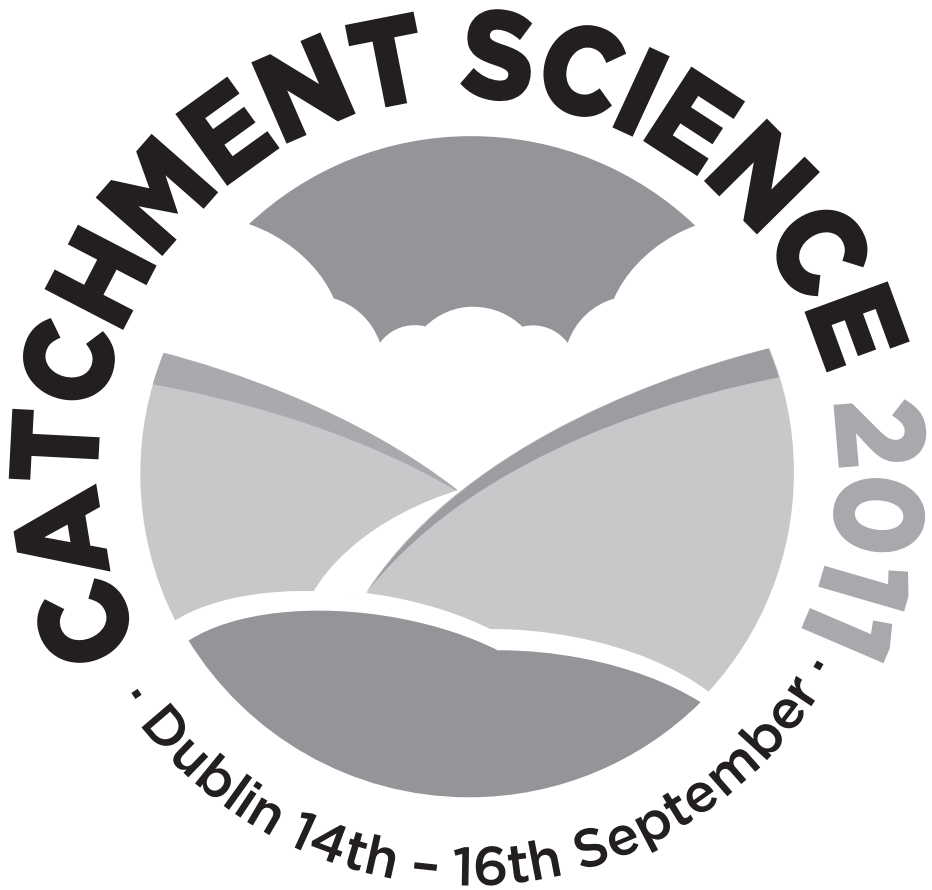

THE MANSION HOUSE, DUBLIN, IRELAND

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INTRODUCTION

River catchments represent the most appropriate scale for the sustainable management of water resources and associated ecological services. In agricultural landscapes, the interplay between economic and environmental sustainability is reflected in national and international regulations.

Evaluating the performance of regulatory standards, monitoring the sudden impacts of adaptive management to economic pressures and undertaking innovative agri-environmental research is also most suited within the scale of the river catchment. Policy drivers such as the EU Water Framework Directive and similar legislation across the world mean that there is great urgency to gather evidence for forward planning and management.

- **Can we manage agricultural catchments for economic and environmental objectives?**
- **How does this translate into policy?**
- **Where are we seeing successes and why?**

These are central questions which were asked at the Catchment Science 2011 conference hosted by Teagasc and Defra under the Agricultural Catchments Programme and Demonstration Test Catchments consortium in Dublin, 14th to 16th September 2011. The conference aimed to discuss current ideas and experiences from progressive initiatives around the world which conduct research, monitoring, and demonstration on water resources management regulation, eco-system service promotion, stakeholder engagement and socio-economic evaluation. Four themes were; Case Studies, Scale, Uncertainty and Counting the Costs.

KEYNOTE SPEAKER PROFILES

Prof Andrew Sharpley

MANAGING AGRICULTURAL CATCHMENTS FOR WATER QUALITY: ADDRESSING SCALES, UNCERTAINTY, COSTS, AND DEMONSTRATING SUCCESSES

In 2006, Andrew Sharpley joined the Department of Crop, Soil and Environmental Sciences, University of Arkansas, Fayetteville. He is Chair of the Division of Agriculture's Environmental Task Force and Associate Director of the Watershed Sustainability and Research Center. He received degrees from the University of North Wales and Massey University, New Zealand and spent 25 years with the USDA-ARS in Oklahoma and then Pennsylvania. His research investigates the cycling of phosphorus in soil-runoff-river systems in relation to productivity and water quality and developed the equations describing the fate of applied phosphorus in soil and its release to runoff, which are still used in many nonpoint source models. He has also developed decision making tools for agricultural field staff to identify sensitive areas of the landscape and to target management alternatives and remedial measures that have reduced the risk of nutrient loss from farms. He works closely with producers, farmers, and action agencies, stressing the dissemination and application of his research findings and is leading an on-farm demonstration, verification, and research program to show the benefits of Best Management Practices that protect water quality and promote sustainability of Arkansas farming systems. He is a Fellow of the American Society of Agronomy and Soil Science Society of America and received their Applied Soil Science, and Environmental Quality Research Awards. In 2008 was inducted into the USDA-ARS Hall of Fame. Dr. Sharpley serves on National Academy of Science Panels and EPA's Scientific Advisory Board.

http://cses.uark.edu/1864.htm

CASE STUDIES

Prof Dennis Frame

CATCHMENT PROGRAMS
- GETTING CHANGES ON THE LAND THAT IMPROVE WATER QUALITY

Dennis Frame has degrees from UW Madison in dairy science and animal science, minoring in agriculture economics. He is Co-Director/founder of UW-Discovery Farms with Dr. Fred Madison; which is a producer led research program that evaluates the impacts of varying farming systems on the environment. Farms are studied through the implementation phase to determine the effectiveness of these best management practices and to evaluate the affects on profitability. Dennis works closely with agricultural organizations on producer education regarding soil and water conservation and nutrient management. He is involved in education, information dissemination, data collection, funding and coordination of this program. Dennis and his family have a herd of beef cattle and live on a small farm in Trempealeau County, Wisconsin.
http://www.uwdiscoveryfarms.org/AboutUs/Staff.aspx

Dr Ross Monaghan

MANAGING WATER QUALITY IN CATCHMENTS USED FOR INTENSIVE DAIRY FARMING:
EXPERIENCES FROM CASE STUDY CATCHMENTS IN NEW ZEALAND

Dr Ross Monaghan is a soil scientist who works for AgResearch, New Zealand's Pastoral Agriculture Research Institute *(http://www.agresearch.co.nz),* based at the Invermay campus near Dunedin, Otago. Ross has degrees from Lincoln University and The University of Reading (UK). His broad focus of research is the management of pastoral land to achieve desired levels of water quality and farm business profitability. Much of his current research focuses on quantifying N and P losses to water and assisting end user groups with policy development and/or management guidelines that can reduce these losses. He currently co-leads the national Dairy Catchments study, an Industry-led initiative that aims to benchmark soil and water quality in 5 contrasting catchments located in the country's key dairy regions. He is also heavily involved in a wide range of Dairy Industry-funded research projects that seek to develop on-farm mitigation practices, such as improved effluent management systems and nitrification inhibitors, which allow for profitable dairy farming whilst meeting regionally-based targets for water quality.
http://www.agresearch.co.nz/about-us/our-people/science-staff/pages/profile.aspx?Name-id=monaghan-ross

SCALE ISSUES

Dr Brent Crothier

NUTRIENT LEACHING LOSSES: FROM THE POINT, THROUGH THE FARM, TO THE CATCHMENT

Brent Clothier is Group Leader of Systems Modelling within Plant & Food Research. He is an Adjunct Professor in the School of Earth & Environment of the University of Western Australia, and an Adjunct Professor in the New Zealand Life Cycle Management Centre of Massey University. Brent is a Fellow of the Royal Society of New Zealand, the Soil Science Society of America, the American Agronomy Society, the New Zealand Soil Science Society, and the American Geophysical Union. With over 200 scientific papers on the movement and fate of water, Brent specialises on carbon and chemicals in production systems, as well as on environmental policy and natural capital valuation. He is Joint Editor-in-Chief of the international journal Agricultural Water Management.
http://nzsss.rsnz.org/nzssscouncil/clothier.html

Dr Scott Wilkinson

FROM PADDOCK TO CATCHMENT: PRACTICES, PROCESSES AND POLLUTANT BUDGETS

Dr Scott Wilkinson is a research scientist with CSIRO division of Land and Water. His research focuses on understanding the mobilisation and fluxes of sediments and nutrients in river basins using field measurement of runoff and erosion, sediment tracing and spatial modelling. Key questions are the influences of changes in land management and climate on pollutant loads, the effectiveness of changes in land management practices, and impacts on aquatic ecosystems. Further information on CSIRO Land and Water is available at *http://www.csiro.au/org/CLW*

CATCHMENT UNCERTAINTY

Prof Helen Jarvie

MURKY WATERS: MULTIDIMENSIONAL ISSUES LINKING MACRONUTRIENT SOURCES AND IMPACTS IN CATCHMENTS

Co-authored with Andrew Sharpley (University of Arkansas, USA) & Paul Withers (Bangor University, UK)

Helen Jarvie is a principal scientist in Hydrochemistry at the Centre for Ecology & Hydrology in Wallingford. She undertakes interdisciplinary, fundamental and applied research on the fate, behaviour and transport of macronutrients (P, N and C), major ions, trace elements, sediments and emerging contaminants (nanoparticles), to promote sustainable management of surface freshwater resources. Helen's major research interests include biogeochemical cycling of P and N in rivers; evaluating the macronutrient buffering capacity of rivers and streams and implications for catchment management and ecosystem sustainability; and the impacts of P and N enrichment and mitigation on the quality and ecology of rivers, in relation to climate variability, effluent disposal, agricultural practice and changing rural land use.
http://www.ceh.ac.uk/staffwebpages/DrHelenJarvie.html

Prof Brian Kronvang

DO NATURAL PROCESSES COUNTERACT THE EFFECTS OF AGRICULTURAL NUTRIENT ACTION PLANS? EXAMPLES FROM DENMARK

Co-authored with J. Windolf, R. Grant, G. Blicher-Mathiason, J. Bøgestrand and S.E. Larsen

Brian Kronvang, MSc, PhD is a research professor in catchment management at the Department of Freshwater Ecology, The National Environmental Research Institute, Aarhus University. He has a long research experience from Danish and international research projects with studies of sediment and nutrient cycling, dynamic and fate in watersheds with strong links to catchment monitoring, modelling and management.
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COUNTING THE COSTS

Prof Catherine Kling

COST EFFECTIVE PLACEMENT OF CONSERVATION PRACTICES IN WATERSHEDS: INTEGRATING ECONOMIC AND BIOPHYSICAL MODELS

Catherine L. Kling is Professor of Economics at Iowa State University and the Center for Agricultural and Rural Development. She has published extensively in environmental economics on the theory and measurement of non-market values and on interdisciplinary analyses of policy design and incentives for the provision of ecosystem services from agriculture. Cathy is a Fellow of the American Agricultural Economics Association, a member EPA's Science Advisory Board, current President of the Association of Environmental and Resource Economists and past board member of the AAEA. She has served on several NRC committees, most recently the "Committee on Health, Enviromental, and Other External Costs and Benefits of Energy Production and Consumption." She has held editorial positions with the American Journal of Agricultural Economics, the Journal of Environmental Economics and Management, among others, and has been the principal investigator or co-principal investigator on over $7 million of grants. She received her Ph.D. from the University of Maryland.
http://www.card.iastate.edu/facstaff/profile.aspx?id=24

Dr Julia Martin-Ortega

ECONOMIC ASPECTS OF THE EUROPEAN WATER FRAMEWORK DIRECTIVE: EXPERIENCES AND CHALLENGES IN AGRICULTURAL CATCHMENTS

Dr. Julia Martin-Ortega has a background in environmental and ecological economics, with an emphasis on environmental valuation and a growing interest in multi-criteria and qualitative analysis. Her work focuses on water related services and she has experience in the valuation of environmental benefits of water quality and quantity. She has worked in several European and international projects, looking at issues such as water services valuation, the cost of drought, environmental damage compensation, forest water services and adaptation to climate change impacts in freshwater systems. She has provided advice in different stages of the implementation of the European Water Framework Directive in Spain and has advised the Andalusian Regional Government on its water policy. Julia joined The James Hutton Institute in September 2010 and is involved in water management and the economics of ecosystem services research. She is currently a member of the EU FP7 REFRESH Project, looking at the cost-effectiveness analysis of measures for water management. She is also part of the International Pantanal Water Network (Brazil).
http://www.macaulay.ac.uk/staff/staffdetails.php?juliamartin-ortega

NOTES

KEYNOTE SPEAKER ABSTRACTS

MANAGING AGRICULTURAL CATCHMENTS FOR WATER QUALITY:

ADDRESSING SCALES, UNCERTAINTY, COSTS AND DEMONSTRATING SUCCESSES

ANDREW SHARPLEY

Crop, Soils, and Environmental Sciences, Division of Agriculture University of Arkansas, Fayetteville, Arkansas, USA *(sharpley@uark.edu)*

The impairment of surface water quality has been well documented, as has the contribution of agriculture to nutrients accelerating this impairment. In response, widespread implementation of beneficial management practices (BMPs) to reduce nutrient losses and mitigate impairment has occurred over the past 20 years with varying degrees of success. This has led some to question whether resources were adequately targeted and if stricter guidelines are needed. For instance, while voluntary adoption of BMPs has decreased P export at field and farm scale, a continued robust, adequately supported and transparent monitoring and assessment program is needed to ensure their long-term effectiveness. However, some financial support may be needed to help farmers address some of the costs of decreased productivity with environmentally-based management, as long as predetermined and agreed minimum environmental stewardship standards are maintained.

The need for agriculture to document environmental stewardship has led to on-farm research and demonstration programs, as a new paradigm to involve farming and scientific communities, providing innovation and documentation that has been able to more effectively transfer conservation technology among farming and regulatory groups than traditional research and extension programs. In several U.S. states for example, the Discovery Farm program has shown that farm management can respond to mitigate nutrient loss in a cost-effective and transparent manner.

While edge-of-field reductions in nutrient loss can occur within months of changing management, spatial complexities increase response time at a catchment scale, as a function of groundwater flow pathways and the slow release of legacy nutrients stored in soils and fluvial sediments. Legacy issues must be addressed to avoid public disillusionment and impatience with costly conservation efforts. Given spatial and temporal uncertainties in BMPs and a need to scale up from fields to catchments, use of appropriate and reliable nonpoint source models are a critical, yet challenging component of catchment management policy decision making.

As least costly "low-hanging fruit" measures are implemented, catchment management is beginning to address additional measures that decrease the mobilization and transfer of nutrients to meet load reduction targets, which raises the old dilemma "who benefits and who pays?" It is important to recognize that market prices do not always motivate farmers to manage nutrients in an environmentally sustainable way. In some areas, we cannot and should not expect that pristine waters are achievable with ever increasing population densities and more intensive agricultural production systems to meet market demands. The bottom line is that this may require either a reassessment of water-use designations and/or far-reaching societal commitment and support of agricultural system changes.

This conference "Catchment Science 2011" brings together agricultural scientists and practitioners from around the world to provide a forum to present successes in environmentally-based management of agricultural catchments, why they succeeded, and formulate ways to ensure the success of future mitigation measures.

CATCHMENT PROGRAMS – GETTING CHANGES ON THE LAND THAT IMPROVE WATER QUALITY

DENNIS FRAME

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Catchment programs should be designed to engage agriculture and other members of the watershed community in improving and protecting water quality. The Discovery Farm watershed projects currently underway in Wisconsin have the overall goal of: *"To demonstrate, with tangible data, a relationship between changes in land management and improvements in water quality."*

In order to achieve this goal the projects conduct a variety of research and outreach programs including:

- In-stream as well as in-field water quality monitoring collecting information on flow, sediment, nitrogen and phosphorus loss.
- Providing water quality information that empowers farmers and their advisors to make changes to their farming system that improves and protects water quality.
- Engaging producers and their advisors in the identification and adoption of practices which take into ac
- Identification and adoption of changes to the management system for critical sites that either contribute high levels of nutrient loss or that could become major sinks within the watershed system.
- Engaging farmers, their advisors, agency personnel and the general public within the small watersheds.

It is time to move forward from the establishment of water quality goals to the development and support of programs that engage and empower people living within a watershed to make changes that improve water quality. These programs cannot be run on a national level or by people living and working hundreds of miles away from the watershed. Information on land management and water quality has to be collected locally, has to apply to the local conditions and has to be believed and trusted by the community. Local information can be put into context and augmented with other similar research conducted elsewhere, but some of the data needs to be collected locally. This session will focus on the lessons learned in three watersheds in Western Wisconsin. The discussion will focus on the need for monitoring, the use of water quality data to drive changes in land management, evaluation of all the contributing factors in a watershed and building a relationship with farmers that is based on mutual trust and respect.

MANAGING WATER QUALITY IN CATCHMENTS USED FOR INTENSIVE DAIRY FARMING:

EXPERIENCES FROM CASE STUDY CATCHMENTS IN NEW ZEALAND

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2 NIWA, PO Box 11-115, Hamilton, NZ
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Concern about deteriorating trends in water quality in many intensively farmed catchments prompted the New Zealand dairy industry to initiate a study in 2001 in which four regionally-representative dairying catchments were chosen for long-term monitoring. These were located in two traditional dairy farming areas of the North Island and in two areas of the South Island that have only recently undergone conversion to dairy farming. Monitoring of a fifth catchment on the West Coast of the South Island began in 2004. As part of this project, a catchment management planning process was followed to strategically direct science activities and extension efforts targeting farmer adoption of key land management practices.

Within each catchment this planning process has, in sequential order, (i) made an assessment of water quality status, (ii) identified the key linkages between land management activities and water quality, (iii) defined the key values associated with each catchment, which in turn defined a set of catchment-specific water quality targets, (iv) determined the most appropriate land management guidelines required to deliver to these targets, and (v) developed and implemented farm plans of varying complexity that address the key environmental performance indicators identified. This planning process has identified a number of lessons pertinent to the success of extension/adoption initiatives in the catchments.

Our analysis indicates that there is a range of technological measures that can deliver substantial reductions in pollutant losses from farms to water. The effective implementation of these technologies on New Zealand dairy farms will first require clearly defined environmental goals for the catchment/water body that is to be protected and the implementation of measures that target the major sources of water pollutants. Given that the major sources of these pollutants often differed between catchments, it is important that measures are matched to the physical resources and management systems of the existing farm businesses. Farmers also identified that they prefer to consider a suite of mitigation options so that they can match individual practices to their farm context, rather than have prescriptive practices imposed upon them. This recognises that factors such as soils, topography, existing farm infrastructure and lifestyle combine to influence farmer decision-making. Accordingly, a range of Best Management Practices (BMPs) have been incorporated into a Toolbox of practices which documents their effectiveness, cost-effectiveness and relevance. This Toolbox has been used to guide the Farm Planning initiatives underway within the catchments. Field-day presentations followed by one-on-one interactions via Farm Planning initiatives show some success in improved farm environmental performance, as evidenced by changes in fertiliser and effluent management practices. However, the adoption of other more costly or complex management practices has occurred at a much slower pace.

NUTRIENT LEACHING LOSSES:
FROM THE POINT, THROUGH THE FARM, TO THE CATCHMENT

BRENT CLOTHIER [1], STEVE GREEN [1], MARKUS DEURER [1], ALEC MACKAY [2] & JON ROYGARD [3]

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A measurement-modelling dualism is needed to link and upscale knowledge of nutrient leakages losses at the local scale in order to develop policy options and implement management actions at the catchment scale. New measurement technologies and networks of remote devices, aided by a suite of rapidly improving modelling techniques, are leading to the development of new policy initiatives based on recognition of the catchment's inventory of natural capital stocks, and consideration of the sum value of the diverse ecosystem services that flow from them (Clothier et al., 2011).

Tension fluxmeters, which mimic field hydraulic conditions, are reasonably priced devices that can be installed in networks across remote locations and connected wirelessly to record drainage in real-time. This enables timely sampling of their reservoirs to determine nutrient leaching. The results from our network of over 350 fluxmeters in New Zealand, Australia, and the Pacific Islands are providing detailed information to parameterise our mechanistic models. These biophysical models can then provide understanding so that we can develop functional meta-models of nutrient leaching at the scale of the farm enterprise. From this modelling, landscape-wide nutrient leaching from the patchwork of farm enterprises can be linked to the measured water quality of receiving water bodies. A challenge is to understand, upscale, and model the attenuation of nutrients from enterprises, through landscape transport-pathways to the receiving water bodies. Initial attempts, just based on empirical inference, are described.

Policy to improve catchment-wide water quality can take various forms: be it by direct regulation of nutrient inputs, or by 'grand-parenting' through benchmarking and then mandating for a reduction in nutrient losses, or by assessing the value of the provisioning ecosystem services flowing from the landscape's natural capital stocks. We discuss the merits and disadvantages of the various approaches that have been used in different jurisdictions in New Zealand to address the critical issue of water quality.

Clothier, B.E., A.J. Hall, M. Deurer, S.R. Green and A.D. Mackay 2011. Soil Ecosystem Services: Sustaining Returns on Investment into Natural Capital. In "Sustaining Soil Productivity & Climate Change: Science, Policy and Ethics", Wiley-Blackwell, Chapter 9, pp 115-137.

FROM PADDOCK TO CATCHMENT:
PRACTICES, PROCESSES AND POLLUTANT BUDGETS

SCOTT N. WILKINSON [1], REBECCA BARTLEY [2] & PETER J. THORBURN [3]

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How can agricultural systems be managed to effectively reduce off-site impacts at acceptable economic cost, while harnessing social incentives for change? This is a challenge faced in many basins throughout the world, such as those draining into the Baltic Sea in Europe, Chesapeake Bay in USA, and also the Great Barrier Reef (GBR) in Australia where sediments and nutrients are degrading the health of this World Heritage ecosystem. Australian governments are investing >AU$150M in paddock-scale management practice changes to improve the water quality delivered to the GBR.

Spatial patterns of pollutant generation and connectivity of pollutants are unique to any catchment, and so assessing the effect of agricultural management practices on pollutant mobilisation and transport can be addressed by coupling paddock process models with catchment-scale spatial models. In the GBR for example, pollutant mobilisation has been modelled using the Universal Soil Loss Equation to link paddock vegetation cover to plot erosion rates, and the Agricultural Production Systems Simulator to predict nitrogen losses from different farm management practices. The SedNet (Sediment budget river Network) model has been used to construct spatially-distributed budgets of fine and coarse sediment, particulate-attached and dissolved (organic/inorganic) nutrient forms for each subcatchment and route these downstream through the river network.

However, pollutant delivery between scales is too dependent on local deposition or other trapping processes to be predicted well. For example, pollutant connectivity between hillslope and streams is dependent on local variations in surface roughness and soil permeability. Pollutant delivery to catchment outlets must consider trapping and transformations in river channels, impoundments and floodplains. A range of measurements across scales are required to constrain modelling, including erosion measurements, water quality data and sediment tracing techniques. Together, modelling and monitoring can form 'multiple lines of evidence' about the effectiveness of practice changes to reduce downstream loading.

The timelines of implementing large investment programs to achieve agricultural practice changes can preclude detailed modelling studies. As an alternative method to prioritise management practice options in GBR catchments, conceptual frameworks have been developed of the physical processes linking agricultural practices to paddock-scale pollutant losses, using metrics such as Nitrogen-surplus (t ha^{-1} y^{-1}). This approach combines the latest knowledge about practice effectiveness with empirical delivery functions to estimate impacts of alternate practice changes on downstream pollutant loading. Using a range of empirical, conceptual and mechanistic models, in combination with water quality data and sediment and nutrient tracing/dating techniques provides a robust platform for being able to evaluate the impact of agricultural land management change at a range of scales.

