tool might helpfully be deployed at open meetings and technical events, as a device for awareness raising amongst farmers and demonstrating the cost/benefit of undertaking particular on-farm practices. The workshop also highlighted the importance of functionality for data inputs for individual farms.

The farmers felt that when used by "farm advisors with a good knowledge of farm circumstances" the tool could help provide a generic 'base line' indication/direction of risk that may be helpful as the basis for targeted farm level guidance. There was recognition that FARMSCOPER could never be a substitute for the "de-

*FARMSCOPER is a decision support tool that can be used to assess diffuse agricultural pollutant loads on a farm and quantify the impacts of farm mitigation methods on these pollutants. It also determines potential additional consequences of mitigation method implementation for biodiversity, water use and energy use.

Table 1 Advisor assessments of FARMSCOPER

Evaluation Criteria	Mean Response
General applicability of FARMSCOPER to the advice giving process	3.9
Potential usefulness of FARMSCOPER in your own advisory work	3.1
Capacity of FARMSCOPER to identify potential problems	4.4
Capacity of FARMSCOPER to provide information that will help support farm profitability	6.4

Criteria ranked by participants on a scale of 1 to 8, where 8 = maximum positive score

tailed local knowledge stored by the farm adviser" but had potential utility as a "background guide" to be used at the formative stage of the advice giving process.

So what? Farm advisors and farmers clearly like tools to be specific to the farm in question. A good advisor with local technical knowledge will always be the best and most trusted option, though there is a clear role for developing and using generic tools, but with functionality for bespoke inputs, to assist in decision-making. Such tools need to be relatively easy to use. The DTC provides a platform to test new and emerging tools, and we intend in phase 2 to continue testing the reliability of, and stakeholder engagement with, the outputs of various models.

"Having run through the programme, I can see that whilst giving generic answers, this information could be used by an advisor to develop a more targeted plan."



Testing Mitigation Measures

The DTCs have been a test bed for new and advanced approaches to monitor the aquatic environment and develop, implement and verify pollution mitigation plans. Measures have included soil management interventions, run-off attenuation features, improvements to farm infrastructure (e.g. modifications to yards and tracks) and streamside fencing/livestock exclusion from watercourses. Monitoring at field and sub-catchment scales enables the cumulative downstream effect of measures to be assessed and compared with control sub-catchments, which continue running business as usual. Modelling provides an important tool to help interpret and extrapolate monitoring results, and we aim to use a range of models to understand spatial and temporal patterns. These will include geographic information system (GIS) based approaches to set the DTC catchments in relative context with other areas, and temporal simulation models will be used to extend the validity of our understanding from the focus catchment datasets. The models will be aligned with EA and Defra toolsets to facilitate the sharing of DTC knowledge. Case studies 7, 8 and 9 give some examples of the measures we are testing.

Case Study 7: Do cover crops in winter mitigate nitrate pollution?

The challenge: Across the River Wensum catchment, 40% of water bodies have nitrate concentrations above the drinking water quality standards (50 mg/l) as a consequence of diffuse agricultural pollution. On-farm mitigation measures are therefore required to reduce nitrate inputs and mobilisation at source before it can enter the river. Losses of nitrogen are also a cost farmers wish to reduce, due to the potentially detrimental effects on crop yields.

The mitigation trial: In conjunction with the Salle Estate, we trialled a system of cover crops and reduced cultivation measures on nine fields (totalling 143 ha of land) during autumn/winter 2013-14. Two fields were kept as controls and managed in accordance with standard farm practice (ploughed, no cover crops), whilst the other seven were planted with an oilseed radish cover crop in August 2013. Of these seven, three were subsequently direct drilled with spring beans in

March 2014, whilst the other four were cultivated prior to drilling. We assessed the impact of the cover crops on water quality by measuring nitrate concentrations in the outflows of the subsurface tile drainage network that underlies all nine fields.

