Crops,
Environment
& Land-use
Programme

Johnstown Castle

Agricultural Catchments Programme

Phase 1 Report






Teagasc
Agriculture and Food Development Authority

Department of Agriculture, Food and the Marine
An Roinn Talmhaíochta, Bia agus Mara

Agricultural Catchments Programme

Phase 1 Report – 2008 to 2011

Teagasc

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Johnstown Castle Environment Research Centre

Foreword

This is the first report of the Agricultural Catchments Programme (ACP) and covers Phase 1, the first four years of the programme (2008-2011). A significant proportion of the programme outputs covered in the report are based on data collected in Phase 1 but were published subsequently in 2012 and early 2013 . The Department of Agriculture, Food and the Marine (DAFM) has been very supportive of ACP and have funded it from its inception. The DAFM is currently funding Phase 2 (2012-2015).

There have been considerable socio-economic changes since the start of the ACP. The European Union (EU) Nitrates Directive and Water Framework Directive were the principal drivers of the ACP initially. These directives were designed to protect our water resources and have set ambitious water quality targets for Ireland. The next review of the Nitrates Action Plan and the Derogation to farm above 170kg organic nitrogen/ha under the Nitrates Directive is due in 2013 and the ACP is focussed on addressing the issues likely to arise in this review.

One of the so-called "Grand Challenges" for agriculture is meeting the growing demand for food from the world's population. To face these challenges farming must improve resource use efficiency and environmental management. In July 2010 the DAFM launched the FoodHarvest2020 report which proposes that Ireland can grow its exports of food and beverages by one-third, to €12 billion annually, and can increase the value of primary production from agriculture and fisheries by €1.5 billion per year including a 50% increase in milk production. This is a very different and more challenging climate for food production that the one in which the ACP began. In seeking to ensure that Irish agriculture meets its environmental and food production goals the ACP is eager to play its part in delivering this 'double-dividend' for farming and the greater economy

The ACP approach is founded on partnership, good science, integrating research with advice and dissemination of our findings. There are over 300 farmers involved in the ACP and our most important partnership is with them – they facilitate us by allowing access to their farms and sharing information on their businesses and without their support the programme could not operate. The trust the ACP advisers and technicians have built up with the farmers is the cornerstone of the programme's success.

The publication of peer-reviewed papers in international journals is our primary scientific dissemination method. Importantly, all papers are accessible to stakeholders and the public but will be subject to copyright access specific to each institution and individual. This report is principally based on these papers and conveys the main findings from the research. The topics and findings from each paper are first presented as bullet points which very concisely give the reader an understanding of the key messages. A synopsis then expands on these points and, for readers who wish to access the specific detail in the paper, a full reference is supplied. Our intention is to make the information easily accessible, available to a wide audience and easily understood.

Finally, we wish to thank all of those who have contributed to this report – farmers, the ACP team, colleagues in Teagasc, the DAFM, Department of Environment, Community and Local Government, the ACP Consultation and Implementation Group and the ACP Expert Steering Group – for their support, co-operation, hard work and encouragement over the four years of Phase 1. We look forward to continued success for the ACP in Phase 2.

Ger Shortle – Programme Manager **Phil Jordan – Principal Scientist**

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Executive Summary

The first four-year phase of the Agricultural Catchments Programme (ACP) was completed at the end of 2011. It was run by Teagasc and funded by the Department of Agriculture, Food and the Marine (DAFM) with the principal objective of evaluating the effectiveness of the package of measures implemented in Ireland's National Action Programme (NAP) under the EU Nitrates Directive. This Phase 1 was concerned with the establishment of an extensive catchment scale experiment, and providing an agri-environmental baseline of agricultural activity and water quality response in the years following the implementation of the NAP.

Implicitly, the evaluation included an investigation of the efficacy of the derogation under the Nitrates Directive which permits farmers to exceed the 170kg ha^{-1} limit for organic nitrogen (N) from livestock manure and farm at up to 250kg ha^{-1} organic N. Among the evidence in supporting Ireland's original case for a derogation in 2005 for crops with a high nitrogen requirement was the generally large denitrification potential of Irish soils due to maritime weather conditions (giving high net precipitation) and a relatively (in the EU) long growing period.

However, the NAP is concerned with controlling the mobilisation of residual N beyond the root-zone to mitigate groundwater impacts and transfers to downstream water bodies. Additionally, phosphorus (P) had been identified by the Irish Environmental Protection Agency (EPA) as a significant influence in the process of eutrophication of surface and groundwaters in Ireland, and other NAP measures (some coincident with N measures) had been introduced to deal with this (SI 378 2006; SI 101, 2009; SI 610, 2010). Furthermore, the suite of mitigation measures in the NAP were recognised as the agricultural contribution towards helping to implement the Water Framework Directive (and associated daughter Groundwater Directive) objectives in Ireland.

These factors were carefully considered in the design of the ACP and focussed on in the operation of the programme. Specifically, the experimental design was cognisant of the Article 8(4) clause in the Irish Derogation (EC, 2007):

"Monitoring of shallow groundwater, soil water, drainage water and streams in farms belonging to the agricultural catchment monitoring sites shall provide data on nitrate and phosphorus concentration in water leaving the root zone and entering groundwater and surface water."

At the outset, on an EU level, it is proposed that the NAP in Ireland is a highly regulated and progressive programme of measures to mitigate diffuse pollution from agricultural sources. The hypothesis tested in the ACP is that the NAP is addressing these issues satisfactorily. The first phase of the ACP has provided significant evidence to support this hypothesis; assertions which will require validating in Phase 2.

The ACP integrates bio-physical with socio-economic processes in the evaluation of the impacts of NAP measures. Conducted at the catchment scale, the evaluation was more concerned with the water quality response of the package of NAP measures in agricultural catchments, rather than individual measures. However, the status of some of the individual measures, as obligated under the NAP, was investigated. While Phase 1 provided a project design and base line, Phase 2 is concerned with validation (of assertions from Phase 1), modelling (key bio-physical and socio-economic processes) and assessment of policy impacts. Six catchments were instrumented to monitor nutrient sources and loss pathways to surface and groundwater bodies. Intensive biophysical monitoring was conducted according to a common experimental design with the aim of evaluating the effect of changes in farm management practices on the transfer of nutrients from source to water and their impact on water

quality. Measurements, modelling and socio-economic studies were used to evaluate the efficacy of the measures and aspects of their cost effectiveness and economic impact.

The ACP's socio-economic work also explored farmer attitudes to implementation of regulations, adoption of nutrient management practices, provision of ecosystem services and the economic impacts of efficient nutrient management.

OUTCOMES

This report provides an overview of the results from Phase 1 which have been published in a series of peer-reviewed scientific papers. Some of the most significant outcomes from these are summarised below and then are provided as synopses of published papers. In some sections, below, reference has been made to results following on from Phase 1 results, which aren't peer-reviewed, but give an indication of current data interpretation and intention.

Nitrogen

Nitrogen was measured in surface water as total oxidised nitrogen and reported as nitrate-N. While Phase 1 was cognisant that nitrate standards and thresholds in flowing waters may be reviewed in the future according to ecological relationships, in all six catchment streams, concentrations were found to be below the maximum acceptable concentration (MAC) for drinking water of 11.3 mg l^{-1} (as nitrate-N) (partly published in Melland *et al*., 2012). However, the nitrate concentrations were over a surrogate standard of 1.8 mg l^{-1} which is used by the EPA to support at least 'Good Status' classification in rivers

Comparing two contrasting arable catchments, annual average nitrate loads leaving the well-drained catchment via the stream were higher (28 kg ha^{-1}) than from the moderate to poorly drained catchment (17 kg ha^{-1}). This finding is in keeping with expectations of higher N transfer risk in more permeable catchments (Melland *et al*., 2012). Annual nitrogen loads leaving catchments in rivers can influence the eutrophication of estuarine waters depending on the magnitude of the load and morphology of the estuary. While certain legislated threshold N and P concentrations determine the trophic status of estuaries, there is no similar threshold for N (or P) loads that will cause the estuary to become impacted – hence, there is no clear way of indicating whether these nitrate-N loads were excessive from an environmental perspective. Nevertheless, Melland *et al*. (2012) noted that a modelled 15% reduction in current N (and P) loads would be sufficient to reduce estuarine impacts (on average), and this will be explored in Phase 2 but with recognition that hydromorphological controls in some estuaries will require further reductions to avoid eutrophication. It is clear, however, that the agricultural cost of these example nitrate loads provide a potential economic loss to farmers seeking greater N efficiency.

Phase 1 installed several borehole transects for investigating nitrate-N (and P) losses to groundwater beyond the root zone (Wall *et al*., 2011). At the end of Phase 1, a multi-year dataset from three catchments showed a variable range of nitrate concentrations, rarely over the MAC in deep groundwater, and with extremely high denitrification potential (inferred from low concentrations) in certain near-stream strata. During this period, ploughing and reseeding of long-term grassland in one transect indicated a two year phase of increased nitrate concentrations followed by recovery that were not mirrored in the wider groundwater body. This suggests a local influence on immediate borehole water quality following land-use change but which does not reflect wider nitrate status, and which could not be properly interpreted using standard WFD groundwater monitoring data. However, these data and assertions are subject to peer-review and are, therefore, not explored further in this Phase 1 report and will become part of Phase 2 reporting. Nevertheless, it is becoming increasingly recognised that long lag times can be expected for the recovery of N enriched groundwaters following the implementation of mitigation measures. In a supporting study, Fenton *et al*. (2011) proposed that, where present in sub-soils >3 m depth, enriched groundwater bodies were estimated to reach acceptable threshold nitrate concentrations by between 2019 and 2033 from mitigation measures fully implemented by 2012 (as a WFD target scenario and which were assumed to have successfully reduced inputs).

Phosphorus

The loads[1] of total phosphorus (TP) leaving the catchments annually were between 0.18 and 0.79 kg ha^{-1}. However, annual mean total reactive P (TRP; operationally equivalent to molybdate reactive P - MRP) concentrations in three of the six catchment streams regularly exceeded the Irish Environmental Quality Standard (EQS) of 0.035 mg l^{-1} (Jordan *et al*., 2012; Melland *et al*., 2012; Mellander *et al*., 2012a) - albeit measured at a much higher sample resolution[2]. It was assumed that high soil P status was a primary factor in diffuse P losses from catchments and that the magnitudes of each were correlated (from previous research and as addressed in the NAP). The Phase 1 period could not report on soil P trends (part of the Phase 2 work programme) and less so on inter-annual effects on diffuse losses. However, as with N in groundwater, expectations of P improvements in flowing water must be cognisant of the long lag times of ca. 5-20 years that can be expected between changed nutrient management under the NAP and changed soil P status, for example (Schulte *et al*. 2010; Wall *et al*. 2012a). These two studies in Phase 1 provided the baseline for expectations of high soil P change following the NAP measures and which can be reviewed in Phase 2.

Other indicators of changes that will lead to improved water quality must be considered during this lag period. Soil P status was found to be highly variable throughout the catchments as were nutrient application rates relative to recommended rates. There is, therefore, significant potential to improve nutrient management at the field scale on Irish farms while working within the current NAP measures – that is to say, through advisory support promoting optimal nutrient use and status on a field scale. While field-by-field soil testing is a particular feature of derogation farming requirements, non-derogation farmers are permitted to base their nutrient applications on assumptions of optimal P status. Policy tools available to close this gap, such as the promotion of agronomic soil testing as part of efficient farm practice either through an advisory programme or by regulation need to be carefully considered. This could deliver a 'double dividend' - improving nutrient use efficiency while decreasing the risk of nutrient losses to water by reducing the occurrence of excessive levels of soil P (Wall *et al*. 2012b).

Soil P status was found to be not the only factor in determining the risk of P loss to water; the interaction across the landscape and over time between field nutrient applications and mobilisation and transfer risks associated with soil type and geology are likely also to be important in determining nutrient losses. This means that meeting chemical water quality targets may be more challenging in less well drained catchments where drainage water quickly moves into water courses through overland flow, carrying nutrients with it. This means that, even with the acceptance of lag-time concepts in high soil P fields, further constraining soil fertility may not be as effective a solution for reducing nutrient loads as controlling transport factors in these heavy soil types. The policy challenge will be to define what and where runoff mitigation features could or should be implemented as part of multi-objective environmental schemes – Phase 2 will add to the knowledge base in this debate.

Also, streams and rivers draining these types of impermeable catchments have lower dilution of nutrients in the summer because of lower groundwater contributions to streamflow and higher losses during storm flow (Jordan *et al*. 2012; Melland *et al*. 2012); this lower summer dilution resulted in higher P concentrations in some catchments proposed to be from non-agricultural sources and this will require careful consideration in future analysis of river chemistry-ecology relationships – briefly discussed below.

[1] These loads are combined from continuous discharge and concentration measurements and may change slightly in future reporting as discharge rating curves are further developed.

[2] This sampling resolution included frequent storm peak P concentrations during runoff events - which are proposed to be under-represented in normal EQS monitoring.

While it was generally found that quick-flow P transfer pathways dominated poorly drained catchments and below-ground N transfer pathways dominated in well-drained catchments, substantial below-ground P losses were found in well-drained catchments, while poorly drained catchments produced N loss via ephemeral ditches. This suggests that below-ground transfer pathways need to be considered when mitigating both N and P loss to receiving waters and highlights the importance of considering catchment-specific nutrient transfer pathways when assessing mitigation measures. Opposite to the narrative, above, with regard to catchments with impermeable soils, in catchments with permeable soils and geology, measures targeted at nutrient sources (i.e. existing measures aimed at soils and nutrient inputs) may be a better long term strategy than those targeted at overland pathways such as buffer strips and critical source areas for runoff (Mellander *et al*. 2012a); or, at least, it may be more challenging to determine the most effective location of these features in permeable catchments.

Ecology

A twice per year (spring and late summer) ecological survey was conducted over Phase 1 (i.e. a higher resolution than normal WFD monitoring). The in-stream benthic diatom ecological quality ratio achieved Water Framework Directive ‘good’ quality status in the karst catchment only during September 2009 and in all four grassland catchments in May 2010 (Wall *et al*. 2011). This highlights the lower environmental pressure on in-stream ecology following the closed period, despite disproportionately higher nutrient loads being transferred during that period. Summer background stream P loading, including from persistent point and diffuse sources, caused ecologically significant P concentrations as a result of the lower dilution (as described above). A more mature dataset of all ecological and hydromorphological metrics was established at the end of Phase 1 and which is subject to peer-review and not fully reported here. However, these Phase 1 findings should elicit a response from agencies (with longer data-sets) seeking to define the agricultural contribution to river ecological status based on standard sampling protocols to ensure that the correct (seasonal) source pressure is being assigned to the correct (seasonal) impact.

Karst Areas

Many Irish karst aquifers are classified as having poor status; contributing to the eutrophication of receiving surface waters and this status had been identified by the EU Commission and other authorities as being of particular concern. Therefore, to evaluate the efficacy of the NAP measures a karst spring zone of contribution in Co. Mayo was included in the programme. It was found that high P source (soil P status) and aquifer vulnerability did not elevate P in the emergent groundwater and it was concluded that definitions of risk and vulnerability for P delivery in karst systems need further evaluation (Mellander *et al*. 2012b). This work has concluded with a new definition of P susceptibility based on the recognition that soils of at least 0.5m over karst geology (combined with specific soil P chemistry retention capacities) offer P buffering potential and that karst features are not ubiquitously at risk of P transfer if they are coincident with underlying soil layers. This latter part of the work is still subject to peer review and, beyond establishing the need for further evaluation in Melland *et al.* (2012b), specific P susceptibility over karst is not discussed further in this report and will be an interim Phase 2 output. Nevertheless, the work has highlighted the need for a tighter definition of the specific P risk from karst catchments and it follows that the definition of poor status groundwaters under karst may need similar review.

Closed Period

Due to a close relationship between stream flow volume and stream nitrate exports, the nitrate-N load exported during the closed slurry spreading period (approximately 25% of the year) was disproportionately high at 47 to 57 % of the annual nitrate exports (for two arable catchments over two years). Results for P exports showed a similar pattern on grassland, particularly in the less well-drained catchments, thus indicating the synchronicity between increasing stream flow volume and nutrient losses (Jordan *et al*., 2012; Melland *et al*., 2012). It follows that in a scenario where slurry spreading (or other nutrient applications) was carried out during these closed periods, the potential for incidental losses (of slurry/manure/fertiliser) would be high due to exposure to runoff. While recent weather conditions appear to challenge the seasonality of high runoff risk periods (such as the wet summer of 2012), the premise of reducing slurry runoff exposure during winter periods (i.e. "calendar farming") appears founded and will be investigated further in Phase 2.

Socio-economic outcomes

Phase 1 of the ACP explored a range of socio-economic issues and laid the groundwork for longer-term studies concerning farmer attitudes, economic impacts and uptake of new practices which will be completed through the analysis of data to be collected in Phase 2. This research uses data gathered as part of the programme as well as national datasets.

Farmer subjective opinions on the implementation of the NAP were investigated using data collected from a group of farmers in each catchment. The data were analysed to enable the extraction of a number of 'typical' opinion groups with different patterns or shared ways of thinking on the issue. The results indicated four main opinion groups of farmers:

- Farmers that remain unconvinced about the appropriateness of certain measures from a farm management, environmental and water quality perspective (classed as Constrained Productionists).
- Farmers that share some of the same concerns but are generally more positive regarding other farm management and environmental benefits accruing from the regulations (classed as Concerned Practitioners).
- Farmers that indicated quite an environmentalist position and are generally very positive towards regulation implementation and associated environmental and farm management benefits (classed as Benefit Accepters).
- Farmers who have some concerns but are mostly unaffected by the regulations (classed as Regulation Unaffected).

Results from this work suggest that there is acceptance among some farmers of environmental benefits accruing from the regulation but scepticism remains around the validity of certain measures, especially in the area of temporal farm practices such as "calendar farming". Better dissemination of new and existing information on the scientific rationale behind certain NAP measures may help to embed considerations on diffuse pollution and associated nutrient loss into the decision making processes of farmers (Buckley, 2012). In terms of targeted advice resources (and possibly agri-environmental schemes), the profile of farmers relating to Constrained Productionists (and to an extent Concerned Practitioners) may be the groups where extra emphasis is placed on the scientific validity and rationale for the maintenance of NAP measures, especially as these groups are the most likely to embrace the objectives of FoodHarvest2020.

Scope for addressing diffuse nutrient losses was identified and is being explored on an ongoing basis across a range of farm practice areas, both within the catchments and nationally. For example, results from a nationally representative sample of specialist dairy and tillage farms stratified by land use potential indicate that the average farmer applied an extra 23 to 33 kg ha^{-1} of N and 2.9 to 3.5 kg ha^{-1} of P as chemical fertiliser when benchmarked against the most efficient farmers in a nationally representative sample. Potential cost savings on chemical fertilisers across all systems ranged from €39 to €49 ha^{-1}. Some of the main factors influencing efficiency were found to be level of agricultural education, hours worked off-farm and farm size (Buckley and Carney, 2013).

In a survey of catchment farmers with land adjacent to a watercourse, 53% indicated a negative preference for provision of a fenced 10 metre riparian buffer zone under a 5 year scheme. Willingness to adopt the proposed buffer zone was influenced by economic, attitudinal and farm structural factors. The mean payment required by those willing to adopt the measure was estimated at €1.51 m^{-1} per linear meter of stream reach (Buckley *et al*., 2012).

National farm survey data showed that 9-15% cent of farmers nationally would be willing to pay for poultry and pig manures manure respectively and a further 17-28% would import if offered it on a free of charge basis. Demand for these manures is strongest among arable farmers, younger farmers and those of larger farm size with greater expenditure on chemical fertilisers (Buckley and Fealy, 2012).

Knowledge Transfer and Dissemination

The ACP has always been envisaged as a partnership between farmers and Teagasc. For this reason the integration of the advisory and research elements was fundamental to the programme design. Seven of the ACP team (three advisers, three technicians and a technologist) were based in the catchments to ensure that farmers were consulted and supported from the outset and that, through regular contact with the farmers, the programme was highly visible in the catchments. In addition to this local contact the catchments have also been used as focal points for dissemination of information to a wider audience. A range of methods have been used to communicate these messages from the programme.

The main knowledge transfer method used with farmers in the catchments has been one-to-one visits and consultations by members of the ACP team – mainly the advisers. There were approximately 1,800 planned adviser/farmer contacts and many more informal contacts during Phase 1. This regular contact facilitated the imparting of information and advice to farmers as well as the collection of farm management and attitudinal data from the farmers. It also provided a channel for feedback from the farmers about the operation of the programme.

Group activities such as farm walks and farmer meetings played an important part in the knowledge transfer process. The group approach facilitated the sharing of knowledge and ideas among the farmers and stimulated discussion of the issues concerning agriculture and water quality. To raise awareness of the ACP and its findings across the organisation, briefings and catchment visits were delivered to Teagasc advisers and specialists. External groups such as Local Authority staff, students and visiting groups of farmers and other stakeholders were also briefed during visits to the catchments or at meetings and conferences.

The policy of the ACP is to publish only results that have passed the peer-review process required by international scientific journals. Only when this standard has been met were these outputs more widely disseminated. A variety of media were used to aid dissemination of information about the programme and its outputs. These included the ACP website, video clips, radio, television, local and national press, technical publications and scientific journals. Summaries of the papers produced by members of the ACP team and their collaborators using data from the ACP and other appropriate sources are published in this report as part of the dissemination effort.

Chapter 1

Establishment & Operation of the Programme

Under Article 5.6 of the Nitrates Directive (ND) Member States (MS) are required to implement monitoring and evaluation programmes. It states that "MS shall draw up and implement suitable monitoring programmes to assess the effectiveness of action programmes ...." On foot of this the Department of Agriculture, Food and Marine (DAFM) requested Teagasc to prepare an Operations Action Plan for the establishment of an agricultural mini-catchment monitoring programme. In drawing up this request the DAFM defined the objectives for the programme (see below).

1.1 Objectives

- To establish baseline information on agriculture in relation to both the ND and the WFD.
- To provide an evaluation of the NAP measures and the derogation in terms of water quality and farm practices as set down in legislation as the Good Agricultural Practice regulations[3].
- To provide a basis for a scientific review of NAP measures with a view to adopting modifications where necessary.
- To achieve a greater understanding of the factors that determines farmer's understanding and implementation of the NAP.
- To provide national focal points for technology transfer and education for all stakeholders in relation to diffuse nutrient loss from agriculture to water.
- To include any specific monitoring requirements deemed necessary by the River Basin District Management Systems (RBDMS) for the purposes of the Water Framework Directive (WFD) and daughter Groundwater Directive (GWD).

From the outset the integration of the twin goals of profitable farming and good environmental quality was a guiding principle adopted in the planning of the programme.

1.2 Vision

The vision for the Agricultural Catchments Programme (ACP) is a national project of excellence based on a stakeholder partnership which will generate knowledge to underpin profitable food production in a clean environment that will enhance the well being of society. The experiment was designed at the small agricultural scale (c. 10km2) – a novel scale of study and that encompasses all aspects of the nutrient transfer continuum at a high spatial and temporal bio-physical and socio-economic resolution but which also fully accounts for land management by incorporating the influence and feedback of all catchment farmers.

1.3 Background

Irish agriculture must compete in a competitive world food market that is changing and will continue to change rapidly against the background of re-alignments of European agricultural and environmental policies. The ACP was planned against this background with the aim not only to provide the data specified by DAFM but also to generate knowledge and transfer this knowledge to farmers and other stakeholders so as to contribute to the achievement of farming's production and environmental goals.

[3] These regulations essentially constrain the use of agricultural nutrients – comprehensive detail at: http://www.environ.ie/en/Legislation/Environment/Water/FileDownLoad,25133,en.pdf

Farm profitability that contributes to rural development is the main production driver of the programme and this has been somewhat bolstered by FoodHarvest 2020 (FH2020), an industry strategy. The two environmental drivers are the ND and the WFD/GWD.

Nitrates Directive

The European Commission (EC) has provided non statutory draft guidelines for the monitoring of freshwaters required under the ND based on Article 7 of the Directive. These Guidelines provide the broad basis of the national response outlined in the NAP. They identify the need to include phosphorus as well as nitrate but loss from diffuse agricultural sources to water in long rather than short term monitoring programmes which should operate at a number of different scales from field to catchment.

The NAP emphasises that the outputs of such a programme should include a "...valid and transparent evaluation of the efficacy of the NAP measures ….improved understanding of the links between sources, pathways and impact …long term monitoring and demonstration sites that can be used… as national focal points for technology transfer and education…elucidation of socio-economic and behavioural impediments that must be overcome …"

Against this background, Article 27 (1) of S.I. 610 of 2010 states, the Minister for Agriculture and Food shall carry out, or cause to be carried out, such monitoring and evaluation programmes in relation to farm practices as may be necessary to determine the effectiveness of measures being taken in accordance with these Regulations.

The ACP has been developed to address the monitoring and evaluation monitoring requirements outlined above and form an integral part of the national monitoring programme.

The Water Framework Directive

The fundamental aim of the WFD is to protect all waters in rivers, lakes, canals, groundwater, transitional (estuarine) waters and coastal waters and includes terrestrial ecosystems and wetlands directly dependant on aquatic systems. The default objectives of the WFD include the prevention of any deterioration in the existing status of waters including the specific requirement to maintain the "high status" of sensitive waters where they exist and achieve at least "good status" in relation to all waters by 2015. Member States will have to ensure that a co-ordinated approach is adopted for the implementation of programmes of measures for this purpose and can also argue for derogation in target dates over six-year cycles (for example, achieving at least 'Good Status' by 2021 or 2027, etc., with reference to certain bio-physical and/or socio-economic constraints). The WFD is therefore a significantly more integrated and ecologically based Directive with more stringent targets, based on ecological rather than chemical criteria, compared with the ND. It clearly links water quality with land management activities including those associated with agriculture. The ACP focuses on the WFD water quality targets and contributes to the requirements of establishing measures and monitoring their impact. Furthermore, the Groundwater Directive (GWD) is a daughter directive of the WFD and, where appropriate, the success of mitigation measures is compared against specific groundwater thresholds and standards therein.

As a policy package, the ND and WFD/GWD in Ireland are applied in the recognition that there is a potential agricultural contribution to water quality impact (which builds on earlier research[4]) and, while this contribution is part of wider catchment pressures, the challenge is to reduce the reported 15 % groundwater at poor status and 29 % river channel polluted.

[4] http://www.epa.ie/pubs/reports/research/water/ertdireport81.html

FoodHarvest2020

FoodHarvest 2020 has set out the strategy for Irish farming and food for the rest of this decade and, like our water quality targets, is very ambitious. It states that:
'**…**the most compelling picture that emerges of the decade ahead is one of opportunity. In particular, the opportunity for the Irish agri-food industry to grow and prosper sustainably through the delivery of high quality, safe and naturally based produce.'

Targets of a 33% increase in the value of primary output in the agriculture, fisheries and forestry sectors compared to the 2007-2009 average and a 40% increase in the value added compared to 2008 have been set. The target of a 50% increase in milk output presents a significant challenge for farmers and processors in terms of production, health and environmental protection.

The core FoodHarvest2020 strategy focuses on acting Smart, thinking Green and achieving Growth. Improving the efficiency of production at farm level through improved nutrient management is central to achieving the targets; delivering a potential 'double dividend' of reduced costs of production and reduced risk of nutrient emissions from farming. The ACP objectives are well-aligned with this strategy.

2. The Programme Challenge

Scientific evidence

The major scientific challenge for the ACP is to provide the evidence on which the NAP measures can be evaluated. The basis of this is the reduction in the nutrients (nitrogen and phosphorus) leaving agricultural land, transported to water and their impact on its quality. In addition, there is a requirement to identify any modifications to existing measures that are necessary to improve their efficacy where the evidence generated indicates that water quality targets are not being achieved.

This challenge was addressed by tracing back and linking the delivery of nutrients to water through the pathways (soil/subsoil/bedrock) to the source (point and diffuse). The approach is based on a monitoring programme that will generate a long term dataset of nutrient sources, the transport of the nutrients leaving the catchment through the pathways, their delivery to water bodies and their impact on water quality. The data generated in Phase 1 and subsequently will be analysed and modelled to provide the evidence linking the water quality responses to the changes in agricultural practices arising from the implementation of the NAP measures.

The programme considers nutrient delivery to streams and groundwater within the catchments. It does not directly consider the impact of this nutrient delivery on the larger water bodies (rivers, lakes, transitional and estuarine). The relevance and application of the findings to other catchments with contrasting physical, agricultural and social characteristics is a major scientific challenge. In addition, the scaling up of the results to larger areas and the expected timescale for the responses to any changes present further challenges requiring the development and/or the adaptation of models to address spatial and temporal scale. This will be addressed in Phase 2 of the programme through collaboration with suitably skilled and experienced national and international research groups

Integration

The integration of environmental monitoring with profitable farming to provide models for more sustainable agriculture is fundamental to the ACP approach and from the outset there has been an emphasis on encouraging participation by the farming community at national and local level. Apart from the integration of advisers and researchers within the team the Programme has successfully co-operated and collaborated with colleagues in the mainstream Teagasc Knowledge Transfer and Research Directorates to increase the impact of the new information being generated. Considerable success has also been achieved in linking with other stakeholders in local authorities, regulatory bodies and government agencies; in Phase 2 it is planned to substantially increase this aspect of stakeholder engagement.

The participation of the farming community is the cornerstone of the programme and there has been a very successful involvement of the farm organisations through the Consultation and Implementation Group. The programme is generating evidence of the farmers' engagement with the measures, the linkages between nutrient flows on the farm and water quality, the impact of the measures on farm profitability and a greater insight into farmers' attitudes to agri-environmental issues and influences on their decision making. Lack of understanding of the environmental issues that farmers perceive as important to them in carrying on their businesses has caused them legitimate concern in the past and the collection of further socio-economic data in Phase 2 will help to address this deficit.

3. Operational Programme.

The six catchments which have been established by the ACP were selected to cover a range of combinations of farming systems and soil nutrient loss risk scenarios (see Chapter 3).

The outline of the management structure and the operational programme are described below.

Management Structure

From its inception it was agreed that the ACP management structure would include two groups, external to Teagasc, which would play a role in its operation. These are the Expert Steering Group and the Consultation and Implementation Group. A short description of their roles is given below as well as a more detailed overview of the internal Teagasc structures and the ACP team make-up and roles.

Expert Steering Group

The primary role of the ESG, established by DAFM, is to provide expert advice on scientific and operational aspects of the programme and to ensure that its outputs meet the highest international scientific standards and those required in the draft EU guidelines for monitoring the effectiveness of the Action Programme including the derogation.

During Phase 1 of the ACP the ESG met 9 times – the first meeting was in October 2007 and there were spring and autumn meetings each year from 2008 to 2011. The Chair of the ESG rotated among the scientific experts from outside the Irish state agencies.

For each meeting the agenda was determined by the Programme Manager (PM) in conjunction with the DAFM and any issues that required input from the ESG were identified. At the meetings the PM provided a programme update. At the conclusion of each meeting the ESG agreed their recommendations following discussion with the PM and Principal Scientist (PS). These recommendations were recorded in the minutes and incorporated into the operational plan for the programme. The minutes and recommendations were circulated to the ESG members, PM and PS.

Consultation and Implementation Group

The Consultation and Implementation Group was originally established by the DAFM as the Consultative Group for the ACP to facilitate the dissemination to the farming organisations information on the aims, implementation strategy and on-going progress of the ACP and to elicit their views. Following negotiations at the early meetings of the group it was agreed to change the name of the group to the "Consultation and Implementation Group" (CIG) to reflect its critical role in the implementation of the programme. It was also agreed that the CIG would nominate a member to the ESG and Prof James Roche was their nominee.

The CIG met 9 times during Phase 1 of the programme with the first meeting in December 2007. The meeting were chaired by the DAFM and at each of them presentations were made by the PM and other ACP team members reporting on the progress of the programme and focussing on aspects of its operation, experimental design and outcomes.

The CIG has proven to be a very valuable asset in the successful operation of the programme and had provided an effective channel for communicating the sometimes complex issues that have needed to be resolved. These issues were most challenging during the establishment of the catchments and the support and advice of the CIG was a significant help in overcoming some early difficulties.

Programme team

The PM, reporting to Teagasc Head of Crops, Environment and Land Use Programme (CELUP) is responsible for the development, implementation and delivery of the agreed programme. The programme consists of six specific Tasks each of which is the responsibility of the Task Leaders (TL) who report to the PM and PS. The PM, PS and TLs are supported by a Data Manager (DM) and Data Technologist who comprise the Data Management Team (DMT), an Instrumentation Technologist and an Administrative Assistant. The DMT is central to ensuring the collection, management, analysis and interpretation of the large datasets is cost effective and at an appropriate level to provide the scientific evidence for the monitoring and evaluation programme. The Instrumentation Technologist's role is to manage the water quality data stream by ensuring the efficient operation of field and laboratory protocols, analytical field equipment, Laboratory Information Management System protocols and facilitating data quality control protocols with the Programme team prior to final data storage. An overview of the Teagasc management structure for the project team of 16 staff is shown in Figure 1.

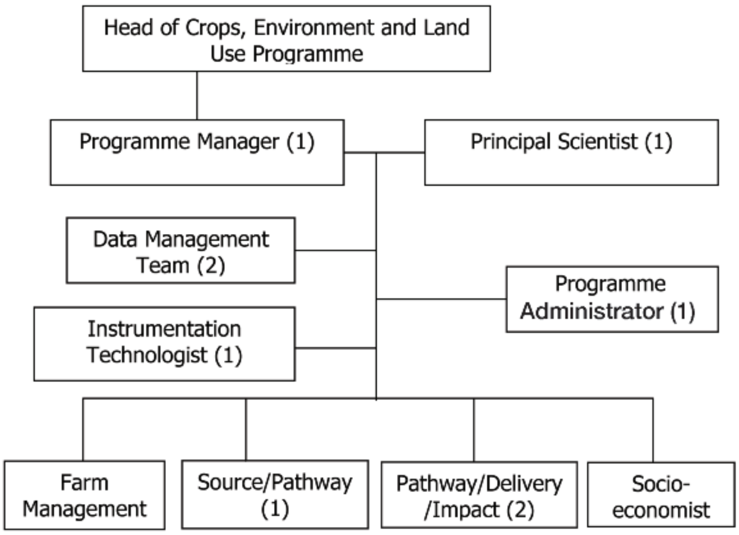


Figure 1. The ACP management structure - the number in brackets represents the number of staff associated with each task.

Task 1- Programme Management

The PM has responsibility for the overall management of the programme and delivery of its outputs. The Administrative Assistant supports the PM and the project team. The objective of the PM post is the development, implementation and delivery of the work programme required to ensure the proposal objectives and any other tasks mandated by the ESG are met within the agreed timeframe. The PS works with the PM to ensure scientific rigour in experimental design and scientific quality of outputs.

