
The River Blackwater in Northern Ireland

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Executive Summary

This report outlines the work carried out as part of the CatchmentCARE project to assess the technical and economic challenges for agriculture in achieving the phosphorus (P) targets of the Water Framework Directive in the cross border Blackwater Catchment. The work was carried out over catchment, sub-catchment farm and field scale, and involved an assessment the P load reduction required from agriculture, scenarios for reducing the loads, evaluation of nutrient management practices and the affordability for agriculture to achieve these targets. There are separate reports link with each element of this work, while this report provides summaries and draws overall conclusions from the work.

The Blackwater catchment is 1500 km^2 in area with 300 km^2 of the total area located in the RoI. The catchment generates a major source of the nutrient loads discharging into Lough Neagh which has eutrophic status and would take several decades to re-establish Good status even if P loads were drastically reduced due to internal lake loadings. The load reduction analysis using observed data was combined with modelling of the diffuse and point source TP loads using the EPA SLAM model. Results indicated that diffuse sources of P dominated in the Blackwater with 87% of the total P load originating from agricultural land use (mainly pasture). Load reductions were required in most of the 51 sub-catchments of the Blackwater and according to the model results should be targeted at sources of P originating from pasture such as slurry and soil P.

Four hundred fields across seventeen farms in the Blackwater catchment were soil sampled in 2018/2019 as part of the Catchment CARE project. In total, 66% of these fields contained excessive soil P, above what is required for agronomic production. The Catchment CARE project aimed to identify strategies to manage P inputs at farm scale and individual field level, and develop an evidence base that will help shape future regulations in relation to soil nutrient management. Nutrient management plans were produced for each of the seventeen farms, providing farmers with visual, colour-coded maps indicating the nutrient and lime requirements for each field on their farm. As a result of these plans, along with one-to-one farmer advice, a 42% reduction in P applied through inorganic fertiliser was achieved by 2021/22. Agronomic trials on three farms also demonstrated that the revised P fertiliser recommendations within the 2019-22 NI Nutrients Action

Programme and P Regulations, were suitable for extensively managed grassland farms within the Blackwater catchment.

Economic modelling was used to investigate how changes to reduce the risk to water quality impact farm profitability. A representative farm model was used to measure the opportunity cost of removing grassland from suckler beef production to provide a riparian buffer. In extensive systems, the opportunity cost takes the form of additional inputs to increase grass growth on the land remaining in beef production. Farms operating at optimal stocking density for profitability, and at higher stocking rates, face a relatively larger opportunity cost, because of the need to purchase feed. A simulation-tool was developed making use of data collected as part of the project to model hypothetical changes in management for specific farms in the Blackwater catchment. The impact of achieving a target level of phosphorus on farm profitability was simulated over a ten-year period. In some contexts, the management changes lead to productivity improvements (the ability to get the same output using fewer inputs) by reducing fertiliser or feed costs. Some farms face additional costs instead. This is due to the inability to make use of slurry, or reduced grass production, which leads to purchasing additional fertiliser or feed. The importance of price changes due to market conditions is common across all farms simulated, as these can minimise or exacerbate the impact on profitability. A modelling approach was also used to consider opportunity cost at a more aggregate level, in this case, for a sub-catchment. The aggregation model combines farm-level census data and optimisation modelling to compare variation in the pattern of economic impacts within and between sub-catchments. The framework is applied by modelling more extensive stocking in dairy, beef and sheep enterprises as a measure to reduce diffuse phosphorus loading in the Ballymartrim Water. Results indicate that using modelling to identify the most economically efficient approach results in a lower overall cost to agriculture in the sub-catchment than if the stocking is reduced uniformly across enterprises. However, the burden of the opportunity cost falls most heavily on the sheep enterprise, with much less impact on beef, and no impact on dairy.

1 Introduction

Despite a significant investment in mitigation measures, improvements in water quality in line with the expectation of the Water Framework Directive (WFD) (2000/60/EC), have not been realised in many catchments across the island of Ireland. Phosphorus (P) from agriculture remains one of the biggest water quality concerns, with changes in the policy environment, strategic ambitions for growth (e.g. Green Growth Strategy [1] and Food Vision 2030 [2]), and the environmental consequences of current and historical land use practices (e.g. stocking densities), all impacting on the agri-food industry's ability to achieve sustainable nutrient management. With spatial expansion of agriculture in Ireland limited by the availability of suitable land, increases in agricultural outputs have been driven by intensification of farming in existing areas through an increase in inputs alongside improvements in technology and resource efficiency. For example in NI, following a decrease in the national P surplus from a high of 19.5 kg P ha^{-1} in 1995 to 8.7 kg P ha^{-1} in 2008, there has been a steady increase back up to 12.5 kg P ha^{-1} in 2020. This has been accompanied by a steady increase in the average soluble reactive P (SRP) in rivers across NI during the same period. Whether sustainable nutrient management can be achieved is still unclear, with agricultural intensification, climate change and competition for land (e.g. bioenergy crops) further increasing the pressures on the environment.

1.1 Aim of Report

The aim of this report is to detail the findings of a study undertaken in the Blackwater catchment which focused on assessing current on-farm nutrient management practices and evaluating the trade-off that may be required to achieve the P targets of the WFD. In particular, the study gathered the evidence and developed a methodology to determine whether it will be disproportionately expensive for agriculture in the catchment to achieve the phosphorus target(s) set under the WFD. There were three key objectives of the work carried out.

I. Conduct an assessment of the P load reduction required from agriculture to achieve the P targets of the WFD;

II. Identification of the source and mitigation scenarios for achieving these reductions at farm and catchment scale;

III. Determine the cost to agriculture of achieving these targets at both farm and catchment scale.

The report provides an integrated summary of a large work programme carried out on catchment modelling, agronomic trials, nutrient management assessments, and economic modelling, with further details on

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[1] https://www.daera-ni.gov.uk/articles/green-growth-strategy-northern-ireland-balancing-our-climate-environment-and-economy#:~:text=The%20Green%20Growth%20Strategy%20is,crisis%20in%20the%20right%20way.

each of these sub-projects available in the links provided below.

2 Setting Phosphorus Targets

With uncertainty surrounding likelihood of achieving the targets of the WFD, how and why alternative target can be established has received increased attention. Since the implementation of the WFD there has been a diverse approach to setting water quality targets across EU member states (Poikane et al. 2019). There is no stipulation within the WFD that member states use the same targets or when setting targets that consideration is given to the unique climatic, soil, geologic and landscape conditions of a waterbody. However, this can create inconsistencies in classification of cross-border catchments, which is further confounded on the island of Ireland by the application of different catchment modelling approaches, statutory soil phosphorus test methods and soil index systems and programme of measures.

The Republic of Ireland (RoI) diverges from most member states in the stringency with which it sets P targets for waterbodies, applying a common target across all waterbodies, irrespective of the 'natural' conditions of each watercourse prior to anthropogenic influence. The approach in Northern Ireland (NI) is consistent with the rest of the United Kingdom (UK), in which P targets are set according to altitude and alkalinity (Equation 1) (UK Technical Advisory Group, 2013).

Equation 1 – Reference Conditions $= 10^{(0.454 (\log_{10} alk) - 0.0018 (altitude) + 0.476)}$

Where *alk* is the concentration of $CaCO_3$ in mg l, and *altitude* is in meters (AOD).

The class widths within status categories tend to be greater within NI (0.014-0.033 mg L^{-1}) than in RoI (0.01 mg L^{-1}). With the exception of upland calcareous (high alkalinity) scenarios, the thresholds are more stringent in RoI than in NI. A comparison of targets for NI and RoI are presented in Table 1.

2.1 Setting Alternative Targets

Under Article 16 and 17 of the WFD, countries can extend deadlines for environmental objectives (Art. 16) and/or set less stringent objectives (Art. 17). Article 16 &17 can be applied under circumstances where the targets would be disproportionately expensive or technically infeasible or due to natural conditions were the target cannot be achieved. (Table 2). Since the implementation of the EU WFD, the practice of setting alternative targets in impaired water bodies has largely focused on Article 16 (extend deadlines) which has been mainly driven by the uncertainty in lag-times between the implementation of programmes of measures (POMs) and improvements in water quality (Doody et al 2012; Fenton et al., 2011; Schulte et al., 2010). However, extensions to deadlines cannot go beyond 2027, unless specific exemptions apply. In the third cycle of the River Basin Management Plans DAERA proposes that 100% of all water bodies will be at "good" or better status by 2027. However, alternative targets have been established for Lough Neagh based on the long term impact of legacy phosphorus in the lake sediment arising from input from point and diffuse source. It is estimated that it would take 41 years for the lake to return turn to good status (Rippey et al 2022) and currently it is technically infeasible to reach this target using other means.

Under Article 17 there can be a change in the target but the timeline for its achievement remains the same. For example, the nutrient target in the 2015 reporting cycle for the Elbe River Basin were reduced on the basis of hydrologic and biogeochemical lags within the watershed (Scheuere and Naus, 2010), with a continued commitment to achieve overarching WFD goals in subsequent cycles.

In the current study setting alternative targets based on disproportionate costs is the main focus. The concept of disproportionate costs is not clearly defined within the WFD, and to date has been interpreted as either an assessment of the cost-benefit of or affordability for a sector in achieving the targets (Klauer et al 2016). Across the EU there has been greater focus on cost benefit analysis (Martin-Ortega et al 2014) which involves an assessment of the monetary cost of the options to reduce impacts on water quality compared to monetary benefits of achieving ‘good status’. This approach has been recently applied in the Derg catchment in the west of Ireland where a CBA was carried out on the implementation of an agri-environment scheme to reduce pesticide losses from agriculture to drinking water sources (Cassidy et al 2022). The study reports a cost benefits ratio of 3.36, meaning that over 30 years for every £1 spent in the Derg catchment to reduce MCPA loss from agricultural land there was a £3.36 benefit in terms of the operational and capital cost at the water treatment plant. While the results of the Derg study highlight the value of tackling issues at source, a key challenge related to CBA is monetarising non-market benefits such as biodiversity, or in the case of the WFD, ‘good status’.

The affordability for sectors (e.g., household, industry and agriculture) in achieving ‘good status’ has also been explored in a number of EU countries and takes into consideration the ability of a specific sector to absorb the costs of the changes required. However, in terms of threshold for affordability for a specific sector is largely a societal/political decision as no guidance is provided on this within the WFD.