Effectiveness of mitigation: The results (Figure 8) were stark. Nitrate concentrations in water draining from fields with no cover crop (blue lines) were substantially greater than those measured from the cover crop fields (other colours) across the six-month period. Importantly, although the application and variable costs for establishing and managing the cover crop (£704-748/ha) were higher than normal practice (£589/ha), yields were also higher for the subsequent bean crop, and thus there was negligible difference in the final spring bean gross margins between cover crop (£731-758/ha) and normal practice (£745/ha) operations.

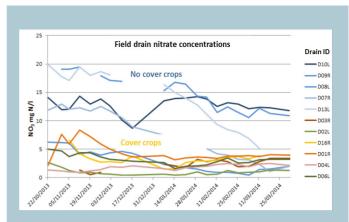


Figure 8 Results from monitoring of nitrate-N in field drains in the Wensum DTC, October 2013 – March 2014.

So what: The results provide compelling evidence to support the wider adoption of cover crops for mitigating diffuse nitrate pollution in arable rotations.

Case Study 8: How effective are control measures to exclude livestock from watercourses on faecal pollution?

The challenge: Faecal indicator organisms (FIOs) are a major faecal-derived pollutant from livestock, and a key cause of bathing water quality failure in the UK under the EU Water Framework Directive (WFD). Stream bank fencing and drinking bays are measures deployed to restrict livestock access to water courses, with the aim of reducing FIO pollution. We need to understand the efficacy of such measures better in order for policy to support the most appropriate interventions for FIO reduction.

The mitigation trial: Caudworthy Water drains into the River Ottery tributary of the River Tamar, and has been the focus of our work to test the efficacy of onfarm mitigation measures for FIO pollution. We collected water samples from nine longitudinal locations along Caudworthy Water, at regular intervals, to capture both the 2013 and 2014 bathing seasons (April–September) using sites where cattle had varying degrees of access to the stream. Samples were analysed for FIOs following standard filtration methods, as well as for total nitrogen (TN) and total phosphorus (TP).

Effectiveness of mitigation: We tested the effectiveness of excluding cattle in both years and show the results from 2013 in Figure 9, which shows the percentage similarity, as clusters, for each sampling site. It was not possible to analyse the data for both 2013 and 2014 together, because of the observed differences in stocking rates of the fields at the study sites. However, analysis using the data for 2014 showed the level of livestock access to the river ('No Livestock', 'No Access', 'Drinking Bay' or 'Unrestricted Access') to have a significant effect on the FIO concentrations in water samples at the study sites during both base flow and high flow

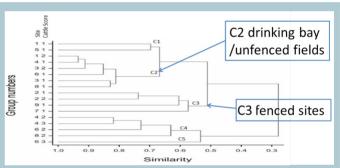


Figure 9 Percentage similarities as clusters for each faecal indicator organism (FIO) sampling site. Group numbers are expressed as sample site number (N total=162) and cattle score (e.g. site number 3 cattle score 1, as 3 1). Cattle scores were given as (1=cattle absent; 2=cattle present; 3=cattle in stream) and all were scored immediately after water sample collection. Clusters of similar groups are labelled as cluster 1 (C1), cluster 2 (C2) etc.

events, broadly in keeping with the results from 2013. Our main findings so far suggest that:

- High *E. coli* concentrations are associated with grazing livestock having direct entry to the stream
- Fenced fields significantly decrease FIO concentrations (CFU/100 ml; p<0.05)
- An improvement was observed with all pollution parameters (Log₁₀ transformation of *E. coli*, intestinal enterococci, TN and TP) in drinking bays compared to unfenced sites.

So what? Reducing livestock access to streams and rivers is highly beneficial to reducing FIOs and should be encouraged. We will be continuing our evaluation of the effectiveness of measures and using information and research findings from other sources (e.g. modelling study from the Cloud to Coast project) to develop better guidance.

Case Study 9: How can 'slowing the flow' help diffuse pollution mitigation?

The challenge: Baseline monitoring indicates that the highest concentrations of pollutants can be delivered to the stream network during rainfall-runoff events. Specific surface runoff pathways and field drains tend to be the main routes and therefore need to be targeted for mitigation.

