Scotland's centre of expertise for waters

Developing a method to monitor the Rural Diffuse Pollution Plan: Providing a framework for interpreting catchment data

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Abbreviations

BACI	Before-After/Control-Impact
CSF	Catchment Sensitive Farming
DP GBR	Diffuse Pollution General Binding Rules
FIOs	Faecal Indicator Organisms
IACS	Integrated Accounting and Control System
RBMP	River Basin Management Plans
SG	Scottish Government
SRDP	Scotland Rural Development Programme
TDML	Total Daily Maximum Load
WFD	Water Framework Directive

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The questions

Has water quality improved as a result of the Rural Diffuse Pollution Plan? Why are changes in water quality occurring and what is a practical approach to assessing them? Are there indications that water quality is likely to improve?

Key findings

- A practical weight-of-evidence method has been developed to enable monitoring, and to demonstrate and interpret change in water quality in response to the implementation of diffuse pollution control measures.
- The method uses water quality data, uptake of measures, and modelled reductions in pollutants to assess the direction of travel and effectiveness of measures.
- Catchment (land use) data has shown potential diffuse pollution risks e.g. from fertiliser inputs, erosion risk crops, livestock and rainfall.
- To enable improvements in water quality and ecology to be assessed with adequate certainty monitoring data should be collected for more than four years pre and post-implementation, if the Before-After/Control-Impact (BACI) design is being applied; or for more than four years post-implementation, if the objective is to detect a trend.
- The weight-of evidence method is essential for understanding the interplay between the major factors influencing water quality and identifying where further action is needed.

The method was trialled in five priority catchments. The results are summarised in the table below.

Background

The Rural Diffuse Pollution Plan was launched in Scotland in 2011 to promote the uptake of diffuse pollution control measures in rural areas as part of the national response towards achieving WFD objectives. Given that assessing the impacts of diffuse pollution control measures on water quality is notoriously difficult to do there is a need to develop an approach to assessing the direction of travel of change, allowing the effect of measures to be assessed in the context of wider catchment pressures.

Research undertaken

The method was trialled in five priority catchments shown below. It uses open-access data from national surveys, allowing

Trial data	Comparison of post-implementation avarage with WFD standard*		Step change (Before vs After DP GBRs)									Trend (post-DP GBRs)		Current WFD/ Protected Area status		Direction of travel
	Pollutant	Ecology	Pollutant	Ecology	DP GBRs	SRDP	Fertilizers	Erosion	Total livestock	Grazers	Rainfall	Pollutant	Ecology	Pollutant	Ecology	
Lemno Burn	P ⇧⇧ Sed (no standard)	Diatoms ⇧⇧ Inv ⇧⇧	P ⬄ Sed ⬄	Diatoms ⬄ Inv ⬄	⇧ ⇧	⬄ ⬄	⇩	⇩ ⇩	⬄	⬄	⇩ ⇩	P ⬄ Sed ⬄	Diatoms ⬄ Inv ⬄	P High no standard	Diatoms High no standard	✔ Success story
North Ugie	P ⇧⇧	Diatoms ⬄	P ⬄	Diatoms ⬄	⇧	⇧	⇩	⇩	⇩	⇩	⇩	P ⬄	Diatoms ⬄	P Good	Diatoms Moderate	☺ Positive
Eye Water	FIOs ⬄		FIOs ⬄		⇧	⬄			⇧	⇧	⇩	FIOs ⬄		FIOs Poor		😐 Uncertain
River Ayr	FIOs ⬄		FIOs ⬄		⬄	⇧			⬄	⬄	⇩	FIOs ⬄		FIOs Sufficient		
Cessnock Water	Sed (no standard)	Inv ⬄	Sed ⬄	Inv ⬄	⬄	⇧		⬄			⇩	Sed ⇩	Inv ⬄	no standard	no standard	☹ Negative

* in the event of changing WFD standards, chemical or ecological improvements can only contribute to "success stories" where there has been an actual detected improvement.

P: Dissolved phosphorus; Sed: Sediment; FIOs: Faecal Indicator Organisms; Inv: Macroinvertebrates; DP GBRs: Diffuse Pollution General Binding Rules; SRDP: Scotland Rural Development Programme.

⇧⇧ shows (i) that post-implementation average of pollutant and ecological data agree with WFD standards; (ii) magnitude of pollutant change matches model predictions; (iii) 100% DP GBR uptake.

⇧ shows improvements (step-change and trend) in ecology, pollutants, and land use indicators.

⬄ indicates (i) insufficient change (step-change/trend) in pollutants, ecology, DP GBRs and the land use indicators (ii) post-implementation average of pollutant and ecological data fails WFD standards.

⇩ indicates deterioration (step-change/trend) in ecology, pollutants and the land use indicators it to be applied in any catchment of interest, and included:

- Modelled predictions of reductions in pollutant loads.
- Step-change and trends based on pollutant and ecological monitoring data.
- DP GBR uptake across a catchment.
- Spend for options with the potential to benefit water quality via the Scotland Rural Development Programme (SRDP).
- Indicators of agricultural management i.e. nitrogen and phosphate fertiliser inputs; high erosion risk area; and total and grazing livestock density.
- Indicator of regional climate, i.e. deviation of current rainfall from 1981–2010 average.

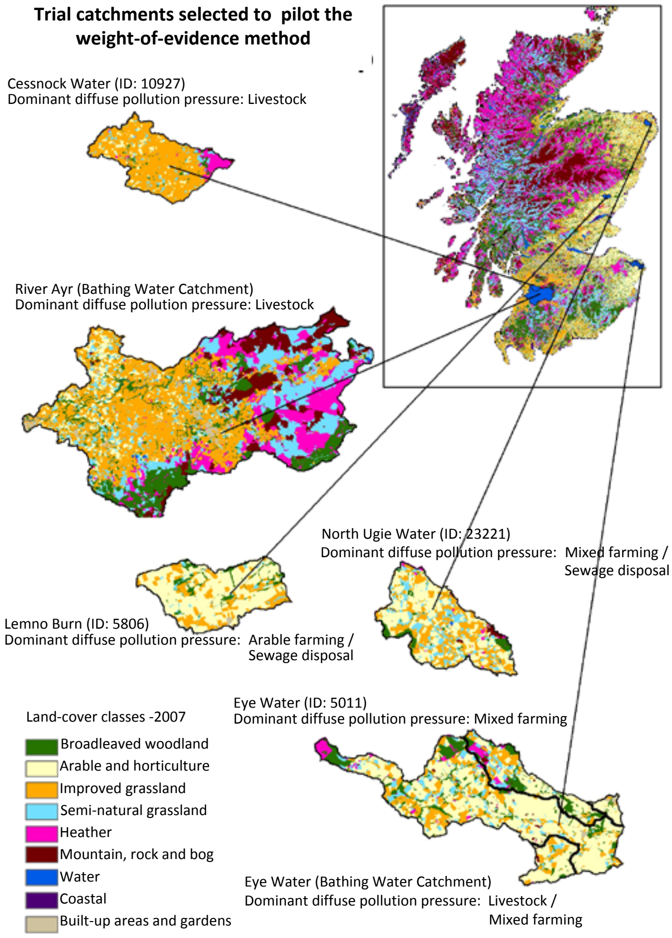
Results for trial catchments

The method identified change on a pollutant and catchment basis. Results showed:

- A **success story** for phosphorus and sediments at the Lemno Burn, because (i) the four-year post-implementation average of phosphorus concentrations and diatoms exceeded the WFD standards for good status and the four-year post-implementation average of sediment and macroinvertebrates diatoms exceeded the WFD standards for good status; and (ii) DP GBR uptake was sufficient to benefit water quality although SRDP uptake was not sufficient. Step-change in pollutants and ecology could not be detected with adequate certainty to help identify direction of travel because of small sample size. Inputs of fertilisers, potential losses through rainfall, and area of crops at risk from erosion increased post-implementation indicating diffuse pollution risks.

- A **positive direction of travel** for phosphorus at the North Ugie Water, because (i) the four-year post-implementation average of phosphorus concentration exceeded the WFD standard for good status but diatoms failed the WFD standard for good status; and (ii) DP GBR and SRDP uptake were sufficient to benefit water quality. Step-change in pollutants and ecology could not be detected with adequate certainty to help identify direction of travel because of small sample size. SRDP uptake was sufficient to benefit water quality but inputs of fertilisers, potential losses through rainfall, and area of erosion risk crops increased post-implementation indicating diffuse pollution risks.

- An **uncertain direction of travel** at the two bathing water catchments. At the Eye Water, uncertain progress was indicated by (i) average FIO concentrations post-implementation exceeding the bathing water standards; and (ii) lack of significant step-change in FIO concentrations because of small sample size despite sufficient DP GBR uptake to benefit water quality. At the River Ayr, uncertain progress was indicated by (i) average FIO concentrations post-implementation exceeding the bathing water standards; (ii) lack of significant step-change in FIO concentrations because of small sample size; and (iii) insufficient DP GBR uptake to benefit water quality. SRDP uptake was insufficient to benefit water quality at the Eye Water but sufficient at the River Ayr. Step-change in fertiliser use, livestock density and erosion risk could not be detected but rainfall increased indicating increased risk of FIO losses.



- A **negative direction of travel** at the Cessnock Water, because (i) sediment increased post-implementation and the four-year average of macroinvertebrate data failed the WFD standard; and (ii) DP GBR uptake was insufficient to benefit water quality because farmer engagement had only recently started at the time of assessment. Again, the increase in rainfall indicated increased risk of FIO losses.

Current monitoring, as shown by sample size analysis, is insufficient to detect the magnitude of change in pollutants predicted by the model. In general, more than four years of pre- and post-implementation monitoring are required to enable step change in pollutants and ecology to be assessed reliably. Ideally, this should be combined with weekly sampling for nutrients and sediments and event-based sampling along with fixed-date sampling for FIOs[1]. Applying the BACI design will help to distinguish between the effects of measures and site-specific variation on pollutants and ecology.

For catchment change, indicators of agricultural management were tested for statistically significant step-change to determine sufficient improvement. The approach helped to identify the direction of change in the major factors driving diffuse pollution, such as:

- Increases in nitrogen and phosphate fertiliser inputs after 2011 in the N. Ugie Water and Lemno Burn, mainly associated with increases in the area of winter oilseed rape

[1] CREW Water Monitoring report: Akoumianaki, I, Potts, J, & MacDonald J 2015, *Monitoring guidance to assess the effectiveness of the Rural Diffuse Pollution Plan*. CD2014/14, Available online at: crew.ac.uk/publications.

and winter and spring barley; fertiliser application rates remained unchanged.

- Increases in the area of high erosion risk crops (i.e. oats, potatoes, and winter wheat/barley/oilseed rape) post-2011 in the N. Ugie Water and Lemno Burn; high risk crops remained unchanged at the Eye Water but occupied 32 to 42% of cropland both pre- and post-implementation the Diffuse Pollution Plan.

- Increases in total livestock density at the N. Ugie Water, mainly associated with significant rise in the numbers of pigs and poultry.

- Declines in the total livestock density at the Eye Water, mainly because of significant reduction in the number of grazing livestock (i.e. cattle, sheep and goat).

DP GBR uptake exceeding 50% was deemed (via expert judgement) likely to achieve a detectable improvement in water quality. DP GBR uptake sufficiently improved (⇧) in three of the trial catchments (i.e. Lemno Burn, N. Ugie Water, Eye Water) but has not yet reached 100%. SRDP uptake was deemed (via expert judgement) sufficient when spend for water quality options exceeded 80% of total SRDP spend for Rural Priorities and addressed catchment-specific diffuse pollution pressures. Sufficient improvements (⇧**)** were found at the N. Ugie Water, Eye Water (waterbody: 5011), Cessnock Water, and at the River Ayr. Hedgerows dominated SRDP spend in the N. Ugie Water and Eye Water but this option must be targeted to enable the dominant diffuse pollution pressures to be tackled. Importantly, manure and slurry storage dominated SRDP uptake in catchments with livestock pressures (Cessnock Water, River Ayr).

Regional rainfall increased in all seasons in both east and west Scotland. This indicates diffuse pollution risks because rainfall increases runoff and has the potential to counteract the effects of measures installed to prevent or reduce pollutant losses in runoff.

In summary, water quality monitoring alone is insufficient to provide an understanding of the diffuse pollution risks at play in a catchment. For example, despite sufficient DP GBR uptake, expected improvements may be negated by increases in rainfall and land use change. Evaluation of the weight-of-evidence method in the trial catchments clearly shows the need for additional catchment evidence.

The table below summarises the feasibility the method to assess why and when change is happening.

Recommendations

- Additional indicators should be developed from modelled source apportionment data to assess change in loads from septic tanks, sewage treatment works, and forestry.
- Uptake rates of each DP GBR separately and the results of 1:1 farm visits and indicators of farmer awareness in priority catchments should be part of the weight-of-evidence method.
- The effectiveness of the Ecological Focus Areas should be tracked and assessed.
- Further consideration should be given to alternative metrics for assessing ecological response, such as biomass; public perceptions of ecological recovery; riparian tree-cover; flow-measurements prior to ecological sampling; and total community species composition.
- Catchments assessed as "Success story" and "Uncertain" should be re-evaluated on the basis of the magnitude of step-change after longer-term data become available.

Rural Diffuse Pollution Plan challenges	Evidence/analyses needed for the weight-of-evidence evaluation	Feasibility
Has water quality improved (yes /no)?	Pollutant and ecological monitoring data	Yes
Are the measures in place?	Data from priority catchment inspections and SRDP	Yes
Are the measures technically suitable and effectively implemented?	Data on the implementation/targeting of each measure separately	Not yet
When will the measures deliver improvements in pollutant reductions?	Sample size analysis on pollutant data	Yes. Longer-term data required for ecology
Why are expected improvements not being observed?	1 Catchment data on pressures/risks 2. Sample size analysis on pollutant data*	Yes. Longer-term data required for ecology
Can the effects of measures from land use change and other rural pressures be separated?	Indicators assessing the uptake of measures, fertilizer inputs, erosion risk, livestock density and rainfall	Yes
Has awareness raising been effective?	Awareness and farm visit data	Not yet

* The CREW water quality monitoring report has developed recommendations to enable modelled reductions in pollutants to be detected with adequate certainty.

1 Introduction

Scottish Environment Protection Agency (SEPA) asked Scotland's Centre of Expertise for Waters (CREW), to develop a weight-of-evidence method to enable change in priority catchments to be recorded, understood, and interpreted in the context of catchment data. The proposed approach aims to combine WFD classification with indicators of catchment factors influencing water quality, such as the uptake of DP GBRs and SRDP measures; fertiliser and pesticide use; livestock density; and other rural pressures, e.g. regional rainfall.

This report outlines the method for collecting and combining data to assess the effectiveness of the Rural Diffuse Pollution Plan that represents Scotland's strategy to reduce water pollution caused by agricultural land use. The report also evaluates the efficacy of the method to monitor the progress of the strategy using data from selected priority catchments. Recommendations for improving the robustness of the weight-of evidence approach are also provided. A parallel report using the same data evaluates the suitability of the current water quality and ecological monitoring programme to provide reliable estimates of change (Akoumianaki *et al*. 2016).

1.1 Assessing the effectiveness of the Rural Diffuse Pollution Plan

Water quality is generally good across Scotland. Yet, SEPA estimates that around 30% of water bodies are expected to be at less than the good status required by the Water Framework Directive (WFD) at the end of 2015 due to the adverse effects of rural diffuse pollution (SEPA 2015). More than 200 of these waterbodies are rivers. The areas affected also include 35 lochs, 40 groundwater bodies, 27 bathing waters, 52 shellfish waters, seven drinking water areas, and thirteen designated areas for wildlife conservation (SEPA 2015). The most widespread diffuse pollution pressures remaining on water quality are losses of nutrients, pesticides and faecal indicator organisms (FIOs) in runoff from a variety of rural land uses. Intensive arable and livestock farming are the dominant sources, but inputs of pollutants from forestry, septic tanks and low-intensity hill farming and sheep grazing can also contribute.

For Scotland, the overall WFD objective is for 98% of Scotland's waterbodies to be at good status by 2027. The Diffuse Pollution Management Advisory Group (DPMAG)[2] launched the Rural Diffuse Pollution Plan in 2011 to underpin the delivery of this objective. A two tiered approach is implemented (DPMAG 2011):

- A 'national awareness raising campaign' involving guidance, training, and inspections.
- A 'priority catchment approach' comprising a sequential process of monitoring of change (i.e. environmental, uptake of measures, and awareness), modelling of risks and effectiveness of measures, awareness raising, farm visits, and one-to-one advice to farmers.

SEPA identified fourteen priority catchments as the highest priority for action in the first cycle (2009-2015) of Scotland's river basin management plans (RBMPs). SEPA works with partner organisations and land managers to ensure the uptake of regulatory measures, such as the Diffuse Pollution General Binding Rules (DP GBRs). It also encourages the adoption of supplementary measures e.g. via the Scotland Rural Development Programme (SRDP), where the regulatory baseline has been complied with.

Assessing the efficacy of these measures to deliver benefits for water quality and the rural environment is complex. SEPA and partners need to answer the following questions:

- Has water quality improved (yes or no)?
- Why and how are changes happening?
  - Are the measures in place?
  - Are they technically suitable and effectively implemented?
  - When will the measures deliver required improvements?
  - Why are expected improvements not being observed?
  - Can we separate the effect of measures from land use change and other rural pressures?

Monitoring and modelling in their own right are unable to answer these questions. Several challenges must be tackled to enable the evaluation of measures.

Firstly, effectiveness is site-specific; it depends on implementing the right measures at the right place. Identifying poorly-managed land generating pollutants of concern in close proximity to receiving waterbodies is important but modelling is key in targeting the measures. Source apportionment for each pollutant (e.g. the amount lost from grassland or arable land within that area, or the amount lost per unit of fertiliser or manure applied) in combination with catchment modelling is the only way of illustrating which measures affect some farm sources and not others. However, the effectiveness of measures can only be a general model estimate because the models of pollutant mobilisation and delivery are incomplete on a site-specific scale whereas pollutant transport pathways are site-specific.

Secondly, most measures are implemented at a field scale but improvements in water quality are measured at a waterbody or protected area scale. This mismatch increases the risk of underestimating the positive effects of the measures, especially in the case of sparsely non-targeted implementation across a catchment. Assessing effectiveness of measures at appropriate spatial scales is a crucial requirement.

Thirdly, monitoring to underpin WFD classification is unable to account for the effect of the range of flows at a site as it is based on monthly spot sampling for nutrients; biannual, not replicated sampling for ecological assessments; and fixed-date, weekly to fortnightly sampling for FIOs during the bathing season. Yet, large amounts of pollutants are delivered to rivers and lakes during high intensity rainfall events. Without long-term datasets collected with adequate sampling frequency, it is difficult to identify reliably how much of a change in pollutants has resulted from a change in land management or rainfall, especially when small changes are accumulating over time.

In addition, detecting improvements in response to measures is key in assessing the effectiveness of measures. A simple way of determining improvements is by means of trend analysis on post-implementation data. A trend analysis, however, is

[2] Members include SEPA, the Scottish Government, National Farmers Union of Scotland, Scottish Land and Estates, the Tennant Farmers Association, the Scottish Crofting Foundation, Forestry Commission Scotland, SNH, Scottish Environment LINK and Scottish Water.

unable to distinguish between the effects of the measures and other factors influencing water quality post-implementation, and requires long-term monitoring (Meals *et al*. 2011), maybe longer than a RBMP cycle. In this respect, the so-called Before-After/ Control-Impact (BACI) design (Smith 2002; Underwood 1994), is a more effective way of assessing the effects of measures. The typical BACI design compares data between a catchment where the measures are sufficiently implemented (impact) and a catchment where the measures are not implemented (control), to enable site-specific and year-to-year variation in the response to measures to be accounted for. The BACI design can be tailored to fit site-specific circumstances as discussed in the priority catchment context by Akoumianaki *et al*. (2016) and shown by Underwood (1994) and Smith (2002). Ideally in Scotland, the BACI design should be combined with four years pre- and post-implementation weekly sampling for phosphorus and sediments and event-based sampling for FIOs (Akoumianaki *et al*. 2015).

Furthermore, identifying the progress of the Diffuse Pollution Plan on the basis of WFD data may be part of the problem. The WFD classification scheme combines biological, physio-chemical, chemical, and hydro-morphological "quality elements" to assess ecosystem health using the *One-Out, All-Out* rule. This ensures that any classification errors caused by inadequate monitoring frequency in ecology are addressed on a precautionary basis. Yet, this approach fails to separate diffuse pollution and other pressures (e.g. river morphology) and does not include all significant diffuse pollution risks, most notably sediments. If ecology fails, WFD status is unable to distinguish between compliance with a nutrient standard, improvement or no-change between pre- and post-implementation. Exceeding a nutrient WFD standard is insufficient to judge the risk of impacts on ecology. Also, WFD classification alone is unable to account for biogeochemical and biophysical lag-times. Several processes, which are difficult to quantify, such as hydrological variability, large soil or in-stream pools of pollutants and land use pressures (e.g. fertiliser use, crop patterns), may confound detection of improvements in WFD status, let alone response to measures (Hamilton 2012). These uncertainties further compromise understanding of whether the measures targeting water quality are working or not.

Finally, achieving modelled improvements in water quality in view of lag-times and with the current monitoring is an additional issue. Model predictions are based on detailed source apportionment from a variety of land use scenarios with baseline land management and 100% uptake of DP GBR measures (Gooday *et al*. 2014). But even with targeting and sufficient implementation of measures, lag times control how long it will take for a response to occur, and monitoring duration, design and sampling frequency determines the magnitude of change that can actually be detected. Therefore, it would be unwise to interpret direction of travel of mitigation based on the gaps between modelled and observed reductions. These gaps may also reflect model uncertainties in the representation of lag-times , or insufficient monitoring to capture small changes.

It must be recognised that preventing or reducing pollutant losses to water bodies to the degree that their ecological function is fully restored is a major challenge worldwide. Despite the enormous efforts and resources invested by citizens and governments at all levels to restore agricultural catchments impaired by diffuse pollution in Europe, US and elsewhere, **very few impaired waters have been fully restored** (Meals *et al*. 2010; Palmer *et al*. 2014; US EPA 2011)**.** In addition to the significant lag times between removal or reduction of a pollutant source and waterbody response, major reasons for the limited success of diffuse pollution mitigation include:

- The historical focus on the "worst first" approach to the implementation of measures.
- Ineffective regulation of diffuse pollution sources (e.g. agriculture).
- Lack of a robust effectiveness monitoring plan aimed at demonstrating effectiveness.

SEPA proposed a 'weight of evidence' approach to address monitoring and policy challenges, and to enable a routine interpretation of change in priority catchments. The approach outlines a framework of multiple layers of readily available data, from water quality and ecology to indicators of change in land management (e.g. uptake of measures, fertiliser use, livestock density, crop patterns). The framework must measure and assess progress (i.e. short-term direction of travel) towards achieving WFD objectives and modelled effectiveness. CREW developed the method and criteria required for a transparent assessment.

2 Methodology and data

2.1 The framework of data needed to interpret catchment change

The feasibility of the weight-of-evidence approach depends primarily on two criteria: the availability of datasets at a waterbody or protected area scale; and the availability of data records for a period that enables reliable comparisons between before and after launching the Diffuse Pollution Plan in 2011. The minimum amount of data satisfying this condition entails a baseline of four years before 2011 (January 2007 to December 2010) and a post-implementation period from 2011 onwards (January 2011 to December 2014).

It must be noted here that for catchments where the land management measures have been introduced before 2011 or are planned to be introduced during the second RBMP cycle, baseline and post-implementation periods should be selected to fit catchment-specific circumstances.

Within this report, monitoring and evaluation of catchment change are considered in a tiered approach comprising ten levels (Table 1a) designed to enable the effectiveness of the Diffuse Pollution Plan to be evaluated in a catchment context. The framework combines modelled predictions and observed evidence from WFD-based pollutant and ecology data, and from indicators representing the major factors influencing water quality (Table 1a). These indicators are assessed by their potential to improve, directly or indirectly, water quality according to a simple conceptual source- pathway-receptor model (Appendix 1). For example, pollutants in receptor waters are linked to pollutant inputs with land use and losses through rainfall and runoff. This aims to maximise our ability to capture the effects of biophysical time-lags, which are otherwise difficult to quantify or model on a catchment-specific basis.

2.2 Outline of the weight-of-evidence method

The term weight-of-evidence is commonly used in the scientific and policy-making literature, and most often seen in the context of public health and environmental risk assessment. It broadly refers either to assessing the methods used for generating and interpreting evidence or to providing a narrative or criteria to interpret combined evidence (Appendix 2). In consultation with SEPA and experts from the James Hutton Institute (Hutton), we developed a simple and fit-for-purpose weight-of-evidence method to assess the effectiveness of measures. The weight-of-evidence method developed here relies on sound evidence and draws on the catchment-based approaches implemented in England by the Environment Agency and Natural England (CSF Team 2014; McGonigle *et al*. 2012) and by the Environment Protection Agency (EPA) in the US (US EPA 2011; Johnson *et al*. 2012) (see also Appendix 2C). Both quantitative (i.e. magnitude of change) and qualitative (significance of change) data were considered. Evidence came from water quality and ecological monitoring; monitoring of diffuse pollution drivers (e.g. fertiliser use, rainfall, livestock density) and any relevant catchment data; farmers' compliance with regulations and best practices; model predictions; and expert judgement of potential diffuse pollution risks.

The method uses quantitative data to make qualitative inferences. Collection, analysis and weighing (i.e. evaluation) of the efficacy of evidence to indicate change with the potential to bring about WFD objectives and modelled effectiveness encompassed three steps:

Step 1: Qualitative analysis of change in water quality and ecology.

Step 2: Qualitative analysis of change in indicators of the major catchment factors influencing water quality.

Step 3: Combination of water quality, ecology, and the

Table 1a Framework of catchment data on a pollutant-specific basis

Levels of evidence	Phosphorus - P	Sediment - Sed	Ammonium	FIOs
Modelled reductions*	P predictions	Sed predictions	No modelled predictions	FIO predictions
Water quality monitoring	Data for WFD	Monthly	Data for WFD	Bathing season
Ecological monitoring	Diatoms	Inv	Fish	NOT RELEVANT
DP GBR uptake	Percent of farms in a catchment/waterbody complying with DP GBRs**			
Supplementary measures (SRDP spend)	Options reducing P losses	Options reducing Sed	Options reducing N losses	Options reducing FIO losses
Inputs from fertilisers	Phosphate fertilisers	NOT RELEVANT	Nitrogen fertilisers	NOT RELEVANT
High erosion-risk crops	Winter wheat+barley+ Oilseed rape oats; potatoes		No direct source-pathway-receptor relationship at the waterbody scale	
Total livestock density	Poultry+Pigs+Grazers	NOT RELEVANT	Poultry+Pigs+Grazers	
Grazing livestock density	Cattle+Sheep+Goat	NOT RELEVANT	Cattle+Sheep+Goat	
Regional Climate	Winter/Annual rainfall			Bathing season rain

P: dissolved phosphorus; Sed: Sediment; N: Nitrogen; FIOs: Faecal Indicator Organisms in bathing waters; Diatoms: benthic diatoms; Inv: Benthic macroinvertebrates. SRDP spend: Uptake of 2007–2014 SRDP options to benefit water quality as annual spend (£).

N.B. This report did not use nitrate and pesticide data to trial the evaluation of the weight-of-evidence method.

*assuming 100% DP GBR uptake (Gooday *et al*. 2014)

**demonstrated in catchment walks before and after 2011 catchment indicators to identify the potential risks and synergies in reducing diffuse pollution pressures .

