CENTRE OF EXPERTISE FOR WATERS

Lags in water quality response to diffuse pollution control measures: a review

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Executive Summary

Research questions

1. What key catchment processes influence lags in water quality response to diffuse pollution control measures (hereafter the measures)?
2. What (inter)national evidence base is available on lags in water quality response to measures for each type of measure and pollutant, i.e. *total phosphorus (P), soluble reactive inorganic phosphorus (SRP), total nitrogen (TN), nitrate, faecal indicator organisms (FIO), and sediment*?
3. Is it possible to define/identify catchment typologies in Scotland to estimate lags in water quality response for each pollutant and type of measure? If not, why not?

Background

SEPA implement regulatory and incentivised measures to protect and improve water quality. The intended effects of the various measures implemented are to: (i) avoid or reduce inputs of pollutants at source (*Source control*); (ii) control / delay transport of pollutants in-field (in field *Transport control*); and (iii) trap pollutants before they reach waterbodies (riparian *Trapping*). Estimating lags in water quality response to measures (Definition 1) based on catchment typologies (Definition 2) could help SEPA to improve diffuse pollution control and communicate to stakeholders the causes of the perceived lack of response to measures in waterbodies that have not improved yet.

Research undertaken

This project undertook a systematic review of the literature on water quality response and lags in response to the measures implemented. Overall findings were discussed in a sense-checking workshop. This Executive Summary (ES) presents the key findings and policy recommendations.

Key Findings

1. There is paucity of empirical evidence and lack of understanding about precisely how long it takes a water quality response to measures to occur, whether it be the first detectable improvement or the trajectory to the first response or to the end-point of compliance with water quality standards. There is no evidence that fixed timeframes for a water quality response to measures can be set. Predicted lags in water quality response based on a catchment typology were not found in the literature. Long-term water quality and catchment data are key to quantifying lags.
2. Lack of water quality response to measures was attributed to combinations of the reasons below:
   - Uncertainties about the effectiveness of measures and the level of implementation required for a water quality response;
   - Low efficiencies of the measures in the context of background catchment variability and pressures such as climate change, which translate to small, undetectable improvements;
   - Lack of effectiveness due to non-optimal implementation of the measures;
   - Longer time required for the measures to become fully effective;
   - Variable function and performance of the measures in response to environmental conditions;
   - Lack of appropriate long-term water quality and catchment data to account for catchment factors;
   - Poor understanding of the start time of the post-implementation period at the catchment scale, which affects statistical analyses and study designs;
   - Monitoring design, which may be introducing a statistical lag, or is unable to detect the magnitude of improvement that has occurred or can occur under site-dependent circumstances.
3. Studies that observed a water quality response to measures, found that lags broadly increase with:
   - Catchment size (Fig. ES1) but differ for the same pollutant in catchments with similar size/ measures;
   - Legacy effects from past pollutant inputs stored in the soils and in-stream;
   - Travel time from sources to receptors, e.g. when groundwater hydrologic pathways predominate;
   - Residence time in-field, in-stream and in the aquifer, which is generally enhanced by storage;
   - Presence of multiple, non-agricultural sources (e.g. wastewater discharges) of that pollutant.
4. Lags reported in temperate regions were in the range of 1-25 years for river waterbodies (Fig. ES1. A) and potentially longer than 20 years for a groundwater nitrate response. Studies based on a Before-After/ Control-Impact (BACI) design used 2-4 years of baseline data. The Trend design involved long-term (over ten years) monitoring and comparisons between catchments and was used in cases of gradual implementation of the measures across medium-sized catchments (size: 20-300km^2). Based on long-term data, river and groundwater water quality trajectories of response to measures are subject to site-dependent seasonal, interannual and decadal, climate-related, variation.

5. Studies that reported a water quality response within five years post-implementation of the measures (Fig.ES1) attributed the relatively fast response to optimal implementation, i.e. extensive and spatially integrated implementation, targeting to match pressures to biogeochemical and hydrologic processes at farm scale and application of a combination of *Source control*, *Transport control* and *Trapping* across the landscape.
6. No catchment typologies for lags in water quality response were identified because of:
   - Complexity: Multiple interacting catchment factors involved in diffuse pollution control;
   - Paucity of long-term water quality and catchment datasets, which are required to quantify lags;
   - Localised, case-study nature of most studies on effectiveness of measures and related response;
   - Inconsistent reporting of catchment factors in studies of water quality response to measures;
   - Lack of knowledge about the function of measures across a range of conditions and environments;
   - Inconsistencies in available evidence per type of pollutant;
   - Difficulty in quantifying the complex processes determining catchment typologies.

Definitions: (1) Any statistically significant improvement in water quality in the waterbody downstream of the catchment where the measures are implemented at or above the level projected to deliver a water quality improvement at a catchment scale. (2) Characteristics such as waterbody type, catchment size, land use, precipitation, pollutant retention and travel / residence time, legacy effects and implementation of measures.