The mitigation trial: We constructed a number of runoff detention features in the Newby Beck sub-catchment (Eden) and instrumented the watercourse with a network of level-triggered automatic water samplers. These were located directly upstream and downstream of features to capture changes in pollutant concentration, principally during storm events. We analysed the samples for concentrations of suspended solids (SS), total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate-nitrogen (NO $_3$ -N) and ammonium-nitrogen (NH $_\Delta$ -N).

Effectiveness of mitigation: Figure 10 shows SRP (10b) and NO₃-N (10c) data we collected from a small ($\approx 10 \text{m}^3$) instream detention feature during a 24-hour storm event in January 2015. Table 2 contains the mean concentration change data (between upstream and downstream, as a percentage) for each nutrient pollutant, showing that all concentrations were reduced by approximately 30-40%.

So what? Early results suggest that this approach has great potential to reduce the losses of various diffuse pollutants via surface pathways.

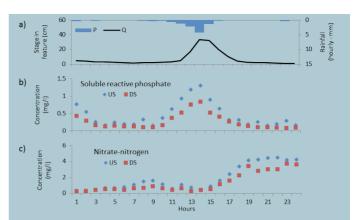


Figure 10 Storm event data collected hourly from a runoff detention feature in January 2015, including: a) rainfall and water level in the feature; and simultaneous upstream (US) and downstream (DS) concentrations of b) soluble reactive phosphorus and c) nitrate-nitrogen.

Table 2 Runoff detention feature mean pollutant concentration changes during a storm event (January 2015)

Pollutant	Mean percentage change in concentration (- equates to reduction)
TP	-28
SRP	-39
NO ₃ -N	-27
NH ₄ -N	-31



Small ($\approx 10\text{m}^3$) instream detention feature from which soluble reactive phosphorus and nitrate-nitrogen data were collected (Eden)

Three-celled detention feature in the Newby Beck catchment (Eden)



Summary of Current Findings and Experience Gained from DTC Phase 1

The first phase of DTC brought together three multi-disciplinary research consortia around a set of central objectives. We set up four outdoor laboratories, in study catchments, establishing a baseline, building relationships with local and national stakeholders, and undertaking research. There is still some way to go to understand how effective combinations of mitigation measures are at local or whole catchment scales. Answers to policy and operational questions take time if there is to be a degree of certainty about them. Nevertheless, the programme has reached a number of conclusions concerning the dominant sources in each of the DTCs, including the range of nutrient chemistries mobilised; the timing of sediment and nutrient export from land to water; and the consequential impact on stream ecosystems in each of the catchments.

The Agricultural and Environmental Data Archive platform, managed by the Freshwater Biological Association, is being used to store the wealth of monitoring data that the DTCs are producing and make them available for others to access and use in the long-term.

Understanding the Problem

• Inter-annual variability in the hydrology, water quality and ecology is strongly influenced by rainfall patterns. This means that monitoring water chemistry alone to verify the efficacy of mitigation measures will always carry a degree of uncertainty over anything less than 10-20 year timescales. The techniques developed and tested in the DTCs provide the elements of a toolkit to gather the evidence needed to assess the main pressures and effectiveness of measures in catchments. Modelling will play an important role in interpreting the long-term impact of different measures, and is essential in scaling up the effects from the sub-catchment to the full catchment scale.



Storm events are highly important in driving the flux of diffuse pollution in catchments where there is a high proportion of rapid runoff in preferential flow pathways. The importance of a relatively few storm events in transporting the majority of sediment and associated adsorbed pollutants (e.g. up to 90% of sediment and 75% of phosphorus in the Eden sub-catchments are transferred in high flows) has profound implications for the design of mitigation features and catchment management planning. The same applies to dissolved nitrogen species in surface water dominated catchments, especially when the timing of fertiliser applications corresponds to saturated soil conditions. Where groundwater is a significant component of baseflows in streams and rivers, storm events become less influential. It is therefore important to understand the character of any catchment before embarking on a mitigation strategy. In surface water catchments, mitigation should focus on breaking up pollution pathways. In groundwater-dominated catchments, mitigation should focus on tackling sources.