MURKY WATERS:
MULTIDIMENSIONAL ISSUES LINKING MACRONUTRIENT SOURCES AND IMPACTS IN CATCHMENTS

HELEN JARVIE [1], ANDREW SHARPLEY [2] & PAUL WITHERS [3]

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2 University of Arkansas, Fayetteville, Arkansas, USA
3 School of Environment, Natural Resources & Geography, Bangor University, Gwynedd, UK

This presentation seeks to shine a light into the murky waters and uncertainties surrounding land-based nutrient source controls to improve river water quality and ecology. We examine the current policy focus on phosphorus (P) source remediation to control river eutrophication and deliver improved ecological status. We highlight the rapid improvements in river water P concentrations and fluxes which have been achieved through point source controls and review the evidence of water quality improvements as a result of agricultural diffuse source controls (best management practices, BMPs), from the field to catchment scale. Issues of scale, intensity and location of BMP implementation, the confounding influences of other sources and lags associated with the macronutrient legacy within catchments are discussed.

The role of macronutrient attenuation, retention and release are presented using Extended Endmember Mixing Analysis, combined with in-situ process measurements. These show how P, nitrogen and carbon cycles can be tightly coupled with ecological dynamics, and we discuss the implications, complexities and uncertainties for predicting catchment water quality responses to land-based nutrient controls based on P.

Progressing beyond water quality to evaluate impacts of land-based P controls on river ecology, the waters become even murkier! We show how even dramatic reductions in riverine P concentrations have, in some circumstances, failed to produce improvements in nuisance algal growth in rivers and, in some cases, have corresponded with degradation of river ecology. Issues of macronutrient limitation thresholds, highly variable, site-specific physical controls (e.g. light, temperature, flow velocities) and biological feedbacks are discussed. The current focus of policy on diffuse source P controls and development of numeric nutrient criteria, may not always achieve the desired ecological and water quality outcomes within short policy-relevant timescales. Thus, we highlight opportunities for more integrated approaches to resource and aquatic habitat management, which capitalise on the remarkable macronutrient buffering and attenuation capacity along the catchment-river continuum.

DO NATURAL PROCESSES COUNTERACT EFFECTS OF NUTRIENT ACTON PLANS AT DIFFERENT TEMPORAL AND SPATIAL SCALES?

BRIAN KRONVANG, JØRGEN WINDOLF, RUTH GRANT, GITTE BLICHER-MATHIASEN, SØREN E. LARSEN & JENS BØGESTRAND

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Several Danish Action Plans for the Aquatic Environment (APAE) have been implemented for reducing nitrogen and phosphorus losses to groundwater and surface water bodies starting with the first APAE being adopted in 1987 by the Danish Parliament. The APAE I set reduction targets of 50% for nitrogen and 80% for phosphorus and since then APAE II from 1998 and APAE III from 2003 have been adopted by the Danish Parliament to especially combat nutrient pollution from diffuse sources utilizing a combination of general and targeted mitigation options. A national monitoring programme was initialised in 1989 to monitor the effect of the APEAs. The national monitoring programme documents any trends in pressures, state and impact on the aquatic environment. A vital part of this monitoring programme has been the agricultural mini-catchment approach where crop, animal and nutrient management by farmers as well as the agricultural nutrient cycling have been monitored in groundwater, soil water and surface waters since 1989. The outcome is used for the national assessment of the EU Nitrates Directive and for documenting the outcome of APAE's. At the national scale we are monitoring around 100 larger catchments which combined with a model for water flow, nutrient emissions and nutrient sinks makes it possible to obtain national data on nutrient concentrations and loads. In this contribution we will focus on analysing the linkages and responses (trends) between changes in agricultural practices and nutrient concentrations and losses at two scales: i) micro-catchment scale utilizing 20 years of monitoring results from soil, groundwater and surface waters; ii) national scale utilizing 20 years of combined monitoring and modelling data on sources and sinks. A special focus will be directed against showing the importance of natural processes such as background nutrient concentrations and loads, nutrient sinks in groundwater and surface waters and delays in responses between groundwater and surface waters.

COST EFFECTIVE PLACEMENT OF CONSERVATION PRACTICES IN WATERSHEDS:

INTEGRATING ECONOMIC AND BIOPHYSICAL MODELS

CATHERINE L. KLING

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Agricultural nutrients remain a primary source of water quality degradation. Nitrogen and phosphorous runoff from intensive row crop agriculture in the central U.S. is an archetypical example. While many conservation practices have been developed to reduce the problem, these practices can be costly to implement on a wide scale; thus it is important to consider cost-effectiveness in the design of policies to best use conservation dollars. Further complicating the issue is the complex hydrologic pathways by which nutrients move from their source to waterways where they cause environmental problems.

In this talk, I discuss the use of integrated economic and biophysical models as a guide to design of policy. Specifically, the tool of evolutionary algorithms are used to demonstrate how an optimal set of conservation practices and land uses can be approximated when a detailed watershed based water quality model is used in conjunction with cost information on agricultural conservation practices.

Using a finely detailed and spatially explicit data set on agricultural land uses in the Boone River Watershed in north central Iowa, a pareto frontier that represents the tradeoffs between abatement costs and two nutrients of concern, nitrogen and phosphorous is developed. The set of conservation practices that achieve the least cost approach to meeting a given water quality goal is identified. The evolutionary algorithm is also used to explore the cost savings from targeting relative to requiring all producers in a watershed to use the same set of practices/land uses. Finally, the sensitivity of the optimal conservation practice set to a variety of cost and water quality target assumptions is evaluated.

ECONOMIC ASPECTS OF THE EUROPEAN WATER FRAMEWORK DIRECTIVE:

EXPERIENCES AND CHALLENGES IN AGRICULTURAL CATCHMENTS

JULIA MARTIN-ORTEGA

The James Hutton Institute, Craigiebuckler, Aberdeen, Scotland, UK
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In October 2000, Directive 2000/60/CE, better known as the Water Framework Directive (WFD), entered in to force leading to a deep and substantial reform of water management in Europe. The main objectives of the WFD are to stop deterioration and improve the state of aquatic ecosystems to promote the sustainable use of water and to ensure public participation in water management. A key element of the WFD is the role that economic tools and principles have been assigned in achieving its objectives. This is where the Directive is most innovative and interesting, as the use of economics forms integral part of its design and implementation. The explicit purpose of including economics is to create the integrated regulation necessary for a sustainable management of water resources. This has raised an important number of research and implementation questions that have set the water agenda in Europe in the last ten years and will continue to do so for the next decades.

Two phases of the economic analysis in the WFD can be distinguished. The first (already completed) entailed the economic characterization of the different water uses and the construction of future scenarios (article 5), as well as studying the potential for cost recovery of water services for a more transparent an efficient water tariffs system (article 9). Here we focus on the second phase: the cost-effectiveness analysis of the measures to be included in the so-called Program of Measures (article 11) required to achieve the good ecological status; and the assessment of (dis)proportionality of the costs of the measures in relation to the benefits produced by the good ecological status, including environmental and resource benefits (article 4). Although it was due by the end of 2009 with the publication of the River Basin Management Plans (RBMP) several countries (eg. Spain, Italy, Czech Republic, among others) have yet to complete this phase. Even those that have completed it (e.g. UK, Norway), have still to resolve important gaps (eg. accountability of multiple benefits and better consideration of uncertainty).

We review the progress that has been made up to date at the European level in the economic analysis of the WFD, with special focus on agri-environmental measures. We then look at the remaining research challenges ahead. These relate to continuing to do "normal" (mode 1) science regarding the refinement of methods (e.g. how to improve value transferability of environmental benefits), but also the challenge of addressing "wicked" problems (mode 2 science). This includes: i) how can the operationalization of the ecosystem service approach help in a better implementation of the WFD; ii) how to combine the application of the cost-effectiveness and cost-benefit rameworks into practical decision making for (dis)proportionality of WFD; and iii) how to effectively co-construct knowledge and practice with stake-holders. Addressing these challenges requires stronger interdisciplinary research and multi-level stakeholder involvement moving towards evidence-based policy making.

SPEAKER ABSTRACTS

FARM NUTRIENT REGULATIONS;
CONTRASTING IMPACT ON WATER QUALITY IN DIFFERENT CATCHMENTS

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Regulating farm nutrient management on a whole territory basis through measures that minimise sources and their exposure to runoff or drainage pathways are fundamental to Ireland's approach to reaching good water quality status by 2015. Six catchments (5-30 km^2) representing the range of physiographic settings for intensive agriculture were instrumented to observe interactions between regulations, nutrient losses and lotic ecological status over one to three years.

Two catchment evaluation scenarios are presented here to illustrate where these regulations are currently more or less effective, and why. In a catchment with predominantly well-drained soils, high land use intensity (spring barley, beef and sheep) and 18% of fields with soil P above agronomic optimums, fish populations were healthy. Benthic macro-invertebrate and diatom quality ratings ranged from bad to good with poorer ratings downstream of a village sewage treatment works outfall. High total P concentrations and turbidity (frequently >0.1 mg L^{-1} and 200 NTU respectively) during storms indicated high connectivity of farm nutrient sources with streams but high baseflows (230 L s^{-1} in winter and 40 L s^{-1} in summer) maintained stream P concentrations below the ecological threshold in winter and marginally above in summer.

Depletion of excess soil P is likely to occur over time (5-20 years) under the current regulations and this may reduce elevated groundwater inputs of P during summer and further improve water quality, however, sewage work discharges are likely to remain constant. In a contrasting catchment on moderate to heavy soils farmed for winter wheat, dairy and beef, water quality chemical and ecological standards were rarely met. Phosphorus loss in winter 2011 was about four times larger than from the well-drained catchment and was again linked to land use, particularly erosion from cropland. Whilst baseflow P loads were lower than the well drained catchment, stream P concentrations were four times higher than the ecological standard of 0.035 mg L^{-1} due to about a ten-fold reduction in baseflow discharge from winter to ~9 L s^{-1} in a summer period. Monthly spatial surveys of water quality indicated summer baseflow P losses were related to both urban and agricultural point sources with the latter possibly residual losses from historical accumulation of nutrients in highly connected parts of the landscape. Poor to moderate ecological quality was observed post-summer with observations of good quality in early summer at some sites indicating the potential for seasonal recovery in this catchment. However, lotic ecology was more stressed than in the well-drained catchment during summer possibly due also to the lack of hydrological buffering of nutrient pressures.

Further to the current regulations, practices that minimise urban point source connectivity, remediate historical rural point sources, minimise soil loss during storms, protect stream habitats from degradation and stock access and remove downstream barriers to fish migration may accelerate improvement in water quality in this catchment and require further investigation.

THE TARLAND CATCHMENT INITIATIVE:

LESSONS FOR ASSESSING THE ACHIEVEMENT OF MULTIPLE BENEFITS FOLLOWING CATCHMENT RESTORATION

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The mixed farming sub catchment of Tarland is a priority for action in the Dee Catchment Management Plan and Scotland River Basin Management Plan, due to downgraded water quality and morphological condition. The Tarland Catchment Initiative is addressing these issues using a catchment restoration approach. The ethos for this is that water quality and stream ecological improvements can best be realised through a set of nutrient and erosion control measures linked with riparian and stream habitat restoration. Over a decade approximately 20% of the stream network has been buffered, fenced and planted with alders, stream meanders recreated, farm management targeted, a large septic tank input treated and the village WWTP effluent diverted to a wetland. There is an ongoing natural flood management project and a range of initiatives to encourage community engagement and awareness.

We have aimed to follow the expected improvements with a standard 'regulatory type' chemical and macroinvertebrate monitoring programme. This has been supplemented with additional riparian habitat observations and targeted experimental approaches to assess nutrient cycling in streams and buffer soils and morphological manipulations. At the whole catchment scale (50 km2) sediment concentrations have declined, yet buffer strip installations in the headwaters had no measurable effects (beyond possible weak trends) on either water quality or macroinvertebrate scores. Either the buffer strips have so far been ineffective or ineffectiveness of assessment methods, sampling frequency, and time lags in recovery prevent us to detect reliable effects. Separation of the buffer effects from P concentration declines associated with the point source improvements has proved difficult, but point source controls could not be linked to ecological improvement. Restored riparian habitat have shown increased terrestrial species numbers, but insect species traits showed that signs of an unstable, degraded habitat remained. Instream habitat improvements were associated with increases in numbers of juvenile salmonids.

We suggest that more research is needed to understand the role of specific key management practices (e.g. buffer strips) in achieving multiple benefits. We found that buffer soils stimulated microbially-mediated P turnover potentially increasing P leaching. Greater mechanistic understanding could lead to better advice on how to manage such features. We conclude that a better suite of indicators is needed to appraise the early trajectory of catchment restoration, especially given increasing concerns to achieving multiple benefits in maximising a range of ecosystem services. New improved water quality-ecosystem functional indicators are part of this, but equally so is the feedback from communities and stakeholders.

THE DEMONSTRATION TEST CATCHMENTS PROJECT – AN OVERVIEW

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Our environment is a complex system of interactions between natural processes and the social pressures that disrupt them. Defra and its agencies has to manage the balance for continued food production with the quality of the environment. As a consequence we now face the challenge of managing the whole system rather than considering the services we derive from it – e.g. agriculture, water supply and biodiversity - as separate and isolated. This requires us to understand the critical system linkages as well as we can; how does the land interact with the river and groundwater and the ecosystems they support? The understanding needs to be derived not just from scientific research, but also local knowledge and experience, at different scales.

An appropriate scale for the necessary building of collaborations between multiple stakeholders and the development of capacity to deal with the issues identified is that of the river catchment. The Demonstration Test Catchments (DTC) project is an exciting 5-year (£6.5m) initiative of Defra, WAG and the Environment Agency. The project establishes a research platform in 3 separate locations (Eden – Cumbria; Wensum – Norfolk; Avon – Hampshire) where a number of on-farm measures to reduce agricultural diffuse pollution are being evaluated in nested catchments. Based on a better understanding of the system, the project draws together researchers and local stakeholders as well as using experience from elsewhere. The paper will describe the approaches being taken to monitoring, modelling and up-scaling the research work from farm and field to the catchment and the fit to Defra policy priorities.

IMPLEMENTING PRACTICES TO IMPROVE WATER QUALITY IN AN AGRICULTURAL WATERSHED IN THE CENTRAL UNITED STATES

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The Little Arkansas River watershed is located in central Kansas (USA). Ninety-seven percent of the land area in the watershed is in agricultural production (78% cropland and 19% grazingland). 52% of stream segments and 50% of lakes have water quality problems that violate water quality standards. The most common pollutants are faecal coliform bacteria, excess nutrients, atrazine herbicide, and sediment and total suspended solids. A 9- element watershed plan was developed by local watershed stakeholders, who determined the top priorities for implementation were to reduce atrazine herbicide and sediment delivery to surface waters.

Pesticide BMP Discovery and Implementation: Three (2006), 5 (2007) and 6 (2008, 2009, 2010) watersheds were targeted for rapid implementation of best management practices (BMPs) for atrazine herbicide. An education and demonstration program, surface water monitoring plan, and incentive program for atrazine BMP implementation were developed and delivered to the targeted watersheds. Twenty-one educational meetings were conducted to train 641 farmers and pesticide dealers. An atrazine BMPs publication was developed and distributed. BMP demonstration/research sites were developed at three farmer field sites to discover, demonstrate, and evaluate the effectiveness of BMPs for pesticides, sediments, and nutrients. The city of Wichita, KS, state agencies and EPA provided funding for incentive payments to farmers for implementing atrazine BMPs. Payments were based on the amount of pollutant reduction practices the farmers were willing to implement. A KSU extension agronomist made 483 on-farm visits with farmers to get their commitment to implement atrazine BMPs. Forty-one (2006), 72 (2007), 95 (2008), 95 (2009), and 114 (2010) farmers implemented atrazine BMPs on 76,447 corn and grain sorghum acres. An automated surface water monitoring system was installed in the streams at the base of the watersheds targeted for BMP implementation and also at the base of four adjoining watersheds. Water quality monitoring of treated and untreated watersheds found 66% (2006), 40% (2007), 65% (2008), 51% (2009), and 40% (2010) lower atrazine concentrations in streams in targeted watersheds in which BMPs had been implemented.

Sediment BMP Discovery and Implementation: Watershed GIS maps and modelling were used to select Black Kettle Creek subwatershed for targeted BMPs adoption efforts. Using ArcSWAT, 10% of the sediment yield was estimated to come from 1.9 to 4.4% of the watershed and 20% from 4.6 to 10.7% of the watershed. The results were used to develop a schedule of BMP cost per unit sediment reduction for targeted locations in the watershed. An education program, which included educational meetings and on-farm visits, was delivered to watershed stakeholders. Using special funding from a grant, a BMP implementation incentive program was developed to reduce sediment delivery from cropland. Outcomes included 25 farmers committing to implementing BMPs on 138 crop fields (4,810 acres), resulting in 40% reduction annual sediment delivery to streams within the watershed.

IS MECHANICAL SOIL AERATION A STRATEGY TO ALLEVIATE SOIL COMPACTION AND DECREASE PHOSPHORUS AND SEDIMENT LOSSES FROM IRRIGATED AND RAIN-FED CATTLE-GRAZED PASTURES?

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Agriculture is a major source of phosphorus (P) and suspended sediment (SS) losses to aquatic ecosystems promoting eutrophication. Mechanical soil loosening equipment, such as aerators, has been reported to improve the physical quality and infiltration of soils damaged by livestock treading. We hypothesized that soil aeration on a poorly structured silt-loam soil under cattle grazed pasture would decrease the volume of surface runoff and consequent losses of P and SS compared to non-aerated soil (control). Hydrologically-isolated plots were installed in aerated and control plots to collect surface runoff following irrigation or rainfall and analysed for P and SS losses for one year. Soil physical properties (% macroporosity, bulk density, saturated and unsaturated hydraulic conductivities at 0-5 cm depth) were measured in the aerated and control treatments and taken before each irrigation event (n = 12).

Six months after mechanical aeration was employed, but before cattle grazing commenced, no significant differences in soil physical quality were found between aerated and control treatments. This lack of treatment difference continued after grazing and was largely attributed to rapid re-settling of the poorly structured soil studied. Flow weighted mean concentrations and annual loads of dissolved reactive P (DRP) on the aerated soil (2.24 kg DRP ha^{-1}) were approximately double those from the control treatment (1.20 kg DRP ha^{-1}). However, no significant differences were observed between treatments for surface runoff volumes and losses of P and SS, which may reflect the similar soil physical conditions exhibited between treatments throughout most of the trial.

We conclude that aeration did not decrease P and SS losses. Any changes in soil physical quality were short-lived and therefore unlikely to influence surface runoff and subsequent P and SS losses for this soil type. These findings demonstrate that potential environmental mitigation practices need to be thoroughly tested before implementation to landowners is recommended.

EVALUATING MULTIPURPOSE SOFT ENGINEERED MITIGATION MEASURES IN THE BELFORD BURN CATCHMENT, NORTHUMBERLAND, UK

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Intense farming plays a key role in increasing runoff rates, resulting in various water quality issues and flooding problems. Hence, there is great potential for agricultural management to become a major part of improved strategies for controlling runoff. By targeting runoff flow pathways in fields and farm ditches, a significant component of the runoff generation can potentially be managed at the catchment scale, thus improving water quality and ecological habitats. Farm productivity should not have to be compromised.

The Belford Burn (Northumberland, UK) catchment is a small rural catchment with an upstream area of 6 km^2. The village at the outlet has a flooding problem and there are water quality issues within the catchment that need addressed. The Environment Agency (EA) and the Northumbria Regional Flood Defence Committee wanted to deliver an alternative catchment-based solution to the flooding problem in Belford. In addition, there was a desire to take the opportunity to help improve water quality, such as sediment management through sediment traps. A variety of runoff attenuation features have been implemented throughout the catchment to address both of these issues. The measures include low cost bunds disconnecting flow pathways, diversion structures in ditches to spill and store high flows, 'Beaver dams' placed within the channel, and riparian zone management.

The project provides the evidence needed to understand whether these multi-functional mitigation measures are working at the local and catchment scale. A critique of the types of features implemented is presented here. The study shows it is possible to work with farmers to solve numerous issues by using soft engineered mitigation measures. The scheme also acts as a demonstration site for interested stakeholders where they can learn the flow pathway management approach. As the project has progressed and lessons have been learnt, it has been possible to develop a runoff management toolkit that is now being implemented in other catchments of similar size. Runoff regimes in small rural catchments can be managed effectively using a bottom up approach which involves all stakeholders working together on local farms across catchments.

THE ANNE VALLEY PROJECT (AVP) AND THE APPLICATION OF THE 'INTEGRATED CONSTRUCTED WETLAND' (ICW) CONCEPT:

AN EXAMPLE IN CATCHMENT MANAGEMENT.

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The Anne Valley Project (AVP) and associated Integrated Constructed Wetland (ICW) concept commenced with specific land and water challenges on a single farm in 1987. The AVP project has since expanded to include the whole 2,500ha Dunhill/Annestown stream catchment near the south coast of Co Waterford. Today >80% of farmyards and >50% of village conurbation point-sources, and c. 50% diffuse sources in the catchment are intercepted by wetland infrastructures. These intercepting wetlands reanimate natural wetland infrastructure that have been lost mainly to agriculture. These new wetlands strive to mainly mimic natural wetland ecologies with sequential-flow, multiple cells, shallow, densely helophyte-vegetated and free-surface-water. Some wetland cells may have deeper (c. 2m) open water areas.

The catchment's landowners, the State Forest Service, Waterford County Council, National Parks and Wildlife Service, Department of Environment, Community and Local Government and the EU INTERREG IIIA have contributed the necessary scientific, technical and financial support to this wetland initiative. Today the receiving waters of the main stream and its tributaries support trout and salmon populations, wetland segments provide biodiversity comparable to similar natural areas and new resources and services such as recreational amenities and important ecosystem services have become key elements in the welfare of its rural community. The explicit integration of water management needs with that of landscape fit and biodiversity enhancement, which initially formed the basis of the AVP, gave rise to the 'Integrated Constructed Wetland' (ICW) concept. This concept was further developed and incorporated into the AVP. It has been a key element in the successes of the project.

The achievements and progress made in the AVP were largely achieved through innovative joined-up thinking, collaboration and cooperation amongst all participants. The Department Environment Heritage and Local Government published on 13 December 2010 its guidance documents on ICW systems for farmyard soiled water and domestic wastewater applications:

http://www.environ.ie/en/Publications/Environment/Water/FileDownLoad,24931,en.pdf

EVALUATION OF CONSTRUCTED WETLANDS FOR MITIGATION OF DIFFUSE POLLUTION FROM AGRICULTURE: UNCERTAINTIES

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Excess nitrogen and phosphorus production, with resulting pollution of soils and water, has been identified as one of nine main areas contributing to a deteriorating global environment. Legislation has resulted in a reduction of pollution from point sources, so that the significance of diffuse (non-point) sources, and the contribution from agriculture in particular, has become increasingly important. Land management approaches, such as constructed wetlands, can help to break the connection between sources of runoff and the waterways, with the aim of preventing or reducing problems such as siltation and eutrophication. However, there is a shortage of evidence for the effectiveness and viability of such mitigation options in the UK.

The 'Mitigation Options for Phosphorus and Sediment' project (funded by the UK Department for Environment, Food and Rural Affairs, 2008-2013) aims to make recommendations on the design and effectiveness of constructed field wetlands for diffuse pollution control in UK landscapes. Ten experimental wetlands on four farms in Cumbria and Leicestershire have been built, with combinations of different wetland design (single, paired shallow, paired deep/shallow), soil type (sand, silt, clay), wetland size (0.025%, 0.05%, 0.1% of catchment area) and runoff source (surface runoff, drain, ditch/stream). The wetlands are continuously monitored for water level and turbidity, with water samples collected at inlets and outlets during storm events. Annual sediment surveys are used to estimate sediment trapping rates.

Each of these methodologies results in data with very different uncertainties. It is clear that the wetlands are effective in trapping a substantial proportion of the sediment load. Annual estimations of sediment trapped, based on observed volumes and density, are robust, (25 tonnes at sandy site in 2009/10 and 20 tonnes so far in 2010/11; 0.05 – 3 tonnes at less erosive silt/clay sites). However, P trapping rates of 0.01 kg/ha (clay) and 0.96 kg/ha (sand) are less certain due to spatial variation in sediment TP concentrations and estimation of contributing area.

