Development of indicators of the impact of SRDP (2007-2013) measures on water quality and applications to the Lunan Water catchment and at national level.

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0. Executive summary

a. EC Agri-environment payments account for around 2.5 billion ECros per year and are financially the largest fund for implementation of the ECEC's rural development policy. In Scotland, expenditure for 2008-2011 was around £263m. In the context of water quality, the ECEC require post-hoc evidence (in the form of policy impact indicators) to assess whether these payments are well designed.

b. The preferred impact indicator for Water Quality in the UK has been the Gross Nutrient Budget (GNB), on the assumption that changes in the surplus between inputs and outputs of key nutrient pollutants (N and P) will have an indirect impact on loss to the environment (both the atmosphere and water). However, the GNB methodology does not consider the mode of action of measures, loss pathways, how the nutrient loadings are lost from the soil or whether they impact on air quality or water quality.

c. The work reported here develops a methodology to provide an impact indicator for relevant agri-environment payments (principally Scotland Rural Development Plan (SRDP) water quality options) funded in Scotland from 2007-2013. The Rural Priorities (RP) options were grouped into several categories according to similarity of impact on water quality:
   - Manure/slurry storage
   - Arable reversion to grassland
   - Woodland creation and managment
   - Low intensity grazing
   - Water margins
   - Organic farming
   - Creation, restoration and management wetlands
   - Extended hedges and grass margins
   - Restoration of floodplains
   - Biodiversity of in-bye land

d. We have defined an indicator for the impact of SRDP spend on water quality as: "*An index of the size of change in a critical water quality metric for relevant water bodies or areas, relative to the standard required for Good Ecological Status (GES) as defined by the Water Framework Directive, that is the result of measures funded by SRDP*".

e. The pollutant that is most frequently associated with failure of Scottish fresh waters to meet GES is phosphorus in the form of inorganic phosphate. This often strongly influences the aquatic plants growing in surface waters (eg. algae, cyano-bacteria, diatoms, higher plants). A rationale for the estimation of the impact of each of the categories of measure on Total Phosphorus loads to water, has been devised (see Appendix 1). Where we have fields with these options, it is assumed that there is some mitigation of loss of P to water.

f. For example, with manure/slurry storage the model assumes that the investment helps avoid surface run off and rapid losses of P down field drains and ultimately into the watercourses. Similarly, with arable reversion to grassland options it is assumed that the transport of sediment and associated P to watercourses will be slowed down.

g. To calculate these impacts of SRDP on TP loads on a 1km^2 scale a Geographic Information System process has been described in a handbook developed by James Hutton Institute (JHI). This enabled processing of confidential field level data by the Scottish Government's Geographic Information Science and Analysis Team (GISAT) in conjunction with the Rural and Environment Science and Analytical Services (RESAS) division. Data was supplied by the Rural Payments and Inspections Directorate (SGRIPID). The output was a set of maps presenting the impact of these measures at 1km2 scale across Scotland. This generated a set of maps describing the impact of these measures at 1km^2 scale across Scotland (see Appendix 3).

h. The impacts on the annual amount of TP transported by river water bodies to their outlets have been summarised by JHI for individual categories and in total, at national and priority catchment (PC) scales. An impact indicator based on the average concentration of TP and the standard for good ecological status has been determined for each PC. Fig 1 summarises the process used to provide this indicator.Category F measures, ***Creation and management of woodland*** and Category J measures, ***management and restoration of wetlands*** have had the strongest impact on P loads, each accounting for 45% of the P loads mitigated, a total of 2.7 kT TP). The largest number of 1 km^2 squares affected is the 17,820 squares impacted by category G, ***management of low intensity grazing***.The strongest overall impact of SRDP measures on water quality status is likely to be in the Buchan coastal and Ugie catchments.

i. The methodology used, especially the impact of woodlands on remote, west coast catchments, the impact of wetland creation, and the method for accumulating impacts over multiple years, will benefit from further review, now that the initial spatial datasets have been generated and output of the analysis assessed.

j. An approach for cost:effectiveness analysis (CEA) of SRDP measures for mitigating TP loads to standing waters at catchment scale has been described for the Lunan Water Catchment in Angus, which illustrates the sensitivity of the measures employed to target P load reductions.

k. There is likely to be, over the long term, a net present benefit through the impact of SRDP measures on P loads to water across Scotland. A large proportion of this impact is associated with two measures, creation of woodland and creation, restoration and management of wetlands. The benefits of spend on these measures is larger partly because they continue to accrue over time. However, more data on the previous land use for sites where these measures have been introduced, is needed to confirm this.

1. Introduction

1.0 Purpose of project. The objective of the work described here is to develop and apply a water quality impact indicator for the 2007-2013 Scottish Rural Development Plan (SRDP) measures. This is required for the EC Common Monitoring and Evaluation Framework (CMEF).

1.1. Water quality objectives in the SRDP programme. Agri-environment payments are financially the largest measure for implementation of the EC's rural development policy, with around 2.5 billion ECros per year spent. In Scotland, expenditure for 2008-2011 was around £373m for agri-environment and forestry. http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/RuralPrioritiesStats. In the context of water quality in Scotland, there is a need to develop post-hoc evidence based impact indicators for relevant agri-environment payments funded from 2007-2013, to assess whether these payments are well designed, with respect to the objectives of the Water Framework Directive (WFD). This will also mean that when revision of the SRDP is implmented post-2013, the measures funded will have improved potential to enhance water quality, in line with the requirements of WFD, as set out in Scottish national and regional River Basin Plans.

1.2 Common Monitoring and Evaluation Framework (CMEF). The Common monitoring and evaluation framework (CMEF) is designed to report on financial execution, outputs, results and impacts of rural development programmes. Impact indicators are used to measure longer term socio-economic and environmental effects for rural development policy established at programme level. The indicators relevant for agri-environment are: reversal in biodiversity decline, trends in farmland bird populations, maintenance of High nature value farmland and forestry, improvement in water quality and contribution to climate change mitigation. It has been noted that environmental benefits of agri-environment payments are unclear, that little targeting occurs, and the evidence base is weak (ECropean Court of Auditors, 2011).

In its recent communication 'The CAP towards 2020', the Commission advocates improved targeting of the measures under the rural development policy. Selection procedures can ensure that those projects selected provide the best value for money. In practice, more than 90 % of the EC agri-environment budget is implemented on the basis of eligibility criteria only, and not expected impacts.

1.3 Requirements for impact indicators for water quality. Water quality needs to be assessed, and to some extent managed, at catchment level. Reporting of water quality change is generally at catchment scale (eg SEPA's Harmonised Monitoring Scheme reports trends in nutrients, sediments and pesticides for the main rivers in Scotland) and in national trends (eg Water

Framework Directive River Basin Management Plans summarise trends in the overall quality of river, estuarine and coastal water bodies). Hence addressing impacts on water quality directly requires exercises in scaling and source apportionment.

Impact indicators could potentially be either be focused qualitatively on the spatial distribution of implemented measures, relative to water quality concerns in regulated water bodies, or quantitatively, as attempts to describe the relative and absolute impact of measures on water quality in selected water bodies. Efforts to arrive at qualitative impacts have been made under the CREW (2014) project commissioned by Scottish Government (http://www.crew.ac.uk/projects/assessing-potential-water-and-soil-quality-options-srdp). For this project, it is assumed that an impact indicator needs to estimate the effect of SRDP measures on a specified outcome (e.g. % change in P load, or P concentration, to surface water bodies at appropriate scales, relative to WFD standards).

1.4. Existing data sources used in the CMEF. The preferred impact indicator for Water Quality in the UK has been the Gross Nutrient Budget (GNB), on the assumption that changes in the surplus between inputs and outputs will have an indirect input on loss to the environment (both the atmosphere and water) of key nutrient pollutants, Nitrogen (N) and Phosphorus (P). For this purpose, the CMEF has defined an impact indicator based on changes in GNB as follows:

"Quantitative change in the estimations of GNB that can be attributed to the intervention once double counting, deadweight and displacement effects have been taken into account.

However, Fernall (2010) also notes that:

•The current methodology does not consider loss pathways, how the nutrient loadings are lost from the soil and whether, for example, they impact on air quality or water quality.

•The balances provide an estimate of total annual loadings but do not attempt to quantify the cumulative or long term impacts of these annual loadings.

This is in keeping with the widespread understanding of the factors influencing P losses to water, as illustrated by the following quote:

"Reducing P inputs to levels that can be efficiently used in the agricultural systems would be part of the solution. However, more importantly, to accomplish this balance it is necessary to have a good understanding of the pathways P follows to reach surface waters (terrestrial processes) and the way P behaves (aquatic processes) once it reaches those waters. In most cases, controlling the processes and pathways that transport P to surface waters is the most realistic solution (Gburek et al., 2000)".

We therefore consider, at least for P, that focusing directly on the impact of specific SRDP measures on P loads and P concentrations in surface water bodies, is a more robust way of obtaining impact indicators.

1.5. The SRDP Scheme. Based on SRDP key statistics released on 4 September 2013 (http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/RuralPrioritiesStats) between April 2008 (when SRDP- Rural Priorities were opened) to 04/09/2013, contracts worth over £610 million were agreed for over 8,900 cases – including over £167 million to support business development, over £373 million for agri-environment and forestry and almost £68 million to support rural enterprise and rural communities. The SRDP-rural priorities encompass 37 packages[1]. 'Reducing Diffuse Pollution (RDP)' is one of these packages. The key aim of this package is to help deliver the 'Water Quality' outcome through the implementation of various actions listed under the package. The package supports actions which are needed under existing water legislation and codes of good practice. See:

http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/Packages/ReducingDiffusePollutio.

A total of 42 potential options were identified under this package – 7 options ('always deliver the required output'); 27 options ('help to achieve the desired outcome in specific circumstances') and 8 options ('other'). • those which will: "always deliver the desired outcome"

These measures are associated with the following types of change:

- land use change,
- land management change
- grazing management change
- riparian management change
- drainage management change
- manure management change

In terms of uptake of RP measures (number of approved cases with options) within the SRDP options, about 67% of the cases were accounted for by only 6 options: Water margins and enhanced riparian buffer areas (16.7%), Open grazed or wet grassland for wildlife (15.7%), Management of wetland (10.4%), Management of species rich grassland (9.9%), Woodland creation - Native

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[1] These packages are not mutually exclusive. Several actions or list of options can appear in more than one package. Also, implementation of actions in one package can deliver outcomes required not only in that These These packages are not mutually exclusive. Several actions or list of options can appear in more than one package. Also, implementation of actions in one package can deliver outcomes required not only in that particular package but also those outcomes targeted to be achieved in a different SRDP-RP package. Example – 'Reducing Diffuse Pollution' package and 'reducing Losses of Nitrates' Package

woodland planting (8.2%), and Management of habitat mosaics (6.3%). Options such as Livestock tracks, gates and river crossings; Manure/slurry treatment; Treat run-off of pollutants (farm wetlands); Management of grass margins and beetle banks in arable fields, and Reducing bacterial contamination in watercourses have shown slow uptake rates.

Examining the approved or spent cost allocation across SRDP-RP measures, nearly 42% of the costs out of the over £610 expenditure was associated with 'reducing diffuse pollution (RDP)' package. Out of the 42 potential actions or options within the RDP package, only 5 options accounts for about 80% of the money spent on options related to RDP– Woodland creation (Native woodland planting) (42%); Manure/slurry storage (16%); Open grazed or wet grassland for wildlife (13); Water margins and enhanced riparian buffer areas (5%); and Management of habitat mosaics (4%). Table 1 summarises the SRDP options in the diffuse pollution package.

Comment [u1]: If this is in the introduction I feel it should be summarised and/ or included in the methodology as it gets quite technical and detailed i.e. moving onto what was undertaken.

1.6 Project timeline.

The process for this project developed over time, as initially the remit for this project was to review and *if necessary* amend the Gross Nutrient Budget Indicator. As it became clear that a new approach would be useful, further support for the work was sought from the RESAS Strategic Research Programme through the Scottish Government liason officer (Helen Jones) . We set out in BOX 1 the timetable of the project process, since July 2011.

Key Dates	*Activity*	Rural Development company (John Grieve)	Rural Statistics Unit (Gilly Diggins/Allan Bragg)	JHI (Andy Vinten/James Sample)	SG RESAS (Helen Jones)	SG RIPID (Paul Jarron, Richard Murray)	SEPA(Jannette Macdonald/Brian McCreadie)
Aug-11	***Rural Development Company agree contract with SG Rural Statistics Unit for ongoing evaluation of SRDP 2007-2013***	X	X				
Jan-12	***RDC agree subcontract with MSCL for evaluation of impact of SRDP measures on Water Quality and climate change***	X		X			
	Brief review of UK Gross Nutrient Budgets as impact indicators (methods, availability of data)			X			
	Summary and categorisation of SRDP measures			X			
	Review of literature on measures impact			X			
Jun-12	***Report describing impact indicators for each category of SRDP measure***	X	X	X	X		X
Jul-12	***Agree incorporation of spatial analysis of impact indicators into RESAS Core research work package 2.3***		X	X	X		
	Develop GIS process for calculation of SRDP Water Quality impact indicators at Ikm^2 scale			X			
Dec-12	***GIS Handbook to Rural Statistics Unit for processing and anonymisation***		X	X			
Sep-13	***SGRPID provide RSU access to farm and field level SRDP returns for ?2009***		X			X	
Mar-14	***Data returned to JHI for summarisation, spatial anlysis and graphics***		X	X			
	Loading impact indicators at national level estimated			X			
Mar-14	***Draft maps to RSU for CREW SRDP***		X	X			
	Agree use of PC catchment shapefiles with SEPA			X			X
	Loading Impact indicators for Priority catchments estimated			X			
	Cost Effectiveness Analysis of SRDP impact indicators for example (Lunan Water) catchment			X			
	Discharge and areas of PCs calculated			X			
	Obtain GES standards for PCs			X			
	Concentration impact indicators calculated for PCs			X			
May-14	***Draft final report***		X	X			

BOX 1. SRDP impact indicators project timeline.

Figure 1. Process for development of impact indicators of SRDP measures on water quality

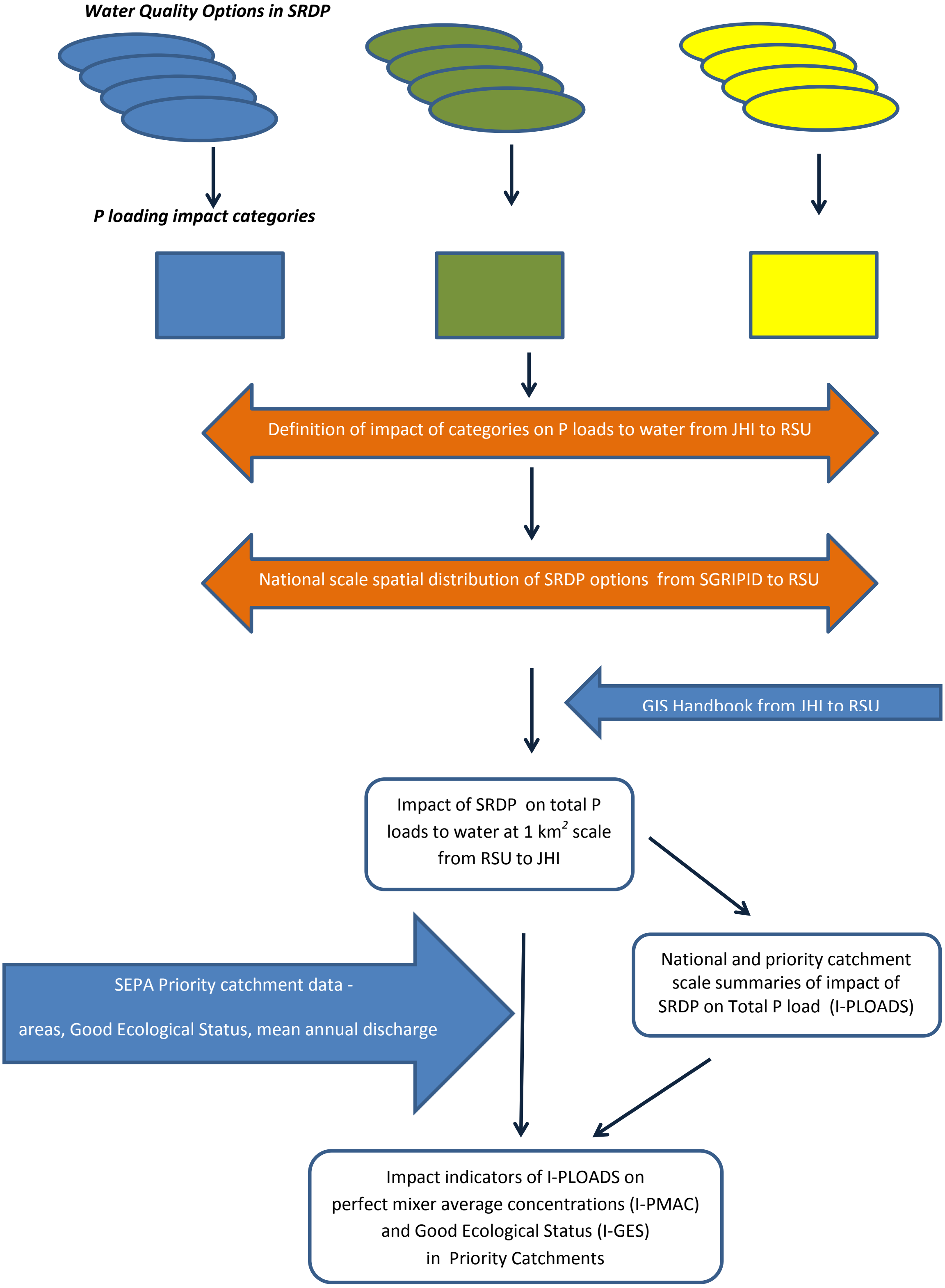

TABLE 1
Scottish Government Website on SRDP Options for Diffuse Pollution
http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/Packages/ReducingDiffusePollution

Section 1: These Options will always deliver the desired outcomes

CATEGORY	AXIS	OPTION NUMBER	RURAL PAYMENTS CODES	NO. OF SCHEMES WITH THIS OPTION	EXPENDITURE 2008 - 2013
A. Manure/slurry storage and treatment – manure storage	1	6	RP12102A	450	29,438,004
A. Manure/slurry storage and treatment – manure treatment	1	7	RP12102B	8	192,902
B. Arable reversion to grassland	2	40	RP21440	24	659,923
C. Treat run-off of nutrients + other pollutants – farm wetlands	1	16	RP12502B	5	76,076
D. Nutrient management plan reducing bacterial contamination in water	1 3	36	RP32101	43 1	9,892 8,000
E. Treat run-off of nutrients and other pollutants – biobeds	1	15	RP12502A	0	0

Section 2: These Options will help to achieve the desired outcome in specific circumstances.

CATEGORY	AXIS	OPTION NUMBER	RURAL PAYMENTS CODES	NO. OF SCHEMES WITH THIS OPTION	EXPENDITURE 2008 - 2013
F. Woodland creation and managment	2	47	RP22301	1,220	86,137,205
G. Low Input Grassland	2	9, 14, 16, 17, 38, 39, 43	RP21416,21414,21409,21438, 21441,21417,21439	2,570	17,353,123
H. Water Margins	2	21	RP21421	1,935	9,518,776
I. Organic Farming	2	1	RP21401	402	7,807,394
G. Moor and Peatland Management	2	26, 27, 28	RP21426,21427,21428	433	4,346,892
J. Wetlands	2	18, 19	RP21419	1,261	4,070,756
K. Field Margins	2	34, 35	RP21434,21435	832	3,873,511
G. Lowland Heath	2	24, 25	RP21424,21425	157	1,676,245
L. Lowland Bog and Fen	2	20, 23	RP21420	71	1,467,586
M. Floodplains	2	22	RP21422	119	412,032
N. Biodiversity Cropping In-Bye Land	2	36	RP21436	7	13,714
O. Tracks, Gates, Crossings	2	42	RP21602	14	88,574
P. Soil and Water Management	1	4	RP11402	27	7,275

2. Methods

2.0 Requirements of impact indicator.

The Gross Nutrient Balance (GNB) surplus for P from agricultural land in 2010, was 16 kT. A large change in soluble P concentration in Scottish Rivers of 10 ug/L, based on information on 3000 rivers catchments in Scotland in the Screening Tool database (SNIFFER, 2007) would require a change in loading to rivers of only 0.5 kT. Hence only a very small pool (<5%) within the GNB surplus can be amenable to management and hence impact directly on changes in stream water quality. So we need to focus on what SRDP (only one of many factors influencing water quality) does more directly. Moreover, the reliability of the data sources diminishes as the geographic scale reduces, so that when we enquired of DEFRA about data at NUTS1 level, the response was that the analysis does not take sufficient account of regional differences for Scotland. There are also significant shortcomings with the exclusion of rough grazing, and all stock are attributed to managed areas. As the overestimates for grazed land are also significant the GNB was discounted as a data source for this study. As an alternative to the GNB, a quantitative indicator for the impact of SRDP on water quality could be defined as:

"An index of the size of change in a critical water quality metric for relevant water bodies or catchments, relative to the standard required for Good Ecological Status (GES) that is the result of measures funded by SRDP"

In addition, impact indicators should preferably also be:

a. easily calculated by SG from the SGRIPID/IACS returns (i.e. not dependent on regular external researcher or consultant input), if at all possible;

b. provide an index of effectiveness of individual SRDP measures;

c. provide an index of cost-effectiveness e.g. grant payment or total expenditure per change in water quality at appropriate scales;

d. Filter out any double counting such as:

Deadweight – the proportion of change in outcome that would have occurred anyway (i.e. without SRDP);

Displacement - proportion of change in outcome that is counteracted by an adverse change elsewhere;

Substitution - effect of change in outcome on other impact indicators;

be amenable to "simple" what-if questions, for example, about targeting of SRDP measures .

2.1 Estimation of impact indicator for measures with respect to P loads.

Within each of the two sections in Table 1, we have collated SRDP options into categories that are likely to generate similar impact indicators for P losses from land to water, and then ranked these categories according to spend in the period 2008-2011, according to the expenditure recorded on the SG website: http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/RuralPrioritiesStats

Also worthy of consideration are some of the Options available under the SRDP that can help reduce diffuse pollution and the risk to the water environment, available under the Land Managers' Options (LMO) Scheme, or elsewhere in the SRDP scheme, but not in the diffuse pollution package. Also worth considering are the options from the earlier Land Management Contracts (LMC) scheme, which the LMO scheme replaced. At this stage we have not developed impact indicators for most of these measures, but have done for nutrient management plans (previous LMC scheme) and extended Hedgerows, Woodland creation and Organic farming (LMOs or biodiversity measures not considered by SG to be effective for water quality improvements).

For each category of measure in Table 1, a rationale for the estimation of the impact of land management change associated with each SRDP category on water quality has been developed. This is set out in detail in Appendix 1. Use is made of information from the literature and from the PLUS+ model (Donnelly et al., 2011; Fozzard et al., 1999; Ferrier et al., 1996) and elsewhere (Balana et al., 2012) to assess changes in baseline loads associated with land management changes. Table 2 summarises:

- the sources of information on the baseline, and the impact of the measure,
- an estimate of the quantitative impact on P loads from land to water,
- data requirements to make the impact indicator estimate.

2.2 Accounting for impact of expenditure. Expenditure on measures from SRDP grants can be either in the form of capital (eg building a slurry store, erecting a fence) or recurrent expenditure (eg payments for loss of gross margin, or for management of vegetation through cutting or grazing).Having explored a sample of the returns that SGRIPID holds for individual fields that are receiving SRDP grant monies, it was clear that it would be difficult to determine which type of expenditure was occurring (with obvious exceptions for non-field scale expenditure, such as manure and slurry storage), and also the period over which expenditure recurred for each field within the SRDP program from 2008-2013. We therefore made the decision to estimate a **Net Present Benefit** (NPB) of measures in terms of the kg of P that could be accounted as the result of a measure being in place in a particular reference year. The benefit of any P mitigation measure occurs over the period over which the investment is effective. Some measures have an impact over only the year for which the payment is made (eg annual payments for grass margins), but some expenditure has an impact over several years (eg slurry storage, woodland creation, creation of wetlands). So to assess impacts, we propose to account all the impact of a measure as occurring in the year when the measure has received payment, and so is recorded as a field ID on the SGRIPID returns for that year. The equation for calculating the NPB is the same as that for Net Present Value of investment made over a number of years:

$$NPB = \frac{r\,IMP(1+r)^n}{(1+r)^n - 1} \qquad (1)$$

Where r is the discounting rate as a fraction (e.g. 0.07 for 7%),
IMP is the annual impact of the measure any year for which payment is made and
n is the number of years for which the measure is effective.

For example, assuming the discounting rate is 7% , for a field that receives investment in a given year (as recorded in the SGRIPID returns) the NPB of this investment, for a measure such as field margin buffer strip creation that works for 5 years, is 4.1 times the annual impact of the measure; and for measures that have impact over 10 years (slurry storage) and 25 years (woodland creation and management), the NPB is 7.02 and 11.65 respectively. Thus we have estimated the annual benefit of the measures recorded for a reference year, and then multiplied by these factors, depending on the period over which the expenditure for that year is effective. Table 2 provides the net present benefit factor to be applied to each measure, depending on the assumed period over which is effective. This method does assume that all fields recorded as having measures in place in a reference year have received their funding from the 2008-2013 SRDP scheme, and are not carried over from the previous scheme. For longer term measures, such as woodland creation and management, this may be an incorrect assumption (eg there may be areas receiving small payments for maintenance of woodland created under a previous scheme. Using a large NPB factor for such areas would over-account for the impact of current spend). This methodology is altered slightly for manure and slurry storage, where we do not know the size of the store built and the measure is not allocated to a particular field, but to a farm. In this case we estimate the annual impact of the measure per m^3 of additional slurry storage (this varies with soil type and form of the manure), and then assume the recorded expenditure buys additional storage at the rate of £100/m^3.

2.3 Calculation of impact indicators for loads, concentrations and ecology. We have taken as simple an approach as possible to defining impacts on water quality in each of the SRDP categories in Table 1. This is in keeping with the feedback received from the Steering Group at the start up meeting. The calculations are summarised in box 2. Such impacts can be assessed independently of knowledge of the current status of water bodies with respect to WFD standards, but then applied to specific catchment conditions. Note that in rivers , the ecological impact is assessed by concentrations of soluble reactive P (SRP), which is generally considered to be the bioavailable fraction of P in the environment. So we ideally would like an indicator that estimates change in soluble P concentration as river water standards for GES (UKTAG, 2008) rather than total P concentration.

BOX 2. Approach to calculating impact indicators for SRDP categories of water quality measure

For category x of SRDP measures undertaken on certain of the fields i = 1 to n on a 1 km^2 area y, the impact on total P (TP) loads to water is given by:

$$\text{IMP(x,y)} = = \sum_{field\ ID\ i=1}^{field\ ID\ i=n} \text{IMP(x, i)}$$

The total impact of all categories of measure on TP loads in1 km^2 area y is:

$$\text{IPLOADS(y)} = \sum_{Category\ A}^{Category\ P} \text{IMP(x, y)}$$

The impact of all categories of measure on larger areas (such as priority catchment PC j) consisting of k squares of 1 km^2 is given by:

$$\text{IPLOADS(PC j)} = = \sum_{area\ y=1}^{area\ y=k} \text{IPLOADS(y)}$$

For a simple index, others have used the Perfect Mixer Average Concentration (PMAC – see SNIFFER, 2006) to estimate impact on water quality. This is the annual load of total P divided by the annual mean discharge Q (j) of the river water body concerned.

IPMAC (PC j) = (IPLOADS(PC j))/ Q (j)

The importance of this I-PMAC for achieving GES can be indicated by scaling the impact by GES (PC j), the soluble P standard for the catchment concerned.

IGES (PC j) = IPMAC (PC j)/ GES(PC j)

The fourteen priority catchment have annual mean SRP standards for GES which differ according to whether they are low alkalinity (<50 mg/L) ,siliceous waters (mean SRP < 50 ug/L for GES) or high alkalinity (>50 mg/L), calcareous waters (mean SRP<120 ug/L for GES) (UKTAG, 2008).
However, estimates of impact of P export often do not distinguish between soluble P and particulate P so at this stage we do not attempt to make this adjustment (but see CREW, 2014; Gooday et al., 2014; Gooday and Anthony, 2010;Ekholm and Krogerus (2003), Ellison and Brett (2006)).

