DOES FARMYARD RUNOFF REPRESENT A SIGNIFICANT SOURCE OF FAECAL INDICATOR ORGANISMS FOR THE BATHING WATERS OF SW SCOTLAND?

Kay, D.[1], Edwards, A.C.[2], Ferrier, R.C[2]., Francis, C.[1], Kay, C[1], Rushby, L.[1], Wakins J.[1], McDonald, A.T.[1], Wyer M.[1], Crowther, J. and Wilkinson, J.

[1]Centre for Research into Environment and Health, IGES, University of Wales, Aberystwyth, UK
, [2]Macaulay Institute, Aberdeen, UK

ABSTRACT

This project was initiated by the Scottish Executive to quantify the contribution of farm hard standing areas and roof surfaces to faecal indicator loadings in streams draining to bathing waters in Ayrshire. Four farms within the River Irvine catchment were instrumented and sampled intensively over a four-week period from the 17th June 2002. Continuous recordings of rainfall and river/drain flows were made throughout the period. Samples of receiving streams, roof and yard runoff were collected periodically under 'dry' and 'wet' conditions. These were tested for total coliform (TC), faecal coliform (FC) and faecal streptococci (FS). The significance of farmyard runoff as a source of faecal indicator delivery to the diffuse source contribution has been confirmed. Interestingly, the roof runoff samples contained surprisingly high levels faecal streptococci. For three of the four study farms where 'above and below' data were available, significant increases in the high flow faecal indicator organism pollution loading could be attributed to the farmyard. The rapid connectivity between farmyard runoff with ephemeral, first order streams was very evident, although the exact routing differed between farms. Reducing the extent of this physical connectivity together with reducing the actual volumes of contaminated runoff represent achievable and practical remediation strategies.

Key words: bathing waters, faecal indicator organisms, farm runoff, streams, storm events.

INTRODUCTION

Bathing beach compliance with EU standards is dependent on maintaining water quality within defined microbiological standards. Point source control of sewage pollution through advanced sewage treatment and disposal systems has formed the principal UK strategy for the maintenance of bathing water quality and the acquisition of seaside awards such as the 'Blue Flag' scheme. At many UK bathing beaches, sewage is now treated with advanced tertiary systems (UV disinfection or microfiltration) designed to minimise bacterial loadings. These expensive treatment systems have produced a marked improvement in bathing water quality in the UK. However, the virtual elimination of the principal point sources, i.e. human bacterial loadings, has not guaranteed compliance with microbial standards at all compliance locations. Increasingly, the problem of diffuse bacterial pollution derived from agricultural activities within catchments draining to the bathing zone is recognised as a major cause on non-compliance. The occurrence of this pollution loading is highly episodic and further remediation of this diffuse pollution source requires the type of upstream catchment management and control noted in the CEC Draft Bathing Water Directive (2002) which suggest the implementation of Water Framework Directive (Directive 2000/60/EU) principles of integrated diffuse and point source control in the management of complex pollution sources.

However, there is currently a lack of empirical information on catchment (i.e. diffuse source) microbial dynamics (Tyrrell and Quinton, 2003). In particular, the relative importance of different catchment microbial sources such as farm hardstanding areas, direct access to streams by livestock, farm waste spreading, small sewage treatment works, septic tanks and soakaways and combined sewage overflows. Thus, the policy community has not been able to provide clear advice and guidance through codes of practice for the farming and rural contracting communities which would result in lowered faecal indicator loadings from diffuse sources to recreational waters.

Several authors in Europe and North America have reported the importance of episodic microbial pollution, driven by rainfall events, on bathing beach non-compliance (Nobel *et al*., 2003; Fiandrino *et al*., 2003; Crowther *et al*., 2001, 2002; Kay *et al*., 1999a,b; Wyer *et al*., 1996). Given their impervious nature, the relatively small farmyard areas become hydrologically dynamic faecal indicator sources very early in the rainfall event. In view of the observed relationship between faecal indicator concentrations and stage height in small catchment streams, i.e. a rapid increase in concentration on the rising limb of the hydrograph followed by a fall in concentration preceding the recession limb (Morrison and Fair, 1966; Kunkle, 1970; McDonald and Kay, 1981; Wilkinson *et al*., 1995) a feasible explanation for this early concentration increase could be direct inputs of rapid flow and faecal indicator loadings from farm hard standings direct to stream channels.

