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

Research Stimulus Fund

Final Report

'High status waterbodies: managing and optimising nutrients (HARMONY)'

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Principal Coordinator and Institution: Dr. Karen Daly, Teagasc
Email: karen.daly@teagasc.ie

Collaborating Research Institutions and Researchers: NUI Galway, Dr. Mark Healy. University of Ulster, Prof Phil Jordan. AFBI, Dr. Donnacha Doody; DR. Mary Ryan, Teagasc

Please place *one* "x" below in the appropriate area on the research continuum where you feel this project fits

Basic/Fundamental ⟶ Applied ⟶ Pre Commercial

1	2	3 x	4	5	6	7

Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report;

Priority Area (s)	Sustainable Food Production and Processing

Key words: *high status, water quality, nutrients, farming*

1. Rationale for Undertaking the Research

The Water Framework Directive is the most comprehensive piece of water quality legislation in Europe as it seeks to incorporate all sectors of society to improve and maintain good water quality throughout Europe. High status water bodies (HSW) are described as surface water bodies whose measured values reflect undisturbed conditions and Ireland has a total of 689 river, 320 lakes and 44 transitional and coastal water bodies defined as high status. However, not all surface water bodies are monitored under the WFD monitoring network and of the 1,937 river water bodies and 222 lake water bodies monitored, 176 rivers and 20 lakes were classified as high status. The EPA water quality monitoring network has noted a decline in the numbers of high status river monitoring sites between 1998 and 2008 (EPA, 2010) and a recent study (Ni Chathain et al., 2013) reports a steady decline in the percentage of high status river sites from 41% of total sites monitored in 1998-2000, to 27% in 2007-2009. This report also documents highest rates of decline from counties Cavan, Clare, Cork, Donegal, Galway, Sligo and Mayo (between 1998 and 2006). Of the 210 sites lost nationally in this time frame, 27% were lost in Donegal (58 sites).

There is an urgent need to stem the degradation of high status sites, not least because Ireland is in breach of a European Directive, but because of the unique ecosystem services these areas deliver and their significance in supporting aquatic species (e.g. freshwater pearl mussel) and overall catchment biodiversity. It is generally accepted that most of these sites are located in upland areas characterised by extensively farmed land, however, Ni Chathain et al., (2013) hypothesise that 'relatively low intensity activities' can become a significant pressure and a have a disproportionate impact on high status sites relative to the same pressure on an already degraded system. Whilst agricultural nutrients are a pressure on water quality, a catchment's response to this pressure is driven by the mosaic of soil types that characterise the source and hydrology in a catchment. Melland et al., (2011) report that despite similar farming intensities in two catchments, winter P export from one catchment was four times higher, largely owing to variations in catchment characteristics such as soil drainage and hydrology.

The predominant soils in these areas are peat soils and soils classed as peaty gleys and peaty podzols which previous studies have identified as vulnerable to phosphorus (P) loss due to their poor P retention capacities (Daly et al., 2001; Daly et al., 2002, Daly and Styles, 2005). The Lough Melvin catchment study classified soils in the catchment as 47% peat and 47% gleys (Schulte et al., 2009), both soil types contributing a source and transport factor to P transfers from land to water, due to poor P retention of peats and the impeded drainage characteristics of gleyed soils. Nutrient application to these soils requires a different management strategy compared to mineral soils due to the high potential for P transfer to water, in fact, Ni Chathain et al. (2013), recommend that addition of P to peat soils should be prohibited unless demonstrated to have minimal impact.

As Ireland seeks to implement the schedule of the WFD the maintenance of HSW is now accepted as being of paramount importance, especially in light of the steady decline reported by the EPA. The participatory approach adopted by the Lough Melvin study included farmers in discussion with researchers on the acceptability of potential measures highlighted in the study (Doody et al., 2009). Farmer preference for measures and their cost-effectiveness were considered, and whilst most famers preferred measures that required low labour input, some preferred measures that included soil analysis and nutrient management planning (Schulte et al., 2009). This project will build on the learning from previous studies in sensitive catchments and integrate research-based strategies with a comprehensive socio-economic evaluation of farmer acceptance and preference for measures

2. Research Approach

The research will combine fundamental research hypotheses in soil and catchment science across different scales with applied socio-economic methods to deliver the project objectives. The platform for this research is a number of case-study catchments selected using GIS analysis. A farm survey and soil sampling campaign will be undertaken to obtain a realistic appraisal of farm practice and nutrient management in these areas. The research agenda will be supported by 2 Ph.D. students (***Source*** and ***Pathways*** research) and two post-doctorates; a socio-economics scientist and an Agri-environmental scientist. The project participants will distil and evaluate the research outcomes and a comprehensive socio-economic evaluation of the proposed measures will be carried out within the farming community.

3. Research Achievements/Results

Using the population of high status sites recorded in 2010-2012, the project examined historical trends in status at these sites over the past 10 years and analysis of 508 high status sites showed that sites had either maintained high status or varied from high status over the 10 year period. Figure 1 illustrates those that had varied out of high status, i.e. down to good or below, since 2001 (*n*=337) and those that had maintained high status since 2001 (*n*=171) based on the premise that the WFD requires member states to maintain high ecological status where it exists.

