CREH

CENTRE FOR RESEARCH INTO ENVIRONMENT AND HEALTH

MONITORING THE EFFECTIVENESS OF FIELD AND STEADING MEASURES TO REDUCE DIFFUSE POLLUTION FROM AGRICULTURE TO BATHING WATERS

Reference ENV/7/4/04

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MONITORING THE EFFECTIVENESS OF FIELD AND STEADING MEASURES TO REDUCE DIFFUSE POLLUTION FROM AGRICULTURE TO BATHING WATERS IN THE ETTRICK, CESSNOCK, NAIRN AND SANDYHILLS CATCHMENTS

REFERENCE: ENV/7/4/04

To

Scottish Executive
Water Division

by

Centre for Research into Environment and Health (CREH)

March 2005

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Context of this report

This report provides a synthesis of data acquired between October 2002 and October 2004 at the four regional study sites within which measures were implemented to reduce fluxes of faecal indicator bacteria. These sites were chosen as the fluxes were contributing to adverse effects on bathing water compliance under Directive 76/160/EEC. The project to install these measures was undertaken by a multidisciplinary team led by the Scottish Agricultural College (SAC) and comprising Macaulay Land Use Research Institute (MLURI), the Farming and Wildlife Advisory Group (FWAG) and CREH. The remedial measures were designed and planned by SAC and FWAG. Environmental monitoring was completed by CREH and the results are outlined in this report. A parallel project, conducted at Brighouse Bay, which is to the west of the Sandyhills study area, is reported separately by Dickinson *et al*. (2005). This investigation provides complementary data to the study reported here and the Observations and REcommendations and Executive Summary draw on the lessons of both studies.

David Kay
March 2005

Acknowledgements

We are very grateful for the support of the Scottish Executive for the opportunity to undertake the environmental monitoring component of this study. The Project Steering Group, which includes representatives of NFUS, Scottish Environment Protection Agency and SEERAD, has consistently offered excellent advice and direction. Staff of the Scottish Executive Agriculture Division kindly provided data on land use and the remedial measures implemented in each subcatchment selected for detailed study. Colleagues in SAC and MLURI were involved with the establishment of this project and the pre-remediation monitoring effort and they have generously contributed expertise and advice throughout. We are especially grateful to the farming community and land owners in the four study regions who gave access permission for sampling and instrumentation. Finally, we acknowledge the efforts of our sampling teams who have worked tirelessly to acquire high flow data which always involves inclement weather.

Acronyms

BMP	Best Management Practice
CREH	Centre for Research into Environment and Health
FWAG	Farming and Wildlife Advisory Group
MLULRI	Macaulay Land Use Research Institute
NFUS	National Farmers Union Scotland
PEPFAA	Prevention of Environmental Pollution from Agricultural Activity
SAC	Scottish Agricultural College
SEERAD	Scottish Executive Environment and Rural Affairs Department
SEPA	Scottish Environment Protection Agency

Executive Summary

1 Context of the environmental monitoring

Bathing beach compliance with the microbiological standards specified in Directive 76/160/EEC is affected by both point-source discharges of faecal indicator organisms (FIOs) and diffuse pollution, primarily from farms. The latter source is thought to be a significant problem in South West Scotland and many other parts of the United Kingdom. Significant resources have been deployed to remediate agricultural pollution impacting on bathing waters principally through the application of The 4 Point Plan (SAC, 2002) and the PEPFAA code (Scottish Executive, 2003) which together contribute to the Forward Strategy for Scottish Agriculture and the Bathing Water Strategy (Scottish Executive, 2002a,b). Integrated efforts to inform and implement this policy development at the farm level are underway including the production of a handbook for farm advisers on best management practices (BMPs) (SAC, 2005), the development of a GIS-based screening tool to identify water bodies at risk from diffuse pollution pressures (SEPA, 2005a), an appraisal of rural BMPs by SEPA (2005b) and a number of farm pilot projects by SEERAD for which this report covers the monitoring element of one and compares results with another.

Microbial dynamics within catchment ecosystems is a very young science which has received much less research attention than, for example, the dynamics of the nutrient parameters (Kay *et al*., 2005a,b,c). Thus, the efficacy and practicality of available 'on farm' remediation options in reducing fluxes of faecal indicator compliance parameters is not well researched and insufficient, policy-relevant, empirical data are available to the Scottish Executive on the likely impacts of the various BMPs available.

