# CATCHMENT SCIENCE 2015

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# INTRODUCTION

Food production and environmental stewardship continue to be essential considerations from local to global scales. Food production for a growing world population and how this interfaces with the needs of a clean water resource and healthy biodiversity, and in the face of a changing climate is a challenge across the science-policy-industry-consumer spectrum. For agriculture, the key challenge is for sustainable intensification.

In ***Catchment Science 2015***, hosted by the Teagasc Agricultural Catchments Programme in Wexford, Ireland, we consider some of these challenges within the scope of water quality management in agricultural landscapes. We draw on experiences from international science and policy programmes, and advisory and stakeholder engagement initiatives.

Five inter-related themes provide a framework for this international symposium:

**Detecting change and lag times - patience and policy implementation**

Agri-environmental nutrient measures are required to fit into a Driver-Pressure-State-Impact-Response (DPSIR) framework of improving water quality or to provide evidence of at least no change to acceptable water quality status. We explore evidence-based examples of positive outcomes to policy measures and also confounding influences that require further consideration in policy reviews.

**Integrated management, stakeholder engagement and catchment economics**

Sustainable intensification of agriculture requires consideration of environmental and economic objectives. We highlight monitoring and modelling approaches to achieve these objectives showing if and where trade-offs could occur. Additionally, we showcase initiatives to promote the adoption of best management practices among the diverse farming population at farm and catchment scale.

**Soil analysis and nutrient management – achieving environmental and agronomic goals**

Fertiliser recommendations aimed at reducing the risk of nutrient loss to water while addressing production needs are based on soil analysis and adaptive nutrient management strategies. We highlight the soil parameters and nutrient management approaches needed to improve nutrient use efficiency and deliver a win-win - improved water quality and profitable production.

**Adaptive management approaches to reducing nutrient loss risk**

The majority of catchment scale nutrient transfers occur from a small proportion of catchment areas during a few storm events. We explore the latest developments in the identification and management of critical source areas and critical source times of nutrient transfer in agricultural catchments.

**Disentangling the impact of multiple stressors on aquatic ecology**

Achievement of water quality objectives requires an understanding of the links between land management, water chemistry and ecological quality. We explore the impact of nutrient and sediment dynamics in headwater streams on biological water quality indicators from a range of point, diffuse, acute and chronic pressures.

Catchment Science 2015

Agricultural Catchments Programme – Teagasc

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# REFERENCES

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**ENQUIRIES**

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# PROGRAMME OF SPEAKERS

**SESSION 1: Detecting change and lag times - patience and policy implementation**

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|---|---|
| - **Dr Nicholas Howden**, | University of Bristol, UK. |
| - **Dr Per-Erik Mellander**, | ACP, Teagasc, Ireland. |
| - **Dr Alice Melland**, | University of Southern Queensland, Australia. |
| - **Dr Paul Murphy**, | University College Dublin, Ireland. |
| - **Prof Andrew Wade**, | University of Reading, UK. |
| - **Dr Faye Outram**, | University of East Anglia, UK. |
| - **Dr Rachel Cassidy**, | Agri-Food and Biosciences Institute, UK. |
| - **Mr Eoin McAleer**, | ACP, Teagasc, Ireland. |

**SESSION 2: Integrated management, stakeholder engagement and catchment economics**

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|---|---|
| - **Prof Cathal O'Donoghue**, | Teagasc, Ireland. |
| - **Dr Dennis Collentine**, | University of Gävle, Sweden. |
| - **Dr Micheál Ó'Cinnéide**, | Director, EPA, Ireland. |
| - **Dr Stina Olofsson**, | Swedish Board of Agriculture. |
| - **Dr Cathal Buckley**, | ACP, Teagasc, Ireland. |
| - **Mrs Sharon Morrell**, | Massey University, New Zealand. |
| - **Mr Dermot Leahy & Mr John Walsh** | ACP Advisor, Teagasc, Ireland and ACP Catchment Farmer. |

**SESSION 3: Soil analysis and nutrient management – achieving environmental and agronomic goals**

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|---|---|
| - **Dr Jaap Schröder**, | Wageningen University, Netherlands. |
| - **Dr Noeleen McDonald**, | ACP, Teagasc, Ireland. |
| - **Dr Tim Sheil**, | Alltech Bioscience Centre, Ireland. |
| - **Mr Bernard Simmonds**, | AgResearch, New Zealand. |
| - **Dr William Roberts**, | Teagasc, Ireland. |

**SESSION 4: Adaptive management approaches to reducing nutrient loss risk**

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|---|---|
| - **Dr Mairead Shore**, | ACP, Teagasc, Ireland. |
| - **Dr Ranvir Singh**, | Massey University, New Zealand. |
| - **Dr Faruk Djodjic**, | Swedish University of Agricultural Sciences. |
| - **Mr Remi Dupas**, | INRA, France. |
| - **Mr Ian Thomas**, | ACP, Teagasc, Ireland. |

**SESSION 5: Disentangling the impact of multiple stressors on aquatic ecology**

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|---|---|
| - **Prof Adie Collins**, | Rothamsted Research, UK. |
| - **Dr Maria Snell**, | Lancaster University, UK. |
| - **Ms Kirsty Ross**, | Lancaster University, UK. |
| - **Dr Miriam Glendell**, | University of Exeter, UK. |
| - **Ms Sophie Sheriff**, | Teagasc, Ireland. |
| - **Dr Sorcha Ni Longphuirt**, | EPA, Ireland. |

# SPEAKER ABSTRACTS

# DAY 1 - SESSION 1
## Detecting change and lag times - patience and policy implementation

## Short-term (<5 yr) decisions and long-term (>15 yr) responses of catchment systems

**Nicholas Howden**

*Faculty of Engineering, University of Bristol, Bristol, UK*

Widespread pollution of freshwater by nutrients is an externality of modern intensive agriculture. Rising nitrate and phosphorus concentrations in freshwater have been of concern throughout the developed world for several decades. Initial worries focused on human health but more recently eutrophication has also become a cause for concern. Because the impact on water quality often comes decades after land use change, the challenge for science is to produce an integrated model of catchment hydrology and quality applicable to the long time-scales involved and that can cope with the complexity of connectivity among land, aquifer, and river. Beyond this challenge is the need to use such approaches to determine how food production can be maintained whilst ensuring minimal damage to downstream ecosystem services.

This presentation will discuss the balance between food production, and therefore food security, reasonable disposal of wastewater effluent, and protection of both ground and surface water resources. Results from 140 years of data collection and a catchment-scale model of the River Thames in the United Kingdom will be used to demonstrate that the response time of catchments can be on the order of decades, given the delays induced by groundwater flow through aquifers, such that the fluvial response to land use and land management change might not be immediately evident, and perhaps not even within what would normally considered to be a lengthy monitoring period. In other cases, it will be shown that certain policy-driven interventions can be highly effective in achieving the desired outcomes, albeit at the cost of transferring the problem elsewhere.

Historically, the main drivers for changes in N and P fluxes were massive land use change associated with wartime ploughing of permanent pastures and post-war modernisation and intensification of agriculture, leading to the current quasi-steady state of N and P -dependent but leaky agriculture. This is in addition to the large increases in population and therefore domestic effluent, which flows directly to rivers from water treatment facilities with potentially limited attenuation. It is clear that restoration of water quality to pre-twentieth-century levels would require very severe changes in land use and land management, significantly affecting UK food supply and security.

The major challenge is to understand what measures we ought to consider, and how we assess the positive and negative outcomes that are likely to result from those choices.

# Large-scale fluctuations of Atlantic Ocean weather patterns and water quality in agricultural river catchments

**<u>Per-Erik Mellander</u>[1], Phil Jordan[2], Mairead Shore[1], Noeleen McDonald[1], Ger Shortle[1]**

[1]*Agricultural Catchments Programme, Teagasc, Wexford, Ireland*
[2]*School of Environmental Sciences, Ulster University, Coleraine, N. Ireland*

The influences of temporal variability of rainfall, land modification that alters hydrological pathways, associated lag times and nutrient transformations that may occur along the pathways all challenge our interpretations of the efficacy of mitigation measures for reducing nitrogen (N) and phosphorus (P) losses from agricultural sources to water bodies. The objective of this study was to assess and disentangle the natural climate effects of nutrient transfers to those occurring due to adaptive management change (e.g. increased intensity, decreased nutrient use etc.). In large parts of Europe weather patterns and trends are influenced by large-scale systems such as the North Atlantic Oscillation and the position of the Gulf Stream, the latter expressed as the Gulf Stream North Wall index (GSNW*i*). Here we present five years of monthly data of nitrate-N and total reactive P (TRP) concentrations and loads in stream water and concentrations in groundwater (aggregated from sub-hourly monitoring in the stream outlet and monthly sampling in monitoring wells) in two agricultural catchments with different hydrological flow controls. The catchments (ca. 10 $km^2$) are situated in the southeast of Ireland and are susceptible to sudden and seasonal shifts in oceanic climate patterns. Trends in N and P concentrations were compared with the annual source pressure, long-term weather data and to the GSNW*i*. Rain anomalies and soil moisture deficit dynamics were linked to the GSNW*i*. There were monitored changes in nitrate-N concentration in both groundwater and surface water with no apparent connection to agricultural management; instead such changes appeared to be linked to the GSNW*i*. For example, in the catchment with poorly drained soils and a 'flashy hydrology' there were seasonal dynamics in nitrate-N and TRP concentration that correlated with the seasonal dynamics of the GSNW*i*. In the groundwater driven catchment there was a consistent increase in nitrate-N concentration over the monitored period that may be the result of increasingly more recharge in summer and autumn. The results highlight that the large scale fluctuations of the North Atlantic weather patterns influence concentrations of N and P in groundwater and stream water, differently depending on the catchments flow controls. There is a risk that monitored changes in water quality due to nutrient management could be confounded by the effect of a larger weather cycle. These results need to be considered in the context of existing measures to mitigate diffuse pollution, possible reviews of measures and the expectation of water quality trends and targets.

## Detecting the blue shoots of recovery in agricultural catchments

**Alice Melland**[1], **Phil Jordan**[2]

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*[2]School of Environmental Sciences, Ulster University, Coleraine, N. Ireland*

Measuring the impacts of agricultural practice on catchment water quality is critical for making and implementing policies to improve surface water quality, and has been the focus of significant effort. In 17 of 24 studies of meso-catchments (1-100 $km^2$), positive water quality effects have been measured. The studies used temporal, spatial and/or cause-effect analysis to attribute changes in water quality to agricultural practice. Successful farm practices included reductions in the intensity of the farming, improved engineering and improved crop management. The successful practices normally addressed more than one of the sources, pathways, delivery or impact of the nutrient or pollutant. Positive effects occurred 1.5 to 10 years after the measures were implemented, with the response time broadly increasing with catchment size. However, it took from four to 19 years to confidently detect the effects. Policy makers and scientists should account for these lag times when setting policy and planning monitoring in meso-catchments. To successfully measure effects the rates of practice change should also be measured.

To enhance the information and knowledge that meso-catchment studies generate, catchment scientists should also explore a) practice change scenarios that are likely to be ineffective, b) the degree to which water quality targets are likely to be achieved, c) the temporal and spatial extent of practice change effectiveness, d) the potential for pollution swapping and e) the costs and benefits of agricultural practice change. Policy makers should ensure that a) water quality mitigation practices are implemented to required threshold levels, b) indicators of water quality improvement have cause-effect linkages with the changed practice, and are measured in the right place and at the right time and that c) catchment studies are able to discern 'ineffective measures' from other cases of 'no measurable effect' on water quality.

# Time lag in effects of mitigation measures on phosphorus loss across the transfer continuum in a monitored dairy grassland catchment

**Paul Murphy[1], Per-Erik Mellander[2], Alice Melland[3], Cathal Buckley[4], Mairead Shore[2], Ger Shortle[2], David Wall[5], Mark Treacy[2], Oliver Shine[2], Sarah Mechan[6], Phil Jordan[7]**

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[3]*National Centre for Engineering in Agriculture, University of Southern Queensland, Toowoomba, Australia*
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Phosphorus (P) loss from soils to water can be a major pressure on freshwater quality and dairy farming, with higher animal stocking rates, may lead to potentially greater nutrient source pressures. In many countries with intensive agriculture, regulation of P management aims to minimise these losses. In Ireland, this falls under the EU Nitrates Directive Regulations. This study examined the P transfer continuum, from source to impact, in a dairy-dominated, highly stocked, 7.6 $km^2$ grassland catchment in southwest Ireland with predominantly free-draining soils over three years. The aim was to measure the effects of P source management and regulation on P transfer across the nutrient transfer continuum and subsequent water quality and agro-economic impacts. Monitoring included farm P management, surface soil P concentrations, ground- and stream-water concentrations and stream flow. Low or reduced P source pressure was indicated by: a) low average farm-gate P balances (2.4 kg $ha^{-1}$ $yr^{-1}$), high P use efficiencies (89%) and low inorganic fertilizer P use (5.2 kg $ha^{-1}$ $yr^{-1}$) relative to previous studies, b) almost no recorded P application during the winter closed period, when applications were prohibited to avoid incidental transfers, and c) decreased proportions of soils with excessive P concentrations (32% to 24%) within the measurement period. Concurrently, production and profitability remained comparable with the top 10% of dairy farmers nationally with milk outputs of 14,585 l $ha^{-1}$, and gross margins of €3,130 $ha^{-1}$. Whilst there was some indication of a response in P delivery in surface water with declines in quick flow and interflow pathway P concentrations during the winter closed period for P application, delayed baseflows in the wetter third year resulted in elevated P concentrations for long durations and there were no clear trends of improving stream biological quality. This suggests a variable response to policy measures between P source pressure and delivery/impact where the strength of any observable trend is greater closer to the source end of the nutrient transfer continuum and a time lag occurs at the impact end. Assessment of policy effects will need to be cognisant of this lag.

# Using high-frequency water quality data to assess sampling strategies for the EU Water Framework Directive

**Richard Skeffington[1], Sarah Halliday[1], Andrew Wade[1], Michael Bowes[2], Helen Jarvie[2], Matthew Loewenthal[3]**

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*[2]Centre for Ecology and Hydrology, Wallingford, UK*
*[3]Environment Agency, Reading, UK*

This paper is concerned with the accuracy and precision with which chemical status in rivers can be measured given certain sampling strategies, and how this can be improved. High-frequency (hourly) chemical data from four rivers in southern England were subsampled to simulate different sampling strategies for four parameters used for Water Framework Directive (WFD) physico-chemical classification: dissolved phosphorus, dissolved oxygen, pH and water temperature. These data sub-sets were then used to calculate the WFD classification for each site. Monthly sampling was less precise than weekly sampling, but the effect on WFD classification depended on the closeness of the range of concentrations to the class boundaries. In some cases, monthly sampling for a year could result in the same water body being assigned to three or four of the WFD classes with 95% confidence, due to random sampling effects, whereas with weekly sampling this was one or two classes for the same cases. In the most extreme case, the same water body could have been assigned to any of the five WFD quality classes. Weekly sampling considerably reduces the uncertainties compared to monthly sampling. Low-frequency measurements will generally be unsuitable for assessing standards expressed as high percentiles. A modest improvement in precision can be obtained by sampling at the same time of day within a 3 h time window, and this is recommended. For parameters with a strong *diel* variation, such as dissolved oxygen, the value obtained, and thus possibly the WFD classification, can depend markedly on when in the cycle the sample was taken. Specifying this in the sampling regime would be a straightforward way to improve precision, but there needs to be agreement about how best to characterise risk in different types of river. These results suggest that in some cases it will be difficult to assign accurate WFD chemical classes or to detect likely trends using current sampling regimes, even for these largely groundwater-fed rivers. A more critical approach to sampling is needed to ensure that management actions are appropriate and supported by data.

# Antecedent conditions, hydrological connectivity and anthropogenic inputs: dominant factors affecting nitrate and phosphorus transfers to agricultural headwater streams

**Faye Outram**, **Richard Cooper, Kevin Hiscock, Andrew Lovett**

*University of East Anglia, Norfolk, UK*

The transfer of nitrogen (N) and phosphorus (P) fluxes from agricultural sources in managed catchments is complex due to a range of interacting variables. This paper examines the relationship between rainfall-runoff, catchment connectivity, antecedent moisture conditions and fertiliser application with nitrate-N and total phosphorus (TP) fluxes in an arable 20 $km^2$ headwater catchment over three hydrological years. Annual precipitation totals in all three years were above the long-term average and did not vary significantly between the years, yet the timing of rainfall had a profound impact on runoff generation and subsequent nitrate-N and TP fluxes. The greatest daily nitrate-N and TP fluxes (> 250 kg N $day^{-1}$ and >10 kg TP $day^{-1}$, respectively) only occurred when shallow groundwater exceeded 42.2 mOD and runoff coefficients were greater than 0.1. These threshold criteria were reached less frequently in 2012 due to drought recovery which resulted in significantly lower annual nitrate-N and TP fluxes (0.74 kg N $ha^{-1}$ and 0.12 kg P $ha^{-1}$) in comparison to 2013 (15.1 kg N $ha^{-1}$ and 0.21 kg P $ha^{-1}$). The wetter winter of 2013 and elevated shallow groundwater from previous recharge led to more frequent activation of sub-surface pathways and tile drain flow. Dry antecedent conditions had a temporary effect in raising nitrate-N and TP loads although this was more noticeable for TP than nitrate-N. Evidence of TP source exhaustion after consecutive storm events was attributed to temporary connectivity of critical source areas, such as sugar beet hardstandings, to the river network via impermeable road surfaces. Fertiliser applications varied significantly between the years due to crop rotation patterns with a reduction in N and P fertiliser inputs between 2013 and 2014 of 23% and 53%, respectively. Proportional reductions in annual riverine nitrate-N and TP loadings were not observed at the sub-catchment outlet as loadings were largely influenced by annual runoff. Nitrate loadings were slightly higher during times of fertiliser application but there was little relationship between P fertiliser application and riverine load. These data suggest that this intensively managed arable catchment is in a state of biogeochemical stationarity whereby legacy stores of nutrients buffer against any changes in nutrient inputs. This has long-term implications for catchment managers as legacy stores could take a long time to deplete. Mitigation options which deal with mobilisation of accumulated stores of nutrients, such as constructed wetlands, are recommended in conjunction with mitigation efforts aimed at reducing contemporary inputs.