Task 2 – Farm Management

Advisory and technical services are delivered in the catchments by teams consisting of and Agricultural Adviser and Technician except for Timoleague which has a Technologist who provides both technical and advisory support. Overall there are three Agricultural Advisers, three Technicians and one Technologist carry out these roles in the catchments; they report to the PM. The Task 1 objectives are

- To encourage, foster and develop local farmer and stakeholder participation in the project.
- To provide participating farmers with detailed development and management advice and planning to ensure farm profitability and environmental sustainability in conjunction with the appropriate Teagasc advisory services.
- To provide detailed baseline data on nutrient inputs and management on participating farms as well as financial records on a representative group of farms.

In addition ongoing farm management data is collected to quantify the nutrient inputs from farm yards (point sources) and field sources (diffuse losses). This data is used to quantify their respective contribution to the pool that forms the source of the field/farm nutrient loss.

The critical role of the Agricultural Advisers in the programme is to encourage active farmer participation and to facilitate access by the programme to their lands for data collection, sampling, equipment installation etc. This task also involves the mainstreaming of the programmes activities with Teagasc Knowledge Transfer programmes and other local/national water quality initiatives to develop the catchments as national focal points for technology transfer.

Task 3 - Source/Pathway

This task is delivered by the programme's soil scientist. The task objective is to link the nutrient sources from the field and farm with the supply of nutrients available for transport and loss to water. The soil scientist works collaboratively with Teagasc's Nutrient Efficiency research sub-programme. The output contributes to the delivery of the scientific evaluation of the effectiveness of the NAP measures through a greater understanding of how farm nutrient decisions determine the supply of nutrients for transport from the farm systems and assist in the identification of possible changes required in the measures to improve their efficacy.

Task 4 - Pathways/Delivery

A Hydrogeochemist and Environmental Hydrologist make up the Pathways/Delivery team and their objective is to link the nutrient sources identified in the Source/Pathway task with the movement of water through the pathways from field/farm to streams leaving the catchment. The Hydrogeochemist investigates the changes in stream water quality in each of the catchments identifying the physical and chemical processes contributing to the nutrient export from the catchments as well as the fate and impact of the nutrients entering the stream. The Environmental Hydrologist works on determining the contributions of water and nutrient that reach the stream via the various surface and subsurface pathways. The approach involves monitoring, data analysis and modelling. The challenges are the complexities of scale involved that arise from the spatial variability of soil physical/chemical properties that determine the pathway, the temporal variability of rainfall and the nutrient transformations that occur in the soil. The output from this task contributes to the scientific evaluation of the effectiveness of the measures through an improved understanding of the pathways and will also provide a basis for any modifications to the measures.

Task 5 - Socio-economic studies

The Socio-economist provides the socio-economic information in relation to the attitudes and awareness of the farming community to water quality issues, the measures used to address them and the potential economic farm level impact of changed agricultural practises arising from compliance with the measures. The Socio-economist also oversees a financial assessment of the farming system. This is undertaken in conjunction with the Agricultural Advisers.

The approach taken is to collect data in relation to socio-economic activity on the farms in the catchments. It involves the establishment of a baseline in Phase1 followed by a review survey of farmers' attitudes in Phase 2. When combined the output from these surveys will be used to identify important issues regarding the farmer's attitudes to nutrient management and water quality protection measures and will seek to identify improved methods of bringing about changes in farm practice. The output from the surveys will also be used to compare the degree to which improved management practices are taken up by farmers involved with the programme versus non non-participant farmers.

The task also involves the collection and examination of detailed farm financial records to determine the financial impact, if any, of the implementation of the measures and to model potential impacts of the introduction of new or modified measures. The collection and analysis of the main attitudinal survey was sub-contracted to a survey company whose recorders did not have any contact with the farmers as this is best practice in the conduct of attitudinal surveys.

The output from this task will contribute to the monitoring and evaluation report by identifying the socio-economic factors that affect the implementation of the measures on farms, the cost implications of implementation and the relative cost effectiveness in terms of reducing nutrient loss.

Task 6 - Data Management, Modelling and Statistics

The objective of this task is to provide the project team with the necessary data management and modelling/statistical support to ensure that the design and analysis of each task can deliver on its objectives, that the management and sharing of all data sets generated is efficient and effective and to integrate and address the scaling up of the catchment results to catchment and river basin district level.

The programme generates very large quantities of farm management, soil, weather, water quality/quantity, attitudinal, spatial and cost data from each of the catchments. These very large data volumes from disparate sources require careful collection, quality control and storage. This task poses substantial challenges in areas such as tracking and using existing data; collection and integration of new data which is often captured and stored in hardcopy and other inflexible formats and limited data sharing and linkages due to both technical issues involving the inflexibility of storage/retrieval systems and organization cultural issues.

To meet these challenges an information management system has been built for the ACP on the following key guiding principles:

- Most efficient data capture and integration from multiple sources retaining the spatial component of collected data
- Industry standard data storage and management
- Flexible and timely distribution of data to all identified users for analysis and reporting
- Seamless integration into existing corporate-wide geospatial and database systems

While the DMT provides modelling and statistical support for the team a collaborative approach will be used to ensure that the ACP gains access to the most appropriate models and modellers internationally. Links have already been established in Phase 1 with key researchers at a number of universities and institutes and these will be developed to ensure that the large amounts of high-quality data held by the ACP is exploited as fully and as expertly as possible.

The publication of the results in peer reviewed journals is the most effective QC on the programme outputs to underpin DAFM reporting requirements to the Commission. The high resolution water quality monitoring programme combined with the detailed sources and pathway data requires new statistical and modelling techniques to be developed to assess the effectiveness of the measures, to advise on possible changes necessary to improve their efficacy and cost effectiveness and to extrapolate the results to other areas. Modelling will also be used to develop conceptual frameworks that can be used to integrate productivity data with the wider environmental impacts. These will include not only water quality but gaseous emissions. This integration will contribute to the knowledge that will deliver the crucial but delicate balance between farm profitability and society's environmental objectives required for a sustainable rural environment.

Chapter 2

Catchment selection

Key messages

- Catchment selection was based on a novel spatial analysis tool which used national spatial datasets, expert opinion and stakeholder engagement and was followed up with site selection field work to assess programme suitability
- Six catchments were subsequently chosen as examples of grassland and arable agriculture over varying soil types and with different considerations of phosphorus and nitrogen transfer risk

Synopsis

Catchment selection was based largely on a multi-criteria decision analysis process linked to a geographical information system. The process was top-down and, as far as possible, no *a priori* considerations were used.

Following elicitation through the ACP Expert Steering Group (ESG), a number of criteria were considered to shortlist candidate catchments. The starting point was catchment scale, or area, to provide for the programme objectives and enable elements of stakeholder engagement and practical management. A search pattern was set at headwaters of no less than 4 km^2 and no greater than 12 km^2.

National spatial datasets were used for this purpose and 1,517 catchments within this scale were identified (Fig. 1). These were filtered according to four principle landuse types (grassland, arable, woodland, other) and then by maximising landuse intensity within landuse parcels and minimising non-agricultural landuse (Table 1). Each landuse category was weighted for importance using expert judgement.

This process ranked catchments according to programme suitability; the next filtering process was based on whether the ranked and nutrient susceptible catchments were predominantly grassland or predominantly arable. A final filtering stage was based on whether the soil/geological controls on hydrology were likely to cause a phosphorus risk to nutrient transfer (lateral runoff susceptibility) or a nitrogen risk to groundwater (vertical leaching susceptibility).

Field investigations started from the most suitable catchments remaining after the previous filtering process. These included knowledge exchange with local Teagasc agricultural advisors and on-site reconnaissance to gauge the suitability of establishing long-term hydrometric instrumentation. Four grassland and two arable catchments were initially chosen and paired according to regional staff planning. Two of these catchments were abandoned due to site and stakeholder issues subsequently identified.

The ESG determined that along with the four remaining, a low residence aquifer, groundwater dominated catchment would be required. As this was not possible to identify as a discrete catchment entity, a karst contributing area was identified following data mining of individual spatial data layers and subsequent site visits. This was also coincident with the EU's specific interest in western-lake protection in the karst region.

Table 1. Criteria used to select catchments showing the influence and source of the national datasets.

Selection Criteria	Limits/Direction	Source Dataset
Size (km^2)	≥4 and ≤12	EPA catchment
Stream Order	≤ 3	EPA catchment
Forage (% area)	Maximise	LPIS (2006)
Grazing intensity (LU ha^{-1})	Maximise	DAFM statistics (2007)
Arable (% area)	Maximise	LPIS (2006)
Non Ag (% area)	Minimise	LPIS (2006)
Housing density (buildings km^{-2})	Minimise	Geodirectory (2007)
Peat soils (% area)	Minimise	IFS Indicative soils map

Following the identification of this fifth 'catchment' a further grassland catchment was identified from the ranked dataset of suitable grassland catchments and based on drumlin soils.

The final inventory of six catchments included exemplars of grassland and arable, P transfer risk to surface water considerations and P and N transfer risk to groundwater considerations (Fig. 3).

This catchment selection process (up to the stage of five catchments) is described in detail in Fealy *et al*. 2010.

Reference

Fealy, R. M., Buckley, C., Mechan, S., Melland, A., Mellander, P. E., Shortle, G., Wall, D. and Jordan, P. (2010) The Irish ACP: catchment selection using spatial multi-criteria decision analysis. Soil Use and Management, 26, pp. 225-236.

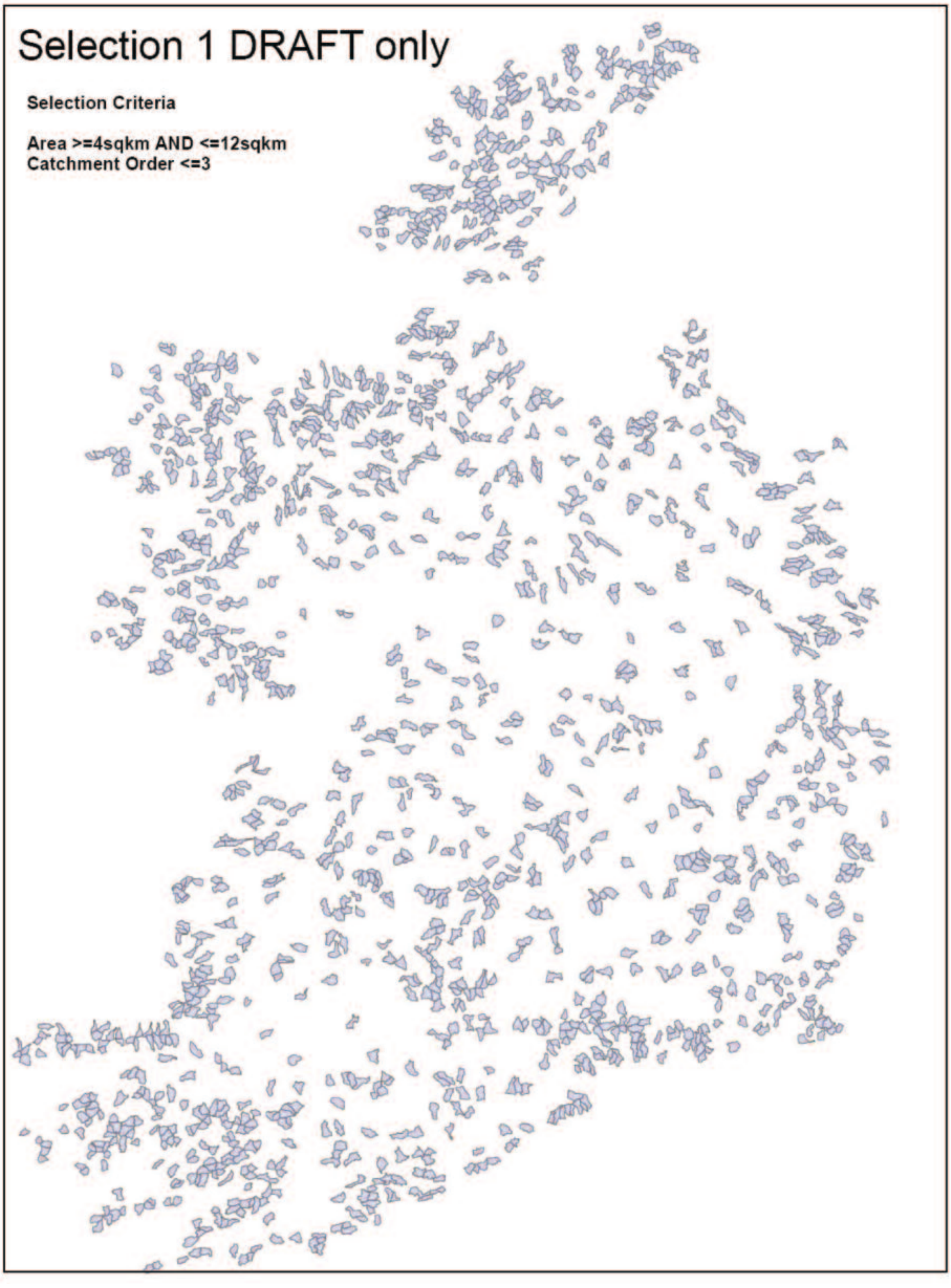


Figure 1. Map of Ireland showing the delineation of all possible catchments within the range 3-12 km^2. These were used as a starting point on which to rank suitability according expert weighting of further selection criteria.

A final inventory of ranked grassland and arable catchments was produced with identification of P and N transfer risk. The fifty most suitable from each landuse were isolated and investigated for programme suitability (Fig. 2). These investigations included desk studies of potential fatal flaws such as current and future road building plans.

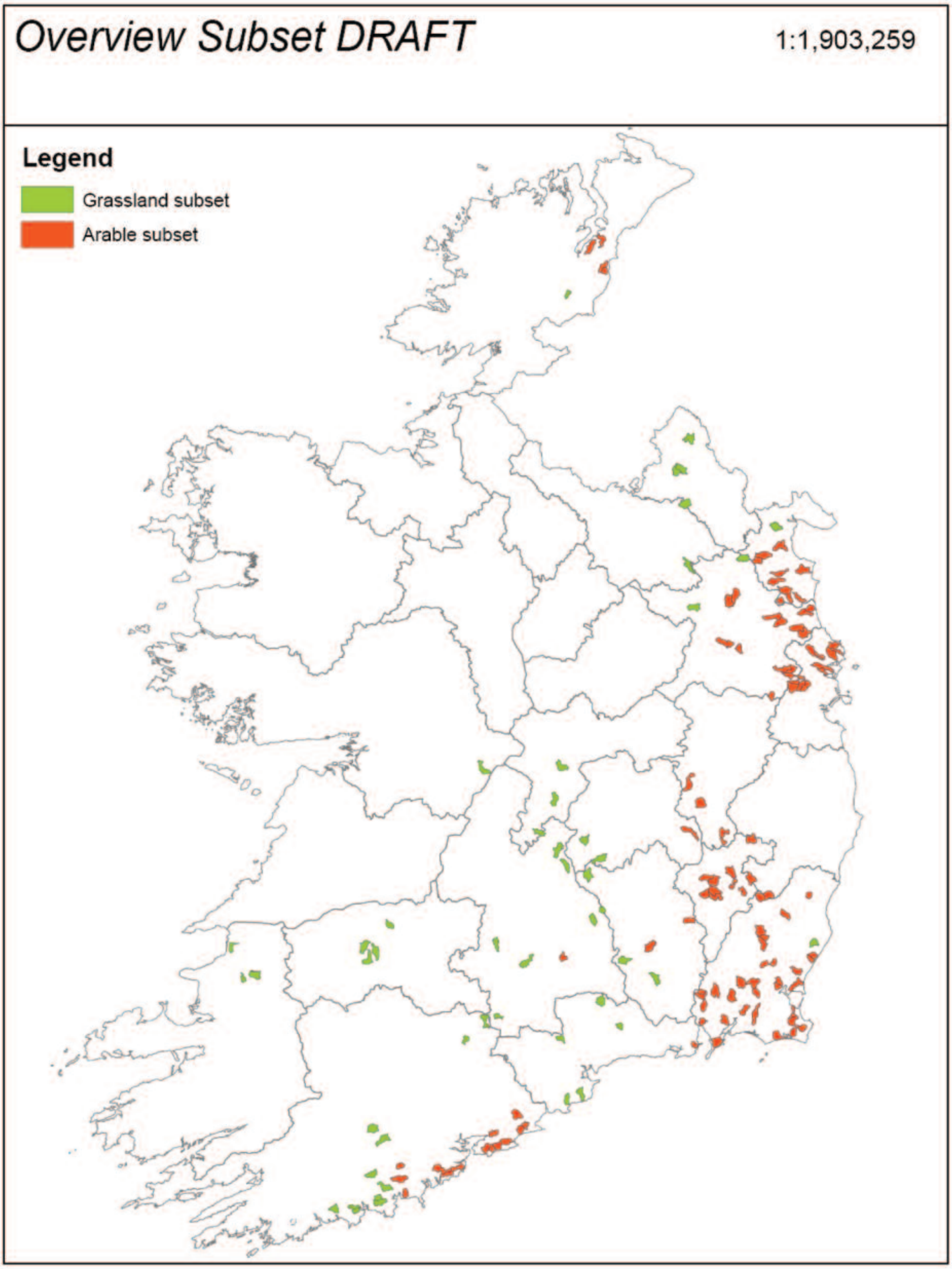


Figure 2. Highest fifty ranked grassland and arable catchments following the multi-criteria selection approach.

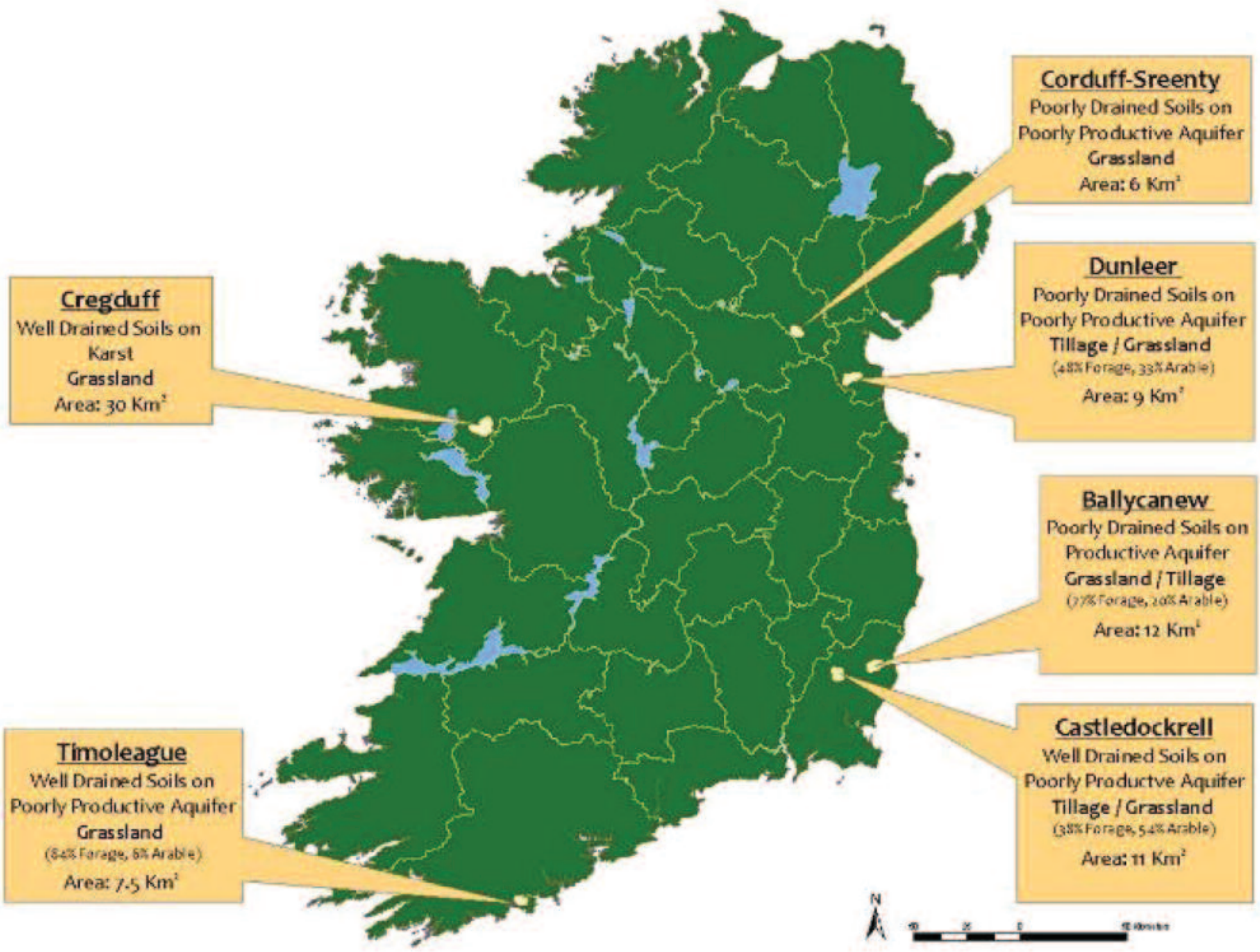


Figure 3. Final selection of catchments based on a landuse and nutrient susceptibility gradient.

Chapter 3

The Six Agricultural Catchments

1. Sreenty/Corduff

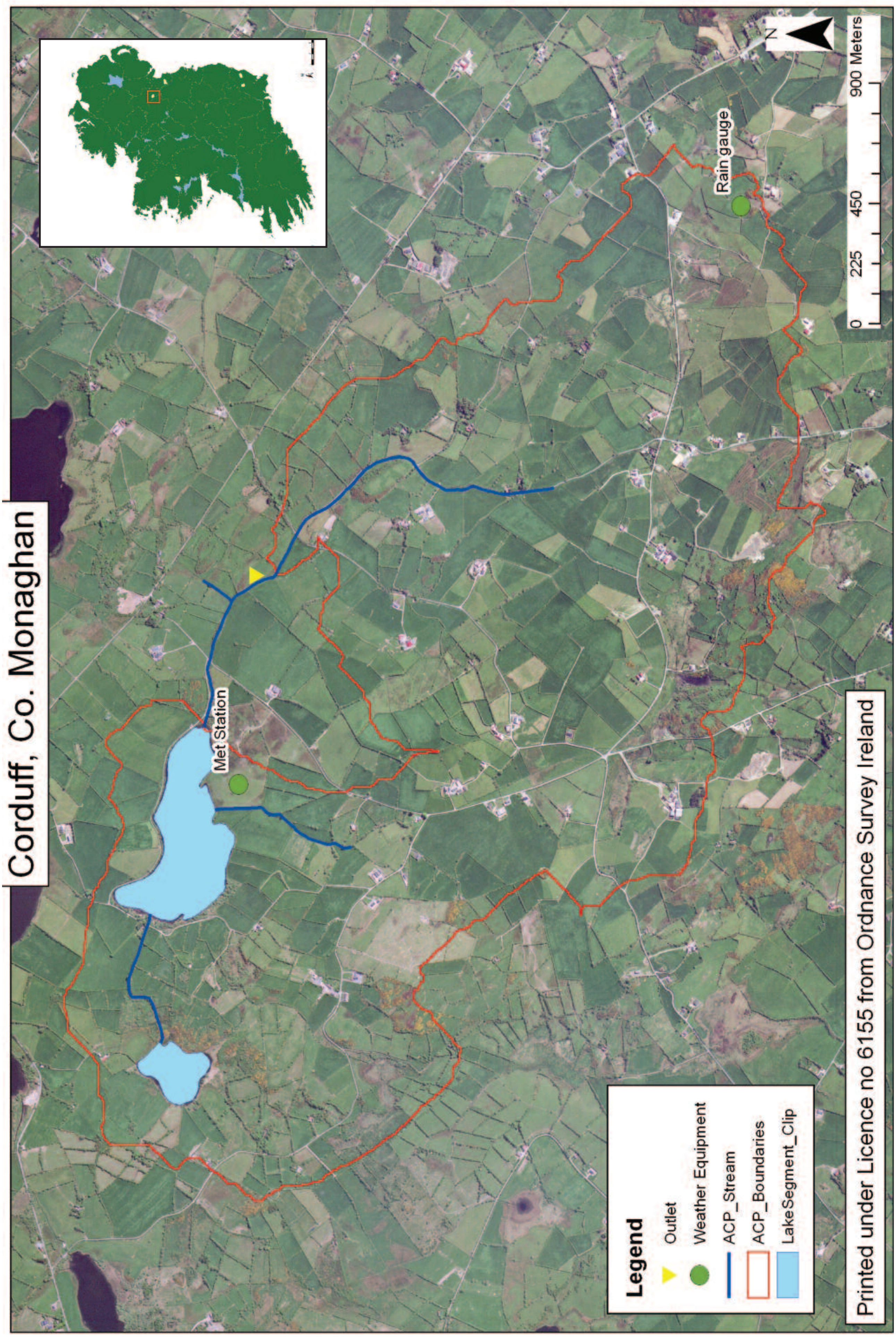
The Sreenty/Corduff site is comprised of two adjoining catchments and is located north west of Carrickmacross in Co. Monaghan. The northern catchment drains into Sreenty Lake while the southern one is drained by a stream like the other stream catchments in the programme. The two catchments are 578ha in combined area and 89% of the area is grassland with the balance in non-agricultural uses. The main farming enterprise is beef production with some dairying, sheep and horse production.

These catchments are in an area where the topography ranges from alluvial flatlands to variously shaped, recurrent drumlins with fairly steep slopes and with intervening U-shaped valleys. These drumlin features were formed when the advancing glacial ice sheet moved over this area compressing the till deposits into interlocking hump backed hills. There are often small lakes in the valleys and this catchment has two, the larger of which is Sreenty Lake.

The soils vary with the nature of the till deposits and vary from drumlin to drumlin. The underlying rock is mainly sandstone in this catchment and the glacial till is relatively free draining and can be quite shallow. Acid brown earths dominate the hill tops, with stagnic luvisols and gleys on the hill slopes, foot slopes and valley bottoms. Given the soil type and topography phosphorus is considered the main nutrient at risk of loss to water.

Sreenty Lake is the water source for the local group water scheme. The lake outflow and the stream join just downstream of the two catchments and flow into the Annaghlee/Erne system.

Sreenty Lake – catchment drumlins in background


Corduff, Co. Monaghan
Met Station
Rain gauge
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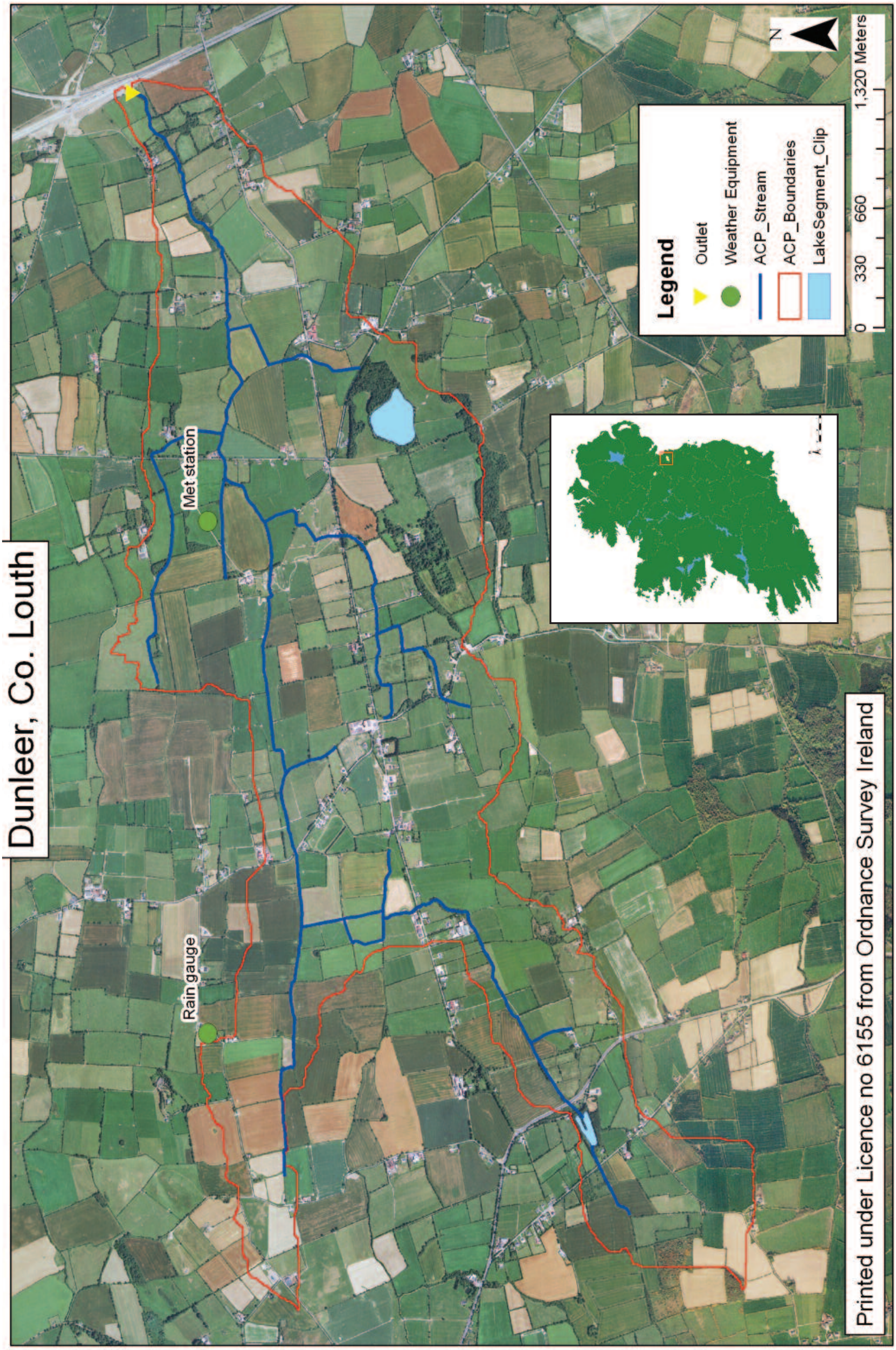
2. Dunleer

The Dunleer catchment lies west of the village of Dunleer, in Co. Louth. It is just over 948ha in area and in a typical year half of the land is in grass with a third in tillage, however this varies somewhat from year to year. The balance of the land is in woodland and other uses. Winter wheat is the main tillage enterprise in the catchment but with considerable areas of other crops such as winter and spring barley, oil seed rape and potatoes. A substantial area of the land is rented on the 11-month conacre rental system and much of the tillage, especially potato production, is carried out on this land. The use of the conacre system means that management responsibility of a significant proportion of the land changes from one farmer to another from year to year making the collection of farm management records more of a challenge. The grassland area of the catchment is mainly used for dairying and beef production with some sheep, goat-dairying and horses.

In this catchment the influence of past glacial movement is apparent with its undulating landscape dissected by ditches and streams and many different deep soil types derived from glacial drift underlain by greywacke and mudstone geology. The dominant soils in this catchment are typical surface water gleys and stagnic/gleyic brown earths or gleyic luvisols. In the better drained areas on the head slopes well drained brown earths and luvisols belonging to the Dunboyne soil series dominate. On the hill slope and foot slope areas gleyic luvisols and stagnic brown earths belonging to the Fethard soil series, are more prevalent, these soils exhibiting impeded subsoil drainage. In many of these soils artificial drainage has improved water flow making them suitable for both grass and crop production. Pockets of gleyic brown alluvial soils adjoin the stream in the valley, 70% of the catchment is classified as poorly drained and so phosphorus is considered the main nutrient at risk of loss from this site through overland flow. There is a much smaller risk of nitrogen loss through leaching on the more freely drained soils mainly. The main division in the catchment is between the northern (better drained) and southern (more poorly drained) ridges.

Dunleer catchment – mid-summer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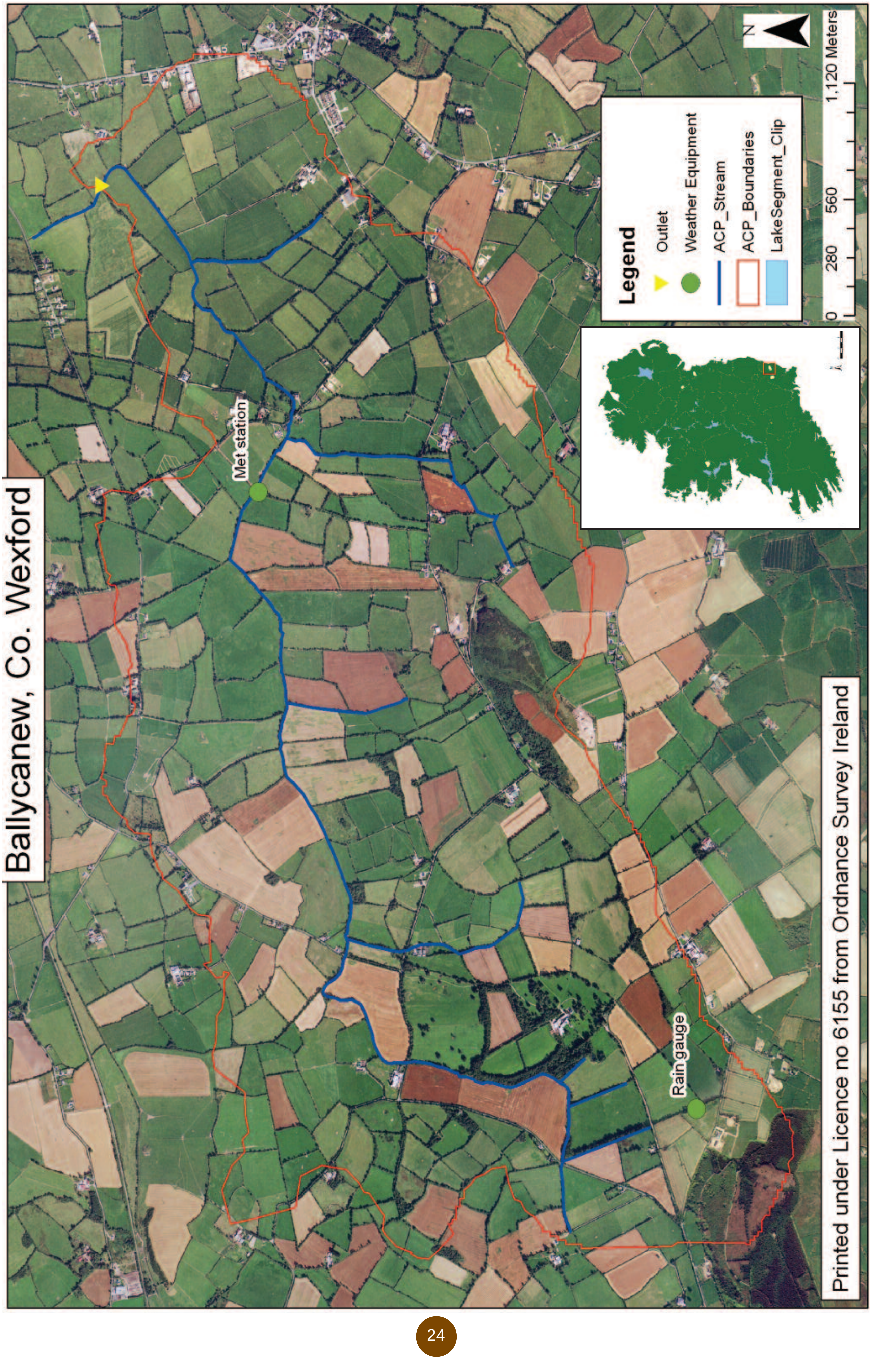
3. Ballycanew

The Ballycanew catchment is located just north of the village of Ballycanew, near Gorey in Co. Wexford. It is 1,191ha in area and grassland makes up approximately 78% of the landuse with 20% in tillage and the balance in woodland and other uses. The main grassland-based farm enterprises are beef production and dairying with some sheep production and sport horses. Spring barley is the main tillage crop with small areas of other cereals.