This project was initiated in October 2002 with the overall aim of implementing a range of remediation strategies on 48 farms spread over 4 regions in Scotland. The Scottish Agricultural College (SAC), together with the Farming and Wildlife Advisory Group (FWAG), designed two principal types of on-farm remediation strategy based on either: (a) stream bank fencing to exclude stock from stream margins; or (b) farm steadings drainage control. These were installed during 2003 and early 2004. In the Ettrick and Cessnock (Killoch) catchments, steading-based measures were employed and in the Sandyhills and Nairn catchments, fencing-based measures were installed. CREH were responsible for establishing the pre- and post-remediation faecal indicator concentrations and delivery rates in the study regions.

The intention in the design of the monitoring programmes was that these pre- and post-remediation faecal indicator organism (FIO) delivery patterns could be compared to gain information on: (i) remediation strategies; (ii) the likely effects of these measures on faecal indicator delivery from agricultural sources; and hence, (iii) the likely impacts of such remediation measures on bathing beach compliance.

2 Structure of this report

This report provides an explanation of the protocol design (Section 1) and details of the results from the individual regional studies (i.e. Sections 2 to 5). For each region, any problems encountered in the fieldwork period are noted. Section 6 provides a set of general observations on these data and suggests a protocol for any future investigations in this area.

3 Specific aims

The environmental monitoring sought: (i) to instrument key stream sites which would be impacted by the potential remediation; (ii) to provide a stream level (stage) record through the monitoring period of four weeks at each site; (iii) to collect water samples to facilitate characterisation of the low flow and high flow microbiological quality of each location; and (iv) to acquire local rainfall data. The discharge and microbiological concentration data were combined as outlined in Wyer *et al*. (1997, 1999) to produce plots of the faecal indicator flux (i.e. in terms of presumptive total coliforms (TC), faecal coliforms (i.e. presumptive *Esherichia coli*) (EC) and presumptive intestinal enterococci (IE)) passing the monitoring point through the period of fieldwork.

4 General observations

Details of the sampling periods and numbers of samples analysed in each study area are presented in Table 1.

Table 1 Study periods and samples analysed

Study site	Samples analysed	Fieldwork period 2002 to 2004	
Ettrick Bay	420	14/10/02	10/11/02
	313	28/07/04	16/08/04
Cessnock	417	11/11/02	07/12/02
	341	31/07/04	17/08/04
Sandyhills	797	09/12/02	22/01/03
	879	05/07/04	30/09/04
River Nairn	456	23/01/03	31/03/03
	621	26/08/04	07/10/04

Figure 1 shows the locations of each regional study. In previous studies, attention on faecal indicator delivery to coastal waters from diffuse sources has focused on the bathing season which spans the period May to September in the United Kingdom. Some of the data reported in this project were acquired outside this period because completion of the pre-remediation environmental monitoring was required before remediation efforts could begin and this monitoring phase was scheduled for completion within the 2002/3 financial year. The CREH field team was, therefore, deployed in the Ettrick catchment immediately after project commencement in October 2002. This produced data for the pre-remediation monitoring period acquired outside the bathing season for the 4 regions (i.e. October 2002 to February 2003).

The timing of the pre-remediation monitoring through the winter period uncovered patterns in faecal indicator delivery which were not envisaged at the initial protocol design stage. This pattern suggests that the elevation in faecal indicator delivery observed during high flow events, when concentrations increase markedly producing the well-documented episodic flush (Wyer *et al*., 1997,1999; Kay *et al*., 1999), is much less marked in the winter period. Figure 2 shows the pattern of geometric mean faecal coliform concentration 100 ml^{-1} for each of the 4 sites during the pre-remediation monitoring period (i.e. the mean of all low flow and high flow samples collected in each of the four regional studies over the four week periods). Clearly, this amalgamates a great deal of data for each study and masks 'within study' differences between subcatchments in the pre-remediation period.

Figure 1 Location of the four study regions.