# Impact of legacy soil phosphorus (P) on P loss in runoff from a grazed grassland hillslope

**Rachel Cassidy**, **Donnacha Doody, Catherine Watson**

*Agri-Food and Biosciences Institute (AFBI), Belfast, UK*

Despite the implementation of EU regulations controlling the use of fertilisers in agriculture, legacy soil P remains a significant threat to water quality across Europe. This is due to the significant time lag between the implementation of measures and the decline in soil P to levels compatible with good water quality, with estimates ranging from years to decades for this to occur. Although the positive relationship between soil P accumulation and losses to water has been elucidated, fewer studies have evaluated this relationship under a scenario of declining soil P. Between 2000 and 2005 0, 10, 20, 40, 80 kg P $ha^{-1}$ was applied to five 0.2 ha hydrologically isolated grazed grassland plots, building the Olsen soil P up to 19, 24, 28, 38 and 67 mg P $L^{-1}$, respectively. From 2005 to 2012, the plots received zero P applications, except for manure deposited by grazing animals.

Over this period losses from overland flow and drainage were monitored, with flow measured at 5 minute intervals using an automatic sampler and samples collected for analysis at 20 minute intervals during runoff events. Analyses were completed within 24 hours for dissolved reactive P and total P. Flow weighted mean concentrations (FWMC) were calculated on an event basis for both overland flow and drainage flow, where events were defined by at least 24 hours without flow being recorded at the respective plot outlets. Additionally the DRP and TP time series were synchronised with rainfall and modelled soil moisture deficit to examine the hydrological drivers of runoff and drainage losses.

Results demonstrated that from 2005-2012 there was no significant difference between TP and DRP concentrations recorded in either overland flow ($p < 0.05$) or drainage flow ($p < 0.05$) from any of the plots despite the Olsen soil P value ranging from the lower end of Index 2 to Index 4. In individual events the plot receiving zero P fertiliser inputs since 2000 often lost as much, or occasionally more, P than the plot which received 80 kg $ha^{-1}$ $yr^{-1}$ up to 2005. Strong interannual variations in losses were observed and plot responses varied considerably from event to event. The hydrological drivers, particularly the antecedent dry period and soil moisture, were observed to have a greater influence on P loss from the plots than soil P status.

# Environmental parameters regulating groundwater nitrate attenuation and gaseous accumulation in two agricultural river catchments

**Eoin McAleer[1,2], Catherine Coxon[1], Karl G. Richards[3], M. M. R Jahangir[3], Per-Erik Mellander[2]**

[1]*Geology Department, School of Natural Sciences, Trinity College Dublin, Dublin 2, Ireland*
[2]*Agricultural Catchments Programme, Teagasc Environment Research Centre, Johnstown Castle, Wexford, Ireland*
[3]*Crops, Environment and Land Use Programme, Teagasc Environment Research Centre, Johnstown Castle, Wexford, Ireland*

At the catchment scale, a complex mosaic of environmental, hydrogeological and physico-chemical characteristics combine to regulate the distribution of groundwater (GW) nitrate ($NO_3^-$). The efficiency of $NO_3^-$ removal (via denitrification) versus the ratio of gaseous reaction products, dinitrogen (excess $N_2$) and nitrous oxide ($N_2O$), remains poorly understood and while $N_2$ is environmentally benign, $N_2O$ is a potent greenhouse gas. Spatial and temporal monitoring (shallow to deep GW pathways) was undertaken along four hillslopes in two ca. 10km$^2$ catchments. Both catchments are characterised by well drained soils, but exhibit contrasting subsurface lithologies (Devonian sandstone vs. Ordovician slate). The capacity for GW denitrification was assessed by measuring the concentration and distribution patterns of N species and aquifer hydro-geochemistry, in monthly samples from a network of piezometers ($n$=37). Excess $N_2$ and $N_2O$ were measured seasonally while stable isotope $NO_3^-$ signatures ($\delta^{15}N$- $NO_3^-$ & $\delta^{18}O$- $NO_3^-$) were collected during a once off sampling round from each piezometer. GW in the slate catchment was characterised by homogeneity. The five year spatio-temporal mean $NO_3^-$ concentration of 6.8 mg N/L exhibited limited variation throughout the sampling period (SE: 0.06, CV: 25%). Elevated dissolved oxygen (DO) and positive redox potential (Eh) across hillslope zones i.e. upslope vs. midslope vs. near stream and sample depths indicated a setting with little denitrification potential. This was reflected in a low accumulation of excess $N_2/N_2O$ and a mean $N_2O$ emission factor ($EF_5g$) of 0.00034, an order of magnitude lower than the Intergovernmental Panel on Climate Change (IPCC) default value (0.0025). Stable isotope ratios reflected water, which had undergone limited microbial transformation. GW in the sandstone catchment had a lower mean $NO_3^-$ concentration (5.6 mg N/L) but exhibited substantially greater variability (SE: 0.12, CV: 81%), with hillslope zone and groundwater depth being statistically significant ($p < 0.001$). $N_2/N_2O$ accumulation was high with $NO_3^-$ and $N_2$ strongly correlated to DO ($NO_3^-$ positively & $N_2$ negatively). Results indicated that complete denitrification of $NO_3^-$ to $N_2$ occurred in anaerobic conditions, while at intermediate DO, $N_2O$ was the dominant reaction product, with a mean $EF_5g$ (0.0035) in excess of the IPCC default. $NO_3^-$ removal was greatest in low permeability deep GW pathways, while a shallow unsaturated zone supported the development of anaerobic conditions. Contemporaneous enrichment of $^{15}N$-$NO_3^-$ and $^{18}O$-$NO_3^-$ supported the inference of denitrification. Results in both catchments indicated that hydrogeological setting significantly affected the distribution of GW nitrate, with denitrification acting as a governing process.

# DAY 1 - SESSION 2
## Integrated management, stakeholder engagement and catchment economics

### A spatial analysis of the major forces affecting ecological status of rivers across the Republic of Ireland

**Cathal O'Donoghue**[1], **Cathal Buckley**[1], **Askana Chyzheuskaya**[2], **Stuart Green**[4], **Peter Howley**[3], **Stephen Hynes**[2], **Vincent Upton**[2]

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The Water Framework Directive aims, at a minimum, to achieve 'good' and 'non-deteriorating status' for surface, underground and coastal waters and sets common approaches and goals for water management. The Directive calls for a consideration of all the benefits as well as costs of improvements to good status in catchment management plans. Hence, understanding the factors affecting river water quality at various catchment scales will play an important role in the assessment of the proportionality of costs which is part of WFD implementation.

This study undertakes an econometric analysis exploring the effects of land use, geomorphological and climatic variables on river water quality in the Republic of Ireland. This is achieved by combining a number of spatial datasets from a range of sources relating to agricultural, residential, forestry, geomorphological and climatic data with the biological measures of water quality (Q values) using an ordered probit panel data model. This modelling framework allows a spatial and temporal examination of the different drivers of river water quality at a national level.

Findings from this research indicate that various agricultural activities such as livestock, cereal and pig production have a significant negative effect on river water quality. However, analysis indicates that this effect is significantly reduced over time. In Ireland, wastewater from a significant proportion of the population (generally in rural areas) is treated by small-scale on-site systems (septic tanks). Results indicate a statistically significant and negative association between septic tank density and river water quality. Findings from this analysis indicate that an active landfill site upstream of a monitoring station was associated with lower Q value outcomes. Conversely, greater forestry cover was found to be positively associated with better river water quality outcomes. The analysis also indicates that river water quality is affected by a combination of geomorphological (e.g. soil type, slope) and climatic (e.g. rainfall) variables.

# FyrisSKZ: Model support for estimating the cost efficiency of riparian buffer zones to reduce phosphorus losses from agricultural land

**Dennis Collentine**

*Swedish University of Agricultural Sciences, Uppsala, Sweden*

Riparian buffer zones, designed to reduce erosion of particulate phosphorus (P), are the only measure that has been used extensively in Sweden to reduce P loss from agricultural land. Implementation of riparian buffer zones in Sweden has been supported by payments to landowners from the EU Rural Development Program (RDP). These payments have been a uniform reimbursement per hectare for buffer zones from 6-20 meters wide in eligible areas for a five year commitment. The reimbursement is compensation for the average loss of income for developing the zone and taking the land out of agricultural production, i.e. the opportunity cost of the land. This opportunity cost is related to the land productivity and can vary based on agronomic factors. The effectiveness of a riparian buffer zone depends on the parameters that have an effect on surface runoff (among others topography, soil type, climate and width of the buffer) and the P load to the zone.

Under an assignment from the Swedish National Water Authorities in Spring 2012 the FyrisCOST model was used to develop a database for calculating the cost efficiency of riparian buffer zones for 12,864 Swedish sub-catchment areas. The database FyrisSKZ is a web application completed in November 2012 and available as a public domain web application (http://fyrisskz.slu.se/haro/). The database allows the user to select one or a set of sub-catchments from a GIS supported map on the web site and view a table of results for the selected area(s). FyrisSKZ provides the user with information on the potential for buffer zones in the selected sub-catchment, the P reducing effect of buffer zones on 5 widths ( 2, 6, 10, 15 and 20 meters), the total cost per hectare of buffer zones and the cost per reduced kilogram of P for each buffer zone width in the selected sub-catchment. The database represents the state-of-the-art in bio-economic modelling, combining high resolution input from national statistical databases on crops, soil types, soil P, landscape gradients on RDP support eligible watercourses, opportunity costs for agricultural land, climate and existing areas of supported buffer zones. The model is currently used in Sweden by researchers and regional and national authorities to assist with estimating the impact on water quality of buffer zones and the costs of action plans to achieve the environmental quality standards of the Water Framework Directive.

# Social Learning and the farming sector, adapting to the Water Framework Directive in Scandinavia, Scotland and Ireland

**Micheál Ó'Cinnéide**

*Environmental Protection Agency, Ireland, Ireland*

This paper looks at social learning in the context of the European Water Framework Directive, (2000/60/EC). The research examines the challenges of building a shared understanding of water management - how do participants learn to improve water quality? The concept of social learning as a hidden but vital element of catchment management is a guiding theme. The data are viewed though the theoretical lens of social learning, which sees learning as part of a dynamic, interactive process between individuals and their social environment (Bandura, 1997 and Pahl Wostl, 2007). Social learning is an iterative process where communities such as groups of farmers learn to adapt to new policy paradigms, by means of engagement and modelling of behaviours.

The research took place in Finland, Sweden, Scotland and Ireland, based on interviews with participants from the governmental, farming and environmental sectors. The interviews focussed on the participants' experiences of the Water Framework in the decade since 2000. The case studies explored the essence of the learning process, as participants engaged with Water Framework issues, at a national, regional or community level.

The findings show that three of the four European regions studied built effective structures to foster learning and improved water outcomes, whereas in the Irish case, the policy direction and structures for water management were not as favourable to participation or social learning. Shared learning is a key mechanism in a time of regulatory change, in developing support for River Basin measures to improve water quality. This element of social learning emerges as a common denominator in the effective delivery of Water Framework outreach programmes with the farming sector in Sweden, Finland and Scotland. The SEPA/NFUS programme on diffuse pollution in Scotland and the Focus on Nutrients project in southern Sweden are examined.

The theoretical framework is validated and insights are gained into how public agencies can influence environmental practices. The findings have implications for the design of outreach programmes and for public engagement praxis. The research suggests that social learning is a key ingredient in adaptive processes for tackling water as part of sustainable catchments for the 21st century. This has a resonance in other facets of building a sustainable Europe, including in the areas of climate change, nature protection and natural resource management.

# Focus on Nutrients, a voluntary on-farm initiative that benefits both the environment and the economy

**Stina Olofsson**

*Swedish Board of Agriculture, Alnarp, Sweden*

The Swedish 'Focus on Nutrients' (*Greppa Näringen, in Swedish*) campaign was designed to promote adoption of measures in agriculture to reduce losses of nutrients to air and water, ensure a safe use of plant protection products and increase farms revenues. The objective is to increase awareness and knowledge in order to change behaviour trough individual on-farm education.

The campaign was started to meet government environmental objectives introduced in 2000 and, later, the Baltic Sea Action Programme and the Water Framework Directive. It is funded by the Swedish RDP, which is co-financed by the EU budget. The project offers advice that is free of charge to the farmer. The on-farm visits are performed by more than 250 advisors that are employed by advisory firms across Sweden and 50,000 farm visits have been carried out since the start. Around 8,500 farmers cultivating around 1 million hectares, take part. 'Focus on Nutrients' has a systematic planning approach to ensure the quality of the advisory services and the environmental benefits, which includes calculating the farm nutrient balance. Planning is based on the specific challenges that the farm is facing, depending on type of production and environmental impact. Topics covered by the advisor include: soil structure, plant protection, feeding, energy efficiency and construction of wetlands. Planning also offers tools for efficient use of nutrients, such as manure spreading and how to optimize nitrogen fertilization levels. Farmers can receive twice-weekly emails providing the latest research reports and other related news.

Surpluses on the farms within the project have decreased due to reduced inputs of plant nutrients with mineral fertilizers (primarily dairy farms) and feed (primarily pig farms). Purchases of mineral fertilizer have been reduced through better utilization of manure, combined with fertilizing techniques and adjusted doses.

Independent reports suggest that the measures implemented to reduce leaching of nutrients from agricultural land have had the intended effect. The decrease in transport of nutrients in rivers, for nitrogen 20-30 % in ten years, has been greatest in regions where the measures have been most extensive and where 'Focus on Nutrients' has been operating.

The Swedish experience suggests that: 1) frequent visits are key to influencing farmers' behaviour; 2) the advisor has to relate how measures will influence farm economies; 3) it is important to inform farmers of progress of their achievements, and; 4) to inspire change the scheme needs to be voluntary for the farmer.

# Developing sustainability indicators to evaluate changes in farm level nutrient management efficiency through time

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Reducing residual farm nutrients by managing towards a balance and away from a surplus improves efficiency and has the potential for environmental benefits, including water quality. This paper used the Teagasc National Farm Survey, which is part of the European Union Farm Accountancy Data Network, to develop environmental sustainability indicators in the use of nitrogen (N) and phosphorus (P) for a panel of specialist dairy farms across the Republic of Ireland. Specialist dairying farms were the focus of the study as they are associated with more intensive nutrient use. The study period coincided with the introduction of EU Nitrates Directive based regulations in the Republic of Ireland in 2006 to 2012. Results indicated that N/P balances (kg $ha^{-1}$) declined and N/P use efficiencies improved over the study period concurrently with more optimal use of chemical fertilisers. In addition to the introduction of EU Nitrates based regulations, results of a random effects panel data econometric model indicate that balances and use efficiency are influenced by factors such as fertiliser prices, stocking rates, land use potential, off-farm employment, contact with extension services and climatic variables.

# Engagement of dairy farmers in the Lake Rotorua Catchment in meeting nutrient loss targets on dairy farms in the Lake Rotorua catchment

**<u>Sharon Morrell</u>**[1,2]

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Lake Rotorua is a volcanic caldera lake in the Central North Island of New Zealand. Increasing concerns over eutrophication in the 1990-2000s led to development of lake health targets and nutrient caps, with significant reductions in N and P from the catchment also required over the next 17 years.

The Sustainable Farming Fund (SFF) is a resourcing mechanism for tackling the economic, environmental and/or social sustainability issues of NZ's primary industries. "Communities of interest" are supported to undertake applied research and extension projects on a shared problem or opportunity.

The most recent of two Rotorua SFF projects provides the engagement case study for this presentation. Titled "Meeting nutrient loss targets on dairy farms in the Lake Rotorua catchment" it had three strands: field trials to measure biophysical responses to low and nil N fertiliser inputs; modelling farm systems; and utilising group events to engage farmers in achieving the aim. Multiple parties were involved as project team members and/or funders.The science and modelling have not revealed a 'silver bullet' in meeting nutrient loss targets. However farmer hosts of trials and modelling became deeply involved with the issue, while attendees at workshops and field days have both learnt and contributed. Non-SFF activities related to the issue have divided farmer's time, but by contributing to a 'matrix of engagement' have been beneficial in the overall process of change. Specific barriers and enablers of engagement will be presented.