In this study, disproportionately is considered from the perspective of affordability of the agricultural sector to make the changes required to mitigate P export to waterbodies to levels required to achieve the targets of the WFD. Although significant steps have been taken to reduce agricultural P load to waterbodies, insufficient improvement in water quality has been observed in many catchments and in some cases increases in SRP concentration have been reported. There are a number of key challenges for agriculture on the island of Ireland if sustainable phosphorus management is to be achieve. There are;

- a high percentage of soils are above the agronomic optimum soil P concentration. For example, Cassidy et al (2019) reported that 41% of soils are above the agronomic optimum soil P concentration across the Upper Bann catchment and the percentage in the Blackwater catchment is likely to be of a similar magnitude.

- a significant surplus of manure beyond what is required for agronomic purposes. For example, Rothwell et al (2020) found that approx. 7000 tons of P was being applied to NI soils each year, in excess of what required for agronomic purposes.
- an increase in the reliance on animal feed concentrates, especial in NI, which O'Rourke et al (2022) demonstrated had caused significant increases in soluble P losses to water.
- Slurry spreading on Irish soils is inherent risky, in terms of nutrient losses due to the high frequency of rainfall and high soil moisture in many area (Adams et al 2022a)

3 Overview of the Blackwater Catchment

This study takes a case study approach using the Blackwater cross border catchment which is one of the largest rivers flowing into Lough Neagh (Catchment area - 1490 km^2), and forms part of the Neagh-Bann (NB) International River Basin (NBIRB) (Fig. 1). Approximately 300 km^2 of the catchment is located in the RoI. The Blackwater headwater sub-catchments are largely located in NI but some discharge south or south-west into the ROI before the tributary streams eventually join the main Blackwater River flowing north in Lough Neagh.

The outlet of the Blackwater for measurement and modelling purposes is Verners Bridge, a level-only station (IGR: 288239, 361156). A long-term AFBI monitoring station has been co-located here since the 1970s to measure water quality by weekly grab sampling (Foy et al., 1995) with an upstream area of 1380.9 km^2. The Tall River flows into the main Blackwater immediately upstream of this station and is considered part of the basin for the P load assessment.

In 51% of the rivers in the NI part of the Blackwater catchment, SRP concentrations failed to achieve "Good" or better status in 2015 (DAERA, 2015). Long term statistics indicated that mean SRP concentrations in NI catchments including the Blackwater have started to increase ($P < 0.01$) following a long term decline between 1998 and 2018 (DAERA 2021). Figure 1 shows the most recent WFD status of all waterbodies in the Blackwater catchment (for surface waters. Diffuse sources of P in the catchment are largely from pastoral agriculture which covers about 80% of the catchment area, with small areas of both lowland and upland bog and forestry. Point sources of P are mostly due to human activities and settlements rather than industrial discharges. Except for Dungannon, Monaghan and Armagh City the towns are relatively small, although there are numerous villages and settlements which have either small, secondary-level wastewater treatment works or rely on septic tanks for effluent disposal.

3.1 Phosphorus Source Appointment

The Environmental Protection Agency (EPA) SLAM model was used to calculate the diffuse and point loads of Total P (TP) in each of the sub-catchments in the northern side of the Blackwater catchment. A detailed description of the adaption of the model for NI is available in Adams et al (2022b). The southern component of the catchment was previously modelled by the EPA using SLAM. As such the modelling carried out required the coupling together of SLAM results from the RoI portion of the catchment with the newly modelled NI sub-catchments. For the non-agricultural part of the catchment, SLAM uses an export coefficient method, where the diffuse load of P is calculated by multiplying the area of a particular land use by the export coefficient assigned to that land use (Mockler et al., 2017).

For point sources SLAM includes four different categories (wastewater treatment plants; septic tanks; CSOs and Industrial discharges) with the loading calculated by multiplying the loading of P by a population figure. The methods also account for retention or removal of P by processes in the treatment plant or septic tank. Only wastewater treatment plants and septic tanks were modelled in the Blackwater catchment as the other two sources were either unknown and/or associated with urban areas. For the calculation of diffuse P loads from pasture and arable land the sources of P are broken down into three categories: Slurry P, Fertiliser P and Soil P. When the SLAM modelled was applied to the southern component of the catchment slurry P and fertiliser P were combined into a “Maximum Fertilisation Rate for pasture or arable land (Mockler et al., 2017).

The SLAM model results (combining NI & RoI) demonstrated that the Blackwater catchment is dominated by diffuse agricultural P loads, which account for 87% of the total P loading of the overall catchment area. In NI the total P export into watercourses was almost 117 t P/year of which point sources contributed 20.3 t P/year, and other non-agricultural diffuse P loads were not significant. Values obtained from the EPA from their assessment for the southern part of the Blackwater indicated a similar proportion of point and diffuse P loads, with the total P loading from the RoI part of the catchment at 44.2 t P/year from their area of 302.3 km^2. Figure 2 below Illustrates the percentages contribute different source are making to the overall P load from the catchment while Figure 3 breaks the P load appointment down by sub-catchment with the grey shading indicating those areas with a higher percentage of point source loads, which correspond to the locations of the main population centres in the catchment.

3.2 Phosphorus Load Reduction Assessment

The observed Soluble Reactive P (SRP) concentrations were used to classify the water quality status of each of the 51 Blackwater sub-catchments of the Blackwater. Any of the sub-catchment that were assessed to be “Good status” or better should not require load reductions. The P Load reductions (LR) for the remaining sub-catchments were then established using the difference between observed and target concentrations of SRP multiplied by the mean discharge (*Q)* (EPA, 2016, Mockler et al., 2017). Long term annual average *Q* data were either obtained from a National River Flow Archive (NRFA) gauging station (e.g. Maydown Bridge on the Blackwater). Where NRFA data was not available *Q* was estimated using the annual rainfall data for the sub-catchments (obtained from the CEH-GEAR dataset) using the annual mean rainfall and NI mean AET over the 12-year period: 2005-2016.

Measurements of TP were not widely available in the catchment and the WFD targets used NI and RoI are set in terms of SRP not TP, however SLAM predicted TP. As such the SRP LR estimates were converted to Total P using a scaling factor (assuming that SRP = 0.7 * TP). The TP LRs for the full catchment equates to 39.4 T P/year and based on the SLAM modelling 87% of this reduction needs to come from agriculture. Figure. 2 indicates the percentage LRs required in each of the sub-catchments to achieve the targets of the WFD.

4 Reducing Nutrient Losses from Agriculture

In many of the sub-catchments of the Blackwater the export of phosphorus from agriculture to waterbodies is unsustainable. Achieving the targets of the WFD is likely to involve additional measures that go above and beyond the current regulations and measures in the Nutrient Action programme and/or WFD programme of measures. To reduce agriculture phosphorus loss from agricultural sources, the quantity, timing and location of phosphorus applications (fertiliser and slurry) need to be addressed and in addition, a reduction in the number of soils above the agronomic optimum soil P concentration is required. Improving the timing and location of slurry spreading was not addressed in the CatchmentCARE project however further information on this can be found at Adams et al (2022a) which evaluates current and additional measures for reducing P loss as a result of slurry application.

Within the CatchmentCARE project mitigating diffuse soil P losses was investigated from the perspective of reducing the quantity of fertiliser applied and the overall P balance of the farm. The aim of the work was to investigate whether farmers could reduce fertiliser applications rates and farm-gate P balance with a view to reducing soil P concentration and losses to water without impacting on agronomic productivity. The following sections summarise the work carried out to reduce soil P, with a more detailed description available in Higgins et al 2023. The work of Higgins et al (2023) also fed into the development and application of the PhARM model described in section 6.

4.1 Whole-Farm P Balances and Farm Nutrient Management Plans

Current on-farm nutrient management practices were evaluated on seventeen farms within the Blackwater catchment to identify improvement that could be made in nutrient management to reduce soil P down to agronomic levels and the risks to water quality (Figure 4). These farms were primarily beef and sheep farms and less intensive dairy farms which account for the biggest areas of agricultural land in the catchments. A programme of nutrient budgeting and nutrient management monitoring was implemented, including farm N and P balances shown in Table 3 (for P). A detailed description of this work can be found at Higgins et al (2023)

Four clusters of four to five farms were selected around (1) Emyvale, Co. Monaghan, (2) Augher & Clougher, Co Tyrone (3) Caledon & Benburb, Co. Tyrone and (4) Derrynoose, Co. Armagh. This gave a good geographical coverage of farms across the catchment, including a number of soil types and farm intensities.

All farms (over 400 fields in total) were soil sampled in January and February 2019 and re-sampled in December 2021 and January 2022. Samples were analysed for soil pH, and the main plant nutrients phosphorus (P), potassium (K), magnesium (Mg) and sulphur (S). 66% of fields sampled in 2019 contained excessive soil P (above the agronomic optimum of Index 2) (Figure 5).

Packages of nutrient management advice were developed for each of the seventeen farms, based on the soil testing results. Approximately 120 colour-coded maps were produced for soil pH, P, K, Mg and S for each farm (Figure 6). These maps were very well received by the farmers, providing a visual tool to enable farmers to interpret their soil results and implement improved nutrient management (Okumah et al 2021). Farmers also completed field diaries, along with a farm survey questionnaire. This questionnaire acquired information on land management, livestock numbers, organic manures, and chemical fertiliser use, along with quantity of purchased feedstuffs. A farm P balance was calculated each year for the seventeen farms, enabling change following implementation of nutrient management advice to be evaluated. Pre-Nutrient Management Plans (NMP), the average farm P balance was 6.26. Post-NMP implementation, the average farm P balance had reduced to 3.78, indicating the success of the measures introduced. Maintaining this reduced farm P balance over an extend period of time (5-10 years) will help reduce soil P in areas that are above the agronomic optimum of Index 2 and hence losses to water (Cassidy et al 2017)

4.2 Soil P Requirements for Extensively Managed Pasture

For extensively managed grassland (defined as grassland receiving less than 60 kg N/ha/yr of chemical N fertiliser and with manure N loadings of less than 120 kg N/ha/yr, an Olsen P Index of 2- (16 – 20 mg P/l) was proposed as being sufficient to meet crop requirements. Experimental grassland plots were established at three farm sites within the Blackwater catchment to test the soil and crop response to lower fertiliser recommendations for an Index 2- soil. Sixty experimental plots were established at the three grassland sites in Counties Armagh, Tyrone and Monaghan (Figure 7). Two of the sites were grazed fields and received 60 kg N/ha/yr along with low, medium and high rates of chemical P fertiliser, reflecting the fertiliser recommendations presented in the NAP (2019 – 2022). The third site was managed in a two-cut silage system, thus receiving higher N inputs (148 kg N/ha/yr) along with the same low, medium and high P inputs as the grazed sites. Experimental plots were harvested twice per year, to reflect typical management on these farms. Grass yields and grass quality were measured.

