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A participatory approach for comparing stakeholders' evaluation of P loss mitigation options in a high ecological status river catchment

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Abstract

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 adopted a participatory approach including stakeholders with conflicting interests in the selection of P transfer mitigation policies. Fifteen P transfer mitigation options were shortlisted based on agronomic and environmental data from a case-study agricultural catchment and presented to a group of experts and farmers. Results showed significant disparities between perceived effectiveness by farmers and experts groups, with experts prioritizing problems related to connectivity issues, while farmers to soil compaction and erosion. In addition, measured agronomic and environmental variables were used to model effectiveness from a decision support tool (FARMSCOPER) and compared with stakeholder groups' perceived effectiveness. This approach combined the scientific research with the empirical knowledge of farmers and the modelling of quantified field and farm data. This study showed that stakeholders are diverse, and perceive effectiveness based on group-specific operational and social factors. Experts identified effectiveness at catchment scale, whilst farmers identified field scale effectiveness. For decision support tools and simulation models to be beneficial for policy makers, they need to be calibrated to local conditions and farm typologies to select the right measure at farm scale. The study recommends improved 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.

1. Introduction

Clean unpolluted waters are vital for our ecosystems. The EU Water Framework Directive (WFD) (2000/60/IEC) assigns ecological status to all water bodies based on physico-chemical, hydro-morphology and biological quality conditions. This legislation seeks to maintain those water bodies that reflect undisturbed conditions or high ecological status, and improve all waters to good[1] status. However, more than half of the surface waters in the European Union are reported to be in less than good ecological status.

Generally speaking, 30–50% of surface water bodies are affected by pollution pressures, with diffuse sources contributing the most severe pollutants (see Fig. 1). Around 40% of river and coastal water bodies are affected by diffuse sources while approximately 25% are also subject to point source pollution, with nutrient enrichment causing eutrophication the most significant pressure (EEA, 2012). The highest proportion of river bodies in worst ecological status is reported in North-Western Europe, where pressures on freshwaters are higher (Fig. 1).

Agriculture is a key source of diffuse pollution (European Environmetal Agency, 2005). Measures exist to tackle

[1] According to the EU Water Framework Directive a water body river is assigned its ecological status based on its physico-chemical, hydro-morphology and biological quality elements conditions. When these reflect undisturbed or nearly undisturbed conditions the waterbody is assigned "high" or "good "ecological status respectively. The High Status River Catchments in the republic of Ireland are monitored by the Environmental Protection Agency and the Teagasc Agricultural Catchments Programme. In total 508 and sites are monitored. Most of these sites are located in upland areas or along the western seaboard and, have a high proportion of peat soils.

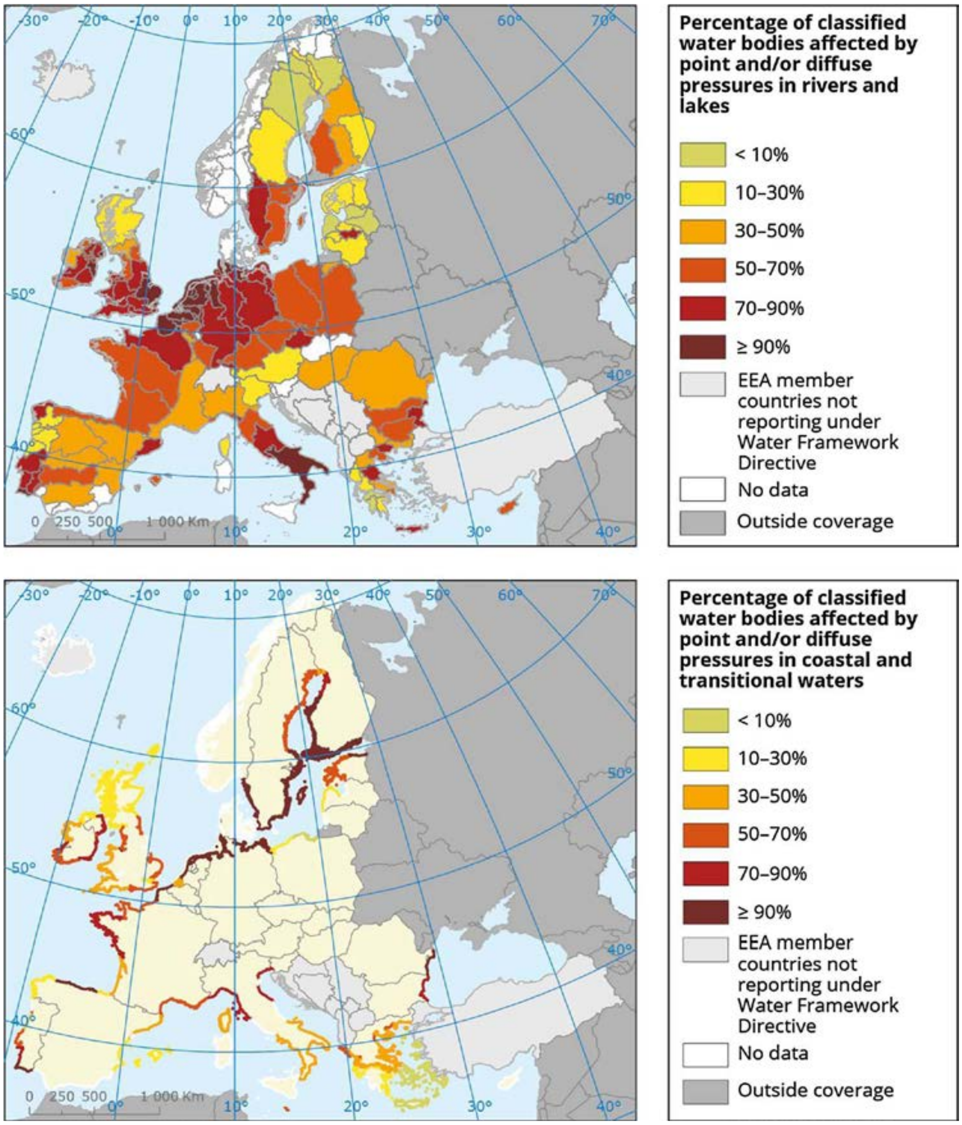

Fig. 1. Maps of spatial extent of affected freshwater and transitional waterbodies across Europe.
Source: European Environmental Agency (EEA).

agricultural pollution need to be implemented according to the WFD. The WFD has identified agricultural sources of phosphorus (P) as a pressure on water quality and requires member states to implement measures to mitigate P losses to surface waters including the restriction on P use on farms. However, these measures are implemented at farm scale and do not account for landscape and soil conditions (Doody et al., 2014). Additionally, in low intensity farming systems P surpluses often exist due to poor nutrient and farm management practices on marginal soils (Roberts et al., 2017) rather than high inputs, therefore restrictions on P use may not guarantee their reduction (White et al., 2014).