- Nutrients (N and P) and fine sediment were identified as the two most prevalent contaminants causing sites to fail to achieve WFD Good Ecological Status at all of the DTC sites.
- Ecological and water quality monitoring based on single season sampling may conceal important temporal dynamics over seasonal cycles in flashy upland headwaters, but also between contrasting years where hydrology and hydrochemistry vary markedly. For example, on the Wensum there was a 5-6 fold difference in nitrate and phosphorus losses between autumn 2011 and autumn 2012.
- The form of nutrient flux from land to stream differs. depending on the type and intensity of farming practice. Organic fractions make up at least half of the total nutrient flux in livestock dominated catchments, while particulate fractions are dominant in eroding landscapes. Mitigation measures selected based on soluble inorganic nutrient flux data may underestimate the scale of enrichment and lead to inaccurate targeting of mitigation efforts.



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• When investigating a new catchment, the most important things to consider when identifying pollution risk are pollutant sources, forms of mobilisation, hydrological pathways and the delivery mechanism to receiving water bodies. Non-agricultural sources of pollution can be equally significant, even in very rural catchments. Effective catchment management approaches need to take into account sources such as septic tanks and eroding road verges.

Building Stakeholder Consensus

- During phase 1 each of the DTCs successfully built networks of local partners. Three factors that have been particularly important for these achievements are:
 - * Recognising the local setting each of the DTCs operates in a very different environment regarding physical characteristics, the nature of the farm businesses (in terms of type of farming operations, size and profitability) and the presence of other organisations (river trusts, water companies etc.)
 - * *Utilising knowledge brokers* reflecting the differences in setting, each of the DTCs has required individuals who can act as intermediaries between the research team, the farming community and other stakeholders
 - * Having ime to build relationships and trust each of the DTCs has a background of previous research in their catchment, but in all cases it took at least two years to get locally known and begin to receive requests to participate in other events and activities. It is a distinct advantage of the research platform concept that it provides the necessary timescale for such relationships to evolve.



- The baseline farm survey in 2012-13 provided awareness regarding the current uptake of mitigation measures by farmers and their attitudes to future adoption of measures. The findings have provided insights relevant to the formulation of agri-environmental policy and also informed the selection of mitigation measures for detailed evaluation.
- Since the DTCs were established there has been substantial promotion of the catchment-based approach (CaBA) and a growing prominence of river trusts. The DTC study catchments vary between those where river trusts are well-established (the Eden and Tamar) and



those where such organisations are a much more recent development (the Avon and Wensum). Nevertheless, the growth in activity across all four catchments has been substantial, and it has become apparent that there is an important role for the DTCs to support such organisations with scientific and technical expertise. Examples of such collaboration have occurred through the involvement of the DTCs in the Evidence and Impacts forum of the Saving Eden coalition and the Broadland Rivers Catchment Plan. This trend is expected to continue, and it is likely that more future DTC knowledge exchange activities will be embedded amongst those of other organisations (e.g. participating in meetings or initiatives which they arrange) rather than stand-alone events. These partners will include river trusts, Catchment Sensitive Farming and other organisations involved in on-farm advice (e.g. agronomists, environmental non-government organisaations (NGOs) and water companies).

Testing Mitigation Measures

- Effective mitigation approaches try to adopt, where possible, the reduction of sources and the mitigation of mobilisation and delivery from farmyard and field to surface water. Mitigation measures are different and bespoke to suit local conditions, with inherent or built-in capacity to operate and function successfully across a range of weather conditions.
- High concentrations of pollutants are delivered to streams via surface pathways and field drains during rainfall-runoff events. Emerging results show that instream detention features provide an effective way to reduce the losses of diffuse pollutants via these routes and decrease their impact on downstream systems.
- Cover crops (e.g. oilseed radish) are a key on-farm mitigation measure that can effectively reduce nitrate concentrations in water draining from planted soils, and can also increase subsequent crop yields. This renders the adoption of cover crops for mitigating diffuse nitrate pollution in arable rotations a viable and practical option.
- Many seemingly surface water dominated catchments have complex shallow groundwater systems that can affect pollution movement, which implies a

wide range of travel times for pollutants from source to receptor. An understanding of underlying geology is essential to mitigate groundwater as both a receptor of diffuse pollution and a pathway to surface waters and wetlands, and unless flow routes are fully characterized, it will be difficult to gauge the success of control measures in the short term. For example, in the chalk catchments of the Wensum, more than 90% of streamflow is routed through the groundwater aquifer, and

year round management of runoff pathways during storm events and subsurface pathways is required.