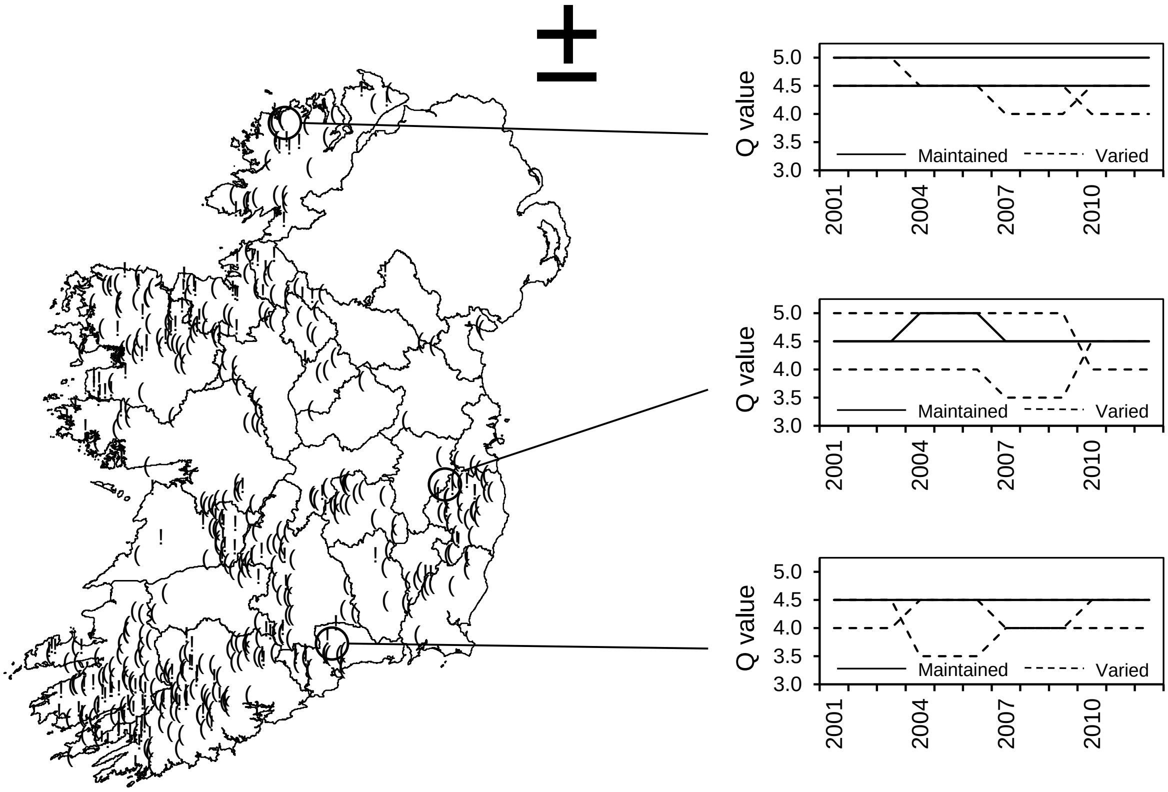


Figure 1. Distribution of the 508 river monitoring sites included in the study and examples of how they might vary or maintain high status through the four monitoring periods from 2001 to 2012. Transparent circles indicate sites that have varied in status and opaque circles indicate sites that have maintained high status. A Q value ≥ 4.5 is required to achieve high status.

A spatial analysis of these sites described land use, soil type, soil drainage and livestock density in these catchments and provided the basis for an initial farm survey to assess the current nutrient management and farm practice in these areas. Three case-study areas were chosen for farm survey and these were the River Urrin, Co. Wexford, the River Allow, Co. Cork, and the River Black Co. Galway/Mayo.   These areas are highlighted in Figure 2.