Two of the experimental sites had soil P indexes of 2-. One of the sites had a P index of 1. The new NAP fertiliser recommendations for index 1 and 2- soils were followed and were found to be sufficient. Mean total annual dry matter (DM) yields of 6 – 8 t DM/ha/yr in two cuts were achieved. No herbage P deficiencies were detected in plots receiving P inputs. The finding of this study demonstrates that many of the farms in the Blackwater catchment can achieve sustainable yields with lower soil P values.

5 Affordability for Agriculture

5.1 PhARM Model – Farm Scale

The Phosphorus and Agricultural Resilience Model (PhARM) was initially developed to explore the impact of different economic and nutrient balances on farm types across the UK (Figure 8). A detailed description of this model can be found at Sherry et al 2022[3]. The model is an optimisation model, such that several variables (fertiliser use, feed use, and land use) are solved so that the objective is optimised (Figure 8 provides an overview). For the PhARM model the objective is set as either maximising gross margin on the farm or minimising the nutrient surplus nutrient. This duality in the model provides flexibility in terms of looking at the same issue from more than one perspective.

The 'core' model is designed to reflect a range of different farm typologies within beef production, as the majority of agricultural activity in the study catchment is beef cattle production. Where the objective is to maximise gross margin (revenue – cost), the model finds the land use options (silage, grazing or buffer), fertiliser application, and feed purchased that delivers the highest margin considering constraints such as output and input prices, land and breeding herd endowments, yields, and regulation/policy incentives. The results can be used to calculate the net change in soil P for that farm, which is used within the PhARM framework as a general indicator of the risk to P loss to waterbodies.

The relative impact on the return to the farm enterprise under different conditions can be compared by calculating a marginal cost for each unit of P pollution expected to be avoided. This is calculated as the difference in the farm margin divided by the expected reduction in P lost.

The model was applied to compare the impact of taking some land out of production (between 1 and 5%) on a hypothetical 50 hectare suckler farm, across a range of stocking densities (1.2 to 1.6 cow equivalents per hectare). Results (Figure 9) show the enterprise margin peaking at 1.4 cow equivalents per hectare with no land reserved for buffering P loss on the hypothetical farm. At stocking densities below 1.4, taking land out of beef production increases fertiliser costs, and lowers the margin up to £400. Stocking at or above 1.4, the buffer zone reduces fertiliser costs up to £150. However, due to additional purchased feed required, the margin decreases up to £3,500. (Figures 10 and 11).

Expected phosphate loss is calculated as an assumed proportion of slurry, fertiliser and soil P per hectare not absorbed by grass. The level of expected phosphate loss is lower at stocking densities of 1.2 and 1.3 livestock units per hectare, than at more intensive stocking (see Figure 12). Increasing the amount of land set aside as a buffer has the opposite impact on expected phosphate loss in the case of 1.2 livestock units compared to 1.3 livestock units. When there are 1.2 livestock units per hectare, increasing the buffer area reduces the expected loss. This is because the amount of phosphate absorbed

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[3] The full model documentation is available by request (erin.sherry@afbini.gov.uk).

by the buffer exceeds any additional expected phosphate loss due to an increase in fertiliser. The expected phosphate loss increases as the area of buffer increases in the case of 1.3 livestock units per hectare. This is because there is relatively more slurry per hectare, as well as a greater feed requirement, and so in this case the phosphate absorbed per area of buffer is less than the expected increase in phosphate loss associated with additional fertiliser per hectare. At 1.4 livestock units per hectare and above, the general level of expected phosphate loss is higher. As the buffer area increases, expected phosphate loss decreases. This is because as the area of land in active production decreases, total fertiliser use also decreases, because regulatory limits don't allow a significant increase in the rate of nutrient application. Instead of increasing yields through more intensive grass production on the remaining land, purchased feeds are required to continue to meet the dietary requirement.

5.2 Farm Simulation Tool (PhARM-SIM)

The model was further developed to make use of farm-level data collected as part of the project and described in section 5 of this report. The information available on soil tests, land management, and farm inputs and outputs were used to generate a simulation tool (PhARM-SIM). The tool was applied to four farms and used to estimate field-level grass dry matter yields, as well as farm revenue and main costs for the three historic years available. The observed changes in soil pH and phosphorus were used to generate indicators of field-specific characteristics.

The simulation tool was used to investigate the expected economic impact of implementing an alternative hypothetical management approach for ten consecutive years in the future. The management approach maintains soil pH very close to optimal every year (all fields at 6.2 or above), which, in turn increases the amount of phosphate that can be accessed from the soil. The amount of slurry that can be applied to a field is restricted to the amount required to meet the crop requirement for P (based on the grass dry matter yield from that field the year before), the initial soil P of that field, and characteristics of that specific field in terms of changes to soil P, and the desired level of P to maintain in the soil. The target is that all soils will be maintained at close to an Olsen P of 21, or, between a Soil P Index 2- and 2+. Nitrogen application rates are kept the same as in the last historic year, 2021. If slurry applied to a field reduces under the hypothetical management approach, then N fertiliser will be used to compensate (assuming slurry N is only 40% available to the crop and chemical N is 100% available). The economic impact of the regime change is determined by calculating the revenue and main costs at both current[4] and constant prices[5].

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[4] Current prices are based on published prices from the Department of Agriculture, Environment and Rural Affairs, and, reflect price changes from year to year. In the future period, prices are based on projected prices generated by the FAPRI-UK Project (a partial equilibrium model of the main UK agricultural commodities). Additional information on the projected prices can be requested via email fapri.uk@afbini.gov.uk .

[5] Constant prices apply the same price to every year, so that price changes are not reflected, but quantity changes are clear. In this case, constant prices are defined as the average annual price covering the three historic years (2019 – 2021).

Farm A

Farm A is around 55 hectares, maintaining 50 suckler cows, and selling 40 finished cattle a year. Only some fields are suitable to spread slurry and cut silage, covering about 23 hectares, with the remaining land used as grazing. The Olsen P ranges widely between fields (between 9 and 92 milligrams per litre). Weighted by area, the average Olsen P is 23.3 milligrams per litre (between index 2+ and 3) based on the final soil test. After ten years under the hypothetical management regime, all fields reach and maintain an Olsen P of 21 milligrams per litre (between 2- and 2+). There is a surplus of slurry in the first year of the management change, such that 12% of the slurry available cannot be spread because it would exceed the phosphate requirement. In the remaining nine years all slurry can be spread and maintain the soil P at the target level.

The cost impact of implementing the hypothetical regime in the future is favourable when using constant prices (averaged over 2019, 2020 and 2021) as shown in Figure 13. The N fertiliser use, and so also cost, increases modestly in the first year (2022), and phosphate fertiliser use, and so cost, increase for the entire future period. There is no cost assumed for exporting the additional slurry. The initial increase in the quantity of N fertiliser is driven by the need to reduce the fields receiving slurry on high soil P fields. Therefore, some N that would have been supplied by slurry is replaced with chemical N from fertiliser. The increase in phosphate fertiliser use reflects the restriction on slurry spreading to certain fields which increases the phosphate fertiliser requirement on grazing fields to bring up relatively low P soil stocks (which also improves yields). These additional costs are offset by an increase in grass dry matter available allowing a decrease in purchased feed. The net cost impact for fertilisers and feed settles close to £1000 per year of a cost reduction, assuming prices remain constant.

The cost impact is considerably different when price changes year on year are taken into account (current prices). In this case, although the physical amount of inputs is the same as when constant prices are used, the changes to the cost profile are shaped by price swings as well as the management change. Another difference between constant and current prices, is that output prices also change over time, and so additional revenue may offset some of the cost changes in some years, but not in others. In the first year of the hypothetical management change (2022), high fertiliser prices increase the cost implications of using chemical N fertiliser to replace some slurry applications on silage fields, and phosphate fertiliser on grazing land to improve yields. The additional cost is only partially offset by higher beef prices increasing revenues, resulting in a net cost increase, of £2700 that year. In the next four years, the net cost impact is beneficial to *Farm A*, by up to £10,000, due to additional revenues from high beef prices, combined with a reduction in purchased feed when feed prices are very high. After 2027, beef prices normalise closer to long-term historic averages, reducing the revenue earned compared to 2021 – 2026. In these years, the net cost impact is not beneficial, increasing costs up to £4400, mostly due to the reduced revenue, and to a much lesser extent due to the increase in phosphate fertiliser on grazing fields.

Farm B

Farm B has a total area of around 9 and a half hectares, keeping around 6 cows and selling 4 finished cattle per year. As with *Farm A*, only some fields are suitable to take slurry and be cut for silage, covering 4 hectares. The Olsen P ranges between 25 and 113 milligrams per litre across fields. The average Olsen P for the entire farm weighted by area is 62 milligrams per litre across fields (a soil P index of 4). The high soil P levels on fields able to take slurry means no slurry at all can be spread in the first year of the hypothetical management, and only about 70% of slurry in the second year after the change. In subsequent years, all slurry can be utilised while maintaining the target soil P level (between 2- and 2+) farm-wide. The generally high soil P levels mean that there is an initial reduction in phosphate fertiliser compared to 2021, then a small increase from 2024 onwards. The inability to spread some slurry initially leads to additional N fertiliser used in the first two years.

Grass dry matter reduces and so purchased feed increases. The management regime includes all P in the soil towards the phosphate requirement. However, even with an optimal pH, only 70% of the soil P is assumed to be available for grass growth. Therefore, in fields such that there is a larger relative contribution of soil P compared to fertiliser P, the yield may end up being lower, than other fields. Fields with a relatively high soil P at the start, and those with a large buffering capacity (the release of organic P to mineral P with have a higher proportion of their P requirement met from soil P, and therefore, will be more likely to reduce grass dry matter under the hypothetical management.

The cost impact of implementing the hypothetical regime on *Farm B* in the future is only favourable for the first year when using constant prices (averaged over 2019, 2020 and 2021) as shown in Figure 14. This is because the reduction in phosphate fertiliser purchases offsets the increase in N fertiliser and purchased feed. In the remaining years, the need to supplement lower grass yields with additional purchased feed means there is an unfavourable net cost impact. This is driven by initial levels of soil P and field-specific buffering capacity. When considering price changes over time, and calculating costs at current prices, the net cost impact is more varied. In the first year of the hypothetical management regime (2022) high N and feed prices mean the additional use of these inputs is not offset by reduced phosphate fertiliser use and additional revenue, and there is a net additional cost of £309 incurred by *Farm B*. However, over the next three years (2023-2025) N fertiliser and feed prices come down closer to historic levels, with strong beef prices remaining, reducing net costs compared to 2021 by up to £3900. From 2026 onwards, beef prices weaken, and so net costs increase up to £1000.

