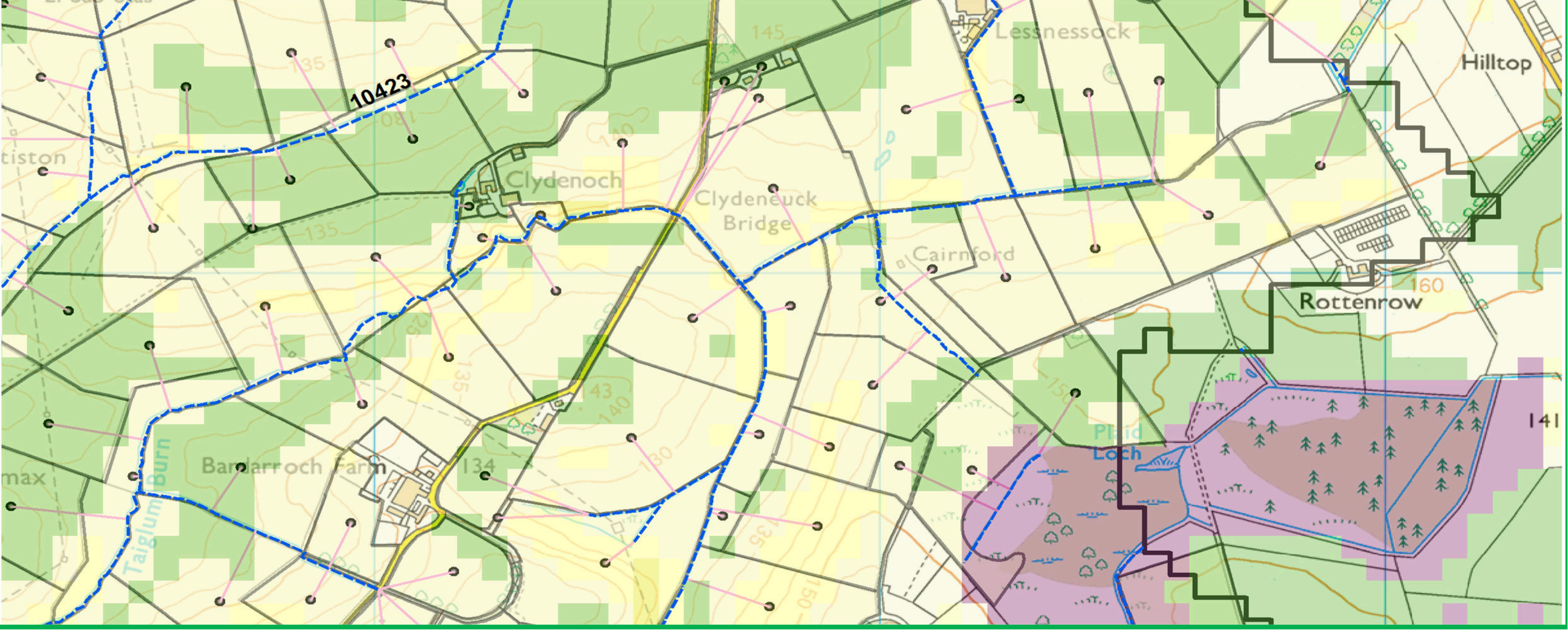

Development of framework for a Red-Amber-Green assessment on phosphorus application to land

Prepared for SEPA

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EXECUTIVE SUMMARY

The purpose of this project was to develop a framework for Red-Amber-Green (RAG) assessments to establish the relative phosphorus (P) pollution risk for watercourses in response to the application of P-rich materials to land. The intention is for SEPA to implement this framework within their Spotfire application to assess the risk to watercourses if further P is applied to fields and to inform decisions where there is the potential for a decrease in water quality.

The development of the RAG P-risk assessments was based on the Source-Pathway-Receptor (SPR) concept. It used a multi-step approach that established meaningful linkages between an array of required datasets (spatial and numerical) using scientifically-robust decision rules to assess a) the risk of a field acting as P source; b) the risks of P being lost from a field and of P transport to the receiving watercourse, and c) the risk of downgrading water quality in the P-receiving watercourse. These P-risks were assessed separately for the two main transport pathways: 1) Surface flow pathway: runoff and soil erosion for assessing particulate P risks; and 2) Subsurface flow pathway: leaching of dissolved P to the artificial drainage system in agricultural soils with imperfect or poor natural drainage.

The effectiveness and performance of the RAG P-risk assessment methodology was evaluated in two test catchments, the Coyle and East Pow, that are representative of Scottish cultivated areas and have contrasting characteristics such as land use, drainage status and soil type composition. A spatial framework was developed that combined the decision rules with the required numerical and spatial datasets to produce new maps that show the individual RAG P-risk assessments for the number of fields present at each catchment.

The results from the trial and test study in the two catchments indicated that the developed RAG P-risk assessment methodology provides sensible and robust assessments for the different stages of the SPR model. Decision rules used were based on clear and scientifically-robust combinations of different datasets and provided P-risk assessments that were consistent with expert knowledge and previous findings in the test catchments. The trial and test study results found that surface runoff and soil erosion posed a greater risk to water quality in the Coyle than leaching to drains, while the opposite was found for the East Pow. Water quality risk assessments in the two catchments were being driven by the different proportions of soils with high binding capacity and of soil erosion risk classes and by the evidence of an eutrophication problem in the respective water bodies.

The assessment of the RAG P-risk methodology showed that more research is necessary to fill the gaps concerning P speciation and mobilization under different soil characteristics (e.g. organic matter content) and different land uses and assess the relative presence of different P forms in soil pore water, surface runoff, sediments and drain waters. In addition, it is necessary to better characterize the general properties of materials spread to land and their environmental behaviour in order to improve the accuracy of the RAG P-risk or other similar environmental risk assessments.

1. INTRODUCTION

1.1. Purpose of the project

The purpose of this project is to develop a framework for Red-Amber-Green (RAG) assessments to establish the relative phosphorus pollution risk for watercourses in response to the application of P-rich materials to land.

Phosphorus (P) is generally regarded as the main driver of eutrophication (nutrient enrichment), with diffuse pollution from both particulate and dissolved nutrients being one of the main reasons for the downgrading of water quality in many Scottish watercourses. Excess P application, poor application methods or soil management can lead to runoff and erosion of P rich materials and a breach of General Binding Rule (GBR) 18. Agricultural good practice expects that soil P is kept at an appropriate level for optimum crop growth. Where the current soil P level is greater, P application, either as mineral fertiliser, waste products or manure, should be reduced, or no P application should occur.

The development of the RAG P-risk assessments is based on the Source-Pathway-Receptor concept and used a multi-step approach that established meaningful linkages between an array of required datasets (spatial and numerical) using scientifically-robust decision rules. These decision rules will be implemented by SEPA within their Spotfire application in order to assess the risk to watercourses if further P is applied to fields and to inform decisions where there is the potential for a decrease in water quality.

1.2. Application of P-rich materials to land

1.2.1. Background

Paragraph 7 Waste Management Licencing (WML) exemptions allow the application of certain wastes to agricultural land[1] if it provides agriculture benefit. For these exemptions, there is a maximum limit to the amount of (nitrogen) N that can be applied (250kg N/ha), but there are no limits prescribed for P. Where the amount of waste applied results in P being in excess of crop requirements, P can accumulate in the soil. Some agricultural land in Scotland has consistently received the same type of organic waste material for many years resulting in elevated soil P levels in those areas. Around 22 million tonnes (wet weight) of materials are spread on land (both cultivated and non-cultivated) in Scotland each year. Almost three quarters of these materials are organic in nature and just over one quarter is non-organic. Almost all (95%) of the organic materials are manures and slurries from agriculture. The remaining 5% is derived from residues from food and drink production, sewage sludge from the water industry and small amounts of organic materials derived from other industrial processes.

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[1] Forms for activities exempt from waste management licencing: https://www.sepa.org.uk/regulations/waste/activities-exempt-from-waste-management-licensing

1.2.2. Benefits from the application of organic materials to land

According to Cundill et al. (2015), applying organic materials to land is a practical example of sustainable management and can be used to reduce the need for inorganic fertilisers, which are either mined from natural resources or manufactured in energy intensive processes. Another possible energy benefit that can result from organic materials use is improved workability of clayey and compacted soils, which can result in lower fuel use in land preparation. Well managed use of materials on land for agricultural benefit or ecological improvement can be the Best Practical Environmental Option (BPEO) in many circumstances. Potential benefits to soil from spreading organic materials to land include soil conditioning, fertilising and liming:

- Soil conditioning: Certain organic materials can act as a soil conditioner by adding useful amounts of organic matter, which can improve soil structure and increase water holding capacity. Such improvements to soil conditions will be maximised where regular and well managed dressings of bulky and highly organic materials are made to a low organic matter soil.
- Fertilising: Some organic materials contain significant quantities of major plant nutrients, particularly N and P, which encourage crop growth and can have long-term benefits for soil fertility as nutrients are mainly present in organic forms which will be slowly released. The rate and timing of application of organic material must be matched to the nutrient requirements of the crop. To be of fertiliser value, at least part of the nutrient content should be available or become available for plant uptake within 3 years. Some organic materials contain other important nutrients (e.g. sulphur and magnesium) or a range of trace elements such as copper and zinc.
- Liming value and pH: Materials such as lime-treated sewage sludge can have a high neutralising value which makes them useful liming material for increasing or maintaining soil pH. Liming acidic agricultural soils can provide multiple benefits, including increasing crop yields and reducing the rate at which some contaminants such as Potentially Toxic Elements (PTE) are leached to watercourses.

1.2.3. Risks to water quality from additional P inputs

Agriculture is the single largest cause of rural diffuse water pollution in Scotland. Application of inorganic fertilisers, slurries and manures to agricultural land in excess of crop requirements is one of the most serious problems affecting the water environment in Scotland with impacts upon: 15% of groundwater; 13% of rivers; 10% of lochs; and 5% of estuaries (Cundill et al., 2015).

Excess nutrients (especially nitrogen and phosphorus) can reach watercourses through surface runoff and erosion and transfer via field drains. In particular, excess P in surface waters can lead to the formation of algal blooms, which in severe cases can be toxic to humans, livestock and fish. In addition, nitrogen can also be lost to the atmosphere. Excessive application of organic materials to land, especially those that contain large quantities of available nutrients (e.g. manures and slurries), wrong timing of application, or unsuitable application techniques can all contribute to the loss of nutrients from soil resulting in water pollution (Cundill et al., 2015). The main consequences of nutrient pollution of the water environment is degraded ecological status, reduced fisheries, damage to the recreation potential of rivers and additional costs for industrial and drinking water treatment.

1.3. Project objectives

The principal objectives of the project are:

- Objective 1: Identify the type of data required for each of the steps of the Source-Pathway-Receptor model using existing datasets and information received with Paragraph 7 WML exemptions.
- Objective 2: Develop a methodological framework that establishes meaningful linkages between datasets required for each of the risk assessments: (i) field acting as a P source, (ii) potential P being lost from a field, (iii) P being transported into a watercourse, and (iv) the impact of additional P entry on the water quality.
- Objective 3: Trial and test the approach developed for the risk assessments to ensure the consequences of the proposed combinations are meaningful and fit for purpose and explain the implications for the outcomes of the risk assessments. The risk assessment approach will be tested in two contrasting catchments in Scotland, in terms of their soil and land-use composition.

1.4. Report outline

This report is organised in the following sections:

- Section 2 provides the description of the datasets required to conduct the RAG P-risk assessments.
- Section 3 presents the methodology used to develop the decision rules that are required to assess the individual P-risks based on the components of the SPR model.
- Section 4 presents the spatial framework developed for the trial and test study and provides the results of the RAG P-risk assessments in the two test catchments. It also gives an overall assessment of the developed RAG P-risk assessment framework with regards to its effectiveness for identifying risks related to the application of P-rich materials to land.
- Section 5 provides a discussion of identified knowledge gaps and gives recommendations for future improvements to the RAG P-risk methodology.

2. REQUIRED DATASETS

2.1. Selection criteria

The datasets required for conducting the RAG P-risk assessments need to provide the necessary linkages with the different components of the Source-Pathway-Receptor (SPR) model:

A. Risk assessments of a field/group of fields being a source of P (Source).
B. Risk assessments of a P loss from a field/group of fields (Pathway).
C. Risk assessments of P reaching a watercourse (Pathway).
D. Risk assessments of P impacting the receiving watercourse (Receptor).

In addition, the selection of the required datasets for the development of the RAG P risk assessments should consider the following criteria:

- Datasets that provide readily-available information.
- Datasets that are straightforward to implement.
- Datasets that are scientifically-robust (no double-counting).

Based on the above requirements, we selected the following types of datasets:

a) Information included in the Paragraph 7 WML forms to register or renew an exemption submitted to SEPA by applicants of waste application for each field or group of fields.
b) Information extracted from a set of soil mapping products that are freely-available from Scotland's Soils website[2].
c) Information on water quality classifications for the Water Framework Directive (WFD) water bodies produced by SEPA.

Table 2-1 shows the main datasets required to conduct the different stages of the RAG P-risk assessments. A detailed description of the decision rules used to combine these datasets to produce the individual P-risk assessments is given in Section 3.

Table 2-1. List of key datasets required for conducting the P-risk assessments.

a/a	Data sets	Risk assessments			
		A	B	C	D
1	Field geographical location				
2	Soil P status				
3	Soil map of Scotland (partial cover)				
4	Soil Phosphorus Sorption Capacity Index Map				
5	Crop information and crop risk class				
6	Soil erosion risk map				
7	Run-off risk map				
8	Distance to nearest watercourse/ Connectivity				
9	SEPA water body classification for rivers				
10	SEPA Eutrophication Risk spreadsheet for rivers				

[2] https://soils.environment.gov.scot

2.2. Description of required datasets

2.2.1. Information from the Paragraph 7 WML exemptions

The form to register or renew a Paragraph 7 WML exemption includes a variety of information that are essential for developing the methodology for the RAG P-risk assessments. This includes the following:

- Geographical location (grid reference) of the treatment area within each field. The geographical location is used to extract the relevant values from the soil series, soil erosion risk and runoff risk maps (see sections 2.2.2-2.2.5) for each field and also for assessing a field's distance to the nearest watercourse (connectivity).
- Crop type information in descriptive form or as an IACS code. Crop type and land use is used to assess the risk of soil erosion occurring within a field as result of land management and cultivation practices.
- Soil P status, which is a measure of the amount of P present in soil in a form that plants can use. Soil P status is determined using the results of the soil sample analysis that is required during the waste exemption application process. Based on the application guidelines, the soil sample is analysed for extractable P (in mg/L) using either the SAC (Modified Morgan's extraction) or DEFRA's/RB209 (Olsen extraction) analytical methods and the results are used to assess a field's soil P status according to Figure 2-1 (SRUC, 2013).

SAC Status	P	
	SAC	RB209
VL	0-1.7	0-9
L	1.8-4.4	10-15
M-	4.5-9.4	16-20
M+	9.5-13.4	21-25
H	13.5-30.0	26-45
VH	>30.0	>45

Figure 2-1. Classification of soil P test results (values in mg/l) into status for P based on the SAC and DEFRA (RB209) analytical methods (Technical Note TN633).

2.2.2. Soil Map of Scotland (partial cover)

The map gives the distribution of Scottish soils at a 1:25,000 scale and covers the cultivated land in Scotland. This digital dataset was created by digitising the Soils of Scotland 1:25,000 Soil maps and the Soils of Scotland 1:25,000 Dyeline Masters, and where no 1:25,000 published maps exist then Soils of Scotland 1:63,360 maps have been digitised instead. The majority of the Soil Map polygons contain single soil series. Information included in the Soil Map that is most relevant to this project is soil type (Major Soil Subgroups) and the soil's natural drainage class.

2.2.3. Map of soil Phosphorus Sorption Capacity (PSC)

The map shows the inherent ability of soil to retain P and depends on soil chemistry, texture, pH and organic matter content (SRUC, 2015). The soil properties pH, organic carbon content, clay content and oxalate extractable iron and aluminium concentrations were determined from a dataset of 399 soils samples from 38 different soil associations. This dataset included topsoil samples from the National Soil Inventory of Scotland (2007-9), various topsoil samples taken for other research projects and samples from the National Soils Archive and was used to estimate the P sorption capacity of each soil association using a model. These values were grouped into 3 categories of P sorption capacity index from 1 (Low) to 3 (High). Where no data were available, the areas are mapped as "not determined". The soil PSC map is based on the map units of the National Soil Map of Scotland at 1: 250,000 scale.

2.2.4. Map of Runoff Risk

The map gives information on the likelihood of a potential pollutant applied to the soil surface running off the land to a watercourse in 3 classes: High, Moderate or Low (Lilly and Baggaley, 2014). The risk of runoff depends on how easily water can drain away from the soil surface. It also depends on how much water the soil can store. These in turn depend on fundamental soil characteristics such as soil porosity and flow pathways through the soil. The runoff risk map was developed by allocating one of the 29 Hydrology of Soil Type (HOST) classes to each of the soils in the Soil Map of Scotland (partial cover) dataset and then the Standard Percentage Runoff for these classes was determined from Boorman et al. (1995). These runoff values were then allocated to one of 3 classes that reflected the likelihood of a soil becoming saturated leading to water flowing over the land. The three classes, High, Moderate or Low, equate to more than 40, 20 to 40 and less than 20 percent runoff. Where the soil map units were described as complexes (that is, more than one soil type if found in a soil map unit), the precautionary principle was applied and the soil at most risk of generating runoff was used to describe the whole map unit. The runoff risk map is based on the map units of the National Soil Map of Scotland (partial cover) at 1: 25,000 scale.

2.2.5. Map of Soil Erosion Risk

The map shows the risk of a bare soil being eroded by water under intense or prolonged rainfall and primarily covers the cultivated land in Scotland (Lilly and Baggaley, 2014). The susceptibility to erosion based on soil texture and capacity to absorb rainfall was combined with the slope to determine how erosive the overland flow could be with steeper slopes leading to faster runoff. Soils with mineral topsoils have been classified separately from those with organic (peaty) surface layers. For mineral soils, the risk of soil erosion is shown in three (3) main classes for soils with mineral topsoils: High (H), Moderate (M) or Low (L), which are further subdivided in 3 sub-classes (H1/H2/H3; M1/M2/M3; L1/L2/L3). Organic soils (peats) are considered to be highly erodible so are always considered to be at a high risk of erosion. Organo-mineral soils are less likely to erode and have four (4) sub-classes for moderate erosion risk (Mi/Mii/Miii/Miv) and three (3) for low erosion risk (Li/Lii/Liii). The soil erosion risk map is available at 50m grid resolution for the area covered by cultivated land in Scotland.

2.2.6. Water Quality information

P is regarded as the primary driver of eutrophication in Scotland. Therefore, the reliability of the water quality risk assessment from P inputs greatly depends on the selection of an appropriate water quality risk index that provides effective linkages between P inputs and the likelihood of downgrading water quality due to eutrophication in the receiving watercourses.

In this context, after consultation with SEPA, we selected the Weight of Evidence (WoE) eutrophication problem assessment as the water quality risk index to be used within the RAG P-risk assessments. WoE eutrophication problem is assessed for all water bodies in Scotland monitored under the WFD guidelines using information of wider evidence about a) water reactive P concentrations; b) macrophytes and c) phytobenthos (diatoms). The assessment is done using the SEPA Eutrophication risk spreadsheet and results in the following classes: a) certain no eutrophication problem; b) uncertain eutrophication problem; c) quite certain eutrophication problem and d) very certain eutrophication problem (Figure 2-2). If information is missing for a water body, then the WoE eutrophication problem is "not assessed".

