THE EFFECTS OF DE-STOCKING ON MICROBIAL DELIVERY FROM CATCHMENT DIFFUSE SOURCES IN AN AREA AFFECTED BY FOOT AND MOUTH DISEASE (THE CALDEW STUDY).

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ABSTRACT
The virtual elimination of the principal point sources of human bacterial pollution through advanced treatment systems has not produced 100% compliance with microbial standards at all UK bathing water locations where they have been installed. This is partly explained by the existence of diffuse bacterial pollution derived from agricultural activities within catchments draining to the bathing zone. This pollution loading is highly episodic and driven by catchment hydrological dynamics producing a short term flush of faecal pollution early in the hydrograph event. Remediation of this diffuse pollution loading requires the type of upstream catchment management and control noted in the CEC Draft Bathing Water Directive (CEC, 2002) which suggest the implementation of Water Framework Directive (CEC, 2000) principles in the management of complex pollution sources. There is very little information on diffuse source microbial dynamics. In particular, the relative importance of different catchment microbial sources such as grazing animals, farm hardstanding areas, direct defecation in streams by livestock, farm waste spreading, small sewage treatment works, septic tanks and soakaways and combined sewage overflows. Thus, the policy maker has not, to date, been able to provide clear advice and guidance through codes of practice for the farming and contracting communities which would result in lowered faecal indicator loadings from diffuse sources to recreational waters. This opportunistic project was initiated by the Environment Agency, North West Region, to quantify the contribution of grazing animals to faecal indicator loadings in streams draining the Caldew catchment in Cumbria. Some sub-catchments of the Caldew were almost entirely de-stocked following the UK-wide outbreak of foot and mouth disease in 2001-2002. Water sampling programmes were undertaken by Environment Agency field officers to quantify the effects of de-stocked and re-stocked conditions within the Caldew catchment. Detailed sub-catchment data describing land use were acquired by ADAS and CREH have analysed the resultant data to provide a longitudinal comparison of water quality changes within the sampled sub-catchments and to place the Caldew data into the context of other 'normally stocked' UK catchment investigations. The Caldew sub-catchments case study provides a unique illustration of the faecal indicator delivery from a principally grassland, UK catchment where the major sources of faecal indicators are livestock, wildlife and small sewage systems such as septic tanks and soakaways. In so doing, it provides a possible baseline scenario against which other pollution prevention strategies, such as the implementation of farm waste management plans, use of buffer strips, or de-intensification of farming, might be assessed.

Key words: bathing waters, faecal indicator organisms, foot and mouth disease, de-stocking, rivers, storm events

INTRODUCTION
The UK Environment Agency (EA) routinely measures the microbiological quality of waters that are designated as bathing or shellfish waters under the respective EC Directives. There are 16 coastal bathing areas in Cumbria, plus 3 inland sites in Lake Windermere, and 6 shellfish waters/harvesting areas. At most of these, water quality is impacted both by point source and diffuse source pollution. A key question for the EA as environmental regulator is the balance between these two source types, as this has a fundamental influence on the approach required to improve water quality from compliance with the Directive's 'Imperative' standards towards the more aspirational and stricter 'Guideline' standards of the bathing waters Directive (CEC, 1975).

Despite considerable investment by the water industry to upgrade sewage treatment facilities, including disinfection in some cases, some waters still fail to meet the required standard in all years. Recent research has suggested that poor microbiological quality is, in some cases, linked to livestock grazing and manure spreading in local catchments (Aitken *et al.*, 2001). Thus, removal of point source discharges alone through sewage infra-structure improvements may not ensure the compliance of these waters with existing directives establishing the framework for regulation of bathing water quality and shellfish hygiene (Crowther *et al.*, 2001, 2002). Studies undertaken by CREH have identified the broad balances between, for example, sewage and agricultural sources for a series of UK catchments shown in Figure 1. However, there is little reliable information on the relative impact of different 'agricultural' sources, for example, farm hard standing areas versus direct spreading of farm waste onto land described by Kay *et al.* (2003).

A major difficulty in assessing the contribution of diffuse farm pollution is the design of an appropriate experiment, first to separate the agricultural diffuse element from the anthropogenic point source component and second to investigate the components within the agricultural element to facilitate targeted and cost effective remediation. Several studies have sought to address the general issue including:

- the CREH catchment budget studies (Fewtrell *et al.*, 1998; Stapleton *et al.*, 1999, 2000a,b, 2002a,b; Wither *et al.*,2003; Wyer *et al*., 1997, 1998. 1999a,b, 2000, 2001) (Figure 1);
- the CREH diffuse source 'black box' models (Crowther *et al.*, 2002, 2003)
- the SAC PAMIMO 'deterministic' catchment models;
- the CREH/Macaulay work for the Scottish Executive in Ayrshire on faecal indicator delivery from farm hard-standing areas (Kay *et al.*, 2003); and
- the ADAS work investigating and modelling the impact of diffuse pollution from manure spreading on faecal indicator concentrations in commercial shellfish beds (FSA Project B05006; 2003).