The local regulatory drivers for reducing farm nutrient losses are still evolving. New regulations that require major reductions in N leaching will probably take several years to emerge from the legal process. Given the weak imperative for immediate action, many farmers choose to "wait and see", particularly with regard to major on-farm changes. Nonetheless there is evidence of behaviour change - some farmers continue to both participate and lead, seeking to constructively question policy and science, better understand nutrient mitigation practices and discover opportunities to innovate. There is some reassurance that recent efforts by catchment dairy farmers to reduce costs and improve productivity have also reduced average N leaching rates by about 8% per effective hectare. The capacity of farmers engaged with this SFF project has grown and they hope to gain approval for another SFF project.

Seeking insights from personal experiences my own Nuffield research will explore some options to further enrich farmer engagement.

# An advisory-industry perspective to nutrient management in the Agricultural Catchments Programme

**Dermot Leahy**[1], **John Walsh**[2]

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[2]*Dairy Farmer, Timoleague, Co. Cork*

The Irish Agricultural Catchments Programme (ACP) is a Nitrates Directive evaluation and monitoring initiative, operated by Teagasc and working at the science-advisory-policy interface in six intensively farmed catchments. In addition to a research component, the ACP works with catchment farmers through an advisory network. One of the catchments near Timoleague in Co. Cork, is an exemplar grassland catchment with one of the highest concentrations of intensive dairy farmers in the country. Among the potential diffuse nutrient source pressures to be regulated and evaluated under the Nitrates Directive is excessive soil nutrient status. This presentation will highlight the experiences from an advisory and industry perspective.

Dermot Leahy is a Research Technologist with the ACP and has a dual role as agricultural advisor and technician working on the Timoleague catchment. Dermot will provide an overview of his role in the programme, outlining the extent of the data capture required for monitoring the nutrient continuum and also his role as an advisor. Mr John Walsh is a dairy farmer with an intensive herd based in the heart of the Timoleague catchment since the early 1990s where his farming system is very typical of the area. John will speak about his farm system, dairy expansion and his interaction with the ACP and its effect on his farming system. John has used the information provided by the programme to improve the soil fertility of his land by taking a more focused approach to nutrient management planning resulting in more efficient farm practices.

# DAY 2 - SESSION 1
## Soil analysis and nutrient management – achieving environmental and agronomic goals

## Fertile soils: friend or foe for a clean catchment?

**Jaap Schröder**

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Soil fertility is an ambiguous concept. Connotations range from a desire to fill up soils with nutrients to a level where production risks can be entirely excluded; the wish to maintain existing soil fertility indices regardless whether they are required at all; a thoughtful acknowledgement of the many functions soils are expected to perform next to production; up to the opinion that fertile soils are nothing but a time bomb for the environment. On the one hand we can say that the utilization of any nutrient is, *inter alia*, determined by the sufficient availability of other nutrients, as illustrated by the classical metaphor of Von Liebig's barrel with staves of different length. Consequently, nutrient deficiencies in soils may increase the risk of losing other nutrients. Conversely, if nutrients are applied too generously, they can easily end up in the wider environment, nitrogen (N) and phosphorus (P) in particular. Managing soil fertility is therefore a delicate balancing act. In view of the undeniable relationships between N and P inputs and their emissions to water bodies, it is tempting to assume that 'extensification' of our agriculture is the key. However, the implication of that strategy could be that more hectares are needed to produce the same volume of food, feed, fibre and fuel. The product of hectares and emissions per hectare may then remain the same. Instead, it could be more effective to develop, disseminate and apply fertilizer application methods that contribute to an improved crop recovery of nutrients. These methods pertain to better interpretations of soil fertility indices, handling of heterogeneity across and within fields, and smart combinations of fertilizer types, the timing of their applications and their positioning into soils. Examples of the above will be presented.

# Soil variability impacting nutrient source mobility

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Worldwide, studies have identified that in addition to the soils physical structure (e.g. controlling drainage) soil chemistry can have a large influence on the mobilisation of nutrients, in particular phosphorus (P). Currently soil chemical factors related to soil types are not explicitly considered under EU Nitrates Directive programme of measures, which under Ireland's National Action Programme (NAP) are adopted as a blanket approach. The Irish, Agricultural Catchments Programme has being conducting an evaluation of the NAP measures and the importance of considering the variability in soil properties when administering effective nutrient management advice to farmers.

Soil nutrient concentrations (e.g. soil test P (STP)) across five intensively farmed agricultural catchments, ranging from 7.5 to 12km$^2$ in area, were surveyed at a resolution of approx. 2ha per sample, at two time points (2009-2010 and 2013-2014-2015). In addition a stratified grid soil sampling scheme (n=149) was also carried out in each catchment to assess the chemical and physical properties of the soils present in more detail. Nutrient management data were also collected from the farms within each catchment.

The analysis of STP over the 4 year period showed a decline (area weighted) in soils with excessive plant-available P concentrations in four out of five catchments (decrease of between 3 and 8 %). However, these data show that a large spatial variability in STP concentrations still remains at both farm and catchment scales. There was similar variability in the P sorption capacity across these soils, indicated by the ratio of Mehlich (M3) extractable aluminium (Al) and M3 P (i.e. Al/P), which ranged from 3.6 to 65.8. Mineral soils with ratios of Al/P above a threshold level of 11.7 are characterized as high P fixing with low plant-available P. Based on the stratified soil survey 68% of the soils across the five catchments had values above this P availability threshold, which indicates lower risk for P loss. These differences suggest more in-depth assessment of soils to identify their agronomic requirements for P vs. their risk of P loss is required.

Overall, this study indicates that different soil specific and spatially explicit P management strategies are warranted for effectively achieving production and water quality goals in these catchments. The impact of P source regulation on farms will likely produce different temporal outcomes, which are dependent on the variability in the physical and chemical nature of the soils, and must be considered in future policy expectations.

# Optimising soil fertility leads to efficient fertilizer use

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To sustain soil productivity and crop growth, fertilizer inputs are required to replace crop nutrient offtakes, meet crop nutritional requirements and sustain soil fertility levels. However, over and improper use of fertilizer (especially phosphorus) to farmland can lead to reduced farm profitability and potentially negative effects on surface and ground water quality.

Currently approximately 12% of farmland in Ireland is at the optimum soil fertility status for phosphorus (P), potassium (K) and soil pH. Low soil test P levels are particularly concerning as this will potentially lead to reduced herbage yield and herbage P concentrations that are inadequate to meet the nutritional requirements of grazing livestock. As phosphate reserves are finite, with P a potential cause of eutrophication of surface waters, it is important that farmers make best use of this limited and increasingly expensive resource.

A recent study at Teagasc, Johnstown Castle examined the interaction between P and lime in a series of experiments designed to improve nutrient (mainly P) efficacy. A controlled soil microcosm experiment was conducted to examine the effects of soil type on soil P availability and soil pH following applications of P fertilizer and lime. Separately, statistical analysis was carried out on a long term P grassland trial where annual applications of P fertilizer have been made since 1995. In addition new field trials were established on two contrasting soil fertility (soil P and soil pH) sites and investigated the effect of nitrogen (N), P and lime applications on grassland establishment, nutritive value and herbage yield.

The results showed that soil type, soil pH and initial soil test P influence soil P availability and efficiency of recently applied fertilizer. Phosphorus fertilizer increased early season growth and this work also highlighted the potential decline in the herbage P concentration during summer months. The study also observed increases in herbage yield due to P fertilizer application at establishment even where soil P levels where high. Furthermore, both a field trial and microcosm experiments found significant increases in soil P and herbage yield following lime addition.

This study demonstrated the importance of P fertilizer both for grass quality and quantity. Applying P fertilizer at the time of greatest demand will ensure maximum efficiency and least risk of loss to the aquatic environment. Where soil pH is sub-optimum corrective action should be seen as the first step in nutrient management planning.

# The management of a marginal acid Organic soil to decrease phosphorus losses and meet an ecological target

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The development of 'marginal' soils is increasing globally due to population growth and a demand for agricultural products. The development of Organic soils typically involves drainage and the application of lime and P fertiliser amendments to rectify acidic soil conditions and poor fertility for pastoral production. Coupled with poor P retention, as a result of low concentrations of P-sorbing metal oxides, these factors enhance the risk of P losses in runoff which can impair surface water quality. This paper details a series of trials to measure and manage P losses from intensively-managed Organic and Podzol soils that drain into an internationally-recognised lagoon ecosystem, and asks the question can a target designed to improve water quality by decreasing P losses by 25-50% be achieved?

Two primary trials were undertaken. The first, to determine how the potential for topsoil and subsoil P losses from an array of soils changes since development from scrub, and what physical, chemical and management properties those losses were related too. Findings indicated that the first 10 years since development are the most critical for P losses. The second trial quantified the effect of different soil moisture levels, varying from hydrophobicity to saturation, on the pathway (surface runoff and leaching) for P loss from an Organic soil and a mineral soil. After establishing the timeframe and pathway most important for P losses, a series of trials examined relevant soil management activities that could be modified to reduce P losses. The first trial looked to see if liming altered soil P solubility and the quantity of P in leachate (the dominant pathway) in the Organic soil. Building on these data, a second trial tested the use of poorly water soluble P fertiliser to decrease P losses in leachate from the acid Organic soil at a range of pH levels. The final trial designed a pasture system that used pasture plants that grew well at a low pH, Olsen P and fertiliser regime unlikely to lose significant quantities of P in leachate, but that still produced quality forage. The results and findings of each of these trials will be presented and an answer given to the ability to meet the targeted 25-50% decrease in P loss.

# Variability in farm and field scale phosphorus balances within and between high status river catchments in the Republic of Ireland

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Efficient nutrient management at the farm and field scale can help to lower the risk of phosphorus transfer to surface waters whilst optimising crop yields and the use of phosphorus resources. Recent research into farm nutrient management suggests that in high intensity farming systems and areas, the Nitrates Directive National Action Programme (NAP) of measures has been effective in improving phosphorus use efficiency at the farm scale to the point where farm scale P balances have been reduced to near optimal levels. However, in lower intensity farming systems and areas, like those found in high status river catchments where soil and climatic factors constrain farming intensity, NAP measures for nutrient management are much less comprehensive, for example, soil tests are not mandatory. Therefore, our hypothesis was that there would be considerable variability in farm and field scale P balances within and between high status river catchments. To test this, we conducted an observational study of farm and field scale P management practices on 39 farms across three high status river catchments that were selected on the basis of soil type as a key constraint on farming. Fields with positive P balances were common across all three catchments, whereas farms with positive farm scale balances were concentrated in the catchment with the lowest grazing intensity where nutrient management planning was poor. These positive balances meant that there was an overall P surplus, indicating an increased risk of P transfer to water bodies. As uptake of agri-environment schemes was high in this sample of farms, future schemes should include field scale nutrient management for sustainable P use in high status river catchments.

# DAY 2 - SESSION 2
## Adaptive management approaches to reducing nutrient loss risk

## Adaptive management approaches for reducing nutrient mobilisation and transfer in surface flows

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Surface flows can deliver a large proportion of nutrient losses annually and can be separated into two types: (i) those occurring on the soil surface and (ii) those occurring in downstream ditches and streams.

As type (i) flows are transient in nature and often occur on productive soils, nutrient loss mitigation measures generally are aimed at reducing the nutrients available for loss via these pathways, rather than managing these pathways *per se*. For example under the E.U. Nitrates Directive, nutrient applications are restricted during 'closed-periods' in winter when these pathways are most active. A review of the slurry closed-period in Ireland (15$^{th}$ October - 12/15/31$^{st}$ January), conducted by the Agricultural Catchments Programme (ACP), has shown that these pathways are still very active during the four weeks after the end of the slurry closed-period on poorly-drained soils. However in five representative agricultural catchments there was no evidence of nutrient transfers from slurry/manure applications during this time over a four year period. If slurry spreading was occurring during these four weeks, the data suggest that farmers were choosing to spread on more freely draining soils where nutrient transfer risk was low. Such practices could be promoted among farmers through appropriate knowledge transfer methods to mitigate risks associated with storm driven slurry transfers during the early closed-period, derogated periods and more importantly, during sensitive summer periods.

Type (ii) flows are channelised and occur on non-productive soils/sediments thus are easier to manage than type (i) flows. Nevertheless, a poor understanding of the nutrient retention/mobilisation processes in these channels has limited the development of appropriate nutrient loss mitigation strategies for these flows. A study by the ACP has shown that channel slopes and geometries can have a large influence on the phosphorus retention/mobilisation/transfer potential of these flows, with lower slopes and wider geometries enhancing phosphorus retention on channel beds. Tailoring management strategies according to channel slopes and enlarging ditches may reduce downstream phosphorus transfers in 'risky' catchments.

These research findings can help inform farmers and policy makers of how to optimise slurry application timing and channel management to reduce nutrient mobilisation and transfer in surface flows.

# Research for Catchment Attenuation Processes (ReCAP): Advancing knowledge and tools to account for nitrogen transport and transformation in NZ agricultural catchments


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Productive farms and their associated processing industries make a significant contribution to New Zealand's future economic and social welfare. Dairy, meat and wool products from grazed pastures generate approximately 30% of New Zealand's export income. However, grazed pastoral systems and other intensive landuses are inherently leaky with respect to nitrogen, the key nutrient implicated in the deterioration of surface and ground water quality in New Zealand's agricultural catchments.

Farming industry advisors, regional councils and farmers, have devoted significant effort and investment to the development and implementation of best management practices to reduce runoff and leaching of farm nutrients to surface and ground waters. Sophisticated nutrient budgeting software (Overseer®) has been developed to assist farm managers to use nutrients efficiently within their farming enterprise. Current nitrogen (N) management efforts are focused within the farm boundary and concentrate on identifying and reducing nitrogen loss from the root zone of intensive farms. In many regions, the predicted farm rootzone N loss must comply with a set limit or allocation. This approach ignores the transport and transformation of nitrate-nitrogen ($NO_3$-N) along flow pathways from farms to rivers and lakes. Farm N loss allowances, specified in regional council rules are generally derived using assumptions about the attenuation of $NO_3$-N as it passes from the paddock root zone to rivers and lakes as relatively little is known about these processes in NZ agricultural catchments. This information is increasingly being sought to derive a robust understanding of the contribution farming systems make to water quality outcomes, as is required by New Zealand's National Policy Statement for Freshwater 2014.

Our research in the Manawatu River catchment suggests that N loads measured in the river are significantly smaller than the estimates of N leached from the root zone. The on-going field observations, surveys and experiments indicate that denitrification is a key $NO_3$-N attenuation process in the catchment. This N attenuation capacity appears to vary among the sub-catchments within the catchment. Further research to understand and quantify this N attenuation capacity in NZ agricultural catchments is important for a number of reasons. Firstly, by taking a catchment perspective, we will be able to unlock the potential that exists in spatially aligning intensive landuse practices with high nutrient attenuation pathways. Secondly, we will be able to align the seasonal temporal variation in nitrate generation with built or enhanced attenuation to improve outcomes.

# Targeting critical source areas benefits both farmers and water quality

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In spite of the extensive body of scientific evidence suggesting that P losses are episodic and spatially variable, current environmental protection programs are designed and applied in a rather general way, without targeting the most vulnerable parts of the landscape. At best, targeting efforts include soil P content, in an attempt to address the source part of the P transfer continuum. Farmers use their knowledge and experience to co-ordinate and to (re-) shape a wide range of socio-technical growth factors within specific localities and networks towards desired outcomes. The nutrient abatement programs are not by any means an exception and general rules need to be adjusted to farmer's specific settings and integrated in different farming domains and processes.

The main aim of this study was to study if the local adjustment of agri-environmental programs and measures is possible based on the combination of results of high-resolution overland flow and erosion modelling, and independent risk assessment by farmers. Spatial comparison of problem areas observed by farmers and modelled features showed that top 2% of all 2 x 2m-cells with highest modelled erosion values intersected 109 out of total 128 (85%) observed problem areas. Simultaneously, a simple laboratory test with local soil samples was useful to better illustrate soils vulnerability towards losses of different phosphorus forms to farmers. Modern farmers are well-educated and skillful entrepreneurs willing and able to take into account different aspects of their activities. However, current regulations of agri-environmental measures in rural development programs are, in many cases, not flexible enough to allow farmers to do what they are best at: adapting general measures to local-specific conditions. The current fairness criterion (Producer Compensation Principle, PCP) and compensation principle (compensation for lost income) actually counteracts the optimization of the placement of the measures in two ways. Firstly, a fixed payment (per hectare) does not take into account that farmland value varies both in time and in space. Thus, farmers who have higher incomes per hectare than suggested payment are opting out of the environmental measures. Secondly, with a fixed payment amount it is impossible to prioritize placement of measures based on their cost-effectiveness by for instance having higher payments for high-risk areas.

