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Assessing the combined effectiveness of Scotland's rural diffuse pollution measures in reducing FIO from a livestock catchment

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Research Summary

Research Questions

1. Is waterbody scale monitoring required to assess the effectiveness of the combination of measures currently implemented in Scotland to reduce faecal indicator organisms (FIO) from livestock?
2. Could the predictions of the ADAS Framework Model for FIO loads be used as a substitute for FIO monitoring?
3. How should FIO be monitored to detect reductions in response to the measures?
4. Is FIO monitored data available in Scotland suitable for assessing effectiveness of the measures?
5. Is the proposed FIO monitoring suitable for assessing effectiveness of measures?

Main Findings

- Both FIO monitoring and modelling are required to assess effectiveness of measures in Scotland. Monitoring is essential in providing baseline FIO data; documenting FIO variations in response to measures and catchment change; providing data to test the ADAS FIO Model predictions and support novel modelling; and providing credibility to assessments of effectiveness.

- The ADAS FIO Model is essential in calculating source apportionment; identifying critical source waterbodies for prioritising the measures and FIO monitoring; predicting FIO loads and reductions as a hypothesis that needs to be tested against monitored FIO data; and analysing the cost-effectiveness of alternative management and monitoring frequency scenarios.

- The ADAS FIO Model can be used as a substitute for monitoring only when it is used for assessing where FIO reductions are expected; identifying a suitable monitoring design and frequency; and comparing alternative management scenarios.

- Detecting and quantifying change in in-stream FIO concentrations between before and after the installation of measures requires credible monitored evidence of (1) FIO during low- and storm-flows; (2) year-round variations of FIO and flow; and (3) year-to-year variation in FIO and flow through long-term monitoring, with more than one year pre-implementation sampling.

- There is no waterbody-scale FIO monitored data suitable to assess the effectiveness of the package of measures currently implemented in Scotland and test the ADAS FIO Model predictions.

- The strengths of the proposed monitoring include:
  - o Collection of baseline data (during low- and storm-flow) and year-to-year data post-installation.
  - o Covering a widespread geographical distribution of monitoring sites under a limited budget.
  - o Collection of waterbody data to enable interpretation of change, or lack of, in FIO data.

- The proposed monitoring is not suitable to assess effectiveness of measures because of:
  - o Short duration of pre-implementation monitoring precluding robust Before-After comparisons.
  - o No year-round monitoring of FIO for estimation of annual FIO loads, as in the ADAS FIO Model.
  - o No potential to factor out random variation because of using one Control waterbody per land use type and Impact waterbodies influenced by a range of practices and unquantified processes.
  - o No accounting of FIO transport processes across the waterbody and river catchment network.

- FIO monitoring should be carried out with the proposed frequency/technique on a year-round basis in the Solway area (in three Impact and three Control waterbodies, if possible) because this area:
  - o Is characterised by uniformity in terms of land use (i.e. livestock farming), non-agricultural pressures, geology, rainfall and protection areas and thus enables the effect of FIO control measures in Impact waterbodies to be assessed against a narrow range of background variation.
  - o Enables the assessment of effectiveness to be targeted and tested against the predictions of the ADAS FIO Model and novel modelling at sites with the greatest livestock pressures.
  - o Is programmed for installation of mandatory measures at the end of 2017 thus allowing for a longer than one year pre-implementation monitoring, if monitoring starts within 2016.

Background

SEPA are proposing to monitor in-stream FIO concentrations at Impact waterbodies (i.e. remediated with the package of measures) and Control waterbodies (i.e. having similar land use as the Impact but not remediated with the measures) as follows:

Design / Statistical analysis	Before-After/Control-Impact (BACI) with one Control and two Impact waterbodies in SW Scotland representing land use dominated by livestock farming; and in NE Scotland to represent land use characterised by mixed farming.
Duration	Up to a year before and four years after installation of measures; Bathing season sampling only.
Frequency / Technique	Twice a week / 24-hr composite samples collected with autosamplers.
Catchment data	Land use (livestock numbers, fertiliser application), rainfall, waste water treatment and septic tank densities, as in the Weight of Evidence method, and water quality data.

The aim is to assess the effectiveness of the combined implementation of mandatory and voluntary measures in reducing FIO from livestock at the waterbody scale and test the predictions of the ADAS FIO Model for FIO reductions in response to 100% compliance with mandatory measures and 100% implementation of voluntary measures. Before embarking on this, SEPA wish to check the evidence-base and assess the strengths and weaknesses of the proposed monitoring.

Research Undertaken

A review of the literature on monitoring the effectiveness of measures to reduce FIO from agriculture at a waterbody scale was carried out to explore (1) whether there is any in-stream FIO data in Scotland; (2) best in-stream FIO monitoring practice to assess effectiveness of measures. The key findings were discussed at a workshop to enable feasible recommendations to be developed and agreed.

[1] AKOUMIANAKI I,POTTS J, BAGGIO A, GIMONA A, SPEZIA L, SAMPLE J, VINTEN A, & MACDONALD J 2016b. Developing a Method to Monitor the Rural Diffuse Pollution Plan: Providing a Framework for Interpreting Catchment Data, CRW2014/13. Available: crew.ac.uk/publications.

Contents

1.0 Background

A package of diffuse pollution mitigation measures is being implemented in Scotland's priority catchments to reduce losses of pollutants from farms to rivers and other waterbodies as part of the Rural Diffuse Pollution Plan. The Plan was launched in 2011 to promote the uptake of the package of measures towards achieving the objectives of the Water Framework Directive (WFD). SEPA works with partner organisations and land managers to ensure 100% uptake of regulatory (mandatory) measures, such as the Diffuse Pollution General Binding Rules (DP GBRs). SEPA also encourage the adoption of supplementary measures e.g. via the Scotland Rural Development Programme (SRDP), where the regulatory baseline has been complied with.

The evidence on uptake of measurers in the priority catchments of the first River Basin Management Planning (RBMP) cycle has been integrated with computer models of pollutant losses to quantify the impact of current and future levels of DP GBR compliance and SRDP implementation. The export coefficients from all pollutant models have been combined to develop the ADAS Framework Model of rules for calculating all pollutant emissions from farm inputs at SEPA's waterbody scale (Gooday et al. 2014). The ADAS Framework Model predictions for faecal indicator organism (FIO) loads in relation to land use and for FIO reductions in relation to the implementation of DP GBR and SRDP measures will hereafter be referred as the ADAS FIO Model.

FIO monitoring is currently being carried out at the river catchment scale as part of the compliance monitoring at bathing waters under the Bathing Water Directive. SEPA are proposing to monitor FIO at source sub-catchments at the waterbody scale. The aim is to assess the effectiveness of the combined implementation of DP GBR and SRDP measures in reducing FIO from livestock and to test the predictions of the ADAS FIO Model in response to 100% compliance with mandatory measures and 100% implementation of voluntary measures. Impact waterbodies (i.e. remediated with the package of measures) and Control waterbodies (i.e. having similar land use as the Impact but not remediated with the measures) are proposed to be monitored in line with guidance provided in Akoumianaki et al. 2016a, as follows:

- Design: Before-After/Control-Impact (BACI).
    - One Control waterbody (outwith any of the priority catchments) and two Impact waterbodies in SW Scotland to represent land use dominated by livestock farming pre- and post-implementation of the measures. The Impact waterbodies are nested within the operational area of two priority catchments, one draining into but not directly connected to bathing waters.
    - One Control waterbody (outwith any of the priority catchments) and two Impact waterbodies in NE Scotland to represent mixed farming pre- and post-implementation of the measures. The Impact waterbodies are nested within the operational area of two priority (bathing water) catchments but not directly connected to bathing waters.

- Duration: three months to one year pre-implementation / four years post-implementation. Sampling only during bathing season (April to October).

- Frequency/Technique: Twice a week / 24-hr composite samples collected with autosamplers.

Supplementary catchment data on land use will be collected as part of the proposed approach and in line with the Weight-of-Evidence method (Akoumianaki et al. 2016b) for the evaluation of the Rural Diffuse Pollution Plan, such as stocking rates per type of livestock, fertiliser application, land cover, rainfall, SRDP uptake, non-agricultural FIO sources including number of waste water treatment plants, septic tank densities, and other pollutant data (e.g. sediment, phosphorus).