WFD policy suggests that measures should be implemented at river basin scale by identifying sources and pathways of P. However, such measures will have to be examined from the point of view of applicability at farm level (McDowell et al., 2015). Multiple stakeholder participation is also a requirement of the WFD, particularly during the process of measures selection design.

This study focuses on Ireland where recent reports by the Environmental Protection Agency (EPA) recorded a decline in the percentage of high status waters (HSW) from 30%, in 2000, to 17% in the period 2007–2009 (Ni Chathain et al., 2013). In Ireland, WFD policy is implemented on a whole territory basis (including those pertaining to agricultural P), through national River Basin Management Plans (RBMP). Intensive agriculture is often perceived as imposing a higher source pressure on water quality compared to extensively farmed areas, however, HSW are typically located in less developed and less intensively farmed areas (White et al., 2014) often characterized by high levels of annual rainfall on marginal and poorly drained soils with little capacity for nutrient assimilation (Gibbons et al., 2006; Roberts et al., 2016).

To date, the design of pollution mitigation measures is based on scientific research which is transformed into standardized tools that assist agricultural policy design (Obermeister, 2016). This approach facilitates the production of objective pollution mitigation options, based on “professional and technical expertise” and is less likely to be biased by the opinion of public actor’ groups (Fung, 2006). However, Cash et al. (2003) concluded that knowledge systems for environmental sustainability that put science into action are more likely to be effective when communication, translation and mediation is included. The authors cite case studies where agricultural production, aquifer management and reducing air pollution include scientific advice for policy at the interface between experts, communities and decision makers, and conclude that effectiveness suffered when communication was one- way, when participants were misunderstood and when mediation was not facilitated.

The current approach to policy design under the RBMP omits the view of non-scientific or expert groups, such as farmers, and this could significantly influence the outcome of policy decisions. This is often because of the resistance from the research and government authorities to include farmers in the decision-making process as they consider their contribution uninformed and biased (Doody et al., 2012). Exclusion of farmers however, from the decision-making framework may lead to conflicts and uncertainty in the practical implementation of policies. Inclusion of farmers however, could require policy makers, scientists and farmers to adopt an approach different from their traditional roles and open to collaboration. This integration can be difficult to achieve as there are often differences in perceptions on the main environmental issues that need to be tackled (Doody et al., 2009).

Using a river catchment as a case study, we identified a list of options for P transfer reduction based on current farm practice observed within the catchment, and the constraints imposed by soil and land- scape conditions. These measures were then used to describe and compare ‘perceived effectiveness’ of a number of farm scale water quality measures that could mitigate P losses. The objectives of this study were to explore the potentials of participatory decision-making and to compare the perceived effectiveness of measures across different stakeholder groups. In addition, we compared perceived effectiveness of measures with modelled effectiveness derived from a decision sup- port tool (FARMSCOPER) using quantified agronomic and environ- mental variables collected at farm level within a river catchment. This decision support tool was developed to help policy makers, farmers and catchment managers evaluate and select measures at farm scale to mitigate environmental losses at catchment scale.

This paper presents the river Black catchment in Ireland as a case- study catchment that has lost its high ecological status during the EPA monitoring period 2010–2012 (Environmental Protection Agency, 2015). This catchment was used to represent an extensively farmed river catchment with soil and landscape characteristics typical of high status areas and was selected from a GIS database of Irish HSW in Roberts et al. (2017). In this present study, we describe a selection of P transfer mitigation measures that would be most appropriate for high status catchments, based on the catchment characteristics and the farm management practices and reported in (Daly, 2015; Roberts et al., 2017), and compare perceived and modelled effectiveness as tools for selecting mitigation options.

2. Methodology

2.1. *The river Black catchment*

The river Black catchment is located in the west of Ireland and covers an area of 142 km^2. It is a lowland system (elevation 22.11 m), with an average annual rain fall of 1197 mm/year. Mean annual temperature is 9.8 °C. Soils consist of a mix of brown earths and large areas of blanket peat and marginal soils (Fig. 2).

Average farm size is 34 ha. Fields are considered free draining and susceptible to poaching and poor grass growth. ‘Poaching’ of soil is caused by the continuous trampling of animals (cattle) near drinking points, which results in soil compaction that reduces infiltration capacity (Byrne and Fanning, 2015). Land use is mostly grassland with approximately 63% of land used for agriculture. Most of the agri-cultural activity is mainly extensive grazing, under cattle dry-stock production (average grazing intensity of 90 kg ON/ha^{-1} on a poorly drained soil). Cattle in the catchment tend to be housed for longer periods of time (average grazing period is 30 weeks/year), due to poor soil drainage conditions and many fields were susceptible to poaching (Fig. 2).

2.2. *Identification of measures*

To select the most appropriate P transfer mitigation options for evaluation, we first had to identify the most frequently appearing nutrient and farm management practices likely to promote P transfer from farm to stream. For this purpose, the study used data from an extended field survey and risk assessment conducted by Roberts et al. (2017).[2] Data from this survey revealed that 46% of fields surveyed were on marginal soils with high organic matter (OM) values (> 20%) which has been shown to pose a high risk of P loss due to poor P retention reported for organic soils (Daly et al., 2001; Guppy et al., 2005). Soil test P (Morgan's P) levels ranged from 0.9 to 28 mg/l and 60% of fields recorded positive P balances, indicative of fields receiving applications in excess of crop demands. A previously reported field based risk assessment for this catchment recorded 21% of fields surveyed at high risk of P transfer (Roberts et al., 2017) based on data describing nutrient management and soil conditions (Fig. 3). Table 1 presents farm and nutrient management practices and field conditions (erosion and connectivity potential) and the frequency at which they were observed (Roberts et al., 2017).

Based on the frequency of farm practices that could promote P transfer, a list of potential measures was derived and validated using international literature sources (Cuttle et al., 2006; Haygarth et al., 2009; Newell Price et al., 2011).