For individual storm events, concentrations of sediment and total phosphorus are shown to decrease between the inlet and outlet of the wetlands. However, there is large variability in the estimation of total loads, with uncertainties in the discharge estimation at low flows (too shallow for sensors), high flows (beyond lab calibration range) or flooded conditions (backwater effects). Additional uncertainties result from inferring sediment concentrations from turbidity, where relationships are not representative (sandy site), sensors are subject to algal growth or data is missed due to blocked sensors. Elevated concentrations of dissolved fractions of N, P and C in groundwater immediately underlying the wetland suggest leaching of pollutants from the wetland into the wider groundwater system during some seasons: a potential case of pollution swapping.

Overall, field wetlands are shown to be effective traps for sediment and nutrients, although further work is required to improve estimates of the contributions from individual storm events.

APPLICATION OF FARMSCOPER TO OPTIMISE OPTIONS FOR MITIGATING AGRICULTURAL DIFFUSE POLLUTION ACROSS THE HAMPSHIRE AVON DEMONSTRATION TEST CATCHMENT

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FARMSCOPER (Farm Scale Optimisation of Pollutant Emission Reductions) is a new Excel-based tool for characterising diffuse agricultural pollutant loads for farm types and quantifying the expected impacts of control options on these losses to the environment. It has been selected by Defra UK to help provide integrated farm advice across England and Wales to mitigate diffuse pollution associated with intensive agricultural activities and practices. This work describes the application of FARMSCOPER in the Hampshire Avon Demonstration Test Catchment (DTC) in order to assess its utility for use at catchment, as opposed to, farm scale.

Spatial datasets and the Agricultural Census returns for 2009 specific to the Avon catchment were integrated to produce a collection of representative farm types which capture the characteristics of the local physical environment, land use patterns and farm management practices. FARMSCOPER was used to estimate the annual loadings of nitrate (N), phosphorus (P), sediment (SS), nitrous oxide (N_2O), methane (CH_4) and ammonia (NH_3) for each representative farm type. The results demonstrate that field drainage status has a significant influence on SS and P losses to the environment and estimates were, in general, in agreement with available measured data. Occupying around 50% of the agricultural area, cereal farms deliver 54% of the nitrate and 67% of the sediment load. For methane, the respective relative contributions from dairy farms, lowland grazing farms and mixed farms are 30%, 29% and 41%. Mixed farms have the highest specific loadings for nitrate, nitrous oxide and ammonia. Dairy farms have the highest specific loadings for P and NH_3.

Some issues were identified in applying FARMSCOPER at the catchment scale, including ambiguity in integrating Rural Land Registry (RLR) polygon and agricultural census returns data, uncertainty in soil drainage status and differences between the rationalised model farm definitions and the detail of the census data, e.g. the large number of poultry reported on some cereal farms. Modelling outputs from FARMSCOPER will be presented to key stakeholders in the catchment for consensus building and formulation of practical mitigation strategies.

NITROGEN AND PHOSPHORUS BALANCES AND EFFICIENCIES ON CONTRASTING DAIRY FARMS IN AUSTRALIA

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Nitrogen (N) and phosphorus (P) imports, exports and within-farm flows were measured during a standardised production year on 41 contrasting Australian dairy farms, representing a broad range of geographic locations, productivity, herd and farm size, reliance on irrigation, and soil types. The amount of N and P imported varied markedly, with feed and fertiliser generally the most significant contributors and principally determined by stocking rate and type of imported feed. Whole-farm N surplus ranged from 47 to 600 kg N/ha/year and was strongly ($P < 0.01$) and linearly related to the level of milk production. Whole-farm N use efficiency ranged from 14 to 50%, with a median of 26%. Whole-farm P surplus ranged from -7 to + 133 kg P/ha/year, with a median of 28 kg/ha. Phosphorus use efficiencies ranged from 6 to 158%, with a median of 35%. The poor relationship between P fertiliser inputs and milk production from home-grown pasture and crops reflected the high soil P levels measured on these farms.

The N and P intakes of each dairy herd, the locations the cows visited and the time they spent there, were also determined during five visits throughout the year. As N and P intakes increased so did excreted N and P, with use efficiencies generally less than 20%. On average 432 g N and 61 g P were excreted by each lactating dairy cow/day. Overall, cows spent a small proportion of their time in the milking parlour (2%) and yards (9%) where dung and urine were generally collected, however greater time was spent on feedpads (11%) and holding areas (26%) where manure was not routinely collected. The largest amounts of excreted N and P were deposited by cows in grazed paddocks but particularly those closest to the milking parlour.

Derived industry based relationships and individual farm case studies have been developed to identify opportunities to improve N and P use efficiency within grazed dairy systems. These include reducing unnecessary nutrient intake, improved spatial and temporal movement of animals within dairy farms to reduce heterogeneous N and P deposition, increasing the capture, storage and redistribution of excreted N and P in non-productive areas, and more strategic fertiliser and effluent applications. We also suggest that simple on-farm assessments can be used in contrasting dairy production operations to assess N and P use efficiencies, which will assist in developing appropriate industry benchmarks and benefit productivity and environmental outcomes.

EVALUATING MANAGEMENT REGULATIONS AT DIFFERENT SCALES IN AGRICULTURAL CATCHMENTS IN IRELAND

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During 2009 and 2010 Ireland established an experiment in six agricultural catchments (6-30 km^2) in order to monitor the effectiveness of the EU Nitrates Directive programme of measures (SI 610 of 2010). In these catchments the identification and quantification of nutrient sources is a component of a larger research programme encompassing biophysical and socio–economic research and extension elements.

To evaluate specific measures that focus on limiting N and P inputs to levels that minimise potential losses to water, detailed nutrient input, off-take, soil nutrient status and crop and production type data were collected at farm and field level. These data allow calculations of nutrient requirements for optimum production on a farm, taking into account the variability in soil and crop requirements per field basis. It also allows nutrient balances to be developed for different production systems, and for whole farms and larger catchment scales which are used to assess nutrient efficiency levels and potential nutrient losses.

In this paper nutrient balance data are presented for the different catchments and farming enterprises. The scales at which these specific measures are implemented and practical considerations for effective nutrient management will be discussed in relation to the part of Irish agriculture in achieving water quality targets.

INTERACTION BETWEEN LAND AND SURFACE WATER QUALITY IN DIFFERENT TYPES OF CATCHMENTS

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Water quality is highly determined by the interaction between the land system and surface water system itself, especially regarding the fate of nutrients within catchments. In order to evaluate the impact of mitigation options to improve surface water quality composed information for land and surface water is needed dealing with the sources and pathways from land to surface water, response time of mitigation options and the role of processes in surface water regarding changes in nutrient input. In this presentation the interaction between land and surface waters will be illustrated for nitrogen (N) and phosphorus (P) for different aquatic systems based on monitoring and modelling approaches.

Both natural draining areas (thick sandy soils) and engineered systems (peat and clay polders) will be discussed which can be found in different parts of the Netherlands. The dynamics and contribution of different type of point and non-point sources on the nutrient losses from land to surface water is quantified for these areas and estimates of the nutrient retention within soil and surface waters are given resulting in different time responses of mitigation options on the surface water quality.

Finally, based on the system characteristics of the catchments and the behaviour of nutrients within the catchment better monitoring programs have been set up by combining the outcome of nutrient modelling approaches with standard measuring programs of the catchments. Such a monitoring program approach will also help for a better understanding and quantification of the impact of mitigation options on the surface water quality.

THE ENVIRONMENTAL VIRTUAL OBSERVATORY:
A NEW VISION FOR CATCHMENT SCIENCE

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Catchment managers and policy makers face a challenging future trying to ensure a wide range of ecosystem services are delivered from increasingly constrained budgets whilst complying with a range of regulation requirements. This comes with a greater requirement for transparency and access to data and the decision making process from the public. The Environmental Virtual Observatory Pilot project (EVOp) is a new initiative from the UK Natural Environment Research Council (NERC) designed to deliver proof of concept for new tools and approaches to support these challenges. The long term vision of the Environmental Virtual Observatory is to:

- Make environmental data more visible and accessible to a wide range of potential users including public good applications;
- Provide tools to facilitate the integrated analysis of data greater access to added knowledge and expert analysis and visualisation of the results;
- Develop new, added-value knowledge from public and private sector data assets to help tackle environmental challenges.

The EVO will exploit cloud computing and in this two year pilot project we will develop three exemplars to demonstrate and test the opportunities and constraints from such an approach. Specific IT tasks include exploring possible structures for the cloud environment, IPR and data security issues and providing training and awareness of these new IT technologies and their potential for delivering more integrated environmental science. The three question-based exemplars being developed are focused on (i) management options for diffuse pollution at a local scale, (ii) developing approaches for transferring hydrological models from data rich to data poor areas and (iii) defining the uncertainty bounds of current climate change predictions on change in soil carbon at a global scale. By developing exemplars focussed on some major environmental questions at a local, national and global scale we are able to directly test issues such as data assimilation, adapting models to work in a cloud environment, and portal design for a wide range of end-users. A working prototype portal will be delivered in December 2012 together with potential national and international partners for a possible next phase.

PARTNERSHIP WORKING TO TACKLE DIFFUSE PHOSPHORUS POLLUTION

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The Environment Agency (of England and Wales) is working in partnership with the National Farmers Union (NFU) to identify ways of quantifying and reducing the contribution of farming to phosphate pollution causing aquatic eutrophication. Under the Water Framework Directive, failure to comply with river phosphorus (P) standards in England and Wales is considerable – 41 per cent of river water bodies and 64 per cent of lakes. There are no regulatory controls on P export from agricultural land and it is an issue that farmers will need to manage in the future.

The rationale for this project was to establish a jointly agreed, independent, evidence base on the sources, impacts and potential measures to combat P pollution at a range of spatial scales. This evidence base will inform discussions with the agricultural industry and government on a strategic approach to tackling aquatic eutrophication. At the local level, the evidence base will support farmer-led identification of measures coupled with a monitoring programme to determine the effectiveness of the measures over time in two pilot catchments.

WRc and Bangor University undertook the evidence-based review at three scales: national, Anglian River Basin District (RBD), and pilot catchment scales (Bourn Brook in Cambridgeshire and Harpers Brook in Northamptonshire). Anglian RBD was selected as it has the joint lowest projected improvement in water bodies achieving Good Ecological Status by 2015 – just 1%. The pilot catchments were selected because the water bodies are failing good status due to P, the modelled (PSYCHIC) agricultural contribution was relatively high (35-40%), and there are no existing initiatives addressing P loss.

The evidence was presented at a workshop on 7th April 2011 to scientific peer reviewers and a farmer group. Point sources of P (e.g. wastewater) dominated P export at all three scales but the contribution of agriculture can locally be high and needs to be managed as part of an integrated solution to eutrophication problems. The distribution of sewage treatment works, a high density of village communities and a general lack of river dilution capacity in a region with very low annual rainfall were key factors contributing to high river P concentrations in the region. A predominance of arable farming and associated high P fertiliser use, localised animal farms and rapid delivery of runoff through field underdrainage systems were key factors contributing to P export from farmed land in East Anglia. Groundwater concentrations were found to be low in the two pilot catchments but were locally high in the wider RBD. The next stage is to identify agronomic measures the farmers will implement (on a voluntary basis) in the two pilot catchments and set up a monitoring programme to evaluate success.

DESIGNING AND CREATING THE NORTH WYKE FARM PLATFORM

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The North Wyke Farm Platform is a large, farm-scale experiment which was established during 2010 as a UK national capability for collaborative research, training and knowledge exchange in agro-environmental sciences which addresses agricultural productivity and ecosystem responses to different management practices. Since the farm platform was commissioned in April 2011 a standard beef and sheep system has been implemented across the site in order to obtain baseline data in hydrology, nutrient cycling and productivity. Here we describe the details behind the platform design. In 2008 a detailed topographical survey and hydrological assessment identified 15 grassland catchment blocks on about 67 ha of land at North Wyke located principally on clayey soils. Full planning permission was required for the project to proceed and this required a range of assessments including a species and condition survey of almost 1000 trees located around the edge of the blocks plus a constraints plan in relation to Root Protection Areas. In addition, during 2010 habitat and protected species surveys were undertaken, together with an Environmental Impact Assessment and Archaeological Survey in order to identify how the impact of the groundworks were to be mitigated.

The hydrological monitoring design was based on a predicted 50-year flood event, using H-flumes at the block outlets, each sized according to the catchment characteristics. French drains totalling 9.2 km in length, set at 800mm depth and containing perforated plastic drainage pipe were installed to collect surface and near surface flow from the experimental block areas. All the flumes receive water supplied by 2 branches of each French Drain system and where these join in a confluence pit, clay bungs were placed around the pipe to ensure the drainage water is always captured. The water then proceeds via concrete piping and a sampling pit into the flume. Where required, the blocks are protected on the upslope boundaries by open ditches and sealed pipes to prevent external groundwater and surface runoff ingress from adjacent land. Each flume is supplied with mains electric power and a fibre optic based data telemetry system which totals over 5 km in length. Water flow is measured using bubbler flowmeters and other water measurements include dissolved organic carbon, ammonium, nitrate, dissolved oxygen, total-P, ortho-P, chloride, temperature, pH, conductivity, turbidity; together with rainfall and soil moisture. The baseline data will be collected for 2 years along with soil, atmosphere and agricultural productivity data before 3 radically different land-use scenarios are imposed across the blocks and then monitored from April 2013 onwards.

UNCERTAIN DIFFUSE PHOSPHORUS PATHWAYS IN CATCHMENTS

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Nutrient transfers from land can be a major influence on water quality deterioration, causing eutrophication and subject to regulatory mitigation efforts. The status of all Ireland's groundwater bodies has been assessed. If the mean annual molybdate reactive phosphorus (MRP) concentration exceeds 0.035mg L^{-1} (the Environmental Quality Standard for good water quality status, EPA, 2009) and the groundwater contributes at least 75% of the receiving river's flow, the aquifer is defined as being of 'poor status'. However, there are uncertainties with defining groundwater vulnerability to phosphorus (P) transfer within agricultural river catchments. This includes uncertainty in defining the groundwater vulnerability, conceptualising transfer pathways, understanding processes during transfer and distinguishing diffuse from point sources. The definition of groundwater vulnerability to P is based on the soil P use and status and the water recharge capacity (high recharge implies a high groundwater vulnerability). It is assumed that P may be mobilised to groundwater only when the soils are P saturated. In this study groundwater vulnerability to P transfer was investigated. Phosphorus was quantified in the top soil (yearly), sub soil, groundwater (monthly) and surface water (sub-hourly). Spatiotemporal patterns of P in groundwater were investigated. Flow pathways were identified and quantified for a major summer storm from four agricultural catchments with intensive management (arable and grassland) and different flow regimes.

In a well-drained grassland catchment with sandstone geology P from agricultural sources was transferred to groundwater even when soils were not P saturated. Groundwater P concentrations were elevated, especially in the near-stream zone where yearly average DRP concentration ranged from 0.035 mg L^{-1} in the bedrock to 0.060 mg L-$^{-1}$ in the sub soil. During a summer storm, with a 46 day recession of P load, three pathways for P transfer to streamflow were identified. Surface runoff lasted for 19 hours of the recession and contributed 27% of the total P load (41 g ha^{-1}) in the stream. Phosphorus transfer from drains and/or shallow groundwater contributed 21% of the total P load, and after four days the entire P load in the stream originated from the groundwater, which in total contributed 51% of the P load. During the same storm in a contrasting, poorly drained grassland catchment (with rhyolitic volcanic and slate geology) runoff lasted for 41 hours of the recession and contributed 78% of the total P load (95 g ha^{-1}). Drains and/or shallow groundwater contributed 9% of the total P load, and after 14 days the entire P load in the stream originated from the groundwater, which in total contributed 13% of the P load. These data reveal new insights on P transfer to surface water, where apparent surface runoff buffering is offset by increased groundwater P transfers, highlighting the uncertainty in defining P transfer risk. Lag times for P source mitigation in both soil and groundwater will therefore need to be built into expectations of timeframes for water quality recovery following implementation of agri-environmental regulations.

CRITICAL SOURCE AREAS OF PHOSPHORUS IN EXTENSIVELY FARMED GRASSLAND CATCHMENTS

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Mitigation strategies for decreasing phosphorus (P) loss from agricultural land have typically been targeted at intensive agricultural systems. Often these strategies have little relevance to more extensive farming systems, which operate at stocking densities that are considered to pose a limited threat to water quality.

A recent study in the Lough Melvin catchment in Ireland has highlighted the potential impact of extensive agriculture on P export from soil to water. Agriculture in the catchment is largely based on suckler cows, and sheep farming and due to the predominance of soils with impeded drainage, operates at an average stocking rate of 0.5 LSU ha^{-1}. Limited nutrient inputs are required to maintain such stocking rates, which are well below the soils potential grazing capacity of 1.3 LSU ha^{-1}. Despite this, agriculture is estimated to contribute 62% of the P load to Lough Melvin, with P concentration in the lake increasing from 19 to 29 $\mu g\ L^{-1}$ between 1991 and 2007, raising concerns about eutrophication in the lake. Total P export from the Glenaniff sub-catchment, which has little forestry, a sparse population and is classed as a high status water body (HSW) under the Water Framework Directive (WFD), increased from 0.71 tonnes yr^{-1} in 1990 to 1.27 tonnes yr^{-1} by 2007. A survey of 50 farms in the Lough Melvin catchment demonstrated that 31% of fields surveyed using a P risk index approach were categorised as high risk for P loss, with a further 30% posing a medium risk. Despite not requiring further P application for agronomic purposes, 37% of fields at Index 4 (Morgan P >8mg l^{-1}) were receiving in excess of 10 kg ha^{-1}P. In addition 81% of the fields were a medium or high risk in terms of their connectivity to a waterbody. These results present an apparent paradox in which extensive farming, operating at low stocking densities, is having a significant impact on water quality.

This paper provides an analysis of the factors controlling the development of critical source areas (CSA) of P in extensively farmed catchments, through an exploratory case study of landuse changes and agri-environmental policy implementation in the Lough Melvin catchment. The identification of CSAs in such catchments is vital for achieving the WFD quality objectives for HSW, as the location of these waterbodies often coincides with extensively farmed areas.

THE IMPACT OF SEPTIC TANK SYSTEMS ON WATER QUALITY IN RURAL CATCHMENTS

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Septic tank systems (STS) are often ignored in national or catchment source apportionment because of a lack of data on, and understanding of, their eutrophication impact. Approximately 2million such systems discharge nutrient laden waste effluent into potentially sensitive surface waters across the UK and Ireland. Recent catchment studies indicate they are an important and underestimated source of nutrients (N and P) to headwater streams in rural catchments contributing to downstream eutrophication. Using boron (B) as a tracer for detergent inputs, positive relationships between B and soluble reactive P (SRP) under both low flow and high flow conditions, in areas with no known sewage treatment works, have implicated septic tanks as a significant nutrient source. Direct monitoring of surface waters in one rural catchment showed 4-10 fold increases in average stream ammonium N (NH_4-N) and SRP concentrations downstream of domestic dwellings. The very high concentrations, inter-correlation and dilution patterns of SRP, NH_4-N and the effluent markers sodium (Na) and B suggested that septic tank soakaways in the heavy clay catchment soils were not retaining and treating the septic tank effluents efficiently. Stream discharge was the most important factor determining the eutrophication impact of these STS with greatest impact during summer low flow. In another catchment, removal of STS resulted in a dramatic reduction in river P concentrations.

Although individually STS may contribute small nutrient loads because they generate only a small amount of annual flow, their collective contribution to rural P loads can be significant depending on STS density. STS failure seems quite widespread and discharges occur throughout the year, including the ecologically sensitive spring and summer periods. Rural communities, water regulators and the water industry need to be made more aware of the potential impacts of STS on water quality so that their management can be optimised to reduce the risk of potential eutrophication and toxicity to aquatic ecosystems.

NITROGEN LOADINGS AND CONCENTRATIONS TO ESTUARIES IN DENMARK DURING THE PERIOD 1990-2009: REGIONAL DIFFERENCES IN SOURCES, LOADINGS, SINKS AND ESTUARINE RESPONSES

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Since the late 1980s a wide range of measures have been taken to reduce land based nitrogen (N) loading of Danish freshwater and coastal waters. On a national scale, the N-loading has been reduced by 47%. The loading figures are derived from monitoring stations in streams covering 50% of the national territory, whereas loadings from the remaining part are estimated using empirical models. The different mitigation measures and the resulting effect for reduction of N loadings will be presented for around 10 paired catchments and estuaries in order to analyse for regional differences in the outcome of the national action plans. The analysis of N sources, loadings and trends in flow-weighted concentrations in inlet water to the estuaries shows that there are large regional differences caused by different anthropogenic and natural processes. Trends in nitrogen concentrations in the estuaries are also varying between the estuaries analyzed but show in general a lower trend than found in inlet waters. The reason for this apparent discrepancy is discussed.

Finally, some major challenges in the Water Framework Directive N reduction targets for the estuaries and the efforts needed for obtaining these reductions in nutrient loading in the years to come are briefly highlighted.

EXPERIENCES FROM 20 YEARS OF AGRICULTURAL CATCHMENT MONITORING –

FACTORS INFLUENCING DATA QUALITY

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Nutrient losses to waters have been monitored in 21 small Swedish agricultural catchments for a period of 20 years. That includes water quality measurements in the streams and yearly collection of crop management data. The catchments serve as indicators of how agriculture responds to subsidies, regulations, advice and markets within the agricultural sector. They are also used for verification of models such as those included in national load calculations. Monitoring is a qualitative investigation without any controls and repetitions. In addition, many types of data are collected, each with known and unknown uncertainties in quality. Here we describe some factors, both technical and social, that we have recognized as having influence on data quality.

As an example of a technical factor, the method for water sampling at stream outlets has a large impact on calculated losses. When changing from manual grab sampling to automatic flow proportional water sampling we found that we had underestimated phosphorus losses in seven of eight catchments with the manual method.

The collection of crop management data brings light upon the social factors influencing the monitoring. Besides putting a lot of effort on well-designed questionnaires, the relation between the farmer and interviewer has shown to be of high importance. When changing interviewer in one catchment, the participation increased from 30% to 100%. Another consequence was that the quality of crop management data increased. When evaluating data, there is a risk that uncertainties in separate datasets add up and together become larger than calculated effects of changes in agricultural practices. To handle this, there is a need for well-structured databases that are able to store, in addition to the data, detailed information on the methods used to collect the data. By having documented information as completely as possible the potential for accurate assessment of data increases.

WILLINGNESS OF FARMERS TO ENGAGE WITH RIPARIAN ZONES ACROSS SMALL SCALE CATCHMENT AREAS IN THE REPUBLIC OF IRELAND

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There is scientific evidence that riparian zones can act as a nutrient buffers and assist in the provision of environmental public goods and in achieving water quality objectives. This paper in the first instance uses farm survey data and GIS methodology to establish the opportunity cost to agriculture from implementation of a structured 10 m riparian margin across a number of small scale river catchment areas. Secondly the paper uses data from an attitudinal survey of the relevant landowners adjacent to watercourses to examine the factors which influence farmers' willingness to engage with and supply riparian zones.

A survey of 247 landowners indicated that 53 % would not engage with a 10 m riparian margin, 7 % were willing to provide the riparian margin on a free of charge basis, while 40 % were willingness to implement if appropriately financially compensated.

Finally, the paper uses non-market contingent valuation methodology to estimate landowners' willingness to accept price schedules for riparian zone implementation.

DEVELOPMENT OF COST EFFECTIVE NITROGEN MANAGEMENT STRATEGIES:
SCENARIO EVALUATION WITH THE DSS FYRISCOST

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This paper describes the structure of the FyrisCOST model and uses the model to calculate the cost efficiency of alternative scenarios for nitrogen management in an agricultural catchment in Southern Sweden. The scenarios include the spatial distribution by sub-catchment of three measures (catch crops, spring plowing and a combination of these) with alternative crop distributions. The model FyrisCOST is a catchment scale DSS for the evaluation of alternative nutrient mitigation strategies. This model is able to evaluate a range of mitigation approaches for phosphorus and nitrogen from several sources (point and diffuse). This allows cost efficiency to be estimated for a catchment based on a combination of measures. Hydrological flows in the FyrisCOST model are built on the semi-distributed model Fyris NP and nutrient losses are derived from simulations from the Nutrient Leaching Coefficient Calculation System (NLeCCS) which includes the ICECREAM-DB model for estimating phosphorus losses and the SOILN-DB model for soil nitrogen leaching.