Step 1 identifies direction of change in water quality and ecology. Change was estimated through step-change, trend and change-point analyses using a variation of the BACI design, i.e. the Before-After design (Appendix 3B; see also Akoumianaki *et al*. 2015 for step-change and trend analyses). For the comparisons between the estimated step-change and the modelled reductions, we used the range of predictions for each pollutant provided by Mr Brian McCreadie (SEPA, pers. com., February 2015). The number of samples (sample size) required to detect modelled reductions with 80% statistical power was also estimated (Appendix 3A; see also Akoumianaki *et al*. 2015).

Step 1 compares average[3] values of pollutants and Ecological Quality Ratios (EQRs) over the entire post-implementation period with specified WFD standards. **This should not be perceived as WFD status classification[4], which uses a three-year window of data, but as an alternative way of exploring whether pollutants and EQRs are below a specified and widely accepted threshold.** It must be also noted that average values post-implementation could be compared to the thresholds for good or moderate status, depending on objectives in each waterbody. In this trial we used thresholds for good status. When the post-implementation average pollutant and Ecological Quality Ratio (EQRs) indicate that pollutant concentrations are below the specified thresholds and EQRs are close to specified reference values, then this is strong indication that WFD objectives have been delivered and thus it is indicated as ⇧⇧ in Table 2a. But failure to show that pollutants are below the specified thresholds and that EQRs indicate reference conditions for biological communities is indication that WFD objectives have not been delivered and thus it is indicated as ⬄ in Table 2a.

In parallel, Step 1 estimates step-change in pollutants and biological parameters after launching DP GBRs. Change can be estimated as a trend, step-change, and change point. In the case of step-change, the magnitude of step change in pollutants is compared with modelled reductions of diffuse pollutants resulting from the implementation of measures (Gooday *et al*. 2014). If a statistically significant step-change in a pollutant's concentration matches or is greater than the modelled reduction, then this is a strong indication that the model predicted target for reduction in this particular pollutant has been achieved and thus this is indicated as ⇧⇧ in Table 2a. But if step-change is significant but smaller than the modelled reduction then this is an indication that the model predicted target for reduction in this particular pollutant has not been achieved and thus this is indicated as ⇧ in Table 2a. If step-change is not significant then there is uncertainty as to why change could not be detected and this is indicated as ⬄ in Table 2a. Finally, statistically significant increase in a pollutant's concentration would indicate that change is occurring in the opposite direction from what is indicated by the model and as such it is indicated as ⇩ in Table 2a.

Likewise, improvement in EQRs between before and after the measures are indicated as ⇧ in Table 2a, whereas failure to detect a significant step-change is indicated as ⬄ in Table 2a. Deterioration in EQRs between before and after the measures would indicate failure to deliver expected improvements and it is indicated as ⇩ in Table 2a.

It must be also emphasised that improvements in monitoring data may not lead to class improvement or compliance (using a three-year window of data) with WFD standards. For this reason, Step 1 does not include the WFD status but compares post-implementation average with specified WFD standards. Also, it may not be possible to identify change between before and after (step-change) the measures except as a trend or using change-point analysis.

Step 2 identifies direction of change in the catchment indicators (Table 2b). For the indicators of fertiliser inputs, erosion risk and livestock density criteria were based on estimation of step-change between before and after the measures with Mann-Whitney tests. The threshold of change needed to assess whether a change in DP GBR (see footnote 5) and SRDP (see footnote 6) uptake is sufficient, or not, to benefit water quality was decided in consultation with SEPA and Hutton experts. The threshold was identified after estimating the detectable magnitude of change in pollutants with current monitoring data to ensure that sufficient

[3] The standard error should be calculated to inform whether the post-implementation mean falls in the specified confidence interval. If it is exceeded then the weight that should be assigned for the comparison with the respective WFD standard should be: ⬄.

[4] The ration between the value of the observed biological quality elements (BQEs), namely fish, macroinvertebrates, phytoplankton, phytobenthos, and macrophytes, for a given waterbody and the expected value under reference conditions (EU 2000: Annex V, Sect. 1.4).

Table 2a Weighing direction of change in water quality and ecology

Step 1 tasks	Direction of step-change in phosphorus, ammonium, sediments, FIOs, EQRs	Weight
Comparison with WFD standards	Post-implementation average of pollutants and EQRs agrees with WFD standards*	⇧⇧
	Post-implementation average of pollutants and EQRs does not agree with WFD standards*	⬄
Step-change	Step-change in pollutants matches model predicted reductions**	⇧⇧
	Step-change in pollutants shows improvements but fails to match model predicted reductions**	⇧
	Step-change in EQRs shows improvements	⇧
	Step-change in pollutants and EQRs is not significant	⬄
	Step-change in pollutants and EQRs shows deterioration	⇩

FIOs: Faecal Indicator Organisms; EQRs: Ecological Quality Ratios (EU 2000: Annex , Sect. 1.4).

*No sediment WFD standard; sediment effects are assessed by the Proportion of Sediment-sensitive Invertebrates (PSI), which provides a provisional good threshold for siltation impact on invertebrates.

**Relevant for pollutants for which the model provides predictions of reductions in response to 100% DP GBR uptake (Gooday *et al*., 2014), i.e. phosphorus, sediment, and FIOs.

uptake can be practically evaluated by detectable changes in pollutants. The provisional threshold for the climate indicator was based on the difference between successive 30-yearly periods in Scotland. This is in line with the Met Office approach for providing an indication of the way the UK's climate has changed over recent decades (MetOffice_UK climate averages 2013).

Step 3 combines the outputs from Step 1 and Step 2 to identify whether water quality has been improved while land management improved and why.

Direction of travel is assessed using four criteria of effectiveness:

1. Agreement of pollutants and EQRs with WFD standards;
2. Agreement of step-change in pollutants with modelled reductions
3. Significance of step-change in pollutants and biological monitoring data
4. Degree of uptake of measures (DP GBRs).

The indicators for land management and rainfall indicate risks or synergies and help understand why changes have occurred, or not. But they are not used for assessing whether the measures are implemented effectively or whether water quality improvements have been negated by land use change or rainfall because cause-effect relationships between catchment processes and water quality and ecology are unknown at a catchment-specific scale.

The Diffuse Pollution Plan can result to four different situations, as follows.

A success story occurs when:

- The average post implementation values of a specific EQR and its associated pollutant-stressor concentration indicate agreement with specified WFD thresholds, depending on objectives for each water body.
- The magnitude of step-change of a specific pollutant matches or exceeds the magnitude of reductions predicted by Gooday *et al* (2014).
- Step change in a specific EQR shows improvement.
- DP GBR uptake is sufficient, i.e. it exceeds 50%, or reaches 100% of the farms in a waterbody.

It is important to note that **in the event of changing WFD standards, chemical or ecological improvements can only contribute to ìsuccess storiesî where there has been an actual detected improvement as step-change or significant trend.**

A positive direction of travel occurs when:

- The average post implementation values of a specific EQR fail the specified WFD thresholds, depending on objectives for each waterbody, but the average post implementation value of its associated pollutant-stressor concentration indicator agrees with specified WFD thresholds.
- The magnitude of step-change of a specific pollutant is smaller the reductions predicted by Gooday *et al* (2014).
- DP GBR uptake is sufficient, i.e. it exceeds 50% or reaches 100% of the farms in a waterbody.

Table 2b Criteria and threshold of change for sufficient improvement or potential deterioration in water quality (WQ) used for demonstrating effectiveness and direction of change

Indicator	Step-change between before and after or threshold of change	Direction of change between pre- and post-implementation	Weight
DP GBR uptake	100% uptake	100% Improvement	⇧⇧
	DP GBR uptake higher than 50%[5]	Sufficient improvement to benefit WQ	⇧
	DP GBR uptake lower than 50%[3]	Insufficient change to benefit WQ	⇔
SRDP uptake	Spend for water quality options higher than 80% of total SRDP spend for Rural Priorities[6]	Sufficient improvement to benefit WQ	⇧
	Spend for water quality lower than 80% of total SRDP spend for Rural Priorities[4]	Insufficient change to benefit WQ	⇔
Fertiliser inputs	Significant reduction post-implementation	Sufficient improvement to benefit WQ	⇧
	Not significant step-change	Insufficient change to benefit WQ	⇔
	Significant increase post-implementation	Potential risk for deterioration	⇩
Area of erosion-risk crops	Significant reduction post-implementation	Sufficient improvement to benefit WQ	⇧
	Not significant step-change	Insufficient change to benefit WQ	⇔
	Significant increase post-implementation	Potential risk for deterioration	⇩
Livestock density	Significant reduction post-implementation	Sufficient improvement to benefit WQ	⇧
	Not significant step-change	Insufficient change to benefit WQ	⇔
	Significant increase post-implementation	Potential risk for deterioration	⇩
Rainfall post-2011	Post-2011 rain averages are lower by more than 11% from the 1981–2010 rain average	Sufficient improvement to benefit WQ	⇧
	Post-2011 rain averages are not different from the 1981–2010 rain average	Insufficient change to benefit WQ	⇔
	Post-2011 rain averages are higher by more than 11% from the 1981–2010 rain average	Potential risk for deterioration	⇩

[5] It is uncertain whether 50% DP GBR uptake, the provisional threshold used here, will bring about half of the reductions predicted by the model assuming 100% DP GBR uptake.

[6] The provisional threshold of 80% for SRDP uptake required to bring about sufficient improvements in water quality needs to be targeted to specific diffuse pollution pressures to be effective.

An uncertain direction of travel occurs when:

- The average post implementation values of a specific EQR and its associated pollutant-stressor do not agree with specified WFD thresholds, depending on objectives for each waterbody.
- Step-change in pollutants and EQRs is not significant.
- DP GBR uptake may be sufficient, i.e. it exceeds 50%, or insufficient to benefit water quality.

A negative direction of travel occurs when:

- The average post implementation values of a specific EQR and its associated pollutant-stressor do not agree with specified WFD thresholds, depending on objectives for each waterbody.
- Step-change in pollutants and EQRs is not significant.
- DP GBR uptake may be sufficient, i.e. it exceeds 50%, or insufficient to benefit water quality.

It must be noted here that Step 3 may need to be revisited after gathering long-term data (i.e. longer than four years) collected at a higher frequency (i.e. weekly) for analysing step-change and on the basis of the BACI design, in line with the findings described in Akoumianaki *et al*. (2015). With the currently available data, it is not possible to detect changes as small or smaller than those predicted by Gooday *et al*. (2014), as shown by Akoumianaki *et al*. (2015). As a result, the effectiveness of the Diffuse Pollution Plan cannot be currently evaluated on the basis of change in the readily available monitoring data but only on the basis of comparisons of post-implementation averages with WFD thresholds. This may create the impression that only agreement with WFD standards is taken to account to identify a success story.

On the contrary, detecting change in monitoring data is equally important. It is understood that **it is possible to evaluate the Diffuse Pollution Plan on the basis of the magnitude of change but only after more data are collected with the BACI design to enable a sufficient sample size and robust statistical analyses (Akoumianaki *et al.* 2015). It is recommended that the catchments assessed as representing a 'success story' and 'uncertain direction of travel' should be re-evaluated in view of the longer-term data.**

It should be also noted that if data for Step 1 (change in WFD classification and monitoring data) are not available, the method allows for direction of travel to be evaluated on the basis of data from DP GBR uptake and the risks and potential benefits from land use and rainfall to be accounted for.

2.3 Trial catchments

This report analysed data from four river waterbodies, i.e. the North Ugie Water, Lemno Burn, Eye Water (ID: 5011) and the Cessnock Water; and two bathing water catchments, i.e. the Eye Water and the River Ayr (Figure 1). Arable land dominates land cover in the North Ugie Water, Lemno Burn, and Eye Water with mixed and arable farming comprising the main diffuse pollution pressure; other important pressures include sewage disposal at the N. Ugie Water and the Lemno Burn, and livestock (i.e. poultry) at the Eye Water. Improved grassland dominates Cessnock Water and River Ayr, with livestock comprising the main diffuse pollution pressure.

The trial catchments were selected by SEPA, mainly on the grounds of availability of baseline data, before launching the Diffuse Pollution Plan. It is reminded that baseline data must be collected with the same sampling frequency as post-implementation data to enable step-change in pollutants and ecology to be estimated. Selection of trial catchments has not accounted for hydrological, landscape, land management or other catchment-type classifications or modelled response to measures. In addition, only DP GBR effects were evaluated. For example, nitrate data from catchments where measures to reduce pollution of vulnerable groundwater and estuaries by agricultural nitrates introduced in 2003 in NVZ designated areas (Nitrate Vulnerable Zones n.d.), were not provided by SEPA for this evaluation report. For all these reasons, the results from the trial catchments should not be considered as representative of the effectiveness of diffuse pollution measures and the land use pressures in Scotland.

Data used for developing the method came from:

(i) Water bodies already at good status, i.e. Lemno Burn, North Ugie Water (Waterbody classification 2013).
(ii) Waterbodies at less than good status, i.e. Cessnock Water, Eye Water (Waterbody classification 2013).
(iii) Bathing waters at poor status according to expected classification for Scotland's bathing waters to meet the requirements of the new EU Bathing Water Directive i.e. Eyemouth and Heads of Ayr (SEPA's Bathing water classifications 2015).

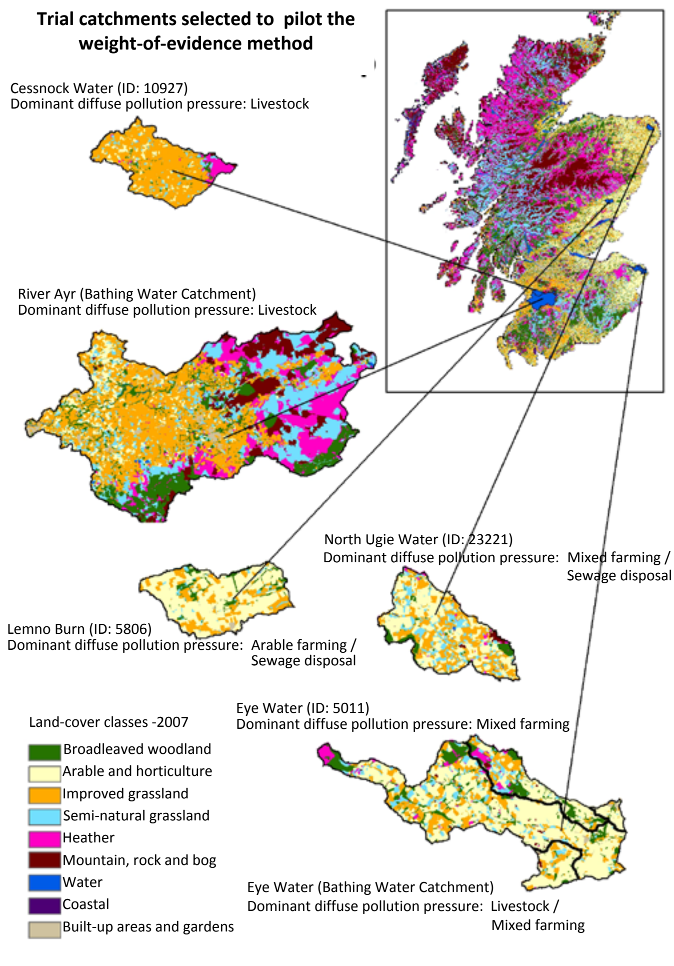


Figure 1 Trial catchments selected to evaluate the feasibility of the weight-of-evidence method. Crown copyright 2015.

2.4 Data

2.4.1 Water quality and ecology

Estimates of step-change, trends and change-points, and the sample size required to detect expected (modelled) change using SEPA's WFD-based monitoring data were analysed using:

- Monthly spot sample data of dissolved phosphorus ammonium, and suspended sediment.
- Biannual monitoring assessments of Diatoms for Assessing River Ecological Status (DARES) and the Proportion of Sediment-sensitive Invertebrates (PSI).
- Bathing season spot sample data (18 to 20 samples a year) of Faecal Indicator Organisms (FIOs), i.e. Faecal Coliforms (FC) and Faecal Streptococci (FS), in combination with flow.
- Continuous flow and monthly rainfall data; these were available from only two trial catchments (Cessnock Water, River Ayr).

2.4.2 Indicators of change

Developing the indicators of change involved collection and analysis of data from a variety of sources.

- SEPA's data from catchment walks to develop the DP GBR uptake indicator.
- Parish features at national level (http://data.gov.uk/dataset/agricultural-parishes/resource/e7671b14-5096-42fc-af06-49dbb897c53d).
- SEPA's shapefiles for waterbody boundaries.
- Edina Agcensus (http://edina.ac.uk/agcensus/) data derived from Agricultural and Horticultural Censuses of Great Britain; national scale annual data from 2007 to 2013 were downloaded to develop indicators from crops at risk from erosion, fertiliser use, and density of total livestock and grazing livestock, i.e. cattle, sheep, goat, assuming intensive pig farming (Appendix 3B).
- The LCM 2007 25m (Land Use map) raster resolution layer derived from a vector dataset consisting in 23 target classes and produced by the Centre for Ecology & Hydrology (http://www.ceh.ac.uk) as a baseline map for all the analyses.
- Field application rates of nitrogen and phosphate fertilisers for eight land use classes[7] from 2007 to 2013 reported in the British Survey of Fertiliser Application (BSFA) (https://www.gov.uk/government/collections/fertiliser-usage) to develop the indicators of nitrogen and phosphate inputs with fertiliser (Appendix 3B).
- Farm Soil Planning's classification of crops according to their vulnerability to erosion to inform the indicator of crops at risk from erosion (Farm Soil Plan 2005).
- Scottish Government parish level data on the 2007-2013 SRPD spend to develop the SRDP uptake indicator; arable areas in each parish were intersected with the trial catchments to calculate the SRDP spend at a waterbody or bathing catchment scale (Appendix 3C).
- MetOffice (http://www.metoffice.gov.uk) regional East and West Scotland average seasonal (winter, spring, summer, autumn), bathing season (from May to September) and annual rainfall (mm) data from 2007 to 2014 to develop the indicator of change in regional climate. East Scotland rainfall data captures weather trends in the N. Ugie Water, Lemno Burn and Eye Water; West Scotland data approximates weather at the Cessnock Water and the River Ayr.
- SEPA's priority catchment reports for any additional evidence on improvements and pressures.

[7] These include: tillage crops including potatoes, oats, winter oilseed rape, winter wheat and barley, and spring barley; and grassland (less and more than five years old).

3 Method Evaluation

3.1 Change in WFD data versus modelled reductions

Comparing pre- and post-implementation average pollutant concentrations and ecology data with WFD standards provides important evidence about the effects of measures on achieving WFD objectives. Comparing average modelled and observed reductions (i.e. step-change in pollutants between before and after 2011) is key in identifying gaps between modelled effectiveness and the evidence base.

Estimation of step-change in water quality and ecology data demonstrated significant changes ($p<0.05$) only for diatoms (DARES) and benthic invertebrates sensitive to siltation (PSI) at the Lemno Burn[8](Appendix 4). Although these results were statistically significant, confidence is very low due to small sample size.

The comparisons between predicted and observed change per pollutant (i.e. phosphorus, sediments, FIOs) clearly show that **the magnitude of change predicted by the model is unlikely to be statistically significant with the current monitoring** (Table 3). The national model predictions provide a summary of potential losses. The sample size required to detect change with adequate certainty was assessed and the need for more samples to detect changes smaller than 30 % in all pollutants was demonstrated (Table 3 and Appendix 5). It must be stressed, however, that the dissolved phosphorus and ammonium data provided by SEPA were already well below the standard in the trial catchments both pre- and post-implementation the measures. In this respect, monitoring to demonstrate change may not be cost-effective because compliance has already been achieved and detecting a smaller percent change would require a larger sample size.

[8] PSI significantly deteriorated at the Lemno Burn although it remained above the moderate/good provisional threshold for PSI in Scotland.

Combining the findings from step-change, trend and change-point analysis in combination with comparison of pre- and post-2011 average with WFD standards helped to identify direction of change in WFD monitoring data (Table 4):

Table 4 Direction of change in pollutant and ecology in the trial catchments

Direction of change in WFD data	Weight
Dissolved phosphorus (P):	
• Average P concentration pre- and post-2011 are below WFD standard at the Lemno Burn and Eye Water (ID: 5011) and below WFD standard post-2011 at the N. Ugie and Cessnock Water*	⇧⇧
• No significant step-change	⇔
Ammonium:	
• Average pre- and post-2011 is below the WFD standard in all trials	⇧⇧
• No significant step-change	⇔
Sediment:	
• No change in concentrations at N. Ugie, Lemno Burn and Eye Water	⇔
• Increase in concentrations at the Cessnock Water	⇩
FIOs:	
• Average is above mandatory guidelines in Eye Water and River Ayr but no deterioration	⇔
• No significant step-change	⇔
Diatoms (DARES):	
• Average post-2011 is above WFD standard at the Lemno Burn	⇧⇧
• Average post-2011 is below WFD standard (failure) at the N. Ugie and Eye Water	⇔
• No sufficient data to perform analyses from Cessnock Water	⇔
• No significant step-change in any of the trial waterbodies	⇔
Invertebrates sensitive to siltation (PSI):	
• Average post-2011 is above Scotland's provisional threshold for good status at the Lemno Burn and the Eye Water (ID: 5011) both pre- and post-2011	⇧⇧
• Average post-2011 is above Scotland's provisional threshold for good status at the at N. Ugie Water	⇔
• No sufficient data to perform analyses from Cessnock Water	⇔
• No significant step-change in any of the trial catchments	⇔

*Dissolved phosphorus data from the N. Ugie Water and Cessnock Water are not available pre-2011.

Table 3 Comparison between modelled reductions and observed step-changes in the trial catchments. Significant step-changes could not be detected in any of the trial catchments.

	Modelled reductions for specified uptake of measures		Observed step-change*	Sample size analysis**	
Pollutant	100% DP GBR	100% DP GBRs+SRDP#		% change	Years of monthly sampling
Phosphorus	15–25%	20–30%	ns	15% 30%	19 – 33 4 – 7
Sediments	2%	6%	ns	5% 30%	346 – 564 7 – 12
Faecal coliforms	17%	31%	ns	15% 30%	39 – 75 8 – 16
Faecal streptococci	17%	31%	ns	15% 30%	44 – 89 9 – 19

*Observed reduction with 48 samples pre- and post-implementation of measures; see Appendix 4.

**Sample size required to have an 80% chance of being able to detect the specified changes before and after implementing the measures (Appendix 5).

#Reference to SRDP within the ADAS tool by Gooday et al. (2014) is really referring to good practice as much of what is termed 'SRDP' is not available as a fundable option (pers. com. Darrell Crothers). Analysis of trends from 2007 to 2014 demonstrated significant concentration declines only for dissolved phosphorus at the Eye Water and significant increases only for sediments at the Cessnock Water. Change-point analysis in flow-adjusted sediment concentrations at the Cessnock Water also revealed that the latest change-point is higher than values before 2011 (Appendix 6). This indicated a deterioration for water quality which could not be detected from step-change and trend analysis.

ns: non-significant

Confidence in this evidence, including that from bathing waters, was generally low because of **lack of sufficient data to**:

- Assess reliably step-change, trends and change-points in pollutants and ecology.
- Adjust concentrations of pollutants for flow and rain variation.
- Address the effects of large soil or in-stream pools of pollutants.
- Address the effect of phosphorus bio-availability on ecological response.
- Separate the effects of recent and in-stream sources of FIO contamination.
- Rule out the effects of other, non-diffuse pollution, pressures on ecology, e.g. morphology or riparian shading on diatoms.
- Understand diatom and benthic invertebrate recovery trajectories.
- Guarantee that the phosphorus levels affecting diatoms in the field match the phosphorus standard adopted.

Nevertheless, confidence in WFD and bathing water data increased when:

- Compliance of phosphorus concentrations with WFD standard **coincided** with **compliance of diatom index with the WFD threshold for good status** at the **Lemno Burn**; this suggested a higher probability that water quality has indeed improved allowing for the diatom community to achieve a good status post-implementation.
- Compliance of phosphorus concentrations with WFD standard post-implementation **coincided** with a **significant decreasing trend in phosphorus concentrations** from 2007 to 2014 at the Eye Water (ID: 5011); this indicated that regardless of the implementation of the measures, other catchment factors influencing water quality have the potential to bring about reductions in phosphorus concentrations.
- No significant step-change was observed in sediments; this **coincided** with achieving the provisional ecological threshold for natural levels of sedimentation in streams at the Lemno Burn and Eye Water, thus it provides indirect evidence that sediment concentrations have not changed or worsened.
- A significant increasing trend in sediment concentrations from 2007 to 2014 coincided with change-points showing increase post implementation at the Cessnock Water; this showed gradual increases in sediment concentrations regardless of the launching of measures.
- Not-significant step-change in FIO concentrations, and failure to comply with mandatory guideline even after flow-adjustment at the River Ayr; this helped rule out the effects of runoff variation in interpreting the lack of significant FIO improvements.

These findings show that improving confidence in monitoring data needs additional evidence to understand the interplay among the major factors influencing water quality change. Without a weight-of-evidence approach, it remains uncertain whether the measures are ineffective because their effects are (i) negated by gaps in implementation, or by other catchment pressures; or (ii) go unnoticed because of insufficient monitoring frequency and duration.

The following sections show how different layers of evidence were assessed to enhance understanding implementation and catchment pressures.

3.2 Direction of change in the implementation of measures

The success of the Diffuse Pollution Plan relies on the effective implementation of the measures. In this report, this was measured as:

- DP GBR uptake, defined as the percent of farms in compliance with DP GBRs demonstrated in catchment walks and one-to-one farm visits.
- SRDP uptake, defined as the percent spend for options with the potential to benefit water quality over total SRDP spend for Rural Priorities, Axis 2).

3.2.1 DP GBR uptake

The DP GBRs were introduced in 2008 via the Water Environment (Diffuse Pollution) (Scotland) Regulations. The seven DP GBRs (Box 1) provide a statutory baseline of good practice. This report considers **uptake of DP GBRs as one group of measures** due to limited documentation of compliance per DP GBR at a waterbody scale during this study.

A 100% DP GBR uptake (⇧⇧), i.e. compliance of all farms in a catchment, has the maximum potential to reduce losses of phosphorus, nitrogen, pesticides nitrogen and FIOs from farms to waterways. In consultation with SEPA it was agreed to assign DP GBR compliance exceeding 50% as sufficient improvements (⇧) in the uptake of measures. It must be recognised, however, that even 100% uptake of a DP GBR that has little or no effect on reducing the dominant diffuse pollution pressures in a catchment, would not bring about sufficient improvements. This caveat shows the need for breaking down the DP GBR evidence as in Box 1 to understand how DP GBR targeting affects effectiveness. Besides, longer-term data from the priority catchment work are needed to show whether benefits can be delivered with lower DP GBR uptake rates or whether the cut-off for sufficient implementation should be higher.

BOX 1 List of Diffuse Pollution General Binding Rules (DP GBRs)

GBR 10: Runoff from roads, hard standings and steading areas.

GBR 18: Storage and application of fertiliser.

GBR 19: Keeping of livestock.

GBR 20: Cultivation of land.

GBR 21 Runoff from rural land use via drainage systems.

GBR 23 Application of pesticides.

GBR 24: Operating sheep dipping facilities.

Catchment walks and one-to-one farm visits demonstrated differences in DP GBR uptake among the trial catchments. Uptake increased from 13–30% pre-implementation to 30–80% post-implementation (Table 5). Two of the trial catchments showed uncertain or insufficient improvement in GBR uptake: Cessnock Water had an incomplete record of GBR breaches; River Ayr displayed low uptake rates both pre- and post-implementation of the Diffuse Pollution Plan. Sufficient improvements in DP GBR uptake were observed at the N. Ugie Water, Lemno Burn, and the Eye Water.