2.3. *Evaluation process*

Perceived effectiveness of these measures was examined across two different stakeholder groups and compared against effectiveness modelled by a decision support tool developed for policy makers to select measures at farm scale. The stakeholder groups included experts (scientists and policy makers) and farmers. FARMSCOPER was selected as the decision support tool evaluated in this study. FARMSCOPER (Gooday et al., 2014) is a Microsoft Excel based tool developed to evaluate pollutant losses at farm scale and cost-effect ratios of pollutant transfer mitigation options. The tool uses a range of existing models to calculate effectiveness, and for P specifically it uses the Phosphorus and Sediment Yield Characterization in Catchments (PSYCHIC: Collins et al., 2007; Davison et al., 2008). FARMSCOPER has the ability to classify mitigation options from most to least effective for each individual farm based on agronomic and environment data. Farm management practices are simulated based on representative farm systems derived from the UK Department for Environment Food & Rural Affairs (DEFRA) Farm classification scheme (DEFRA, 2010) (see Appendix A for more details). The effectiveness of selected measures was modelled using data from our case-study catchment to appraise the choices of the other two groups by comparing them to the outcomes of a decision making support tool.

2.3.1. *Ranking of perceived effectiveness: expert workshop*

Fifteen scientists, policy makers and professionals participated in an expert workshop to rank their perceived effectiveness of selected measures. They were presented with the list of P transfer mitigation options (Table 2) and asked to individually rank the options, according to perceived cost-effectiveness, given the specific characteristics of the catchment and the frequency of appearance of P transfer promoting management practices. A group rank was produced from the individual rankings, which provided a score for each option using the formula:

$$R_{gi} = \frac{w_1x_1 + w_2x_2 + w_3x_3 + \cdots + w_nx_n}{Total} \quad (1)$$

[2] A field survey was conducted on 112 fields, with sizes ranging from 0.3 to 7.7 ha, in a total of 10 farms, in the river Black catchment. For the needs of this study The survey assessed nutrient management and farm practice, such as distribution of soil P on the farm, uptake of nutrient management plans, and soil conditions e.g. erosion and drainage. More specifically, the survey collected information from 112 fields with sizes ranging from 0.3 to 7.7 ha on organic and inorganic fertilizers application, soil types and content of organic matter in soils, and detailed information on farm systems (number of animals, area etc.) and on field operation and nutrient and farm management practices (For further information on the field survey refer to Roberts et al. (2017).

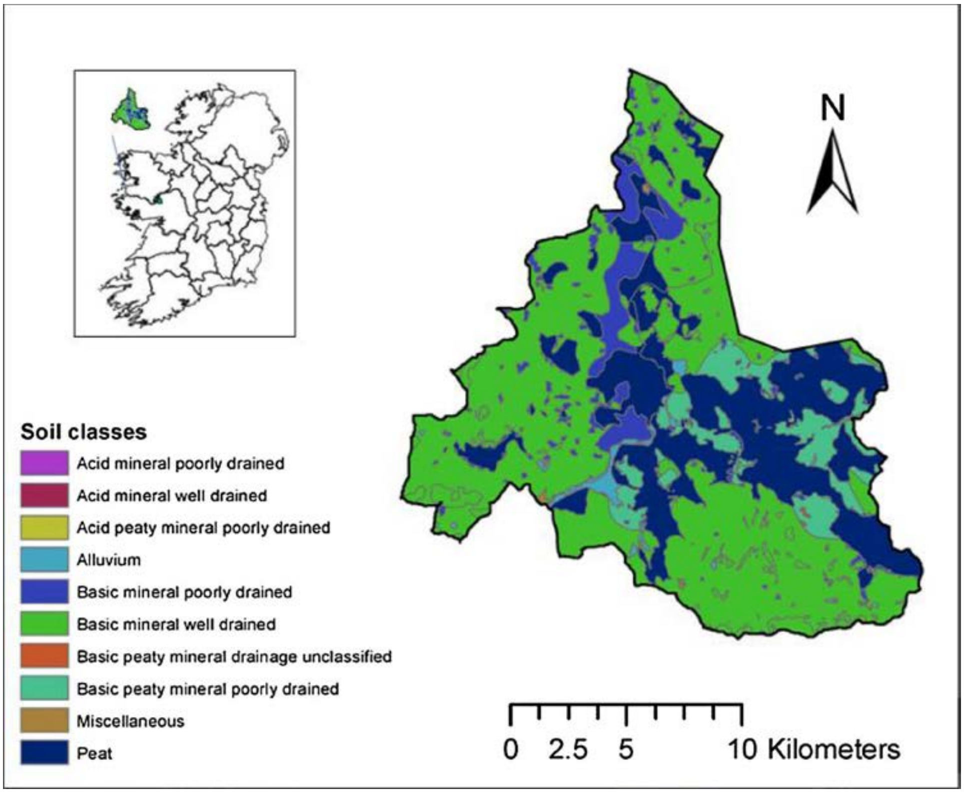

Fig. 2. Distribution of soil classes in the river Black catchment.