FyrisCOST calculates nitrogen concentrations in effluent water for each sub-catchment. The concentration of nitrogen is dependent on the current land use and geographical conditions. In order to evaluate agricultural scenarios in FyrisCOST a method for calculating N leaching from agricultural land was constructed. The calculation includes crop rotations and tillage systems and differentiates between annual and perennial crops. The model is able to take into account the probability that a primary crop is followed by a specific crop/tillage system and the effect on nutrient losses estimated using a specially developed leaching concentration calculator. Each measure or combination of measures in a scenario is evaluated based on reduction effects and costs for each sub-catchment. The measures can be ranked by gross cost efficiency in a sub-catchment or on net cost efficiency in a recipient. The recipient may be a lake, a coastline or a sub-catchment. An important feature in calculating cost efficiency is downstream retention. FyrisCOST has the capacity of including all features for a future emissions trade system where single measures are individually evaluated in combination with other existing measures in the catchment.

INTEGRATING SCIENCE AND GOVERNANCE FOR CATCHMENT MANAGEMENT

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Investigation of catchment management programmes in the USA, Australia, and north-west Europe, illustrate both successes, and tensions between top-down regulation and participatory-collaborative catchment management. A 'template' for catchment governance has been derived which assimilates scientific understanding and governance; this integrates interdisciplinary appraisal and implementation of measures to manage land and water resources. The framework is informed by analysis of international experience and piloting of approaches in two UK catchments.

The inevitable trade-offs of catchment management necessitate an adaptive management cycle, collaboration between agencies and levels of government and a 'twin-track' of deliberative partner and stakeholder engagement supported by targeted scientific research. Deliberation with partner organizations and other stakeholders can integrate environmental and public health criteria with economic and social goals. Stakeholders can contribute to catchment assessments and programme design, and implementation will be enhanced by local knowledge, acceptance and ownership.

Programmes must be able to assess the condition of and all threats to water resources and prepare comprehensive and integrated plans. Ideally all partners will agree and refer to one integrated plan for the catchment. Planning and implementation must be based on credible science, with the capacity to commission external expertise and scientific peer review. Trusted technical providers are needed for capacity building and advisory work, and their essential functions include convening and mediating to foster trust, participation, collaboration and co-production of knowledge.

Monitoring and evaluation is essential to the management cycle, and for the effectiveness, efficiency and equity of outcomes. Reporting on governance, achievements and outcomes is also inherent to sustaining stakeholder and partner engagement, and to demonstrating the benefits of catchment management. Programme technical providers act to compile, synthesize and communicate information, enabling decision makers to consider and use diverse data sources. Education for children, parents and communities can be a facilitator of commitment and action.

Programmes should be built from existing organisations and partnerships, which establish shared goals and recognize differentiated interests and responsibilities. Catchment management requires technical capability, leadership and coordination for agriculture, water supply, wastewater and waste management, highway and other storm runoff, stream corridors, and development planning. Catchment management involves local responsibilities and requires inclusive deliberation at local level under the legal framework of multi-level government. Thus locally acceptable responsibilities and rights must be translated from higher level regulation, with provision for inter-locality cooperation and coordination. Informal partnerships with effective leadership are often a starting point but growth in funds, capacity and authority usually necessitate standing, legitimacy and a formalised legal status.

THE USE OF BENEFIT TRANSFER IN ESTIMATING THE VALUE OF ACHIEVEING 'GOOD ECOLOGICAL STATUS' IN IRISH RIVER CATCHMENTS

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The aim of the Water Framework Directive (WFD) is "to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and ground waters". The WFD calls for integrated catchment management plans to be prepared for all river basins in order to achieve 'good ecological status' (GES) in all EU waters by 2015. This concept is a broader measure of water quality than the chemical and biological measures, which were previously dominant. As such the WFD aims at a minimum for a 'good' and 'non-deteriorating status' for surface, underground and coastal waters and sets common approaches and goals for water management in the EU Member State countries.

An important element of the WFD is that it calls for a consideration of the economic costs and benefits of improvements to ecological status in catchment management plans, along with the introduction of full social cost pricing for water use. Hence, benefits play an important role in the assessment of the proportionality of costs of implementation. Ireland is somewhat behind in terms of measuring the economic value of achieving "good ecological status" under the WFD across catchments. This paper therefore explores the use of benefit transfer (BT) in placing a value of achieving this main objective (good ecological status) of the WFD across river catchments in Ireland.

While primary valuation research with regards to placing a value of achieving good ecological status is a 'first best' strategy, it is also very expensive and time consuming. Thus, secondary analysis through the use of BT can yield very important information that can form a meaningful basis for water management policy.

PAYING FARMERS FOR ECOSYSTEM SERVICES: COSTS AND CHARACTERISTICS OF LONG TERM AGREEMENTS

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Payments for Ecosystems Services (PES) schemes involve a voluntary transaction in which an environmental service (often a land use providing this service) is paid for by one or more buyer(s). In short, the beneficiaries of environmental services pay for their provision and the providers of those services get paid to provide them. The Westcountry Rivers Trust is currently developing a PES scheme designed to mitigate the negative impacts of diffuse pollution from agriculture on raw water quality and aquatic ecosystems more broadly. Scientific evidence suggests that targeted reversion of intensive agricultural land to more extensive systems can deliver numerous ecosystem services ranging from water quality improvements through to flood attenuation and carbon capture. The scheme proposes to make one-off payments to landowners who are prepared to take areas of farmland out of intensive agricultural production on a long-term basis (999 years). Payments to landowners would be financed through a regional fund made up of financial contributions from businesses and private individuals wishing to 'off-set' or redress some of the environmental impacts caused by their activities. This paper first presents findings from an exploratory survey designed to assess landowner attitudes and receptiveness towards the scheme, undertaken during Autumn 2009. The methodology comprised a questionnaire survey of 42 landowners located approximately evenly across 3 catchments in the South West of England. Findings from this survey informed the design of a second survey of 100 farmers in South West England conducted to examine more fully the factors influencing decisions to participate in a scheme and to estimate the private costs for landowners of land management changes proposed. These cost estimates inform assessment of the payments needed to secure long term agreements. A range of farm economic modelling techniques have typically been used for such assessments though all suffer from the limitation that current farm practice and market conditions may not provide an accurate guide as to how farmers will behave under future conditions, particularly given the uncertainty of environmental change and the long term nature of the agreements proposed. The methods are also data intensive. Another approach used in this survey is to assume that the land users themselves are the best source of information about the private costs and benefits of alternative land management scenarios. Consequently, the survey tested the applicability in this context of 'stated preference' methods to appraise the costs to land users. Stated preference methods elicit the value of goods through a survey approach. Respondents are presented with a series of hypothetical alternatives that differ in their attributes. Each alternative has an associated cost or payment to the respondent. The choices of the respondent can then be used to derive their valuation of the attributes and the tradeoffs between different attributes. Within this study the attributes within the choice sets were alternative land retirement scenarios.

POSTER ABSTRACTS

THE AGRICULTURAL CATCHMENTS PROGRAMME:
AN EVALUATION FRAMEWORK FOR THE NITRATES DIRECTIVE NATIONAL ACTION PROGRAMME

1

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The Agricultural Catchments Programme (ACP) is a science-farmer-advice action research initiative to assess the Nitrates Directive National Action Programme regulations in Ireland. As the Action Programme is legislated on a whole-territory basis, the regulations form the Programme of Measures as mitigation actions to manage diffuse nutrient transfers from land to water under the Water Framework Directive. These effectively constrain the timing and magnitude of nutrient management and the processes that influence mobilisation, although with recognition of the need to maximise productivity under optimum nutrient use and land management conditions.

More specifically, the ACP uses the nutrient continuum concept to gauge uptake and social acceptance of changed nutrient management, and the economic and biophysical consequences from agricultural sources to water body receptors. This also effectively covers a legislative spectrum from the Nitrates Directive regulations at one end to more specific regulations concerned with water body status; each having a place under the overarching Water Framework Directive.

ACP operates in six intensive agricultural catchments covering a landuse and physiographic gradient (6-30km^2) although with an emphasis on grassland to reflect the national trend. A high resolution approach to biophysical monitoring has been adopted to cover elements of the source, pathway and delivery components of the nutrient transfer continuum. Embedded in the evaluation experiment, is an advice network to enable farmers to engage with the scientific programme and also to avail of the best agricultural advice on production within the constraints of the National Action Programme.

In the early years of the Action Programme, ACP is defining a focussed extended baseline of landuse status and water quality response that can compliment (and be used to interpret) national inventories on, for example, nutrient use, farm nutrient status and water body response. Early data are also indicating where theory on source to impact processes may need re-evaluating to ensure that benefits accruing from catchment management are properly described and quantified. Further, important socio-economic information on farmer behaviour towards involvement in on-farm nutrient management programs is being gathered that will help future catchment actions in this and other EU countries.

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THE AGRICULTURAL CATCHMENTS PROGRAMME:
INSTRUMENTATION AND DATA MANAGEMENT

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The Agricultural Catchments Programme is conducted in six river catchments working in partnership with farmers and landowners to generate data on nutrient transfers from source use and status, hydrological pathways and delivery into river systems. An agronomic advice network is a cornerstone of this partnership. These data are used in an evaluation framework to assess land-nutrient-water interactions in the early years following the whole-territory adoption of the Nitrates Directive National Action Programme. An emphasis has been placed on high spatio-temporal empiricism in each component of the nutrient transfer continuum. In so far as is practicable, a field-by-field assessment of nutrient use and status is compared with the requirements of the Action Programme and nutrient delivery to water bodies is monitored at up to sub-hourly resolution using high sensitivity field equipment with an emphasis on phosphorus and nitrogen transfers.

Data generated includes soil and water chemistry, hydro-meteorological and ecological data captured using state of the art field instrumentation and sampling protocols, extensive series of laboratory soil and water chemistry data, socio-economic surveys, spatial surveys and maps, and time series of sub-hourly data at over 250 sites throughout the six catchments. This requires a robust centrally managed information system to maintain proper collection, quality control, archiving and access with emphasis on optimising data integrity.

Key elements of the system include a continuous hydro-meteorological time-series database, a Laboratory Information Management System (LIMS) database, topography and land cover geodatabases, farm business monitor data, farm nutrient management records and farm socio-economic and attitudinal surveys. Outside of this central information system is a cloud based application giving field staff access to real-time and user-selective time-series of bankside data.

The ACP generates a complex string of datasets on a daily basis and this complexity is managed by a dedicated data management team who provide a seamless delivery of processes involving data extraction, manipulation and analysis for scientific research and advice.

THE RIVER EDEN DTC PROJECT:
A NATIONAL DEMONSTRATION TEST CATCHMENT

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The Defra-funded EdenDTC project, led by Lancaster University, is engaged in a five-year environmental scheme, aiming to reduce agricultural diffuse pollution. The project will study multiple diffuse pollutants, in the context of impacts and effects on both ecosystems and sustainable production. The £6.5 million scheme encompasses two other river demonstration test catchments, the Avon (Hampshire) and the Wensum (Norfolk). Catchments were selected due to their variable geographical, geological, climatic and land use features

Essential to the study is the involvement of farmers and landowners, with the aim of bringing together researchers, policy-makers, farmers, water companies and NGOs to develop a common approach to tackling diffuse water pollution. Combinations of novel and existing diffuse pollution mitigation measures will be tested, by monitoring their effect on water quality and biodiversity, whilst maintaining productive and sustainable farm businesses.

This poster presents the background and progress of the EdenDTC to date, including installation of instrumentation, sampling regimes, mitigation measures and current data.

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EDEN DEMONSTRATION TEST CATCHMENT:
THE MITIGATION APPROACH

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The Eden catchment is a mixed grassland catchment in the North West of England. Eden DTC is focussing activities on three sub catchments 10km^2 (Pow, Moreland, Dacre) and one demonstration farm (Newton Rigg) 2km^2. The general approach to mitigation in the Eden is that mitigation should be approached through the source – mobilisation – delivery framework and that mitigation uptake needs to work closely with local farmers and landowners. Hence co-ownership and empowerment of stakeholders during the delivery process is at the heart of the approach. The Eden is already eligible for a range of stewardship schemes and it is imperative that these existing approaches are maximum rather that substituted. The Eden is already a priority catchment for Catchment Sensitive Farming Initiative and the mitigation strategy should also complement/work with existing initiatives particularly local livestock programmes and Catchment Sensitive Farming Officers. There are already many funded stream of activity in the Eden and the potential to expand the partnerships through Defra, EA , CSFOs, research councils and European funding is either already in place or is being pursued. The EdenDTC is already committed to 'cleaning' up three, 2km^2 'catchments' within the DTC sub catchments. The EdenDTC should carry out the bulk of the mitigation installation and help to create the research/evidence in partnership with appropriate UK experts. 'Source' management will be part funded through existing farm advice and KE packages. However the impact of the source management approach is best supported though detailed farm balance survey and by complementary fingerprinting and tracing technologies. 'Mobilisation' will require all 'hotspots', e.g., farm standing local foul water drains and vulnerable fields, to be indentified and addressed. Examples of 'hotspot' management have already been targeted on several EdenDTC farms and example remedies will be shown. A series of interventions including new guttering, drains, ponds, lagoons and soakaways will have to be designed, built and monitored. The evidence base for strategy can be largely determined by before-after, control-impact studies. 'Delivery' management will require a landscape scale assessment of flow pathways, including edge of fields, roads, tracks, land drains, riparian areas and both small and larger scale wetlands. Advice to farmers will be available from the EdenDTC and KE team, for example good soil and tillage practise. The EdenDTC equipment and experts can thus provide the before–after, control-impact studies required to prove the cost effectiveness of this approach. Complementary to the high level of instrumentation required in the mitigated areas, there is still a need to carry out landscape scale finger printing and tracer work to look at broader improvement in pollution reduction. Together the source-mobilisation-delivery approach can supply evidence of mitigating technologies working and the degree of mitigation intervention required to 'clean up' a catchment.

THE EdenDTC AND INSTRUMENTATION

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Diffuse pollution from agricultural land poses a threat to the health of the British river networks through eutrophication and soil erosion. Defra envisage that the Water Framework Directive (WFD) objectives will be met in England through exiting schemes and initiatives, particularly through Cross compliance, the England Catchment Sensitive Farming Delivery Initiative (ECSFDI) and the Agri-environment schemes.

The Demonstration Test Catchment (DTC) project aims to evaluate the effectiveness of potential mitigation measures on diffuse pollution from agriculture areas at multiple scales. The project is jointly funded by Defra, the Environment Agency and the Welsh Assembly Government. There are three DTC's across the country; the Eden in Cumbria, the Wensum in Norfolk and Avon in Hampshire.

The approach taken by the Eden DTC has been to establish three 10km2 study catchments, chosen to reflect the different farming practises and geologies observed across the Eden. Within each of the 10km^2 focus catchments, two sub-catchments have been chosen; one control and one mitigated in which a number of existing and novel mitigation measures will be tested.

In order to achieve this, the project has purchased state of the art hydrometeorlogical logging systems. The outlets of the 10km^2 study catchments have a 'high-tech' multi-parameter station that will provide data for total P, soluble reactive P, nitrate, ammonium, temperature, conductivity, dissolved oxygen, turbidity, pH and flow. At the 2-5km^2 scale are 10 sub-stations which provide a record of turbidity and water level. All are continuously sampling at a 15 minute and are telemetered. The goal is to give an abundance of high quality, multi-scale continuous data provided in real time. Additional storm sampling will be done at all stations using ISCO automatic water samplers.

This project has adopted GPRS and meteor burst technologies as the means for telemetry. This allows for real time connection to the instruments and provides the capability for setting alarms on sensors. GPRS cameras at the catchment outlets will provide qualitative information on flow dynamics. A demonstration of the technology and data streams will be displayed alongside this poster.

The project aims to have a significant stakeholder involvement taking a bottom up approach, adopting many the principles of the Big Society. A wealth of information at a number of different scales will be gathered that will help improve the effectiveness/efficiency of schemes such as the ECSFDI. It is also hoped that many of the mitigation features will be multipurpose, having positive effects on flooding, carbon sequestration, habitat creation and biodiversity.

6 ESTABLISHING THE RIVER WENSUM DEMONSTRATION TEST CATCHMENT IN EASTERN ENGLAND

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The Demonstration Test Catchments (DTC) Programme is a UK initiative to test the hypothesis that it is possible to reduce the impact of agricultural diffuse pollution while maintaining sustainable food production via multiple on-farm mitigation measures. The River Wensum DTC has been established in an area of intensive arable farming in East Anglia, UK. The Wensum is a nationally important Chalk river habitat and is covered by Quaternary deposits. There is moderate rainfall and warm, dry summers. Under these conditions, under-drainage on clay loam and irrigation on sandy loam soils are required for arable farming of cereal and root crops.

In the first 18 months of the project, water quality sampling has adopted a nested-scale approach as well as a 'before-after-control-impact' experimental design. Monthly, catchment-wide sampling is supported by weekly, sub-catchment scale sampling in the Blackwater field experimental area. At the mini-catchment scale within the Blackwater, bankside monitoring stations have been installed that facilitate continuous 30-minute interval and event-based sampling of inorganic and organic parameters, as well as a programme of groundwater level monitoring and sampling. In-stream ecology in the Blackwater is assessed following standard Environment Agency invertebrate and fish survey methods, as well as including a survey of diatoms.

Results so far demonstrate the influence of soil type and field drainage system in affecting water quality. A marked reduction in nitrogen concentrations from 9.5 to zero mg N L^{-1} between December 2010 and June 2011 in the Swanhills -A mini-catchment (4.61 km^2 clay loam soil with surface water runoff dominant) contrasts with steadily increasing nitrogen concentrations from 6.0 to 9.0 mg N L^{-1} for the same period in the adjacent Heydon-D mini-catchment (6.62 km^2 sandy loam soil with groundwater baseflow dominant). Unlike these trends, total phosphorus (TP) concentrations are controlled by total suspended sediment (TSS) concentrations and runoff events with TP and TSS concentrations up to 1877μg L^{-1} and 407 mg L^{-1}, respectively, recorded in the Swanhills-A mini-catchment and 303 μg L^{-1} and 59 mg L^{-1}, respectively, recorded in the Heydon-D mini-catchment.

The signal of reduced nitrogen concentrations in the Swanhills -A mini-catchment is also observed at downstream monitoring points at the larger sub-catchment scale and suggests that on-farm mitigation measures such as planting cover crops and minimum tillage that restrict loss of nitrogen from soils during autumn and winter can potentially improve the water quality and ecological status of the Wensum catchment.

CEFN CONWY:
IMPROVING CATCHMENT ENVIRONMENTAL QUALITY THROUGH BETTER SOIL AND NUTRIENT MANAGEMENT

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Activities within the Conwy catchment in North Wales are of significant economic importance as they support a number of industries (agriculture, shellfish, and tourism). However, the catchment has suffered numerous outbreaks of microbial pollution and eutrophication events. 'CEFN Conwy' is an EU-funded project between the Conwy Rural Partnership and Bangor University. The objective is to support the local agricultural sector in the efficient management of on-farm nutrients, soil and vegetation so reducing the potential for diffuse pollution. Fifty farmers registered with the project, incorporating 12% of the total agricultural land in Conwy. The farm types were representative of those within the catchment (mixed beef suckler cow and sheep > sheep only > dairy only; mostly on improved grassland with a mosaic of fragmented and diverse habitats present between upland and lowland habitats which is farmed extensively). Farms received free soil testing (for P_2O_5, K_2O, MgO and pH) for two fields in return for taking part in an on-farm survey to collect data on imports and exports of all goods, manures and livestock in the year of 2009. These data and an empirical farm-gate nutrient model were used to estimate annual nutrient balances for each farm. From the soil testing, 77% of fields were below the optimum pH 6.0 for grass production; 77% of fields were either P index 2 or 3, with only 4% > index 3; 35% of fields were either K index -2 or +2, with 60% < index 2. For beef suckler cow and sheep farms, the mean farm N balance was +104 kg ha^{-1} (median +97; range +26 to +189); the mean P_2O_5 balance was +8.0 kg ha^{-1} (median +6.5; range -0.9 to +26); the mean K_2O balance was +18 kg ha^{-1} (median +15; range +0.9 to +45). The field testing results suggest that both soil acidity and available potash are limiting production in Conwy. Estimated mean nutrient balances are comparable to benchmark estimates for beef suckler cow farms. The finding highlights that eutrophication events are more likely to relate to improper timing of fertilizer and/or organic waste application, not the common misconception of over-application of nutrients.

8 THE RURAL DIFFUSE POLLUTION PLAN FOR SCOTLAND

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The Rural Diffuse Pollution Plan describes Scotland's first national strategic approach to improving water quality by reducing diffuse pollution from rural land use. A two tiered approach is being implemented, both to ensure protection and target improvements to where they are required. This involves; a national campaign of awareness raising, a targeted 'priority catchment' approach with a sequential process of evidence gathering, awareness raising, and farm visits to identify hotspots, target measures and provide one to one advice on measures.

Both voluntary and mandatory measures are being used including a statutory baseline of good practice and funding through the SRDP for measures such as water margins and arable reversion to grassland. Key to the success of the approach has been the establishment of a stakeholder group to provide governance and coordinate activities.

Evidence gathering through catchment walking of the main tributaries in priority catchments has shown widespread problems relating to basic good practice including cultivation too close to watercourses and poaching and erosion by livestock. These results raise the question of the importance of bad practice versus land use decision making. What contribution do these observed problems make to the overall loading? How far will achieving these widely accepted standards of good practice get us to achieving good status?

A monitoring framework has been developed to assess and understand the effectiveness of the plan. This includes assessing land manager awareness and behaviour change, assessing changes in land use and management, water quality monitoring, predictive modelling and costs.

This paper describes the Rural Diffuse Pollution Plan for Scotland and the monitoring put in place to assess and understand change.

DUTCH MINERALS POLICY MONITORING PROGRAMME (LMM): SET-UP OF THE MONITORING NETWORK AND COLLECTION OF FARM DATA

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This contribution describes the methodology of the Dutch Minerals Policy Monitoring Programme (LMM) and specifically the set-up of the network and the collection of farm data. LMM uses an effect monitoring approach to study the effectiveness of the EU Nitrates Directive Action Programmes in the Netherlands. It was developed to assess the contribution of nitrate from agriculture to receiving waters and the effects of changing agricultural practice on these losses. LMM monitors therefore both water quality and the farm management that might influence this quality.

The LMM programme focuses on the 4 main soil type regions in the Netherlands: sand, loess, clay and peat. In every region only the farm types that dominate soil use are included in the network. In total four different farm types are distinguished: dairy farms, arable farms, intensive husbandry farms and other farms with livestock. With this approach largely 80% of the cultivated land in the Netherlands is represented. Currently, LMM consists of approximately 450 farms per year.

LMM is a two-phase stratified sample. This implies that most of the participants are recruited from farms that already participate in the Dutch Farm Accountancy Data Network (FADN). The FADN consists of 1,500 farms, selected from the Agricultural Census through stratified random sampling and forms a representative sample of Dutch agriculture. The FADN network is a participant in the EU networks with the aim to monitor the economic performance of agricultural and horticultural firms.

Data collection in the LMM is organised through the structures of the FADN. Regional accountants collect in close cooperation with the farmers all necessary financial and technical data required to report on the economic performance. In the course of the years, this economic monitoring is extended with information on environmental and social aspects. For the LMM programme, nutrient management data like for instance fertilizer use and yields per crop, animal housing systems, manure application methods, grazing, cutting and feeding regimes are collected and reported on. With this information farm nutrient balances are calculated.

This approach enables us not only to report on the changes in water quality under Dutch farms and the related changes in nutrient management but also to make an assessment on how these changes are related to the economic farm performance.