For estimating annual mean discharge in the Priority catchments, we use the UK Hydrometric Register (UKHR; http://www.ceh.ac.uk/products/publications/ukhydrometricregister.html), which gives data on long-term annual runoff for a wide variety of catchments. The runoff values quoted are for the entire monitoring period at each station._However, in some cases (i.e. the Dee, Deveron, Irvine, South Esk and Tay) the PC boundaries extend further downstream than the most downstream monitoring station given in the UKHR. The UKHR data is therefore only approximate for these catchments. In addition, the "coastal" PCs are not true catchments, but rather collections of small sub-catchments and their intervening areas. It is therefore not possible to get data from the UKHR for these coastal PCs. We need a method of estimating the long-term runoff for the coastal PCs. The NIRAMS Water Balance Model (WBM) can outputs averages for any interval between 1961 and 2010 and has been shown (appendix 3) to do a reasonable job (slope = 1.1 and R^2 = 0.74 for WBM). The obvious outlier on both plots corresponds to the River Doon which, according to the UKHR, has a flow regime that is heavily influenced by abstractions and impoundment. For this reason, the observed runoff in the UKHR data is lower than would be expected if the flows were natural. If this point is removed, the regression line for the WBM has a slope of 1.1, an R^2 of 0.97 and an intercept of -206 mm – pretty good, except for the consistent underestimate of runoff by about 200 mm/yr. Previous work has highlighted similar issues, although the problem here is particularly extreme. The error is partly due to the way in which we estimate AET and partly due to the Met Office's spatial interpolation of the rainfall data clipping off intense rainfall peaks.Despite these issues, the WBM seems to offer the best option for patching the missing runoff data. If we assume that this regression line holds true for other time periods, we can re-run the WBM for the period from 1961 to 1990 and then generate estimates for the actual runoff by adding 206 mm to the annual runoff estimates and dividing by 1.1

2.4. Spatial methods for summarising impacts. The calculations described in appendix 1 were translated into a series of instructions for implementation within a Geographic Information System (GIS). Full details of the GIS procedure are given in appendix 2. SRDP data for the period from 2008 to 2013 was first combined with spatial data from the agricultural census to provide information on the location of fields receiving funding under each category. The average annual amount of funding awarded to each field was also calculated.

For the majority of the calculations, the amount of P mitigated depends primarily on the area of the field receiving funding. In other cases (e.g. Category A, Manure/slurry storage and treatment), the mitigation effect is assumed to be proportional to the amount of money awarded. This information was obtained from the pre-processed SRDP data and combined with a variety of national scale datasets to estimate the P mitigation effect within each field. These other datasets were pre-calculated and include, for example, information representing local slopes, runoff characteristics, hydrological connectivity, crop risk, soil types etc. For a detailed description of the datasets considered to be relevant to the calculations for each measure, refer to appendices 1 and 2.

The amount of P mitigated within each field was next converted from vector format to a 100 m resolution raster, with each 100 m by 100 m (i.e. 1 ha) cell assigned a value representing the average amount of P miti,gated in that location. This raster was then aggregated to a coarser 1 km resolution and multiplied by an appropriate Net Present Benefit (NPB) factor to allow for the fact that some measures are expected to provide several years of P mitigation for just a single year of expenditure. The final output is a series of 1 km resolution rasters showing the spatial distribution and amount of P mitigated by each category of measure. These are presented as maps and also form the basis for the "effectiveness of measures" calculations.

The results of the application of this impact analysis, using data from the SRDP spend in the priority catchments, are generated for 1km^2 squares. From this information, in combination with catchment discharge data for the outlets of priority catchments, we will be able to provide estimates of mean annual impact on [TP] at the catchment outlet, assuming no retention.

2.5 Estimating impact indicators for SRDP measures on water quality in the Priority Catchments (PC). The effects of each measure have been estimated at national scale on a 1km^2 grid. The aims here are to use these grids to:

1. Estimate the total amount of P mitigated in each PC (in kilograms).
2. By considering long-term average annual runoff for each catchment, estimate the change in perfect mixer total P concentration resulting from load reductions estimated in step 1.
3. Weighting of the impact according to the SRP standard for Good Ecological Status for each catchment.

2.6 Developing an optimisation of SRDP spend for a given catchment. We have developed a matrix of applicable SRDP measures and their impacts across the fields providing IACS returns in the Lunan catchment (using 2009 IACS data). This has been inputted into the EXCEL based optimisation software RISK SOLVER PLATFORM (Frontline solvers, http://www.solver.com/risk-solver-platfor) which enables optimisation of the measures to achieve the most cost:effective approach to P load mitigation. The costs included in this analysis are only those incurred by SG ie the payments made to farmers for adopting the measure. These costs are based on SG estimates of income foregone, and though they may not be locally accurate, they provide the relevant information for SG to assess the potential performance of their recommended measures, if adopted. These costs are available on the SG website, (see http://scotland.gov.uk/Topics/farmingrural/SRDP/ Background/RDCsmanagementpaymentrates)

Cost estimates were calculated to reflect income foregone and/or additional costs as a result of implementing management options, using gross margin data from a number of sources[2].

Costs estimates and effectiveness model outputs were integrated in a cost optimization model (equation 2), where the objective function being minimized was the aggregate cost of measures at sub-catchment scale to achieve target nutrient load reductions

$$\left.\begin{aligned} &Min.\ C = \sum_m \sum_s \alpha_{m,s} C_{m,s} \\ &subject\ to: \\ &\sum_m \sum_s (EQ_s - R_{m,s)}) \times \alpha_{m,s} \le Q \end{aligned}\right\} \qquad (2)$$

And the following constraints hold.

$$\sum_m \alpha_{m,s} = 1, \quad \forall\ s \text{ and } \alpha_{m,s} \in [0,1], \quad \forall\ s, m \qquad (3)$$

where $\alpha_{m,s}$ is a binary variable taking the value of 1 which selects mitigation measure 'm' on emission source 's' 0 if it is not; C_i is the total cost of TP load reduction in £/year; EQ_s the export of TP emission load for the reference state; R_m is the efficiency of measure 'm' in reducing P load; and Q denotes the P load beyond which the water body may fail to achieve the WFD 'good status'. In the case of the upper Lunan Water, the reduction in P load required for the standing water, Rescobie Loch, to achieve good status is estimated from previous work to be 366kg P (Balana et al., 2011).

Table 2 . Summary of impact indicators for P loads to surface water for the SRDP options in the Diffuse Pollution package.

	Section 1. These Options will always deliver the desired outcomes:									
Impact Category	**SRDP Diffuse Pollution Package**	**Summary of Management Actions**	**Summary of Impacts**	**RP codes**	**Impact period**	**Net Present Benefit Factor**	**Cases**	**Main Data Sources**	**Impact on P Export Load**	**Other Data Needed**
A	Manure/slurry storage and treatment - manure storage	minimising dirty water into slurry tank; improved application	greater flexibility in timing of spreading; improvement in storage capacity	RP12102A	10	6.5	450	DEFRA project WT0932; Aitken (2003); www.teagasc.ie	lookup table of change in P loss from manure spreading/cow;	Expenditure; impact period = 10yrs; light or heavy soils (defined by HOST class)
A	Manure/slurry storage and treatment - manure treatment	composting to improve nutrient availability	composting to improve nutrient availability	RP12102B	10	6.5	8			
B	Arable reversion to grassland	convert high risk arable areas to unfertilised grass	convert high risk arable areas to unfertilised grass	RP21440	1	0.9	24	Donnelly et al., 2011; Balana et al., 2012	Crop risk index changes from 4 to 2	Assume slope index 1 (intended for floodplains) ΔP = 0.54 kg/ha
C	Treat run-off of nutrients + other pollutants- farm wetlands	CFW to treat dirty water from steading	CFW to treat dirty water from steading	RP12502B	10	6.5	5	Gouriveau, 2008	P removal is 0.005kg/£ spend	expenditure; impact period = 10yrs;
D	Nutrient management plan	soil testing and nutrient budgeting	soil testing and nutrient budgeting	RP11401	5	4.1	43	Farm Nutrient budgets from Sinclair (2003) plus updated data if available	P_2O_5 surplus of 45 kg/ha for improved grassland and 37 kg/ha for arable land; each 1 kg P_2O_5/ha change leads to change in P leaching of 0.034 ug/L	Hydrologically Effective Rainfall (HER), Overland and subsurface flow for area A ; Impact =f(A,HER,[P]) slope of P sorption isotherm (current SEPA project)
E	Reducing bacterial contamination in water	septic tank disinfection	septic tank disinfection	RP32101	10	7.0	1		Disinfection has no significant impact on P loads	
E	Treat run-off of nutrients and other pollutants - biobeds	skip	skip	RP12102A	10	7.0	0		No uptake of this option	

	Section 2. These Options will help to achieve the desired outcome in specific circumstances:									
Impact Category	**SRDP Diffuse Pollution Package**	**Summary of Management Actions**	**Summary of Impacts**	RP codes	Impact period	Net Present Benefit Factor	**Cases**	**Main Data Sources**	**Impact on P Export Load**	**Other Data Needed**
F	Woodland creation - Productive conifer - low cost	Planting payment of £1900-£3000/ha. Maintenance payment can only be paid for planting on agricultural land or abandoned agricultural land	Woodland will generally act as a sink for sediment, and for N, especially if grown on productive former farmland, as required by SRDP funds. However, it can be a source for soluble P to water, especially when present as riparian forest.	RP22301A	25	11.7	59	Nisbett et al. (2011); Donnelly et al. (2011)	Movement from crop risk class 3 to 2 in PLUS+ (average over whole forest cycle);	slope, area, previous crop export (default, assume risk class 3) Connectivity Period of impact
F	Woodland creation - Productive conifer - high cost			RP22301B	25	11.7	13			
F	Woodland creation - Productive broadleaf woodland			RP22301C	25	11.7	23			
F	Woodland creation - Native woodland planting			RP22301D	25	11.7	774			
F	Woodland creation - Native woodland - natural regeneration			RP22301E	25	11.7	70			
F	Woodland creation - Mixed conifer/broadleaved woodland			RP22301F	25	11.7	281			

Impact Category	SRDP Diffuse Pollution package	Summary of Management Actions	Summary of Impacts	RP codes	Impact period	Net present benefit factor	Cases	Main Data Sources	Impact on P Export Load	Other Data Needed
G	Open grazed or wet grassland for wildlife	low nutrient inputs in spring/early summer	low nutrient inputs in spring/early summer	RP21409	1	0.9	1645	Withers et al. (2007); Donnelly et al. (2011)	Movement from crop risk class 3 to 2 in PLUS+ ;	slope, area, previous crop export (default, assume risk class 2) Connectivity Period of impact
G	Management of species rich grassland	create low intensity grassland from arable or improved grass	create low intensity grassland from arable or improved grass	RP21414	1	0.9	1129			
G	Creation and management of species rich grassland	grazing or cutting to reduce sward height in spring and autumn	grazing or cutting to reduce sward height in spring and autumn	RP21416	5	4.1	278			
G	Management of habitat mosaics	management of low intensity grassland	management of low intensity grassland	RP21416	1	0.9	613			
G	Scrub and tall herb communities	light grazing in the summer, and none in the winter; no fertilisers	light grazing in the summer, and none in the winter; no fertilisers	RP21439	1	0.9	271	Withers et al. (2007); Donnelly et al. (2011)	Movement from crop risk class 2 to 1 in PLUS+ ;	slope, area, previous crop export (default, assume risk class 2) Connectivity Period of impact
G	Conservation Management for Small Units - Collective	managing a mosaic of habitats	managing a mosaic of habitats	RP21441B	1	0.9	37			
G	Conservation Management for Small Units - Individual	managing a mosaic of habitats	managing a mosaic of habitats	RP21441A	1	0.9	242			
G	Wildlife Management on peatland Sites	avoid peatland erosion by deer etc.	avoid peatland erosion by deer etc.	RP21426	1	0.9	26			

Impact Category	SRDP Diffuse Pollution Package	Summary of Management Actions	Summary of Impacts	RP codes	Impact period	Net present benefit factor	Cases	Main Data Sources	Impact on P Export Load	Other Data Needed
G	Moorland grazings on uplands and peatlands	address impacts that can lead to erosion on hill grazings	address impacts that can lead to erosion on hill grazings	RP21428	1	0.9	67	Withers et al. (2007); Donnelly et al. (2011)	Movement from crop risk class 2 to 1 in PLUS+ ;	slope, area, previous crop export (default, assume risk class 2) Connectivity Period of impact
G	Management of moorland grazing	You must use the moorland for agricultural livestock production.	You must use the moorland for agricultural livestock production.	RP21427	1	0.9	340			
G	Ancient Wood Pasture - In-bye Land	livestock exclusion Apr-mid Jun; no fertiliser	livestock exclusion Apr-mid Jun; no fertiliser	RP21438A	1	0.9	15			
G	Ancient Wood Pasture - Rough Grazing	livestock exclusion Apr-mid Jun; no fertiliser	livestock exclusion Apr-mid Jun; no fertiliser	RP21438B	1	0.9	11			
G	Management of Coastal, Serpentine + special interest heath	grazing exclusion from Apr-Aug; 1.2 LU max therafter	grazing exclusion from Apr-Aug; 1.2 LU max therafter	RP21424	1	0.9	130			
G	Lowland heath	no grazing Sept to Feb; no fertiliser	no grazing Sept to Feb; no fertiliser	RP21425	1	0.9	27			

Impact Category	SRDP Diffuse Pollution Package	Summary of Management Actions	Summary of Impacts	RP codes	Impact period	Net Present Benefit Factor	Cases	Main Data Sources	Impact on P Export Load	Other Data Needed
H	Water Margins - Enhance biodiversity	5 times bed width (for up to 1.2m watercourse) or 6-12m for >1.2m; light grazing	5 times bed width (for up to 1.2m watercourse) or 6-12m for >1.2m; light grazing	RP21421A	1	0.9	1675	Balana et al., 2012; Collins et al.,2009, Krongvang et al., 2005, Uusi-Kamppa et a., 2000, Hoffmann et al, 2009,Weller et al., 1996	Look up tables from Balana et al. (2012) on of impact of dry buffers on P loss, assume 6m buffers;	slope, area, previous crop export (default, assume risk class 2); assume riparian
H	Water Margins - reduce diffuse pollution	5 times bed width (for up to 1.2m watercourse) or 6-12m for >1.2m; nograzing	5 times bed width (for up to 1.2m watercourse) or 6-12m for >1.2m; nograzing	RP21421B	1	0.9	260			
I	Conversion to organic farming - arable	payment rates should indicate previous land use:	payment rates should indicate previous land use:	RP21401A	5	4.1	43	Stockdale and Watson (2002) along with Category D above	P2O5surplus of 50 kg/ha for improved grassland and 34 kg/ha for arable land; each 1 kg P2O5/ha change leads to change in P leaching of 0.034 ug/L	Hydrologically Effective Rainfall (HER), Overland and subsurface flow for area A ; Impact =f(A,HER,[P]) slope of P sorption isotherm (current SEPA project) period of impact
I	Conversion to organic farming - fruit and veg	http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/Packages/ReducingDiffusePollutio/Supportfortheconversion#top	http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/Packages/ReducingDiffusePollutio/Supportfortheconversion#top	RP21401C	5	4.1	10			
I	Conversion to organic farming - improved grassland			RP21401B	5	4.1	50			
I	Conversion to organic farming - rough grazing			RP21401D	5	4.1	37	Stockdale and Watson (2002) along with Category D above	no change	

Impact Category	SRDP Diffuse Pollution Package	Summary of Management Actions	Summary of Impacts	RP codes	Impact period	Net Present Benefit Factor	Cases	Main Data Sources	Impact on P Export Load	Other Data Needed
I	Maintenance of organic farming - arable			RP21401A	1	0.9	79	Stockdale and Watson (2002) and see Category D above	P2O5surplus of 50 kg/ha for improved grassland and 34 kg/ha for arable land; each 1 kg P2O5/ha change leads to change in P leaching of 0.034 ug/L	Hydrologically Effective Rainfall (HER), Overland and subsurface flow for area A ; Impact =f(A,HER,[P]) slope of P sorption isotherm (current SEPA project) period of impact
I	Maintenance of organic farming - fruit and veg			RP21401C	1	0.9	5			
I	Maintenance of organic farming - improved grassland			RP21401B	1	0.9	101			
I	Maintenance of organic farming - rough grazing			RP21401H	1	0.9	77		no change	
J	Management of wetland	grazing management of wet grassland	grazing management of wet grassland	RP21418	1	0.9	1181	Acreman (2004), Weller et al., 1996	Each hectare of riparian wetland removes 30 kg P	previous land use (Agriculture or Forestry) Assume agricultural land is crop risk factor 3; forest land is crop risk factor 2 Connectivity Period of impact
J	Create, restore and manage wetland	no mowing/grazing April to July, no fertiliser	no mowing/grazing April to July, no fertiliser	RP21419	5	4.1	80	Acreman (2004), Weller et al., 1996		

Impact Category	SRDP Diffuse Pollution Package	Summary of Management Actions	Summary of Impacts	RP codes	Impact period	Net Present Benefit Factor	Cases	Main Data Sources	Impact on P Export Load	Other Data Needed
K	Management of extended hedges and hedgerow trees	Exclude all livestock and do not cultivate within a strip extending to at least 3m from the centre line of the hedge	Exclude all livestock and do not cultivate within a strip extending to at least 3m from the centre line of the hedge	**RP21434**	**1**	**0.9**	334	Balana et al., 2012; Collins et al.,2009, Krongvang et al., 2005, Uusi-Kamppa et a., 2000, Hoffmann et al, 2009,Weller et al., 1996	Look up tables from Balana et al. (2012) on of impact of dry buffers on P loss, assume 6m buffers;	riparian or not? slope, area, previous crop export (default, assume risk class 3); Connectivity period of impact
K	Grass Margins and Beetlebanks - mixed arable	grass margin strip 1.5 - 6 m width in an arable field	grass margin strip 1.5 -6 m width in an arable field	**RP21435A**	**1**	**0.9**	487			
K	Grass Margins and Beetlebanks - organic	grass margin strip 1.5 - 6 m width in an arable field	grass margin strip 1.5 -6 m width in an arable field	**RP21435B**	**1**	**0.9**	11			
L	Lowland Raised Bogs - Basic management	keep wet and unfertilised	keep wet and unfertilised	**RP21420A**	1	0.9	22	Hoffmann et al. (2009);Verhoeven and Arts, 1987	2 kg P/ha/year	Area of wetland
L	Lowland Raised Bogs - Basic plus Grazing Management	keep wet and unfertilised	keep wet and unfertilised	**RP21420B**	1	0.9	25			
L	Buffer areas for fens and lowland raised bogs	grass/semi-natural vegetation buffer; drainage blocking	grass/semi-natural vegetation buffer; drainage blocking	**RP21423**	**1**	**0.9**	24	Hoffmann et al. (2009);Verhoeven and Arts, 1987	2 kg P/ha/year modified by proportion of wetland protected by SRDP option	Area of wetland; proportion of wetland margin treated by SRDP measure.
M	Management of flood plains	allow watercourse to flood naturally	allow watercourse to flood naturally	**RP21422**	**1**	**0.9**	119	Hoffmann et a. (2009) ; Walling et al. (1999); Kiedrzyńska et al. (2008)	13 kg P/ha/year	Area of floodplain re-instated

Impact Category	SRDP Diffuse Pollution Package	Summary of Management Actions	Summary of Impacts	RP codes	Impact period	Net Present Benefit Factor	Cases	Main Data Sources	Impact on P Export Load	Other Data Needed
N	Biodiversity Cropping on In-Bye - basic management	Sow plots of spring cereals, fodder root crops or fodder rape each up to 2 hectares	Sow plots of spring cereals, fodder root crops or fodder rape each up to 2 hectares	RP21436A	1	0.9	107		Movement from crop risk class 4 to 3 in PLUS+ on 50% of area ; connectivity = 1 for riparian fields, and for class 5-7 land; otherwise connectivity = 0	slope, area Connectivity
N	Biodiversity Cropping on In-Bye - with binders/stooks	Sow plots of spring cereals, fodder root crops or fodder rape each up to 2 hectares	Sow plots of spring cereals, fodder root crops or fodder rape each up to 2 hectares	RP21436B	1	0.9	7			
O	Livestock tracks, gates and river crossings	not on website, but assume fencing, controlled drainage, etc	not on website, but assume fencing, controlled drainage, etc	RP21602	10	7.0	14	Shukla et al. (2011)	0.4 kg P/dairy cow/year on affected farm Or assume 60 kg P/case funded	no. of dairy cows on affected farm
P	Soil and water management programme - plan	prevention or mitigation of soil erosion or compaction	prevention or mitigation of soil erosion or compaction	RP11402B	1	0.9	27		reduction in the crop risk class by one class, for all arable areas	previous crop risk class
P	Soil and water management programme - deliver plan	prevention or mitigation of soil erosion or compaction	prevention or mitigation of soil erosion or compaction	RP11402A	1	0.9	0			

3. Results and Discussion

3.0. Summary of measures at national scale. Figure 1 shows a summary of the impacts of measures at 1km^2 scale for the whole country. Similar maps, for each individual category of measure, are given in Appendix 3. It is notable that the impact is unevenly spread, with large areas receiving no SRDP payments for water quality measures; there are large areas with evenly spread impact but others with more variable impacts. With the exception of a number of areas in the central and western Scotland (mainly associated with woodland creation), the overall impact of measures is <0.3kg P/ha.

A summary of impacts of each measure on P loads per 1 km^2 across Scotland are presented in Table 3. The total impact on P loads is 3.0kt P. The measure with the largest impact is category F, creation and management of woodland (1.37 kT TP) closely followed by category J, creation, restoration and management of wetlands (1.33 kT P).

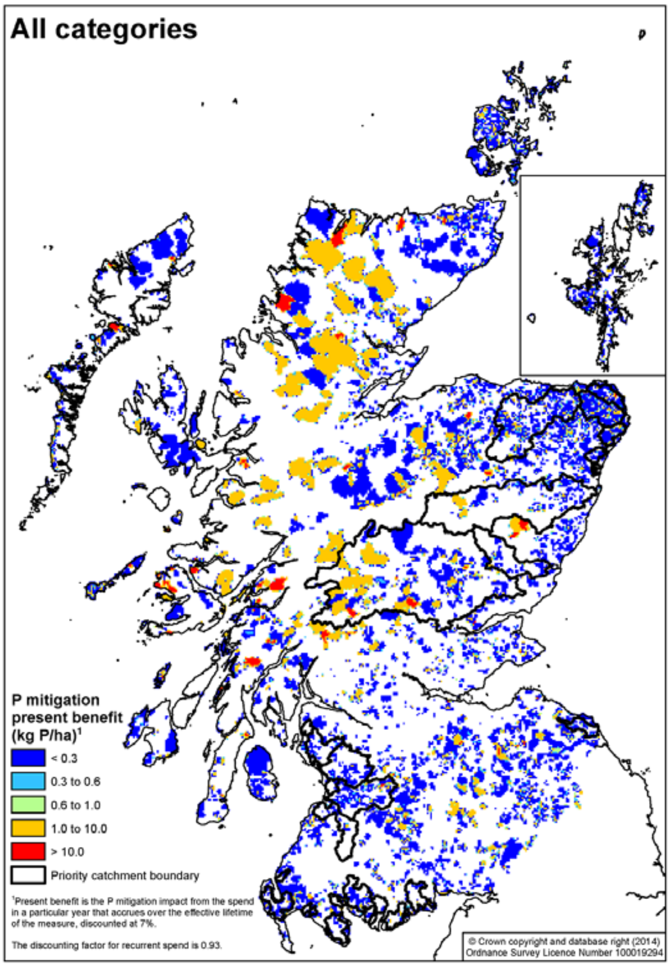

Figure 1. Estimated impact on Total P loads of all SRDP measures likely to impact water quality.*Note: Priority catchment areas are outlined in black.*

The largest number of 1 km^2 squares affected is the 17,820 impacted by category G, management of low intensity grazing. The large number of squares impacted by category K, extended hedgerows and grass margins, has a very small impact on P loads (0.001 kt P).

Category	Category name	no. of 1km^2 squares affected	Impact (kt P)
A	Manure/slurry storage and treatment	1730	0.010
B	Arable reversion to grassland	58	0.000
F	Woodland creation	8394	1.367
G	Low intensity grazing	17820	0.061
H	Water margins	1957	0.002
I	Organic farming	1726	0.000
J	Create, restore and manage wetlands	3946	1.334
K	Extended hedgerows and grass margins	2891	0.001
M	Restoration of floodplains	566	0.225
N	Biodiversity cropping on in-bye land	253	0.000
		Sum of all categories	3.00

Table 3. Number of 1km^2 squares affected and estimated present benefit impacts of SRDP measures on P loads from 1 km^2 squares and total impact across Scotland.

Figure 2 shows the spatial distribution of impacts in the Priority Catchments for all categories of measure. Catchments are sorted to those in the east of Scotland and those in the west, and the categories of measure in order of total impact across the Priority Catchments. Note the decline in scales of pairs of plots, as you go down the diagram. The two categories with the largest impacts (woodland and wetland creation) are mainly associated with large continuous areas of land receiving funding in the uplands of Scotland. These may be associated with relatively low productivity upland grassland and rough grazing, so the impacts in these areas may be overestimates, but without data on previous land use it is not possible to be sure if this is the case. There are some Priority Catchments with relatively large impacts from measures such as restoration of floodplains (such as Ugie, Tay and Ayr catchments) while there is no impact of this measure on some other catchments. The impact of manure storage on P loads is mainly in western Priority Catchments associated with Bathing Waters compliance issues.Impacts of hedgerows (category K) is surprisingly low which may reflect their location in the landscape relative to riparian zones, and absence of uptake in the west of the country.

Comment [u2]: Can you also make reference to the map and any patterns that have come out of that – tie it into the results of figure 2?

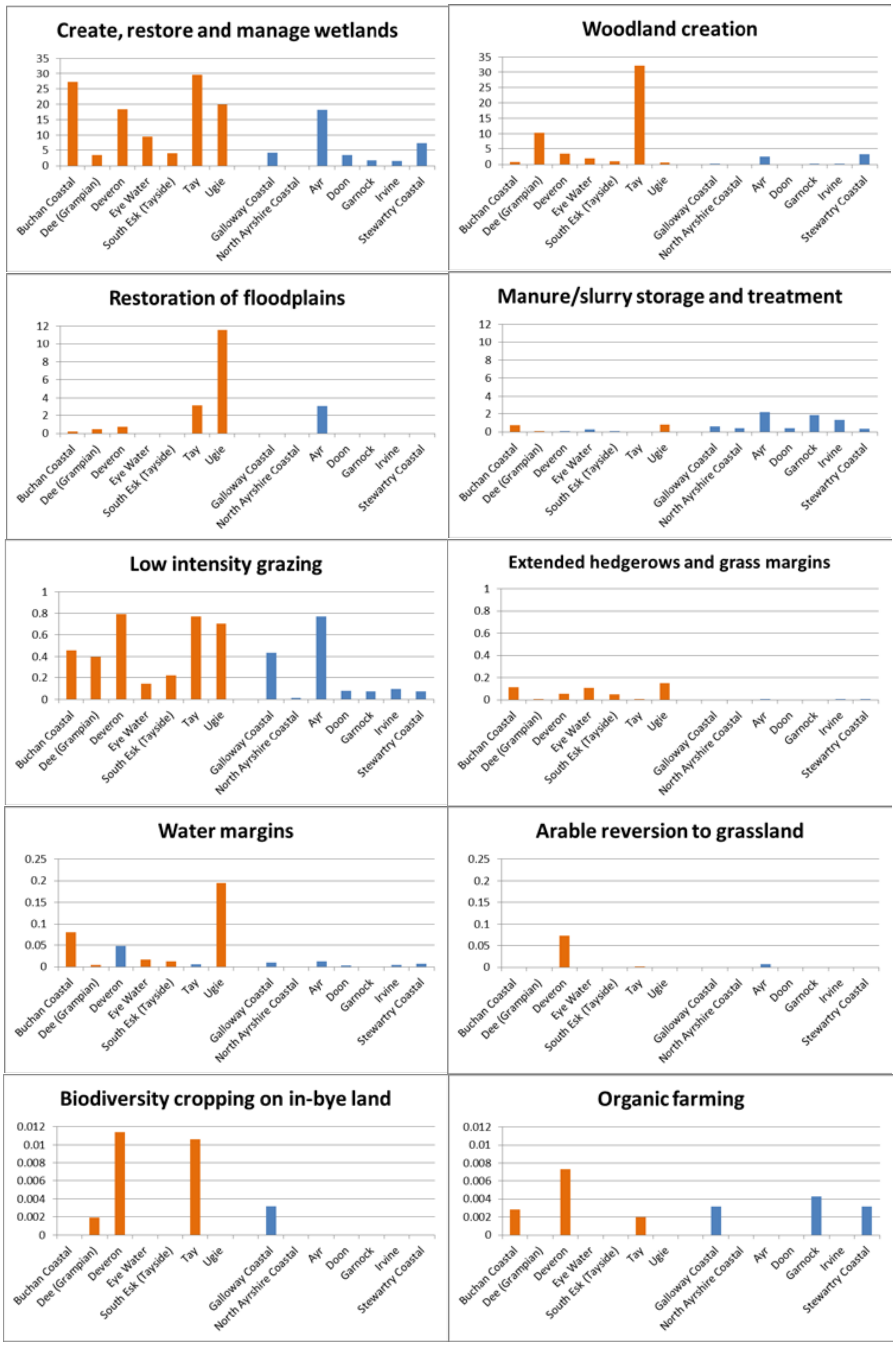

Figure 2. Impacts of categories of measure on P loads to water in kg P/km^2 of catchment. Note that catchments are sorted to those in the east of the country (brown) and those in the west (blue), and the categories of measure in order (from top left to bottom right) of total impact across the priority catchments. Note the change in scales of pairs of plots, as you go down the diagram.