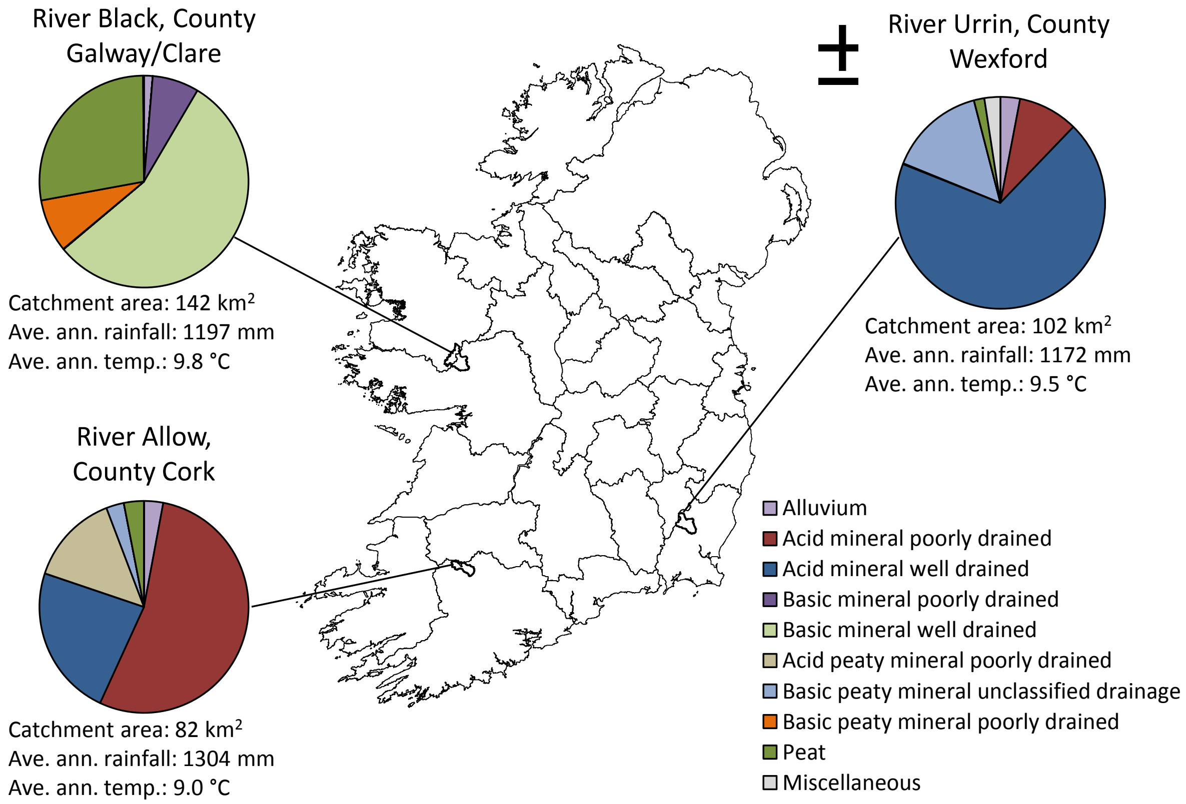


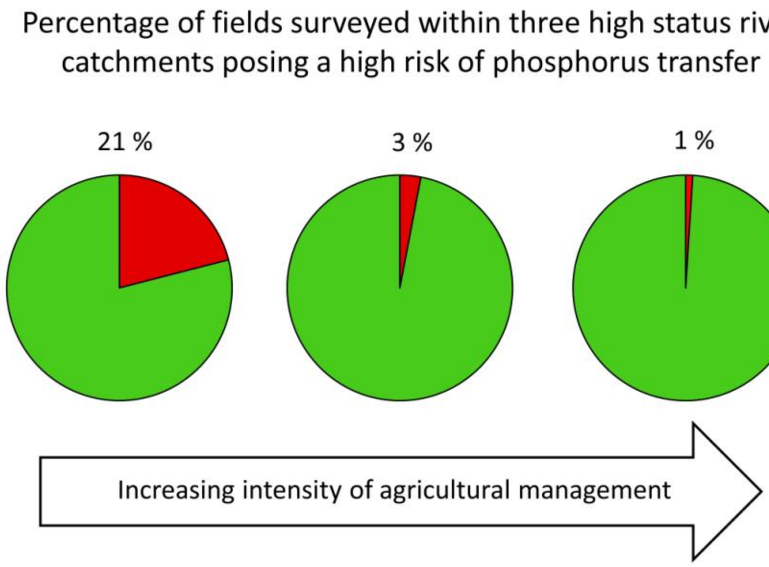
Figure 3. *Case-study areas for farm survey showing the variation in soil type.*

Farm Survey & Risk Assessment

This survey assessed the risk of P loss at field scale from farms under contrasting soil conditions within three case-study catchments upstream of near-pristine river sites. Data from 39 farms showed P surpluses were common on extensive farm enterprises despite a lower P requirement and level of intensity. At field scale, data from 520 fields showed that Histic topsoils with elevated organic matter contents had low P reserves due to poor sorption capacities, and received applications of P in excess of recommended rates. On this soil type 67 % of fields recorded a field P surplus of between 1 and 31 kg ha^{-1}, accounting for 46 % of fields surveyed across 10 farms in a pressured high status catchment. A P risk assessment combined nutrient management, soil biogeochemical and hydrological data at field scale, across 3 catchments and the relative risks of P transfer were highest when fertilizer quantities that exceeded current recommendations on soils with a high risk of mobilization and high risk of transport as indicated by topographic wetness index values. This situation occurred on 21 % of fields surveyed in the least intensively managed catchment with no on-farm nutrient management planning and soil testing. In contrast, the two intensively managed catchments presented a risk of P transfer in only 3 % and 1 % of fields surveyed across 29 farms. Future agri-environmental measures should be administered at field scale, not farm scale, and based on soil analysis that is inclusive of OM values on a field-by-field basis.