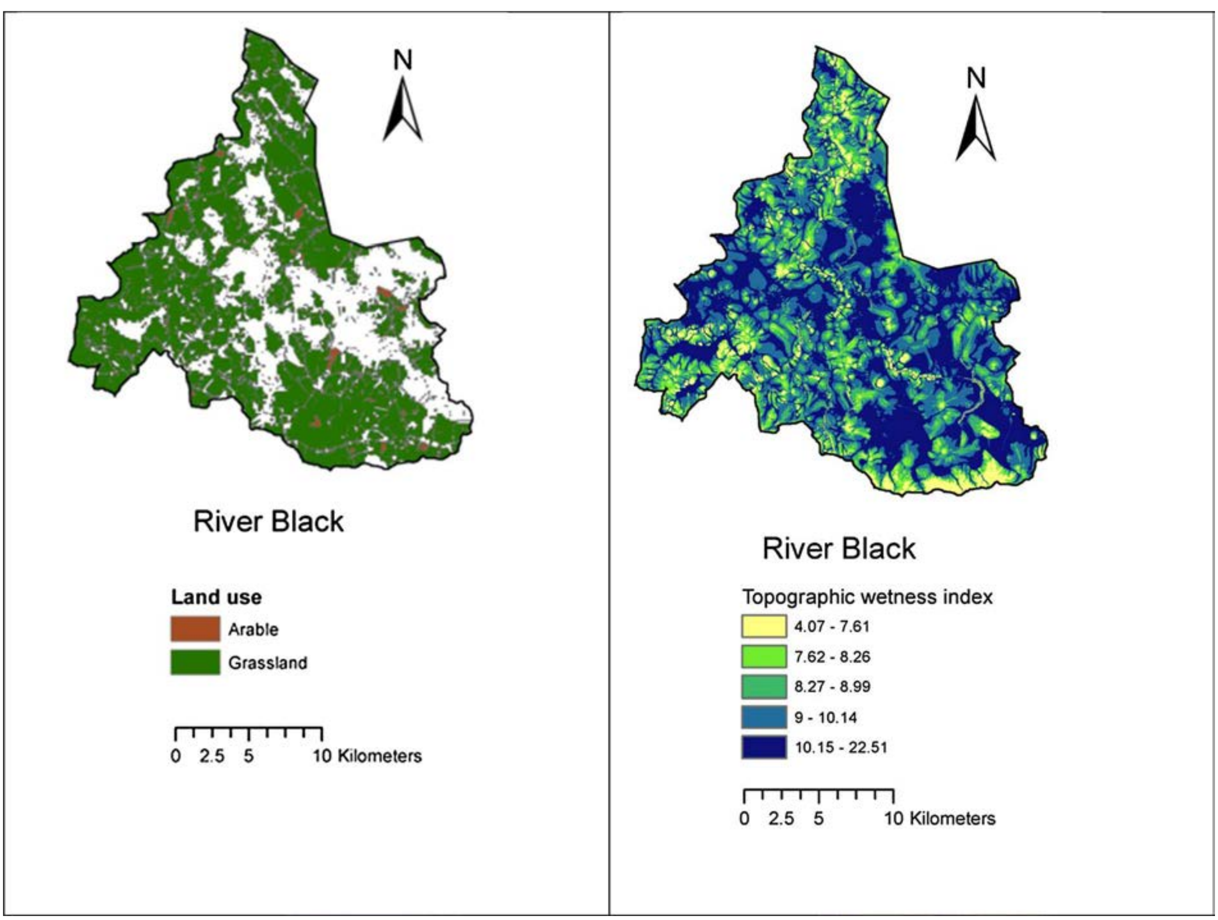

Fig. 3. Land use and topographic wetness index in the river Black catchment.

Table 1
P transfer promoting practices observed in the farm and fields under survey (%).

Problem	Practices/observations	% of fields surveyed
Poor nutrient management	Positive field P balances 4	60%
	High organic matter levels (OM > 20%)	46%
	Mineral soil fields with high STP/ P index	17%
Erosion	Poaching around troughs/feeders/gateways	9%
	Cattle access to streams	5%
Soil drainage/transport	Artificial drainage	20%
	Waterlogged field	18%
	Open ditches	On average 10% of the perimeter of a field is an open ditch
	Sediment	No buffer strips/hedgerows/sediment traps

Where R_{gi} is the group rank for option i, w is the ranking number, x is the number of times the ranking number appears for each measure and n is the total number of “voters”. To ensure the robustness of the ranking and to avoid duplications, the group rank was weighted, using the formula:

$$WR_{gi} = \frac{1/R_{gi}}{\frac{1}{R_{g1}} + \frac{1}{R_{g2}} + \cdots + \frac{1}{R_{gn}}} \tag{2}$$

Where WR_{gi} is the weighted rank for each measure, R_{gi} is the group rank for measure i produced by formula (1), and j is the total number of measures being ranked.

2.3.2. *Ranking of perceived effectiveness: farmer mini-surveys*

Ten randomly selected farmers who participated in mini-surveys were also asked to rank the elected list of measures according to their perceived effectiveness, given the conditions on their farms. The questionnaire for farmers followed the structure of the expert workshop and group ranking.

2.3.3. *Modelling effectiveness at farm level*

The FARMSCOPER decision support tool was used to estimate and rank the potential impact of the uptake of the suggested mitigation options, based on data from the field survey conducted by Roberts et al. (2017) on farm structure (area and number of cattle), and data on farm operations and fertilizer/slurry inputs. FARMSCOPER then produces a P transfer reduction coefficient for each of its mitigation options at farm level and uses the produced coefficients to give a ranking of measures from most to least effective. As the FARMSCOPER works at farm level, for the needs of the study, survey field level data were aggregated and expressed at farm level, where needed. A detailed description of the data used for evaluation by FARMSCOPER is provided in Appendix A. For t this study, a rank per farm was assigned to each mitigation option based on its mitigation coefficient; and these ranks were used to produce a group ranking per options using formulas (1) and (2).

2.4. *Interpretation*

To inform discussion on the reasons and motivations behind perceived effectiveness, three experts and three farmers were interviewed individually to provide insights on the outcomes of the rankings.

3. Results

3.1. *P transfer mitigation options*

Based on the P transfer promoting practices identified (Table 1) in the farm surveys and the soil and landscape characteristics of the case-study catchment, 14 phosphorus transfer mitigation measures were selected and are presented in Table 2. Three measures related to poor nutrient distribution, six to connectivity and transport and four to erosion.

After group rankings were produced for the experts, farmers and FARMSCOPER ranking exercises, an integral rank was assigned to each measure. Table 3 presents a comparison of the group rankings resulting from the three ranking exercises.

The measures ranked as 1st by each group and by FARMSCOPER are:

- Experts: Avoid fertilizer application in high risk areas
- Farmers: Reduce effects of poaching around drinking points/gateways
- FARMSCOPER: Loosen compacted soils

The five top-ranked measures were considered here as the most effective by each group. In the results presented in Table 3 experts and farmers seem to agree on the high effectiveness of two measures: 'adopt a nutrient management plan' (2nd & 4th) and 'do not apply fertilizers in high risk areas' (1st & 3rd). Farmers' and FARMSCOPER rankings ap- pear to agree on the high effectiveness of three measures: 'loosening compacted soils' (2nd and 1st), 'consolidating areas around drinking points' (1st and 4th) and 'repositioning gateways away from high risk areas' (5th and 5th). Finally, experts and FARMSCOPER do not appear to concur on any measure in the list. Since there was no consensus among the three groups for any of the measures, those measures that were top-ranked by at least two groups were perceived to be most effective for the river Black catchment and are discussed in more detail.