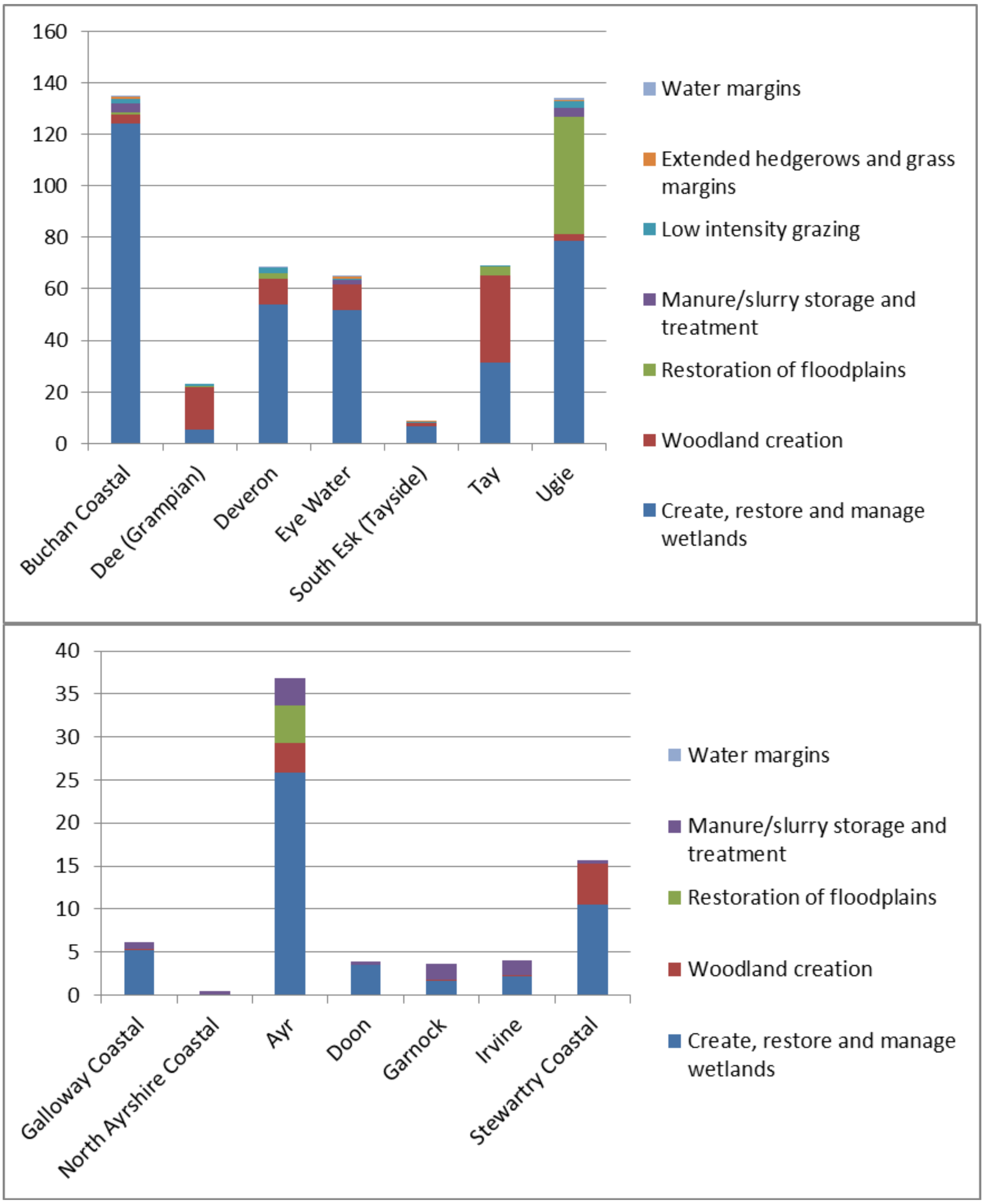

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Figure 3. Impact of categories of measure on total P perfect mixer concentration in micrograms per litre .(a) East coast catchments (b) West Coast catchments. Note that this impact estimate is a present benefit, which includes annual impacts for recurrent expenditure and multiple years impact for expenditure for measures lasting severeal years (see Table 2 for the Present Benefit factors used). Note also that these are total P concentrations, not soluble P (ecological standards are based on the latter).

3.1 Impacts on Total P concentrations relative to standards for good ecological status in Priority Catchments (PCs).

The impact of measures on perfect mixer total P concentration is defined as the impact on annual total load of pollutant (section 3.1) divided by the annual discharge (see appendix 4) at the outlet to the catchment. Figure 3 summarises the results for each measure and Priority Catchment. Overall impact of measures on P concentration is largest in the Buchan coastal catchments and river Ugie. On some catchments (eg North Ayrshire Coastal, River Irvine) the impact is much lower. These results demonstrate the need for better spatial targeting of water quality measures for the new programme. Table 4 provides the indicator for impact of measures on ecological status, calculated as the ratio of the impact on perfect mixer average concentration to the Water Framework Directive soluble P standard for good ecological status for the individual catchments. Catchments have been ranked according to the size of impact. Again we see a widely differing impact of SRDP measures across the different Priority Catchments. Overall we see a much greater impact of SRDP on Priority Catchments in the east of the country than in the west.

Priority catchment	Coast	Calcareous or siliceous?	Mean soluble [P} for Good Ecological Status (ug/L)	IGES (PC j) Impact indicator of SRDP spend on water quality
Buchan Coastal	East	S	50	2.69
River Ugie	East	S	50	2.68
River Tay	East	S	50	1.39
River Deveron	East	S	50	1.37
Eye Water	East	S	50	1.29
River Dee (Grampian)	East	S	50	0.46
River Ayr	West	C	120	0.32
River South Esk (Tayside)	East	S	50	0.17
Galloway Coastal	West	S	50	0.13
Stewartry Coastal	West	C	120	0.13
River Doon	West	S	50	0.08
River Irvine	West	C	120	0.04
River Garnock	West	C	120	0.03
North Ayrshire Coastal	West	C	120	0.00

Table 4. Ranked impact indicators of SRDP categories on ecological status, IGES (PC j) in the priority catchments.

3.2 Example of impact assessment and CEA at local catchment (Lunan). A key part of the implementation of the River Basin Management Plan is a group of 14 Priority Catchments (PCs) where catchment wide implementation of pollution control measures are more proactively promoted: (http://www.sepa.org.uk/water/river_basin_planning/dp_priority_catchments.aspx).

This has involved campaigns of awareness-raising, river walks to monitor regulatory compliance, one to one visits with farmers to tackle issues, and revisits where appropriate. To support this strategy for achieving good ecological status in water bodies, identification of patterns of changes and trends of nutrients is required to assess the effectiveness of the nutrient management policy and provide better evidence for the future. Diffuse Pollution Monitored Catchments (DPMCs) have also been established to assess trends in water quality, using a level of monitoring that would not be possible across the 14 PCs. One of these DPMCs, established in 2007, is the Lunan Water, a 134 km^2 catchment in Angus, Eastern Scotland. In this catchment, improved diffuse pollution management has been promoted by raising awareness of the GBRs, through an Environmental Focus Farm and associated farmer focus group, through diffuse pollution auditing on several farms, and through active engagement with key farmers to promote control of hotspot diffuse pollution issues.

A cost-effectiveness analysis (CEA) using the impacts of SRDP measures described above was undertaken at a field-by-field level for the upper Lunan catchment. A total of 347 fields with a total area of about 2000 ha were considered. Detailed land use data and biophysical information were identified for each the fields. Out of the list, 11 measures considered by the Scottish Government guidance to be highly relevant to diffuse P mitigation were examined in the CEA. The impact of each measure was assessed for each of the347 fields by producing a matrix of 347 rows x 11 columns data for the impacts and similarly 347 rows x 11 columns for the costs of implementation (based on Scottish Government payment rates). Some measures are technically not feasible in some fields with specific land uses, and here the impact is set to zero.

We first assessed the maximum potential impact at a catchment level if each of the 347 fields were assigned the measure with maximum impact in terms of mitigating P. Aggregation of these figures resulted in a combined total impacts of 2410 kg P removal. We then removed from the analysis fields where a very low impact of measures on P loads occur, to simplify the optimisation. Results show that measures on 131 fields with a total area of 906 ha (covering 45% of the total catchment area under consideration) contribute to 99% of the mitigation impact on P loads and we only considered these fields in the CEA.

As an example, Table 6 summarises the results of the CEA for the upper Lunan catchment, including all measures considered with the exception of category A measures (as we don’t have information on where dairy/slurry based units operate in the catchment), or biobeds, nutrient management for bacterial pollution, and farm wetlands, because of the known poor uptake across the country (see Table 1 section 1). The costs increases rapidly when the target mitigation exceed about 600 kg TP, with marginal cost:effectiveness of >£60/kg TP for large levels of mitigation.

Amount P removed	Total cost (TC)	Cost-effectiveness (CE) (in £/ Kg P)	Marginal cost (MC)= change in TC/change in removed) (in £/ kg P removed at the margin)
250	1370	5.48	5.48
500	2937	5.87	6.27
750	7804	10.41	19.47
1000	21083	21.08	53.12
1250	34593	27.67	54.04
1500	48380	32.25	55.15
1750	62222	35.56	55.37
2000	76684	38.34	57.85

Table 5. Cost effectiveness analysis of the impact of SRDP measures on P mitigation in the upper Lunan catchment.

Figure 4 shows the spatial distribution of the measures identified for two scenarios of P mitigation, 500kg P and 1500kg P. Figure 5 presents the allocation of measures to potential fields under various measures to achieve various P mitigation scenarios. For instance, in order to achieve a 500 kg P removal target, a combination of 3 measures, i.e., ‘creation of wetlands’ in 49 fields; ‘nutrient management’ in 30 fields; and ‘soil and water management’ in 45 fields are required.

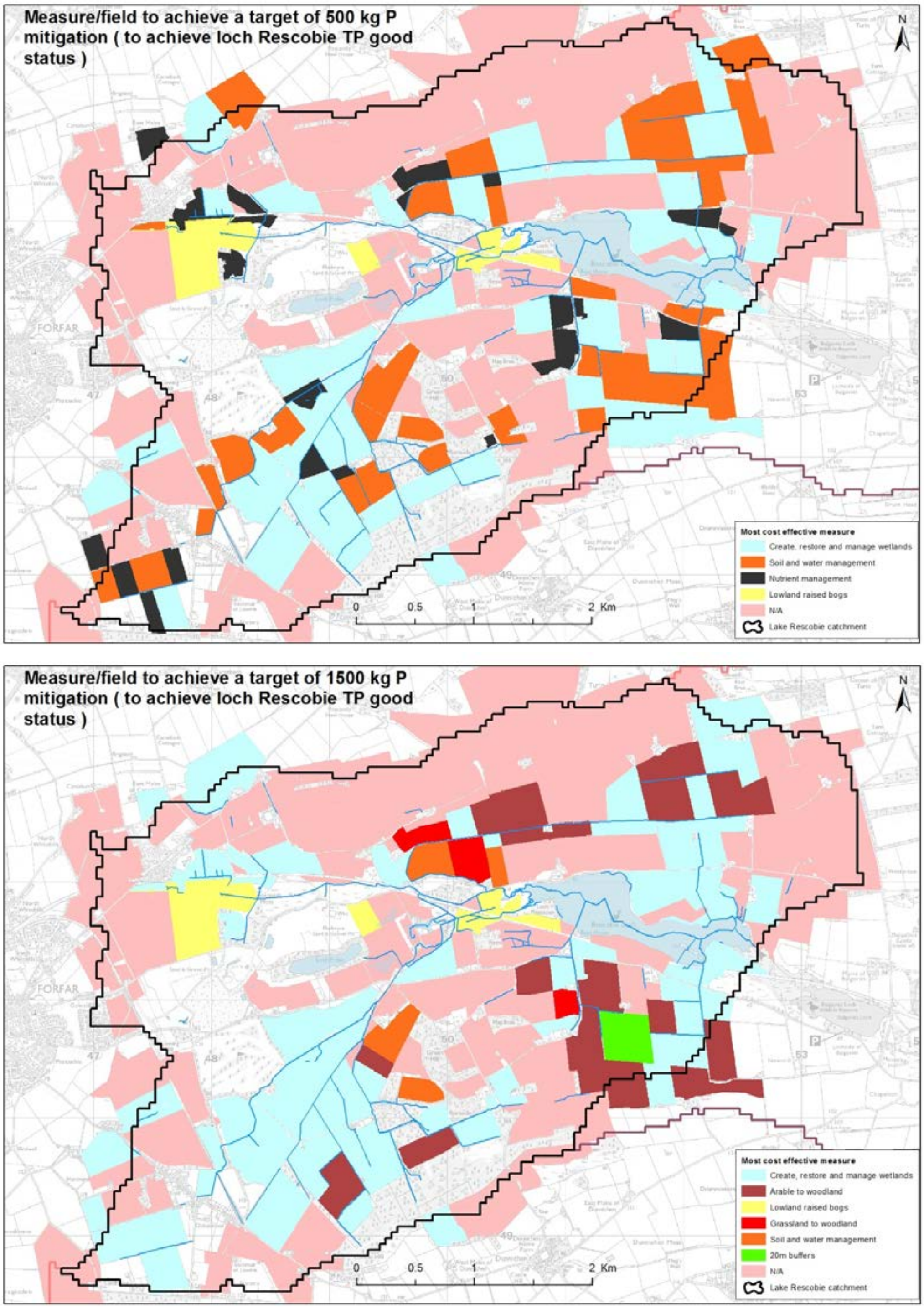

Figure 4.Example plots of outcome of CEA of most cost:effective SRDP measures for achieving TP load reductions to Rescobie Loch of 500 and 1500 kg.

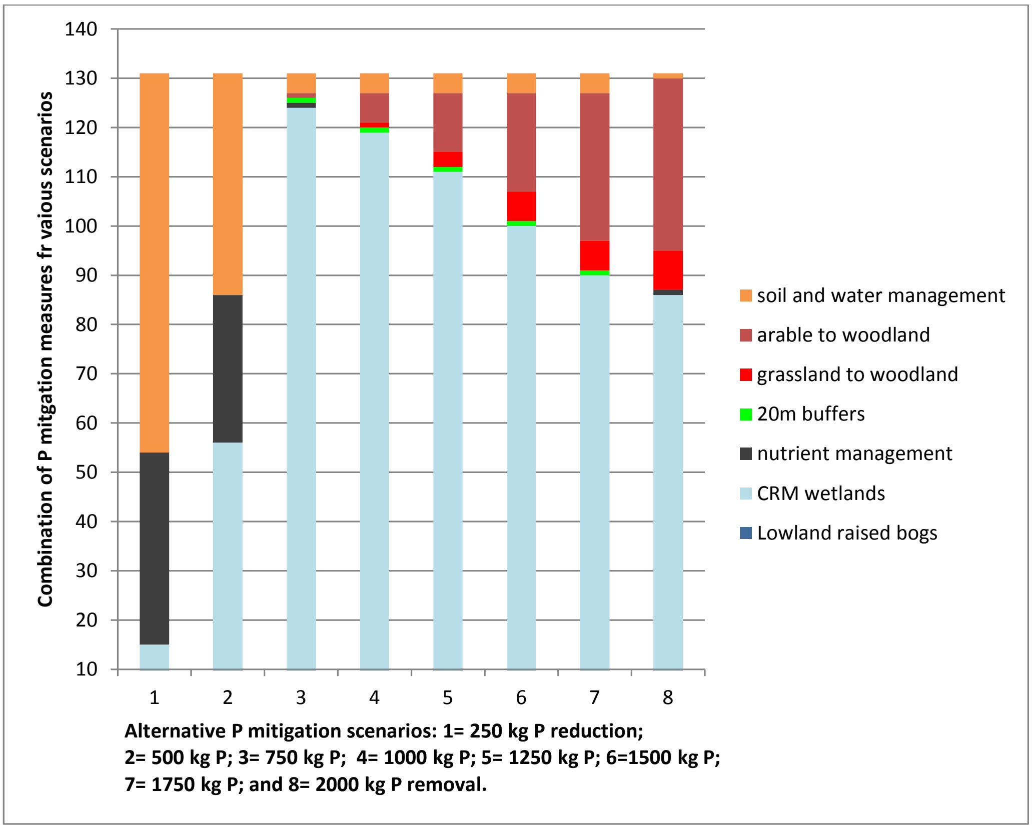

Figure 5. Distribution of measures generated by optimisation process across the 131 fields considered by the SOLVER routine in the upper Lunan catchment to achieve alternative P mitigation scenarios.

4. Conclusions

The impact indicator approach developed here suggests the following provisional inferences concerning the effect of SRDP spend on water quality in Scotland

1. Category F (Creation of woodland) and category J (creation,management and restoration of wetlands) have had the strongest impact nationally, accounting for 90% of the impact on P loads. This is partly because of large areas receiving support in the north and west of the country, and it would be valuable to explore more closely the land use from which these changes took place, as it may be there is a consistent over-estimate of impact if previous land use was rough grazing or extensively managed upland grazing. Within the priority catchments, the impact of woodland creation is principally in the Tay and Dee catchments, and elsewhere in east coast catchments, whereas the impact of wetland creation is more widely spread.

2. The next tier of impact is category M (restoration of floodplains), with largest influence on water quality in the Tay, Ayr and Ugie catchments, and manure/slurry storage, principally in the west coast catchments. The impact of spend on these measures is an order of magnitude lower than that of the woodland and wetland creation, as it is very localised (see appendix 3 diagrams) even in catchments where impact occurs.

3. Expenditure on low intensity grazing measures (category G) is very widespread and generates a small impact across most of the east coast Priority Catchments and the Galloway coastal and Ayr catchments in the west.

4. By contrast the expenditure on extended hedges and field margins (category K) is concentrated in the east of the country. Its impact is perhaps smaller than expected, which may reflect the fact that the extended hedges measure, although having potential to mitigate soil erosion and runoff losses was not included in the measures for mitigation of water pollution, and so measures are not necessarily well connected with riparian zones.

5. The impact of expenditure on water margins (category J) is also very small. In the priority catchments, impact is similar to that on extended hedgerows and grass margins, which is surprising, but again the targeting of water margin expenditure is not very closely linked to priority catchments or necessarily to water pollution priority areas.

6. Apart from the river Deveron, there was minimal impact of category B (arable reversion to grassland). Category N (biodiversity cropping on in-bye land) and category I (organic farming) have negligible impact.

7. The strongest overall impact of SRDP measures on ecological status (IGES) is likely to be in the Buchan coastal and Ugie catchments. Several catchments have a lower level of impact (Tay, Deveron, Eye) while impacts on the Dee, Ayr and S.Esk are smaller still, and dominated by measures with long term impact that have been rolled up into year 1 impacts through the present benefit approach, which may need some further appraisal (see below). There is likely to be negligible impact of SRDP measures in the Stewartry and Ayrshire coastal catchments, or the Irvine, the Doon and the Garnock.

8. The methodology used to generate the impact index for SRDP measures across Scotland has many uncertainties, and will benefit from further modification based on expert comment and sense checking, now that spatial representations of the data are available. Some of the key issues are:

- Accounting for impact of measures functioning for several years.
- Appropriate impact factors for high impact measures. Measures such as creation of woodland and creation and management of wetland will benefit from consideration of previous land use.
- Distinguishing impacts on TP loads from impacts on soluble P. Our monitoring data on the Lunan water, and associated estimation of P loads (Dunn et al., 2014) suggests that the soluble P loads are about 50% of total P loads in the upper Lunan catchment. Algal available total P determined by Ekholm and Krogerus (2003) for source runoff waters varied from 16% for forest runoff, to 31% for arable field runoff to 69% for dairy house runoff. Such factors could be included as a further tier of analysis.
- Updating of field export coefficients based on new data analysis and of impacts of measures based on new information from literature and expert judgement (eg Gooday et al., 2014; CREW ECO-P (2014)).

9. The approach demonstrated for cost:effectiveness analysis of P mitigation at catchment scale shows that as the requirements for mitigation of P increases, the measures used become more costly, and potentially less acceptable to farmers. For example for 500 kg P mitigation in the Rescobie Loch catchment, significant areas of wetland creation would be among the most cost:effective solutions, but for 1500kg TP mitigation, significant areas of conversion to woodland would be more cost effective. This highlights the need for other considerations than cost, including other societal benefits and costs than P mitigation. Nonetheless the approach could be used for retrospective optimisation of the 2007-2013 measures across priority catchments, or (with new work on effectiveness) the new post 2013 SRDP measures.

10. In overall conclusion, this report has shown that there is likely to be, over the long term, a net present benefit through the impact of SRDP measures on P loads to water across Scotland; a large proportion of this impact is associated with two measures, creation of woodland and creation, restoration and management of wetlands. The benefits of spend on these measures is larger partly because they continue to accumulate over time. However, more data on the previous land use on which these measures have been introduced, is needed to confirm this. The impacts on river ecological status of SRDP measures are likely to vary greatly across Scotland, with most impact in the Buchan coastal and Ugie catchments, and very small impacts in many of the priority catchments in SW Scotland.

There is potential for using the approaches described here for the Lunan Water to inform catchment scale targeting of measures, alongside locally salient information held by local stakeholders about what measures would be appropriate in what locations.

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APPENDIX 1. Description and rationale for impact indices for categories of 2009-2013 SRDP measures to enhance water quality.

Measures funded under SRDP for improvement of water quality are classified into two sections:

- those which will: “always deliver the desired outcome”
- those which will: “help to achieve the desired outcome in specific circumstances”.

Within each of these two sections, we have collated SRDP options into categories that are likely to generate similar impact indicators of P loading, and then ranked these categories according to spend in the period 2008-2011, according to the expenditure recorded on the SG website:

http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/RuralPrioritiesStats

Also worthy of consideration are the Options available under the SRDP that can help reduce diffuse pollution and the risk to the water environment, available under the Land Managers' Options (LMO) Scheme, or elsewhere in the SRDP scheme, but not in the diffuse pollution package. Also worth considering are the options from the earlier Land Management Contracts (LMC) scheme, which the LMO scheme replaced. At this stage we have not developed impact indicators for these measures.

For each category of measure an index of impact is developed under the following headings:

a. Description of Category, including Axes and Options Covered
b. Description of Expected Impact of Measure
c. Literature and Background Databases
d. Suggested Indicator for Impacts of Category A Measures
e. Sources of bias and uncertainty
f. Data Requirements and Sources
g. Comments

SECTION 1: Options that will always deliver the Desired Outcomes:

CATEGORY A. MANURE / SLURRY STORAGE AND TREATMENT: CODE - RP12102A AND B

h. Description of Category, including Axes and Options Covered:

Axis 1 Option 6:

The Option is designed to expand or otherwise improve facilities for the collection and storage of slurry and manure (including dung and farmyard manure, FYM), and their application to farmland.

Axis 1 Option 7:

Converting livestock manure into products which are easier to handle for agricultural benefit or which (e.g. biogas) have a non-agricultural use.

i. Description of Expected Impact of Measure:

Greater flexibility in the timing of slurry spreading, leading to farmers being able to spread slurry at the most appropriate time when the nutrients are most likely to be taken up by the crop /grass. Excluding rain and run-off water from the slurry store will release capacity, allowing more slurry storage. Help avoid surface run-off and rapid losses down field drains, which will result in reduced ammonia or nitrate losses and lead to reduced Biochemical Oxygen Demand (BOD) on watercourses.

Composting converts manure, into a product which may be of more agricultural benefit than the raw manure, either because the nutrients are more readily available or because it is easier to handle. The products of manure treatment can be expected to have a reduced Biochemical Oxygen Demand (BOD) if they do get into watercourses.

j. Literature and Background Databases:

A survey of slurry storage capacity in Ayrshire (Aitken et al., 2001; Aitken, 2003) suggested most dairy farmers had less than 3 months storage for slurry, with the result that autumn/winter slurry application was a necessity. Improved manure storage and composting would allow storage for over 6 months, leading to spring spreading. DEFRA project WT0932 found, based on measured and modelled data, the export coefficients used to calculate P losses from the contrasting manure application timings on medium/heavy soils were 1.6% of slurry P applied for summer and autumn timings, 2.4% for winter and 1.8% for spring timings, respectively. P loss coefficients for slurry applications to light and shallow soils and solid manure applications to all soil types were based on 0.2% of total P applied. See Table A1.

k. Suggested Indicator for Impacts of Category A Measures:

The capital costs of slurry storage are around £100 per m^3,

http://www.teagasc.ie/environment/publications/other/Buildings/build_feat_111106.pdf

We assume the average P content of cattle slurry is 0.5 kg P/m^3 (ADAS, 2001) and we assume that the extra storage allows manure that would have been applied in winter to be applied in spring, the loss coefficient for this manure changes on medium / heavy soils by 0.6% of stored P.Then:

$I_{\text{manure storage}}$ =0.5x0.006 /100 = 30mg P/£ spent, for medium and heavy soils.

Using the Net Present Benefit factor, assuming a lifetime of 10 years, of 7.02, this gives a net mitigation benefit of

30 x 7.02 =210mg P/£ spent, or a cost:effectiveness of 4746 £/kg P mitigated

On light soils, there is no impact of expenditure on storage on these losses and

$\mathbf{I_{manure\ storage} = 0}$

The funding rate for this category of measures is only 50%. We therefore have to consider the impact of the grants on the construction of slurry storage facilities – would the same number of stores been built without the SRDP contribution, or would none have been built? We assume that the grant actually catalysed the building of stores. This assumption has the effect of halving the cost:effectiveness ratio used in the calculations.

l. Sources of bias and uncertainty:

We assume that the all payments are for slurry based schemes.
The impact would apply only to farms where the dominant HOST class shows poor or imperfect drainage. For those where the drainage class is free, the impact of expenditure on direct P losses would be zero.

m. Data Requirements and Sources:

We assume that this farm level measure will be effective on farms with poor or imperfect drainage, as defined by HOST class. This classification is held nationally for Scotland by JHI, but would need to be applied to the location and farm areas where this expenditure has taken place.

n. Comments:

By determining the impact factor is based on expenditure on slurry storage, we do not need to make an estimate of manure P production from livestock.

One could also argue that improved manure storage would reduce direct losses from farm steading runoff, so the impact of this measure (Category C, see below) could be added to the farms where Category A measures are in place.

One could argue that improved manure storage will also increase the management of nutrients, so the impacts of this measure (Category D, see below) could be added to the fields for farms where Category A measures are in place).

The reduction of gross pollution by organic matter from slurries and manures is an additional benefit, but as it does not appear that this impacts on WFD compliance directly, we can only assess its impact qualitatively.

TABLE A1
P Loss Coefficients from Manures and Slurries (DEFRA Project WT0932)

PERCENT OF APPLIED P	SLURRY (Heavy Soils)	SLURRY (Light Soils)	MANURE (All Soils)
Summer / Autumn	1.6%	0.2%	0.2%
Winter[1]	2.4%	0.2%	0.2%
Spring[2]	1.8%	0.2%	0.2%

http://www.defra.gov.uk/consult/files/20111220nitrates-directive-consult-evid6.pdf - PAGE 60

So the impacts of improved slurry storage on P loads are:

(1) *That the spring export coefficient applies to 100% of the manure produced during housing (6 months storage), instead of 50% (3 months storage)*

(2) *In addition, improved manure storage will have the same impact as nutrient management on soil solution P leaching*

CATEGORY B. ARABLE REVERSION TO GRASSLAND: CODE - **RP21440.**

a. **Description of Category, including Axes and Options Covered.**
Axis 2 Option 40

The aim of this Option is to convert problem areas within arable fields that are prone to flooding, run-off and/or erosion to permanent grassland. However a Diffuse Pollution Audit OR Soil and Water Management Programme must be in place. Priority should be given to applications in priority areas, e.g. where diffuse pollution from agriculture has been identified as a pressure affecting watercourses, especially those identified as at risk of failing to meet WFD GES by 2015.

b. **Description of Expected Impact of Measure:**
Arable reversion to grassland will reduce nitrate leaching, soil erosion risk and the transport of sediment and associated P to watercourses.

c. **Literature and Background Databases:**
There is a wide range of literature on the estimation of P losses as a function of land cover. For this specific case the PLUS+ model gives estimated P losses as a function of Land Cover. (Donnelly et al., 2011; Ferrier et al., 1999). This model has been shown (Figure 1) to represent loads to Scottish Lochs quite well (Vinten et al., 2012). Balana et al. (2012)

d. **Suggested Modifier for Impacts of Category B Measures:**
For this specific case the PLUS+ model gives estimated P losses as a function of Land Cover. (Donnelly et al., 2011; Ferrier et al., 1996). A modified version of this table we propose to use is that used by Balana et al (2012) (See TableA2). We used the export value for rough grazing from Johnes and Heathwaite (1997) for the low crop risk class.

If the slope index for the field concerned is available, then the appropriate risk index can be used. If not, as this option is specifically design for management of fields prone to flooding, we can assume slope index 1.

In either case we assume that the crop P loss risk index declines from index 4 to index 2 as a result of this measure.

We do not think it appropriate to drop the risk class to 1, because (a) such soils make still erode, even under grass, in flood conditions (b) the soil will be relatively rich in P and will not quickly revert to low P status.

e. **Sources of bias and uncertainty:**
Reliable process based modelling of P export is a very challenging area of research, and there are no reliable process based models that take into account mitigation measures. Several research groups, including the catchment group at JHI are active in this field, but useable results from this are a way off. Hence the use of an export based model is preferred, although the export coefficients are chiefly the result of expert judgement. Monitored P loads from research catchments (Vinten et al., 2010) give P export from arable catchments of around 0.5 kg/ha/y, similar to those used for the moderate crop risk/moderate slope risk class in PLUS+.

f. **Data Requirements and Sources:**
Slope index (<4, 4-13, >13 degrees) for affected fields can be determined by JHI.

g. Comments:

If these sites are located on re-instated floodplains, then they may become net sinks for P (see category M measures).