Table 5 Direction of change of DP GBR uptake

Trial catchment	% DP GBR uptake Years: 2008–2010	Years: 2011–2014	Direction of change	Weight
N. Ugie Water	16	80	Sufficient improvement	⇧
Lemno Burn	30	57	Sufficient improvement	⇧
Cessnock Water	?	?	Uncertain	⇔
Eye Water	28	63	Sufficient improvement	⇧
River Ayr	13	30	Not sufficient improvement	⇔

3.2.2 SRDP uptake: percent spend for water quality over total SRDP spend (Rural Priorities, Axis 2)

The SRDP uptake indicator for water quality options (SRDP-WQ uptake) uses data from the Rural Priorities (RP) scheme of the 2007–2013 SRDP. The RP scheme provided an important financial incentive for farmers to engage with and take action towards the delivery of regional environmental priorities through a competitive mechanism. Axis 2 included options aiming to benefit biodiversity and water quality and mitigate green-house gas emissions and flooding risks (List of rural priorities options n.d.).

To develop the SRDP-WQ uptake indicator , the water quality options under Axis 2 of the RP scheme shown in Box 2 were used. The method, however, is designed to indicate uptake of any voluntary measures with the potential to benefit water quality, irrespective of funding scheme. These options have the potential to benefit water quality as well as biodiversity and climate change and flood risk mitigation, as shown in a recent evaluation of the evidence base for SRDP options compiled by the Scottish Government in preparation to the 2014–20 SRDP (Scottish Government 2015).

The SRDP uptake indicator is based on cumulative spend data[9] for each option from years 2008–2010 and 2011–2014, separately, and uses the percent of spend for water quality options (SRDP-WQ spend) over the total spend for all options (SRDP-total spend) under Axis 2 of the RP scheme:

$$SRDP - WQ\ uptake\ indicator = \%\ \frac{SRDP - WQ\ spend}{SRDP - total\ spend}$$

The method can also be used to indicate wider environmental benefits from the uptake of SRDP in priority catchments, accounting for the spend allocated to water quality options with additional (or not) biodiversity and climate change and flood risk mitigation benefits, which are shown in Box 2.

Ideally, farm-scale data or farm numbers data should be used to develop the SRDP-WQ uptake indicator but such data were not available during this study. Therefore, using SRDP-WQ spend based on parish data to suggest water quality and other associated benefits at a waterbody scale comes with **caveats**.

Firstly, splitting ‘parish spend’ into its constituent water body spend assumed homogenous SRDP uptake and water quality benefits across a parish; this remains to be proven by farm scale analyses of SRDP uptake. In addition, evaluations of the 2007–2013 SRDP programme to date (e.g. RSPB 2011) have revealed poor targeting, presumably resulting in a scattered and diluted spend and water quality benefit.

[9] Water quality commitment (or award) is the value of funding Scottish Government (SG) approve to each applicant. EU funding tends to be based on reimbursement of monies. Therefore, commitment only turns into expenditure once the activity or item being approved is carried out or purchased by the applicant, claimed by the applicant and, finally, payment made by the Scottish Government to reimburse the applicant. As a rule of thumb, 95% of commitment turns into spend (Mr Paul Jarron, SG, pers. com., March 2015) and therefore commitment is hereafter referred to as spend.

BOX 2 Options under Axis 2 of the RP scheme with the potential to benefit water quality according to a recent evaluation of the multiple benefits of agri-environment schemes in Scotland and Europe (Scottish Government 2015). Evaluation of potential benefits for biodiversity and climate change and flood risk mitigation is also presented.

SRDP Option for water quality (Rural Priorities, Axis 2)	Evidence for benefits: Water Quality	Biodiversity	Climate change and flood risk mitigation
Manure /slurry storage	Yes	No	Yes
Livestock tracks, gates, river crossings	Yes	No	No
Water margins (e.g. buffer strips)	Yes	Yes	Maybe
Management of flood plains	Yes	Yes	Yes
Hedgerows - 2 years for landscape benefits	Yes	Yes	Yes
Management of extended hedges and hedgerow trees	Yes	Yes	Yes
Wetlands (creation, management, restoration)	Yes	Yes	Yes
Management of habitat mosaics	Yes	Yes	Yes
Species rich grassland (creation, management)	Yes	Yes	Maybe
Grass margins/Beetlebanks	Yes/Maybe	Yes/ Yes	Yes/Maybe
Arable reversion to grassland	Yes	No	Yes
Management/Restoration of Lowland Raised Bogs	Yes	Yes	Yes
Buffer areas for fens and of Lowland Raised Bogs	Yes	Yes	Yes
Wader grazed grassland	Yes	Yes	Yes
Native Woodland planting	Yes	Yes	Yes

Secondly, it remains uncertain what levels of spend are sufficient to bring about reductions in pollutants; no published evidence demonstrates a straightforward link between spend and environmental benefits. Moreover, a major issue of 2007–2013 SRDP uptake in Scotland has been the limited area of land under agreement, meaning that the scale of implementation is insufficient to deliver the landscape scale benefits needed (Baldock *et al*. 2013).

Thirdly, in voluntary schemes of measures it is difficult to match the time of approval of spend with the start of implementation of an option and the maintenance needed to ensure effectiveness.

Finally, there has been a particularly high uptake of capital grants to install manure and slurry storage but not for payments for buffer strips beyond the compulsory two metres (Baldock *et al*. 2013). This indicates that spend for water quality options on its own right is an inadequate proxy of the benefits expected.

The method developed here addresses these caveats by assuming that only with a high uptake of water quality options we can safely use the SRDP-WQ uptake indicator to assess the progress of the Diffuse Pollution Plan. **In consultation with SEPA we considered SRDP-WQ uptake as sufficient to benefit water quality in priority catchments when two conditions are met:**

- **SRDP-WQ uptake exceeds 80% of SRDP-total spend.**
- **SRDP-WQ uptake refers to options targeting the dominant rural diffuse pollution pressures in a catchment**.

Trial data show differences in SRDP-WQ spend among catchments, largely due to different regional priorities, number of farms, and number of applications (data can be requested from SG). SRDP-WQ spend increased post-2011. This is because the RP scheme had a slow start, with applications practically submitted after 2009, and because it is only since 2011 that SRDP started operating at its full financial potential. SRDP-WQ uptake pre-2011 was generally sufficient, i.e. exceeded 80% of SRDP-total spend (Table 6), indicating potential benefits for water quality pre-implementation of the Diffuse Pollution Plan in the N. Ugie Water, Eye Water and the Cessnock Water.

The option 'Native woodland', which aims to create riparian and non-riparian woodland including broadleaf tree species, has the potential to benefit water quality (Macleod *et al*. 2013; Nisbet *et al*. 2011; Scottish Government 2015; see also Box 2 this report). But the 'broadleaved woodland' is not targeted to benefit water quality and thus its uptake could not be related to water quality improvements, as concluded in an earlier CREW report (Macleod *et al.* 2013). For this reason, although the spend for 'broadleaved woodland' dominated SRDP spend at the Lemno Burn, it was not considered as the top WQ option.

Using the agreed criteria for sufficient SRDP uptake, we demonstrated sufficient SDRP-WQ uptake only at the N. Ugie Water and the Cessnock Water (Table 6). This finding can be refined when numbers of farms and applications in each catchment become available.

Analysis of the top water quality option by spend helped understand whether uptake of water quality options matches the dominant pressures shown in Figure 1 for each of the trial catchments. At the Cessnock Water, for example, manure storage topped spend for water quality (Table 6), meeting the need for tackling livestock pressures. Hedgerows dominated the SRDP-WQ spend at the N. Ugie Water, Lemno Burn and Eye Water in both the pre- and post-2011 periods (Table 6). In addition, spend for species rich grassland and grassland for wildlife substantially increased and almost reached the spend for hedgerows in the Eye Water after 2011 (Table 6).

Hedgerows and species rich grassland have the potential to trap and retain nutrients and sediments, if targeted at runoff pathways and properly maintained, from arable land and mixed farming, as for example in the N. Ugie Water, the Lemno Burn and the Eye Water (Table 6) ; they can also provide important benefits for biodiversity and climate change and flood risk mitigation. It is unclear, however, whether they can effectively reduce the FIO losses causing failure to bathing water standards, e.g. at the Eyemouth (Table 6). FIOs can be effectively reduced by capital grants such as for manure and slurry storage facilities, as in the River Ayr where this option dominated SRDP-WQ spend. Therefore, we considered that SRDP uptake at the River Ayr was sufficient to bring about reductions of FIOs in the Heads of Ayr bathing water, although SDRP-WQ uptake was slightly lower than 80% (Table 6).

Table 6 Direction of change of the SRDP uptake indicator (% SRDP-WQ spend/SRDP-total spend). SRDP-WQ spend: SRDP spend for water quality options as in Box 2. SRDP-total spend: total SRDP spend of options under Axis 2, Rural Priorities scheme, 2007–2013 SRDP.

Trial catchment	SRDP-WQ spend at a waterbody scale		Direction of change	Weight
	Years: 2008–2010	Years: 2011–2014		
N. Ugie Water	SRDP-WQ uptake: 93% Top WQ option: Hedgerows	SRDP-WQ uptake: 85% Top WQ option: Hedgerows	Sufficient improvement	⇧
Lemno Burn	SRDP-WQ uptake: 25% Top WQ option: Hedgerows	SRDP-WQ uptake: 62% Top WQ option: Hedgerows	Insufficient improvement	⇔
Eye Water (ID: 5011)	SRDP-WQ uptake: 88% Top WQ option: Hedgerows	SRDP-WQ uptake: 85% Top WQ option: Hedgerows	Sufficient improvement	⇧
Cessnock Water	SRDP-WQ uptake: 97% Top WQ option: Manure/Slurry storage and treatment	SRDP-WQ uptake: 89% Top WQ option: Manure/Slurry storage and treatment	Sufficient improvement	⇧
Eye Water bathing water catchment	SRDP-WQ uptake: 88% Top WQ option: Hedgerows	SRDP-WQ uptake: 85% Top WQ option: Hedgerows/ Species rich grassland	Insufficient improvement	⇔
River Ayr bathing water catchment	SRDP-WQ uptake: 76% Top WQ option: Manure/Slurry storage and treatment	SRDP-WQ uptake: 74% Top WQ option: Manure/Slurry storage and treatment	Sufficient improvement	⇧

To sum up, sufficient improvements (⇧) in SRDP-WQ uptake were found at the N. Ugie Water, Eye Water (ID: 5011), Cessnock Water, and at the River Ayr.

3.2.3 Direction of change in indicators of agricultural management

The simultaneous presence of land-use changes and the implementation of the Diffuse Pollution Plan presents a number of challenges in the assessment of the effectiveness of measures. This is because changes observed in water quality cannot be attributed solely to the implementation of the Diffuse Pollution Plan. Changes in land-use can have potential positive impacts on water quality, e.g. where grassland or arable land have been replaced by forests due to associated reductions in nutrient and sediment losses; or negative impacts, e.g. where grassland or forests have been urbanised or replaced by cropland. **Thus, water quality impacts of land-use change can either serve to complement (synergies) or to counteract (conflicts) the effects of the measures.**

Preliminary analyses of recent trends in land-use change for Scotland since the 1980's show that the area of prime agricultural land, i.e. offering a wide range of cropping and management options and favourable climate, has expanded (Brown & Castellazzi 2015). Nevertheless, the area of arable land has declined since the 1980's by about 15% due to reduction in temporary grassland area rather than tillage area; permanent improved grassland has expanded by about 50%; rough grazing has declined; and new woodland planting has mainly occurred in uncultivated land in western Scotland (Brown & Castelazzi 2015). In addition to these large-scale changes, some parts of Scotland have significant variability in land use from year to year due to changing climatic conditions, as in SW Scotland (Brown & Castellazzi 2014), and adaptation to demographic change and economic incentives (Critchlow-Watton *et al*. 2014). The crop varieties chosen or specialised management practises adopted by farmers to minimise sensitivity of yields to climatic, demographic and economic conditions may effectively constrain good practice in agricultural management due to the higher risks involved.

Here, indicators were developed for nitrogen and phosphorus inputs with fertilisers, soil erosion , and livestock using annual land use data from the Edina Agcensus database. Future applications of the weight of evidence method, however, should use the IACS database which has a finer, field-scale, spatial resolution than Edina and thus provides outputs with higher certainty.

Cropping patterns (Appendix 7a) varied from 2007 to 2013, but significant step-changes between pre- and post-2011 could be observed only at the N. Ugie Water and Lemno Burn. At N. Ugie Water, increases occurred in: the area of grassland less than five years old (by 38%); winter oilseed rape (by 28%); and spring barley (by 33%). At the Lemno Burn, winter oilseed rape and spring and winter barley increased by almost 50%. The area of grassland older than 5 years decreased by 30% in the N. Ugie Water and by 19% at the Lemno Burn.

Cattle, sheep, goat, pig and poultry densities fluctuated from 2007 to 2013 (Appendix 7b). Significant reductions from the pre-2011 to the post-2011 period could only be detected in cattle numbers at the Cessnock Water (by 6%) and poultry density at the Eye Water (by about 90%). Poultry outnumbered cattle in all trial catchments except in Eye Water after 2007; sheep outnumbered cattle at the River Ayr (Appendix 7b). The highest pig numbers among the trial catchments were found at the N. Ugie Water (Appendix 7b).

3.2.3.1 Indicator of nitrogen- and phosphate-fertiliser inputs

Estimating both fertiliser inputs and associated nutrient losses is essential for understanding how economic (e.g. crop demand, market prices), climate and policy (e.g. measures) factors affect water quality and land use change. For example, statutory measures, such as GBR 18, regulate fertiliser storage and handling practices so that application rate is not over the nutrient needs of the crop. Uptake of voluntary measures, such as SRDP options for water quality, ensures that fertilisers remain in the field and losses to water courses are minimised. On the other hand, fertiliser prices influence decisions of farmers in terms of cropping and fertiliser application rates; and weather conditions (e.g. rainfall) affect the proportion of winter to spring crops, the latter often requiring less fertiliser. With losses being difficult to estimate on a catchment-specific basis, assessing fertiliser inputs is a practical way forward.

The indicator of nitrogen and phosphate inputs with fertilisers combines the area of tillage crops and grassland in each of the trial catchments with the estimates of the annual average field rates from 2007 to 2013:

Nitrogen (N)-fertiliser input = area (ha) of each crop type annual average N field rate for each crop type (kg/ha)*

and

Phosphate (P_2O_3)-fertiliser input = area (ha) of each crop type annual average P_2O_3 field rate for each crop type (kg/ha).*

Using field rates and waterbody-specific cropping patterns are the key advantage of this approach. Field rates are based on the combination of confidential trade and sales data representing 90% of the market with a sample of Scottish farms[10] compiled using the June Agricultural Census, a sample survey conducted annually recording information on farm size, cropping, stocking and employment (June Agricultural Census n.d). Average field application rate is calculated from the sown area rather than the total field area, thus addressing the potential that margins of fields remain uncropped as a result of cross-compliance. In addition, the indicator for nitrogen- and phosphate-fertiliser inputs can be combined with DP GBR 18 (fertiliser use regulation) uptake data, once these become available, to enhance our understanding of the synergies or conflicts between the measures and trends in fertiliser inputs.

The major disadvantage of this method is the uncertainties in estimating the area of tillage crops and grassland in each year in each waterbody using Edina Agcensus data but this does not affect before-after comparisons. Use of the fine resolution IACS farm-plot data will minimise such uncertainties.

The method developed here recognises that significant increases in nitrogen- and phosphate-fertiliser inputs indicate a

[10] including holdings less than 20 hectares in size.

potential risk of deterioration (⇩) in nitrogen and phosphorus concentrations and presumably plants and algae in rivers, lochs, groundwater bodies and estuaries; significant declines in their inputs indicate a higher chance for improvements (⇧) in nitrogen and phosphorus concentrations and presumably diatoms.

Overall, nitrogen application rates to all crops in Scotland have remained largely unchanged since 2007, i.e. 104 and 105 kg/ha in the pre- and post-2011 periods, respectively. These rates lie within the lowest range of values for nitrogen usage to all crops and grass since 1983 for Scotland (i.e. 82 to 130 kg/ha). Likewise, the rates of phosphate application in Scotland fluctuated between 38 and 43 kg/ha during the 2007–2013 period. These values lie within the long-term range of phosphate rates for all crops and grass since 1983 for Scotland (i.e. 29–48 kg/ha).

Nitrogen- and phosphate-fertiliser inputs increased after 2011 only in two of the trial catchments, notably at the N. Ugie Water and Lemno Burn (Table 7 for nitrogen inputs, Table 8 for phosphate inputs). Rise in fertiliser inputs is mainly associated with increases in the area of winter oilseed rape and winter and spring barley rather than with increases in fertiliser application rates, which remained unchanged. These findings indicate a higher risk of deterioration (⇩) in ammonium and dissolved phosphorus at the N. Ugie Water and the Lemno Burn (Table 7, 8).

3.2.3.2 Crops at high risk from erosion

Some cropping patterns can lead to a greater risk of soil erosion and losses of soil-bound pollutants (i.e. nutrients, pesticides) in runoff, regardless of the implementation of measures. This risk could be assessed to understand whether cropping patterns negate or support diffuse pollution mitigation measures. The Farm Soil Plan (2005) identifies erosion risk by crop type as follows:

- Low risk: Grass <5 years old, and >5 years old.
- Moderate risk: Spring barley.
- High risk: Winter wheat / barley / oilseed rape, oats, and potatoes, which are very high-risk crops.

The indicator of erosion risk describes the area covered by high risk crops in hectares. Here, we used high-risk and very high-risk crops as one group to illustrate the approach. But there could be two indicators for erosion risk: one for high risk crops (i.e. winter wheat/barley/oilseed rape, oats) and the other for very high-risk crops (i.e. potatoes).

It must be also noted that the method recognises that erosion is a higher risk to water quality in farms adjacent to watercourses: however small the area of high risk crops may be, the potential risk may be high. This limitation could be tackled by using farm scale data[11] to select high risk fields adjacent to watercourses.

For the needs of this report, significant increases in the high risk hectarage indicate a potential risk of deterioration (⇩) in sediments, nutrients, pesticides, ecology and FIOs; significant decreases indicate a higher chance of improvements (⇧) in water quality.

High risk area ranges between about 800 and 1200 ha at the N. Ugie Water and Lemno Burn and is lower than 150 ha at the Cessnock Water (Table 9). A greater diversity of cropping pattern is observed at the Eye Water, with high risk crops occupying 32 to 42% of cropland and exceeds 2000 ha in both before- and after-2011 periods (Table 9). The area covered by high risk crops clearly increased after 2011 at the N. Ugie Water and the Lemno Burn but no change could be discerned at the Eye Water and the Cessnock Water (Table 9, Appendix 7a). Therefore, the trial indicates a risk of deterioration in water quality (⇩) at the N. Ugie Water and Lemno Burn, particularly for dissolved phosphorus and sediments, but uncertain direction of change (⇔) at the Eye Water and Cessnock Water and River Ayr (Table 9).

3.2.3.3 Total and grazing livestock density

Livestock density is a tool for understanding animal pressures in an area. For example, cattle, pig and poultry factory farms, where densities per hectare are very high, usually produce far more waste (manure/slurry) than can be managed in line with best practice and regulations. If this waste is over-applied to fields as a way of getting rid of it, it greatly increases the risk of FIO, nutrient, and other pollutant losses in agricultural runoff. In addition, grazing livestock, such as cattle, sheep and goats, with access to watercourses give rise to pathogens in drinking, shellfish,

[11] in line with Common Agricultural Policy's Integrated Administration and Control System (IACS n.d.).

Table 7 Direction of change of the indicator of nitrogen-fertiliser inputs in the trial catchments

Trial river waterbodies	Range of nitrogen-fertiliser inputs (tonnes per catchment)		Direction of change in terms of risks and benefits to water quality	Weight
	Years: 2007–2010	Years: 2011–2013		
N. Ugie Water	364–436	486–510	Deterioration	⇩
Lemno Burn	308–367	449–470	Deterioration	⇩
Eye Water (ID: 5011)	455–927	515–944	Insufficient improvement	⇔
Cessnock Water	483-577	494-586	Insufficient improvement	⇔

Table 8 Direction of change of the indicator of phosphate-fertiliser inputs in the trial catchments

Trial river waterbodies	Range of phosphate-fertiliser inputs (tonnes per catchment)		Direction of change in terms of risks and benefits to water quality	Weight
	Years: 2007–2010	Years: 2011–2013		
N. Ugie Water	137–157	178–186	Deterioration	⇩
Lemno Burn	162–183	186–220	Deterioration	⇩
Eye Water (ID: 5011)	177–343	190–359	Insufficient improvement	⇔
Cessnock Water	154–162	151–162	Insufficient improvement	⇔

Table 9 Direction of change of the indicator of erosion risk in all trial catchments				
Trial river waterbodies	Range of high risk crops area (Ha)		Direction of change as benefits to water quality	Weight
	Years: 2007–2010	Years: 2011–2013		
N. Ugie Water	789–952	997–1107	Deterioration	⇩
Lemno Burn	834–1041	1133–1212	Deterioration	⇩
Eye Water (ID: 5011)	1328–3162	1616–3179	Not sufficient change	⇔
Cessnock Water	8–112	67–148	Not sufficient change	⇔
Eye Water bathing water catchment	2071–4485	2482–4518	Not sufficient change	⇔
River Ayr bathing water catchment	268–492	244–562	Not sufficient change	⇔

fishing and bathing waters. Given the uncertainties in determining retention and losses of livestock-generated pollutants at a waterbody scale, stocking densities are essential for understanding catchment specific livestock pressures and risks to water quality.

The two indicators for livestock pressures simply sum the numbers of total and grazing livestock per catchment (waterbody or protected area), as follows:

Total livestock density= Animal numbers (cattle + sheep + goat + pig + poultry) per catchment.

Grazing livestock density= Animal numbers (cattle + sheep + goat) per catchment.

The major advantage of these two indicators is the simplicity in their calculation. Each indicator catchment – specific and lumps together inputs from animals living far away and adjacent to recipient waterbodies and protected waters. This is maybe a disadvantage for the grazing livestock indicator, as risk of pathogen contamination is greater when animals graze fields neighbouring with waterways or manure and slurry and spread over such fields. Nevertheless, it is an advantage for the total livestock indicator, as it reflects the overall diffuse pollution risk from livestock across all types of waterbodies and designated areas in a catchment.

The major limitation of the livestock indicators is that it remains largely unknown what magnitude of reduction in animal numbers is required to bring about improvements in nutrient concentrations and FIOs. In the face of this uncertainty, the method considers any step change indicating reduction in density as a potential for improvement (⇧) in FIOs, nitrogen and phosphorus and any rise in numbers as a potential for deterioration (⇩) in FIOs, nitrogen and phosphorus. It must be recognised, however, that land management rather than density is key in understanding the link between livestock density and diffuse pollution. Therefore, livestock indicators should be examined in tandem with indicators of livestock management from keeping to waste reduction.

Total stocking density per catchment fluctuated from 2007 to 2013 with ranges pre- and post-2011 overlapping in all trial catchments (Table 10, Appendix 7b). Significant step changes could be detected only in the N. Ugie Water, indicating increased risk of deterioration (⇩) in water quality, and the Eye Water (waterbody 5011 and bathing water catchment), indicating opportunities for improvements (⇧) in water quality (Table 10). Similarly, grazing livestock densities fluctuated and overlapped between before and after 2011 (Table 11, Appendix 7b). Sufficient improvements (⇧), i.e. reductions, in grazing livestock density could be detected only in the Eye Water (Table 11).

Table 10 Direction of change in total livestock density in all trial catchments				
Trial river waterbodies	Range of total livestock density (numbers of animals per catchment)		Direction of change in terms of benefits to water quality	Weight
	Years: 2007–2010	Years: 2011–2014		
N. Ugie Water	41,790–94,353	78,215–105,052	Deterioration	⇩
Lemno Burn	28,433–62,980	47,986–50,891	Not sufficient change	⇔
Eye Water (ID: 5011)	32,159–59,763	13,723–34,806	Improvement	⇧
Cessnock Water	35,269–40,190	30,856–51,633	Not sufficient change	⇔
Eye Water bathing water catchment	43,196–71,627	18,615–47,147	Improvement	⇧
River Ayr bathing water catchment	160,065–306,839	281,064–296,525	Not sufficient change	⇔

Table 11 Direction of change in grazing livestock density in all trial catchments				
Trial river waterbodies	Range of total livestock (numbers of animals per catchment)		Direction of change in terms of benefits to water quality	Weight
	Years: 2007–2010	Years: 2011–2014		
N. Ugie Water	8,681–9,681	5,353–12,762	Not sufficient change	⇔
Lemno Burn	3,044–3,374	2,054–4,968	Not sufficient change	⇔
Eye Water (ID: 5011)	30,170–31,901	12,009–32,978	Improvement	⇧
Cessnock Water	21,750–22,233	12,038–33,104	Not sufficient change	⇔
Eye Water bathing water catchment	40,571–42,987	16,415–44,796	Improvement	⇧
River Ayr bathing water catchment	114,935–123,155	113,536–160,386	Not sufficient change	⇔

3.2.4 Direction of change in regional rainfall

Catchment specific rainfall-driven variations in pollutants can be determined using paired rainfall-concentration and flow-concentration measurements to adjust for rain and flow effects, i.e. separate the effects of land use and hydrology on pollutant concentrations. More importantly, we need to understand how weather conditions influence transport of pollutants and land management. For example, prolonged wet weather can increase runoff and leached losses of pollutants, especially in winter when many fields are bare, and increase the risks from fertiliser and pesticide spraying. Rainfall and temperature can also affect nutrient availability and plant growth; a very wet (or very dry) autumn might delay the establishment of winter sown crops increasing erosion risk and nutrient losses. Rainfall can alter the annual fertiliser inputs by affecting the ratio of winter to spring sown crops, the latter having lower requirements. In addition, wet weather during bathing season (May to September) increases pathogen contamination risk in bathing waters. Therefore, the regional rainfall indicator is key in understanding weather-driven changes in rural indicators over time and can help interpret water quality differences among priority catchments with similar pressures and measures in place.

The indicator of the regional climate – weather uses regional rainfall data for East and West Scotland. For the needs of this report, annual, winter and bathing season rainfall averages for the 2007–2010 and the 2011–2014 periods were estimated and compared with the 1981–2010 rain averages, as follows:

Regional climate-weather indicator =
Deviation of rain average in 2007–2010
and 2011–2014 from 1981–2010 rain average.

This simple and transparent approach based on MetOffice datasets available online, comes with a **caveat**. It is uncertain how much rain is sufficient to increase losses of dissolved and particulate pollutants from fields to watercourses.

To address this knowledge gap, we examined the change in annual, seasonal and monthly rain averages in the UK and Scotland from 1971–2000 to 1981–2010 to assess long-term rainfall trends and rates of weather change. Annual, seasonal and monthly averages increased from 1971–2000 to the 1981–2010 period up to 11% in both East and West Scotland and throughout the UK. These changes are partly related to warming, as a warmer atmosphere holds more moisture (MetOffice-UK climate averages 2013).

Thereby, we assume that any deviations of the 2007–2010 and 2011–2014 rainfall averages from the 1981–2010 rain averages in West and East Scotland exceeding 11%, represent a faster weather change than that observed in recent decades; as such, above 11% deviations mark a higher risk of deterioration (⇩) in water quality even if the measures are in place and land management has improved. Conversely, a 11% decline or greater in the 2007–2010 and 2011–2014 rainfall averages compared to Scotland's long-term average indicates a lower risk of losses of pollutants than in previous years, even if measures are not in place and land management has not improved; as such, it indicates a higher potential for improvements (⇧) in water quality.