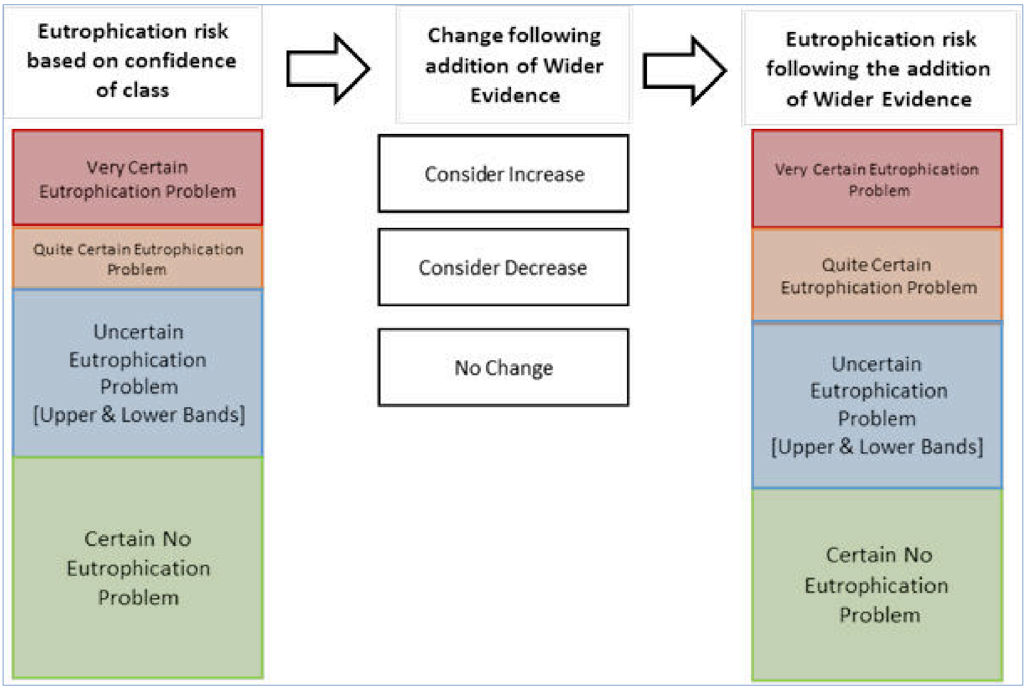

Figure 2-2. Classification system of eutrophication risk problem (Weight of Evidence/WoE) using information of wider evidence. Image provided by SEPA.

3. DEVELOPMENT OF DECISION RULES

3.1. Overview of methodological approach

The RAG P-risk assessments for each component of the Source-Pathway-Receptor (SPR) model are developed using decision rules that provide scientifically-robust linkages between the required datasets based on relevant research findings and expert opinion. The individual steps of the RAG P-risk assessment are combined to produce a water quality risk that can be used by SEPA during the WML exemption regulatory process to help determine if adding P-rich material to land is acceptable or not based on the potential of P adversely impacting the quality of the receiving watercourses.

Sediment-bound (particulate) P eroding from arable fields is a principal contributor to ecological downgrading of water quality of lakes, and, more indirectly, of rivers in Scotland (Stutter et al., 2009). Particulate P is expected to be the primary P loss from agricultural fields due to runoff and soil erosion, but recent research findings (Stutter and Richards, 2018) identified that dissolved P loss pathways are often overlooked relative to soil erosion P losses and showed that dissolved reactive P was prevalent in drains in arable soils with low organic matter. In addition, Lumsdon et al. (2016) have found that for a given soil P status (defined using the modified Morgan's method), the soils of high P sorption capacity (PSC) pose the greatest risk to water bodies if particles from these soil types are transported into water bodies, but pose the least risk of leaching and will maintain the lowest P concentrations in soil porewater. Therefore, in relation to soil properties, the risks of P loss posed by runoff and erosion and that by leaching are diametrically opposed.

In order to be consistent with the above research findings, we developed the RAG P-risk assessments separately for the two main transport pathways:

1) Surface flow pathway: runoff and soil erosion for assessing particulate P risks.
2) Subsurface flow pathway: leaching of dissolved P to the artificial drainage system in agricultural soils with imperfect or poor natural drainage.

A detailed description of the decision rules for assessing the individual P risks for the two main transport pathways is given in Section 3.2.

3.2. Decision rules: Surface flow pathway

The decision rules for conducting the RAG P-risk assessment for the surface flow pathway were developed based on SPR model approach and assessed the following risks:

a) Source: risk of a field acting as P source;
b) Pathway: risk of P being lost from a field and risk of P transport to the receiving watercourse, and
c) Receptor: risk of downgrading water quality in the P-receiving watercourse.

3.2.1. Source

The risk of a field acting as a particulate P source (P-source risk) is assessed by combining the soil P sorption capacity (PSC) map and a field's P status. The rationale for this assessment is that research using soil samples from Scottish agricultural catchments has shown that for a given soil P status, the soils with high P binding capacity pose the greatest risk to water due to runoff and soil erosion (Lumsdon et al., 2016). This may be seen as high P sorption soils accumulating large amounts of P that then contributes a major load if soil erosion occurs. Additionally, high P sorption indicates a disproportionate release to water if the eroded soils enter the watercourse. We developed an appropriate set of decision rules for assessing the particulate P-source risk by exploring the possible scientific linkages between soil P status and soil PSC based on relevant research findings and expert opinion.

Soil P status is a measure of the amount of P present in soil in a form that plants can use and is assessed by the analysis of soil samples for soil extractable P. The approach used currently for the management of soil P in intensive modern agriculture is to build-up and maintain a reserve over time in the soil, such that plant-available forms are present on an annual basis in adequate amounts to meet crop requirements (SAC Consulting, 2018, unpublished). This approach to P management has been adopted because P present in soil is primarily in a form that is unavailable for plant uptake and works, even in soils with a large potential capacity for binding P, because the reserves held are dynamic and a small proportion of bound P will be released in a plant-available form in the year of production. The recommendation for most cropping systems in Scotland is to maintain soil at a moderate P status. According to Technical Note TN 633 (SRUC, 2013), the current target soil P for cereal-based arable rotations status is Moderate (M), target soil P status would be in the upper half of Moderate (M+) for rotations with potatoes and moderate for grass. According to Technical Note TN668 (SRUC, 2015), soils with a higher PSC (PSC 3) that are maintained on target for soil P status (i.e. moderate) represent the greatest risk to water quality as they will contain a higher level of adsorbed P from fertiliser application. At the same time, while soil P status has been found to correlate well with soluble P in soil, the relationship is not direct between soil P status and soil total P (dissolved and particulate) and contrasting soils will have required differing historical application of P to achieve the same target P status (SAC Consulting, 2018, unpublished).

Based on above, we combined soil P status with PSC to assess particulate P-source risk when P status is moderate and higher. In this context, P-source risk becomes high for moderate P status when PSC is moderate or high and becomes high when P status is also high, regardless of soil PSC class (Table 3-1). When soil P status is low (i.e. P is not or less available to plants), we decided to assess particulate P-source solely based on soil PSC because this gives as a direct estimate of how much P is potentially bound to the soil due to historical application of P.

Table 3-1. Decision rules for the assessment of a field being a source of particulate P (P-source).

Soil PSC	Soil P status		
	Low	**Moderate**	**High**
Low	Low	Moderate	High
Moderate	Moderate	High	High
High	High	High	High

3.2.2. Pathway

A. <u>Risk of P lost from a single field</u>:

The risk of particulate P being lost by a field is assessed by combining the P-source risk with the inherent soil erosion risk that is prior adjusted by the crop type or land use in each field. The rationale for this assessment is that P in particulate form has a greater likelihood of being lost from fields with soils at target P status and with the ability to bind P and with high inherent soil erosion risk. At the same time, using crop type information to modify the inherent soil risk of a field reflects the effect of different cultivation methods and crop characteristics on the susceptibility to soil erosion.

Rural diffuse pollution in Scotland can be exacerbated through a wide variety of poor land management practices, including inappropriate livestock grazing and cultivation practices, that can lead to soil issues such as soil capping, compaction, presence of anaerobic layers, poor drainage and erosion. These soil management issues depend on cropping systems and directly affect the ability of soils to infiltrate surface flow, with greater runoff leading to soil erosion and loss of sediment-bound P from fields.

In this context, we assigned crop risk classes to all crop types and land uses present in Scotland based on the list of Integrated Administration and Control System (IACS) codes to reflect the effect of different cultivation methods and crop characteristics on the susceptibility to soil erosion (Table 7-1, Appendix). A simplified and generic version of this list is given in Table 3-2. Similar crop risk classification schemes have been proposed and used successfully in other P-modelling and P-risk assessment applications (Balana et al., 2012). The proposed classification system assigns a crop risk class to each field using the information on main crop type for each field, as stated in the WML exemption forms.

Table 3-2. Classification of main crops and land uses into risk classes for adjusting soil erosion risk. A detailed list of crop risk classes based on IACS codes is given in the Appendix.

Risk class	Crops types/ land uses
Low	Rough grazing, grassland, set aside
Moderate	Barley, oats, wheat, fodder grass, grass for mowing, fallow
High	Turnips/swedes, bulbs/flowers, fodder roots, ware potatoes, seed potatoes, other vegetables, fruits

Crop risk classes were then used to modify the nine (9) classes of inherent soil erosion risk for mineral topsoils[3] according to the following approach:

- Grasslands provide a complete and continuous cover of soil by vegetation that provides a sufficient protection against soil erosion due to the stabilizing capacity of the grass's rooting system. Therefore, it is assumed that there is less risk of soil erosion in grassland fields and thus the soil erosion risk class was lowered by one class.

[3] The same approach should be used for the moderate and low erosion risk classes for organo-mineral topsoils (Mi/Mii/Miii/Miv and Li/Lii/Liii).

- Soil erosion risk is assumed to be greater in land used for root vegetables and potatoes because this land is often left bare during the vulnerable autumn-winter periods and also due to the greater risk of soil compaction and soil aggregate instability caused by the use of heavy machinery and seed-bed preparation. Therefore, for these crop types the soil erosion risk class was increased by one class.
- For cereals, it is assumed that a field's erosion risk class remains the same because these crop types represent an intermediate situation whereby there is adequate annual plant coverage and thus soil protection, but cultivation practices may cause some degree of soil compaction. Although winter cereals are assumed to be more susceptible to soil erosion than spring cereals, we assigned the same crop risk class to both because this was more appropriate in the context of a three class (RAG) risk assessment.

The decision rules for the assessment of crop-adjusted soil erosion risk classes are given in Table 3-3.

Table 3-3. Decision rules for the adjustment of soil erosion risk using crop risk classes (Crop-adjusted Soil Erosion Risk).

Soil Erosion Risk	Crop Risk		
	Low	**Moderate**	**High**
L1	L1 (Low)	L1 (Low)	L2 (Low)
L2	L1 (Low)	L2 (Low)	L3 (Low)
L3	L2 (Low)	L3 (Low)	M1 (Moderate)
M1	L3 (Low)	M1 (Moderate)	M2 (Moderate)
M2	M1 (Moderate)	M2 (Moderate)	M3 (Moderate)
M3	M2 (Moderate)	M3 (Moderate)	H1 (High)
H1	M3 (Moderate)	H1 (High)	H2 (High)
H2	H1 (High)	H2 (High)	H3 (High)
H3	H2 (High)	H3 (High)	H3 (High)

The risk of particulate P being lost from a field (P-loss) by runoff and soil erosion that involves the detachment of soil particles is then assessed based on the rules given in Table 3-4 that combine the crop-adjusted soil erosion risk (Table 3-3) with the risk of a field acting as a P-source (Table 3-1).

Table 3-4. Decision rules for the assessment of P being lost from a field (P-loss) due to surface runoff and soil erosion.

P-source risk	Crop-adjusted Soil erosion risk		
	Low	**Moderate**	**High**
Low	Low	Moderate	Moderate
Moderate	Low	Moderate	High
High	Moderate	High	High

B. Risk of P reaching a watercourse:

The risk of particulate P being lost from a field reaching a watercourse depends on the field's level of connectivity to the nearest surface water feature. Connectivity has been previously assessed in similar applications (Andersen and Kronvang, 2006) using the contributing distance to the nearest watercourse. In this context, we assessed connectivity levels according to Table 3-5, where contributing distance is measured as the straight line from the geographical location of the treatment area in each field (as given in WML exemption form) to the nearest river, stream or ditch.

Table 3-5. Classification of field connectivity using the contributing distance to the nearest watercourse.

Contributing distance	Connectivity
<50m	High
50-150m	Moderate
>150m	Low

Then, the risk of P reaching the receiving watercourse (P-transport) was assessed by combining the P-loss risk with the level of connectivity to the nearest watercourse using the rules given in Table 3-6.

Table 3-6. Decision rules for the assessment of P lost from a field reaching the nearest watercourse (P-transport) due to surface runoff and soil erosion.

P-loss risk	Connectivity		
	Low	**Moderate**	**High**
Low	Low	Low	Moderate
Moderate	Low	Moderate	High
High	Moderate	High	High

Based on this approach, riparian fields (within 50m from a watercourse) are always considered to have a moderate or high risk of P-transport to the respective stream or ditch, whereas fields with low connectivity to watercourses (>150m distance) are assumed to have a low P-transport risk, unless there is a high risk of P being lost from the field from soil erosion and P mobilization risk; in this case we adopted a precautionary approach and raised P-transport risk from low to moderate. The decision rules assume that there will always be some degree of connectivity of a field to a surface water body; this should be valid for almost all cases. However, we were unable in the context of the RAG P-risk assessment to account for cases where man-made features impede or increase a field's connectivity to the watercourse, respective examples being the presence of walls or roads, or assess the effect that vegetated riparian buffer strips and other in-field mitigation can have on the transport of particulate P-transport.

3.2.3. Receptor

The risk of water quality in the receiving watercourse being downgraded by transport of additional P (Water Quality Risk) is assessed by combining the P-transport risk (Table 3-6) with the assessments for the WoE eutrophication problem for the nearest watercourse as shown in Table 3-7. For the purpose of the RAG P-risk assessments, the "Quite Certain" and "Very Certain" assessments of eutrophication problem (Figure 2-2) were aggregated to one “Certain Yes” assessment.

The rationale behind the development of the decision rules for the water quality assessments was that the application of P-containing material to land that has a moderate to high likelihood of reaching a watercourse can potentially impact the quality of only those watercourses that show some evidence (chemical and/or biological) of eutrophication (expressed as uncertain or certain/ quite certain eutrophication problem assessment).

Table 3-7. Decision rules for the assessment of P impacting the water quality of the receiving watercourse (Water Quality Risk).

P-transport risk	WoE Eutrophication problem			
	Certain No	**Uncertain**	**Certain Yes**	**Not assessed**
Low	Low	Low	Moderate	NA
Moderate	Low	Moderate	High	NA
High	Low	Moderate	High	NA

It needs to be noted that the assessment of the eutrophication problem is available only for the main WFD water bodies in Scotland. This means that most streams and ditches used to assess levels of connectivity with fields and the risk of P-transport do not have a eutrophication problem assessment assigned to them. Connecting fields directly to the main water body yields unrealistic assessments of the P-transport risk because this greatly underestimates the risk of P reaching a watercourse since it ignores the true hydrologic connectivity of smaller watercourses with the fields. Therefore, it is recommended that where WFD water eutrophication risk is not calculated for headwater parts or tributaries of rivers then these should consider the same eutrophication risk class as the classified reaches that they deliver to downstream. The eutrophication risk of these downstream water bodies is then linked to the risks in the field using the connectivity distances of the field to the headwaters of these waterbodies.

3.3. Decision rules: Subsurface flow pathway

3.3.1. Identify fields with drains installed

In order to develop the RAG P-risk assessment for drainflow, it was necessary to determine in which fields drains have been installed in the past because this information is generally lacking. WML exemptions state whether field drains were installed within the last year before the application but are not required to provide any information on past field drainage.

In order to overcome this problem, we made the assumption that drains are expected to be present in all cultivated land in Scotland on poorly or imperfectly-drained soils; this approach is well-supported by previous research findings (Lilly et al., 2012). For the purpose of the RAG P-risk assessments, cultivated land is defined by crop type or land use and generally includes improved grasslands and all types of arable land. Alternatively, cultivated land can also be defined as land belonging to classes 1, 2, 3 and 4 of the Land Capability for Agriculture (LCA) map (available from

Scotland's Soils website[4]). The status of a field's natural soil drainage is derived from the Soil Map of Scotland (partial cover) at 1:25, 000 scale, and fields are selected for the P-risk assessments for all soils with imperfect and/or poor drainage, excluding fields with free-draining soils or with undifferentiated soil drainage.

P-risk assessments for subsurface flow did not include soluble P leaching to groundwater via infiltration from fields with free-draining soils; infiltration of dissolved P in soil water is a much slower process than leaching to drains due to the greater soil hydraulic conductivity of drained soils and therefore it is expected that soils have greater capacity to buffer incoming P via the soil infiltration pathway, for example, see O' Dochartaigh et al. (2005).

3.3.2. Source

As in the case of the surface flow pathway, the risk of a field acting as a source of dissolved P (P-source risk) is assessed by combining a field's soil PSC with soil P status. This approach is based on recent research findings in agricultural soils in Scotland (Lumsdon et al., 2016; Stutter and Richards, 2018) that found that a) soil P status correlates well with soluble P; b) soils with high binding capacity pose the least risk of leaching and will maintain the lowest P concentrations in soil porewater and c) there is a strong and linear relationship between soil P status and total dissolved P in drainwater.

Table 3-8 gives the rules for assessing the risk of dissolved P being lost from a field (P-loss). Based on this approach, when soil P status is high then the dissolved P-source risk is high, with the exception of soils with high binding capacity (PSC3) where P-source risk is assessed as moderate. Instead of assessing dissolved P-source as always low when soil P status is low (i.e. regardless of soil PSC), we decided to assess P-source as moderate when PSC is low; this precautionary approach was taken to account for additional contributions of P in particulate form that have been found to be present in drainwater (Stutter and Richards, 2018) but cannot be directly assessed by the proposed P-risk methodology for the subsurface flow pathway.

Table 3-8. Decision rules for the assessment of a field being a source of dissolved P (P-source).

Soil PSC	**Soil P status**		
	Low	**Moderate**	**High**
Low	Moderate	High	High
Moderate	Low	Moderate	High
High	Low	Low	Moderate

3.3.3. Pathway

Leaching of dissolved P to drains is assessed by combining the P-source risk with a field's soil infiltration capacity (IC), the latter taken as the inverse of a soil's runoff risk class (Table 3-9). The rationale for this approach is that soils with high P-source and high IC will have a high P-leaching risk as soluble P will have the capacity to quickly infiltrate the soil and reach the drainage system.

[4] https://soils.environment.gov.scot

Table 3-9. Rules for converting surface runoff to infiltration capacity.

Runoff Risk	Infiltration Capacity
Low	High
Moderate	Moderate
High	Low

Table 3-10 gives the decision-rules applied for assessing P-leaching to drains. Because the location of the artificial drainage network is unknown, it is not possible to directly assess the connectivity level of a field to a particular watercourse as in the approach used to calculate P-transport risk for runoff and soil erosion (Table 3-6). However, we adopted the simplistic but realistic approach where all P leaching to drains from a field is assumed to reach the nearest watercourse, which is identified during the P-transport assessment for runoff and soil erosion (Section 3.2.2).

Table 3-10. Decision rules for the assessment of P leaching from a field to artificial drains (P-leaching).

P-source risk	Infiltration Capacity		
	Low	**Moderate**	**High**
Low	Low	Low	Moderate
Moderate	Moderate	Moderate	High
High	Moderate	High	High

3.3.4. Receptor

The risk of water quality in the receiving watercourse being downgraded by leaching of dissolved P to drainflow (Water Quality Risk) is assessed by combining the P-leaching risk (Table 3-10) with the assessments for the WoE eutrophication problem for the nearest watercourse as shown in Table 3-11. The decision rules are the same with the ones used to assess Water Quality risk for the surface flow pathway (Table 3-7).

Table 3-11. Decision rules for the assessment of P impacting the water quality of the receiving watercourse (Water Quality Risk).