2.0 Objectives

Before embarking on the proposed FIO monitoring programme, SEPA requested CREW to review the evidence-base referring to the effectiveness of combined implementation of these measures and assess the benefits of the proposed monitoring.

The specific questions are:

1. Is waterbody scale monitoring required to assess the effectiveness of the combination of measures currently implemented in Scotland to reduce faecal indicator organisms (FIO) from livestock?
2. Could the predictions of the ADAS Framework Model for FIO loads be used as a substitute for FIO monitoring?
3. How should FIO be monitored to detect reductions in response to the measures?
4. Is FIO monitored data available in Scotland suitable for assessing effectiveness of the measures?
5. Is the proposed FIO monitoring suitable for assessing effectiveness? If not, provide feasible recommendations.

3.0 Methods

Evidence on monitoring the effectiveness of measures to reduce FIO from agriculture at the sub-catchment/waterbody scale was gathered through the Web of Knowledge, organisational websites (e.g. Scottish Government; DEFRA; SEPA; Environment Agency) and Google. Keywords used included: Scotland, package OR programme of measures OR combination of measures; catchment OR watershed; waterbody OR sub-catchment; FIO; fecal OR faecal; coliforms; enterococci; and the range of key FIO mitigation measures implemented in Scotland (Appendix 1).

The aim of the literature review was to capture the evidence-base for monitored data of effectiveness in Scotland and the range of monitoring practices to inform the assessment of the suitability of the proposed monitoring in assessing effectiveness reliably. The focus was on studies: (1) referring to widespread uptake of the measures listed in Appendix 1 at the waterbody scale and with hydro-climatic and land use conditions similar to those prevailing in Scotland; (2) reporting data at the sub-catchment scale draining an area of approximately 10 km2 (as SEPA's baseline waterbodies); and (3) demonstrating or indicating effectiveness and reporting lessons learned from monitoring practice.

A workshop held at the James Hutton Institute on 30 September 2016 enabled discussion of the key findings to develop the recommendations provided in this report.

4.0 Results

4.1. Strengths and limitations of monitoring and modelling

Both monitoring and modelling are useful tools in understanding the effectiveness of measures in improving water quality (Easton et al. 2008; Meals and Dressing 2016; Oliver et al. 2016).

Monitoring of in-stream FIO concentrations in Scotland is essential for:

- Providing baseline in-stream FIO data; their availability in Scotland is discussed in section 4.3.
- Documenting FIO variations in response to the measures

implemented and catchment factors.
- Providing data to test the ADAS FIO Model calculations / predictions and support novel modelling.
- Contributing to awareness of the consequences of certain land use management practices.
- Providing credibility to assessments of the effectiveness of measures in improving water quality.

FIO monitoring to assess effectiveness of measures in improving water quality however, faces several challenges. A review of the literature showed the limited ability of monitoring to demonstrate FIO change in response to measures mainly because of inadequate sampling design (e.g. inappropriate selection of Control sites); frequency (e.g. insufficient accounting of storm-flow effects on in-stream FIO); and duration (insufficient duration of pre-implementation monitoring); see section 4.3 and Appendix 2 for accounting of monitoring practice and associated shortcomings. In addition, budgetary constraints may preclude monitoring with the appropriate design, duration, frequency and technique to enable water quality improvements to be detected. The problem of inadequate monitoring in detecting change between before and after the installation of measures has been demonstrated in SEPA's waterbodies for phosphorus data to assess WFD status and for FIO data to assess the status of bathing waters (Akoumianaki et al. 2016a).

The ADAS Framework Model was developed to help SEPA assess the effectiveness of the package of measures in improving water quality in Scotland's priority catchments (Gooday et al. 2014). The methodology involves the derivation of a meta-model of export coefficients per pollutant (i.e. phosphorus, nitrogen, sediment, FIO) from the output of more detailed pollutant-specific process-based models applied to common descriptions of farm systems representative of typical practice (Gooday et al. 2014). Each of these models has been previously used at catchment and national scale for policy support. It has been adapted to share common farm management data inputs and a common water balance and drainage pathway calculation based on the PSYCHIC model (Davison et al. 2008) for consistency of results. Each of these models has been integrated with a common landscape connectivity and delivery model to address sensitivity of mitigation to the location of risk activities.

The ADAS Framework Model predictions for FIO losses (i.e. the ADAS FIO Model) in relation to land use and the mandatory and voluntary measures implemented in Scotland (Appendix 1) are based upon the FIO-Farm model developed by Anthony and Morrow (2011). This is a simple process-based model assigning relative risks of FIO losses to pre-identified source areas. The risk apportionment methodology utilises a number of sub-models of FIO survival and mobilisation, to explicitly represent the seasonal inputs to and runoff from, each source area on a farm: septic tanks; hard-standings; roofs of farm buildings; farm tracks; fording and loafing in streams; storage and spreading of managed manures; and excreta at grazing. Model parameter ranges are based on experimental data in the published literature (for example the half-life of indicator bacteria and sediment adsorption characteristics) and on measurements taken during a field experimentation phase. Additional variability in the source apportionment is associated with the livestock and manure management decisions made by individual farms. It is understood that the FIO-Farm model calculates FIO reductions on the basis of on-farm and not in-stream reductions.

Therefore, the ADAS FIO Model is essential for:

- Calculating FIO source apportionment.
- Identifying critical source waterbodies for prioritising the measures and FIO monitoring.
- Predicting FIO loads and reductions as a hypothesis that needs to be tested against monitored data.
- Analysing the cost-effectiveness of alternative management and FIO monitoring scenarios.
- Providing opportunities for stakeholder involvement in targeting and enhancing the effectiveness of DP GBRs and SRDP measures on the basis of management scenarios.

The ADAS FIO Model approach to assessing effectiveness presents a range of challenges related to the requirement for robust monitored data for reliable model parameterisation and calibration, as in any modelling approach (Meals and Dressing, 2016) and validation of predictions for FIO reductions at the waterbody scale. Gooday et al. (2014) tested the predictions of the ADAS FIO Model against in-stream FIO monitored data from two studies by Kay et al. (2008b) and Tetzlaff et al. (2012). Both studies concluded that there is need for (1) higher frequency of FIO concentration data during storm-flows; (2) year-to-year FIO monitoring data; (3) year-round data; and (4) sampling at multiple sub-catchments (i.e. at farm or waterbody scale) within the same river catchments to understand the effect of hydrology and weather (rainfall, temperature) on FIO connectivity and survival across the river network (see Appendix 3 for details on these studies). In this context, the poor agreement between the modelled and monitored data indicates the need for robust monitoring data to test the predictions of the ADAS FIO Model. This conclusion is further supported by growing evidence showing that, in general, model performance is enhanced when model predictions are tested against high-frequency data e.g. hourly FIO measurements, as in Bougeard et al. (2011).

In addition, interpretation of model output must be context-specific. As recommended by Anthony and Morrow (2011) for the FIO-Farm model: "the model output is used as an index of the relative risk associated with each source area rather than as an absolute prediction of the indicator load." In this regard, Akoumianaki et al. (2016a;b) demonstrated a way of integrating monitoring and the ADAS Framework Model in SEPA's waterbodies in developing the Weight-of-evidence method on the basis of the lessons learned from trialling the Weight-of-evidence method in SEPA's waterbodies and other studies reviewed by Meals and Dressing (2016) and Oliver et al. (2016). It is suggested that enabling integration of FIO monitoring and the ADAS FIO Model output as well as novel modelling may involve:

- Using the predictions of the ADAS FIO Model (or novel modelling tools) for FIO reductions as a guide for monitoring where reductions can be detected with a given frequency.
- Collect FIO monitored data at the scale of ADAS FIO Model predictions for reductions, i.e. waterbody scale.
- Use monitored flow and FIO data to validate the ADAS FIO Model or develop novel modelling.
- Evaluate existing FIO data (see section 4.3 and Appendix 2a) and planned data (e.g. based on the proposed monitoring) for quality, consistency, and suitability for effectiveness interpretation.
- Link monitoring data to a GIS framework used for the ADAS FIO Model (i.e. the SAGIS model used by SEPA) or for novel modelling tools and provide for compatibility between monitored data and modelling data requirements and assumptions to permit calibration and validation.