Farm C

Farm C has an area of about 45 hectares. Silage is cut on about 13 hectares, and slurry can be spread on all fields. The Olsen P ranges between 12 and 67 milligrams per litre, with an average, weighted by area, of 33 milligrams per litre (Soil P Index of 3). There are 43 suckler cows, and the farm sells 31 finished cattle per year. In the first year of the management change, only half of the usual amount of slurry can be spread, in order to bring down relatively high P soil fields. In the remaining years, all the slurry can be spread and the target of an Olsen P close to 21 milligrams per litre across the entire farm be met. There are no purchased feeds historically, and the hypothetical management regime maintains at least the same level of grass dry matter yield per livestock unit available to *Farm C* in the preceding years. The reduction in slurry use in the first year increases N fertiliser use, but phosphate fertiliser use decreases considerably for all years under the new management regime.

The cost impact of implementing the hypothetical management on *Farm C* in the future is relatively neutral when using constant prices (averaged over 2019, 2020 and 2021) as the reduction in phosphate fertiliser helps offset initial increased use of N fertiliser, and over the remaining nine years there is very little change to total fertiliser use compared to 2021 (see Figure 15). Recent high fertiliser prices mean that in current prices, N fertiliser costs in the year 2021 are £4200 (compared to £3100 using constant prices). A near doubling of fertiliser price between 2021 and 2022, combined with an increase in the quantity of N fertiliser used in 2022, leads to a difference in the costs of £3449. However, record high beef prices provide additional revenue that offsets the additional fertiliser spend, and leads to a reduction in net costs for *Farm C* in 2022. The net cost reduction improves further (up to £5700 per year) in the years 2023 – 2026, as price changes reduce the net cost of fertiliser, and additional revenue is retained due to strong beef prices. The net costs of fertiliser in the year 2027 is very close to 2021, then increases for the remaining years due to lower beef prices compared to 2021.

Farm D

Farm D has an area of 32 hectares, with about 6 hectares cut for silage, and the remaining used for grazing. There are no cows on the farm, instead 70 store cattle are purchased, finished, and sold each year. The cattle are finished on grass produced on the farm, purchased feed, and vegetable waste obtained at no charge to *Farm D*. The soil Olsen P ranges by field between 12 and 39 milligrams per litre, and the average weighted by area is 25 milligrams per litre (Soil P index 2+). Historically, all fields receive slurry, and no chemical fertiliser is used at all.

In the first year of the hypothetical management regime, one third of the slurry on farm is not spread. This is because, even when the rate slurry is applied is adjusted by field to reflect existing stocks in the soil (so high soil P fields receive less and low soil P fields receive more than in 2021). The total P requirement for that year is less than the total P supply from slurry. However, in subsequent years, all slurry can be spread and still reach the target of soil Olsen P close to 21 across the entire farm. The redistribution of slurry at varying rates across fields based on phosphate requirement (instead of N requirement) means that a small amount of chemical N fertiliser use is required on some fields to keep total N input the same as it was in the year 2021. After the initial year of the hypothetical management, the use of a small amount of chemical P from fertiliser is also required. This reflects the general boost in grass dry matter yield under the hypothetical management regime, and associated increase in crop P requirement. The additional grass production leads to a decrease in purchased feed.

The cost impact of implementing the hypothetical management on *Farm D* in the future is favourable when using constant prices (averaged over 2019, 2020 and 2021) with a net reduction in fertiliser and feed costs close to £1000 each year (see Figure 16). Even when current prices are used, the relative position for *Farm D* applying the alternative hypothetical management approach compared to the year 2021 is a net cost reduction up until the year 2028. At that point, price changes bring net costs to the same level as in 2021, with revenue losses being offset by reduced feed costs. For the final three years net costs are relatively higher, driven by additional revenue loss as beef prices fall closer to longer term historical averages.

Future applications

The simulation tool illustrates how a hypothetical management change is likely to impact real-life farms. In this case, the intervention was designed to achieve a soil P target across all fields. Alternative hypothetical changes can also be explored using this tool, such as revised fertiliser application guidelines, or identifying specific fields or areas considered high risk for P loss, and introducing a farm-specific restriction on how that area is managed.

5.3 Catchment aggregation tool

A framework based on economic modelling was developed to anticipate the opportunity cost to grass-based agricultural enterprises at a more aggregate level. This facilitates analysis of the relative economic impact of alternative interventions across hydrological boundaries (in this case sub-catchment scale) and enterprises within agriculture (in this case dairy, beef and sheep).

Farm-level agricultural census data for the Ballymartrim Water, a sub-catchment of the Blackwater, is used to establish three grass-based meta-enterprises (dairy, beef and sheep). Farms with more than one enterprise undergo an allocation procedure to divide livestock and grassland across enterprises. Cattle are allocated to dairy or beef based on the final output generated (milk or beef). Grassland is allocated using a mathematical optimisation programme that minimises the deficit, or surplus, of grass dry matter yielded from the allocated land to each enterprise on the farm. The livestock, and grassland, assigned to each enterprise activity are aggregated across farms into the three, sub-catchment scale, meta-enterprises. A summary of the meta-enterprises, (dairy, beef and sheep) is provided in Figure 17.

The organic and chemical nutrient application, grass dry matter yield, revenue, and costs are modelled for each meta-enterprise. These are used to establish a reference value of income. The enterprise-level income is defined as market and area-based subsidy revenue less feed, fertiliser, and sundry costs. Sub-catchment income is the sum of income across enterprises.

A SLAM model (see section 3.1 above) is used to identify the diffuse and point source loads in the sub-catchment and determine a target reduction in diffuse phosphorus loading from agricultural grassland (slurry, fertiliser and soil P). This provides a reasonable range in terms of the scale of intervention likely to be required to reach Good water quality status. In this case, the intervention selected was a

20% of reduction ruminant livestock units. This is because slurry applied to grassland is the largest diffuse source of P in the sub-catchment.

The opportunity cost of reducing livestock is measured as the income foregone due to stocking fewer cattle and sheep on the same area of grassland [6]. Two alternative de-stocking patterns are analysed (see Figure 18). The first decreases sheep, beef and dairy livestock units[7] each by 20% to meet the sub-catchment target. Sub-catchment income is 19% below the reference value (an almost proportionate reduction).

A second scenario also reduces livestock units by 20% in the sub-catchment, but varies the rate of de-stocking across sheep, beef and dairy so that the impact on sub-catchment income is as small as possible. Minimising the overall cost requires the sheep meta-enterprise to de-stock by 68% (compared to 20% in the first scenario), beef by 16%, and dairy maintains the same stocking density. The prioritisation of economic efficiency in the second scenario results in a relatively lower opportunity cost for the sub-catchment (11% below the reference value). The sub-catchment income by enterprise and scenario is shown in Figure 18. The percent difference in revenues and costs between the two de-stocking scenarios and the reference scenario are provided in Figure 19.

Future application

The sub-catchment economic modelling tool provides a framework to compare the aggregate economic impact at sub-catchment scale of alternative approaches to reduce diffuse sources of P loadings. Application of the framework to the Ballymartrim Water illustrates how prioritising economic efficiency reduces the aggregate cost to the sub-catchment, but distributes that cost unevenly across sheep, beef and dairy enterprises.

The tool may also be applied to additional sub-catchments (for which farm-level census data is available). Extending to additional sub-catchments allows analysis of how opportunity costs are distributed between, as well as within, sub-catchments. This can help identify relatively low-cost points of intervention (e.g. sub-catchments or enterprises with relatively low opportunity costs compared with others). The evidence can inform policy design and implementation by illustrating trade-offs between overall costs and how those costs are likely to be distributed, regionally and in the agricultural sector. However, results need to be contextualised within a broader context that accounts for additional trade-offs, such as potential trade-offs between water and air quality. This could in part be addressed by developing an extension to the model that anticipates the expected change to ammonia and greenhouse gas emissions associated with the alternative patterns of de-stocking.

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[6] It is assumed that grassland allocated to sheep, beef or dairy remain associated with sheep, beef or dairy production, just at a more extensive rate of stocking. Land can not be re-allocated to a different meta-enterprise activity as part of the scenario analysis.

[7] Livestock is measured in livestock units (cow equivalents).

Table 1: Threshold concentrations for river phosphorus in Northern Ireland (NI) and the Republic of Ireland (RoI).

			Soluble Reactive P (mg l^{-1})		
	Elevation	**Alkalinity**	**High Status**	**Good Status**	**Poor Status**
NI (UK)	Lowland (<80 m asl)	Non-Calcareous (<50 mg l CaCO$_3$)	<0.019	0.019-0.040	>0.040
	Lowland (<80 m asl)	Calcareous (>50 mg l CaCO$_3$)	<0.036	0.036-0.069	>0.069
	Upland (>80 m asl)	Non-Calcareous (<50 mg l CaCO$_3$)	<0.013	0.013-0.028	>0.028
ROI	Upland (>80 m asl)	Calcareous (>50 mg l CaCO$_3$)	<0.024	0.024-0.048	>0.048
	All elevations	All alkalinities	<0.025	0.025-0.035	>0.035

Table 2: Reasons under Article 16 and 17 of the Water Framework Directive for the establishment of alternative targets

Category	Reason
Technically Infeasible	No known technical solution is available
	Cause of adverse impact unknow
	Practical constraints of a technical nature prevent implementation of a measure by an earlier deadline
Disproportionately Expensive	Unfavourable balance of costs and benefits
	Disproportionate burden
Natural Conditions	Ecological recovery time
	Groundwater status recovery time
	Background conditions