Other potential sources of this 'first flush' of faecal indicators could be stock watering directly from the stream producing a faecal store on the bank areas which would be flooded by stage rise and/or a store of faecal indicators in the stream bed which was reported by McDonald *et al*. (1982) and Kay and McDonald (1983) and modelled by Jenkins *et al*. (1983) and Wilkinson *et al*. (1995).

Appropriate targeting of remedial measures requires a broad understanding of the relative balances of these potential sources and this project was initiated as part of a broad integrated monitoring and modelling effort undertaken under the direction of the Scottish Executive to address these questions.

METHODS
Four study farms, broadly characteristic of many livestock enterprises in south west Scotland with a mixture of dairy and beef cattle, were recruited in the River Irvine catchment Ayrshire. This area has been extensively studied because bathing beach non-compliance has been associated with agricultural diffuse source pollution and a series of microbial budget investigations have recently been completed (Wyer *et al*., 1999, 2001). Three of the four farms had an adjacent stream receiving the hardstanding drainage. At the fourth, the hardstanding area represented the headwater catchment of a first order stream. In this case, an 'above and below' design was not possible and the bacterial flux at the stream monitoring point represented the loading derived from the hardstanding area. Three of the four farms had livestock using the hardstanding area through the four-week sampling period from June 17th to July 13th 2002.

A data logging rain gauge was positioned adjacent to the hardstanding of each farm. These US sourced Onset^{TM} tipping bucket gauges recorded each 0.01 inch of rainfall through the sampling period. Stream and/or drain discharge measurements were completed at each farm to obtain data on faecal indicator flux. The measurement locations were tailored to the hydrology and morphometry of each site outlined in Table 1.

Table 1 Data acquisition locations for each of the four study farms

Site	Sampling locations	Discharge measurement locations
Farm 1	Stream above and below site Hardstanding drainage Roof drainage	Stream below site
Farm 2	Stream above and below site Hardstanding drainage Roof drainage	Stream below site
Farm 3	Stream below site (farm was source) Hardstanding drainage Roof drainage	Stream below site
Farm 4	Direct drainage from hard standing discharged to stream via a porous soil pipe	Drainage pipe

Stream stage was determined at each site using a fixed stage board and an Eijkelkamp^{TM} barometric diver (ME.11.11.50.E, FSD zero to 150cm) together with three compensation divers distributed over this small catchment area to facilitate correction for atmospheric pressure. At two sites (farms 3 and 4), the relatively small flows were suitable for the installation of vertical 'v notch' weir plates where the barometric divers were housed in the slack water behind the weir plate. At farms 3 and 4, he modelled discharge from the weir plates was check by volumetric measurement of discharge using a 1 litre measuring cylinder and a stage reading was recorded at each sampling event as a check on the barometric diver reading. At farms 1 and 2 Ott horizontal paper chart recorders and heavy galvanized stilling wells were installed in stream channels immediately downstream of the points where farm hardstanding inputs entered the stream channels. Here, the barometric divers were installed in the stilling well and compensation divers were housed in the chart recorder security casings. Again, a stage reading was recorded at each sampling event and the diver reading compared to the stage reading as a further check on the barometric depth measurements. At farms 1 and 2 a stage discharge relationship was calculated using the 'normal velocity area' approach (see Richards, 1982 page 127; Buchanan and Somers, 1969, British Standards Institute, 1964 and ISO, 1996). Stream velocity measurements were undertaken using an Aqua Data Services SENSA-RC2 electromagnetic water velocity meter (number P42-035) with RV4 probe calibrated in accordance with ISO 3455 standards by the manufacturer. This unit was chosen over a moving element system because it maintained high resolution (i.e. < 0.002 m sec^{-1} over range of flows 0.0 to 0.4 m sec^{-1}). For the larger stream monitoring site at farm 2, which had a clearly defined catchment of 4.9 km^{2}, the calculated stage discharge relationship was further checked using a rainfall runoff model (Littlewood and Jakeman, 1993).