This study characterised the soil geochemical and hydrological properties of farms in high status catchments in Ireland and examined field scale nutrient management and the relative risk of P loss from fields, under different soil conditions Low adoption of soil testing and nutrient management planning on extensive farms led to increased risks of P transfer on Histic topsoils when application of P sources failed to account for soil conditions that promote the mobilisation and transport of P such as highly organic matter and wet soils. Furthermore, the risk assessment based on fields surveyed revealed that the catchment, with the highest occurance of Histic topsoils, (wet soil) posed the greatest risk of P loss, based on positive P balances and fields with high % OM. Current EU water policy measures for agriculture centers on nutrient management planning and soil testing on intensive farms, however, this study has illustrated the need for better nutrient use efficiency on extensive grassland farms on marginalized land. To increase nutrient use efficiency and reduce P loss risk and based on the results of this study the following recommendation include:

- Regular soil testing to monitor soil P and pH on should be used to optimize nutrient management on mineral soils, but not be relied upon for nutrient management on Histic topsoils.
- Extensive farm enterprises in high status catchments should have access to soil information on % OM on a field-by-field basis. Organic matter testing at high spatial resolution need only be carried out once to establish which parts of the farm are comprised of mineral and Histic topsoils. This will ensure that nutrient management is soil type specific and will restore P surpluses to balance at both field and farm scale.
- Hydrologically sensitive areas within high status river catchments could be delineated using simple topographic indices as done here, and the timing and rates of P applications tailored to account for risk, as is the case for high OM soils.
- Agricultural measures for high status catchments will need to be administered at field scale (not farm scale) with the aid of appropriate soil geochemical and hydrological data at this scale.



Phosphorus characterisation of organic soils

Soils identified as predominant were chosen from three different case-study catchments. Six soil types, namely four organic and organo-mineral soil and two mineral soils were collected, based on organic matter content and P status. The soils were classified following the new Irish Soil Information System and characterized, in triplicate, for pH ($CaCl_2$ and water), fresh and dry bulk density, lime requirements, soil organic matter (%), calcium carbonate content, particle size distribution and clay content, textural class, total and organic carbon, total nitrogen, ammonium oxalate-extractable Al (Al_{ox}) and Fe (Fe_{ox}), exchangeable bases (EB) and cation exchange capacity (CEC), soil tests P (Morgan's P and FeO strips), as well as Morgan's K and Mg.

Yield response to fertilizer P on high organic matter soils.

Current phosphorus (P) recommendations for grassland in Ireland are well established for mineral but not for high organic matter soils. Poor P retention capacity due to competitive sorption reactions between labile phosphate anions and organic acids in organic matter-rich soils could have implications for sustainable production on these soils. Furthermore, the chemical nature of P fractions in organic-rich soils and their ability to supply P for pasture is not well understood. The aim of this research is to compare and evaluate grass yield response to fertiliser P under controlled conditions across a range of mineral, peaty mineral and peat soils in Ireland. A growth chamber study was established on low P status soils with % organic matter ranging from 8 to 76. Fertiliser P rates from 0 to 145 kg/ha were applied and dry matter yield of perennial ryegrass measured after a 4 month period. Results indicate that grass yield responses differ between mineral and organic matter-rich soils at similar fertiliser P rates under controlled conditions. For example, at low fertiliser P rates (0-40 kg P/ha), grass yields were significantly ($p < 0.05$) higher in mineral compared to organic matter-rich soils, indicative of the limited ability of the latter to mobilise soluble P from moderately labile and stable P fractions. In this work we describe the distribution of inorganic and organic P fractions in mineral and organic matter-rich soils and combine these data with yield responses following P treatments. This research will enhance our knowledge of P uptake in high organic matter soils and establish criteria for sustainable P management for grassland on these soils.

Fate of applied P on P fractions in high organic matter soils

With the intensification of agricultural production in many European countries, more marginal soils with elevated organic matter (OM) content are being brought into cultivation. However, little is known about the fate of phosphorus (P) fertiliser in the constituent P pools of organic soils. Soil P fractions were measured before and after receiving fertiliser in a controlled experiment to determine the change in the soil pools and path analysis was used to evaluate the relationships between P pools. In this study, P deficient soils ranging in OM content from 8 to 76 %, were placed in large pots, planted with ryegrass and subjected to P fertiliser applications ranging from 10 to 145 kg ha^{-1}, and monitored over an eight-month study period. High OM soils had a diminished ability to build-up the labile pool from freshly applied P, with relatively low increases up to 200 % of the initial value, compared to mineral soils in which the labile pool increased to more than 2500 % of the initial concentration. Additionally, organic soils had higher P uptakes in the grass yield than mineral soils, indicating a higher availability of added P in the soil solution than mineral soils due to their limited sorption ability. In general, there was a reduction in the organic P pool over applications from 0 to 55 kg ha^{-1}, which was indicative of partial mineralisation, but was followed by an accumulation of added P over applications from 55 to 145 kg P ha^{-1}. The residual P pools did not build-up with P additions, but data indicated the occurrence of mineralisation in most of the soils with decreases of around 40 % of the initial concentrations. Organic and residual pools therefore displayed potential to supply P to more labile P pools across all soils of this study. Path analysis indicated that applied P was the only source of labile P in the soil with the highest OM content, leaving it dependant on continuous P applications to supply P for productivity, whereas in the rest of the soils there were interrelations between the non-labile and labile pools. Low pH strongly immobilised the applied P and should be corrected before the initiation of any fertilisation program, even in soils deficient in plant available P. The results demonstrated that P added as fertiliser to organic soils does not accumulate as in mineral soils, which may leave them susceptible to P losses in surface runoff. Therefore, organic soils under agricultural production located in high status catchments should receive low P applications and only during periods with low probability of precipitation to minimise the possibility of P exports to receiving waters.

