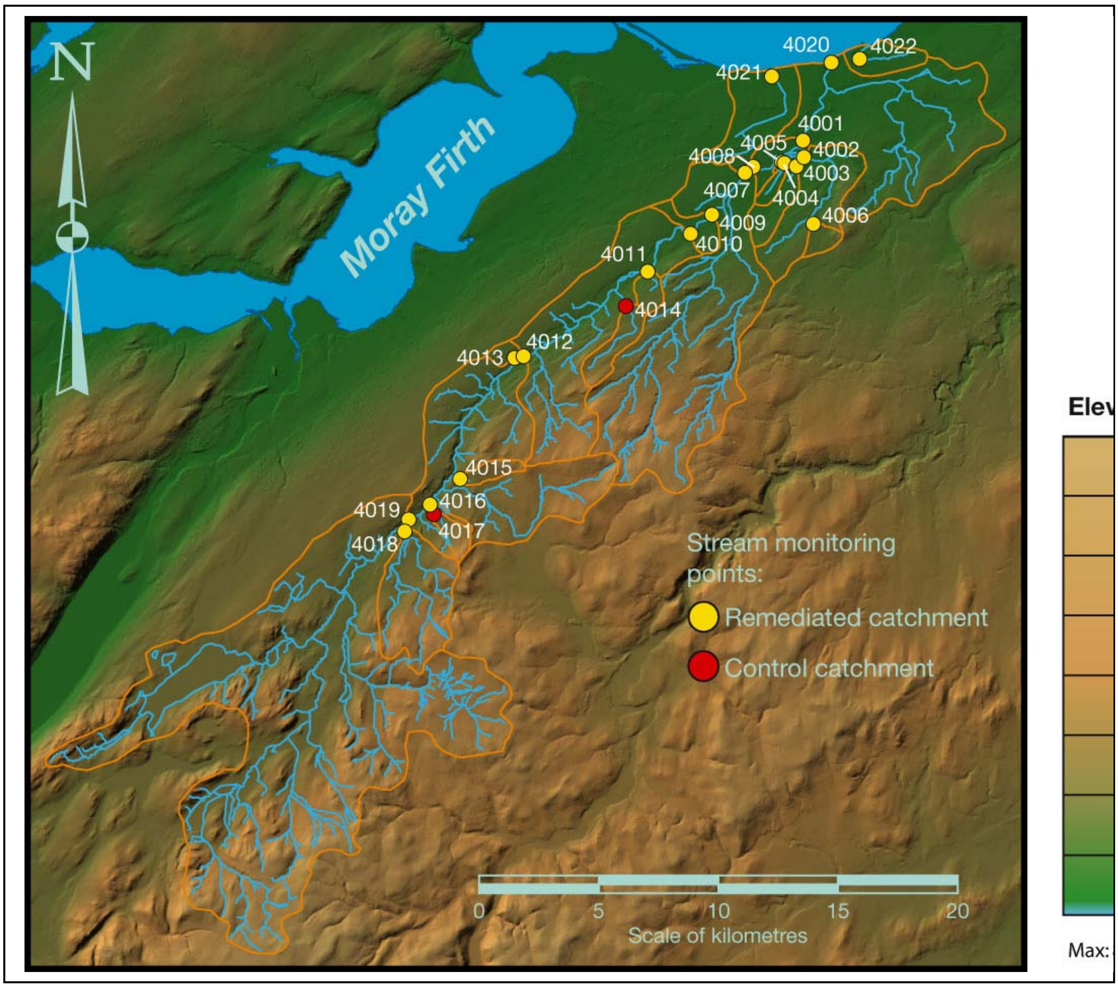
5 Results of the Nairn monitoring

Figure 5.1 Nairn monitoring sites



5.1 Catchment characteristics

The Nairn catchment monitoring commenced on 23rd January 2003. However, during the next five weeks there was insufficient rainfall to produce elevated stream flows. Although one snow melt event did produce an elevation in the subcatchment stream levels. All hydrological instrumentation and the field laboratory remained installed in the catchment to facilitate further sampling. A field team was again deployed for five weeks in June and July 2003 in a further attempt to acquire high flow data but, again, no high flows occurred in this period. By this time, installation of remediation measures was advancing, which made further attempts to acquire pre-remediation high flow data pointless. Thus, characterisation of the high flow pre-remediation water quality in the Nairn streams was not achieved. In the post-remediation period, it again proved difficult to acquire high flow data from this catchment. This required the field team to be deployed for a total of six weeks spanning the period from 26th August to 9th October 2004 (i.e. longer than the four weeks planned for each regional study).