P-leaching risk	WoE Eutrophication problem			
	Certain No	**Uncertain**	**Certain Yes**	**Not assessed**
Low	Low	Low	Moderate	NA
Moderate	Low	Moderate	High	NA
High	Low	Moderate	High	NA

3.4. Summary of decision rules

Tables 3-12 and 3-13 give a step-by-step short description of the RAG P-risk assessment for the surface (runoff and soil erosion) and subsurface (leaching to drains) flow pathways, respectively. A summary of the P-risk assessments steps is also given in the flowcharts shown in Figure 3-1.

Table 3-12. List of actions and required information for conducting the RAG P-risk assessment for the surface flow pathway (runoff and soil erosion).

a/a	Action	Parameter	Source-Dataset	Decision Rules
1	Identify the geographical location of the treatment area in each field	Grid reference coordinates	Section 3(ii) Paragraph 7 WML exemption form	-
2	Assess a field's soil P status	Soil extractable P values in mg/L	Soil analysis results/Paragraph 7 WML exemption Technical Guidance Note Annex 3/Table 1	Figure 2-1
3	Assess a field's soil PSC	Soil PSC index value	• Geographical location • Map of soil PSC	-
4	Assess the risk of a field acting as a source of particulate P (P-source)	Soil P status and soil PSC index values	See actions 2 and 3	Table 3-1
5	Assess a field's crop risk class	Crop information & IACS code	Section 2(i) Paragraph 7 WML exemption form	Table 3-2, Table 7-1
6	Assess a field's soil erosion risk class	Soil erosion risk class value	• Geographical location • Map of soil erosion risk	-
7	Adjust a field's soil erosion risk by using crop risk	Crop risk and soil erosion risk class values	See actions 5 and 6	Table 3-3
8	Assess the risk of particulate P being lost by a field (P-loss)	P-source risk and crop-adjusted soil erosion risk class values	See actions 4 and 7	Table 3-4
9	Identify the nearest watercourse to a field and relevant WFD body	Geographical location of treatment area	• Available river feature information (map layers)	-
10	Assess a field's connectivity to the nearest watercourse	Geographical location of treatment area	Available watercourse features	Table 3-5
11	Assess the risk of particulate P reaching the nearest watercourse (P-transport)	P-loss risk and connectivity class values	See actions 8 and 10	Table 3-6
12	Assess the WoE eutrophication problem for the P-receiving watercourse	WoE eutrophication problem class for nearest WFD water body	SEPA WFD database and Eutrophication excel spreadsheet	-
13	Assess the risk of P impacting the water quality of the receiving watercourse	P-transport risk and WoE eutrophication problem class values	See actions 11 and 12	Table 3-7

Table 3-13. List of actions and required information for conducting the RAG P-risk assessment for the subsurface flow pathway (leaching to drains).

a/a	Action	Parameter	Source-Dataset	Decision Rules
1	Identify the geographical location of the treatment area in each field	Grid reference coordinates	Section 3(ii) Paragraph 7 WML exemption form	-
2	Assess whether the land has been artificially-drained in the past	• Land is used for agriculture AND • Soil drainage is imperfect of poor	• Crop type information or/and Land Capability for Agriculture • Soil Map Partial cover 1: 25,000	-
3	➢ If field assessed as not having been artificially-drained → P-risk assessment is not necessary ➢ If field assessed as artificially-drained → continue to Action 4			
4	Assess a field's soil P status	Soil extractable P values in mg/L	Soil analysis results/ Paragraph 7 WML exemption Technical Guidance Note Annex 3/Table 1	Figure 2-1
5	Assess a field's soil PSC	Soil PSC index value	• Geographical location • Map of soil PSC	
6	Assess the risk of a field acting as a source of dissolved P (P-source)	Soil P status and soil PSC index values	See actions 4 and 5	Table 3-8
7	Assess a field's infiltration capacity	Runoff risk class values	Runoff risk map	Table 3-9
8	Assess the risk of dissolved P leaching to drains (P-leaching)	• Infiltration capacity • P-source risk	See actions 6 and 7	Table 3-10
9	Identify the nearest watercourse and WFD water body and assess the WoE eutrophication problem for the P-receiving watercourse	Geographical location of treatment area and WoE eutrophication problem class for nearest WFD water body	• Available river feature information (map layers) • SEPA WFD database and Eutrophication excel spreadsheet	-
10	Assess the risk of P impacting the water quality of the receiving watercourse	P-leaching risk and WoE eutrophication problem class values	See actions 8 and 9	Table 3-11

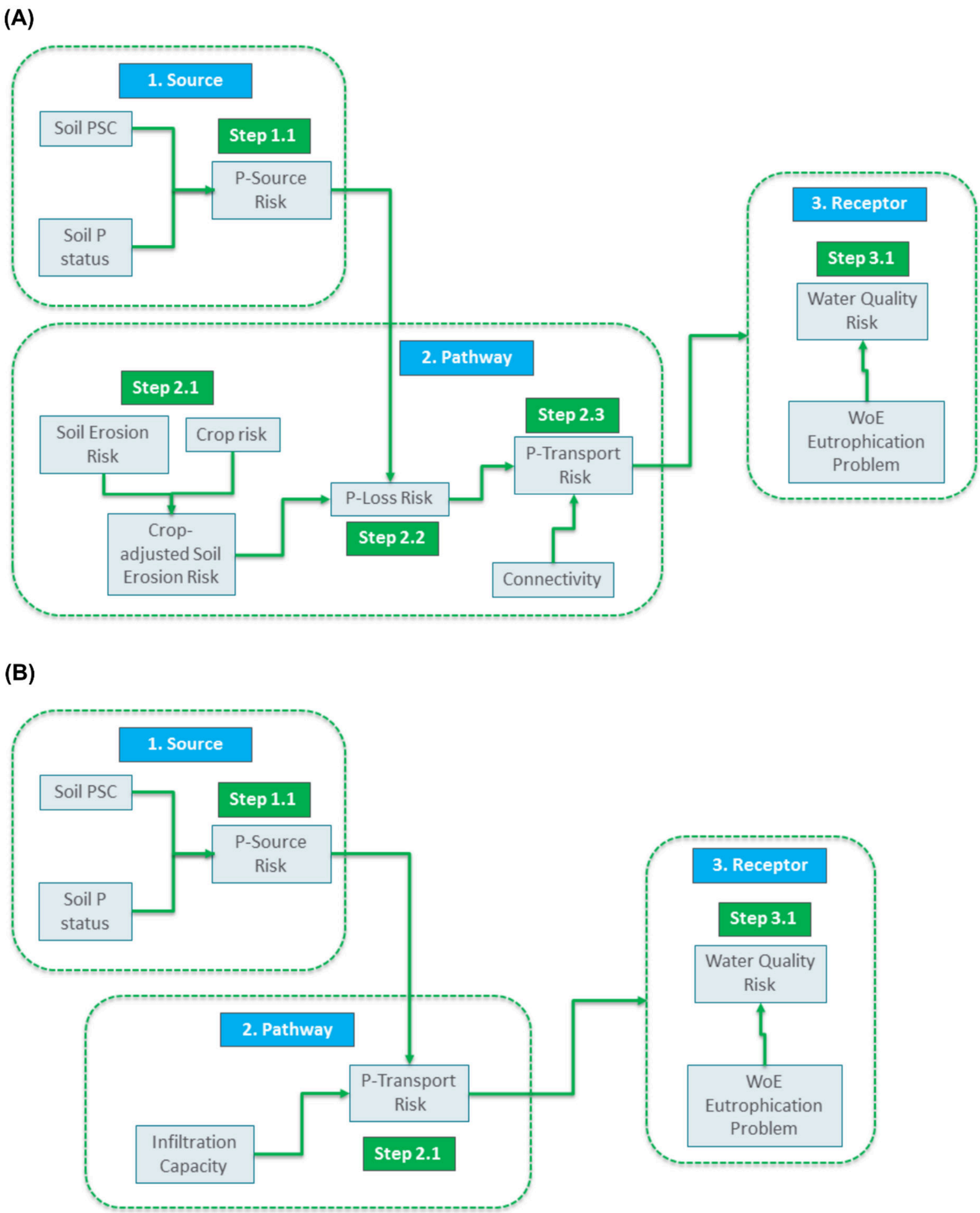

Figure 3-1. Flowchart of main steps used for conducting the RAG P-risk assessments for a) surface runoff and soil erosion and b) leaching to drains.

4. TRIAL AND TEST STUDY

4.1. Overview

The effectiveness and performance of the RAG P-risk assessment methodology was evaluated in two test catchments, the Coyle and East Pow, that are representative of Scottish cultivated areas and have contrasting characteristics such as land use, drainage status and soil type composition and where there was available information on soil P and water body quality status. The test catchments were regarded as appropriate for testing the developed P risk because they have been previously used for testing the soil risk maps (Lilly and Baggaley, 2014) and for providing training for farmers on nutrient and soil management to improve water quality (SAC Consulting, 2018, unpublished).

A spatial framework was developed that combined the developed decision rules with the required numerical and spatial (maps) datasets to produce new maps that show the individual RAG P-risk assessments for the number of fields present at each catchment. The P-risk assessment maps were then used to evaluate their effectiveness and identify weaknesses and/or gaps with the proposed RAG risk assessment methodology. In particular, the following components of the P-risk assessment methodology were evaluated:

- Whether the developed decision rules and the proposed combinations of the required datasets produce meaningful results of P-risk assessment: this was assessed using findings from previous projects and knowledge of the prevalent conditions (e.g. land use, soil drainage, risk of eutrophication) in the two test catchments.
- Whether the RAG P-risk methodology was capable for accurately and consistently assessing P-risks at a field scale: This was assessed using two different “virtual” point sampling methods for assessing the P-risks at each field in the study catchments:
    a) Individual P-risks were assessed at the centroid location of each field polygon for fields with area <10 ha or at each centroid of the 10ha parts for fields with area >10 ha. For multi-part fields, the greatest P risk was assigned to the whole of the field. This method replicated the procedure used for the Paragraph 7 WML exemptions. The polygon centroids were used as an appropriate point for the RAG P-risk assessments because they are consistent with recommendations for selecting treatment areas, e.g. away from field boundaries and watercourses.
    b) Individual P-risks were assessed at the centre of the 50m regular grid cells covering the two study catchments (based on the grid cells from the soil erosion risk map). This approach aimed to draw a number of virtual soil samples from the fields and replicate an intensive sampling strategy for assessing the P-risks that can capture the spatial variation of all input parameters within each field. The most frequent P-risk assessments for the sampling points falling within each field was used to assign a P-risk for the whole of the field.

Based on the above approach, the RAG P-risk assessments were regarded as consistent in assessing P-risks at field scale if both sampling methods gave the same or very similar results for the fields within the study catchments. An example of the two virtual sampling schemes is given in Figure 4-1 for a number of fields in the East Pow catchment.

4.2. Description of test catchments

The Coyle is a sub-catchment of the River Ayr and covers an area of around 81 km^2. The land is mainly improved grassland and rough grazing, though there are some arable areas (generally as part of mixed farming). In the north of the catchment, dairy farms dominate whilst to the south beef cattle and sheep are found in the upland and rough grazing (SAC Consulting, 2018, unpublished). Most of the land has either imperfect or poor natural drainage and the requirement for effective land drainage is a well-recognised across the catchment. The catchment receives around 940 mm rainfall annually (Met Office statistics), which is a key contributory factor influencing diffuse pollution risk, and is characterized by livestock-related issues, including poaching by livestock within 5 metres of watercourses and run-off or leaching from fertiliser or manure applications. If poorly managed, cultivations and field operations can increase the risk of runoff and erosion. Most livestock enterprises are slurry-based systems.

The East Pow is a sub-catchment in the River Tay and covers an area of around 48.5 km^2, receiving around 811mm rainfall annually (Met Office statistics). Cereals (barley, wheat and oats) cover around 80% of the catchment area, 5% of the land is in potatoes and the remaining mainly comprises productive and/or rotational grassland. Naturally well-drained loamy soils are found at the southern part of the catchment, which are intensively farmed and are suitable for arable cropping including potatoes. Most of the catchment is farmed in-hand though a small proportion land is let out for potato cropping by large specialist businesses based normally out with the catchment. The land is valuable and highly productive, managed through traditional cultivation techniques with little or no min-till in evidence. Farm yard manure (FYM) is the main source of organic manures spread in the catchment, though some businesses also use bio solids and poultry manures (SAC Consulting, 2018, unpublished).

4.3. Required datasets and additional processing

The required spatial datasets that were used for the trial and test study were loaded and processed in the open-source software QGIS[5] (version 2.18). These included the following freely-available maps (see Section 2):

- The Soil Map of Scotland (partial cover) at 1:25,000 scale and in ESRI shapefile format.
- The map of Phosphorus Sorption Capacity (PSC) at 1:250,000 scale and in ESRI shapefile format.
- The map of Runoff Risk at 1:25,000 scale and in ESRI shapefile format.
- The map of Soil Erosion Risk at 50m grid resolution and in GeoTiff format.

For the purpose of the trial and test study, we also used the following datasets:

- Boundaries and crop type information for each field within the test catchments from the IACS database, provided under license by SEPA in ESRI shapefile format.
- The WFD river body classification for the two test catchments provided by SEPA in ESRI shapefile format, in which the WoE eutrophication problem risk classification for each

[5] https://qgis.org

river body (calculated with the SEPA Eutrophication risk spreadsheet) was added. WFD water bodies present within each test catchment include the following (WoE eutrophication problem in brackets):
    - Coyle: 10422 (Quite Certain) and 10423 (Uncertain).
    - East Pow: 6510 (Quite Certain) and 6511 (Not Assessed).
- The water feature layers from OS MasterMap in ESRI shapefile format.

All mapping products had the same projection information (British National Grid). Processing of the spatial datasets included the following tasks:

i. Removal of areas within the test catchments where no data were available: this included urban areas and open water and areas of organic soils (basin peat) in the test catchments where soil PSC was not determined.
ii. Removal of non-cultivated field polygons with semi-natural vegetation: these included woodland and forestry, trees, shrubs, bushes and scree or scrub.
iii. Information of P status from each field were taken from the study done by SAC Consulting (2018, unpublished) that used the same test catchments and the same IACS fields and included maps of P levels. The two P status maps were georeferenced within QGIS, the P status values were extracted from the maps based on the location of the common field polygons and these values were then attributed to the respective fields.
iv. Fields with areas >10 ha were split into two or more parts using Polygon Divider QGIS Plugin[6]: this was done to replicate the procedure followed during the Paragraph 7 WML exemptions.
v. Generation of the virtual sampling point shapefiles for the test catchments based on:
    - The geographical locations of field polygon centroids.
    - The geographical locations of the 50m regular grid cell centre points.
vi. The virtual sampling points were used to calculate connectivity of fields to the nearest water feature (Distance to nearest hub tool in QGIS) using a similar approach as in Grauso et al. (2018). We used the OS MasterMap water feature that included both inland waters and surface ditches because it provides a detailed representation of the surface drainage system. These water features were spatially linked with WFD water body classification layers in order to assess to which water body section they were draining; this enabled assigning a WoE Eutrophication problem class to each water feature. An example of mapping connectivity using the two sampling datasets is given in Figure 4-1.
vii. The virtual sampling points were intersected with all required datasets and were attributed with the respective values required to generate the RAG P-risk assessments. These values were exported from the GIS point layers as text files.
viii. The decision rules for the P-risk assessments were written into scripts using the open-source statistical software R[7]. The sampling point text files were then used to run the decision rules scripts and generate the individual P-risk assessments for each field using the two different sampling approaches.

[6] Produced by Roy Ferguson Consultancy Ltd for Zero Waste Scotland Ltd.
[7] https://www.r-project.org

ix. The generated P-risks for each field were then joined back to the field polygon layers and respective maps of RAG P-risk assessments were produced for both catchments that are presented in Sections 4.4 and 4.5. An example of this process is presented in the Appendix (Section 7.2, Figures 7-1:7-12) for three fields in the Coyle catchment.

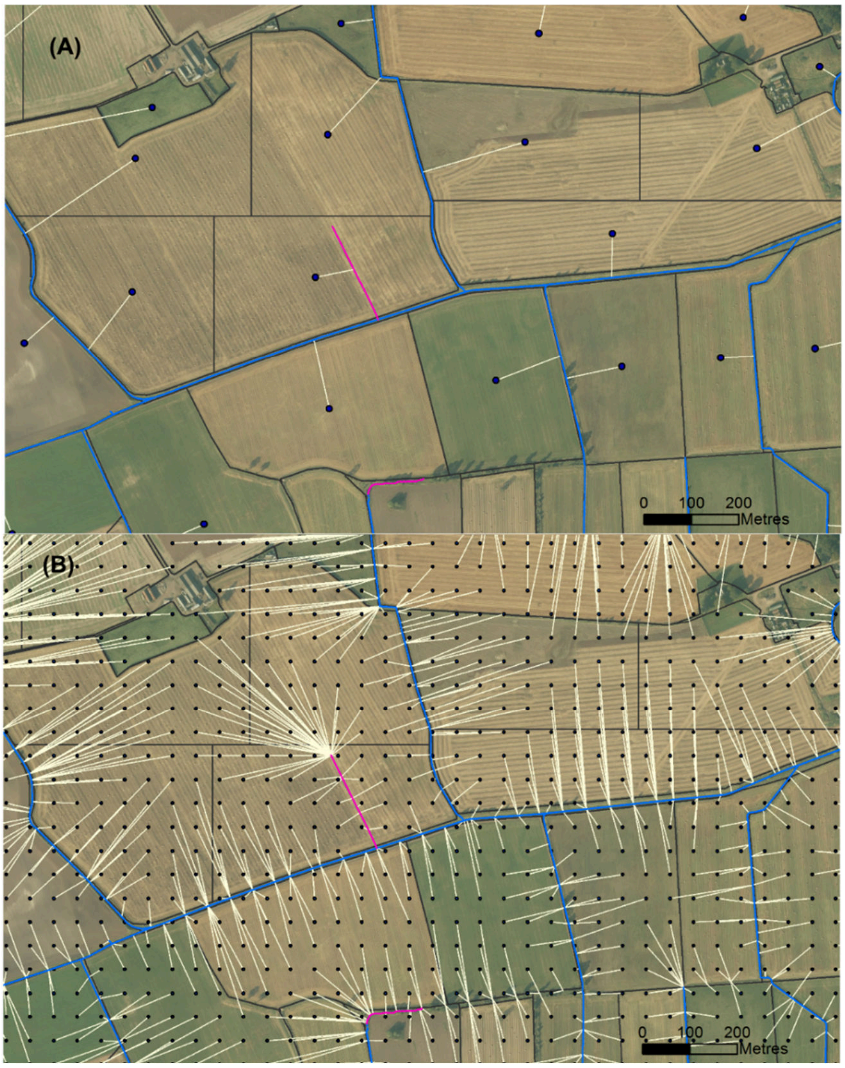

Figure 4-1. Example of mapping field connectivity to the nearest watercourse in the East Pow catchment assessed using a) samples on field centroids and b) samples based on a 50m-regular grid. Watercourse layer: blue lines represent streams/rivers and purple lines are ditches according to OS attribute table. Background satellite imagery from GetMapping PLC. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

Table 4-1 gives the information for both test catchments derived from the datasets that were used to conduct the RAG P-risk assessments and Figure 4-2 shows the distribution of soil PSC and soil erosion risk classes within the test catchments.

Table 4-1. Areal proportions in each study catchment of dominant soil types (Major Soil Subgroup from Soil Map 1:25,000), crop types (from IACS data), soil drainage (from Soil Map 1:25,000), soil Phosphorus Sorption Capacity (PSC), runoff risk and areal proportions in each catchment draining to a water body with WoE eutrophication risk problem.