Ballycanew catchment – mid winter

The dominant soils in the lowland of this catchment are surface water gleys, mostly belonging to the Kilrush and Macamore soil series. These soils are derived from glacial till which includes a large component of marine muds giving them poor drainage characteristics. The drainage in this area has been improved somewhat by the owners through tile and mole drainage. The soils on the elevated land to the southern catchment boundary are non calcareous brown earths over a geology of rhyolite-andesite agglomarates with slaty mudstones and felsic volcanics. Tillage in the catchment is limited to this area. With good management the heavy soils in the catchment are well suited to grassland farming and dairying is expanding in the area.

Based on the type of soil and subsoil in this catchment phosphorus would be considered to be the main nutrient at risk of loss to water in the heavy lowland soils. The main pathway for loss would be through overland flow during heavy rain events.


Ballycanew, Co. Wexford
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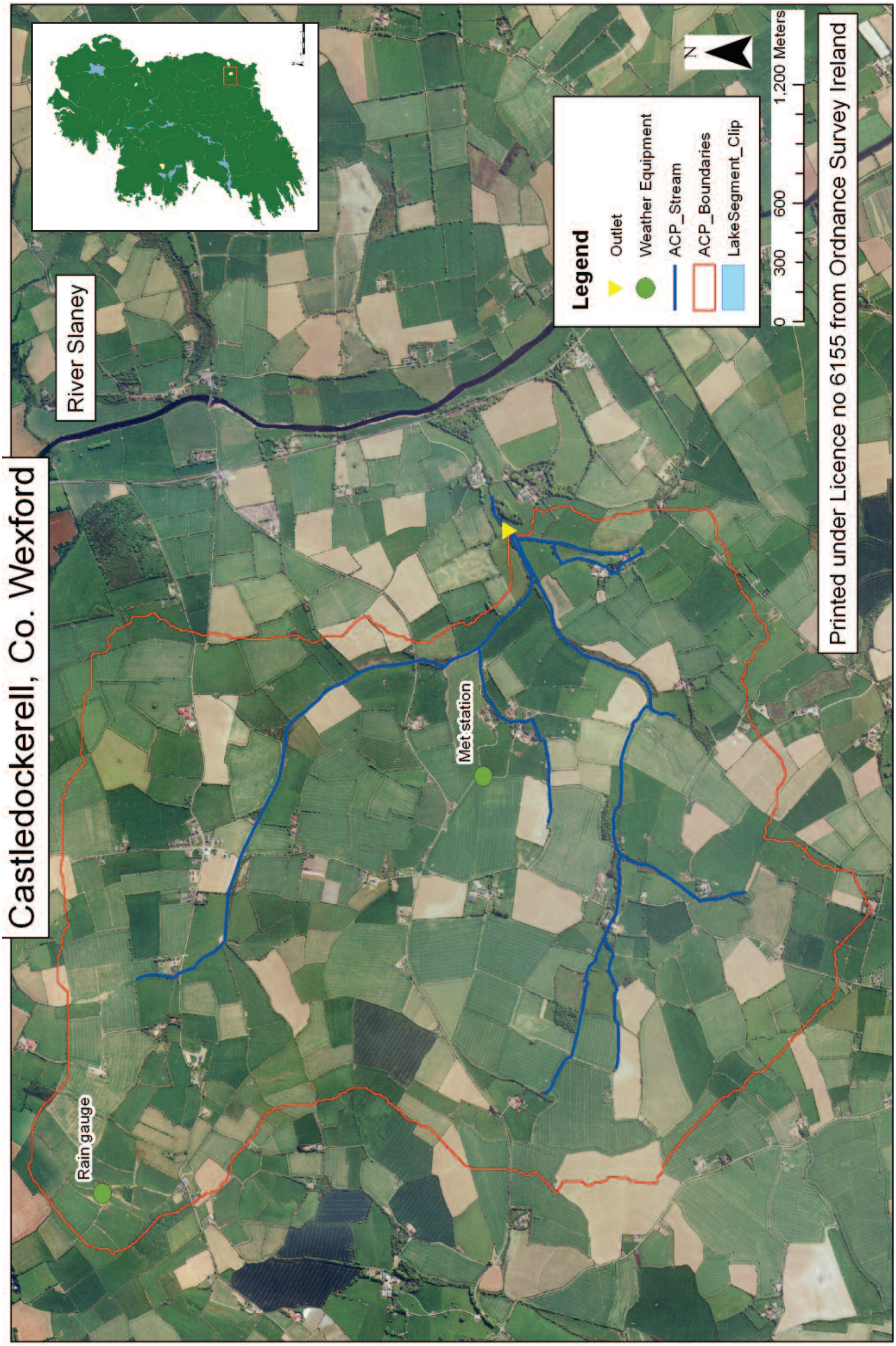
4. Castledockerell

The Castledockerell catchment is situated between Enniscorthy and Bunclody in Co. Wexford. The stream that drains the catchment is a tributary of the Slaney River which drains much of the south-east region. It is 1,117ha in area and in a typical year 54% of the catchment area is used for tillage with 39% in grass and the balance in non-agricultural uses. The type of farming in the catchment is typical of the tillage/drystock mix that is found in much of the south-east and south of Ireland on well-drained soils.

Castledockerell catchment – autumn sowing

Spring barley production is the main tillage enterprise with some other cereals such as winter barley as well as some oil-seed rape and potatoes. Sheep production is traditional in the area and is still carried on by many farmers as well as beef production. The majority of the land in the catchment has free draining typical brown earth soils, belonging to the Ballylanders and Clonroche Soil Series. These soils, which are underlain by slate and shale geology, are ideal for spring barley growing. In the low lying areas near the stream there are some poorly-drained groundwater gley soils, most of which are artificially drained.

Based on the type of soil and subsoil in this catchment nitrogen is considered to be the main nutrient at risk of loss to water and the main pathway for loss is considered to be leaching through the soil to the groundwater.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5. Timoleague Catchment

The Timoleague catchment is located south of the village of Timoleague near Clonakilty in west Cork. It is 758ha in area and 85% of the land is in grass with 4% in tillage. The balance of the area is used for non-agricultural purposes. Dairying is by far the predominant land use in this catchment and the stocking rate is among the highest in the country. The West Cork area where the catchment is located is representative of the most intensively farmed dairying areas in Ireland. It has the highest concentration of dairy farms in the country with large herds producing milk using an intensive, grass-based system.

Only a small proportion of the catchment is not used for dairy farming. This area is used for beef and sheep production on the grassland and a variety of tillage crops including spring and winter barley and wheat, oil-seed rape and maize. The maize is used to produce silage mainly for winter fodder on the dairy farms. There is also a small area of fodder crops such as kale grown for grazing in the winter.

Timoleague catchment – grass-based milk production

The soils in this catchment are brown earths over old red sandstone geology belonging mostly to the Clashmore and Ballyglass soil series. They are well drained with the exception of small areas of gleyic brown alluvial soils neighbouring the stream in the valley bottoms. These soils support a long growing season and early livestock turnout, and are generally well suited to the grassland dairy production that dominates in this catchment. Based on the free draining nature of the soils nitrogen would be considered the main nutrient at risk and the main loss pathway would be leaching through the soils to the groundwater. The stream that drains the catchment flows directly into Courtmacsherry Bay.


Timoleague, Co. Cork
Met station
Rain gauge
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Outlet
Weather Equipment
ACP_Stream
ACP_Boundaries
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6. Cregduff Catchment

The Cregduff catchment is estimated to be 2,998ha in area and is situated to the east of Ballinrobe in Co. Mayo. Grassland makes up 92% of the landuse with only 1% arable and the rest in non-agricultural use. It was chosen to represent areas of free-draining, shallow soils over karstified limestone. The karst landscape, as found in Cregduff, is typical of much of the area which contributes groundwater to the three large western lakes, Lough Corrib, Lough Mask and Lough Carra. Groundwater pathways predominate in this type of landscape and there are few if any open drains or streams given the free-draining nature of the soils and the underlying karstified limestone with its network of fissures, and conduits. The Cregduff spring, which is used to supply water to the local community, was selected for monitoring based on water quality and discharge data collected by the EPA.

Dolines and swallow features are prevalent here, as dissolution of the underlying bedrock proceeds, leading to collapse and depressions at the soil surface. The area has many turloughs or seasonal lakes which fill up during the winter and recede each year in the spring as the water table falls.

The western half of the catchment, closest to the spring, has shallow soil, mostly less than 3 m deep, where the epikarst is often exposed to the surface. The eastern half of the catchment has somewhat deeper soils with brown earths and brown podzolics on the head slopes and typical and humic rendzina soils on the hill slopes and foot slopes. In the turlough areas groundwater gleys and peat soils dominate due to the fluctuating groundwater. Based on the typically shallow soils, karst geology and connection to the surface through the exposed karst features, both nitrogen and phosphorus would be considered at risk of loss to the groundwater in this catchment. The main nutrient loss pathway is through direct connection of the soil surface and runoff through the karst system to the groundwater.

Cregduff catchment – spring grazing dairy cows with receding turlough lake

Most of the farms in the catchment produce beef cattle and sheep at moderate stocking rates. There are a number of dairy farms which make up a significant area of the catchment and which are intensively farmed with high stocking rates and high inputs of nutrients from imported fertilisers and feedstuffs.

The spring at Cregduff flows into the Bulkaun River, a tributary of the Robe which flows into Lough Mask just to the west of Ballinrobe.


Cregduff, Co. Mayo
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Met Station
Rain gauge
Rain gauge
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Chapter 4

Experimental Design

Key messages

- A common experimental design is applied to all ACP catchments.
- This is based on the nutrient transfer continuum conceptual framework considering nutrient sources, mobilisation, pathways and delivery, and impacts in river catchment.
- Socio-economic components are cross-cutting and gauge financial and farm management consequences and farmer opinion towards agri-environmental policies.
- The design allows for audits for comparison against national standards and also to increase knowledge of the causal relationships between the agricultural contribution to water quality issues which will be important in future reviews of agri-environmental policies.

Synopsis

The experimental design of the ACP follows a similar framework in each catchment. This framework is based on a nutrient transfer continuum conceptual model from sources to impact (Fig. 1). Nutrient mobilisation and pathways to delivery from land to water are also considered.

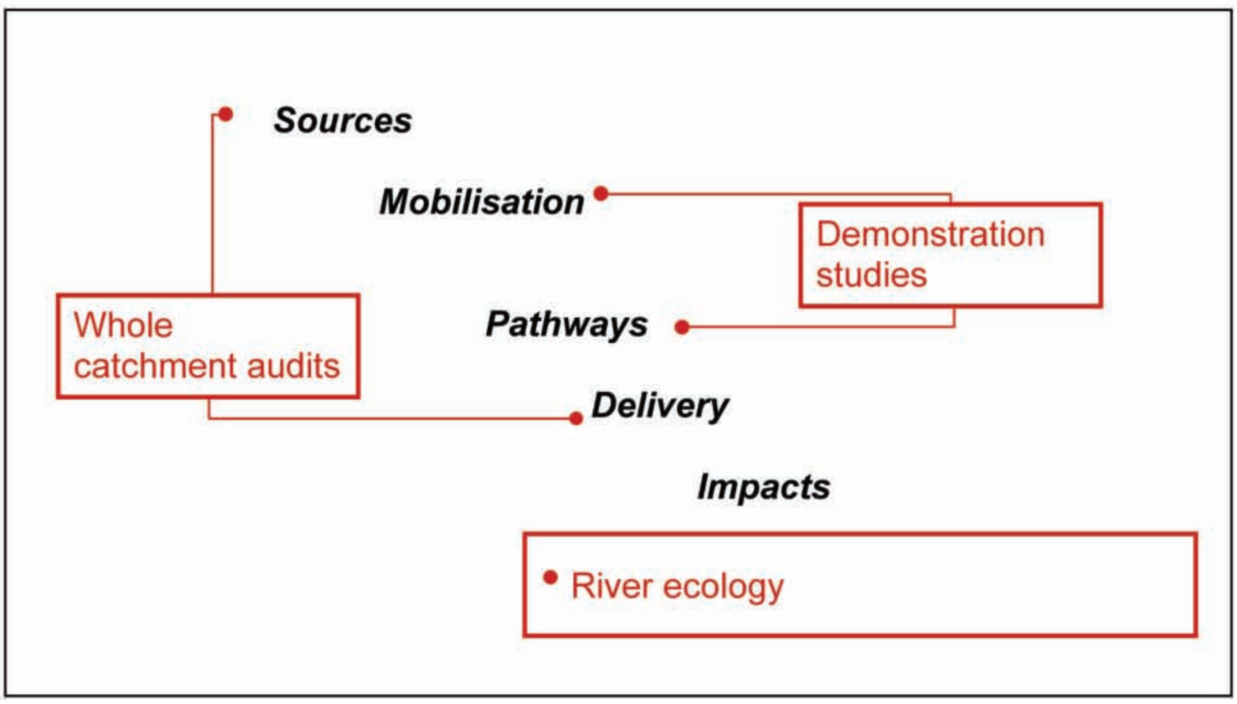

Figure 1. Conceptualisation of nutrient transfer continuum and as an experimental design for the Agricultural Catchments Programme.

An emphasis on high-resolution monitoring, wherever this is possible, has been applied according to established precepts on diffuse pollution issues which are related to soil hydrology and weather patterns.

The ACP experimental design considers the Nitrates Directive NAP at source level and national water body surveillance regulations at the impact level; both being part of the Water Framework Directive assessments in the Republic of Ireland.

Nutrient sources (use and status) are being audited, as far as possible, on a whole-catchment basis (field-by-field with a maximum sample area size of 2ha). This high spatial resolution coverage includes inventories of nutrient use and soil status (Fig. 2) for direct comparisons with NAP regulatory standards.

Mobilisation potential of P is being studied by soil P chemistry attributes of key soil types and subsurface pathways of P and N are being studied in a series of representative multi-level bore holes where vertical flux of nutrients was hypothesised to occur at the catchment selection stage.

Delivery of nutrients to the river system and passage out of the study catchments is being monitored at new hydrometric stations installed as part of the programme. Combined with in-situ sub-hourly P and N analysis (with supporting metrics of turbidity and conductivity), the monitoring stations provide a high resolution audit of nutrient flux at all stages of the hydrological cycle (Figs. 3&4).

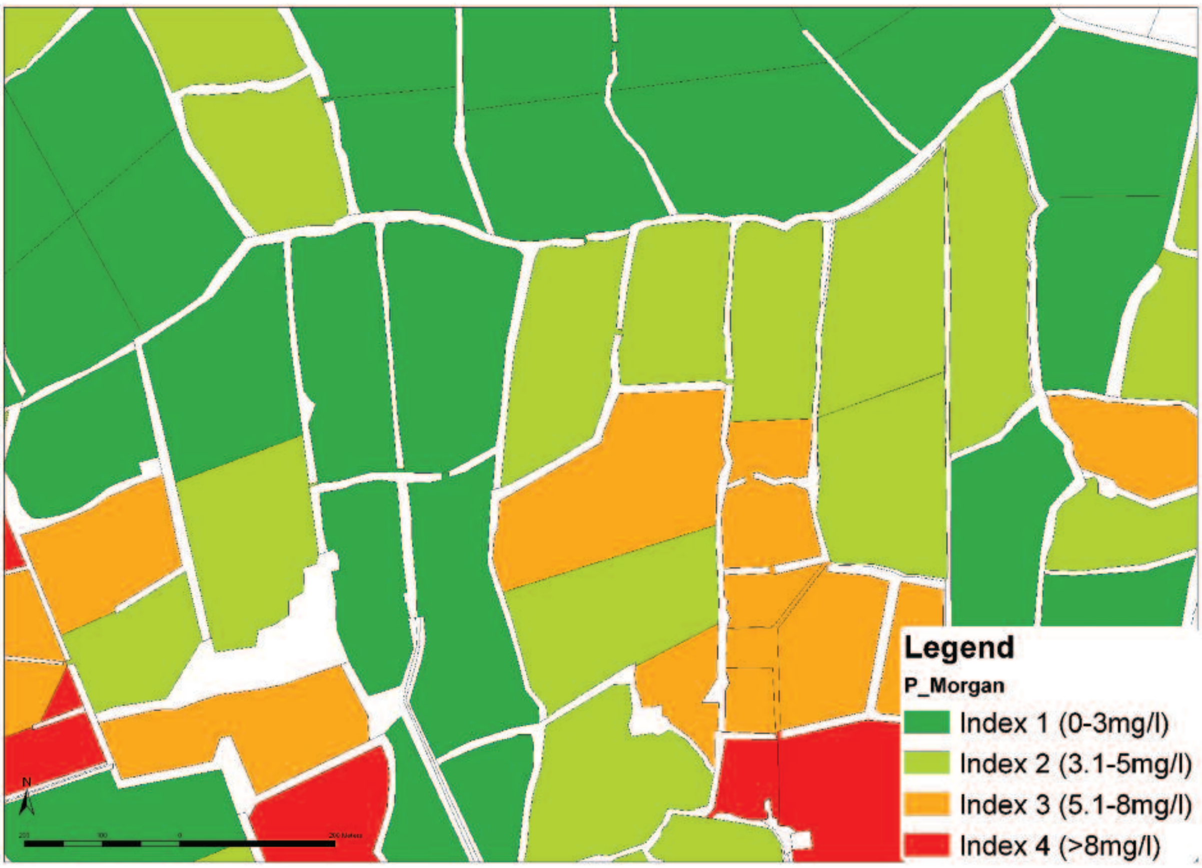

Figure 2. Example of a section of a whole catchment audit of soil phosphorus status, a major source component in the nutrient transfer continuum, which is regulated under the Irish NAP.

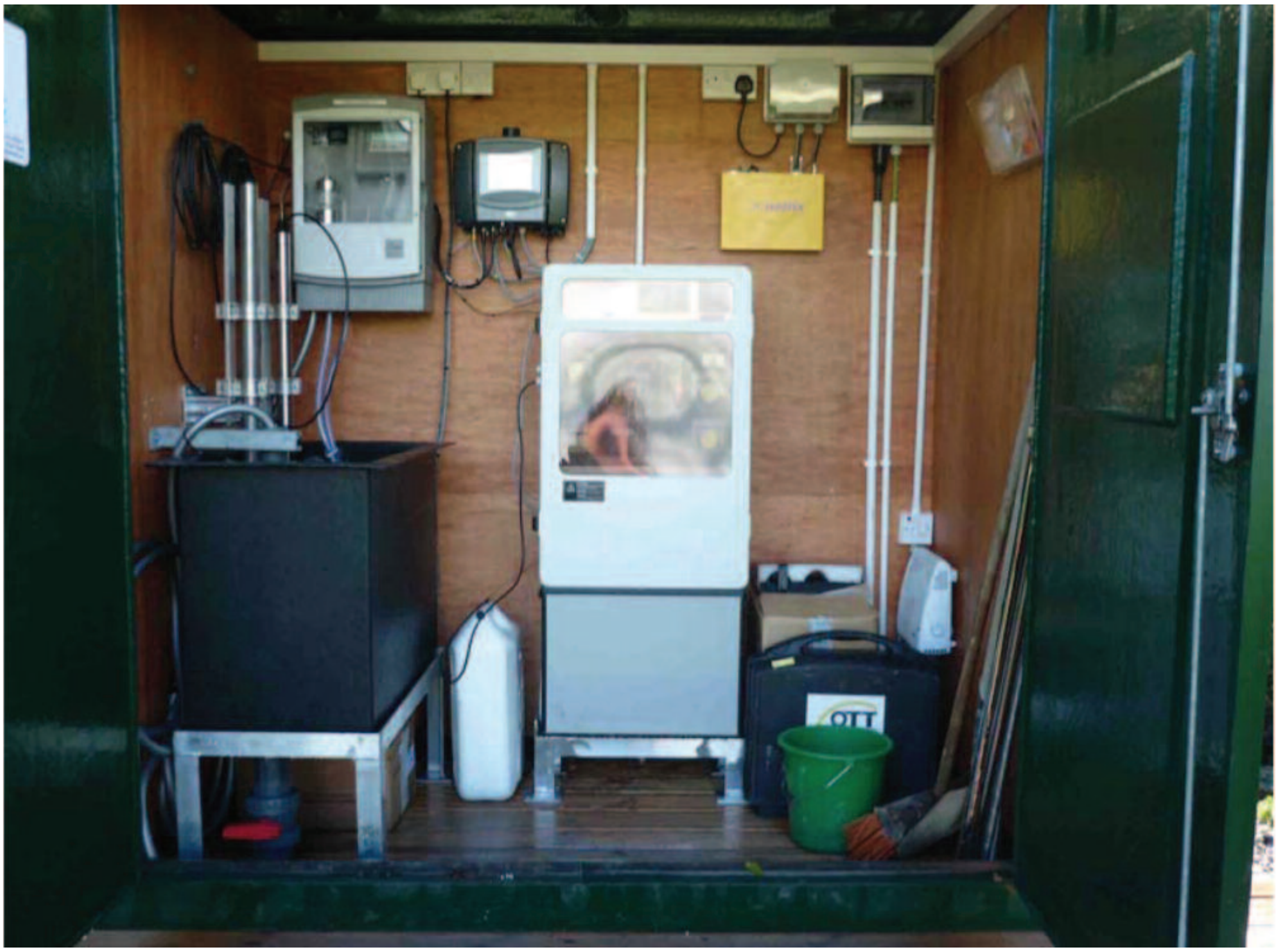

Figure 3. Example of equipment in a high-resolution water quality monitoring station at the outlet of a study catchment. Each station monitors two fractions of phosphorus (TP and TRP), nitrate (as TON), turbidity and conductivity on a sub-hourly basis and synchronous with river discharge. Within each catchment are various snap-shot water quality monitoring sites, meteorological stations and groundwater bores (as appropriate for the catchment). Data are accessed manually and via a telemetry link and managed in the WISKI 7 time-series database management system.

The ecological impact of nutrients in the ACP catchments is being assessed using a suite of national and international ecological monitoring tools based on diatoms, macroinvertebrates, macrophytes, filamentous algae and fish. Metrics of hydromorphology are also used.

A socio-economic element is cross-cutting and is designed to gauge the financial, farm management and attitudinal aspects of the NAP. Included is an evaluation of advisory services related to agri-environmental policies.

As well as providing state-of-the-science catchment experimentation and infrastructure, the design also provides the ability to question causal relationships between nutrient sources and water quality impacts and the role played by the agricultural component in catchments. This will be important in interpreting such relationships in wider, national surveillance monitoring – but where the monitoring resolution is less – informing expectations of recovery where other forcing factors (such as hydrometeorology and rural point sources) are present, and moderating reviews of mitigation measures.

This experimental design is described in detail in Wall et al. (2011).

Figure 4. Example of outlet monitoring infrastructure based on a hydrometric control weir and water level recording equipment. All water quality monitoring equipment are housed in the green 'kiosk'.

Reference

Wall, D., Jordan, P., Melland, A.R., Mellander, P.-E., Buckley, C., Reaney, S.M. and Shortle, G. (2011) Using the nutrient transfer continuum concept to evaluate the European Union Nitrates Directive National Action Programme. Environmental Science and Policy, 14, 664-674.

Chapter 5

Sources

5.1 Forecasting soil P decline

Key messages

- NAP measures aim to reduce soil test P (STP) levels from excessive (P Index 4) to agronomically optimum (P Index 3) to reduce the risk of P loss to water. In this study a 'Soil P Decline' model was used to evaluate this expectation for 4 ACP catchments.
- At a field P deficit scenario of -7 kg P ha^{-1} it was predicted that an average of between 5 and 20 years would be required for all Index 4 soils to reach index 3. At -30 kg P ha^{-1} it was predicted to take between 2 and 10 years. These predictions highlight the likely time lag between implementation of soil P mitigation regulations and the desired outcome of few or no fields with excessive soil P.
- Expectations for water quality improvement through diffuse P source mitigation must also factor in additional time for P decline model uncertainty, land management variability, and time for P to transfer to and within river networks.

Synopsis

The NAP measures aim to reduce soil P levels from excessive (Index 4; > 8 mg l^{-1} for grassland and > 10 mg l^{-1} for arable) to agronomically optimum (Index 3) to reduce the risk of P loss to water over time. However, it is likely that there will be a time lag between implementation of these measures and achievement of reductions in soil P level. In this study a 'Soil P Decline' model (Schulte *et al.* 2010) was used to evaluate this expectation for 4 ACP catchments; two grassland-dominated and two arable-dominated (Table 1).

Table 1. Catchment area, total rainfall, percentage area of catchment occupied by different soil types and predominant landuse for each catchment soil type.

Catchment	Area and rainfall for 2010	Soil type and % of area		Predominant land use for different soils
Grassland A	7.47 km^2	Typical Brown Earth	91	Grass (dairy)
		Shallow Brown Earth	6	Grass (dairy)
	1013 mm	Groundwater Gley	1	Grass (dairy)
		Other	2	Other
Grassland B	12.07 km^2	Undifferentiated Gley	71	Grass (beef & dairy)
		Typical Brown Earth	16	Grass & Arable (spring barley)
	999 mm	Shallow Brown Podzolic	11	Grass (beef & dairy)
		Other	2	Other
Arable A	11.27 km^2	Typical Brown Earth	72	Arable (spring barley)
		Shallow Brown Earth	14	Grass (sheep)
	921mm	Groundwater Gleys	13	Grass (beef & sheep)
		Other	1	Other
Arable B	9.40 km^2	Gleyic Brown Earth	44	Arable (winter wheat) & Grass
		Groundwater Gley	29	Grass (beef & dairy)
	820 mm	Typical Brown earth	21	Arable (winter wheat) & Grass
		Other	6	Other

Soil P status in the catchments reflects management history, with the intensive dairy farming catchment (Grassland A - Timoleague) having the highest number of soil sampling units in Index 4 (141) and a higher mean P concentration of these Index 4 soils (19.74 mg l^{-1}) than the less intensive grassland catchment (Grassland B - Ballycanew) (32 and 10.44 mg l^{-1}, respectively) (Fig. 1). The two arable catchments had similar numbers of Index 4 soil sampling units (76 and 68) and mean Index 4 P concentrations (14.27 and 15.68 mg l^{-1}). Current soil P status reflects the legacy of historical management practices. High soil P status fields (Index 3 and 4) mostly occur in dryer fields or fields adjacent to farm yards.

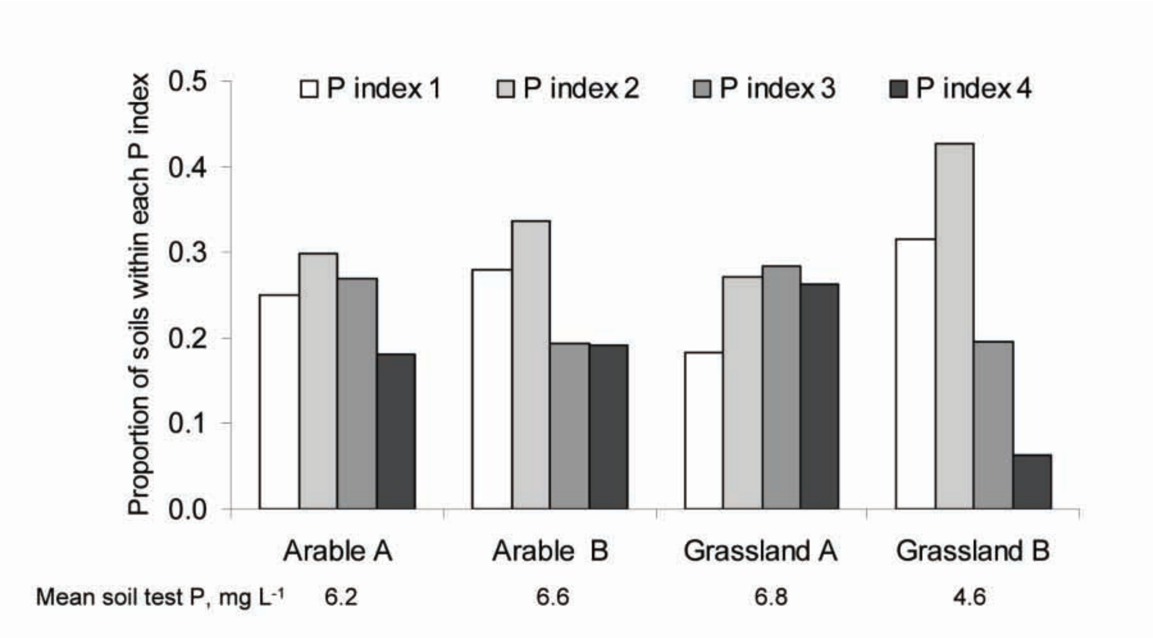

Figure 1. Area-weighted proportion of soils within each phosphorus index (data bars) and area-weighted mean soil test phosphorus (Morgan's extractable-P, mg L^{-1}) for each catchment.

Three field P deficit scenarios were modelled; at -30 kg P ha^{-1} there are no limitations to reduce STP (e.g. silage fields or arable fields with P applications withheld), at -15 kg ha^{-1} there are some limitations to reducing STP (e.g. silage fields or arable fields with only slurry P applications) and at -7 kg P ha^{-1} there are severe limitations to reducing STP (e.g. a grazed field on a farm with all fields in Index 4, a reasonably high stocking rate and with slurry recycled evenly across the farm). At a field P deficit scenario of -7 kg P ha^{-1} it was predicted that an average of between 5 and 20 years would be required for all Index 4 soils to reach Index 3 (< 8 mg l^{-1}). At -30 kg P ha^{-1} it was predicted to take between 2 and 10 years.

For the intensive dairy catchment (Timoleague), the model predicted that there will still be soils in Index 4 in 2015 (WFD reporting year), even at a deficit of -30 kg P ha^{-1}, reflecting the higher number of soils with very high STP values in this catchment (Fig. 2). The dominance of Index 4 soils is predicted, on average, to have abated by 2014 for the less intensive grassland catchment (Ballycanew). For the two arable catchments, under the moderate and large P deficit scenarios, 10% or less of the original Index 4 soils were predicted to remain by 2015.

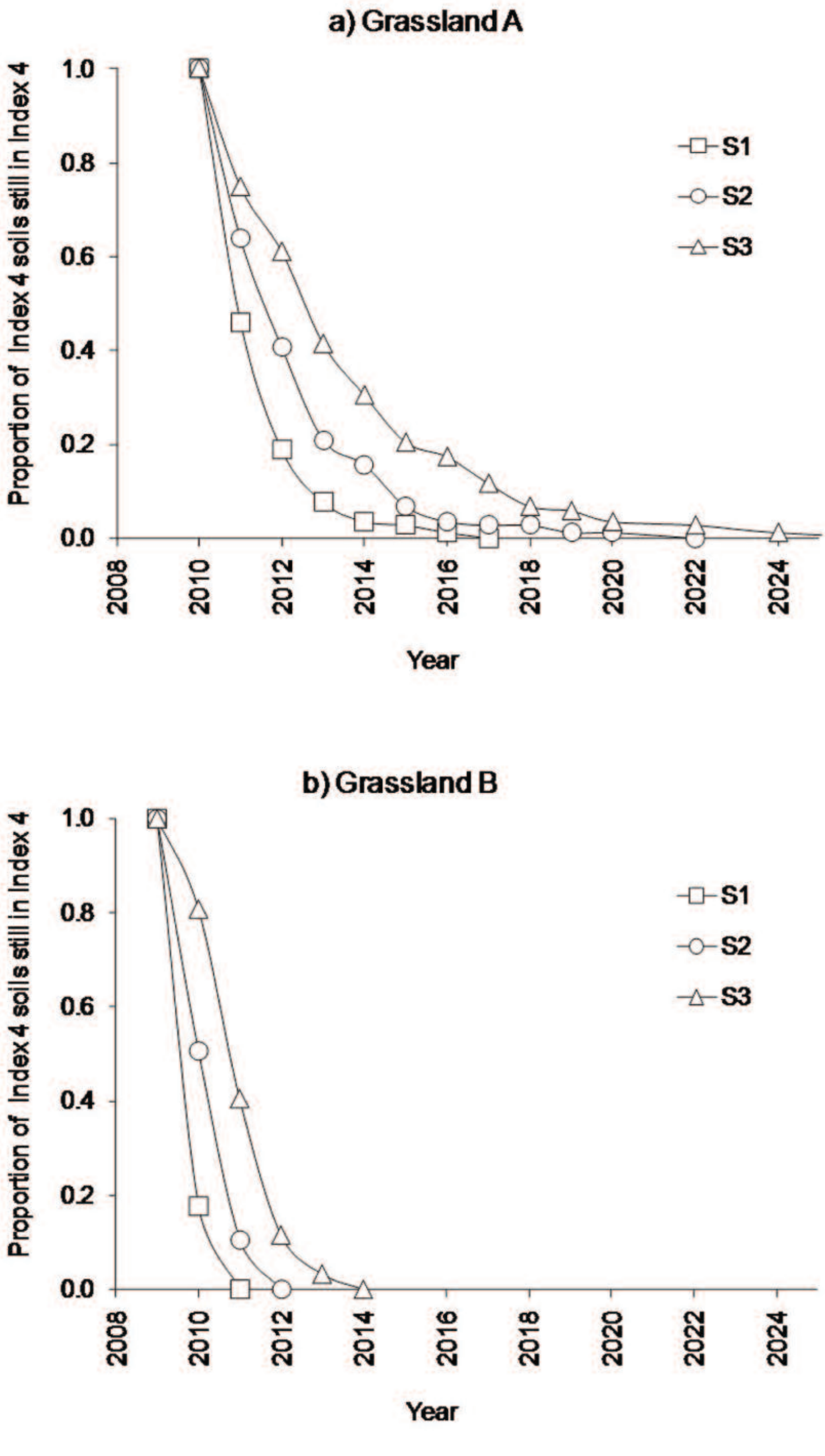

Figure 2. Expected prevalence of P index 4 soils over time, for three P deficit scenarios (S1, S2, S3, corresponding to -30, -15 and -7 kg ha^{-1} yr^{-1} respectively), for the Grassland A and Grassland B catchments.