# Groundwater control of biogeochemical processes causing phosphorus remobilization in vegetated riparian wetlands

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To trap phosphorus (P) mobilized through erosion and delivered to streams via surface pathways, establishment of vegetated riparian buffers has been promoted worldwide, sometimes in wetland areas. Vegetated riparian wetlands (VRW) have proved effective at reducing P transfer to streams in many contexts but the high hydrological connectivity of these zones with the streams and their high biogeochemical reactivity raise concerns about the long term fate of the P they accumulate.

To investigate the risk of VRWs releasing dissolved P into streams, we monitored molybdate-reactive P (MRP) in the soil pore water of two VRWs in an agricultural catchment. Two main mechanisms released MRP under the control of groundwater dynamics. First, soil rewetting after the dry summer period was associated with the presence of a pool of mobile P, limited in size. Its mobilization started under water saturated conditions caused by a rise in groundwater table. Second, anoxic conditions at the end of winter caused reductive dissolution of Fe (hydr)oxides along with a release of MRP. Comparison of sites revealed that the first MRP release occurred only in VRWs with high soil P status, whereas the second was observed even in VRWs with low soil P status. Seasonal variations in stream MRP concentrations were similar to concentrations in VRW soils. Hence, VRWs can act as a key component of the P transfer continuum in agricultural landscapes by converting legacy P and particulate P from croplands into MRP transferred to streams.

Given the risk of P remobilization in VRWs, management options should focus on: i) preventing P mobilization in upslope fields to avoid further enrichment of VRWs by erosion; ii) recovering legacy P from VRWs by exporting biomass (P mining) ; iii) in highly sensitive areas, emerging technologies involving the use of P-sorbing materials could be implemented to increase P immobilization in riparian zones.

# Identifying hydrologically sensitive areas using LiDAR DEMs to mitigate critical source areas of diffuse pollution: a policy-applicable index

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Identifying critical source areas (CSAs) of diffuse pollution at the sub-field scale is needed, but this requires complex or data-intensive approaches that hinder their immediate applicability as agricultural policy tools. Parsimonious methods are therefore required which focus on the dominant CSA factor, which in some catchments are hydrologically sensitive areas (HSAs). These are where the propensity for surface runoff generation, pollutant transport and delivery via hydrologically connected pathways is highest.

A new GIS-based HSA Index is presented for identifying HSAs at the sub-field scale. It integrates Topographic Wetness Index (TWI) and soil drainage class maps to account for saturation-and-infiltration-excess overland flow, and reduces risk in areas with low hydrological connectivity where reinfiltration is likely or where flow is topographically impeded within sinks such as depressions or hedgerow banks. High resolution (0.25-2 m) LiDAR Digital Elevation Models (DEMs) are utilised to capture these microtopographic controls on flow pathways and hydrological connectivity.

In two catchments (well-drained arable; poorly drained grassland) HSA sizes were empirically estimated using rainfall depths and quickflow separations of hydrographs at catchment outlets measured during storm events from 2009-2014. These were used to validate inter-catchment differences in HSA Index values and define a threshold value for delineating HSAs within the catchments. HSA maps were used to identify breakthrough and delivery points along surface runoff pathways where pollutants could be transported between fields or delivered to the drainage network, respectively. This is a first step to propose targeted mitigation measures such as riparian buffer strips (RBS) at these locations.

Scenarios of farmer compensation costs of targeted versus blanket implementation of RBS, within a potential agri-environment scheme, were also analysed. HSAs represented 16% of the well-drained arable catchment compared to 65% of the poorly-drained grassland catchment, agreeing with HSA Index values. Targeting RBS at delivery points within HSAs reduced potential costs on average by 58% and 83% over 1 and 5 year scenarios, respectively, which included the cost of LiDAR DEM acquisition.

The HSA Index allows accurate targeting of mitigation measures without requiring source, mobilisation and land use datasets that may be unavailable and expensive to obtain. HSA measures can also mitigate a range of pollutants transported within surface runoff, do not require relocation following changes to CSA locations upslope, and can indirectly mitigate incidental losses and legacy transfers. Therefore, it is potentially a longer-term, more sustainable and policy-applicable strategy for mitigating diffuse pollution at catchment to sub-field scales.

# DAY 2 - SESSION 3
## Disentangling the impact of multiple stressors on aquatic ecology

### Linking agricultural fine sediment pressure and impacts on aquatic ecology for informing catchment management across England and Wales

**Adie Collins**

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Although fine sediment represents an essential component of fluvial habitats, excessive inputs to river systems can degrade water quality and ecological status. Improved management of the fine sediment problem requires revised targets for compliance assessment and tools for guiding management decisions at catchment scale to help close the estimated gap. In view of these requirements, a recent science project has reviewed sediment targets used internationally for compliance assessment and constructed a national scale framework for supporting targeted sediment management interventions across England and Wales. This work was driven, in part, by the repeal of the EU Freshwater Fish Directive and its guideline annual mean suspended sediment concentration of 25 mg $L^{-1}$, which left Member States needing to decide how to assess the sediment gap and guide catchment management in the second round of River Basin Management Planning.

The project (a) reviewed the current evidence on the impacts of fine sediment on aquatic ecology (diatoms, macroinvertebrates, macrophytes, fish) with a view to identifying critical gaps; (b) established a new predictive index combining the risk of sediment pressure from agriculture and in-stream sediment retention; (c) reviewed palaeolimnological evidence for estimating modern 'background' sediment pressures on rivers across England and Wales, (d) improved the existing evidence base on the ecological impacts of fine sediment by undertaking targeted new data collection and experimental work on the impacts on macroinvertebrates and fish, and (e) developed a novel national scale modelling framework coupling prediction of agricultural sediment pressure under different scenarios (e.g. structural land cover, changing uptake of agricultural sediment mitigation measures) with biological endpoints for macroinvertebrates and fish, to be used to help inform river catchment sediment management. An overview of this work will be presented.

# ‘Real time ecology’ to understand the nutrient and community dynamics of headwater streams. Implications for biomonitoring and policy from the River Eden Demonstration Test Catchment programme

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Headwater ecosystems are a central feature of the landscape dominated by benthic biofilms comprised largely of diatoms. Benthic biofilms constitute major sites for the uptake and storage of stream N, P, C with their diversity in structure and associated ecological function contributing significantly to catchment nutrient cycling and primary production. Colonisation of benthic substrate, and subsequent development of diatom biofilm architecture, results from progressive responses of diatoms to physico-chemical factors (e.g. rainfall, discharge, nutrient availability). Biofilms dominated by benthic diatoms integrate the effects of environmental conditions over extended periods of time, mainly because of their small size, species richness and rapid growth. The effects of environmental parameters on these biofilms can be expressed as variations of species composition and growth over temporal and spatial scales from streams to larger downstream rivers. Consequently, biofilm communities are widely used in ecological assessment but how these communities develop in the fluctuating, dynamic environments characteristic of headwaters is poorly understood.

Assessment of the spatial and temporal dynamism of headwater systems through their dominant biota, the benthic biofilm, together with deployment of near-continuous monitoring technology in sub-catchments of the River Eden, NW England, is one of the first quantitative studies of long-term diatom community development in response to continuously-measured stream nutrient concentration and discharge fluctuations. Our data revealed the sensitivity of headwater benthic diatom communities to mean discharge-nutrient conditions over the preceding 7 - 21 days, with discharge as the dominant variable. Moreover, investigation of seasonal periodicity of diatoms composition and biomass over 50 months demonstrated clear seasonal cycles the in the Trophic Diatom Index, which reflects sensitivity in diatom composition to catchment productivity, but there was not a strong correlation between composition and biomass. These findings illustrate that local climate and catchment characteristics influence community composition but that the relationship between biofilm structural components and catchment productivity is not straightforward. Such understanding highlights the importance of exploring benthic community composition and productivity in appropriate spatial-temporal frameworks for determining key physical and chemical drivers of these communities. Environmental legislative and management objectives, such as those of the European Water Framework Directive, must accommodate dynamic event-driven physical and chemical processes under changing climate and land use scenarios, as only by understanding real-time environmental dynamics can we fully understand the real-time ecology of headwaters streams specifically and wider river systems more generally.

# Assessing the impacts of climate change on catchment sensitivity to phosphorus pollution

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Phosphorus (P) and its impairment to inland and coastal waters is a continual and evolving threat, especially under a changing climate. A major difficulty lies in identifying and linking catchment P inputs (i.e. pressures) directly with water quality and ecological impacts across highly distinct catchment behaviours and characteristics, both now and into an uncertain future. This has hindered and confused restoration efforts across the land-water continuum, causing uncertainty in attaining Water Framework Directive (WFD) targets by 2027, and beyond as agricultural and urban intensification will increase and our climate changes. To help resolve these uncertainties, we consider how the response of a catchment to P pollution is a function of its sensitivity to three key factors all of which are affected by climate change: (a) hydrological regime and residence time, (b) net biochemical retention, and (c) ecological response. The degree of sensitivity to each factor will collectively determine the overall buffering capacity of that catchment to P pollution, which in turn will direct strategies for mitigation and water quality remediation or preservation.

Using the (Eden National) Demonstration Test Catchment (DTC) (in Cumbria, UK) as our main example, we assess how future climate change, and land use change might impinge on individual buffering pathways into the future and alter catchment sensitivity to future P pressures. We illustrate how the results of this analysis informs understanding of the ability of a catchment to attain WFD targets, and what mitigation efforts will likely be most effective at reducing a catchment's sensitivity to factors a, b or c and increasing catchment buffering capacity. In identifying the dominant sensitivity factor (a, b or c) under climate change, highly specific catchment management plans for targets and mitigation can be applied in order to preserve ecosystem functioning and sustainable intensification targets, whilst considering both social and political agendas.

# Is the pressure-specific invertebrate index PSI an ecologically relevant tool for determining water quality sedimentation targets?

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Sedimentation is a major cause of river impairment and water quality problems worldwide. However, setting of meaningful water quality thresholds is proving challenging due to significant gaps in the understanding of quantitative links between sedimentation and ecological response as well as variability between different types of surface waters. In addition, many freshwaters are vulnerable to a simultaneous impact of multiple-stressors, which can result in unexpected ecological effects due to complex interactions, thus complicating the setting of water quality targets at different levels of these interacting pressures. Therefore, tools that would distinguish between multiple causes of river impairment at any one location are needed.

This study evaluates the utility of a new pressure-specific macro-invertebrate index Proportion of Sediment-sensitive Invertebrates (PSI) to act as a simple tool for measuring sedimentation impacts and setting ecologically relevant sedimentation targets.

Five macro-invertebrate indices were calculated from 51 samples taken from 13 sampling locations across two neighbouring, but contrasting study catchments in spring and autumn 2010 and 2011. For four of these, Environmental Quality Indices (EQIs) were also calculated as a proportion of observed to expected (O:E) macro-invertebrate scores, which were predicted for a theoretical pristine invertebrate community using the RIVPACs model.

Principal Component Analysis has shown a clear hydromorphological and sedimentation gradient within the two study catchments. A generalised hierarchical mixed model with site as a random factor and % fine bed sediment as a fixed factor found a significant relationship between PSI and O:E PSI and % fine bed sediment cover at reach-scale sampling resolution over a moderate gradient of impact ($P = 0.002$ and $P = 0.014$). PSI was more strongly related to % fine bed sediment cover than either Lotic Index for Flow Evaluation (LIFE) or Ephemeroptera-Plecoptera-Trichoptera abundance (EPT % abundance). While PSI and O:E PSI were correlated with LIFE and O:E LIFE ($r = 0.58$-$0.91$), with the strength of the relationship increasing over the sampling period, PSI was not correlated with EPT % abundance, which suggests a differentiated response of these metrics to multiple stressors. These findings suggest that PSI and % fine bed sediment cover have the potential to provide simple, sensitive and effective tools for setting of 'twin' ecological and physical sedimentation targets and add additional explanatory power to the existing suite of macro-invertebrate indices. Currently, the UK Water Framework Directive Technical Advisory Group is using PSI to develop a new river status classification that would reflect sedimentation pressures.

# Combining sediment flux and fingerprinting to target soil erosion and sediment management strategies in agricultural catchments

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Excessive suspended sediment supply to aquatic ecosystems can degrade the physical and chemical condition of rivers. To manage soil erosion risk in a cost-effective manner, quantification of sediment export and identification of sediment sources must be robustly defined. Sediment fingerprinting is a catchment scale management tool, which utilises natural soil and sediment characteristics (termed tracers). The tracer characteristics of the target sediment are considered to be a mixture of the sources, which can be statistically 'un-mixed'. The aim of this study was; i) to quantify suspended sediment yields at the outlet of five intensively managed and monitored agricultural catchments (3-11 $km^2$) in Ireland, and ii) to identify sediment sources in catchments with the greatest sediment loss risk.

Suspended sediment yield (tonnes $km^{-2}$ $yr^{-1}$) was calculated from calibrated turbidity and discharge outlet data. Sediment fingerprinting was conducted in three of these catchments. Source sampling targeted channel banks, field topsoils, damaged road verges, farm tracks and eroding ditches (edge of field open drains). River sediments were collected every six to twelve weeks using time integrated suspended sediment samplers located at the catchment outlet from May 2012 to May 2014. Samples were dried (<40$^{o}$C) and sieved (125 µm) before analysis for mineral magnetics, geochemistry, radionuclides, particle size distribution and organic carbon. Source contributions were statistically un-mixed following correction for selectivity processes using an uncertainty inclusive algorithm, FR2000, which assigned median source predictions and 95% confidence intervals to contribution results.

Optimal fingerprints included tracers from all analysis methods (mineral magnetics, geochemistry and radionuclides) confirming the importance of multiple parameters. Sediment fingerprinting showed seasonal source fluctuations in the three study catchments; management strategies must consider such variations to ensure effective mitigation strategies are applied. Improved knowledge and mitigation of catchment sediment sources can more effectively reduce sediment pressures on downstream ecology.

# Processes controlling the response of algal blooms to nutrient enrichment in estuaries and coastal waters around Ireland

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Human population growth, industrialisation and the intensification of agricultural practices in the second half of the last century has resulted in the degradation of many aquatic ecosystems along the freshwater-marine continuum. Estuarine and coastal systems, the end recipient of nutrient loads from land-based activities, have exhibited increased nutrient concentrations and sometimes a concurrent increase in micro- and macroalgal blooms. At present 46% of Irish estuarine and coastal waters are at good or high ecological status, leaving 53% of systems requiring improvement. National nutrient loads in 19 major river catchments have shown a 52% and 24% reduction in total phosphorus (TP) and total nitrogen (TN) from 1990 to 2010. Although the reductions are indicative of recent policy successes, the disproportionate reduction in P loads relative to N can have implications for the transport of nutrients to downstream coastal systems.

Field observations have revealed that the link between nutrient loads and biological responses can be complex and a full understanding of this link can only be attained through the consideration of the factors and processes which mediate the response (e.g. hydrological regime, hydromorphology, nutrient and light availability). In Ireland two recent tools have been applied which have facilitated a deeper understanding of the importance of these factors. A conceptual phytoplankton-nutrient model suggests that while many Irish estuaries are nutrient-enriched, relatively few display phytoplankton-related symptoms of eutrophication as the response to nutrients is primarily affected by insufficient retention time and in some by inadequate light availability. The recent use of the Dynamic Combined Phytoplankton and Macroalgal (DCPM) Model further reinforced the phytoplankton-nutrient conceptual model through a focused study on two catchments (the Argideen and the Blackwater) under similar anthropogenic pressures yet exhibiting divergent responses as a result of large differences in hydrological regime. Moreover, the DCPM model allows for projected nutrient reduction scenarios to be examined to support target setting to improve the status and ecological health of each system. Use of tools, described above, is of direct value and use to water managers in determining the relative susceptibility of these systems to nutrient enrichment and can be used to develop targeted and effective programmes of measures.

# NOTES

# POSTER PRESENTATIONS

## Detecting change and lag times - patience and policy implementation

# 1

# Variable response to phosphorus mitigation measures across the nutrient transfer continuum in two contrasting arable catchments

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The aim of this research was to investigate the regulation of excessive soil phosphorus (P) concentrations and the effect on the P transfer continuum (i.e. source to impact). The study took place in two contrasting arable catchments in Ireland over a 4 year period. The Arable A catchment is 11.2 $km^2$, on well drained soils and mostly spring barley. Arable B catchment is 9.5 $km^2$ on a mixture of poor-moderately drained soils, with approximately equal areas of grassland and arable (mostly winter wheat) landuse.

During 2009-2010 and 2013-2014 full soil surveys for plant-available P were carried out at a <2 ha sample resolution in both catchments and P use was monitored. Concurrently, high temporal resolution monitoring of water discharge and P concentration data were collected at each catchment outlet across five hydrological years and used for estimating the proportion and concentrations of P in hydrological transfer pathways. Ecological surveys of benthic macro-invertebrate and diatom quality were carried out at four sites within each catchment in May and September between 2009 and 2014.