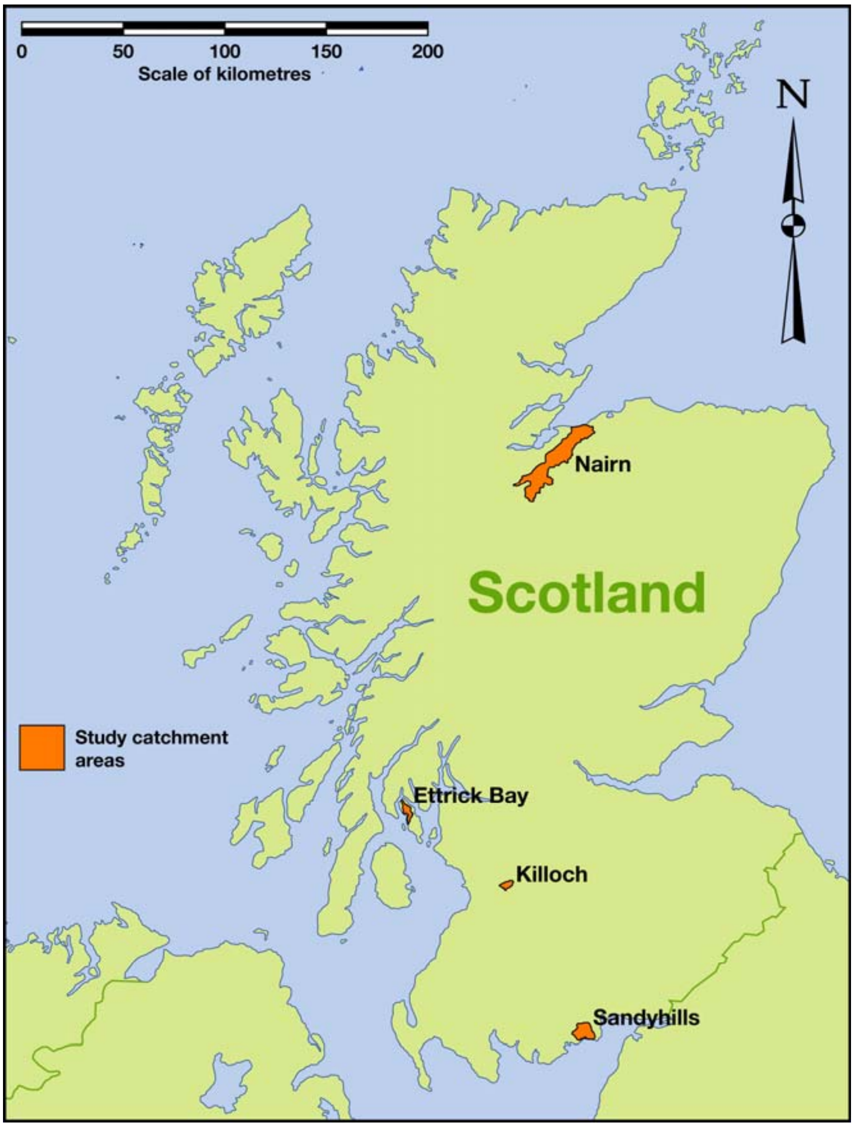

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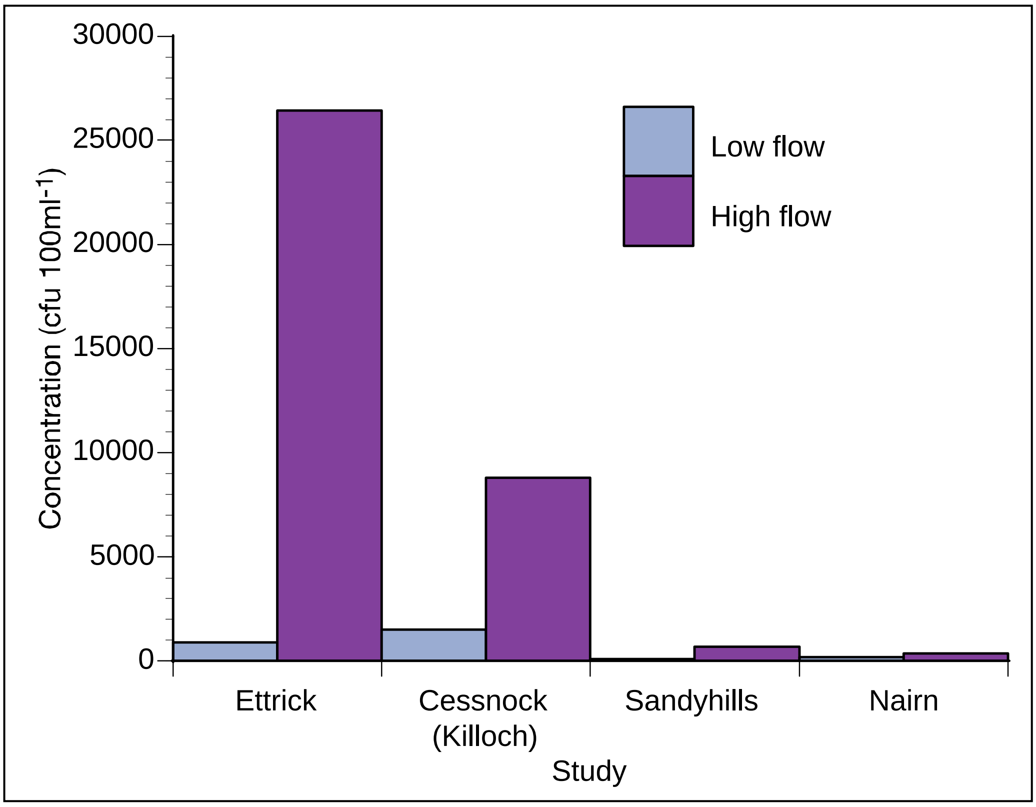
Figure 2 **Seasonal trends in pre-remediation low flow and high flow geometric mean presumptive *Escherichia coli* concentration**



By the time of the third study at Sandyhills (December 2002 to January 2003), there is a marked reduction in faecal indicator elevation under high flow conditions. This pattern might suggest a reduction in faecal indicator delivery when stock, particularly cattle, are taken off the fields and housed in farm buildings.

A parallel investigation in the Brighouse Bay catchment, approximately 25 km to the west of the Sandyhills study area, confirmed this seasonality pattern (Dickson *et al.*, 2005). Thus, the decision on when to undertake the post-remediation monitoring in the present study was difficult and two options were considered: (i) to monitor each of the four regions at the same time as in the pre-remediation campaigns; or (ii) to undertake post-remediation monitoring in the summer bathing season. The latter option was chosen by the Project Steering Group because this would provide data relevant to the summer bathing season. However, it was appreciated that these data may not be directly comparable to the autumnal and winter data acquired in the pre-remediation monitoring.

In all four studies, the post-remediation bathing season data on faecal indicator concentrations showed higher geometric mean values in high flow samples than had been observed in the pre-remediation, autumnal and winter sampling programme. This seasonality makes direct comparison of 'before' and 'after' faecal indicator concentrations at subcatchment outlets difficult. In