Split phosphorus fertiliser applications in organic soils reduce incidental losses in surface runoff

Organic soils have low sorption capacities for phosphorus (P), and may pose a risk of P loss to water if P applications to these soils coincide with runoff events. Little is known about the magnitude of exports of P in overland flow following application of P fertiliser onto these soils, or on the influence of the frequency on P losses and persistence. The number of P fertiliser applications was surveyed across 39 commercial farms to assess current practice and inform the design of a rainfall runoff experiment to evaluate the effect of frequency of P applications on losses and persistence across time. Superphosphate (16 % P) was applied in single (equivalent to 30 and 55 kg P ha^{-1} applied at day 0) and split (equivalent to 15 and 27.5 kg P ha^{-1} applied in two doses at days 0 and 55) applications to an organic soil inclined at a slope of 6 % in a rainfall simulator experiment. The surface runoff of dissolved reactive phosphorus (DRP) was measured in controlled 30-min rainfall simulations conducted intermittently over an 85-day period. The DRP loads in surface runoff from the soil that received single applications of 30 and 55 kg ha^{-1} were exponentially greater than those receiving the same amounts applied in two doses. The results indicated that single P applications of superphosphate had disproportionately bigger impacts on losses than split applications. Additionally, the rate at which P concentrations decreased was similar for the different treatments, further supporting the idea that frequent, but smaller, P applications can minimise the impact of fertilisation on organic soils. Dissolved reactive P concentrations remained significantly higher than those from the control samples until the end the experiment for almost all the P treatments, highlighting the long-lasting effects of added P and the elevated risk of P losses on organic soils.

Main implications arising from the findings

1. When organic soils are managed as mineral soils, the risk of P transfer from the soil to the surrounding waters greatly increases as added P tends to remain, to a greater extent, in the soil solution. Fertilisation of organic soils should be therefore tailored to meet plant requirements during the growing year in order to avoid over-fertilisation, which may result in an increased risk

of environmental damage and additional economical costs for the landowners. Furthermore, many organic soils tend to be located within high status catchments, which are vulnerable even when subjected to relatively low intensity activities (Ni Chathain et al., 2013). Therefore, agricultural activities in these areas, particularly those relating to fertilisation, should be restricted, controlled and even prohibited if water quality is to be preserved.

2. Another important implication for the management of organic soils is the interaction of pH with the freshly added P. The acidity of some organic soils tends to be very low, especially shortly after reclamation, and this characteristic can be the main limiting factor affecting productivity in these soils. Therefore, liming should be prioritised before any P fertilisation plan. Increasing the pH of organic soils may promote the formation of Ca-P compounds that may remain sparingly soluble at elevated pH levels. However, liming has been shown to increase ammonia volatilization and stimulate nitrification in organic soils (Parent and Khiari, 2003), and these side effects need to be evaluated in further research.
3. Split applications may be a good management decision for P loss mitigation following P fertilisation, especially in countries/regions with elevated rainfall amounts. From an environmental point of view, frequent but smaller P fertiliser applications in organic soils can have two positive implications: (1) it significantly reduces the P loads generated in overland flow when a rainfall event occurs shortly after P application and (2) plants have better access to soluble P throughout the year, resulting in higher herbage P concentrations for ruminants and enhanced grass yield as the P limitations for plant growth are overcome.

Evaluating land use and hyrological change in high status waterbodies

High status water-bodies (HSWs), as designated under the European Union (EU) Water Framework Directive (WFD), are rivers, lakes, transitional waters and coastal waters, that are close to natural status, representing conditions that are largely un-impacted by anthropogenic activities. These HSWs are sensitive areas that require special attention. However, in recent years large declines in the number of HSWs in Ireland have been observed, with these declines being attributed to pressures from point source pollution or unintentional discharges, along with low intensity practices potentially resulting from changes in land use and land cover. With this background, this PhD set out to present a review of HSWs and their management strategies in the European Union, and to investigate in three separate studies, the potential for HSW deteriorations to be caused by: 1) land use and land cover change; 2) hydrological (streamflow) modifications; and 3) sediment pressures. For these three studies, HSWs in Ireland were determined to have either: "Lost" their high status (e.g. gone from high to good, moderate, poor or bad); consistently "Maintained" their high status; or "Gained" in status (e.g. from good to high).

The review of HSWs in Europe (Chapter 1) highlighted how it may be counter-productive for countries to focus exclusively on achieving the "good" status objective of the WFD, while ignoring deteriorations to HSWs. Additionally, using case studies from four Member States with relatively large numbers of HSWs (Sweden, Austria, Ireland, and UK (Scotland)), the review assessed variations in strategies employed to manage HSWs. Based on these case studies it was determined that lag times between implementing management strategies and seeing actual benefits make assessing the effectiveness of such measures difficult, but that countries that have developed strategies may benefit from the sharing of knowledge, for example Ireland and Scotland.