In East Scotland, the winter, and bathing season averages post-2011 increased by 15% compared to the 1981–2010 average (Table 12). Change in annual average was 11% (Table 12). It must be also recognised that the summer and bathing season rainfall decreased post-implementation compared to pre-2011 (Appendix 8). In West Scotland, annual, winter, and bathing season average rainfall increased by more than 11% post-2011 compared to 1981–2010 (Table 12, Appendix 8).

These results indicate that regional climate-weather conditions increase the risk of losses of pollutants and therefore have a deteriorating effect (⇩) on water quality (Table 10) except in the case of annual average rain in East Scotland, where change is insufficient to influence water quality.

3.3 Direction of travel of the Diffuse Pollution Plan

Combining evidence from pollutants and ecology and catchment indicators helped inform the framework for the interpretation of catchment data on catchment-and pollutant-specific basis.

The framework of catchment data for assessing the direction of travel of **phosphorus mitigation** (Table 13a) indicated:

- **A success story at the Lemno Burn but with low certainty because of small sample size**. The success story has been indicated by (i) the average phosphorus concentrations post-implementation being below the WFD standard in tandem with the average DARES (diatoms) being above the WFD standards and (ii) the sufficient DP GBR uptake, which exceeded 50%. Yet, step-change in diatoms and phosphorus and the phosphorus trend were not significant; sample-size analysis showed that monitoring will enable the expected change (assuming 100% DP GBR and SRDP uptake) in phosphorus to be detected in four to five years after launching the measures. Also, step-change in DARES was significant but with low confidence due to small sample size. This estimate along with increase in SRDP uptake measures post-2011, mainly hedgerows which help trap nutrients in the soil (section 3.2.2), are signs of response to

Table 12 Direction of change in regional climate-weather indicator

Region	Indicator: Regional climate change increase in average rainfall post-implementation compared to the 1981–2010 rainfall average		Direction of change	Weight
East Scotland includes N. Ugie Water Lemno Burn, Eye Water	Winter Bathing season Annual	15% 15% 11%	Deterioration Deterioration Insufficient change	⇩ ⇩ ⇔
West Scotland includes Cessnock Water River Ayr	Winter Bathing season Annual	17% 17% 13%	Deterioration Deterioration Deterioration	⇩ ⇩ ⇩

the implementation of measures. Other catchment indicators indicated diffuse pollution risks, i.e. inputs of fertilisers, area of erosion-risk crops, rainfall and possibly sewage inputs increased post-2011. Step-change in total livestock was not significant and change in annual rainfall was not sufficient to benefit water quality.

- **A positive progress at the North Ugie Water and the Eye Water (ID: 5011)**. Positive progress has been indicated by (i) the average phosphorus concentrations post-implementation being below the WFD standard but the average DARES post-implementation being below the WFD standard, indicating failure of the standard; and (ii) the sufficient uptake of DP GBRs (>50%) and SRDP options (>80%). But step-change in phosphorus and diatoms was not significant. In addition, the risks from fertiliser use, crops prone to erosion, and livestock either increased (N. Ugie Water) or remained unchanged (Eye Water). A significant decreasing phosphorus trend and the estimates of detecting the modelled change in five to seven years are opportunities for improvement in the near future.

- **Uncertain progress** at the Cessnock Water because (i) average phosphorus concentrations post-implementation met the WFD standard but DARES failed the standard and (ii) DP GBR uptake was insufficient to benefit water quality. There were not baseline data for phosphorus and adequate data for DARES to test for step-change and a trend. Winter and annual rainfall increased and risks from fertiliser use, crop patterns and livestock were not reduced post-2011. Yet, sufficient SRDP uptake pre- and post-2011 shows opportunities for improvement.

The framework of catchment data indicated **successful mitigation of ammonium (Table 13b)** because ammonium concentrations complied with WFD standards and fish population data (not included in this report) indicated good conditions. **As ammonium concentrations were well below the standard in both pre- and post-implementation of the measures, this success is not related to the implementation of the Diffuse Pollution Plan measures launched in 2011**. Synergies between DP GRBs and SRDP measures, and total and grazing livestock declines at the Eye Water, and between DP GBRs and high hedgerow uptake at the Lemno Burn, are positive signs of measures for protection from nitrogen losses being in place.

The framework of data to assess direction of travel of **sediment mitigation** (Table 13c) showed:

- **A success story with low certainty at the Lemno Burn and the Eye Water (ID: 5011).** Evidence from benthic invertebrate and fish indicated natural levels of sediments. In addition, there was sufficient DP GBR uptake. But step-change or trend in sediments was not significant; sample size analysis indicated that the current monitoring is inadequate to enable the expected change in sediments to be detected even with 100% DP GBR uptake. Besides, diffuse pollution pressures (e.g. erosion risk) have not been tackled. Synergies occurred between DP GBRs and SRDP measures at the Eye Water. High SRDP uptake of hedgerows at the Lemno Burn is a positive sign.

- **Uncertain progress at the North Ugie Water**, because (i) average PSI (benthic invertebrates sensitive to siltation) failed the provisional WFD standard (ii) step-change or trend could not be detected in sediment or PSI; and (iii) the measures seem to be in place as DP GBR and SRDP uptake were sufficient to benefit water quality. This indicates uncertainty as to why there is no improvement although the measures are sufficiently implemented. Uncertainty is also derived from the need for very long-term monitoring with higher frequency (see section 3.1) to detect a relatively small (5 – 10%) change in sediment concentrations. Risks have also been evidenced from the increases in the area of erosion-risk crops post-2011 and in winter rainfall.

- **Negative progress at the Cessnock Water,** because of (i) insufficient DP GBR uptake and (ii) increase in the 2007–2014 trend in sediments. This conclusion is also backed by higher sediment concentrations in 2014 as shown by change-point analysis (see section 3.1).

The framework of data to assess direction of travel of **FIO mitigation** showed **uncertain progress** at the Eye Water and River Ayr (Table 13d) because of failure to detect significant reduction in FIOs. At the Eye Water, synergies occurred between DP GBRs and SRDP measures and significant declines in total and grazing livestock were observed. High SRDP uptake of manure/slurry storage and concurrent declines in sewage inputs (from septic tanks) provide opportunities for improvements at the River Ayr.

Table 13a Framework for interpreting catchment data and assessing direction of travel in mitigating phosphorus in river waterbodies using the weight-of-evidence method

Evidence		North Ugie Water	Lemno Burn	Eye Water	Cessnock Water
P conc. vs WFD standard		⇧⇧	⇧⇧	⇧⇧	⇧⇧
DARES vs WFD standard		⇔	⇧⇧	⇔	⇔
P conc.		⇔	⇔	⇔	Baseline data not available
DARES		⇔	⇔	⇔	Insufficient data
DP GBR uptake		⇧	⇧	⇧	⇔
SRDP uptake		⇧	⇔	⇧	⇧
P in fertilisers		⇩	⇩	⇔	⇔
Erosion risk crops		⇩	⇩	⇔	⇔
Total Livestock		⇩	⇔	⇧	⇔
Regional rain (winter)		⇩	⇩	⇩	⇩
Regional rain (annual)		⇔	⇔	⇔	⇩
Post-DP GBR Trend	P conc.	⇔	⇔	⇔	⇔
	DARES	⇔	⇔	⇔	Insufficient data
Current WFD status	P conc.	Good	High	To be filled by SEPA	To be filled by SEPA
	DARES	Moderate	High	To be filled by SEPA	To be filled by SEPA
Additional evidence		Large P losses from septic tanks	• P losses from septic tanks and WWT • P conc. much lower than standard • Increase in SRDP uptake post-2011	• P inputs from septic tanks/ WWT • P conc. much lower than standard	Low P losses from septic tanks
Interpretation of combined evidence		P conc. is below WFD standard BUT risks and uncertainties remain. **Uncertainties**: (i) DARES still fails the WFD standard; (ii) step-change in P and DARES is not signif.; (iii) Trend of P is not signif.; and (iv) Change in annual rainfall is insufficient to benefit water quality. **Risks**: Conflicts between sufficient DP GBR and SRDP uptake and increased risk of P losses from fertiliser use, erosion, livestock density, sewage, and winter rain. **Synergies**: Sufficient uptake of both DP GRB and SRDP measures.	P conc. and DARES met the WFD standard BUT risks and uncertainties remain. **Uncertainties**: (i) Step-change in P and is not signif. and for DARES it was significant but with low confidence; (ii) Trend in P is not signif.; (iii) Change in annual rainfall is insufficient to benefit water quality; and (iv) Step-change in total livestock is not signif. **Risks**: Conflicts between sufficient DP GBRs uptake and increased risk of P losses from fertiliser use, erosion, sewage, and winter rain. **Opportunities**: increase in SRDP uptake post-2011.	P conc. is below standard BUT without sufficient reduction of risks and uncertainties. **Uncertainties**: (i) Step-change in P and DARES are not signif.; (ii) Step-change in fertiliser inputs and area of risk crops is not signif.; and (iii) Change in annual rainfall is insufficient to benefit water quality. **Risks**: Conflicts between sufficient DP GBR and SRDP uptake and increased risk of losses with winter rainfall and sewage. **Synergies**: between sufficient DP GBR and SRDP uptake and declines in total livestock. **Opportunities**: 2007–2014 P trend showing reduction.	P conc. is below WFD standard BUT risks and uncertainties remain. **Uncertainties**: (i) DP GBR uptake is insufficient; (ii); Post-2011 P trend is not signif.; (iii) Reduction in fertiliser inputs, erosion risk, total livestock are not signif. **Risks**: Conflicts between sufficient SRDP uptake and increased risk of losses with winter and annual rain. **Opportunities**: High SRDP uptake pre- and post-2011.
Direction of travel		Positive progress ☺	Success story with uncertainty ✔	Positive progress ☺	Uncertain progress 😐

⇧⇧: WFD standards have been met post-implementation; ⇧: step-change shows improvement; ⇔: not significant (not signif.) step-change; ⇩: step-change shows deterioration. P: phosphorus. WWT: Waste Water Treatment.; conc. concentration; DARES: diatom EQR.

Table 13b Framework for interpreting catchment data and assessing direction of travel in mitigating ammonium in river waterbodies using the weight-of-evidence method				
Evidence	**North Ugie Water**	**Lemno Burn**	**Eye Water**	**Cessnock Water**
NH_4^+ conc. vs WFD standard	⇧⇧	⇧⇧	⇧⇧	⇧⇧
NH_4^+ conc.	⬄	⬄	⬄	⬄
DP GBR uptake	⇧	⇧	⇧	⬄
SRDP uptake	⇧	⬄	⇧	⇧
N in fertilisers	⇩	⇩	⬄	⬄
Total Livestock	⇩	⬄	⇧	⇩
Grazing Livestock	⬄	⬄	⇧	⬄
Regional rain (winter)	⇩	⇩	⇩	⇩
Regional rain (annual)	⬄	⬄	⬄	⇩
Additional evidence	• Small N losses from septic tanks/WWT • NH_4^+ conc. very low	• Unknown N losses from septic tanks/WWT • NH_4^+ conc. very low	• Unknown N losses from septic tanks/WWT • NH_4^+ conc. very low	• Unknown N losses from septic tanks/WWT • NH_4^+ conc. very low
Interpretation of combined evidence	**NH_4^+ conc.was below WFD standard since before launching the Diffuse Pollution Plan** BUT risks and uncertainties remain. **Uncertainties**: (i) Step-change in grazing livestock is not signif. and (ii) change in annual rainfall is insufficient to benefit water quality. **Risks**: Conflicts between sufficient DP GBRs and SRDP uptake and increased risk of nitrogen losses from fertiliser use and winter rainfall. **Synergies**: Concurrent and sufficient DP GBR and SRDP uptake.	**NH_4^+ conc was below FD standard since before launching the Diffuse Pollution Plan** BUT risks and uncertainties remain. **Uncertainties**: (i) SRDP uptake is Insufficient; (ii) Step-change in grazing livestock is not signif.; and (iii) change in annual rainfall is insufficient to benefit water quality. **Risks**: Conflicts between sufficient DP GBR uptake and increased risk of nitrogen losses from fertiliser use and winter rainfall. **Opportunities**: increase in SRDP uptake (hedgerows) post-2011.	**NH_4^+ conc. was below WFD standard since before launching the Diffuse Pollution Plan BUT risks and uncertainties remain.** **Uncertainties**: (i) Step-change nitrogen fertiliser inputs is not signif.; (ii) Change in annual rainfall is insufficient to benefit water quality. **Risks**: Conflicts between sufficient DP GBR and SRDP uptake and increased risk of nitrogen losses with winter rainfall. **Synergies**: Concurrent and sufficient DP GBR and SRDP uptake and declines in grazing livestock density.	**NH_4^+ conc. was below WFD standard since before launching the Diffuse Pollution Plan BUT risks and uncertainties remain.** **Uncertainties**: Step-change in grazing livestock and nitrogen fertiliser inputs is not signif. **Risks**: Conflicts between sufficient DP GBR and SRDP uptake and increased risk of nitrogen losses with rainfall. **Opportunities**: High SRDP uptake (manure/slurry storage) before and after 2011.
Direction of travel	Success story with risks ✔	Success story with risks ✔	Success story with risks ✔	Success story with risks ✔

⇧⇧: WFD standards have been met post-implementation; ⇧: step-change shows improvement; ⬄: not significant (not signif.) step-change; ⇩: step-change shows deterioration. NH_4^+ : Ammonium; N: nitrogen; WWT: Waste Water Treatment.; conc. concentration.

Table 13c Framework for interpreting catchment data and assessing direction of travel in mitigating sediments in river waterbodies using the weight-of-evidence method

Evidence	North Ugie Water	Lemno Burn	Eye Water	Cessnock Water
PSI (Inv) vs WFD pro-standard	⇔	⇧⇧	⇧⇧	⇔
Sed conc.	⇔	⇔	⇔	⇩
PSI (Inv)	⇔	⇔	⇔	⇔
DP GBR uptake	⇧	⇧	⇧	⇔
SRDP uptake	⇧	⇔	⇧	⇧
Erosion risk crops	⇩	⇩	⇔	⇔
Regional rain (winter)	⇩	⇩	⇩	⇩
Regional rain (annual)	⇔	⇔	⇔	⇩
Additional evidence	Fish communities unimpacted	Forestry pressures		
Interpretation of combined evidence	Increased risk of sediment losses post-implementation without sufficient reduction of siltation effects on benthic Inv. Also, uncertainties and risks remain. **Uncertainties**: (i) Step-change and trend in Sed are not signif.; (ii) Step change in PSI is not signif.; (iii) Change in annual rain is insufficient to benefit water quality. **Risks**: Conflicts between DP GBR and SRDP uptake and increased risk of erosion and winter rain. **Synergies**: Simultaneous DP GBR and SRDP uptake at a sufficient degree.	Reduction of siltation effects on benthic Inv so that PSI meets the provisional WFD standard in tandem with sufficient DP GBR uptake BUT uncertainties and risks remain. **Uncertainties**: (i) Step-change and trend in Sed are not signif.; (ii) Step-change in PSI is not signif.; (iii) SRDP uptake is insufficient to benefit water quality; and (iv) Change in annual rain is insufficient to benefit water quality. **Risks**: Conflicts between sufficient DP GBR uptake and increased risk of erosion and winter rain. **Opportunities**: Increase in SRDP uptake (hedgerows) post-2011.	Reduction of siltation effects on benthic Inv so that PSI meets the provisional WFD standard in tandem with sufficient DP GBR uptake BUT uncertainties and risks remain. **Uncertainties**: (i) Step-change and trend in Sed are not signif.; (ii) Step-change in PSI is not signif.; (iii) SRDP uptake is insufficient to benefit water quality; (iv) Step-change in erosion risk is not signif.; and (v) Change in annual rain is insufficient to benefit water quality. **Risks**: Conflicts between sufficient DP GBR and SRDP uptake and increased risk of winter rain. **Synergies**: Simultaneous DP GBR and SRDP uptake at a sufficient degree.	Increasing Sed trend and insufficient DP GBR uptake, while uncertainties and risks remain. **Uncertainties**: (i) Step-change in Sed is not signif.; (ii) Step-change in PSI is not signif.; (iii) Step-change in erosion risk is not signif. **Risks**: Conflicts between sufficient SRDP uptake and increased risk of winter and annual rain.
Direction of travel	Uncertain progress 😐	Success story with uncertainty ✔	Success story with uncertainty ✔	Negative progress ☹

⇧⇧: WFD standards have been met post-implementation; ⇧: step-change shows improvement; ⇔: not significant (not signif.) step-change; ⇩: step-change shows deterioration. conc. concentration. Sed: sediments; Inv: Benthic Invertebrates sensitive to siltation; PSI: Proportion of Sediment-sensitive Invertebrates. pro-standard: provisional standard.

Table 13d Framework for interpreting catchment data and assessing direction of travel in mitigating faecal indicator organisms (FIOs) in bathing waters using the weight-of-evidence method		
Evidence	**Eye Water (Eyemouth)**	**River Ayr (South Beach)**
FIO conc. vs Bathing water standards	⇔	⇔
FIO conc.	⇔	⇔
DP GBR uptake	⇧	⇔
SRDP uptake	⇔	⇧
Total livestock	⇧	⇔
Grazing livestock	⇧	⇔
Regional rain (bathing season)	⇩	⇩
Regional rain (winter)	⇩	⇩
Regional rain (annual)	⇔	⇩
Current Bathing Water status	Poor	Sufficient
Additional evidence	• No significant change in the grassland area ⇔ • Potentially important sewage sources from septic tanks ⇩	• No significant change in the grassland area ⇔ • Reduced sewage sources from septic tanks ⇧
Interpretation of combined evidence	No reduction of FIOs in tandem with DP GBR uptake but increased risk of mobilisation and transport of FIOs through increased rain. **Uncertainties**: (i) step-change and trend are not-signif.; (ii) SRDP uptake not sufficient to benefit water quality; (iii) Step-change change in grazing livestock density is not signif. **Risks**: conflicts between DP GBRs and rainfall in bathing season. **Opportunities**: Synergies between DP GBR uptake and declines in total livestock.	No reduction of FIOs in tandem with DP GBR uptake but increased risk of mobilisation and transport of FIOs through increased rain. **Uncertainties**: Not-significant step-change, trend; not sufficient. SRDP uptake; not significant change in total and grazing livestock **Risks**: Conflicts between sufficient DP GBR and SRDP uptake and winter rain deteriorated. **Opportunities**: Synergies between sufficient SRDP uptake (manure/slurry storage) and declines in sewage inputs from septic tanks.
Direction of travel	Uncertain progress 😐	Uncertain progress 😐

⇧⇧: WFD standards have been met post-implementation; ⇧: step-change shows improvement; ⇔: not significant (not signif.) step-change; ⇩: step-change shows deterioration. FIOs: Faecal Indicator Organisms; conc. concentration.

3.4 What are the benefits of the framework?

The weight of evidence method provided a quick, simple way of understanding and interpreting WFD data in the context of land management improvements, rural agricultural pressures, regional climate, and despite uncertainties due to monitoring.

The method relied on sound and open-access evidence from SEPA, Scottish Government, MetOffice, British Survey of Fertiliser Survey and EDINA Agcensus; robust statistical analyses; and expert judgement. This ensured transparency in interpreting change. It also has the potential to facilitate the implementation of the method in any catchment of interest.

The tiered approach developed here allowed consideration of all types of interactions, (i.e. conflicts, synergies) potential risks and opportunities for improvement through all the levels of the data framework for each pollutant in a semi-quantitative way. The method considers annual evidence on inputs of pollutants with land management and direction of change in inputs and rain. This bypasses the difficulties in modelling on a year-by-year basis to assess what magnitude of step-change in each catchment indicator alone is sufficient to bring about change in water quality and ecology. It also reduces the errors due to incomplete representations of pollutant losses in models .

Before-after comparisons showed that significant step-change in pollutants and ecology could not be detected with 80% or higher statistical power in any of the trial catchments; even if step-change in pollutants were significant it would still be difficult to interpret change in terms of the effectiveness of measures, unless it matched modelled reductions. The method, however, weighed pollutant data by their compliance, or not, with WFD and bathing water standards and with expected (modelled) change from national model assessments in the context of wider catchment evidence. This enabled a better understanding of whether water quality objectives have been achieved post-implementation as a result of the measures, or not and how this knowledge can underpin planning.

The framework also allowed for a meaningful comparison between modelled (i.e. expected) and observed step-change reductions in pollutants between before and after the introduction of the Diffuse Pollution Plan. Sample size analysis can help interpret failure to detect the expected improvements in pollutant concentrations. This is essential for planning monitoring and recovery time-scales.

Testing separately for significant step-changes in water quality and ecology enabled the progress of the Diffuse Pollution Plan to be interpreted independently of ecological time-lags, e.g. at the North Ugie Water for diatoms; and regardless of lack of physio-chemical standards, e.g. at the Lemno Burn and Eye Water, accounting for evidence from PSI (benthic invertebrates).

Discriminating between achieving compliance and detecting the expected reductions in pollutants has the potential to enhance confidence in WFD. SEPA uses ‘confidence’ statistics for all parameters involved in the classification to assess where there is > x% certainty that a physiochemical or chemical element is a cause of downgrading (Boyce n.d.). The weight-of-evidence method allowed for assigning a success story without requiring detection of modelled reductions in pollutants on the condition of synergies between DP GBR uptake and the other indicators of change. At the Lemno Burn, however, success has occurred in the context of conflicts between DP GBR uptake and the inputs of fertilisers, the area of erosion-risk crops, and rain, which all increased post-implementation. In view of such diffuse pollution risks, water quality and catchment monitoring is necessary until modelled reductions in pollutants are detected. This will help to understand how catchment change affects aquatic ecosystems, and, in the case of detecting the modelled change in pollutants in tandem with achieving good ecological status, will ensure delivery of WFD objectives.

3.5 What are the limitations of the framework?

A major limitation of the approach is the low number of samples currently available for the estimation of step-change in water quality, ecology and catchment indicators. Sample size analysis demonstrated the need for a much larger sample size than that currently available to detect significant change in pollutants, diatoms and benthic invertebrates with 80% or higher statistical power. Adjusting for flow removed the effects of runoff on pollutant concentrations but not the uncertainties due to small sample size. It must be also recognised that change in certain indicators (livestock, fertiliser inputs, area of erosion-risk crops) may be too small or fluctuating from year to year, needing a longer-term period to manifest a statistically significant change or influence water quality. Overall, these results translate into the **need for longer-term monitoring data before and after the introduction of measures**.

In the case of pollutants, a higher sampling frequency is also needed to capture naturally and man-made variability before and after launching the measures and to allow for the detection of change with adequate certainty. For the time being, it is difficult to collect baseline data collected with adequate frequency in the fourteen priority catchments of the first RBMP; but **it is feasible to keep monitoring post-implementation** and, in addition, **to establish an adequately monitored**[12] **baseline in the priority catchments to be taken forward for the next RBMPs**.

Developing and evaluating the weight-of-evidence method was based on levels of readily available evidence but more levels of evidence can be added from the priority catchment work to represent:

- Modelled inputs of pollutants from specific land uses in a catchment (i.e. source apportionment). For example, knowing relative percent of FIO inputs from sewage and livestock could help understand opportunities for reducing contamination of bathing waters.
- Uptake of each DP GBR separately, depending on pollutants of interest in each catchment.
- The role of advice delivery (i.e. the number of 1:1 farm visits per waterbody).
- The degree of farmer engagement (i.e. compliance with DP GBRs in repeat 1:1 visits).
- Supplementary measures taken forward for the 2014–2020 SRDP.
- The supplementary effect of the Ecological Focus Areas (specifically buffer strips and hedges) that have to be implemented under the new CAP greening requirements for the Basic Payment Scheme.

It must be recognised, however, that there are other rural non-agricultural factors with the potential to influence water quality. These include indicators of inputs from septic tanks and waste water treatments, forestry, and aquaculture; and indicators of the scale of processes involved in the transport of pollutants, e.g. catchment size.

In addition to nutrients and sediments, there are other biophysical and biogeochemical factors influencing ecological status, which, directly or indirectly, depend on land use but not strictly on pollutant change with land management and rain (Hamilton 2012). A growing body of evidence shows that the measures may be effective in reducing pollutants but not in achieving ecological targets in the foreseeable future (e.g. Jarvie *et al*. 2013 and literature cited there in). Benthic diatom habitats, for example, are affected by legacies of phosphorus (i.e. surplus of phosphorus from inputs past land use that is stored in soils or stream-bed); decoupling of diatom growth from phosphorus concentrations (e.g. because of variability in phosphorus bioavailability, grazing, light availability, change in nitrogen to phosphorus ratio, flow regime, riparian tree-cover, toxic substances); and functional changes (biomass, metabolism) altering the diatom community's resilience, i.e. its ability to recover from disturbance. **Accounting for biogeochemical and functional metrics for each group of biological indicators of water quality to assess effectiveness will improve understanding of ecological response to measures.**

A clear **scientific understanding** is key in justifying costly or targeted regulatory action. Yet, **developing indicators of public perceptions of 'meaningful' ecological metrics in a given catchment (e.g. presence of 'murky waters'; riparian landscape aesthetics) to assess effectiveness from a civic perspective is an option that merits further examination** (e.g. Jähnig *et al*. 2011)**.**

Finally, the resolution of the spatial data used for developing the indicator of SRDP uptake and the indicators of fertiliser use, and area of erosion-risk crops is an additional source of uncertainty, but not to the extent of confounding the detection of step-change. Using the IACS instead of the Edina Agcensus Database could easily improve the evidence from land use data.

3.6 The weight-of-evidence method in the context of effectiveness monitoring plans elsewhere

The weight-of-evidence method evaluated here prescribes the essential data needed to identify the direction of travel of the Rural Diffuse Pollution Plan and demonstrate its effectiveness (Figure 2a). It is recognised that the evidence required to assess effectiveness should be bespoke to the pressures and the objectives set for each waterbody to enable risks and uncertainties to be identified. For example, in catchments with sewage and forestry pressures, the framework of catchment data should involve evidence on loads from sewage disposal and forestry. Although the specifics of evidence may differ

[12] Recommendations on how to improve sampling design and implement a monitoring programme at a frequency fit for detecting change have been developed in a parallel CREW report (Akoumianaki *et al*. 2015).

from one waterbody to another, the basic steps to developing effectiveness monitoring plans should be common to all priority catchments regardless of RBMP cycle.

The weight-of-evidence approach developed here has adopted critically elements from the effectiveness monitoring plans implemented in the US (Figure 2b) and England (Figure 2c) to evaluate water quality improvements. In the US, effectiveness monitoring plans have been developed in tandem with the Total Maximum Daily Load (TDML) procedures, and US EPA's current strategic plan for the improvement of water quality (CFR-Water quality planning and management 2015). In England, the Environment Agency and Natural England have developed an extensive programme monitoring both the Catchment Sensitive Farming (CSF), an advice-led approach encouraging action from farmers to help deliver WFD objectives, and the observed changes resulting from CSF advice, support and incentives. The understanding accumulated from TDML monitoring and evaluation provides a valuable pool of evidence and examples on diffuse pollution mitigation on an international level. On the other hand, the CSF effectiveness monitoring programme provides a new paradigm of evaluating the effectiveness of measures to deliver WFD objectives.