The strengths and limitations of monitoring and modelling (based on the ADAS FIO Model) are summarised in Table 1.

Table 1. Strengths and limitations of monitoring and the ADAS FIO Model in assessing effectiveness of measures to reduce FIO from livestock at the waterbody scale. Source: Easton et al. 2008; Gooday et al. 2014; Meals and Dressing 2016; Oliver et al. 2016; see also section 4.2 and Appendix 2.

STRENGTHS	
Monitoring	**ADAS FIO Model**
(1) Establishes FIO baseline conditions	(1) Provides initial estimates of FIO loads
(2) Documents in-stream FIO concentrations	(2) Calculates source apportionment
(3) Assesses magnitude of FIO change in response to measures	(3) Identifies critical areas /waterbodies for the implementation of measures.
(4) Provides credibility to assessments of effectiveness of measures	(4) Predicts FIO reductions and waterbody response to the measures and land use as a hypothesis that needs to be tested against monitored data
(5) Provides FIO data to support modelling, i.e. test the ADAS FIO Model predictions and develop novel modelling tools.	(5) Identifies alternative management and monitoring scenarios and analyses cost-effectiveness of alternatives
(6) Informs stakeholders	(6) Guides monitoring design and addresses issues of lag time (Akoumianaki et al. 2016a;b)
(7) Contributes to behavioural change by documenting actual waterbody conditions	(7) Provides estimates of uncertainty associated with the ADAS FIO Model and monitoring
	(8) Provides opportunities for stakeholder involvement in targeting and enhancing the effectiveness of DP GBRs and SRDP measures
LIMITATIONS	
Monitoring	**ADAS FIO Model**
(1) Has limited ability to demonstrate FIO change in response to measures because of inadequate sampling frequency/ duration/technique; and selection of Control waterbodies	(1) Requires robust data for credible model parameterisation, calibration and validation
(2) Monitoring at the appropriate number of sites (e.g. multiple Control and Impact sites) and at the appropriate frequency and duration	(2) Should be based on appropriate analysis and interpretation of data

In conclusion, in-stream FIO monitoring is essential for assessing effectiveness of measures and cannot be replaced by the ADAS FIO Model. The effectiveness of the package of measures in reducing in-stream FIO concentrations can be assessed by testing the ADAS FIO Model predictions against robust monitored FIO data at a waterbody scale. If the ADAS FIO Model predictions for FIO reductions per waterbody agree with robust monitored data, then this is very strong evidence that the measures are effective. If the ADAS FIO Model and monitored data are poorly correlated, then monitored practice, the measures and the export coefficients predicted by the ADAS FIO Model need to be re-evaluated and adjusted to address empirical evidence. In addition, any new understanding of in-stream fate of FIO could be incorporated in the ADAS FIO Model, or help to develop new modelling tools, to improve targeting and effectiveness of measures at high-risk FIO source areas. Finally, the ADAS FIO Model can be used as a substitute for monitoring only when it is used for assessing where FIO reductions are expected; identifying suitable monitoring design and frequency for assessing effectiveness of measures; and comparing alternative management scenarios to stakeholders.

4.2 Evaluation of FIO monitoring practices to assess effectiveness of measures

The evidence-base of the effectiveness of farmland interventions for reducing FIOs in bathing (and shellfish-harvesting) waters refers mainly to farm-scale studies for single measures (Millington and Randall 2014; Randal et al. 2015). In Scotland and Europe, this is largely due to the legacy of riverine monitoring programmes that have focused on nutrients rather than bacteria and a greater focus on long-term monitoring of bathing waters (Kay et al. 2007a). In contrast, countries such as New Zealand, the USA and Canada carry out much greater spatial sampling of bacteria across catchments and their sub-catchments driven by policies for recreation in inland waters, including protection of small drinking water supplies, and therefore have a far better understanding of FIO dynamics and experience with monitoring practices. Most examples of monitoring in-stream FIO from agriculture come from these countries.

Of the 104 studies selected through literature searches on the basis of the criteria stated in the Methods, only 14 were found to be relevant to the project's objectives: four referred to FIO monitoring to assess effectiveness at the waterbody scale in Scotland and 10 further studies outwith Scotland. However, in-stream FIO concentration data are reported in a large number of studies in relation to land use, flow conditions, and point-source and urban FIO sources as well as modelling (30% of literature search results) of FIO export from single farm practices. Such data are not considered in this report.

The 14 studies can be classified into three categories with respect to their aims. The features of each study (i.e. design, waterbody size, duration of pre-implementation and post-implementation monitoring, frequency, technique and outcome) are detailed in Appendix 2a (for Scotland) and 2b (outwith Scotland).

The first category includes studies that assess effectiveness in the context of the river network transport pathways. Achieving compliance with FIO standards at receiving waters (i.e. outlet of waterbody, river catchment, or bathing waters) or model verification are the major purpose for monitoring in this category. Monitoring is carried out at the outlet of waterbodies nested within the same river catchment to account for FIO transport across the river network and FIO contribution from different source waterbodies. These studies use BACI-like approaches to factor out random variation, which is crucial in assessing effectiveness of measures in reducing pollutants. FIO monitoring takes place before and after the installation of measures and at multiple nested waterbodies to enable robust comparisons. It must be noted that designs are site-specific because of different circumstances and availability of monitoring resources.

For example, the BACI design was applied when Control and Impact water bodies had been selected for monitoring before the installation of measures on the basis of similar land use in a three-year long pre-implementation period (Meals 2001; 2004). In the absence of proper Control waterbodies (i.e. tested for similarity during a long-term pre-implementation period), comparisons can be carried out between waterbodies with livestock farming pressures that are remediated by FIO control measures (Impact) and waterbodies with pressures from arable farming and non-agricultural FIO sources (Mostaghmi 1999; Inamdar et al. 2002). Alternatively, Impact waterbodies can be compared against a reference waterbody, i.e. without farming pressures (Simon and Makarewitz 2009a; b). The monitoring details of these studies are detailed in Appendix 2b.

The aim of the studies in the second category is to understand effectiveness of measures in the context of contrasting conditions (e.g. land use, geology, and hydrology). Monitoring is carried out at the outlet of Impact waterbodies nested in separate river catchments to take account of different responses to FIO control measures and other catchment factors across a range of conditions. The data are analysed at a single waterbody scale to extract information on waterbody-specific effects of measures on FIO concentrations and to calculate export coefficients, which could be compared with modelled export coefficients. The studies are based on a trend design, i.e. examine the trend in FIO concentrations post-implementation, and thus have limited potential in distinguishing between the effects of measures and other catchment factors influencing FIO. Examples include the studies by Wilcock et al. (2007, 2013) in New Zealand and by Boyer (2005) in West Virginia, US; these studies are detailed in Appendix 2b.

The third category includes studies that assess effectiveness of measures in the context of FIO transport dynamics from farm to waterbody outlet. The aim here is to understand the linkages between farm-scale and waterbody scale effectiveness and inform catchment modelling and management. Monitoring takes place at the outlet of the waterbody but also at Impact and Control farms within the waterbody of interest before and after the installation of measures to enable robust comparisons. This enables the effects of measures on FIO source areas within a waterbody to be better understood. Examples include the studies carried out in Scotland (see section 4.3 and Appendix 2a), at the Demonstration Test Catchments (DTCs) to test the effectiveness of the Catchment Sensitive Farming (CSF) approach in England (Monitoring Highlights: River Wensum-DTCs 2010; Davey 2010; McGonigle et al. 2014; see also Appendix 2b); and at the Long Creek river catchment (Linne et al. 2003; see also Appendix 2b).

Results and monitoring practice from these studies showed that when applying the BACI design there is a need to consider:

- Year round sampling to understand the effectiveness of measures when livestock pressures are greatest (bathing season) and to assess annual FIO export to inform modelling.
- Flow monitoring to assess the year-to-year, stream-specific hydrological effects on FIOs.
- Managing and monitoring all sources of faecal pollution (livestock, domestic and wildlife) to address non-compliances with FIO standards at bathing and shellfish-harvesting waters.