A number of points were highlighted regarding the current NAP measures and their effects. On non-derogation farms, if no soil test is available, fertiliser P can only be applied at a replacement rate which limits P inputs and potential build up. However, where soils have sub-optimal STP levels (Index 1 and 2) the restriction of P application may have a negative impact on yield and quality of crops. Nevertheless, P additions at replacement rates on soils already above optimum (Index 4) may present a further P transfer risk. While the less intensive grassland catchment has a lower proportion of Index 4 fields and these are predicted, on average, to decline rapidly, other evidence (see Jordan et al., 2012) suggests that this Grassland B catchment is more risky due to soil hydrological properties rather than soil chemical properties. The current NAP measures do not explicitly account for these other factors affecting P loss risk.

The decline to optimum soil P status remains a desirable aim for both agronomic efficiency and environmental risk objectives (and used, with assumed P deficits, as a scientific basis for extending WFD targets beyond 2015 in some (I)RBDs). Expectation of soil P decline can be realised under P deficit scenarios but concerted effort on management and advice needs to be focussed to realise these deficits without losing production. Expectations for water quality improvement through diffuse P source mitigation must also factor in additional time for P decline model uncertainty, land management variability, and time for P to transfer to and within river networks.

This work is described in detail in Schulte et al. (2010) and Wall et al. (2012a).

References

Jordan, P., Melland, A.R., Mellander, P.-E., Shortle, G. and Wall, D. (2012). The seasonality of phosphorus transfers from land to water: Implications for trophic impacts and policy evaluation. Science of the Total Environment, 434, 101- 109.

Schulte, R.P.O., Melland, A.R., Fenton, O., Herlihy, M., Richards, K. and Jordan, P. (2010) Modelling soil phosphorus decline: Expectations of Water Framework_Directive policies. Environmental Science and Policy, 13, 472-484.

Wall, D.P., Jordan, P., Melland, A.R., Mellander, P-E., Mechan, S., and Shortle, G. (2013). Forecasting the decline of excess soil phosphorus in agricultural catchments. Soil Use and Management. 29 (Suppl.1) 147-154

5.2 Evaluating nutrient source regulations at different scales

Key messages

- This paper evaluated nutrient sources and regulations at a range of spatial scales (national, catchment, farm, field and soil process).
- At the national level, P fertiliser use has declined by 6 kg ha^{-1} (55 %) for grassland and 5 kg ha^{-1} (16-30 %) for arable crops between 2003 and 2008. The proportion of tested soils with excessive P (Index 4) has declined from 30 % to 22 % between 2007 and 2011.
- In 5 ACP catchments, between 6 and 26 % of soils had excessive P status, showing the legacy of historic P surpluses. Large spatial variability was found at farm and field scale, indicating scope to correct imbalances with better nutrient management.
- Significant differences in P attenuation and loss were found between the catchments, reflecting different soil types. Regulations do not currently reflect these differences.
- A better farm scale nutrient management tool, accounting for the influence of soil type and landscape hydrology could be useful to improve the spatial distribution of nutrients on-farm.

Synopsis

Linking the effects of agricultural management practice to impacts on water quality is challenging in terms of deciding on appropriate measurement scales.

At the national level, P fertiliser use, based on Lalor et al. (2010) has declined by 6 kg ha^{-1} (55 %) for grassland and 5 kg ha^{-1} (16-30 %) for arable crops between 2003 and 2008 (Fig. 1). Over the same period, N fertiliser use has declined by 27 kg ha^{-1} (24 %) for grassland and 15 kg ha^{-1} (2-10 %) for most arable crops. The sharpest decline was from 2006 onwards, the proportion of soils tested by Teagasc with excessive P (Index 4) has declined from 30 % to 22 % between 2007 and 2011 (Fig. 2).

At the catchment scale, in 5 ACP catchments, between 6 and 26 % of soils had excessive P status, showing the legacy of historic P surpluses (Fig. 3). For the grassland catchments, soil P status reflected land use intensity with 26 % of soils in Index 4 in the intensive dairy catchment (Timoleague), decreasing to 16 % and 6 % with decreasing land use intensity in the other two grassland catchments (Cregduff and Ballycanew respectively). The corollary of this is that 74 to 94 % of soils in the grassland catchments have agronomic capacity to receive P applications for maintenance or build-up of soil P reserves to agronomic optimum level (Index 3; 5.1-8 mg l^{-1} for grassland). The two arable catchments (Castledockerell and Dunleer) had a similar proportion of Index 4 soils, at 18% and 19%.

At the farm level, whole farm P balances for 5 sample farms (one in each catchment) in 2010 showed that the dairy farm in the lowest intensity grassland catchment had the highest farm gate surplus (16.5 kg ha^{-1}), while the beef-tillage farm in the winter-wheat dominated arable catchment had the highest farm gate deficit (-12.6 kg ha^{-1}). The tillage-lamb farm in the spring barley-dominated arable catchment (1.7 kg ha^{-1}), the dairy farm in the intensive dairy catchment (1.9 kg ha^{-1}) and the beef-lamb farm in the grassland catchment of intermediate intensity (-0.7 kg ha^{-1}) were closer to being in balance. However, when the soil P requirement is considered (level of fertiliser P required to build-up and maintain agronomic soil P levels), these balances become negative, even for the highest dairy farm surplus above. An intensive dairy farm with an N derogation in the intensive dairy catchment had just 4 % of the farm area requiring soil P additions and low P fertiliser imports on this farm resulted in an overall farm P deficit of -4.5 kg P ha^{-1}.

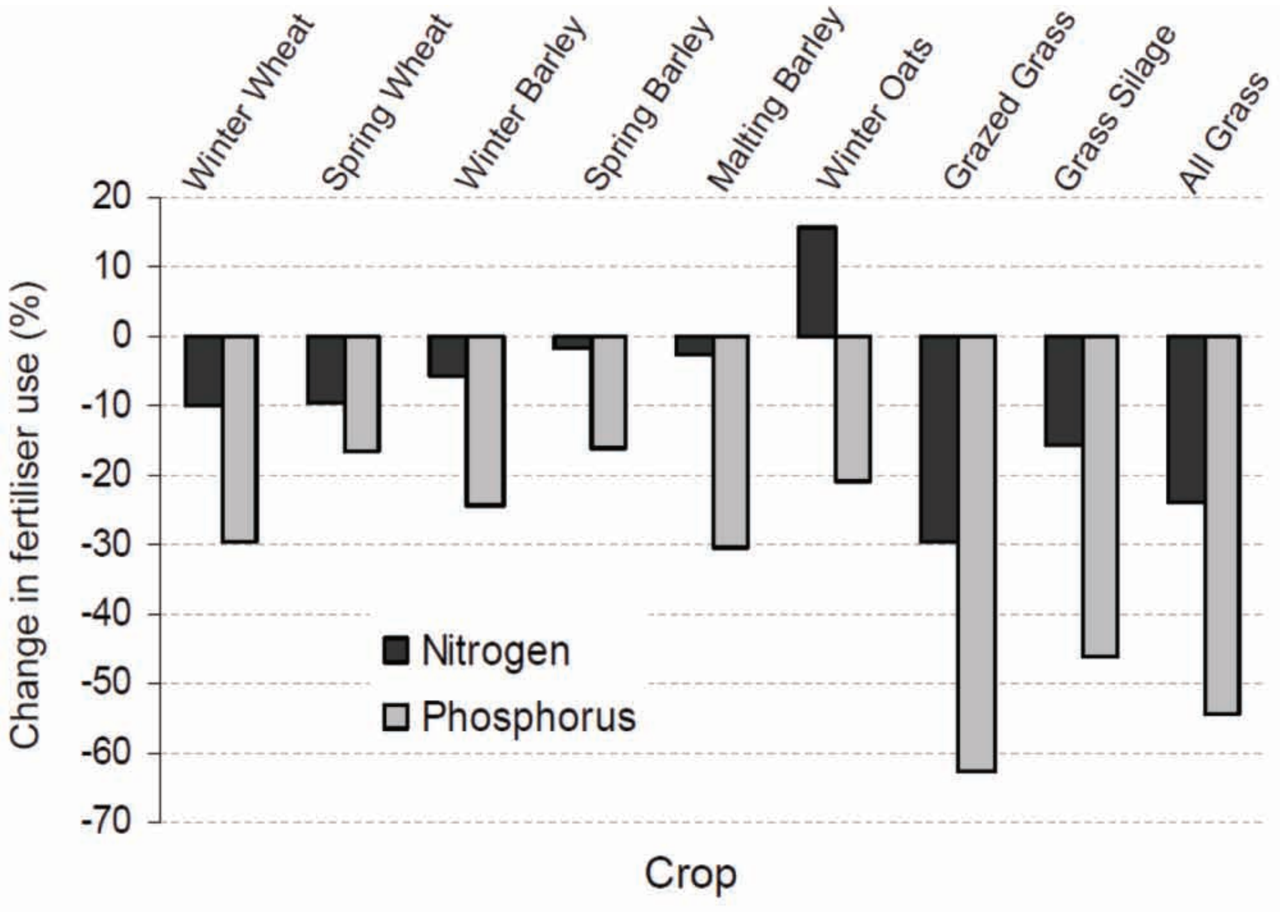

Figure 1. National nitrogen and phosphorus fertiliser use trends between 2003 and 2008.

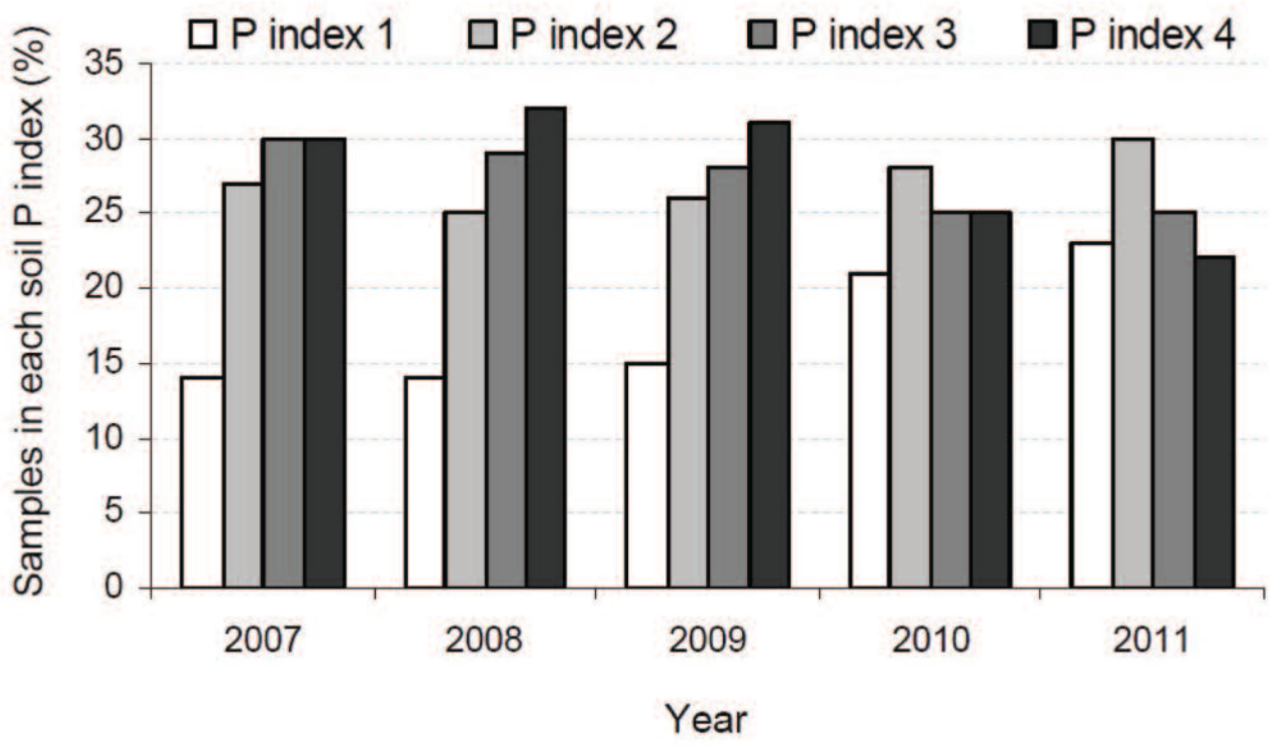

Figure 2. National soil phosphorus fertility trends for samples submitted for analysis to Johnstown Castle Laboratories between 2007 and 2011.

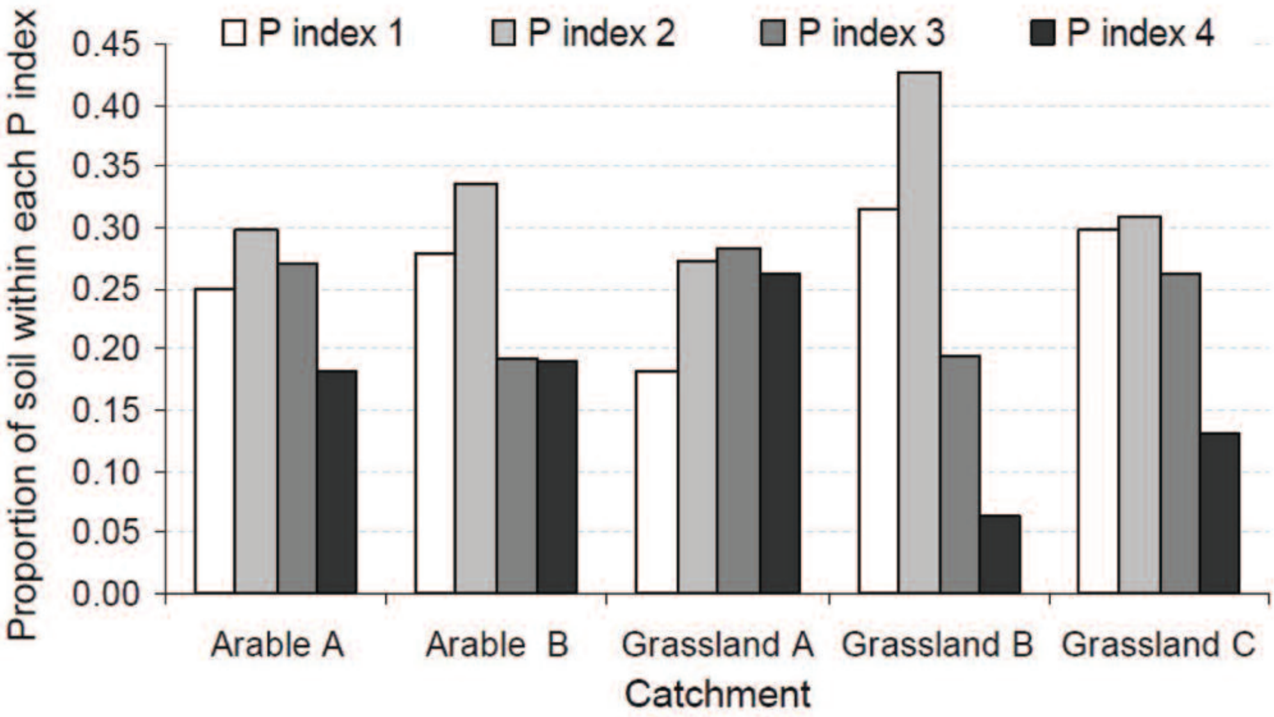

Figure 3. The area-weighted proportion of soils within each phosphorus index for each catchment- Arable A (Castledockerell), Arable B (Dunleer), Grassland A (Timoleague), Grassland C (Cregduff)

At the field scale, large spatial variability was found (Fig. 4), indicating scope to correct imbalances with better nutrient management on farms and redistribute P to lower status soils, potentially increasing P use efficiency and decreasing P loss risk. The large spatial variability is associated with historical nutrient management practices such as slurry application on fields close to the farmyard.

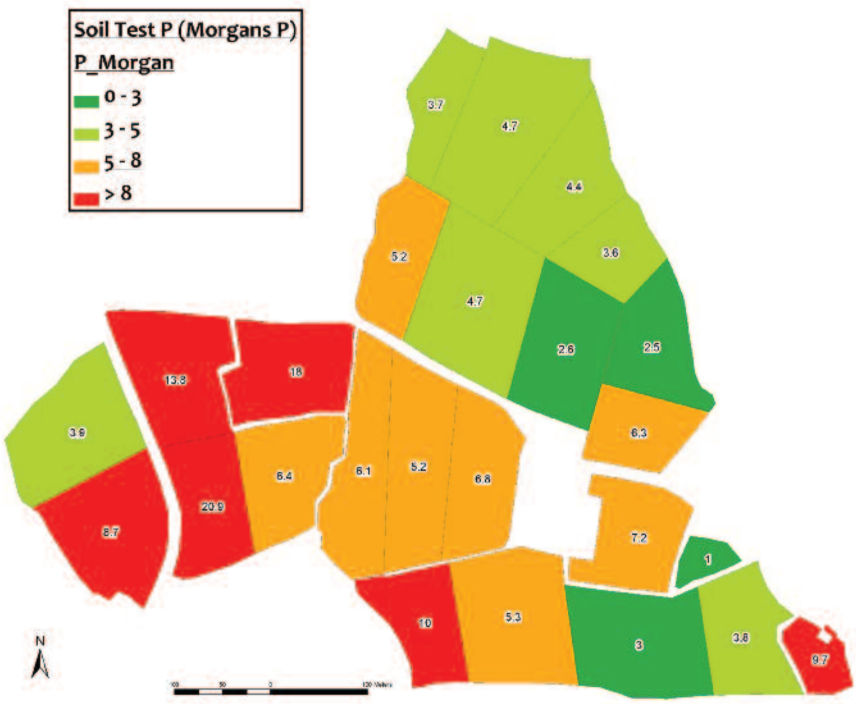

Figure 4. Spatial representation of soil phosphorus status across a farm holding. Soil test phosphorus levels (Morgan's extractable-P, mg L^{-1}) and the corresponding soil phosphorous index are given for each field.

Trends in soil P status, fertiliser P inputs and surplus P availability can be misrepresented at larger scales (national, catchment, farm scale) and may be better represented at smaller scales (field, soil process scale) where management and soil factors can be considered. Results demonstrate the importance of a multi scale monitoring approach including national, catchment, farm, field and soil process scales for a complete overview and understanding. A better farm scale nutrient management tool, accounting for the influence of soil type and landscape hydrology could be useful to improve the spatial distribution of nutrients on-farm.

This work is described in detail in Lalor et al. (2010) and Wall et al. (2012b).

References

Lalor, S, Coulter, BS, Quinlan, G., Connolly, L., 2010. A survey of fertiliser use in Ireland from 2004-2008 for Grassland and arable crops. Teagasc end of project report. ISBN 1-84170-557-8.

Wall, D.P., Murphy, P.N.C., Melland, A.R., Mechan, S., Shine, O., Buckley, C., Mellander, P-E., Shortle, G. & Jordan, P. (2012). Evaluating agricultural nutrient source regulations at different scales in five Irish catchments. Environmental Science and Policy, 24:34-43

Chapter 6

Pathways

6.1 Nutrient transfer pathways

Key messages

- Surface hydrological connectivity by surface (overland) or near-surface flow, might not be as important in nutrient transfer from land to water as is often assumed in some catchments of high permeability soils and aquifers.
- Current NAP measures targeted at surface nutrient sources (soil nutrient status and nutrient inputs) may provide a more effective mitigation of nutrient loss over time in landscapes of high permeability, than supplementary measures such as buffer strips which target overland flow pathways (notwithstanding the multi-functional nature of such features).
- Due to the long time scales that can be involved in below-ground nutrient transfers, there are likely to be significant lag-times between implementation of a source measure and impact on water quality.
- A method of quantifying sub-surface N and P transfer to streams is presented using high-resolution hydro-chemistry data.

Synopsis

There are uncertainties in the quantification of phosphorus (P) and nitrogen (N) transfer pathways within agricultural river catchments due to spatiotemporal variations such as water recharge and the farming calendar, or catchment soil and hydrogeological properties. A holistic insight into processes and spatiotemporal variability is thus required to identify the most important nutrient transfer pathways in catchments.

This study combined site specific pathway studies with catchment integrated studies (Fig, 1) to characterise N and P transfer pathways in four agricultural catchments with different land management, soil drainage and geology.

For a major summer flow event in two catchments with well drained soils (Castledockerell and Timoleague), below-ground delivery pathways of total oxidized N represented up to 97% of the total load, and up to 63% of the total reactive P and total P load. In these catchments, hydrological quick flow pathways were only 2–8% of total event flow but were efficient in delivering P (up to 50%) (Fig. 2, Table 1).

In two other catchments, with poor to moderately drained soils (Ballycanew and Dunleer), up to 55% of the hydrological pathways were quick flow (surface and near surface) during a summer storm flow event. This quick flow delivered up to 88% of the event flow P load (Fig. 2, Table 1). Background groundwater flows were apparently mixed with point source inputs

Even though quick-flow P transfer pathways (largely surface and shallow subsurface or artificial drain flow) appeared to dominate catchments with poorly drained soils and below-ground N transfer pathways dominated in catchments with permeable soils, a substantial P loss below-ground was found in the catchments with permeable soils. There was some evidence for N loss via ephemeral surface ditches in catchments with predominantly moderate to poorly drained soils.

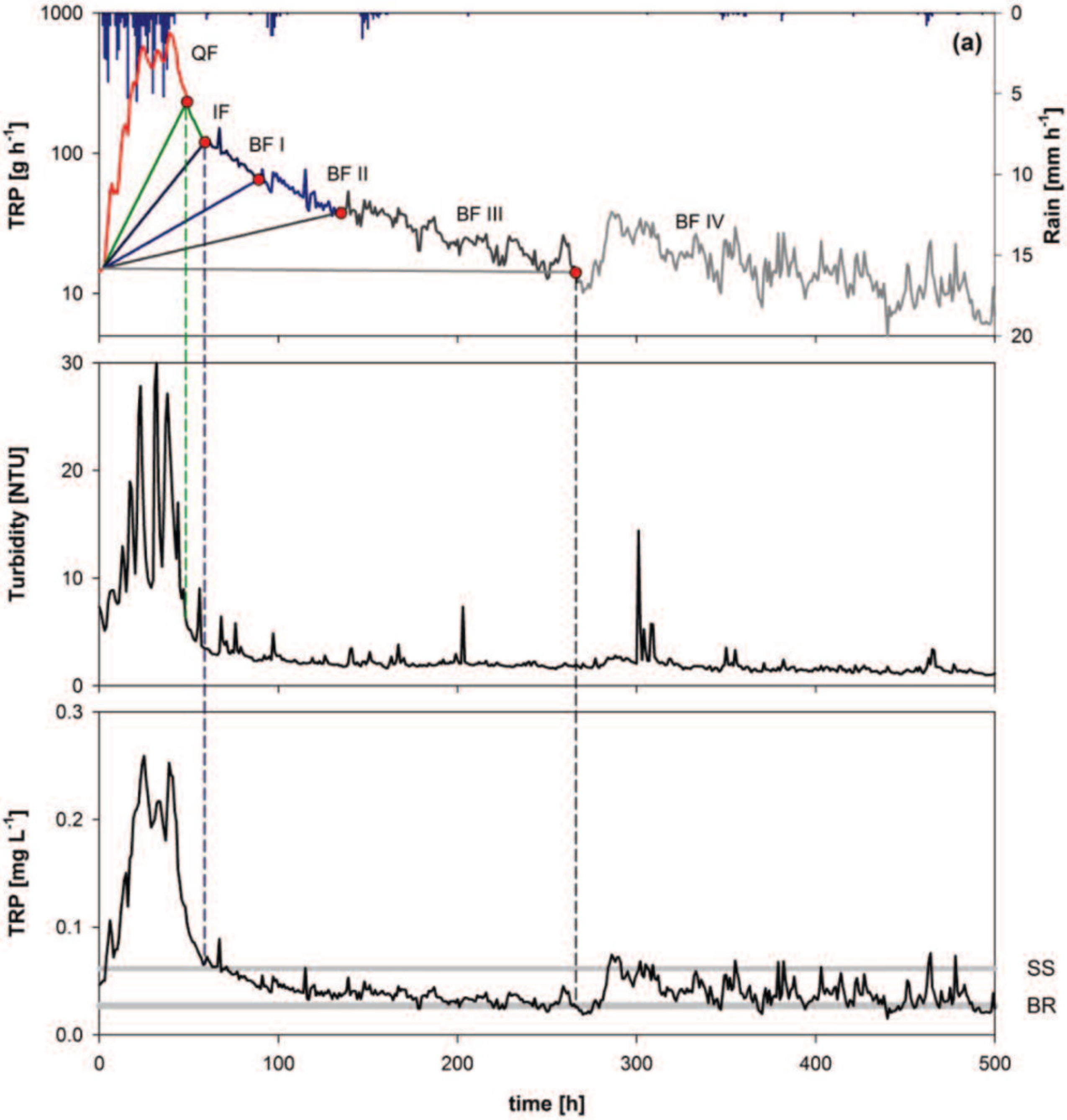

Figure 1. Example of a "Loadograph Recession Analysis" used together with hydrograph separation for identifying and quantifying water and nutrient transfer pathways for flow events. This example illustrates identification of Total Reactive Phosphorus (TRP) transfer pathways identified as quickflow (QF), interflow (IF) and baseflow (BF) for a major summer event in a grassland dominated catchment (Grassland A). Top: hourly loadograph with inflection points. Middle: hourly averaged turbidity in the catchment outlet. Below: hourly averaged TRP concentration in the catchment outlet and averaged dissolved reactive phosphorus concentration over two years (n=23) in groundwater of subsoil (SS) and bedrock (BR) geological strata (the thickness of the line represents the standard error).

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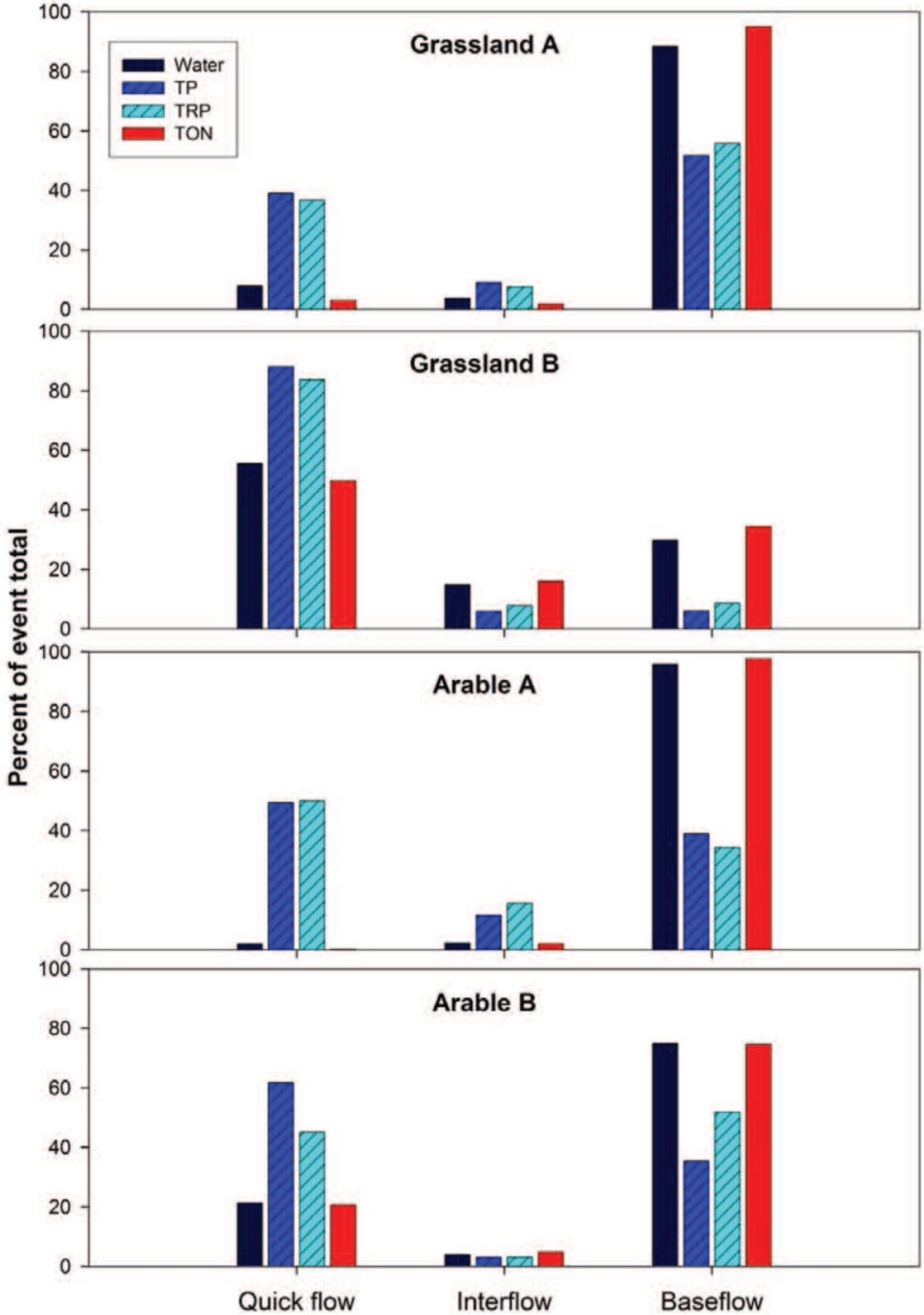

Figure 2. Stream flow and nutrient (TP, TRP and TON) transfer pathways identified and quantified by Loadograph Recession Analysis and expressed as a percenage of event total (total stream discharge and total nutrient flux at catchment outlet) for four agricultural catchments - Arable A (Castledockerell), Arable B (Dunleer), Grassland A (Timoleague), Grassland B (Ballycanew).

Table 1. Summaries of stream flow, TP, TRP and TON loads, load rates and concentrations for dominating transfer pathways from the Loadograph Recession Analysis for the investigated flow events in four agricultural catchments. Concentrations of TP, TRP and TON within the transfer pathways are expressed in mg L^{-1} of pathway activity. QF, quick flow; IF, interflow; and BF, baseflow.

	Pathway	Grassland A			Grassland B			Arable A			Arable B		
		[mm]	[mm h^{-1}]	[%]	[mm]	[mm h^{-1}]	[%]	[mm]	[mm h^{-1}]	[%]	[mm]	[mm h^{-1}]	[%]
Stream flow	**QF**	5.2	0.12	8	12.1	0.34	55	1.0	0.06	2	10.8	0.32	21
	IF	2.4	0.04	4	3.2	0.05	15	1.2	0.02	2	1.9	0.04	4
	BF	57.8	0.05	88	6.5	0.01	30	52.3	0.05	96	38.1	0.04	75
		[g ha^{-1}]	[g $ha^{-1}h^{-1}$]	[mg L^{-1}]	[g ha^{-1}]	[g $ha^{-1}h^{-1}$]	[mg L^{-1}]	[g ha^{-1}]	[g $ha^{-1}h^{-1}$]	[mg L^{-1}]	[g ha^{-1}]	[g $ha^{-1}h^{-1}$]	[mg L^{-1}]
TP	**QF**	27.9	0.61	0.54	40.9	1.14	0.34	16.3	0.74	1.63	107.0	3.15	0.99
	IF	6.5	0.11	0.27	2.7	0.04	0.08	3.8	0.07	0.32	5.2	0.12	0.27
	BF	37.0	0.03	0.06	2.8	0.00	0.04	12.8	0.01	0.02	61.4	0.06	0.16
TRP	**QF**	16.2	0.35	0.31	17.7	0.49	0.15	10.9	0.50	1.09	36.5	1.07	0.34
	IF	3.3	0.06	0.14	1.7	0.03	0.05	3.4	0.06	0.28	2.5	0.057	0.13
	BF	24.7	0.02	0.04	1.8	0.00	0.03	7.5	0.01	0.01	41.8	0.04	0.11
TON	**QF**	93.1	1.98	1.79	178.2	4.95	1.49	7.1	0.37	0.71	490.8	14.44	4.54
	IF	54.1	0.97	2.25	57.2	0.89	1.79	65.1	1.07	5.43	113.0	2.57	5.95
	BF	2835.5	2.58	4.91	123.0	0.11	1.89	3287.0	2.99	6.28	1774.8	1.62	4.66

Below-ground transfer pathways need to be considered when mitigating both N and P loss to receiving waters, and these results highlight the importance of considering the dominant catchment nutrient transfer pathways when selecting mitigation measures.

In catchments with permeable soils and geology, measures targeted at surface nutrient sources (soil nutrient status and nutrient inputs) may be a better long term strategy than those targeted at overland pathways such as buffer strips and critical source areas for runoff. In such catchments, baseflow can deliver substantial loads of both N and P, which may persist into ecologically significant periods and a long recession in water flow and nutrient delivery from an event may become significant for the ecological status of receiving rivers.

Reference

Mellander, P-E., Melland, A.R., Jordan, P., Wall, D.P., Murphy, P.N.C. and Shortle, G (2012a) Quantifying nutrient transfer pathways in agricultural catchments using high temporal resolution data. Environmental Science and Policy, 24, 44-57

6.2 Seasonality of phosphorus transfer

Key messages

- Comparisons from two grassland and two arable catchments indicated low to moderate TP exports (0.175 kg/ha/yr to 0.785 kg/ha/yr).
- Between 29 % and 40 % of these exports occurred during the closed period for slurry spreading, confirming that the closed period is synchronous with the annual period during which risks of incidental nutrient losses to water are highest.
- Higher P exports were attributed to lower soil permeability, leading to flashier runoff (and P mobilisation into fast pathways), more so than to landuse or the magnitude of the P source (soil P status).
- Emerging high P concentrations during sensitive low-flow summer periods were attributed to loss of dilution of rural point sources.

Synopsis

The NAP in Ireland constrains the magnitude of the nutrient source pressure (through limits on livestock numbers and fertiliser use, for example) and minimises mobilisation potential (through closed periods for nutrient application and ploughing and slurry/manure handling and storage requirements, for example). This closed period takes account of the fact that diffuse nutrient mobilisation and transport is more prevalent in times of greatest hydrological action.

Where concurrent annual data were available, in four of the ACP catchments (two grassland and two arable), this study compared the magnitude and seasonality of phosphorus transfers using data from the catchment outlets where synchronous chemistry and hydrology data were gathered at high resolution (sub-hourly time scales) (Fig. 1).