The high flow flux and geometric mean values reported in Appendix I, thus, represent an illustrative assessment for the pre-remediation monitoring period. They are based on SEPA flow measurements at the Firhall and Balnafoich gauging stations (and a constructed mid-point composite flow), scaled by the subcatchment areas of the Nairn monitoring locations taken from the GIS. The high flow and low flow pre-remediation geometric mean faecal indicator concentrations are calculated from the observed low flow concentrations at each site (n=20) and data acquired during one moderate snow melt event which produced four bacterial enumerations for all 19 sites in the Nairn catchment.

It should be noted that one apparent flow elevation on the Nairn main channel between the 6th and the 10th February 2003 was due to rainfall in the catchment upstream of the study area. Flow increases were not evident in the Nairn subcatchment monitoring locations, where only light rainfall was observed.

Land use and remedial measures are outlined in Tables 5.1 and 5.2, respectively. The total study area contained fifty farms which were characterised by mixed farming systems (i.e. beef, sheep, pigs and arable). On ten farms, field-based measures were implemented. The Nairn had the largest catchment at 33,890 ha. The Nairn Central bathing water compliance point has achieved the Directive 76/160/EEC *Guide* (recommended) level, which is required to achieve a 'Blue Flag' seaside award, in four years since sampling began in 1990, It has failed to achieve the mandatory standards specified in Directive 76/160/EEC in one of these years.

5.2 Data analysis

Given the unavailability of robust pre-remediation water quality data for the Nairn subcatchment streams, a quantitative seasonal shift analysis for the Nairn study area would not be appropriate. However, Figure 5.2 was produced to illustrate the ranges in presumptive GM *E. coli* experienced in the pre- and post-remediation periods (equivalent plots for the total coliform and intestinal enterococci parameters are presented in Appendix II).

The highest FIO concentrations are seen at sites 4006, 4007, 4011 and 4013 which were all small flows impacted by farm hardstanding areas. The 'main channel' monitoring locations, listed from the upstream end, were sites 4019, 4012, 4010, 4009, 4008, 4001 and 4020. Sites 4019 (upstream) and 4001 (downstream) bracket the area where side stream subcatchment remedial measures were implemented. Figure 5.2 suggests that the mean $\log_{10}$ *E. coli* values at site 4001 are not statistically significantly different from site 4019. Indeed, the 95% CIs for all 'main channel' sites overlap, indicating no significant difference between any pair of Nairn main channel sites in the post-remediation period.

Table 5.1 Land use in selected Nairn subcatchments

		Percentage land use				
Subcatchment	Area (ha)*	Improved pasture	Rough grazing	Forest	Arable	Built-up
4001	30,604.72	No data				
4002	1,265.32	22.47	2.58	33.53	39.07	2.35
4003	311.42	No data				
4004	100.65	No data				
4005	9.55	No data				
4006	145.95	30.79	0.00	45.32	20.54	3.35
4007	40.67	No data				
4008	28,628.92	No data				
4009	23,299.69	No data				
4010	23,052.07	No data				
4011	162.78	No data				
4012	19,440.82	No data				
4013	92.00	54.32	1.70	6.21	30.64	7.14
4014	356.05	17.88	8.50	72.95	0.28	0.39
4015	164.88	8.28	3.80	85.16	0.00	2.76
4016	42.29	36.02	25.20	38.36	0.00	0.42
4017**	163.46	12.37	69.43	18.20	0.00	0.00
4018	1,399.59	No data				
4019	15,163.59	No data				
4020	34,324.76	No data				
4021	347.10	No data				
4022	970.92	No data				