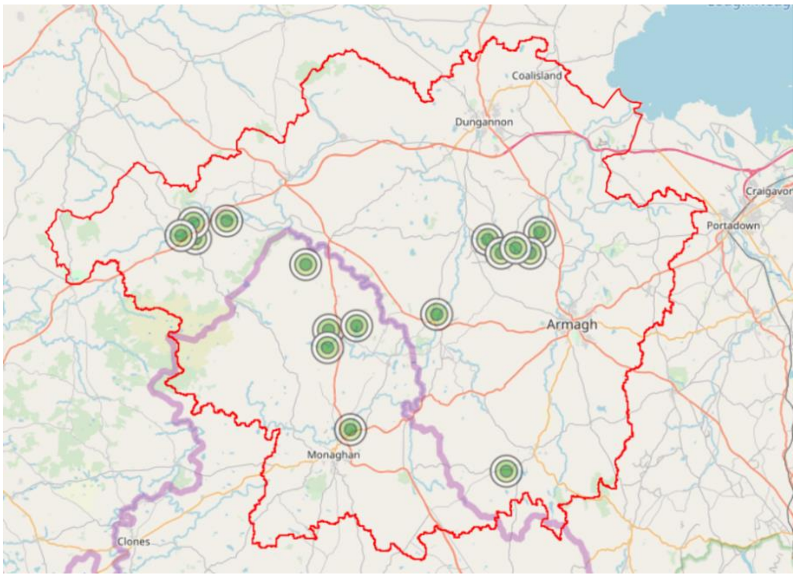


Figure 4: Location of 17 farms selected farms within the Blackwater Catchment

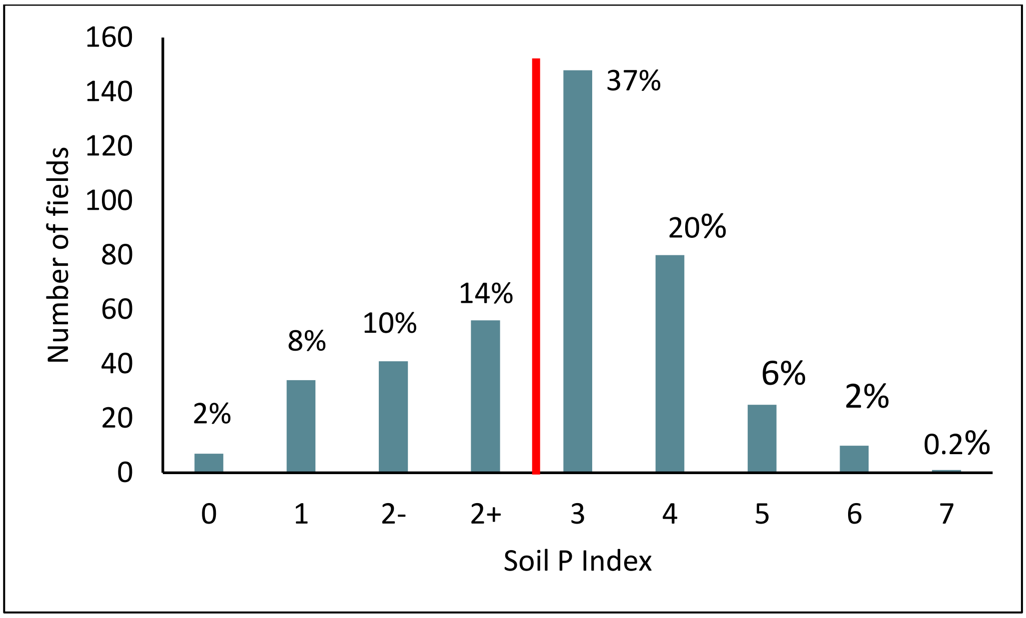
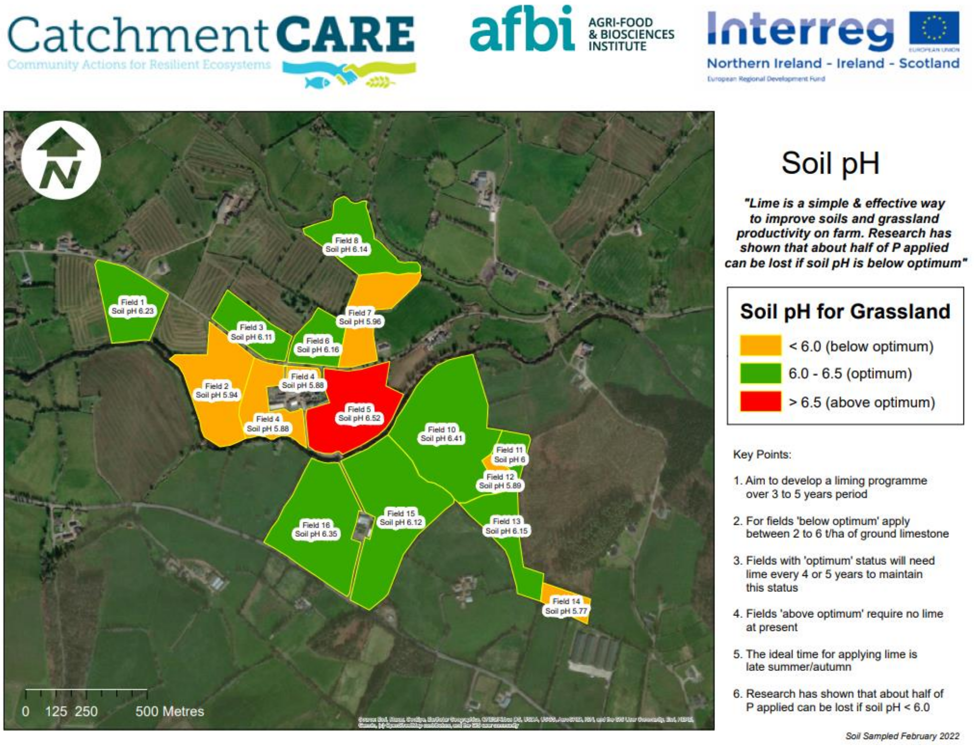


Figure 5: Olsen P soil index of over 400 fields sampled in the Blackwater catchment in 2019



Soil pH

"Lime is a simple & effective way to improve soils and grassland productivity on farm. Research has shown that about half of P applied can be lost if soil pH is below optimum"

Soil pH for Grassland

- 🟧 < 6.0 (below optimum)
- 🟩 6.0 - 6.5 (optimum)
- 🟥 > 6.5 (above optimum)

Key Points:

1. Aim to develop a liming programme over 3 to 5 years period
2. For fields 'below optimum' apply between 2 to 6 t/ha of ground limestone
3. Fields with 'optimum' status will need lime every 4 or 5 years to maintain this status
4. Fields 'above optimum' require no lime at present
5. The ideal time for applying lime is late summer/autumn
6. Research has shown that about half of P applied can be lost if soil pH < 6.0

Soil Sampled February 2022

Figure 6: Example of Soil pH map generated for each farmer

Table 3: Average Farm P Balance across selected farms in the Blackwater catchment

Average Farm Phosphorus Balance				
Pre-NMP	*2019*	*2020*	*2021*	*3 Year Mean*
6.26	*4.29*	*3.17*	*3.90*	*3.78*

Figure 7: Experimental plots on three extensively managed grassland sites, receiving low, medium and high fertiliser P inputs over 3 years, in a two-cut regime

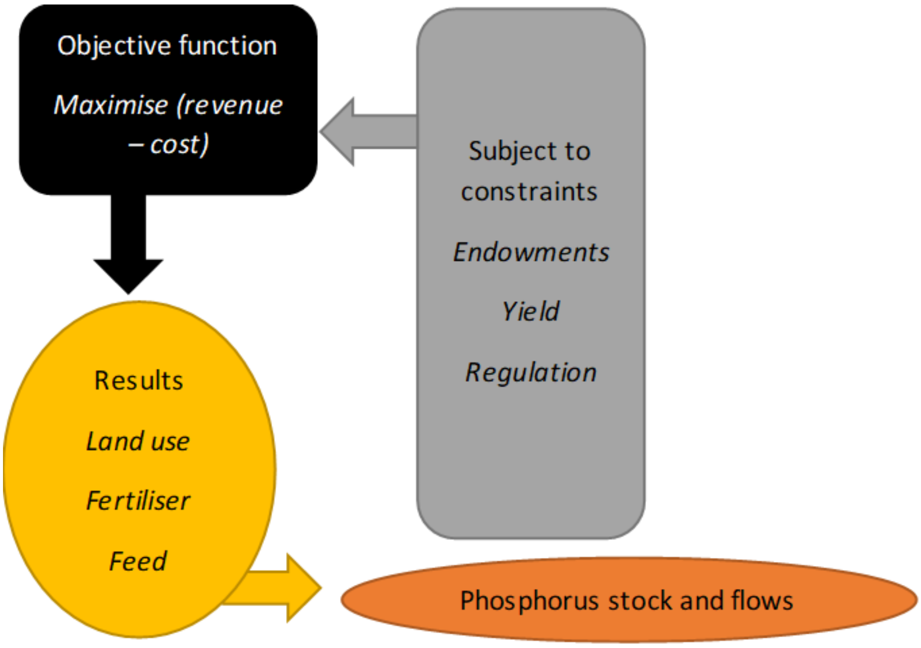


Figure 8. PhARM Model Overview

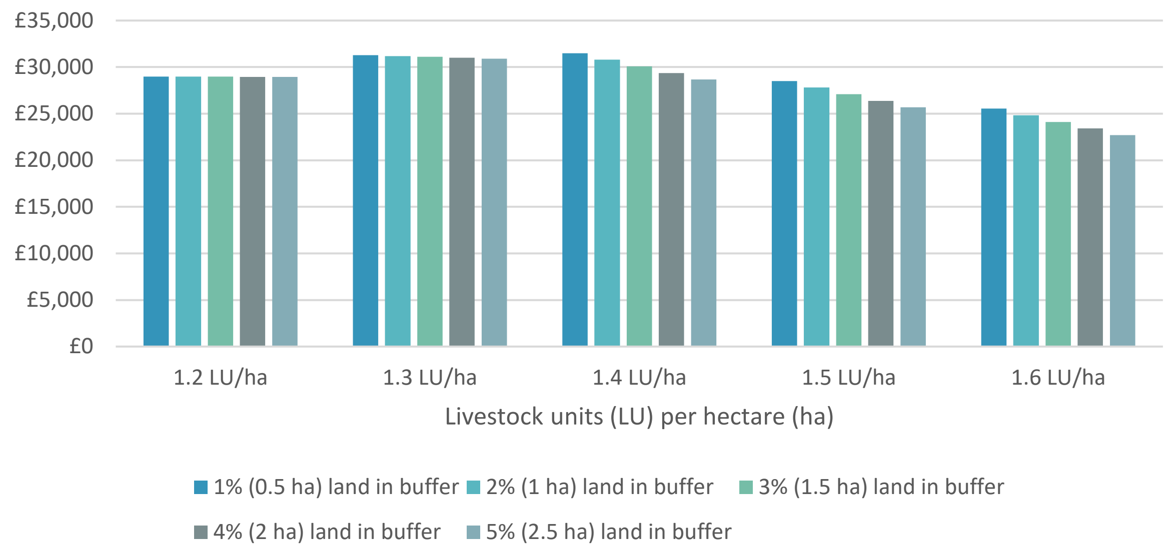


Figure 9: Suckler farm gross margin in £s for different stocking densities and sizes of buffer strips