Parameters	Coyle	East Pow
Soil type	Non-calcareous gleys (57%) Brown earths (24%)	Brown earths (73%) Humus-iron podzols (12%)
Crop types	Grass over 5 yrs (53%) Grass under 5 yrs (40%)	Spring barley (37%) Grass under 5 yrs (13%)
Soil drainage	Imperfect (57%) Poor (23%)	Imperfect (54%) Free (32%)
Soil P status	Moderate (80%) Low (17%) High (3%)	Moderate (79%) Low (12%) High (9%)
Soil PSC	Low (66%) High (31%) Moderate (3%)	Low (94%) Moderate (6%)
Soil Erosion Risk	Moderate (85%) Low (14%) High (1%)	Moderate (81%) Low (18%) High (1%)
Runoff Risk	Moderate (92%) High (6%) Low (2%)	High (92%) Moderate (7%) Low (1%)
WoE Eutrophication Risk Problem	Uncertain (56%) Quite certain (44%)	Quite certain (89%) Not assessed (11%)

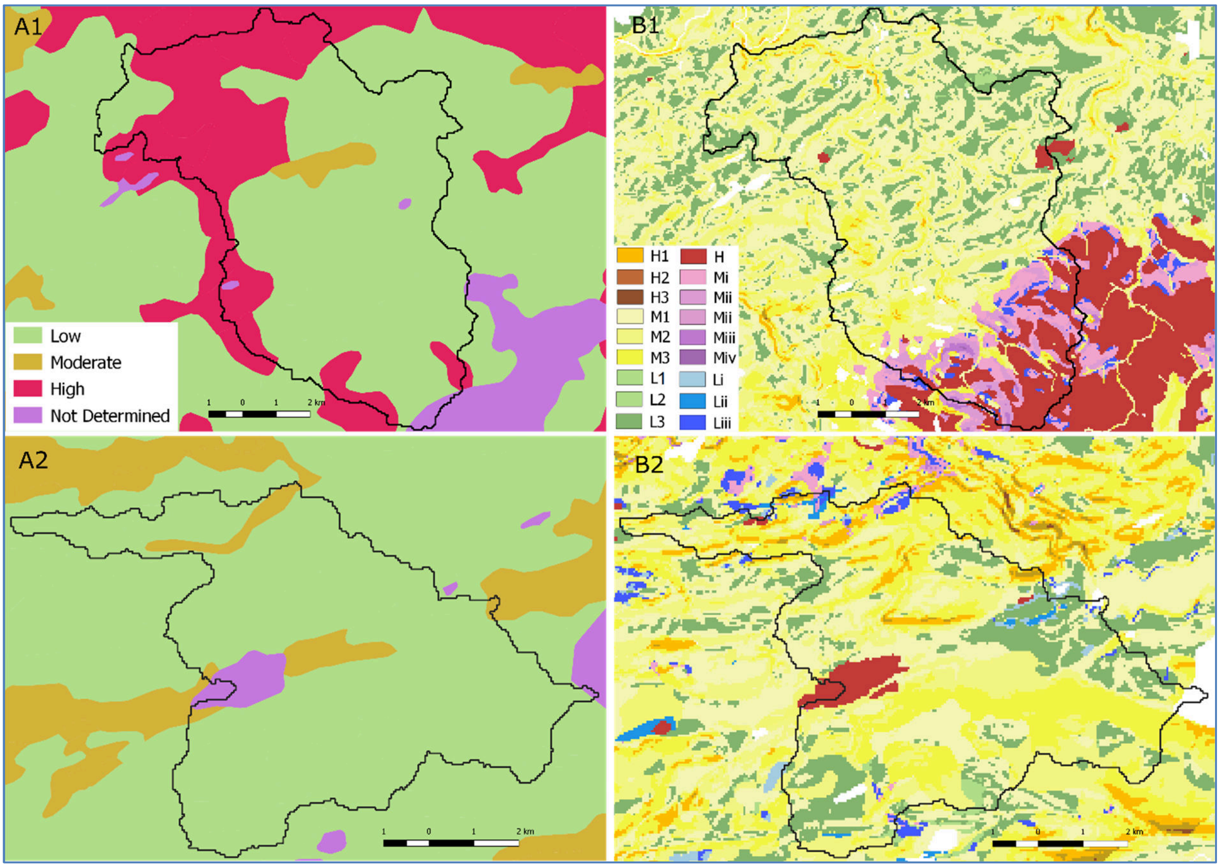

Figure 4-2. Maps of soil Phosphorus Sorption Capacity (PSC) in the A1) Coyle and A2) East Pow, and of Soil Erosion Risk in the B1) Coyle and B2) East Pow.

4.4. Risk assessments for overland flow

4.4.1. Overview

This Section presents the results of the trial and test study for the overland flow pathway. These include maps of the individual RAG P-risk assessments for each Source-Pathway-Receptor (SPR) model component for the 1,016 and 415 individual field polygons selected in the Coyle and East Pow catchments, respectively. The maps presented were produced using the two different sampling approaches, i.e. field assessments based on field centroids and dominant risk assessments at each field based on 50m regular grid points. A summary of the field RAG P-risk assessments for both test catchments is given in Tables 4-2 and 4-3.

Table 4-2 gives the number of fields that were assigned to a particular P-risk class using the two different sampling approaches.

Table 4-2. Number of fields assessed for the individual RAG P-risk assessments for runoff and soil erosion in the two study catchments using a) field centroids and b) 50m regular grid points.

P-Risks	Classes	Coyle		East Pow	
		Field centroids	Field 50m grid	Field centroids	Field 50m grid
P-Source Risk	Low	79 (8%)	76 (7%)	49 (12%)	37 (9%)
	Moderate	506 (49%)	508 (50%)	325 (78%)	335 (81%)
	High	431 (43%)	432 (43%)	41 (10%)	43 (10%)
P-Loss Risk	Low	370 (36%)	442 (43%)	109 (26%)	104 (25%)
	Moderate	484 (48%)	483 (48%)	263 (63%)	273 (66%)
	High	162 (16%)	91 (9%)	43 (10%)	38 (9%)
P-Transport Risk	Low	505 (50%)	562 (55%)	219 (53%)	224 (54%)
	Moderate	363 (36%)	273 (27%)	137 (33%)	111 (27%)
	High	148 (15%)	181 (18%)	59 (14%)	80 (19%)
Water Quality Risk	Low	302 (30%)	293 (29%)	0	0
	Moderate	396 (39%)	408 (40%)	174 (42%)	163 (39%)
	High	318 (31%)	315 (31%)	168 (40%)	184 (44%)
	Not Assessed	0	0	73 (18%)	68 (17%)

Table 4-3 gives the overall accuracy metrics for individual P-risk assessments for the two sampling approaches in the test catchments. In this application, overall accuracy shows the level of agreement between P-risk assessments done using the two sampling approaches. It is calculated as the number of fields where P-risk assessed using the field centroids was the same with when the 50m regular grid points were used, divided by the total number of fields assessed. Accuracy is expressed as a percentage, with 100% accuracy meaning that a P-risk assessment was the same for all fields using both sampling approaches.

Table 4-3. Overall accuracies (in %) based on the comparison between individual RAG P-risk assessments conducted using the two sampling approaches in the two test catchments.

P-Risks	Coyle	East Pow
P-Source Risk	100	97
P-Loss Risk	77	90
P-Transport Risk	74	79
Water Quality Risk	84	91

Figure 4.3 breaks down the accuracy results into the individual risk classes illustrating the degree of agreement between the two methods. For example, in the Coyle catchment, both methods classified around 480 fields as being of moderate risk of P loss (Table 4-2). However, only 367 were the same field (i.e. 76 %). The remaining 107 fields classified as moderate were not the same fields.

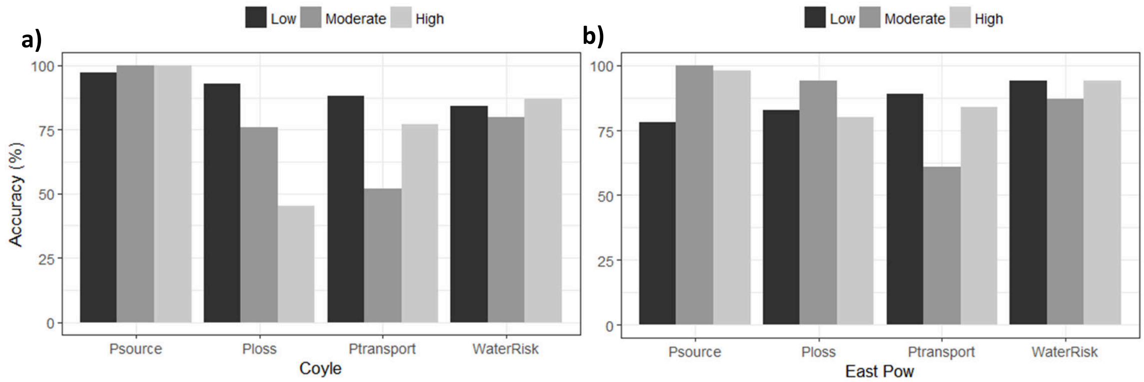

Figure 4-3. Accuracies of individual risk classes based on the comparison between P-risk assessments conducted using the two sampling approaches in the a) Coyle and b) East Pow catchments.

4.4.2. Source

Figures 4-4 and 4-5 give the results of the risk assessments for a field being a source of particulate P due to surface runoff and soil erosion in the Coyle and East Pow catchments. The risk assessments were produced by combining a field's soil P status and soil PSC based on the decision rules in Table 3-1.

Soil P status was moderate for around 80% of both test catchments, while soil PSC was low for 66% and 94% of the Coyle and East Pow catchment areas, respectively (Table 4-1). This resulted in the majority of the fields in both test catchments being classified as having a moderate particulate P-source risk based on their centroid samples. This was more evident in the East Pow where 325 (or 81%) fields were classified as having moderate P-source risk, while 506 (or 49%) fields were classified as of moderate P-source risk in the Coyle (Table 4-2). In the Coyle, 431 (or 43%) fields were assessed as having a high P-source risk; these fields had moderate soil P status and lay in areas of moderate P binding capacity (Figure 4-4).

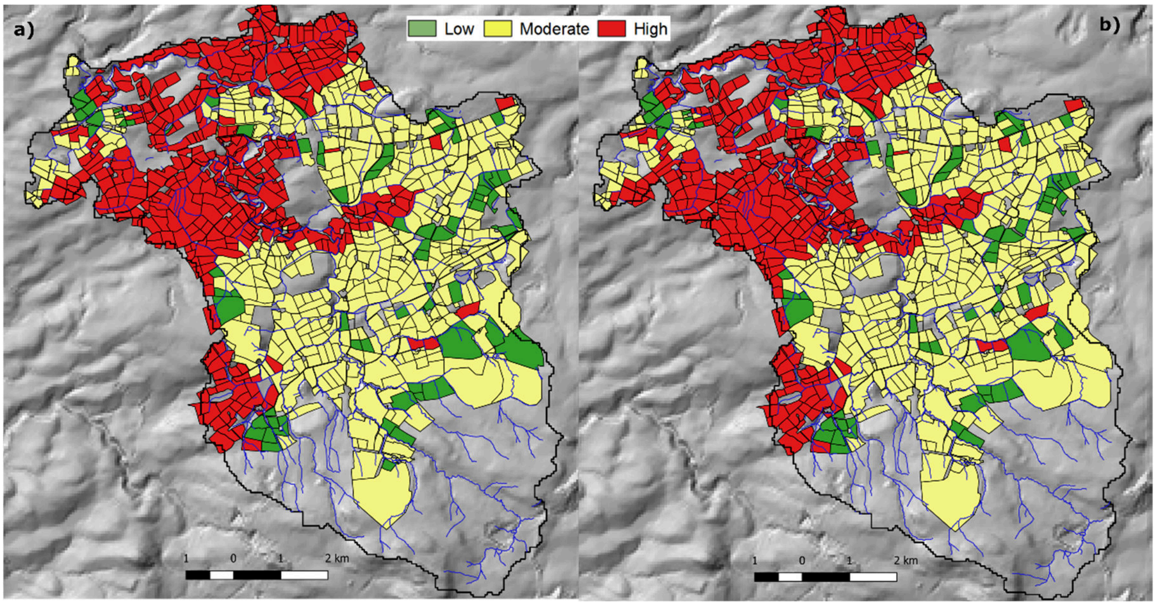

Figure 4-4. Map of fields assessed for P-source risk for runoff and soil erosion in the Coyle catchment using a) field centroids and b) 50m regular grid points.

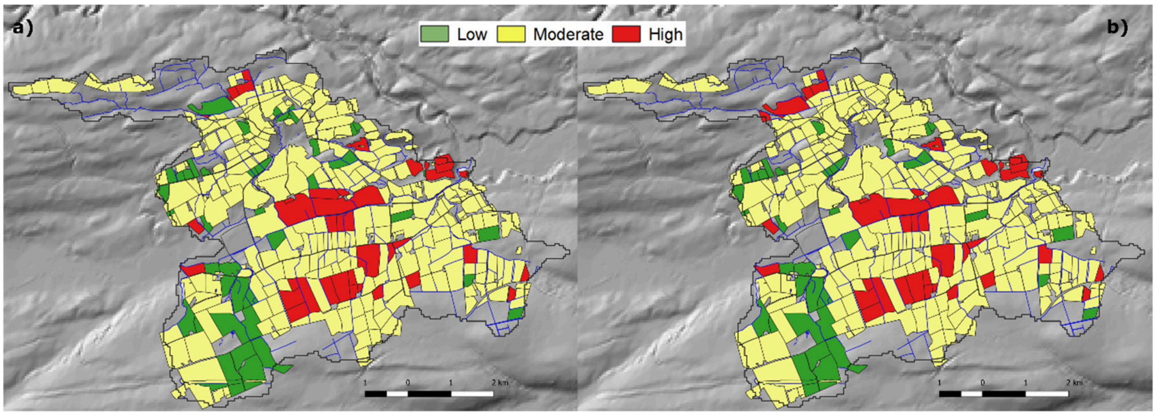

Figure 4-5. Map of fields assessed for P-source risk for runoff and soil erosion in the East Pow catchment using a) field centroids and b) 50m regular grid points.

The number of fields assigned to each P-source risk class using the two different sampling approaches was very similar in both catchments (Table 4-2). Figure 4-6 also shows that in almost all cases the same fields were given the same P-source risk class in both catchments using the two different sampling approaches. Overall accuracies for P-source risk assessments (Table 4-3) and for individual risk classes (Figure 4-3) were high in both catchments. This indicated that both sampling approaches produced very similar P-source risk assessments for the same fields in both test catchments.

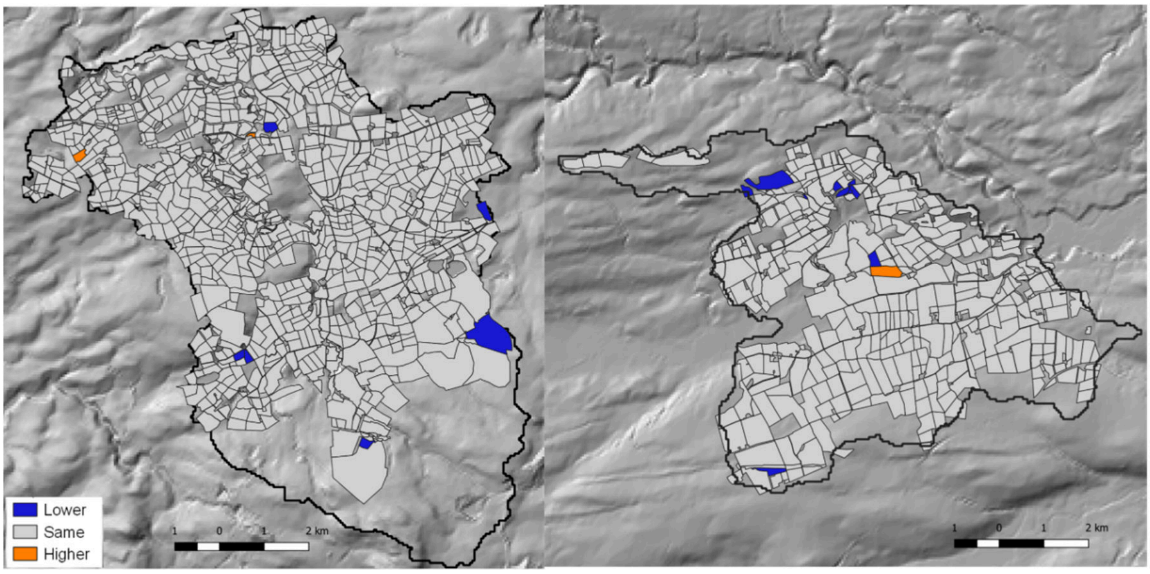

Figure 4-6. Map showing fields where a lower, same or higher P-source risk class was assigned when using field centroids compared to when the 50m regular grid approach was used in the two test catchments. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

4.4.3. Pathway

In this section we present the results of two RAG P-risk assessments:

A. The risk of particulate P being lost from a field (P-loss risk), and
B. The risk of particulate P reaching the nearest watercourse (P-transport risk).

A. <u>P-loss risk</u>

Figures 4-7 and 4-8 give the results of the risk assessments of particulate P being lost from a field due to surface runoff and soil erosion in the Coyle and East Pow catchments. The risk assessments were produced by adjusting a field's soil erosion risk using crop type information (Table 3-3) and then by combining the crop-adjusted soil erosion risk map with the P-source risk assessments for each field based on the decision rules in Table 3-4.

Most of the land in the Coyle is under grass, which has a low crop risk class, and exhibits moderate soil erosion risk (Table 4-1); this led to around 85% of the land assigned a moderate crop-adjusted soil erosion class. In the East Pow, most land is used for cereals, which has a moderate crop risk class, and exhibits moderate soil erosion risk, resulting in around 75% of the catchment's land assigned to a moderate crop-adjusted soil erosion class (a system with more than 3 classes would likely show a greater distinction between the two catchments). Combining the particulate P-source risks with the crop-adjusted soil erosion risks resulted in most of the catchments being classified as having a moderate P-loss risk for both catchments; 484 (or 48%) fields in the Coyle and 263 (or 63%) fields in the East Pow using the field centroid assessments (Table 4-2).

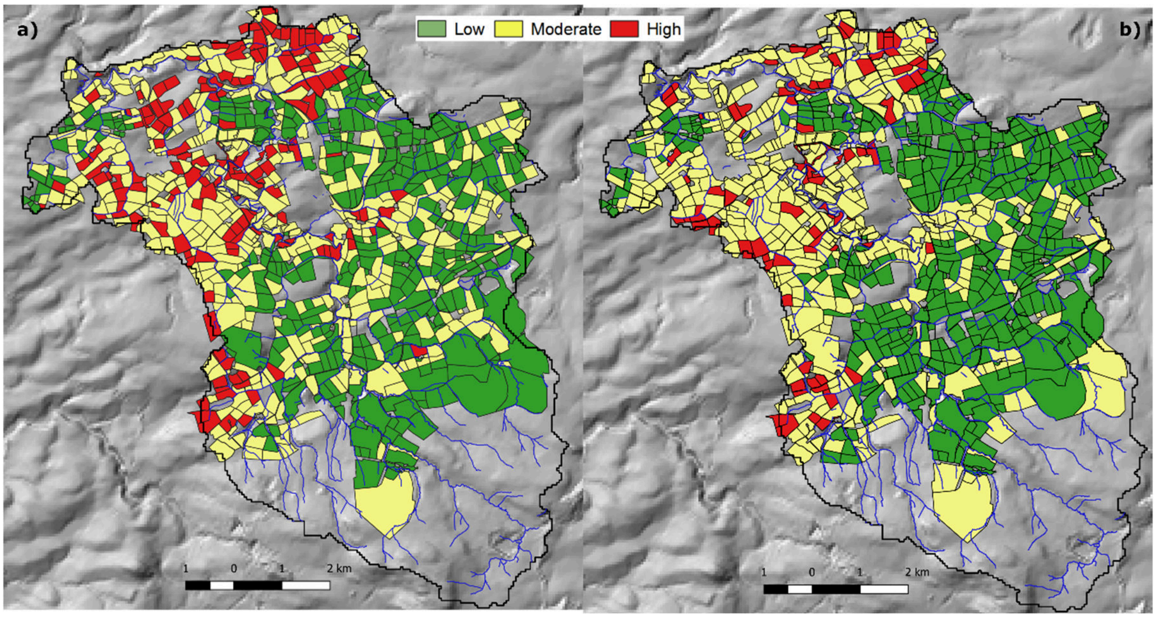

Figure 4-7. Map of fields assessed for P-loss risk for runoff and soil erosion in the Coyle catchment using a) field centroids and b) 50m regular grid points.