Results in Arable A showed an average increase in P inputs (2.6 kg $ha^{-1}$ $yr^{-1}$) over the sample period, but excessive soil P concentrations decreased (20 % to 12 %) indicating increased efficiency. In Arable B overall P inputs increased on average by 2.8 kg $ha^{-1}$ $yr^{-1}$ and excessive soil P concentrations increased (22 % to 26 %). Within the Arable A catchment, total reactive P (TRP) and total P (TP) concentrations declined across most hydrological pathways, but with no clear trend in TRP concentrations in the groundwater pathway. With the exception of the baseflow pathway for TRP, concentrations of TRP and TP were higher in the Arable B catchment across all pathways compared to Arable A, particularly in the shallow groundwater pathway. Also in Arable B, over the five year period, TRP concentrations slightly increased in this pathway, but there was no apparent trend in TP. However, these subtle changes in soluble P transfers were not reflected at either catchment outlet, which showed no consistent trend over the survey period.

Daily TRP concentrations exceeded the environmental quality standard (0.035 mg $l^{-1}$) 20% of the time in Arable A and almost 100% of the time in Arable B. However, seasonal trends of better ecological quality post-winter than post-summer were stronger than any inter-annual trends over the five years. These trends were not linked to the small changes in hydrological pathway P concentrations.

2

# Identifying changes in catchment phosphorus load - a parsimonious model for a small agricultural catchment

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Knowledge of the sources and transfer pathways of phosphorus (P) from agricultural land to water is essential if efforts to mitigate diffuse pollution and improve water quality are to succeed. However, the understanding and modelling of high frequency P dynamics necessary to inform successful mitigation requires data of sufficient temporal resolution to identify the effects of natural inter-annual weather variability and overcome the limitations imposed by the shortage of long-term observations and monitoring data. This study identifies a simple linear transfer function model with a non-linear rainfall input to relate observed rainfall with monitored total P (TP) load for a small (12.5 km$^2$) agricultural catchment in the River Eden basin, UK. The model is then used with hourly rainfall data generated with the UKCP09 Weather Generator for conditions representative of the current climate in the study catchment, to show the magnitude of inter-annual variability in TP export.

For the study catchment, the simple linear model was able to account for 66% of the variation in the observed TP load for the hydrological year 2011/12, and this was improved further with a non-linear rainfall input. When combined with rainfall data from UKCP09, the model suggested that the variation in the non-linear effect of rainfall (heavy rainfall transports disproportionately more TP) is much smaller (by a factor of about seven) than the inter-annual variability in total rainfall, and hence the inter-annual variability in TP load. This has implications for measuring the effects of on-farm mitigation at the catchment outlet, as any changes in water quality attributable to targeted intervention may be masked by other factors, which have a stronger influence on the observed variability in TP load. Observations alone, therefore, will not be sufficient to identify improvements, but models such as this one, particularly if they can be derived from long-term (many years) data, can help to disentangle the trends due to weather from other land management variables.

# 3

## A toolkit for assessing soil time lag in agricultural catchments

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Predicting water quality changes subsequent to implementation of programmes of measures (e.g. the Nitrates Directive under the European Union Water Framework Directive), is critical for policy makers. This intrinsic time lag is typically divided into unsaturated/soil ($t_U$) and saturated/groundwater ($t_S$) components. Analysis of the preliminary stages of $t_U$ (indicated by initial solute breakthrough at the base of the soil profile) can identify trends in water quality response, and so, provide an early indication of the efficacy of programmes of measures. The following study presents a toolkit by which this objective has been achieved within the free-draining Grassland A and Arable A catchments (Irish Agricultural Catchments Program), using soil data derived from the Irish Soil Information System and the Hydrus 1D numerical model.

In the grassland catchment, watertable depths typically range from 0.7 to 7.25 m. For the dominant soil series (Ballylanders) (c. 50% of the land area) trends may begin to be observed in groundwater between at 0.10 yrs in the near-stream area, and 1.12 yrs, upslope. However, the remainder of the catchment may exhibit time lags in initial breakthrough of up to 1.09 yrs. The minimum time lag for full exit of the solute from the unsaturated zone was predicted at 1.07 yrs, adjacent to the receptor, but for most scenarios, exceeded the three-year period subsequent to implementation of programmes of measures in 2012, in all but the shallowest soil profiles.

For the arable catchment, (watertable: 1 to 8.5 m depth) trends for the dominant soil series (Clonroche and Ballylanders) (c. 75% of the area) could first be observed at 0.16 yrs (near-stream) and 1.28 yrs for most landscape positions. For the remainder of the catchment, initial breakthrough time lags ranged from 0.15 to 1.56 yrs, depending on soil type and landscape position. As with the grassland catchment, long-term $t_U$ was not less than 1.91 yrs for the majority of the catchment, but typically exceeded the three-year period subsequent to implementation. Bromide tracer studies conducted at two locations within each catchment indicate time lags within the ranges predicted by the toolkit approach.

The full effects of programmes of measures in groundwater cannot, therefore, be guaranteed by the 2015 deadline, although the approach presented here represents a toolkit by which trends may be predicted, both under current conditions, and for various meteorological and management scenarios.

4

# Modelling of unsaturated and saturated zone time lag at hillslope scale

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Following the introduction of overarching water policies (e.g. the EU Water Framework Directive (WFD)), there is a greater need for evidence-based quantification of the efficacy of mitigation measures (e.g. the Nitrates Directive). Hence, elucidation of a catchment-specific subsurface “time lag” in response to such measures has become essential. Time lag has two components: unsaturated ($t_U$) and saturated ($t_S$), or for simplicity “soil” and “groundwater”. Initial estimates, which assumed fully saturated conditions, proved that achievement of good status in all water bodies by 2015 was not possible. The present paper combines results from two PhD studies and presents, for the first time, hillslope-scale estimates of time lag in two catchments (grassland and arable). Soil profiles were excavated and multi-level borehole transects were installed to obtain soil/subsoil and aquifer hydraulic parameters and watertable positions, respectively.

For the grassland site, results of unsaturated zone modelling (Hydrus 1D) using local meteorological data and hydraulic properties derived from soil physical data, indicated that initial breakthough of a solute to groundwater (indicating trend changes in water quality) could be expected within 0.07 to 0.71 years, depending on slope position, with full exit of the solute from the soil ($t_U$) expected to exceed 3 years. Equivalent results of the saturated zone modelling, using aquifer permeability and groundwater elevation as input data (1D advective model), indicate $t_s$ (upslope to stream) ranging from 0.41 to 3 years in the shallow and deep pathways, respectively. For the arable site, trend changes are predicted within 0.18 to 1.8 years, with $t_U$ likewise, frequently exceeding the three-year WFD reporting periods. Predictions of $t_s$ indicated a range of 0.23 to 1.2 years.

This means that for the hillslopes investigated, the combined effects of $t_U$ and $t_S$ would preclude trend changes in surface water quality before a minimum time lag of 0.48 to 3.71 years (grassland) and 0.41 to 3 years (arable). However, the full effects of measures are unlikely to be observed in less than 6 years for either hillslope. The modelling approach described herein facilitates site-specific assessment of the efficacy of mitigation measures.

A potassium bromide (KBr) tracer was applied at both locations in December 2014, the results of which will be forthcoming within 2015, and will allow the accuracy of these estimates to be examined.

5

# Agricultural pollution of headwater streams in Northern Ireland: Assessing the impact of control measures from 1990 to 2014


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The water quality status of agricultural headwater catchments in Northern Ireland and their intensities of nitrogen (N) and phosphorus (P) export are compared over a 25 year period when a series of measures targeting farm nutrient management were implemented. In 1990 widespread agricultural point source pollution meant that only 40% of headwaters exhibited chemistry suitable for salmonids, but this had increased to 85% in 2009. Throughout this period nitrogen (N) and phosphorus (P) exports were correlated with agricultural land use intensity assessed as normalised catchment livestock manure rates, but as nutrient exports and agriculturally derived organic pollution declined these regressions became stronger. Reductions to diffuse P exports were less pronounced than for N exports suggesting legacies of high farm P surpluses and tighter coupling of N export with lowered fertiliser inputs; however the impact of more recent measures targeting diffuse P export, notably winter closed seasons for manure applications, remain to be fully assessed. Widespread reductions observed in diffuse P losses suggest that pessimism regarding the capacity to control P losses may be overstated. As headwater P concentrations at higher livestocking rates remain variable but largely in excess of nutrient standards, the identification of further factors impinging on nutrient losses is critical for the formulation of realistic expectations for nutrient controls.

6

# Specific groundwater phosphorus vulnerability in two groundwater driven agricultural catchments

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The importance of flow and phosphorus (P) mobilisation influence on P transfer below the rooting zone, *via* the aquifer and into the river was investigated in two agricultural catchments. Both catchments had stream flow dominated by groundwater (baseflow index = 0.75), but had contrasting land use (Grassland and Arable) and soil chemistry (iron-rich and aluminium-rich). A five year dataset of sub-hourly hydrochemistry, monthly groundwater chemistry and extensive soil chemistry analysis was analysed. Despite the two catchments having similar inorganic P reserves, the iron-rich soils of the Grassland catchment favoured P mobilisation into soluble form and transfer to groundwater. Sites in that catchment had elevated dissolved reactive P concentrations in groundwater (>0.035 mg $l^{-1}$) and the river had flow-weighted mean total reactive P (TRP) concentrations near three times that of the aluminium-rich Arable catchment (0.067 mg $l^{-1}$ compared to 0.023 mg $l^{-1}$). While the average annual TRP flux was low in both catchments (although three times higher in the Grassland catchment; 0.385 kg $ha^{-1}$ compared to 0.128 kg $ha^{-1}$), 50% and 59% of TRP was lost *via* groundwater pathways, respectively, during winter periods that were closed for fertilizer application. For policy reviews, slow-flow pathways and associated lag times should be carefully considered when reviewing mitigating strategies in groundwater fed catchments. This consideration should also include extraneous surface pollution of river baseflows; for example, while the Grassland catchment indicated a susceptibility to soil-P chemistry (weak P binding capacity), the Arable catchment indicated a transient point source control; both resulted in sustained or transient periods of elevated low river-flow P concentrations, respectively. Nevertheless, the findings contribute to a better process based understanding of specific P susceptibility of groundwater at the catchment scale, providing a deeper assessment and targeted support for best management practice in intensively managed free draining agricultural catchments.

# Integrated management, stakeholder engagement and catchment economics

7

# Co-Click'Eau: a participatory method to draw out a collective action toward good status of drinking water resource in water catchment areas

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The European Water Framework Directive (2000/60/EC) requires member states to achieve good status of their water bodies. In France, legislation demands that stakeholders in priority water catchment areas (WCA) design and implement local action plans to improve water quality. One thousand priority WCAs are directly targeted by the legislation, but more than 30,000 WCAs are also potentially concerned.

As agriculture is highlighted as a major lever to achieve good status of water resources, changes in farming practices are often in question. Differences and difficulties among local stakeholders who do not share the same set of goals and constraints regarding water quality rapidly emerge during the initial steps of designing action plans. While public authorities focus on the impact of agricultural practices on water quality, farmers typically focus on the technical feasibility and economics of alternative practices. Up to now, such potential conflicts often result in actions plans that are generic, removed from the local challenges and opportunities, showing a weak compromise without any link to specific to the WCA in question. These action plans reflect a weak compromise and are not expected to contribute efficiently to the restoration of water quality.

To meet the challenge, INRA, the French National Institute for Agricultural Research, developed a participatory method named Co-Click'Eau. The method aims at improving collective stakeholder communication and sharing regarding agricultural practices thanks to multi-criteria assessment of territory-based scenarios. It involves a decision support system based on a mathematical programming model and takes into account a set of indicators including environmental and socio-economic indicators - for example pesticide use and nitrate loss for the former, and margins and labour costs for the latter. This method ensures that the emerging action plans are tailored to local realities because it:

i. generates territory-based scenarios built upon local knowledge of agricultural practices and their collectively agreed-upon multi-criteria performances

ii integrates within scenarios the expectations and constraints expressed by the diversity of local stakeholders during participatory workshops

The Co-Click'eau team designed and tested the method in three WCAs from 2010 to 2012. The method is now made explicit, formalised and available for implementation in other water catchments.

# 8

## Functional Land Management concepts to support sustainable intensification

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Agricultural soils offer multiple ecosystem functions and the demand for the primary production function is expected to increase with a growing world population. Other key functions on agricultural land have been identified as water purification, carbon sequestration, habitat biodiversity and nutrient cycling. These five functions all contribute to the achievement of goals in agronomic policy and targets in EU environmental legislation.

Functional Land Management (FLM) comprises a novel land management approach to support sustainable intensification through the provision of soil based ecosystem services (soil functions). It capitalises on the soil's multi-functional capacity (MFC) by matching the nature/degree of farming activity to the soil type, which is best at "supplying" the preferred suite of functions.

Conceptual models were developed for each soil function, based on a comprehensive literature review, to create a simplified matrix for assessing the multi-functional capacity of soils. This matrix summarises the range in capacity of individual functions across land use types (arable, bio-energy, broadleaf forest, coniferous forest, managed grassland, other grassland and Natura 2000) for three drainage categories (well, moderately/imperfect, poor).

The functional soil matrix indicates the consequential changes to the capacity of the entire five soil functions associated with land use change on soils with contrasting drainage characteristics. Where policy prioritises the enhancement of particular functions, the matrix indicates the potential trade-offs for individual functions or the overall impact on the multi-functional capacity of soil.

The functional soil matrix shows that most soils are capable of performing all functions simultaneously but to varying extents. For example, the capacity to supply primary productivity is highest on well drained arable soils; while the capacity to sequester carbon is highest in poorly drained coniferous forestry. Similarly, the capacity to supply water purification (by denitrification) is highest under poorly drained broadleaf forests. All soil types contribute to the goal of sustainable intensification due to their overall MFC and/or their capacity to perform individual functions.

The FLM framework simplifies complex information on soil processes, which influence soil functions, and their interaction with land use to facilitate the effective design and assessment of agri-environmental policies. The next important stage of the study will be to provide a quantitative dimension to the conceptual framework using real data at river catchment level. The project will work in conjunction with the Teagasc Agricultural Catchments Programme.

# 9

## Trans-P program: how to identify areas at risk regarding P transfer from catchment to regional level

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The Trans-P program is focused on soil phosphorus (P) and on its transfer and transformation at catchment (5km$^2$, Kervidy-Naizin, a long term Research observatory) and regional levels (North Western France). This program starts from one spatial level to go to the other one, and from soil P storage to P emission in streams and rivers. Three axis have been defined which will be illustrated: i) how to better estimate extractable P and total P content in soil at catchment (5km$^2$) and regional level; which co-variates can be used at both spatial levels; how to use landscape features to improve regional estimation of P stocks; ii) which methodology is best to estimate P fluxes in stream at catchment level, how to identify temporal storm patterns from high frequency time series, and, by this way, identify flow pathways, and how to separate diffuse and point sources by analysing low frequency time series at regional level; iii) which dynamic of P in soil, in groundwater and in stream, and how to model them, best simulates SRP emission in stream water at catchment level. These different parts are original contributions to phosphorus transfer and transformation, which can be partly used at regional level.

10

# A comparison of methods for inviting expressions of interest in the KerryLIFE project

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The freshwater pearl mussel (*Margaritifera margaritifera*) is a critically endangered freshwater species that is vulnerable to fine sediment and nutrient inputs to its habitat, as well as changes to hydrology. The Caragh and -Blackwater (Kerry) rivers in South Kerry are important rivers for this species, containing almost half of the Irish population and almost one quarter of the EU population.

KerryLIFE is an €5 million EU LIFE Nature project supporting the local communities in the Caragh and Blackwater river catchments in demonstrating practical conservation methods of freshwater pearl mussel habitat. The project is co-funded by the European Commission, Department of Arts, Heritage and the Gaeltacht, Department of Agriculture Food and the Marine, Forest Service, Coillte, Teagasc,the South Kerry Development Partnership and Pobal. The KerryLIFE project aims to develop approximately 50 farm plans that will trial freshwater pearl mussel conservation actions between 2015 and 2019. Therefore, expressions of interest in participating in the project were sought from all farmers in the project area between December 2014 and April 2015 through five methods: (i) public information meetings (one in each catchment), (ii) door to door delivery of information leaflets, (iii) information stalls at two local mart meetings, (iv) radio advertisement and (v) newspaper advertisement.

There were 288 farmers with at least some land within the project area and 118 (41 %) of these farmers expressed interest in participating in the project. Of these 118 farmers, 48 (41 %) stated that they became interested in the project from the public information meetings, 35 (30 %) from the door to door delivery of flyers, 7 (6 %) from mart information stalls, one from the radio advertisement and none from the newspaper advert. An additional 27 (23 %) stated that they heard about the project through word of mouth (friends, neighbours or relatives). However, it should be noted that public information meetings may have been preferentially attended by farmers with a pre-existing interest in the project. Furthermore, it was observed that farmers that were met face-to-face when delivering flyers tended to be more likely to express interest than those that were not at home and had flyers dropped in the door.

To conclude, public information meetings, door-to-door meetings and word of mouth were the most successful methods. This may have been due to the fact that these methods provided the farmers with opportunity to discuss aspects of the project, rather than simply reading/hearing about it.

