Demonstration
Test
Catchments

SCIENCE, POLICY AND PRACTICE NOTE 2

Holistic monitoring needed to underpin effective pollution mitigation

The issue

Nutrient enrichment of inland and coastal waters is a growing global problem with significant adverse effects on both human health and the landscape. Existing UN and EU policies require effective monitoring to identify pollution sources for mitigation. Despite this nutrient pollution remains a problem with substantial implications for the public purse and the living world.

Our work has highlighted the need to monitor the full range of nutrient forms in waters, at a higher frequency than is currently undertaken, to understand the nature and origins of nutrient pollution in catchments. Consequently, we will then be able to implement appropriate, targeted mitigation measures to tackle the problems nutrient pollution generates for ecosystem and human health.

Recent research evidence data from the Demonstration Test Catchments (DTC)

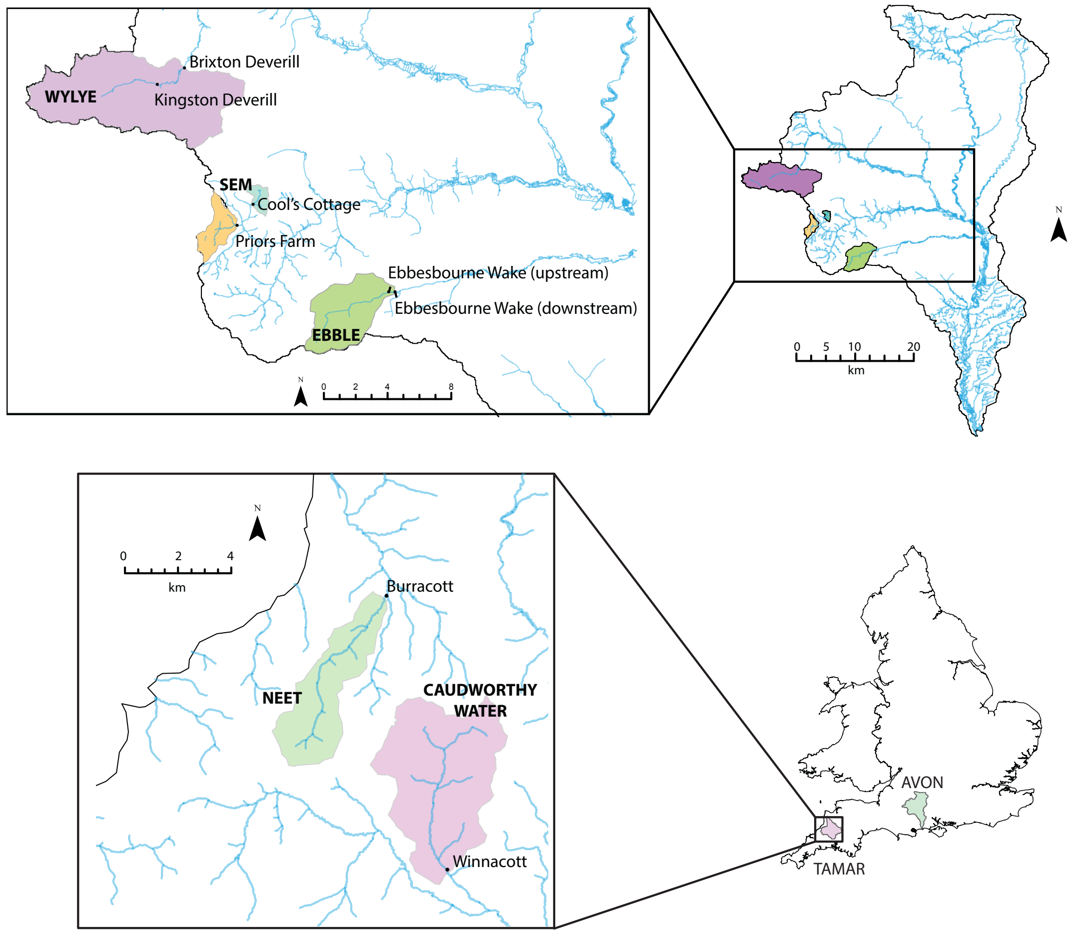

Figure 1: Monitoring of nutrient and sediment fluxes from land to water in the Hampshire Avon and Tamar DTCs which support different types of farming system: intensive cereal cropping/mixed farming on chalk soils (Wylye and Ebble subcatchments, Hampshire Avon) and intensive livestock/ mixed production on clay soils (Sem subcatchment, Hampshire Avon; Tamar).