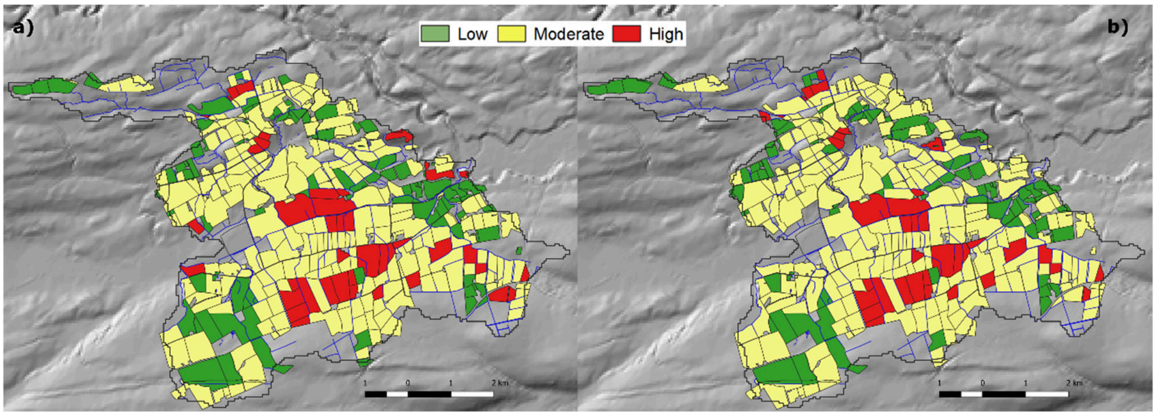

Figure 4-8. Map of fields assessed for P-loss risk for runoff and soil erosion in the East Pow catchment using a) field centroids and b) 50m regular grid points.

In the Coyle, using the field centroid sampling approach resulted in a greater number of fields (162) assigned to the high P-loss risk class than when the 50m regular grid points were used (91 fields) (Table 4-2 and Figures 4-3 and 4-9). The two different sampling approaches gave very similar particulate P-loss risk assessments for the fields in the East Pow (Table 4-2 and Figures 4-3 and 4-9). Overall accuracy for P-loss risk assessments in the Pow was 90% and in the Coyle was 77%. This indicated that both sampling approaches produced the same P-source risk assessments for most of the fields in the Pow, but less agreement was observed for the fields in the Coyle.

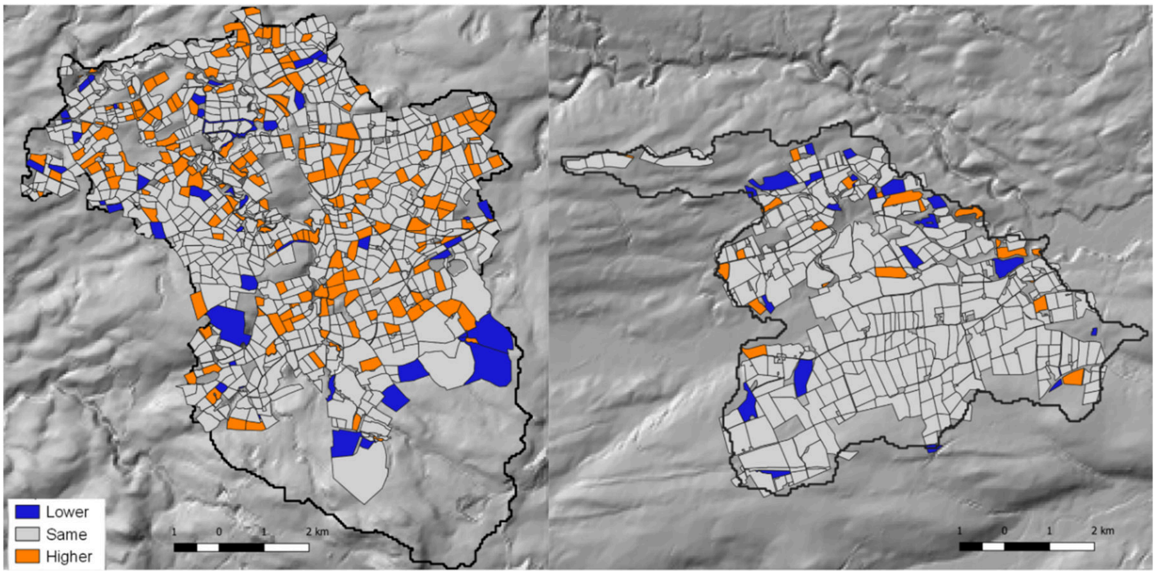

Figure 4-9. Map showing fields where a lower, same or higher P-loss risk class was assigned when using field centroids compared to when the 50m regular grid approach was used in the two test catchments.

B. <u>P-transport risk</u>

Figures 4-10 and 4-11 give the results of the risk assessments of particulate P being lost from a field due to surface runoff and soil erosion reaching the nearest watercourse in the Coyle and East Pow catchments. The risk assessments were produced by combining the P-loss risk assessments for each field with the connectivity of each field to the nearest watercourse based on the decision rules in Table 3-6.

As expected, the P-transport risk assessments were greatly influenced by the distance of fields from the watercourses. Connectivity was assessed as being very similar for both the Coyle and East Pow catchments; around 45%, 35% and 20% of each catchment area was classified as low, moderate and high, respectively. The results of the connectivity assessments when combined with the P-loss risk assessments, which classified most fields as having low or moderate risk, resulted in most fields in both test catchments being assigned a low or moderate risk of particulate P reaching the nearest watercourse (Table 4-2). For example, around 15% of all fields in both test catchments were classified as having a high P-transport risk using the field centroids, and as expected they were all riparian fields, i.e. all or most of their area was within a 50m distance from a watercourse (Figures 4-10 and 4-11).

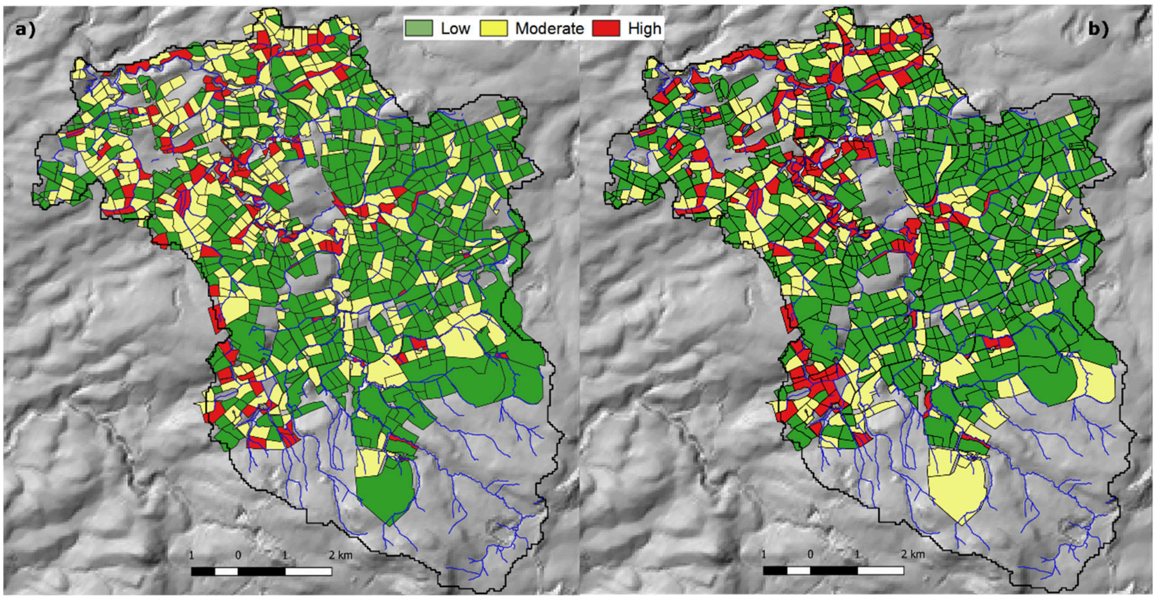

Figure 4-10. Map of fields assessed for P-transport risk for runoff and soil erosion in the Coyle catchment using a) field centroids and b) 50m regular grid points. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

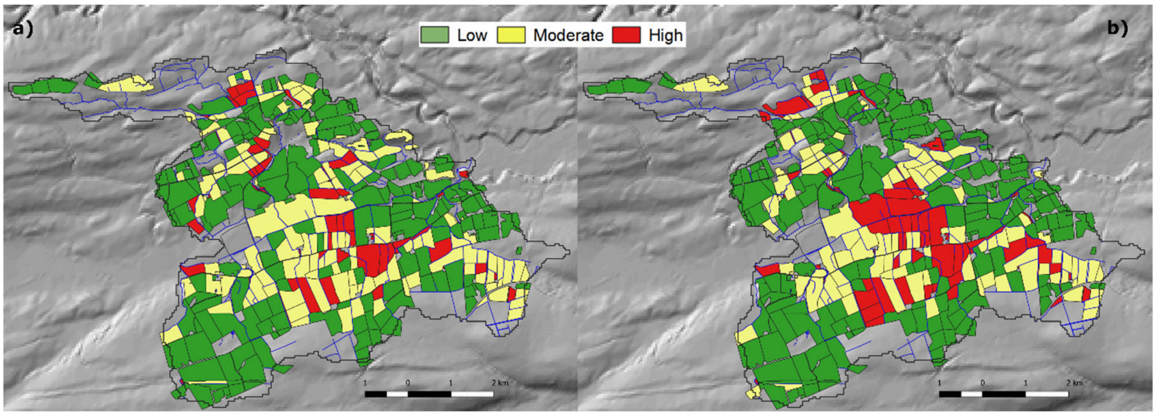

Figure 4-11. Map of fields assessed for P-transport risk for runoff and soil erosion in the East Pow catchment using a) field centroids and b) 50m regular grid points. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

Assessments of particulate P-transport risk made using the 50m regular grid points resulted in more fields being designated as high risk; fields classified as having a high P-transport risk increased from around 15% to 20% (Table 4-2 and Figure 4-12). This was caused by the more detailed assessment of field connectivity made using the 50m regular grid points compared to when field centroids were used (see Figure 4-1), which pushed assessments of riparian fields (based on the more frequent P-risk class assigned to the points lying within each field) towards the high P-transport risk class.

This effect is also shown in the accuracy metrics for the field P-transport assessments. Overall accuracy was 74% and 79% in the Coyle and Pow catchments, respectively (Table 4-3). Looking at individual assessments of P-transport risk classes, the least agreement between the two sampling methods was observed for the moderate risk class (Figure 4-3); this further indicates the important influence that the more detailed assessments of field connectivity has on the respective P-transport field assessments.

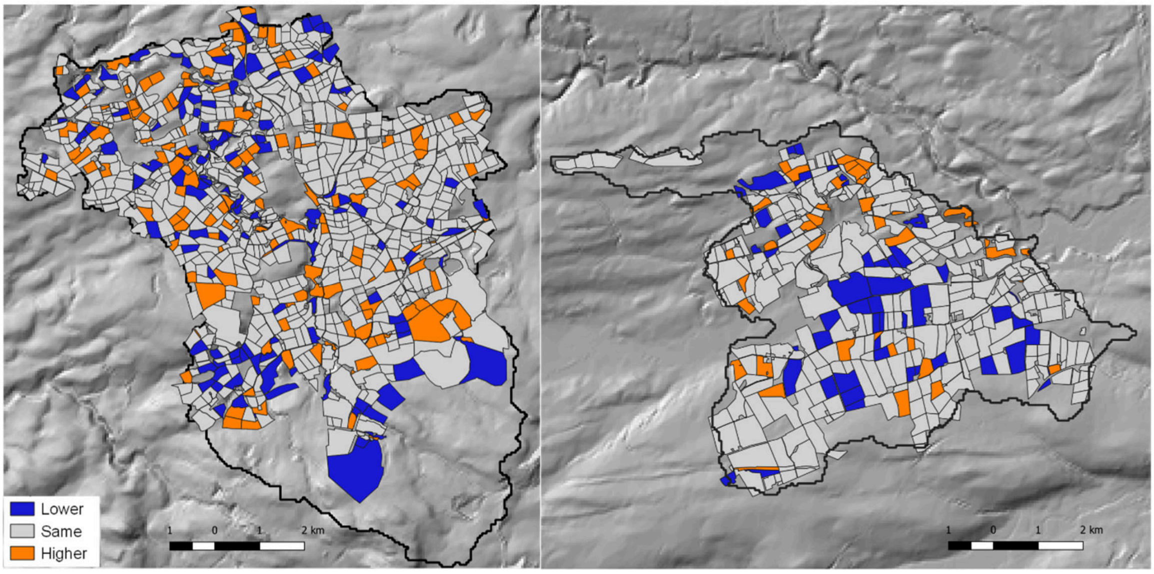

Figure 4-12. Map showing fields where a lower, same or higher P-transport risk class was assigned when using field centroids compared to when the 50m regular grid approach was used in the two test catchments.

4.4.4. Receptor

Figures 4-13 and 4-14 give the results of the risk assessments of particulate P impacting the water quality of the nearest watercourse in the Coyle and East Pow catchments with regards to the risk of eutrophication (Water Quality risk). The risk assessments were produced by combining the P-transport risk assessments for each field with WoE Eutrophication problem risk assessments for the nearest watercourse based on the decision rules given in Table 3-7.

The water quality risk in the Coyle was assessed as being low in 302 fields (30%) using the field centroids (Table 4-2); these fields had a low P-transport risk and were connected to watercourses with uncertain eutrophication problem. A further 396 fields (39%) were classified as posing a moderate risk to water quality, which was either because these fields had a moderate P-transport risk and were connected to watercourses with uncertain eutrophication problem or had a low P-transport risk but were connected to watercourses with a quite certain eutrophication problem. The remaining 318 fields (31%) posed a high risk to water quality because they had an either moderate or high P-transport risk and at the same time were connected to watercourses with a quite certain problem of eutrophication (Figure 4-13).

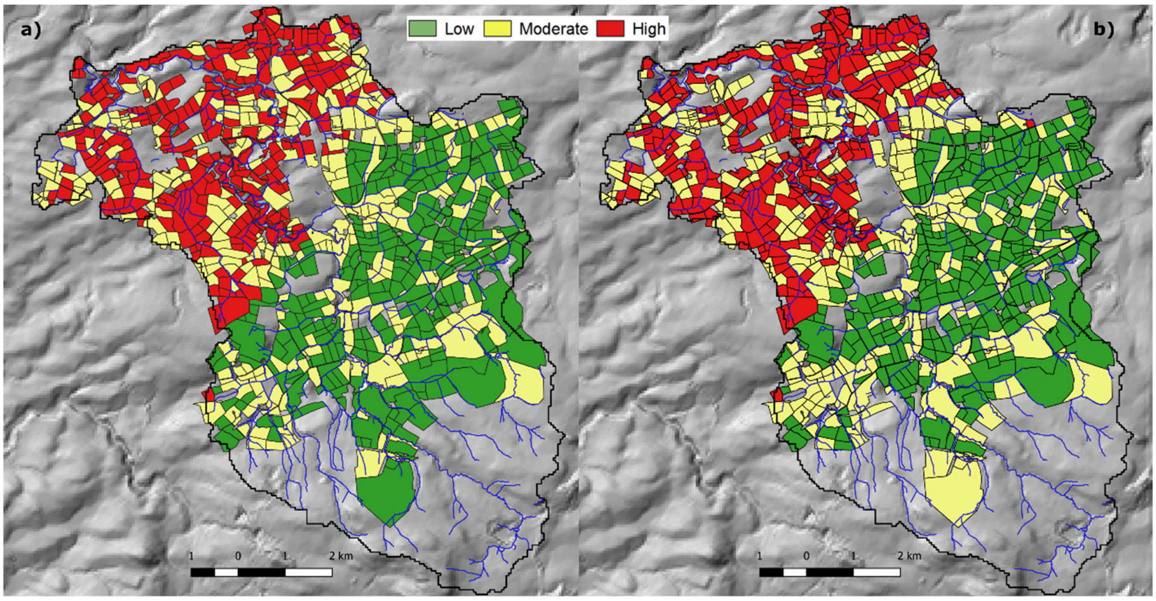

Figure 4-13. Map of fields assessed for Water Quality risk for runoff and soil erosion in the Coyle catchment using a) field centroids and b) 50m regular grid points. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

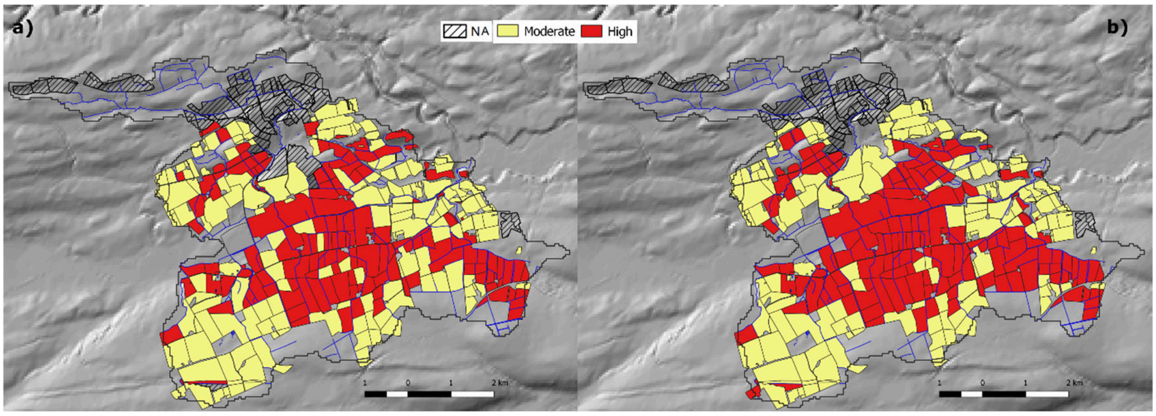

Figure 4-14. Map of fields assessed for Water Quality risk for runoff and soil erosion in the East Pow catchment using a) field centroids and b) 50m-regular grid points. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

Despite the differences in P-transport risk assessments produced in the Coyle using the two different sampling approaches, the water risk assessments were similar for both sampling schemes (Table 4-2 and Figures 4-13 and 4-15). Overall accuracy in fields assessments was 84% (Table 4-3), while accuracies were greater than 80% for all three water quality risk classes (Figure 4-3). This indicates the importance of the eutrophication problem assessment of the P-receiving watercourse for defining the overall water quality risk from the addition of P-containing materials to land.