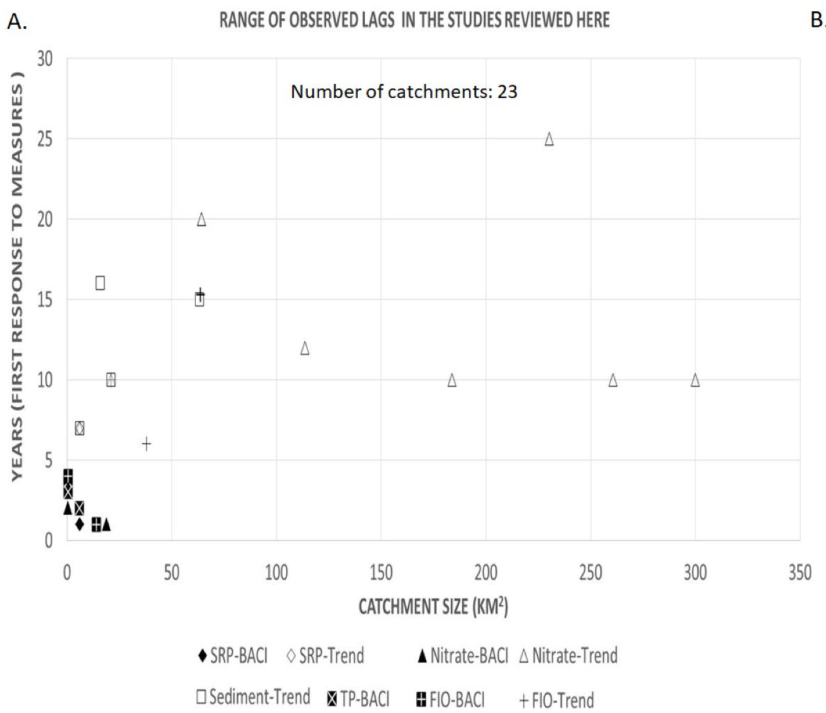
Literature-based recommendations to improve understanding of lags in water quality response

1. Account for dominant legacy effects and hydrologic paths when targeting the measures to address pressures.
2. Promote spatially integrated implementation of a combination of different types of measures.
3. Include *Source control*, as the intended effect (i.e. reducing inputs at source) is independent of legacy effects and hydrologic paths.
4. Collect long-term monitoring data from catchments where the measures are implemented and from control catchments (pristine, or without measures); control data are key to separating effect of measures from the effects of other factors on water quality.
5. Apply a BACI or Trend monitoring design using long-term data depending on availability of pre-implementation data or on mode of uptake of measures (gradual or not).
6. Account for catchment-scale influences on water quality of factors such as rainfall, land use, application of fertiliser, livestock numbers, streamflow, discharges from point-sources, and data on soil sorption capacity and rates of biogeochemical processes.
7. Model water quality responses to catchment processes to derive catchment-specific typologies and understand sensitivity to measures over time and guide further action.

Practical implications - recommendations for Scotland

1. Keep monitoring water quality to help understand lags and inform further action.
2. Adjust expectations for water quality response and recovery, i.e. there is no evidence supporting fixed timeframes for waterbody improvement.
3. Plan for lags in water quality response. This may involve:
   - Planning for longer-term monitoring and flexible objectives as in "learning by doing";
   - Prioritising measures that deliver immediate results by accounting for hydrologic paths;
   - Targeting sources nearest to receiving waters for faster improvements;
   - Demonstrating results to the public in areas delivering immediate water quality responses.
4. Account for dominant hydrologic paths at farm scale during catchment characterisation surveys and when targeting; this means collecting evidence on soil properties, soil sorption capacity, legacy nutrients, geology, streamflow and precipitation along with evidence on land use and pressures.
5. Match the measures to the pollutant(s), pollutant source(s), and hydrologic transport pathways.
6. Promote spatially integrated implementation of a combination of types of measures.
7. Avoid inputs at source (*Source control*).
8. Consider soil pore-water nutrient measurements to demonstrate effectiveness of *Source control*.
9. Consider retro-fitting the correct measure(s) to site-specific losses when assessment of the measures in place shows that the predominant sources of pollutants have not been addressed.
10. Develop modelling approaches (e.g. a decision support tool) examining the effect of a suite of catchment factors on water quality using readily available desk-based GIS data.
11. Investigate strategies for the effective communication of scientific evidence on lags and adaptive management approaches in the context of cost-effectiveness of the measures.

A.



B.

Nutrients

Source control measures

- Reduction in N and P fertilisers
- Optimisation of N
- Manure storage
- Livestock restrictions (fencing)
- Reduction of stocking rates
- Farmyard runoff control
- Removal from crop production
- Irrigation management

In-field *Transport control* measures

- Catch crops

Riparian *Trapping* measures

- Constructed wetland
- >8 m Riparian buffers
- Riparian restoration with woody vegetation

FIO

Source control measures

- Livestock exclusion with off-site watering, bridges, crossings
- Improved farm infrastructure

Riparian *Trapping* measures

- Streambank stabilisation (incl. revetments)
- Riparian restoration (2-8m up to 30m) with woody vegetation

Sediment

Source control measures

- Livestock exclusion

In-field *Transport control* measures

- In-field erosion control

Riparian *Trapping* measures

- Streambank stabilisation
- Riparian restoration

Figure ES1. A. Relationship between time (years) elapsed between the start of implementation of measures and the first detectable water quality response to measures in river waterbodies in temperate regions based on BACI and Trend monitoring designs. No compliance with water quality standards was observed in any of these studies. B. Combinations of measures implemented per catchment per pollutant in the studies presented in A.

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