• Because of the varying speed of nutrient flows, seeing a catchment scale response to positive mitigation action may be delayed longer than would be ideal for demonstration purposes. Expectations need to be managed accordingly!

DTC Phase 2 Objectives

Phase 2 of DTC runs from April 2015 to September 2017 and will focus on four main research themes, designed to provide policy support for Defra:

- Ongoing characterisation of the experimental target sub-catchments and iterative conceptual modelling
 - * to provide robust evidence on the key sources, delivery pathways, magnitude and timings of impact (biophysical and ecological) of agricultural pollutants, together with corresponding environmental damage costs
- Ongoing implementation and testing of on-farm interventions
 - * to provide robust evidence on the efficacy of individual on-farm measures for water pollution control (nutrients, sediment, FIOs, pesticides) and the protection of aquatic ecology, as well as bespoke suites of on-farm measures designed on the basis of a 'treatment-train' approach for the experimental test landscapes
- The socio-economics of on-farm mitigation for diffuse pollution control
 - * to provide robust evidence on the key motivations for, and barriers preventing, uptake of on-farm interventions for water pollution control, as well as updated costs for the implementation and maintenance of priority measures available to farmers
- Monitoring and evaluation techniques for assessing the efficacy of on-farm interventions using biophysical and socio-economic data in an iterative 'weight-of-evidence' approach
 - * to provide robust advice on techniques (e.g. high and low tech) for assessing the efficacy of on-farm measures for improving water quaility and aquatic ecology, as well as developing an iterative 'weight-of-evidence' approach for synthesising the outcomes of targeted on-farm interventions along a timeline designed to keep farmers and other stakeholders engaged in catchment-based work, focusing on the protection of water quality and aquatic ecology



Socio-economic aspects of integrated catchment management and supportive research will be more prominent than in phase 1, and there will be particular priorities to:

- address a series of emerging policy-relevant questions concerning current and future potential uptake of on-farm interventions and their integration into potential new policy packages and instruments
- support the on-farm measures work, particularly through the provision of updated economics data, to allow the impact of interventions on farm businesses to be assessed explicitly, as well as cost-benefit analyses for the experimental landscapes, the entire DTCs and nationally
- collect information and develop analytical approaches that will allow upscaling and extrapolation of the local findings to regional and national scales on the basis of the new Catchment Matcher framework, as well as modelling tools/frameworks being constructed, refined and used by the DTC consortia
- provide a sounding board on topics relevant to policy development on water quality and aquatic ecology

Deliverables

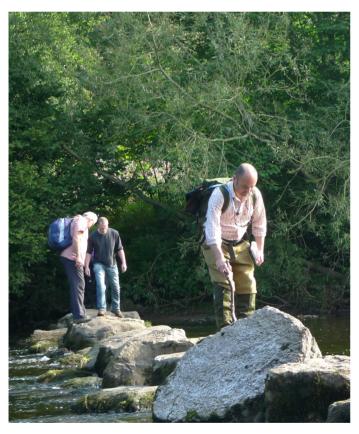
The DTCs will generate a set of catchment case-studies capturing learning points. Through a parallel project, Catchment Matcher, we intend to provide a framework for extending the learning points from the DTCs to most other catchments containing similar farming systems, climate and topography, comprising about 80% of English farms.

Beneficiaries of DTC Phase 2 Outputs

The DTCs will continue to provide a multitude of benefits to a range of parties operating at different stages in the policy cycle, including: (1) those re-designing and developing policy; (2) those delivering policy (government agencies and NGOs); (3) stakeholders on the receiving end of policy; and (4) those funding or undertaking research to inform catchment science and corresponding strategic policy.

1. Informing and supporting policy

We will continue to provide scientifically robust, peer reviewed and internationally recognised research to improve the credibility of our evolving UK evidence base on integrated catchment management for agricultural diffuse water pollution mitigation for stakeholder and policy audiences, including the European Commission and Defra.