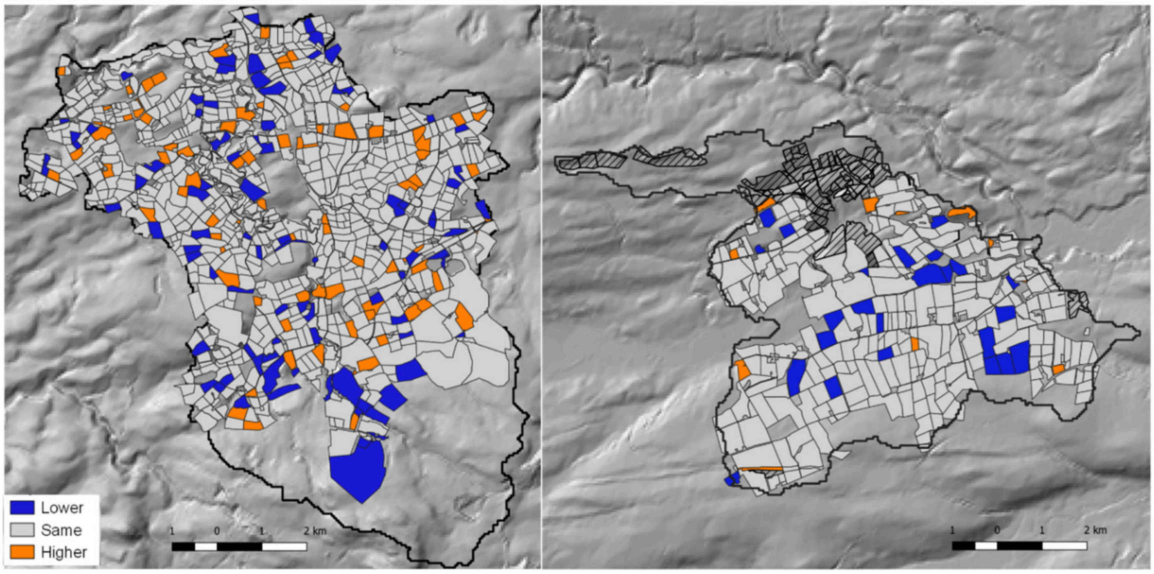

Figure 4-15. Map showing fields where a lower, same or higher Water Quality risk class was assigned when using field centroids compared to when the 50m regular grid approach was used in the two test catchments. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

In the East Pow catchment, no fields were assessed as posing a low risk to water quality (Table 4-2). Water quality risk was not assessed in 73 fields (using field centroids) because the WoE eutrophication problem was not assessed in the receiving watercourses due to missing data. The remaining fields were connected to watercourses with a quite certain eutrophication problem, which meant that according to the decision rules given in Table 3-7 the water quality risk could then be assessed as either moderate or high, regardless of a field's P-transport risk. Of these fields, almost half (168) were found to pose a high risk to water quality of the receiving watercourses because these had either a moderate or high P-transport risk. As in the Coyle, the water risk assessments in the East Pow were similar for both sampling approaches. Overall accuracy in fields assessments was 91% (Table 4-3), while accuracy for the low and high water quality risk classes was 94% and 87% for the moderate risk class (Figure 4-3).

4.5. Risk assessments for drainflow

4.5.1. Overview

This Section presents the results of the trial and test study for the subsurface flow pathway/ drainflow. These include maps of the individual RAG P-risk assessments for each SPR model component for the 846 and 247 individual field polygons selected in the Coyle and East Pow catchments, respectively, where drains were expected to have been installed in the past. The maps presented were produced using the two different sampling approaches, i.e. field assessments based on field polygon centroids and dominant risk assessments at each field based on 50m regular grid points. A summary of the field RAG P-risk assessments for both test catchments is given in Table 4-4.

Table 4-4. Number of fields assessed for the individual RAG P-risk assessments for drainflow in the two study catchments using a) field centroids and b) 50m regular grid points.

P-Risks	Classes	Coyle		East Pow	
		Field centroids	Field 50m grid	Field centroids	Field 50m grid
P-Source Risk	Low	290 (34%)	294 (35%)	0	0
	Moderate	90 (11%)	89 (11%)	26 (11%)	27 (11%)
	High	466 (55%)	463 (55%)	221 (89%)	220 (89%)
P-Leaching Risk	Low	290 (34%)	294 (35%)	0	0
	Moderate	97 (11%)	96 (11%)	229 (93%)	229 (93%)
	High	459 (54%)	456 (54%)	18 (7%)	18 (7%)
Water Quality Risk	Low	31 (4%)	32 (4%)	0	0
	Moderate	643 (76%)	646 (76%)	0	0
	High	172 (20%)	168 (20%)	189 (77%)	191 (77%)
	Not Determined	0	0	58 (23%)	56 (23%)

Overall accuracies for individual P-risk assessments were around 100% for both test catchments. This indicates that both sampling approaches designated the same P-risk assessments and risk classes in almost the same fields in the two test catchments (Figure 4-16).

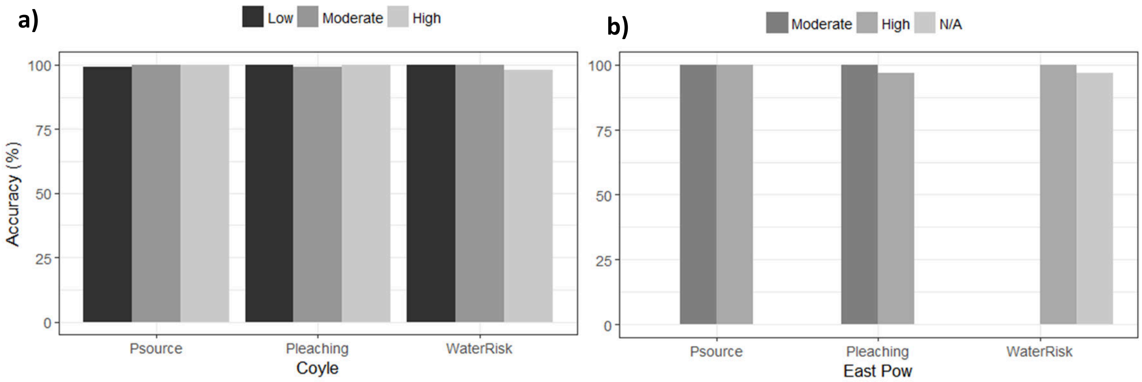

Figure 4-16. Accuracies of individual risk classes based on the comparison between P-risk assessments conducted using the two sampling approaches in the a) Coyle and b) East Pow catchments. N/A: Not Assessed.

4.5.2. Source

Figures 4-17 and 4-18 give the results of the risk assessments for a field being a source of dissolved P in the Coyle and East Pow catchments. The risk assessments were produced by combining field soil P status and soil PSC based on the decision rules given in Table 3-8.

As described previously (see Section 4.4.2), soil P status was moderate for around 80% of both test catchments, while soil PSC was low for 66% and 94% of the Coyle and East Pow catchment areas, respectively (Table 4-1). This resulted in most fields in both test catchments being classified as having a high dissolved P-source risk based on their centroid samples. This was more evident in the East Pow where 221 (or 89%) fields were classified as having high P-source risk with no fields having a low P-source risk, while 466 (or 55%) fields in the Coyle were classified as having high P-source risk (Table 4-4). However, in the Coyle, 290 (or 34%) fields were assessed as having a low dissolved P-source risk; these fields had a moderate soil P status and lay in areas of high P binding capacity (Figure 4-17).

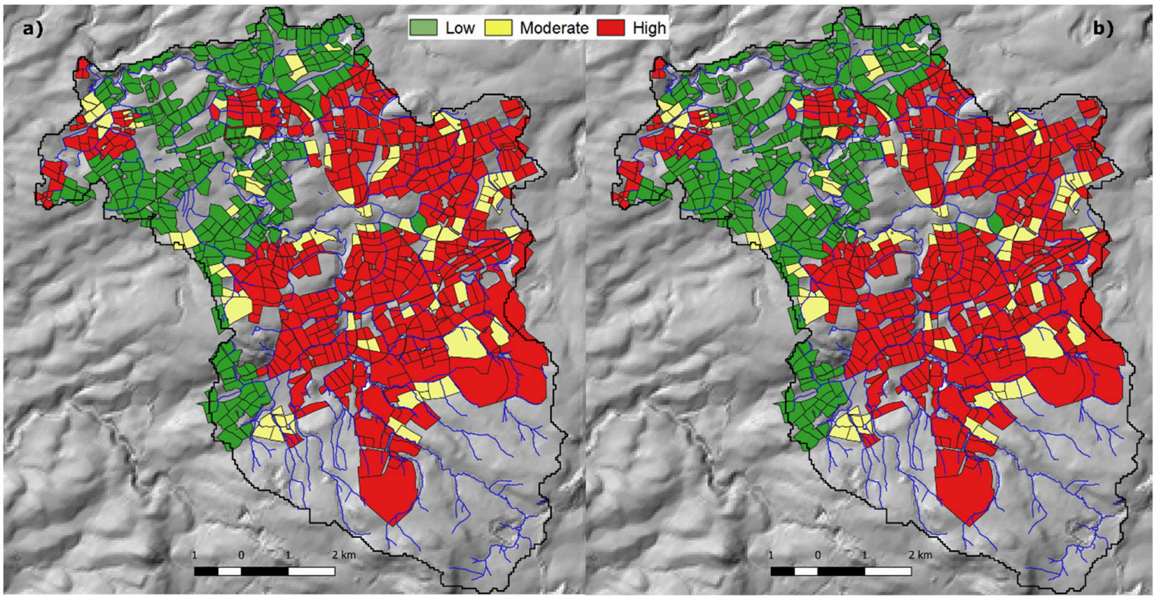

Figure 4-17. Map of fields assessed for P-source risk for drainflow in the Coyle catchment using a) field centroids and b) 50m regular grid points.

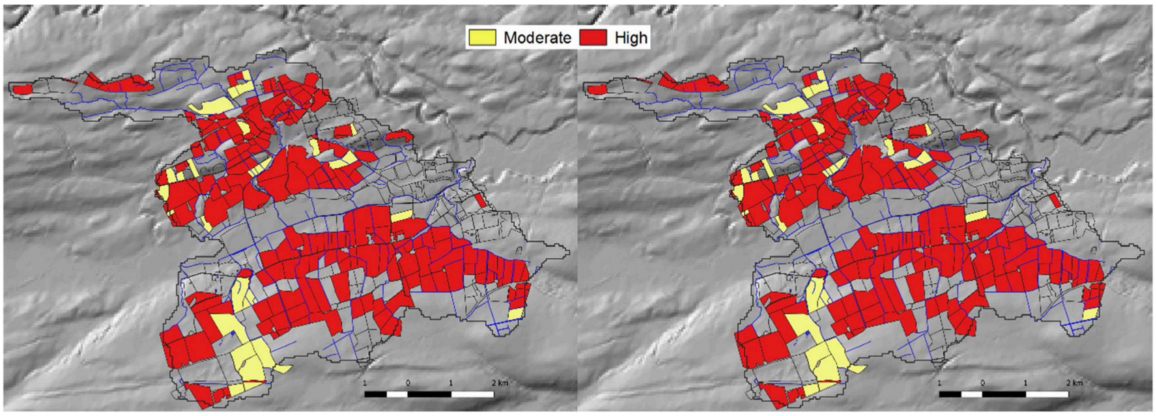

Figure 4-18. Map of fields assessed for P-source risk for drainflow in the East Pow catchment using a) field centroids and b) 50m regular grid points.

With regards to the two different sampling approaches, both gave very similar, almost identical, dissolved P-source risk assessments for the fields in both test catchments (Table 4-4 and Figures 4-16 and 4-19).

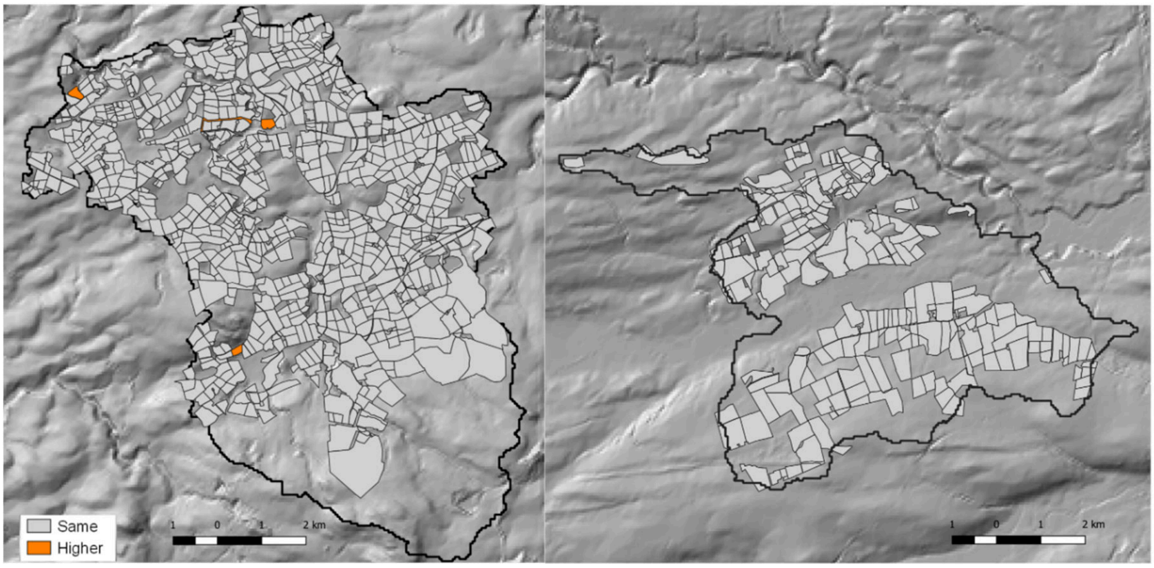

Figure 4-19. Map showing fields where a same or higher P-source risk class was assigned when using field centroids compared to when the 50m regular grid approach was used in the two test catchments. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

4.5.3. Pathway

Figures 4-20 and 4-21 give the results of the risk assessments for dissolved P leaching to drains in the Coyle and East Pow catchments. The risk assessments were produced by combining field P-source risk with soil infiltration capacity (IC) based on the decision rules given in Table 3-10.

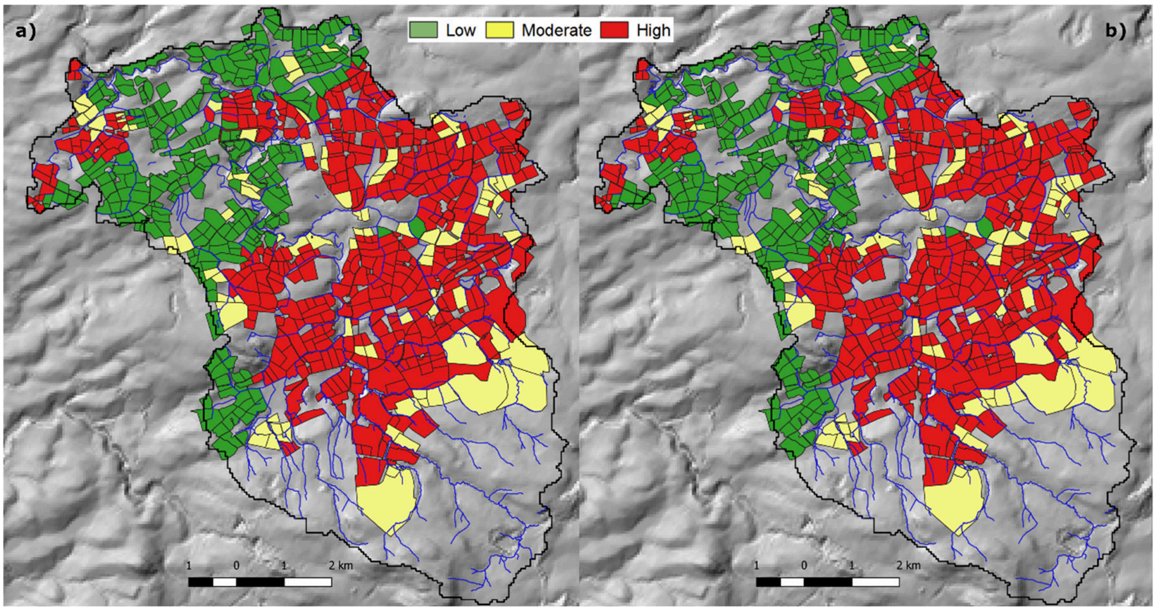

Figure 4-20. Map of fields assessed for P-leaching risk for drainflow in the Coyle catchment using a) field centroids and b) 50m regular grid points. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

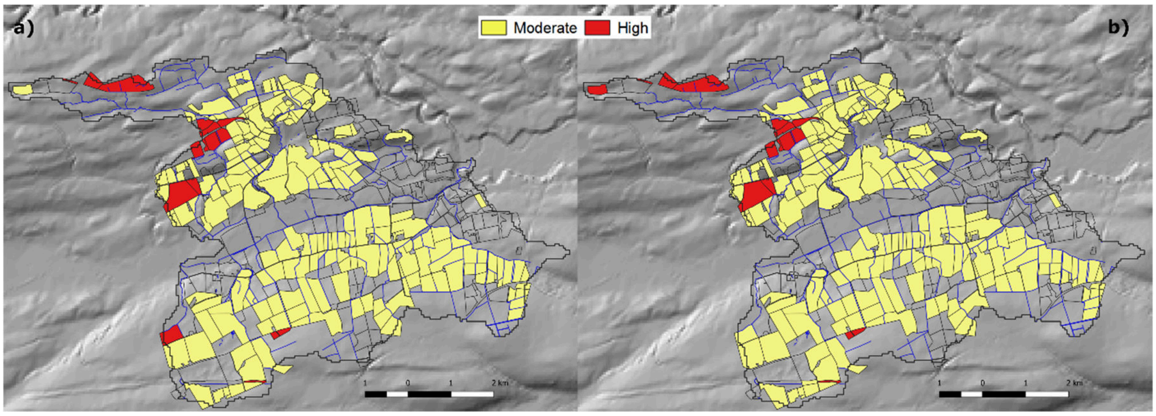

Figure 4-21. Map of fields assessed for P-leaching risk for drainflow in the East Pow catchment using a) field centroids and b) 50m regular grid points.

Soil IC was moderate for around 85% of Coyle's area but low for around 92% of the East Pow's area. This resulted in most fields in the Coyle (459 or 54%) being classified as having a high P-leaching risk (Table 4-4); these fields had a moderate soil IC but a high P-source risk. On the other hand, most fields in the East Pow (229 or 93%) were assigned a moderate P-leaching risk as result of high P-source risk combined with low soil IC.

With regards to the two different sampling approaches, both gave again very similar assessments of dissolved P-leaching risk from the fields in both test catchments (Table 4-4 and Figures 4-16 and 4-22).

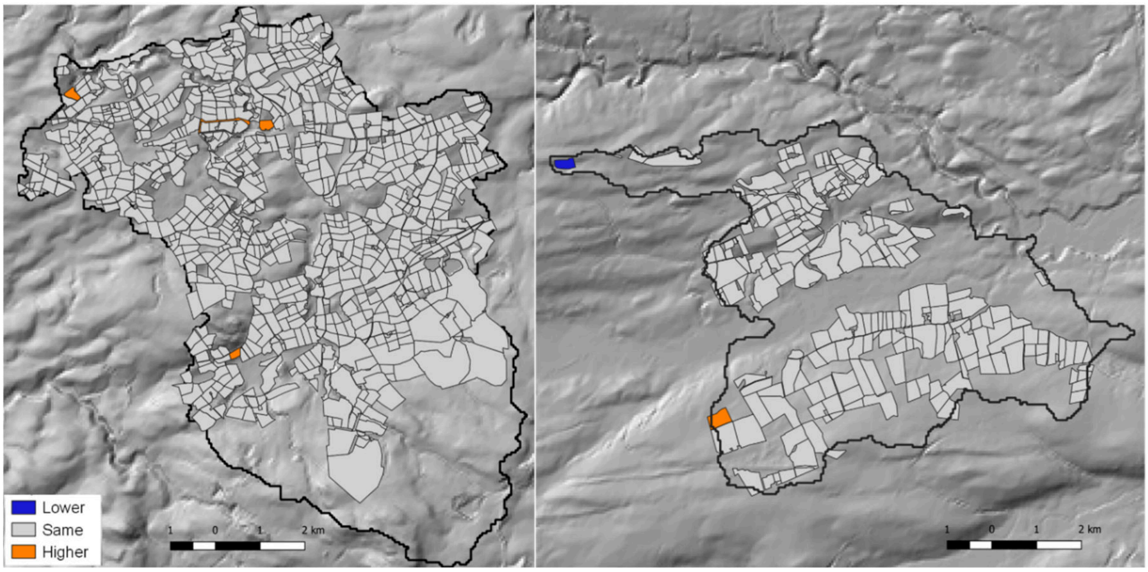

Figure 4-22. Map showing fields where a lower, same or higher P-leaching risk class was assigned when using field centroids compared to when the 50m regular grid approach was used in the two test catchments.