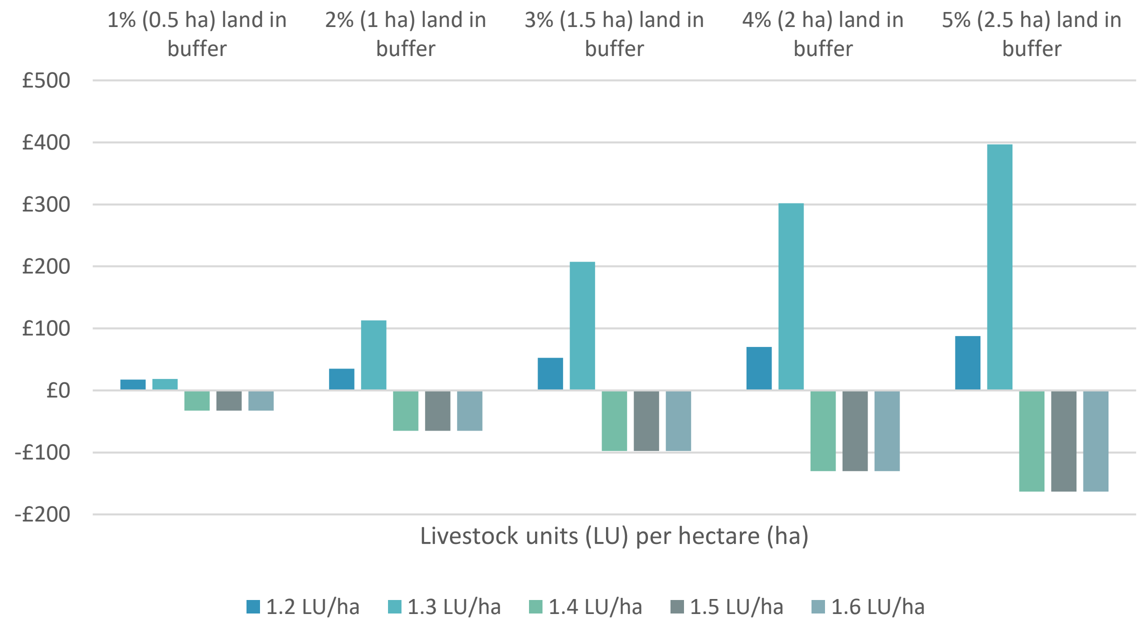


Figure 10: Comparative difference in fertiliser costs for the suckler farm as stocking density and the size of buffer strip changes

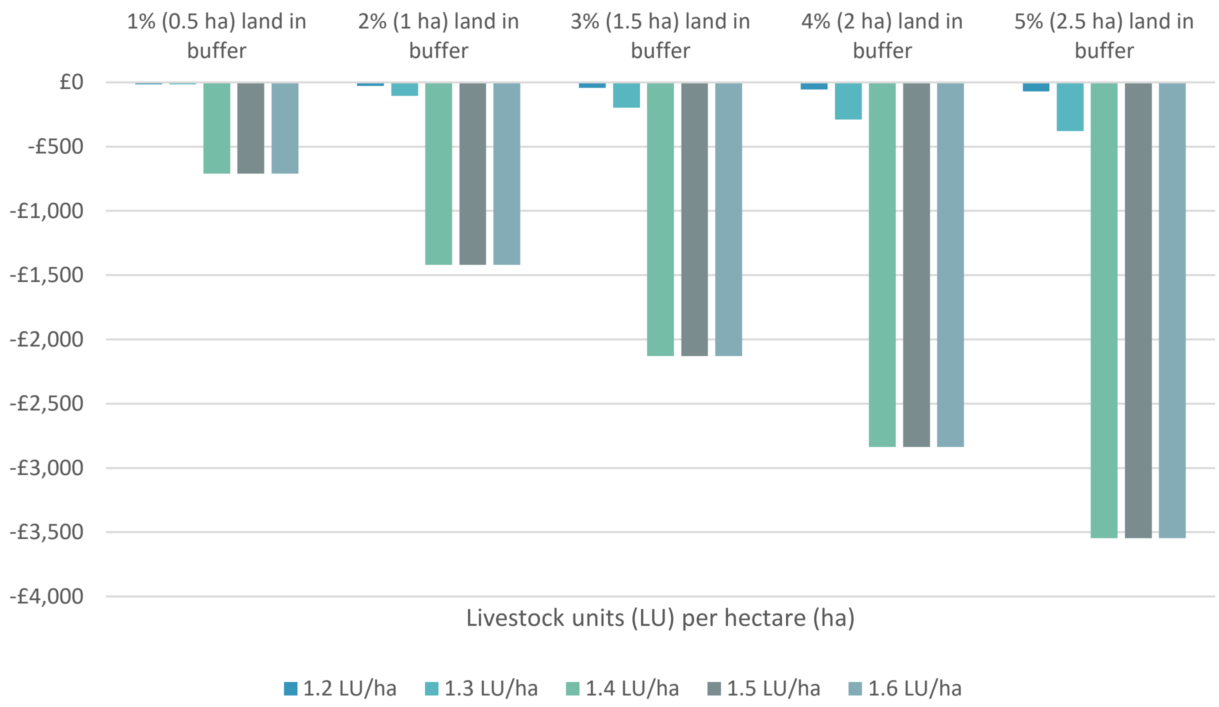


Figure 11: Comparative difference in suckler farm gross margin as the stocking density and size of the buffer strip changes

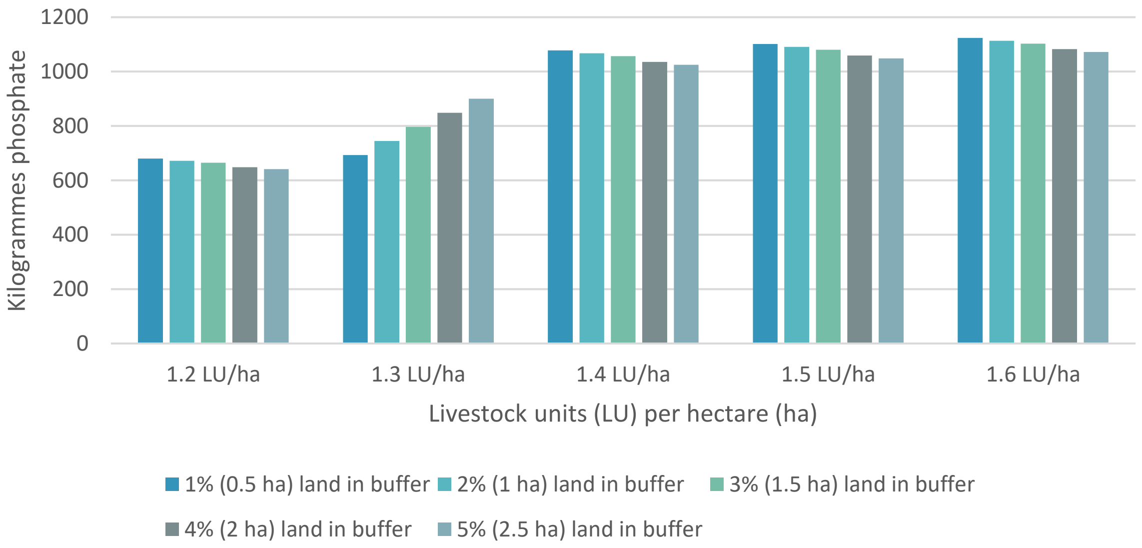


Figure 12: Expected phosphate loss (kilogrammes) from the suckler farm as stocking density and the size of the buffer strip changes

Figure 13: Farm A cost differential using hypothetical management compared to status quo management in 2021 expressed in both constant and current prices

Figure 14: Farm B cost differential using hypothetical management compared to status quo management in 2021 expressed in both constant and current prices

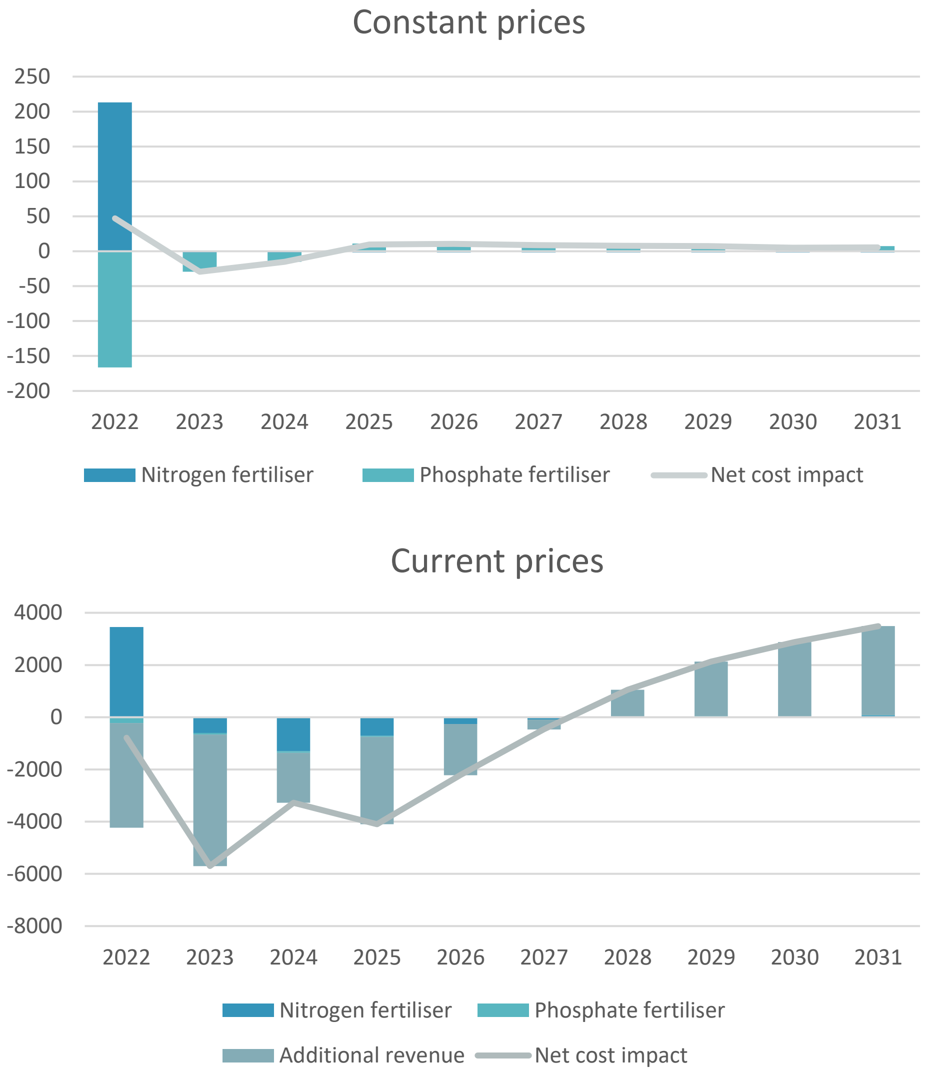


Figure 15: Farm C cost differential using hypothetical management compared to status quo management in 2021 expressed in constant and current prices