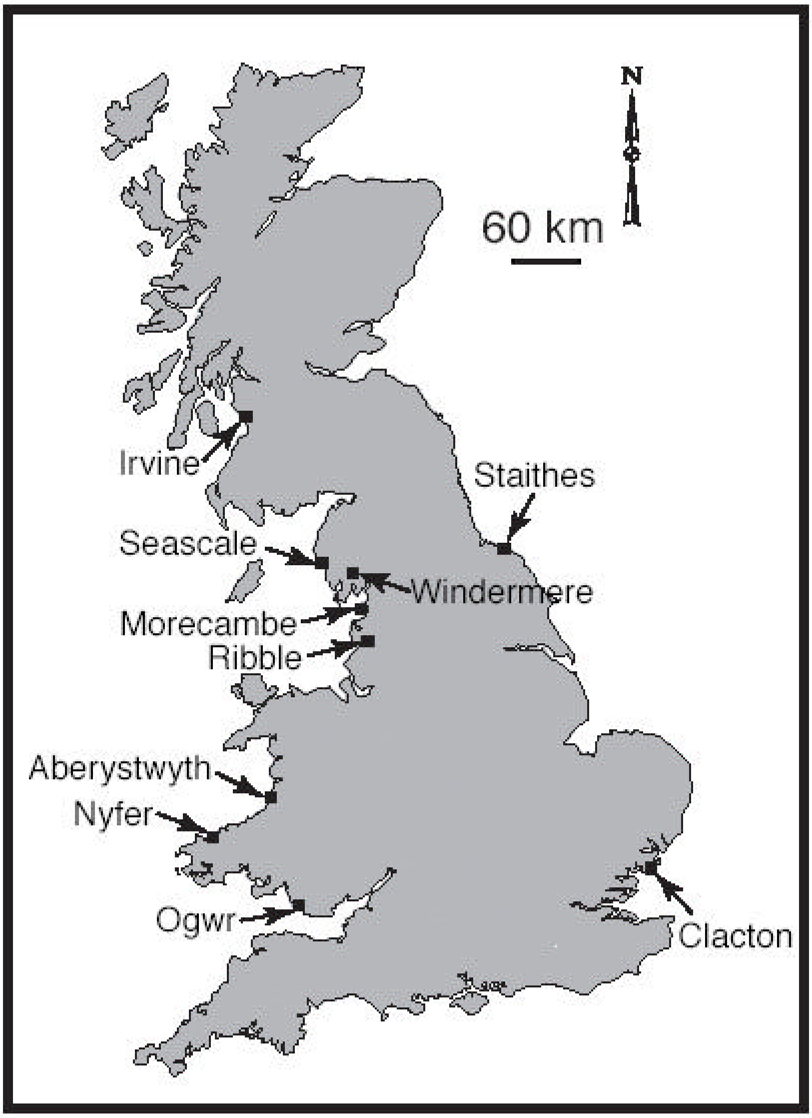

Figure 1 Location of CREH catchment studies

These studies have primarily adopted a comparative approach between multiple sub-catchments under a range of complex land use types. The research challenge has been to quantify the potential impacts of specific land use changes from the existing and historical data, thus, to provide operational guidance on appropriate management. Clearly, this approach is difficult and its central flaw is that the research data generated derives from existing use (i.e. driven by existing CAP support structures) and, thus, predictions of effects outwith the current data envelop may be, at best, speculative.

A more credible research design would involve the experimental manipulation of land use and farming practice in a longitudinal (or prospective) protocol. This would require the willing collaboration of large numbers of farmers and involve huge expenditures. However, an opportunity to investigate an extreme type of land use manipulation has arisen following the Foot and Mouth epidemic which commenced in the spring of 2001. In essence, if data could be acquired characterising faecal indicator and pathogen delivery after de-stocking and through re-stocking, then the impacts of pastoral agriculture could be quantitatively assessed.

BACKGROUND

Project Objectives

The purpose of this project is to monitor and describe the impact of changes in stocking density on the microbiological water quality of the Caldew catchment in Cumbria, which was heavily affected by FMD. The Caldew has been chosen as the trial catchment for this study on the basis of its mix of land use and degree of FMD impact. Furthermore, the catchment was the subject of a sampling programme which acquired some 500+ samples of water and faecal matter which has been analysed for the presence (and genotype) of the protozoan parasite *Cryptosporidium*. This study has been funded by UKWIR and is nested into a larger investigation of Cryptosporidium genotype analysis and mapping funded by the Drinking Water Inspectorate and water companies. Although the catchment does not directly impact on any designated bathing or shellfish water, the principles of microbial delivery, and the results from studies such as this, may be portable to such scenarios.

The specific objectives of the project are: (i) to design and implement a programme of sampling and data collection to investigate the relationship between stocking density and microbiological quality of water in a catchment affected by the FMD cull; (ii) to produce a reasoned description of the impact of de-stocking on microbiological quality in the catchment, taking into account catchment topography, land use, manure and stock management practices; and (iii) to investigate the potential for design and application of a predictive tool (probably in the form of a suite of computer programmes) linking stock density, stock and manure management practices, topography and precipitation with the microbiological quality of the watercourse.

The water quality sampling was initiated in December 2001 and is projected to end in June 2003, whereafter a period of data analysis and modelling will ensue. Thus, this paper aims to outline the methodology of the project to form a template for future investigations, and to present initial results from the first year of sampling. It is our intention to publish full results of the study when these become available.

Catchment Characteristics

The River Caldew has its headwaters on the northern fells of the UK Lake District in Northwest England. The river drains east, then north, from the peak of Skiddaw (931m) for approximately 42km to its confluence with the River Eden at Carlisle (15m), and has a catchment area of 255km^2. The fells and rough grazing areas of the headwaters merge into pasture of the middle catchment with a limited amount of arable land towards the lower course of the river. Several small villages can be found along its course although the only major urban area is that of Carlisle at the river's confluence with the River Eden.

The catchment is predominantly a productive grass growing area mainly supporting dairy and stock rearing systems. Most farms are family run and of medium size although there are a significant proportion of large livestock holdings including a small number of intensive pig and poultry units towards the lower end of the catchment. The DEFRA June 2000 Census shows 332 registered holdings in the Caldew catchment of which 92 where less than 5 hectares.

Dairy farms predominate in the lower and middle parts of the catchment and pre-FMD, these farms typically had fairly high stocking rates and almost all reared sheep and cattle. On higher and more marginal land towards the upper end of the catchment, beef cattle and upland sheep systems become most common where stocking rates are generally lower.

Cattle are typically housed for 6 to 7 months per year with the majority of livestock waste collected as slurry. Slurry storage capacity varies from farm to farm. Slurry spreading, whilst more common at certain times of the year, can be observed during almost any month of the winter/early spring. During summer, slurry is also generally applied to silage/hay aftermaths. Slurry is spread by the farmer or contractors with the latter becoming increasingly important in recent years especially on larger units.

Soil types are typically medium or heavier textures. Most of the area has a fairly high annual rainfall increasing from 850mm around Carlisle to 1700 mm around the fell bottoms at the upper end of the catchment. Topography is predominantly gently sloping or level land at the lower end, becoming more undulating further up the catchment. Moderate and steep sloping fields become more common nearer to the fells although such slopes can also be found in some areas of the middle and lower parts of the catchment.

The Foot and Mouth Disease outbreak

The Foot and Mouth Disease (FMD) outbreak which started in February 2001 caused widespread impact to the agriculture industry in England, Scotland, and Wales. The outbreak came at a time when the industry was already experiencing financial pressures, and there was considerable speculation as to the extent to which the industry would change post-outbreak (Francis *et al.*, 2002).