4.5.4. Receptor

Figures 4-23 and 4-24 give the results of the risk assessments of dissolved P impacting the water quality of the nearest watercourse in the Coyle and East Pow catchments with regards to the risk of eutrophication (Water Quality risk). The risk assessments were produced by combining the P-leaching risk assessments for each field with WoE Eutrophication problem risk assessments for the nearest watercourse based on the decision rules given in Table 3-11.

The water quality risk in the Coyle was assessed as being moderate in 643 fields (76%) using the field centroids (Table 4-4); most of these fields had a high P-leaching risk but were connected to watercourses with uncertain eutrophication problem. A further 172 fields (20%) were classified as posing a high risk to water quality, because these fields had an either moderate or high P-leaching risk and were connected to watercourses with a quite certain eutrophication problem. The remaining 31 fields (4%) posed a low risk to water quality because they had a low P-leaching risk and at the same time they were connected to the watercourses with an uncertain problem of eutrophication (Figure 4-23).

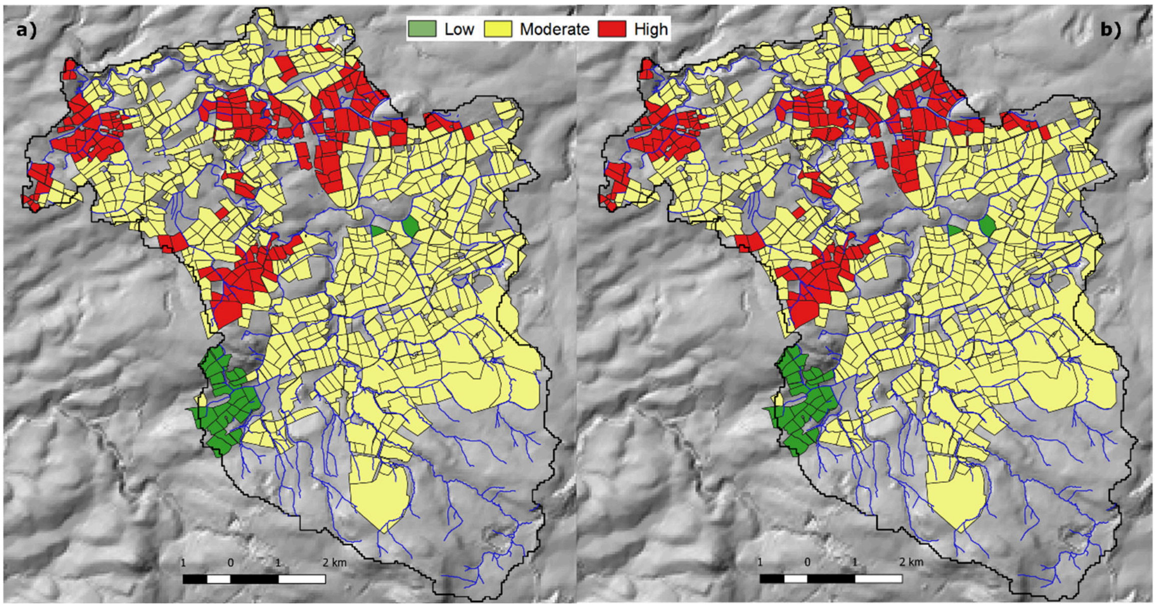

Figure 4-23. Map of fields assessed for Water Quality risk for drainflow in the Coyle catchment a) field centroids and b) 50m regular grid points. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

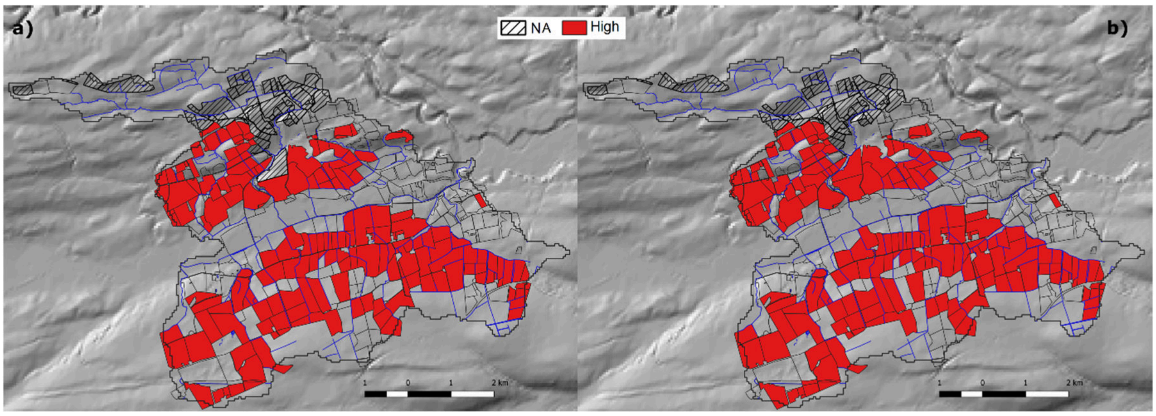

Figure 4-24. Map of fields assessed for Water Quality risk for drainflow in the East Pow catchment a) field centroids and b) 50m regular grid points. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

In the Coyle, water risk assessments done using the two different sampling approaches produced very similar results (Table 4-4 and Figures 4-16 and 4-25); this was observed also for the surface flow pathway and indicates the importance of the eutrophication problem assessment of the nearest watercourse for defining the overall water quality risk from the addition of P-containing materials to land.

In the East Pow, no fields were assessed as posing a low risk to water quality (Table 4-4). Water quality risk was not assessed in 58 fields (using field centroids) because the WoE eutrophication problem was not assessed in the receiving water courses due to missing data. The remaining fields were all found to pose a high risk to water quality because they had either a moderate or high P-leaching risk and were connected to watercourses with a quite certain eutrophication problem. The two different sampling approaches produced the same water quality risk assessments in the fields in the East Pow.

Figure 4-25. Map showing fields where a lower, same or higher Water Quality risk class was assigned when using field centroids compared to when the 50m regular grid approach was used in the two test catchments. © Crown copyright and database right (2019). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

4.6. Overall assessment of the RAG P-risk methodology

The results from the trial and test study in the two catchments indicate that the developed RAG P-risk assessment methodology provides sensible and robust assessments for the different stages of the SPR model. Decision rules used were based on clear and scientifically-robust combinations of different datasets and provided P-risk assessments that were consistent with expert knowledge and previous findings in the test catchments.

Conducting the P-risk assessments separately for the two transport pathways enabled us to identify which factors/processes were driving the risk of additional P adversely impacting the quality of watercourses within the test catchments. This information can be directly used to assist with the Paragraph 7 WML exemptions procedures. For example, the trial and test study results found that surface runoff and soil erosion posed a greater risk to water quality in the Coyle (31% of fields) than leaching to drains, while the opposite was found for the East Pow (77% of fields) (Tables 4-1 and 4-2). For the Coyle, the water risk assessment was driven by the high P-binding capacity of soils in around a third of the catchment coupled with the moderate soil erosion risk and the quite certain problem of eutrophication in one of the two water bodies. For the East Pow, the high risk to water quality was attributed to the low P soil sorption capacity coupled with the quite certain eutrophication problem that characterizes almost all land and the majority of watercourses within the catchment.

The comparison of the P-risk assessments done with the different sampling schemes (field centroids vs 50m regular grid points) showed that the P-risk assessments were relatively insensitive to scale issues rising from the combination of mapping products produced at different levels of spatial detail. For drainflow, both sampling approaches tested produced almost identical P-risk assessments for all fields in the two test catchments. Some differences were observed in the overland flow pathway, mainly in the Coyle catchment, for the assessment of P-loss and P-transport. However, the final water quality risk assessments were very similar for all fields in the two catchments. This showed that using one location within a field would most likely produce the same assessment of eutrophication risk for nearby watercourses due to P application in a field as the one produced when many more locations are considered. Overall, the results from this comparison proved that the P-risk assessments are capable of providing assessments that work at a field-scale level, which is essential for the applicability of the P-risk assessment approach for assisting the Paragraph 7 WML procedures. The only inconsistencies observed due to combining different datasets for applying the P-risk decision rules involved three (3) fields in the East Pow where no soil PSC information was determined; this was due to the coarser nature of the soil PSC map (1:250,000 scale) compared to the soil erosion risk map (50m grid resolution) and the soil series and runoff risk maps (1:25,000), which led parts of these fields lying within an area of organic soils (basin peat) where soil PSC was not determined (also see Figure 4-2/A2). Similarly, limited inconsistencies could also arise from the presence of water features and urban areas that are mapped more coarsely in the soil PSC map. It is recommended that if a dataset value (e.g. soil PSC) is not available for a field, then the value from analogous soil associations should be used instead.

As expected, the assessment of the risk of P applied to land adversely impacting the water quality of a watercourse was greatly influenced by the level of connectivity of a field to the receiving watercourse (i.e. how likely it is for P lost from a field to reach the watercourse) and the current status of the watercourse's water quality.

The level of field connectivity was assessed 2-dimensionally on the shortest distances from the river network and did not consider the true hydrological connection of fields or part of fields with respect to surface drainage lines. This can imply, in some cases, that a single field can be connected to a stream that does not drain that particular field, because it can lie, in whole or in part, beyond its water divide. This was checked by overlaying the field centroids on the OS 50m grid cell resolution DTM and it was found that this situation was infrequent. Also, a comparison with using the 50m regular grid points showed that it produced a negligible effect on the P-transport and water risk assessments for both transport pathways. Using a detailed river network as the one used in this project (that included smaller natural streams/tributaries and man-made features such as ditches) has the advantage of accurately depicting the terrain characteristics in each field, such as slope and flow direction; this minimises the likelihood of a field being connected to the "hydrologically-wrong" watercourse when using the shortest distance as the method for establishing this connection. As mentioned before, our approach cannot consider the presence of man-made features that impede a field's connectivity to a watercourse or assess the effect that vegetated riparian buffer strips can have on the mitigation of P transport to watercourses. This means that it is likely that the RAG P-risk assessments may overestimate the risk of P-transport in fields where hedges, walls or roads exist or where there are established woodland buffer strips in the riparian zone.

The impact of applied P to land on the water quality of the receiving watercourse was assessed using the weight of evidence (WoE) of eutrophication problem. This was considered as the most appropriate water quality index for this type of application because P is regarded as the main driver of eutrophication. The WoE eutrophication problem index also has the advantage of incorporating information on both chemical and biological status of water bodies plus on identified pressures and thus provides an insight on the resilience of aquatic ecosystems to incoming P diffuse pollution. However, the RAG P-risk assessments are only capable of providing a static assessment of whether P applied to land could worsen the problem of eutrophication in a water body and other frameworks, based on conceptual modelling, may need to be developed if a more dynamic assessment is required in the future.

The water quality risk assessments are greatly influenced by the decision rules that we developed to combine the risk of P reaching the watercourse (P-transport and P-leaching for runoff/soil erosion and drainflow, respectively). For example for the subsurface flow pathway, potential over-application of P-rich materials to all fields in the East Pow was found to pose a high risk to watercourses because we took the precautionary approach of assigning a high water quality risk class to fields that have a moderate P-leaching risk but are connected with watercourses that have a certain or quite certain problem of eutrophication. If we decided to assign a greater water quality risk class only to fields with a high P-leaching risk, then all fields within the East Pow would pose a moderate risk to water quality. However, this example also shows the inherent flexibility of the developed decision rules; they can be modified or fine-tuned depending on the level of protection required or if more scientific evidence is available. Therefore, we conclude that the RAG P-risk assessment developed in this project is both scientifically-robust and flexible and can be used with confidence for assisting the Paragraph 7 WML exemption procedure with regards to the risk to water quality.

5. KNOWLEDGE GAPS & RECOMMENDATIONS

5.1. Pathways of P transport

An important element of the development of the RAG P-risk assessment methodology was to consider the forms of P (particulate and dissolved) and their relative importance with regards to the two main pathways; transport via runoff and soil erosion and via leaching to drains. We decided that it was not possible in the context of the RAG P-risk application to jointly and simultaneously assess P risks for both particulate and dissolved P and for both surface and subsurface flow pathways. Thus, P-risk assessments and respective decision rules were developed separately for runoff and soil erosion, which related to particulate P, and for leaching to drains, which related to dissolved P. This approach aimed to cover all possible scenarios and was consistent with findings that particulate P is expected to be the primary source of P in agricultural fields due to runoff and soil erosion, but that dissolved P is also important and has been found to be prevalent in drains in arable as well as grassland soils (Stutter and Richards, 2018). However, recent research findings from drain waters in agricultural catchments revealed that drains can also be pathways for particulate P losses (Stutter and Richards, 2018), while surface runoff is also thought to be a pathway for dissolved P.

Effort was made during developing the decision rules for the two pathways to allow for additional P inputs, for example particulate P inputs to drains. However, the three-class system used in the RAG P-risk application coupled with the kind of information that can be derived from the available datasets provided a limited ability for adjusting the decision rules to account for both P forms at the same time. More research is necessary to fill the gaps concerning P speciation and mobilization under different soil characteristics (e.g. organic matter content) and different land uses and assess the relative presence of different P forms in soil pore water, surface runoff, sediments and drain waters. These findings could then be used to update or improve the decision rules developed for the RAG P-risk project and enable an overall assessment for the risk posed to watercourses by the application of P-rich material to land.

5.2. Effect of different P-containing materials applied to land

The developed RAG P-risk assessment methodology assessed the individual P-risk from the application of P-rich materials to land but was not able to adjust these risks based on the type of P-rich materials and their respective characteristics. According to Cundill et al. (2015), the properties of organic materials spread to land are highly variable, even for materials that are produced by the same economic sector and from similar processes. These properties may further be affected by treatment processes and the length and conditions of storage of the material. Therefore, it must be recognised that a specific batch of organic material spread to land may have properties that differ from the general properties of that type of material, resulting in different benefits and risks from the application to land.

For example, Stutter (2015) examined nutrient compositions including P speciation of seven soil amendments (sewage sludge, anaerobic digestate, green compost, food waste compost, chicken manure, biochar and seaweed) and the P leaching vs retardation of transport on contact with soil surfaces and P availability on a subset of four materials (sewage sludge, anaerobic digestate, green compost and chicken manure). Results showed strong P retention for sewage sludge and compost, but weak P sorption for chicken manure and especially anaerobic digestate, suggesting short-term leaching risks when anaerobic digestate was applied to soil. Also, it was found that sorbed P was strongly fixed, potentially limiting crop availability. The study concluded that variation in P forms and environmental behaviour needs to be understood to both maximise P usage and minimize leaching and soil P accumulation, and that different alternative P source materials need differing recommendations for their agronomic management.

These findings highlight the inherent uncertainties in the RAG P-risk assessment methodology with regards to how different materials applied to land can influence soil characteristics and the ability of soils to retain or mobilise P, which then affects the assessments of P being lost and transported from a field to the watercourses. Therefore, more research is necessary to better characterize the general properties of materials spread to land and their environmental behaviour that can be used to adjust the RAG P-risk or other similar environmental risk assessments.

5.3. Effect of soil pH on P-risk assessments

Information about a field's soil pH was not integrated in the RAG P-risk decision rules because it was assumed that for most cultivated land in Scotland soil pH should be at target (>5.5-5.6). This was considered to be a valid assumption because a basic assumption underlying effective nutrient management and fertiliser planning is that soils are maintained at target acidity status in order to maximise the plant uptake of fertiliser inputs. In mineral soils in Scotland with pH 5.6 and below, key plant nutrients such as P become less available to the growing crop and will reduce potential yields. At soil pH values below 5.5, soluble aluminium inhibits root growth, again having an impact on crop yield, nutrient use efficiency and profitability (SAC Consulting, 2018, unpublished).

Based on the study by SAC Consulting (2018, unpublished), around 56% of productive farmland in the East Pow had pH 6 or greater and almost 98% of the land had pH greater than 5.5. However, around 22% of the productive land in the Coyle had soil pH less than 5.5 and around 32% of the land had pH below 5.5 and 5.7. Soils that are on target for P but maintained at pH below target represent a higher diffuse pollution risk due to the less efficient use of available plant nutrients. Assessing the risk of additional P entering watercourses due to the combined effect of low pH and high soil P status is difficult to predict because soil pH influences chemical fixation of P in soil. However, for soils with a pH of less than 5.5, the larger availability of soluble forms of aluminium and iron hydroxides will reduce plant available P as applied in slurry, manures and bagged fertilisers; this will increase the capacity of soils to lock up P, increasing the risk of P loss to aquatic systems via eroded soils.

Therefore, based on the above, it is possible that around half of the productive land in the Coyle could be at an increased risk of P loss to aquatic systems via soil erosion if more P is applied. Quantifying the additional risk of P transport to watercourses caused by P accumulation in strongly P-fixing acid soils is very difficult in the context of the RAG P-risk application. However, the soil P sorption capacity map provides an accurate estimate of the soil's capacity to bind incoming P and has been produced by using soil pH amongst other parameters (see Section 2.2.3). Therefore, we conclude that although soil pH has an important influence on the processes that control P binding to soils, using soil PSC instead is more appropriate for the RAG P-risk assessments. If soil acidity is found to be an issue in a field, it is recommended to encourage the farmer to mediate it using the current lime recommendations in order to both increase nutrient use efficiency and profitability and minimize the risk of diffusion pollution caused by the application of P-rich materials to land.

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7. APPENDIX

7.1. Classification of crop risk classes

Table 7-1 gives the proposed risk classes for each crop type and land use in the IACS database that is used to adjust a field's erosion risk class.