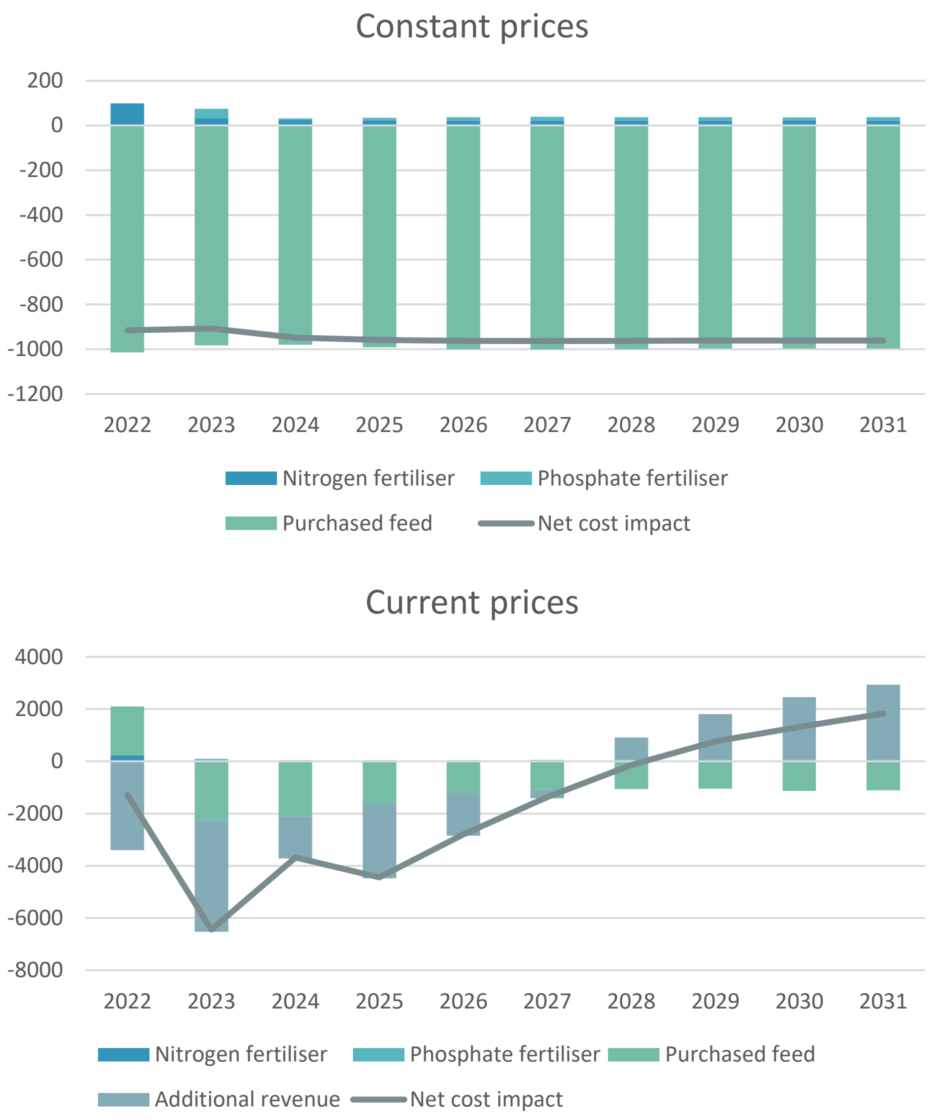


Figure 16: Farm D cost differential using hypothetical management compared to status quo management in 2021 expressed in constant and current prices

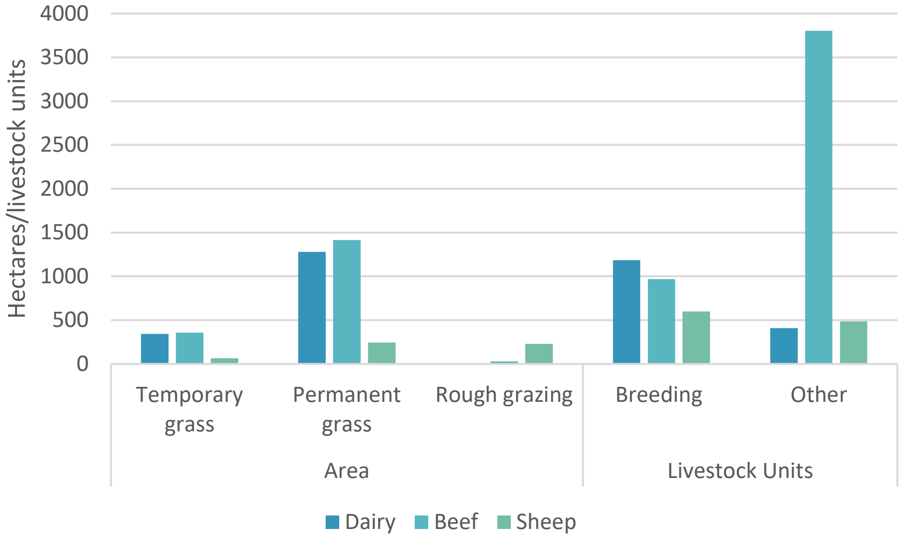


Figure 17: Hectares of grassland and livestock units of breeding and other stock for the three meta-enterprises in Ballymartrim Water sub-catchment

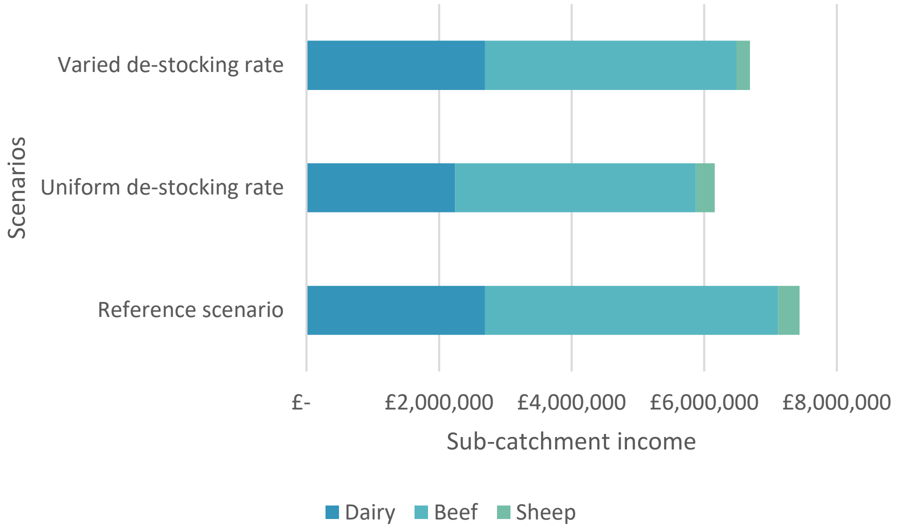


Figure 18: Sub-catchment income from dairy, beef and sheep enterprises in the reference scenario compared to uniform de-stocking in each enterprise and varied de-stocking to maximise sub-catchment income

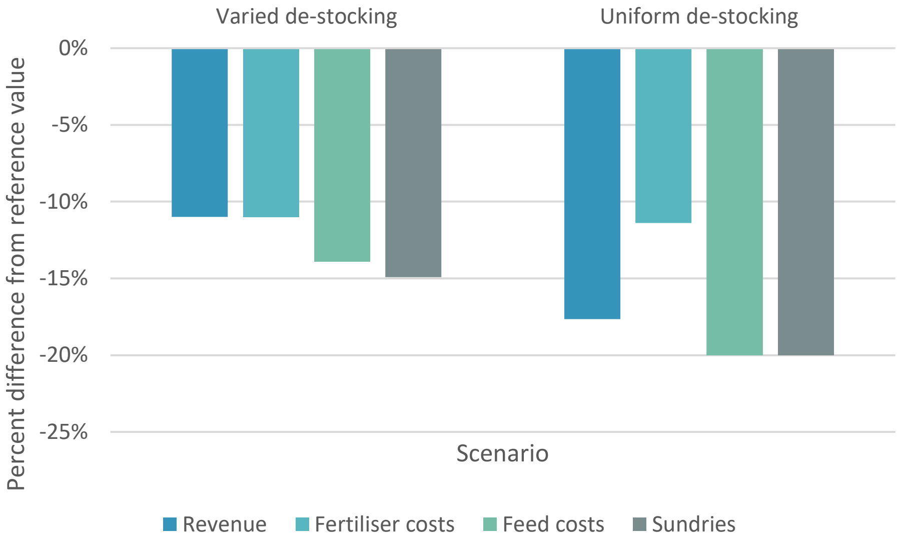


Figure 19: Percent difference in revenue and costs between the two de-stocking scenarios and the reference scenario

Figure 1 Map of the Blackwater catchment indicating latest WFD surface water status (EPA is 2013-2018, NIEA is 2018)