The River Caldew catchment was heavily affected by FMD. Cattle numbers were reduced by 80% and sheep numbers by 90% (Table 1). The majority of stock in the catchment were slaughtered during April and May 2001 and FMD disrupted livestock movement, normal slurry production and timing of spreading from March 2001. Spreading of slurry from affected farms was delayed for at least 90 days after preliminary disinfection of the farm due to 'Form A' restrictions. On farms where storage capacity was plentiful, slurry was stored for a much longer period than normal until the lifting of Form A restrictions. For many farms this extended to the final months of 2001.

Only a limited number of farms started re-stocking before the end of 2001 and significant re-stocking got underway in the early months of 2002 and increased through the spring.

Table 1. Livestock numbers on holdings located within the catchment areas above each monitoring site on the river Caldew, before and during the FMD outbreak. Data provided by DEFRA.

	June 2000 Census Livestock Counts				June 2001 Census Percent Remaining			
Monitoring Site	Cattle	Pigs	Sheep	Fowls	Cattle	Pigs	Sheep	Fowls
1 Caldew d/s Grainsgill Bk	0	0	120	0	-	-	94.5	-
2 Mosedale Bridge	0	0	120	0	-	-	94.5	-
3 Hesket Newmarket	4,320	1,950	34,480	3,450	8.2	0.1	7.2	100.0
4 Calbeck Village	1,680	0	23,650	60	21.8	-	8.0	100.0
5 Parkend	470	0	9,100	50	25.1	-	19.7	100.0
6 Skelton Wood End	30	0	20	0	99.7	-	96.0	-
7 Crown Point	480	0	880	10	48.9	-	0.0	100.0
8 Low Braithwaite Bridge	3,550	0	7,790	50	9.3	-	7.5	100.0
9 Roebank Bridge	2,470	20	8,320	20	20.9	0.0	4.1	100.0
10 Sebergham	7,820	1,950	63,460	3,560	9.6	0.1	6.9	100.0
11 Gaitsgill	11,290	20	22,870	240	18.4	0.0	7.3	100.0
12 Green Dalston	12,270	1,950	67,710	6,720	14.8	0.1	6.5	100.0
13 Holmehead	29,560	14,050	96,480	7,120	18.6	0.0	6.9	100.0

MATERIALS AND METHODS

Hydrology and water quality

Twelve sites along the River Caldew and on some of its tributaries were initially identified for water quality monitoring (Figure 2). These are particularly concentrated in the upper catchment and define relatively small sub-catchments selected for their particular catchment characteristics of topography, potential land-use, stocking densities and management practices. This was undertaken after a preliminary survey of the catchment and in liaison with local Environment Agency and ADAS staff. A further two sites were added early in 2003 when it became apparent that Common Grazing Agreements under The Lakes Environmentally Sensitive Area scheme has restricted the level of stocking allowing further quantification of water quality from destocked areas.

These sites are being sampled on a once weekly basis for the faecal indicator organisms total coliforms, faecal coliforms and intestinal enterococci (faecal streptococci) and a suite of physico-chemical parameters including turbidity, suspended solids and nutrients. Microbiological analyses are undertaken by the EA at accredited laboratories using standard methods outlined in Environment Agency (2002). In addition, one week in each month involves more intensive sampling with the aim of characterising water quality during a number of 'high flow' events on the premise that microbial water quality deteriorates during periods of rainfall-induced increased flows (Wyer *et al*., 1997, 1998). Sampling encompasses the months of December through to June for 2001-02 and 2002-03. The distribution of microbial concentrations found in the river samples, taken under base flow and high flow conditions, showed a closer approximation to normality when $\log_{10}$ transformed. Geometric mean concentrations were calculated as the antilog of the mean of $\log_{10}$ transformed concentrations and the significance of differences between geometric mean concentrations was examined using Student's t-test to compare the means of $\log_{10}$ transformed concentrations.

The EA hydrological monitoring network includes two discharge (m^3 s^{-1}) monitoring stations within the catchment at Stockdalewath (NGR: NY 38745 45009) on Roe Beck (confluent with the River Caldew in the middle catchment) and Cummersdale (NGR: NY 39489 52727) on the River Caldew in its lower reaches. The EA also monitors rainfall at a number of locations. In addition Eijkelkamp™ baro-divers were installed in the streambed at 8 sites (Figure 2) together with two 'compensation' baro-diver deployed to record atmospheric pressure. These provided a measure of stream depth every 15 minutes that can be linked to stage boards to provide an indication of the provenance of each water quality sample. Flow velocity profiles are also being taken at four sites, two in the upper catchment, and two in the middle catchment, to derive stage-discharge relationships which can be applied to the continuous stage traces, thus providing flow estimates for the relevant catchments. Two checks will be implemented to ensure the best possible stage discharge relationships within the time available. First, supplementary analysis will be undertaken, based-on rainfall volume and catchment area, as a check on the top-end discharges suggested by the power function calculated for each site. Second, a rainfall-runoff model will be employed following the approach of Littlewood and Jakeman (1992), again to check the upper end of the stage discharge relationship. The discharge records from the four sentinel sites together with existing EA sites will be used to construct discharge plots for the other sites scaled by catchment area from a digital elevation model (DEM).