The nature of the study necessitated opportunistic sampling of flows from the roofs, hardstandings and streams following rainfall events to supplement dry weather data acquisition. This was facilitated using a mobile microbiology laboratory sited close to the sampling sites. All laboratory equipment was calibrated prior to use and had calibration records maintained to UKAS standards by staff of the CREH fixed laboratory facility in Leeds, UK. Total coliform, presumptive faecal coliform, and presumptive faecal streptococci were enumerated by membrane filtration using standard UK methods (Environment Agency, 2002). All samples were collected in sterile plastic containers (sterile pipettes were used to acquire shallow hardstanding drainage), and transported to the laboratory in a dark cold box. Here, they were immediately transferred to a dark refrigerator <4^{o}C where the sample containers were in contact with melting ice to effect rapid temperature reduction. To avoid 'greater than' and 'less than' results, three serial dilutions were initially employed for all sites. Where appropriate, this was adjusted to two dilutions as the laboratory staff were better able to predict the concentrations expected from each site.

There were significant operational and physical differences between the farms (Table 2) which provided different opportunities for sample collection. Only at farm w were cattle not present in the farmyard during the samp ling period (they had been removed just prior to sampling), this location was therefore considered to represent a possible control (background) situation where no fresh faeces were deposited through the study period. The farms all differed with respect to the connectivity that existed between the farmyard and the nearest open drainage channel.

Table 2 Broad comparison between farms

	Farm 1	Farm 2	Farm 3	Farm 4
Livestock present in farmyard	YES	YES	YES	
Direct drain connectivity to stream	YES			YES
Other direct connectivity to stream		YES	YES	

For farm 1 this consisted of a small open ditch running along the farm access road (used for collecting dairy cattle) culverted through the farm which receives farmyard drain discharge from dairy washings and storm runoff. The connectivity was tested using a microbial tracer (*Serratia marcescens* bacteriophage). This demonstrated a direct connection between the sump receiving drainage from the farm hardstanding and the stream monitoring point. Tracer was evident in the stream fifteen minutes after release into the sump. The travel distance was approximately 80 yards which indicates rapid flow through a constructed piping system. This ditch also probably receives seepage from the septic system.

For farm 2, runoff from the farmyard was evident during storms and this ran from the farmyard to the adjacent stream along a hardcore track also used to bring cattle from the fields to the milking parlour. Additional runoff routes could have contributed, but none were observed even during high flow events. Farm 3 provided a good example of where runoff from the farmyard represents the main contribution to a 1^{st} order stream. Runoff passes through a heavily contaminated gate/collection area prior to flowing over grassland into a small ephemeral channel. At farm 4, periodic discharge via a buried plastic field drainage pipe originating from the vacated farmyard emptied directly into an open field ditch. At each farm, any yard drainage was supplemented by roof runoff which initially discharged onto the hardstanding or joined with hardstanding drainage via a sump and pipework system.

RESULTS

The total amount of rainfall over the study period varied between 75 and 126 mm (average 107 mm) for the individual farms which, when compared to data for Auchincruive over the same period in previous years, indicates that this four week period in 2002 was certainly wetter than average.

Table 3 Total rainfall (mm) at Auchincruive during the period 17th June to 13th July over previous years.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Rainfall	83	66.9	39.9	44.5	70.2	57.2	45.2	38.6	69.4	62.3

Daily rainfall for each of the farms is shown in Figure 1 and flow duration curves are shown for each site in Figure 2.

Discharge from the field drainage pipe at farm 4 was ephemeral.

Figure 3 shows upstream and downstream (i.e. for farms 1, 2 and 4) load duration curves for the four farms for presumptive faecal coliform organisms during the period of the study.

These plots present some interesting patterns. The stream below farm 1 which had very low flows in dry weather, was clearly impacted by dairy parlour washing disinfectants under low flow conditions. This produced a marked reduction in low flow faecal indicator concentrations downstream of the farm input. Farm 2 hardstandings impacted on the largest stream in the study which had other farmyards and stocked fields contributing to the upstream bacterial loadings. However, the hardstanding drainage from farm 2 clearly elevated the stream loadings under high and low flow conditions. Farm 3 hardstanding area was the principal source of discharge and bacterial loading for the measurement location described in Figure 3. Again, for farm 4, there is a clear elevation in faecal indicator loading below the ephemeral faecal indicator inputs from the hardstanding areas.