Between 2011-2014, samples were collected at daily and sub-daily frequency and analysed to determine the full range of nutrient pollutants flushed to multiple sites within the Hampshire Avon and Tamar drainage networks from sources in their catchments. Rainfall and river discharge were also measured, allowing calculation of the total load of each nutrient form in the river at each site. This allowed a holistic assessment of the total nutrient load moving into and through each water system, and the likely origins of this material within the landscape at each site.

What is nutrient cycling?

All living organisms need carbon, nitrogen and phosphorus to sustain life. These are referred to as essential or limiting nutrients. A nutrient cycle refers to the use, cycling, uptake and transfer of nutrients in the environment.

Nitrogen and Phosphorus cycling

Nitrogen (N) is needed to create amino acids, the building blocks of all animal and plant protein. The largest store of N is as N_2 gas in the atmosphere. Soil Bacteria convert this N_2 gas into N compounds that can be used by plants e.g. nitrate (NO_3^-), and ammonium (NH_4^+). Soil bacteria and fungi also decompose excreted organic compounds containing N such as urine, manures, slurries, as well as dead organic matter such as animals and leaf litter, recycling N for further biotic uptake. The decomposition process also builds up N in the soil organic matter. Dissolved and particulate organic nitrogen (DON, PON) are forms of N in the soil that can be readily flushed out with water flowing through the soils to streams. They can also be created instream through the uptake of all dissolved N forms by the biota and their subsequent breakdown by microbial action, releasing fresh DON and PON into the water column. Both DON and PON can be taken up directly by the biota. Similarly, excess N added directly to the soil as either an inorganic fertiliser, or DON and PON in the form of slurries and manures can be washed from the land into streams.

Phosphorus (P) is needed as a key element of DNA, nucleic acids, the sugar phosphate (ATP) backbone that holds the DNA helix together, and as a key element in phospholipids which form all cell membranes in plants and animals. Only a limited amount naturally occurs in the soil via the decomposition of dead organic matter, or much more slowly by weathering of P minerals in rocks. As for N, excess forms of P are added to the soil as either an inorganic fertiliser or organic slurries and manures. P may be flushed to streams from P-enriched soils as dissolved inorganic (PO_4^{3-}, P_2O_5) or dissolved organic P (DOP), or delivered in the form of particulate P (PP) as soils erode. If these P-enriched soil particles are eroded from bare agricultural land e.g. freshly tilled fields (arable systems) or grasslands poached by livestock, they are transported to streams, where the particulate P can be released into the water column as inorganic phosphate. All P and N forms can be taken up by the biota, generating the adverse impacts on ecosystem health associated with the process of eutrophication.