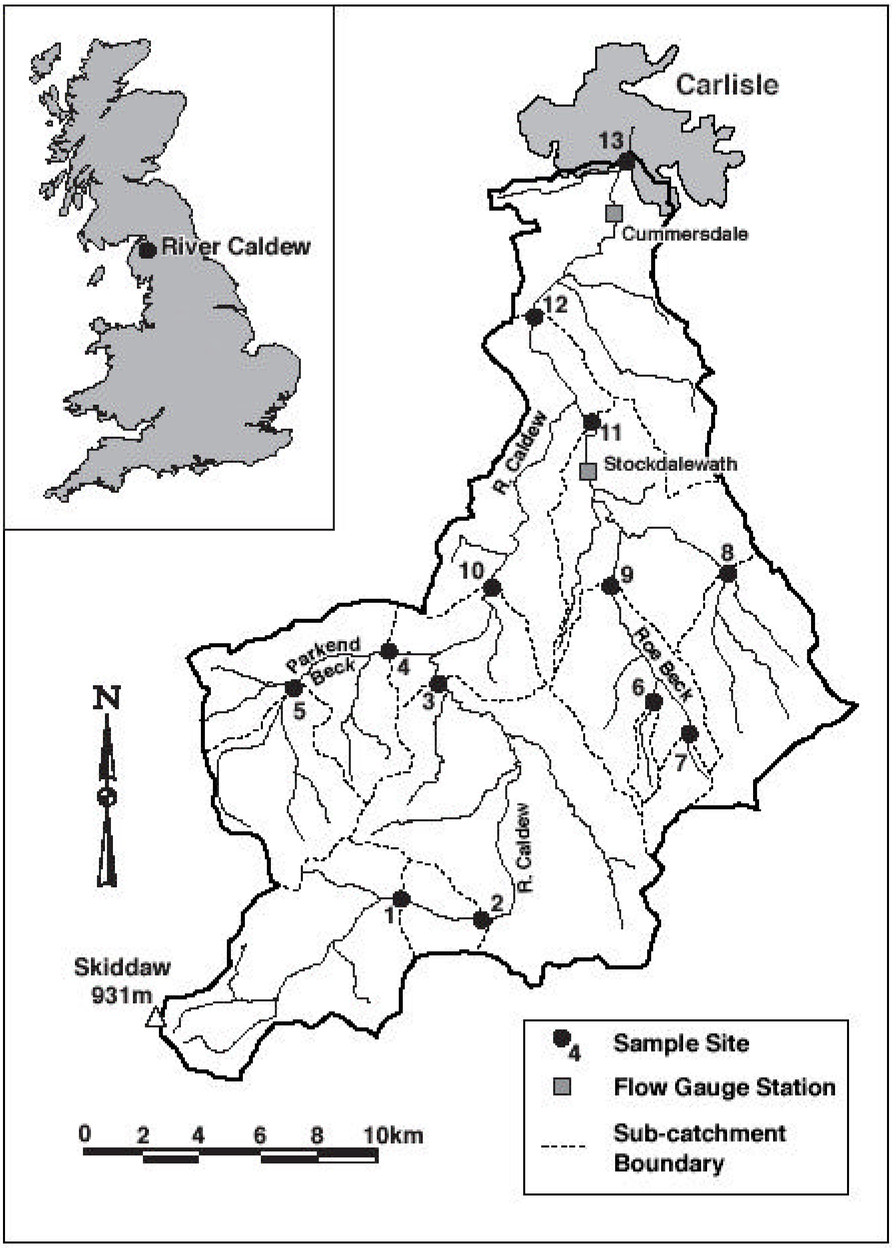

Figure 2 Location of water quality monitoring points and Environment Agency flow gauge stations in the River Caldew catchment

The hourly discharge records are split into two components: (i) base flow and (ii) high flow event response to rainfall (Wyer *et al*., 1996). This was achieved using a combination of computer programs (Pascal) and visual inspection of individual events. The computer programs apply smoothing to the time series and then examine the change in the smoothed values at each time step to define the start and peak of events above a defined threshold. For the preliminary analysis reported here the event end, or cut off, was set at a decay to 56% of the event peak. This value was derived from an analysis of over 100 events separated manually in previous CREH catchment investigations. Whilst this process worked well for larger events, a degree of manual intervention was required for smaller events and some event sequences. The final separation was then applied to the unsmoothed hourly time series. Each water quality sample is then assigned either to base flow or high flow categories according to flow conditions at the time of sampling.

Livestock and Manure Management

The loading of faecal indicators to agricultural land is dependent upon the volumes of animal excreta and manure applied, and the methods of manure storage and application that control bacterial survival (Fraser *et al*., 1998; Nicholson *et al*., 2001). The faecal indicator loading varies seasonally with livestock type and numbers, weather conditions, and land availability. Timing with respect to weather conditions and soil moisture status is then a major factor in controlling the risk of transport to the river system by leaching and soil erosion (Tian *et al*., 2002). ADAS have developed a Manure Management Database methodology that integrates national and regional manure practice survey data with local agricultural census information to provide monthly estimates of faecal indicator loading for each sub-catchment. The survey data include quantification of excreta production (Smith and Frost, 2000; Smith *et al*., 2000), manure type, store type and length of storage (Nicholson and Brewer, 1994; 1997) and the timing of applications to arable and grassland (Smith *et al*., 2000). These have been supplemented with information on animal turn-out dates taken from the National Ammonia Emissions Inventory (Pain *et al*., 1998) and the areas of crops receiving different types of manure from the British Survey of Fertiliser Practice.

To better represent local manure management practices, ADAS have undertaken a survey of 25 livestock holdings within the catchment. This has involved a comprehensive questionnaire on livestock and manure practices pre-FMD, and an on-going monthly report of animal numbers, turn-out times, manure production, storage and spreading. The holding survey also provides critical information on grazing densities, the period of manure storage and spreading rates. The monthly reports provide information on sheep grazing of common land, which cannot be determined from the Agricultural Census.

RESULTS AND DISCUSSION

Preliminary results from the farm survey show that 95% of dairy manure and 35% of beef manure is handled as slurry and the remainder as Farm Yard Manure (FYM), typically mixed with straw bedding. Summary output from the Manure Management Database for excreta and manure production within the catchment is illustrated by Figure 3. Preliminary calculations indicate that 309,000 t yr^{-1} of excreta is produced by cattle and 45,600 t yr^{-1} by sheep within the catchment, of which 46% is collected from sheds and hard-standings and managed as manure.

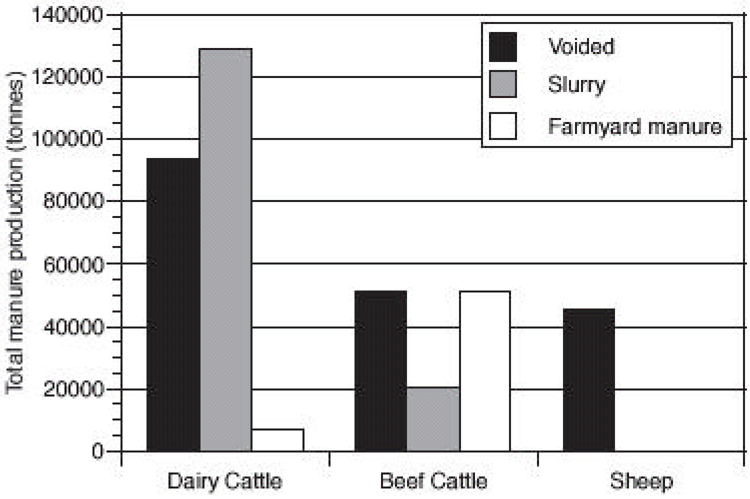

Figure 3 Calculated quantities of managed manure and voided excreta produced by grazing livestock, at pre-FMD stocking levels, within the River Caldew catchment.