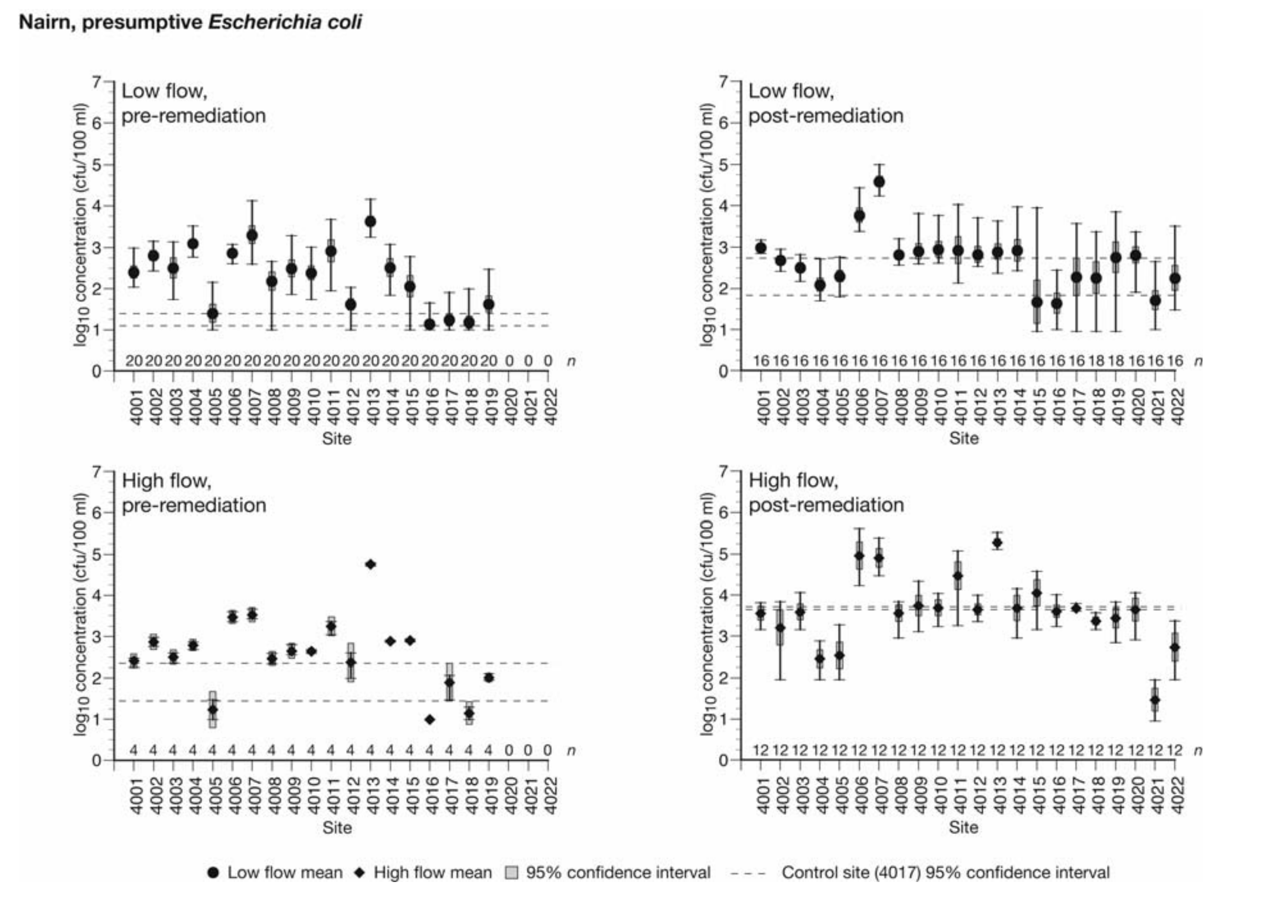
* *As these catchments were nested, the area of all subcatchments summed together is greater than the total study area, this is true of each of 4 study sites.*
** *Potential control sites*

Table 5.2 Fencing measures within selected Nairn subcatchments

Sub catchment	Stream length (m)	New fencing (m)	New fencing/ stream length (%)	New fencing/ area (m/ha)	Improved pasture fencing (m)	Imp past fencing/imp past area (m/ha)	Rough grazing fencing (m)	Arable fencing (m)
4002	7,925	1,510	9.53	1.19	899	3.15	0	611
4006**	0	299	-	2.05	299	7.11	0	0
4013	220	405	92.05	4.40	405	7.96	0	0
4014	4,120	776	9.42	2.18	776	12.19	0	0
4015	400	530	66.25	3.21	530	39.35	0	0
4016	940	1,050	55.85	24.83	0	0	0	0
4017*	1,780	50	1.40	0.31	0	0	0	0

* *Control site*
** *No stream mapped at 1:50,000 for this small subcatchment principally draining a farm hardstanding area*