The land cover change study (Chapter 2) demonstrated methods for assessing land cover change using CORINE data for three time periods: 2006-2012, 2000-2006 and 2000-2012; and found that anthropogenically influenced changes in land use and land cover types were linked to declines in water body status, with a higher level of natural/semi-natural land occurring in Maintained catchments. For example, in the period 2006-2012, land that changed from Forestry to Heterogeneous Agricultural areas was 17.5 times more likely to result in Lost status, whereas land that remained as Forestry or remained as Inland Wetlands reduced the chance of Lost status occurring by 15 % and 4 %, respectively. However, the similarity of land cover trends between sites that have Lost and Gained status provided further research questions. In the hydrological (streamflow) modifications study (Chapter 3), despite differences being found in Lotic Index for Flow Evaluation (LIFE) scores between the Lost and Maintained status categories, all LIFE scores were generally above 7.25 and reflective of rivers hosting invertebrate communities with a preference for medium/high streamflow rates. While some hydrometric stations in the wider study area did display changing streamflow trends, which may potentially be linked to drainage and/or change in status, the overall conclusion was that for most sites, streamflow alterations are not likely to have been a major factor leading to deteriorations. However, for certain sites, and potentially in combination with other stressors, streamflow alterations may be problematic. The sediment study (Chapter 4) found that, macro-invertebrate taxa occurring in HSWs were pre-dominantly sediment sensitive taxa. However, for two sediment specific metrics, the Proportion of Sediment-sensitive Index (PSI) and the Empirically-weighted PSI (E-PSI), significant differences were observed between sites that Lost status and those that Maintained status, implying that at some sites, sedimentation is impacting on macro-invertebrates. Again, no difference between Lost and Gained sites was observed, leaving an important caveat. While weak to moderate relationships were observed between the sediment metrics and the physical sediment variables, no difference between status categories for any of the physical sediment variables was observed, although this may be related to the sampling resolution. Chapter 4 also highlighted the potential for multiple-stressors, such as the interaction between sediment, organic pollution and streamflow alterations, to contribute to deteriorations in status. However, nutrient sampling indicated little or no evidence of nutrient enrichment at the majority of sample sites, and it is suggested that nutrient analysis at HSWs may be better served by higher resolution monitoring. Finally, key recommendations were suggested based on the overall findings of the PhD, that included: investigating if measures being implemented in catchments with Gained status may be replicated and possibly used to improve conditions at Lost status sites; and potentially including "impacting on high status water-bodies" as an additional category requiring Environmental Impact Assessments (especially in relation to drainage works).

Socio-economic evaluation of measures for high status waterbodies

Main findings

Phosphorus (P) transfer from land to water is a source of diffuse pollution that contributes to the decline in ecological status of river bodies in the European Union. The Water Framework Directive (2000/60/EC) provides for the protection of water bodies that represent pristine or near-pristine condition, classified as high ecological status through the adoption of an agri-environmental decision making process that promotes stakeholder participation. However, successful implementation of agri-environmental policies can prove challenging when faced with uncertainties and diverging opinions due to the variety of actors involved. This study explores a participatory approach including stakeholders with conflicting interests in the decision making for the P transfer mitigation policies. Farm data from a river catchment that recently lost its high status provide the framework for the evaluation of a list of targeted P transfer mitigation options by various stakeholder groups. The process involved the individual and group ranking of 15 P transfer mitigation options, specific for the catchment under study, by a group of experts, groups of farmers and through simulation modelling. This approach combines the scientific research with the empirical knowledge of farmers and the modelling of "real life" field and farm data. Results show significant disparities between perceived effectiveness by the three groups, with experts prioritizing problems related to connectivity issues, while farmers and modelling to soil compaction and erosion. The study highlights the importance of knowledge transfer between interested actors and the need for integration of conflicting opinions in policy design. A bottom-up approach to decision making is suggested, to assist in the decentralization of the procedures towards more effectively implemented P transfer mitigation policies.

Willingness to adopt nutrient management measures

Nutrient management planning (NMP) is considered a win-win strategy for farmers in terms of potential financial and environmental benefits, yet implementation of NMP on farms remains below expectations and varied globally. This remains a puzzling contradiction for researchers and policy makers alike and raises the question: what factors influence farmer intentions to implement NMP? Despite an extensive body of research on the adoption of innovations, little attention has been given to socio-psychological issues in relation to adoption of NMP by farmers. This study uses data collected from 1,009 Irish farms to examine the influence of both socio-economic (e.g. farmer age, education and farm size) and a range of socio-psychological factors on farmer intention to implement two separate NMP practices: 1) apply fertiliser on the basis of soil test results and, 2) follow a formally developed nutrient management plan. The research problem was framed using a conceptual framework based on the social-psychology theory of planned behaviour. The results reveal that attitudes, social norms, behavioural control and resource based issues significantly and positively influence intention for both practices. Furthermore, a number of socio-economic factors were significantly and positively associated with intention across the two practices including farm system, younger age, higher education levels, participation in an agri-environmental scheme and contact with an agricultural advisor. This study confirms the importance of socio-psychological issues in relation to farmer intention to implement NMP. Thus, this leads us to argue that, a failure to address farmer beliefs regarding NMP could lead to policy and behavioural change initiatives not producing desired outcomes despite favourable socio-economic circumstances. The results suggest that such initiatives must pay attention to demonstrating the benefits of NMP to enforce positive attitudes, however information should also be provided to significant others rather than just to the main decision maker on the farm which may help to increase social pressure on the farmer to implement NMP.