As part of the farm survey, a risk assessment has been carried out which enumerated the numbers of fields to which manure is spread, in which grazing livestock have access to flowing water, and which have artificial drainage. Overall, 86% of the surveyed fields are under grass. Of these fields, 54% receive manure, 70% have artificial drainage, 49% are immediately adjacent to flowing waters, and 25% have free access for livestock. These data indicate apotentially high risk environment for the transfer of faecal indicators in excreta and managed manure to the river system.

Characterisation of changing stock levels is critical to the analyses of the water quality monitoring data. Holding level statistical data from the annual Agricultural Census, aggregated to sub-catchments to preserve confidentiality, have been collated to quantify the changing numbers of livestock. Prior to the FMD outbreak, there were 29,500 cattle and 96,500 sheep within the catchment. Cattle numbers were reduced by 80% and sheep numbers by 90% in the middle of the outbreak (Table 1). Detailed data on the subsequent re-stocking of the catchment have been provided by field surveys of grazing animals and by data extracts from the Animal Movement Licensing System (AMLS), provided by the State Veterinary Service. Data on actual cattle numbers and the number of sheep movements on and off individual holdings within the catchment have been summarised on a monthly basis (Figure 4). Significant re-stocking occurred in early 2002. The AMLS data are only a guide to the changing number of stock as they cannot show the impact of calving. Many animals were purchased in calf and gave birth in the late spring of 2002. By June 2002, the Agricultural Census reported that cattle numbers had recovered to 75% and sheep to 50% of pre-FMD numbers.

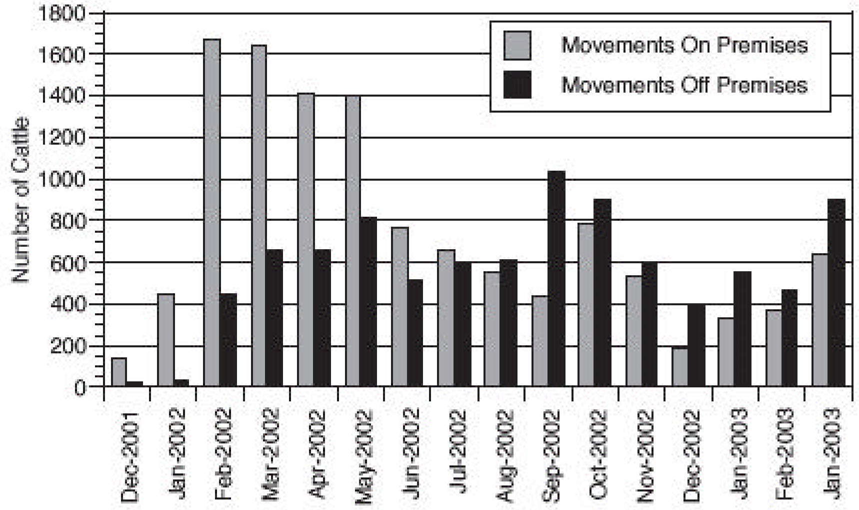

Figure 4 Licensed number of cattle moved onto and off farm premises within the catchment of the River Caldew (data provided by the State Veterinary Service)