3.1.1. *Adoption of a nutrient management plan (NMP)*

This measure involves fertilizer application based on results of regular field soil testing, and taking into account soil and management factors including % organic matter, nutrients added by organic fertilizers, soil pH, field P balances and crop requirements. This system has been recognized as an effective P control measure (Coad et al., 2014). Furthermore, Schulte et al. (2010) found the measure to be the most cost effective among a list of options suggested for low intensity grassland systems (35% reduction of total P losses). Cherry et al. (2008) however highlight the low effect of this measure in the short term and Tayyab and McLean (2015) point out that for best results, the measure has to be combined with other strategies in areas with high connectivity and P transfer potential.

Experts ranked this measure as 2nd most effective and farmers as 4th. Further discussion with experts indicated that they perceive this measure as effective in the long-term. In addition, as few farmers currently use this measure, implementation should have a significant effect also on farm gate P balances in the short-term and which should reduce diffuse losses in the longer term.

Farmers ranked the measure among the top most effective (4th). As explained, participants understood the positive effect the method would have on their farm gate balances but, also, recognized the economic benefits that may arise from using NMP.

This measure was ranked only 9th by the FARMSCOPER analysis. A possible explanation is given by Newell Price et al. (2011), who suggest that although the measure would be highly effective on intensive farms, it would have less impact on low intensity grassland systems "as manufactured fertilizer additions are already low/moderate". While there is a perception that only intensive agriculture with high fertilizer inputs and high stocking rates and/or tillage can pose a threat to aquatic systems, recent studies have shown that extensive agriculture can pose a higher risk of nutrient loss in the absence of nutrient management planning (Roberts et al., 2017).

Schulte et al. (2010) suggests that farmers might resist this measure as it would add further restrictions on nutrient use. However, other studies suggest that acceptance of this measure can vary from moderate to high, depending on cost of soil testing and fertilizer prices and availability (Newell Price et al., 2011). Discussion with participating farmers revealed that farmers in general consider the option necessary, not only for its environmental benefits but also for the economies of their farms, however, acceptance depends on availability and accessibility of local advisory services.

3.1.2. *Loosen compacted soils*

The purpose of this measure is to break compacted topsoil layers, and reduce surface run-off (Cuttle et al., 2006; Newell Price et al., 2011). Therefore, this option would be effective in grassland dry-stock systems, where animal trampling is constant and compaction is common (Haygarth et al., 2009).

Table 2
List of mitigation options, description and main P transfer promoting practice they address.

Problem	Method	Description[a]
Poor nutrient distribution	Adopt Nutrient Management Plan (adjusted for High % OM):	Adoption of a recommendation system to plan manufactured fertilizer applications, based on standard soil testing for pH, Index 4 soils and soils with OM > 20%
	Fertilizer band spreading	Apply slurry to land in a series of narrow bands.
	Fertilizer Injection	Deliver slurry to the soil in shallow surface slots
Transport	Loosen compacted soils	Reduce surface runoff by loosening compacted soil layers
	Riparian buffer strips	Establish vegetated grass/woodland buffer strips alongside watercourses
	Hedgerows across slopes	Plant new hedges along slope-lines to break-up the hydrological connectivity of landscape
	Allow drainage system to deteriorate	Cease to maintain existing drainage systems forcing the water to percolate through soil at a slower rate.
	Sediment traps in open drainage ditches	Install artificial farm track sediment traps
	Avoid fertilizer applications in high risk areas	Do not apply manufactured fertilizer to field areas where there are direct flow paths to watercourses.
Erosion	Move drinking toughs and feeders regularly	Feed and drinking troughs for outdoor stock are re-positioned at regular intervals.
	Reduce the effect of poaching around drinking points	Construct water troughs with a solid base using a firm, yet permeable material.
	Reposition gateways away from high risk areas	Move gateways from high-risk to lower-risk areas
	Fence watercourses	Erect fences in grazing fields and on track ways near rivers and streams.
	Bridge watercourses	Construct bridges to allow livestock to cross streams without damaging the banks or defecating in the water.

[a] All description are from Cuttle et al. (2006), Newell Price et al. (2011) and Haygarth et al. (2009).

FARMSCOPER ranks this option as the most effective. Experts on the other hand ranked this as the least effective for the conditions in the case-study catchment (14th) as although results can be significant in the short-term, a systematic use is required for it to be permanently effective (Djodjic et al., 2005). In addition, pathways created by soil compactions may be considered as point sources which do not contribute highly to overall P loss, as the problem is localized to areas of high animal traffic (McDowell and Nash, 2012)

Farmers ranked the measure as 2nd most effective. In further discussions it was clarified that farmers in the case-study catchment were faced with waterlogged fields due to high rainfall and poor soil drainage. Therefore, they judged the option as effective because they perceived the problem as important and its effects easily identified. The measure would also be well accepted by farmers as it was perceived as highly effective, and it does not require expert knowledge nor collective action. Additionally, compacted grassland soils also inhibit nutrient uptake by plants, so the option would have an additional positive affect on grass yields and quality (Newell Price et al., 2011).

Table 3
Group ranking of list of P transfer mitigation option by the three stakeholder groups.

Method	Experts weighted rank		Farmers weighted rank		FARMSCOPER weighted rank	
Adopt nutrient management plan	0.0983	(2)[a]	0.0540	(4)	0.0336	(8)
Band spreading	0.0511	(6)	0.0643	(11)	N/E[b]	
Fertilizer Injection	0.0404	(8)	0.0397	(9)	0.1031	(2)
Loosen compacted soils	0.0329	(14)	0.0887	(2)	0.2886	(1)
Riparian Buffer strips	0.0597	(4)	0.0493	(8)	N/E	
Hedgerows across slopes	0.0351	(11)	0.0403	(12)	0.0385	(7)
Allow drainage system to deteriorate	0.0470	(7)	0.0864	(14)	N/E	(10)
Sediment traps in open drains	0.0586	(5)	0.0469	(6)	N/E	
Avoid fertilizer application in high risk areas	0.1485	(1)	0.0388	(3)	0.0401	(6)
Move drinking toughs regularly	0.0343	(13)	0.0465	(13)	0.1031	(3)
Consolidate area around drinking points	0.0363	(12)	0.0570	(1)	0.0759	(4)
Reposition gateways away from high risk areas	0.0374	(10)	0.0397	(5)	0.0489	(5)
Fence watercourses	0.0718	(3)	0.0512	(7)	0.0283	(9)
Bridge watercourses	0.0376	(9)	0.0332	(10)	N/E	

[a] Integral numeric rank in brackets, top 5 options in each group highlighted.
[b] Measure is not effective.