Furthermore, providing technical assistance regarding implementing NMP and continuing to provide resources to implement NMP through agri-environmental schemes to farmers may also help to improve implementation levels.

Cost effectiveness of nutrient management measure, a case-study.

Using two case study farms from Task 2, with different systems and intensity, we applied a scenario analysis to evaluate the costs and time taken for an integrated measure to be effective. In this measure, P applications were avoided on excessively fertilised fields and soil fertility (N, P, K, pH) was optimised across all fields. The measure was assumed effective when excessive soil P declined to a value where soil P can match the crop demand for P and the time taken for this to occur ranged from 1 to 8 years and varied from field-to-field based on land use, initial available P and total P reserves. Minimising the source pressure on local water quality are also likely to vary spatially which has implications for establishing water quality targets in catchments and the design of measures to achieve them.

A policy implication of this study is the significance of measuring costs and effectiveness in the long term. Effectiveness in this study took up to 9 years to be realised at field scale and informing farmers of the long term benefits of applying this measure, despite additional costs at the start, is key for the successful implementation and adoption of measures into the future. Information that provides a clear understanding of the causes of water pollution and the mechanism of mitigation, in combination with the long-term environmental/economic benefits, should be available to farmers.

In order to increase adoption and implementation of sustainable agricultural practices, policies need to be equally focused on farm profitability and environmental quality. Sustainability measures could include water quality protection coupled with agronomic measures to maintain productivity and are environmentally effective, providing a dual benefit to policy makers and farmers.

The recommendations arising from this work are as follows:

- Measures applied to soils will have lag times. The rate of soil P decline to environmentally sustainable levels will vary at field scale, which has implication for design of measures and monitoring effectiveness at farm, and catchment scale.
- Accelerated soil P decline could be achieved with changing land use from grazing only, to grazing plus silage.
- Despite higher costs in the first years of implementation, correcting deficiencies in P, N and K and balancing soil pH on all fields, and avoiding P applications on high soil P fields and high organic matter fields is proven cost-effective in the long term.
- Spatial variation in soil P showed that cost for soils testing and advisory services on a field-by-field basis is expensive in the first 2 years of implementing the measure. Providing financial relief for this initial phase of measures implementation would encourage farmers to adopt the measure in the future.

4. Impact of the Research

The impact of the research carried out in this project can be summarised as providing additional nutrient management strategies for farmers living in High Status Catchments. Based on the results from both the biophysical and socio-economic research, farmers can be provided with nutrient management advice that is more soil-type specific, which will allow for more efficient use of fertiliser and slurry produced on the farm. The acceptance of detailed nutrient management planning by farmers in the socioeconomic study will provide a better outcome for farmers, as they save money on more efficient nutrient use, and for water quality, as rates and timing of applications are tailored to high organic matter soils which will protect water quality in local areas. The specific outcomes of the research are listed below.

4(a) Summary of Research Outcomes

(i) Collaborative links developed during this research

The project developed collaborative links with researchers and advisors in the Agricultural Catchment Programme (ACP) and shared research findings and scientific outputs. The project team also established a collaboration with DUHALLOW LiFE project and helped with the submission of a follow-on funding proposal for the Duhallow Blue Dot EIP.

(ii) Outcomes where new products, technologies and processes were developed and/or adopted

No new technologies or products were developed from the project

(iii) Outcomes with economic potential

Farmers who were not using fertiliser efficiently were encouraged to follow a nutrient management plan, thereby saving money each year on fertiliser.

(iv) Outcomes with national/ policy/social/environmental potential

Our recommendation that farmers in High Status Catchments should receive free organic matter testing of soils on their farm, would have an environmental impact on water quality, as these soils would only receive maintenance rates of P and knowledge of the spatial distribution of these soils around the farm would allow for more sustainable nutrient management and eventually lower diffuse and incidental losses of P from these areas. In addition our recommendation that farmers apply P 'little and often' i.e. in split applications to these areas would reduce the environmental impact of P use in these areas.

4 (b) Summary of Research Outputs

(i) Peer-reviewed publications, International Journal/Book chapters.

1. Evgenia Micha, William Roberts, Mary Ryan, Cathal O'Donoghue, Karen Daly. 2018. A participatory approach for comparing stakeholders' evaluation of P loss mitigation options in a high ecological status river catchment. Environmental Science and Policy. 84. 41-51.

2. Daxini, A., O'Donoghue, C., Ryan, M., Buckley, C., Barnes, A., Daly,K. (2018). Which factors influence farmers' intentions to adopt nutrient management planning? J. Environ. Manag. 224, 350-360.