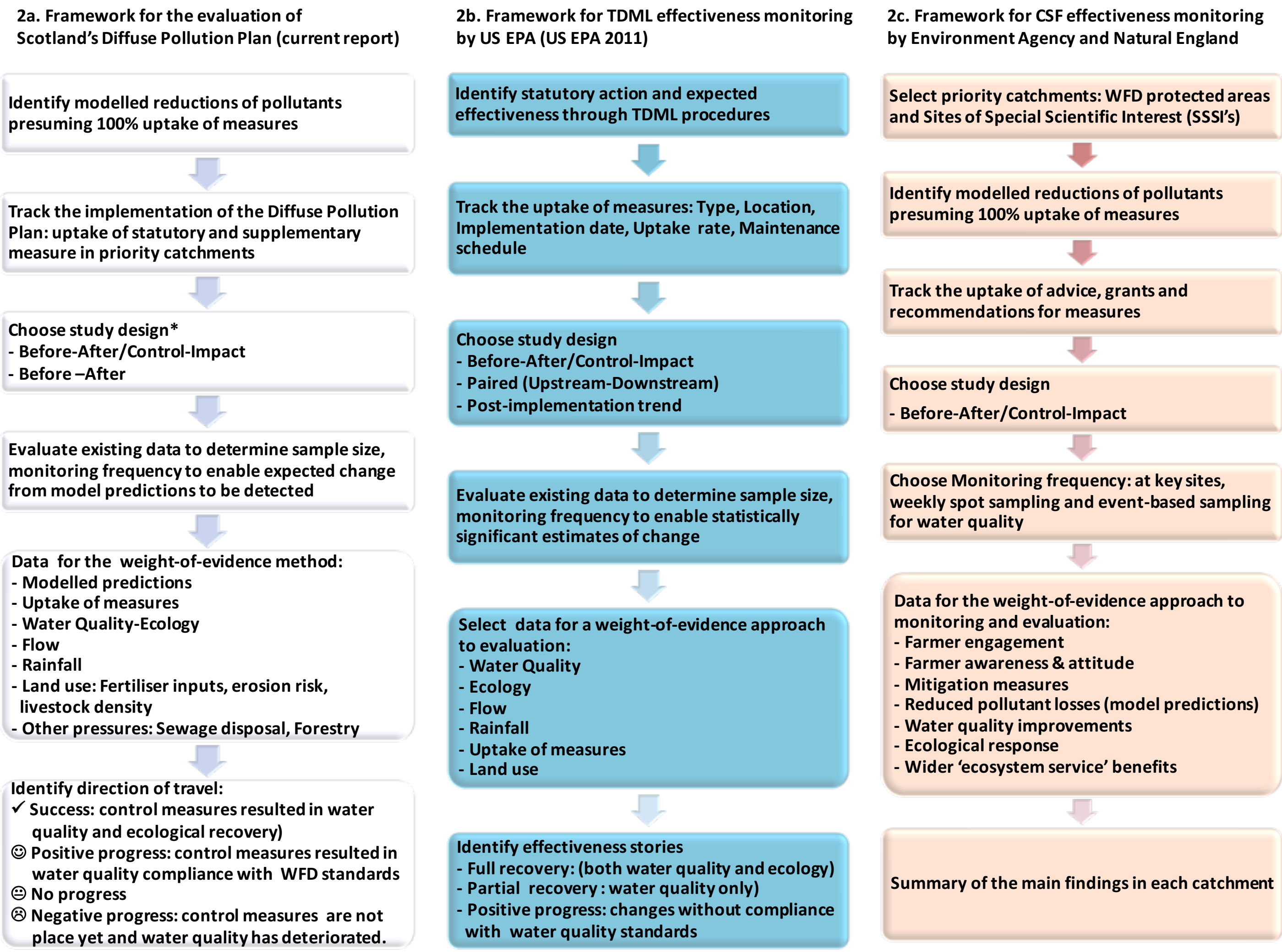
At this point, it is useful to compare and contrast the weight-of-method developed here with the TDML and the CSF effectiveness methods to show how two effective but different evaluation approaches were tailored to fit the objectives of the Diffuse Pollution Plan. The three effectiveness monitoring plans have several features in common (Figure 2). Firstly, they have embraced a catchment-based, weight-of-evidence approach to evaluating effectiveness. A second way in which they are similar is that they require enhanced water quality monitoring and Before-After comparison either with or without control catchments to enable change to be identified reliably. A parallel CREW report demonstrated that spot monthly monitoring and a before-after design (a variation of the typical BACI design) at a single catchment are insufficient to provide robust estimates of change in Scotland (Akoumianaki *et al*. 2015). Thirdly, they require a proper tracking system of the implementation of measures and delivery of advice and grants. Finally, they quantify gaps between observed and modelled reductions in pollutants to enable the failure to achieve expected effectiveness to be explained and tackled.

However, these plans are also different in many ways. For example, demonstrating TDML effectiveness is a statutory requirement although the uptake of measures (Best Management Practices, BMPs) is voluntary. As such, effectiveness monitoring informs classification of waterbodies. By contrast, in Scotland and England effectiveness monitoring is supplementary to WFD classification, which is the overarching statutory tool for assessing effectiveness and delivery of water quality objectives.

Another difference is in the criteria for demonstrating effectiveness. For example in the US, water quality improvements can be demonstrated in three ways: as a removal of diffuse pollution sources in at least 40% of the waterbody area; as a statistically significant improvement with a 90% or greater level of confidence in one or more water quality parameters; or as a catchment-wide improvement assessed using statistically robust estimates of change (US EPA 2011). On the other hand, the CSF effectiveness monitoring has not clearly identified criteria to demonstrate effectiveness; any action with the potential to improve water quality and any statistically significant improvement is considered as progress towards achieving CSF objectives.

Finally, while the CSF approach provides a narrative of the combined evidence, the method for assessing the effectiveness of the Diffuse Pollution Plan and the TDML effectiveness monitoring plan provide both a narrative and typology of catchments with regard to response to measures. For example in the US, agricultural waterbodies are separated into three categories of **effectiveness stories**, depending on the type of water quality improvement achieved (US EPA 2015). Stories about fully restored waterbodies, include waterbody meeting all water quality standards or designated uses (e.g. drinking and bathing water, aquatic life support). Stories about partially restored waterbodies, include waterbodies that meets some, but not all, of the water quality standards or designated uses. Stories that show progress toward achieving water quality goals include waterbodies that have achieved measurable, in-stream reduction in a pollutant or ecology (e.g. diatoms, invertebrates). This typology is similar to the output of our weight-of-evidence method but it is unable to provide an evaluation of whether modelled reductions have been achieved, or not, and why.

To sum up, the weight-of evidence method developed here to monitor and evaluate the effectiveness of the Diffuse Pollution Plan is a fit-for-purpose effectiveness monitoring plan that has tailored best international practice to the Scottish context.



*Monitoring recommendations are developed and explained in a parallel CREW report by Akoumianaki et al. (2015).

Figure 2 Comparative presentation of effectiveness monitoring plans using a weight-of evidence approach: 2a. Framework for the monitoring and evaluation of Scotland's Rural Diffuse Pollution Plan developed in this report. 2b. Framework for the TDML effectiveness monitoring plan implemented by US EPA. 2c. Framework for the CSF effectiveness monitoring plan implemented by the Environment Agency and Natural England.

4 Recommendations

The weight-of-evidence method developed here is a useful tool in assessing the effectiveness of the Rural Diffuse Pollution Plan. Certain evidence gaps and uncertainties, however, need to be tackled to improve understanding of catchment response to measures. CREW reviewed approaches for the evaluation of restoration projects and the effectiveness of diffuse pollution mitigation measures to develop recommendations on what needs to be done to enhance the weight of evidence method.

The weight-of-evidence method developed here can be further improved by:

- Planning for long-term water quality, ecology and catchment monitoring post-implementation (i.e. longer than four years) using current SEPA's routine spot sampling.
- Adding data from longer than four years of baseline monitoring for pollutants, diatoms and ivertebrates, where possible.
- Carrying out enhanced pollutant and ecological monitoring, where the framework has indicated uncertain progress. The BACI design with more than four years of pre and post-implementation monitoring should be applied to analyse the effect (impact) of measures on water quality and to account for background and site-specific variation. Monitoring recommendations have been described in a parallel CREW report (Akoumianaki *et al*. 2016).
- Using taxonomic metrics (such as DARES and PSI) in combination with flow measurements before and during ecological sampling
- Developing additional indicators for ecological response to water quality improvements such as functional metrics (e.g. biomass; functional groups) and additional habitat evidence (e.g. riparian tree-cover; river morphology).
- Using IACS database to assess change in land management indicators (e.g. fertiliser use, area at risk from erosion).
- Using field scale data to assess SRDP uptake.
- Using the numbers of farms implementing specific SRDP options or the area (in hectares) with SRDP measures in place within each waterbody instead of SRDP spend per waterbody.
- Accounting for source apportionment of pollutants to help understand opportunities for targeting action in the context of risks and synergies between DP GBRs and catchment indicators and in order to assess change in loads from septic tanks, sewage treatment works, and forestry.
- Treating each DP GBR separately to address tackling sources of each pollutant specifically.
- Adding data on advice delivery (i.e. the number of 1:1 farm visits per waterbody).
- Factoring in farmer engagement (i.e. percent compliance with DP GBRs in repeat 1:1 visits).
- Monitoring degree of uptake of all options taken forward for the 2014-2020 SRDP.
- Accounting for the supplementary effect of the Ecological Focus Areas (specifically buffer strips and hedges) that have to be implemented under the new CAP greening requirements for the Basic Payment Scheme.
- Exploring supplementary metrics to assess ecological response (e.g. algal biomass, public perceptions of ecological recovery, combine response from different biological communities) and considering additional evidence (e.g. riparian tree-cover, alkalinity, river restoration work).
- Developing indicators for other rural, non-agricultural, effects on both water quality and ecology, such as inputs from septic tanks and waste water treatment works; forestry, aquaculture; and catchment size.
- Re-evaluating catchments assessed as "Success story" and "Uncertain" on the basis of the magnitude of step-change after longer-term data become available.

5 Conclusions

This report evaluated the ability of a framework combining available water quality and catchment evidence to assess the effectiveness of DP GBRs in delivering expected changes and WFD objectives. It described the methods for collecting evidence of change in the major factors influencing water quality in rural areas and provided criteria for interpreting water quality in the context of catchment data. The report also analysed the gaps between modelled and observed reductions to inform whether, where and why expected improvements have not been achieved.

To sum up, the method:

- Collects and combines ten levels of evidence to assess the effectiveness of measures in reducing diffuse pollution pressures. These levels comprise estimates of change from: modelled outputs and evidence from water quality and ecology data; indicators of land management (DP GBR uptake, SRDP uptake, inputs from phosphate and nitrogen fertilisers, area of crops at risk from erosion, total livestock density, and grazing livestock density); and regional rain. Box 3 summarises the challenges tackled by the weight-of-evidence method.
- Evaluates effectiveness of measures at **appropriate spatial scales**.
- Compares water quality, ecology, land management practices and rural pressures between pre- and post-implementation (**step-change**) of the Diffuse Pollution Plan.
- Identifies the progress of the Diffuse Pollution Plan in reducing pollutants in a catchment context **in addition to WFD classification,** and expected effectiveness.
- Accounts for **biophysical risks and opportunities for improvement** by combining levels of evidence from the major factors influencing water quality in rural areas.
- Informs where compliance with pollutant WFD standards has resulted from **improvements in sewage treatment works or other practices** preceding the launching of measures as in the case of ammonium compliance with WFD standard.
- Specifies **where and whether the expected reductions** resulting in 100% DP GBR have not been met because of uncertainties (i.e. lack of sufficient baseline data, change too small to be detected with current monitoring of the data comprising the framework) or conflicts between the effects of measures and diffuse pollution pressures.
- Classifies response to measures on a **catchment- and pollutant-specific basis**.
- Provides a typology of four categories of catchment response:
- **Success story,** shown by (i) agreement of both pollutant and ecological monitoring data with WFD standards; (ii) agreement of pollutant reductions with the magnitude of model predicted reductions; (iii) significant step-change in ecological data and (iv) sufficient DP GBR uptake.
  1. **Positive progress**, shown by (i) agreement of pollutants with WFD standards but lack of agreement in ecological data; (ii) significant step change in pollutants but lower than that predicted by the model; and (iii) sufficient DP GBR uptake.
  2. **Uncertain progress,** shown by failure to show agreement with WFD standards and failure to detect significant step-change in pollutant and ecological data, regardless of degree of DP GBR uptake.
  3. **Negative progress,** shown by an increase in pollutant concentrations and possibly deterioration or no improvement of biological communities and insufficient DP GBR uptake.

Evaluation will remain a core element of the Rural Diffuse Pollution Plan. The framework for the interpretation of catchment data with the weight-of-evidence method developed here provides a simple, robust and transparent way of identifying the progress of the Diffuse Pollution Plan. As such it is a useful tool for communicating the time-scales needed for water quality improvement with stakeholders. The method developed here will help to evaluate all stages from the monitoring of water quality and ecology to the monitoring of land management and rural pressures, and to assessing catchment-wide response and the need for further action.

BOX 3 Challenges facing the implementation and effectiveness of the Rural Diffuse Plan and evidence needed for the weight-of-evidence evaluation

Rural Diffuse Pollution Plan challenges	Evidence/analyses needed for the weight-of-evidence evaluation	Feasibility
Has water quality improved (yes/no)?	Pollutant and ecological monitoring data	Yes
Are the measures in place?	Data from priority catchment inspections and SRDP	Yes
Are the measures technically suitable and effectively implemented?	Data on the implementation/targeting of each measure separately	Not yet
When will the measures deliver improvements (in pollutant reductions)?	Sample size analysis on pollutant data	Yes. Longer-term data are required to understand recovery time lags.
Why are expected improvements not being observed?	1 Catchment data on pressures/risks 2 Sample size analysis on pollutant data*	Yes. Longer-term data are required to understand ecological time lags.
Can we separate the effects of measures from land use change and other rural pressures?	Indicators assessing the uptake of measures, fertilizer inputs, erosion risk, livestock density and rainfall	Yes
How effective has awareness raising been?	Awareness and farm visit data	Not yet

*A parallel CREW report (Akoumianaki *et al*. 2015) has developed monitoring recommendations to enable modelled reductions in pollutants to be detected with adequate certainty.

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Appendices

Appendix 1 The source-pathway-receptor model for each pollutant

Diffuse pollutants	Source	Pathway	Receptor	WFD quality elements	
	Land use/management	Rain-Runoff	Waterbody type	Water quality	Ecology
Phosphorus (P)	• Fertilisers • High risk crops • Septic tanks	Surface runoff	Rivers	Dissolved P	Benthic diatoms
			Lochs	Total P	• Macrophytes • Diatoms
Nitrogen (N)	• Fertilisers • Total livestock • Erosion risk crops • Septic tanks	Surface runoff	Rivers	Ammonium (NH_4^+)	Benthic invertebrates
			Estuaries	DIN	DIN
	• Fertilisers • Livestock density • Septic tanks	Subsurface runoff	Groundwater	Nitrates (NO_3^-)	Nitrates (NO_3^-)
Plant Protection Products (PPPs)**	• Erosion risk crops • PPP application	Surface runoff	• Rivers • Lochs • Protected areas*	Particulate PPPs	Benthic invertebrates
	Pesticide application	Subsurface runoff	Groundwater	Dissolved PPPs	Not relevant
Sediments	• Erosion risk crops • Livestock density	Surface runoff	• Rivers • Lochs • Protected areas*	Sediments and associated pollutants	Benthos sensitive to siltation (provisional)
Faecal Indicator Organisms (FIOs)	• Livestock • Septic tanks	Surface/subsurface runoff	Protected areas*	• Coliforms • Streptococci	Not relevant

DIN: Dissolved Inorganic Nitrogen

*Protected areas: Bathing, drinking, and shellfish waters

**PPP application is not part of this report

Appendix 2 Peer-reviewed and grey literature on the uses of the weight-of evidence concept in environmental risk assessments and restoration projects

Appendix 2a Aim of W-o-e: Enhance certainty of assessments with additional data (eg indicators, expert judgement, extra-WFD classification)

Approaches	Examples
Explicit (semi-) quantitative weighting and ranking schemes to interpret combined evidence about an impact by • Scoring strength of evidence (e.g. positive vs negative, increasing versus decreasing) from indicators of impact based on statistical tests and/or expert judgement • Ranking certainty of impacts or magnitude of response	• Eutrophication impact maps for 2nd cycle River Basin Plans in England: Environment Agency 2015 with scoring system detailed in Pitt *et al*. 2015. • Ecological risk assessment (ERA) and sediment contamination in rivers, lakes and estuaries: Smith, Lipkovich & Ye 2002; Thompson & Low 2004. • Environmental assessments: Suter & Cormier 2011; Rusyn *et al*. 2015.
Qualitative estimation of probability of impact by • Relevance: degree of evidence making an impact more or less probable • Reliability: degree of evidence making inferences about impacts possible • Sufficiency: the threshold "weight" of the evidence needed for causal inferences • Levels of evidence needed for inferences	• A framework for screening scientific evidence before it is presented for evaluation to non-experts: Weed 2005 and reference 91 cited therein. • Review of qualitative frameworks in environmental risk assessment: Linkov *et al*. 2009 and references by Chapman *et al*. cited therein; Suter & Cormier 2002.

Appendix 2b Aim of W-o-e: Assess the methods for generating and interpreting data

Approach: Weighing methods (e.g. indicators, approaches) for summarizing and interpreting scientific evidence based on the following approaches, or their combination	Examples
• Systematic literature review of to make research recommendations, claims about causality (or risk), preventive recommendations • Quality or causal criteria for reliability and relevance of each method to enhance certainty	• Identifying ecological indicators of the effects of abstraction and flow regulation: Bradley, Cadman & Milner 2012. • Assessing contaminated land: Weeks *et al*. 2004. .

Appendix 2c Aim of W-o-e: Assess catchment or ecosystem response to cumulative effects (e.g. restoration projects, evaluation of diffuse pollution mitigation measures)

Approaches	Examples
Summary interpretations of all available evidence from all different factors influencing a system (catchment, ecosystem)	• Evaluation of Catchment Sensitive Farming Initiative in England: CSF Team 2014. • Diffuse pollution mitigation in the UK: McGonigle *et al*. 2012. • Evaluation of ecosystem restoration : Johnson *et al*. 2012. • Monitoring effectiveness of the Total Maximum Daily Loads plans: US EPA 2011.

Step change and trend: The change between the 'before' and 'after' periods was assessed by fitting a regression model with a dummy variable for the two periods. If the p-value for the t-test on the slope of this dummy variable is <0.05 then this indicates a significant change. Trends were similarly assessed by fitting a regression model with the date (effectively the number of days from some starting point) as an explanatory variable. For the chemical data adjustment for seasonal effects was carried out by adding a harmonic cycle to the regression model. This was done by calculating $\sin(2\pi \times \text{day of year}/365)$ and $\cos(2\pi \times \text{day of year}/365)$ and including both terms in the regression model For the ecological data the adjustment for seasonal effects was made by simply adding a dummy variable in the regression for spring/autumn. Where flow at the time of sampling was available this was also included as a covariate in the regression model (flow adjustment). The chemical data are highly skewed and as an assumption of regression is that the data are normally distributed, the data were transformed by taking natural logarithms prior to the regression analyses. Without this transformation the results would be strongly influenced by a small number of outliers. If a change of $-d$ is found in the log transformed data, this corresponds to a percentage decrease of $100\times(1-e^{-d})\%$.

Sample size analysis: The sample size that would be required to have an 80% probability of being able to detect a given percentage change (80% power), assuming equal sample sizes 'before' and 'after' the introduction of measures, was found using standard statistical software for calculating the power of a t-test. It was assumed that the variance in both periods was equal to the residual variance from the model with seasonal or seasonal and flow adjustment. Flow adjustment will generally decrease the residual variance and therefore mean that fewer samples are required to detect a given change than without flow adjustment. It should be noted that if there are fewer samples in the 'before' period than in the 'after' period (which is likely to be the case since 'before' samples cannot be collected retrospectively) then even larger sample sizes would be required than those calculated. The magnitude of change that could be detected with 80% power given the 'before' and 'after' sample sizes that are currently available was also calculated. These calculations were also based on the assumption that there is no temporal autocorrelation between one sample and the next. The more frequent the sampling, the greater the autocorrelation. So, for example, a greater number of weekly samples than monthly samples would be needed to detect a given change.

Change-point analysis: Monthly spot samples were analysed by AutoRegressive Moving Average models, whose autoregressive order was p and moving average order was q, ie ARMA(p,q). A periodic component was also added to the model: it was described by a single harmonic component. Models were applied within the Bayesian paradigm and non-informative priors were set. The analyses of the time-series were performed along three consecutive steps:

1 model choice;
2 model fitting and residual computation;
3 change-point detection within the residuals Analyses at points [1] and [2] were performed by using Fortran codes written by Luigi Spezia; analyses at point [3] were performed by using the package "cpm" (Ross, 2013) within R (R Core Team, 2013).

Appendix 3b Methods of transforming land use data into indicators of fertiliser inputs, erosion risk crops, and total and grazing livestock density.

All the spatial analyses have been made by ESRI ArcGIS 101 using the Spatial Analyst toolbar. The analyses included the following **steps**:

Step 1 Production of the raster layers from csv tables at 2000 m resolution
Step 2 Each type of crop (crop layer) was downscaled to the Arable class present in the LCM 07
Step 3 Each type of grassland (grassland layer) was downscaled to the Improved grassland class present in LCM 07
Step 4 Each type of livestock (livestock layer) was downscaled to the corresponding Land use class of LCM 07 (e.g. Cattle to the Improved grassland, sheep to the Semi-natural grassland)
Step 5 Due to inconsistency between the LCM 07 and the data downloaded from Edina, the crops statistic was then normalized with the total sum of the Arable area calculated in the catchment
Step 6 A series of ZonalSum for each crop for each year were performed to obtain the total quantity of crops present inside each waterbody
Step 7 All data (crop, grassland, livestock) were sampled together in a dbf table and exported
Step 8 From the BSFA reports downloaded from the https://wwwgovuk/government/collections/fertiliser-usage portal the Total Fertilizer in kg/ha across all the period (2007–2013) was downloaded and inserted in a new spreadsheet; the application rate multiplied by the ha of each crop in the sub-catchment provides the total amount of fertilizer input per year
Likewise, we reclassified the LCM 07 into two new different raster layers for the presence/absence (1 and 0) of the two main land use (arable and improved grassland). Lastly, we created a fishnet vector layer based on any of the livestock/crops raster of 2x2km squares, used to count the number of the land use associated with livestock, arable land and grassland contained in each square by the Zonal Statistic spatial tool, as summarized in the Model Builder ArcGis tool below.

Step 1: The LCM 07 has been reclassified on the basis of the presence/absence of each type of animals in the land use class with 0 as absence and 1 as presence, as shown here:

Class number	Land use class	Cattle	Pig and poultry	Sheep and goat
1	Broadleaved woodland	0	0	0
2	Conifer woodland	0	0	0
3	Arable	0	0	0
4	Improved grassland	1	0	1
5	Rough grassland	0	1	1
6	Neutral grassland	1	0	1
7	Calcareous grassland	1	0	1
8	Acid grassland	0	0	1
9	Fen, Marsh and Swamp	0	0	0
10	Heather	0	0	1
11	Heather grassland	0	0	1
12	Bog	0	0	1
13	Montane habitats	0	0	0
14	Inland rock	0	0	0
15	Saltwater	0	0	0
16	Freshwater	0	0	0
17	Supra-littoral rock	0	0	0
18	Supra-littoral sediment	0	0	0
19	Littoral rock	0	0	0
20	Littoral sediment	0	0	0
21	Saltmarsh	0	0	1
22	Urban	0	0	0
23	Suburban	0	0	0

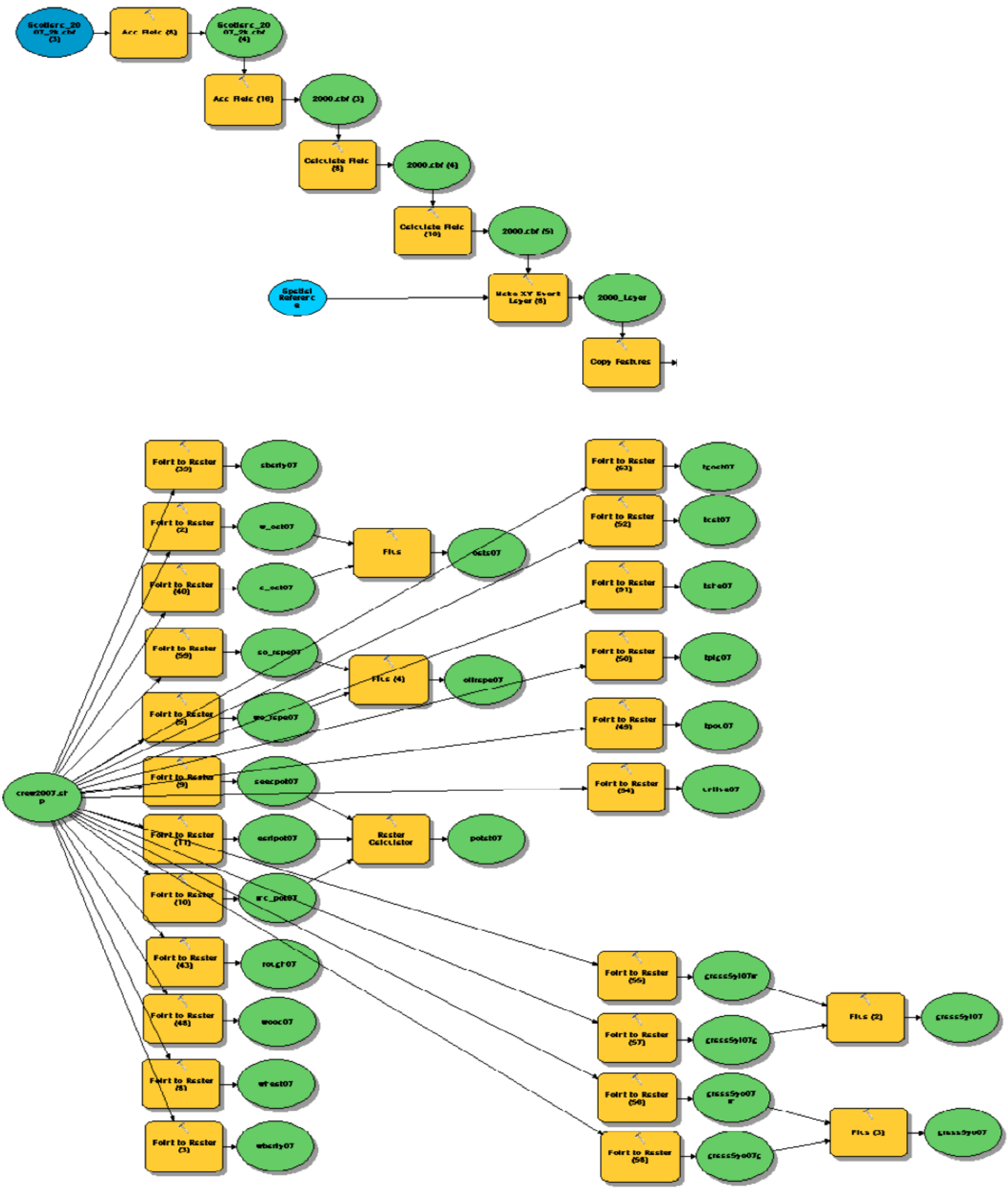
Lastly, we created a fishnet vector layer based on any of the livestock/crops raster of 2x2km squares to account for the area (and therefore land use)associated with livestock, arable land and grassland contained in each square by the Zonal Statistic spatial tool, as summarized in the Model Builder ArcGis tool below.