TABLE A2
Risk Classes Used in Balana et al., 2012

RISK FACTOR TABLES				
		< 4	4 to 13	> 13
	Slope Risk	1	2	3
	Field Average	4	13	13
	Slope Category	Low	Medium	High
Crop Risk Class 1. 2. 3. 4. 5.	 Very Low Low Moderate High Very High	 0.01 0.06 0.2 0.7 1.3	 0.02 0.1 0.5 1.1 2.2	 0.03 0.14 0.7 1.5 3.1

CATEGORY C. TREAT RUNOFF OF NUTRIENTS AND PESTICIDES WITH FARM WETLANDS AND BIOBEDS: CODE - RP12502B AND A.

a. Description of Category, including Axes and Options Covered:
Axis 1 Option 15, 16

Capital investments are needed to reduce such pollution, targeted at areas where water bodies are of low quality. Constructed Farm Wetlands (CFWs) can collect, store and treat lightly contaminated run-off from roofs, roads and yards and so reduce inputs of diffuse pollutants to the water environment. Constructed farm wetlands may also intercept emergency leaks or spillages, control storm water run-off, and provide habitat and biodiversity benefits. Biobeds may be useful for treating dilute pesticide waste and steading runoff on arable farms.

b. Description of expected Impact of Measure:
A CFW will help to reduce the risk of diffuse water pollution. Constructed wetlands can trap sediment and, through the retention of run-off and biological action, reduce Nitrogen, Phosphorus (soluble and particulate) and faecal indicator organism (FIO) loads to watercourses.

c. Literature and Background Databases:
CFWs should be designed in accordance with the SEPA Constructed Farm Wetlands Design Manual. Performance is very sensitive to design and a study (Dunne et al., 2005 reported in Carty et al., 2008) of the treatment performance of 13 wetland systems (ICWs) in Ireland analysed the relationship between wetland design and mean molybdate reactive phosphorus (MRP) concentration at the outlet, which showed that a system with four cells and a CFW aspect ratio of less than 2.2 (ideally closer to 1) is required to obtain an outlet mean MRP concentration of 1 mg l-1 or less. The aspect ratio is defined as the mean length of the wetland system divided by the mean width. The study has also shown that the wetland area required can be related to the farmyard area; the former should be twice the area of the latter. Also by increasing wetland area there is greater capacity to further remove MRP levels.

Gouriveau et al. (2007) assessed nutrient removal from two constructed farm wetlands in Scotland receiving light or heavy pollutant loads. They found that treatment efficiencies were around 50% for soluble N and P species, but much lower in autumn / winter. In the $5000m^2$ CFW receiving heavy loading area removal rates of 22,1180 and 3 mg /m2 / d for ammonium N, nitrate N and phosphate P and overall efficiencies were 34%, 26% and 31% respectively. It may therefore be simples to take estimates of costs per unit area of constructed wetland, assuming these are well designed.

Estimated median capital costs for CFWs are £3.5/m^2 (Gouriveau, 2008). Using the treatment efficiencies found in this thesis the N removal impact per £ of spend is 117 ±11g /y /£ spend and the P removal is 5.1 ± 5.7 g / y / £ capital spend. These figures give a means of assessing impact of spend directly on P mitigation. Assuming a 10 year depreciation period for the capital spend for CFWs (Culleton et al., 2005), the Net Present Benefit factor is 7.0, corresponding to a 10 year impact period, with depreciation rate of 7%. So the net present impact is given by:

5.1 x 7 = 0.036kg P/£ spend

d. Suggested Modifier for Impacts of Category C Measures:

We propose using the mean P removal impact from Gouriveau et al. (2008), namely 0.035 kg P/£ spend.

The spend from SRDP on category C measures during the 3 years 2008-2011 £76,076/3 is £25,359 achieving a P mitigation of :

£25,359x0.035= 888 kg P

e. Sources of Bias and Uncertainty:

Gouriveau quotes a >100% coefficient of variation for impacts of CFWs on P removal. CFWs may be sinks and sources and different stages in their development, and depending on the loading intensity.

f. Data Requirements and Sources:

Locations of CFWs

g. Comments:

This measure has a much better cost-effectiveness ratio than slurry storage, so far as P mitigation goes, but it is not popular, possibly because of the land take required.

CATEGORY D. NUTRIENT MANAGEMENT PLAN. CODE RP11401

a. Description of Category, including Axes and Options Covered:
Axis 1 Option 3:

The measure is to implement nutrient planning and management on the arable land and improved grassland of the farm: Carry out soil testing in selected fields;Calculate nutrient requirements of both arable and grass crops. This should take account of the soil analysis results, the nutrients available from previous inputs and the cropping history. For N, follow the Scottish Agricultural College (SAC) recommendations in the Technical Note T516 "Nitrogen recommendations for Cereals, Oilseed Rape and Potatoes". For P and K, follow SAC Technical Note T308 "Removal by crops and P, K balance sheets". Keep records of the quantities and date of application of mineral fertiliser (e.g. 20:10:10), farmyard manure and slurry applied to the field. This should take account of the levels of N, P and K contained in organic manures.

b. Description of Expected Impact of Measure:
The expectation is that this will reduce losses to water and atmosphere. Farming land in this Option must be arable land or improved grassland. Farm land in nitrate vulnerable zones (NVZs) is required to be included in manure and fertiliser plans and is therefore not eligible under this Option.

c. Literature and Background Databases:
The size of the impact depends critically on the pre-implementation nutrient budget. Sinclair et al. (2003) give data on field scale nutrient budgets for arable and grassland areas across eastern Scotland (where the majority of NVZs are located).

d. Suggested Modifier for Impacts of Category D Measures:
Plots of P inputs vs P outputs for fields in the Sinclair (2003) data set show an envelope, with some farms/fields fitting on a line which could be interpreted as good practice, while others deviate to the right of this line. We assume that many of these points deviating to the right represent the situation that would occur pre-implementation of nutrient management plans, and that those close to the envelope represent what can be achieved by good practice with regards to nutrient management. We ranked the fields according to their closeness to a 1:1 line (P_{output} = P_{input}). Taking an arbitrary cut-off point of the best 25% of fields, as those exhibiting good practice in nutrient management, we then plotted linear regression lines between input and output for the two groups of fields. By subtracting one line from the other, we get a net effect of poor budgeting on potential for P losses to the wider environment. This gap depends on input level, so for all the fields outside the 25% considered as showing good practice, we calculated the net effect. The average of these figures can be considered to be the net impact per field in terms of P losses, of nutrient management planning. The regression lines for the arable and grassland fields are shown in Figs 1a and 1b.

The Net Effects of Nutrient Management Planning are thus estimated to be reduction in P surplus of 45 kg/ha P_2O_5 for improved grassland and 37 kg/ha P_2O_5 for arable land.

We now need to estimate an impact of these changes in nutrient budgets on P losses. We assume the principal loss mitigated is soluble P leaching, because losses of P by erosion derive from the total P content of the soil, which hardly changes as a result of these changes in nutrient budget. The pool that responds to changing inputs of P is the oxalate extractable P, which correlates well with the soil solution P concentration. To estimate the change in soluble P concentration, we have made use, as an example, of a set of soil analysis data for 60 samples collected across the range of soil series and land uses in the Lunan water (Richards et al., 2012, as yet unpublished).

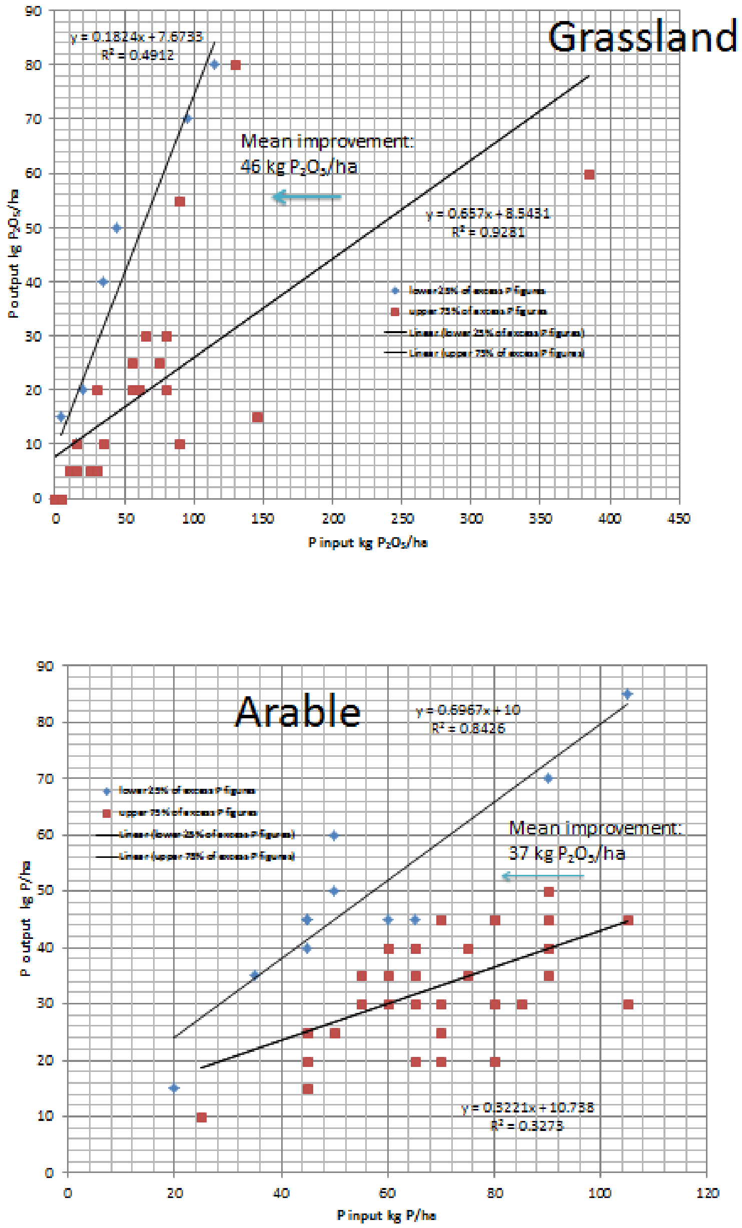


FIGURE A1: Summary of farm nutrient budget data for grassland (a) and arable (b) farms in Scotland. The regression lines show the relationships for the best 25 and for the other 75 of farms.

This work gives an index of the change in soil solution P for the Lunan catchment soils per 1kg P_2O_5/ha change in P budget of 0.034 ug/L.

We assume that the main impact of changing the P status of the soil will be on soluble P leaching. The Water Framework Directive standards for GES specify an annual time based mean [SRP], which will be dominated by base flow concentrations, so changes in this [SRP] are assumed to be the main impact of nutrient management planning at field level. This assumption neglects effects of nutrient management on soil erosion losses and incidental losses (for SRDP impact assessment, these are covered elsewhere). The impact on mean soil solution P of nutrient management was and 1.00 and 0.80 ug/L for grassland and arable land respectively.

We now make the (rather heroic) assumption that this change in soil solution concentration is reflected in the mean annual concentration of the drainage water reaching streams from fields which are subject to nutrient management option. This can be considered as the subsurface flow (SSF) and surface runoff (oF) associated with each 1km2 grid square.

For example, change in P load from improved grassland field under nutrient management (kg P/ha)

= {oF+ SSF} (mm/year) x 1.00 ug/L x 10^{-9} kg/ug x 10^{4} L/mm ha:

For example, for a value of HER of 300mm/year (typical of eastern/arable Scotland), this gives a change in P load of 0.003 kg/ha for grassland under nutrient management.

Multiplying this figure by the area of grassland in the catchment under nutrient management, gives the total change in P load for the catchment for this measure. For example, We can then estimate the absolute change in P load for the Lunan catchment (with 900 ha out of 14,000ha under nutrient management in 2009) as :

(Grassland Area under SRDP x 0.003 kg/ha) + (Arable area under SRDP x 0.0024 kg/ha)

For the Lunan water this works out for 2009 as a reduction in P load of 2.7 kg P. This measure is additive year on year, so it is appropriate to consider this measure as having an impact over many years – we assume 5 years. The Net Present Benefit factor is then 3.4.

Impact of measure =
NPB(measure D) x {OF+ SSF} (mm/year) x 1.00 ug/L x 10^{-9} kg/ug x 104 L/mm ha:

e. Sources of Bias and Uncertainty:

This analysis requires a knowledge of the slope of the P sorption isotherm for the soils considered. The dataset for the Lunan Water catchment (one of the diffuse pollution monitoring catchments in Scotland) is representative of many arable soils in Eastern Scotland, but with different texture, clay mineralogy, and where the initial P status of the soil is very Low, the slope may be very different. SEPA are currently funding a project with SAC and JHI to make use of basic soil data to estimate these adsorption isotherms, after which the slopes appropriate for a wider range of soils will be available (Sinclair et al., 2012).

f. Data Requirements and Sources:

Summaries of Hydrologically Effective Rainfall (HER) are available for the catchments of > 500 loch water bodies and > 3,000 river water bodies in the Screening Tool database (SNIFFER 2007).

Slope of adsorption isotherm for dominant soil series on farms where nutrient management is practiced.

In order to estimate a cost : effectiveness index for this measure, the area of land to which the nutrient management measure has been applied would need to be known.

In order to apply this impact indicator to farms in which category A measures have been implemented (see Comments section below), the area of grassland and arable land on such farms would need to be determined.

g. Comments:

The nutrient management measure can also be assumed to apply to all fields on farms that have spent SRDP money on improved slurry storage (Category A).

A modified version of this approach is also relevant to SRDP support for organic farming (Category I, see below).

It should be noted that the impact of year-on-year nutrient management planning on changes in P loads is cumulative. For example, applying nutrient management planning for 10 years, in the grassland example above would mean the effect on annual P loads would increase year on year by 0.003 kg P/ha up to 0.03 kg P/ha in 10 years.

This is in addition to the use of a Net Present Benefit factor for this measure of 3.4.

The robustness of this impact indicator will be improved by availability of data from a more recent survey of nutrient budgets for the PLANET project, held by Alex Sinclair of SAC (Sinclair et al., 2012).

CATEGORY E. REDUCING BACTERIAL CONTAMINATION FROM SEPTIC TANKS. CODE RP32101.

a. Description of Category, including Axes and Options overed:
Axis 1 Option 15.

This measure, which involves disinfection of septic tanks is not thought to have a significant impact on nutrient loads.

SECTION 2:

“OPTIONS THAT WILL HELP TO ACHIEVE THE DESIRED OUTCOME”:

Category F. FARM WOODLANDS. CODES RP22301D AND E

a. Description of Category, including Axes and Options Covered:
Axis 2 Option 47

The options that are considered to help achieve improved water quality are:

- Woodland Creation - Naturally regenerated Native Woodland
- Woodland Creation - Native Woodland planting

These attract a planting payment of from £1,900-£3,000/ha depending on area (70%-90% support), and maintenance payments for 5 years of £218 - £229/ha.

b. Description of Expected Impact of Measure:
Woodland will generally act as a sink for sediment, P and N, especially if grown on productive former farmland, as required by SRDP funds. However, it can be a source for soluble P to water, especially when present as riparian forest.

Woodland can pose a direct risk of diffuse water pollution, especially when involving more intensive management practices on sensitive soils (Nisbet et al., 2011). The risks are greatest for conifer forest crops on poor upland soils, where cultivation, drainage, fertiliser and pesticide applications, road construction and harvesting are potential sources of water pollution. Most pollution incidents resulting from forestry are associated with harvesting operations, usually linked to poor practice in timber extraction. Ground damage due to machinery can lead to soil erosion and increased sediment delivery to watercourses. Clear felling also presents a risk of both phosphate and nitrate contamination of watercourses. Soil type is a key factor with clear felling on peaty soils most at risk of phosphate leaching.
These pollution risks are addressed by good practice measures under the Forests & Water Guidelines. Implementation of the Guidelines has been shown to be generally successful in controlling diffuse pollution (Newbold et al., 2009).

c. Literature and Background Databases:
Modelled N-losses from forestry accounted for only 1.2% of total N-losses in Scotland in 2004, compared to an estimated 73.5% from agriculture (Anon, 2006).Forests are expected to be quite efficient in nutrient cycling, at least in their early stages of growth, and annual mean N leaching losses for woodland in the Marlborough catchment in Southeast England, a predominantly lowland area were estimated to be less than a sixtieth of that for arable (26.4, 15.5 and 0.4 kg N ha^{-1} yr^{-1} for arable, grassland and woodland, respectively) based on a modelling study by Koo and O’Connell (2006). The woodlands for water monograph (Nisbet et al., 2011) documents impacts of farm woodland on N losses, but there is rather little information on P.

The main threat to water quality is likely to be the delivery of sediment to watercourses. The losses of P associated with forest harvesting on blanket peat were 5 kg/ha in the 4 years following harvesting in a study in Ireland. Soluble P losses from riparian forest may increase, due to trapping of sediment. For example, Sediment P trapped (43% of input sediment) by forest buffers for 15 years in the Piedmont region of the US was compensated by increased soluble P loss, so that total P was not, overall, removed by the buffer (Newbold et al., 2009). Stutter et al. (2009) and Roberts et al. (2012) also note increases in the soluble P concentration in surface soils of riparian buffer strips.

d. Suggested Modifier for Impacts of Category F Measures:

In considering the impact of SRDP funding for woodland on water quality, because funding is for new planting, it is important to note that the full impact of this on water quality will not be apparent till the whole life cycle of the woodland stand has been completed. Therefore both impacts and expenditure need to be appropriately depreciated over time, an exercise arguably out with the scope of this project. Sediment P losses are mainly associated with planting and felling phases.

Export coefficients for forestry in the PLUS+ model used to predict P losses to standing waters in Scotland (e.g. Balana et al., 2012) provide a basis for estimating the impact of woodland creation on P losses. The impact for a given slope class of land depends on previous land use, and we can assume losses from normal forestry class land are in the crop risk class 1. However, where agricultural land is converted to forestry, the situation is different. We can assume that the previous land use was either arable or intensive grass, to qualify for SRDP support, in which case the risk class for the land, reduces from crop risk class 3, but once allowance is made for excess losses during harvesting and planting phases, and for release of soluble P over a woodland planting cycle, the benefits will be smaller than from movement from class 3 to class 1 index.

We therefore propose that the impacts of woodland planting on P loads from runoff should be represented by a reduction from crop risk class 3 to risk class 2, and that the impact on soluble P losses should be considered as nECtral, relative to previous land use.

We assume the connectivity to water is given by the multiplicative connectivity index used in the Screening Tool database (which ranges from 0.2-0.7).

We assume the Net Present Benefit of this measure is based on an impact of the spend for Creation and Management of woodland over 25 years. This gives a NPB factor of 11.7

e. Sources of Bias and Uncertainty:

The nature of the planting and harvesting elements of the cycle will have a large impact on P losses.

f. Data Requirements and Sources:

Field IDs of woodland
Connectivity index (from Screening Tool database)
Modal previous land use risk category (otherwise assume crop risk class 3)

g. Comments:

Assessing cost : effectiveness of SRDP spend will require appreciation of the length of the woodland cycle, so that discounting can be determined

CATEGORY G. LOW INPUT GRASSLAND, UPLAND AND MOORLAND: CODES - RP21416, RP21425, RP21414, RP21409, RP21438A, RP21438B, RP21424, RP21441B, RP21441A, RP21417, RP21427, RP21428, RP21439, RP21426

a. Brief Description of Category, including Axes and Options Covered.
Axis 2 Options 9,14,16,17,24,25,26,27,28,39,43:

These options require development of grazing plans for livestock measurement to further a range of biodiversity and other environmental goals. For example,

- Exclusion of farm livestock for 6 consecutive weeks between 15 March and 15 June inclusive, restricting farm livestock to a maximum of 1 LU/ha during the whole 3-month period (management of open grazed or wet grassland, option 9);
- Management of grazing levels to create a sward at a range of heights, including some short grassland and some dense tussocks, in accordance with published guidance (enhancing of species rich grassland, option 14);
- a livestock management and grazing regime on areas that support a patchwork or mosaic of traditional semi-natural habitats on inbye farmland (management of habitat mosaics - options 17,43);
- Management of grazing levels to enable plants to flower and set seed in the summer to maintain a balance between the cover and vigour of the dwarf shrubs and fine grasses with broad-leaved herbs (Management of coastal or serpentine heath - option 25);
- Exclusion of farm livestock from the area from 1 November to the end of February and low stocking rates (0.3 LU/ha) at other times (management of lowland heath – option 24);
- Enhancement of the condition of upland and peatland habitats by promoting good soil management and undertaking wildlife management on uplands and peatlands (Wildlife management on upland and peatland sites – options 26,27,28);
- Addressing impacts that can lead to erosion on hill grazings (moorland grazings on uplands and peatlands– options 26,27,28)
- livestock exclusion Apr-mid Jun; no fertiliser (ancient wood pasture, in by land; rough grazing – option 38)
- light grazing in the summer, and none in the winter; no fertilisers (Scrub and tall herb communities – option 39)

b. Description of Expected Impact of Measure:

All the options in this category of mitigation are dealing with land that may have hotspots of P loss by erosion from affected areas, and also result in livestock de-intensification of the area affected, leading to lowered soil P status, and lowered risk of faecal runoff.

c. Literature and Background Databases:

Withers et al. (2007) monitored two adjacent headwater catchment areas of the River Rede in Northumberland with different proportions of previously improved grassland (7 versus 47% of total area) to assess potential P enrichment of their peaty top soils and draining streams. Pastures had been improved during the 1970s and 1980s mostly by liming, fertilisation, pioneer cropping with stubble turnips for 2 years, reseeding with grass and clover and subsequently grazed by sheep. Fertiliser P inputs during and subsequent to improvement maintained available (Olsen) P concentrations in the soil (0–7.5 cm) at optimum levels for grass production (16–25 mg L^{-1}), whilst unimproved areas contained only 4–6 mg L^{-1} of Olsen-P. Between 1994 and 1997, stream annual flow-weighted concentrations of dissolved reactive (inorganic) P (DRP), dissolved unreactive P (DUP) and particulate P (PP) were increased from 10, 29 and 39 µg L^{-1}, respectively in the largely unimproved catchment to 21, 35 and 97 µg L^{-1}, respectively in the catchment with 47% improved land.

There is some research on the benefits for livestock and farm business of temperate agroforestry, but little information on the quantitative impacts on nutrient losses. Nair et al. (2007) found that trees integrated into the sandy range- and pasturelands of Florida could remove nutrients from deeper soil profiles that would otherwise be transported to water bodies and cause pollution. Soil analysis showed that P concentrations were higher in treeless pasture (mean: 9.11 mg kg^{-1} in the surface to 0.23 mg kg^{-1} at 1.0 m depth) compared to silvo -pastures (mean: 2.51 and 0.087 mg kg^{-1}, respectively), and ammonium–N and nitrate–N concentrations were higher in the surface horizon of treeless pasture.

d. Suggested Modifier:

The improved catchment in the Withers et al. (2007) study had land use and P losses comparable to the crop risk class 3 category in Table A2. The increase in P loads assuming 750 mm of excess rainfall (mean HER across Scotland, according to the screening tool database, SNIFFER, 2006, 2007) associated with this intensification is around 0.5 kg P/ha. This is similar to the increase associated with going from risk class 1 or 2, to risk class 3, In Table 2. On the basis that the measures described reduce the risk of hotspots of P pollution within otherwise low emission land use categories, we assume that all the options in this category of SRDP diffuse pollution measures take the risk class down by one class, for the area affected, as follows:

- management of open grazed or wet grassland:
  from risk class 3 to 2 (impact of 0.14 to 0.56 kg P/ha depending on slope)
- enhancing of species rich grassland:
  from risk class 3 to 2 (impact of 0.14 to 0.56 kg P/ha depending on slope)
- management of habitat mosaics:
  from risk class 2 to 1 (impact of 0.05 to 0.11 kg P/ha depending on slope)
- management of coastal or serpentine heath:
  from risk class 3 to 2 (impact of 0.05 to 0.11 kg P/ha depending on slope)
- management of lowland heath:
  from risk class 3 to 2 (impact of 0.14 to 0.56 kg P/ha depending on slope)
- Wildlife management and grazing on upland and peatland sites:
  from risk class 2 to 1 (impact of 0.05 to 0.11 kg P/ha depending on slope)
- Ancient Wood Pasture - In-bye Land:
  from risk class 2 to 1 (impact of 0.05 to 0.11 kg P/ha depending on slope)

We assume the Net Present Benefit of this measure is based on the impact in the year of spend. This gives a NPB factor of 0.93. The exception is money spent for Creation and Management of Species-Rich Grassland, where we assume impact over 5 years, so a NPB factor of 3.4.

e. Uncertainty Estimation:

The estimation of these impacts is highly uncertain, and ideally the impact indicators would be tuned to the background P export from each catchment, which will vary with initial geology.

f. Data Requirements and Sources:

Areas of land affected by measures in appropriate catchments.

g. Comments:

The Withers et al. (2007) study noted a change in SRP in streams in intensified grassland catchment of 11 ug/L. This is after 15-20 years of intensification, giving an annual impact on SRP of grassland intensification of 0.5 to 0.7 ug/L/year. This is comparable to the 0.8 to 1 ug/l/y estimated as the impact of improved nutrient management in the Lunan catchment, and suggests that impacts on soluble P in this range are not unreasonable to apply more widely across the country. **Note: This impact indicator assumes that stock removed from category G areas are not relocated elsewhere, but rather contribute to an overall reduction in stock numbers in the countryside.**

CATEGORY H. WATER MARGINS AND ENHANCED RIPARIAN BUFFER AREAS. CODES: RP21421A AND B

a. Brief Description of Category, including Axes and Options Covered:
Axis 2 Option 21:

A managed, established, vegetated and unfertilised grass/woodland buffer alongside watercourses enhances biodiversity and encourages the following of a natural course, which contributes to flood control and improves water quality.

Riparian buffer areas can reduce diffuse pollution by distancing agricultural activity from the riparian area thus reducing the risk of direct pollution from applied fertilisers and by intercepting overland water flow to watercourses and acting as a sediment trap to reduce sediment from adjacent fields and nutrient losses to watercourses.

The option for diffuse pollution mitigation will also help to reduce the risk of diffuse pollution caused by faecal contamination of water bodies and watercourses by farm livestock.

The option for biodiversity is designed for sites with existing semi-natural vegetation; species-rich grassland, fens and riparian woodland. On such sites with species-rich grassland, very occasional, light grazing will maintain a sward at a range of heights, to benefit a wide variety of plants and invertebrates.

Water margins will comprise either land bordering still water or land bordering a watercourse.

- for a site bordering still water, the water margin must be between 12m and 24m wide.
- for a site bordering a watercourse with a bed width of less than 1.2m, the water margin must be at least 3m wide on any side and the overall width of the margin at least 5 times the bed width of the watercourse. The maximum width of the water margin is 12m on any one side.
- for a site bordering a watercourse with a bed width equal to or greater than 1.2m, the minimum width of the water margin is 6m on any one side and the maximum width is 12m wide on any one side.
- On sites with steep ground or existing semi-natural habitat, the water margin width may be extended to 20m. This will provide an enhanced buffer to intercept run-off and allow you to graze the site more easily.

b. Description of Expected Impact of Measure:

The aim of this Option is to protect water margins from erosion and diffuse pollution, whilst encouraging the development of waterside vegetation that stabilises the banks and enhances biodiversity.

c. Literature and Background Databases:

There is a vast range of literature on the efficacy of buffer strips installed at water margins (eg Collins et al.,2009; Krongvang et al., 2005; Uusi-Kamppa et a., 2000; Hoffmann et al, 2009), including recent special issues of Journal of Environmental Quality in 2009 and again in 2012 (see Hoffmann et al, 2009 and Roberts et al., 2012 for examples of papers in these issues). Dry buffer strips intercept surface runoff of sediment, containing a fraction of the nutrient pollution.

Balana et al. (2012) identified 3 policy relevant buffer widths, as mitigation options. These were:

2m - the minimum width required by current regulations for arable agriculture in Scotland under the so-called General Binding Rules (GBRs) .

8m - a typical buffer width (6m) receiving payment for water margins or grass margins and beetle banks under SRDP or LMOs , plus the 2m minimum requirement. Note that he payment for grass margins requires a margin to be established around the whole perimeter of the field.

20m - a buffer width expected to be near 100% efficient in removing sediment from runoff except where concentrated rill or gully flows occur.

The mitigating effect of buffer strips was estimated by Balana et al. (2012) using the metadata set of Collins et al. (2009) who summarised the efficiency of sediment and nutrient removal by buffer strips as a function of width, slope and soil texture, from over 40 papers. In the medium slope class, the efficiency of P removal was determined by the exponential model fit between sediment or total P removal and buffer width from these data (Table A3). In the other slope classes we assumed higher or lower efficiencies than the medium class, based on expert judgement. The buffer efficiencies generated by this process agreed reasonably well with another metadata analysis by Liu et al (2008). It should be noted that variability in buffer performance cannot be explained by buffer width and slope alone, being a complex function of the soil type, catchment area, microtopography, soil cover and management etc., which cannot be reasonably incorporated into a simple export model.