3. Daly, K. Breuil, M. Buckley, C. O' Donoghue, C. Ryan M. and Seale C. (2017). A review of water quality policies in relation to public good benefits and community engagement in rural Ireland. European Countryside. 1. 99-115. DOI: 10.1515/euco-2017-0006

4. Roberts, W., Doody, D., Gonzalez, J, Jordan, P. and Daly, K. 2017. Assessing the risk of phosphorus transfer to high ecological status rivers: Integration of nutrient management with soil geochemical and hydrological conditions. Science of the Total Environment. 589, 25-35.

5. Roberts, W., Fealy, R., Doody, D., Jordan, P. and Daly K. (2016) Estimating the effects of land use and environmental characteristics on high ecological status in Irish rivers at different scales. Science of the Total Environment. 618-625

6. Gonzalez Jimenez, J. L., Healy, M. G., Roberts, W. M. and Daly, K. (2018). Contrasting yield responses to phosphorus applications on mineral and organic soils from extensively managed grasslands: Implications for P management in high ecological status catchments. J. Plant Nutr. Soil Sci. 1-9.

7. González Jiménez, J. L., Healy, M. G., and Daly, K. (2019). Effects of fertiliser on phosphorus pools in soils with contrasting organic matter content: A fractionation and path analysis study. Geoderma 338, 128-135

8. González Jiménez, J. L., Daly, K., Roberts W.M., and Healy, M. G. (2019). Split phosphorus fertiliser applications as a strategy to reduce incidental phosphorus losses in surface runoff. J.Environ.Mang. 242, 114-120.

9. Evgenia Micha, William Roberts, Lilian O'Sullivan, Kay O'Connell, Karen Daly. (2020). Examining the policy-practice gap: the divergence between regulation and reality in organic fertiliser allocation in pasture based systems. Agricultural Systems. 179. 102708

10. Bragina, L., Micha E., Roberts W.M., O'Connell, K., O'Donoghue C., Ryan, M. and Daly, K. (2019). Spatial and temporal variability in costs and effectiveness in

phosphorus loss mitigation at farm scale: A scenario analysis. J. Environ. Manag. 245. 330-337.

(ii) Popular non-scientific publications and abstracts including those presented at conferences

- Catchment Science conference 2016
- Agricultural economic conference 2017
- Organic Phosphorus symposium 2017

(iii) National Report

None

(iv) Workshops/seminars at which results were presented

- Stakeholder workshop (Task 5)
- Teagasc Water Quality working group

(v) Intellectual Property applications/licences/patents

None

(vi) Other

5. Scientists trained by Project

Total Number of PhD theses: 2

- González Jiménez, J. L. Phosphorus and organic soils under grassland production. Ph.D. thesis submitted to NUI Galway, April 2019.
- Gabriel Gaffney, Environmental change and high status waterbodies. Ph.D. thesis submitted to Ulster University, Coleraine, June 2019.

Total Number of Masters theses: 0

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
Teagasc	2	
University of Ulster	1	
AFBI	1	
NUIG	1	
Total	**5**	

7. Researchers Funded by DAFM

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	2	4
PhD students	2	8
Masters students	0	
Temporary researchers	0	
Other	0	
Total	**4**	**12**

8. Involvement in Agri Food Graduate Development Programme

Name of Postgraduate / contract researcher	Names and Dates of modules attended
N/A	

9. Project Expenditure

Total expenditure of the project: €590,010.64

Total Award by DAFM: €583,190.46

Other sources of funding including benefit in kind and/or cash contribution(specify): €0

Breakdown of Total Expenditure

Category	Teagasc	UU	NUIG	AFBI	Total
Contract staff					
Temporary staff					
Post doctorates	183,462.52				183,462.52
Post graduates	87,999.97	85,657.68			173,657.65
Consumables	19,954.26	4,451.65	9,906.01		34,311.92
Travel and subsistence	17,600.89	8,640.30	1,032.76		27,273.95
Sub total	309,017.64	98,749.63	10,938.77		418,706.04
Durable equipment	2,298.31	2,259.55			4,557.86
Other	41,134.92				41,134.92
Overheads	92,705.30	29,624.89	3,281.63		125,611.82
Total	**445,156.17**	**130,634.07**	**14,220.40**		**590,010.64**

10. Leveraging

Sarmenti: Based on the research carried out on the importance of soil testing, H2020 funded proposal SARMENTI will develop real time soil probes for high spatial resolution soil analysis.
WaterMARKE: EPA and DAFM co funded project WaterMARKE was leveraged on the basis of the risk assessment at farm scale, and the socio-economic study in Harmony.
SENSUS: This DAFM funded work will build on the work carried out in Harmony by continuing to engage with participating farmers from Harmony.

11. Future Strategies

The plan is to develop results of the research from the farm survey into training and demonstration material for improving agronomic advice for farmers in high status catchments. This will include recommendations that soil testing to include % organic matter as part of routine analysis, so that parts of the farm with soils at risk of nutrient loss can be identified. The development plan is to provide mapped case studies derived from the results of the project as material for demonstration. The results examining changes in high status between 2000 and 2012, at national scale have been developed to include additional years survey to 2016 to track changes in high status and these results are used to inform research needs for high status catchments. These data can be developed further with additional years survey as it become available.