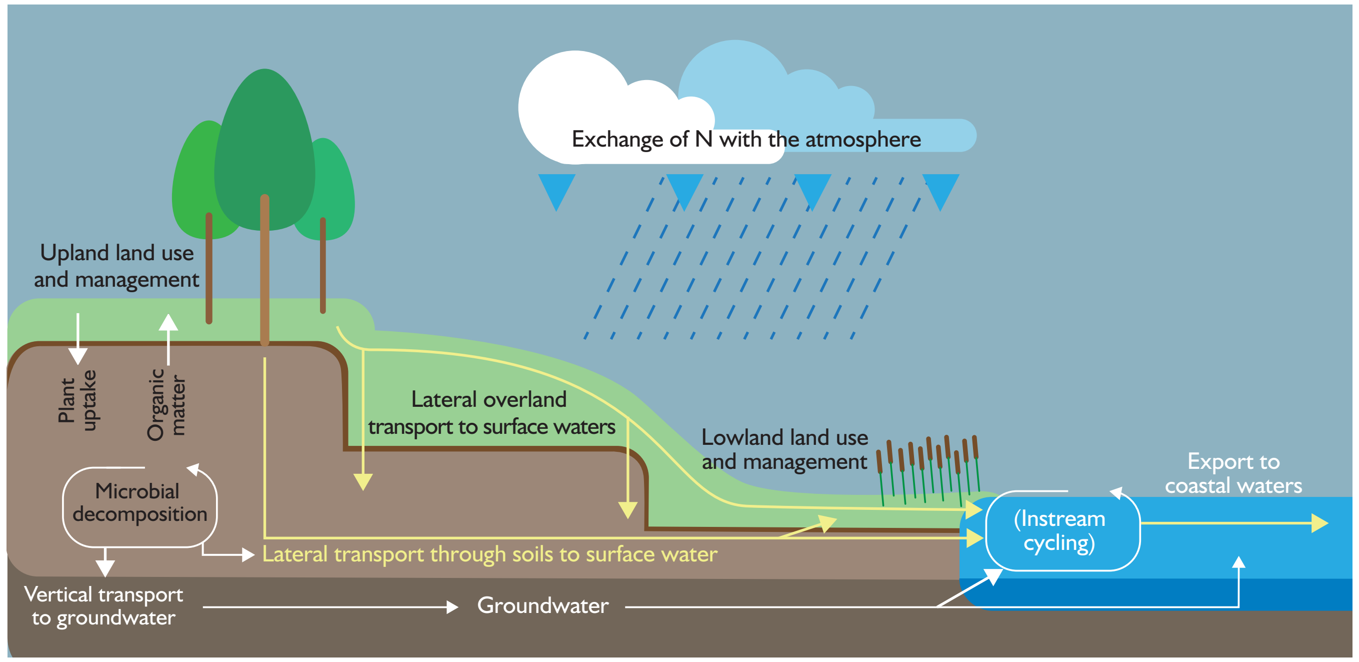

Figure 2: How pollutants flow through the landscape.

The impact of agriculture on nutrient cycling

Modern farming practices rely on fast growing crops which require readily available soil nutrients for growth. Typically, the demand for meat is achieved through Intensive livestock farming. Consequently, animal manures and urine are directly passed onto the soils or collected in yards and applied as a slurry or manure to agricultural land. Many farmers, however, fail to take into account the nutrient content of these organic additions when calculating the inorganic fertiliser application rate for crops and grass and continue to apply high loadings of inorganic fertilisers. Subsequently, the quantity of nutrients outstrips the crop's demand, leading to the excess nutrients being flushed out of the soil during periods of rainfall, either in a soluble form, or attached to eroded soil particles. These mobilised nutrients may leach downward into groundwater aquifers or move laterally into surface waters such as streams, rivers and lakes. Applying fertilisers or manures or slurries during periods of wet weather or very close to watercourses further increases the risk of nutrient export to waters.

The rate at which nutrient fractions flush from their sources in catchments to adjacent waterbodies depends on the:

- **Climate:** how often there are sudden intense rainfall events which have the energy to move large quantities of nutrients and sediments from land to water
- **Geology:** how permeable the rock is and whether there is an aquifer which might reduce the amount of water running quickly from land to stream during rainfall events
- **Soils:** how wet soils are, their exposure to rainfall, their binding capacity and water storage capacity, and their susceptibility to erosion
- **Topography:** how steeply sloping the land is, and how well-connected distant areas of land are to the stream network and
- **Land use:** whether there is crop cover all year round, the nature and intensity of crop production, the nature and timing of fertiliser applications to the land surface, the stocking density and manure/slurry management regime.

As a result, there are varying sources, chemistries and characteristics of nutrient pollution in catchments with differing environmental character.

While the geoclimatic character of a landscape cannot be controlled, we can strongly influence how we use and manage the land, and thus control the nature, rates and timing of pollutant flux within a catchment. First, we need a better understanding of the interaction between the environment, land use and management in creating the particular rates and chemical nature of the nutrient pollution in any catchment. Then we can identify the most effective methods of measuring and mitigating pollutant flux in that landscape.

The Demonstration Test Catchments (DTC) programme focused on assessing these fluxes in the different types of intensive farming system practiced in catchments with different environmental character (Figure 1). The particular combinations of farming type and environmental character were selected to represent conditions typically found across much of lowland Britain, allowing the findings from this work to be extrapolated to other unmonitored locations.

Sources of nutrient and sediment flux to waters in intensive arable farming catchments


Fertiliser application rates and practices to crops and grass


Bare arable soils in the winter months


Rill and gully formation on steep, cultivated slopes


Strip grazing of fodder crops


Cultivation practices: ploughing downslope


Field drain and ditch discharge to rivers

Sources of nutrient and sediment flux to waters in intensive livestock farming catchments

Leakage from slurry lagoons

Over-full FYM store

Run-off from dirty yards

Drain connecting dirty farm yard to ditch

Ditch run-off from farm yard to stream

Excessive slurry applications

Farm track channelisation

Lessons learnt

Catchment character determines the nature and timing of nutrient flux to waters. It also determines the nature and rate of the ecosystem response to pollution mitigation measures. Specifically:

- Chalk catchments supporting intensive arable/mixed farming show slow responses to heavy rainfall, with most of the rainfall travelling to streams via slower groundwater flow pathways. In this investigation, N flux was dominated by nitrate leaching from soils to groundwater, while P delivery to waters was dominated by the erosion of P-rich soils from arable land. P-rich fine sediments stored in the gravel bed in chalk streams contributed to significant adverse ecosystem impacts on aquatic plant, insect and fish health.