3.1.3. *Reduce the effects of poaching around drinking points*

This measure consists of constructing solid bases to drinking and feeding points, using permeable materials that would allow for infiltration of nutrients and thus reduce poaching effects.

Farmers ranked this measure as the most effective. Similar to the previous measure, the problem of compaction is visible and consolidation options can be effective without the need for collaboration between farmers. FARMSCOPER also ranked the measure among the top most effective (4th). Newell Price et al. (2011) confirm the effectiveness of the options at farm level. Singh et al. (2008) and von Wachenfelt (2011) also found it to have a high supporting and draining function, while Byrne 2008 found this measure to be effective against run-off and consider the measure a good alternative when less costly options are not possible or popular.

Experts on the other hand ranked the measure among the least effective (12th) as they suggest the problem of poaching is localized and results in little reduction in overall P losses at catchment level. Furthermore poaching was not considered an important issue, given that the percentage of fields with severe poaching in the catchment was relatively low (see Table 1).

In terms of applicability, the method would be applicable to all farms with grazed livestock, but according to Newell Price et al. (2011) adoption by farmers would be moderate. Farmers themselves further explained that although they appreciate the effectiveness, they would consider the options costly in terms of capital costs and labour. However depending on their farm management approach some would strongly consider applying it–subject to access to finances –as apart from the environmental benefits, it would facilitate equipment mobility and would decrease damage in the sward caused by poaching, thus improving grass quality and yields (Singh et al., 2008).

3.1.4. *Reposition gateways*

Similarly to drinking points, concentrations of cattle around gate- ways can lead to increased risk of surface run-off and sediment trans- port that could cause P transfer if gateways are positioned on sloping ground in proximity to a watercourse or drainage network.

The options is suggested by Newell Price et al. (2011) and Cuttle et al. (2006) as relatively effective for all farming systems but especially those in sloping areas and Byrne et al. (2009) include it in their list of suggested measures for P transfer mitigation. Dorioz et al. (2008) consider the measure effective under heavy poaching conditions.

Both the FARMSCOPER and farmers ranked the measure as 5th most effective. Farmers clarified that, similarly to drinking points, although poaching is a localized problem they often observe severe conditions around gateways. Experts on the other hand perceived the option as one of the least effective for the conditions in the Black catchment (10th). Again, this may be related to the low percentage of fields where poaching problems were observed (see Table 1).

In terms of applicability, Newell Price et al. (2011) find that the measure is likely to receive low to moderate acceptance by farmers, depending on grants available for applying it. Furthermore, Byrne et al. (2009), found that the measure was not particularly popular among farmers due to its high cost and lack of practicality, despite its potential environmental benefit.

3.1.5. *Avoid fertilizer applications in high risk areas*

This measure involves avoiding spreading fertilizers at any time to "hydrologically" active areas between fields and watercourses. Where a source of P coincides with a pathway, these areas are known as critical source areas (CSA) (White et al., 2009). Special attention should be paid to these areas as they combine P sources and P transport factors that can severely increase field scale P transfer (Schoumans et al., 2014; Strauss et al., 2007). Avoiding fertilizer applications to these areas can significantly reduce surface run-off. This is particularly effective in high risk fields with open drainage networks or gullies within fields (Taylor and Garnier, 2011).

Heathwaite et al. (2005) indicated that the measure would not have high impact at field/farm level but its effectiveness would depend on the number of farms implementing the measure. This might explain the lower ranking of the measure by FARMSCOPER (6th), while experts ranked it 1st and farmers 3rd most effective. However, Taylor and Garnier (2011) suggest that avoiding application of fertilizer to these areas at field/farm level can significantly reduce surface run-off and this would be particularly effective in high risk fields. Newell Price et al. (2011) found that the measure would make a significant difference in grassland farms where drains and waterlogged areas are common. Cuttle et al. (2006), estimated a potential reduction of up to 15% of total P losses where the measure is appropriate.

Discussion with farmers revealed that acceptance of the measure would be high as it is easy to understand and low cost, however this measure is highly dependent on knowledge transfer.

3.2. *Evaluation of the participatory method*

3.2.1. *Ranking process*

One of the main challenges faced during the study was to ensure that participants and data used in the experiment were representative of the groups intended to be investigated, thus the expert group included targeted representatives from the main research and policy making bodies in Ireland (Teagasc, Department of Agriculture Food and the Marine, and EPA).

For the farmer group, efforts were made to avoid influence of self- selection bias, as certain population cohorts would be more willing to participate than others depending on background, education, age, in- come levels and environmental awareness (Doody et al., 2009; Fung, 2006). Additionally, the process required the establishment of certain levels of trust between researchers and participants as farmers may mistrust the procedure based on previous experiences (Prager and Freese, 2009). Although this was achieved with the help of local ad- visors, a general mistrust of the outcome of the process was implied as most farmers were still convinced that their opinion "will not count" in the decision making process.

As far as the participants' approach is concerned, the workshop was considered the best option for experts as it gave the opportunity for scientists and policy makers to exchange opinions and to provide feedback on the group ranking. On the other hand, mini-surveys with farmers were completed through face-to-face interviews, although this approach limited the number of participants. However this method was preferred because of an expected bias from a group meeting as all opinions may not be equally expressed (Doody et al., 2009). Also, the face-to-face approach ensured adequate time for communicating the process and gaining participants' trust (Abelson et al., 2003).

3.2.2. *Evaluation of model use*

The FARMSCOPER decision support tool was used in this study to model and rank the effectiveness of selected P transfer mitigation options. FARMSCOPER models mitigation options based on coded simulation models (See Appendix A for more details). It does, however, include some deterministic elements such as rainfall bands, soil drainage categories, robust farm types and prior implementation rates based on data from England and Wales. Based on these factors the model is able to calculate P load reduction coefficients before and after measure implementation.

The model was used here under the assumption that Irish landscapes, farm types/catchments system behaviour are similar to those in England and Wales. However, it was expected that potential differences between the river Black catchment and the sample catchments in England and Wales, as well as assumptions made regarding application of the model in the river Black catchment, could generate uncertainties in P load reduction coefficients (Kovacs et al., 2012). However the level of uncertainly is not easy to validate (Strauss et al., 2007). When it comes to P transfer reduction coefficients, model results are sensitive to these uncertainties and accepting them for interpretation in different context that the ones designed for could be misleading. In this study the P transfer reduction coefficients produced by FARMSCOPER are not directly interpreted, instead options are ranked after being compared with each other. It was considered robust to accept the ranking for interpretation as it would explain the relation between options rather than the absolute magnitude of effectiveness. Results however should be used with caution and should be independently checked and vali- dated before informing policy design.