Step 2: Each Edina csv table was exported in dbf tables, in which we created two different columns for the X and Y coordinate correction X_corr = X + 1000 and Y_corr = Y + 1000 to shift all the 2km squares in the right place snapped to the British National Grid. Next, each field attribute was used to produce a point feature file and the raster layers of interest. Some of the crops were grouped together to match the fertiliser use per crop data as in the British Survey of Fertiliser Practice reports. Furthermore, not all the attribute data was taken into account but only land uses with a potential to influence diffuse pollution pressures, as shown below:

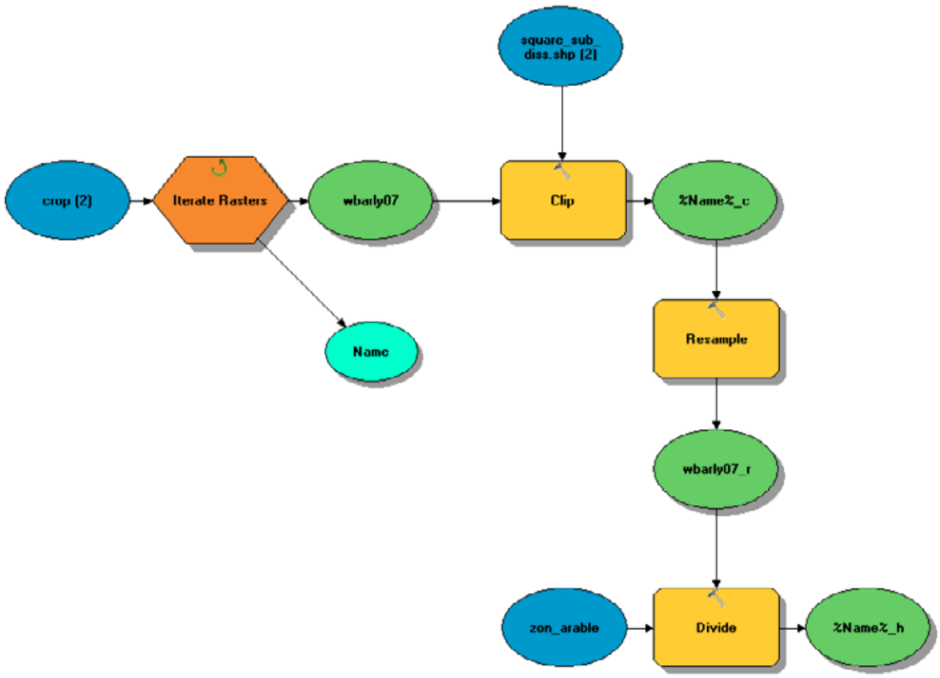
Type	Layer considered
Grassland	Grass 5yr older mowing
	Grass 5yr younger mowing
	Grass 5yr older grazing
	Grass 5yr younger grazing
Animals	Total cattle
	Total sheep
	Total pigs
	Total poultry
	Total goats

Type	Layer considered
Crops	Spring barley
	Winter oat
	Spring oat
	Winter oil rape
	Sping oil rape
	Seed potato
	Early potato
	Main crops potatos
	Rough grassland
	Woodland
	Winter heat
	Winter barley

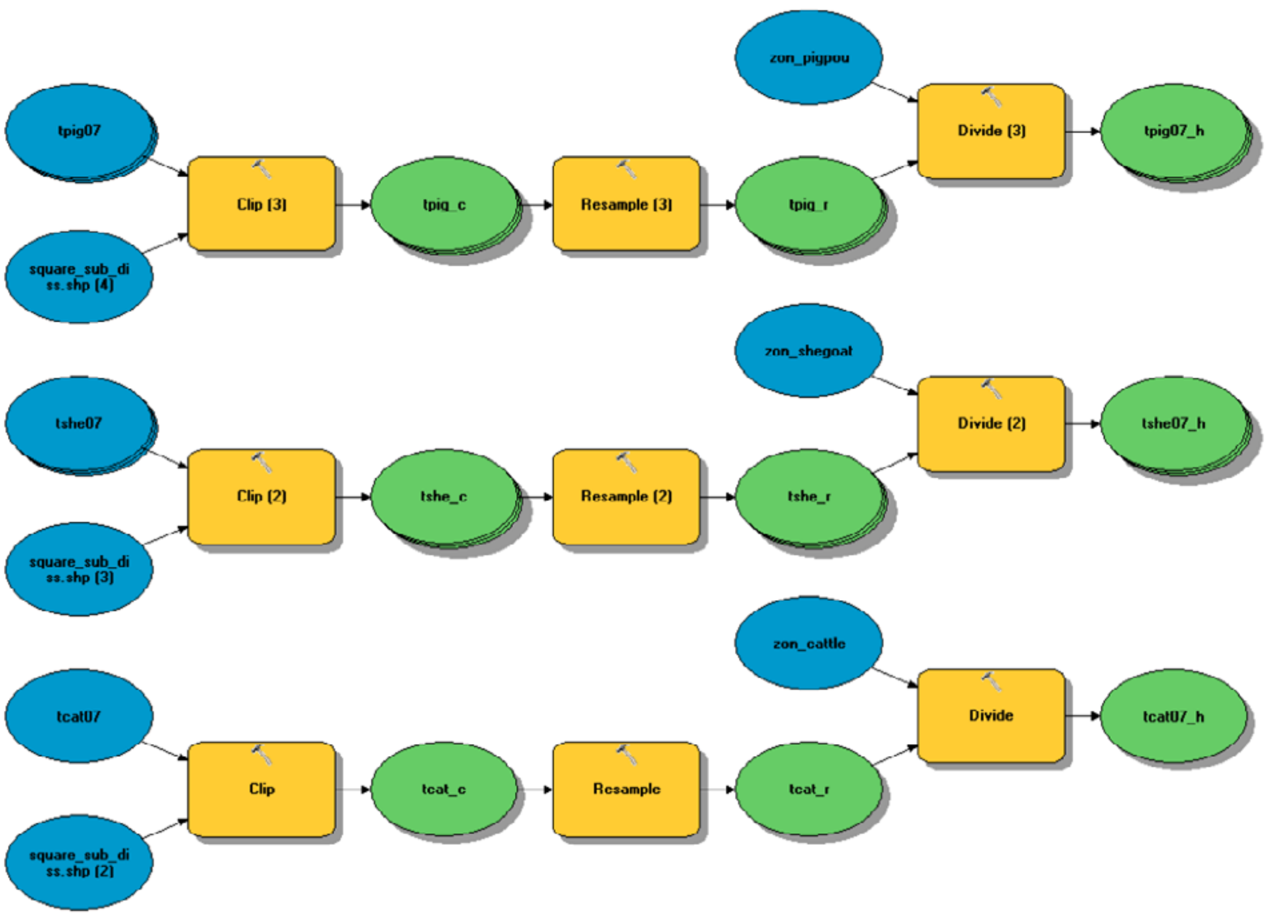
Step 2 is summarised in the Model Builder ArcGIS tool below.



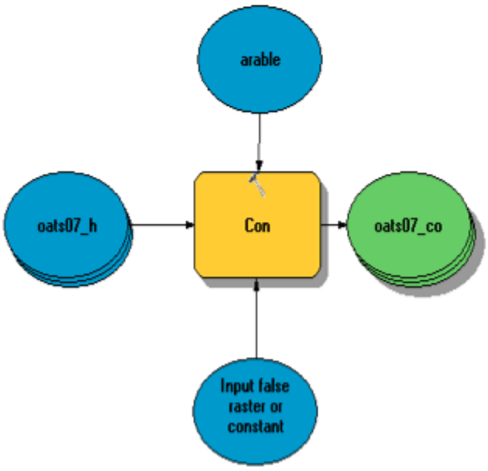
Step 3: We produced a mask of the waterbody area from the fishnet to select the squares intersecting the waterbodies of interest and clip all the crops, livestock and grassland raster layers. Each crop layer was first resampled at 25m resolution and then divided by the ZonalSum of the amount of arable pixels in each 2km square. An iterator across the folder containing all the crops raster layers (folder name = Crop) was used. Each result from this process could be used just for the next step and not for other analysis, as a result of the inconsistency between the Edina and the LCM07 dataset making it likely for each crop's pixel to be larger than the total sum of the effective area of the pixel Step 3 is summarised in the Model Builder ArcGIS tool shown below.

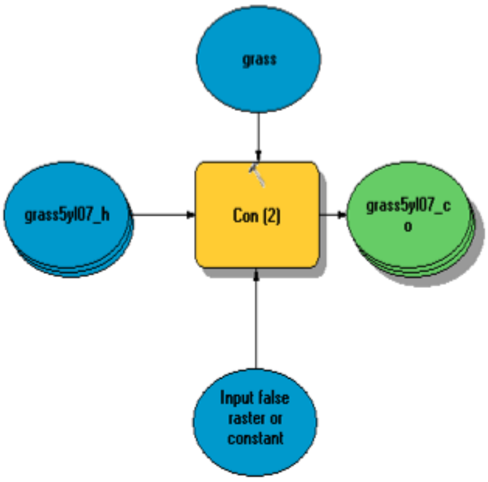


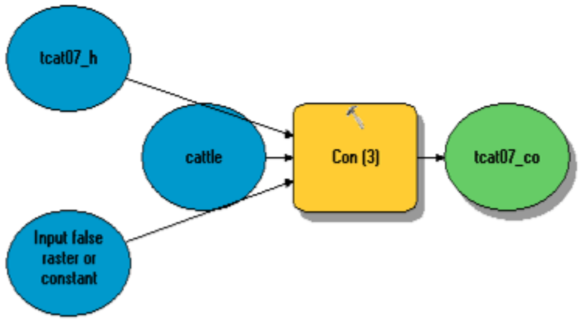
Step 4: Each livestock layer was first resampled at 25m resolution and then divided by the count of how many ha of land use class could be suitable for that animal in line with the LCM 07 reclassification shown in Step 1. For example, cattle was placed in the *Improved grassland*, *Calcareous grassland and Neutral grassland* so after the classification in 1 and 0 and the ZonalSum in each square, the real number of the animals was divided by the ZonalSum in order to obtain the number of animals in each 25m pixel of the LCM 07. Step 4 is summarised in the Model Builder ArcGIS tool shown below.

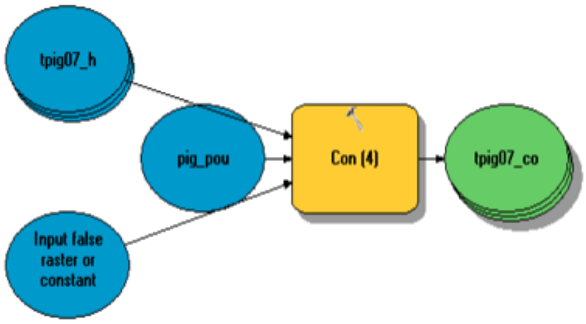


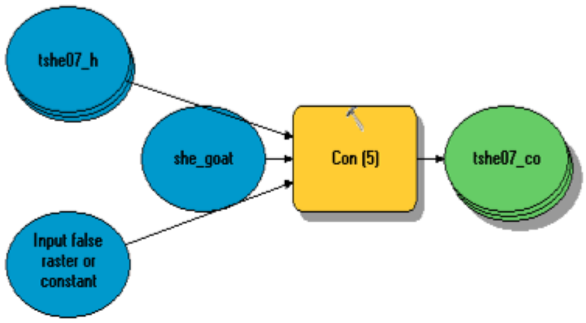
Step 5: We normalised the Edina-based value of the crops, grassland and livestock divided by the number of area present in each 2km resolution square by using a conditional statement tool where the new value is placed where just the value 1 is present (0 = absence) in the LCM 07 reclassification tables. This process is summarized below in a cluster of model builder modules which loop across all the layers that are contained in a particular folder divided by (animals, crops and grassland).



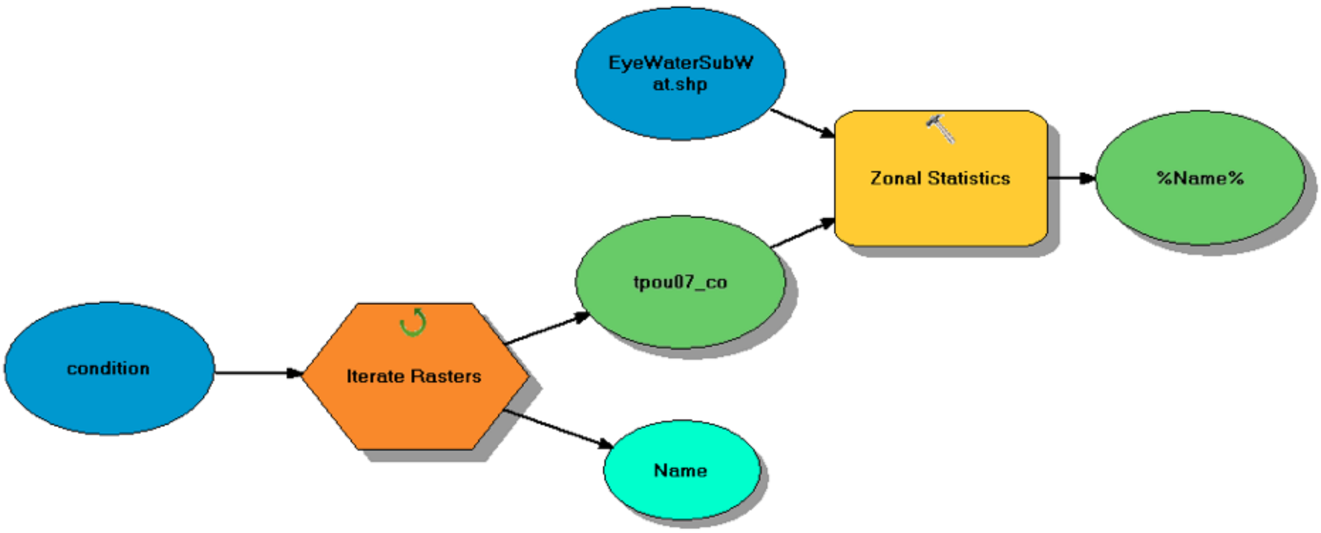




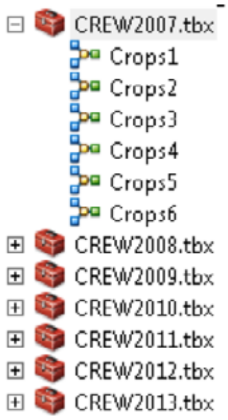


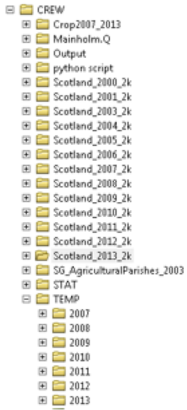


Step 6: Once the data have been spread in the LCM 07, we counted the total amount of ha per crop type and the numbers of livestock inside each water body by a ZonalSum which takes into account as zone the waterbody feature layer and as input value all the raster layers already produced. These processes have been looped (iterate raster tool) on the condition folder where the raster layers have been stored, as shown below, to maintain the consistency of the file name between a series of different spatial operations.

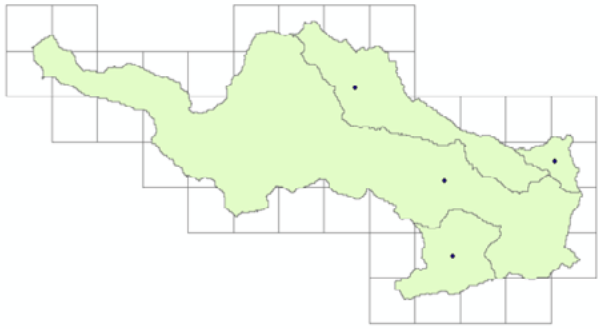


Step 7: We created a new Toolbox for each year where all the different 6 steps already described are present and each model referring to the output files is named in 6 different folders by year to simplify the process.

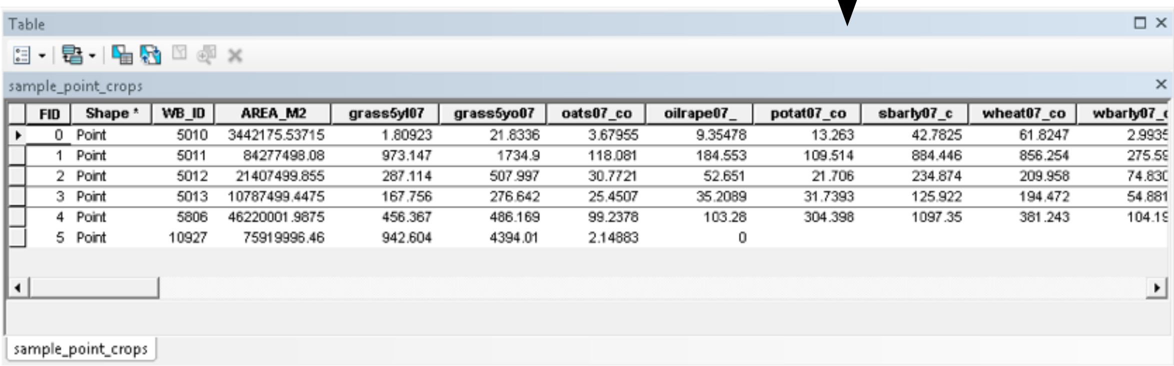




Once all the modules have run, a point vector feature has been created in the centroid of the waterbody to sample all the output raster files produced by the Extract Multi Value to Point tool (spatial analyst ArcGIS package).



The resulting file is an attribute table containing all the livestock, crops and grassland data per waterbody. The table was then exported in dbf to be suitable in Excel environment.



Table

sample_point_crops

FID	Shape *	WB_ID	AREA_M2	grass5yl07	grass5yo07	oats07_co	oilrape07_	potat07_co	sbarly07_c	wheat07_co	wbarly07_
0	Point	5010	3442175.53715	1.80923	21.8336	3.67955	9.35478	13.263	42.7825	61.8247	2.9935
1	Point	5011	84277498.08	973.147	1734.9	118.081	184.553	109.514	884.446	856.254	275.59
2	Point	5012	21407499.855	287.114	507.997	30.7721	52.651	21.706	234.874	209.958	74.830
3	Point	5013	10787499.4475	167.756	276.642	25.4507	35.2089	31.7393	125.922	194.472	54.881
4	Point	5806	46220001.9875	456.367	486.169	99.2378	103.28	304.398	1097.35	381.243	104.19
5	Point	10927	75919996.46	942.604	4394.01	2.14883	0				

sample_point_crops

Step 8: We normalised values based on the sum of the arable and the sum of the grassland to tackle the discrepancies between the Edina and LCM 07 datasets, especially with regard to the areas dedicated for grassland and arable, as well between the Edina data and the crop data considered in the BSFA reports. The total crops to arable land was calculated to help estimate the area of each crop corresponding to the total arable land, shown below. This approach was used for grassland, too but was unnecessary for livestock as the data was derived from the spatial analysis made in ArcGIS.

16	WB_ID	5010	5011	5012	5013	5806	10927	23221	WB_ID	5010
17	AREA_M2	3442176	84277498	21407500	10787499	46220002	75919996	51335000	AREA_M3	63595092
18	TOT_ARABLE(ha)	251	4797	893	726	2983	595	2199	TOT_ARABLE(ha)	0
19	TOT_GRASS(ha)	26	1506	380	223	1057	5678	1837	TOT_GRASS(ha)	0
20	grass5yl07	1.81	973.15	287.11	167.76	456.37	942.60	750.40	grass5yl07	1.81
21	grass5yo07	21.83	1734.90	508.00	276.64	486.17	4394.01	1040.42	grass5yo07	21.83
22	oats07_co	3.68	118.08	30.77	25.45	99.24	2.15	54.86	oats07_co	3.68
23	oilrape07_	9.35	184.55	52.65	35.21	103.28	0.00	269.46	oilrape07_	9.35
24	potat07_co	13.26	109.51	21.71	31.74	304.40	0.30	28.88	potat07_co	13.26
25	sbarly07_c	42.78	884.45	234.87	125.92	1097.35	356.56	861.23	sbarly07_c	42.78
26	wheat07_co	61.82	856.25	209.96	194.47	381.24	25.41	209.87	wheat07_co	61.82
27	wbarly07_c	2.99	275.60	74.83	54.88	104.20	34.45	403.70	wbarly07_c	2.99
28	ARABLE	**152.74**	**3887.75**	**1057.96**	**689.43**	**2471.68**	**4778.42**	**2464.72**	ARABLE	**1.65**
29	GRASS	**23.64**	**2708.05**	**795.11**	**444.40**	**942.54**	**5336.61**	**1790.82**	GRASS	**1.12**
30	grass5yl08	1.79	987.30	295.20	167.91	447.12	979.33	667.05	grass5yl08	1.95
31	grass5yo08	22.49	1637.71	483.96	264.09	437.03	4009.10	1010.80	grass5yo08	24.49
32	oats08_co	4.57	148.40	38.71	14.35	61.80	0.27	52.74	oats08_co	4.57
33	oilrape08_	8.65	184.56	48.96	42.91	110.74	0.00	226.16	oilrape08_	8.65
34	potat08_co	9.96	87.09	17.08	28.19	352.94	0.31	41.70	potat08_co	9.96
35	sbarly08_c	51.97	1104.38	294.34	155.09	1271.30	429.95	995.93	sbarly08_c	51.97
36	wbarly08_c	4.68	325.51	84.84	57.63	136.72	48.51	446.13	wbarly08_c	4.68
37	wheat08_co	70.51	982.70	241.00	230.81	378.90	56.48	228.69	wheat08_co	70.51
38	ARABLE	**102.32**	**3487.65**	**967.88**	**562.27**	**2370.51**	**4488.15**	**2773.46**	ARABLE	**2.46**
39	GRASS	**24.29**	**2625.01**	**779.16**	**432.00**	**884.14**	**4988.43**	**1677.85**	GRASS	**1.09**
40	grass5yl09	5.99	1239.60	375.76	215.31	512.80	1296.42	1319.81	grass5yl09	6.46
41	grass5yo09	18.54	1619.99	489.57	264.60	373.95	4040.52	661.52	grass5yo09	19.98
42	oats09_co	5.40	122.78	30.39	12.80	67.88	0.00	83.18	oats09_co	10.07
43	oilrape09_	3.59	89.30	23.96	17.97	118.89	0.00	254.21	oilrape09_	6.68
44	potat09_co	0.00	2.86	0.00	0.10	200.52	0.00	20.33	potat09_co	0.00
45	sbarly09_c	58.79	1209.11	317.72	197.20	1362.53	411.45	948.12	sbarly09_c	109.54
46	wbarly09_c	18.09	371.78	92.66	80.90	109.86	11.64	390.29	wbarly09_c	33.70
47	wheat09_co	49.01	741.28	192.04	150.52	337.33	28.04	194.93	wheat09_co	91.32
48	ARABLE	**134.87**	**2537.10**	**656.77**	**459.48**	**2197.01**	**451.13**	**1891.04**	ARABLE	**1.86**
49	GRASS	**24.54**	**2859.59**	**865.33**	**479.90**	**886.75**	**5336.94**	**1981.33**	GRASS	**1.08**

Following normalisation data were exported in a new spreadsheet where all the data were combined with the corresponding fertilizer rate associated, as shown below.

					WATER_BODIES						
	WB_ID	5010	5011	5012	5013	5806	10927	23221			
	AREA_M3	63595092	69015662	74436233	79856803	85277374	90697944	96118514			
	TOT_ARABLE(ha)	251.3125	4797.375	893.0625	726.3125	2983.375	595.3125	2198.9375	N_fertilizer_kg/ha		
	TOT_GRASS(ha)	26.4375	1506.125	380.0625	223.1875	1056.5625	5677.75	1836.9375	N	P2O5	K2O
	Grass less than five years olc	1.80923	541.23175	137.24029	84.251149	456.367	942.604	750.4	110	34	45
	Grass five years and over	21.8336	964.89325	242.82221	138.93635	486.169	4394.01	1040.42	85	27	29
2	Oats	3.67955	118.081	25.975895	25.4507	99.2378	0.267709	48.944284	107	58	79
0	Winter oilseed rape	9.35478	184.553	44.444703	35.2089	103.28	0	240.40244	182	63	76
0	Potatoes	13.263	109.514	10.322057	31.7393	304.390	0.0369219	25.762216	126	120	202
7	Spring barley	42.7825	884.446	198.26604	125.922	1097.35	44.421038	768.35835	99	52	65
	Winter wheat	61.6247	656.254	177.2335	134.472	301.243	3.1651466	107.24177	175	60	67
	Winter barley	2.99353	275.596	63.167597	54.8815	104.198	4.291694	360.16516	140	69	85
	Grass less than five years olc	1.9510617	987.299	295.203	167.905	447.115	979.326	667.052	120	36	47
	Grass five years and over	24.486438	1637.71	483.959	264.092	437.025	4009.1	1010.8	81	23	27
2	Oats	4.57345	148.4	38.7055	14.3549	61.8032	0.273767	41.814966	81	42	61
0	Winter oilseed rape	8.64798	184.559	48.9625	42.9116	110.735	0	179.30961	172	53	77
0	Potatoes	9.95765	87.0913	17.0798	28.1863	352.935	0.314614	33.061811	148	149	225
8	Spring barley	51.971	1104.38	294.34	155.09	1271.3	429.945	789.621	93	49	61
	Winter wheat	4.67739	325.511	84.835	57.6313	136.716	48.5147	353.71624	146	64	78
	Winter barley	70.5143	902.699	240.995	230.011	370.099	56.4044	101.31553	170	67	94
	Grass less than five years olc	6.4558666	652.88819	165.03852	100.13238	611.00232	1379.2077	1223.6293	107	30	42
	Grass five years and over	19.301633	653.23601	215.02390	123.05512	445.56010	4230.5423	613.30023	69	22	20
2	Oats	10.07137	122.775	30.387	12.7991	67.8752	0	83.1841	79	49	62
0	Winter oilseed rape	6.6817378	89.2966	23.9603	17.9678	118.892	0	254.205	173	55	65
0	Potatoes	0	2.8637	0	0.104543	200.521	0	20.3262	153	159	240
9	Spring barley	109.5387	1209.11	317.724	197.195	1362.53	411.45	948.116	98	50	63
	Winter wheat	33.700303	371.778	92.6571	80.8984	109.858	11.6403	390.285	151	56	75
	Winter barley	91.320388	741.277	192.042	150.52	337.329	28.0438	194.925	192	67	81
	Grass less than five years olc	5.80606	1241.77	363.86	209.292	625.63159	1369.44	1243.0576	111	35	44
	Grass five years and over	18.5206	1575.23	476.596	260.455	430.93091	3845.1	593.87992	79	20	23
2	Oats	11.574525	243.70011	42.509901	24.506496	104.246	0.4695565	58.3106	91	50	61
0	Winter oilseed rape	63.968008	639.71267	121.71228	127.55434	128.345	0.0582509	216.976	177	63	74
1	Potatoes	0	2.0324096	0	0.145300	207.133	0	17.6101	123	146	109
0	Spring barley	54.702363	1635.7727	315.5187	176.61745	1158.01	483.58182	896.833	97	51	68
	Winter wheat	13.706345	628.54018	116.27043	104.60856	108.857	48.902318	440.598	155	59	72
	Winter barley	107.36126	1646.669	297.05119	292.87966	383.155	62.300557	218.896	183	55	85
	Grass less than five years olc	4.8059	1201.75	353.34	202.047	512.21	1353.85	1257.1133	103	28	38
	Grass five years and over	17.9224	1598.62	481.751	263.755	369.676	3772.68	579.82422	75	21	23
2	Oats	12.970965	274.3429	52.27575	32.430482	80.953322	0.2272506	65.111293	98	60	64
0	Winter oilseed rape	26.914795	400.7038	74.60248	86.989889	208.86576	2.7105445	312.04953	193	56	60
1	Potatoes	0	3.0051023	0	0.198454	264.15254	0	35.021133	170	136	199
1	Spring barley	47.992519	1617.994	311.37024	172.74996	1771.5907	447.72775	1092.0421	104	54	68
	Winter wheat	14.592335	580.50598	105.10825	91.168827	134.79849	33.60604	443.9832	164	65	81
	Winter barley	140.04109	1320.0232	349.69779	342.77409	523.01410	111.04092	250.73020	194	69	91
	Grass less than five years olc	7.1585087	669.40186	166.28156	99.064738	468.168	1465.347	1404.44	112	32	41
	Grass five years and over	19.278991	836.72314	213.78094	124.12276	372.316	4212.403	560.605	78	20	23
2	Oats	8.10748	159.866	43.031	17.9516	113.94782	4.87017	63.233789	109	54	69
0	Winter oilseed rape	18.9174	229.857	59.9951	58.5303	158.83408	0	274.5742	180	48	58
1	Potatoes	0	4.19483	0.214168	2.09965	250.23993	0	25.796405	127	57	75
2	Spring barley	38.2507	939.486	253.676	138.062	1842.1745	398.088	1093.2537	105	53	68
	Winter wheat	14.1361	372.64	96.1188	66.0648	159.57042	4.35799	487.50224	156	61	78
	Winter barley	76.9171	969.087	245.637	215.845	458.60827	52.0749	254.57719	185	62	83