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THE EFFECTIVENESS OF A CATCHMENT-SCALE, ECOSYSTEM MANAGEMENT APPROACH TO DELIVER WATER QUALITY IMPROVEMENTS:

A CASE STUDY OF THE NATIONAL TRUST HOLNICOTE ESTATE, EXMOOR, UK.

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The implementation of the EU Water Framework Directive has made the abatement of diffuse pollution from agriculture a critical goal. It requires Member States to restore watercourses to 'Good Ecological Condition' by 2015 and calls for catchment-wide management of water resources. However, the 'reference conditions' to which rivers should be restored are still subject of debate and there are still significant gaps in the understanding of quantitative links between chemical parameters of water quality and their effects on freshwater ecology. Monitoring of pre-work and post-work mitigation impacts is necessary to guide and inform catchment management strategies and to investigate cumulative effectiveness of various mitigation measures at a catchment scale in different local conditions.

Many studies have focussed on quantifying the effectiveness of terrestrial habitat restoration strategies on annual pollutant loss, however a new approach quantifying the frequency of pollutant concentration exceedance may be more meaningful in assessing ecological threat.

As part of a Defra catchment-scale, flood-management demonstration project, this research aims to understand the effects of terrestrial habitat restoration measures on aquatic biota and to link key physicochemical parameters (suspended sediment, DOC, TON, SRP and TC content of suspended sediment) to their biological effects using a range of macro-invertebrate indices (BMWP, ASPT, LIFE, PSI, EPT) and quantifying the spatio-temporal distribution of these variables in the landscape.

The study is undertaken in two neighbouring catchments (Aller and Horner) on the 50km^2 National Trust Holnicote Estate on Exmoor, UK. The Aller is a low-lying catchment dominated by mineral soils and intensive agriculture whilst the Horner is characterised by extensive upland semi-natural habitats on organo-mineral soils. Monitoring is ongoing to establish a baseline relationship between water quality parameters and aquatic biota. Mitigation measures, including water meadow and wet woodland restoration in the former and upland ditch management in the latter will be deployed in autumn 2011 and monitored in terms of both water quantity and quality to quantify ecologically relevant pollutant loads and exceedance frequencies before and after habitat restoration and assess the cumulative effects of mitigation measures at a catchment scale.

Initial results demonstrate that the Horner might be perceived as a 'clean' catchment, whereas the Aller suffers from significant sediment problems. This study will establish whether restoration is effective in reducing the Aller water quality problems to a level approaching the Horner, which provides a local reference of 'good ecological status'.

CASE STUDY:
THE IMPORTANCE OF SPANNING THE BOUNDARIES OF RESEARCH, POLICY AND OPERATIONAL NEEDS AT THE NATIONAL SCALE FOR MANAGING CATCHMENTS

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It is widely recognised that to improve our ability to carry out integrated and adaptive managing of catchment systems then natural and social scientists need to work together with policy makers and water managers to span the boundaries of research, policy and operational activities. There is a need for individual researchers and water managers as well as bridging organisations to span these domain divides. There are at least three dimensions to boundary spanning in this context: sectoral, spatial scale and temporal scale. It is important for catchment scientists to contribute to boundary spanning activities and here I report on two national scale case studies.

The first case study was a three year boundary spanning role that set out to increase awareness and integration of policy, operational and research efforts in catchment management and introduced a new bridging role linking policy makers with researchers at the national scale. Integrating Water and Agricultural Management (IWAM) was a coordination activity (2007-2010) for a government department in England and Wales (Department for Environment, Food and Rural Affairs). The aims of IWAM were to: 1) provide a think tank to critically assess the 'evidence base'; 2) highlight the uncertainties and gaps in our knowledge and 3) encourage interdisciplinary science, interactions between the social and natural science communities and integrated science between the science and policy communities. During this innovative role we tried and tested several approaches to boundary spanning. These ranged from science and policy driven facilitated workshops, field based knowledge exchange events, self organising science domain hubs and a web portal and blog. In this paper I will critically reflect on when and why these approaches worked and did not work in the context of IWAM.

The second case study is a newly established boundary spanning organisation for the Scottish Government: Centre of Expertise for Waters (CREW). The aims of CREW are to build networks between science, policy and practice, create new capacity to carry out leading edge research and increase the impact of Scottish science in the global knowledge economy. Core components of CREW include mechanisms to respond to policy and operational needs on short time scale (days) to longer term working groups and projects (months). An effective web presence is vital for integration along with evaluation of the boundary spanning activities.

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THE IMPORTANCE OF SPATIAL AND TEMPORAL SCALES FOR THE INTEGRATION OF A RISK BASED AND AN ECOSYSTEM APPROACH IN THE CONTEXT OF CATCHMENT SCIENCE

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There is a need to understand the linkages between biotic and abiotic processes and structures and their resultant patterns and functions at single and multiple scales and the services with regards the provision and regulation of water. At the same time regulatory risk based approaches for multiple aspects of catchment management are becoming common and allow the identification of significant risks and their control within a framework of catchment governance. To advance our understanding and managing of catchment systems across spatial and temporal scales we need to explore and test how the key concepts of a risk based and of an ecosystem approach can be integrated.

It is increasingly realised that our understanding, observations and models of the land and water components of landscapes and riverscapes need to be more integrated. Landscape ecology and catchment hydrology both deal with patterns and processes as well as their interactions and functional implications at a variety of scales. By considering both landscapes and riverscapes as hierarchical patch dynamics it is possible to construct a new approach to how we understand and manage catchment systems and the components they contain in a more integrated manner. Landscapes are increasingly being referred to as complex adaptive systems in which patterns at higher levels emerge from smaller scale local interactions. This complexity arises from abiotic constraints and disturbances interacting with interspecific and intraspecific biotic processes within a hierarchy of spatial and temporal scales. Interdisciplinary approaches with complementary perspectives are required to enable greater understanding of these complex interactions between biotic and abiotic processes and patterns occurring across temporal and spatial scales.

To advance the integration of a risk based and an ecosystem approach there is a need for a conceptual understanding linked to semantic approaches of the role of multifunctional areas in hierarchical patch dynamics of catchment systems. Here I propose a systems perspective that integrates the key concepts of scale, connectivity, thresholds and their indicators.

In addition to setting out a conceptual framework, I will report on previous studies that underpin the proposed approach including a qualitative expert assessment of the influence of forecast changes in event, seasonal and annual weather patterns on the mobilization of diffuse substances from UK model farm systems..

CATCHMENT RESEARCH:
A NEED FOR GREATER KNOWLEDGE EXCHANGE

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Significant catchment research has taken place over the last 10 years in the UK with Defra, Natural Environment Research, Engineering Sciences and Physical Research Council and the Environment Agency contributing in excess of £100m towards the cost of this research. Much of this work has identified agricultural land as a source of water, and air pollution along with soil loss. Water pollution has occurred in the form of nitrate pollution along with phosphorus, pesticides and faecal indicator organisms. This work has contributed to our understanding of behavioural traits of these pollutants in the soil-water continuum and advanced our understanding of processes in environmental and agricultural systems. More recently the research has focused on the scaling issues associated with many of these pollutants. The research has greatly improved our understanding on catchment pressures and how catchments function from the plot to field to catchment scale.

However, there is a need for greater knowledge exchange within catchment research and delivery communities. The majority of the knowledge from the research described above generally resides in academic publications or internal reports. This has limited knowledge transfer to those seeking the information. More extensive knowledge exchange between stakeholders, including policy makers, regulators and the wider lay community and the research scientists has been limited. If the research is to benefit policy making and influence consumer behaviour there needs to be much greater engagement of end-users and scientists in the process of knowledge generation and use.

While there has been some focus on the building on previous understanding this limits the capacity to move forward in our understanding. There is a considerable wealth of knowledge within the farming and land management communities that is often not utilised or engaged with. Two of the significant factors contributing to this omission are the differences in language and framing that the scientific, policy and lay communities call upon.

There is a need to determine ways that the knowledge held within the research communities, farmers and land managers can be accessed and exchanged in a manner that helps to deliver the evidence base that is needed to meet the demands of the 21st century. We propose that one way is to develop ‘communities of practice’ (COP) within catchments across the UK at the local scale linking to a national scale. While this is time consuming and resource hungry it is necessary to build such communities where true KE can take place. These COP would span both geographical scales and policy scale influencing government policy to meet the challenging pressures of the need for greater food production and the help alleviate the effects of climate change.

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DEVELOPING COMMUNICATION TOOLS FOR STAKEHOLDER ENGAGEMENT

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There is increasing recognition that local community involvement in land and water management issues (i) aids better environmental decision making, (ii) enhances social, economic and environmental benefits, and (iii) increases a sense of ownership.

Through engagement with local community stakeholders in three different catchments (The Rivers Eden, Tarland and Dyfi), we are starting a process of developing prototype visualisation tools as part of the NERC pilot Environmental Virtual Observatory (EVO), to address the specific land and water management issues identified in each area. As such, local stakeholder groups are being invited to assist the EVO's development and participate in local decision making alongside policy makers, government agencies and scientists.

Through this local collaboration, we will provide novel visualisation tools through which to communicate complex catchment science outcomes in ways that better meet end-user needs as well as facilitate a far broader participatory approach in environmental decision making. To this end a Local Landscape Visualisation Tool will be evolved across the life of the project that will reflect the needs and capabilities of a wide range of stakeholders. The tool will use the latest concepts and technologies to communicate with the public, with government agencies and scientists. This local toolkit will reside within a wider EVO platform that will include national datasets, models and state of the art cloud computer systems.

MEASURING THE MARGINAL ABATEMENT COST OF REDUCING NITROGEN POLLUTION IN AGRICULTURE

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With the deadline indentified by the Water Framework Directive (2000/60/EC) approaching in 2015 there is a rising pressure on the policymakers to introduce new regulations protecting water resources. These regulations have significant implications for Agriculture as one of the contributors to diffuse pollutants to waters. From an economic perspective, the least costly method in deciding which mitigation measures to implement is to apply the measures with the lowest Marginal Abatement Costs. This paper uses a simulation model based upon Farm Management data to produce Marginal Abatement Cost Curves for eight different policy measures to reduce nitrate leaching from agricultural land to dairy farmers in Ireland: 1) reduction of fertiliser application by 10%; 2) reduction of fertiliser application by 20%; 3) LU reduction to achieve N 170 kg/ha; 4) reduction of stocking rates by 20%; 5) utilisation of new more expansive feeds to reduce N dietary intake; 6) fencing off streams; 7) higher performing dairy breeds; 8) efficient slurry application. The study ranks the marginal abatement cost not only at the average for the country, but also allows for farm specific heterogeneity in MAC's. This paper shows that any measure introduced in command-control fashion will not yield the efficient results.

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SOIL TESTING ON IRISH FARMS

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Against the backdrop of EU legislation and the voluntary behaviour of individuals, this analysis investigates factors which promote soil testing among Irish farmers. The empirical analysis is based on data from the national farm survey (NFS) and a survey of farmers in small scale agricultural catchments. The NFS is a nationally representative survey carried out annually by the surveys department of Teagasc. The catchments survey was conducted in twelve river catchment areas where the population was split evenly between farmers within the Agricultural Catchments Programme (ACP) who have access to an intense advisory programme and a control group outside the ACP. This is the first survey of its kind in these catchments and as such will act as a benchmark for future studies. The NFS is reflective of the national position. This allows us to investigate the dynamics between and among the farming populations in relation to soil testing.

EVALUATING THE ENVIRONMENTAL AND ECONOMIC IMPACT OF TAXES ON PESTICIDES:
A CASE STUDY OF A TAX ON TOXICITY

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Regulation of pesticides has often followed a command and control approach. However, economic instruments allow for environmental goals to be used for targeting as well as provide users (farmers) with flexibility in their response. The primary environmental effects of concern from the use of plant pesticides are related to the toxic effects on non-targeted organisms in environmental media. This paper describes a methodology for ex ante evaluation of policy alternatives for reducing the impact on the aquatic environment from pesticide use.

The proposed methodology consists of several components. It uses the Pesticide Toxicity Index (PTI) for defining an environmental goal and for evaluation of the environmental effect of policy alternatives, a field based model MACRO-DB for describing the impact of crop management programs and agricultural land use on concentrations of active compounds from pesticide use and the use of economic modelling to determine the effect on farm income from alternative tax schemes.

The paper presents an application of this method using empirical data from a small agricultural catchment in Southern Sweden and compares the economic and environmental effects of a differentiated tax on the most toxic class of pesticides and a flat tax on all pesticides.

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ECOTOURISM ESTABLISHMENT BY RESTORATION AND CONSERVATION FAUNA AND FLORA IN THE RE-FLOODED DETERIORATED FARMLAND OF THE HULA WETLAND IN NORTHERN ISRAEL.

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The drainage of the 6,000 ha Hula Lake and wetland, in Northern Israel, in the late 1950's resulted in the loss of a very diverse and rare ecosystem and an important phytogeographic meeting zone for holoartic and paleotropic species and increased the nutrient flux to the Sea of Galilee, the main drinking water source of Israel.

The establishment of the 320 ha Hula Reserve in 1958, did help partial rehabilitation of the original habitats, but not the ecosystem as a whole. The aim of draining the Hula wetland to reclaim a large fertile area for cultivation was only partially successful. Oxidation, wind erosion and underground fires resulted in soil subsidence and led the authorities in 1994 to re-flood 100 ha of the valley, the Agamon, aiming at rehabilitation of the diverse wetland, ecotourism, as well as to create a clear-water body, which would contribute to the purification of the Sea of Galilee.

With regards to the Sea of Galilee, it was found that the newly created lake Agamon is being a sink of sulfate and nitrogen; however it is a source of phosphorus.

Vegetation monitoring of the restored wetland was carried out for 10 years (1997-2006) recording vascular species' establishment and abundance. Over 20 emerged, submerged and riparian species were established.

The Agamon, as a number of other, shallow-water wetlands, is characterized by considerable ecological fluctuations. This phenomenon finds expression in the prominent changes in the flora of the Agamon since its establishment. An increased abundance of Ceratophyllum demersum and Najas minor and a drop in Potamageton spp., Najas delilei and filamentary algae was observed. A long-term drop in the water level and sediment accumulation evidently brought about a significant rise in the incidence of Phragmites australis, Typha domingensis and Ludwiga stolonifera in the south-eastern area, with Potamageton nodosus, C. demersum and N. minor in local spots of higher coverage. A GIS analysis of species dominance changes, by a computerized comparison of yearly maps and a stability map showing the frequency of changes over the years, show fluctuability over the years, with only some trend of succession of P. australis, T. domingensis and L. stolonifera community.

Successful establishment of wildlife in the Agamon is an attraction to ecotourism being developed in the area, such as bird watching, hiking, biking and B&B in the surrounding villages.

ESTIMATION OF MANURING IN CATCHMENTS

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The mineral management of agriculture farms is relevant for the losses of nitrogen and phosphate to the environment. The poster illustrates the method of estimation the soil loads of minerals from agriculture for the study 'Monitoring Catchments in The Netherlands'.

For the calculation of the ground and surface water quality, input is needed on the amount of nutrients used in agriculture. For four catchments those inputs are calculated with data from: the national agriculture censes, manure transport registrations by the regulatory agency of the Dutch ministry of Agriculture, excretion coefficients per animal type, and the Dutch Farm Accountancy Data Network. All this data is input for the manure and ammonia model for policy support (MAMBO). MAMBO is a nutrient flow model for the Dutch agriculture, but it can also be used for other countries or regions. To establish this, five key processes regarding animal manure are processed in MAMBO:

- manure and mineral production on farm;
- optimization of on-farm manure with application subject to statutory and farm level constraints;
- manure excess at farm level (production minus maximum application amount);
- manure distribution between farms (spatial equilibrium model);
- soil loads with minerals.

The calculation take place at three spatial levels. The first three processes are calculated at farm level, whereas manure distribution is calculated at the level of 31 predefined manure regions, and soil loads are calculated at municipality level.

In MAMBO, the total mineral load of the soil depends on three factors: the application of on-farm manure, the application of off-farm manure and manure products, and the application of artificial mineral fertilizers. The Dutch Farm Accountancy Data network provides data and statistics available about the use of mineral fertilizers at regional and crop level. Results regarding the distribution of fertilizers contain information on the time of manure application, the effectiveness of the nutrients and the amount of nutrients in the applied manure. The results of manure transfers on regional level are disaggregating to lower levels.

The soil loads of minerals can be aggregated to different kinds of aggregation levels. For the study 'Monitoring Catchments in The Netherlands', the soil loads were aggregated to catchment levels.

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NITROGEN FERTILISER RECOMMENDATIONS THAT ACCOUNT FOR SOIL N SUPPLY:

MITIGATING N LOSSES BY IMPROVING N USE EFFICIENCY

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The Current nitrogen (N) recommendations do not account for N provided by the process of N mineralisation (N_o) in the soil. A testing procedure and decision support system that can predict N_o would help to improve the efficient use of N fertilisers on farms and thus reduce fertiliser input costs and losses of N to the environment. Biological soil testing methods have been used to successfully estimate soil N availability. However, for practical reasons a more rapid and equally dependable alternative soil N testing method is required. Chemical soil N testing methods have been in development for many years. However their success has been mixed and can often only be used in climatic conditions where they were originally developed. To date there is no proven soil N test to predict N_o in temperate grassland, which is applicable to 90% of Ireland's utilisable agricultural area.

The objectives of this study are (a) to identify the range of N_o in various productive Irish grassland soils and (b) to evaluate the potential of selected soil N tests for quantifying N_o. A total of thirty seven different grassland soils were sampled (10cm depth) from around the island of Ireland. All soils were analysed for various physical, chemical and biological properties, e.g. textural class, Morgan's P and Total C & N. A 7 day anaerobic incubation (AI-7) test was carried out on all 37 soils to determine the N_o. The rapid N tests evaluated in this study included: (1) Cold and (2) Hot (100^{o}C water bath for 4 hours) 2M KCl extractable nitrate (NO_3^--N), nitrite (NO_2^--N) and ammonium-N (NH_4^+-N); (3) Mild acid-oxidation yielding NH_4^+-N; (4) the recently developed Illinois soil N test (ISNT), measuring amino sugar & NH_4^+-N concentrations; and (5&6) Ultraviolet (UV) absorbance of 1M KCl filtered soil extract at 260nm and 210nm, respectively. The results of these tests were compared to the AI-7 values.

These 37 soils showed a large range in No from 92.17 to 723.08 mg NH_4^+-N kg^{-1}. The ISNT had the strongest relationship (R^2 0.69) with AI-7 values, followed by UV 260nm (R^2 0.38), UV 210nm (R^2 0.31) and hot 2M KCl (R^2 0.24). There was no significant relationship with acid oxidation and cold 2M KCl tests. The large range in potential soil N mineralisation indicates the need to account for the variability in No in these soils. The ISNT by itself was the best predictor of No and is being further evaluated in a microcosm and field study. These results will be discussed in further detail in the presentation.

CATCHMENT IMPLICATIONS OF SOIL HEALTH STUDIES IN INDIVIDUAL FARMS

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The Northern Rivers Catchment Authority (NRCMA) is responsible for the health of some 50,000 km^2 of lands ranging from montane area at 1500 m to estuaries opening onto subtropical waters. The region has some 8676 landholdings. These include hobby farms, dairies, grain cropping farms, extensive sheep and beef holdings, potato farms and subtropical lands producing bananas, sugarcane, coffee, avocado, macadamia nuts, sweet potato, vegetables and berries. Since 2007 the NRCMA has sponsored a series of 100 site soil health assessments each year. This paper reports on the findings and catchment implications of the study.

Each year the CMA targeted a specific geographical area or issue. For example, in 2007, farms on coastal volcanic soils were assessed. In 2010 potato farms and sheep and cattle holdings on lands above 800m were assessed. Selecting 'typical' farms is considered essential to developing a catchment based overview of health and sustainability issues. 'Natural' bushland and forests were included as 'control' sites.

Soil health analysis and risk assessment components included: ground cover %, ease of soil penetration, diversity of soil macrolife, earthworm frequency, root frequency, soil structure, plant health and vigour, slope%, ground cover % and slope length (m). Distance to drainage lines and presence of buffer lands were noted. RUSLE was used to calculate likely erosion rate (t/ha/y). Runoff Curve Numbers, total and likely dissolved P were used to estimate P loss rate (kg/ha/y).

Soil attributes measured included Field texture, Bulk density, Moisture Content, Soil pH, Soil salinity, Extractable Bray II Phosphorus, Total Carbon and Nitrogen, aggregate stability and exchangeable cations.

The results varied among the soil types, localities, landuses and field history. Intensively cultivated fields, e.g potato and sweet potato sites, had highest bulk densities, lower aggregate stability, lowest pHs and few if any soil fauna. In some soils over 60% of the CEC consisted of exchangeable Al. Liming rates of less than 0.5 t/ha/y were insufficient to counter acidification. Bray No II available P ranged from 3 mg/kg in bushland and some pastures to 900 mg/kg under macadamias that were heavily fertilised with chicken manure. Modelling indicated that the high available P created a stream contamination risk. Indicative nitrogen loss rates via erosion were up to 25 to 50 kg/ha/y from some macadamia orchards and sweet potato lands. P and N losses from pastures were minimal because of relatively low nutrient concentrations and low rates of erosion.

After the each year's results are collated, the landholders are invited to participate in seminars. The seminars concentrate on 2 to 4 'take-home' messages tailored to their specific area and enterprise. Funding for follow-up demonstration trials to address key issues can be provided by the NRCMA. The NRCMA is also interested in the potential for extending site specific data and risk models to estimate landuse impacts on individual valleys and on the entire catchment.

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VARIATIONS IN FERTILIZATION INTENSITY:

HIDDEN PROBLEMS IN NUTRIENT BALANCED AGRICULTURE

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Soil surface nutrient balances are often used as an indicator of potential nutrient losses from agricultural soil to water recipients. In Sweden, according to national statistics there was an surplus of 32 kg nitrogen (N) and only 1 kg phosphorus (P) per ha in year 2009, which is an reduction by 45 and 80 % for N and P, respectively, in comparison to year 1995. Still, in spite of these substantial reductions there is little evidence of reduced nutrient loading to inland waters and surrounding seas as eutrophication remains an important issue and agriculture continues to be major source of nutrients. Surveys on the use of fertilizers and animal manure show modest nutrient fertilization rates with an average national level of 107 kg ha^{-1} plant available N and 25 kg ha^{-1} P, where N fertilization occurs on 76 % of total arable land and the corresponding value for P is 57 %.

Nutrient losses in general and P losses in particular are often described as episodic and spatially variable. Considering the nonlinear responses of nutrient losses to nutrient inputs, episodic and spatially scattered losses are very difficult to describe and quantify by use of the large-scale average values since variations and extremes may be more important. In our study we quantified the variations of the intensity of nutrient applications. We used two sets of data, firstly the data from national-wide statistical survey on the use of fertilizers and animal manure, to cover regional and national scales, and secondly, data from the Swedish environmental monitoring program for agricultural land to cover local scale with 11 small catchments (5-33 km^2).

The results show consistently for both nutrients and at all scales that high application rates occur on a relatively small fraction of arable land, but which might have a high impact on nutrient losses. For instance, 14 % of fertilized area receives more than 170 kg ha^{-1} plant available N, whereas 5 % of fertilized area receives more than 60 kg P ha^{-1}. Analyses of fertilization and yield data and comparisons with Swedish fertility experiments and recommendations show that high N applications could not be justified by yield data, i.e. surplus fertilization was evident in relation to harvested yield. Taking into consideration these high variations in nutrient inputs may help us both to better quantify and reduce losses since some of the most cost-effective countermeasures may be hidden by seemingly low average values.

POTENTIAL OF DITCH SEDIMENTS TO POSE A PHOSPHOROUS SOURCE RISK IN AGRICULTURAL CATCHMENTS IN IRELAND

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The role of ditch bed sediments, in providing a phosphorus (P) 'source risk' i.e. sources of P which may cause eutrophication in the channel water column, particularly during small rainfall events in spring and summer, was investigated. Two ditch networks (A and B) from separate agri- catchments were the focus of investigation. Network A is situated on soils derived in-situ from slate stone and are generally acidic with low P index values. The ditch network is composed of eight perennial ditches and five ephemeral ditches. Network B is mainly situated on heavy lowland soils derived from marine clays, with mid-high P index values. The ditch network is composed of 19 perennial ditches and five ephemeral ditches. Land usage is primarily beef production at both sites. Phosphorus source risk of bed sediments (0-5 cm) was compared with that of field soils (0-5 cm) in the hydrologically connected vicinity. It was hypothesised that ditch bed sediments pose a higher P source risk than surrounding field soils as a result of deposition and accumulation of field derived P-rich particles during storm recessions.