Drawing on the results of Norwegian experiments on plots of varying erosion risk (Krongvang et al.,2005), Balana et al., (2012) assumed that the proportion of particulate P in the export from fields increased from 0.5 to 0.9 with increase in crop risk class 1 to 5 (see Table A3). Using results from the same paper which showed an increasing proportion of P transported via surface runoff, rather than subsurface drainage, as the erosion risk increased, the proportion of P transported by surface runoff was assumed to increase from 0.6 to 0.8 from erosion risk class 1 to 3. Combining these two assumptions gave estimates of the ratio of soluble P from surface runoff to total P exported from the field for each crop/slope risk combination from Table A3. These are given in Table A4. Note that the classes and coefficients used for the P export for fields varies from that in PLUS as follows:

- Arable crops are separated into three classes: moderate, high, and very high. This differs from PLUS (which only has one class for arable crops) to reflect the observation that winter cereals are more vulnerable to soil erosion than are spring cereals (e.g., Speirs and Frost, 1985) and that there is much greater soil erosion observed from vegetables and potatoes due to the fine seedbeds and ridge and furrow cultivation up- and downslope. Land used for these crops is also often left bare during the vulnerable autumn–winter periods, leading to increased erosion risk and P loss.
- The P export coefficients used for the low (2) and high (4) crop risk classes are the median figures for rough grazing and arable classes in PLUS.
- We used the export value for rough grazing from Johnes and Heathwaite (1997) for the low crop risk class.

Where the riparian zone is managed as wetland, interception may be more efficient, as under-drainage is also intercepted. Weller et al., 1996, working at a landscape scale, found that the inclusion of a variable based on the area of riparian wetlands located along low- and medium-order streams in conjunction with the area of agricultural and nonwetland forested lands explained 88% of the variance in phosphorus loading to surface waters. The best fit model coefficients (Pload = 0.86Ag + 0.64For − 30Ripwet + 160, all units in ha) suggest that a hectare of riparian wetland may be many times more important in reducing phosphorus than an agricultural hectare is in producing phosphorus. The standard errors on these coefficients were 8.8 for Ripwet and 0.14 for Ag.

d. **Suggested Modifier to P Export:**

Field by field estimates of P loss using PLUS+ are available for loch catchments where the impact of P loading is felt most directly. **Tables A3 and A4 (derived from Balana et al., 2012) provide a basis for estimating the impact of dry riparian buffer strips funded by SRDP on these export coefficients.** Where the width of such buffers is not known, the middle width category can be assumed (i.e. 2m GBR plus 6m SRDP/LMO). The impact on P export will depend on the P (=f(slope,crop)) export from the field adjacent to the funded wetland margin, and on the width of the buffer. The width of the buffer can be estimated as:

$$W(BUFFER) = A(buffer)/\sqrt{A(adjacent\ field)}$$

A(buffer) =Area receiving SRDP payment for water margin; A(adjacent field)=area of field upslope of water margin payment.

Note: need to check if buffer field ID and adjacent field ID are the same, or can they be linked??

Where such detailed information is not known, or where it is known that the riparian margin is restored by SRDP to a wet condition, we propose use of the regression equation derived by Weller et al (1996):

$$\mathbf{Pload = 0.86Ag + 0.64For - 30Ripwet + 160} \qquad \mathbf{(3)}$$

Thus each hectare of riparian wetland removed 30 kg of P in these catchments.

We assume the Net Present Benefit of this measure is based on the impact in the year of spend. This gives a NPB factor of 0.93.

e. **Uncertainty Estimation:**

The coefficients and 95% confidence intervals determined by the metadata analysis referred to in section C were 0.3 (upper bound 0.34, lower bound 0.24) for 2m buffers, 0.75 (upper bound 0.82, lower bound 0.67) for 8m buffers and 0.97 (upper bound 0.99, lower bound 0.94) or 20m buffers.

The standard errors on the coefficients of Weller et al. (1996) were 8.8 for Ripwet and 0.14 for Ag.

King et al. (2006) note that variability in buffer width across a landscape has important effects on landscape discharge. A variable width buffer retains less material than a uniform width buffer of equivalent average width. Gaps in riparian buffers are important sites of material delivery, particularly in narrower or more retentive buffers.

f. **Data Requirements and Sources:**

Field by field export coefficient and slope from PLUS+ for loch catchments

Areas and (if available) lengths of riparian margins affected, with adequate spatial resolution (i.e. field by field), to link measure to field export coefficient.

Data on riparian geography must have adequate spatial resolution. Stream networks from smaller scale maps miss smaller streams and are not adequate to quantify the presence and extent of riparian areas.

g. **Comments:**

Note: Where the **option for biodiversity** has been funded, we assume that this occurs adjacent to semi-natural grassland, so the impact is limited, because the initial export coefficient is very low.

TABLE A3
Buffer Strip Efficiency Factors as a Function of Width and Slope

Slope Risk Class	1	2	3
2m (GBRs) †	0.5	0.3	0.1
6m + 2m (LMOs + GBRs) ‡	0.9	0.75	0.5
20m	1	0.97	0.94

† GBRs = General Binding Rules (regulatory standard):
(http://www.sepa.org.uk?water_regulation/regimes/pollution_control/diffuse_pollution.aspx

‡ LMOs = Land Management Options (economic option):
http://www.scotland.gov.uk/Topics/farmingrural/SRDP/Land-Managers-Options/Availableoptions/Grassmarginsbeetlebanks)

TABLE A4
Fraction of P Export From Field which Amenable to Removal by Buffer Strips

		SLOPE RISK CLASS		
		1	2	2
		Proportion of P Travelling as Run Off		
Crop Risk Class	Proportion Particulate P	0.6	0.7	0.8
1	0.5	0.3	0.35	0.4
2	0.6	0.36	0.42	0.48
3	0.7	0.42	0.49	0.56
4	0.8	0.48	0.56	0.64
5	0/9	0.54	0.63	0.72

CATEGORY I. MAINTENANCE OF ORGANIC FARMING: CODES RP21401A, B,C, E F AND G.
Axis 2 Option 1:

a. Brief Description of Category, including Axes and Options Covered:

Organic farming plays a valuable role in helping to protect and enhance the environment as well as assisting producers to meet consumer demand for organic products. Evidence has shown that there are significant biodiversity, pollution control, energy efficiency and soil protection benefits associated with organic farming.

b. Description of Expected Impact of Measure:

The main effect of organic farming adoption will be through nutrient budgets for affected farms, so far as P is concerned. Other effects may include greater reliance on agricultural manures, leading to greater losses from direct runoff; greater presence of weeds in arable seedbeds, reducing soil erosion losses; changed efficiency of feed nutrient utilisation;

c. Literature and Background Databases:

In a review of nutrient budgets on organic farms in the UK, Stockdale and Watson (2002) found that all the nitrogen budgets showed an N surplus (average 83 kg N ha^{-1} $year^{-1}$). The phosphorus (P) and potassium (K) budgets showed both surpluses and deficits (average 3.4 kg P ha^{-1} $year^{-1}$; 13.7 kg K ha^{-1} $year^{-1}$) – see Table A5. Overall, the data illustrate the diversity of management systems in place on organic farms, which consequently lead to significant variability in nutrient use efficiency and potential nutrient sustainability between farms. There are opportunities for almost all organic farmers to improve the efficiency of nutrient cycling on the farm and increase short-term productivity and long-term sustainability.

TABLE A5
N and P Budgets for Organic Farms (Stockdale and Watson 2002)

	Nitrogen				Phosphorus			
	No. of farms	**N SURPLUS**	**SE**	**RANGE**	**No. of farms**	**P_2O_5 SURPLUS**	**SE**	**RANGE**
ARABLE	2	26	24	1 to 50	1	-6		
BEEF	5	112	26	18 to 164	4	-2	1	-6 to 0
DAIRY	67	90	7	2 to 217	56	3	1	-6 to 36
HORTIC	3	194	101	91 to 396	3	39	26	2 to 89
MIXED	8	55	9	21 to 92	6	-2	1	-7 to 4

d. Suggested Modifier:

For livestock farms the organic beef farms have a larger mean N surplus than the "normal" farms, so the impact of conversion to organic beef would be to increase the N losses. On the other hand the dairy farms have a lower N surplus on the organic farms. Since the SRDP funding does not distinguish between dairy and beef production systems, and given the wide range of nutrient budgets observed on organic farms, it may be safer to assume that organic farming has an overall nECtral impact on N budgets on an area basis.

On the other hand, the P budgets for the "normal" farms show a clear surplus of P (34 kg P_2O_5 for arable farms, 34 and 66 kg P_2O_5 for beef and dairy farms respectively), compared to the organic farms, which are pretty much in balance, with the exception of the horticultural farms. On this basis, for P, we assume the impact on WQ can be calculated in the same way as for the conventional farms undertaking nutrient management – with reduced surpluses of P applied to arable and improved grassland areas on organic farms. We assume the rough grazing elements are unaffected by type of farm:

Arable areas on organic farms: impact of organic management or creation of organic farming, no effect on N, 34 kg P_2O_5 / ha reduction in P surplus.

Managed grassland areas on organic farms: impact of organic management or creation of organic farming, no effect on N, 50 kg P205 / ha reduction in P surplus (mean of figure for beef and dairy).

We assume the impact on water quality can be calculated in the same way as for the conventional farms undertaking nutrient management (**Category D**) – with reduced surpluses of P applied to arable and improved grassland areas on organic farms. We assume the rough grazing elements are unaffected by type of farm.

We assume the Net Present Benefit of this measure is based on the impact over the 5 years of the funding. This gives a NPB factor of 3.39.

e. Uncertainty Estimation:

Sources of uncertainty include the same issues as those for nutrient management (Category D).

The review of data by Stockdale and Watson (2002) for organic farm nutrient budgets has limited data for arable farms.

f. Data Requirements and Sources:

Areas of improved grassland/arable land undergoing conversion to organic farming
Areas of improved grassland/arable land receiving payment for maintenance of organic farming

g. Comments:

The robustness of this impact indicator will be improved by availability of data from a new review of nutrient budgets on Scottish organic and coventional farms, which is being undertaken by Christine Watson and Kirsty Topp of SAC.

CATEGORY J. CREATING, RESTORING AND MANAGING WETLANDS. CODE - RP21419
Axis 2 Option 18, 19:

a. Brief Description of Category, including Axes and Options Covered:

The management of water levels may range from highly sophisticated systems involving dams and sluices through to a simple system where the normal water level in an outfall ditch is controlled.

Arable land or improved grassland under this Option provided the raised water levels resulting from creation of wetland would not adversely affect other land.

b. Description of Expected Impact of Measure:

The aim of this Option is to create and then manage wetlands to help improve biodiversity, the landscape and flood management. This Option promotes the growth, structure and species composition of vegetation on the land by limiting and managing grazing

c. Literature and Background Databases:

In a review of the functioning of natural wetlands for removal of nutrients from water by Acreman (2004), 80% of wetlands caused a retention of N and 84% caused retention of P. Mean % change was 67±274 4 kg ha^{-1} $year^{-1}$ for N and 58±234 kg ha^{-1} $year^{-1}$ for P. However 13% of wetlands caused a release of N and 10% caused release of P. Mean % change was 351±432 for N and 221±328 for P. For riparian wetlands, 70% retained nitrate, and 60% retained ammonium, while 90% retained total P and 35% retained soluble P. 60% of riparian wetlands released soluble P. This dataset suggests that older wetlands are more likely to release P and that % reduction in loads is related to loading rate per ha for N (r2 = 0.3534), but only weakly so for P (r^2=0.0503). Gouriveau (2008) found the efficiency of constructed wetlands at P removal to be 51-57 kg/ha/year.

Weller et al. (1996) found that the inclusion of a variable based on the area of riparian wetlands located along low - and medium-order streams in conjunction with the area of agricultural and non-wetland forested lands explained 88% of the variance in phosphorus loading to surface waters. The best fit model coefficients (Pload = 0.86Ag + 0.64For − 30Ripwet + 160) suggest that a hectare of riparian wetland may be many times more important in reducing phosphorus than an agricultural hectare is in producing phosphorus. The standard errors on these coefficients were 8.8 for Ripwet and 0.14 for Ag. The total area of wetland in the watershed, on the other hand, had very little influence on r^2 in the multiple regression analysis.

d. Suggested Modifier:

New wetlands, funded by SRDP, are more likely to be retainers of nutrients than old, established ones. Based on the literature, wetlands that are not riparian are unlikely to have a significant impact on P loads at landscape scale, so the impact indicator has to consider the position of the measure in the landscape. Where wetlands are adjacent to watercourses, we propose to use the coefficient from the study by Weller et al. (1996), namely that 30kg P/ha are removed by riparian wetland. If the relationship with the riparian zone can be determined, a connectivity factor of 1 can be assumed for riparian wetland, and 0 for non-riparian wetland. In the absence of this information, the connectivity factors for the 1km2 Grid squares (tbl connectivity: CON008) can be used to correct this factor.

We assume the Net Present Benefit of this measure is based on the impact in the year of spend for management of wetland (RP21418) and 5 years for creation, management and restoration of wetland(RP21419). This gives a NPB factor of 0.93 and 3.4 respectively.

e. Uncertainty Estimation:

The age of the wetland may affect effectiveness. Longer term, there is evidence that measures designed to be a sink for P become a source (e.g. Roberts et al., 2012).

f. Data Requirements and Sources:

Area of wetland supported
Connectivity with riparian zone

CATEGORY K. FIELD MARGINS. CODES RP21434, RP21435A AND B
Axis 2 Option 34, 35:

a. Brief Description of Category, including Axes and Options Covered:

- The creation of hedges on a strip of arable land or improved grassland that are wider and taller than normal, with adjacent undisturbed grass margins. No cultivation within a strip extending to at least 3m from the centre line of the hedge.
- The creation and management of grass strips along the boundary of or across an arable field.

b. Description of Expected Impact of Measure:

Cross-field strips on sloping fields will help to reduce the risk of erosion and soil and nutrient run-off. Slower surface-water flow rates can also help to reduce flooding downstream.
Extended field margins provided by extended hedges will enhance nutrient retention especially on the margins of riparian fields.

c. Literature and Background Databases:

Options in this category have a similar impact to dry buffer strips, but unless they are located in riparian fields, the effect at catchment scale will be relatively small (Weller etal., 1996). There is a vast range of literature on the efficacy of buffer strips installed at water margins (e.g. Collins et al.,2009, Krongvang et al., 2005, Uusi-Kamppa et a., 2000, Hoffmann et al, 2009), including recent special issues of Journal of Environmental Quality in 2009 and again in 2012 (see Hoffmann et al, 2009 and Roberts et al., 2012 for examples of papers in these issues). Dry buffer strips intercept surface runoff of sediment, containing a fraction of the nutrient pollution.

d. Suggested Modifier:

Tables A3 and A4 provide a basis for estimating the impact of dry riparian grass margins, or extended hedges funded by SRDP on these export coefficients. Where the width of such buffers is not known, the middle width category (buffer width=2) can be assumed (ie. 2m GBR plus 6m SRDP/LMO).

For non-riparian field margins we assume no impact on P loads to water.

For riparian fields, since neither of these options require the measure to be undertaken only on the riparian margin of riparian fields, **we assume that the impact of the measures is only present on 25% of the field margin lengths/area affected.**

Where position relative to riparian zone is unknown, we assume the connectivity factor is 25% x tbl connectivity: CON008.

We assume the Net Present Benefit of this measure is based on the impact in the year of spend. This gives a NPB factor of 0.93.

e. Uncertainty Estimation:

Location of field margin SRDP measures relative to riparian margins may be difficult to assess accurately.

f. Data Requirements and Sources:

Length and area of grass margins and extended hedges funded on a field basis
Position relative to riparian zone.

CATEGORY L. LOWLAND BOG AND FEN. CODES - RP21420A, RP21420B AND RP21423
Axis 2 Options 20, 23:

a. Brief Description of Category, including Axes and Options Covered:

There are ca. 250 ha of lowland fen and 13,000 ha of lowland raised bog in Scotland (http://jncc.defra.gov.uk/page-5855-theme=textonly). Around 5,600 ha of raised bog is degraded and capable of restoration. The external boundary of the buffer area must be at least 10 metres in width, and field drains and culverts need to be broken, bringing the water in them to the surface to reduce the direct flow of water, nutrients and chemicals into the wetland and encourage drainage water to flow across the established sward in the buffer.

b. Description of Expected Impact of Measure:

Fens are peat-forming wetlands that form in places where water naturally collects, such as valley bottoms and basins. In addition to rainfall, fens receive their water and nutrients from their catchment, through seeps, springs and ground water. Fens have unique habitat features including water of high alkalinity, which supports plants and animals not widely found elsewhere. Fens are particularly vulnerable to nutrient input from adjacent fields which encourages rank growth of weeds on the wetland. The aim is to support the range of plant and animal communities found in these wetlands, and achieve restoration where possible. There is potential for the drying out of a fens and bogs to lead to significant release of P and other nutrients. The establishment of wet buffers for lowland fens and bogs will help to prevent such mineralisation and release of P.

c. Literature and Background Databases:

Hoffmann et al. (2009) have reviewed the impact of riparian wetlands receiving runoff from agriculture. They emphasise the importance of establishing the pathways of transport, but this category of measure requires the breaking of tile drainage, so that the majority of transport is via the surface route. For wetlands and floodplains recharged with surface water only, retention was generally negative or nECtral. For wetlands recharged by groundwater, or surface and groundwater, retention was generally positive, but highly variable. In a study of the P mass balance of a 21m wide wet meadow fringing a stream, the meadow went from being a net source (0.88 kg/ha/year) to a net sink (0.47 kg/ha/year) over 3 years. A survey of P retention on restored riparian fens and meadows which have previously been in agricultural use shows that some retained and some release phosphorus. This range of behaviours was attributed to the potential impact of lowered redox potential on release of iron-oxide bound P from soil and sediment.

As Bogs and fens are effective natural sinks for water and nutrients, the impact of buffers will be principally on their ecological status, rather than on the export of nutrients to standing waters to which they drain, unless they become very degraded. However P mineralisation rates in fens can be significant (eg 34.1 kg P/ha/year for a surface water fen and 2.3 kg P/ha/year for a groundwater fen (Verhoeven and Arts, 1987). Verhoeven et al. (1990) found that P mineralisation rates in fen and bog soils similar to the lower of these two rates.

d. Suggested Modifier:

The variable impact of buffers for fens on delivery of P to lowland bogs and fens, means that with respect to impacts of wet buffers on delivery downstream of the fens to standing waters**, the impact is better considered as preventative – i.e. ensuring that the fen does not become a net source of P –** rather than thinking of the buffer as mitigating P runoff from surrounding land.

We propose to assume that **2 kg P/ha/year is prevented from mineralisation and loss downstream** from each fen/raised bog subject to this measure, the impact of the measure can be accounted from the area of each scheme.

We assume the Net Present Benefit of this measure is based on the impact in the year of spend. This gives a NPB factor of 0.93.

e. Uncertainty Estimation:

The estimate assumes that the fen or raised bog is actively degrading, and that the SRDP measure is fully effective.

f. Data Requirements and Sources:

Area of each fen or raised bog for which this measure has been implemented

Desirable: area of measure implemented and width of buffer implemented

The area of fen or raised bog managed by protective buffers would need to be known.

The proportion of the margin of the wetland treated by wet buffers would also need to be known.

CATEGORY M FLOODPLAINS: CODE - RP21422
Axis 2 Option 22:

a. Brief Description of Category, including Axes and Options Covered;

The whole flood plain must be allowed to flood naturally at times of high water level creating a mosaic of wash lands, dry lands and wetlands. The watercourse must be allowed to flow naturally, with any impediment to natural flooding removed. This will occur where the watercourse meanders through a relatively flat area.

b. Description of Expected Impact of Measure:

This Option will create and maintain a mosaic of wash lands and dry lands by allowing the watercourse to overflow onto its natural flood plain. The water flowing from the river into the floodplain will deposit sediment and nutrients, promote denitrification of nitrate, and potentially also cause release of soluble P from the soil due to development of anoxic conditions. Under some circumstances it may also erode soil.

c. Literature and Background Databases:

Hoffmann et a. (2009) reviewed evidence for P deposition in riparian floodplains and found deposition rates varying from 1-127 kg P/ha/year. Noe and Hupp (2009) investigated P deposition in the flood plains of the non-tidal, freshwater Coastal Plain reaches of seven rivers in the Chesapeake Bay watershed, USA. They found a mean deposition of 59% of the riverine P load in coastal floodplains. Kiedrzyńska et al. (2008) found 10-15 kg P deposition/ha in a vegetated floodplain designed to mitigate ECtrophication of a public water supply reservoir. This is in keeping with the lower end of the range (13-116 kg P/ha) for UK rivers estimated by Walling et al. (1998).

We assume the Net Present Benefit of this measure is based on the impact in the year of spend. This gives a NPB factor of 0.93.

d. Suggested Modifier:

We propose to use the lower end of the range **(13 kg P/ha/year)** for UK rivers estimated by Walling et al. (1999), as a conservative estimate of impact of floodplain reinstatement on P loads for Scottish rivers.

e. Uncertainty Estimation:

The expected deposition depends on the hydrological conditions and P load of the river flooding the floodplain.

f. Data Requirements and Sources:

Area of floodplain reinstated.

CATEGORY N BIODIVERSITY CROPPING ON IN-BYE LAND. CODES - RP21436A AND B
Axis 2 Option 36:

a. Brief Description of Category, including Axes and Options Covered:

Sow plots of spring cereals, fodder root crops or fodder rape each up to 2 hectares; their total area must not exceed 4 hectares over the whole unit. Only undertake cultivations and spread fertiliser between 1 March and 15 May inclusive. Exceptionally, for fodder rape or root crops, cultivations may be carried out after 15 May

b. Description of Expected impact of Measure:

This Option will increase the conservation value of arable land by encouraging traditional crop rotations to provide cover and feeding areas for birds. Spring cropping and low input management will support wildflowers and provide invertebrate food for birds. The structure of a spring crop is also favourable to ground nesting birds

c. Literature and Background Databases:

d. Suggested Modifier:

The absence of autumn/winter cultivations will have a beneficial effect on the export of P from inbye land. We assume the crop risk index for the land affected by this measure changes from index 4 (winter cereals) to index 3 (spring cereals) for half the area, while the other half is unaffected, as the fodder crops, if grazed off in the fields during autumn or winter, are also allocated to risk index 4.

We assume the Net Present Benefit of this measure is based on the impact in the year of spend. This gives a NPB factor of 0.93.

Index changes from 4 to 3 for half the area on which this measure is adopted.

e. Uncertainty Estimation:

f. Data Requirements and Sources:

Area and slope of inbye land affected

CATEGORY O TRACKS, GATES, CROSSINGS. CODE - RP21602.
Axis 2 Option 42:

a. Brief Description of Category, including Axes and Options Covered:

Farmers should identify if they have any livestock tracks, gateways or river crossings that are not suitably positioned or could be improved to prevent soil, nutrient or faecal contamination of watercourses. Repositioning gateways to lower risk areas (for example, away from the bottom of slopes and to where run-off may be diverted to buffer areas) can decrease the quantities of potential pollutants entering watercourses.

b. Description of Expected Impact of Measure:

Tracks, gateways and river crossings can be significant sources of the loss of soil, nutrients (such as phosphates) and faecal material to watercourses. This Option will improve tracks, gateways and river crossings in order to reduce the possible adverse effects of livestock on the water environment.

c. Literature and Background Databases:

Shukla et al. (2011) investigated water quality effectiveness of ditch fencing and culvert crossing in the Lake Okeechobee basin, southern Florida, USA. They found that during the pre-measure period, downstream total P (TP) load was 20% (67.0 kg) higher than the upstream, indicating the cattle crossing to be a source of P. Downstream loads of TP in 2006 and 2008 (post-measure periods) became 26% (14.7 kg) and 11% (85.9 kg) lower than the upstream loads, respectively indicating that the BMP reduced the P loads. Unusual dry conditions during 2007 resulted in the addition of P and N at the treated site, probably due to the release of P and N from soil and plants. Average of three post-measure period load showed a 10% reduction of TP loads at the downstream (251.8 kg) compared to the upstream (281.0 kg) location. To consider potential P contributions from the soil and plant, two scenarios, conservative and liberal, were considered to estimate P load reductions due to the BMP. For the conservative scenario, P contribution from soil and plant was considered, while for liberal it was not. Reductions in P loads for conservative and liberal scenarios were 0.35 and 0.44 kg/day, respectively.

d. Suggested Modifier:

The P in faeces deposited in tracks, gates and crossings can all be considered as at risk of transport to water. Cows have an average walking speed of 2-3km per hour. The distance travelled by cows from pasture to dairy on two farms in the Cessnock catchment, Ayrshire was estimated as 200-300m giving a walking time of around 6m. For two milking's per day this gives 24m of excretion time. The P excretion in this period will be above average for the day. Aland et al. (2002) found that 75% of defecation occurred during milking and feeding time (9h), so if a dairy cow excretes 70 g P/day (Nenninch et al., 2005), the P excretion at risk from runoff to watercourses is:

(4 x 0.75 x 70 x 6) / (9 x 60) = 2.4 g P/cow/day ≈ 0.4 kg P/cow/year for a 180 day grazing season.

We assume that this is the potential load that can be mitigated by measures to control direct runoff from tracks, gates and crossings. The measure is only applied to sites where a specific problem has been identified, which will generally be on dairy farms.

As there is unlikely to be data to estimate the no. of cattle impacted by each scheme, we assume that each funded project (14 from 2008-2011) relates to 150 cows (average size of dairy herd; http://www.meattradenewsdaily.co.uk/news/080110/scotland_mass_exodus_from_dairyfarming.aspx),
than the average impact of tracks, gates and crossings is ca. **60 kg P per case**.

We assume the Net Present Benefit of this measure is based on the impact over 10 years. This gives a NPB factor of 6.5.

e. Uncertainty Estimation:

The estimation of these impacts is highly uncertain, and ideally the impact indicators would be tuned to the background P export from each catchment, which will vary with initial geology.

f. Data Requirements and Sources:

Dairy Livestock numbers on farms where the measure is adopted.

CATEGORY P. SOIL AND WATER MANAGEMENT. CODES - RP11402A AND B
Axis 1 Option 4:

a. Brief Description of Category, including Axes and Options Covered:
The SWMP will assess the risks to soil and water on the farm including soil erosion, compaction, structural degradation, and losses of organic matter and of nutrients.

b. Description of Expected Impact of Measure:
Where risks to soils or to the water environment have been identified, management practices should be outlined in the SWMP to protect soils and the water environment. This may include the prevention or mitigation of soil erosion or compaction, or preventing water pollution resulting from soil erosion, manures or other nutrients.

c. Literature and Background Databases:

d. Suggested Modifier:
We suggest this measure leads to **a reduction in the crop risk class by one class, for all arable areas** of the farm.

We assume the Net Present Benefit of this measure is based on the impact over 1 year. This gives a NPB factor of 0.93.

e. Uncertainty Estimation:
The impact of this measure depends strongly on the initial baseline level of soil erosion on the farm.

f. Data Requirements and Sources:
Field areas under arable cultivation and slope indices for farms adopting this measure.

APPENDIX 2. GIS handbook for assessing the effectiveness of SRDP measures

This document describes how to carry out the calculations described in Section 4 and Appendix 1 of *SRDP_WATERQUALITYIMPACT 2012_AV5.pdf* using ArcGIS Desktop. These instructions are based on ArcGIS version 9.3.1 with the spatial analyst extension, but the calculations could equally be performed using other versions of ArcGIS, or with other software packages entirely. A working knowledge of ArcGIS is assumed throughout.

The aim is to generate, for each category of measure, a 1km by 1km grid representing the amount of P mitigated in kilograms per year. In some cases the processing also involves deriving an intermediate grid which gives an indication of the spatial distribution of SRDP funding for each measure.

Due to a lack of available SRDP data, it has not been possible to test the workflows described for all of these categories. Because of this, please consider this document as a preliminary draft at this stage. Also note that, once any issues have been ironed out and the methodology fully tested, it should be possible to automate all of the calculations described here and to package them as an ArcToolbox script. This would save a great deal of manual processing, but is currently beyond the scope of this project.

NB: When working through the steps below, it is recommended that you ***start a new ArcMap document for each category***.

Data sources

All of the datasets required for the calculations described (apart from the SRDP data itself) are contained within an ESRI file geodatabase called *SRDP_Effectiveness_Data.gdb*. It is probably best to ***make a copy of this database*** rather than modifying the original.

The SRDP data for each category should be supplied as a ***DBF table*** with column headings *Field_ID* and *Spend* (in pounds sterling). As far as I can tell, SRDP funding is always attached to a particular field ID, even when the measure is likely to have an impact farm-wide. The calculations below attempt to allow for this to some degree.

In some cases SRDP funding is awarded annually, whereas in others it is awarded in a single ("capital") payment, which is assumed to have an impact over subsequent years. For those categories where funding is awarded annually, these instructions assume that you are supplying a single year's worth of SRDP data not, for example, the total paid in instalments over a five year period. For measures where capital payments are appropriate, please supply the total value of the capital payment awarded (i.e. don't divide this over the five year period): these instructions include the calculation of annualised costs where necessary.