Figure 5.2 Water quality in the Nairn subcatchments, presumptive *E. coli*, compared with site 4017[1]



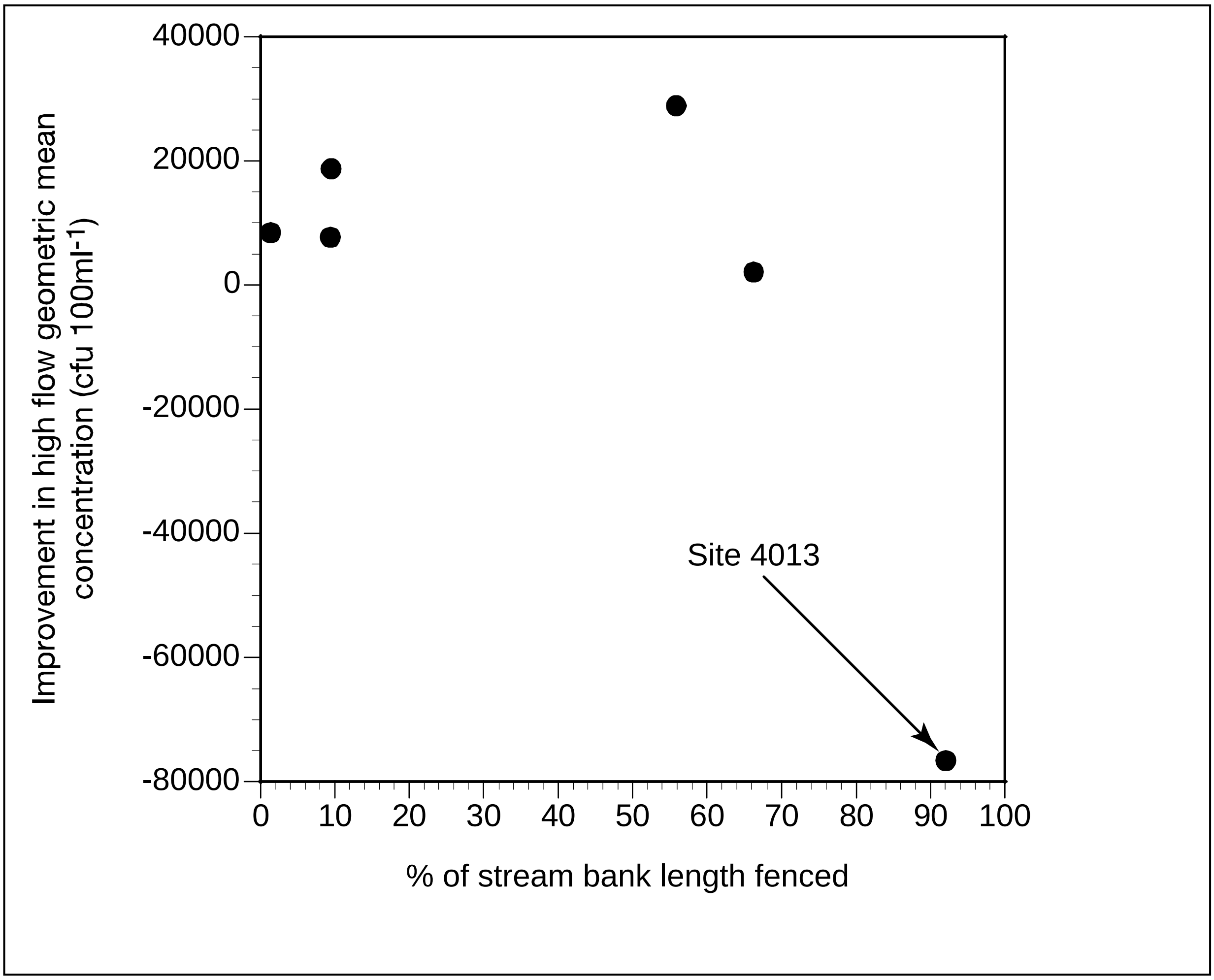
Sites 4021 and 4022 were streams flowing directly to the coast. Here, monitoring data were acquired in the post-remediation period to assess whether they represented a risk to bathing beach compliance. Site 4021 was a discharge through the sea wall with flow derived from an ornamental pond in the grounds of a hotel. This exhibited very low faecal indicator concentrations, with no observed elevation in concentration following rainfall, probably due to the retention and attenuation effect of the pond. This site exhibited statistically significantly lower *E. coli* concentrations than all other sites in the Nairn study. The same is also true of the intestinal enterococci comparisons (see Appendix II). Site 4022 was a small stream draining an agricultural catchment with some residential properties. Only sites 4021, 4004 and 4005 exhibited lower FIO concentrations than this site, which was significantly cleaner (in terms of *E. coli* concentration) than all Nairn main channel sites, although its enterococci concentration was not significantly different to site 4020 (the lowest Nairn site).