Sediments and soils were analysed for total P (TP), bioavailable P (Mehlich3-P), water soluble P (WSP) and erosion potential (Despral test), results of which were used as a descriptor of potential source risk. An iron-oxide strip test was used specifically as a descriptor of stability and bioavailability of sediments over time after a simulated small disturbance event (typical of small rainfall events). Results were analysed in the context of other key variables which may affect source risk such as particle size, Al, Fe, Ca and organic matter content.

Initial results illustrated similar levels of WSP and Mehlich3-P (M3-P), across soils, sediments and catchments, with overall mean concentrations higher in soils (M3-P = 50.5mg/kg) than sediments (M3-P = 38mg/kg). Particle size results indicated higher clay content in network B than network A with more clay in sediments than soils in network B and more sand in sediments than soils in network A. This doesn't follow the expected trend in terms of the WSP and M3-P data. Overall, results indicate a rejection of the hypothesis. However the mean pH of the sediments in network B (6.8) was higher than all other sites and the mean M3-Ca (3345mg/kg) was twice as high as other sites thus Ca-P precipitates could be reducing the M3 and WS availability of P in these sediments. Low pH values in sediments in network A (mean = 5.7), along with substantial Al and Fe content (mean = 751, 393mg/kg respectively) may contribute to P binding in these sediments. In conclusion sediment mineralogy may serve as a buffer to decrease soluble P available for release and dispersion into water columns and receiving streams in these ditch networks.

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PHOSPHORUS CONTENT IN DRAINAGE DITCH SEDIMENTS FROM FOUR AGRICULTURAL CATCHMENTS IN SOUTHERN AND CENTRAL SWEDEN

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Drainage ditches are common elements in the agricultural landscape and serve as an important link between fields and water recipients. In our study we made phosphorus (P) characterization of ditch sediment in four small (7-33 km^2) agriculture-dominated catchments with a focus on comparisons to both soil P content in surrounding arable fields and measured long-term in-stream P concentrations at the outlet from each catchment. We found high spatial variations in both plant available and water soluble P content in ditch sediment both within and between catchments. Strong correlation was found between agronomic soil P test (P-AL) and water soluble P content in ditch sediments. Our results show P enrichment in ditch sediment in comparison to surrounding fields in three out of four investigated catchments. It appears that P is enriched in ditch sediments in catchments dominated by finer textural soil classes. A strong correlation was found between median values of plant available or water soluble P content in ditch sediment and median in-stream long-term P concentrations of both total and dissolved P at the outlet of catchments. If confirmed for further catchments, this relationship can serve as a simple and inexpensive way to identify catchments with high P losses.

CONTROLS ON THE PHOSPHORUS CONTENT OF FINE STREAM BED SEDIMENTS IN AGRICULTURAL HEADWATER CATCHMENTS AT THE LANDSCAPE-SCALE

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The concentration and forms of bed sediment phosphorus (BSP) in agricultural headwater catchments has profound implications for water quality. To date there have been no landscape-scale assessments which quantify the relative importance of both organo-mineral properties of BS (bed sediment) and associated catchment characteristics (geology, land cover and topsoil phosphorus (P) content) for BSP. In this study we applied mid infra red diffuse reflectance spectrometry (MIR-DRS) to estimate the quantities of organic matter, dithionite extractable aluminium- (Al_d) and iron (Fe_d), kaolinite, dioctohedral clay and mica (D&M) minerals in 1052 snapshot samples of fine (< 150 μm) BS. The BS were collected from small to medium-sized (5-50 km^2) agricultural headwater catchments during summer months across a large area (15 400 km^2) of central England. Analyses of the bed sediments also included accurate estimates of: i) mineral specific surface area (by BET N adsorption), ii) residual iron concentration (total Fe minus Fe_d), iii) cerium (Ce) concentrations - a rare earth indicator of apatite- or fertilser-P, and iv) average topsoil catchment P content.

Simple linear regression demonstrated that the proportion of variance in BSP explained by specific components across all catchments declined in the following order: Al_d > Fe_d > topsoil P = kaolinite = residual iron > organic matter = Ce > D&M > mineral SSA. There was significant correlation amongst them so principal components were taken prior to forming a multiple regression model (MRM) which included a classification of dominant bedrock lithology in each catchment and proportions of arable and grassland by area. The optimum regression model accounted for 61.9% of the variance in BSP including a signature from Ce content, inferred as denoting some combination of input from either naturally occurring apatite or P-fertilser. The geological classification - and four interactions with other BS predictors - was statistically significant because bedrock type partly accounts for the processes controlling the transport and delivery of P to headwater BS. Although the proportions of arable and grassland by area in each catchment were statistically significant in the MRM, the coefficients were negative for arable and positive for grassland, which was counter-intuitive. This relationship should be explored further based on a detailed examination of hydrological connectivity and sediment delivery. The principal component analysis showed that across this large region - with widely differing geology and soil types Fed in BS is more strongly associated with kaolinite than D&M minerals. This is likely due to the contemporaneous formation and association of iron-oxyhydroxides and kaolinite during pedogenesis. The SSA of fine bed sediments is largely determined by catchment area; this relationship can be fitted accurately by a power function.

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PORE WATER MOVEMENT AND QUALITY IN THE QUATERNARY DEPOSITS OF THE WENSUM DTC CATCHMENT.

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The Chalk aquifer in Norfolk is overlain and confined by a thick and complex sequence of Quaternary deposits. Pore waters from these deposits were obtained by spinning and squeezing of the sands and clays, respectively. The chemical analyses and stable isotope data of these pore waters provide information on both the processes occurring in, and age of water in, these unconsolidated deposits. It appears that the redox boundary occurs within the clays rather than at their upper surface. This has assisted the understanding of groundwater movement through the Quaternary sequence and into the principal Chalk aquifer, as well as providing information that can be fed back into geological and hydrogeological models of the Wensum DTC.

ASSESSMENT OF THE METHODS USED TO QUANTIFY FLUVIAL FINE SUSPENDED SEDIMENT TRANSFER IN THE EDEN DEMONSTRATION TEST CATCHMENT PROJECT (EDENDTC)

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In the Eden catchment, three sub-catchments were selected based on their varying geographical, geological, climatic and land-use features which were deemed representative of the wider Eden catchment. In each of these chosen areas, two 2km^2 focus catchments were selected. These focus areas, in addition to the wider 10km^2 sub-catchment are monitored at high frequency to determine the flux of fine fluvial suspended sediments. This poster presents preliminary findings of validation work for two methods which measure this flux. These are:

- McVan Analite turbidity probes housed in flow through cells, and
- Time integrated Time-Integrated Mass-flux Samplers (TIMs).

In-stream turbidity probes used are frequently used as a proxy for quantifying the flux of fine suspended sediment. However, in some environments, fouling of the optical sensor by micro-organisms and larger debris may act to corrupt the flux record. In response, this research uses flow-through cells that have been designed to allow turbidity measurements to be made away from debris. However, given that the water-sediment mix is pumped out of the river using a non-isokinetic pumping system, potential bias maybe introduced into the measurements, especially where particles greater than 63Qm are present. Comparisons between in-stream and out-of-stream turbidity measurements are therefore important in order to assess the methods' validity. The second method is a novel technique which is suited to characterising the spatial patterns of fine suspended sediment transfer in small catchments. Time-Integrated Mass-flux Samplers (TIMs) are able to trap a mass of suspended material which is proportional to the ambient sediment flux. These cheap devices afford a time-integrated approach which can be applied widely throughout river catchments to highlight areas of high suspended sediment transfer; however they are largely untested in upland environments.

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PORE WATER MOVEMENT AND QUALITY IN THE QUATERNARY DEPOSITS OF THE WENSUM DTC CATCHMENT.

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Global agricultural soil erosion rates are estimated at 22 ± 6 Pg yr^{-1} for croplands and 11 ± 3 Pg yr^{-1} on pasture lands. With agricultural river basin sediment delivery ratios typically at 10-20%, the environmental and socioeconomic consequences of sediment transfer from agricultural land to downstream aquatic ecosystems are a major concern, adding to anticipated 21st Century climate change threats to food and water security. Reliable information on sediment sources is critical if mitigation measures are to be targeted effectively but existing geochemical sediment tracing tools cannot discriminate soil derived from specific crop types, a major shortcoming in the above context.

Here we demonstrate the application of a new biomarker approach to trace problem sediment back to crop-specific source areas in agricultural river basins. Data from a mixed landuse agricultural catchment show that the carbon (C) Compound Specific Stable Isotope (CSSI) signatures of particle-reactive fatty acids, leached from vegetation and attached to mineral soil particles, label surface agricultural soil with crop-specific signatures thus permitting sediment eroded from each land cover to be tracked downstream.

High resolution sediment sampling during a storm event and analysis for CSSI and geochemical fingerprints elucidated temporal patterns in erosion under different crop regimes and the specific contribution that each crop type makes to downstream sediment load. These data match runoff and erosion response predictions, based on soil hydrological characteristics, which indicate rapid runoff generation from pasture. Comparison of biomarker and geochemical fingerprinting data indicates that the latter overestimates cultivated land inputs to catchment sediment yield due to inability to discriminate ley pasture (in rotation) from cultivated land. This difference however presents an opportunity since combination of the two datasets reveals the extremely localised nature of erosion from permanent pasture fields in this system. The combined use of CSSI and geochemical tracers elucidated important details about sediment source dynamics that could not have been derived from each method alone.

Information provided by the biomarker tracing approach could prove critical for supporting soil resource management policies and inform sediment risk assessment for the protection of aquatic habitats and water resources.

SEDIMENT PROVENANCE AND DYNAMICS IN IRISH CATCHMENTS

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Within agricultural catchments a small proportion of the total area often contributes the majority of the sediment and phosphorus load. Such critical source areas (CSAs) occur where zones of high contaminant loading coincide with hydrological connectivity to a waterbody.

With the aim of supporting the implementation of the European Water Framework Directive (WFD), work has been carried out in order to identify CSAs of sediment and associated phosphorus in two mini-catchments in Co. Down (5.5km^2) and Co. Louth (15km^2). Catchments have similar soils (till) and hydrogeology (poorly productive greywacke) but contrasting ecological status. Land use within both catchments is predominantly intensive grassland, with some cultivated land and forestry. Geochemical fingerprinting techniques have been applied to suspended sediment, bed sediment, and potential source materials within the catchments. This is complemented by continuous monitoring of turbidity, calibrated for suspended sediment in order to give sediment yields and quantify in-storm sediment transfers. To spatially delineate CSAs, improved soil hydrological data from high resolution soil moisture and field connectivity mapping is compared to known sediment contributions from each source.

Early results show differences in sediment storage regimes with the upper and lower reaches of the Co. Louth Catchment having mean storage rates of 0.25 kg m^{-2} and 0.43 kg m^{-2} , respectively, with Co. Down mean storage rates of 0.79 kg m^{-2} . Continuous monitoring of suspended sediment has shown a dominance of in-storm transfers with minimal export in low flows. Mean Olsen-P content of the mobile fraction '(<63μm)' for sources in Co. Down were found to be 17.4 mg kg^{-1}, 35 mg kg^{-1}, 39 mg kg^{-1} 42.3 mg kg^{-1}, for woodland, cultivated land, pasture, and channel bank sources, respectively, highlighting the importance of channel bank sediment as a potential PP source.

To sustain ecological status, in good and high status catchments, sources of sediment need to be identified and abated. Tracing of sediments offers an opportunity to identify sources of sediment to effectively target supplementary measures. This work contributes to an EPA-STRIVE funded project led by QUB with UCD and TCD for the development of a catchment management tool for Ireland which aims to quantify contaminant transport, attenuation rates and ecological responses.

30 VARIABLE SOURCE AREA HYDROLOGY AND SEDIMENT AND PHOSPHORUS TRANSFERS

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Current knowledge of the generation of surface runoff recognizes the spatial variation at the field scale. Such temporally and spatially dynamic contributing areas are a result of variable source area hydrology where areas expand and contract in response to rainfall.

With the aim of furthering the understanding of connectivity and improving the reliability of model assumptions for predicting contributing areas in Irish catchments, a mechanistic study of the relationship between runoff, soil moisture, rainfall, and water quality from a 0.2 ha field plot is being carried out.

Soil moisture is being monitored at 30 min intervals at six locations along a drumlin grassland hillslope. A network of 30 surface runoff detectors are also installed, each consisting of a field weir and runoff sensors logging every 5 minutes. Rainfall is monitored on a 5 minute basis using a tipping bucket rain gauge and surface runoff recorded at 5 minute intervals through a 6" v-notch weir using an ISCO automatic sampler and bubbler flow module.

Early results show that surface runoff is spatially limited within the site and varies with rainfall. However, a poor correlation was found between volume of discharge and runoff generating area (R^2 (R^2 = 0.2), with rainfall intensity (mm hr^{-1}) found to be the best predictor (R^2 = 0.66). From observation, surface depressions tended to store surface runoff until storage capacity had been reached, which may explain the low R^2 values.

Rates of expansion to peak contributing area size (average 20m^2) varied considerably, from 0.57$m^{2\ -1}$ to 0.16$m^{2\ -1}$ decreased with expanding and contracting runoff areas. In addition to continued monitoring of surface runoff events, further work is currently being completed mapping the micro-topography of the site and spatial variation in soil compaction.

A greater understanding of the influence of variable source area dynamics during storms will assist with the identification of critical source areas of phosphorus and sediment at the catchment scale and guide the implementation of targeted measures. This study contributes to a larger EPA-STRIVE funded project led by QUB with UCD and TCD for the development of a catchment management tool for Ireland, which aims to quantify contaminant transport, attenuation rates and ecological responses.

NUTRIENT AND SEDIMENT TRANSPORT REGIMES IN THE RIVER EDEN AND THE IMPLICATION OF MANAGEMENT USING RUNOFF ATTENUATION FEATURES

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Despite good farming practises incidental runoff from agricultural land can still contain significant concentrations of pollutants, particularly nutrients (phosphorus - P and nitrate - N) and suspended sediment - SS. The predominantly rural upper Eden catchment in Cumbria, northwest England, is being monitored in a multi-scaled, nested experiment to identify parts of the landscape that contribute Diffuse Water Pollution from Agriculture (DWPA) by measuring P, N and SS losses in the river network. Results have been analysed spatially and temporally, with a focus on storm events and high flows, and it is believed that the majority of polluted runoff is delivered via a relatively low number of flow pathways. It is therefore hypothesised that by targeting these distributed point sources and 'engineering' catchments, it is possible to mitigate the impacts of DWPA without compromising agricultural productivity.

Runoff Attenuation Features (RAFs) are examples of catchment engineering measures, which include ponds, wetlands, sediment traps, filters, etc. They are designed to intercept polluted flow pathways in order to slow, store and filter runoff. A number of RAFs have been designed and constructed and their ability to trap SS and remove P and N are currently being monitored, with a focus on storm events, to determine their efficacy. Previous work has shown that P-rich fine sediment is difficult to remove from runoff when relying on settlement alone. In response to this a filter feature, comprising wood-chip filled gabions is also being trialled.

Any catchment modifications must integrate with everyday farming practises as well as protect, or even enhance, the freshwater environment; thus satisfying the needs of the Water Framework Directive. The impacts of climate change and the potential need to increase food production in the UK could exacerbate freshwater pollution problems thus enhancing the need to develop an appropriate DWPA mitigation strategy.

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DEVELOPMENT OF A TECHNIQUE TO MODEL THE VOLUME OF SEDIMENT GENERATED BY BANK EROSION PROCESSES WITHIN UK CATCHMENTS.

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Increased sediment loads within river catchments have well-documented detrimental effects including an increase in turbidity, causing reduction in the depth of the photic zone and decreased primary and secondary productivity. Sediments are also a key vector for the transport of nutrients, trace and heavy metals and a range of additional harmful substances. The delivery of sediment and associated nutrients and contaminants to rivers therefore has important implications for river ecosystem health and the supply of potable water.

In response to the EU Water Framework Directive (WFD), River Basin Management Plans have been developed which seek to tackle issues associated with diffuse pollution, including sediment. Additionally, the England Catchment Sensitive Farming Delivery Initiative (ECSFDI) aims to reduce diffuse water pollution from agriculture. In order to inform the revisions to policy-driven management plans and advice programmes, modelling is required to predict expected sediment pressures under future climate, land-use and catchment management scenarios. Several studies have noted the significance of river bank erosion as a sediment source within UK catchments. Therefore, to enable improved accuracy in predictions of future sediment pressures under environmental change, greater accuracy is required in modelling rates of sediment production due to the bank erosion component of the catchment sediment budget.

In this study, a prototype national bank erosion index has been refined as part of a wider study modelling the response of sediment budgets to climate and land use change scenarios. Channel bank lines within ECSFDI priority catchments were digitised in GIS from historical Ordnance Survey data. These lines were then overlayed to calculate channel migration rates and from this comparison, the volume of eroded sediment due to bank erosion was estimated. Relationships between volume of eroded sediment and factors controlling the rates of channel migration were investigated, including channel sinuosity, slope, upstream catchment area, and restriction of migration due to valley width. Significant correlations between bank erosion and sinuosity, upstream area and channel confinement were observed.

TOWARDS RELIABLE PORTABLE MONITORS FOR OVERLAND FLOW

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Overland flow (OLF) is the major pathway to transport phosphorus (P) from farmland to surface water. It is difficult to gather the detailed information regarding OLF and the P concentration which is only available for a few locations. There is a need for mobile inexpensive equipment that can be used in numbers adequate to gather useful information in fields, farms and catchments around Ireland. Work on a small, OLF measuring, instrument is ongoing. The field instrument recording the duration of OLF was previously reported (Ryan, 2004). The object of the work reported in this paper is to develop a model to calculate accurately overland flow volume from the field data. A third aspect of the work will focus on the capture of a representative OLF sample in the field instrument.

Overland flow was recorded at three tillage plots at Oak Park in the period 2005 – 2007. An earlier trial was conducted on a grassland plot at Oak Park in 1998. Data from these trials were analysed to identify the duration of each overland flow event in November and December in each case. For each event time, 24 hours rainfall was added at the start to allow for the time it takes soil to become saturated. The OLF and rain data were found to be skewed so a log transform was used to generate a normalised data set. Four variables in log transform were input to a multiple regression function in Microsoft Excel.

An equation (Eq. 1) was obtained for each plot. The Multiple R^2 value for each plot is given in Table 1.

$OLF = Rain^a \times Time^b \times Area^c$

Table 1. Performance of the model

Plot	Area (ha)	Multiple R square (R^2)
Tillage 1	0.7	0.85
Tillage 2	1.0	0.85
Tillage 3	1.0	0.80
Grass	0.48	0.91
Multi 3[1]	2.48	0.92
Multi 3 Vs Tillage 3	-	0.81

1. Multi 3 consists of; Tiillage1, Tillage 2 and Grass combined

The values for multiple R^2 indicate a good model. They approach the accuracy of a typical vee-notch flow-meter for OLF which achieves an accuracy of approximately +/- 10%. Combining data from 3 sites in the Multi 3 version and using this to predict flow at an independent site Tillage 3 gave an acceptable result (R^2 = 0.81). The model offers a good prospect of generating reliable values for OLF and the deployment of low cost mobile equipment on wide-spread investigations.

Reference

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34 EFFECT OF SOIL MANAGEMENT ON SOIL AND PHOSPHORUS LOSSES AT THE CATCHMENT SCALE IN NORWAY

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Surface soil erosion is an important process for phosphorus (P) losses from agricultural areas in Norway. A number of soil management methods were shown to reduce soil and nutrient losses compared to the conventional autumn ploughing. These, so called, reduced tillage methods include among others direct drilling (no-till), shallow autumn cultivation and spring tillage. In this study, the implementation of reduced tillage at the field scale was evaluated for the effect at the catchment scale.

As part of the Norwegian Agricultural Environmental Monitoring Programme (JOVA), runoff from the Mørdre catchment has been monitored during the period 1991-2011. The Mørdre catchment is situated on marine deposits in south-east Norway, 50 km north of Oslo. The database consisted of long term (1991-2010) monitoring data from a catchment (680 ha) dominated by agricultural land use (61 %). Measurements consisted of discharge measurement, water quality analysis and a yearly survey on agricultural practice within the catchment. At the outlet of the catchment, discharge measurements were carried out in a cross-section of the stream by measuring the flow depth with a pressure transducer. Data loggers recorded flow data with a timestep of 1 hour. The cross-section in the stream was a Crump weir. Discharge proportional composite water samples were analysed for suspended sediments (SS) and plant nutrients. In addition, a turbidity-sensor was installed in 2008.

Results from the survey on soil management showed a dramatic reduction in autumn ploughing, an increase in spring ploughing and an increase in autumn harrowing during the two decades of monitoring. However, reduced tillage was not targeted to high risk areas.

Monitoring in the Mørdre stream during the same period showed increased concentrations of SS and increased losses of SS and P. Runoff and temperature have also increased, though not significantly, during the monitoring period.

To conclude, the soil management effect measured for medium to high risk areas in field lysimeters was not registered at the catchment scale in Mørdre. At the catchment scale, other sources of sediments, variations in weather and non-targeted implementation of reduced tillage may mask the effect of mitigation methods. Changes in climate and other changes in agricultural practices may be more important for soil losses than the actual methods meant to control erosion and nutrient losses.

DECREASING NITRATE LEACHING IN THE SANDY REGION OF THE NETHERLANDS DURING THE 1992-2009 PERIOD:

THE INFLUENCE OF THE DUTCH AGRICULTURAL MINERALS POLICY

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Only small areas in the Netherlands are recognized as individual catchments. Maybe this lack of catchments with distinguishable water divides has resulted in a tradition to sample the uppermost groundwater randomly in order to show effects of agricultural management on water quality. This tradition goes back to the beginning of the seventies of the previous century. The sampling is carried out manually within agricultural fields. In most parts of the Netherlands groundwater can be found within 2.5 m.

Since the beginning of the fifties of the previous century, agricultural nitrogen use increased until about 1985. After 1985 there are two periods during which there is a decrease, caused by implementation of the Dutch agricultural minerals policy. In 1991 the Dutch government ordered to monitor the environmental effects of its minerals policy. The aim of the Dutch minerals policy is to reduce the concentration of nitrate in groundwater to less than 50 milligram per litre. Therefore, in 1992, the Minerals Policy Monitoring Programme (LMM) became active.

In 1992 the uppermost groundwater was sampled in the sandy region at about 100 farms, comprising four different types (dairy, cattle, factory and arable). In later years the number of farms monitored and the number of farms monitored per farm type varied. It was decided to monitor nitrate concentrations because nitrate is the best indicator of changes in agricultural practices in groundwater in the sandy region. The sandy region is the most important agricultural region and soils in the sandy region are more vulnerable for leaching than soils in other regions.

Nitrate concentrations in the uppermost groundwater of farms in the sandy region of the Netherlands have decreased by more than 50%, from 150 to 65 milligram per liter, between 1992 and 2009. The nitrogen surplus has dropped by 50% during this same period. These reductions can be attributed to implementation of the Dutch agricultural minerals policy, which has led to a decrease in the use of artificial fertiliser and manure. The greater decrease in the nitrate concentration relative to the nitrogen surplus is likely due to a decrease of forage grazing by cows. More nitrate is leached directly from cow dung left in the pasture than when it is collected and later dispersed over the fields more evenly.

In addition to the minerals policy, variations in the annual precipitation excess and annual changes in the composition of the type of farms being monitored have also influenced the changes in the measured mean nitrate concentration in the sandy regions, as have annual changes in the total surface area used by the different farm types. A statistical technique, residual maximum likelihood, is used to estimate annual mean nitrate concentrations for the sandy region, which are indexed for these annoying influences, with measured values from individual farms.