Finally, the notes make use of the IACS data from 2009/2010, which is the most up-to-date information currently available to the JHI. This should be broadly compatible with the SRDP data from the period from 2008 to 2012.

A note on performance

Many of the datasets involved in the procedures described are very large, so some of the operations may be frustratingly slow on a standard desktop computer. In addition, the table join operations are significantly slower in ArcGIS Desktop than they are in other database software (e.g. PostGIS, Oracle or SpatialLite).

Performance can often be improved by building appropriate indices on the join fields. This has been done in most cases, but you may wish to add additional indices for some operations. Nevertheless, ArcGIS is still slow in many respects: by using alternative software, it is possible to perform many of these calculations more efficiently, but a full description of such optimisation is beyond the scope of these notes. Please use whatever additional software you are comfortable with to streamline the workflow described here.

One simple way of significantly improving performance is to copy the file geodatabase *SRDP_Effectiveness_Data.gdb* to a local drive i.e. don't attempt these calculations over a network connection.

Section 1: Options that will always deliver the desired outcomes

1.1. Category A: Manure/slurry storage and treatment

As this measure has no impact on light soils, we need to estimate what fraction of the total spend is going towards farms with predominantly medium or heavy soils. Proceed as follows:

1. Start ArcMap. Add the raster *Soils_Lt_Hv*, the feature class *Fields_2010* and the geodatabase table *IACS_Land_Use_2009*.

2. Money for this measure is associated with a particular field ID, but the effects of manure storage are felt farm-wide. The first step is therefore to use the IACS data to determine the relevant *Owner_Holding_Code(s)* from the *Field_IDs*.

    i. First, use the SRDP data to generate a table listing the *Field_IDs* receiving funding under this measure together with the amount of funding. Add this table to ArcMap and ***join*** it to *IACS_Land_Use_2009* (use *Field_ID* as the join field). Choose to ***keep only matching records***.

    ii. Open the attribute table of *IACS_Land_Use_2009*, ***right-click*** the *OWNER_HOLDING* column and choose ***Summarize***. Choose to calculate the ***Sum*** of the amount spent, name the output table *Holding_Codes* and, after saving it, add the table to ArcMap. This table contains a list of holdings receiving funding under this measure, together with the total amount received by each holding. ***Remove the join*** from *IACS_Land_Use_2009*.

3. Next, ***join*** *Holding_Codes* to *IACS_Land_Use_2009* using *OWNER_HOLDING* as the join field. Choose to ***keep only matching records***. Then join *IACS_Land_Use_2009* to *Fields_2010* using *Field_ID* as the join field (again, ***keep only matching records***). The *Fields_2010* feature class should now only show fields belonging to farms receiving funding for this measure.

4. From ArcToolbox, open the ***Dissolve*** tool. Set *Fields_2010* as the input dataset and choose *OWNER_HOLDING* as the dissolve field. Choose to include ***FIRST*** of amount spent in the *statistics fields* options. Call the output *Holdings_Dissolve* and add it to the map. ***Remove all joins*** from *Fields_2010* and *IACS_Land_Use_2009*.

    Holdings_Dissolve now contains one polygon for each holding receiving funding under this measure and its attribute table stores the total amount of funding received by each holding. In the final few steps, we will convert the vector holding data to raster data at 100m resolution, and then aggregate this to 1km^2 grids showing the spatial distribution of spend for this measure and the estimated P mitigated.

5. ***Add a new field*** to *Holdings_Dissolve* and convert the total capital spend into annualised spend. This can be done using the field calculator and the formula:

$$NPB = \frac{rC(1+r)^n}{(1+r)^n - 1} \qquad (1)$$

   Where *r* is the interest rate as a fraction (e.g. 0.07 for 7%),
   C is the capital cost (i.e. the amount spent column in *Holdings_Dissolve*) and
   n is the number of years for which the measure is effective.

   For this measure, assume ***r = 0.07*** and ***n = 10***.

6. ***Add a new field*** to *Holdings_Dissolve* and calculate the annualised spend divided by the total holding area in ***hectares*** (take care with any unit conversions!). The field calculator equation will look something like this:

   [Annualised_Spend] / ([Shape_Area] / 10000.0)

   This gives the average annualised spend per 100m by 100m square for each holding. **NB:** If *Holdings_Dissolve* doesn't already contain a [Shape_Area] column you'll need to add one and use ***Calculate Geometry*** to get the area of each holding.

7. Use the ***Polygon to raster*** tool to convert *Holdings_Dissolve* into a 100m by 100m grid. The *Value* field should be set to the annualised spend per hectare field (calculated above). *Cell assignment type* should be ***MAXIMUM COMBINED AREA*** and c*ell size* should be ***100***.

8. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m annualised spend grid into a grid with a resolution of 1km^2. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main geodatabase). Call the output grid ***Cat_A_Spend***.

9. The *Cat_A_Spend* grid shows the total annualised spend for this measure in each 1km^2 cell. For the final step, we will use the equation from Appendix 1, Category A to convert this spend into an estimate of the amount of P mitigated per grid square. Do this using raster calculator from the spatial analyst toolbar. The expression for the raster calculator is:

   [Soils_Lt_Hv] * [Cat_A_Spend] / 4746.0

   Save this raster as ***Cat_A_P_Mit*** (the units here are in kilograms of P mitigated per 1km^2 cell per year).

1.2. Category B: Arable reversion to grassland

For this calculation we need to know the area of each field receiving money under this measure. We make the simplifying assumption that the entire field is converted from arable to grassland (ignoring complications such as the fact that some fields have multiple uses, so only part of a field may revert to grass). It is therefore likely that this calculation will overestimate the amount of P mitigated.

1. Start a new ArcMap document and add *Fields_2010* to it.

2. From the SRDP data, generate a list of the *Field_IDs* associated with this measure, together with the total amount of money awarded. Add this table to ArcMap too.

3. ***Join*** the SRDP data to *Fields_2010* using *Field_ID* as the join field. Choose to ***keep only matching records***.

4. ***Right-click*** *Fields_2010* in the table of contents and choose ***Data > Export***. Export all records to a new shapefile called *Cat_B_Fields* and add it to the map. This shapefile contains all of the fields receiving support under this measure.

5. Open the attribute table of *Cat_B_Fields* and add a new field called ***Ones***. Use the field calculator to set every entry in this column to ***1***.

6. Use the ***Polygon to raster*** tool to convert *Cat_B_Fields* into a 100m by 100m grid. The *Value* field should be set to the ***Ones*** field (created above). *Cell assignment type* should be ***MAXIMUM COMBINED AREA*** and *cell size* should be ***100***.

7. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m grid from step 6 into a grid with a resolution of 1km^2. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main FGDB). Call the output grid ***Cat_B_Area***.

8. Values in the *Cat_B_Area* raster indicate the number of hectares of land (within each 1km square) that receive funding under this measure. As described in Appendix 1, Category B, the amount of P mitigated in each 1km^2 cell can therefore be estimated by multiplying the values in this raster by 0.54. Use the following equation in the spatial analyst raster calculator to generate a new grid:

   [Cat_B_Area]*0.54

   Save this grid as ***Cat_B_P_Mit*** (the units here are in kilograms of P mitigated per 1km^2 cell per year).

<u>1.3. Category C: Farm wetlands</u>

To estimate the spatial distribution of P mitigated by this measure, we first need to calculate the distribution of annualised spend.

1. Start ArcMap and add the feature class *Fields_2010*.

2. Use the SRDP data to generate a table listing the *Field_IDs* receiving funding under this measure together with the total amount of funding. Add this table to ArcMap and ***join*** it to *Fields_2010* (use *Field_ID* as the join field). Choose to ***keep only matching records***.

3. ***Right-click*** *Fields_2010* in the table of contents and choose ***Data > Export***. Export all records to a new shapefile called *Cat_C_Fields* and add it to the map. This shapefile contains all of the fields receiving support under this measure.

4. Open the attribute table of *Cat_C_Fields* and add a new field called ***Ann_Spend***. Use the field calculator and ***equation 1*** (above) to calculate the annualised spend for each field. Assume ***r = 0.07*** and ***n = 10***.

5. Add another field called ***Ann_pHa*** and use the field calculator to calculate the annual spend per hectare of field. The field calculator expression will be something like this:

   [Ann_Spend] / ([Shape_Area] / 10000.0)

6. Use the ***Polygon to raster*** tool to convert *Cat_C_Fields* into a 100m by 100m grid. The *Value* field should be set to the annualised spend per hectare field (calculated above). *Cell assignment type* should be ***MAXIMUM COMBINED AREA*** and *cell size* should be ***100***.

7. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m annualised spend grid into a grid with a resolution of $1km^2$. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main FGDB). Call the output grid ***Cat_C_Spend***.

8. The *Cat_C_Spend* grid shows the total annualised spend for this measure in each $1km^2$ cell. For the final step, we will use the equation from Appendix 1, Category C to convert this spend into an estimate of the amount of P mitigated per grid square. Do this using the raster calculator from the spatial analyst toolbar. The equation for the raster calculator is:

   [Cat_C_Spend] / 10.0

   Save this raster as ***Cat_C_P_Mit*** (the units here are in kilograms of P mitigated per $1km^2$ cell per year).

1.4. Category D: Nutrient management

This calculation is a little more complicated, as we need to incorporate some aspects of the hydrology as well as allowing for the fact that a single field can have multiple land uses.

1. Start ArcMap. Add the rasters *SSF_mm* and *OF_mm*, the feature class *Fields_2010* and the geodatabase tables *IACS_Land_Use_2009* and *IACS_Land_Use_Codes*.

2. Use the SRDP data to generate a table listing the *Field_IDs* receiving funding under this measure. Add this table to ArcMap.

3. ***Join*** *IACS_Land_Use_2009* to *IACS_Land_Use_Codes* using *Land_Use* as the primary key and *RC_CODE* as the foreign key. Then ***join*** this table to your SRDP data using *Field_ID* as the key. In both cases, choose to ***keep only matching records***.

4. ***Export*** all the records in the joined attribute table to a new table called *Cat_D_Fields* (***right-click***, ***Data > Export***). Add the new table to the map.

5. Open the attribute table of *Cat_D_Fields* and add a new field called ***Area_x_LU***. Use the field calculator with the following expression to populate this field:

   [CLAIMED_AR]*[CatD_Fac]

6. Still working with the *Cat_D_Fields* attribute table, ***right-click*** the *Field_ID* column and choose ***Summarize***. Under the summary statistics options, choose to calculate the ***SUM*** of the *Area_x_LU* column. Call this table ***Cat_D_Fields_Sum***.

7. ***Join*** *Cat_D_Fields_Sum* to *Fields_2010* using *Field_ID* as the join field. Choose to ***keep only matching records***. Then ***right-click*** *Fields_2010* and export the data to a new shapefile called *Cat_D_Fields_Spatial*.

8. Open the attribute table of *Cat_D_Fields_Spatial* and add a new field called ***AxLU_pHa***. Use the *field calculator* with the following expression to populate this field:

   [Sum_Area_x] / ([Shape_Area] / 10000.0)

9. Use the ***Polygon to raster*** tool to convert *Cat_D_Fields_Spatial* into a 100m by 100m grid. The *Value* field should be set to the *AxLU_pHa* field (calculated above). *Cell assignment type* should be ***MAXIMUM COMBINED AREA*** and *cell size* should be ***100***.

10. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m grid into a grid with a resolution of $1km^2$. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main FGDB). Call the output grid ***Cat_D_1km***.

11. Finally, to estimate the amount of P mitigated, we need to multiply this grid by the average annual drainage (i.e. overland flow plus shallow sub-surface flow). This can be done using the following expression in the spatial analyst raster calculator:

    [Cat_D_1km] * ([SSF_mm] + [OF_mm])

    Save this raster as ***Cat_D_P_Mit*** (the units here are in kilograms of P mitigated per $1km^2$ cell per year).

1.5. Category E: Reducing bacterial contamination from septic tanks
This measure is not being considered in this analysis. See the main report for further details.

Section 2: Options that will achieve the desired outcomes in specific circumstances

2.1. Category F: Woodland creation
For this calculation we need to know (i) the area of each field, (ii) the slope class for each field, and (iii) the connectivity values of the appropriate $1km^2$ grid cell(s).

1. Start ArcMap and add the raster *Connectivity* together with the features classes *Fields_2010* and *Slopes_2010*.

2. Use the SRDP data to generate a table listing the *Field_IDs* receiving funding under this measure. Add this table to the map as well.

3. ***Join*** *Fields_2010* to *Slopes_2010* using *Field_ID* as the key, and then ***join*** this table to your SRDP data (again, using *Field_ID* as the key). In both cases, choose to ***keep only matching records***.

4. ***Export*** the joined dataset to a new shapefile called *Cat_F_Fields* (***right-click*** *Fields_2010*, ***Data > Export***) and add it to the map.

5. Use the ***Polygon to raster*** tool to convert *Cat_F_Fields* into a 100m by 100m grid. The *Value* field should be set to the *CatF_SlpFac* field. *Cell assignment type* should be ***MAXIMUM COMBINED AREA*** and *Cell size* should be ***100***.

6. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m grid into a new grid with a resolution of $1km^2$. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main FGDB). Call the output grid ***Cat_F_1km***.

   Cat_F_1km shows the amount of P that would be mitigated if all the grid cells were equally connected to the stream network and if all of the P coming off the fields ended up in the stream. The final step is therefore to multiply this grid by a stream connectivity factor to represent the fact that some grid cells are more "connected" than others.

7. Use the following expression in the spatial analyst raster calculator to allow for connectivity:

   [Cat_F_1km] * [Connectivity]

   Save this raster as ***Cat_F_P_Mit*** (the units here are in kilograms of P mitigated per $1km^2$ cell per year).

2.2. Category G: Low intensity grazing

The processing required for this category is split into two, depending on the exact diffuse pollution package(s) being considered. The workflow is identical for both groups, except for a ***slight change in step 5***. You will therefore need to perform the steps described here twice – once for each group of SRDP options.

1. First, divide the SRDP data for this category into two groups, and generate a list of field IDs associated with each:

Group 1	Group 2
Open grazed or wet grassland for wildlife	Management of habitat mosaics
Management of species rich grassland	Scrub and tall herb communities
Creation and management of species rich grassland	Conservation management for small units - collective
Lowland heath	Conservation management for small units - individual
	Wildlife management on upland and peatland sites
	Moorland grazing on uplands and peatlands
	Management of moorland grazing
	Ancient wood pasture - in-bye land
	Ancient wood pasture - rough grazing
	Management of coastal, serpentine & special interest heath

For each of your two lists of fields, you will need to perform the following steps.

2. Start ArcMap and add the raster *Connectivity*, the features class *Fields_2010* and the geodatabase table *Slopes_2010*. Also add the SRDP data table for whichever of the above groups you are currently processing.

3. ***Join*** *Fields_2010* to *Slopes_2010* using *Field_ID* as the key, and then ***join*** this table to your SRDP data (again, using *Field_ID* as the key). In both cases, choose to ***keep only matching records***.

4. ***Export*** the joined data to a new shapefile called *Cat_G_Fields_GrpX,* where ***X*** is the number of the group that you're processing (***right-click*** *Fields_2010*, ***Data > Export***) and add it to the map.

5. Use the ***Polygon to raster*** tool to convert *Cat_G_Fields_GrpX* into a 100m by 100m grid. If you're processing the data for *Group 1*, the *Value* field should be set to ***CatG_Op1***; if you're processing *Group 2*, set it to ***CatG_Op2*** instead. The *cell assignment type* should be ***MAXIMUM COMBINED AREA*** and *cell size* should be ***100***.

6. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m grid into a new grid with a resolution of 1km^2. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main FGDB). Call the output grid ***Cat_G_GrpX***, where ***X*** is the number of the group that you're processing.

8. Use the following expression in the spatial analyst raster calculator to allow for connectivity:

   [Cat_G_GrpX] * [Connectivity]

   Save this raster as ***Cat_G_GrpX_P_Mit*** (the units here are in kilograms of P mitigated per 1km^2 cell per year).

9. Repeat steps 2 to 8 for the other group. You should now have two rasters called ***Cat_G_Grp1_P_Mit*** and ***Cat_G_Grp2_P_Mit***. Finally, use the raster calculator and the expression:

   [Cat_G_Grp1_P_Mit] + [Cat_G_Grp1_P_Mit]

   to calculate the total P mitigated by the group G measures. Save this raster as ***Cat_G_P_Mit*** (as above, the units here are in kilograms of P mitigated per 1km^2 cell per year).

2.3. Category H: Water margins

This calculation is fairly involved as we need to calculate (i) the slope and crop risk factors for each part of each field, (ii) the total P mitigated by this measure in each field, (iii) the total P mitigated by this measure in each 1km^2 grid cell, and (iv) how stream network connectivity modifies the actual amount of P mitigated.

We also need to make some assumptions regarding buffer widths (see Appendix 1, Category H). For the calculation here, we assume that all buffers are in width class 2 (i.e. 4 – 14 metres wide).

1. Start ArcMap. Add the raster *Connectivity*, the feature class *Fields_2010* and the geodatabase tables *IACS_Land_Use_2009*, *IACS_Land_Use_Codes*, *Slopes_2010* and *Slope_Crop_Risk_Lookup*.

2. Use the SRDP data to generate a table listing the *Field_IDs* receiving funding under this measure. Add this table to the map as well.

3. ***Join*** *IACS_Land_Use_2009* to *IACS_Land_Use_Codes* using *Land_Use* as the primary key and *RC_CODE* as the foreign key. ***Join*** this table to *Slopes_2010* using *Field_ID* as the join field, and then ***join*** this table to your SRDP data (again, using *Field_ID* as the key). In all cases, choose to ***keep only matching records***.

4. ***Export*** all the records in the joined attribute table to a new table called *Cat_H_Fields* (***right-click***, ***Data > Export***). Add the new table to the map.

5. Open the attribute table of *Cat_H_Fields* and add a new ***Text*** field called ***Slp_Crp***. Use the field calculator with the following expression to populate this field:

   [Slp_Class]&"_"&[P_Risk]

6. ***Join*** *Slope_Crop_Risk_Lookup* to *Cat_H_Fields* using *Slp_Crp* as the join field. Add a new field to this attribute table called ***Pmit_kg*** and use the following expression in the field calculator to populate this field:

   [CLAIMED_AR]*[CatH_kgpHa]

7. ***Remove all joins*** from the *Cat_H_Fields* attribute table, then ***right-click*** the *Field_ID* column and choose ***Summarize***. Under the summary statistics options, choose to calculate the ***SUM*** of the *Pmit_kg* column. Call this table ***Cat_H_Fields_Sum***.

8. ***Join*** *Cat_H_Fields_Sum* to *Fields_2010* using *Field_ID* as the join field. Choose to ***keep only matching records***. Then ***right-click*** *Fields_2010* and export the data to a new shapefile called *Cat_H_Fields_Spatial*.

9. Open the attribute table of *Cat_H_Fields_Spatial* and add a new field called ***Pmit_kgpHa***. Use the field calculator with the following expression to populate this field:

   [Sum_Pmit_kg] / ([Shape_Area] / 10000.0)

10. Use the ***Polygon to raster*** tool to convert *Cat_H_Fields_Spatial* into a 100m by 100m grid. The *Value* field should be set to the *Pmit_kgpHa* field (calculated above). *Cell assignment type* should be ***MAXIMUM COMBINED AREA*** and *Cell size* should be ***100***.

11. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m grid into a grid with a resolution of 1km^2. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main FGDB). Call the output grid ***Cat_H_1km***.

12. Finally, to estimate the amount of P mitigated, we need to allow for stream connectivity. This can be done using the equation given in Appendix 1, Category H, which can be entered into the spatial analyst raster calculator as follows:

    [Cat_H_1km] * [Connectivity]

Save this raster as ***Cat_H_P_Mit*** (the units here are in kilograms of P mitigated per 1km^2 cell per year).

2.4. Category I: Organic farming
The calculation for this measure is identical to that for *Category D* (nutrient management). Follow the instructions given above (in Section 1.4), but ***use the field IDs associated with this category instead***. In step 5, use ***[CatI_Fac]*** instead of ***[CatD_Fac]*** in the field calculator expression and, in step 11, remember to call the final raster ***Cat_I_P_Mit***.

2.5. Category J: Create, restore and manage wetlands
For this calculation we need to estimate the total area of land receiving funding for this measure within each 1km^2 grid cell.

1. Start a new ArcMap document and add the raster *Connectivity* and the feature class *Fields_2010*.

2. From the SRDP data, generate a list of the *Field_IDs* associated with this measure and add this table to the map as well.

3. ***Join*** the SRDP data to *Fields_2010* using *Field_ID* as the join field. Choose to ***keep only matching records***.

4. ***Right-click*** *Fields_2010* in the table of contents and choose ***Data > Export***. Export all records to a new shapefile called *Cat_J_Fields* and add it to the map. This shapefile contains all of the fields receiving support under this measure.

5. Open the attribute table of *Cat_J_Fields* and add a new field called ***Ones***. Use the field calculator to set every entry in this column to ***1***.

6. Use the ***Polygon to raster*** tool to convert *Cat_J_Fields* into a 100m by 100m grid. The *Value* field should be set to the ***Ones*** field (created above). *Cell assignment type* should be ***MAXIMUM COMBINED AREA*** and *cell size* should be ***100***.

7. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m grid from step 6 into a grid with a resolution of 1km^2. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main FGDB). Call the output grid ***Cat_J_Area***.

8. Values in the *Cat_J_Area* raster indicate the number of hectares of land (within each 1km square) that receive funding under this measure. To estimate the amount of P mitigated, we will use the spatial analyst raster calculator together with the equation given in Appendix 1, Category J:

    30.0*[Cat_J_Area]*[Connectivity]

Save this grid as ***Cat_J_P_Mit*** (the units here are in kilograms of P mitigated per $1km^2$ cell per year).

2.6. Category K: Hedgerows and grass margins

This calculation is fairly involved as we need to calculate (i) the slope and crop risk factors for each part of each field, (ii) the total P mitigated by this measure in each field, (iii) the total P mitigated by this measure in each $1km^2$ grid cell, and (iv) how stream network connectivity modifies the actual amount of P mitigated.

10. Start ArcMap. Add the raster *Connectivity*, the feature class *Fields_2010* and the geodatabase tables *IACS_Land_Use_2009*, *IACS_Land_Use_Codes*, *Slopes_2010* and *Slope_Crop_Risk_Lookup*.

11. Use the SRDP data to generate a table listing the *Field_IDs* receiving funding under this measure. Add this table to the map as well.

12. ***Join*** *IACS_Land_Use_2009* to *IACS_Land_Use_Codes* using *Land_Use* as the primary key and *RC_CODE* as the foreign key. ***Join*** this table to *Slopes_2010* using *Field_ID* as the join field, and then ***join*** this table to your SRDP data (again, using *Field_ID* as the key). In all cases, choose to ***keep only matching records***.

13. ***Export*** all the records in the joined attribute table to a new table called *Cat_K_Fields* (***right-click***, ***Data > Export***). Add the new table to the map.

14. Open the attribute table of *Cat_K_Fields* and add a new field called ***Slp_Crp***. Use the field calculator with the following expression to populate this field:

    [Slp_Class]&"_"&[P_Risk]

15. ***Join*** *Slope_Crop_Risk_Lookup* to *Cat_K_Fields* using *Slp_Crp* as the join field. Add a new field to this attribute table called ***Pmit_kg*** and use the following expression in the field calculator to populate this field:

    [CLAIMED_AR]*[CatK_kgpHa]

16. ***Remove all joins*** from the *Cat_K_Fields* attribute table, then ***right-click*** the *Field_ID* column and choose ***Summarize***. Under the summary statistics options, choose to calculate the ***SUM*** of the *Pmit_kg* column. Call this table ***Cat_K_Fields_Sum***.

17. ***Join*** *Cat_K_Fields_Sum* to *Fields_2010* using *Field_ID* as the join field. Choose to ***keep only matching records***. Then ***right-click*** *Fields_2010* and export the data to a new shapefile called *Cat_K_Fields_Spatial*.

18. Open the attribute table of *Cat_K_Fields_Spatial* and add a new field called ***Pmit_kgpHa***. Use the field calculator with the following expression to populate this field:

    [Sum_Pmit_kg] / ([Shape_Area] / 10000.0)

13. Use the ***Polygon to raster*** tool to convert *Cat_K_Fields_Spatial* into a 100m by 100m grid. The *Value* field should be set to the *Pmit_kgpHa* field (calculated above). *Cell assignment type* should be ***MAXIMUM COMBINED AREA*** and *Cell size* should be ***100***.

14. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m grid into a grid with a resolution of $1km^2$. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main FGDB). Call the output grid ***Cat_K_1km***.

15. Finally, to estimate the amount of P mitigated, we need to allow for stream connectivity. This can be done using the equation given in Appendix 1, Category K, which can be entered into the spatial analyst raster calculator as follows:

    0.25*[Cat_K_1km] * [Connectivity]

    Save this raster as ***Cat_K_P_Mit*** (the units here are in kilograms of P mitigated per $1km^2$ cell per year).

2.7. Category L: Lowland raised bogs & fens, and their buffer areas

The exact methodology for this measure will depend on what additional information (if any) is available from the SRDP data. The calculation is therefore not currently described.

2.8. Category M: Restoration of floodplains

For this calculation we need to know, for each $1km^2$ grid cell, the total area of land receiving funding under this measure.

1. Start a new ArcMap document and add the feature class *Fields_2010* to it.

2. From the SRDP data, generate a list of the *Field_IDs* associated with this measure and add this table to the map as well.

3. ***Join*** the SRDP data to *Fields_2010* using *Field_ID* as the join field. Choose to ***keep only matching records***.

4. ***Right-click*** *Fields_2010* in the table of contents and choose ***Data > Export***. Export all records to a new shapefile called *Cat_M_Fields* and add it to the map. This shapefile contains all of the fields receiving support under this measure.

5. Open the attribute table of *Cat_M_Fields* and add a new field called ***Ones***. Use the *field calculator* to set every entry in this column to ***1***.

6. Use the ***Polygon to raster*** tool to convert *Cat_M_Fields* into a 100m by 100m grid. The *Value* field should be set to the ***Ones*** field (created above). *Cell assignment type* should be ***MAXIMUM COMBINED AREA*** and *cell size* should be ***100***.

7. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m grid from step 6 into a grid with a resolution of $1km^2$. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main FGDB). Call the output grid ***Cat_M_Area***.

8. Values in the *Cat_M_Area* raster indicate the number of hectares of land (within each 1km square) that receive funding under this measure. To estimate the amount of P mitigated, we will use the spatial analyst raster calculator together with the equation given in Appendix 1, Category M:

    13.0*[Cat_M_Area]

    Save this grid as ***Cat_M_P_Mit*** (the units here are in kilograms of P mitigated per $1km^2$ cell per year).

2.9. Category N: Biodiversity cropping on in-bye land

The calculation for this measure is identical to that for *Category F* (woodland creation). Follow the instructions given above (in Section 2.1), but ***use the field IDs associated with this category instead***.

In step 5, be sure to set the *Value* field to ***[CatN_SlpFac]*** (instead of ***[CatF_SlpFac]***). In step 7, remember to call the final raster ***Cat_N_P_Mit***.

2.10. Category O: Tracks, gates and crossings

For this calculation, we need to consider the spatial distribution of the fields receiving funding under this measure. We will assume that the P mitigation effect is concentrated in the area immediately around the field(s) receiving funding.

1. Start a new ArcMap document and add the feature class *Fields_2010*.

2. From the SRDP data, generate a list of the *Field_IDs* associated with this measure and add this table to the map as well.

3. ***Join*** the SRDP data to *Fields_2010* using *Field_ID* as the join field. Choose to ***keep only matching records***.

4. ***Right-click*** *Fields_2010* in the table of contents and choose ***Data > Export***. Export all records to a new shapefile called *Cat_O_Fields* and add it to the map. This shapefile contains all of the fields receiving support under this measure.

5. Open the attribute table of *Cat_O_Fields* and add a new field called ***Pmit_kgpHa***. Use the following expression in the field calculator to populate this field:

    60.0 / ([Shape_Area] / 10000.0)

6. Use the ***Polygon to raster*** tool to convert *Cat_O_Fields* into a 100m by 100m grid. The *Value* field should be set to the *Pmit_kgpHa* field (created above). *Cell assignment type* should be ***MAXIMUM COMBINED AREA*** and *cell size* should be ***100***.

7. Use the ***Aggregate*** tool in ArcToolbox to convert the 100m grid from step 6 into a grid with a resolution of $1km^2$. To do this, set the *cell factor* to ***10***, the *aggregation technique* to ***SUM*** and make sure that *Expand extent if needed* is ***checked***. Click the ***Environments*** button and, under ***General Settings***, set the ***Extent*** and ***Snap raster*** to ***Scot_1km*** (located in the main FGDB). Call the output grid ***Cat_O_P_Mit*** (the units here are in kilograms of P mitigated per $1km^2$ cell per year).