- Clay catchments, typically supporting intensive livestock farming, have less water percolating through the heavy soils as the rate of infiltration is slow. Instead, most of the water runs over the soil surface or through field drains, generating relatively rapid delivery of manures, slurries and eroded organic and nutrient-rich soil to adjacent waters. N and P delivery to the streams is then dominated by particulate and organic matter, and this contributes significantly to ecosystem degradation in these waters, stimulating microbial activity in the stream which saps the oxygen needed to support animal life. Similar impacts of nutrient enrichment on aquatic plant health to those observed in chalk streams also arise.

High-resolution monitoring over a 3-year period also showed strong inter-annual variation in both the rate and composition of nutrient flux to waters within any catchment, as well as between catchments of different character. The evidence collected highlighted the large amount of nutrient flux to waters that would be missed in any lower-frequency (weekly, monthly) monitoring programme. This highlighted the need for long term monitoring at high frequency to be able to isolate any response to pollution mitigation measures from natural variations in catchment behaviour.

The evidence also highlighted the high proportion of nutrient loading that is delivered to waters in forms that are not typically determined in routine water quality monitoring programmes. In particular, particulate N and P forms in chalk catchments, and dissolved and particulate organic N and P forms in clay catchments form a substantial portion of the total nutrient load generating adverse impacts on ecosystem health in these systems. Analysis of the data collected from the DTC catchments demonstrates that daily long-term monitoring of all nutrient fractions is essential to capture a representative picture of the total nutrient loads driving ecosystem degradation in rural catchments, and to generate the robust evidence needed to underpin effective targeting of pollution mitigation efforts.

Opportunities for Policy and Practice

Livestock farming generates multiple forms of nutrient pollution in waters, both inorganic and organic in nature, which puts the whole ecosystem under stress. By contrast, arable cropping typically generates a higher proportion of inorganic nutrient flux to streams, with nitrate-N and particulate P as key forms of N and P delivered to streams from agricultural sources in these catchments. By focusing on the full spectrum of nutrient forms and sediments that flush from land to water, the DTC programme has demonstrated the need to develop different suites of on-farm mitigation measures for different farming systems and environments.

Successful pollution mitigation requires the control of multiple pollutants from a variety of sources. This includes the management of nutrient pools accumulated in agricultural soils, aquifers, wetlands, stream sediments and life within the catchment. Current policy does not meet this need.

The response of any catchment and its aquatic ecosystem to mitigation measures will vary according a range of factors including:

- the scale of the enrichment problem relative to unpolluted conditions
- the size of the nutrient pools accumulated to date within the system
- the speed at which water flows through the catchment and the connectivity of flow pathways with these pools
- the scale and targeting of the mitigation effort

Finally, it is important that expectations and outcomes are managed. Farmers are more likely to engage positively with pollution mitigation methods if they feel that the science justifies their efforts, and if the impact is realised in the short term. However, in many systems it may take years, even decades, before any visible effect is seen, particularly in slow response systems with significant accumulated nutrient pools within the catchment. Farmers, practitioners and scientists need to work together to better understand the scale of the nutrient enrichment problem, the causes of this flux from land to water, and the likely response time of the ecosystem to any mitigation efforts. This will allow optimisation of beneficial practices, maximising mitigation engagement and generating effective outcomes for private and public goods and for the environment.

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Further Resources

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Acknowledgements

The Demonstration Test Catchment (DTC) project (Defra projects WQ02010, WQ2011, WQ02012 and LM0304) is a multi-partner collaborative research programme comprising academics, farmers, industry experts, environmental organisations and policymakers. DTC explores solutions to improving water quality in agricultural landscapes. The effects of different mitigation measures have been monitored from 2010/11 - 2017 in four river systems: Eden (Cumbria), Avon (Hampshire, Wiltshire), Wensum (Norfolk) and Tamar (Devon/Cornwall). As these catchments represent major UK soil/rainfall combinations found on typical English and Welsh farms the data collected from this work can be applied to other locations.

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More Information

Visit: **www.demonstratingcatchmentmanagement.net**

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