It is also worth noting that turbidity has been found to be (1) a more reliable estimator of pathogenic bacteria densities in streams than FIO measured under routine monitoring, thus being a reliable proxy of FIO (e.g. Rassmussen and Ziegler 2003; Davies-Colley et al. 2008); and (2) a useful supplementary measurement to explore whether FIO export is related to turbidity and sediment. This is because storm-flows can export up to 98% of the annual Escherichia coli load from agriculture but represent only 6-30% of routine monitoring (e.g. McKergrow and Davie-Colley 2010; Muirhead 2015). The relationship between turbidity and FIO can be explained in two ways. Firstly, the factors influencing turbidity i.e. the rise of turbidity in relation to sediment losses from land to streams and stream-bed resuspension during storm-flows. Secondly, the behaviour of FIO (e.g. coliform bacteria can be transported, while attached to sediment particles, downstream and persist in stream-bed sediments for over a year before being mobilised during storm events (e.g. Koirala et al. 2008).

Turbidity in relation to FIO can be sampled in two ways, depending on the scope of monitoring.

- Using turbidity as a proxy involves in situ continuous measurements of turbidity and flow at several sites across a hydro-climatic region or river basin, which are tested against fortnightly or monthly FIO samples collected during a year (e.g. Rassmussen and Ziegler 2003). This can help estimate the relationship between turbidity and FIO concentrations and derive FIO estimates for unmonitored sites within the river basin and unmonitored storm events and provide real-time assessment of compliance with FIO standards (e.g. Rassmussen and Ziegler 2003).

- Using turbidity or suspended sediment concentration as a supplementary measurement involves concurrent measurements of turbidity or sediment and FIO with spot or composite automated sampling, depending on what sampling technique is applied at a specific site. This helps understand FIO dynamics in relation to in-stream sediment concentrations and the effectiveness of measures in reducing sediment losses in runoff, as evidenced by the majority of the studies considered in this section (e.g. Meals 2001; Linne et al. 2003; Wilcock et al 2007; Simon and Makarewitz 2009a;b; Wilcock et al 2013).

4.3 FIO monitoring data in Scotland's sub-catchments with livestock pressures

The four studies referring to waterbody scale FIO monitoring in Scotland show that the effectiveness of the package of measures currently implemented to reduce FIO in streams draining agricultural areas has not yet been explicitly monitored. The four studies refer to FIO concentration data at the sub-catchment scale from preliminary appraisals of the effectiveness of a range of field and steading measures piloted in 2004 to reduce FIO from livestock farming areas to achieve compliance in bathing waters. It must be noted that the term sub-catchment in these projects corresponds mainly to sub-catchments draining a farm nested within a waterbody (as in SEPA's baseline waterbodies). Data integrated to waterbody scale are also reported and therefore these four studies merit further consideration in this report.

These preliminary appraisals were based on a BACI approach with multiple Impact farm sub-catchments and waterbodies nested in the same river catchment and one Control farm sub-catchment or waterbody in a different or the same river catchment (see Appendix 2a for details). In the most extensive of these pilot studies, Kay et al. (2005) monitored FIO concentrations for one month during the winter before and the summer after the installation of measures on 48 livestock farms, so-called Pilot Farms, spread over four regions. The regions being the Sandyhills and Nairn catchments where fencing-based measures were installed to exclude livestock from stream margins; and in the Ettrick and Cessnock catchments, where steading-based measures to control drainage from farmyards were installed. A more detailed version of the Pilot Farms project was carried out at a farm- and waterbody-scale at Brighouse Bay (SW Scotland) bathing water catchment (Dickson et al. 2005; Kay et al 2007b; Kay et al 2008a). FIO concentrations were monitored immediately before and after the installation of measures and again in the summer three years after installation; monitoring included four samples per week during low flows (baseflow) along with samples during and after rainfall events.

These pilot projects concluded that:

- The measures have the potential to reduce FIOs at the farm sub-catchment scale but the response varies with the waterbody and the river catchment.

- Year-to-year, storm-flow FIO concentrations and data from multiple Impact farm sub-catchments and waterbodies are required for a rigorous statistical analysis to draw firm conclusions on effectiveness.

- Using one Control waterbody affords the opportunity for comparisons in both pre- and post-implementation periods between Control and Impact waterbodies. However assessments of effectiveness would be conditional on the FIO concentrations at the selected Control waterbody. If FIO concentrations decrease in the post-implementation period at the selected Control site because of drier conditions, reduction in numbers of livestock or any other random background processes, then FIO reductions in response to measures at the Impact sites can be detected only when these reductions are higher than those at the particular Control site. On the other hand, if FIO concentrations increase at the Control site compared to Impact sites because of wetter conditions, increase of stocking rates and other background processes, then this will result in misleading conclusions about the effects of measures on reducing FIO at the Impact sites.

To sum up, the data derived from these preliminary appraisals are unsuitable to provide credible evidence of effectiveness at the waterbody scale and test the ADAS Framework Model predictions of FIO reductions in response to measures because these studies:

- Are based on very few samples before and after the installation of measures.
- Use only one Control site per river catchment.
- Refer to uptake of measures on a pilot basis and not 100% uptake as assumed by the ADAS FIO Model.
- Use FIO data mainly referring to farm-scale implementation of measures and very few data referring to the combined implementation of measures at the waterbody scale, as currently carried out in Scotland.

4.4 Evaluation of proposed monitoring

The proposed monitoring draws upon a multiple-catchment BACI approach in line with the guidance provided in an earlier CREW report to inform SEPA's strategy to monitor change in water quality in response to the implementation of the Rural Diffuse Pollution Plan (Akoumianaki et al. 2016a). In the light of evidence presented in sections 4.2 and 4.3 and in Appendix 2, this section discusses the strengths, weaknesses, opportunities and threats (SWOT) of the proposed approach with respect to:

- Monitoring at a waterbody scale (section 4.4.1).
- Selecting waterbodies to represent land use in NE and SW Scotland (4.4.2).
- Statistical design, number of waterbodies and duration (section 4.4.3).
- Frequency and technique (section 4.4.4).
- Collection of supplementary catchment data (section 4.4.5).

4.4.1 SWOT of the proposed approach to monitoring FIO at a waterbody scale

The strengths of waterbody scale monitoring can be summarised as follows:

- The waterbody provides an area that is large enough to capture complex processes influencing FIO sources and transport, yet small enough to focus on land use, agricultural and non-agricultural pressures and measures implemented at that scale.

- A higher potential for detecting FIO change within the programmed duration of monitoring (i.e. four years). Meals and Dressing (2016) state that where documentation of the effects of diffuse pollution mitigation measures on water quality is a critical goal, the duration of monitoring required to detect the expected improvements can be minimised by focusing on small waterbodies with the waterbody outlet being close to pollution sources.

- The waterbody scale is ideal for collecting baseline FIO data before the installation of measures.

The weaknesses of waterbody scale monitoring include:

- Lack of hydrological connectivity as waterbodies are not intended to be part of the same river network thus precluding understanding of FIO linkages according to the source-pathway-receptor model across a river catchment.

- Lack of monitoring at the sub-catchments draining Impact and Control farms nested in the same waterbody in parallel with monitoring at the outlet of this particular waterbody. This precludes understanding of the high risk areas for FIO losses within the monitored waterbody. Thus, FIO reduction at the waterbody outlet could not be linked to specific measures and conditions (e.g. slope, farmer behaviour) at the farm-scale.

The opportunities pertinent to the proposed waterbody scale monitoring include:

- Selecting waterbodies that are hydrologically connected and nested in the same drinking water, bathing water or shellfish harvesting catchment to enable understanding of FIO sources and transport in relation to compliance with FIO standards in receiving waters, or

- Selecting waterbodies nested in an area with uniform land use, geology, hydrology, climate/weather and policy designations to enable understanding of effectiveness against a narrow range of background variation and policies.

The threats to waterbody scale monitoring include:

- Lack of regulatory drivers as FIO standards for bathing and shellfish harvesting waters.