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# How to apply detailed spatialised modelling to support nitrogen attenuation strategies?

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Taking into account spatial interactions and the response time of a catchment is necessary in order to forecast and achieve an optimised and acceptable equilibrium between water quality and economic objectives.

TNT2 is a spatialised agro-hydrological model, specifically designed to study nitrogen dynamics at the catchment scale in temperate pedoclimatic conditions. TNT2 is a half-physical half-process based daily time step model, and uses a spatial grid of a typical 10-50 m resolution. Such an approach allows for the representation of non-linear spatial interactions, *e.g.* subsurface pathways and the dynamics of wetlands and their effective attenuation of nitrate through denitrification. Detailed agricultural practice changes and landscape spatial reorganisations can be effectively simulated.

TNT2 modelling has been used since 2010 in "production mode" on 14 catchments flowing into bays affected by green algae blooms in Brittany, France. The model was used to forecast impacts and validate the different detailed action plans, designed for each catchment by the local stakeholders to achieve a decrease of nitrate concentrations in streams for 2027.

In the presentation, we will first show how we leveraged some key technical constraints to move a high resolution model to a production environment, as follows: agricultural practice time series reconstruction and spatialisation (CSAM), model calibration (genetic algorithms and identification of critical events), confidence intervals (Sensitivity analysis to reduce search space for a bootstrap or a GLUE approach).

In the second part, we will show results on a selection of dairy catchments, and the expected effects of some actions on nitrogen dynamics.

# 12

## The development of an aquatic vegetation classification system and monitoring protocol for Irish rivers to support biodiversity reporting requirements and conservation planning

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Integrated monitoring of our river catchments has become more important with the sustainable intensification of agriculture. To measure the ecological quality of our rivers, we must first have an in-depth knowledge of the environment in order to carry out accurate assessment and monitoring of our river catchments. Assessing water quality using river macrophytes (vascular plants, bryophytes and macroalgae) is well known and used in Great Britain (MTR - Mean Trophic Rank uses chosen macrophytes as indicators of water quality) and intercalibration with Irish river vegetation is underway by the Environmental Protection Agency. However, little consideration has been given to aquatic river vegetation community composition as a whole. The examination of vegetation communities, species presence/absence, and changes in their relative abundance can tell us much about the environment in which they grow and therefore can be important indicators of external stressors and prevailing ecological river conditions in terms of biodiversity. There is an urgent need to gain an understanding of river vegetation communities from rivers of high ecological status to provide us with reference site data which will be invaluable for monitoring and managing our river catchments. These high status rivers are in decline (from 30% to 17% in 21 years).

Ireland does not yet have a comprehensive National Vegetation Classification System for river macrophyte communities. The Fossitt classification, based on habitat, includes two categories for rivers; upland (FW1) and lowland (FW2) which is a very useful tool on a large scale but is not suitable for detailed monitoring and evaluation. Rivers are generally treated all as one when reporting on a European level (Annex 1 Habitat 3260); therefore, a more detailed vegetation classification for Irish rivers is essential for management and assessment purposes.

A river macrophyte database (RMD) has been collated and is currently being analysed to construct a National Vegetation Classification System for Irish Rivers and, importantly, the classification system includes river vegetation from rivers of high ecological status, i.e. reference vegetation. Preliminary analyses show a variety of river plant communities from a range of ecological conditions, where their composition is driven by factors such as conductivity, pH and river bed composition. What is unique about this research is that there is a focus on the ecological quality of the river as a whole and not just water quality. This will inform Water Framework Directive and Habitats directive reporting and site-specific management and conservation measures, where required.

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# Coastwatch: Nitrates in small inflows (Citizen Science)

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Volunteers reported on the quality of 575 streams, drains, piped discharges and seepage entering Irish coastal waters (both jurisdictions) during August, September and October 2014.
Most of these coastal inflows passed visual and smell tests; however, discolouration and/or a bad smell was noted from 7%, raw sewage from 3% and oil from 2 inflows (0.3%). Animal life was observed in 7% but nitrate ($NO_3$) tests carried out using Merck field test strips on 515 of the inflows highlighted regional nutrient input issues.
All around Ireland 55% of the tested inflows showed some $NO_3$ enrichment above the detection limit of 10mg/l. The 111 Northern Ireland inflows included in the survey returned 52% above detection. While most Irish inflows were in the 10-25mg/l $NO_3$ enrichment band, 9% breached the drinking water limits of 50mg/l $NO_3$.
When mapped, the higher $NO_3$ inflows were concentrated in the east and south-east where >80% were enriched, dropping to < 20 % enrichment in west and north-west coastal inflows.
When comparing the 100 August tests with the autumn tests, the east coast rural inflows were worse in August, while in Dublin there was no seasonal difference. This may relate to rural holiday resort use rather than agricultural sources and requires further research. The autumn survey result pattern is similar to that in previous Coastwatch surveys. Where receiving waters are classified as eutrophic by the EPA the majority of small inflows tested were contributing to the load.
The autumn 2015 Coastwatch survey again includes inflow monitoring. The Citizen Science work produces useful complementary data to that gathered officially and also gives citizens a more direct experience raising interest in stream protection and finding the causes of eutrophication.

**Acknowledgements:** Work was carried out by citizen volunteers who were supplied with $NO_3$ test kits, instructions and training by Coastwatch coordinators. The work was coordinated by Karin Dubsky and Isaac Varela. A grant from the department of the environment water services covered $NO_3$ test kits and some training costs.

# 14

# VALERIE - knowledge exchange for innovation in agriculture and forestry

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VALERIE (Valorising European Research for Innovation in Agriculture and Forestry – www.valerie.eu) is a European funded research project (FP7-KBBE-2013-7), which aims to improve the availability and flow of new knowledge and information to drive innovation in agriculture and forestry around six themes: i) crop rotation, soil cover management and integrated pest management; ii) ecosystem and social services in agriculture and forestry; iii) soil management in agriculture; iv) water management in agriculture; v) integrated supply chain services and tools; and vi) recycling and smart use of biomass and food waste.

This is being achieved through: i) repeated cycles of knowledge exchange in 10 case studies working with practitioners to identify current challenges for sustainability in agriculture and forestry; ii) extraction of knowledge from European research projects to help meet these challenges; and iii) the development of the *ask-Valerie.eu* search engine to improve access to information.

The ten VALERIE case studies cover: i) catchment scale resource use efficiency, UK; ii) soil management in livestock supply chains, UK; iii) sustainable forest biomass, Finland; iv) agro-ecology (managing plant protection, France); v) innovative arable cropping, France; vi) sustainable forest management and ecosystem services, Spain; vii) improving milling wheat quality, Italy; viii) drip irrigation management in tomatoes and maize, Italy; ix) sustainable onion supply chains, Netherlands; and x) sustainable potato supply chains, Poland.

Knowledge extraction has focused on the identification of more than 300 innovations, defined in VALERIE as a tool, practice, or piece of software that can solve a problem for a farmer or forest manager. For each innovation, a mini-factsheet will be produced containing useful information on the problems that the innovation aims to solve (the innovation challenge); a list of references; and a list of projects connected to the innovation.

Finally, VALERIE will develop an advanced search engine and repository of structured information that will interactively provide easy access to knowledge created in EU and other research projects for farmers, agricultural organisations and researchers. The *ask-VALERIE.eu* search tool will allow users to retrieve relevant and useful information using available and reliable sources. The first version of *ask-Valerie.eu* was tested by case study leaders in June 2015. Through these activities, VALERIE will promote interactions between practitioners, advisers and researchers in agriculture and forestry by improving access to relevant scientific knowledge and results, thereby boosting the process of innovation.

# Soil analysis and nutrient management – achieving environmental and agronomic goals

# 15

## Essential plant environmental impacts on corn yield

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Fertilizer and rainfall (essential parts of the plant environment) amounts and timing are important factors influencing food production. This paper uses different NPK-fertilization systems and rainfall patterns from 1961 to 2013 to develop Fertilization (N, $P_2O_5$, $K_2O$)-Rainfall-Corn Yield (FRCY) models for drought risk. Rainfall and corn yield data were observed in a National Long-Term Fertilization Trial (Code: NLFT A-17) on a Calcareous Chernozem Soil (CCS) using a "Wheat-Corn-Corn-Pea" (WCCP) crop sequence at Nagyhörcsök, Hungary for 52 yr. There were 20 treatments in the experiment arranged in a Split-Split-Plot (SSP) design with four replications, giving a total of 80 plots. Fertilizer application rates averaged 0, 39, 67, 99, 125 kg N $ha^{-1}$ $year^{-1}$; 0, 22.7, 45.3, 68.6 kg P $ha^{-1}$ $year^{-1}$ and 0, 79.7, 126.2 kg K $ha^{-1}$ $year^{-1}$. Statistical models of fertilization, rainfall, and yield response could be described by significant polynomials in normal years: $R^2$ = 0.916***, dry years: $R^2$ = 0.974***, drought years: $R^2$ = 0.994***, and excessively wet years: $R^2$ = 0.948***. However, both water deficits and excesses rainfall greatly reduce corn productivity and lower yields are expected with both types of stress.

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# Modelling the soil moisture and mineral N balance to support advice for better farming practices. A case study in North-East Flanders (Belgium)

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In the context of the EU Nitrates Directive and supported by the Flemish Land Agency, a project on surface water quality was started in 2012 in the area of the Horstgaterbeek, a stream in North Limburg, Flanders. Due to its characteristics, this is an ideal area to gain more insight in nitrate flows linked with agricultural activities. The area has an important agricultural activity, with many livestock farms and grassland, but also arable crops. It is a flat area with sandy to sandy-loam soils and shallow groundwater tables. In the area, two monitoring sites for surface water quality, belonging to the MAP monitoring network of the Flemish Environmental Agency, are situated in small ditches. In one of them, the nitrate concentration regularly exceeds the standard (50 mg $NO_3$-$l^{-1}$). In the other site, the nitrate concentration has remained below the standard during the last 10 years. The aim of the project was to gain a better insight in the nitrate flows within the catchments of the monitoring sites and to improve surface water quality, through an intensive follow-up of the agricultural activities, in collaboration with the local farmers.

After three years, very interesting improvements were achieved in terms of nitrate residues and nitrate losses from agricultural land, partly thanks to an integrated monitoring of both the farming and fertilization practices and the water quality.

In order to gain a better insight in the N-dynamics in the agricultural parcels, a mechanistic modelling approach of the mineral-N-balance in the soil was developed. In this approach, the different inputs and outputs of nitrogen are estimated. The N-mineralization from soil organic matter is calculated based on the potential mineralization rate and taking into account the temperature and moisture content in the soil. The soil moisture content as well as the water flushing rates are calculated with a soil moisture balance model developed by the Soil Service of Belgium. This model takes into account soil characteristics, changes of the groundwater table, local precipitation and parcel-specific evapotranspiration, crop rotation and soil cover.

The modelling approach of the N-dynamics in the soil allowed us to give the concerned farmers a better understanding of the different factors (fertilization, crop uptake, mineralization, leaching, etc.) affecting the nitrate residues and nitrate losses from their agricultural parcels to the groundwater.

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# Modelling restrictive layers to predict their control on subsurface and surface catchment hydrology

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Restrictive layers (e.g. argillic horizons, fragipans, interfaces at lithologic discontinuities) are known to decrease the effective depth of a soil resulting in less soil moisture storage, thus decreasing the time to runoff generation by saturation excess mechanisms. In landscapes where such runoff occurs, agricultural pollution is more likely to reach waterways. We present research from the WE-38 catchment in Central Pennsylvania, USA of restrictive layers that were described in pedons, and that had their physical and mineralogical properties characterized. In addition, ground penetrating radar profiles were established for each pedon, as well as for random transects across select regions of the watershed. These data sets were used to develop a "signature" of the restrictive layer, which was then modelled using DEM surface derivatives to create extent maps of the location and depth to the restrictive layer across WE-38. These maps can be used to identify areas of the landscape prone to saturation excess runoff, and thus be used to better guide agricultural management.

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## Nitrogen and phosphorus fertiliser use efficiency in grassland systems

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Adequate supplies of both nitrogen (N) and phosphorus (P) are required to maintain grassland productivity for intensive grassland farming. Careful management of these nutrients in fertilisers and organic manures is required due to their potential negative effects on aquatic environments and are tightly regulated at farm level under the EU Nitrates Directive (S.I. No. 31 of 2014). Increasing nutrient utilization efficiency and reducing nutrient losses are key targets for Irish farmers especially those operating more intensive grass based production systems.

Previous research conducted at Johnstown Castle, has shown a large variability in native soil nutrient supply and response to applied fertilisers across different soil types in Ireland. The aim of this work was to validate these findings at field scale and to support the development of new soil specific P advice for farmers. Four regional grassland trial sites were established within four of the Irish Agricultural Catchment Programme sites. These experimental sites had a range in soil P fertility from low to very high. At each experimental site a 7 fertiliser treatment N x P factorial experiment, replicated 4 times was established as a randomised complete block design. Treatment plots were sown with a perennial ryegrass (*Lolium perinne*) mix. Treatments included a control plus three rates of N (100, 200, 300 kg $ha^{-1}$ $yr^{-1}$) applied as SulphaCAN (26.6% N and 5% Sulphur) and three rates of P (20, 40, 60 kg $ha^{-1}$ $yr^{-1}$) applied as triple superphosphate (16% P). Monthly harvests are conducted with grass plots cut to 4cm with dry matter yield and grass nutrient content determined. To assess changes in soil P and N fractions, soil sampling was conducted prior to the initial treatment applications in 2013 and twice per year thereafter.

To date the results show a range of positive yield responses to P fertiliser applications at all sites, including those with a high soil test P (STP, Morgan's extractable P). A P balance approach (P input - P offtake) was used to determine the response of additional chemical P on the change in STP levels over time. As expected high applications of P on low STP soils showed the greatest potential to build STP; however, early indications are that the changes are soil specific. High P fertility soils showed the greatest decline in STP with a negative P balance and results indicate that a positive P balance was required to maintain STP at these high initial levels.

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# Effect of fertiliser nitrogen source on nitrous oxide emissions and yield in spring barley

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Nitrogen (N) fertiliser application to spring barley is essential for achieving target grain yields and quality. The addition of N fertilisers to soils contributes to environmental N losses including nitrate leaching and nitrous oxide ($N_2O$) emissions. The dominant N fertiliser used on spring barley is calcium ammonium nitrate (CAN) which contributes to $N_2O$ emissions and nitrate leaching. Switching from CAN to urea is one alternative for reducing losses. However, N can be lost from urea through ammonia volatilisation. The addition of inhibitors, such as n-butyl thiophosphoric triamide (n-BTPT) or dicyandiamide (DCD), to N fertilisers may reduce these N losses while simultaneously maintaining yields.

The objectives of this study were to assess the effects of nitrogen source on $N_2O$ emissions and yield in spring barley. The inhibitors used were n-BTPT and DCD. The treatments were CAN, urea, urea + n-BTPT, urea + DCD and urea + both inhibitors. This study was conducted on two contrasting sites (a long-term arable free-draining loam and a short-term arable moderately draining sandy loam) in the South East of Ireland for two years. Fertiliser N was applied at 150 kg N ha$^{-1}$ (30 kg N ha$^{-1}$ at sowing and 120 kg N ha$^{-1}$ at tillering). Emissions were measured using the static chamber technique and emission factors (EFs) were generated and compared to IPCC default EF of 1%.

Results showed that CAN, urea and urea + inhibitors produced comparable grain yield. Emission factors at the short-term site in year 1 were higher than the IPCC default and can be attributed to a history of organic manure application. Emission factors at the long-term site in both years and the short-term in year 2 were significantly lower than the IPCC default. Urea + DCD gave consistently lower EFs than the other treatments at both sites.

In summary, we found that fertiliser N source had no significant effect on grain yield. Since urea is cheaper per unit N it may be a more cost effective fertiliser source to use. However, large quantities of ammonia-N can be lost from urea and the inclusion of n-BTPT would protect against this loss and give farmers assurance for maintaining yields. Since the IPCC default overestimates emissions for spring barley in Ireland, there is a need for more accurate measurements for the national inventory. Urea + DCD has the potential to reduce $N_2O$ emissions and leaching without compromising grain yield or quality.

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# Estimating the critical level of plant available phosphorus for ryegrass production in organic soils under controlled conditions


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Current phosphorus (P) recommendations for grassland in Ireland are well established for mineral but not for high organic matter soils. These types of soils are known to have poor P retention capacity due to competitive sorption reactions between P anions and the organic acids for soil sorption sites. Thus, a need arises for assessing the agronomic P optimum in these soils, but taking into account environmental concerns. In this way, P applied in excess of the 'critical P value', a point at which maximum grass production is achieved, may increase the potential for P losses. This value can be determined by measuring the relationship between grass yield and different plant available P concentrations in soil through an asymptotic response curve. The aim of this research is to conduct a growth chamber experiment under controlled conditions to evaluate the fate of, and response to, applied inorganic P on low P organic soils sown with ryegrass. Fourteen treatments of soluble P fertiliser ranging from 0 to 100 kg P $ha^{-1}$ will be applied to the soils that have previously been treated with a basal nutrient solution of nitrogen and potassium. Six cuts of ryegrass will take place at one month intervals over the duration of the experiment and the dry matter amount, as well as herbage-P concentration for each cut, will be estimated. Throughout the duration of the experiment, plant available P concentrations will be measured using the iron-oxide impregnated filter paper ($P_i$ test), a procedure which has been proven to be simple to use, accurate and independent of the type of soil. At the end of the experiment, total P and soil P fractions will be determined. The results derived from this research work will enhance our knowledge of P uptake in these organic-rich soils. We hope to establish the critical P value at which P is optimised and estimate the maintenance P required for replacing the P removed from pastures.