2.11. Category P: Soil and water management

The calculation for this measure is identical to that for *Category K* (hedgerows and grass margins). Follow the instructions given above (in Section 2.6), but ***use the field IDs associated with this category instead***. Note also the following changes:

In step 6, be sure to use the following expression in the field calculator instead of the one given above:

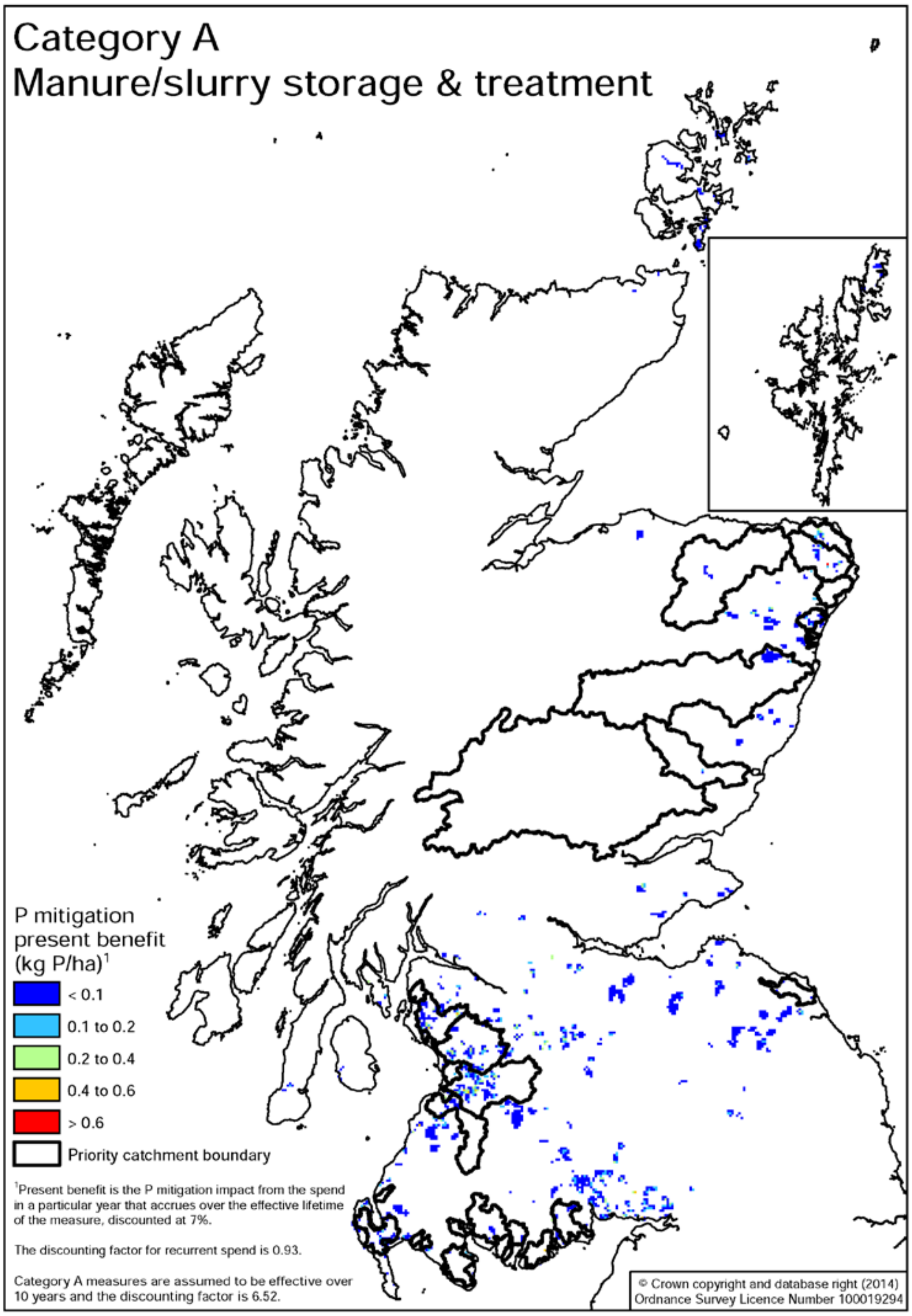
    [CLAIMED_AR]*[CatP_kgpHa]

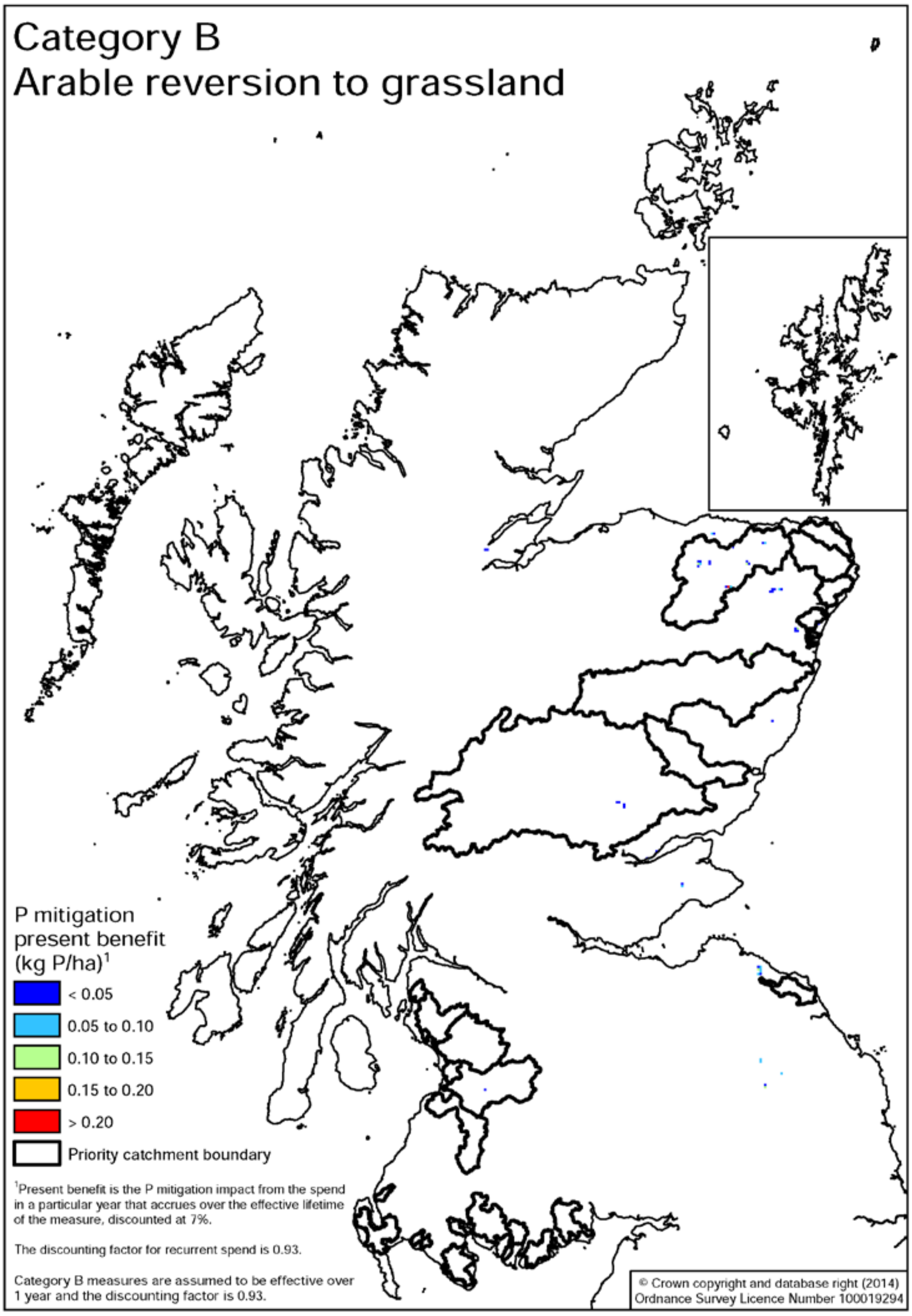
In step 12, use the following expression in the raster calculator:

    [Cat_P_1km] * [Connectivity]

And then save this raster as ***Cat_P_P_Mit*** (the units here are in kilograms of P mitigated per $1km^2$ cell per year).

Appendix 3. Maps of impact of SRDP measures on TP loads for each significant category.




Category B
Arable reversion to grassland
P mitigation present benefit (kg P/ha)[1]
< 0.05
0.05 to 0.10
0.10 to 0.15
0.15 to 0.20
> 0.20
Priority catchment boundary
[1]Present benefit is the P mitigation impact from the spend in a particular year that accrues over the effective lifetime of the measure, discounted at 7%.
The discounting factor for recurrent spend is 0.93.
Category B measures are assumed to be effective over 1 year and the discounting factor is 0.93.
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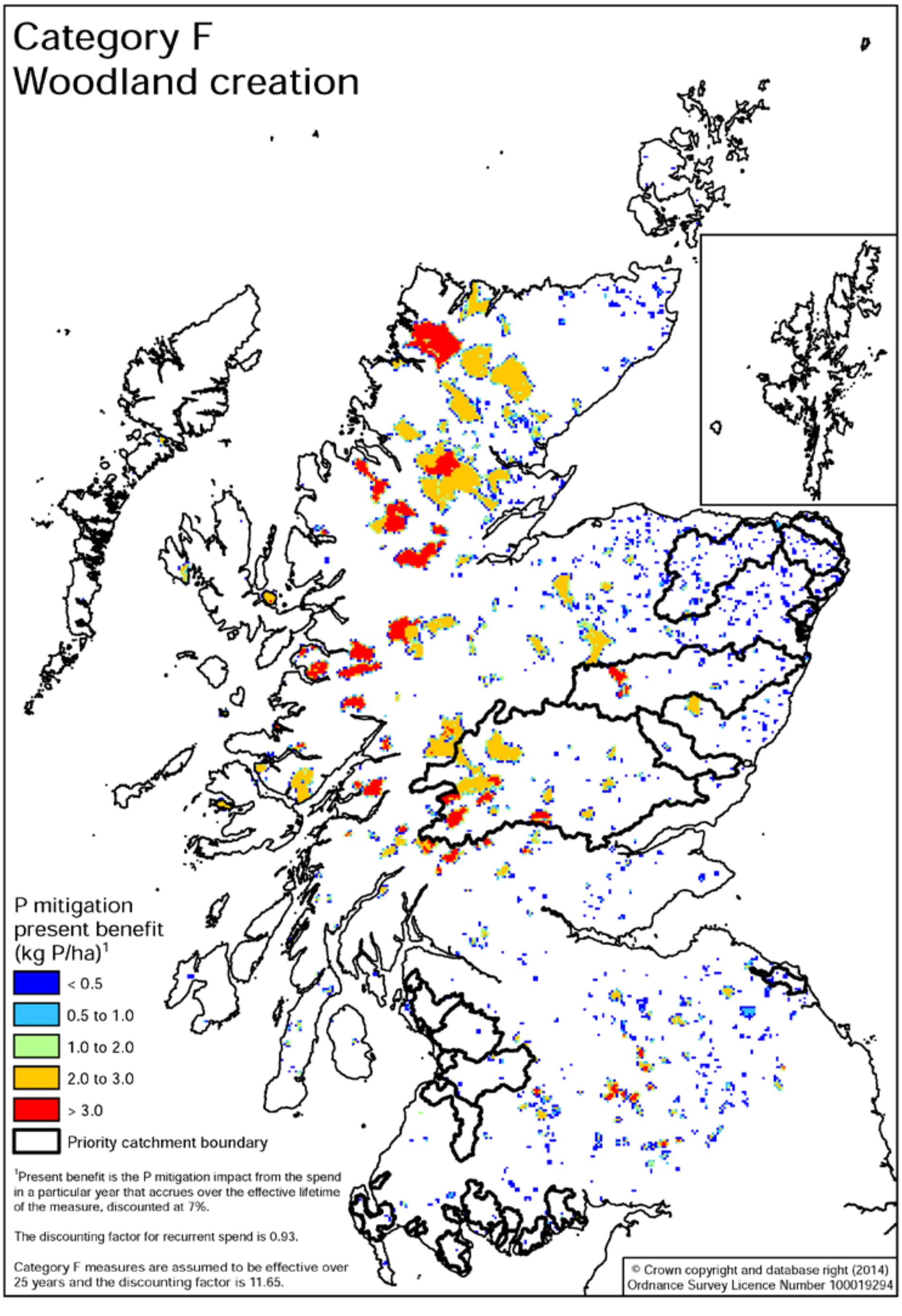

Category F
Woodland creation
P mitigation present benefit (kg P/ha)[1]
< 0.5
0.5 to 1.0
1.0 to 2.0
2.0 to 3.0
> 3.0
Priority catchment boundary
[1]Present benefit is the P mitigation impact from the spend in a particular year that accrues over the effective lifetime of the measure, discounted at 7%.
The discounting factor for recurrent spend is 0.93.
Category F measures are assumed to be effective over 25 years and the discounting factor is 11.65.
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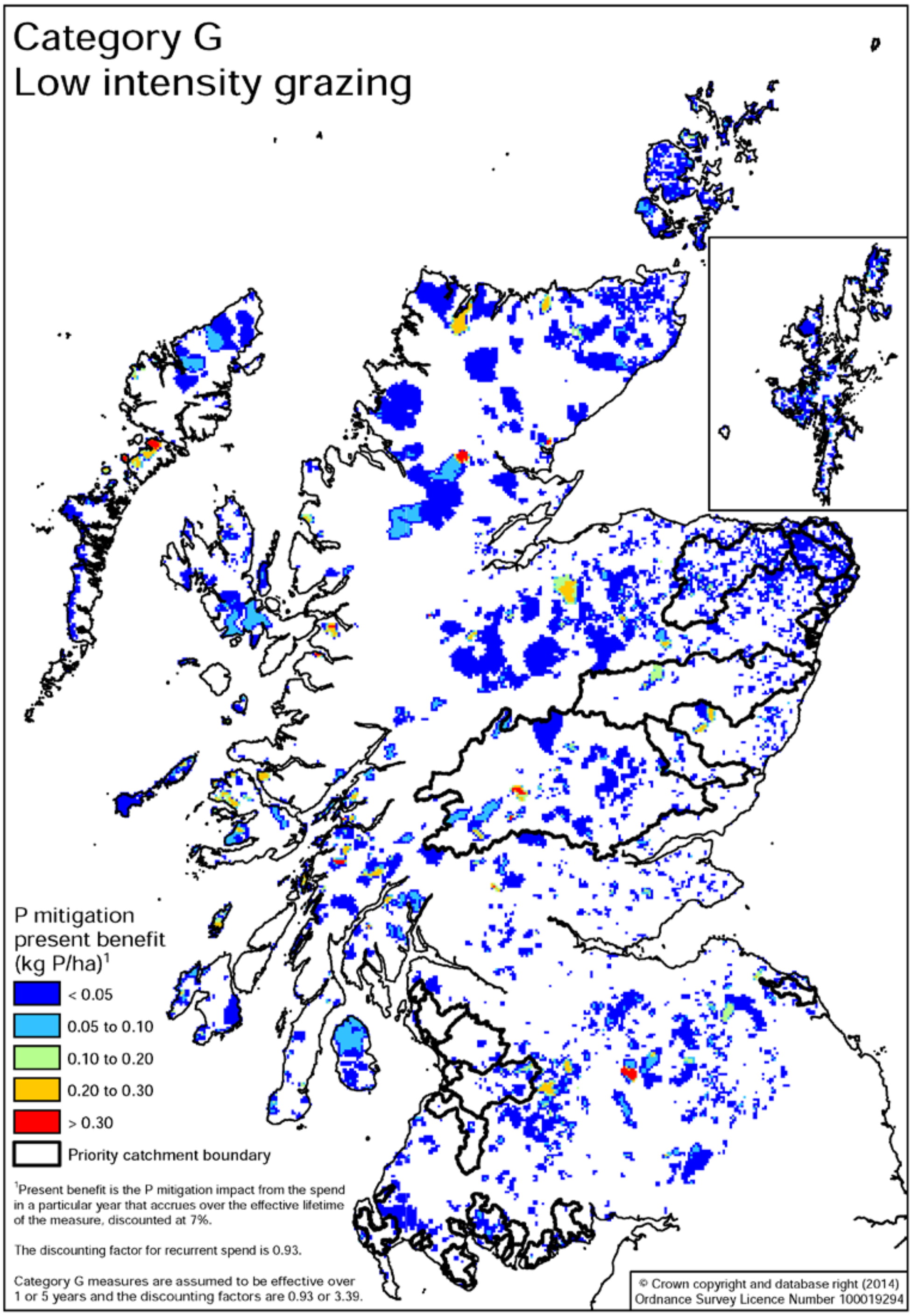
Category G
Low intensity grazing
P mitigation
present benefit
(kg P/ha)[1]
< 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
> 0.30
Priority catchment boundary
[1]Present benefit is the P mitigation impact from the spend in a particular year that accrues over the effective lifetime of the measure, discounted at 7%.
The discounting factor for recurrent spend is 0.93.
Category G measures are assumed to be effective over 1 or 5 years and the discounting factors are 0.93 or 3.39.
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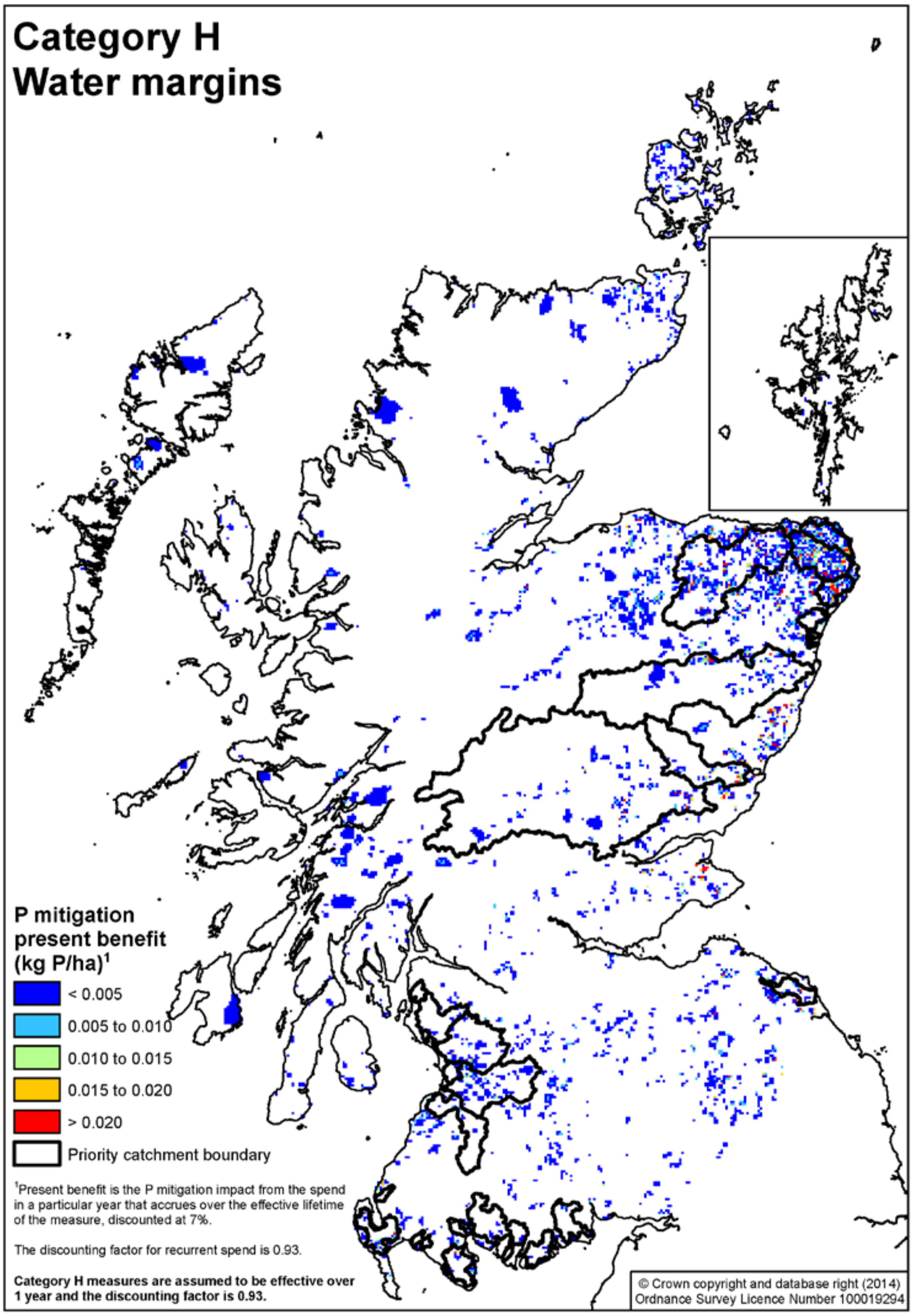

Category H
Water margins
P mitigation present benefit (kg P/ha)1
< 0.005
0.005 to 0.010
0.010 to 0.015
0.015 to 0.020
> 0.020
Priority catchment boundary
1Present benefit is the P mitigation impact from the spend in a particular year that accrues over the effective lifetime of the measure, discounted at 7%.
The discounting factor for recurrent spend is 0.93.
Category H measures are assumed to be effective over 1 year and the discounting factor is 0.93.
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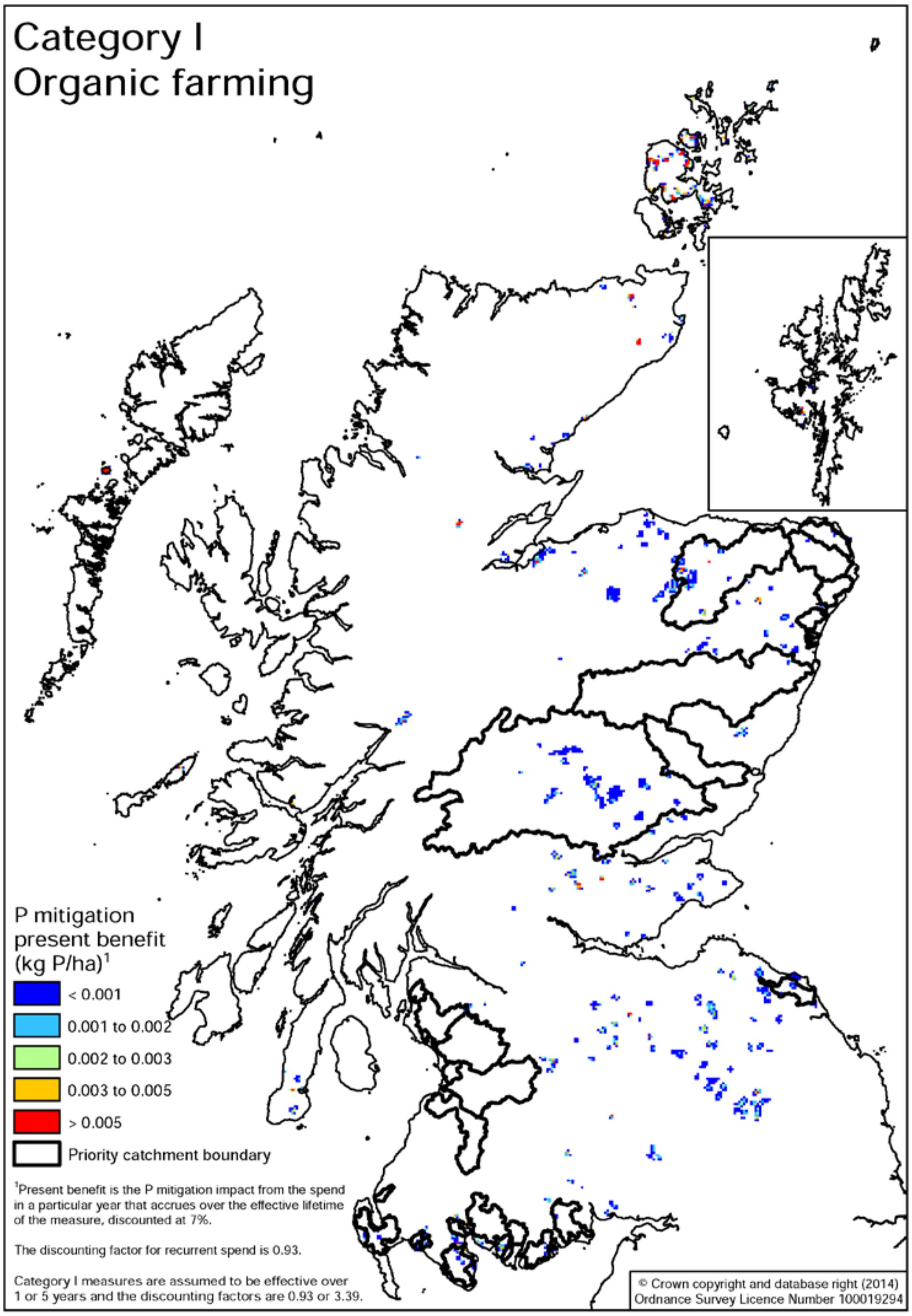
Category I
Organic farming
P mitigation present benefit (kg P/ha)[1]
< 0.001
0.001 to 0.002
0.002 to 0.003
0.003 to 0.005
> 0.005
Priority catchment boundary
[1]Present benefit is the P mitigation impact from the spend in a particular year that accrues over the effective lifetime of the measure, discounted at 7%.
The discounting factor for recurrent spend is 0.93.
Category I measures are assumed to be effective over 1 or 5 years and the discounting factors are 0.93 or 3.39.
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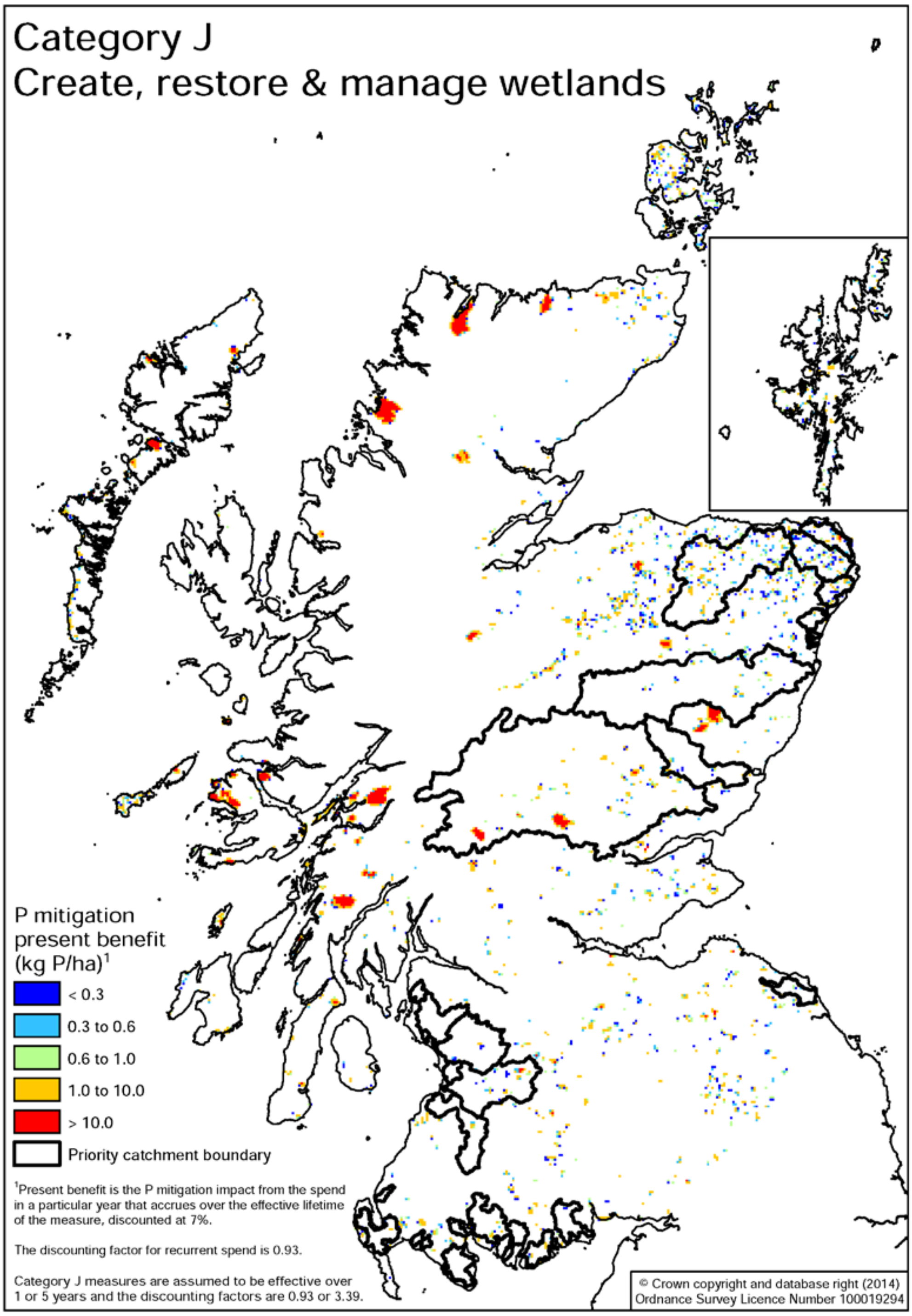