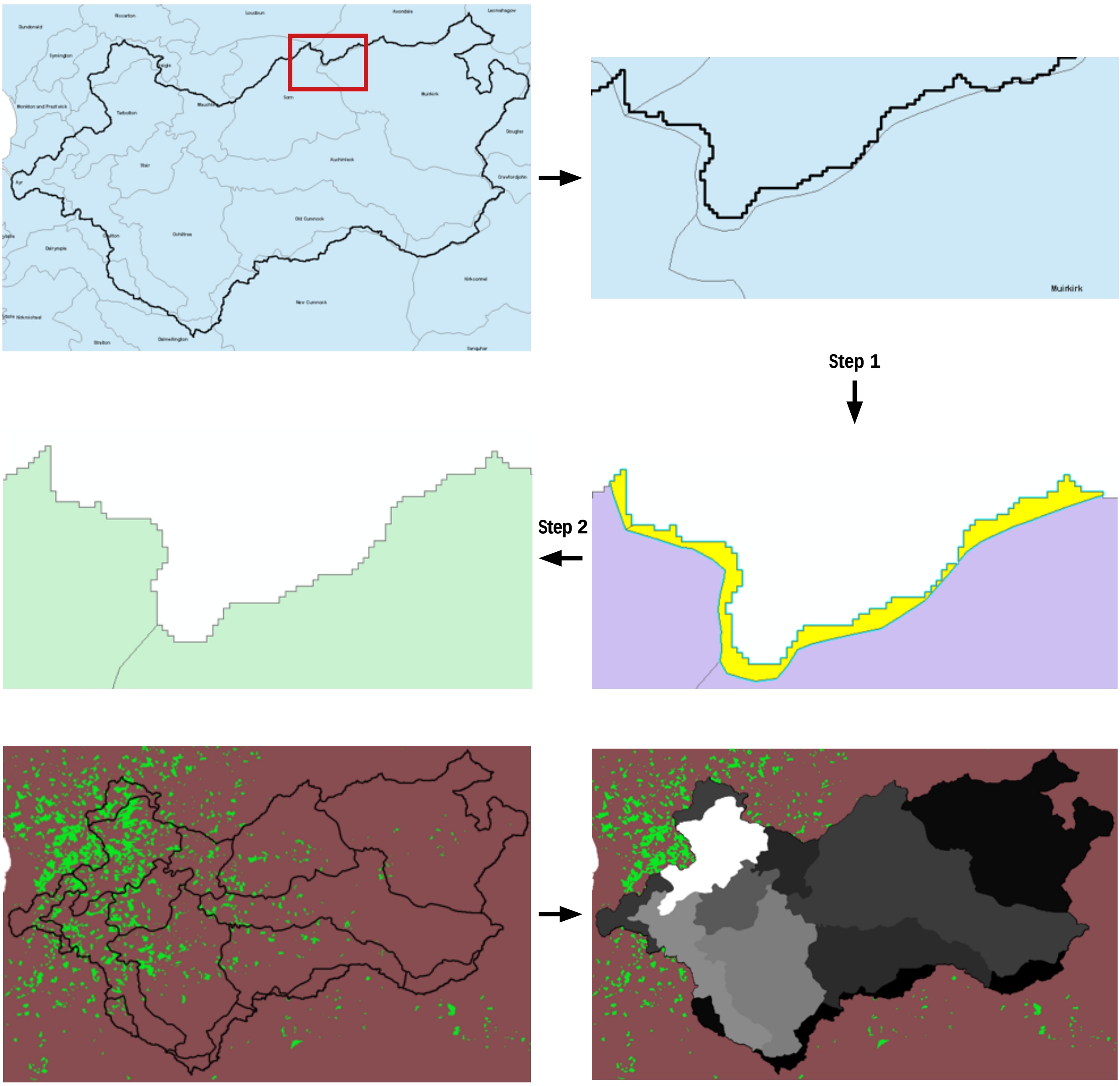
	5010			5011			5012			5013		
	N	P2O5	K2O	N	P2O5	K2O	N	P2O5	K2O	N	P2O5	K2O
Grass less than five years olc	199.0153	61.51382	81.41535	59535.49284	18401.87961	24355.42889	15096.43196	4666.169877	6175.813073	9267.626424	2864.539076	3791.301719
Grass five years and over	1855.856	589.5072	633.1744	82015.92598	26052.11767	27981.90416	20639.88781	6556.199656	7041.844075	11809.58981	3751.281469	4029.15417
Oats	393.71185	213.4139	290.68445	12634.667	6848.698	9328.399	2779.420769	1506.601912	2052.095708	2723.2249	1476.1406	2010.6053
Winter oilseed rape	1702.56996	589.35114	710.96328	33588.646	11626.839	14026.028	8088.935971	2800.016298	3377.797439	6408.0198	2218.1607	2675.8764
Potatoes	1671.130	1697.664	2679.126	13790.764	14017.792	22121.020	2300.67994	2345.325653	3701.217047	3999.1510	4062.6304	6411.3306
Spring barley	4235.4675	2224.69	2780.8625	87560.154	45991.192	57488.99	19628.33783	10309.83401	12887.29252	12466.278	6547.944	8184.93
Winter wheat	10019.3225	4204.0796	5370.7409	143044.45	50225.272	74494.090	31015.06241	12051.07797	15419.31446	34032.6	13224.096	16913.064
Winter barley	419.0942	206.55357	254.45005	38583.44	19016.124	23425.66	8843.463544	4358.564175	5369.245723	7683.41	3786.8235	4664.9275
Grass less than five years olc	234.127399	70.23821969	91.69989793	118475.88	35542.764	46403.053	35424.36	10627.308	13874.541	20148.6	6044.58	7891.535
Grass five years and over	1983.401506	563.1880819	661.1338352	132654.51	37667.33	44218.17	39200.679	11131.057	13066.893	21391.452	6074.116	7130.484
Oats	370.44945	192.0849	278.98045	12020.4	6232.8	9052.4	3135.1455	1625.631	2361.0355	1162.7469	602.9058	875.6489
Winter oilseed rape	1487.45256	458.34294	665.89446	31744.148	9781.627	14211.043	8421.55	2595.0125	3770.1125	7380.7952	2274.3148	3304.1932
Potatoes	1473.7322	1483.68985	2240.47125	12889.5124	12976.6037	19595.5425	2527.8104	2544.8902	3842.955	4171.5724	4199.7587	6341.9175
Spring barley	4833.303	2546.579	3170.231	102707.34	54114.62	67367.18	27373.62	14422.66	17954.74	14423.37	7599.41	9460.49
Winter wheat	682.89894	299.35296	364.83642	47524.606	20832.704	25389.858	12385.91	5429.44	6617.13	8414.1698	3688.4032	4495.2414
Winter barley	12551.5454	4724.4501	6620.3442	174920.422	65040.033	92373.706	42097.11	16146.665	22653.53	41004.350	15404.337	21696.234
Grass less than five years olc	690.7777219	193.6759968	271.1463955	69859.03673	19586.64581	27421.30414	17659.12134	4951.155517	6931.617724	10714.165	3003.971494	4205.560092
Grass five years and over	1770.365376	439.5959357	559.4057363	75930.07576	10771.20974	23830.63057	19137.13447	4730.527621	6020.671510	10951.9054	2707.212571	3445.543272
Oats	795.6382683	493.4971538	624.4249701	9699.225	6015.975	7612.05	2400.573	1488.963	1883.994	1011.1289	627.1559	793.5442
Winter oilseed rape	1155.94064	367.495579	434.312957	15448.3118	4911.313	5804.279	4145.1319	1317.8165	1557.4195	3108.4294	988.229	1167.907
Potatoes	0	0	0	438.1461	455.3283	687.288	0	0	0	15.995079	16.622337	25.09032
Spring barley	10734.79273	5476.935067	6900.938184	118492.78	60455.5	76173.93	31136.952	15886.2	20016.612	19325.11	9859.75	12423.285
Winter wheat	5088.745718	1887.216955	2527.522708	56138.478	20819.568	27883.35	13991.2221	5188.7976	6949.2825	12215.6584	4530.3104	6067.38
Winter barley	17533.51442	6118.46597	7396.951396	142325.184	49665.559	60043.437	36872.064	12866.814	15555.402	28699.84	10084.84	12192.12
Grass less than five years olc	644.47266	203.2121	255.46664	137836.47	43461.95	54637.88	40388.46	12735.1	16009.84	23231.412	7325.22	9208.848
Grass five years and over	1463.1274	370.412	425.9738	124443.17	31504.6	36230.29	37651.084	9531.92	10961.708	20575.945	5209.1	5990.465
Oats	1053.201819	570.7262742	706.0460545	22104.71003	12109.40551	14071.07472	3960.400940	2125.495026	2593.103932	2230.091174	1225.324021	1494.096201
Winter oilseed rape	11322.33747	4029.984524	4733.632616	113229.1432	40301.89841	47338.73782	21543.07282	7667.873375	9006.708409	22577.11864	8035.923582	9439.021351
Potatoes	0	0	0	355.7663734	422.2317339	546.6654122	0	0	0	17.35652205	21.31424663	27.53173023
Spring barley	5306.129205	2789.82051	3719.760679	158669.9493	83424.40632	111232.5418	30605.31398	16091.45374	21455.27166	17131.89313	9007.490205	12009.98694
Winter wheat	2124.483436	808.6743401	986.8568218	97423.72773	37083.87055	45254.89288	18021.91679	6859.955424	8371.471026	16214.32694	6171.905092	7531.816384
Winter barley	19647.11031	5904.869218	9125.706974	301340.4188	90566.79254	139966.8612	54360.36812	16337.81555	25249.35131	53596.97726	16108.38114	24894.77086
Grass less than five years olc	495.0077	134.5652	182.6242	123780.25	33649	45666.5	36394.02	9893.52	13426.92	20810.841	5657.316	7677.786
Grass five years and over	1344.18	376.3704	412.2152	119896.5	33571.02	36768.26	36131.325	10116.771	11080.273	19781.625	5538.855	6066.365
Oats	1271.154523	778.2578713	830.1417294	26885.60402	16460.57389	17557.94548	5123.023541	3136.545025	3345.648027	3178.187188	1945.82889	2075.550816
Winter oilseed rape	5194.555446	1507.228523	1614.887704	77335.83391	22439.41295	24042.22816	14398.27855	4177.738853	4476.148771	16789.0485	4871.43376	5219.393315
Potatoes	0	0	0	510.8673925	408.693914	598.0153595	0	0	0	33.73718282	26.98974626	39.4923493
Spring barley	4991.221957	2591.596016	3263.491279	168271.3707	87371.67739	110023.5930	32303.33676	16814.42406	21173.72019	17965.99557	9328.497690	11746.9971
Winter wheat	2393.142954	948.5017806	1181.979142	95202.98035	37732.88855	47020.9842	17237.7522	6832.035934	8513.767857	14951.68763	5925.973756	7384.674989
Winter barley	20075.32590	10270.09017	13544.61167	372639.6995	132536.0003	174794.9106	67041.37064	24129.14729	31022.4906	66490.32095	23651.46751	31192.51513
Grass less than five years olc	801.752976	229.0722789	293.4988573	74973.00801	21420.85943	27445.47615	18623.53429	5321.009798	6817.543804	11095.25062	3170.071605	4061.654244
Grass five years and over	1503.76132	385.5798257	443.4167996	65264.40514	16734.46286	19244.63228	16674.91362	4275.618876	4916.961708	9681.575462	2482.455247	2854.823534
Oats	883.71532	437.80392	559.41612	17425.394	8632.764	11030.754	4690.379	2323.674	2969.139	1956.7244	969.3864	1238.6604
Winter oilseed rape	3405.132	908.0352	1097.2092	41374.26	11033.136	13331.706	10799.118	2879.7648	3479.7158	10535.454	2809.4544	3394.7574
Potatoes	0	0	0	532.74341	239.10531	314.61225	27.199336	12.207576	16.0626	266.65555	119.68005	157.47375
Spring barley	4016.3235	2027.2871	2601.0476	98646.03	49792.758	63885.048	26635.98	13444.828	17249.968	14496.51	7317.286	9388.216
Winter wheat	2205.2316	862.3021	1102.6158	58131.84	22731.04	29065.92	14994.5328	5863.2468	7497.2664	10306.1088	4029.9528	5153.0544
Winter barley	14229.6635	4768.8602	6384.1193	179281.095	60083.394	80434.221	45442.845	15229.494	20387.871	39931.325	13382.39	17915.135

Appendix 3c Methods of transforming spatial parish and SRDP data into SRDP uptake indicator

A similar approach has been taken to provide the portion of SRDP support in each catchment. Because the data being available were at parish level, we needed to intersect and split up the water body in some more areas by overlapping the parish features.

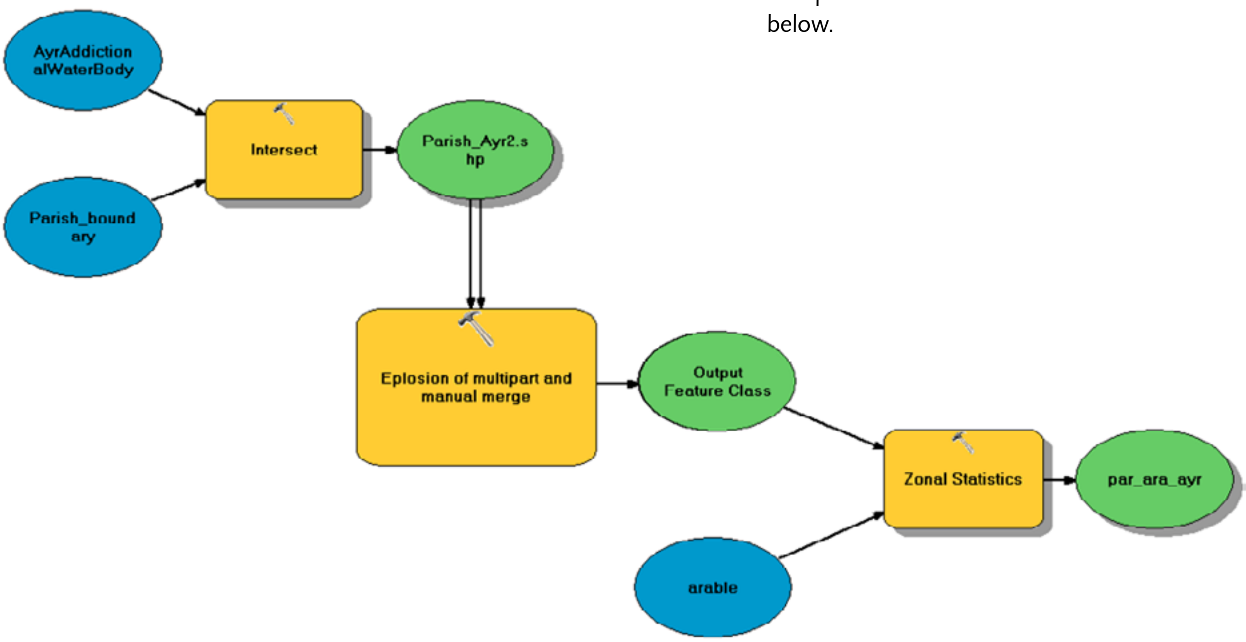
This analysis included the following **steps**:

1. The parish and sub-watershed feature were intersected together.
2. The new multipart polygons were exploded and some small polygon have been removed or merged with the main ones.

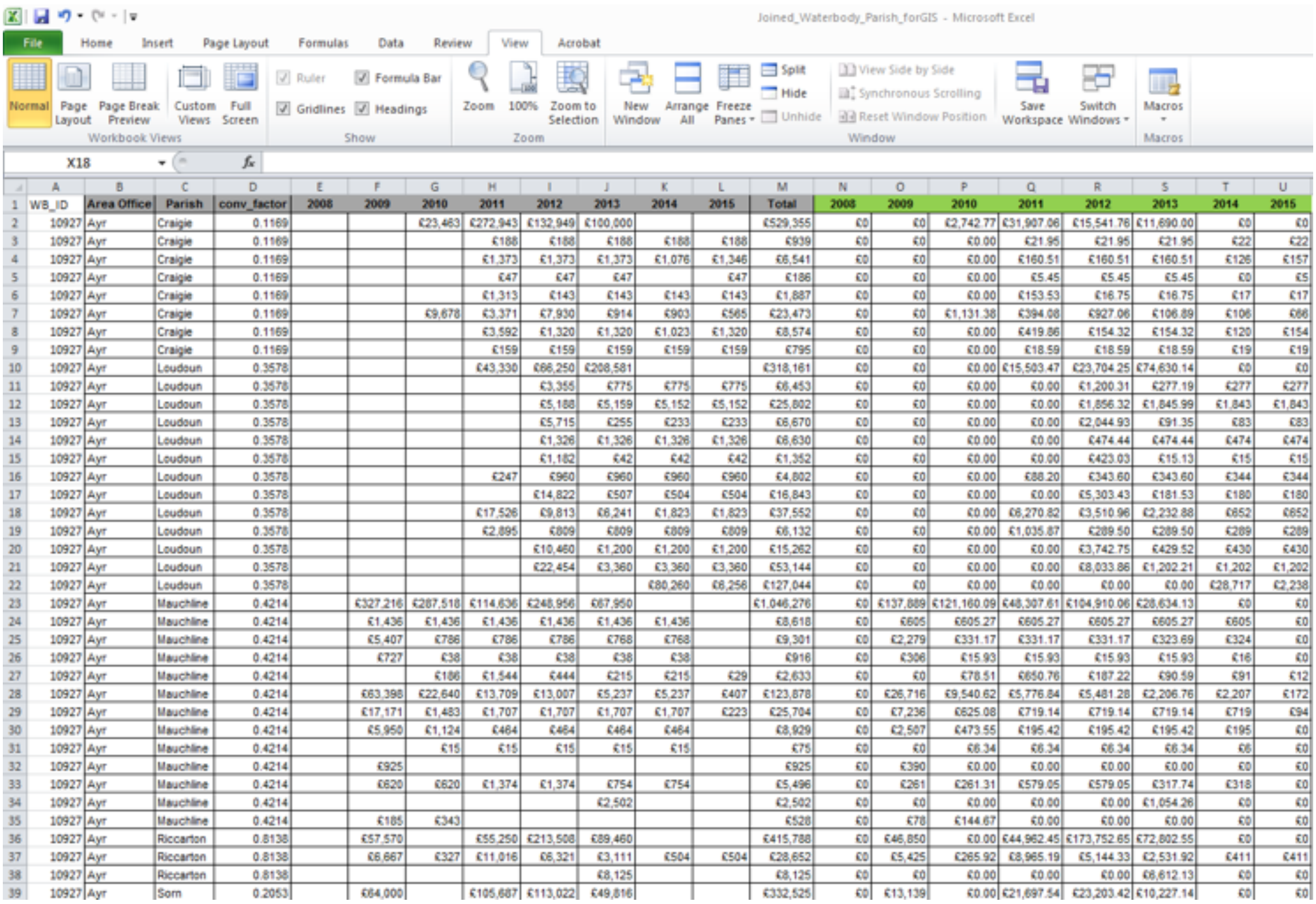


4 The data of the Zonal statistic and the total arable area for parish have then been sampled.

5 Step 4 data were used to obtain the proportion (ha) of arable of each parish belonging to a particular catchment This process is described in the Model Builder ArcGIS tool below.



6 Knowing the proportion of parish in *ha* the proportion of spend from that particular parish was calculated in a spreadsheet xls file.


Joined_Waterbody_Parish_forGIS - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	WB_ID	Area Office	Parish	conv_factor	2008	2009	2010	2011	2012	2013	2014	2015	Total
2	10927	Ayr	Craigie	0.1169			£23,463	£272,943	£132,949	£100,000			£529,355
3	10927	Ayr	Craigie	0.1169				£188	£188	£188	£188	£188	£939
4	10927	Ayr	Craigie	0.1169				£1,373	£1,373	£1,373	£1,076	£1,346	£6,541
5	10927	Ayr	Craigie	0.1169				£47	£47	£47		£47	£186
6	10927	Ayr	Craigie	0.1169				£1,313	£143	£143	£143	£143	£1,887
7	10927	Ayr	Craigie	0.1169			£9,678	£3,371	£7,930	£914	£903	£565	£23,473
8	10927	Ayr	Craigie	0.1169				£3,592	£1,320	£1,320	£1,023	£1,320	£8,574
9	10927	Ayr	Craigie	0.1169				£159	£159	£159	£159	£159	£795
10	10927	Ayr	Loudoun	0.3578				£43,330	£66,250	£208,581			£318,161
11	10927	Ayr	Loudoun	0.3578					£3,355	£775	£775	£775	£6,453
12	10927	Ayr	Loudoun	0.3578					£5,188	£5,159	£5,152	£5,152	£25,802
13	10927	Ayr	Loudoun	0.3578					£5,715	£255	£233	£233	£6,670
14	10927	Ayr	Loudoun	0.3578					£1,326	£1,326	£1,326	£1,326	£6,630
15	10927	Ayr	Loudoun	0.3578					£1,182	£42	£42	£42	£1,352
16	10927	Ayr	Loudoun	0.3578				£247	£960	£960	£960	£960	£4,802
17	10927	Ayr	Loudoun	0.3578					£14,822	£507	£504	£504	£16,843
18	10927	Ayr	Loudoun	0.3578				£17,526	£9,813	£6,241	£1,823	£1,823	£37,552
19	10927	Ayr	Loudoun	0.3578				£2,895	£809	£809	£809	£809	£6,132
20	10927	Ayr	Loudoun	0.3578					£10,460	£1,200	£1,200	£1,200	£15,262
21	10927	Ayr	Loudoun	0.3578					£22,454	£3,360	£3,360	£3,360	£53,144
22	10927	Ayr	Loudoun	0.3578							£80,260	£6,256	£127,044
23	10927	Ayr	Mauchline	0.4214		£327,216	£287,518	£114,636	£248,956	£67,950			£1,046,276
24	10927	Ayr	Mauchline	0.4214		£1,436	£1,436	£1,436	£1,436	£1,436	£1,436		£8,618
25	10927	Ayr	Mauchline	0.4214		£5,407	£786	£786	£786	£768	£768		£9,301
26	10927	Ayr	Mauchline	0.4214		£727	£38	£38	£38	£38	£38		£916
27	10927	Ayr	Mauchline	0.4214			£186	£1,544	£444	£215	£215	£29	£2,633
28	10927	Ayr	Mauchline	0.4214		£63,398	£22,640	£13,709	£13,007	£5,237	£5,237	£407	£123,878
29	10927	Ayr	Mauchline	0.4214		£17,171	£1,483	£1,707	£1,707	£1,707	£1,707	£223	£25,704
30	10927	Ayr	Mauchline	0.4214		£5,950	£1,124	£464	£464	£464	£464		£8,929
31	10927	Ayr	Mauchline	0.4214			£15	£15	£15	£15	£15		£75
32	10927	Ayr	Mauchline	0.4214		£925							£925
33	10927	Ayr	Mauchline	0.4214		£620	£620	£1,374	£1,374	£754	£754		£5,496
34	10927	Ayr	Mauchline	0.4214						£2,502			£2,502
35	10927	Ayr	Mauchline	0.4214		£185	£343						£528
36	10927	Ayr	Riccarton	0.8138		£57,570		£55,250	£213,508	£89,460			£415,788
37	10927	Ayr	Riccarton	0.8138		£6,667	£327	£11,016	£6,321	£3,111	£504	£504	£28,652
38	10927	Ayr	Riccarton	0.8138						£8,125			£8,125
39	10927	Ayr	Sorn	0.2053		£64,000		£105,687	£113,022	£49,816			£332,525

	N	O	P	Q	R	S	T	U
1	2008	2009	2010	2011	2012	2013	2014	2015
2	£0	£0	£2,742.77	£31,907.06	£15,541.76	£11,690.00	£0	£0
3	£0	£0	£0.00	£21.95	£21.95	£21.95	£22	£22
4	£0	£0	£0.00	£160.51	£160.51	£160.51	£126	£157
5	£0	£0	£0.00	£5.45	£5.45	£5.45	£0	£5
6	£0	£0	£0.00	£153.53	£16.75	£16.75	£17	£17
7	£0	£0	£1,131.38	£394.08	£927.06	£106.89	£106	£66
8	£0	£0	£0.00	£419.86	£154.32	£154.32	£120	£154
9	£0	£0	£0.00	£18.59	£18.59	£18.59	£19	£19
10	£0	£0	£0.00	£15,503.47	£23,704.25	£74,630.14	£0	£0
11	£0	£0	£0.00	£0.00	£1,200.31	£277.19	£277	£277
12	£0	£0	£0.00	£0.00	£1,856.32	£1,845.99	£1,843	£1,843
13	£0	£0	£0.00	£0.00	£2,044.93	£91.35	£83	£83
14	£0	£0	£0.00	£0.00	£474.44	£474.44	£474	£474
15	£0	£0	£0.00	£0.00	£423.03	£15.13	£15	£15
16	£0	£0	£0.00	£88.20	£343.60	£343.60	£344	£344
17	£0	£0	£0.00	£0.00	£5,303.43	£181.53	£180	£180
18	£0	£0	£0.00	£6,270.82	£3,510.96	£2,232.88	£652	£652
19	£0	£0	£0.00	£1,035.87	£289.50	£289.50	£289	£289
20	£0	£0	£0.00	£0.00	£3,742.75	£429.52	£430	£430
21	£0	£0	£0.00	£0.00	£8,033.86	£1,202.21	£1,202	£1,202
22	£0	£0	£0.00	£0.00	£0.00	£0.00	£28,717	£2,238
23	£0	£137,889	£121,160.09	£48,307.61	£104,910.06	£28,634.13	£0	£0
24	£0	£605	£605.27	£605.27	£605.27	£605.27	£605	£0
25	£0	£2,279	£331.17	£331.17	£331.17	£323.69	£324	£0
26	£0	£306	£15.93	£15.93	£15.93	£15.93	£16	£0
27	£0	£0	£78.51	£650.76	£187.22	£90.59	£91	£12
28	£0	£26,716	£9,540.62	£5,776.84	£5,481.28	£2,206.76	£2,207	£172
29	£0	£7,236	£625.08	£719.14	£719.14	£719.14	£719	£94
30	£0	£2,507	£473.55	£195.42	£195.42	£195.42	£195	£0
31	£0	£0	£6.34	£6.34	£6.34	£6.34	£6	£0
32	£0	£390	£0.00	£0.00	£0.00	£0.00	£0	£0
33	£0	£261	£261.31	£579.05	£579.05	£317.74	£318	£0
34	£0	£0	£0.00	£0.00	£0.00	£1,054.26	£0	£0
35	£0	£78	£144.67	£0.00	£0.00	£0.00	£0	£0
36	£0	£46,850	£0.00	£44,962.45	£173,752.65	£72,802.55	£0	£0
37	£0	£5,425	£265.92	£8,965.19	£5,144.33	£2,531.92	£411	£411
38	£0	£0	£0.00	£0.00	£0.00	£6,612.13	£0	£0
39	£0	£13,139	£0.00	£21,697.54	£23,203.42	£10,227.14	£0	£0