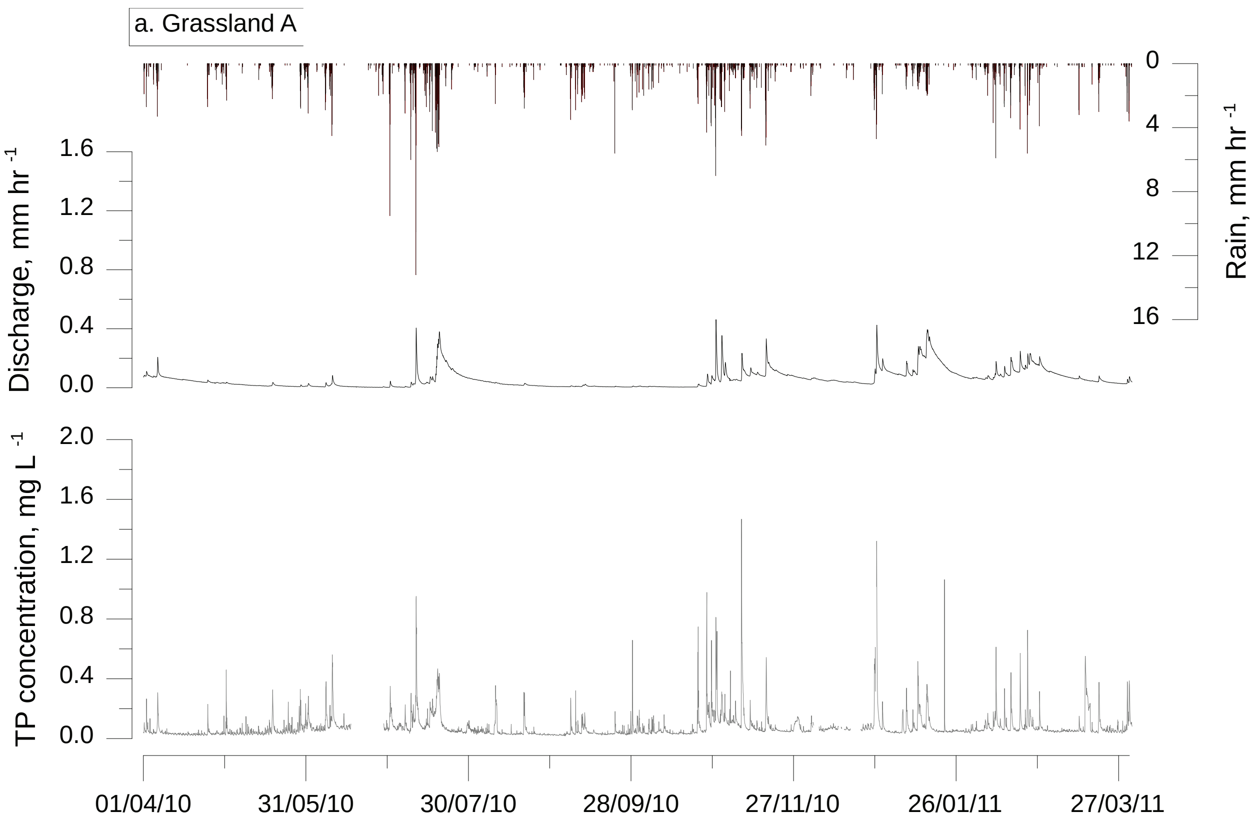

Figure 1. Example of high resolution discharge and P concentration data over a 1year period from one of the study catchments.

Annual TP exports were low to moderate and not defined by landuse as is usual in models which use export coefficients. For example, the two grassland catchments exported 0.541 kg/ha/yr and 0.701 kg/ha/yr and the two arable catchments exported 0.175 kg/ha/yr and 0.785 kg/ha/yr (Fig. 2).

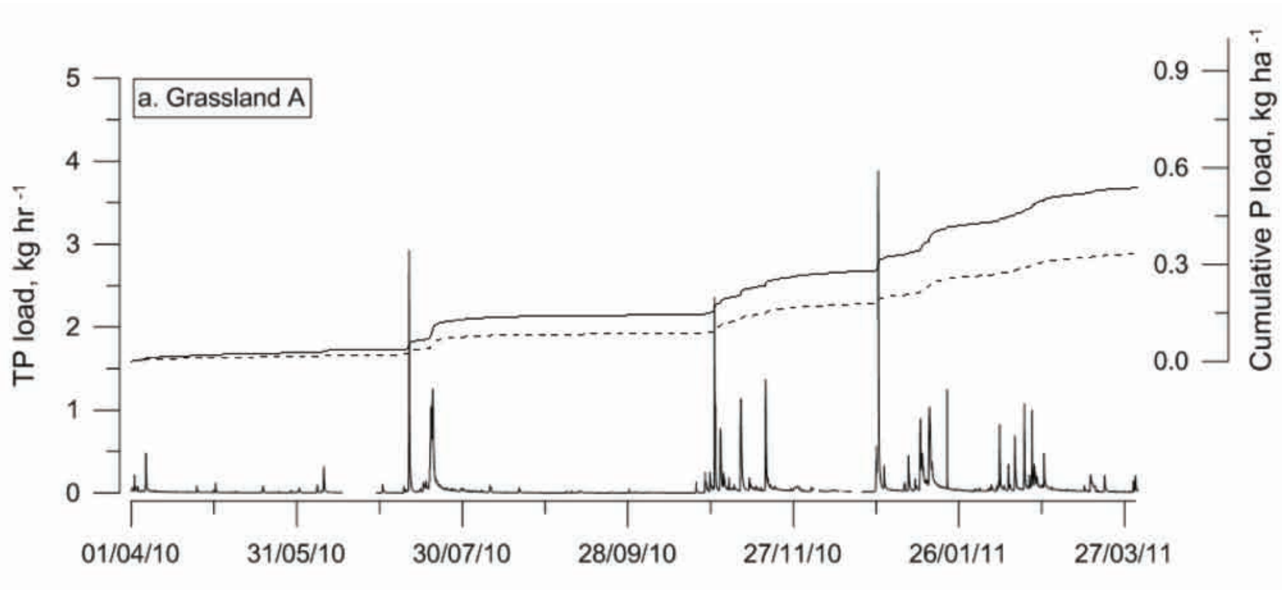

Figure 2. Example of high resolution hourly P load data and evolution of cumulative P load (solid line TP; dashed line TRP) over a 1year period from the Timoleague catchments (Grassland A).

The magnitude of the P source (as defined by organic P loading and the proportion of soils in P index 4) also appeared not to define the magnitude of the P exports. Therefore, expectations that decreasing the P source (through de-intensification or soil P decline) will result in decreasing P exports may need to be moderated, in some circumstances.

Assuming that P exports during the closed period for slurry spreading comprise mostly of residual soil P (i.e. not incidental losses from recently applied P), the proportion of annual P exported in this period was mostly related to the hydrological flashiness of the catchments, as summarised by the ratio of high (5th %ile – Q5) to low flows (95th %ile – Q95) (Fig. 3). As these exports represented 29 % to 40 % of the annual exports (in approximately 25% of the time), the results confirmed that the closed period (or other times of higher runoff risk) is synchronous with periods where incidental losses would be highest.

The data also show that the runoff flashiness is synonymous with soil permeability – a factor not accounted for in the regulations as a limitation to nutrient mobilisation and fast runoff flowpaths.

In a further analysis, one catchment indicated a propensity for high river P concentrations during summer low flows that were less linked to low flow exports but more related to the low level of baseflow and low dilution capacity of the rivers (also a feature of catchments dominated by low permeability soils). These low flow exports were speculated to originate from rural point sources and maintained the rivers in a highly eutrophic state for protracted periods during the summer.

The flashiness and low dilution capacity features of catchments dominated by lower permeability soils will likely be exacerbated in future climate change scenarios which predict wetter winters and drier summers – and be independent of landuse change.

This work is described in detail in Jordan et al. (2012).

Reference

Jordan, P., Melland, A.R., Mellander, P.-E., Shortle, G. and Wall, D. (2012) The seasonality of phosphorus transfers from land to water: Implications for trophic impacts and policy evaluation. Science of the Total Environment, 434, 101- 109.

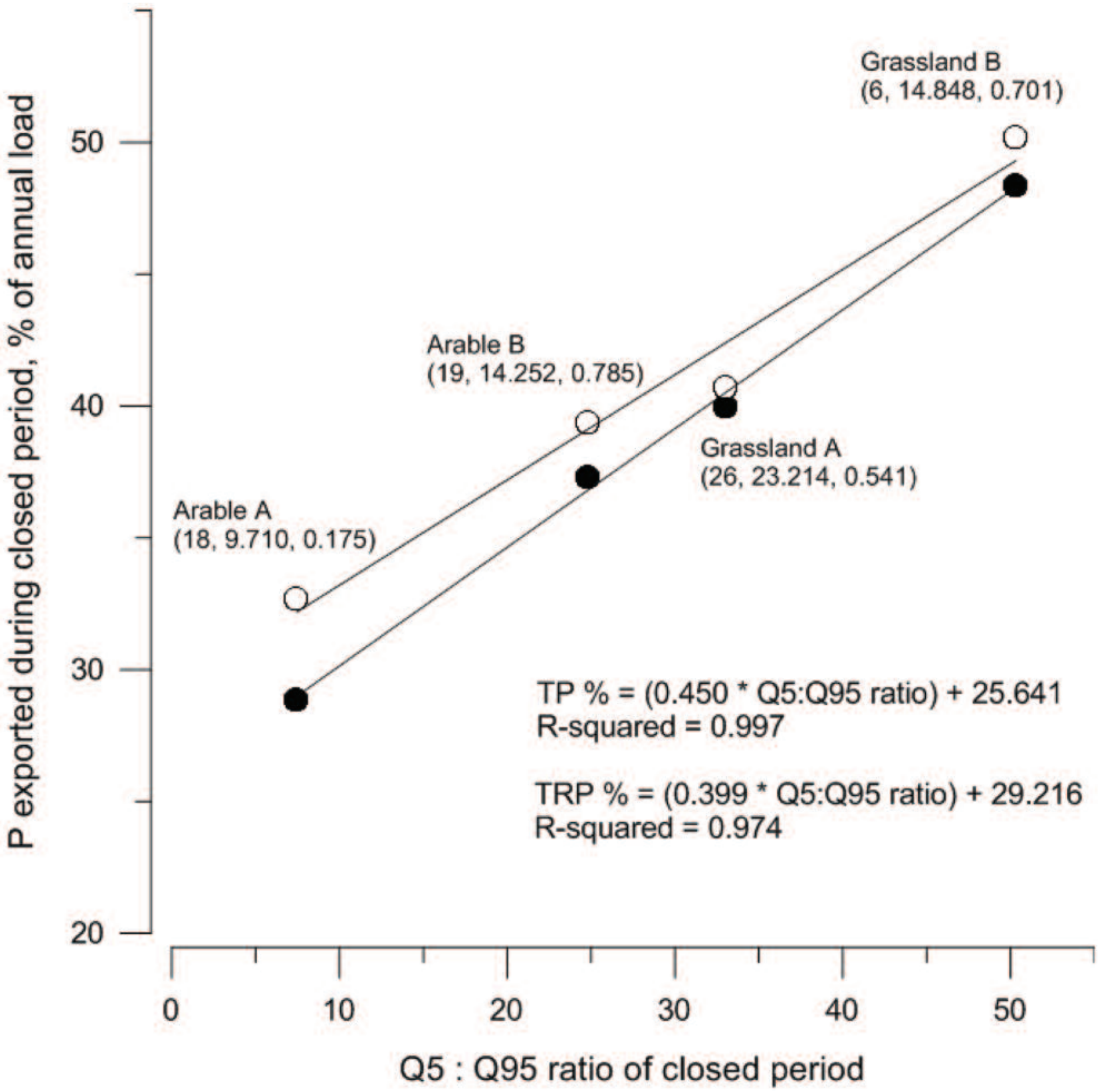

Figure 3. Relationship between the %age of P exported during the closed slurry spreading period (15 October to 12-31 January) and a runoff flashiness metric in four catchments - Arable A (Castledockerell), Arable B (Dunleer), Grassland A (Timoleague), Grassland B (Ballycanew).

6.3 Phosphorus delivery and impact bypass in a karst aquifer

Key messages

- Many Irish karst aquifers are classified as poor water quality status by contributing to eutrophication of receiving waters.
- This study investigated a 46 km^2 agricultural area underlain by a karstic aquifer in the west of Ireland.
- P source/pathway/delivery components were defined at high spatiotemporal resolution.
- High P source (soil P status) and aquifer vulnerability did not elevate P in the emergent groundwater.
- Definitions of risk and vulnerability for P delivery in karst systems need further evaluation.

Synopsis

The nutrient transfer continuum concept describes how agricultural nutrient sources can be mobilised and, *via* hydrological pathways, delivered to streams or other water bodies where a trophic impact may occur. In a karstic spring contributing zone it is essential to understand the small-scale heterogeneity of the karstified landscape, and its associated risks for nutrient transfer.

Conduit and other preferential flows, connecting agricultural soils and farming activities to aquifers, are considered to be the main hydrological mechanisms that transfer phosphorus from the land surface to the groundwater body of a karstified aquifer.

In this study the soil P source and pathway components of the nutrient transfer continuum were defined at a high spatial resolution (Fig. 1) and the inferred risk of P transfer was evaluated using observed P delivery to the primary emergent spring at a high temporal resolution (Fig. 2). This was achieved by surveying soil P status in fields as well as mapping of all surface karst features and depth to bedrock within a 46 km^2 area covering a *ca*. 30 km^2 spring zone of contribution, by sub-hourly monitoring of P concentrations and water discharge in the emergent spring, and by monitoring meteorology within the zone.

Despite moderate to intensive grassland agriculture, a high proportion of soil P Index 4 fields (considered agronomically and environmentally excessive) and a high karstic connectivity potential (Fig. 1), P concentrations in the emergent groundwater were low and indicative of being insufficient to increase the P status of receiving surface waters (Fig. 2).

Episodic P transfers *via* the conduit system did increase the P concentrations in the spring during storm events but not above 0.035 mg total reactive P/L (Fig. 2). This process is similar to other catchments where the predominant transfer is *via* episodic, surface flow pathways, but here the high buffering potential of the karst system delayed and attenuated the infiltrated runoff. Spring hydrographs indicated a large proportion of small fissure flow within the limestone bedrock (Fig. 3), thus inferring a high potential for P attenuation.

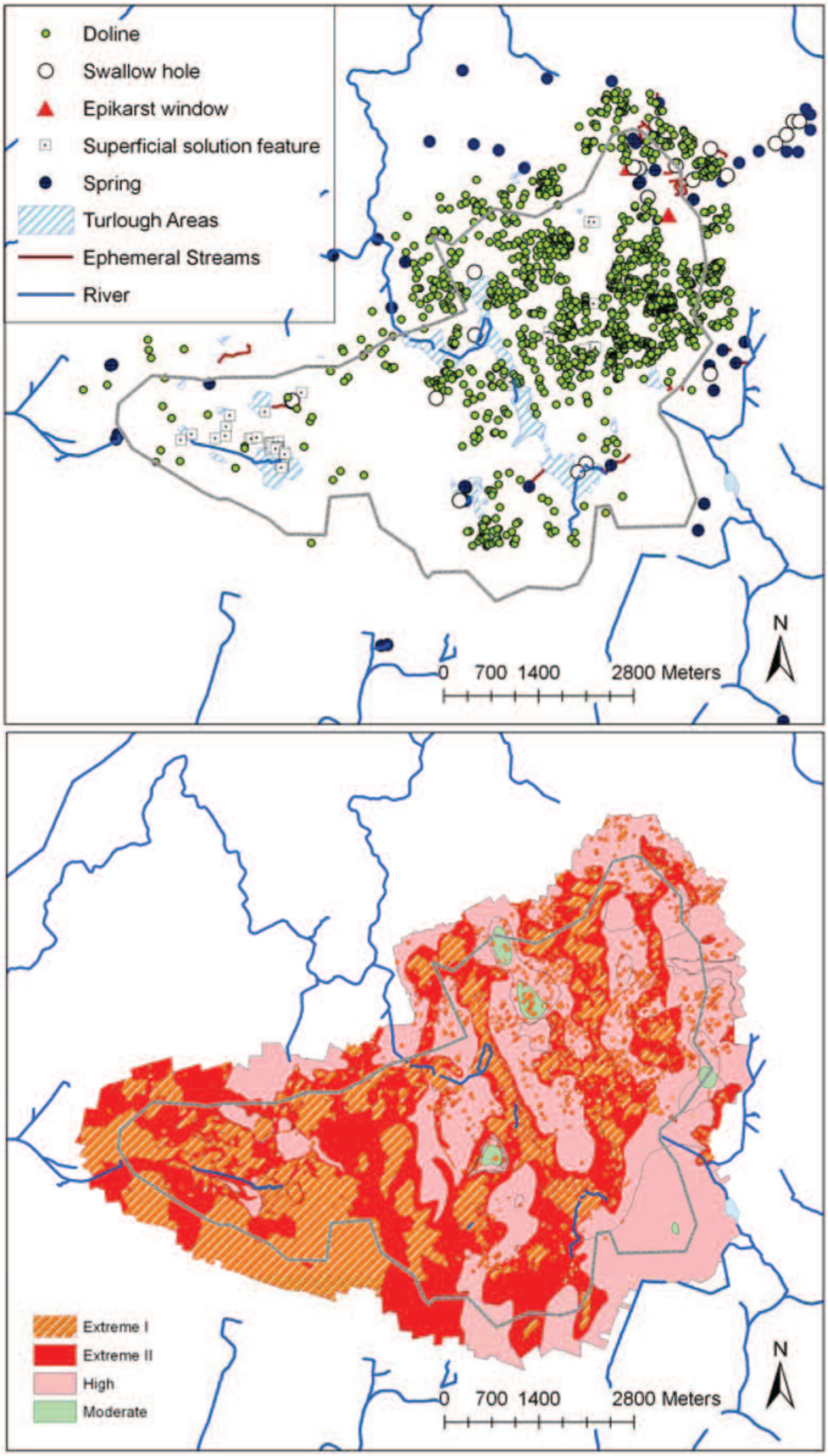

Figure 1. Karst feature map (top) and Groundwater vulnerability map (below). Vulnerability categories were determined by the contributing geological and hydrogeological characteristics that determine the ease with which the groundwater may be constrained by human activity.

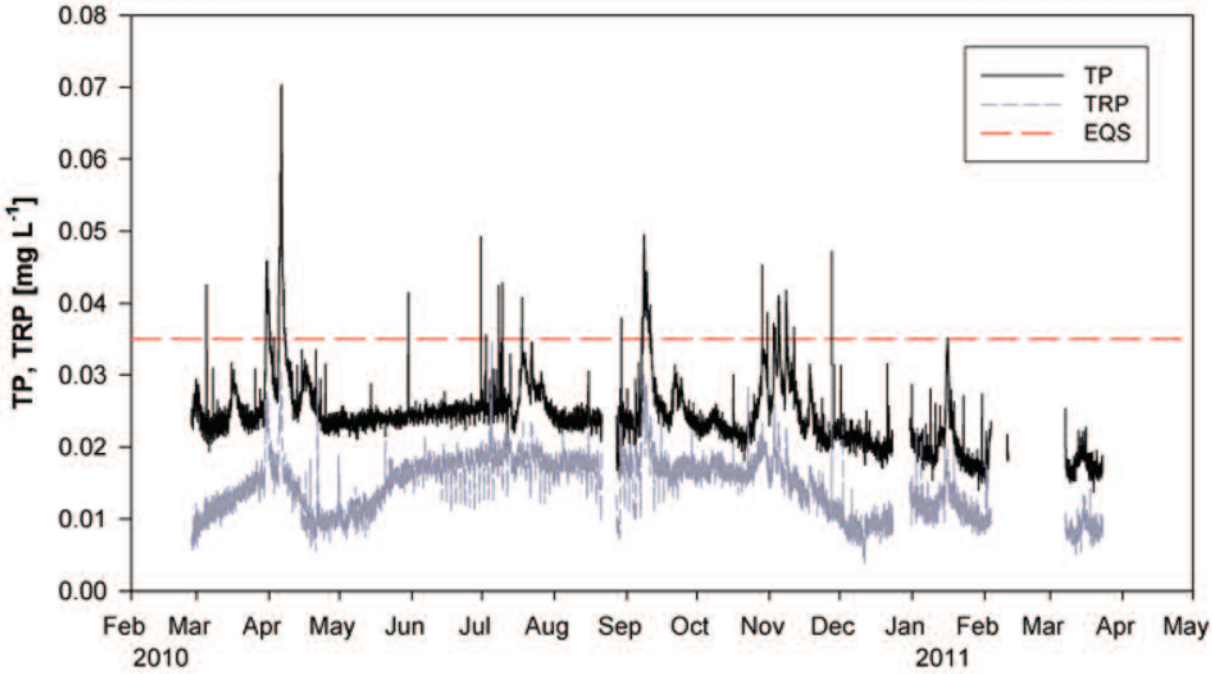

Figure 2. One year of hourly average total phosphorus (TP) and total reactive phosphorus (TRP) concentrations measured in the main emergent spring of the karst aquifer. The dashed horizontal line represents the environmental quality standard (EQS) for good water quality status and is the mean of up to four samples per year that should not exceed 0.035 mg TRP L^{-1}.

A hypothesis of substantial P attenuation within the fissure flow was supported by quantifying the P transfer pathways within the karst aquifer using high time resolution data of P loads in the emergent spring (unpublished).

In a karst spring zone of contribution, capture of conduit flows in datasets of intermittent water quality assessment may over-emphasise the influence of conduit flows on the overall status of the groundwater body.

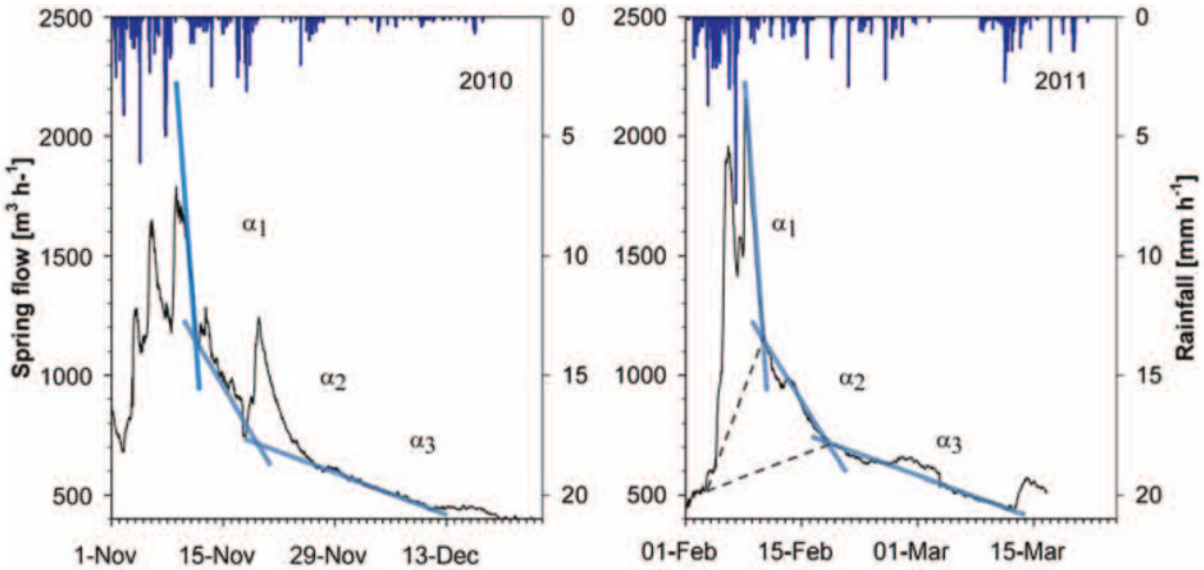

Figure 3. Example of hourly discharge from the main emergent spring during two flow events, November 2010 (left) and February 2011 (right). The 2011 chart indicate a simple graphical hydrograph separation approach using a constant slope method. The discharge is dominated by small fissure flow interpreted by α3.

The findings suggest that the current definitions of risk and vulnerability for P delivery to receiving surface waters should be re-evaluated as high source risk (soil P status) need not necessarily result in a water quality impact due to the nature of transport pathways and attenuation processes.

With detailed surveys and reclassification of karst features, a P susceptibility map of a karst aquifer has been made for development as a critical source area tool for subsurface P transfer (unpublished).

This work is published in Mellander et al. (2012) with further work subject to peer-review.

References

Mellander, P-E., Jordan, P., Wall, D.P., Melland, A.R., Meehan, R., Kelly, C. and Shortle G. (2012b) Delivery and impact bypass in a karst aquifer with high phosphorus source and pathway potential. Water Research, 46, 2225-2236.

Mellander, P.-E., Jordan, P., Melland, A.R., Murphy, P.N.C., Wall, D., Mechan, S., Meehan, R., Kelly, C., Shine, O., Shortle, G., (accepted) Quantification of Phosphorus Transport from a Karstic Agricultural Watershed to Emerging Spring Water. Environmental Science & Technology.

Chapter 7

Delivery and Impacts

7.1 Stream water quality in intensive cereal cropping catchments

Key messages

- Annual stream exports of P (0.12 kg/ha to 0.83 kg/ha) and suspended sediments (3 t/km^2 to 15 t/km^2) were low to moderate despite high rainfall in two representative arable catchments monitored over two years using high resolution techniques.
- Stream nitrate concentrations were below the maximum acceptable drinking water concentration of 11.3 mg/L.
- Disproportionately high nitrate exports during winter confirmed that the closed period is synchronous with the period during which risks of incidental nutrient losses to water are highest.
- Phosphorus loads were higher and the chemical Environmental Quality Standard (EQS; 0.035 mg/L) was exceeded in the arable catchment with lower soil permeability despite lower annual rainfall.
- The P EQS was also impacted by a chronic signal of poor water quality during low flows which was likely to have a significant non-agricultural contribution.
- Meeting water quality targets is likely to be more challenging in the catchment with lower soil permeability due to lower summer dilution of point sources and higher diffuse nutrient losses during storms.

Synopsis

Arable agriculture and especially cereal cropping is a low proportion of overall landuse (approximately 6% of farmed area) in Ireland but has very high yields (7.0 t/ha for barley and 8.6 t/ha for wheat in 2010) by international standards.

Efficacy of the NAP measures at the catchment scale were evaluated by comparing end of catchment stream chemistry with water quality targets and included measurements of phosphorus, nitrogen and suspended sediment in two hydrologically contrasting and intensively cropped catchments.

Export rates of nutrients and sediment are not regulated to standard thresholds but are considered to be important determinants of downstream water quality.

In the more permeable catchment, annual phosphorus loads were as low as 0.12 kg/ha and the background chemical EQS (0.035 mg/l) was never exceeded due to high baseflows, especially during the summer. In the less permeable catchment, P loads were higher (up to 0.83 kg/ha/yr) and background chemical EQS standards were never met, whether calculated as time-weighted or flow-weighted mean concentrations (0.096 and 0.113 mg/l total molybdate reactive P, respectively).

Annual nitrate exports were higher in the more permeable arable catchment with a maximum of 35 kg/ha. The less permeable catchment exported less nitrate (15 to 19 kg/ha over the two years). Most of the difference in load was due to rainfall and stream flow differences and nitrate concentrations in the less permeable catchment were higher than expected. The higher concentrations were attributed to seasonal and episodic hydrological connection of leached nitrate in better drained parts of the catchment (Fig. 1).

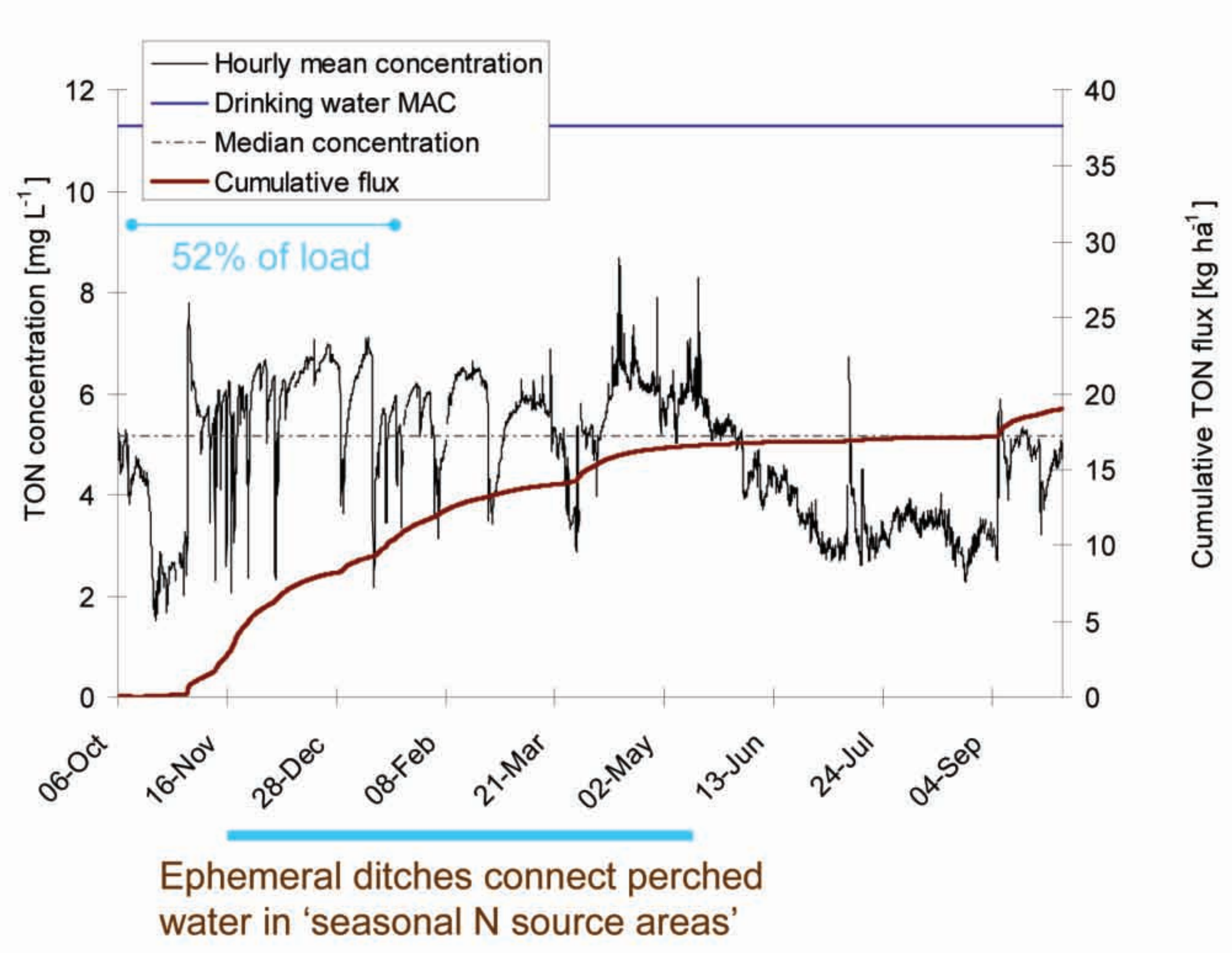

Figure 1. Sub-hourly total oxidised N (TON) concentration (mg/L) and cumulative load (kg/ha) for Arable B (Dunleer) from October 2009 to October 2010. The proportion of the total annual TON load exported during the closed period for spreading fertiliser and slurry is shown. Seasonally active ditches contributed TON during the winter and spring.

Due to a close relationship between stream flow volume and stream nitrate exports, the nitrate-N load exported during the closed slurry spreading period (approximately 25% of the year) was disproportionately high at 47 to 57 % of the annual nitrate exports. Similar to phosphorus, the results support the utility of a closed period for avoiding incidental losses.

Annual suspended sediment exports (as determined from continuous turbidity measurements) were low to moderate (3 t/km^2 to 15 t/km^2) and again reflected soil permeability factors.

Background baseflow P concentrations were high in the less permeable catchment. These patterns are associated with signals of point source pollution and these appeared chronic in this catchment; reflective of much lower baseflows (again due to soil permeability) but with noted stepped change influences at certain points along the river system (Fig. 2). The largest step changes increases in baseflow P concentrations were most likely due to non-agricultural nutrient point sources.

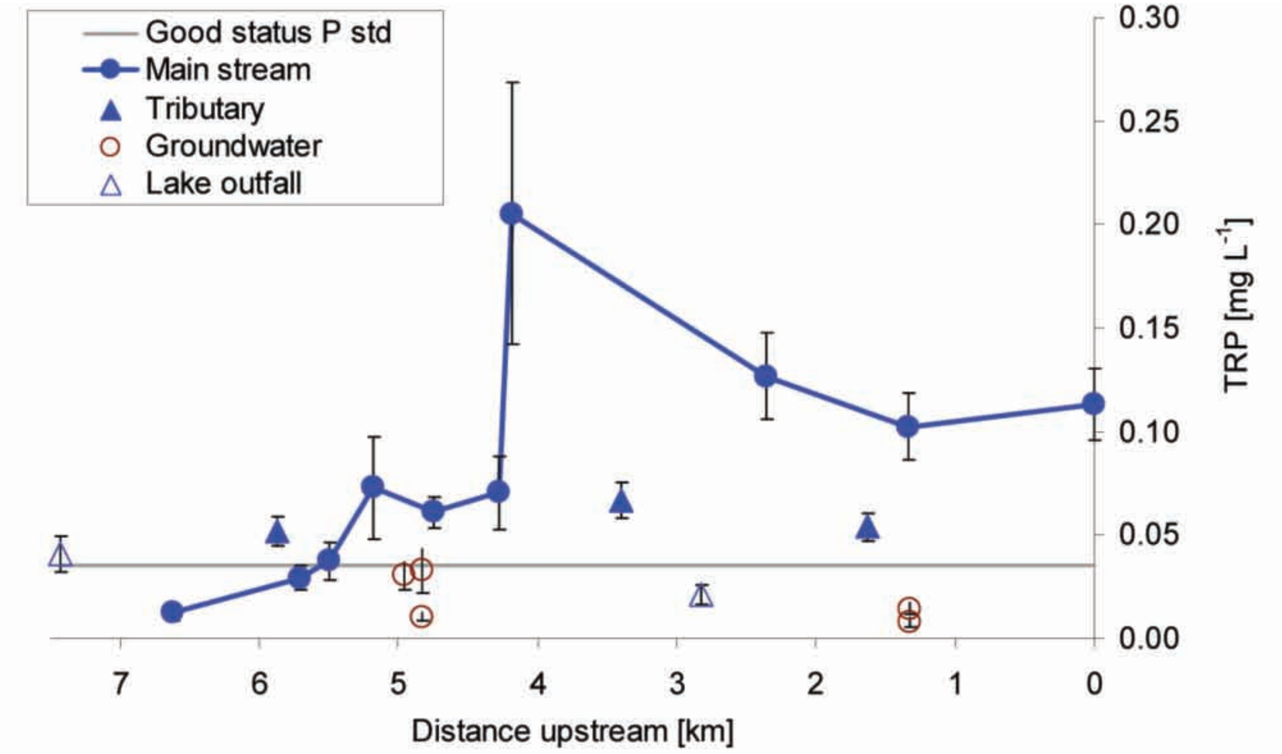

Figure 2. Longitudinal stream baseflow and groundwater mean total reactive phosphorus (TRP) concentrations (mg/L) in Arable B (Dunleer). Groundwater data are means at different depths in near stream and midslope piezometers. Temporal variance of 8-18 monthly samples per site indicated by standard error bars.

Annual loads were highly correlated with the highest flows in each catchment and year and the magnitude was reflective of the magnitude of rainfall-runoff patterns between the years (Fig. 3). For example, rainfall was higher than the long term average in year 1 and lower than the long-term average in year 2. Nutrient and sediment losses reflected these changes and this highlights that load targets may be an unreliable metric to use as a water quality standard due to the fact that loads also reflect rainfall and runoff patterns rather than source changes alone.