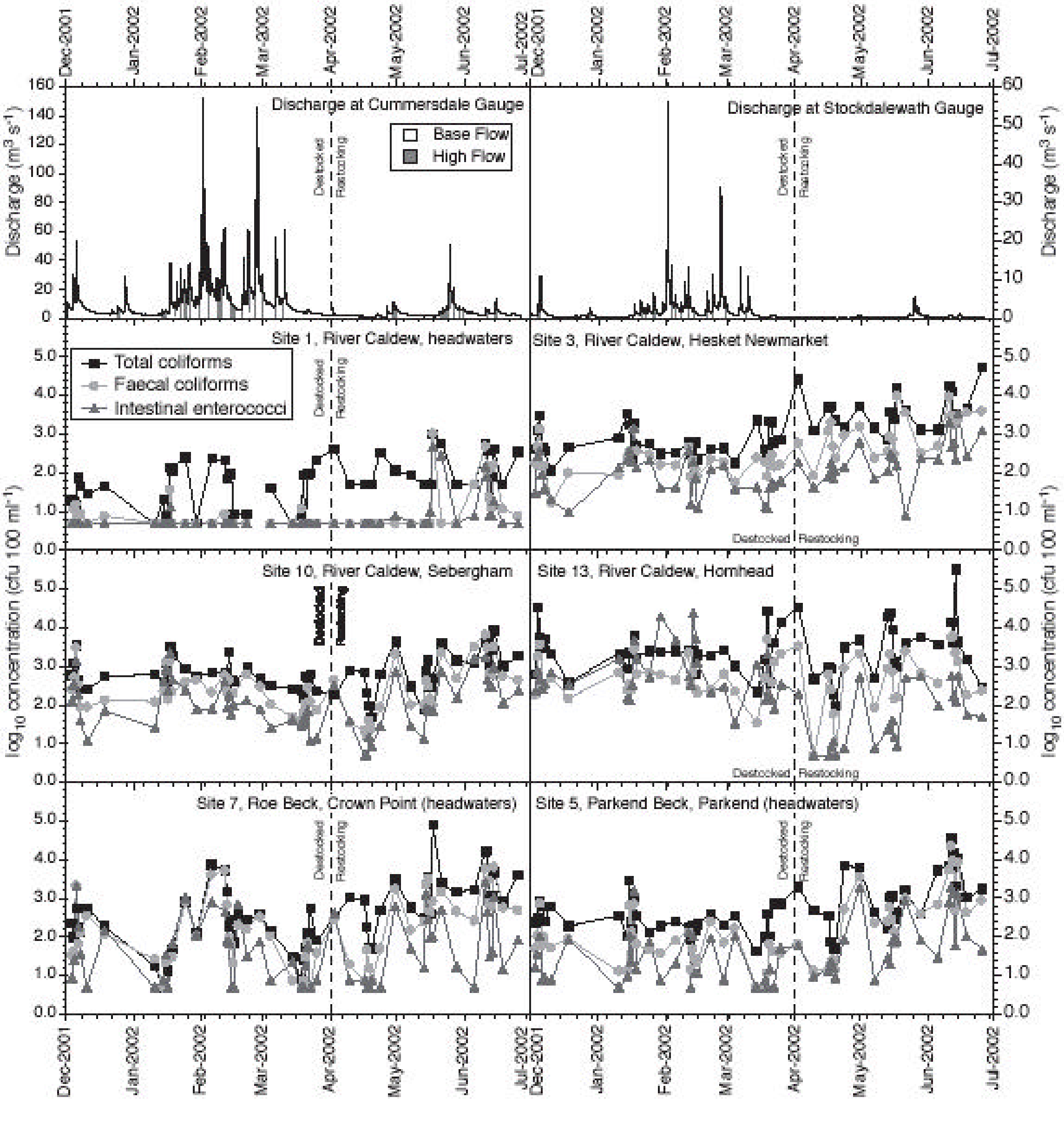

Figure 5 Relationship between discharge and Faecal Indicator Organisms

The discharge for the two EA gauge locations for the first sampling period (December 2001 - June 2002) are shown in relation to faecal indicator organism concentrations in Figure 5. Stage-discharge relationships are not yet available for the non-EA gauged locations and initial flow separation at all sites is based on either Stockdalewath or Cummersdale EA gauge sites

Stock number data to identify destocked and stocked periods over the 2001-02 sampling period on a sub-catchment basis are still being collated. However, to illustrate the impacts of significant restocking early in 2002, an initial analysis separating the faecal indicator organism concentration data at the end of each month between January and May was undertaken. The differences in bacterial water quality between the two periods (referred to here as 'destocked' and 'restocking') were most pronounced when the data were separated at the end of March 2002. This does not coincide with the first large influx of livestock during February although significant numbers of cattle were also imported during March. Furthermore, the turn-out of cattle to pasture usually occurs around this time. However, there may be an element of seasonality associated with these differences which will be investigated when results from year 2 of the study are available.

Flow volumes and the proportions of flow attributable to base flow and high flow event conditions during the December 2001 to end of March 2002 'destocked' and April to June 2002 'restocking' periods are shown in Table 2, whilst geometric mean faecal indicator organism concentrations for selected sites along the course of the River Caldew during base flow and high flow conditions are presented in Table 3.

Table 2: Base flow, high flow and total flow volumes (m^3) and duration (hours) over the first year of field study (09:00 GMT 1/12/01 - 09:00GMT 26/6/02) and split into destocked (09:00 GMT 1/12/01 - 09:00GMT 1/4/02) and restocking periods (09:00GMT 1/4/02 - 09:00 1/6/02).

	Flow volume (m^3) & duration (hours)			% of total flow volume & duration		
	Base Flow	High Flow	Total	Base Flow	High Flow	Total
Study period (09:00 GMT 1/12/01 - 09:00GMT 26/6/02)						
Discharge	59406796	92214929	151621725	39.18	60.82	100.00
Duration	3343	1625	4968	67.29	32.71	100.00
Destocked period (09:00 GMT 1/12/01 - 09:00GMT 1/4/02)						
Discharge	45189076	78430786	123619862	29.80	51.73	81.53
Duration	1814	1090	2904	36.51	21.94	58.45
Restocked (09:00GMT 1/4/02 - 09:00 1/6/02)						
Discharge	14217720	13784143	28001863	9.38	9.09	18.47
Duration	1529	535	2064	30.78	10.77	41.55

Most of the flow volume from the River Caldew between December and June was during the destocked period, accounting for 82% of the flow volume at Cummersdale (Table 2) despite this period accounting for 58% of the time. The hydrographs in Figure 5 also indicate that peak event flows were much greater during the destocked period.

The faecal indicator organism results (Table 3) show that there is a general increase in microbial concentrations downstream from site 1 to site 13 in the lower reaches, under both base flow and high flow conditions. However, there was a slight decrease in concentrations of some indicators between site 10 and site 13 during the restocking period. Concentrations are greater during high flow conditions when saturated overland flow and stream stage rise over bank areas accessed by grazing livestock provides a pathway for faecal indicator delivery to the rivers, whilst increased velocities may re-entrain bacteria from settled sediments (McDonald and Kay, 1981; Wilkinson *et al.*, 1995). Faecal coliform and intestinal enterococci concentrations during the destocked period at site 1, in the headwaters of the river, are in single figures per $100ml^{-1}$ during both base flow and high flow conditions. High flow concentrations in the restocking period display statistically significant elevations over those of the destocked period. Similar patterns are evident at sites 3 and 10. Towards the lower course of the River Caldew (site 13) intestinal enterococci concentrations during the restocking period display a statistically significant decrease over those observed during the destocked period.

Table 3 also includes data for the headwaters of two tributaries of the River Caldew, Parkend Beck (site 5) and Roe Beck (site 7). The topography of these headwaters differ from those of the River Caldew in that no fell areas are present in the Roe Beck catchment, whilst Parkend Beck contains only a proportion of fell area. Associated with the different topography, land-use patterns vary. Here, the geometric mean concentrations are at least an order of magnitude greater than the headwater of the River Caldew (site 1) for each flow state and for the destocked and restocking periods. However, without the detailed information on stocking patterns which is currently being collated, it is not possible to further investigate reasons for such elevations in concentrations in Roe Beck.

Table 3: Geometric mean faecal indicator organism concentrations (cfu 100ml^{-1}) under base flow and high flow conditions during perceived destocked (Dec. 2001- March 2002) and initial restocking (April-June 2002) at selected sites in the River Caldew catchment.