Appendix 4 Before (2007–2010) vs After (2011–2014) comparisons to identify direction of change in water quality in response to the Diffuse Pollution Plan

Water quality parameter	Trial Catchment	WFD Standard *	Average		Agreement with Standard*	Step- change
			Before 2007–2010	After 2011–2014		
Dissolved P (mg/l)	N Ugie Water	0.045	no data	0.0338	Yes	No baseline data
	Lemno Burn	0.065	0032	0.029	Yes	ns
	Eye Water (ID 5011)	0.062	0.025	0.029	Yes	ns
	Cessnock Water	0.07	no data	0.06	Yes	No baseline data
Ammonia (mg/l)	N Ugie Water	0.3	0.0726	0.0724	Yes	ns
	Lemno Burn	0.6	0.055	0.0488	Yes	ns
	Eye Water (ID 5011)	0.6	0.039	0.0594	Yes	ns
	Cessnock Water	0.3	0.19	0.19	Yes	ns
Sed (mg/l)	N Ugie Water	no standard	99	807	no standard	ns
	Lemno Burn	no standard	844	1333	no standard	ns
	Eye Water (ID 5011)	no standard	579	1173	no standard	ns
	Cessnock Water	no standard	1223	2824	no standard	ns
Faecal coliforms (cfu /100ml)	Eye Water	2,000	12,245	14,890	No	ns
	River Ayr	2,000	15,000	25,550	No	ns
Faecal streprococci (cfu /100ml)	Eye Water	100	1800	1680	No	ns
	River Ayr	100	1420	1890	No	ns
DARES	N Ugie Water	0.8	0.654	0.724	No	ns
	Lemno Burn	0.8	0.66	0.874	Yes	Signif.***
	Eye Water (ID 5011)	0.8	0.649	0.586	No	ns
PSI**	Lemno Burn	60	66.61	60.72	Yes	Signif.***
	Eye Water (ID 5011)	60	69.66	73.66	Yes	ns

P: phosphorus; Sed: sediment; ns: not significant; Signif.: Significant

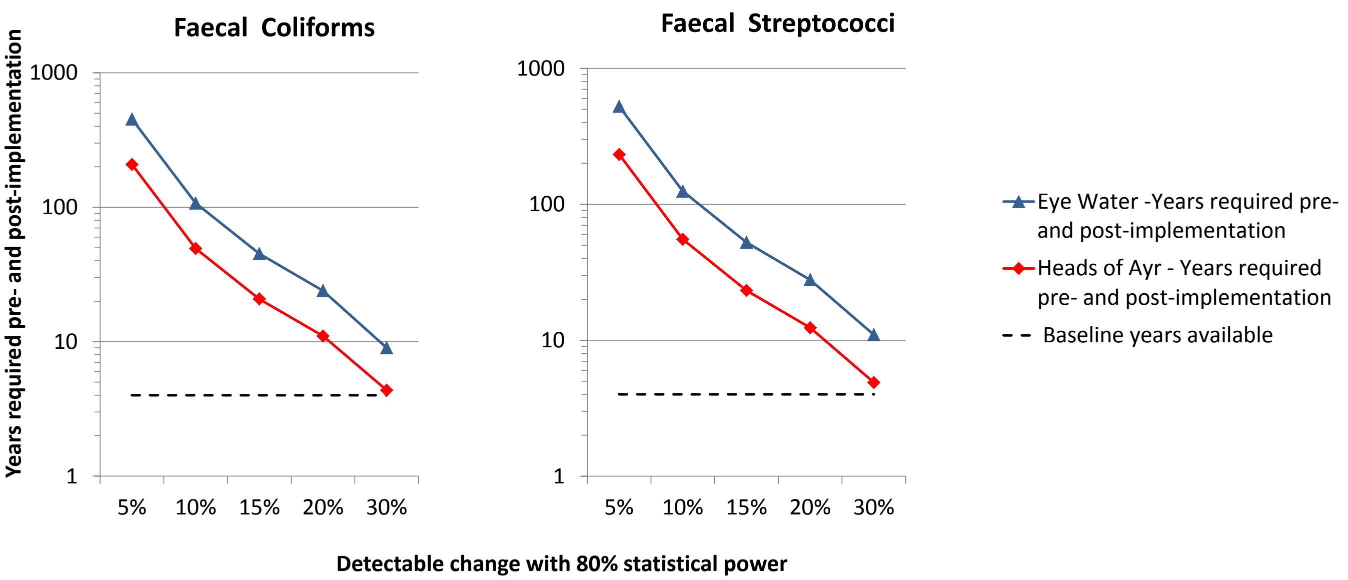
*Regulatory standards stands for: WFD standard for P, ammonia, DARES; provisional good PSI threshold; Bathing water mandatory guidelines for FIOs (ie Faecal coliforms and Faecal streptococci)

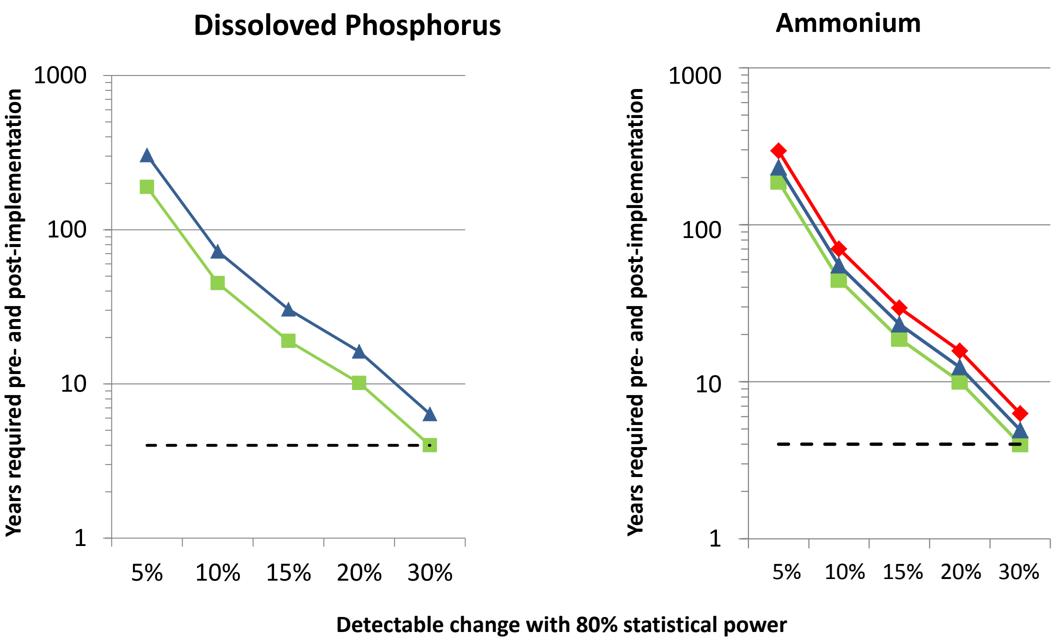
**PSI standard is provisional, specific for Scotland and indicative of absence of siltation pressures on benthic invertebrates

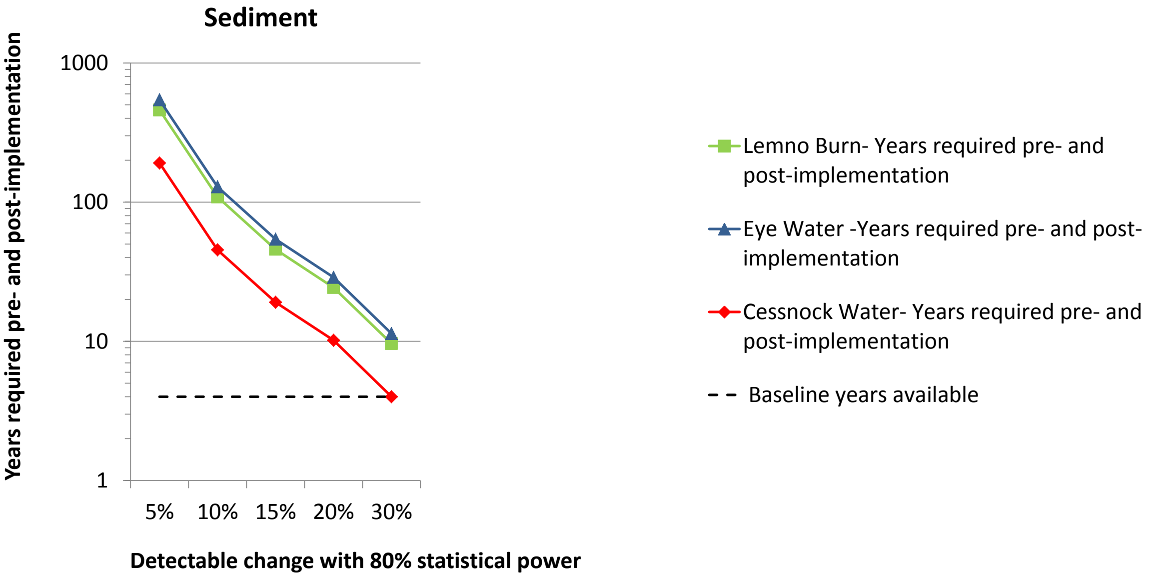
***Step-change was significant but not with adequate certainty (>80% certainty)

ns: not-significant

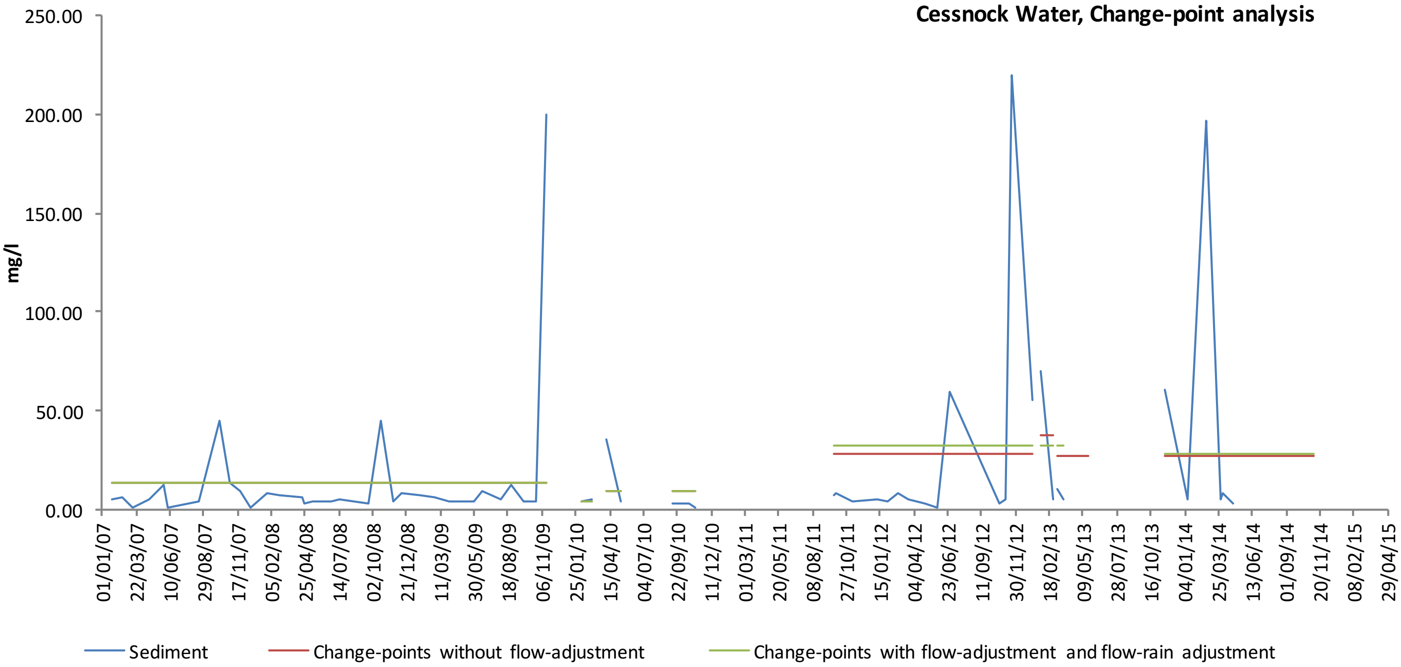
Appendix 5 Sample size (number of samples) before and after required to have an 80% probability of being able to detect a 5, 10, 15, 20 and 30% change in phosphorus, ammonium and sediment concentrations. Data from North Ugie are not shown







Appendix 6 Detection of change-points in the dynamics of in-stream sediment with and without flow adjustment at the Cessnock Water Change-points using flow-adjusted and flow-rain adjusted data were identical



Appendix 7a Crop patterns from 2007–2014

Crop types	River waterbodies				Bathing water catchments	
	N. Ugie Water ID: 23221	Lemno Burn ID: 5806	Eye Water ID: 5011	Cessnock Water ID: 10927	Eye Water	River Ayr
Grass less than five years old						
2007	750	456	541	943	765	3,868
2008	667	447	987	979	1,452	4,038
2009	1,224	611	653	1,379	925	4,246
2010	1,243	626	1,242	1,369	1,821	4,373
2011	1,257	512	1,202	1,354	1,762	4,307
2012	1,404	468	669	1,465	942	4,685
2013	1,364	480	677	1,621	1,057	5,109
Step change between pre- and post-2011	Increase post-2011	No change	No change	No change	No change	Increase post-2011
	ID: 23221	ID: 5806	ID: 5011	ID: 10927	Eye Water	River Ayr
Grass five years and over						
2007	1,040	486	965	4,394	1,368	20,241
2008	1,011	437	1,638	4,009	2,410	19,586
2009	613	446	853	4,299	1,211	20,044
2010	594	431	1,575	3,845	2,331	19,873
2011	580	370	1,599	3,773	2,362	19,242
2012	561	372	837	4,212	1,194	20,262
2013	557	347	829	4,057	1,319	20,109
Step change between pre- and post-2011	Decrease post-2011	Decrease post-2011	No change	No change	No change	No change
	ID: 23221	ID: 5806	ID: 5011	ID: 10927	Eye Water	River Ayr
Oats						
2007	49	99	118	0	173	12
2008	42	62	148	0	206	13
2009	83	68	123	-	176	-
2010	58	104	244	0	322	7
2011	65	81	274	0	372	3
2012	63	114	160	5	229	9
2013	75	109	225	0	331	11
Step change between pre- and post-2011	No change	No change	No change	No change	No change	No change
	ID: 23221	ID: 5806	ID: 5011	ID: 10927	Eye Water	River Ayr
Winter oilseed rape						
2007	240	103	185	-	274	-
2008	179	111	185	-	285	-
2009	254	119	89	-	138	-
2010	217	128	640	0	953	1
2011	312	209	401	3	589	13
2012	275	159	230	-	367	2
2013	270	151	204	-	318	-
Step change between pre- and post-2011	Increase post-2011	Increase post-2011	No change	No change	No change	No change

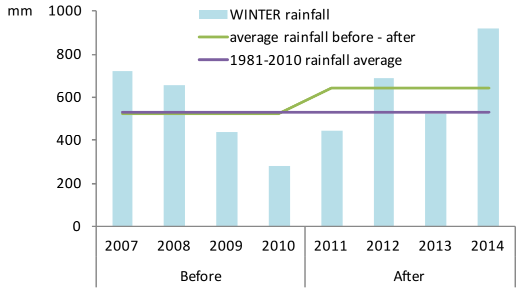
Crop types	River waterbodies				Bathing water catchments	
	N. Ugie Water ID: 23221	Lemno Burn ID: 5806	Eye Water ID: 5011	Cessnock Water ID: 10927	Eye Water	River Ayr
Potatoes						
2007	26	304	110	0	173	10
2008	33	353	87	0	142	12
2009	20	201	3	-	3	-
2010	18	207	3	-	3	-
2011	35	264	3	-	3	-
2012	26	250	4	-	7	-
2013	23	286	9	-	12	-
Step change between pre- and post-2011	No change	No change	No change	No change	No change	No change
	ID: 23221	ID: 5806	ID: 5011	ID: 10927	Eye Water	River Ayr
Spring barley						
2007	768	1,097	884	44	1,251	1,104
2008	790	1,271	1,104	430	1,606	1,341
2009	948	1,363	1,209	411	1,834	1,449
2010	897	1,158	1,636	484	2,183	1,201
2011	1,092	1,772	1,618	448	2,150	1,232
2012	1,093	1,842	939	398	1,369	1,503
2013	1,202	1,851	1,004	380	1,467	1,433
Step change between pre- and post-2011	Increase post-2011	Increase post-2011	No change	No change	No change	No change
	ID: 23221	ID: 5806	ID: 5011	ID: 10927	Eye Water	River Ayr
Winter wheat						
2007	187	381	856	3	1,290	202
2008	354	137	326	49	473	235
2009	390	110	372	12	579	233
2010	441	109	629	49	863	273
2011	444	135	581	34	791	367
2012	488	160	373	4	549	200
2013	439	167	324	8	489	208
Step change between pre- and post-2011	No change	No change	No change	No change	No change	No change
	ID: 23221	ID: 5806	ID: 5011	ID: 10927	Eye Water	River Ayr
Winter barley						
2007	360	104	276	4	397	214
2008	181	379	983	56	1,525	232
2009	195	337	741	28	1,175	35
22010	219	383	1,647	62	2,344	172
2011	251	523	1,921	111	2,762	178
2012	255	459	969	52	1,507	33
2013	189	420	855	59	1,332	122
Step change between pre- and post-2011	No change	Increase post-2011	No change	No change	No change	No change

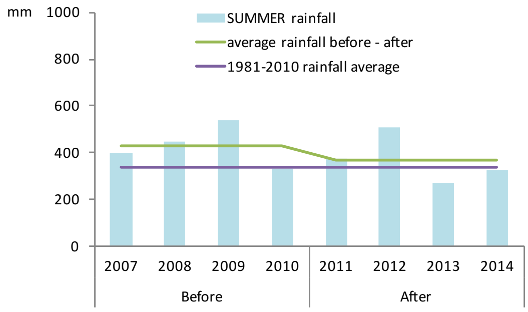
Appendix 7b Livestock numbers from 2007–2014

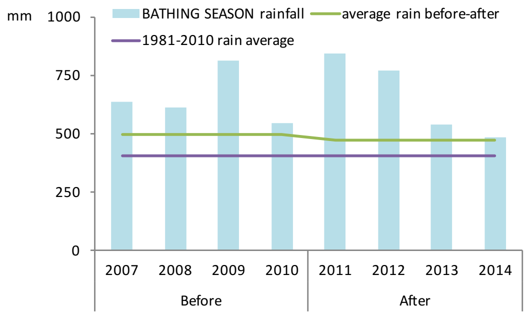
Livestock types	River waterbodies				Bathing water catchments	
	N. Ugie Water ID: 23221	Lemno Burn ID: 5806	Eye Water ID: 5011	Cessnock Water ID: 10927	Eye Water	River Ayr
Cattle						
2007	4495	2006	2943	12507	4321	44079.6
2008	4217	1976	2857	12155	4185	43481.2
2009	4153	1973	2720	12075	3972	42786.9
2010	4193	1970	2753	12138	3967	42661.2
2011	4184	1967	2763	11348	3988	41920.9
2012	4027	1907	2800	11327	4034	41769
2013	5029	1948	2691	11907	3812	43216.4
Step change between pre- and post-2011	No change	No change	No change	Decrease post-2011	No change	No change
	ID: 23221	ID: 5806	ID: 5011	ID: 10927	Eye Water	River Ayr
Goat						
2007	20	3	11	13	16	45.958
2008	21	3	9	11	14	29.445
2009	19	4	11	11	18	31.600
2010	15	4	14	13	22	28.649
2011	18	6	13	15	20	26.252
2012	5	0	4	1	7	26.252
2013	16	5	15	14	24	26.252
Step change between pre- and post-2011	No change	No change	No change	No change	No change	No change
	ID: 23221	ID: 5806	ID: 5011	ID: 10927	Eye Water	River Ayr
Pig						
2007	2117	540	1031	6	1180	148.267
2008	1804	478	1029	7	1196	147.999
2009	1468	434	1065	8	1241	118.369
2010	1540	500	1083	8	1255	110.496
2011	3312	450	1132	11	1304	97.250
2012	2940	439	1090	77	1258	101.554
2013	1723	985	1386	13	1734	103.162
Step change between pre- and post-2011	No change	No change	No change	No change	No change	No change
	ID: 23221	ID: 5806	ID: 5011	ID: 10927	Eye Water	River Ayr
Poultry						
2007	32291	59066	26990	17135	27541	39412.4
2008	57558	24652	979	13266	1481	42501.2
2009	31371	34365	835	15807	1260	68011.1
2010	84133	35447	910	18432	1370	189226
2011	71323	45473	695	18519	1047	136041
2012	96759	45494	624	18742	942	165416
2013	67214	44452	474	18729	720	181599
Step change between pre- and post-2011	No change	Increase post-2011	No change	No change	No change	No change
	ID: 23221	ID: 5806	ID: 5011	ID: 10927	Eye Water	River Ayr
Sheep						
2007	5166	1366	28789	9713	38569	79029.6
2008	4825	1324	29035	9831	38788	73905
2009	4779	1068	27528	9933	36855	72116
2010	4473	1108	27402	9600	36582	74812.4
2011	4533	1087	27402	10414	36754	76670.3
2012	1321	146	9204	710	12375	73751.4
2013	4233	1217	26623	9618	35413	70293.5
Step change between pre- and post-2011	No change	No change	No change	No change	No change	No change

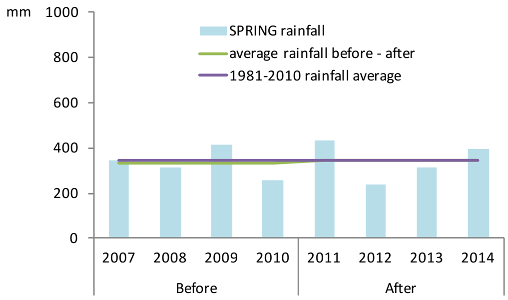
Appendix 8 Seasonal, bathing season, and annual rain averages in 2007–2010 and 2011–2014 compared with 1981–2010 rain averages in East and West Scotland

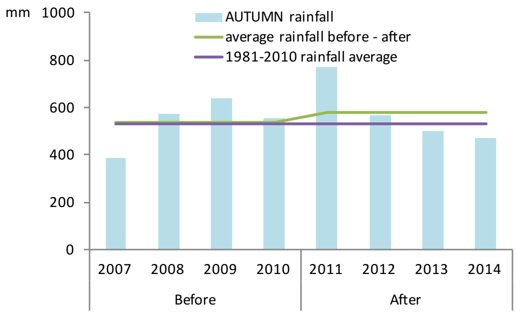
West Scotland rainfall (mm) - metoffice.gov.uk

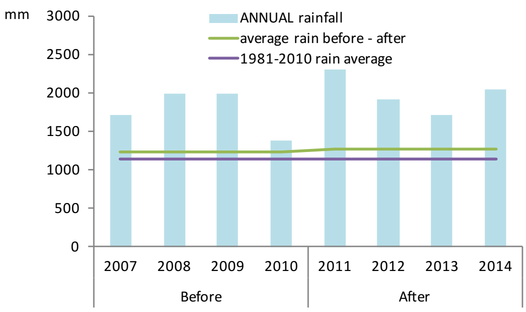




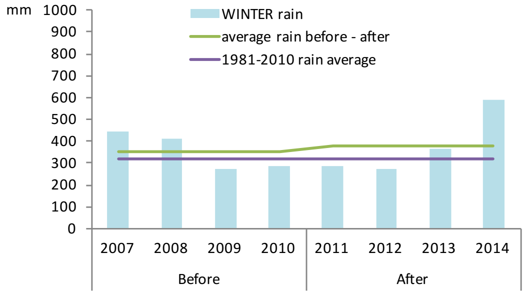


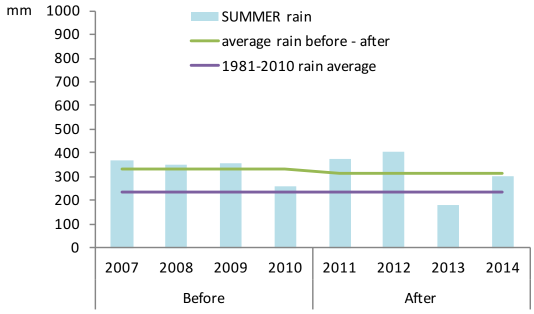


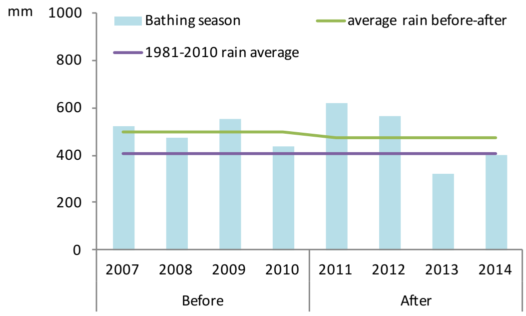


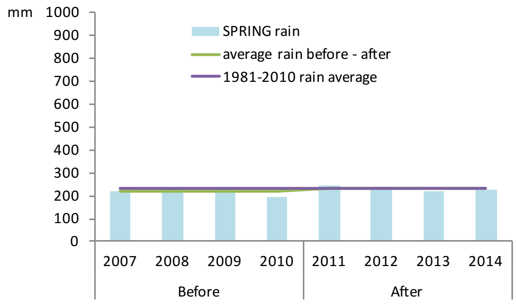


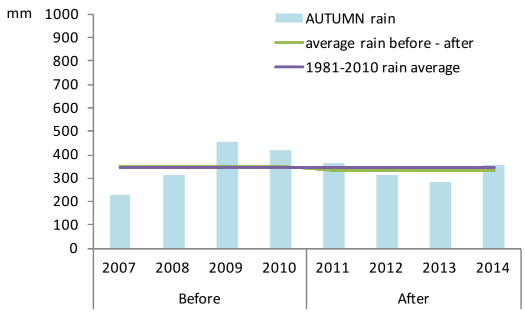
East Scotland rainfall (mm) - metoffice.gov.uk

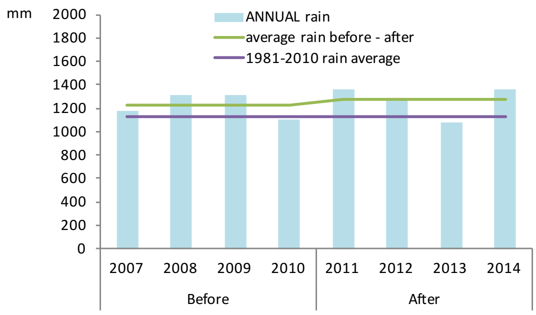












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