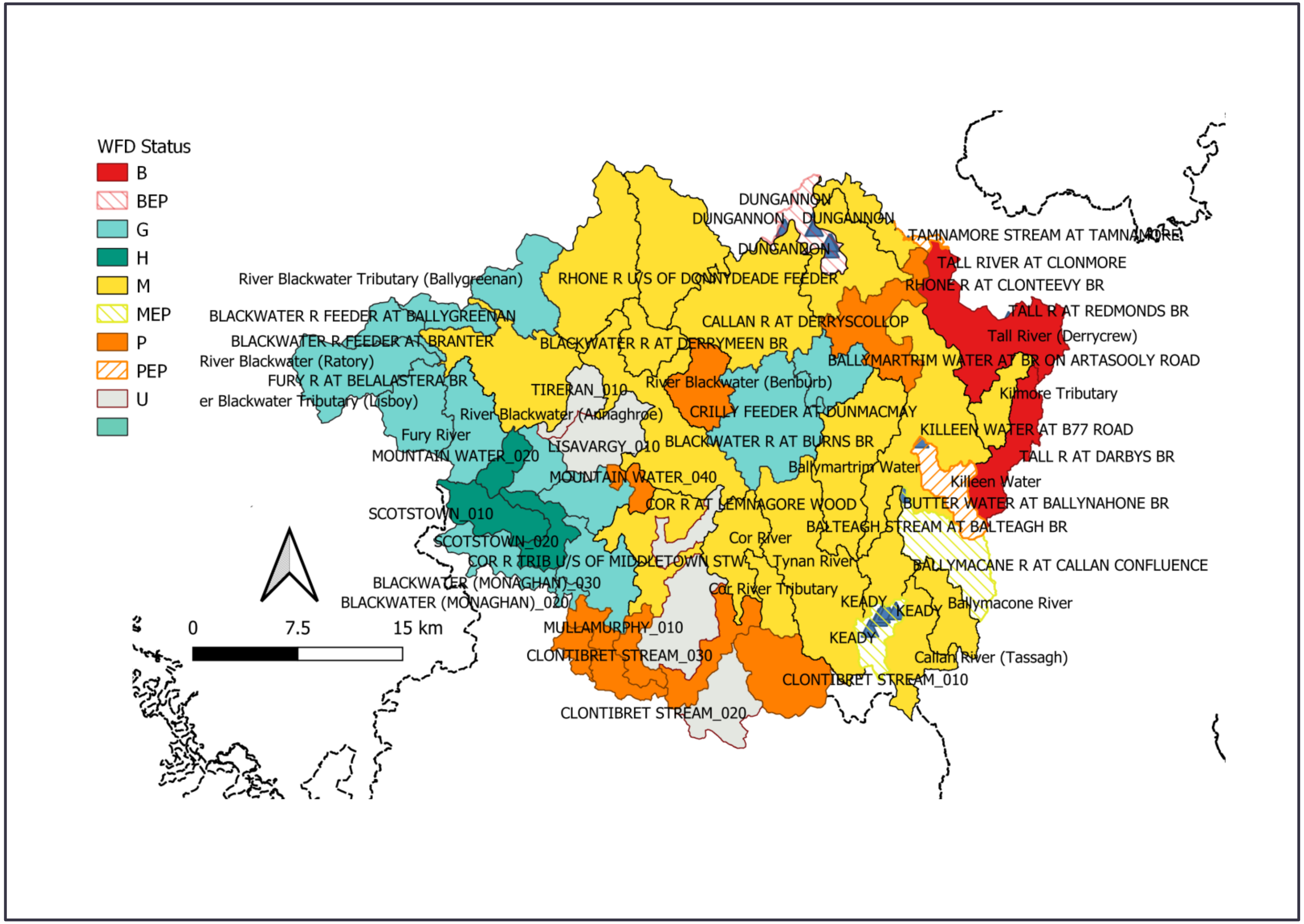


Figure 2 Map of the Blackwater Catchment indicating percentage of total TP loads from diffuse sources

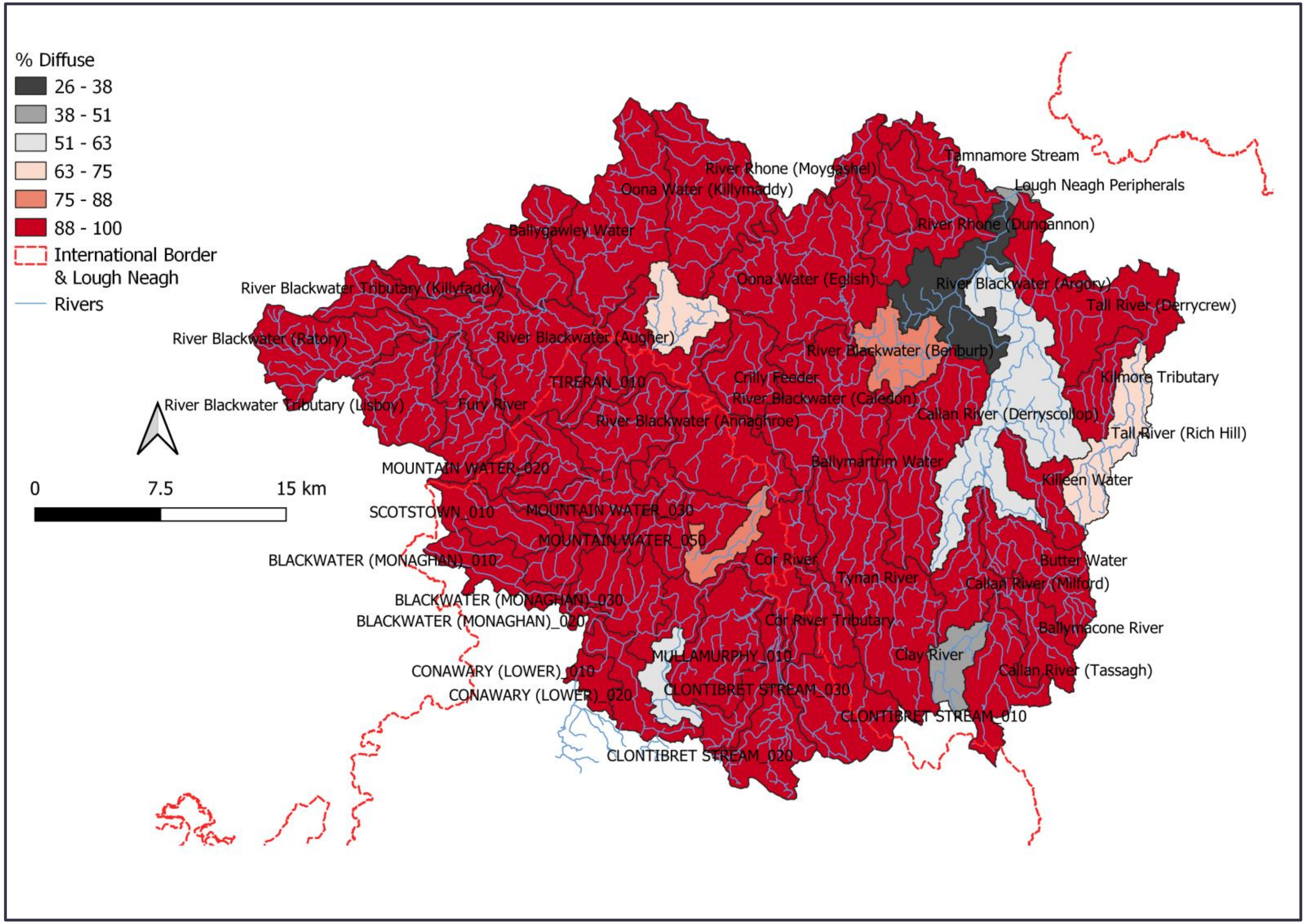
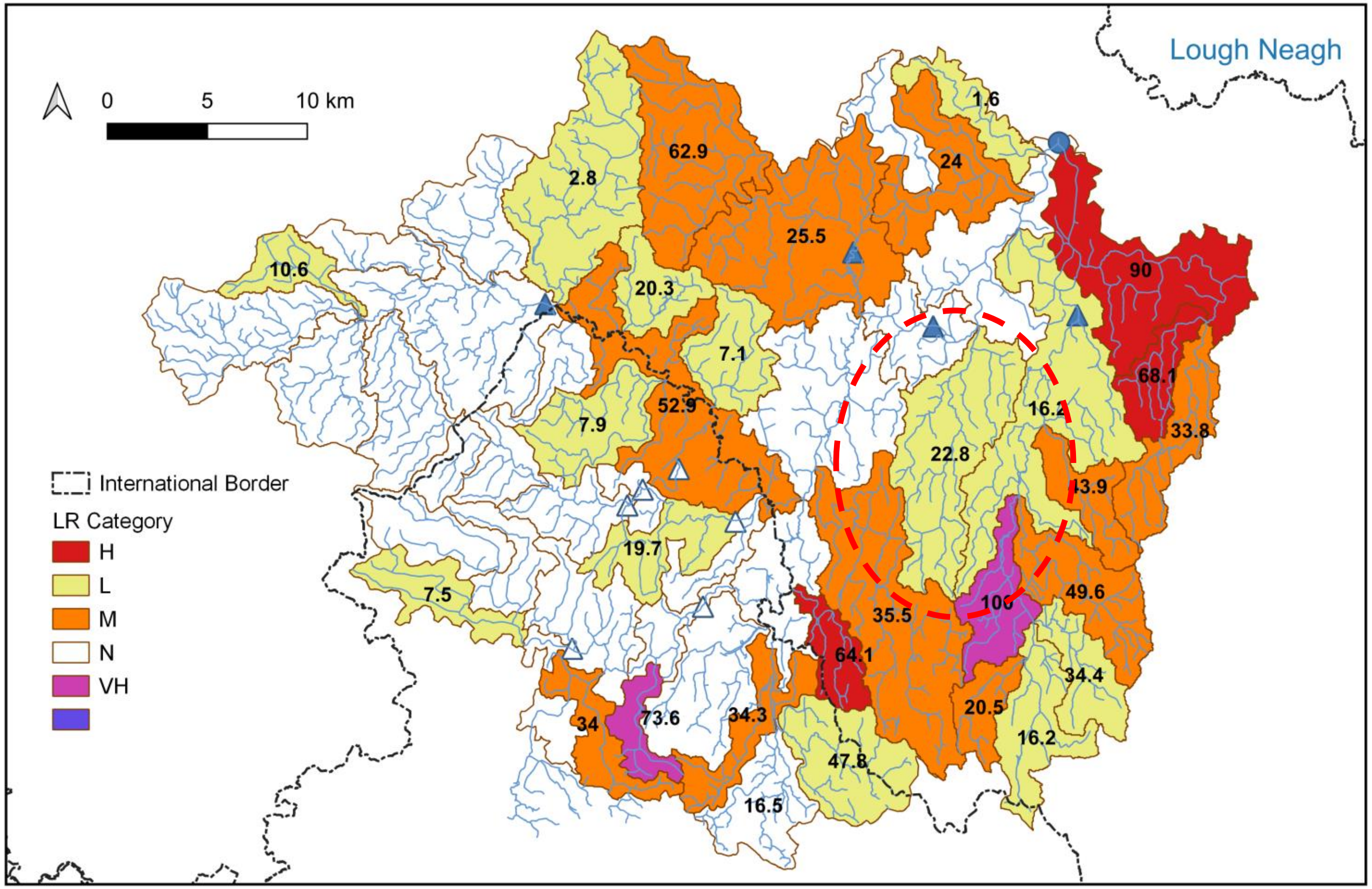


Figure 3 Map of the Blackwater catchment indicating (i) LR categories by colour shading (ii) LR percentages (of baseline loads) as black numbers (e.g. ***22.8****), Ballymartim Water sub-catchment (indicated by red dashed oval)*



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