	Base Flow			High Flow		
	Total Coliforms (cfu 100ml^{-1})	Faecal coliforms (cfu 100ml^{-1})	Intestinal enterococci (cfu 100ml^{-1})	Total Coliforms (cfu 100ml^{-1})	Faecal coliforms (cfu 100ml^{-1})	Intestinal enterococci (cfu 100ml^{-1})
<u>Site 1. R. Caldew, headwaters</u>						
Destocked	25	6	5	62	8	6
Restocking*	91†	9	8	**437**†	**208**†	**59**†
<u>Site 3. R. Caldew, Hesket Newmarket</u>						
Destocked	530	145	52	765	**358**	**158**
Restocking*	3526†	916†	163†	8568†	**4133**†	**1448**†
<u>Site 10. R. Caldew, Sebergham</u>						
Destocked	421	163	67	**1138**	**486**	**248**
Restocking*	619	212	77	**6315**	**4110**†	**901**†
<u>Site 13. R. Caldew, Holmehead</u>						
Destocked	1943	407	343	2973	**708**	**1248**
Restocking*	1794	228	26‡	8501†	2238†	**160**‡
<u>Site 5. Parkend Beck, Parkend (headwaters)</u>						
Destocked	259	44	16	306	109	**50**
Restocking*	779†	214†	57†	**13685**†	**10360**†	**1249**†
<u>Site 7. Roe Beck, Crown Point (headwaters)</u>						
Destocked	101	50	22	351	**240**†	**111**†
Restocking*	926	235	39	**10782**†	**4853**†	**1067**†

* This was the start of the restocking process and does not imply a fully restocked situation.
† statistically significant increase in geometric mean concentration in restocking period
‡ statistically significant decrease in geometric mean concentration in restocking period
Bold concentrations denote statistically significant increase in geometric mean concentration between base flow and high flow conditions
All tests of difference used Student's t-test, 1-tailed, α=0.05, confidence=95% on $\log_{10}$ transformed data to achieve normality.

CONCLUSIONS

Initial results from the Caldew catchment imply an increase in bacterial concentrations at most of the sample sites during the assumed restocking period, particularly during high flow events. The data currently being collated on livestock movements and management within the catchment should aid in quantifying when livestock were re-introduced to the various sub-catchments. This will allow a more detailed assessment of the water quality data on a sub-catchment basis, which, when coupled with the manure management information from the farm surveys, should shed further light on the relationships between land-use and water quality.

It is noticeable that peak hydrograph event flows were greater during the destocked period so there may be an element of dilution of faecal indicator organism concentrations, although increased runoff from the catchment during this period provides a greater potential for organisms to be transported into the water courses. Furthermore, there may be an element of seasonality within the distributions. Data from year 2 should aid in identifying such trends.

A further aspect of this research will be to use the data collected to calibrate generic 'black box' statistical models relating bacterial water quality to land-use which have been developed by CREH (Crowther *et al.,* 2002, 2003; Wyer *et al.,* 2000b). These models use land use information, either generated by satellite imagery or ground truth data acquisition, as the predictor variables to predict both high and low flow faecal indicator concentrations at sub-catchment outlets. The application of these models to the Caldew is of broader significance because the catchment offers perhaps the only UK opportunity to assess the 'potential' water quality change due to altered incentives to affect stocking intensities.

If successful, the study will provide a baseline scenario, illustrating the faecal indicator quality which might be achieved in a catchment with no significant impact from agricultural activity. Pollution prevention strategies such as the implementation of farm waste management plans, use of buffer strips, or de-intensification of farming might subsequently be assessed against this baseline, using the models produced in the study. The work will thus provide a useful supplement to the Agency's information base and help it to influence the future of agricultural subsidy schemes in the UK.

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REFERENCES

Aitken, M., Merrilees, D. W. and Duncan, A. (2001) *Impact of agricultural practices and Catchment characteristics on Ayrshire bathing waters*. Scottish Executive Central Research Unit, Edinburgh, UK.

CEC (1975) Commission of the European Communities. Directive 76/160/EEC of the European Parliament and of the Council concerning the quality of bathing waters. *Official Journal of the European Communities* **L31**, 1-7.

CEC (2000) Commission of the European Communities. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000: establishing a framework for Community action in the field of water policy. *Official Journal of the European Communities,* **L327**. 1-72.

CEC (2002) Commission of the European Communities. Proposal for a Directive of the European Parliament and of the Council concerning the quality of bathing waters. *COM(2002) 518 Final. 24.10.2002*. Brussels.

Crowther J., Kay D. and Wyer M. D. (2001) Relationships between microbial water quality and environmental conditions in coastal recreational water: the Fylde coast, UK. *Water Research* **35** (17), 4029-4038.

Crowther, J., Kay, D. & Wyer, M.D. (2002) Faecal-indicator concentrations in waters draining lowland pastoral catchments in the UK: relationships with land use and farming practices. *Water Research*, **36**, 1725-1734.

Crowther, J., Wyer, M. D., Bradford, M., Kay, D. and Francis, C. A. (2003). Modelling faecal indicator concentrations in large rural catchments using land use and topographic data. *Journal of Applied Microbiology,* (In Press).

Environment Agency (2002). *The microbiology of drinking water (2002). Methods for the examination of waters and associated materials. Standing Committee of Analysts.* Environment Agency.

Fraser, R. H., Barten, P. K., and Pinney, D. A. K. (1998) Predicting stream pathogen loading from livestock using a Geographical Information System based delivery model. *Journal of Environmental Quality*, **27**, 935-945.

Fewtrell L., Kay D., Wyer M. D., Crowther J., Carbo P and Mitchell G. (1998) *Faecal indicator budgets discharging to the Ribble estuary*. A report to Environment Agency (N. W. Region). 32pp. CREH, University of Wales, Aberystwyth.

Francis, J., Hawley, J. and Scott, T., (2002) *Report on a survey of the effects of the 2001 Foot & Mouth disease outbreak (England)*. Prepared for Economics and Statistics Directorate, DEFRA, York. ADAS Consulting Ltd , Wolverhampton.

Kay, D., Edwards, A., Francis, C., Kay, C., Rushby, L., Watkins, J., McDonald, A. T., Wyer M. D., Crowther, J., Stapleton, C. M. and Wilkinson, J. (2003) Does farmyard runoff represent a significant source of faecal indicator organisms for the bathing waters of SW Scotland? *Proceedings of the 7th IWA International Conference on Diffuse Pollution and Basin Management*, University College Dublin, Ireland, 17th-22nd August 2003.

Littlewood, I.G. and Jakeman, A. J. (1992) Characterisation of quick and slow stream flow components by unit hydrograph for single and multi-basin studies. Chapter 12 in Robinson, M. (Ed) *Methods of hydrological basin comparison*. IOH Report 120, 99-111.

McDonald, A. and Kay, D. (1981) Enteric bacterial concentrations in reservoir feeder streams:baseflow characteristics and response to hydrograph events. *Water Research* **15,** 961-968.