- Cost as the monitoring to detect change in response to rural diffuse pollution measures requires high frequency and long-term monitoring before and after the installation of measures (see also Appendix 2).

4.4.2 SWOT of the proposed approach to selecting waterbodies to represent land use in NE and SW Scotland

The strengths of selecting three waterbodies to represent land use in each of the NE and SW of Scotland are:

- It allows the collection of baseline FIO data in the selected waterbodies.
- The widespread geographical distribution of monitoring sites under a limited budget.

The weaknesses and threats of the recommended approach to representing land use include:

- Very little gain is expected from this approach when it is already known that the waterbodies are different, as they represent different conditions, and therefore are expected to have different responses to measures (as previous studies in Scotland have also indicated, see Section 4.3).

- Waterbodies being nested in separate river networks lying far apart, will be subject to different, most likely unquantified and unknown hydrological and climate/weather processes. The interpretation of effectiveness is therefore taken out of the hydrological and climatic/weather context of a river network or a uniform area with a narrow range of background variability and may result in misleading interpretations of FIO change.

The opportunity of the proposed approach to representing land use is that the waterbodies can be nested in an area with uniform land use, geology, hydrology, climate/weather, and policy designations. This will enable meaningful comparisons between Impact and Control waterbodies, as these waterbodies will be representing a narrow range of conditions, and effectiveness of measures will be evaluated against a narrow range of background catchment variation and policies. However, it is important to note that selecting waterbodies nested in one catchment or an area of uniform conditions precludes the geographic spread of FIO monitored data.

4.4.3 SWOT of proposed statistical design, number of waterbodies, duration

Before analysing the strengths and weaknesses of the proposed BACI design it is worth noting that the BACI approach assumes and requires the existence of a quantifiable relationship between Impact and Control FIO data in the pre-implementation period and that this relationship holds until the introduction of measures. After the introduction of measures, the relationship between Control and Impact FIO data will change and the effect of the measures is measured as the difference between the pre- and post-implementation relationships (Meals 2001). Therefore the selection of Control waterbodies to factor out the effect of random variation on interpreting the effects of measures at Impact waterbodies should be based on sufficiently long-term pre-implementation monitoring.

The strengths of the proposed BACI design with the given number of waterbodies and pre- and post-implementation duration depend on meeting four conditions: (1) similarity between Control and Impact waterbodies established during sufficiently long-term pre-implementation monitoring; (2) selecting multiple Impact and Control waterbodies nested within an area that is influenced by uniform hydrology and climate/weather conditions; (3) monitoring for longer than four years post-implementation, to allow the measures to bring about in-stream changes (Akoumianaki et al. 2016a); and (4) monitoring at waterbodies with minimal or known FIO contributions from domestic (Waste Water Treatment, Septic Tanks) and wildlife sources of faecal pollution (Simon and Makarewicz 2009a;b).

If the above conditions are met, the strengths of the proposed BACI design include the ability to:

- Factor out random variation and quantify change in FIO concentrations in response to measures.
- Provide the evidence-base required for testing the ADAS FIO Model predictions.
- (In combination with supplementary catchment data) Feed into the Weight-of Evidence approach developed to evaluate the effectiveness of the Rural Diffuse Pollution Plan (Akoumianaki et al. 2016a;b).

However, the proposed BACI design does not meet the above mentioned conditions and has additional weaknesses, as follows:

- Given the lack of baseline or long-term pre-implementation FIO data it is uncertain on what basis Control and Impact waterbodies nested in separate river catchments could be considered as similar with respect to FIO concentrations in relation to land use, flow, slope, and soil types.

- Three waterbodies per land use type (livestock or mixed farming) per area (NE or SW) have limited potential to provide a reliable representation of management practices, rainfall, soil type, slope and septic tank numbers and allow for an understanding of the response to measures across the broad spectrum of landscape, hydrological and climatic/weather conditions in NE and SW Scotland.

- The differences in FIO concentrations between waterbodies nested in separate river catchments across a range of flow regimes and climate/weather conditions are likely to be larger than the changes in response to measures.

- Sampling for only one bathing water season pre-implementation and at only one Control waterbody fails to account for year-to-year variation in rainfall, flow, and land use, and control for waterbody-specific processes influencing FIO in streams in the absence of measures.

- Selected waterbodies are not directly linked to bathing waters, thus their monitoring is not linked to policy objectives.

- Failing to distinguish between the effects of measures and other catchment factors influencing in-stream FIO concentrations may provide a misleading basis for testing the ADAS FIO Model predictions.

The opportunities of the proposed design are given below:

- The waterbodies could be nested in a uniform area in terms of catchment conditions (i.e. land use, soil types, flows, rainfall, weather). The differences between Impact and Control waterbodies because of catchment conditions are likely to be smaller than the differences caused by the implementation of measures. This will enable the effects of measures to be detected against background variation, or

- The waterbodies could be nested in the same river catchment; the differences between monitored waterbodies will help understand FIO contribution to receiving waters from different source areas within the river network.

- The proposed design with waterbodies nested in NE and SW Scotland is suitable to assess the trend of FIO post-implementation in the selected waterbodies and not to apply the BACI design. In this respect, it is possible to assess effectiveness of measures by monitoring FIO at multiple Impact waterbodies post-implementation (Impact trend approach) without the need for comparisons against long-term pre-implementation data or from Control waterbodies or selecting waterbodies nested in the same river catchment or a uniform area. Several statistical techniques have been developed to deal with non-linear trends of pollutants.

- The monitored waterbodies could be nested in areas characterised as a lower policy priority, where the installation of measures to mitigate FIO from livestock is programmed to take place after a year or longer, thus allowing for sufficient duration of pre-implementation monitoring.

- Year-round sampling to enable understanding of FIO dynamics and in-stream survival.

The threats facing the proposed design are listed below:

- Need for long-term monitoring with uncertain potential for distinguishing between the effects of measures and other catchment factors. Studies in New Zealand have shown that the Impact trend approach requires monitoring for much longer than ten years at a fortnightly or monthly frequency and in conjunction with continuous flow monitoring to allow for flow-adjustment (Wilcock et al. 2007; 2013).

- Need for advanced statistical analyses to asses effectiveness of measures. Scott et al. (2011) studying the suitability of the trend design to demonstrate effectiveness of measures in reducing phosphorus, showed that long-term (twenty years in their case) trends are difficult to quantify without consistent long-term monitoring strategies (i.e. using the same sampling techniques and analytical methods to assess types and locations of different sources of a pollutant within the river network,) and require statistical methods capable of identifying change-point and nonlinear responses. In addition, flow adjustment was deemed mandatory for examining these trends.

- Requirements for increasing the monitoring budget to enable samples to be taken year-round.

To sum-up, the proposed BACI design is unsuitable for reliably detecting change in FIO concentrations between before and after the installation of measures and assessing their effectiveness in reducing FIO by the percentage predicted by the ADAS FIO Model. However, the proposed design can be improved to help to assess effectiveness and test the ADAS FIO Model predictions but will require funding and resources for year-round monitoring, and advanced statistical analyses. It also requires targeting of monitoring in an area of uniform, narrow range of catchment conditions, and outwith areas prioritised under the Bathing Water Directive to allow a longer-term pre-implementation monitoring.

4.4.4 SWOT of proposed sampling frequency and technique

The major strength and opportunity of the proposed sampling frequency and technique is its suitability to reliably assess changes in FIO concentrations across the range of flows in a waterbody.

However, there are weaknesses and threats, such as:

- The proposed sampling frequency is different from what has been described in peer-reviewed literature. For example Francy (2000) prescribes monthly sampling to be complemented by event-based (storm-flow) sampling on a year-round basis. Simon and Makarewicz (2009a;b) report weekly FIO spot sampling supplemented by high-frequency autosampler data taken during storm-flow events year-round.

- The proposed technique is slightly different from what is described in the peer-reviewed literature. For example, analysis within six hours from sampling is described by Simon and Makarewicz (2009b) and within 3-4 hours by Tetzlaff et al (2012). Collection of 6-hour composite samples during storm-flows is reported by Simon and Makarewicz (2009a).