2. Supporting policy delivery

We will continue to provide a national resource for a rapidly growing community of practitioners and stakeholders from local to catchment to strategic scales. These stakeholder groups require compelling evidence and guidance on the effectiveness of on-farm interventions to combat water pollution and its impacts on aquatic ecology and the processes to target them most effectively. Equally, in a two-way process, stakeholder groups have provided DTC researchers with opportunities to test on-farm mitigation options.

3. Demonstrating to industry and stakeholders

We will continue to provide four regional landscape scale demonstration hubs to show how farming can be carried out in ways that help reduce diffuse water pollution and its degradation of aquatic ecology. Each is well networked with local stakeholder groups (agricultural colleges, rivers trusts, local farming groups, NGOs, etc.) who contribute to the DTCs and draw heavily on their emerging findings. Strong local and national stakeholder relations have been established. The direct involvement of farmers in the research adds a sense of reality, practicality and credibility to the findings for both local and national level agricultural industry stakeholders.



4. Research funders and scientists

We are helping improve the national capacity for translational (policy-relevant) research on land-water/ catchment management and to consolidate a previously fragmented UK catchment science community. By bringing these catchment science groups together with policy makers, delivery bodies, and local and national stakeholders, it allows researchers a more direct route to influence both policy and practice (thereby increasing their impact). The DTCs are currently hosting ~£7.5M of additional research funded by the Research Councils UK (RC-UK), the British Geological Survey, UK Water Industry Research (UKWIR) and the Environment Agency. The DTCs have helped strengthen linkages between Defra and other funders of research, especially providing the research councils with a vehicle of translation to improve the pathways to impact of the work they fund. The DTC data archive will make our data freely available to any researchers/stakeholders requiring it and the high-resolution data will support evolving research on catchment pollutant transfer processes and modelling into the future.