Nicholson, F. A., Hutchinson, M. L., Smith, K. A., Keevil, C. W., Chambers, B. J. and Moore, A. (2000) *A study on farm manure applications to agricultural land and an assessment of the risks of pathogen transfer into the food chain*. Ministry of Agriculture, Fisheries and Food Project FS2526 Final Report, London, UK.

Nicholson, R. J. and Brewer, A. J. (1994). *Estimates of types of slurry and manure storage in England and Wales, related to livestock species*. Ministry of Agriculture, Fisheries and Food Project WA0611 Final Report, London, UK.

Nicholson, R. J. and Brewer, A. J. (1997). Estimates of volumes and exposed surface areas of stored animal manures and slurries in England & Wales. *Journal of Agricultural Engineering Research* **66**, 239-250.

Pain, B. .F, Van Der Weerden, T. J., Chambers, B. J., Phillips, V. R. and Jarvis, S. C. (1998) A new inventory for ammonia emissions from UK agriculture. *Atmospheric Environment*, **32** (3): 309-313.

Scott, T., Crabb, J. and Smith, K. (2002) *Report on the 2001 Farm Practices Survey*. Report to DEFRA, ADAS, Wolverhampton, 121pp.

Smith, K. A., Charles, D. R. and Moorhouse, D. (2000). Nitrogen excretion by farm livestock with respect to land spreading requirements and controlling nitrogen losses to ground and surface waters; II. Pigs and poultry. *Bioresource Technology* **71**, 183-194.

Smith, K. A. and Frost, J. P. (2000). Nitrogen excretion by farm livestock with respect to land spreading requirements and controlling nitrogen losses to ground and surface waters; I. Cattle and sheep. *Bioresource Technology* **71**, 173-181.

Stapleton, C. M., Wilkinson, J., Wyer, M. D., Fewtrell, L. & Kay, D. (1999) *Seascale and St Bees bathing waters bacterial impact study*., Confidential report to Environment Agency (N.W.), 55pp.,CREH, Univ. of Wales, Aberystwyth.

Stapleton, C. M., Kay, D., Chudley, J., Fewtrell, L. Wilkinson, J. and Wyer, M. D. (2000a) *Morecambe Bay bathing waters bacterial impact study*. Report to the Environment Agency (N.W. Region). 199pp plus Figures and Appendices. CREH, University of Wales, Aberystwyth.

Stapleton, C. M, Wilkinson, J., Kay, D., Fewtrell, L. and Wyer, M. D. (2000b) *Lake Windermere bathing waters bacterial impact study*. Report to the Environment Agency (N.W. Region). 156pp plus Figures and Appendices. CREH, University of Wales, Aberystwyth.

Stapleton, C. M., Wyer, M. D. and Kay, D. (2002a) *Assessment of point and diffuse sources of faecal indicators in the Ribble catchment. Phase 1 Scoping and Desk Study. Volume I Report.* Report to the Environment Agency, North West Region. 39p.

Stapleton, C. M., Wyer, M. D. and Kay, D. (2002b) *Assessment of point and diffuse sources of faecal indicators in the Ribble catchment. Phase 1 Scoping and Desk Study. Volume II Figures and Tables*. Report to the Environment Agency, North West Region. 122p.

Tian, Y. Q., Gong, P., Radke, J. D. and Scarborough, J. (2002) Spatial and temporal modelling of microbial contaminants on grazing farmlands. *Journal of Environmental Quality,* **31** (3):860-869.

Wither, A., Greaves, J., Dunhill, I., Wyer, M. D., Stapleton, C. M., Kay, D., Humphrey, N., Watkins, J., Francis, C., McDonald, A. and Crowther, J. (2003) Estimation of diffuse and point source microbial pollution in the Ribble catchment discharging to bathing waters in the north west of England. *Proceedings of the 7th IWA International Conference on Diffuse Pollution and Basin Management*, University College Dublin, Ireland, 17th-22nd August 2003.

Wilkinson, J., Jenkins, A., Wyer, M. And Kay, D. (1995). Modelling Faecal Coliform dynamics in streams and rivers. *Water Research* **29**, 847-855.

Wyer, M. D., Kay, D., Dawson, H. M., Jackson, G. F., Jones, F., Yeo, J. and Whittle, J. (1996) Delivery of microbial indicator organisms to coastal waters from catchment sources. *Water Science and Technology,* **33** (2), 37-50.

Wyer, M.D., Kay,D., Crowther, J., O'Neill, J.G., Jackson, G. and Fewtrell, L. (1997) The effects of catchment (i.e. non-outfall) sources of faecal indicators on compliance of marine recreational waters with Directive 76/160/EEC *Water Science and Technology* **35**(11-12), 151-156.

Wyer, M., Kay, D., Crowther, J., Whittle, J., Spence, A., Huen V. Wilson, C., Carbo, P. and Newsome J. (1998) Faecal indicator budgets for recreational coastal waters - a catchment approach. *Journal of the Chartered Institution of Water and Environmental Management*, **12**(6) 414-424.

Wyer M. D., Crowther J., Kay D., Stapleton C. and Wilkinson J. (1999a) *Faecal indicator organism sources and budgets for the Tendring peninsula, Essex*. Report to West of Scotland Water. 42pp (plus Figures and Tables). CREH, University of Wales, Aberystwyth.

Wyer M. D., Crowther J., Kay D. and Fewtrell L. (1999b) *Faecal indicator organism sources and budgets for the Irvine and Girvan catchments, Ayrshire*. Report to West of Scotland Water. 42pp (plus Figures and Tables). CREH, University of Wales, Aberystwyth.

Wyer M. D., Crowther J., Kay D., Francis C., Watkins J. and Bradford M. (2000) *Bathing water quality compliance at north Ceredigion beaches: statistical modelling and catchment investigations*. A report of the Interreg project. 44pp plus Figures, Tables and Appendices. CREH, University of Wales, Aberystwyth.

Wyer, M.D., Kay, D., Stapleton C. M., Francis, C. A., Watkins, J. and Rushby L. (2001) *Faecal Indicator Organism Sources and Budgets for Irvine Bay, Ayrshire*. A Report to West of Scotland Water, the Scottish Environment Protection Agency, South Ayrshire Council and North Ayrshire Council. 15pp. Plus Figures and Tables (68 pages total). CREH, University of Wales, Aberystwyth.