- It is uncertain whether the pre-programmed automated sampling will capture all storm-flows (i.e. the event hydrograph). There is a risk of misrepresenting FIO concentrations during storm-flow conditions if the fixed-day sampling fails to capture the event hydrograph and construct the flow duration curve of the particular waterbody. The only credible way of knowing this is to carry out continuous flow measurements at FIO sampling sites, as already planned by SEPA. In addition, monitoring should take into account that storm-flows happen when the rate of rise of stream level increases. The flow threshold for storm-flows therefore, may differ from year-to-year and waterbody-to-waterbody with storm-flows possibly being as low as elevated baseflows in relatively dry years or locally at the waterbody scale (e.g. Simon and Makarewitz 2009a).

- Spot sampling monitoring in the stream cross-section and vertically is required to calibrate automated samples and ensure they are representative of in-stream flow variation (e.g. vertically and in the cross-section) as suggested by Francy (2000).

- The 24-hour gap between collection and analysis may be even longer for some of the 15-minute sub-samples collected to compose the 24-hour composite sample and this may bias laboratory analyses.

- Monitoring only during bathing water season fails to quantify FIO contribution from winter and thus has the potential to bias understanding of FIO change, or lack of, and comparisons between monitored data from one season and model predictions on an annual basis.

These considerations show the need for selecting Control and Impact waterbodies not only on the basis of livestock pressures and uptake of measures but also of existing flow-gauging.

4.4.5 SWOT of proposed collection of supplementary catchment data

The strengths and opportunities of the collection of supplementary data include:

- Ability to enable the factors influencing FIO from agriculture to be better understood in the context of catchment data.
- Use of the Weight of Evidence methodology (Akoumianaki

et al. 2016b) to assess direction of travel of the rural diffuse pollution measures in the monitored waterbodies.

The weaknesses and threats include:

- Potentially, lack of significant (quantitative) change in catchment data between and after the installation of measures or lack of monitored catchment data (e.g. it might not be possible to collect data of septic tank density or wildlife FIO contributions). This will preclude understanding and testing of potential cause-effect relationships between FIO sources and in-stream FIO concentrations.

4.4.6 Decision on the suitability of the proposed monitoring

In the light of the evidence-base on monitoring, and given the mentioned caveats, it is concluded that the proposed scale, frequency, technique and collection of supplementary data are suitable to enable a reliable assessment of FIO variation at the waterbody scale. However, the proposed design, pre-implementation monitoring duration and bathing season only sampling are unsuitable to reliably assess the effectiveness of measures against background variation. The conclusions are summarised in Table 2.
Overall, the strengths of the proposed monitoring can be summarised as follows:

- Collection of baseline data (during low- and storm-flow) and year-to-year data post-installation.
- Covering a widespread geographical distribution of monitoring sites under a limited budget.
- Collection of waterbody data to enable interpretation of change, or lack of, in FIO data.

The weaknesses and threats of the proposed monitoring include:

- Short duration of pre-implementation monitoring precluding robust Before-After comparisons.
- No year-round monitoring of FIO for estimation of annual FIO loads, as in the ADAS FIO Model.
- No potential to factor out random variation because of using one Control waterbody per land use type and Impact waterbodies influenced by a range of practices and unquantified processes.
- No accounting of FIO transport processes across the waterbody and river catchment network.

Table 2. Evaluation of the proposed monitoring.

Proposed Monitoring	Description	Evaluation
Scale	Waterbody/In-stream	Suitable
Design /Statistical analysis	BACI with one Control and two Impact waterbodies in SW Scotland (livestock farming) and in NE Scotland (mixed farming).	Unsuitable
Duration	Up to a year before and four years after installation of measures in bathing season.	Unsuitable
Frequency /Technique	Twice a week / 24-hr composite samples collected with autosamplers.	Suitable
Catchment data	Land use/management, rainfall, waste water treatment and septic tank densities, as in the Weight of Evidence method, and phosphorus, sediment data	Suitable

5.0 Implications – Recommendations

5.1 What modifications are required to minimise the weaknesses of the proposed monitoring?

The weaknesses of the proposed monitoring should be modified to provide opportunity for:

- Selecting waterbodies where installation of mandatory measures is of lower priority and programmed for the end of 2017 thus allowing for a longer than one year pre-implementation monitoring, if monitoring starts within 2016. This implies that monitoring will be carried outwith bathing water catchments, which are prioritised for immediate installation of measures. However, if demonstrating effectiveness of measures in reducing FIO in bathing waters is a critical goal of monitoring, then the selected waterbodies should be nested in the same bathing water catchment to address FIO dynamics within the river network, despite the fact that there is no opportunity for sufficient pre-implementation monitoring.

- Detecting FIO change against a narrow range of background variation, i.e. uniform catchment conditions.

- Addressing policy needs i.e. demonstrating FIO reductions at sites with the greatest livestock pressures in Scotland.

- Year-round monitoring of FIO concentrations for a reliable representation of FIO dynamics.

The proposed monitoring includes six waterbodies. There is no specific need for modifying the number of waterbodies to be monitored. In addition, the number of waterbodies taken forward for FIO monitoring depends on many factors such as the design (e.g. need for replicate waterbodies to represent the range of catchment conditions over Scotland); the availability of monitoring resources (e.g. staff, autosamplers); and policy priorities (e.g. the package of measures may need to be installed in waterbodies formerly considered as Control).

An additional consideration for the number of waterbodies to be monitored is that monitoring should be carried out where the FIO change predicted by the ADAS FIO Model can be detected with four to eight years of monitoring according to sample-size analysis as in Akoumianaki et al. 2016a[2].

[2] Sample size analyses (i.e. number of samples required to predict a given % of change) were performed on the basis of in-stream phosphorus, sediment and ammonium data collected on a monthly basis and FIO data from bathing water compliance monitoring but not on FIO data from streams with 24-hr composite samples collected twice a week.

5.2 Recommendations

In consultation with staff from SEPA and the James Hutton Institute, who attended the workshop on 30th September 2016, it is recommended that the Solway area has the potential to provide the above mentioned opportunities (the SWOT analysis of the Solway monitoring as developed during the workshop scenario is presented in Appendix 4). The three main reasons for recommending the Solway area for FIO monitoring are:

- It is characterised by uniform conditions in terms of land use (i.e. livestock farming), non-agricultural pressures, geology, rainfall and protection areas and thus enables the effect of FIO measures in Impact waterbodies to be assessed against a narrow range of background variation and policies.
- It enables the assessment of effectiveness of FIO measures to be targeted and tested against the ADAS FIO Model predictions at sites with the greatest livestock pressures in Scotland.
- It is programmed for installation of mandatory measures at the end of 2017 thus allowing for a longer than one year pre-implementation monitoring, if monitoring starts within 2016.

It is also recommended to monitor three Impact and three Control waterbodies in the Solway area to apply the BACI design to distinguish the effects of measures and other catchment factors on FIO concentrations. A potential threat to the BACI design is the lack of appropriate Control waterbodies within the Solway area, i.e. Control waterbodies may be managed under similar practices as the Impact waterbodies.

A way of minimising this threat is to apply the trend analysis in Impact waterbodies to enable the long-term effects of the catchment factors (including the effects of measures) influencing faecal contamination to be tracked and assessed at the selected waterbodies. The trend analysis is suitable for capturing a gradual maturation of the measures, either because of gradual uptake by the farmers of a catchment or because of catchment behaviour, FIO legacy and other catchment-specific variations in transport and retention of FIOs in streams. It would be difficult to detect a step-change between before and after the implementation of measures examining a trend alone. For this reason, the Trend design is unsuitable for reliably assessing when, where, why and what measures are working or not.

Making the best of the recommendation for FIO monitoring in the Solway area requires:

- Reliable continuous flow-measurements collected at the same site/waterbody as the FIO samples to enable flow adjustment of FIO concentrations.
- Detailed year-to-year monitoring of waterbody/catchment data to enable assessment of all sources and causes of FIO change, or lack of, at a waterbody scale, as prescribed for the Weight-of-Evidence approach (Akoumianaki et al. 2016b); non-agricultural FIO sources (e.g. septic tanks, wildlife) and nutrient and suspended sediment (or turbidity) data must be also carefully assessed.
- Use of consistent monitoring (sampling technique, frequency, site) and analytical methods.
- Use of statistical methods capable of identifying step-change, change points along a trend and non-linear FIO responses to catchment change.
- Sufficient duration of pre-implementation (i.e. longer than one year, if possible) monitoring data to enable a comparison of FIO concentrations between before and after the installation of measures.
- Year-round monitoring to capture all sources of catchment change.