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MONITORING THE EFFECTS OF LAND USE AND AGRICULTURAL INTENSITY ON NUTRIENT FLUXES IN LOWLAND SUBTROPICAL STREAMS (URUGUAY)

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Land use is becoming more intensive in recent years and it is expected to become even more intensive in the future, due to stronger demands for agricultural production and changes in production modes. In Uruguay, the intensification of agriculture can be recorded based on the consumption of chemical fertilizers, which shows a sharp increase from 100,000 tonnes in the year 2000 to 780,000 tonnes in 2010. In spring 2009, we established two fully equipped monitoring stations in two micro-catchments in Uruguay with different intensity in their land use, to monitor the effects of land use and agricultural intensity on nutrient fluxes in subtropical streams. For this, we conduct high frequency measurements in the two lowland streams with underwater probes (turbidity, pH, conductivity and oxygen measured every 15 minutes), fortnight grab sampling of water and automatic sampling fortnightly of composite water samples for nutrient analysis (total and dissolved nitrogen and phosphorus and organic matter; sampled every four hours). Moreover, water level and meteorological information is recorded every 10 minutes and periodic flow measurements are taken to calculate instantaneous discharge from continuous records of water level (stage-discharge relationships). In accordance with our expectations, significant differences in nutrient concentrations and fluxes are being found, with highest nutrient exports from the catchment with the most intensive agricultural production. The significance of changes in land use and intensification in agricultural production, in particular under subtropical climates, is discussed.

VISUALISING LAND AND WATER MANAGEMENT ISSUES:
LONG TERM MONITORING OF NUTRIENT LOSSES FROM NORWEGIAN MICRO-CATCHMENTS

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Starting in 1992, the Norwegian Agricultural Environmental Program (JOVA) monitors and reports erosion and nutrient losses from small agricultural catchments at nine locations. The locations are geographically distributed from Bodø in the North to Grimstad in the South. There are five locations in the mid- and Eastern part of the country, and two in the Western part. The locations represent typical agricultural systems in Norway such as cereals, grassland and vegetables. Detailed information about agricultural practices is collected yearly from farmers at seven of the locations. These data show average nutrient application rates of 90-350 kg/ha for nitrogen and 15-69 kg/ha for phosphorus.

Each location has a monitoring station equipped to measure water discharge and to take water-samples automatically. The water-sampling is discharge proportional and approximately 24 samples are taken from each location every year. Total runoff from the individual catchment is calculated at a yearly basis corresponding to the agrohydrological year (May – April). The water samples are analyzed for nitrogen (N), phosphorus (P), pH and suspended solids (SS). Soil and nutrient loss from runoff during the agrohydrological year are then calculated.

There is a large variability in the loss between catchments, mainly due to different weather and topographical conditions, soil properties and different agricultural practice. There is also a large annual variation for each catchment, due to varying temperature, precipitation and winter conditions. The average soil loss for the catchments during the monitoring period ranges from 46 – 1630 kg/ha/year. The highest soil loss which has been registered is 4500 kg/ha/year. The average loss of phosphorus (TP) ranges from 0.2 – 5.1 kg/ha/year, highest being 18.9 kg/ha/year. The maximum levels of soil and phosphorus loss occurred in 2000-2001 at the location in Grimstad. This catchment is dominated by vegetable cultivation. The average yearly loss of nitrogen (TN) ranges from 10 – 70 kg/ha. In general, the data show a close correlation between runoff and loss of both soil and nutrients.

The monitoring program is producing a large amount of data which is widely used, i.e. in research projects and in calibration and validation of models for the simulation of nutrient and soil loss. The program may also become an important contributor in studies related to climate change effects.

Soil and nutrient losses are a result of complex processes that show great variation in time and space. Long term monitoring combined with modelling may contribute to increased understanding of the effect of agricultural management on soil and nutrient losses, and hence increase the potential for minimizing these losses.

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SPATIAL VARIABILITY OF PHOSPHORUS CONCENTRATION AMONG AGRICULTURAL HEADWATERS WITHIN CZECH REPUBLIC

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In solving the question of actual impact of non-point sources on aquatic ecosystems (mostly reservoirs in Czech Republic), we face up to several dimensions of phosphorus (P) emission, which are not satisfactorily quantified: magnitude, timing and availability. But all three are crucial in respect to development of any algal community. Moreover, before we settle somewhere with our sampling equipment to measure above mentioned dimensions, we should know about representativeness of selected profile to exclude future problem with up-scaling. To understand spatial variability in macro-scale we underwent whole-country screening during summer baseflow condition, because: i) highest P concentration during summer is expected, ii) summer is the season when highest abundance of phytoplankton (also cyanobacteria blooms) does occur and iii) P emitted during quiet period is most prone to uptake. In result and with respect to Czech agricultural context we focus mostly on non-erosional P flowing out from arable land. Yes, we anticipate baseflow as the only comparable modus operandi in large scale.

Screening of nearly two hundreds of exclusively agricultural headwaters (A_{mean} = 2 km^2) proceeded during 24 sampling days from May to August 2006. Profiles were selected proportionally to 11 dominant soil groups, with arable land as a prevailing land-use. We analysed 158 one-shot samples. Antecedent Precipitation Index based on meteorological radar measurement was used to indicate samples from falling limb of hydrograph. Soil test P (Mehlich 3) and arable land extension have return only weak correlation with cP in streams. Best predictor is soil type, finally. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) in major soil groups (Cambisols, Chernozems, dystric Planosols and orthic Luvisols) were lower than mean of 0.069 and 0.038 mg/L, respectively. Eutric Fluvisols, albic and albo-gleick Luvisols frequently far exceeded global median of SRP concentrations of 0.024 mg/L. Although they cover less than 10% of Czech arable land they could be important source of bioavailable P at least during summer baseflow. Our results enable us to estimate lower limit of bioavailable P exported from unobserved agricultural land to any reservoir.

INVESTIGATION OF BACTERIAL PATHOGEN SOURCES AND TRANSFER HYDRODYNAMICS IN RURAL CATCHMENTS.

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In Ireland, bacterial pathogens from continual point source pollution and intermittent pollution from diffuse sources can impact both drinking water supplies and recreational waters. This poses a severe public health threat. Observing and establishing the source of faecal pollution is crucial for the protection of water quality and human health. Conventional culture methods, using faecal indicator bacteria, to detect such pollution have been extensively utilised but do not determine the source of pollution. Microbial source tracking, an important emerging molecular tool, is now being applied to identify host-specific markers in faecally contaminated waters.

The aim of this study is to target ruminant and human-specific faecal Bacteroidales and Bacteroides 16S rRNA genes within rural river catchments in Ireland and investigate hydrological transfer dependencies. Large (5-20L) untreated water samples were collected from two catchment sites, Cregduff, Co. Mayo and Dunleer, Co. Louth, during storm and non-storm periods. Samples were filtered through 0.2μm nitrocellulose filters to concentrate bacterial cells which then underwent chemical extraction of total nucleic acids. Animal and human stool samples were also collected from the catchments to determine assay sensitivity and specificity following nucleic acid extraction. Aquifer response to seasonal +<+4: 9 9 99+99+(3 54/: 58/)452/,583 4)525/));88+4+;9/4: + 52/8+ ; 4: /8 99: +3 in conjunction with chemical and hydrological parameters. Host specific primers BacCow-UCD, BacHum-UCD BacUni-UCD and BoBac were then assayed against both faecal and water extracts. As anticipated, the universal primer (BacUni-UCD) detected Bacteroidales in all faecal samples while ruminant primers (BacCow-UCD and BoBac) detected Bacteroidales and Bacteroides in bovine and ovis faecal samples. BacUni-UCD and BacCow-UCD detected faecal contamination in three of the four sample sites in Dunleer.

The microbial source tracking techniques and hydrodynamic model that will be designed by this project will be of vital importance for water quality control in Ireland.

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FROM CATCHMENT TO COAST: THE ACTIVITY OF E. COLI O157: H7 IN WATERCOURSES IS AFFECTED BY LAND-USE

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Rapid transfer of potentially infective E. coli O157:H7 to watercourses may occur during periods of high rainfall due to overland flow and sub-surface carriage from soil or animal waste. In addition to causing human infections, contamination of water sources may also be important in the cycle of reinfection of livestock. The objective of this study was to understand the activity of E. coli O157:H7 in freshwater environments associated with various land uses (e.g. mountains, heathlands, forest, farmland, and estuary). Water samples collected from areas of different land-use throughout the Conwy catchment (North Wales, UK) were used to generate mesocosms, which were then inoculated with a lux-marked strain of E. coli O157:H7 and incubated at 4 °C in diffuse light. Samples were also characterised in terms of their physicochemical properties. The activity of bioluminescent E. coli O157:H7 cells was measured over 7 days using a luminometer and calculated as relative light units (RLU). Initial activity was high with a significant difference in the mesocosms representing areas of different land-use; however, by 7 days the activity had declined in all of the mesocosms and there was no difference between any of the samples.

After 7 days a nutrient solution was added to all of the mesocosms, which resulted in a rapid increase in activity in all samples; however, the intensity and duration of this increase was significantly different between the land-use types. Clearly, water chemistry and the indigenous microflora associated with water from different catchment types are fundamental to the level of E. coli O157:H7 activity. These findings highlight the importance of catchment land-use on the persistence and infectivity of E. coli O157:H7 in the aquatic environment and have important implications for human health and livestock exposure, as activity is a more important indicator of infectivity than cell number alone.

PHYTOBENTHOS AS A MEASURE OF UPLAND STREAM PRODUCTIVITY IN THE RIVER EDEN DEMONSTRATION TEST CATCHMENT

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Headwater streams, being relatively understudied, provide opportunities for investigation into the high frequency responses of biotic communities to changes in water chemistry and flow events. This scale of analysis is important for enhanced understanding of stream ecology and the development of mitigation strategies to address system perturbation. This study focuses on the development of benthic biofilm productivity measures at high spatial resolution and applicable over a range of temporal scales. It uses the catchment of the River Eden, Cumbria, UK, a Demonstration Test Catchment (www.edendtc.org.uk). The research addresses the spatial and temporal variability of headwater benthic diatom communities in terms of both their structure and function, and the chemical and biological parameters influencing this variability. Emphasis is placed on developing benthic diatom communities as an indicator of system integrity based on to their sensitivity to a range of water quality measures.

Here we present preliminary data concerning the structural attributes of benthic biofilms, including community composition and benthic chlorophyll a. We employ a novel technique to assess productivity using a portable field fluorometer: the BenthoTorch. The study focuses on three sub-catchments of the Eden and, in each the heterogeneity of benthic productivity at the reach scale is assessed. The overarching aim is to develop a new biological monitoring method for headwater systems suitable for monitoring stream systems and their response to multiple environmental pressures. By advancing understanding of the role of benthic biofilms as measures of productivity in stream environments, this study demonstrates the value of high frequency routine monitoring and, based on sound ecological principles, has the follow-on objective of refining the current monitoring programmes used for UK river systems. This is important as, with increasing demands for the results of mitigation strategies to be readily assessable by a much wider audience, more informative, representative and reliable assessments of ecological status and water quality evaluation for upland steams is needed.

42 PESTICIDE LEACHING TO GROUNDWATER IN AN AGRICULTURAL CATCHMENT

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Several locations in Ireland have been investigated to attempt to explain pesticide occurrence in groundwater. This paper focuses on two of these sites, both on hillslopes within an arable river catchment in County Wexford, Ireland. For decades the land use at both sites has been spring barley production with associated pesticide applications. The soil at both sites is acid brown earth with parent material of glacial till derived from Lower Paleozoic sandstones and shales. The bedrock is Ordovician metasediments which is classed as a locally important aquifer, moderately productive in local zones with a transmissivity of c.20m^2/day through fractures. At each site three multilevel monitoring wells were installed along a transect downslope. Each well contains three piezometers screening the shallow and deep transition zone between subsoil and underlying bedrock, and deep bedrock.

Monthly samples of groundwater were collected between March 2010 and January 2011 using a low-flow purging method to prevent sediment ingress. At both sites, the most frequently detected pesticides were both transformation products: 2,6-dichlorobenzoic acid (DBA), a transformation product of dichlobenil and dichlorobenzamide (BAM); and phenoxyacetic acid, a transformation product of acidic herbicides. Only transformation products exceeded the drinking water standard (Council Directive 98/83/EC) statutory limit of 0.1ng/ml. Other compounds present at both sites in detectable quantities below the drinking water standard were mecoprop, mecoprop-p, MCPA and bentazone. In addition to these at site 2 triclopyr, 2,4-D, dicamba and pentachlorophenol were observed. Pentachlorophenol is a priority compound listed in Annex II of the Drinking Water Directive (98/83/EC) and was detected only once at site 2 in March 2010. At the midslope borehole at site 1 water is recharging whereas in the near-stream borehole at site 2 water is typically discharging i.e. there is less of a downward gradient between the strata. At the midslope borehole in site 1 vertical movement from the deep transition zone (c.15m b.g.l) to deep groundwater (c.40m b.g.l) may explain why mecoprop was present in the deep transition zone (0.007 ng/ml) yet in the deep bedrock mecoprop (0.0056 ng/ml) and its transformation product phenoxyacetic acid were found (0.4914 ng/ml). At the lower near-stream borehole in site 2 more mecoprop is present in the shallow transition zone (0.0186 ng/ml) in comparison to the deep transition zone (0.0062 ng/ml). Mecoprop is highly soluble in water (250,000mg/L) and mobile (K_{OC} 31 ml/g) making it leachable (Footprint PPDB). The upwelling of water at the near stream borehole at site 2 may be preventing mecoprop from leaching to deeper strata as is occurring at the recharge zone. This may cause less of a risk from pesticides for deep potable groundwater in the near-stream zone, but more of a risk for surface water and associated stream ecology.

CONTROLS ON PESTICIDE LOSS TO WATER IN UK CATCHMENTS.

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This project explored the significance of a number of catchment characteristics for prediction of the annual average concentration of individual pesticides and the probability of an individual sample of stream water containing a pesticide concentration in excess of '0.1 μg/l.' The characteristics influencing the combined annual average concentration of all pesticides was also investigated, as was the probability of a stream water sample exceeding 0.5 μg/l. Nine pesticides were identified for analysis where the water quality records showed frequent detection.

Generalised linear models were used throughout the analysis. In the case of the annual average concentration models, a log-normal distribution of the data was assumed whilst the probability of exceedance models assumed a binomial distribution. Co-variance between independent variables in all models was identified by use of the Cor.prob function (Venables, 2000) running within the R software environment (http://r-project.org/). When co-variance was identified, the variable that co-varied most closely with the dependent variable was retained. Once complete; a full model was developed and a forwards-backwards selection process undertaken, with a significance level of $p > 0.05$, to determine a minimum adequate model.

The results indicated that the annual average concentrations of individual pesticides were influenced by a variety of factors with the most commonly selected variables being those related to the area of crops grown. In the case of individual pesticides this was the crops to which the pesticide was most commonly applied, whilst in the case of total pesticide load it was the combined area of all arable crops. The proportion of free-draining soil types present in the catchment was also shown to be significant in a number of models. These models explained between 50 and 85 percent of variation in the data. The results obtained from modelling the probability of an exceedance occurring showed that the significant variables for both individual pesticides and combined pesticides varied, but that overall rainfall and crop growth patterns, as well as the ease with which a soil drained were important factors. These models explained between 29 and 82 percent of variation in the data.

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A COMPARISON OF THE STRATIFICATION OF NITROGEN IN GROUNDWATER IN CATCHMENTS UNDERLAIN BY A PRODUCTIVE AND POORLY PRODUCTIVE AQUIFER

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Catchment scale water quality models developed for diffuse nutrients routinely treat groundwater as a single lumped parameter and do not consider depth-specific groundwater transport/attenuation in different catchment types. The EPA STRIVE-funded Pathways Project (involving QUB, UCD and TCD) has taken account of the need for models to consider groundwater stratification by investigating variations in nitrate concentration with depth in a regionally productive aquifer (Carboniferous karstic limestone catchment in Co. Kilkenny) and a poorly productive aquifer (Silurian greywacke in Co. Down). Both catchments have comparable landuse, comprising of intensive pasture and arable land.

Investigations into groundwater stratification in both catchments involved pumping tests and artificial tracer tests to identify hydraulically active fractures, as well as depth-specific low flow groundwater sampling in borehole clusters to assess chemical variations. Surface water and groundwater were analysed for nitrate and major ions.

In the karst limestone catchment, springs contributed the vast majority of stream baseflow and exhibited a similar natural hydrochemical signature and nitrate concentration (25 ± 1.3 mg/l NO_3) as groundwater sampled below 35 mbgl (20 ± 3.8 mg/l NO_3). In contrast, nitrate concentrations in shallow bedrock adjacent to the river are lower (0.5 ± 0.4 mg/l NO_3). Hydrochemical data (NO_2 and dissolved oxygen) suggest different fate and transport mechanisms operating along the shallow and deep groundwater pathways. In the lower permeability greywacke catchment, stream baseflow nitrate concentrations (9.0 ± 3.0 mg/l NO_3) were lower than in the karst. Although nitrate levels up to 13.0 mg/l NO_3 were detected in the weathered shallow bedrock, maximum concentrations of 3 mg/l NO_3 were found in the competent bedrock suggesting that the shallow groundwater is the dominant nitrate pathway during baseflow conditions. Attenuation processes may be responsible for decreasing nitrate concentrations with depth, however low transmissivity values determined from pumping tests (0.02 to 0.2 m^2/day) may suggest a possible time lag associated with nitrate transport to depth in the greywacke catchment. In contrast higher transmissivity values in the karst (greater than 100 m^2/d) further support the idea of nitrate transport at depth.

The study shows that while the deep groundwater nitrate pathways are important in the productive catchment, shallow groundwater pathways are of greater significance in the poorly productive catchment. This highlights the need to consider individual groundwater pathways separately in catchment scale models.

A MULTI-METHOD APPROACH TO DEVELOP CONCEPTUAL MODELS OF GROUNDWATER SYSTEMS WITHIN AGRICULTURAL CATCHMENTS

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Conceptual understanding of how agricultural catchments function should underpin effective mitigation of diffuse agricultural pollution. Our focus in this paper is on understanding the hydrogeology of groundwater systems, as part of the broader source-pathway-receptor framework that has been widely used to structure conceptual models of agricultural catchments. Whilst important as receptors and as pathways, groundwater systems are difficult to characterise because of the challenge of gaining physical access to the sub-surface and because the deposits are often spatially heterogeneous. This paper reports the outcomes of a combination of techniques used to characterise the hydrogeology of the Pow, a small sub-catchment of the River Eden in Cumbria, UK which is a Defra Demonstration and Test Catchment.

We focussed on the Quaternary superficial deposits that overlie the regional sandstone aquifers within the sub-catchment. Geophysical surveys based on electrical resistivity tomography (ERT) and electromagnetic induction (EM) were used to characterise the stratigraphy of these superficial deposits. The ERT surveys revealed strong contrasts between a conductive zone (< 40 Ω m) and resistive zone (>40 Ω m). The conductive zone is indicative of clay-rich material whilst the resistive zone may indicate deposits with higher sand/gravel content or, at depth, weathered sandstone bedrock. Whilst in some areas of the sub-catchment the clay rich material was continuous, suggesting recharge to the underlying aquifer may be negligible, possible 'windows' in the clay were observed in other surveys. A programme of borehole drilling was used to corroborate the geophysical surveys and to install piezometers within shallow sand-rich deposits.

Hydrological and hydrochemical monitoring data from these piezometers have been collected to evaluate the role of these shallow deposits as water and solute pathways within the sub-catchment. Finally, CFC/SF6 techniques were used to assess the age of groundwater within the sub-catchment, characterising the potential lag between mitigation at the land surface and evidence of the impact of mitigation in the groundwater system. We bring these individual lines of evidence together to report an initial hydrogeological conceptual model for the sub-catchment, with specific reference to the risks associated with diffuse agricultural pollution.

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MODELLING FLOWS ALONG POLLUTANT PATHWAYS IN IRISH CATCHMENTS

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The main hydrological pathways that may transport diffuse contaminants to rivers in Ireland are overland flow, interflow, shallow groundwater flow, and deep groundwater flow. The aim of the EPA STRIVE-funded Pathways Project, being carried out by a research consortium involving QUB, UCD and TCD, is to achieve a better understanding of these flow pathways, and the fate of waterborne contaminants transported along them. Contaminants under investigation are phosphorus, nitrogen, sediments, pesticides and pathogens. As part of the project, a Catchment Management Tool (CMT) is being developed to assist the EPA and River Basin District Managers in achieving the objectives of the Water Framework Directive.

An important element of the research is to quantify the proportion of the river hydrograph that is derived from each of the main pathways. This involves physical and chemical hydrograph separation techniques, together with hydrological modelling of pathways using a semi-distributed, lumped and deterministic rainfall-runoff model, NAM. One of the main modelling challenges is to achieve credible simulations in relatively small study catchments (sometimes less than 5 km^2). Results of modelling at several catchments are presented to highlight the effects of scale, including catchments being studied as part of the Pathways project and other river catchments in Ireland. The results show that high frequency rainfall and flow data are required to achieve realistic simulations in small catchments.

The results of the flow modelling along each of the four pathways, combined with an understanding of the attenuation of the contaminants along those pathways, will inform the CMT to provide a more robust means of identifying the critical source areas discharging contaminants to rivers.

NITRATES DIRECTIVE COMPLIANCE CHECKING FOR NITRATE IN GROUNDWATER IN THE NETHERLANDS, STAKEHOLDER INVOLVEMENT AND INTERNATIONAL AUDITS AS FOUNDATION UNDER RESEARCH RESULTS

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The EU Nitrates Directive states a threshold level of 50 mg/l nitrate in groundwater. In the Netherlands compliance is currently checked in the upper one meter of groundwater. A draft EU monitoring guideline leaves open the possibility to check compliance in the upper five meters of groundwater.

The nitrate concentration in groundwater in the Netherlands has significantly decreased between 1996 and 2004 due to policy measures. Nitrate concentrations are below the EU threshold level in large parts of the Netherlands. In sandy soils, however, the average nitrate concentration still exceeds the 50 mg/l value in the upper most meter of the groundwater. Additional measures are required to meet EU threshold values.

Changing the checking level from the upper most meter to the upper five meters of groundwater could provide the Netherlands with the possibility to meet the EU threshold level for groundwater, without having to implement major additional measures by farmers. Nitrate concentrations are likely to decrease with depth because of denitrification and dilution. This possibility triggered intensive discussions and political pressures on the present network design.

A Dutch study showed that in sandy soils with relatively deep groundwater tables (i.e. > 1 meter) nitrate concentrations did not decrease with depth in the upper five meters of groundwater. Here, the act of denitrification did not occur. In sandy soils with high and intermediate groundwater tables (within 1 meter) a decrease in nitrate concentrations with depth was shown. Results indicated that in these soils significant loads of agricultural nitrate are transported into surface waters. Thus, allowing higher nitrate concentrations in the upper groundwater may cause eutrophication of surface waters. Soundness of the study has been tested and the results were validated by way of an international audit team of experts from other national institutes.

In the Dutch Parliament introduced a motion in 2009 stating that maintaining the current compliance checking level in the upper one meter of groundwater would result in unfair competition for Dutch farmers. The Dutch Parliament requested the Government to calculate the decrease in nitrate with depth using models and to measure the nitrate concentrations not only in the upper most meter of groundwater, but in the upper second and upper fifth meter of groundwater as well. Requested changes have until now not been introduced in the monitoring network on account of the high cost of the foreseen changes in the network infrastructure.

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QUANTIFYING IN SITU DENITRIFICATION AND N2O/N2O+N2 RATIOS IN GROUNDWATER USING 15N TRACER TECHNIQUE

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Reactive nitrogen, mainly nitrate and nitrous oxide (N_2O), can cascade through a variety of environmental systems, damaging them significantly and impacting on human health. The fate, movement and consumption of nitrate and N_2O in groundwater are poorly understood. An understanding of where, when, and how much nitrate is denitrified reduces the uncertainty of modelling occurrence of catchment-scale nitrate and contributes to management and mitigation of the ecological consequences caused by excessive reactive N in the environment. Construction and validation of robust and predictive models of denitrification, quantification of denitrification rates for many systems and knowledge of how these rates vary temporally and spatially are crucial. In situ groundwater denitrification capacity was determined in subsoil (5 m below ground level), at bedrock interface (12 m bgl) and in bedrock (20 m bgl) with three replications in the research farm (intensively managed grazed grassland) of Teagasc Environment Research Centre, Johnstown Castle, Co. Wexford, Ireland. The site hydrogeology was poorly drained top and subsoils overlying ordovician sediments of sandstones and shales with shallow groundwater tables (1-2 m below ground level).