3.2.3. *Evaluation of results*

The process enabled the identification of differences in the way effectiveness is perceived. There was no consensus for any of the options suggested, and farmers' ranking had more in common with the FARMSCCOPER ranking that with experts' rankings. In general, experts perceived measures relating to sediment loss and connectivity to be more effective. Farmers on the other hand, perceived soil compaction and nutrient management as more important, similarly to FARMSCOPER, which ranked measures related to soil compaction higher than other measures.

3.2.3.1. *Differences between experts and farmers*. Experts and farmers agreed on the effectives of two measures. The main reason for differences between experts and farmers lies in the understanding of effectiveness by the two groups; experts had a wider point of view and evaluated effectiveness at catchment scale, while farmers tended to have little or no understanding of their environmental role beyond the boundaries of their farms (Macgregor and Warren, 2006). It was suggested by the participants that farmers often face multiple situations on their farms, and tend to give higher rankings to measures that can provide potential solutions to more than one problem, whereas experts specifically focuses on the P transfer issue in isolation. Another potential reason for the observed discrepancies is the fact that experts tend to evaluate measures based on their expertise, their knowledge of scientific literature and their experimental results, which can sometimes be framed by optimized conditions which may be contrary to actual conditions on the farm (McGonigle et al., 2012). Finally, farmers tend to perceive visible risks as more important, while experts tend to seek long-term solutions to problems that are not necessarily visible (Clark et al., 2016; MacLeod et al., 2010).

3.2.3.2. *Differences between experts and FARMSCOPER*. In this study, experts and FARMSCOPER outputs did not agree on the effectiveness of any of the selected measures. Experts may have evaluated the measures at catchment scale and under optimal experimental conditions while FARMSCOPER on the other hand used "real life" data to simulate actual farm and field conditions. Additionally, experts may think of effectiveness at catchment level, whereas FARMSCOPER evaluated effectiveness at farm scale. The reason for disagreement may also be context-related, as the FARMSCOPER model is used under the assumption that parameters are interpreted for Ireland as for England and Wales and the model is not calibrated for Irish conditions.

3.2.3.3. *Differences between farmers and FARMSCOPER*. Overall, farmers and FARMSCOPER agreed on the most and least effective measures, with disparities appearing only for 4 measures (NMP, fertilizer injection, avoid fertilizer application in high risk areas and moving drinking troughs regularly). As previously discussed, FARMSCOPER did not consider these options as effective as the fertilizers rates were already low, while farmers did not find injection and moving drinking troughs effective probably because of lack of understanding of their P transfer mitigation mechanism (based on our interviews with farmers).

4. Discussion and conclusion

This study set out to compare perceived effectiveness of P loss mitigation options by experts and farmers and modelled effectiveness using decision support tool developed for policy makers and catchment managers. High diversity in the outcomes was recorded, with the stakeholder groups and a decision support tool showing variations in perceived and modelled effectiveness.

Farmers and FARMSCOPER mostly "agreed" that measures relating to erosion were the most effective. The differences between the farmers and FARMSCOPER were measure specific and relate to the under- standing of management practices.

This study showed that stakeholders are diverse, and tend to perceive effectiveness based on group-specific operational and social factors, which are often not of interest to the actors. This is a valuable lesson on the differences of opinions of different stakeholders and provides some explanation behind ineffectiveness of policy implementation at catchment level. Two main policy implications arise from the results of this study.

First, the diversity of perceptions among actors highlights the need for effective dialogue between them in order to recognize differences before measures are imposed. Experts are reluctant to believe that farmers are capable of objectively assessing effectiveness, and research suggests that farmers tend to evaluate measures based on the assumed costs and profits (Beckmann et al., 2009), ease of application and other socio-economic and cultural factors. However, this study shows that farmers may have significant contributions to make to the decision making process, as the similarities of their rankings with FARMSCOPER, revealed that they may be exposed to more knowledge and understanding of P transfer problems, than is currently assumed by experts. Given these findings, the perspectives of farmers (as the implementing group), need to be included in the decision making process.

Farmer participation in measure selection would not only ensure that farmers’ knowledge is incorporated in the decision making but would increase farmers’ trust in government and result in greater agreement to accept policy changes (Prager and Freese, 2009). Doody et al. (2009) reported that agri-environmental policy design is often highly centralized in EU member states and integrating the outcomes of such a procedure is complicated in top-down systems. In Ireland, farmers can participate in water protection policy design though the public consultation tool provided by the EPA. This is an online platform where local authorities and interested organizations can send submissions or comment to help improve the already designed 2018–2021 River Basin Management Plans (www.catchments.ie). However, this is done on a voluntary basis and it assumes prior knowledge of the plan. However, this model may not be achieving substantial farmers participation, firstly because farmers may find engagement difficult or meaningless and secondly because this type of interaction with policy-making does not fit their accustomed social norms (Ó Cinnéide, 2015). For a participatory tool to be effective a more direct approach is needed, that seeks participation in a clear, easy, and socially compatible way.

Using mini-surveys (as presented in this study), where farmers could be approached by the authorities rather than them having to access policy instruments, would allow for individual rankings by members of the public while giving an opportunity to farmers to receive information and provide constructive feedback. If implemented at an early stage in the decision making process, it could prove useful for two-way direct engagement of policy makers and farmers A participatory approach in the early stages of water quality policy design, that includes communication and mediation between farmers and experts is sup- ported by the framework developed by Cash et al. (2003). Furthermore, including co-management structures as recommended by Cash et al. (2006) across scales and levels that include knowledge co-production may provide solutions to problems that continue to persist in water quality policy, for example low adoption of nutrient management plans. Recognising that top-down approaches do not account for local constraints and complexities could be a first step to providing water quality management solutions based on the concept that co-management could be a continuous problem-solving process as developed by Carlsson and Berkes (2005), which could facilitate joint-learning and improved policy making for water quality.