Monitoring FIO concentrations at the waterbody scale in the Solway area provides the additional opportunities for SEPA to:

- Quantify FIO change in response to measures at the selected waterbodies using the BACI and/or trend analysis.
- Understand when, where, why and what measures are working, or not.
- Transfer this understanding to improve and adjust:
  - o Management in other waterbodies with similar measures in place and land use pressures.
  - o Expectations based on the ADAS FIO Model predictions for FIO reductions.
- Develop synergies with the Main Research Providers (MRPs) supported by Scotland's Strategic Research Programme. More specifically, JHI-based research teams can use SEPA's FIO monitored data to develop, test and apply a range of novel modelling and statistical tools to support and improve the implementation and effectiveness of the Rural Diffuse Pollution Plan.

Table 3. Recommendation for in-stream FIO monitoring at the waterbody scale in Scotland.

Proposed Monitoring	Description
Design/Statistical analysis	Before-After/Control-Impact (BACI) with three Control (if possible) and three Impact waterbodies nested in the Solway area to represent land use dominated by livestock farming and enable the effect of FIO control measures in Impact waterbodies to be assessed in a uniform area against a narrow range of background variation.
Duration	One year before and four years after installation of measures; Year-round sampling.
Frequency /Technique	Twice a week / 24-hr composite samples collected with autosamplers.
Catchment data	Land use (livestock numbers, fertiliser application), rainfall, waste water treatment and septic tank densities as in the Weight of Evidence methodology.

6.0 Conclusions

There is a need for empirical FIO data at the waterbody scale to provide credibility to assessments of the effectiveness of the combination of DP GBR and SRDP measures in reducing in-stream FIO concentrations and to test the ADAS FIO Model predictions. The key findings show that:

- Both FIO monitoring and modelling are required to assess effectiveness of measures in Scotland:
  - Monitoring is essential in providing baseline FIO data; documenting FIO variations in response to measures and catchment change; providing data to test the ADAS FIO Model predictions and support novel modelling; and providing credibility to assessments of effectiveness.
  - The ADAS FIO Model is essential in calculating source apportionment; identifying critical source waterbodies for prioritising the measures and FIO monitoring; predicting FIO loads and reductions as a hypothesis that needs to be tested against monitored FIO data; and analysing the cost-effectiveness of alternative management and monitoring frequency scenarios.

- The ADAS FIO Model can be used as a substitute for monitoring only when it is used for assessing where FIO reductions are expected; identifying a suitable monitoring design and frequency; and comparing alternative management scenarios to stakeholders to support decision making.

- Detecting and quantifying change in in-stream FIO concentrations between before and after the installation of measures requires credible monitored evidence of (1) FIO during low- and storm-flows; (2) year-round variations of FIO and flow; and (3) year-to-year variation in FIO and flow through long-term monitoring, with more than one year pre-implementation sampling.

- There is no waterbody-scale FIO monitored data suitable to assess the effectiveness of the package of measures currently implemented in Scotland and test the ADAS FIO Model predictions.

- The strengths of the proposed monitoring include:
  - Collection of baseline data (during low- and storm-flow) and year-to-year data post-installation.
  - Covering a widespread geographical distribution of monitoring sites under a limited budget.
  - Collection of waterbody data to enable interpretation of change, or lack of, in FIO data.

- The proposed monitoring is not suitable to assess effectiveness of measures in Scotland because of:
  - Short duration of pre-implementation monitoring precluding robust Before-After comparisons.
  - No year-round monitoring of FIO for estimation of annual FIO loads, as in the ADAS FIO Model.
  - No potential to factor out random variation because of using one Control waterbody per land use type and Impact waterbodies influenced by a range of practices and unquantified processes.
  - No accounting of FIO transport processes across the waterbody and river catchment network.

- FIO monitoring should be carried out with the proposed frequency/technique on a year-round basis in the Solway area (in three Impact and three Control waterbodies, if possible) because this area:
  - Is characterised by uniformity in terms of land use (i.e. livestock farming), non-agricultural pressures, geology, rainfall and protection areas and thus enables the effect of FIO control measures in Impact waterbodies to be assessed against a narrow range of background variation.
  - Enables the assessment of effectiveness to be targeted and tested against the predictions of the ADAS FIO Model and novel modelling at sites with the greatest livestock pressures in Scotland.
  - Is programmed for installation of mandatory measures at the end of 2017 thus allowing for a longer than one year pre-implementation monitoring, if monitoring starts within 2016.

This project evaluated the available evidence-base on in-stream FIO monitoring and the key findings were discussed at a workshop with SEPA to enable feasible recommendations to be developed and agreed. FIO monitoring at the Solway area on a year-round basis with the proposed frequency and technique (twice a week with 24-hr composite samples) has the potential to provide robust data to assess the effectiveness of the Rural Diffuse Pollution Plan in Scotland. In addition, the findings of this report will inform SEPA's strategy on the optimum use of monitoring and modelling for the assessment of current rural diffuse pollution package of measures.

The questions and answers provided in the present study can be summarised as follows:

Is monitoring required? Could the ADAS FIO Model be used as a substitute for monitoring?	Both FIO monitoring and modelling are required to assess effectiveness of measures in Scotland.
When can the ADAS FIO Model substitute for monitoring?	When used for assessing where FIO reductions are expected; guiding monitoring design / frequency; comparing alternative management scenarios to involve stakeholders.
What are the lessons learned from FIO monitoring in Scotland and elsewhere?	Need for credible evidence to detect FIO change in response to measures by sampling low-flow and storm-flow FIO concentrations; monitoring on a year-round basis and for at least one year pre-implementation.
Is there any FIO monitored waterbody data suitable for testing the ADAS FIO Model predictions in Scotland?	No, available data refer to short-term FIO data at the scale of waterbody and under varied uptake of mandatory measures.
Is the proposed monitoring suitable for assessing effectiveness in the monitored catchments? Why not?	There are suitable and unsuitable elements: **Suitable:** Sampling frequency/technique, duration of post-implementation monitoring and collection of supplementary catchment data. **Not suitable:** The design / statistical analysis and duration of pre-implementation monitoring because they fail to factor out random and unquantified variation between waterbodies.
What modifications (simple/low cost) could help provide robust evidence?	Monitoring of FIO concentrations at Control and Impact waterbodies nested in the Solway area on a year-round basis.

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Appendix 1. Measures included in the package of measures and used as keywords in literature searches.

Field and steading GBRs:	SRDP measures relating to:
fencing-off watercourses to prevent livestock access	enhanced riparian buffer strip with fencing;
avoiding manure application at high risk times	bridging of fords on livestock tracks
delaying of livestock turn out on fields vulnerable to poaching	increased slurry storage capacity
preventing contaminated runoff from yards	constructed farm wetlands for yard runoff
achieving recommended levels of manure N-efficiency	constructed farm wetlands for field drainage

Appendix 2. Categories of studies monitoring in-stream FIO to assess the effectiveness of measures in reducing FIO from livestock sources.

Appendix 2a. Monitoring features of studies assessing effectiveness of measures implemented in Scotland.