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# Achieving best nutrient management practices on intensive dairy farms in Ireland

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Dairy farmers need to keep costs low to remain viable during times of low milk prices. Despite grazed grass being the cheapest feed source on the farm, it requires a continuous and balanced nutrient supply from the soil to achieve its production potential. Analysis of data from dairy farms across Ireland (PastureBase, National Grassland Database) show large spatial and temporal variability in grass production and quality within farms. Given the range in available nutrient status on grassland farms (i.e. soil samples submitted through Teagasc), nutrient management and distribution within farms is likely to play a major role in grass production variability and nutrient use efficiency.

This study aims to establish the effects of nutrient management practice on grass production, nutrient use efficiency, and economic and environmental sustainability on intensive dairy farms in Ireland. The objectives are:

(1) to establish current levels of nutrient management practice and efficiency;
(2) to identify the appropriate scale to achieve effective nutrient management including environmental and economic sustainability;
(3) to implement appropriate nutrient management related technologies to increase nutrient efficiency;
(4) to identify and quantify nutrient efficiency indicators.

In 2015, twenty one intensive dairy farms were selected based on certain criteria from the main milk producing regions (South East, South, and South West) of Ireland. An assessment of the bio-physical properties and constraints of the land on each farm was conducted (e.g. soil type, drainage, etc.) Soil samples for available nutrient concentration were taken from each paddock on these farms (sub-field scale) in spring 2015 and this will be repeated each spring for 4 years. Grass production and nutrient content from each paddock was measured by pre- and post- grazing residual grass yields and chemical analysis. Farm management data was also collected for each paddock (stocking rates, application rates etc.). Initial data analysis to assess relationships between soil nutrient status and grass production and nutrient efficiency taking into account the biophysical properties and constraints has been conducted. The early results show large variability between paddocks. For example, one quarter of samples taken were suboptimal for grass production (25% were below index 3) while 46% of samples were in luxury status. The remaining samples were Index 3. On average 66% of farm paddocks were below the 6.3 target for pH. Preliminary results also suggest a correlation between soil K and grass K concentrations.

# Adaptive management approaches to reducing nutrient loss risk

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# Developing A Web-Based Forecasting Tool For Nutrient Management: The Fertilizer Forecaster

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US and state nutrient management planning provides strategic guidance that, in the best cases, educates farmers and others involved in nutrient management to make prudent management decisions. The strategic guidance provided by nutrient management plans does not provide the day-to-day support required to make operational decisions, particularly when and where to apply nutrients over the short term. These short-term decisions on when and where to apply nutrients can make the difference between whether the nutrients impact water quality or are efficiently utilized by crops. Infiltrating rainfall events occurring on the heels of broadcast nutrient application are beneficial, as they will wash soluble nutrients into the soil where they are used by crops. Rainfall events that generate runoff shortly after nutrients are broadcast will wash off applied nutrients, producing the largest losses of nutrients possible from that site. Our goal is to develop a research driven support tool for nutrient management, the Fertilizer Forecaster, which identifies the relative probability of runoff or infiltrating events in Pennsylvania (PA) landscapes. This tool will support field specific decisions by farmers on when and where to apply fertilizers and manures over 24, 48 and 72 hour periods. Our objectives are to: (1) monitor agricultural hillslopes in watersheds representing four of the five Physiographic Provinces of the Chesapeake Bay basin; (2) validate a high resolution mapping model that identifies soils prone to runoff; (3) develop an empirically based approach to relate state-of-the-art weather forecast variables to site-specific rainfall infiltration or runoff occurrence; (4) test the empirical forecasting model against alternative approaches to forecasting runoff occurrence; and (5) recruit farmers from the four watersheds to use web-based forecast maps in daily manure and fertilizer application decisions. Data from on-farm trials will be used to assess farmer fertilizer, manure, and tillage management decisions before and after conscientious use of the Fertilizer Forecaster, and will help to understand not only the effectiveness of the tool, but also characteristics of farmers with the greatest potential to benefit from such a tool. We hope that the Fertilizer Forecaster will serve as the basis for state (Pennsylvania), regional (Chesapeake Bay), and national changes in nutrient management planning. Specifically, this project develops an innovative management practice that is designed to enhance the services of aquatic ecosystems by improving water quality and enhance the services of terrestrial ecosystems by increasing the efficiency of nutrient use by targeted crops.

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# The CatchmentTools Project

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The *CatchmentTools* Project (2014-2016) is developing data analysis tools and models for assessing nutrients in Irish catchments to support catchment scientists and managers in (1) characterising catchment nutrient behaviour and (2) implementing appropriate management strategies. This work builds on the STRIVE *Pathways* Project findings by continuing the development of the Catchment Management Support Tools (CMSTs).

The *Pathways* Project investigated contaminant transport pathways in Irish catchments and developed a set of CMSTs, including the Catchment Characterisation Tool (CCT) and the Catchment Modelling Tool (CMT). These tools focus on phosphorus (P) and nitrogen (N), and were developed to assist in the delineation of critical source areas (CSAs) associated primarily with diffuse agricultural sources for use by environmental and water managers. Field and modelling studies were conducted in four rural study catchments to improve the conceptual understanding of contaminant transport along the different hydrological pathways, including their associated impacts on water quality and river ecology. The findings of this work informed the parameters within the CMSTs.

Along with the continued development of the CCT and CMT, the *CatchmentTools* Project is developing a new tool called the Irish Source Loading Apportionment Model (SLAM). In addition to considering loadings from agriculture, this model quantifies the relative contributions from multiple sources of nutrients to Irish rivers e.g. urban areas and forestry. All of the models can improve understanding of catchment processes and identify risks to water bodies in different but complementary ways. These tools enable catchment data and information to be considered in an integrated manner and provide useful outputs to enable characterisation of the Source-Pathway-Receptor relationships in Irish catchments.

This poster outlines the CCT, SLAM and CMT models, and presents some example outputs.

# 24

# Increased phosphorus leaching from the soil during the growth of different riparian grass species


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Riparian buffer strip plants can help to reduce nitrogen (N) leaching to streams but the situation is less clear for phosphorus (P). Compared to N, P concentrations in the soil solution are low so plants release carbon (C) based exudates in the form of organic acids, enzymes and sugars into the soil that solubilise, mineralise and stimulate the microbial biomass, and bring P into solution. If plants bring more P into solution than they require or have the ability to take-up, additional P could be available for leaching. In addition, because different plants specialize in accessing different soil P forms and fractions, a plant growing in a soil that is abundant in the P forms and fractions that it can readily access could solubilise large amounts of P, resulting in elevated P leaching. This study aimed to test the hypotheses that i) plants can increase the leaching of dissolved inorganic P during growth due increased carbon mobility in the soil, and that ii) the extent of dissolved inorganic P leaching would be dependent on a combination plant species and soil management. We modelled the buffer strip, plant-soil system in a soil column experiment to compare the leaching of dissolved P fractions from an arable field soil and the adjacent buffer strip soil (74 g $kg^{-1}$ and 90 g $kg^{-1}$ soil organic matter, respectively) sown with 3 common riparian grass species. A mixture of ryegrass (*Lolium perenne L.*) and red fescue (*Festuca rubra L.*) significantly ($p \leq 0.05$) increased dissolved inorganic P leaching from both soils compared no plants and dissolved organic C was also significant factor in determining the variation in dissolved inorganic P, possibly highlighting the role of plant root exudates. Significant interactions in the data suggested that different plants solubilized different quantities of P in the different soils. These data supports the hypotheses, which we therefore accept under these experimental conditions but appreciate the need for testing under natural field conditions. The physiological characteristics of plants need to be taken into account when selecting species for establishment in riparian vegetated buffer strips so that dissolved P leaching can be minimised.

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# Targeting AES payments for terrestrial ecosystem services to address the favourable conservation status of priority freshwater aquatic ecology


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Agricultural practices can result in the transfer of sediment and nutrients (N and P) through hydrological pathways, affecting and potentially causing deterioration in the ecological status of water bodies and thus leading to a decline in ecosystem function. Under certain circumstances it has been demonstrated that Agri-Environmental Schemes (AES) may mitigate the impact of agriculture on freshwater habitats and species if they are implemented correctly and are spatially targeted. Sediment and nutrients are the key drivers affecting catchments and by controlling sources and delivery pathways, freshwater status can be maintained or improved. The need for spatial targeting of mitigation measures is well documented however to date few AES schemes take hydrological connectivity into account, which impacts on the likelihood of improving or maintaining the ecological status of freshwater bodies. In addition a lack of monitoring and evaluation data in relation to the effectiveness of AES (Finn & Ó'hUallachain, 2012) make it difficult to demonstrate the effectiveness of AES schemes.

The aim of this study is to investigate whether targeting AES payments could improve the ecological status of freshwater ecosystems using the Lough Melvin catchment as case study. By identifying the terrestrial ecosystem services related to land-use activities (e.g. grazing, slurry application) that have the potential to impact on the delivery of water related ecosystem services, provides the necessary link to manage these practices and to measure their impact on the state of the required ecosystem services. The SCIMAP approach provides a framework to identify the high-risk fields based on land-use and hydrological connectivity. Using the SCIMAP approach we can accumulate the risk from the sub-field scale to the catchment scale along the hydrologic pathways. The objective is to link the critical source areas identified through the application of SCIMAP with the delivery of required freshwater ES, to identify the spatial variation of economic ES values throughout the catchment.

This study presents a two-tier approach to targeting payments at the critical source areas (i.e. hydrological connected areas that overlap with a source pressure), allowing for a combination of both national/international policies and a consideration to the sub-catchment-specific hydrological connectivity. Furthermore, the project proposes to examine the distribution of AES payments, by paying farmers for a certain action but basing these payments on the value to society of the required ecosystem services delivered. This is opposed to the AES payments under the EU CAP (Common Agricultural Policy), which evaluates the costs of implementing the measures and compensates farmers for income forgone.

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# Manure management-associated key activities regulating nutrient values and environmental consequences


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Manure (faeces and urine) from livestock is significant both as a nutrient source (N and P) and a C supplement for enriching soil organic matter and improving hydro-biogeochemical properties, leading to improved agricultural productivity. Conversely, unmanaged manure has significant environmental, climate change and animal/public health concerns that are linked to enhanced greenhouse gas (GHG) and air pollutant emissions, excess N and P loadings, and increased pathogens in water bodies.

Dry matter intake mainly governs manure characteristics and thereby C and N emissions. The key activities associated with manure management at field-scale in grazing systems are livestock density, grazing intensity, and the number and distribution of feeding/watering stations, with a major objective to ensure the more even distribution of manure to reduce gaseous and leaching/runoff losses. Strategic grazing (intensity, frequency and rotation) and through controlled movement (fencing, hedgerow and buffer zones) can prevent manure from being deposited in or near waterways.

Other than bioenergy production and composting, the relevant activities at farmyard level that impact on the efficacy of manure utilization are handling, storage and processing methods. Animal housing types (loose, slatted and cubicle), with or without straw bedding, impact on the proportion of solid and liquid manure produced, contributing to the intensity of both GHGs and air pollutants release. There are different types of solid manure storage (sheds and heaps) and covering or turning that creates aerobic/anaerobic conditions that control C and N emissions, and nutrient losses to water bodies. The liquid storage type (e.g., tanks-covered/uncovered, and lagoon) mainly accelerates anaerobiosis to produce $CH_4$ through methanogenesis.

Following the spreading of manure and relative %N deposited directly onto agricultural lands, the form and amount of available N for nitrification and denitrification to form $N_2O$, and through anaerobiosis to produce $CH_4$ and hydraulic loadings for leaching/runoff/seepage, control the extent of any environmental burden. These include $NH_3$ volatilization through enzymatic breakdown of urinary urea/uric acid, and $NO_x$ coupled with, and other air pollutants (NMVOC, $PM_{2.5}$, and TSP) through dispersal and biogeochemical conversion. In addition to leakage/spillage during transportation, time, amount and method related to solid (spreading and incorporation) and liquid (spreading, injection and incorporation) manure application regulate the gaseous and leaching/runoff losses of nutrients.

Retaining the enhanced nutrient value of manures for agricultural use together with the identification of sustainable options to limit manure-induced environmental consequences necessitate the elucidation and quantification of key flow pathways and the development of mitigation measures.

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# Development of a sub-field scale phosphorus critical source area index which utilises LiDAR DEMs and GIS

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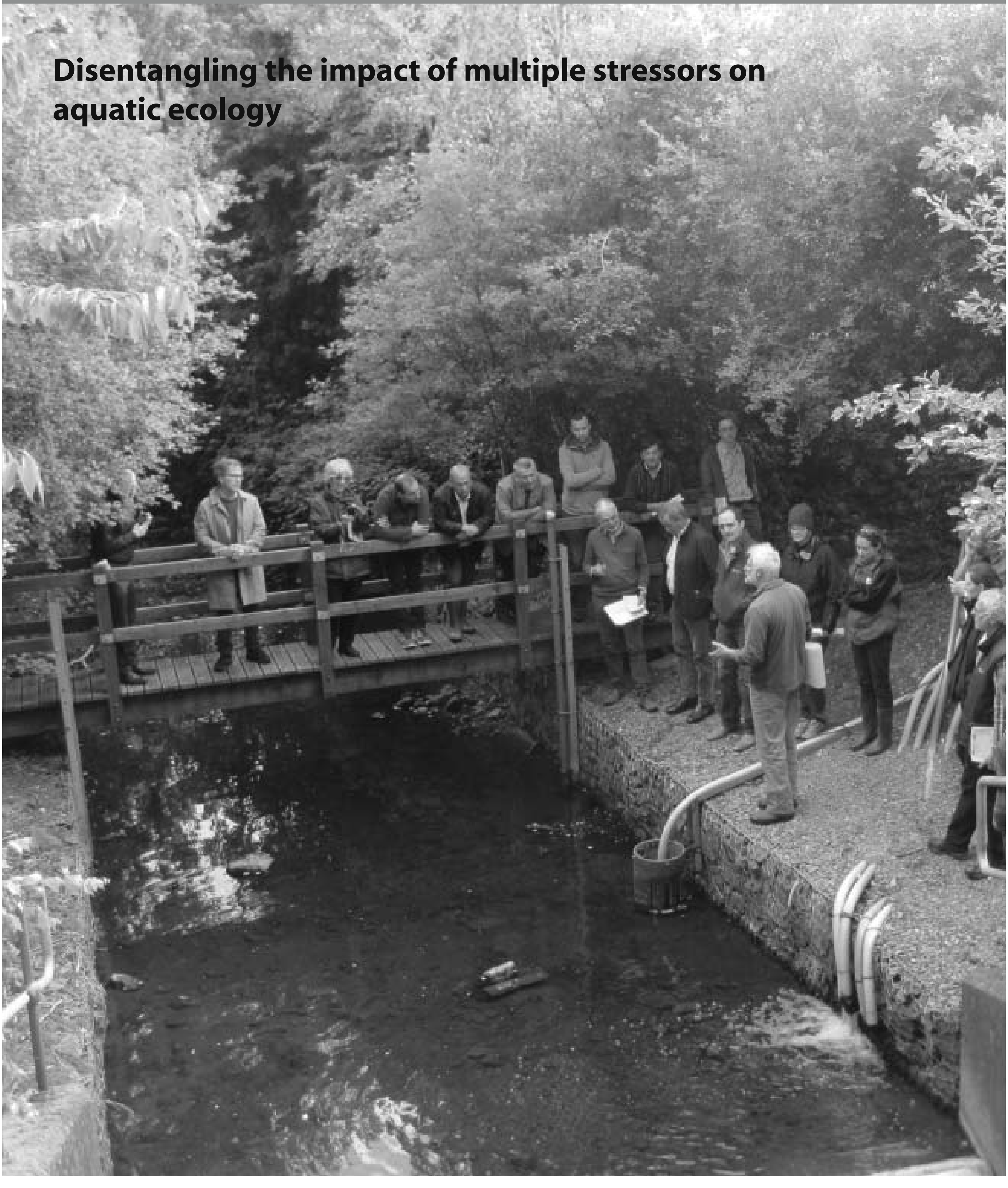
A new sub-field scale critical source area (CSA) index is presented which aims to improve the identification and mitigation of CSAs of phosphorus (P) on agricultural land. The CSA Index integrates multi-scale datasets of source, mobilisation and transport factors of P transfer within a Geographical Information System (GIS), providing spatial risk-based estimates of P loss potential.