Second, this study highlighted the importance of advisory services for effective policy implementation. Farm advisory services are typically available to all farms for a fee. Making use of advisory services is voluntary, meaning that part of the farming community opts out of the advisory service. These usually consists of clusters of farmers with small, extensive (most likely non-profitable) farms (Micha and Heanue, 2015), who despite their low input systems may be contributing equally to water quality degradation. Hence, there is a need for the design of tools that will facilitate knowledge transfer to these farmers, regardless of their access to farm advisory services. Community knowledge transfer schemes developed in Ireland to raise awareness about water quality are aimed at all members of the community, but farmers’ attendance remains challenging due to social and cultural barriers (O’Flaherty, 2015). Effectively, a voluntary participatory scheme cannot be effective if it is not demanded by farmers. However, farmers who participated in this study explained that, although they do not voluntarily seek to be part of knowledge transfer schemes, they would not reject the opportunity express their opinions if approached. That said, it is recommended that policy makers actively seek farmer participation rather than simply providing the means for voluntary engagement.

Furthermore, advisors often perceive themselves as mediators be- tween experts and farmers with the need to satisfy both sides (Mahon, 2010) and based on the belief that farmers interests are mainly financial, they often prioritize subsidy-related advice over agri-environ- mental obligations (Prager and Thomson, 2014). A suggestion to overcome this would be to enforce the linkages between experts and advisors, to provide them with more powerful tools for knowledge transfer. It is also suggested that direct engagement of researchers in knowledge transfer could be particularly useful (Clark et al., 2016; Toderi et al., 2007). Direct interaction between researchers and farmers could prove additionally beneficial, as research has shown that direct access of farmers to experts’ points of view is highly likely to cause a shift in farmers’ perceptions and increase their acceptance of suggested agri-environmental measures (Madlener and Stagl, 2005). This could be achieved through the use of interactive participatory tools that will increase farmers’ awareness of experts’ views and allow them to com- pare them with their own.

In summary, four main policy recommendations arise from the discussion in this study:

a) design bottom-up participatory tools that accommodate farmers' social and cultural norms;
b) approach farmers to seek their participation in policy design rather than expect them to engage in voluntary schemes;
c) reinforce links between researchers and advisors to provide the latter with more powerful knowledge transfer tools; and
d) enhance the direct interaction between researchers and farmers to achieve two-way exchange of opinions.

For a participatory method to be effective farmers have to be willing to actively work with other stakeholders and to provide useful feed- back. To date, farmers perceive the implementation of the WFD as an administrative, technical barrier that results in even more regulation. If farmers are to effectively participate in designing solutions for water protection problems, they need to understand the importance of water management practices and appreciate their substantial role in maintaining water quality.

Participatory approaches (as used in this study), could provide a good starting point for effective communication between different interested actors and a useful tool for direct engagement between experts and farmers. A long term strategy should be established to provide stakeholders with the skills and knowledge to engage in the decision making process. This method can be time-consuming and requires early involvement so that all participants contribute equally. Also, participants may need training and the building of a level of trust, both of which could slow the process. Nonetheless, if established as a long term approach, this type of interaction between stakeholders could help establish a better "understanding" between various actors.

To conclude, a balance between different actors is critical in water management policy decision making, as this study shows that different actors perceive the problems and the effectiveness of solutions from diverse perspectives. Participation of all interested stakeholders is necessary for the integration of these perceptions, to ensure successful policy design and implementation However, if the results of participatory exercises are to be incorporated in policy design, structural changes are essential, as is the willingness of all acting groups to work together and respect perceptions of and needs of other actors.

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Appendix A

The FARMSCOPER tool is built on a number of existing models for nutrient loss estimation. Specifically for P transfer and P transfer mitigation calculations it uses the Phosphorus and Sediment yields Characterization in Catchments (PHYCHIC (Collins et al., 2007; Davison et al., 2008)). The model has been applied in the UK (England and Wales) to produce 6 primary rain zones and three primary soil types that express the main pathways for P transfer:

- Permeable free draining soils
- Impermeable soils requiring artificial draining for arable
- Impermeable soils requiring artificial draining for grassland

The model incorporates 17 representative farm systems based on crop specific data from the UK Farm Business Survey (FBS), which can be customized for each catchment using actual data. The FARMSCOPER contains a list of 120 pollutant mitigation measures, its impact on the transfer of pollutants and its cost of implementation at farm level (data from the FBS). The tool allows for the evaluation of these mitigation options individually or in selected combinations, at farm level, assuming that no prior use of any options is implemented on the farm, producing a P loss reduction coefficient (individually or combined), and also has the ability to rank the measures according to effectiveness per pollutant.

In this study, data collected from the case study farms were used to simulate the farm systems in the river Black catchment. The data required include:

- Farm type and farming system: based on the main farm systems, such as dairy, livestock, mixed, arable etc.
- Rainfall levels: FARMSCOPER includes a range of annual rainfall levels from < 600 mm to 1500 mm
- Soil type: Soils type is characterised by the draining system (free or artificial) and the % of fields with OM (organic matter) levels >20%
- Land use: Expressed in area of UAA (in ha)
- Percentage of farm area allowing animal access to streams
- Type of borders between fields: Wall, hedge, fence or other
- Number of animals
- Slurry spread (kg/ha); per land use
- Manufactured fertilizer spread (kg/ha): per land use
- Farm dirty water destination

Also, certain operational details are required such as

- number of silage cuts in grassland fields (in any),
- time of calving (for livestock farms) and
- ploughing, tilling and harvesting in arable land,
- manure/slurry imports,

Additionally, FARMSCOPER accounts for prior implementation of the mitigation options under investigation. A number of necessary variable are consequently produce by the model:

- Stocking rate
- Slurry production in farm (kg)

All the above data lead through the PHYCHIC model in the calculation of base line P losses at farm level, which assist in the evaluation of the P transfer reduction each measure could have on farm; based on that, then, measures are ranked according to efficiency.

The data required was provided by the survey conducted by Roberts et al. (2017). All farmers were assumed to be on permeable free draining soils and rainfall levels at each farm were assumed to be the catchment overall rainfall levels. The mitigation options investigated by the tool in this study were the ones presented in Table 2.

The FARMSOPER tool was used in this study under the assumption that soil types in Ireland are similar to the ones in the UK and rainfall levels and content of organic matter have the same effect on P transfer as in the UK. The current study does not use the P reduction coefficient produced by the tool per farm, its discussion are based on the ranking of mitigation options after their evaluation individually and per farm.

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