Studies assessing effectiveness in the context of understanding linkages between farm-scale implementation and water-body –scale FIO reductions in Scotland (as of Category 3 in section 4.2)	
Pilot Farms project	
Sandyhills and Nairn catchments Kay et al. 2005	**Design:** Control and Impact (i.e. where fencing-based measures were installed) farms nested within a catchment at Nairn, Control farms were nested within Nairn catchment. **Duration:** one month in Winter before the installation of measures and one month in the Summer after the installation of measures; no bathing season data before the installation of measures. **Frequency/Technique:** Not explicitly reported but FIO concentrations were recorded during low- and storm-flows. However, no storm-flows were monitored pre-implementation at Nairn. **Outcome:** Sandyhills: Effectiveness is proportional to fencing intensity. Nairn catchment: No clear relationship of FIO concentrations with intensity of fencing.
Ettrick and Cessnock catchments Kay et al. 2005	**Design:** Control and Impact (i.e. where steading-based measures were installed) farms nested within a catchment; no details about the characteristics of the Control farm or catchment. **Duration:** one month in Winter before the installation of measures and one month in the Summer after the installation of measures; no bathing season data before the installation of measures. **Frequency/Technique:** Not explicitly reported but FIO concentrations were recorded during low- and storm-flows. **Outcome**: Ettrick: data are suggestive of a relationship between FIO concentrations and remediation intensity Cessnock: no measurable effect of measures.
Bidgehouse Bay Dickson *et a*l. 2005 *Kay et al.* 2007b; *Kay et al.* 2008a	**Design:** One Control waterbody and Impact farms nested within a separate (Impact) waterbody. **Duration:** One month in the period before the installation of measures and one month in the year after the installation of measures and three years after the installation of measures. **Frequency/Technique:** Four samples per week during low flows along with samples during and after rainfall events **Outcome:** 30% reduction in FIO at the farm scale the first year post-implementation but no effects three years post-implementation; no significant effects at the outlet of Impact waterbody.

Appendix 2b. Monitoring details of studies assessing effectiveness of measures outwith Scotland.

1. Studies assessing effectiveness of FIO measures in the context of achieving compliance with FIO standards at receiving waters	
Conesus Lake catchment (US) **Reference:** Simon and Makarewicz 2009a; b monitoring technique: Makarewitz et al. 2009	**Design:** Three Impact waterbodies (area: 1 - 5 km2) and one waterbody without livestock pressures as a reference site (area: 18 km2) nested in Conesus Lake catchment. **Duration:** Nine months to one year pre-implementation and four to five years of post-implementation monitoring. **Frequency/Technique:** Weekly spot sampling and storm-flow automated samples year-round. **Outcome:** Indication of FIO reductions to levels similar to those at Reference waterbody.
Owl Run river catchment (US) **Reference:** Mostaghimi et al. 1999; Inamdar et al. 2002	**Design:** Monitoring at four waterbodies (area: 0.5 – 5 km2) within Owl Run River catchment to distinguish between waterbodies managed with cropland-related measures, livestock-waste targeting measures and urban pressures. **Duration:** 30 months pre-implementation / ten years post-implementation. **Frequency/Technique:** Twice-a-month spot sampling year-round. **Outcome**: Statistically significant reductions at the outlet of river catchment but not at a waterbody scale.
Missiquoi River basin (US/ Canada) **Reference** Meals 2001; 2004	**Design:** BACI design / monitoring at the outlet of one Control waterbody (area: 10 km²) and one Impact waterbody (area: 14 km²) nested in the Missiquoi River basin. **Duration:** Three years pre-implementation /one year post-implementation. Frequency/Technique: twice-a-week spot sampling year-round. **Frequency/Technique:** twice-a-week spot sampling year-round. **Outcome:** 40% reduction in the first year after the installation of measures.
2. Studies assessing effectiveness of FIO measures in the context of contrasting conditions (e.g. land use, geology, hydrology).	
New Zealand **Citation:** Wilcock et al. 2007; 2013	**Design:** Waterbodies (area: 6 - 41 km²) nested in separate river catchments across a range of conditions. **Duration:** Seven to longer than ten years. **Frequency/Technique:** Fortnightly and monthly after the first year of monitoring. **Outcome:** Variable. Significantly decreasing trends not directly related to measures.
West Virginia, US **Citation:** Boyer 2005	**Design:** Waterbodies (area: 5 - 14.5 km²) nested in W. Virginia but not hydrologically connected. **Duration:** Four years and 13 years post-implementation varying with waterbody. **Frequency/Technique:** Monthly spot sampling. **Outcome**: Little evidence of improvement (increasing trend in faecal coliforms).
3. Studies assessing effectiveness in the context of understanding linkages between farm-scale implementation and waterbody –scale FIO reductions	
England, UK Davey 2010; McGonigle et al. 2014; CSF Team-Natural England 2014; Monitoring Highlights 2010	**Design:** Control and Impact farms nested within a waterbody (area: 10 km²) as in BACI **Duration:** Four to six years pre-implementation / ongoing post-implementation. **Frequency/Technique:** Not explicitly reported – Automated sampling every 7 hours at waterbody outlet for all pollutants year-round. **Outcome:** Not explicitly reported.
Long Creek river catchment (US) Line 2003	**Design:** Upstream (Control) versus downstream (Impact) pastures nested in the same waterbody (area: 1 km²) **Duration:** two and half years pre-implementation and five years post-implementation. **Frequency/Technique:** Weekly spot sampling. **Outcome**: Effectiveness of measures demonstrated at Impact sites.

Appendix 3. Brief description of monitoring of the studies used for model verification

Two studies have been used for model verification. Both studies refer to land use pressures in the absence of diffuse pollution mitigation measures (i.e. referring to pre-implementation situations).

The most extensive of the studies by Kay et al. (2008a) included monitored FIO concentrations from 15 river catchments (7 in Scotland) with a total of 205 monitored sub-catchments (50 in Scotland) with different land uses (urban, improved grassland, rough grazing and woodland) for 6-8 weeks during the bathing water season and, in some cases in winter, at some time from 1995 to 2005.

The other study by Tetzlaff et al (2012) included faecal coliform monitoring at several locations in two catchments in North East Scotland (the Dee and North Esk) with varying proportions of improved pasture at approximately weekly intervals between October 2008 and September 2009.

The ADAS FIO Model underestimated storm-flow data and overestimated baseflow data by Kay et al (2008a) while it weakly ($R2=0.38$) correlated with the data by Tetzlaff et al. (2012).

Appendix 4. SWOT analysis of the recommended monitoring in the Solway area

(as documented during the workshop on 30th September held in JHI, Aberdeen).

Strengths

- Baseline data for understanding FIO dynamics and verify/improve model
- Sufficient replication for Impact and control conditions from a homogeneous area in terms of land use, geology, soils, rainfall
- Year-round sampling: understanding of winter FIO contribution
- One year pre-implementation data, i.e. much longer than in the proposed scenario
- Solway area: Baseline/high-frequency data from an area with significant livestock pressures (important to demonstrate effectiveness where pressures are greatest)
- Minimisation of risks related to monitoring design being applied to test effectiveness (depending on hypotheses and findings): BACI, only After Impact trend, Before-After in each sub-catchment , can be applied to test effectiveness

Weaknesses

- Selected Impact sub-catchments not linked to BW Catchment pressures (low political interest)
- Monitored sub-catchments only in one geographic area (low political interest)
- One-year pre-implementation data, i.e. possibly not sufficient to characterise variability before installation of measures and identify step-change with BACI
- No accounting of river network processes: no connectivity between Control and Impact sub-catchments

Opportunities

- Added value:
  - Potential for links to research on effectiveness of measures under RESAS
  - Data may generate ideas/new projects/collaborations
- BACI=robust (not confounding of effects of measures by differences in land use, geology, soils, rainfall across a whole region) + 1 Impact vs 3 Control
- Possible to examine After Only Trend if the measures are to be placed in sub-catchments initially taken forward as Control (E.g. New Zealand example)
- Possible to examine step-change (Before-after) and Before-After trends (as in Owl Run River Example) at each sub-catchment separately if the measures are placed in sub-catchments initially taken forward as Control or Control sub-catchments are extensively managed with SRDP measures
- Availability of statistical tools to examine change points and non-linear response to measures

Threats

- Potential bias due to gradual uptake of both GBR and SRDP measures for a year (after th efirst pre-implementation period)
- Cost of year-round sampling (2x as in proposed monitoring)
- Need for longer than 4-year monitoring post-implementation to identify a significant trend
- Maybe difficult to identify Control in the case of widespread SRDP uptake (e.g. measures targeted for biodiversity and climate/flooding with multiple benefits including WQ improvements
  - Requirement for statistical expertise to analyse non linear trends

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