the Brighouse Bay study, this was also a problem. To partially overcome this, the remediated subcatchments in Brighouse Bay were compared to an adjacent 'control' catchment, which had not been altered during the period of the study. This analysis compared the change in faecal indicator concentrations at the unaltered control site between the pre- to post-remediation periods (i.e. autumn to summer) with the change at the remediated sites. The extent to which the Brighouse Bay remediation (mostly consisting of the creation of a riparian buffer zone by fencing parallel to the stream channel) reduced this change below that observed at the control site was also compared with the intensity of 'measures' (i.e. the percentage of stream bank length protected by a riparian buffer zone) deployed within each subcatchment. This approach was reviewed by the Project Steering Group in January 2005 and it was agreed that a similar exploratory analysis should be undertaken for this report. However, it is important to note that: (i) this approach is far from ideal; and (ii) in the present study, matched 'control' catchments were not pre-selected. The potential control sites available simply represent sites where no remedial measures were implemented. This will introduce bias if, for example, potential control catchments tend to be sited in headwater areas which are likely to be less impacted by active steadings and/or cattle grazing (i.e. the catchments are not necessarily matched in terms of catchment characteristics such as morphometry, soils, land cover and agricultural practices).

Given these caveats, the conclusions and recommendations of this study and comparisons with the Brighouse Bay investigation, are as follows.