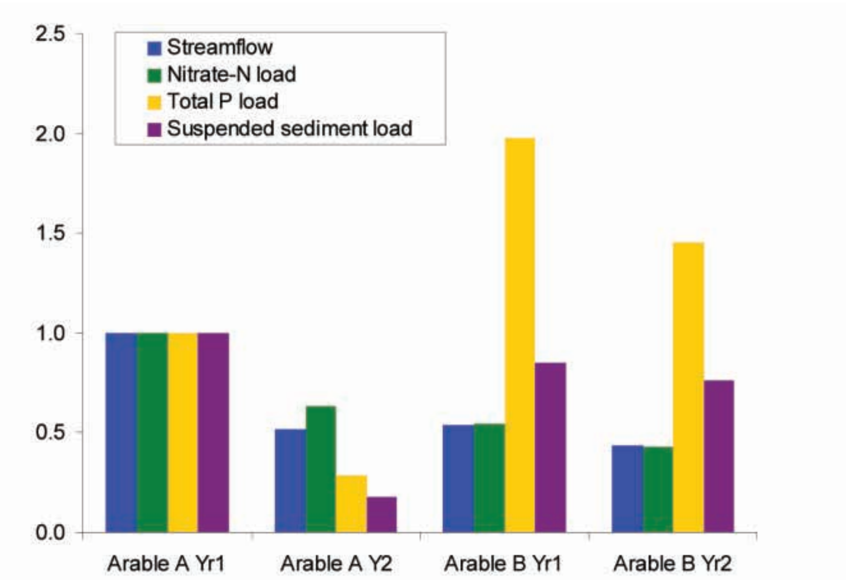

Figure 3. Fig. Total annual area-weighted streamflow, nitrate-N load (as total oxidised N), total P load and suspended sediment load from Arable A (Castledockerell) and B (Dunleer) in years 1 and 2 relative to fluxes in Arable A in Year 1 (expressed as ratios).

Further, decreasing nutrient and sediment losses from each catchment will likely be more successful if loss during higher flows can be attenuated, as is targeted by several of the NAP measures. The summer impact of poor dilution of point sources, however, will not be alleviated under NAP regulations.

This work is described in detail by Melland *et al.* (2012).

Reference

Melland, A.R., Mellander, P.-E., Murphy, P.N.C., Wall, D.P., Mechan, S., Shine, O., Shortle, G. and Jordan, P. (2012). Stream water quality in intensive cereal cropping catchments with regulated nutrient management. Environmental Science and Policy, 24; 58-70.

7.2 Stream ecological status

Key messages (unpublished data – analysis subject to peer review)

- The 'potential' WFD macroinvertebrate status ranged from Poor to High (Q-value 3 to 4-5) across sites, seasons (late spring and late summer) and years. At least good WFD status was achieved in at least one year and site in four of the five surveyed catchments.
- During the September samplings, when pressures on in-stream biology are greatest, the Small Stream (macroinvertebrate) Risk Score showed that 80 - 100% of the sites surveyed across 5 catchments were 'potentially' at risk of not reaching good water quality status by 2015.
- During spring samplings there was an overall improvement in macro-invertebrate health, despite these samplings following the winter periods of proportionately highest nutrient loss to streams, but 50 - 60% of sites remained 'at risk'.
- A stream algal-growth indicator (the trophic diatom index) showed that the karst limestone catchment was the only catchment (on average) without trophic impact. Seasonal variation at some sites in some catchments was also observed.
- Juvenile brown trout were found in the three southern catchments and not in the two north-eastern catchments where downstream physical and/or water quality barriers to trout migration were identified.
- The 'potential' WFD river hydromorphological status ranged from Bad to Good across sites.

Synopsis

As well as nutrient sources, pathways and dynamics of delivery to streams and groundwater, the baseline status of in-stream ecology of the receiving streams is being monitored. Ecological surveys have been conducted by the Aquatic Services Unit at UCC in spring (May) and late summer (September) since September 2009 and will continue during Phase II of the ACP.

These data are being used to identify the link between land management and biological water quality and to identify water quality status according to WFD inter-calibrated chemical, hydromorphological and biological indicators.

Survey metrics used include those used in the EPA (and UK EA) monitoring networks for comparison purposes. However, because the survey sites are not part of the formal EPA surface water quality monitoring network, the use of WFD status descriptors is not justified. Instead, the term 'potential' WFD status is used.

Macroinvertebrate analysis was conducted seasonally in all catchments (19 sites) except the karst limestone catchment in Mayo where sites downstream of the spring emergence were not suitable. Macroinvertebrate metrics calculated were the Q-value, WFD potential ecological quality ratio, Small Stream Risk Score, Average Score Per Taxon and the Biological Monitoring Working Party score.

Benthic diatom (siliceous unicellular algae) analysis was conducted seasonally in all six catchments (23 sites). The trophic diatom index and the WFD potential ecological quality ratio were calculated.

River hydromorphology was measured at each site once according to the River Hydromorphological Assessment Technique (RHAT). One fish survey was conducted in summer 2010. Associated water chemical analysis was conducted on a monthly basis during low flow at each site.

The 'potential' WFD macroinvertebrate status ranged from Poor to High (Q-value 3 to 4-5) across sites and seasons. During the September samplings, when pressures on in-stream biology are greatest, potentially 'good' WFD status was achieved on at least one occasion in at least one site in four of the five stream catchments surveyed. The fifth stream catchment was subject to chronic nutrient pressure from low baseflow dilution of largely non-agricultural point sources during summer.

The Small Stream (macroinvertebrate) Risk Score showed that 80 - 100% of the sites surveyed across 5 catchments were 'potentially' at risk of not reaching good water quality status by 2015 during the normal EPA (summer) sampling period (Fig. 1).

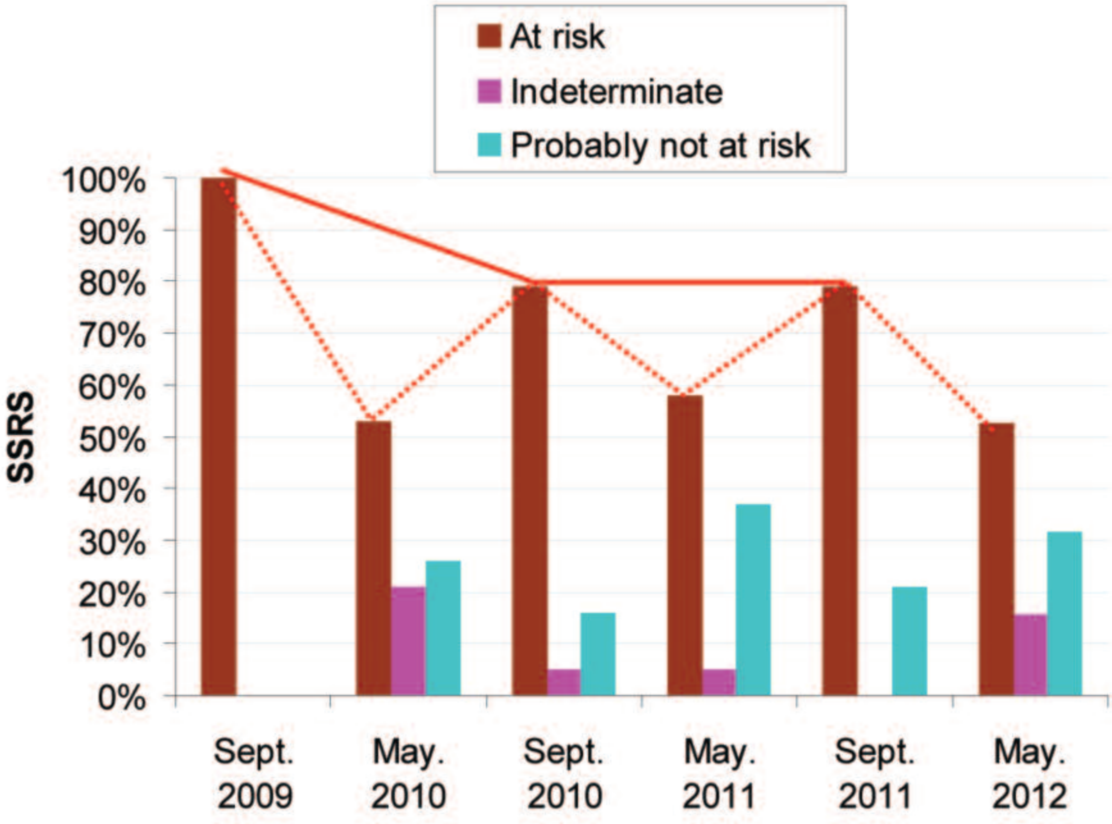

Figure 1. %age of the 19 sites sampled each season with macroinvertebrate 'potential' Small Stream Risk Score (SSRS) in each risk class. Dashed red line highlights seasonal variation. Solid red line indicates values equivalent to normal EPA sampling time.

During spring samplings there was an overall improvement in macro-invertebrate health, despite these samplings following the winter periods of proportionately highest nutrient loss to streams, but 50 - 60% of sites remained 'at risk'.

Diatom status tended to limit overall water quality status when compared with macroinvertebrate indices, based on the "one out, all out" principle of status being defined by the lowest indicator score.

A preliminary comparison of dissolved reactive P (DRP) concentration during baseflow at each site around the time of the late summer biological sampling revealed that sites most frequently having 'good' chemistry (i.e. DRP < 0.035 mg/L) but less than 'good' ecology (as Diatom Ecological Quality Ratio) tended to be in the two catchments dominated by subsurface/groundwater streamflow (Timoleague and Castledockerell) (Fig. 2).

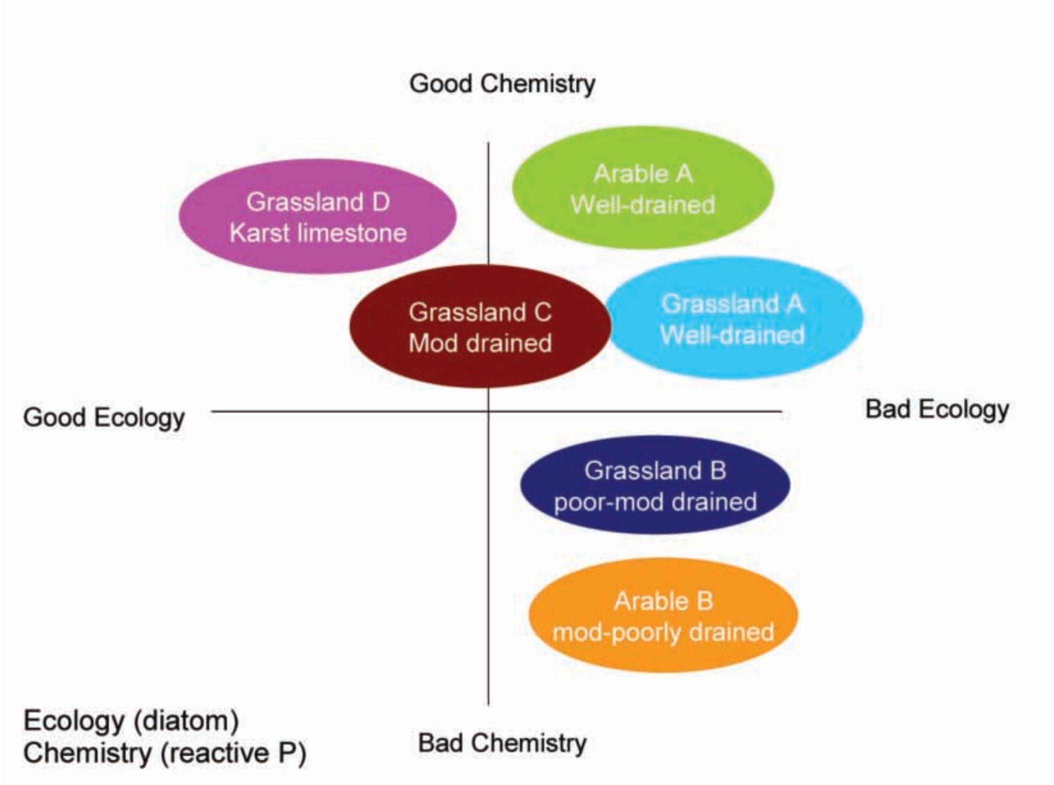

Figure 2. Simplified relationships between ecological status and chemical status across the six ACP catchments based on preliminary analysis of diatom and reactive P concentration water quality indicators.

Initial testing of the hypothesis that ecological quality in these catchments may be limited by stream habitat rather than by land-based pressures indicated that stream habitat was rarely the only factor limiting ecological quality. Of the sites in Timoleague and Castledockerell that had less than 'good' river habitat (according to the RHAT method) and also less than 'good' ecology, all but one site had episodically high DRP concentrations and/or high ammonium concentrations.

Some of these methods and data are published in Jordan et al. (2012) and Wall et al. (2011)

A manuscript reporting the Phase I ecological status results in detail is in preparation and will be subject to peer review.

References

Jordan P, Melland AR, Mellander PE, Shortle G, Wall D (2012) The seasonality of phosphorus transfers from land to water: Implications for trophic impacts and policy evaluation. Science of the Total Environment 434, 101-109.

Wall D, Jordan P, Melland AR, Mellander PE, Buckley C, Reaney SM, Shortle G (2011) Using the nutrient transfer continuum concept to evaluate the European Union Nitrates Directive NAP. Environmental Science & Policy 14, 664-674.

7.3 Investigation into lake impact and recovery

Key messages

- Sedimentary reconstructions of historical lake water quality in Sreenty Lough show trophic impacts by P to be broadly coincident with other similar sized lakes in the region from the 1950s to 1960s.
- Most recently since the late 1990s and especially post-2007, sedimentary evidence suggests a decrease in aquatic enrichment despite a local to regional increase in agricultural intensification during this time.
- The decreased impacts were noted despite this lake having a high potential for internal P loading through seasonal anoxia and also a small apparent increase in soil in-wash.
- This decoupling of (increasing) external P source and (decreasing) P impact is proposed to be due to an increase in agri-environmental measures in this catchment and wider locale.

Synopsis

Sreenty Lough is a small (0.17km^2) lake in the Sreenty-Corduff paired catchments, Co. Monaghan. The lake catchment is 2.5km^2. Despite being smaller than the 50ha WFD requirement for monitored lakes, it is representative of typical inter-drumlin lakes that are a characteristic feature of a large area of north-central Ireland. Many of these lakes have shown susceptibility to eutrophication via P transfers from impermeable soils over several decades and especially post 1950.

The lake is being monitored for continued external and internal P loading to understand the seasonal dynamics of these two impact mechanisms as the lake appeared to be at the sensitive meso- to eutrophic boundary. Part of this work was to investigate the historical impacts of P transfers into the lake through sediment coring – a palaeolimnological approach.

Two short 50cm sediment cores were extracted from the central deep basins of the lake and dated using standard techniques (Pb^{210} and Cs^{137}). Core slices (1cm) were analysed in the laboratory for diatom sub-fossil remains and these results were used in an Irish lakes diatom-inferred total phosphorus (DI-TP) model. The outputs showed that the lake was oligo- to mesotrophic from the start of the dated period – 1860-1870 (and before) and showed signs of enrichment from the 1950s. Eutrophication (above the normal OECD total P threshold of 35 µg/l) was established in the 1960s – and this is coincident with similar studies in other Irish inter-drumlin lakes in agricultural catchments and commonly associated with periods of increased diffuse and/or point source P transfers.

Towards the top of the core, more detailed analysis of diatom remains during the 1990s and 2000s indicated recovery towards the meso-trophic boundary (Fig. 1). This was despite some evidence to suggest that soil in-wash had actually increased over this recent period. The recovery was also noted against a high potential for this lake to be exposed to seasonal periods of anoxia in the deeper waters (from contemporary monitoring); periods often associated with sedimentary P solubilisation and internal loading.

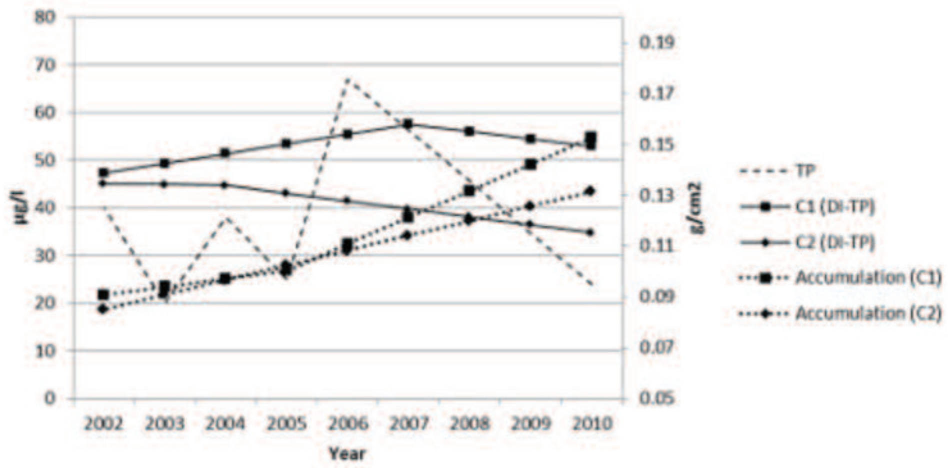

Figure 1. Sedimentary and contemporary data showing apparent recent decreases in TP and increases in sedimentary accumulation (from soil inwash).

An analysis of landuse statistics for six townlands ($5km^2$), for which the Sreenty Lough catchment is part, also showed that landuse intensity (through organic P loading of livestock numbers) increased over the period 1995 to 2010 from 8.0 kg/ha to 15.1 kg/ha (with a peak of 16.8 kg/ha in 2005).

This combined dataset was interpreted as a decoupling between changes in P source pressure (noted as increases) and recent changes in water quality (noted as recovery) and possibly due to the combined ameliorating effect of mitigation measures in Rural Environment Protection schemes, NAP regulations and Group Water Scheme initiatives.

This work is described in detail by O'Dwyer et al. – in press.

Reference

O'Dwyer, B., Crockford, L., Jordan, P., Hislop, L. and Taylor, D. (in press). A palaeolimnological investigation into nutrient impact and recovery in an agricultural catchment. Journal of Environmental Management, doi. 10.1016 / jenvman / 2013.01.034.

Chapter 8

Socio-economics

8.1 Implementation of the EU Nitrates Directive in the Republic of Ireland - A view from the farm

Key messages

- Q methodology was used to investigate farmer subjective opinions of the operation of the GAP regulations after the first 4 year NAP phase.
- Results indicate 4 main opinion groups.
- Farmer in general are sceptical of the validity of certain NAP measures, especially in the area of temporal farm practices, however, there is acceptance among some farmers of environmental benefits deriving from the regulations.

Synopsis

The paper synopsised below investigates opinions towards Good Agricultural Practice (GAP) regulation implementation from the subjective perspective of the farmer stakeholders across the Agricultural Catchments Programme using Q methodology.

Q methodology encompasses a distinctive set of psychometric and operational principles that when combined with the statistical application of factor analysis provides the researcher with a systematic and robust means of examining human subjectivity. Q methodology is expressly aimed at identifying different patterns or shared ways of thinking on a topic that is relatively independent of the researcher.

Implementing a Q methodological study typically involves 6 steps. The first step is to identify the discourse of interest and relevant population. In this instance farmer opinion towards the GAP regulations in the Republic of Ireland. Step 2 involves collection of a full concourse of statements on the discourse by the relevant population. A scoping questionnaire was delivered to 6 farmer discussion groups totalling 51 farmers across a range of farming systems. A total of 556 statements emerged; however, there was a large degree of repetition among statements generated such that the final concourse of statements totaled 120 statements. The third stage of Q methodology implementation involves reducing the concourse of statements down to a representative manageable number, or a Q set. In this application of the Q methodology a total of 30 statements were chosen to be representative of the full concourse and structured along a factorial design, the frequency with which thematic elements appeared in the final Q set was determined by the original concourse structure. The fourth stage of implementation involves selecting participants and instructing them to rank or ‘sort’ the selected statements from most agree to most disagree normally following a forced quasi-normal distribution structure. The Q methodology survey (or set) was administered to a sample of farmers across the agricultural catchments programme (N=71) by a team of farm advisors. Respondents were selected to represent the range and intensity of agricultural production across the 6 case study catchments. Respondents were instructed to sort the statements on a 7 point scale from -3 (most disagree) to +3 (most agree). The fifth step involves statistical analysis and the extraction of a few ‘typical’ sorts which are representative of distinct attitude or understanding of an issue or policy. This involves Q sort correlation, factor analysis and rotation to reduce the data to a limited number of defining factors which define different views on the discourse.

Results indicate 4 main opinion groups. A large group, labelled here "Constrained Productionists" remain unconvinced about the appropriateness of the Good Agricultural Practice regulations both from a farm management and environmental water quality benefit perspective. A second group, labelled "Concerned Practitioners" also objected strongly to closed period restrictions in the winter which restricts practices based on calendar dates. Both groups gave the highest ranking to statement disagreeing with implementation of such closed periods. These groups seem to hold the view that these closed periods are counter productive from an environmental outcome perspective and could actually increase the risk of diffuse pollution by concentrating slurry spreading at certain times. The Constrained Productionists tended to be younger with a median age of between 35-50 years and had the largest average farm size at 90 hectares. Average kg N ha^{-1} was 109 suggesting considerable expansion potential in livestock based enterprises. They also had a significant arable element as nearly one-third of area was under arable crops.

The "Concerned Practitioners" were however, generally more positive regarding some farm management and environmental benefits accruing from the regulations. This group also had a median age of between 35-50 years but their average farm size was smaller at 40 hectares although they were more intensively stocked at 119 kg N ha^{-1}.

A third group, "Benefit Accepters", indicated quite an environmentalist position and are generally very positive towards regulation implementation and associated environmental and farm management benefits. This group had the second largest farm size at 75 hectares and nearly half this area was devoted to arable crops; they had the lowest total organic N at 59 kg ha^{-1} suggesting that compliance with livestock based measures is less of an issue for this group.

The final group "Regulation Unaffected" have some concerns but are mostly unaffected by the regulations. This group tended to be older with a median age in the 51-60 years bracket. The "Regulation Unaffected" had the second smallest average farm size at 46 ha and tended to be predominantly livestock orientated.

Findings suggest scepticism remains around the validity of certain measures, especially, in the area of temporal farm practices; however, there is acceptance among some farmers of environmental benefits accruing from the regulations.

This work is described in detail in Buckley et al. (2012).

Reference

Buckley, C., 2012. Implementation of the EU Nitrates Directive in the Republic of Ireland - A view from the farm. Ecological Economics, 78, 29-36.

8.2 The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level

Key messages

- Results from a nationally representative sample of specialist dairy and tillage farms stratified by land use potential indicates that compared to the most efficient benchmark in the sample the average farm had over application of chemical fertilizers ranging from 22.8 to 32.8 kg N ha^{-1} and 2.9 to 3.51 kg P ha^{-1}. Average excess of imported feedstuffs among dairy cohorts equated to 5.82 to 7.44 kg LU^{-1} of N and 0.92 to 1.17 kg LU^{-1} of P.

- Potential cost savings on chemical fertilisers across all systems on average ranged from €38.9 ha^{-1} to €48.5 ha^{-1}. Additionally, potential cost reductions on imported feeds of €65 to €84 per livestock were indicated for the average dairy farm versus the most efficient cohort benchmark farms.

- Second stage regression analysis generally indicates efficiency if affected by agricultural education, hours worked off-farm and farm size.

Synopsis

Using Teagasc National Farm Survey 2008 data (which is collected annually as part of the Farm Accountancy Data Network requirements of the European Union) research was undertaken to investigate whether there is room to reduce inorganic nitrogen and phosphorus fertiliser applications and imported feeds by exploring the extent to which application rates may have exceeded optimum levels using data envelopment analysis productivity analysis methodology. The investigation concentrates on specialist dairy and tillage farms in the Republic of Ireland stratified by land use potential as these are the most intensive land based agricultural systems and, by definition, may potentially pose the greatest risk in terms of managing nutrient transfer from agricultural land to water courses due to the magnitude of the nutrient input load. This stratification was based on a soil class system. Specialist dairying farms were stratified into two main groups for this analysis namely; average and good land use potential. Tillage farms were exclusively related to land of good land use potential.

Data envelopment analysis (DEA) is used to assess farm level nutrient management efficiency. DEA is a deterministic approach to efficiency measurement. It measures the relative efficiency of a decision making unit, farms in this instance, by comparing relative inputs to outputs. The DEA method establishes the most efficient farms and compares all others to the most efficient. The method uses linear programming to place a non-parametric frontier over the data where the frontier consists of the most efficient farms and all other farms are measured by their relative distance to this frontier as a measure of their level of efficiency. Chemical fertiliser prices in the Republic of Ireland reached record levels in 2008, hence, farmers had significant economic incentives for efficient fertiliser input usage.

Results demonstrate inefficiency in the utilisation of nitrogen and phosphorus fertilisers across these systems. Average over application of chemical fertilizers ranged from 22.8 to 32.8 kg N ha^{-1} and 2.9 to 3.51 kg P ha^{-1} in 2008. Potential cost savings on chemical fertilisers across all systems on average ranged from €38.9 ha^{-1} to €48.5 ha^{-1}. Additionally, potential cost reductions on imported feeds of €65 to €84 per livestock unit were indicated for dairy farms versus efficient cohort benchmark farms. Average excess of imported feedstuffs equated to 5.82 to 7.44 kg LU^{-1} of N and 0.92 to 1.17 kg LU^{-1} of P.

A second stage regression analysis to investigate factors which influence efficiency was also undertaken in this study. The double bootstrap method was applied in a truncated regression of the DEA technical efficiency scores on a set of explanatory variables. Results indicate significant efficiency returns to agricultural education across all cohorts. Number of hours worked off-farm had a negative influence across both dairy cohorts, significantly so for farms of good land potential. Farm size had a positive effect on technical efficiency, but the effect was only significant for the dairy cohort of average land use potential. Farm fragmentation had a negative effect on efficiency for dairying cohorts but it was not significant. Finally, milk recording had a positive effect on the efficiency of the dairying cohorts but the effect was not statistically significant.

This work is described in detail in Buckley and Carney (2013).

Reference

Buckley, C., Carney, P., 2013. The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level. Environmental Science and Policy, 25, 118-126.

8.3 Supply of an ecosystem service—Farmers' willingness to adopt riparian buffer zones in agricultural catchments.

Key messages

- A total of 53 per cent of catchment farmers surveyed indicated a negative preference for provision of a fenced 10 metre riparian buffer zone under a 5 year scheme.
- Willingness to adopt the proposed buffer zone was influenced by economic, attitudinal and farm structural factors.
- The mean willingness to accept for adoption was estimated at €1.51 per linear metre by willing adopters.

Synopsis

This study investigates the potential for implementing riparian buffer zones as a measure to intercept nutrient rich runoff. The objectives were twofold; to investigate the factors which influence the willingness of farmers to supply a riparian buffer zone ecosystem service; and, in the absence of mandatory compulsion, to identify the level of compensation necessary for the change of land use associated with its provision.

Using data generated from a survey of catchment farmer with land adjacent to a watercourse (N=247) the willingness of farmers to adopt a 10 metre riparian buffer zone was investigated. The research was based on a proposal to install a 10 metre deep riparian buffer zone on a five year scheme and the analysis was based on principal components analysis, contingent valuation methodology and a probit and Generalized Tobit Interval model.

A total of 53% of the sample indicated that they would not be willing to participate in the proposed riparian buffer zone scheme. The remaining 47% indicated a willingness to participate at various payment levels. A de-briefing question was administered to farmers indicating a negative preference for provision. Of this cohort 45% indicated that the buffer zone would interfere with their current system of farming or had concerns around nuisance effects such as potential proliferation of weeds in the designated area. A further 22% and 8% of this cohort cited either loss of production or income, respectively, as a constraint to participation, while 10% cited other reasons. Median age was similar across willing and non-willing providers (51-65 years) while average farm size (79 compared to 71 hectares) and mean estimated gross margin per hectare (€797 compared to €701 ha^{-1}) was larger for non willing participants. Non willing participants had proportionately slightly more dairy and tillage systems, while willing participants were composed of more livestock rearing systems.

The questionnaire instrument included a series of scales to test attitudes and peer group subjective norm influences. A principal component analysis was used to extract and identify underlying farmer latent attitudes and peer influences. Latent attitudes that emerged which were most relevant to this study included environmental protection, resource maximisation and bureaucratic load. Subjective norm influences included regulators and other farmers.

A probit model was employed to investigate factors influencing scheme participation. Previous participation in an agri-environment scheme was a significant positive indicator of participation. Farmers with a strong environmental protection attitude were significantly more likely to engage with the proposed buffer zone as were those who indicated a motivation to follow the advice of a regulatory peer group. Finally, farmers with a higher gross margin per hectare return were less likely to be willing to enter the proposed scheme.

A total of 47% of farmers indicated that they were willing to engage with the proposed riparian buffer zone scheme scenario. Of those willing to engage with supply, the mean willingness to accept based cost of provision for a 10 metre riparian buffer zone was estimated to be €1513 ha^{-1} per annum equivalent to €1.51 per linear metre of riparian area. Price demanded was higher among dairy farmers, farmers averse to bureaucracy and those who engage in financial planning and was lower among cereals farmers.

This work is described in detail in Buckley et al. (2012).

Reference

Buckley, C., Hynes, S., Mechan, S., 2012. Supply of an ecosystem service—Farmers' willingness to adopt riparian buffer zones in agricultural catchments. Environmental Science & Policy, 24, 101-109.

8.4 Intra-national importation of pig and poultry manure: acceptability under EU Nitrates Directive constraints

Overview

- Based on a nationally representative survey between 9 and 15 per cent of farmers nationally would be willing to pay to import poultry and pig manures manure respectively and a further 17 to 28 per cent would import if offered on a free of charge basis.
- Demand for these manures is strongest among arable farmers, younger farmer cohorts and those of larger farm size with greater expenditure on chemical fertilisers per hectare and who are not restricted by a Nitrates Directive derogation.

Synopsis

Transitional arrangements in the Republic of Ireland between 2006-2010 allowed pig and poultry manures to be spread subject only to the nitrogen amendment limits of the EU Nitrates Directive and not the phosphorus limits. From 2013 this arrangement is to be phased out, and pig and poultry producers have consequently expressed concerns about the availability of recipient spread lands for these manures. Using a national farm survey and a multinomial model this study investigates the willingness of the farming population to import these manures.

The main data source employed in this analysis is the Teagasc National Farm Survey (NFS) conducted in 2007. The NFS is collected annually as part of the Farm Accountancy Data Network requirements of the European Union. Questions investigating farmers' willingness to import pig and poultry manures onto their land were included and conducted in conjunction with the regular NFS data collection. The final dataset used in this analysis consisted of 986 farmers which represents 97,752 farmers nationally.

Results show that 58 per cent of the sample were not willing to import (WTI) pig slurry and 74 per cent were not willing to import poultry manure. A total of 15 and 9 per cent indicated a WTI pig and poultry manure on a payment basis respectively, while 28 percent indicated a willingness to import pig slurry only if offered on a free of charge basis while the relevant statistic for poultry was 17 per cent.

A multinomial logit model was used to investigate the willingness of farmers to import (WTI) pig and/or poultry manures. The landowner decision process had three exclusive outcomes: not willing to import pig and/or poultry manures onto farm, willing to import pig and/or poultry on a free of charge basis where slurry, transport and spreading was free, or finally willing to import pig and/or poultry manures on a payment basis, where a farmer would pay towards slurry, transport and spreading.

Age was found to be negatively associated with WTI pig manure both on a payment and free of charge basis. Younger farmers were more likely to be WTI pig manures. Farmers who are applying greater quantities of chemical fertiliser are significantly more likely to be willing to import pig slurry on a payment basis. Farm size is positively related to WTI (free and payment). Farmers not restricted under derogation were more likely to be WTI pig manure both on a free of charge and payment basis. Finally, farms with larger proportions of land devoted to arable or root crops were strongly associated with WTI on a payment basis. Results for WTI poultry manure follow a similar pattern to that for pig manure, however the relationships were not seen to be as strong statistically.

Pig and poultry farmers across the Republic of Ireland, have expressed concerns that the phasing out of the transitional arrangements for land spreading of manures from these sectors will pose significant difficulties with associated production cost implications. However, results from this analysis indicate there is a potential market for these manures across the Republic of Ireland which could be revenue generating as there is a cohort of mainly arable farmers who are willing to import these manures on a payment basis. Depending on local supply and demand conditions these manures can be revenue generating or at least have cost sharing around transportation and spreading. If chemical fertiliser prices continue in an upward trend and with the ending of the transitional arrangements a more nationally based market may well emerge where these manures are traded much as other agricultural commodities are at present. However, the export and trade of these manures may be constrained by regional disparities between supply and demand.

This work is described in detail in Buckley et al. (2012).

Reference

Buckley, C., Fealy, R., 2012. Intra-national importation of pig and poultry manure: acceptability under EU Nitrates Directive constraints. International Journal of Agricultural Management, 1(4), 41-47.

Chapter 9

Collaborative Research

9.1 Soil phosphorus lag times

Key messages

- A major policy in the Irish NAP is the management of soil phosphorus with an expectation of reducing excessive soil P to agronomic optima or lower.
- This work provided a modelling framework to predict (with uncertainty) the time taken to decline excessive soil P to an optimum level (index 3).
- The model suggests that the time for high soil P index fields to reach optimum level depends on the magnitude of the deficit but, for a farm or catchment scale scenario with all fields at high P status (25 mg/L Morgan P), it could take >20 years for 95% of soils to reach index 3 (after 3 to 5 years ~5% reach index 3).
- However, the cascade of this soil P decline to improved water quality is expected to be variable and possibly not synchronous with the changes in soil P status due to variations in hydrological pathways and attenuation processes.

Synopsis

Soil P index 3 (5.1 mg/L to 8 mg/L Morgan on grassland) is considered to be the agronomic optimum and environmental maximum soil concentration range for agricultural and water quality objectives (Table 1).

Table 1. The Soil P Index used in nutrient advice and nutrient legislation in the Republic of Ireland.

Soil Index	P Morgan's Soil P range (mg l^{-1})	Interpretation
1	0.0 – 3.0	Soil is P deficient; build-up of soil P required. Insignificant risk of P loss to water.
2	3.1 – 5.0	Low soil P status: build-up of soil P is required for productive agriculture. Very low risk of P loss to water.
3	5.1 – 8.0	Target soil P status: only maintenance rates of P required. Low risk of P loss to water.
4	> 8.0	Excess soil P status: no agronomic response to P applications. Risk of P loss to water increases within this Index.

Managing to this range is explicit as a regulation in SI 610 of 2010. Fields above this range and into index 4 are considered excessive for agronomic production and also pose a higher risk of P transfers to water. The policy prescribes zero P application to index 4 fields with the aim of reducing the index 4 fields to index 3

Using an extensive soil plot research dataset that includes data on soil P dynamics, it was found that the decline of soil P concentration with zero inorganic P amendment follows an exponential decay over time (Fig. 1).