Table 7-1. Proposed system of crop risk classification for the adjustment of soil erosion risk classes

SHORT CODE	LAND USE DESCRIPTION	CROP RISK
AGRI	SFPS BEING CLAIMED ON AGRI-ENVIRONMENTAL OPTIONS	NA
AMCP	AROMATIC, MEDICAL AND CULINARY PLANTS	Moderate
ARTC	ARTICHOKES	High
ASPG	ASPARAGUS	High
ASSF	ARABLE SILAGE FOR STOCK FEED	Moderate
BEAN	BEANS FOR HUMAN CONSUMPTION	Moderate
BFLO	BULBS/FLOWS	High
BKB	BLACKBERRIES	High
BLB	BILBERRIES (AND OTHER FRUITS OF THE GENUS VACCINIUM)	High
BLR	BLACKCURRANTS	High
BOR	BORAGE	High
BPP	BEDDING AND POT PLANTS	High
BSFS	FLOW BULBS AND CUT FLOWS	High
BSP	BRUSSEL SPROUTS	High
BW	BUCKWHEAT	Moderate
CABB	CABBAGES	High
CALA	CALABRESE	High
CANS	CANARY SEED	Moderate
CARR	CARROTS	High
CAUL	CAULIFLOW	High
CMIX	ARABLE SILAGE FOR STOCK FEED	Moderate
COMM	COMMON GRAZING	Low
EX_SS	EX STRUCTURAL SET-ASIDE (AFFORESTED LAND ELIGIBLE FOR SFPS)	Low
FALW	FALLOW	Moderate
FALW_5	FALLOW LAND FOR MORE THAN 5 YEARS	Moderate
FB	FIELD BEANS	Moderate
FFS	FIBRE FLAX	Moderate
GCM	GREEN COVER MIXTURE	Low
GSB	GOOSEBERRIES	High
HS	HEMP	Moderate
HZL	HAZELNUTS	Moderate
LEEK	LEEKS	High
LETT	LETTUCE	High
LGB	LOGANBERRIES	High
LIEM	LFASS INELIGIBLE ENVIRONMENTAL MANAGEMENT	Low

SHORT CODE	LAND USE DESCRIPTION	CROP RISK
LIN	LINSEED	Moderate
LINSEED	LINSEED	Moderate
LLO	LAND LET OUT TO OTHERS	-
LLO_AGRI	LLO-SFPS BEING CLAIMED ON AGRI-ENVIRONMENTAL OPTIONS	NA
LLO_AMCP	LLO-AROMATIC, MEDICAL AND CULINARY PLANTS	Moderate
LLO_ARTC	LLO-ARTICHOKES	High
LLO_ASSF	LLO-ARABLE SILAGE FOR STOCKFEED	High
LLO_BEAN	LLO-BEANS FOR HUMAN CONSUMPTION	Moderate
LLO_BFLO	LLO-BULBS/FLOWS	High
LLO_BLB	LLO-BILBERRIES (AND OTHER FRUITS OF THE GENUS VACCINIUM)	High
LLO_BPP	LLO-BEDDING AND POT PLANTS	High
LLO_BSP	LLO-BRUSSEL SPROUTS	High
LLO_CABB	LLO-CABBAGES	High
LLO_CALA	LLO-CALABRESE	High
LLO_CARR	LLO-CARROTS	High
LLO_CAUL	LLO-CAULIFLOW	High
LLO_CMIX	LLO-ARABLE SILAGE FROM STOCK FEED	Moderate
LLO_EX_SS	LLO-LAND PREVIOUSLY STRUCTURAL SET-ASIDE	Low
LLO_FALW	LLO-FALLOW	Moderate
LLO_FB	LLO-FIELD BEANS	Moderate
LLO_LEEK	LLO-LEEKS	High
LLO_LETT	LLO-LETTUCE	High
LLO_LIEM	LLO-LFASS INELIGIBLE ENVIRONMENTAL MANAGEMENT	NA
LLO_LIN	LLO-LINSEED	Moderate
LLO_MAIZ	LLO-MAIZE	High
LLO_MC	LLO-MIXED CEREALS	Moderate
LLO_NU_FS	LLO-NURSERY - FRUIT STOCK	High
LLO_NU_OT	LLO-NURSERY - ORNAMENTAL TREES	High
LLO_NURS	LLO-NURSERIES	-
LLO_OCS	LLO-OTHER CROPS FOR STOCK FEED	Moderate
LLO_OCS_B	LLO-FODDER BEET	High
LLO_OCS_K	LLO-KALE AND CABBAGES FOR STOCKFEED	High
LLO_ONU	LLO-OTHER NURSERY STOCKS	-
LLO_OSFRT	LLO-OTHER SOFT FRUIT	High
LLO_OVEG	LLO-OTHER VEGETABLES	High
LLO_PEAS	LLO-PEAS FOR HUMAN CONSUMPTION	Moderate
LLO_PEM	LLO-POSITIVE ENVIRONMENTAL MANAGEMENT	NA
LLO_PGRS	LLO-GRASS OVER 5 YEARS	Low
LLO_PP	LLO-PROTEIN PEAS	Moderate
LLO_PRSL	LLO-PONDS, RIVERS, STREAMS OR LOCHS	NA
LLO_PSTS	LLO-PISTACHIOS	Low
LLO_RASP	LLO-RASPBERRIES	High
LLO_RAST	LLO-RAPE FOR STOCK FEED	Moderate

SHORT CODE	LAND USE DESCRIPTION	CROP RISK
LLO_RCG	LLO-REED CANARY GRASS	Low
LLO_RCG_E	LLO-REED CANARY GRASS ENERGY	Low
LLO_RGR	LLO-ROUGH GRAZING	Low
LLO_RYB	LLO-ROADS,YARDS OR BUILDINGS	NA
LLO_SB	LLO-SPRING BARLEY	Moderate
LLO_SB_E	LLO-SPRING BARLEY ENERGY	Moderate
LLO_SC	LLO-SWEETCORN	High
LLO_SCR	LLO-SCREE OR SCRUB	Low
LLO_SL	LLO-SWEET LUPINS	Moderate
LLO_SO	LLO-SPRING OATS	Moderate
LLO_SOSR	LLO-SPRING OILSEED RAPE	Moderate
LLO_SPOT	LLO-SEED POTATOES	High
LLO_SRC_E	LLO-SHORT ROTATION COPPICE ENERGY	Low
LLO_STRB	LLO-STRAWBERRIES	High
LLO_STS	LLO-SHOPPING TURNIPS/SWEDES	High
LLO_STS_E	LLO-SHOPPING TURNIPS/SWEDES ENERGY	High
LLO_SW	LLO-SPRING WHEAT	Moderate
LLO_TGRS	LLO-GRASS UNDER 5 YEARS	Low
LLO_TRIT	LLO-TRITICALE	Moderate
LLO_TSB	LLO-TREES, SHRUBS AND BUSHES	Low
LLO_TSWS	LLO-TURNIPS/SWEDES FOR STOCK FEED	High
LLO_TURF	LLO-TURF PRODUCTION	Moderate
LLO_WAF	LLO-WOODLAND AND FORESTRY	Low
LLO_WB	LLO-WINTER BARLEY	Moderate
LLO_WBS	LLO-WILD BIRD SEED	Moderate
LLO_WCC	LLO-WHOLE CROP CEREALS	Moderate
LLO_WDG	LLO-OPEN WOODLAND(GRAZED)	Low
LLO_WO	LLO-WINTER OATS	Moderate
LLO_WOSR	LLO-WINTER OILSEED RAPE	Moderate
LLO_WOSR_E	LLO-WINTER OILSEED RAPE ENERGY	Moderate
LLO_WPOT	LLO-WARE POTATOES	High
LLO_WPOT_E	LLO-WARE POTATOES ENERGY	High
LLO_WW	LLO-WINTER WHEAT	Moderate
MAIZ	MAIZE	High
MC	MIXED CEREALS	Moderate
MIL	MILLET	Moderate
MSC	MISCANTHUS	Low
NEWTRS	NEW WOODLAND (ELIGIBLE FOR SFPS)	Low
NF_CRBE	NON-FOOD SETASIDE - CRAMBE FOR INDUSTRIAL USE	High
NF_HEAR	NON-FOOD SETASIDE - HIGH ERUCIC ACID RAPESEED	Moderate
NF_IB	NON-FOOD SETASIDE - BARLEY FOR INDUSTRIAL USE	Moderate
NF_IOSR	NON-FOOD SETASIDE - OILSEED RAPE FOR INDUSTRIAL USE	Moderate
NF_IOTH	NON-FOOD SETASIDE - OTHER CROPS FOR INDUSTRIAL USE	-

SHORT CODE	LAND USE DESCRIPTION	CROP RISK
NF_IW	NON-FOOD SETASIDE - WHEAT FOR INDUSTRIAL USE	Moderate
NF_SRC	NON-FOOD SETASIDE - FOREST TREES SHORT CYCLE	Low
NF_TSB	NON-FOOD SETASIDE - TREES SHRUBS AND BUSHES	Low
NS_5S_FWS	NORMAL SETASIDE - 5 YEAR UNDER FWS	Low
NS_5S_WGS	NORMAL SETASIDE - 5 YEAR UNDER WGS	Low
NS_BF	NORMAL SETASIDE - BARE FALLOW	Moderate
NS_G	NORMAL SETASIDE - SOWN GRASS COVER	Low
NS_GCM	NORMAL SETASIDE - GREEN COVER MIXTURE	Low
NS_MU	NORMAL SETASIDE - MUSTARD	Low
NS_NRC	NORMAL SETASIDE - NAT REGEN (AFTER CEREALS)	Moderate
NS_NRO	NORMAL SETASIDE - NAT REGEN (AFTER OTHER CROPS)	Moderate
NS_OL	NORMAL SETASIDE - ORGANIC LEGUMES	Low
NS_OWN	NORMAL SETASIDE - OWN MANAGEMENT PLAN	Low
NS_P	NORMAL SETASIDE - PHACELIA	Low
NS_SAS_W	NORMAL SETASIDE - NEXT TO WATERCOURSES,HEDGES, WOODS,DYKES AND SSSIs	Moderate
NS_WBC	NORMAL SETASIDE - WILD BIRD COVER	Low
NU_FS	NURSERY - FRUIT STOCK	High
NU_OT	NURSERY - ORNAMENTAL TREES	High
NU_SH	NURSERY - SHRUBS	Moderate
NURS	NURSERIES	-
OCS	OTHER CROPS FOR STOCK FEED	Moderate
OCS_B	FODDER BEET	High
OCS_K	KALE AND CABBAGES FOR STOCKFEED	High
OILSEED_RAPE	OILSEED RAPE	Moderate
ONU	OTHER NURSERY STOCKS	-
OSFRT	OTHER SOFT FRUIT	High
OTH	OTHER LAND	-
OVEG	OTHER VEGETABLES	High
PEAS	PEAS FOR HUMAN CONSUMPTION	Moderate
PEM	POSITIVE ENVIRONMENTAL MANAGEMENT	NA
PGRS	GRASS OVER 5 YEARS	Low
PP	PROTEIN PEAS	Moderate
PRSL	PONDS, RIVERS, STREAMS OR LOCHS	NA
PSTS	PISTACHIOS	Low
RASP	RASPBERRIES	High
RAST	RAPE FOR STOCK FEED	Moderate
RCG	REED CANARY GRASS	Low
RGR	ROUGH GRAZING	Low
RHB	RHUBARB	High
RRC	REDCURRANTS	High
RYB	ROADS, YARDS OR BUILDINGS	NA
RYE	RYE	Moderate
SAAP_A	SETASIDE AGRICULTURAL PRODUCTION - ARABLE	Moderate

SHORT CODE	LAND USE DESCRIPTION	CROP RISK
SAAP_F	SETASIDE AGRICULTURAL PRODUCTION - FORAGE	Moderate
SAAP_PROT	SETASIDE AGRICULTURAL PRODUCTION - PROTEINS	Moderate
SB	SPRING BARLEY	Moderate
SC	SWEETCORN	High
SC_E	SWEETCORN ENERGY	High
SCR	SCREE OR SCRUB	Low
SFRT	SOFT FRUIT	High
SHAR	SHARED GRAZING	Low
SL	SWEET LUPINS	High
SO	SPRING OATS	Moderate
SOR	SORGHUM	Moderate
SOSR	SPRING OILSEED RAPE	Moderate
SOSR_E	SPRING OILSEED RAPE ENERGY	Moderate
SPOT	SEED POTATOES	High
SRC	SHORT ROTATION COPPICE	High
SRC_E	SHORT ROTATION COPPICE ENERGY	High
SS_EH	STRUCTURAL SETASIDE - ELIGIBLE HABITATS	Low
SS_WP	STRUCTURAL SETASIDE - WGS, FWPS OR SFGS	Low
SS_X5	STRUCTURAL SETASIDE - EX 5 YEAR STILL IN FWS	Low
STRB	STRAWBERRIES	High
STS	SHOPPING TURNIPS/SWEDES	High
SW	SPRING WHEAT	Moderate
TFRT	TOP FRUIT	High
TGRS	GRASS UNDER 5 YEARS	Low
TRIT	TRITICALE	Moderate
TSB	TREES SHRUBS & BUSHES	Low
TSWS	TURNIPS/SWEDES FOR STOCK FEED	High
TURF	TURF PRODUCTION	Moderate
UCL	UNCLAIMED LAND	NA
WAF	WOODLAND AND FORESTRY	Low
WAFF_LMCMS	WOODLAND/FORESTRY WITH UNIQUE FIELD IDENTIFIER	Low
WB	WINTER BARLEY	Moderate
WBS	WILD BIRD SEED	Low
WCC	WHOLE CROP CEREALS	Moderate
WDG	OPEN WOODLAND(GRAZED)	Low
WO	WINTER OATS	Moderate
WOSR	WINTER OILSEED RAPE	Moderate
WOSR_E	WINTER OILSEED RAPE ENERGY	Moderate
WPOT	WARE POTATOES	High
WRC	WHITECURRANTS	High
WW	WINTER WHEAT	Moderate

7.2. Example of P-risk assessments using the two sampling approaches

7.2.1. Description

Figures 7-2 to 7-15 present maps that show the results from the individual P-risk assessments for overland flow in three adjacent fields in the Coyle catchment (Figure 7-1) with different field characteristics (e.g. crop type and soil phosphorus sorption capacities). These fields were selected to illustrate how differences in field P-risk assessments can occur from using the two different sampling approaches, i.e. field centroids vs. 50m regular grid points. The maps presented follow the steps for conducting the RAG P-risk assessments given in Figure 3-1 (A) and show the differences in the field P-risk assessments due to the different sampling approach used.

Figure 7-1. Map of field boundaries. Crop types: TGRS: Grass under five years; SB: Spring barley; PGRS: Grass over five years. Satellite imagery from Google Maps.

7.2.2. Source

- **<u>Soil P-status</u>**

Fields	Field P-status	
	Field Centroids	50m regular grid points
Field 1	Moderate	Moderate
Field 2	Moderate	Moderate
Field 3	Moderate	Moderate

Figure 7-2. Maps of field soil P-status based on the two sampling approaches. Satellite imagery from Google Maps.

- **Soil phosphorus sorption capacity (PSC)**

Fields	Field PSC class	
	Field Centroids	**50m regular grid points**
Field 1	Low	Low
Field 2	Moderate	Moderate
Field 3	Moderate	Moderate

Figure 7-3. Maps of field soil phosphorus sorption capacity (PSC) based on the two sampling approaches. Satellite imagery from Google Maps.

➢ **<u>P-source Risk Assessment</u>**

Fields	Field P-source Risk class	
	Field Centroids	**50m regular grid points**
Field 1	Moderate	Moderate
Field 2	High	High
Field 3	High	High

Figure 7-4. Maps of field P-source risk assessments made using the two sampling approaches. Satellite imagery from Google Maps.

7.2.3. Pathway

➢ <u>Crop risk</u>

Fields	Field Crop Risk class	
	Field Centroids	50m regular grid points
Field 1	Low	Low
Field 2	Moderate	Moderate
Field 3	Low	Low

Figure 7-5. Maps of field crop risk assessments made using the two sampling approaches. Satellite imagery from Google Maps.

➢ **Soil Erosion Risk**

Fields	Field Soil Erosion Risk class	
	Field Centroids	**50m regular grid points**
Field 1	Moderate	Moderate
Field 2	Moderate	Moderate
Field 3	Moderate	Moderate

Figure 7-6. Maps of field soil erosion risk made using the two sampling approaches. Satellite imagery from Google Maps.

Crop-adjusted Soil Erosion Risk

Fields	Field Crop-adjusted Soil Erosion Risk class	
	Field Centroids	50m regular grid points
Field 1	Moderate	Low
Field 2	Moderate	Moderate
Field 3	Moderate	Low

Figure 7-7. Maps of field crop-adjusted soil erosion risk based on the two sampling approaches. Satellite imagery from Google Maps.

➢ **P-loss Risk Assessment**

Fields	**Field P-loss Risk class**	
	Field Centroids	**50m regular grid points**
Field 1	Moderate	Low
Field 2	High	Moderate
Field 3	High	Moderate

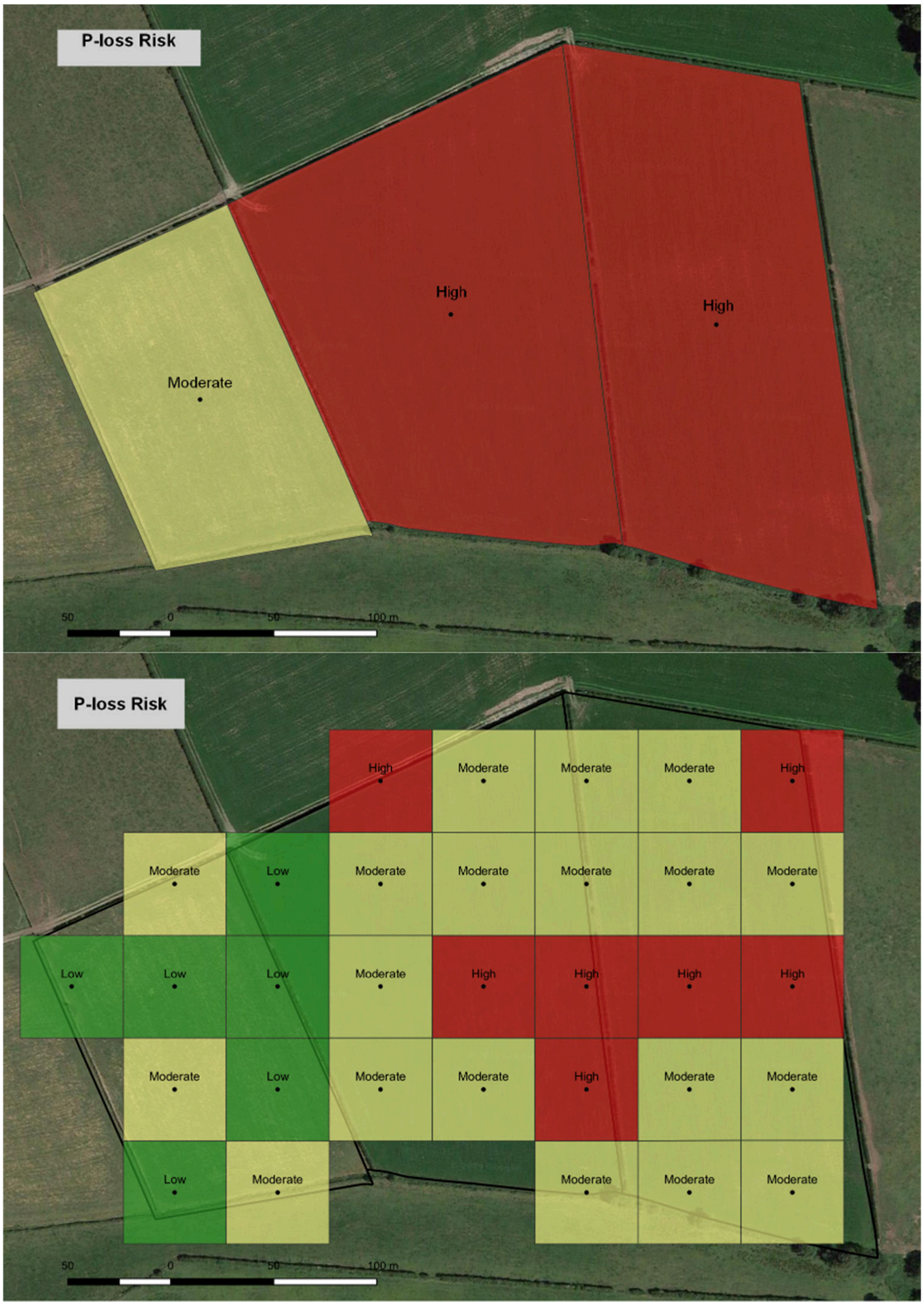

Figure 7-8. Maps of field P-loss risk assessments using the two sampling approaches. Satellite imagery from Google Maps.

➢ **Assessment of connectivity**

Fields	Field connectivity class	
	Field Centroids	50m regular grid points
Field 1	Moderate	Moderate
Field 2	Moderate	Moderate
Field 3	Moderate	Moderate

Figure 7-9. Maps of field connectivity assessment based on the two sampling approaches. Satellite imagery from Google Maps.

➢ **P-transport Risk Assessment**

Fields	Field P-transport Risk class	
	Field Centroids	50m regular grid points
Field 1	Moderate	Low
Field 2	High	High
Field 3	High	High

Figure 7-10. Maps of field P-transport risk assessments using the two sampling approaches. Satellite imagery from Google Maps.

7.2.4. Receptor

➢ <u>**Weight of Evidence (WoE) of Eutrophication problem**</u>

Fields	Field WoE Eutrophication problem	
	Field Centroids	50m regular grid points
Field 1	Uncertain	Uncertain
Field 2	Uncertain	Uncertain
Field 3	Uncertain	Uncertain

Figure 7-11. Maps of weight of evidence (WoE) of eutrophication problem based on the two sampling approaches. Satellite imagery from Google Maps.

- ## Water Quality risk

Fields	Field P-transport Risk class	
	Field Centroids	50m regular grid points
Field 1	Moderate	Moderate
Field 2	Moderate	Moderate
Field 3	Moderate	Moderate

Figure 7-12. Maps of field Water quality risk assessments using the two sampling approaches. Satellite imagery from Google Maps.

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