Conclusions

i. The production of a vegetated riparian buffer zone, through targeted stream bank fencing designed to exclude stock from the stream margins can reduce faecal indicator concentrations. However, a relatively high proportion of the stream bank length must be protected. The Brighouse Bay study and results of the Sandyhills monitoring combined suggest that approximately 30% of the existing stream bank needs buffer zone protection before a measurable change in faecal indicator concentrations is observed. Since very few catchments have been fenced specifically to produce riparian buffer zones, it is likely that this 30% protection would require 'additional' fencing in most catchments.

ii. The Ettrick study does suggest a positive effect of intensive steading measures in a small catchment (range 0.25 to 1.94 steading BMPs km^{-2}). In the Cessnock (Killoch) monitoring, the intensity of steading-based measures was lower (0.35 to 0.60 steadings BMPs km^{-2}) due to the configuration of this catchment and the location of its steadings. No apparent improvement was observed following the steading-based BMPs in the Cessnock (Killoch) catchment.

iii. Even following the remediation measures applied in this study (i.e. fencing and steading measures), with current stocking densities, the remaining summer faecal indicator fluxes would be sufficient to cause bathing waters to fail Directive 76/160/EEC threshold values for the coliform and enterococci parameters where catchment streams discharge close to bathing beach compliance locations (Dickson *et al.*, 2005).

iv. In the Brighouse Bay study, where samples were analysed for nutrient concentrations, the riparian buffer zones were also seen to reduce ammoniacal nitrogen concentrations but were less effective in reducing nitrate nitrogen. Thus, the remedial measures undertaken are likely to have beneficial effects beyond the faecal indicator microbial parameters reported in this document.

Caveats

v. The seasonal shift analysis presented in this report (see Figure 1.4 Page 9) seeks to accommodate the seasonality problems in the pre- and post-remediation data sets by assessing change relative to a ‘control’ site. It is important to note, however, that the magnitude of the calculated ‘improvement’ values are dependent on the absolute value of the post-remediation geometric mean concentration. Thus, direct comparison of the level of the ‘improvement’ between catchments should only be made with this in mind.

Recommendations

vi. Studies to quantify faecal indicator fluxes from agricultural areas should be designed in the light of the observed seasonality, producing peak concentrations during high flow events in the summer bathing season. Any future ‘before and after’ studies should be restricted to the summer bathing season and should incorporate pre-selected adjacent ‘control’ catchments with similar characteristics to the area(s) intended for remediation.

vii. The extreme temporal variability of faecal indicator concentrations in streams draining livestock farming areas and the potential impacts on bathing water compliance is perhaps best managed, in the short term, through the application of real-time prediction and sample discounting suggested in WHO (1999, 2003) and CEC (2004). This approach forms the basis of the Scottish Executive / SEPA ‘Signage’ project.

viii. Natural treatment systems, such as integrated constructed wetlands (ICWs), have been shown to produce very significant reductions in faecal indicator fluxes from livestock farms in Ireland. However, such systems require relatively large areas (up to twice the interception area of the steadings and roofs) and the Irish ‘unlined’ ICWs have raised regulatory concerns regarding leakage of nutrients and faecal indicators to groundwater. Data to assess the efficacy of these systems and address the concerns of the regulatory agencies are needed and this aspect could make a useful component of future studies of faecal indicator flux.

ix. Fencing alters faecal indicator delivery through two mechanisms: (a) by cattle exclusion; and (b) by the development of a vegetated buffer zone. Whilst the first mechanism is instantaneous (and its efficacy is supported by the ‘winter’ FIO data from this project and the Brighouse Bay study which both show a marked reduction in faecal indicator concentrations in the winter high flow period: i.e. when cattle are excluded from stream access by being housed within the steading areas), the second mechanism will be slower to take effect. The need to review the effect of the ‘mature’ buffer strip suggests that a further period of post-remediation sampling would be valuable. However, due to the limitations in the timing of the pre-remediation sampling it is proposed that such further investigations are confined to the sites with a properly matched control catchment, or sites where well-matched controls can be identified. Studies of this nature could be conducted in a subset of the Nairn, Sandyhills and Brighouse Bay study regions (see Section 6.3, Page 35).

Comment

x. This study has produced the most extensive UK data set describing faecal indicator export from agricultural land. This will be an important resource for modelling faecal indicator flux to bathing and shellfish harvesting waters.

CONTENTS