In the absence of a shift analysis for the Nairn region, the intensity of fencing measures was compared with the difference in observed FIO concentration in the post-remediation period and modelled values derived from previous CREH

[1] *E. coli* data are presented in this Figure and throughout the main body of this report. Similar plots for total coliform organisms and intestinal enterococci are located in Appendix II which commences on Page 67 of this report.

investigations. This regression modelling approach has been reported in Crowther *et al*. (2003) and has been employed in recent studies for the Environment Agency, North West Region. Figure 5.3 shows the results of this analysis for *E. coli*. Only five of the six Nairn subcatchments are really appropriate for this plot, the aberrant site being site 4013 which is a small left bank tributary joining the Nairn immediately above Clava Lodge road crossing with over 90% of the stream bank fenced. In fact, this small flow is almost entirely derived from hardstanding areas and, thus, comparison between this and the modelled catchments for which land use data are available is probably inappropriate.

Fig. 5.3 Plot of inferred improvement in high-flow GM *E. coli* concentrations (-ve values indicate a deterioration in water quality) based on land use modelling against percentage of stream bank length fenced in the Nairn region



6 General observations

The extreme seasonality in the stream high flow FIO concentrations was an unexpected finding of the pre-remediation environmental monitoring effort. This has led to (i) retrospective selection of adjacent ‘control’ sites where, fortuitously, no remediation was completed, and (ii) the employment of the ‘shift’ analysis explained in Section 1.5 and illustrated in Figure 1.4 on Page 9. Both may introduce bias, particularly where the control sites are not representative of the modified catchments. We believe this to be the best approach possible with these data, but it must be appreciated that this analysis has not been subject to peer review in the scientific literature. Indeed, the shift analysis has only been developed and applied here because of what might be considered a ‘design flaw’ in the experimental protocol derived from the requirement to complete the pre-remediation sampling in the winter period. Where seasonality is apparent in environmental data, both pre-and post-remediation monitoring would normally be completed in the same season. Thus, the observations outlined here should be treated with caution. For this reason, it is important to note that the observations in 6.1 and 6.2 below are qualitative statements and do not attempt a quantitative linking of the intensity of measures applied and any ‘improvement’ in water quality observed.

6.1 Fencing measures

The Sandyhills fencing measures appear to be producing results comparable to the Brighouse Bay findings, i.e. that this measure can reduce FIO flux when the proportion of stream bank fenced to exclude stock is significant. The figure of 30% is noted in the Brighouse report and Figure 4.3 (Page 27) (with the exclusion of site 3004) is in broad agreement with this, although there is considerable variability in ‘response’ as indicated by the shift analysis. With the exclusion of site 4013, the Nairn prediction model results also suggest improvement in water quality following stream bank fencing although no clear relationship with the intensity of fencing is apparent for the 5 Nairn subcatchments receiving fencing remediation. However, there is a very wide spread in these data and we have specifically avoided fitting lines to these putative relationships as this could imply a precision and relationship which cannot be inferred due to confounders inherent in the shift analysis outlined above.

6.2 Steading measures

Remediation of hardstanding areas was applied in the Ettrick and Cessnock (Killoch Burn) subcatchments. There was no measurable effect in Killoch Burn, as evidenced by the shift analysis and the comparison of high flow water quality at site 2002 (Figure 3.4, Page 21), which was monitored in the summer of 2002 when summer high flow geometric mean *E. coli* was not significantly different to 2004. The Ettrick study, with the exclusion of site 1001 (i.e. a field drain impacted by hardstanding drainage), did suggest a relationship between the intensity of hardstanding remedial measures applied (i.e. remediated steadings km^{-2} of catchment) and the degree of improvement in water quality indicated by the ‘shift’ analysis. The difference between the two study results may be caused by the higher intensity of remedial measures undertaken in the smaller Ettrick subcatchments (i.e. 0 to 1.94 remediated steadings km^{-2}) compared to the range of Cessnock (Killoch Burn) remediation intensities of 0 to 0.60 steadings km^{-2}. Any putative relationships are, however, confounded by the between-subcatchment random variability in 'connectivity' between steadings and stream channels and, again, we have not calculated linear relationships for the plots presented in Figures 2.3 (Page 14) and 3.5 (Page 21).