The ^{15}N-enriched nitrate coupled with natural tracers (Br- and SF6) were injected into the well and incubated for 6-h. After the incubation period, groundwater was pumped back and analysed for $^{15}N\text{-}NO_3$--N, $^{15}N\text{-}N_2O$ and $^{15}N\text{-}N_2$. Mean denitrification rates ($N2O+N_2$) among three different depths of groundwater were similar in subsoil and bedrock but were higher in interface (subsoil: mean =10.9 $\mu g\ N\ kg^{-1}\ d^{-1}$, SEM = 3.5; bedrock interface: mean = 469.5 $\mu g\ N\ kg^{-1}\ d^{-1}$; SEM = 311; and bedrock: mean = 9.2 $\mu g\ N\ kg^{-1}\ d^{-1}$, SEM = 5.8). Similar denitrification rates among depths ($p>0.05$) indicates that denitrification is not limited to shallow groundwater rather it is an important process of groundwater nitrate conversion to N_2O and N_2 at shallow to deeper groundwaters along groundwater flow paths. Mean $N_2O/\ N_2O+\ N_2$ ratios were 0.06., 0.05 and 0.14, respectively in subsoil, bedrock interface and bedrock. The denitrification rates were equivalent to a weighted average of 0.33 mg NO_3^--N $L^{-1}d^{-1}$, which accounts for 5.1% of the injected as $^{15}N\text{-}NO_3^-$. This experiment shows that denitrification is an important nitrate removal process in groundwater as it migrates towards surface waters. Measuring denitrification rates across varying hydrogeochemical conditions and land reduces uncertainty in relation to nitrate occurrence in ground and surface waters and indirect N_2O emissions to the atmosphere.

CATCHMENT-SCALE NITRATE ATTENUATION AND INDIRECT N2O EMISSIONS ALONG GROUNDWATER FLOW PATHS

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Quantification of nitrate attenuation and indirect N_2O emissions via denitrification in groundwater under agricultural systems is crucial for quantifying the effects of human activity on the N cycle and for managing and mitigating the severe environmental consequences associated with excess environmental N.

We investigated groundwater nitrate occurrence, denitrification in relation to N_2O and N_2 and the links between denitrification and existing hydrogeochemical conditions in four agricultural catchments in Ireland (Johnstown Castle, Co. Wexford (JC)), Solohead, Co. Tipperary (SH), Oak Park, Co. Carlow (OP) and Moore Park, Co. Cork (DG)). Soils and glacial tills in JC and SH sites were moderate to poorly drained with shallow water tables. In contrast, OP and DG sites were well to excessively drained with deeper water tables. Multilevel piezometers were installed at three depths: subsoil (5 m); bedrock interface (10 m) and bedrock (20-50 m).

Groundwater was sampled monthly from February 2009 to January 2010. Excess N_2 (denitrified N_2) was estimated using dissolved N_2 and Ar by Membrane Inlet Mass Spectrometry. Dissolved N_2O, CO_2 and CH_4 in groundwater were extracted using a helium headspace method. In situ denitrification rates were measured using 15N tracer (push-pull) test. Denitrification (N_2+N_2O) was a significant pathway for groundwater nitrate depletion resulting in 45, 75, 8 and 4% reduction of NO_3^--N resulting in net NO_3^--N concentrations of 4, 1, 12 and 15 mg $L^{-1,}$ respectively in JC, SH, OP and DG. The main end product of denitrification (N_2) was significantly higher ($p<0.01$) in JC and SH sites (97-99%) compared to OP and DG (79-91%). Mean N2O concentrations were 0.024, 0.012, 0.038 and 0.049 mg N L^{-1} and mean N_2 concentrations were 2.3, 2.3, 0.9 and 0.5 mg N L^{-1}, respectively in JC, SH, OP and DG.

Mean N_2O emission factors across all sites were considerably higher (0.0033-0.0044) than the IPCC default value of 0.0025 (EF_5g). Spatial variability of N_2O and N_2 production in groundwater was higher than the temporal variability. In-situ ammonia generation resulting from dissimilatory nitrate reduction to ammonium (DNRA) was observed with elevated groundwater ammonium occurrence. Groundwater can be an important source of CO_2 and CH_4 emissions to the atmosphere containing 35, 27, 11 and 33 mg C L^{-1} CO_2 and 246, 31, 5 and 1 μg C L^{-1} CH_4 respectively in JC, SH, OP and DG. Generally denitrification increased with the distance from the groundwater divide towards the stream and controlled mainly by hydrogeochemical conditions. Multiple electron donors (both organic C and Fe/S compounds); lower Eh (±150 mV), DO (<2 mg L^{-1}), and permeability (Ksat<0.005 m d^{-1}); and shallow unsaturated zone (<2 m BGL) can create denitrification hot spots in groundwater. Denitrification is an important process in groundwater where groundwater DO and redox potential are low and within low permeability aquifers. It results in nitrate amelioration during catchment transport and can lead to elevated high N_2O emissions.

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AGRICULTURAL NITROUS OXIDE: INDIRECT FLUXES AND EMISSION FACTORS AT THE CATCHMENT, FARM AND FIELD SCALE

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Reductions in greenhouse gas emissions are required from agriculture, in common with all other sectors, in order to meet the reduction targets set by the UK Climate Change Act 2008. Currently, N_2O, which is about 298 times more potent than CO_2 as a greenhouse gas, is estimated to account for more than 50% of UK agricultural greenhouse gas emissions with fertiliser nitrogen applications and manure applications to land being the predominant sources (c. 80% of total agricultural N_2O emissions). The remaining c. 20% of N_2O emissions are indirect emissions from agricultural drainage waters. However, this 20% of N_2O emissions accounts for 2/3rds of the uncertainty in these estimates.

DEFRA have funded the UK Agricultural Greenhouse Gas Inventory project to improve these estimates with the main aims of reducing uncertainty in the inventory and enhancing regional inventory reporting through increased understanding of processes and factors controlling emissions. As part of this project we measure indirect emissions of N_2O from agricultural drainage systems at the field, farm and catchment scale over a selection of geoclimatic regions. High resolution nutrient data is available through the DEFRA Demonstration Test Catchment (DTC) Project based in the Wensum catchment (www.wensumalliance.org.uk) which is evaluating the potential of on-farm mitigation strategies to reduce diffuse agricultural pollution while still maintaining sustainable food production.

N_2O concentration data is used to estimate N_2O fluxes and is also combined with inorganic nitrogen (N) leaching rates to calculate N_2O emission factors (EF). These are then compared with those from current IPCC methodologies. The scale of sampling (field to catchment) is key to accurate estimates of both N_2O flux and EF since both N and N_2 behave differently in drainage systems, with N_2O often being rapidly degassed while N remains in the system.

Further, these high resolution paired nutrient-N_2O measurements form a baseline against which mitigation measures can be assessed as they are implemented under the DTC projects. This should allow the identification of measures which give benefits to both N_2O and nutrient pollution mitigation rather than trading off between them and also allow the true socio-economic cost of measures to be better assessed.

MONITORING WATER QUALITY LOADS IN RIVERS:
ASSESSING A 24/7 APPROACH.

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Accurate quantification of nutrient and sediment loads in catchments is dependent on a sampling frequency that reflects the variability in the system under study. In practice this necessitates a compromise between the scientific optimum and what is feasible in terms of logistics and economic cost. Catchments with a flashy hydrology pose a particular challenge in this respect as high frequency, short duration rainfall events may account for a significant portion of the total diffuse nutrient transfer in any hydrological year. Coarse sampling strategies are unlikely to coincide with all such events and additionally, lack the resolution to detect time-dependent variations in point inputs during low flow periods.

A two-year series of near-continuous (sub-hourly) phosphorus concentration and river discharge data from three small catchments in north-central Ireland provide an opportunity to examine the frequency dependence of load estimates and identify possible monitoring solutions. Both systematic and Monte Carlo techniques are applied to simulate sampling, with loads estimated using a flux-based approach. In addition to a range of monthly, weekly, daily and random sampling strategies we test the use of a standard automated sampler programmed to take 24 samples distributed at 7 hour intervals across a week as proposed by the Centre for Ecology and Hydrology at Plynlimon, Wales.

Results highlight the uncertainty associated with increasing sampling intervals, with a tendency towards underestimation (by up to 60%) attributed primarily to unrecorded short duration storm events. Sampling strategies biased towards capturing high flow events tend to overestimate annual load with similar levels of uncertainty. The 24/7 solution was most accurate and consistent among sampling replicates (inter-quartile range is 96% to 110% of actual load in year 1 and 97% to 104% in year 2) due to the increased probability of sampling storm events and the shifting daily sampling time increasing the likelihood of identifying diurnal signals in point source input. This approach is affordable in terms of technology requirements, the ability to be widely deployed and to represent important point and diffuse nutrient transfer processes in complex catchments.

52 PHOSPHORUS LOAD APPORTIONMENT IN IRISH WATER-BODIES

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Sustainable use of EU water resources and maintaining a high ecological status in water bodies are key aims of the Water Framework Directive. A widespread water quality challenge in developed countries is eutrophication from point and diffuse loadings of nutrients, such as phosphorus (P) and nitrogen (N), from land to water. Daughter directives such as the Nitrates and Urban Waste Water Treatment Directives are the main regulatory instruments to manage these transfers and the efficacy of the measures are being evaluated in national monitoring programmes.

This project is investigating two phenomena linked to the recovery of ecological status in freshwaters and especially from the impacts of P loading. Firstly, the project will determine the comparative P loading of both point (e.g. end of pipe discharges) and diffuse (e.g. storm driven from soils) sources in the White River, Co. Louth with the development of Load Apportionment Models (LAM) and high resolution P concentration and discharge data. The White River catchment is absent of any major municipal point sources but shows evidence of other point source influences as well as diffuse sources during runoff events. The model can then be tested with lower resolution data from existing national monitoring river stations and the applicability, use and performance of LAMs in catchment science will be critically assessed.

The second part of the project is investigating the role of external and internal P loading to a meso-eutrophic inter-drumlin lake. Seasonal anoxia and wind induced resuspension of sediments are both linked to the ongoing eutrophication of lakes where historical external P loads have accumulated in lake sediments. A database is being built showing the extent of catchment derived P loading (external pressure), wind influences and stratification/mixing (internal pressures). This will be augmented using water column monitoring of algae and other parameters.

Untangling the comparative effects of point/diffuse P loads in flowing waters and external/internal P loads in sensitive standing waters will provide policy makers with expectations of recovery from eutrophication episodes against the targets set out in the Water Framework Directive.

A NEW HYBRID SWAT/HSPF DYNAMIC SIMULATION MODEL OF PHOSPHORUS LOADS IN RIVERS: EVALUATION AND UNCERTAINTY ANALYSIS.

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Previous work (Nasr, 2004) demonstrated that, while the Hydrological Simulation Program Fortran (HSPF) model (based on the Stanford Watershed Model and now part of the Better Assessment Science Integrating point and Non-point Sources (BASINS) model) was better than the Soil Water Assessment Tool (SWAT) at simulating daily flows from three test catchments in Ireland, SWAT was better at simulating daily phosphorus loads. This lead to the hypothesis that a hybrid model, combining the hydrological component of HSPF with the phosphorus modelling component of SWAT, would be better than either model on its own. This new model was produced and its performance verified by a PhD research project, funded by a Teagasc Walsh Fellowship, the results of which are reported here.

The SWAT and the HSPF, are two of the most widely used computer programs for river water quality simulation, especially for regulatory and management purposes. In this project, the hybrid combination of model components from each of these was achieved by developing a correspondence between the individual hydrological components of the SWAT and HSPF conceptual models. This allowed the results of a HSPF simulation to be expressed in terms of SWAT variables which were then used to drive the phosphorus modelling component of SWAT. This preserves the possibility of using the SWAT graphical user interface for the combined model

The Irish catchments used to test the new model were the Oona, Dripsey and Bawn (a small subcatchment of the Oona) for which time-series of precipitation, flow and P measurements were available. The new hybrid model produced a better flow simulation for the Oona (Nash-Sutcliffe R2) than SWAT alone for both calibration and validation periods. In addition, calibration for the total phosphorus load gave better R2 values than previously reported results for either HSPF or SWAT and showed better performance for most of the validation period. In the Bawn catchment, the total P load simulation was worse than SWAT during calibration but, critically, was better than SWAT in the validation period. In the Dripsey catchment, the flow calibration gave similar results to a previous study (Nasr, 2004) but it was better than either SWAT or HSPF for total P loads.

Autocalibration of model parameters, selected by a sensitivity analysis, using a multi-criterion method, improved results compared to manual calibration. The PARASOL technique established uncertainty bounds for the phosphorus load estimates.

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The data for the Dripsey and Oona were collected by Prof. Ger Kiely (UCC) and Prof. Phil Jordan (UU) as part of a previous Teagasc/EPA project. The data for the Bawn catchment was made available by Prof. Phil Jordan.

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UNDERSTANDING NUTRIENT CONNECTIVITY AT THE LANDSCAPE SCALE: THE USE OF THE SCIMAP APPROACH IN THE UK AND IRELAND

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Many approaches to understanding diffuse pollution risk at the landscape scale have focused on its 'sources' and 'mobilisation' with a basic representation of the effect of connectivity between the landscape the receiving waters. Connectivity will determine whether source areas become critical source areas and create problems in the receiving waters. It is the landscape position of a source, both in terms of its upslope contributing area and its downslope flow path, that determine the likelihood of a connection being made.

The SCIMAP approach, developed at Durham and Lancaster Universities with the Environment Agency, has taken a strongly connectivity driven approach, set within a risk based framework. SCIMAP aims to predict the location in the catchment that is most likely to be the source of an in stream water quality problem derived from diffuse pollution. The predictions are generated at a 5m-pixel level, to give within field estimates of risk and connectivity, and applied to whole landscapes (from 1 to 2000 km^2 +) to give a broad overview of the issues. Recent work has shown that there is significant value in adding a detailed connectivity treatment when predicting measured patterns of water quality.

The SCIMAP approach to diffuse pollution risk mapping has been applied by: the Environment Agency under the Catchment Sensitive Farming program; the Teagasc 'Agricultural Catchments' program; the Defra funded 'River Eden Demonstration Test Catchment'; and various river and wildlife trusts in the UK. This poster shows an overview of the SCIMAP approach and the interim results from both the Teagasc 'Agricultural Catchments Programme' and the EdenDTC projects.

MODELLING CATCHMENT BOUNDARIES

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Digital elevation models (DEMs) are widely used to identify patterns of water flow in catchment management. However, all DEMs are approximations to some degree and it is widely recognised that their characteristics can vary according to attributes such as the source data (e.g. contours, optical or radar imagery). As a consequence, it is important to assess the 'fitness for purpose' of different DEMs and evaluate how uncertainty in the terrain representation may propagate into products such as delineated drainage networks and catchment boundaries. In areas where the under-drainage of land is common it is also important to evaluate how the presence of such drains may alter the flow patterns estimated from surface topography.

As part of the Wensum Demonstration Test Catchment (DTC) project seven different DEMs (ASTER GDEM, SRTM, Landform Panorama, Landform Profile, Landmap, NextMap and Bluesky DTMs) have been compared in terms of their general data quality and the uncertainty in derived catchment parameters has been examined. The implications of incorporating field drains into estimates of the land areas acting as sources for particular monitoring points have also been considered. Results demonstrate that a number of nationally available DEMs in the UK are simply not 'fit for purpose' as far as local catchment management is concerned and suggest that a more sophisticated approach to matching up contributing land areas and monitoring points is a key prerequisite to any reliable assessment of the consequences of implementing particular land management measures.

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DEVELOPING CATCHMENT LEVEL MEASURES TO REDUCE EUTROPHICATION: THE CROP ROTATION COEFFICIENT CALCULATOR IN THE DSS FYRISCOST

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The FyrisCOST decision support system (DSS) is designed to support public authorities, county administrators and water councils with the evaluation of cost effective programs to reduce eutrophication on a catchment scale. The model allows the user to experiment with a wide range of nutrient loss mitigation approaches from point as well as diffuse sources to value the effects of combined mitigation programmes. The leaching concentrations from farmland used in FyrisCOST, are derived from extensive simulations with the Nutrient Leaching Coefficient Calculation System (NLeCCS).

To provide more localised nitrogen leaching coefficients from agricultural land, a crop rotation coefficient calculator was constructed. Nitrogen leaching coefficients are unique for each crop, crop type, time of termination and subsequent crop. To calculate regional leaching coefficients for a crop distribution in a sub catchment, the probability of each crop being followed by spring sown crops, autumn sown crops or ley is calculated. The coefficients of these three alternatives are then weighed by their probability and then added together. The resulting annual leaching coefficient for each crop is then valid for the specific sub-catchment's crop distribution. The coefficients for crops followed by a spring sown crop are divided into one of three different coefficients (1) sown with a catch crop that is terminated in autumn, (2) sown with a catch crop that is terminated in spring or (3) the main crop terminated in spring (instead of autumn).

The crop rotation coefficient calculator provides a more localised estimation of leaching from cropland depending on the crop distribution. This makes it possible for stakeholders to include crop distribution in catchment mitigation programs. Alternative nitrogen management plans using the crop rotation coefficient calculator are evaluated in the FyrisCOST DSS using data from a catchment area in Southern Sweden to demonstrate the potential of this tool to achieve nutrient reductions.

VALIDATION OF FIELD-SCALE MODEL RESULTS ON NUTRIENT LEACHING IN SMALL AGRICULTURAL CATCHMENTS IN SWEDEN USING THE FYRISNP SOURCE -APPORTIONMENT MODEL

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The FyrisNP source-apportionment model has been set up and calibrated for 7 small catchments (5.8 – 31.7 km^2) dominated by agricultural land and with no major point sources. These catchments represent a subset of the Swedish monitoring programme for agriculture which includes in total 21 small catchments representing major variations in climate, soil types and farming in Sweden and hence also vary widely in long-term average concentration and load of nitrogen (N) and phosphorus (P) at stream outlets. The monitoring programme is tailor-made to quantify the impact of agricultural activities on discharge water. The main objectives of the model applications was 1) to validate leaching coefficients for N and P calculated with the Nutrient Leaching Coefficient Calculation System (NLeCCS), and 2) to evaluate how improvements of input data will affect model performance.

The NLeCCS system includes field-scale models for calculating leaching coefficients for N (SOILNDB) and P (ICECREAMDB). Based on these leaching coefficients area-weighted mean leaching concentrations are calculated for the catchment scale. Current crop distribution is then used in combination with catchment specific data on dominant soil texture, production region, slope and P content in arable soil (the last two only for P calculations). Two main scenarios were run with FyrisNP. First we used the same input data as in the national calculations with NLeCCS. In the second scenario all available local data was collected to improve input data regarding soil type distribution, P content in soil, slope, management data etc. Both N and P were modeled and the results were compared with measured concentrations and loads. The results show that leaching coefficients generally could describe the transport of nutrients in a satisfactory manner, but first after that best available local input data was used.

N and P retention between the field's edge and the streams was also quantified. Although a relationship between P retention and the size of the catchments can be found, the low number of modeled catchments limits possibilities to make general conclusions. Since in most cases reasonable results were achieved with relatively simple adjustments and improvements of the input data, we believe that the applied methodology can be a way to validate leaching coefficients obtained from field models in an early stage before they are used for regional or national applications.

58 NITROGEN AND PHOSPHORUS BALANCES AND EFFICIENCIES ON CONTRASTING DAIRY FARMS IN AUSTRALIA

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Nitrogen (N) and phosphorus (P) imports, exports and within-farm flows were measured during a standardised production year on 41 contrasting Australian dairy farms, representing a broad range of geographic locations, productivity, herd and farm size, reliance on irrigation, and soil types. The amount of N and P imported varied markedly, with feed and fertiliser generally the most significant contributors and principally determined by stocking rate and type of imported feed. Whole-farm N surplus ranged from 47 to 600 kg N/ha/year and was strongly ($P < 0.01$) and linearly related to the level of milk production. Whole-farm N use efficiency ranged from 14 to 50%, with a median of 26%. Whole-farm P surplus ranged from -7 to + 133 kg P/ha/year, with a median of 28 kg/ha. Phosphorus use efficiencies ranged from 6 to 158%, with a median of 35%. The poor relationship between P fertiliser inputs and milk production from home-grown pasture and crops reflected the high soil P levels measured on these farms.

The N and P intakes of each dairy herd, the locations the cows visited and the time they spent there, were also determined during five visits throughout the year. As N and P intakes increased so did excreted N and P, with use efficiencies generally less than 20%. On average 432 g N and 61 g P were excreted by each lactating dairy cow/day. Overall, cows spent a small proportion of their time in the milking parlour (2%) and yards (9%) where dung and urine were generally collected, however greater time was spent on feedpads (11%) and holding areas (26%) where manure was not routinely collected. The largest amounts of excreted N and P were deposited by cows in grazed paddocks but particularly those closest to the milking parlour.

Derived industry based relationships and individual farm case studies have been developed to identify opportunities to improve N and P use efficiency within grazed dairy systems. These include reducing unnecessary nutrient intake, improved spatial and temporal movement of animals within dairy farms to reduce heterogeneous N and P deposition, increasing the capture, storage and redistribution of excreted N and P in non-productive areas, and more strategic fertiliser and effluent applications. We also suggest that simple on-farm assessments can be used in contrasting dairy production operations to assess N and P use efficiencies, which will assist in developing appropriate industry benchmarks and benefit productivity and environmental outcomes.

TELLUS BORDER PROJECT:
CATCHMENT SCALE CHARACTERISATION OF SOIL AND WATER FOR ENVIRONMENTAL MANAGEMENT

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Tellus Border is a £4 million mapping project that will collect scientific data on soils, water and rocks across the six border counties in Ireland (Donegal, Sligo, Leitrim, Cavan, Monaghan and Louth) and integrate these with existing data which was surveyed in Northern Ireland as part of the Tellus project. Mapping will be completed through two surveys which will commence in August 2011 – an airborne geophysical survey and a ground-based geochemical survey sampling soil, stream water and stream sediments. The surveys will provide regional and catchment-scale data which will assist better management of the environment and support sustainable development of our natural resources. Maps and data will be made freely available to all interested stakeholders including landowners, local authorities, planners, policy makers and the general public in 2013.

The project will support objectives of sustainable catchment management by providing information on nutrients, major elements and trace elements in agricultural soils and in low-order streams on a catchment scale. As part of the geochemical survey soil samples will be taken every 4km2 which will allow detailed characterisation of regions where there are excesses or deficiencies of elements which can affect livestock, crops and human health. Elements of interest include selenium, copper and iodine, and particularly molybdenum in Donegal.

Under the Water Framework Directive (WFD), the catchment is a key management unit for inland waters. Water does not stop at borders and River Basin Districts (RBDs) that cross political boundaries present particular challenges for effective cross-border catchment management. There are three cross-border RBDs in the Tellus Border study area: the Northwestern, Neagh Bann and Shannon International RBDs. Tellus Border will contribute to the objectives of these cross-border RBDs by seamlessly integrating catchment data from the Tellus (Northern Ireland) project and thereby gaining better understanding of regional water quality. The project will sample lower order streams than those that are monitored by EPA and NIEA for WFD compliance and will provide a picture of water quality in the upper reaches of the catchments for the first time.

The project is being run by a cross-border partnership between the Geological Surveys of Ireland and Northern Ireland, Queen's University Belfast and Dundalk IT. Tellus Border is funded by the INTERREG IVA programme of the European Regional Development Fund, which is managed in Ireland and Northern Ireland by the Special European Programmes Body (SEUPB). The project is co-funded by the Department of Environment (NI) and the Department of the Environment, Community and Local Government (RoI).

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