Category J
Create, restore & manage wetlands
P mitigation present benefit (kg P/ha)[1]
< 0.3
0.3 to 0.6
0.6 to 1.0
1.0 to 10.0
> 10.0
Priority catchment boundary
[1]Present benefit is the P mitigation impact from the spend in a particular year that accrues over the effective lifetime of the measure, discounted at 7%.
The discounting factor for recurrent spend is 0.93.
Category J measures are assumed to be effective over 1 or 5 years and the discounting factors are 0.93 or 3.39.
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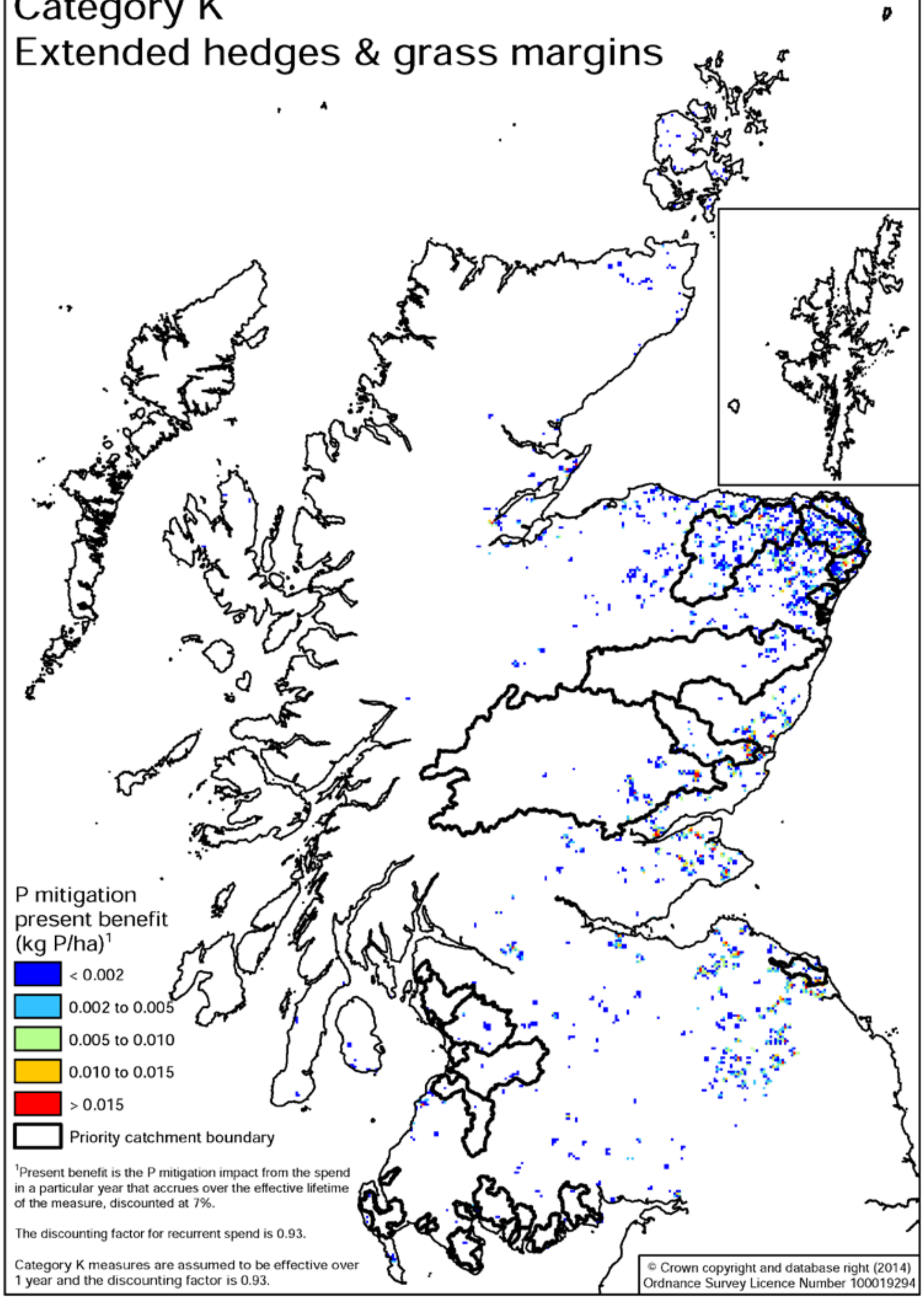
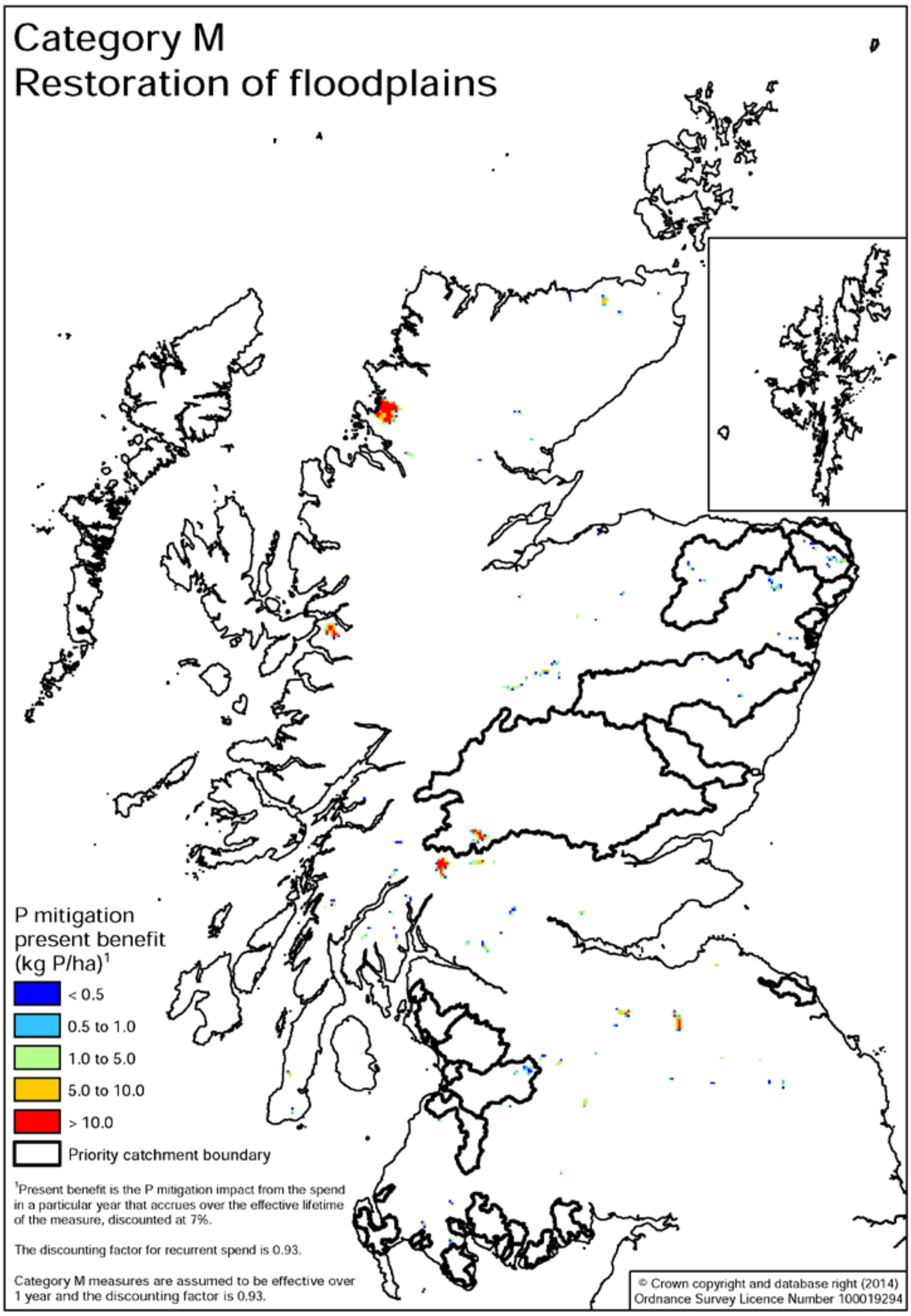
Category K
Extended hedges & grass margins



[1]Present benefit is the P mitigation impact from the spend in a particular year that accrues over the effective lifetime of the measure, discounted at 7%.

The discounting factor for recurrent spend is 0.93.

Category K measures are assumed to be effective over 1 year and the discounting factor is 0.93.



Category M
Restoration of floodplains
P mitigation present benefit (kg P/ha)[1]
< 0.5
0.5 to 1.0
1.0 to 5.0
5.0 to 10.0
> 10.0
Priority catchment boundary
[1]Present benefit is the P mitigation impact from the spend in a particular year that accrues over the effective lifetime of the measure, discounted at 7%.
The discounting factor for recurrent spend is 0.93.
Category M measures are assumed to be effective over 1 year and the discounting factor is 0.93.
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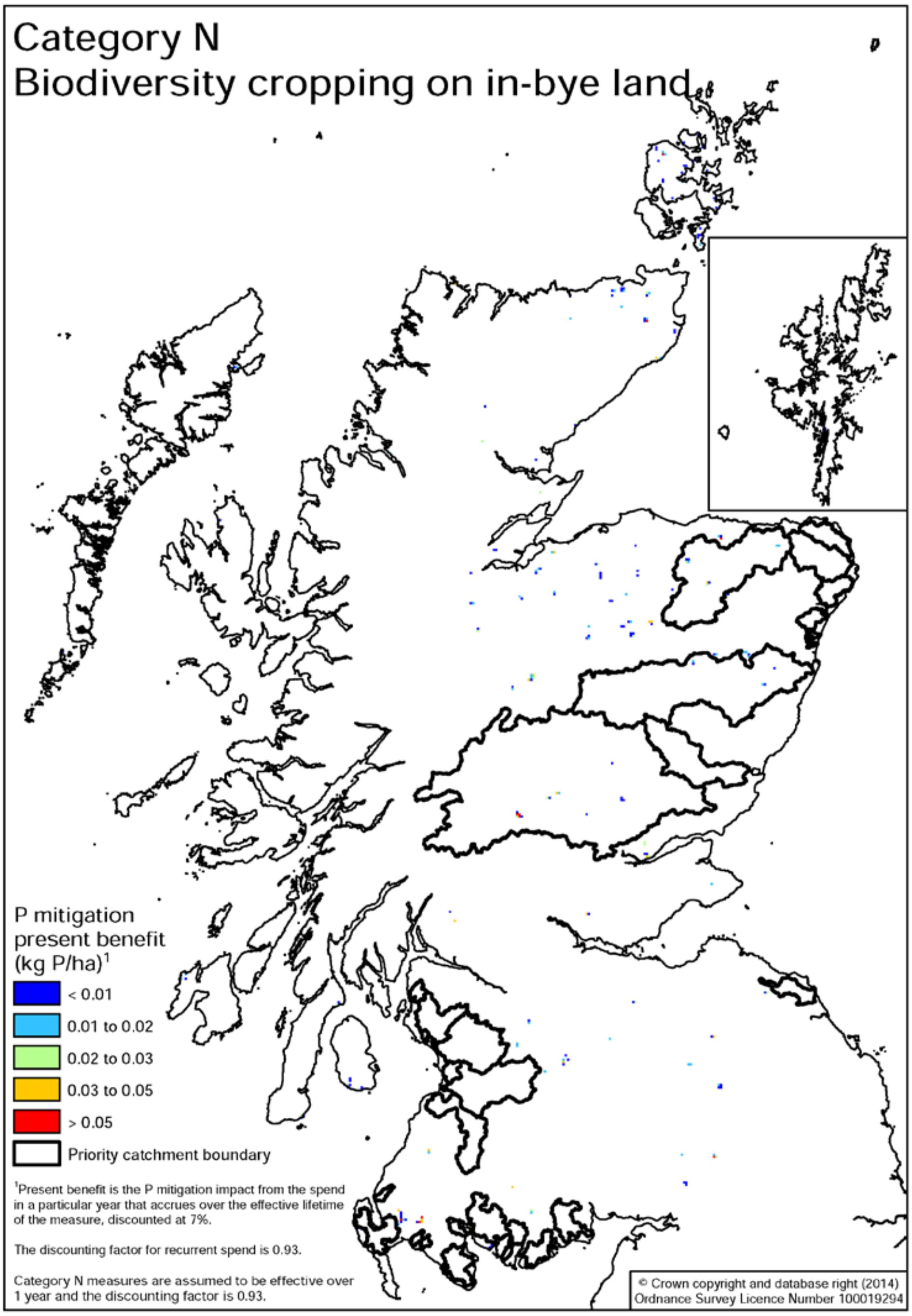
Category N
Biodiversity cropping on in-bye land
P mitigation present benefit (kg P/ha)[1]
< 0.01
0.01 to 0.02
0.02 to 0.03
0.03 to 0.05
> 0.05
Priority catchment boundary
[1]Present benefit is the P mitigation impact from the spend in a particular year that accrues over the effective lifetime of the measure, discounted at 7%.
The discounting factor for recurrent spend is 0.93.
Category N measures are assumed to be effective over 1 year and the discounting factor is 0.93.
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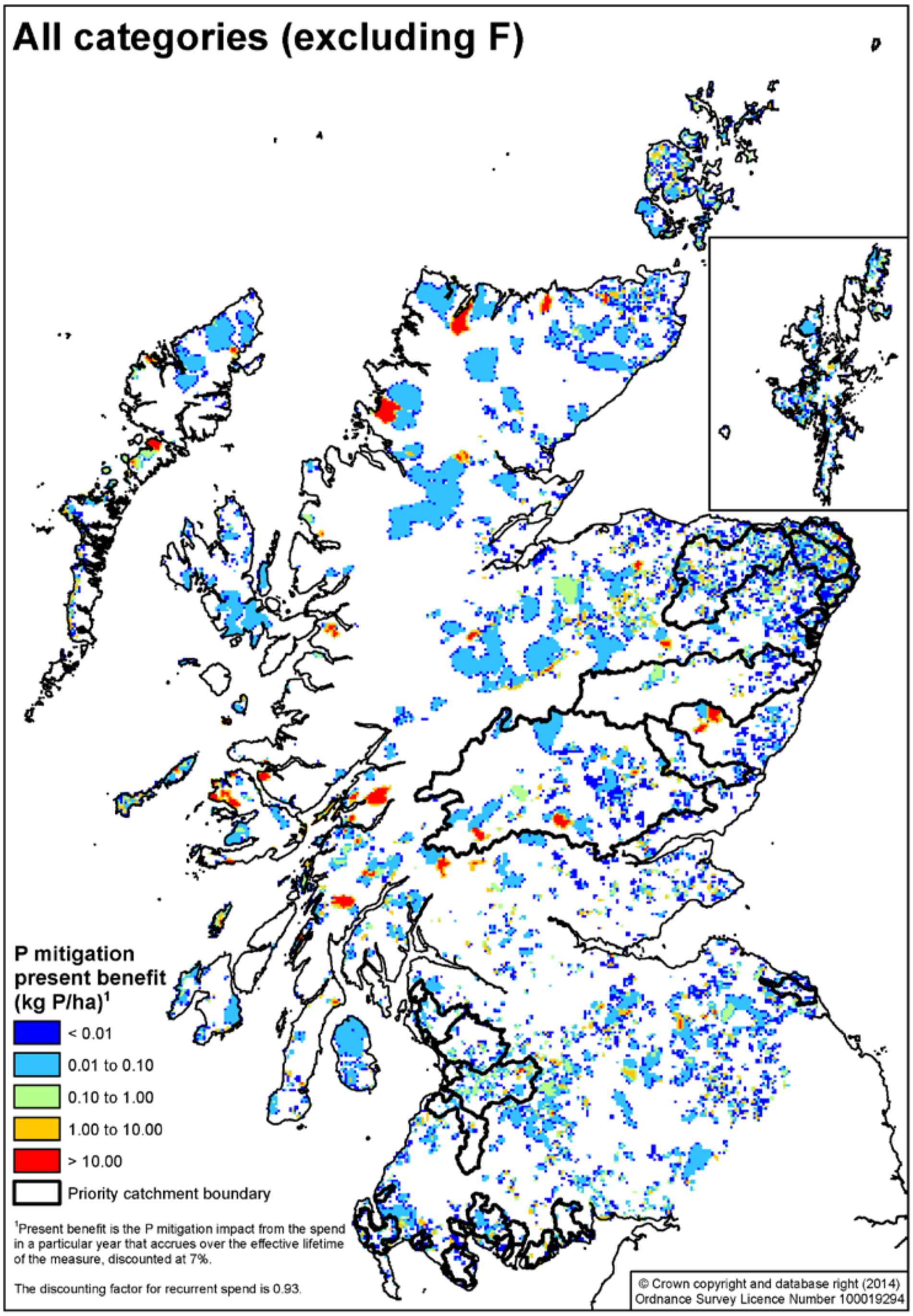

All categories (excluding F)
P mitigation present benefit (kg P/ha)[1]
< 0.01
0.01 to 0.10
0.10 to 1.00
1.00 to 10.00
> 10.00
Priority catchment boundary
[1]Present benefit is the P mitigation impact from the spend in a particular year that accrues over the effective lifetime of the measure, discounted at 7%.
The discounting factor for recurrent spend is 0.93.
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Appendix 4. Estimating the effectiveness of SRDP measures within the Priority Catchments

This document describes a workflow for estimating the amount of P mitigated in each of the 14 priority catchments (PCs) by various SRDP measures. The effects of each measure have already been estimated at national scale on a 1km^2 grid. The aims here are to use these grids to:

1. Estimate the total amount of P mitigated in each PC (in kilograms).

2. By considering long-term average annual runoff for each catchment, estimate the change in concentration resulting from the load reductions estimated in step 1.

1. Estimates of the total amount of P mitigated

This step is straightforward and simply requires summing the total P mitigated by each measure for each 1km^2 cell in each catchment. The script *p_mit_by_pc_by_category.py* performs this calculation. The results are tabulated below:

Priority catchment	All categories (kg)	All categories Excl. F (kg)	Cat A (kg)	Cat B (kg)	Cat F (kg)	Cat G (kg)	Cat H (kg)	Cat I (kg)	Cat J (kg)	Cat K (kg)	Cat M (kg)	Cat N (kg)
Buchan Coastal	10571	10320	266	0	250	163	29	1	9748	40	73	0
Eye Water	1433	1212	33	0	221	17	2	0	1145	13	0	0
Galloway Coastal	3497	3405	362	0	92	276	6	2	2757	0	0	2
North Ayrshire Coastal	42	42	41	0	0	1	0	0	0	0	0	0
River Ayr	15647	14221	1270	4	1426	450	7	0	10688	1	1801	0
River Dee (Grampian)	30896	9110	26	0	21785	818	9	0	7281	5	967	4
River Deveron	28853	24649	7	89	4205	967	59	9	22572	64	870	14
River Doon	1278	1278	135	0	0	25	1	0	1118	0	0	0
River Garnock	867	844	434	0	23	17	0	1	393	0	0	0
River Irvine	1484	1453	631	0	31	44	2	0	776	1	0	0
River South Esk (Tayside)	2955	2404	17	0	551	123	7	0	2228	28	0	0
River Tay	328787	167771	0	6	161016	3839	26	10	147984	39	15814	53
River Ugie	11458	11245	262	0	213	237	66	0	6725	50	3905	0
Stewartry Coastal	3524	2458	99	0	1066	23	2	1	2332	1	0	0

2. Estimating annual runoff

The UK Hydrometric Register (UKHR; http://www.ceh.ac.uk/products/publications/ukhydrometricregister.html) gives data on long-term annual runoff for a wide variety of catchments. The runoff values quoted are for the entire monitoring period at each station.

However, in some cases (i.e. the Dee, Deveron, Irvine, South Esk and Tay) the PC boundaries extend further downstream than the most downstream monitoring station given in the UKHR. The UKHR data is therefore only approximate for these catchments. In addition, the “coastal” PCs are not true catchments, but rather collections of small sub-catchments and their intervening areas. It is therefore not possible to get data from the UKHR for these coastal PCs. The UKHR provides the following runoff data:

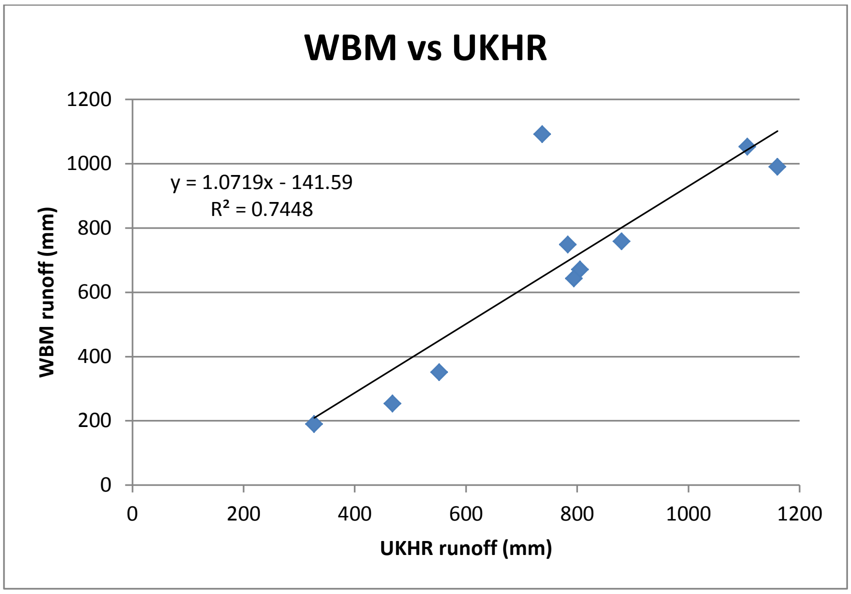
Priority catchment	UKHR start	UKHR end	UKHR av. runoff (mm)
Buchan Coastal	N/A	N/A	N/A
Eye Water	1967	2005	327
Galloway Coastal	N/A	N/A	N/A
North Ayrshire Coastal	N/A	N/A	N/A
River Ayr	1976	2005	880
River Dee (Grampian)	1972	2005	805
River Deveron	1960	2005	552
River Doon	1974	2005	737
River Garnock	1978	2005	1106
River Irvine	1972	2005	783
River South Esk (Tayside)	1983	2005	794
River Tay	1952	2005	1160
River Ugie	1971	2005	468
Stewartry Coastal	N/A	N/A	N/A

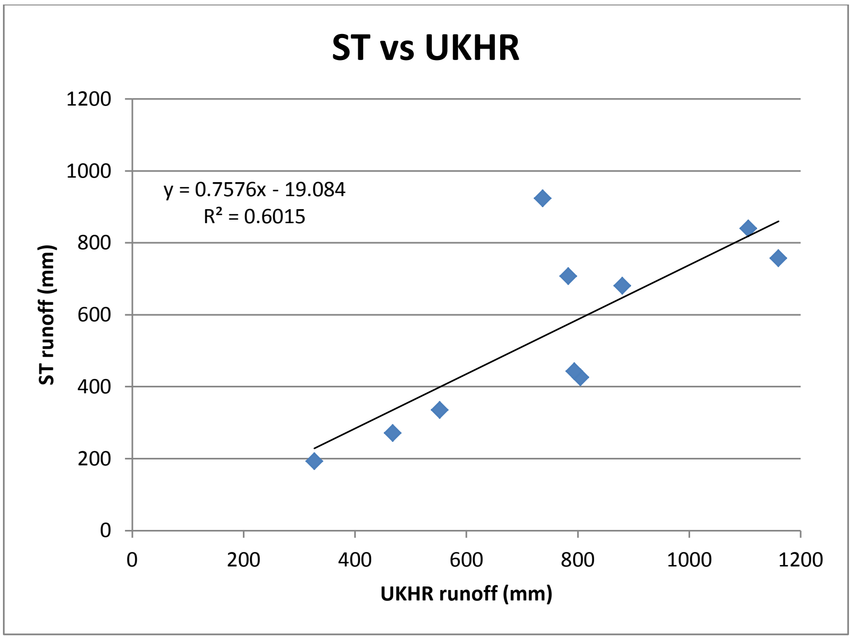
We need a method of estimating the long-term runoff for the coastal PCs. It would also be nice if the averages for each catchment were made over the same time period (e.g. the standard climatological baseline of 1961 to 1990). We have access to modelling results from two sources: the Screening Tool (ST), which provides average annual runoff for the period from 1989 to 1998 inclusive, and the NIRAMS Water Balance Model (WBM) which can output averages for any interval between 1961 and 2010. Before using either of these, it's a good idea to check that they more-or-less agree with the observed data in the UKHR.

The script *wbm_av_ro_by_prior_catch.py* takes the start and end dates for the UKHR data in each PC (as in the table above) and calculates WBM averages for the same time interval. The ST only provides information for the period from 1989 to 1998. The results are tabulated below:

Priority catchment	UKHR (mm)	WBM (mm)	ST (mm)
Buchan Coastal	N/A	220	267
Eye Water	327	189	193
Galloway Coastal	N/A	835	715
North Ayrshire Coastal	N/A	803	733
River Ayr	880	757	681
River Dee (Grampian)	805	670	426
River Deveron	552	350	335
River Doon	737	1091	923
River Garnock	1106	1053	840
River Irvine	783	748	707
River South Esk (Tayside)	794	642	443
River Tay	1160	990	757
River Ugie	468	253	271
Stewartry Coastal	N/A	703	635

The following plots compare the modelled results (WBM and ST) to the UKHR data for those catchments where UKHR data are available.





These plots show that, on the whole, both models do a reasonable job, but the NIRAMS WBM performs better than the ST (slope = 1.1 and R^2 = 0.74 for WBM; slope = 0.76 and R^2 = 0.60 for ST). At least part of this error is because the ST is using data for 1989 to 1998, whereas the WBM is using the same time period as specified in the UKHR data.

The obvious outlier on both plots corresponds to the River Doon which, according to the UKHR, has a flow regime that is heavily influenced by abstractions and impoundment. For this reason, the observed runoff in the UKHR data is lower than would be expected if the flows were natural. If this point is removed, the regression line for the WBM has a slope of 1.1, an R^2 of 0.97 and an intercept of -206 mm – pretty good, except for the consistent underestimate of runoff by about 200 mm/yr. Previous work has highlighted similar issues, although the problem here is particularly extreme. The error is partly due to the way in which we estimate AET and partly due to the Met Office's spatial interpolation of the rainfall data clipping off intense rainfall peaks.

Despite these issues, the WBM seems to offer the best option for patching the missing runoff data. If we assume that this regression line holds true for other time periods, we can re-run the WBM for the period from 1961 to 1990 and then generate estimates for the actual runoff by adding 206 mm to the annual runoff estimates and dividing by 1.1.

The final runoff estimates for each PC are presented in the table below:

Priority catchment	WBM 1961 to 1990 (mm)	Corrected C = (M+206)/1.1 (mm)
Buchan Coastal	220	387
Eye Water	186	357
Galloway Coastal	835	946
North Ayrshire Coastal	803	918
River Ayr	703	826
River Dee (Grampian)	647	775
River Deveron	342	498
River Doon	991	1088
River Garnock	971	1070
River Irvine	717	839
River South Esk (Tayside)	614	745
River Tay	950	1051
River Ugie	253	417
Stewartry Coastal	703	826

3. Estimating changes in concentration

The corrected runoff values given in the table above were combined with catchment areas to give estimates for the total annual volume of runoff in each of the 14 priority catchments. The amount of P mitigated by each category in each catchment was then divided by the volume estimate to give estimates of changes in concentration in micrograms per litre (ug/l). These are shown in the table on the next page. Note that some of these changes are very large, probably highlighting problems with the methodology in several cases.

Priority catchment	All categories (ug/l of P)	All categories excl. F (ug/l of P)	Cat A (ug/l of P)	Cat B (ug/l of P)	Cat F (ug/l of P)	Cat G (ug/l of P)	Cat H (ug/l of P)	Cat I (ug/l of P)	Cat J (ug/l of P)	Cat K (ug/l of P)	Cat M (ug/l of P)	Cat N (ug/l of P)
Buchan Coastal	134.7	131.5	3.4	0.0	3.2	2.1	0.4	0.0	124.2	0.5	0.9	0.0
Eye Water	64.6	54.7	1.5	0.0	10.0	0.8	0.1	0.0	51.7	0.6	0.0	0.0
Galloway Coastal	6.6	6.4	0.7	0.0	0.2	0.5	0.0	0.0	5.2	0.0	0.0	0.0
North Ayrshire Coastal	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
River Ayr	37.8	34.4	3.1	0.0	3.4	1.1	0.0	0.0	25.9	0.0	4.4	0.0
River Dee (Grampian)	22.9	6.8	0.0	0.0	16.2	0.6	0.0	0.0	5.4	0.0	0.7	0.0
River Deveron	68.7	58.7	0.0	0.2	10.0	2.3	0.1	0.0	53.7	0.2	2.1	0.0
River Doon	4.0	4.0	0.4	0.0	0.0	0.1	0.0	0.0	3.5	0.0	0.0	0.0
River Garnock	3.8	3.7	1.9	0.0	0.1	0.1	0.0	0.0	1.7	0.0	0.0	0.0
River Irvine	4.3	4.2	1.8	0.0	0.1	0.1	0.0	0.0	2.2	0.0	0.0	0.0
River South Esk (Tayside)	8.6	7.0	0.0	0.0	1.6	0.4	0.0	0.0	6.5	0.1	0.0	0.0
River Tay	69.3	35.4	0.0	0.0	33.9	0.8	0.0	0.0	31.2	0.0	3.3	0.0
River Ugie	134.1	131.6	3.1	0.0	2.5	2.8	0.8	0.0	78.7	0.6	45.7	0.0
Stewartry Coastal	15.8	11.0	0.4	0.0	4.8	0.1	0.0	0.0	10.5	0.0	0.0	0.0