Source and mobilisation datasets include soil test P concentrations, degree of P saturation and water soluble P. Transport risk for dissolved P is determined using a Hydrologically Sensitive Area (HSA) Index to identify where the propensity for surface runoff generation, pollutant transport and delivery via hydrologically connected pathways is highest. The HSA Index integrates Topographic Wetness Index (TWI) and soil drainage class maps, and reduces risk in areas with low hydrological connectivity where reinfiltration is likely or where flow is topographically impeded within a flow sink. It utilises high resolution (0.25-2 m) LiDAR Digital Elevation Models (DEMs) to capture microtopographic controls on flow pathways and hydrological connectivity. Risk of particulate P mobilisation and transport is determined by modelling soil erosion potential using the Unit Stream Power Erosion Deposition (USPED) model, which integrates DEM-derived flow accumulation and the Revised Universal Soil Loss Equation (RUSLE).

These CSA factor datasets are rasterised, and values assigned relative risk scores ranking P loss potential. CSA Index maps are generated from total risk scores calculated for each grid cell using a component formulation which sums the products of weighted source, mobilisation and transport factor risk scores for both dissolved and particulate P transfers. The CSA Index was applied to four intensively monitored Irish agricultural catchments with contrasting agri-environmental conditions to calibrate factor weightings, using P concentrations and loads measured at subcatchment snapshot sites and high temporal resolution catchment outlet gauging stations during 2009-2014.

Preliminary results show that the new CSA Index identifies CSAs at the sub-field scale, capturing the influence of microtopography. Furthermore, breakthrough points and delivery points along CSA pathways, where P is transported between fields or delivered to the drainage network, are easily identifiable, allowing the targeting of sub-field scale mitigation measures to reduce P losses at these most cost-effective locations. The approach provides more scientifically robust estimates of P loss risk compared to conventional spreadsheet-based CSA Indices, by accounting for P mobilisation potential and microtopographic controls on HSAs, erosion and hydrological connectivity. The methodology can also be applied to identify CSAs of other diffuse nutrients and pollutants.



# Disentangling the impact of multiple stressors on aquatic ecology

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# The effect of chronic and acute hydrochemical disturbances on stream ecology: implications for agricultural policy

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Achieving and maintaining high ecological status in water bodies are the key aims of the Water Framework Directive. In Ireland, the two main threats to water quality are nutrient transfers from municipal (point) and agricultural (diffuse) sources, contributing to eutrophication. Diffuse nutrient losses from agriculture are closely linked with storm (i.e. acute) events whereas municipal point sources pose a chronic pressure, particularly during summer baseflows when dilution effects are minimal. This project is investigating the effect of chronic and acute sources of nutrients on the ecological status of headwater streams.

The project will analyse existing datasets collected as part of the Agricultural Catchments Programme (ACP). Water chemistry data has been collected since 2009 at a ten minute resolution in six agricultural catchments. This will be analysed along with ecological data, collected every May and September over the same period, to identify patterns in water quality and determine how these geochemical parameters can influence aquatic ecological community structure.

The project will also investigate the relative importance of chronic and acute pressures on ecological communities. Monthly ecological sampling will be carried out over the summer, when chronic pressures are thought to be most significant. This higher resolution ecological sampling strategy will facilitate the project team to disentangle the effects of chronic and acute pressures on aquatic ecology. Additional high resolution sampling will be undertaken at a number of consistently high-quality control sites such that natural variation patterns in ecological communities can be identified. To assess the impact of acute pressures, sampling will be carried out before and after a number of storm events throughout the year.

Lastly, the project will investigate the impact of multiple stressors on ecology using controlled laboratory experiments. Freshwater systems are under pressure from multiple sources at any one time. This can make identifying the effect of a single stressor very difficult. In order to isolate specific pressures, mesocosm experiments will be carried out to allow manipulation of individual pressures.

By identifying the relative impact of chronic and acute pressures on stream ecology, the study will help inform how Irish agri-systems can achieve sustainable intensification. Outcomes from the research will also inform policy makers in relation to Good Agricultural Practice and achievement of Water Framework Directive requirements.

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## Sustainable land use management for the conservation of the Freshwater Pearl Mussel: Sediment flux and provenance

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The Freshwater Pearl Mussel (FPM) is a long-lived aquatic invertebrate that is listed as Critically Endangered by the IUCN and a protected species under the EU Habitats Directive (and under the Bern Convention). Ireland is considered a stronghold for the FPM and is believed to support approximately 46% of FPM individuals in the EU. However, recruitment levels are insufficient in all Irish populations, and the species is of unfavourable conservation status, due to multiple pressures including habitat degradation, sedimentation and pollution. This study focuses on two internationally important FPM catchments, in which mussel populations are thought to be chiefly impacted by diffuse sediment losses from agriculture and forestry.

The study has three primary aims. The first is to establish detailed sediment budgets for these systems elucidating the pathways and fate of fine-grained sediments arising from non-point sources. The approach uses conventional high-resolution sediment flux estimation at catchment outlets, combined with novel sediment fingerprinting to apportion event-seasonal and annual loads to their respective sources. We will develop highly-detailed and synchronous discharge and turbidity methods that are tailored to the Irish context and applicable across a land-use gradient. The second aim is to examine the habitat condition in the hyporheic zone, by characterising the structure, composition and hydraulic stability of channel-bed substrates, with particular emphasis on the degree of fine-sediment ingress into framework gravels and the concurrent availability of dissolved oxygen. Finally, the project will undertake field-scale trials on the efficacy of a sub-set of mitigation measures (established as part of KerryLIFE) designed to control the supply and delivery of fine-grained sediments from critical source areas (identified using LiDAR), with the view to upscaling as part of an integrated basin management strategy.

The results derived from this study will highlight areas of high sediment output and assist in the efficient delivery and targeting of management practices in co-operation with the KerryLIFE project. The long-term and more significant international contribution seeks to develop ecosystem-based adaptation (EbA) measures that both contribute to the restoration of endangered species such as the FPM but also realise wider sustainable land management benefits.

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# Cattle Exclusion from Watercourses: Environmental and socio-economic implications

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Loss of nutrients and sediments from grassland systems to waterbodies represents a significant threat to water quality and is one of the main environmental problems facing agri-ecosystems in Ireland. The EU Water Framework Directive requires Member States to achieve or maintain at least 'good' ecological and chemical status in all waters by 2015. However, trends from 1987 to 2011 indicate that water quality has deteriorated over this period with an overall decrease in the length of river channel classed as unpolluted, and an increase in the channel length affected by slight to moderate pollution.

The Food Harvest 2020 report (DAFM, 2010) aims to significantly expand the Irish agri-food sector. It is possible that this expansion may represent an increased pressure on water quality in Ireland. Agri-Environment (AE) legislation may be viewed as a means of addressing the challenge of sustainable agricultural expansion, with AE schemes being considered one of the most important policy mechanisms for the conservation of natural resources. Measures proposed under the forthcoming Green Low carbon Agri-environment Scheme (GLAS) include preventing bovine access to watercourses to improve water quality. Studies suggest that unrestricted cattle access to watercourses can result in deteriorating water quality; however conflicting studies indicate that cattle do not have a significant effect. The majority of studies to date on the impact of cattle access on freshwater ecosystems relate to Australasia and North America, where river hydro-morphology and farming enterprises differ significantly from Irish conditions. There have been very few Irish studies on the impact of agri-environment measures preventing cattle access to watercourses, and preliminary analysis of results from existing studies show divergent results.

This project will evaluate existing literature and use a combination of meta-analysis of existing datasets, and collection of new field and experimentation datasets (temporal and spatial) to assess the environmental, ecological and socio-economic impact of cattle exclusion measures on freshwater ecosystems. The impact of cattle access and cattle in-stream activity on freshwater geochemical and sediment parameters along with freshwater biology and faecal indicator bacteria will be determined. Furthermore the cost-effectiveness of proposed and potential mitigation measures will be assessed through research and expert opinion, along with attitudinal responses of land-owners to the implementation of such measures.

The project will provide important information for policymakers in relation to the Nitrates and Water Framework Directives. It will also help guide agri-environmental policy and facilitate sustainable intensification objectives under Food Harvest 2020.

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# Quantifying sediment export in Irish intensive agricultural river catchments with contrasting soil drainage and land use characteristics


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Suspended sediment transfer to aquatic ecosystems delivers essential nutrients to maintain biological functioning. However, accelerated supply of suspended sediments, for example from intensive agricultural systems, can impair ecological functioning and degrade the physical and chemical quality of rivers and lakes. In Ireland, managing diffuse pollution from agriculture falls primarily under Water Framework Directive obligations but recommended concentration thresholds, such as for nitrate and phosphorus, do not exist for suspended sediments. As a result, suspended sediment research has been limited. This study aimed to quantify suspended sediment export from five intensively-managed catchments with a range of land use types (grassland or arable) and soil drainage characteristics (poorly-, moderately- or well-drained soils).

Suspended sediment concentration data were calculated from calibrated high-resolution turbidity measurements, housed in an ex-situ instrument tank continuously circulating river water. The near-continuous suspended sediment concentration dataset were combined with discharge data to calculate annual average suspended sediment concentrations (mg/l) and yields (t/km$^2$/yr) from October 2009 - September 2014 in three catchments and October 2010 - September 2014 in the other two catchments.

Annual average suspended sediment concentration and yield were higher in poorly-drained (Grassland B and Arable B) compared to moderately- and well-drained catchments (Grassland A, Grassland C and Arable A). The highest suspended sediment export occurred from the predominantly poorly-drained catchment with a higher proportion of arable soils (Arable B), suggesting that reduced groundcover combined with efficient flow pathways increase field-scale soil erosion risk. Despite the highest proportion of arable land use at Arable A, low sediment export suggested well-drained soils reduced hillslope connectivity and sediment loss risk. Despite high ground cover on hillslopes due to grassland land use, higher sediment export suggests non-field sources are important. High inter-annual variability is likely to result from spatial and temporal fluctuations in runoff and soil erosion risk. Overall suspended sediment export risk was increased by poorly-drained soils and to a lesser extent, the proportion of arable land use. Effective soil erosion and management strategies should address catchment specific climate, landscape and land use attributes.

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# Using storm event sediment-discharge hysteresis and control analysis to investigate sediment sources in three contrasting agricultural catchments

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Cost-effective mitigation of soil erosion and sediment loss is necessary where excessive sediment supply impacts downstream aquatic ecosystem functioning. In agricultural landscapes, sediment availability and source-to-receptor connectivity are highly modified by cropping cycles, land drainage networks, in-field trafficking of stock or machinery and track and road networks. The aim of this study was to use sediment-discharge hysteresis metrics, and analysis of controls on sediment delivery, to investigate differences in storm event sediment dynamics between catchments and over time.

High resolution end-of-catchment sediment and discharge data were collected from three (~10 $km^2$) intensive agricultural catchments in Ireland. Catchments featured contrasting dominant land use and soil drainage characteristics; arable on well-drained soils (Arable A), arable on moderate-poorly-drained soils (Arable B) and grassland on poorly-drained soils (Grassland B). Eighteen potential controls on sediment delivery from stream hydrology, rainfall characteristics, and antecedent soil condition categories were calculated for 245 storm events. Categorical hysteresis type (clockwise, anticlockwise, no-hysteresis, figure-8 or complex) and a numerical hysteresis index (positive values indicated clockwise hysteresis, negative values indicated anti-clockwise hysteresis) were assigned to each event. Controls for different hysteresis categories were investigated using Pearson's correlation coefficient.

Grassland B was dominated by clockwise hysteresis controlled by discharge variables, suggesting management of proximal channel sources will reduce sediment load. In the arable catchments, clockwise and anticlockwise hysteresis events were most frequent from Arable A and Arable B, respectively, but no-hysteresis and figure-8 events contributed the greatest sediment load. Proximal and distal surficial sources contributed to sediment export in Arable B suggesting low groundcover or connectivity should be managed to reduce hillslope sediment losses. In Arable A, discharge and rainfall controls on no-hysteresis events suggest well-drained soils were important but infrequently connected sources. Over time, the hysteresis index trend reflected a climatic seasonality. During sustained wetter periods, clockwise sources were depleted in Grassland B, in Arable B the hysteresis magnitude increased suggesting expanding connectivity of hillslope soils and Arable A hysteresis decreased in magnitude towards zero indicating depletion of proximal storage and connectivity of hillslopes. In the arable catchments, storm-events during reduced groundcover periods (<70%) exported more sediment compared to events where groundcover was higher. Hysteresis analysis successfully indicated contrasting sources between the three intensively agricultural study catchments and the impact of seasonality on sediment flow pathways due to interactions between antecedent conditions, event connectivity and source availability. Such analyses will improve the effectiveness of mitigation measures to reduce catchment sediment export.

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# Are nutrients constraining the ecological potential of agricultural headwater streams in Northern Ireland?

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Considerable improvements in the nutrient and chemical water quality status of agricultural headwater streams has been achieved in Northern Ireland in response to agricultural mitigation measures implemented since 1990. This paper explores why biotic responses based on macroinvertebrate community composition have been small and inconsistent by comparison, and examines evidence for nutrient thresholds constraining biotic recovery. Observations of good biotic water quality were generally coincident with low nutrient levels, but were also observed at sites where nutrients were high, and conversely some sites exhibited poor biotic water quality at low nutrient levels. The biotic index employed was nevertheless significantly correlated with stream nutrient concentrations. However, the strongest correlation was with normalised catchment livestocking rates. The finding that elevated nutrients were not exclusively coincident with depauperate biology highlights that arguments in favour of more stringent controls on agricultural nutrient use must be balanced against the uncertainty surrounding the role of other factors constraining biotic recovery.

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# Phosphorus Load Apportionment Modelling in rivers and the effect of sampling frequency and timing

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Remediating water-bodies to good quality status to comply with WFD objectives can be improved by apportioning river phosphorus (P) load to point and diffuse sources. Load Apportionment Models offer a low data requirement solution to source apportionment but may be constrained by the range of river flow and P concentration data available. To investigate this constraint, this study investigated the effect of sampling frequency and timing on two published P load apportionment models using synchronous and high resolution flow and P concentration data. These data were collected from a rural catchment with known point and diffuse P sources. Two thousand new datasets were created for each of nine different sampling combinations from a three-year high-frequency dataset of total reactive P concentration and flow. Large variations in model outcomes, particularly estimation of total P loads, characterised results for each model using different sampling combinations. Daily data seemed to be a reasonable trade-off between model requirements and sample resolution at the scale of study (*c.*9 $km^2$). The most variation, however, was found between the load apportionment for each model. The first model estimated that 51.4% (95% CI: ±3.2%) of the P load was from point sources, compared with only 4.2% (95% CI: ±0.2%) by the second model using the same hourly data. These values became less reliable as sampling frequency decreased and timing changed, especially with monthly data (i.e. similar to extant national river chemistry datasets) generating a range of apportionment to point sources of 0-100% for the first model and 0-10% for the second model. These two load apportionment models, while requiring minimal information, only provide a preliminary estimate of P load apportionment and total P load, and, when subjected to replication indicate imprecision and bias as sampling frequency decreases.

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## Ecological status and dynamics of rural headwater streams in Ireland

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Ecological quality of stream water was measured in six agricultural catchments in Ireland over five years to investigate baseline status and the potential for improvement following implementation of agri-environmental measures. Benthic macro-invertebrates and diatoms were sampled in September (post-summer) and May (post-winter) from 2009 to 2014 at multiple sites within each catchment. Stream hydromorphology and fish populations were recorded in May and July respectively, in 2010 and 2013.

Benthic diatom status was generally high in Grassland D (Karst, spring habitat wasn't suitable for measuring macro-invertebrate status). In the other five catchments, diatom and macro-invertebrate status generally ranged from poor to good, occasionally reaching high status in Grassland C. Stream hydro-morphology ranged from poor to good between catchments and fish communities were generally impaired across all catchments.

Seasonal differences were larger than expected with post-winter ecology of higher quality than post-summer. Ecological quality in summer is likely to be strongly influenced by urban and rural point sources due to a lack of dilution by stream baseflow. Thus, in some catchments, the current protocol for river ecological surveys that requires sampling in summer may not provide appropriate metrics for detecting the changes to the influence of diffuse agricultural pollution, which usually delivers more nutrient and sediment during winter than summer. Seasonal declines were strongest in the poorly-drained catchments where summer baseflows are particularly low. The seasonal trends of better biological quality post- winter were stronger than any other identifiable inter-annual trend over the five years.

A broad relationship existed between total reactive P (TRP) and diatom 'Trophic Diatom Index', showing a positive response to nutrient concentration reduction only at TRP < 0.035 $\mu g\ L^{-1}$ (the current stream P standard in Ireland). This indicates that the current stream P standard was a suitable threshold to describe good quality ecological status in these rural headwater streams. Cases of good chemistry and poor ecology occurred in well drained and poorly drained catchments and may be due to poor hydro-morphology and episodic nutrient pollution.

River ecological quality can potentially be improved by reducing summer point source discharges in the most sensitive catchments.

# NOTES

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