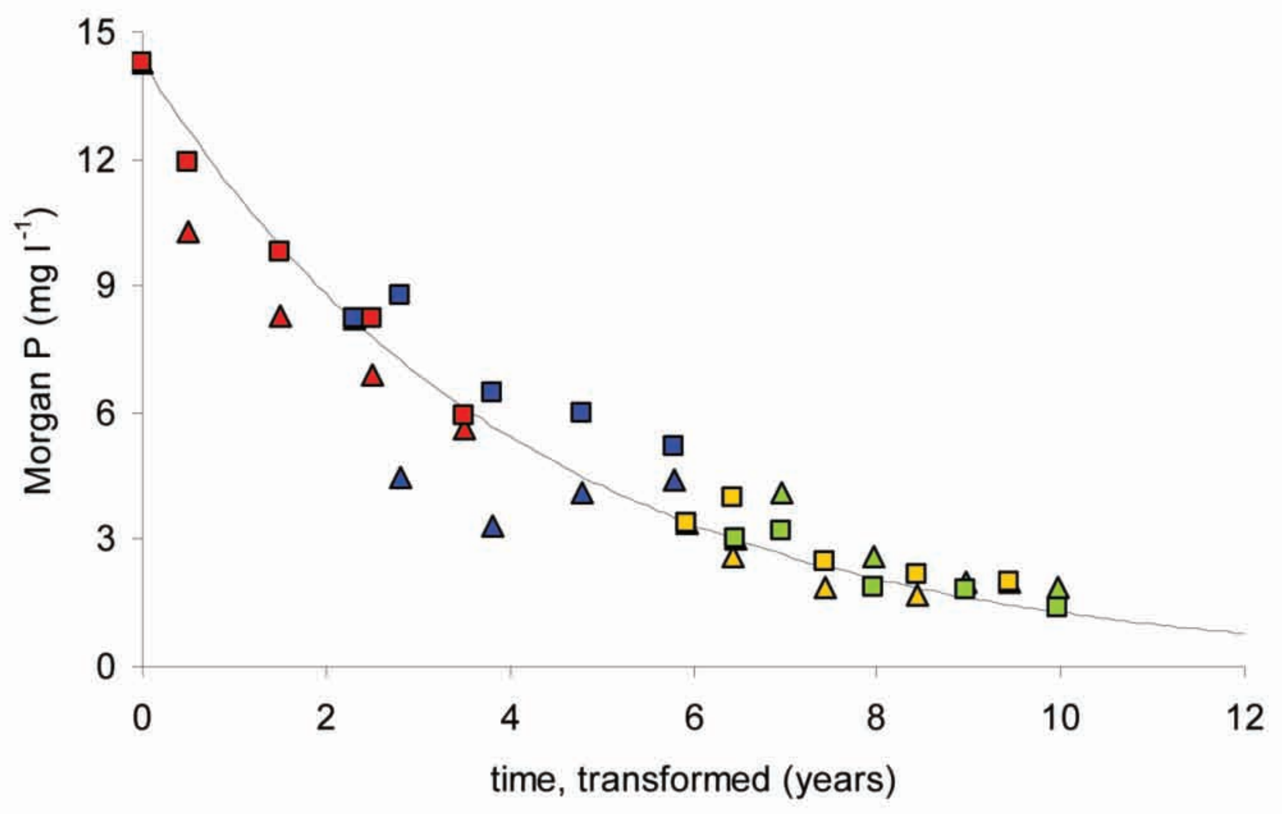

Figure 1. Example of exponential soil phosphorus decline over time in one soil type following zero phosphorus amendment at the plot scale. Red, blue, yellow and green symbols indicate (duplicate) soil phosphorus indices 4, 3, 2 and 1, respectively.

A model was developed that uses the farm P balance [inputs (e.g. fertiliser/manure) minus outputs (e.g. milk/meat)] to total soil P reserves [Total soil P] ratio [P balance ÷ Total soil P], to predict the decay function. The model is robust (R^2 = 0.63) with high significance around the regression mean. However, uncertainty for adding further individual observations is high.

Under three different P balance scenarios, and a range of soil P test and TP starting points, average time to for Index 4 soils to reach index 3 was computed, along with 95% confidence levels for each scenario.

Translating the results to a farm or catchment scale scenario with all fields at a similar soil P test and TP concentration in index 4 (e.g. Morgan P 25 mg/L, total soil P 1,200 ppm), it could be expected that 5% of the fields would reach index 3 after 3 to 5 years and that it would take >20 years for 95% of the fields to reach index 3. For the three P balance scenarios, uncertainty analysis also shows that, for this farm or catchment scenario at a 2010 starting point, 65% of fields with a P deficit of -30 kg/ha would reach index 3 by 2015. With a deficit of -15 kg/ha this figure would be 25% and with a deficit of -7 kg/ha this figure would be 10% (Fig. 2).

In reality, there will be a mosaic of P balances at the field, farm and catchment scale. However, catchments with higher initial soil P levels and extensive grassland-based production might be expected to have lower P off-takes and higher P balances and so take the longest time to reach index 3 (or a lower %age by 2015).

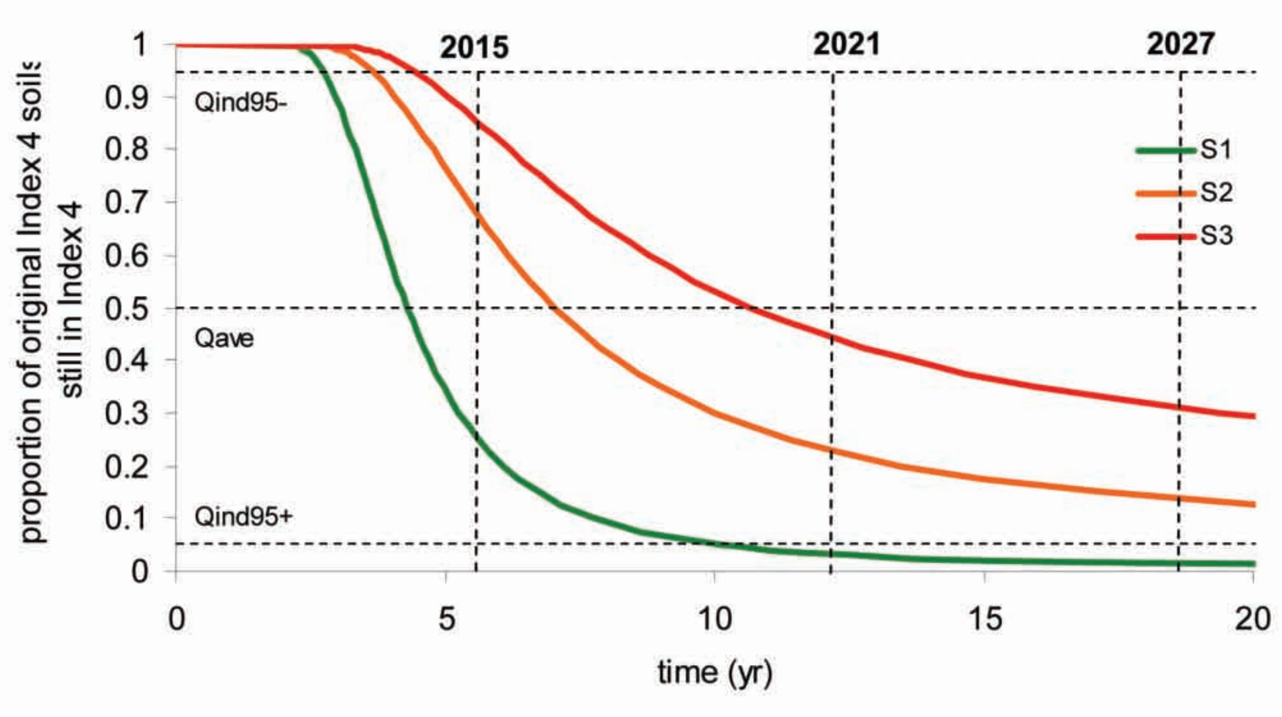

Figure 2. Example analysis of the time required to reduce the relative prevalence of Index 4 soils, for three scenarios (S1, S2, S3, corresponding to P balances of -30, -15 and -7 kg P ha^{-1} yr^{-1}, respectively), and for Total soil P concentration of 1200 mg kg^{-1} and initial Morgan's of 25 mg l^{-1}.

Additionally, changes (declines) in soil P sources may not immediately translate to reductions in diffuse P transfer to surface waters and should be contextualised in terms of P mobilisation pathways, which will differ between catchments due to factors such as soils, geology and climate and can change with management and hydro-climatic variations, and in-stream P equilibria (which can also change). The model in the paper synopsised here does not account for these potential processes in the pathway, delivery and impacts parts of the P continuum. The literature suggests slow and/or variable change in surface water P concentrations over years to decades, might be expected.

This work on soil P decline potential is described in Schulte et al. (2010).

Reference

Schulte, R.P.O., Melland, A.R., Fenton, O., Herlihy, M., Richards, K. and Jordan, P. (2010) Modelling soil phosphorus decline: Expectations of Water Framework Directive policies. Environmental Science and Policy, 13, 472-484.

9.2 Nitrogen transit times in aquifers

Key messages

- The recovery of nitrogen enriched groundwaters is influenced by initial conditions which include soil thickness, bedrock type, annual effective rainfall and background nitrate concentration – which combine to delay responses to mitigation measures.
- In Irish scenarios, simulated enriched groundwaters were estimated to reach acceptable threshold nitrate concentrations by between 2019 and 2033 from mitigation measures fully implemented by 2012.
- Delays in response to mitigation measures of nutrient status of groundwater and water bodies with groundwater contributions should be expected based on this analysis.

Synopsis

It is recognised that the mitigation of nutrient pollution in water bodies has both socio-political and biophysical constraints to achieving success. In groundwater bodies, the status of N enriched groundwaters is a function of source pressures and the rate at which eutrophic water passes through the aquifer.

In short, this is a hydrological memory effect, or time lag, which is noted in all aquifers types and is evident in many EU countries where mitigation measures have been put in place – i.e. the biophysical response to policy is not synchronous. This memory effect may be short in some cases e.g. free draining thin soils underlain by limestone or long in other cases e.g. thick moderately drained soil underlain by a poorly productive aquifer.

Nutrient transfer from the ground surface is a function of hydrological vertical transit through the unsaturated zone, horizontal aquifer travel and dilution/displacement of existing elevated nitrates. The time that a potential mitigation measure (for example for N mitigation) will have to impact on enriched groundwaters is therefore a function of these hydrogeological factors.

Scenarios were modelled based on implementation of N mitigation measures in 2012 (a scenario based on full implementation of WFD measures) and based on a range of soil thicknesses (< 1 m to > 10m), soil-subsoil effective porosity, bedrock porosity, aquifer depth, effective rainfall and background groundwater N concentration (Table 1).

The scenario outputs were generated using a Monte Carlo approach of many iterations (1000 runs for each scenario) to give environmentally realistic distributions based on initial conditions. Hence, an estimate of uncertainty was generated. Outputs were based on achieving a threshold concentration[5] of 37.5 mg NO_3 /L from starting conditions above the threshold and also at the drinking water standard boundary.

Under these conditions and assuming full implementation of Programmes of Measures by 2012, threshold concentrations were reached by between 2019 and 2033 depending on unsaturated zone depth, thickness of aquifer and the specific yield of the aquifer. It should be noted that these time lags represent the fastest recovery times and not averages.

Table 1. Simplified methodology to calculate N lag time under different Irish scenarios.

Zone	Data requirements	Calculation	Scenarios
Nutrients leaving the rooting zone	Farm nutrient management, % of farm used for silage and grazing.	Extension of existing model e.g. NCYCLE_Ireland or development of new model e.g. ERIN model	Under a variety of nutrient inputs, soil and drainage classes, and effective drainage amounts.
Unsaturated zone	Effective drainage amounts (mm),effective porosity (%), depth of unsaturated zone (m) taking into account different vulnerability classes	Gibbons et al (2006) Fenton et al., (2009) Misstear et al., (2009) Richards Equation Others e.g. cited in Sousa et al. (2012)	Effective drainage ranges 200 – 800 mm, depths 0.5 to 10 m for tills and 1.5 to 5 m for sands and gravels Effective porosity 2.5 to 40% includes till and sand and gravel aquifer types. Attenuation capacity
Saturated zone	Hydraulic conductivity (m day^{-1}), hydraulic gradient (%), distance to receptor (m), specific yield (%)	Effective Darcian Velocity	Regionally important pure limestone (Rk, Rf), Regionally important sand and gravel (Rg), Locally important sand and gravel (Lm), Locally important sand and gravel (Lg, Ll), Poorly productive impure limestone (Pl) and poorly productive un-weathered granite (Pu) Attenuation capacity
Flushing of aquifer to threshold concentration	Nutrient concentration leaving the rooting zone (mg L^{-1}), nutrient concentration in the aquifer (mg L^{-1}), threshold nutrient concentration (mg L^{-1}),	Mixing model	Range of nutrient concentrations to leave rooting zone under varied nutrient inputs, crop cover, climatic conditions Range of nutrient concentrations in aquifer breaching current threshold value of 37.5 mg NO_3^- L^{-1} Attenuation capacity
Hyporeic zone	Thickness (m), hydraulic conductivity (m day^{-1}), hydraulic gradient (%),	Effective Darcian Velocity	Different thickness dependent on surface water body, this may be absent in some scenarios e.g. limestone Attenuation capacity

This analysis suggests that expectations of groundwater N recovery should be moderated where this is an issue and be applied in future reviews where other water bodies are considered for N standards.

This work is described in detail in Fenton et al. (2011).

Reference

Fenton, O., Schulte, R.P.O., Jordan, P., Lalor, S.T.J. and Richards, K.G. (2011) Time lag: a methodology for the estimation of vertical and horizontal travel and flushing timescales to nitrate threshold concentrations in Irish aquifers. Environmental Science and Policy, 14, 419-431.

9.3 National Farm Survey of manure application and storage practices on Irish farms

Key messages

- A nationally representative survey of manure application and storage practices on Irish farms indicates that 52 % of all slurry was applied between the end of the closed period in January and April 30th in total volume terms.
- Across all farm systems approximately 71 % of slurry was estimated to be applied to conservation ground (hay/silage), 26 % to grazing land.
- The report indicates an increasing number of farmers are starting to engage with newer slurry application technologies. A total of 6 per cent of dairy farmers reported using the trailing shoe method of slurry application.

Synopsis

A survey on slurry storage and spreading practices was conducted on a base year of 2009 on a subsample of the full Teagasc NFS sample which is part of the EU Farm Accountancy Data network. In total 878 completed questionnaires were returned and analysed. This sample was weighted to reflect a population of approximately 96,000 farms.

A total of 87 % of all farms produced and spread slurry and/or farmyard manure. Half of all farms applied a combination of both slurry and FYM in 2009. In the vast majority of cases where a combination of both slurry and FYM was applied, slurry constituted over half of the total application.

Half of all sheep farms and 45 % of tillage farms applied only FYM. Across all farm systems approximately 60 % of total slurry is applied to conservation ground (hay/silage), 37 % to grazing land with the remaining 3 % applied to maize or tillage crops. These figures indicate a trend toward greater slurry application on land used for livestock grazing compared to the 2003 survey where 80 % of the slurry applications were on conservation land and 16 % were on grazing land.

A total of 52 % of all slurry was applied between the end of the closed period in January and April 30th. This contrasts with a 2003 survey which found that 35% of slurry was applied in the spring season. A further 36 %, in total volume terms, was spread between May 1st and July 31st and 12 % was applied between August 1st and October 15th. The majority (50 %) of FYM was spread between August 1st and the start of the closed period for spreading on November 1st.

Slurry application by tanker with a splashplate was the principle method across 97 % of all relevant farms. However, 6 % or dairy farms used the trailing shoe method. A total of 57 % of farms with farmyard manure used a side discharge rotary system for application. A further 27 % used a rear discharge system. Approximately one-third of all farmers used a contractor to spread all of their slurry and/or farmyard manure and a further one-third used a contractor for partial application.

A total of 4 % of all farmers imported slurry and/or farmyard manure and 1 % exported slurry and/or farmyard manure. Of those importing, three-quarters reported importing pig slurry. Tillage farm systems are the most likely to be importing, almost 20 % of tillage farmers reported importing organic fertilisers in 2009. It is estimated that 652,000 tonnes of slurry and 25,500 tonnes of farm yard manure were imported by farmers in 2009.

One-third of all farms have no storage facilities for soiled water on their farms. These farms are predominately sheep and tillage farms and therefore are less likely to produce soiled water. Four percent of dairy farms have no storage facilities for soiled water. However, the average herd size for this cohort was 12 cows. Ninety-six percent of all soiled water is applied to land by a vacuum tanker (contractor or farmer). Forty-six percent of farmers used a contractor for soil water application to land.

This work is described in detail in Hennessy et al. (2011).

Reference

Hennessy, T., Buckley, C., Cushion, M., Kinsella, A., Moran, B., 2011. National Farm Survey of Manure Application and Storage Practices on Irish Farms. Report published by Teagasc. Available: http://www.teagasc.ie/publications/2011/1001/ TeagascNationalFarmSurveyOfManureApplication.pdf

Chapter 10

Knowledge Transfer and Dissemination

The Agricultural Catchments have been established as national focal points for the dissemination of information generated by the programme. The first level of dissemination is within the catchments and is focussed on the catchment farmers through one-to-one and group events. Outside the catchments this dissemination is being incorporated into Teagasc's advisory and educational programmes via the Knowledge Transfer directorate and is achieved mainly through group events and publications. Dissemination beyond the farming community is done using meetings, conferences and publications. The publication of peer-reviewed scientific papers is the principal and most important dissemination activity for the programme and all the papers published are referenced in this report. Outlined below are the main dissemination activities that have been delivered.

Dissemination and Knowledge Transfer Methods

The ACP Agricultural Advisers (including one Technologist with a dual advisory/technical role) supported by the Technicians have played the key role in the dissemination of information in the catchments as well as providing a broad agricultural advisory service to catchment farmers. In addition to the activities of the Agricultural Advisers and Technicians other members of the ACP team have been actively contributed to the dissemination of information and engagement with farmers within and outside the catchments and a wide range of stakeholders as well as the general public. The main dissemination methods they have used are described below.

<u>One-to-one contact</u>

The Agricultural Advisers have devoted most of their time to dealing with farmers individually and

ACP Agricultural Adviser and Technician chat with a farmer in the Sreenty/Corduff catchment they are supported in this by the Technicians who have regular contact with the farmers as they go about their work in the catchments. Over Phase 1 of the programme the Agricultural Advisers made approximately 1,800 individual visits and consultations with catchment farmers. In addition to this there were many more informal contacts between farmers and individual members of the ACP team (advisers, technicians, researchers, manager) which occurred routinely as part of the operation of the programme. This regular level of personal contact has been critical in gaining the trust of the farming communities in the catchments and is the main contribution from the ACP to the farmers in return for the excellent support they have given us. Apart from delivering an advisory service the Agricultural Advisers and Technicians have a very important role in facilitating the operation of the programme through liaising with farmers regarding the collection of data and samples, siting of instrumentation and establishment and harvesting of trial plots.

Each advisor has a target for the number of farms from which Nutrient Management and financial records are to be collected. The National Farm Survey (NFS) and eProfit Monitor methods are both used to gather information on the farm enterprises and the data is used in the analysis of the farm business as well as for research purposes.

Farmer meetings and Farm Walks

More than 40 events tailored to the farmers needs have been held in the catchments. These vary from discussion of specific topics among small groups of farmers, for example, time-critical grassland management issues, to larger more general events for catchment farmers or for visiting farmer groups. These meeting are an effective way to generate a two-way flow of information between the ACP and the catchment farmers and are also an opportunity for farmers to share their ideas and voice any concerns they may have.

ACP Farm Walk in Timoleague

Briefings for non-farmer groups

Visits by groups of students, agricultural advisers, researchers and other stake holder groups have been organised and facilitated by the ACP team. These events have varied from day-long practical sessions with small groups of environmental science students to large briefing sessions with visiting groups of scientists and local authority staff and have been delivered internally to Teagasc staff and externally to other organisations. While this work is time consuming these visits are accommodated as much as possible given their high potential for dissemination of information from the programme.

Mainstreaming the ACP in Teagasc

Within Teagasc there is an Environment Knowledge Transfer (KT) specialist group which is regularly briefed on the programme and disseminates key results through their regular channels. Catchment team members, in conjunction with the specialists and local Teagasc KT staff, provide an input into the in-service-training schedule of mainstream advisers and farmer training events. Information on the operation, implementation and progress of the ACP features at selected public events (incl. farm walks, demonstrations, meetings etc.) held by Teagasc.

Group and one-to-one contact with Farmers and other Stakeholders

The table below shows the number, by year, of one-to-one contacts with farmers in the catchments as well as the more significant group meetings and briefing sessions with farmers and other stakeholder groups. These groups included Local Authority staff, representatives of farming organisations, visiting farmer groups from Ireland and abroad and student groups.

Stakeholder Contacts

	2008	2009	2010	2011
One-to-one farm visits by advisers	-	388	542	548
One-to-one farmer consultations by advisers	-	57	122	131
Catchment Farm Walks/Farmer Meetings	-	4	7	9
Stakeholder Briefings/Catchment Visits	6	10	8	18

Agricultural Adviser in-service-training in the Castledockerell Catchment

Website

The ACP website provides information in relation to the overall project objectives and those of the individual sub projects. The website is kept updated with regard to the progress of the programme and all publications are listed and weather data from each of the catchments is updated daily. The site also provides links to a wide range of national and international websites that contain relevant information.

Video Clips, Press, Television, Radio

To facilitate the understanding of the programme and how it operates a series of short videos were produced by the ACP team to explain aspects of the programme and to describe each of the catchments. These aim to illustrate the programme's approach and the range of activities undertaken in its operation. They can be viewed on the website at http://www.teagasc.ie/agcatchments/videos/

In 2009 the ACP was featured on RTE television's Eco Eye programme. The programme focussed on the Timoleague catchment in Co. Cork and met some of the farmers who explained how they are farming to improve profits and protect water quality and why they are participating in the ACP. The piece can be viewed at http://www.teagasc.ie/agcatchments/publications/eco_eye.asp

Other video clips explaining the role of the ACP and the science behind it which were recorded at the Teagasc Agri-environment Conferences in 2010 and 2011 can be viewed at http://www.teagasc.ie/publications/2010/20100907/GerShortle.asp

The ACP team also contributed to six local radio programmes over Phase 1 of the project and the programme has featured in a number of articles in local and national newspapers.

Publications

The peer-reviewed papers so far published from Phase 1 data are featured in previous chapters of this report. There will be several other papers published using Phase 1 data, either on its own or in combination with Phase 2 data. These papers are essential to underpin the veracity and quality of the output of the ACP and to support the evaluation of the effectiveness of the NAP measures and the Derogation. They make a significant contribution to the reporting that is mandatory under the ND and WFD. A full list of publications is included in Appendix 1.

In addition to the peer-reviewed papers conference papers, posters and articles for a range of technical publications (including the Teagasc publications, TResearch and Today's Farm) have been produced by the ACP team as part of the dissemination process - these are listed in Appendix 1.

Catchment Science 2011

In September 2011 an international conference, 'Catchment Science 2011' was held in the Mansion House in Dublin. This conference was jointly hosted by Teagasc, the Department of Agriculture, Food and the Marine and the UK Department of Environment, Food and Rural Affairs.

The conference presented current ideas and experiences from progressive initiatives around the world which conduct research, monitoring, and demonstration on water resources management and regulation in agricultural catchments. Catchment science researchers from the USA, New Zealand, Australia, Denmark, Sweden, the Netherlands, Norway, England, Scotland, Wales, Northern Ireland and the Czech Republic as well as the ACP team presented 35 papers on their research over the course of the three day conference. In addition to the papers there were 59 posters presented.

The attendance of 300 scientists discussed key issues in catchment management including how catchment management programmes have worked with farmers to implement water quality improvements and what socio-economic issues relating to environmental policies and farming have been identified and how they can be overcome. The conference included field trips to two of the catchments, Dunleer and Sreenty/Corduff, and the support of the farmers who hosted the field trips was central to the success of these events.

Catchment Science 2011 fieldtrip farm visit in Dunleer

The Minister for Agriculture, Food and the Marine, Simon Coveney TD opened the conference and announced the extension of the funding for Phase 2 of the ACP for a further four year period from 2012 to 2015. Overall the conference was judged to be very successful and played a significant part in aiding the development of catchment science. There are strong indications that the foundation has been laid for further such conferences in the future.

The conference proceedings are available at:
http://www.teagasc.ie/agcatchments/catchsciencedocs/catchsciencepres.asp

Appendix 1 – List of Publications[6]

2008

Shortle, G., Fealy, R., and Jordan, P, Melland, A.R., Mellander, P-E., Mechan, S., Buckley, C. and D. Wall. (2008) Using a mini-catchment approach to evaluate nutrient loss reduction measures on Irish farms. Teagasc Grassland and EU Water Framework Conference Nov 2008 (poster abstract).

2009

Fealy R.M., Shortle, G., Melland, A.R., Jordan, P., Mellander, Wall, D. P. P-E., Buckley, C. and. Mechan, S. (2009) A catchment approach to evaluate the Nitrates Directive National Action Programme in Ireland. 16th Nitrogen Workshop June 2009

Mellander, P-E., Melland, Shortle, G., A., Wall, D., Fealy R.M., Mechan, S., Buckley, C. and Jordan, P. (2009) Patterns and processes of nutrient transfers from land to water: a catchment approach to evaluate Good Agricultural Practice in Ireland. Geophysical Research Abstracts, Vol. 11, EGU2009-10647, EGU General Assembly. April 2009

Shortle, G., Fealy R.M., Melland, A.R., Mellander, Wall, D. P. P-E., Buckley, C. and. Jordan, P. (2009) Sources to Transfers: Evaluating the Nitrates Directive Action Programme in Ireland using a catchment approach (abstract) ENVIRON, The 19th Annual Irish Environmental Researchers Colloquium, Waterford, Ireland. Feb 2009

Shortle, G., (2009) The Agricultural Catchments Programme – innovation for farming and the environment. TResearch Volume 4: Number 2. Summer 2009

Wall, D. P. Melland, A.R., Jordan, P., Shortle, G., Mellander, P-E., Buckley, C. and. Mechan, S. (2009) Managing nitrogen and phosphorus sources on farms within the EU Nitrates Directive framework in Ireland. SSSI/BSSS Joint Conference Johnstown Castle, Co Wexford, Sept 2009

Wall, D. P., Melland, A.R., Jordan, P., Shortle, G., Mellander, P-E., Buckley, C. and. Mechan, S. (2009) Managing Nitrogen and Phosphorus in Agriculture: A Catchment Evaluation of Mandatory Environmental Measures in Ireland. The International Annual Meetings of the American Society of Agronomy (ASA), Crop Science Society of America (CSSA), and Soil Science Society of America (SSSA) Nov 2009

2010

Buckley, C. (2010). Efficient Nutrient Management - A win for the farmer and a win for the environment. In: Agricultural Economics Conference, Edinburgh, 30-Mar-2010, 8 pages

Buckley, C. (2010). Nutrient Management Efficiency in Ireland - A data envelopment analysis of specialist dairy and tillage farms. In: Food, Feed, Energy and Fibre from land - a Vision for 2020, Queens University Belfast, 12-Apr-2010, 1 page

[6] By year, including collaborations

Buckley, C., 2010. Efficient nutrient management across regions - A potential winner for all. Regional Science Association International British and Irish Section 39th Annual Conference Glasgow 25th August, 2010

Buckley, C., 2010. Efficient nutrient management - The potential double dividend. 1st Annual Conference of the Irish Environmental Economist's Network, Athenry, Sept 2010

Buckley, C., (2010). Nutrient Management Efficiency in the Republic of Ireland - Saving the Environment and Reducing Costs. 14th IWA Diffuse Pollution Specialist Group: DipCon Beaupré, Québec, Canada. Sept 2010

Buckley, C., (2010). Socio-Economic Analysis of Attitude to Water Quality Measures 2nd Annual Beaufort Marine Socio-Economic Workshop, SEMRU, NUI Galway, Nov 2010.

Mechan, S. and Burgess, E. (2010). The Irish agricultural catchments programme: supporting sound agricultural practices with GIS. In: GIS for Agribusiness. World Wide Web (Internet) Summer, p4-5

Mechan, S., Burgess, E. and Fealy, R. (2010). Irish Agricultural Catchments Programme protects water quality while supporting productive agriculture. ArcNews Vol. 32, No. 3 p34

Melland, A.R., Jordan, P., Wall, D., Mellander, P.E., Mechan, S., Shortle, G. (2010). Baseline Q-values for streams in intensive agricultural catchments in Ireland. In, Geophysical Research Abstracts EGU General Assembly. Vienna, Austria. EGU Vienna May 2010

Melland, A.R., Wall, D., Mellander, P.-E., Jordan, P., Mechan, S., (2010). Soil management and stream water quality at the agricultural catchment scale in Ireland. In R.J. Gilkes, N. Prakongkep (Eds.), Proceedings of the 19th World Congress of Soil Science; Soil Solutions for a Changing World. Symposium 4.1.2 Management and protection of receiving environments. IUSS, Brisbane, Australia, pp. 175-178. July 2010

Melland, A.R., Jordan, P., Wall, D., Mellander, P.E., Buckley, C., Mechan, S., Shortle, G., 2010. Catchment-scale evaluation of environmental regulations in the agricultural sector in Ireland. AGU Fall Meeting, San Francisco, California. Dec 2010

Jordan, P., Melland, A., Cassidy, R., (2010). Observations on high resolution nutrient monitoring in rivers. In, 6th International Workshop on Phosphorus (IPW6); Towards a sustainable control of diffuse P loss: risk, monitoring, modelling, and mitigation options. Seville, Spain. Sept/Oct. 2010.

Jordan, P., Melland, A., Fenton, O. Richards, K., Schulte, R. (2010). A model to predict soil P depletion to achieve agronomic and environmental objectives. In, 6th International Workshop on Phosphorus (IPW6); Towards a sustainable control of diffuse P loss: risk, monitoring, modelling, and mitigation options. Seville, Spain. Sept/Oct. 2010.

Murphy, S., Bhreathnach, N., Wuertz, S., Jordan, P., O'Flaherty, V., (2010) Investigation of bacterial pathogen sources and transfer hydrodynamics in rural catchments. (Poster) The International Society of Microbial Ecology Conference, Seattle Aug 2010

Shore, M., Melland, A.R., Mellander, P-E., Kelly-Quinn M., Jordan P. Verification of Digital Terrain Derived Hydrological Flow Paths in Agricultural Catchments. 14th IWA Diffuse Pollution Specialist Group: DipCon, Beaupré, Québec, Canada. Sept 2010

Wall, D.P, and Mechan, S. 2010. Soil phosphorus management in agricultural catchments in Ireland. In 6th International Phosphorus Workshop abstracts, Seville, Spain. pp.143. (Poster) Sept/Oct. 2010.

Wall, D.P., Melland, A.R., Buckley, C., Jordan, P., Mechan, S., Mellander, P-E., and Shortle, G. (2010) The Agricultural Catchments Programme; an environmental and socio economic evaluation of the Nitrates Directive National Action Programme in Ireland. In 6th International Phosphorus Workshop abstracts, Seville, Spain. pp.172. Sept/Oct. 2010.

2011

Buckley, C., Hynes, S. and Mechan, S. (2011). Willingness of farmers to engage with riparian zones across small scale catchment areas in the republic of Ireland. (Abstract) Catchment Science 2011

Crockford, L., Jordan, P. and Taylor, D. (2011). Phosphorus load apportionment in Irish water-bodies. Poster Abstract at Catchment Science, The Mansion House, Dublin, 14-16 Sept. (Abstract) Conference Book of Abstracts p98

Jordan, P., Melland, A., Mellander, P., Wall, D., Murphy, P., Buckley, C., Mechan, S., Shine Oliver and Shortle, G (2011). Nutrient loads from agri-catchments: environmental risk or economic write-off? Tresearch Vol 6: No. 4 page 12-13 ISSN 1649-8917

Jordan, P. (2011). Nutrient management at the catchment scale: lessons from Ireland and the European Union. In: Agri Env. Conf, Hodson Bay Hotel, Athlone, 10-Nov-2011, p11-12

Kelly, E., Heanue, K., Buckley, C. and O'Gorman, C. (2011). Soil testing on Irish farms - Catchment Science 2011 The Mansion House, Dublin, 14-16 Sept. (Abstract) Conference Book of Abstracts p62

McDonald, N.T., Wall, D., Watson, C.J., Laughlin, R.J. and Lalor, S. (2011). Evaluating potential nitrogen tests for Irish grassland soils. In: Agricultural Research Forum, Tullamore, Co. Offaly, 14 Mar 2011, pg29

McDonald, N.T., Watson, C.J., Laughlin, R.J., Lalor, S., Hoekstra, N. and Wall, D. (2011). Nitrogen fertilizer recommendations that account for soil N supply. In: Catchment Science 2011, The Mansion House, Dublin, 14-Sep-2011, p66

McDonald, N.T. and Wall, D. (2011). Soil specific N advice - utilising our soil nitrogen resources. In: Agri Env. Conf, Hodson Bay Hotel, Athlone, 10-Nov-2011, p31-35

Mechan, S., Shine, O., Mellander, P., Melland, A., Wall, D., Murphy, P., Buckley, C., Shortle, G and Jordan, P. (2011). The agricultural catchments programme: instrumentation and data management - Catchment Science 2011 The Mansion House, Dublin, 14-16 Sept. (Abstract) Conference Book of Abstracts p48

Melland, A.R., Mellander, P-E, Shore, M., Cushen, M., Mechan, S., Murphy, P.N.C., Wall, D. G Shortle, G., and Jordan, P. (2011) Evaluating the effectiveness of the Nitrates Directive in Ireland for nutrient loss - The Agricultural Catchments Programme. Irish National Hydrology Conference. Irish Joint National Committees of the UNESCO International Hydrological Programme and the International Commission on Irrigation and Drainage, Athlone, Ireland, 15th November 2011, 7 pp. (Invited Speaker)

Melland, A., Wall, D., Mellander, P., Shortle, G and Jordan, P. (2011). Farm nutrient regulations; contrasting impact on water quality in different catchments. (Abstract) Catchment Science 2011 The Mansion House, Dublin, 14-16 Sept. (Abstract) Conference Book of Abstracts p.21

Mellander, P., Melland, A., Jordan, P., Wall, D. and Shortle, G (2011). Uncertain diffuse phosphorus pathways in catchments. Catchment Science 2011 The Mansion House, Dublin, 14-16 Sept. (Abstract) Conference Book of Abstracts p36

Murphy, S., Bhreathnach, N., Wuertz, S., Jordan, P. and O'Flaherty, V. (2011). Investigation of bacterial pathogen sources and transfer hydrodynamics in rural catchments. Poster at Catchment Science 2011, The Mansion House, Dublin, 14-16 Sept. (Abstract) Conference Book of Abstracts

Norton, D., Hynes, S., Buckley, C., Doherty, E. and Cambell, D. (2011). The use of benefit transfer in estimating the value of achieving 'good ecological status' in Irish river catchments. (Abstract) Catchment Science 2011 p44

O'hUallachain, D., Rowan, J., Bruen, M., Gibson, M., Sherriff, S. and Jordan, P. (2011). Sediment loss and soil conservation: measurement of sediment flux in rivers and benefits of enhancement measures. In: Teagasc Agri-environmental Conf, Athlone, 10-Nov-2012, p23-24

Reaney, S.M., Milledge, D.G., Lane, S.N., Heathwaite, A.L., Mechan, S., Melland, A. and Jordan, P. (2011). Understanding nutrient connectivity at the landscape scale: the use of the scimap approach in the UK and Ireland - Poster abstract - Catchment Science 2011, The Mansion House Dublin, 14-16 Sept. (Abstract) Conference Book of Abstracts p100

Shine, O., Mechan, S., Melland, A., Mellander, P. and Shortle, G (2011). WISKI 7 experiences within the Irish agricultural catchments programme. In: Kisters Int. WISKI User Conference April 2011

Shine, O. and Mechan, S. (2011). Agricultural catchments programme instrumentation and data management. ACP Pathways Workshop April 2011

Shore, M., Jordan, P., Sims, J.T., Mellander, P., Kelly-Quinn, M. and Melland, A. (2011). Potential of ditch sediments to pose a phosphorus source risk in agricultural catchments in Ireland. Poster at Catchment Science 2011, The Mansion House, Dublin, 14-16 Sept. (Abstract) Conference Book of Abstracts p69

Shortle G. (2011) A partnership approach to evaluating the NAP. Water 2011 - Mobilising to deliver water outcomes (EPA). Salthill, Galway. (Abstract).16th June 2011

Shortle, G, Mechan, S., Shine, O., Mellander, P., Murphy, P., Melland, A., Buckley, C., Wall, D. and Jordan, P. (2011). The Agricultural Catchments Programme: an evaluation framework for the Nitrates Directive National Action Programme - Poster Abstract. (Abstract) Catchment Science 2011

Shortle, G. (2011) Using GIS in the Agricultural Catchments Programme. Mapping the Public Sector Conference. (Abstract) DECLG Dublin Oct 2011.