Selected Publications

- 1. Allen DJ, Darling WG, Davies J, Newell AJ, Gooddy DC and Collins AL (2014). Groundwater conceptual models: implications for evaluating diffuse pollution mitigation measures. Quarterly Journal of Engineering Geology and Hydrogeology 47: 65-80
- 2. Collins AL (2015). A short primer on sediment source fingerprinting for Catchment Sensitive Farming Officers. Final report to Environment Agency, April 2015
- 3. Collins AL, Stutter M and Kronvang B (2014). Mitigating diffuse pollution from agriculture: international approaches and experience. Science of the Total Environment 468-469: 1173-1177
- 4. Collins AL, Zhang Y, Hickinbotham R, Bailey G, Darlington S, Grenfell SE, Evans R and Blackwell M (2013). Contemporary fine-grained bed sediment sources across the River Wensum Demonstration Test Catchment, UK. Hydrological Processes **27**: 857-884
- 5. Cooper RJ, Krueger T, Hiscock KM, Rawlins BG. 2015a. High-temporal resolution fluvial sediment source fingerprinting with uncertainty: a Bayesian approach. Earth Surface Processes and Landforms 40: 78-92
- 6. Cooper RJ, Pedentchouk N, Hiscock KM, Disdle P, Krueger T, Rawlins BG. 2015b. Apportioning sources of organic matter in streambed sediments: An integrated molecular and compound-specific stable isotope approach. Science of the Total Environment 520: 187-197
- 7. Cooper RJ, Krueger T, Hiscock KM, Rawlins BG. 2014b. Sensitivity of fluvial sediment source apportionment to mixing model assumptions: a Bayesian model comparison. Water Resources Research 50: 9031-9047
- 8. Cooper RJ, Rawlins BG, Leze B, Krueger T, Hiscock KM. 2014a. Combining two filter paper-based analytical methods to monitor temporal variations in the geochemical properties of fluvial suspended particulate matter. Hydrological Processes **28**: 857-884
- 9. Gooday RD, Anthony SG, Chadwick DR, Newell-Price P, Harris D, Deuthmann D, Fish R, Collins AL and Winter M (2014). Modelling the cost-effectiveness of mitigation methods for multiple pollutants at farm scale. Science of the Total Environment 468-469: 1198-1209
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- 11. Lloyd CEM, Freer JE, Collins AL, Johnes PJ, Jones JI (2014). Methods for detecting change in hydrochemical time series in response to targeted pollutant mitigation in river catchments. Journal of Hydrology 514: 297-312
- 12. McGonigle DF, Burke SP, Collins AL, Gartner R, Haft MR, Harris RC, Haygarth PM, Hedges MC, Hiscock KM, and Lovett AA (2014). Developing Demonstration Test Catchments as a platform for transdisciplinary land management research in England and Wales. Environmental Science: Processes & Impacts 16: 1618-1628
- 13. Outram FN, Lloyd CEM, Jonczyk J, Benskin CMCWH, Grant F, Perks MT, Deasy C, Burke SP, Collins AL, Freer J, Haygarth PM, Hiscock KM, Johnes PJ, and Lovett AA (2014). High-frequency monitoring of nitrogen and phosphorus response in three rural catchments to the end of the 2011-2012 drought in England. Hydrology and Earth System Sciences 18: 3429-3448
- 14. Owen G, Perks M, Benskin CM^cWH, Wilkinson M, Jonczyk J, Quinn P (2012) Monitoring agricultural diffuse pollution through a dense monitoring network in the River Eden Demonstration Test Catchment, Cumbria, UK. Area 44 (4): 443-453
- 15. Perks MT, Owen GJ, Benskin CM^cWH, Jonczyk J, Deasy C, Burke S, Reaney SM, Haygarth PM (2015) Dominant mechanisms for the delivery of fine sediment and phosphorus to fluvial networks draining grassland dominated headwater catchments. Science of the Total Environment **523**: 178-190
- 16. Roberts WM, Matthews RA, Blackwell MSA, Peukert S, Collins AL, Stutter MI, Haygarth PM (2013). Microbial biomass phosphorus contributions to phosphorus solubility in riparian vegetated buffer strip soils. Biology and Fertility of Soils 49:
- 17. Snell MA, Barker PA, Surridge BWJ, Large ARG, Jonczyk J, Benskin CM^CWH, Reaney S, Perks MT, Owen GJ, Cleasby W, Deasy C, Burke S, and Haygarth PM (2014). High frequency variability of environmental drivers determining benthic community dynamics in headwater streams. Environmental Science: Processes & Impacts 16: 1629-1636
- 18. Terry JA, Benskin CMCWH, Eastoe EF, and Haygarth PM (2014). Temporal dynamics between cattle in-stream presence and suspended solids in a headwater catchment. Environmental Science: Processes & Impacts 16: 1570-1577
- 19. Whitehead PG, Jin L, Crossman J, Comber S, Johnes PJ, Daldorph P, Collins AL, Butterfield D, Bardon R, Pope L, Willows R, Flynn N (2014). Distributed and dynamic modelling of hydrology, phosphorus and ecology in the Hampshire Avon and Blashford Lakes: evaluating alternative strategies to meet WFD standards. Science of the Total Environment 481: 157-166
- 20. Yates CA and Johnes PJ (2013) N speciation and P fractionation dynamics in a lowland chalk catchment: the Upper Wylye. Science of the Total Environment 444: 466-479
- 21. Zhang Y, Collins AL and Gooday RD (2012). Application of the FARMSCOPER tool for assessing agricultural diffuse pollution mitigation methods across the Hampshire Avon Demonstration Test Catchment, UK. Environmental Science and Policy 24: 120-131

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Useful web links:

A regular newsletter updates a wide range of interested parties on progress.

The latest newsletter can be viewed here:

http://www.demonstratingsatshmentmanagement.net/up.gentent/up.

http://www.demonstratingcatchmentmanagement.net/wp-content/up-loads/2015/04/DTC-Newsletter-Mar-2015.pdf

The DTC monitoring data is contained in an accessible archive here: www.environmentdata.org

DTC Consortia - to find out more please visit: http://www.demonstratingcatchmentmanagement.net/

National DTC Conference 10th June 2015 Stoneleigh Park, Warwickshire