6.3 Observations and recommendations

Taken together with the Brighouse Bay study, these findings suggest that improvements in water quality occur with higher intensities of remedial measures. Given the problems in the study design, precise quantification of the magnitude of the remedial effect has not been possible. If it was felt necessary to quantify the water quality effects of the remedial measures, then the following 'paired catchment' protocol could be employed with the following stages.

i. Subcatchment land use survey and morphometric analysis in each of the 4 regions to identify appropriate 'control' catchments prior to fieldwork.
ii. Combining Sandyhills, Brighouse and Nairn study regions, followed by careful selection of a subset of remediated catchments to examine a range of 'fencing' remediation intensity.
iii. Combining Ettrick and Cessnock (Killoch Burn) study regions to define remediated and control catchments as per the 'fenced' regions.
iv. Parallel sampling in the bathing season of the modified and control sites through a series of high flow events, with low flow data acquisition between event-based sampling.
v. Comparison of FIO geometric mean values during high flow events in the modified and control catchments.
vi. Finally, a further land use survey should be undertaken in the remediated and control catchments immediately following the stream water quality monitoring period to assess the extent of any land use change within the control catchment.

There is very little quantitative information world-wide on the impacts of remedial measures on faecal indicator fluxes. Given the growing importance of this parameter (and the status of bathing waters as 'Protected Areas' in Annex IV and Annex VI of Directive 2000/60/EU with the requirement for member states to implement a 'Programme of Measures' under Article 11 to achieve Directive 76/160/EEC compliance), quantitative information linking the intensity of measures implemented with the degree of resultant improvement in water quality is certainly of great management significance. A paired-catchment study offers the best hope of quantifying this improvement and the existence of so many remediated areas with clearly defined intensities of remedial measures offers a unique opportunity to address this issue in Scotland.

This investigation has not produced a conclusive result due mainly to the seasonality problems noted above. From this study and the Brighouse Bay project, there is strong evidence of improvement where riparian buffer zones cover a significant percentage of the stream bank length (i.e. >30%). However, this effect is certainly smaller than would be needed to guarantee Directive 76/160/EEC compliance where a stream discharges close to a compliance sampling point. For this reason, we suggest the research and management actions noted below.

Data on the water quality improvement produced by the riparian buffer zones as they mature would be of significance to Water Framework Directive implementation and, in particular, for the design of 'measures' required in Article 11. Parallel beneficial effects on certain nutrient parameters would be expected. We would therefore recommend the implementation of further monitoring using the protocol outlined above during the 2005 or 2006 bathing seasons.

The observation in the Brighouse Bay report (Dickson *et al.,* 2005) that non-compliance would still be likely following significant stream protection through riparian buffer zones and associated water quality improvement, suggests two additional recommendations. The first relates to the Scottish Executive / SEPA signage project. The continued threat to bathing waters following riparian remediation measures indicates that sample discounting and a 'predict and protect' approach could remain an important component of bathing water management in Scotland in the medium term. It is therefore important that the current Scottish Executive / SEPA signage project is extended to additional locations impacted by diffuse pollution and that the prediction methods applied are refined and optimised (SEPA, 2001; Crowther *et al.,* 2001). The danger in this recommendation is that this 'beach management' approach, which is recommended by WHO (2003), is not taken forward by the European Union, as a permanent element of the revised Directive (CEC, 2004), as the negotiations on the revision of Directive 76/160/EEC proceed. The second relates to the need to investigate remedial measures not addressed in the current phase of research. Perhaps the most interesting data world wide on the reduction in faecal indicator and nutrient fluxes from agricultural activities has been produced in Co. Waterford, in Ireland where a series of Integrated Constructed Wetlands have been installed in the Anne Valley. These seem to produce a high quality effluent but their impacts on groundwaters have been questioned by the regulatory community. The baseline data created in this investigation and related studies in Scotland offers the unique opportunity to examine the additional effects of constructed wetlands and, at the same time, design into the investigations examination of the actual impact on groundwaters through tracer studies using phage or other microbial tracers.

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