Wall, D. and Shortle, G (2011). Securing Ireland's N derogation; the Agricultural Catchments Programme. Tresearch Vol. 6 No. 1, Spring p14-15 ISSN 1649-8917

Wall, D., Jordan, P., Melland, A., Mellander, P., Buckley, C., Reaney, S.M. and Shortle, G (2011). Using the nutrient transfer continuum concept to evaluate the European Union Nitrates Directive National Action Programme. Environmental Science & Policy 14 664-674 ISSN 1462-9011

Wall, D., Buckley, C., Melland, A., Jordan, P., Mellander, P. and Shortle, G (2011). Evaluating management regulations at different scales in agricultural catchments in Ireland. (Abstract) Catchment Science 2011 p31

2012

Buckley, C (2012) Adoption of desirable nutrient management practices by farmers (abstract) The 86th Annual Agricultural Economic Society Conference, University of Warwick, April 16-18th.

Buckley, C., Wall, D. and Murphy, P.N.C. (2012). Abatement of diffuse pollution from agriculture through efficient nutrient budgeting at farm level. IWA Congress on Water, Climate and Energy 2012. (Abstract) Conference Book of Abstracts

Buckley, C., Wall, D. and Murphy, P.N.C. (2012). Nutrient budgeting at farm level - eco-efficiency of specialist dairy farms. In: Agricultural Economic Society of Ireland October 18, 2012, Dublin. (Abstract) Conference Book of Abstracts

Buckley, C. (2012). Implementation of the EU Nitrates Directive in the Republic of Ireland - A view from the farm. Ecological Economics 78: 29-36 ISSN 0921-8009

Buckley, C. and Fealy, R. (2012). Intra-national importation of pig and poultry manure: acceptability under EU Nitrates Directive constraints. International Journal of Agricultural Management Vol 1 Issue 4: 41-47 ISSN 2047-3710

Buckley, C., Hynes, S. and Mechan, S. (2012). Supply of an ecosystem service - Farmers' willingness to adopt riparian buffer zones in agricultural catchments. Environmental Science & Policy 24: 101-109 ISSN 1462-9011

Couturier, A., Cawkwell, F., Shine, O., Wall, D. and Green, S. (2012). Using Quickbird and LiDAR data for land cover classification of rural areas. In: 6th Irish Earth Observation Symposium IEO2012, DIT, Dublin, 01-Nov-2012,

Hennessy, T., Buckley, C. and Moran, B. (2012). Slurry shift from silage ground to grazing. Irish Farmers Journal pages 2-4, 7 Jan 2012

Jordan, P., Melland, A.R., Mellander, P., Shortle, G and Wall, D. (2012). The seasonality of phosphorus transfers from land to water: implications for trophic impacts and policy evaluation. Science of the Total Environment 434: 101-109 ISSN 0044-9697

Jordan, P., Melland, A., Mellander, P., Murphy, P.N.C., Shortle, G, Wall, D., Mechan, S. and Shine, O. (2012). Sharpening policy instruments with catchment evaluations and the water quality continuum. Euro Geoscience Union General Assembly, 22 April, Vienna. (Abstract) Conference

Jordan, P., Mellander, P., Melland, A. and Murphy, P.N.C. (2012). Water quality expectations in a changing agricultural landscape. Proc. IWA Congress on Water, Climate and Energy, 13-18 May, Convention Centre, Dublin. (Abstract) Conference Book of Abstracts

McDonald, N.T., Watson, C.J., Laughlin, R.J., Lalor, S., Hoekstra, N. and Wall, D. (2012). Investigating the efficiency of soil nitrogen tests to predict soil nitrogen supply across a range of Irish soil types under controlled environmental conditions. In: 17th International N Workshop, Wexford, 26-Jun-2012, pp25-26

Mechan, S. and Wall, D. (2012). Research Update; putting nutrients on the map. Teagasc Advisory Newsletter May 2012

Mechan, S., Shine, O., Buckley, C., Wall, D., Mellander, P., Melland, A., Murphy, Paul, Shortle, G and Jordan, P. (2012). Instrumentation and data management architecture for a large-scale catchments research programme. Proc IWA Congress on Water, Climate and Energy. 13-18 May, Convention Centre, Dublin. (Abstract) Conference Book of Abstracts pp 2

Mechan, S. and Wall, D. (2012). Putting nutrients on the map. TResearch Vol 7 No. 1 Spring p26-27ISSN 1649-8917

Mechan, S., Lalor, S., Shine, O., Jordan, P. and Wall, D. (2012). Using data management systems to facilitate better nutrient management planning on Irish farms. In: 17th International N Workshop, Wexford, 26-Jun-2012, pp486-487

Melland, A.R., Mellander, P., Murphy, P.N.C., Wall, D., Mechan, S., Shine, O., Shortle, G and Jordan, P. (2012). Losses of nitrate in streamflow from intensive cereal crop catchments in Ireland. In: Agricultural Research Forum, Tullamore, Co. Offaly, 12-Mar-2012,

Melland, A.R., Mellander, P., Murphy, P.N.C., Wall, D., Mechan, S., Shine, O., Shortle, G and Jordan, P. (2012). Stream water quality in intensive cereal cropping catchments with regulated nutrient management. Environmental Science & Policy 24, 58-70 ISSN 1462-9011

Melland, A.R., Mellander, P., Murphy, P.N.C., Wall, D., Mechan, S., Shine, O., Shortle, G and Jordan, P. (2012). Catchment monitoring technologies to identify critical source areas and times for nitrate transfer to streams. Proc Geophy Research Abstracts, EGU Gen Assembly, Vienna, 22-27 Apr., Vienna. (Abstract) Conference Book of Abstracts Vol. 14, EGU2012-9867

Melland, A.R., Ryan, D., Shortle, G and Jordan, P. (2012). A cost:benefit evaluation of in situ high temporal resolution stream nutrient monitoring. IWA World Congress on Water, Climate and Energy, 13-18 May, Convention Centre, Dublin. (Abstract) Conference Book of Abstracts

Melland, A.R., Mellander, P., Murphy, Paul, Wall, D., Mechan, S., Shine, O., Shortle, G and Jordan, P. (2012). Process of nitrate-N loss to streamflow from intensive cereal crop catchments in Ireland. In: 17th International Nitrogen Workshop, Wexford, 26-Jun-2012, 268-269

Melland, A.R., (2012). Water policy in Ireland; an agricultural perspective. Invited Seminar, Masters Students from Environmental Science. Trinity College, Dublin 1

Mellander, P., Melland, A., Jordan, P., Murphy, P.N.C. and Shortle, G (2012). Unmixing stream water chemistry: N and P transfer pathways in agricultural catchments. Invited speaker, Seminar, Bangor University, Feb 2012

Mellander, P., Melland, A., Jordan, P., Murphy, P.N.C. and Shortle, G (2012). The use of geophysics in interpreting hydro-geological pathways of diffuse nutrient loss in two agricultural river catchments. Proc. Geophysical Assoc of Ireland, Seminar on Environmental Geophysics, Dublin, 15 Feb. (Abstract) Conference Book of Abstracts

Mellander, P., Melland, A., Jordan, P., Wall, D., Murphy, P.N.C. and Shortle, G (2012). Quantifying nutrient transfer pathways in agricultural catchments using high temporal resolution data. Environmental Science & Policy 24: 44-57 ISSN 1462-

Mellander, P., Wall, D., Jordan, P., Melland, A.R., Mechan, S., Kelly, C. and Shortle, G (2012). Delivery and impact bypass in a karst aquifer with high phosphorus source and pathway potential. Water Research 46: 2225-2236 ISSN 0043-1354

Mellander, P., Melland, A.R., Murphy, P.N.C., Wall, D., Shortle, G and Jordan, P. (2012). Spatiotemporal variation in groundwater nitrate-N concentrations in two agricultural catchments. Proc. In: 17th International Nitrogen Workshop, Opera House, Wexford, 26-Jun-2012, 224-225

Mellander, P., Melland, A.R., Jordan, P., Murphy, P.N.C. and Shortle, G (2012). Agriculture reflected in Irish waters: maintaining good quality with increased production? Invited speaker to Workshop "Water as the mirror of landscapes: How useful a hypothesis for resource management. Workshop, Uppsala, Sweden 1

Mellander, P., Melland, A.R, Jordan, P., Murphy, P.N.C., Wall, D. and Shortle, G (2012). Unmixing stream water chemistry: nutrient load pathways assessed from high resolution data. Geophysical Research Abstracts, EGU General Assembly, Vienna, 22-27 April. (Abstract) Conference Book of Abstracts Vol 14, EGU2012-9867

Mellander, P., Melland, A.R., Murphy, P., Wall, D., Shortle, G and Jordan, P. (2012). Attenuation of phosphorus transfer in an agricultural karstic spring zone of contribution. Proc. IWA Congress on Water, Climate and Energy, 13-18 May, Convention Centre, Dublin. (Abstract) Conference Book of Abstracts

Murphy, P.N.C., Melland, A.R, Mellander, P., Shortle, G, Wall, D. and Jordan, P. (2012). Soil and water chemistry in three Irish agricultural catchments and implications for nutrient loss and catchment management. Proc. IWA Congress on Water, Climate and Energy, 13-18 May, Dublin. (Abstract) Conference Book of Abstracts

Murphy, P.N.C., Melland, A.R., Mellander, P., Shortle, G, Wall, D. and Jordan, P. (2012). Phosphorus sources and losses in two arable catchments and implications for catchment management. Proc Geophy Research Abstracts, EGU Gen Assembly, Vienna, 22-27 Apr., Vienna. (Abstract) Conference Book of Abstracts Vol. 14, EGU2012-9867

Murphy, P.N.C., Wall, D., Melland, A.R., Mellander, P., Shortle, G and Jordan, P. (2012). Soil-landscapes and risks of nutrient loss to water in six Irish agricultural catchments - Eurosoil 2012, 2-6 July, Bari. (Abstract) Conference Book of Abstracts 438

McDonald, N.T., Watson, C.J., Laughlin, R.J., Lalor, S. and Wall, D. (2012). Utilizing the soils nitrogen supply potential for efficient grass production. Noeleen McDonald received overall winner of the Walsh Fellow of the year. In: 17th annual Teagasc Walsh Fellowship Seminar 2012, RDS,

Sherriff, S., Rowan, J.S., Melland, A.R., Jordan, P. and O'hUallachain, D. (2012). Sediment Fingerprinting as a land management tool. In: CECHR Annual Symposium, Dundee, UK, 02-Feb-2012

Sherriff, S., Rowan, J., Melland, A.R., Jordan, P. and O'hUallachain, D. (2012). Sediment fingerprinting: project overview. In: ACP - Pathways Workshop, Queens Uni. Belfast, 03-Apr-2012,

Shine, O., Mechan, S., Melland, A.R., Mellander, P., Murphy, P.N.C. and Shortle, G (2012). INSPIRE - Facilitating End User Analysis. In: GIS Ireland 2012, 16-Aug-2012

Shortle, G. and Jordan, P. (2012). A grand challenge - good food clean water. TResearch ISSN 1649-8917

Shore, M., Mechan, S., Cushen, M., Jordan, P., Mellander, P., Kelly-Quinn, M. and Melland, A.R. 2012). Extent and role of ditches in affecting hydrological connectivity in agricultural landscapes. Proc. IWA Congress on Water, Climate and Energy, 13-18 May, Convention Centre, Dublin. (Abstract) Conference Book of Abstracts

Shore, M., Jordan, P., Mellander, P., Kelly-Quinn, M., Murphy, P.N.C., Cushen, M., Mechan, S., Shine, O. and Melland, A.R. (2012). Applying the SCIMAP hydrological connectivity model in headwater agricultural catchments. In: SCIMAP User Group Meeting, London, 26-Oct-2012

Shore, M., Jordan, P., Mellander, P., Kelly-Quinn, M. and Melland, A.R. (2012). Phosphorus source and mobilisation potential of agricultural headwater ditch sediments. In: Teagasc Walsh Fellowships Seminar, RDS, Dublin, 22-Nov-2012

Wall, D., McDonald, N.T. and Humphreys, J. (2012). Grassland N management: planning for the season ahead. Todays Farm Vol 23, No. 1 Jan Feb

Wall, D., Murphy, P.N.C., Melland, A.R., Mechan, S., Shine, O., Buckley, C., Mellander, P., Shortle, G and Jordan, P. (2012). Evaluating agricultural nutrient source regulations at different scales in five Irish catchments. Environmental Science & Policy 24: 34-43 ISSN 1462-9011

2013

Buckley, C., Carney, P., 2013. The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level. Environmental Science and Policy, 25, 118-126.

O’Dwyer, B., Crockford, L., Jordan, P., Hislop, L. and Taylor, D. (in press). A palaeolimnological investigation into nutrient impact and recovery in an agricultural catchment. Journal of Environmental Management, doi. 10.1016 / jenvman / 2013.01.034.

Mellander P-E, Jordan P, et al. (accepted) Quantification of Phosphorus Transport from a Karstic Agricultural Watershed to Emerging Spring Water. Environmental Science & Technology

Shore, M., Murphy, P.N.C., Jordan, P., Mellander, P-E., Kelly-Quinn, M., Cushen, M., Mechan, S., Shine, O., and Melland A.R. (accepted) Evaluation of a surface hydrological connectivity index in agricultural catchments. Environmental Modelling & Software

Appendix 2 -Agricultural Catchments Programme Staff

Ger Shortle

Role: Programme Manager

Ger has been with Teagasc since 1993 and has worked in a in a variety of roles in research, advisory and training. Prior to his appointment as Programme Manager he ran the Organic Research Unit at Johnstown Castle Research Centre and liaised closely with the Teagasc advisory service in delivering the organic advisory and training programme. His work in organic research was mainly in the areas of breed comparisons and clover establishment.

Before moving to Johnstown Castle research Centre in 2005 he was Principal of Mellows Agricultural College in Athenry, Co. Galway for five years where he managed the delivery of a range of agricultural courses and the conversion of the college farm to organic production. Prior to his time as Principal he worked as an agricultural adviser in Teagasc and in the private sector. In this role Ger is responsible for the development, implementation and delivery of the ACP as agreed with the DAFM.

Phil Jordan

Role: Principal Scientist

Phil is Professor of Catchment Science at the University of Ulster and has a range of research interests in hydrology, hydrochemistry and limnology concerned with the transfer and fate of nutrients and pollutants in the aquatic environment. He was previously Head of the School of Environmental Sciences at the University of Ulster and has had a number of research collaborations with Teagasc and other Irish research and University departments.

In Phase 1 of the ACP his role as Principal Scientist was to direct the scientific team and the bio-physical evaluation of the Good Agricultural Practice regulations as determined in the Nitrates Directive NAP. Specifically, this part of the Programme provides a link between compliance and resulting parameters of water quality in catchment rivers. In Phase 2 Phil maintains his input into the ACP in a consultancy role.

Maria Merriman

Role: Programme Administrator

Maria Merriman has worked in an administrative role in the private and public sectors. Prior to working on the ACP she was Staff Officer for Teagasc in Westmeath having previously worked in the Franciscan College of Agriculture in Multyfarnham.

Maria's role as Administrator is to produce, compile and monitor management budgets and reports and provide administrative support to the ACP team liaising with and supporting a participative project internal and external stakeholder network. She oversees the implementation of agreed protocols, assisting in the development and monitoring of the programme business plan. Maria provides administrative support at programme local, national and international meetings and promotes dissemination of the project outputs and other information through organizing and supporting meetings and open days with participating farmers and other stakeholders in the catchments.

Cathal Buckley

Role: Economist

Cathal's research interests include agricultural, environmental and natural resource economics. Since joining the ACP in December 2008 his research has focused on analysis of the socio-economic impact of the implementation of the measures contained in the NAP under the Nitrates Directive (S.I. 378 of 2006) on farms in the catchments and nationally. This research focuses on nutrient management efficiency among farmers, adoption of nutrient management best practices and provision of environmental public goods related to agriculture.

Prior to joining the ACP Cathal's research was in the area of non-market valuation techniques to estimate recreational demand for walking in Ireland.

Sarah Mechan

Role: Data Manager

Sarah studied in Dundee where her background is in bioinformatics and data analysis in plant science and conservation. She spent several years working in both the public and private sectors ensuring data integrity and consistency for numerous databases and products including GIS systems.

Her core role within the project is to develop and maintain an information management system to ensure the most efficient data capture and integration from multiple sources including data collection via telemetry, surveys, GIS data and imagery.

Alice Melland

Role: Hydrogeochemist

Alice Melland hails from Victoria, in south-east Australia and is the Hydrogeochemist in the ACP. Alice studied an Agricultural Science bachelor's degree and completed her PhD in field studies of phosphorus in runoff and drainage from grassland in Victoria, Australia. Since then Alice has worked in the research division of the Department of Primary Industries in Victoria where she has developed a decision support tool for assessing nutrient loss risk from farms, and more recently has applied farm and catchment scale hydrology and nutrient transport models to investigate the influence of farm management on surface water quality. She has a strong interest in developing ways to keep nutrients on farms, by identifying and concentrating on fields and times of the year when nutrients are most at risk of leaking and developing solutions to minimise the leakage.

Alice's role in the ACP is to measure stream flow and water quality throughout the stream networks in each catchment. Alice is based at Johnstown Castle full time.

Per-Erik Mellander

Role: Environmental Hydrologist

Per-Erik's role in the team is to monitor ground and subsoil water, as well as climate parameters within the selected agricultural catchments. His main contribution is to link the nutrient losses from source to streams by increasing the understanding of how water finds its way to the stream via the soil, sub soil and bedrock.

His previous work has involved climate and hydrology at different spatial scales and within different climatic zones. During his Doctoral studies he worked with water uptake processes in the boreal forests of northern Sweden. This was followed up by post doctoral studies, as a member of cCREW (Cold Climate Research in Boreal Watersheds), where he studied the effects of climate change on snow cover in forests, and its influence on spring flood, water quality and stream ecosystems. Thereafter he worked as a researcher and lecturer at Mid Sweden University in his hometown Sundsvall. His research was focused on runoff processes and leakage of nutrients to streams. In another project he worked with downscaling of precipitation scenarios in the Blue Nile region within the project “securing dry season flow in the north-western highlands of Ethiopia”.

Special interests are; understanding how climate and human impact influence processes in ecosystems, with emphasis on processes related to water quality.

Paul Murphy

Role: Soil Scientist

Paul is a soil scientist with research interests in nutrient (N, P) management and cycling in agricultural and forest soils; solutions to environmental problems in soil and watershed management, particularly relating to soil amendments, water quality and greenhouse gas emissions; soil environmental hydrogeochemistry and geospatial modelling of soil processes and properties at the landscape scale (soil-landscape modelling); geomorphology and soils.

Paul’s role in the ACP is to monitor and quantify nitrogen and phosphorus dynamics on farms in the six agricultural catchments so as to improve our understanding of the linkages between nutrient sources and their availability for transport and loss to water. This deeper understanding of these processes plays a key role in the assessment of the efficacy of the NAP measures.

David Ryan

Role: Technologist (Instrumentation)

David commenced work with Teagasc at Johnstown Castle Environment Research Centre in 2006 as a Research Technician working on Ammonia Emissions and Nutrient Efficiency. Prior to this, since graduating from University College Cork, he had worked extensively in the Food Industry throughout the country.

As Instrumentation Technologist with the ACP, David is responsible for the management of the water quality data stream and ensuring the efficient running of analytical field equipment across all the Agricultural Catchment Programme sites, monitoring of Laboratory Information Management System (LIMS) and facilitating data quality control.

Mark Treacy

Role: Technologist (Advisory/Technical)

Mark started work with the ACP in November 2010 as a Technologist in Timoleague, Co. Cork. This role combines the duties of Technician and Advisor and he facilitates the Programme’s research in the Timoleague catchment as well as delivering an advisory service to the farmers there. Mark is based in the Agricultural College in Clonakilty. He has worked with Teagasc before as an Agricultural Development Officer based in Cork East. His Masters work involved an on-farm study of nutrient management practices on 21 intensive dairy farms in the south of Ireland as part of the Green Dairy Project.

Oliver Shine

Role: Data Technologist

Oliver originally studied Environmental Science for his undergraduate training and has a postgraduate in both IT and GIS systems. He has several years experience in both IT and environmental data management. His previous experience in IT ranges from website and internet technologies, to database and server management. Within the environmental data sector, he has worked as a biological records database manager and has been the technical lead and consultant on many web based GIS systems. He was previously the technical lead on the Irish Spatial Data Exchange Programme, an intergovernmental spatial data portal, which subsequently won an eGovernment award for excellence in 2009.

Oliver's role within the catchments programme is to support data management and spatial analysis.

Edward Burgess

Role: Agricultural Adviser

Prior to joining the ACP, Edward worked as an agricultural adviser with Teagasc in Co. Wicklow for 13 years. For the majority of this time he was a general advisor for cattle, sheep and tillage farmers, based in Tinahely. Following the restructuring of the advisory programme in 2007 he was the Business and Technology advisor for dry-stock (Cattle and Sheep) farmers in Counties Carlow and Wicklow. In this post he established two sheep discussion groups in Co. Wicklow, a Suckler Discussion group in Co. Carlow and a "BETTER" farm on the border of the two counties. (The BETTER programme is a joint research / advisory programme using ten beef farms throughout the country).

Edward's role is as an Adviser to the farmers in the Castledockerell and Ballycanew catchments. He provides an advisory service to help farmer's compliance with NAP measures and maximize farm profits through improved business management and technical performance and facilitate the research team with data collection.

Noel Meehan

Role: Agricultural Adviser

Noel comes from a farming background and has worked with Local Authorities in Offaly and Galway on Water Quality and Waste Management for 5 years. He joined Teagasc in May 2007 as a REPS Advisor in Galway.

Noel commenced work on the ACP in May 2009 as an advisor for the programme. He work with farmers in the Cregduff catchment near Ballinrobe encouraging farmer participation in the programme and delivering an advisory service that helps farmers to fulfil their obligations under the NAP and improve profitability of their farm enterprise through improved business management and technical performance. He also facilitates and aids the research team with data collection and analysis.

Tom O'Connell

Role: Agricultural Adviser

Brought up on a farm in county Kildare Tom has wide experience in both the private and public sector working in the mushroom, food and pharmaceutical sectors. Since joining Teagasc in 2000 he has been based at the National Crops Research Centre, Oak Park, Carlow.

Tom started work on the ACP in 2009 and is based in the Drogheda office covering the Dunleer and Sreenty/Corduff catchments facilitating the research team with data collection and liaising with other stakeholders. He provides an advisory service to help farmer's compliance with NAP measures and maximize farm profits through improved business management and technical performance and facilitate the research team with data collection.

Brian O'Connor

Role: Technician

Brian joined the ACP in January 2011. Based in Johnstown Castle he works in the Ballycanew and Castledockerell Catchments. Prior to joining the ACP Brian worked as an Agricultural Consultant; areas of work included Nutrient Management Planning, Field Registration and Research Trial Management and general Farm Consultancy.

As a Research Technician, Brian is responsible for data collection, sample collection, equipment monitoring and stakeholder interaction.

John Kennedy

Role: Technician

John was brought up on a farm in county Offaly and graduated from Kildalton College of Horticulture with a Senior Certificate in Commercial Horticulture in 1978. He has worked as a Technician in An Grianan College of Horticulture in Termonfeckin Co. Louth and in Warrenstown College Co. Meath since leaving college. He developed and managed a commercial fruit section at An Grianan and designed, constructed and managed organic fruit, vegetable and herb gardens at Warrenstown. As well as teaching a wide range of skills and modules he was Safety Officer and the Manual Handling Instructor for Warrenstown College.

John is based at Drogheda covering the Dunleer and Sreenty/Corduff catchments. He is responsible for data collection, sample collection, equipment monitoring and stakeholder interaction.

Frank Lennon

Role: Technician

Frank comes from a farming background and has 12 years experience in Nutrient Management Planning for farmers throughout a wide area of Ireland and within a wide range of enterprises. He has worked on contract for Industry, REPS planners, and directly for farmers. He joins the Catchment Programme with enthusiasm that the programme will continue to play an important role in gathering valuable information and providing an invaluable guide to farming with a view to achieving excellent water quality. Franks provides Technical support and gathers information for the programme in the Cregduff Catchment in Ballinrobe.

Appendix 3 –
Walsh Fellowship PhD students attached to the Agricultural Catchments Programme

Mairead Shore

Project title: The role of agricultural ditches and streams in phosphorus loss

An investigation of the role of surface ditch networks in phosphorus loss using a case study of two agricultural catchments with contrasting drainage capacity in south-east Ireland. The objectives of this study are to:

- Evaluate a model of surface hydrological connectivity at field and subcatchment scales and investigate the importance of ditch data for achieving accurate connectivity predictions.
- Compare the bioavailability and mobilisation potential of phosphorus in bed sediments of ditches with that in contributing field and stream bank soils.
- Use information on the ditch source and transport potentials identified above, in conjunction with observations of subcatchment water quality during event flows, to assess the potential for attenuation of phosphorus losses and explore optimal ditch management scenarios.

Sinéad Murphy

Project Title: Bacterical pathogen sources and transfer hydrodynamics in rural catchments

Description: Developing a conceptual model of bacterial pathogen transfers from rural catchments and delivered via two principal objectives: to identify the sources of bacterial contamination in runoff pathways and stream discharge using a source apportionment method; to investigate the hydrodynamics of bacterial pathogen transfers in stream discharges across a gradient of low and high flows. Using microbial source tracking methods, sources of bacteria from faecal matter will be distinguished in order to build a theoretical model of bacterial pathogen transfers from rural catchments. Hydrodynamics will also play a key role in this project. Therefore, the movement of bacterial pathogens in stream discharges in storm and non-storm periods will also be examined.

Noeleen McDonald

Project Title: Developing a nitrogen test for grassland soils

Description: Developing a soil-based nitrogen test for grassland soils using a range of soils collected across Ireland including the ACP catchments. The main objectives of this project is to initially relate soil parameters to soil N mineralisation potential in order to predict native soil N supply of Irish soils, to explore and develop soil N tests, for assessing soil N mineralisation capacity and grassland production potential; and eventually to develop an improved framework for soil N testing that is both practical and productive, so that nitrogen management advice can be administered to Irish farmers in the similar manner as P & K advice.

Edel Kelly

Project Title: Facilitating Technology Transfer: An Examination of the Adoption of Grassland Management Practices (GMP) and Environmental-Related Technology

Description: This project is being undertaken to identify the issues influencing the adoption of technologies and practices in the Irish agricultural sector. Through understanding these issues it hopes to add to the body of knowledge which exists and give a greater insight to future policy-makers in optimising technology transfer activities. This project will work in conjunction with a number of ongoing research projects within Teagasc. It will examine the current processes underpinning the facilitation and transfer of knowledge, with specific focus on the Teagasc:

- Germinal Seeds Grass Programme
- Agricultural Catchments Programme

The data emerging from these technologies may be analysed to establish the mechanisms of transfer of such technologies. The barriers of adoption may become more apparent through looking at the array of knowledge in international practices in these areas. There may also be some sociological issues considering attitudinal and social norms which may impact the decision making process of Irish farmers. To get a more accurate picture with context dependent results, this may be analysed in a more rigorous manner by looking at focus groups, interviews and/or case studies.

Lucy Crockford

Project Title: Phosphorus load apportionment in Irish water bodies

Description: A study of P loading dynamics in rivers and lakes. For rivers her work will develop an appropriate model for the point and diffuse source apportionment of phosphorus loads in the River Glyde, in east-central Ireland with the aim of applying and validating this model to high resolution data retrieved from the Dunleer catchment. This will help to determine the importance of spatial and temporal controls of phosphorus transfer during low and high river flows.

For lakes, Lucy will investigate the role of internal and external phosphorus loading mechanisms in a lake that has boundary conditions between meso and eutrophic status. Using high resolution catchment and water quality data, this work will investigate the specific role of winter pulses of external P transfer, seasonal summer hypolimnetic anoxia and wind induced P resuspension to determine the relative importance of these on lake ecological response and risk.

Sophie Sherriff

Project Title: Sediment Flux and Provenance

Description: The study focuses on sediment flux and provenance in three catchments. Excessive delivery of fine sediment into watercourses can have a range of negative impacts such as reduction of biodiversity, deterioration of water quality and infilling of channels. In an Irish landscape, gaps in knowledge exist in relation to the specific processes of sediment production and delivery. It is therefore necessary to quantify sediment outputs and identify critical source areas of sediment production under a range of catchment and hydrological conditions. This will improve understanding of source area characteristics, connectivity, conveyance losses, storage and remobilisation of sediments, as well as indicating pathways for other pollutants such as particulate phosphorus.

The study will utilise novel technologies including radionuclide, magnetic, geochemical and physical properties to characterise in-stream sediments and relate them to potential catchment source areas through a sediment fingerprinting technique. From this, we will be able to identify critical source areas for targeted cost-effective mitigation.

Eoin McAleer

Project title: Nitrogen Attenuation along Delivery Pathways in Agricultural Catchments

Description: This project is concerned with developing the understanding of nitrogen attenuation processes in intensively managed agricultural watersheds. In particular, the study will quantify the horizontal flux of nitrogen in the saturated zone, from the top of the hillslope, to the base of the hillslope where it intersects the stream hyporheic zone. Attenuation processes in both groundwater and the hyporheic zone will be investigated.

Ian Thomas

Project Title: Defining critical source areas of nutrient transfer in agricultural catchments

This project will use data and findings generated by Phase 1 of the ACP that highlight the overarching influence of soils and hydrology on P loss from land to water, giving rise to dissimilarities in P transfer between and within catchments. As national inventories show a decrease in the proportion of high risk P index 4 soils, it will be important to identify zones that maintain higher risk levels despite the management constraints of the NAP. The corollary of this is also to isolate areas of lower risk where intensive agriculture might be less constrained. Using high resolution LiDAR (Light Detection and Ranging) data as part of the ACP geodatabase, the project will use GIS approaches to investigate metrics of hydro-connectivity within ACP catchments, identify the soil and hydrologic parameters controlling catchment water quality response to management measures, define zones of high risk within and between catchments and advise on the option of using these zones as quasi-buffer zones as an alternative to linear riparian features.

Appendix 4 – Acronyms

ACP	Agricultural Catchments Programme
AESI	Agricultural Economics Society of Ireland
AGU	American Geophysical Union
ASA	American Society of Agronomy
BETTER	Business, Environment and Technology through Training Extension and Research
BF	Baseflow
BR	Bedrock
BSSS	British Soil Science Society
cCREW	Cold Climate Research in Boreal Watersheds
CELUP	Crops, Environment and Land Use Programme
CIG	Consultation and Implementation Group
CSSA	Crop Science Society of America
DAFM	Department of Agriculture, Food and the Marine
DEA	Data Envelopment Analysis
DECLG	Department of Environment, Community and Local Government
DipCon	Conference on Diffuse Pollution and Eutrophication
DI-TP	Diatom-inferred Total Phosphorus
DMT	Data Management Team
DMT	Data Manager
DRP	Dissolved Reactive Phosphorus
EA	Environment Agency
EC	European Community
EGU	European Geosciences Union
EPA	Environmental Protection Agency
EQS	Environmental Quality Standard
ESG	Expert Steering Group
EU	European Union
FH2020	FoodHarvest 2020
FYM	Farmyard manure
GAP	Good Agricultural Practice
GIS	Geographical Information System
GMP	Grassland Management Practices
GWD	Groundwater Directive
Ha	Hectares
IF	Interflow
IFS	Irish Forest Soils
IFS	Interflow
INSPIRE	Infrastucture for Spatial Information in Europe
IPW6	6th International Workshop on Phosphorus
IT	Information Technology
IUSS	International Union of Soil Sciences
IWA	International Water Association
KT	Knowledge Transfer
LiDAR	Light Detection and Ranging
LIMS	Laboratory Information Management System
LPIS	Land Parcel Information System
LU	Livestock Units
MAC	Maximum Acceptable Concentration

MRP Molybdate Reactive Phosphorus
MS Member States
N Nitrogen
NAP Nitrates Action Programme
ND Nitrates Directive
NFS National Farm Survey
NO^3 Nitrate
NUI National University of Ireland
OECD Organisation for Economic Co-operation and Development
P Phosphorus
PM Programme Manager
PS Principal Scientist
QC Quality Control
QF Quick Flow
RBD River Basin District
RBDMS River Basin District Management Systems
RDS Royal Dublin Society
REPS Rural Environment Protection Scheme
RHAT River Hydromorphological Assessment Technique
RTE Radio Telefís Eireann
SEMRU Socio-Economic Marine Research Unit
SI Statutory Instrument
SS Subsoil
SSRS Small Stream Risk Score
SSSA Soil Science Society of America
SSSI Soil Science Society of Ireland
STP Soil Test Phosphorus
TL Task Leader
TON Total Oxidised Nitrogen
TP Total Phosphorus
TRP Total Reactive Phosphorus
UCC University College Cork
UK United Kingdom
USA United States of America
WFD Water Framework Directive
WTI Willing To Import






NDP
National Development Plan 2007 - 2013

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