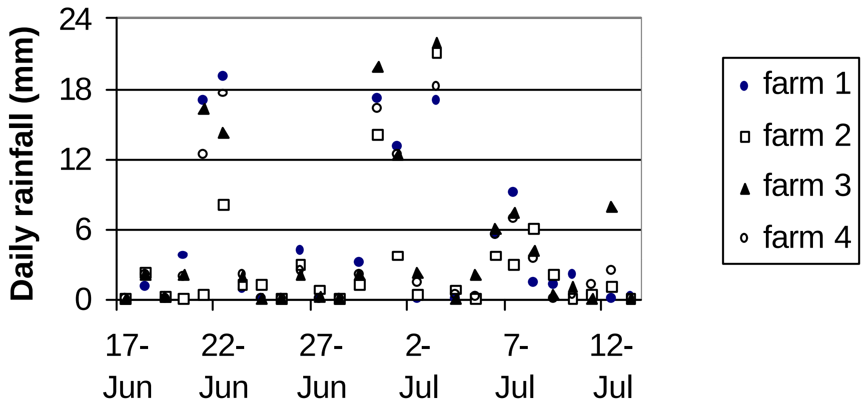

Figure 1 Daily rainfall recorded for each of the study farms

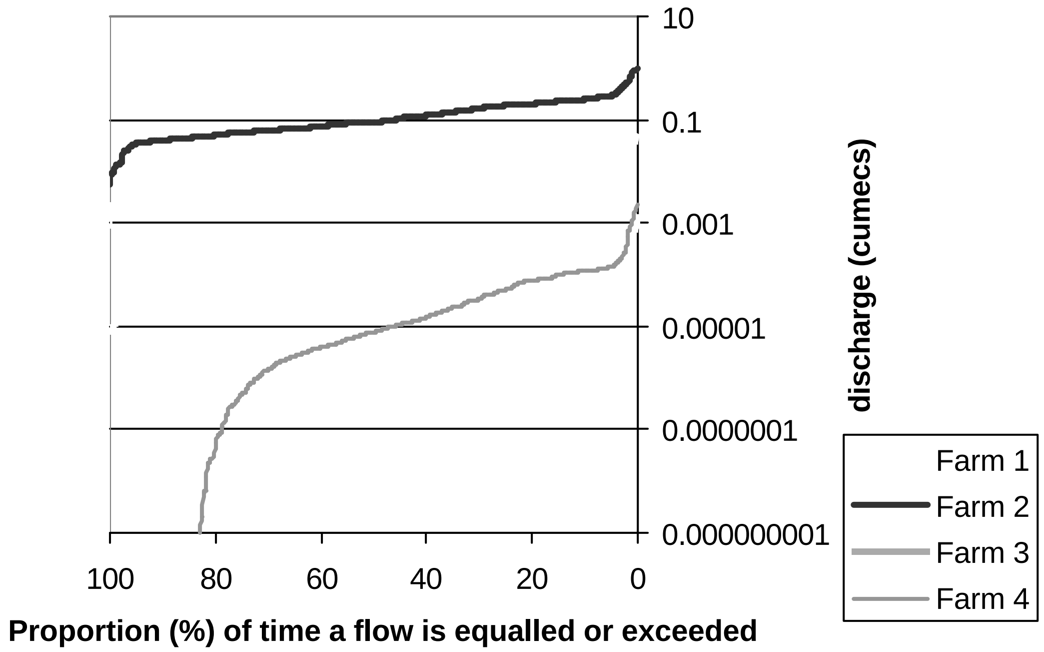

Figure 2 Flow-duration cures for the stream receiving flows from farms 1, 2 and 3 and flow directly from the hardstanding in the case of farm 4.

Table 4 provides a summary of impacts of the four hardstanding areas on the adjacent or first order stream receiving the hardstanding drainage. Figure 4 provides plots describing the means and ranges of faecal indicator concentrations from the four study farms combined.

Roof drainage samples, collected during rainfall events, generally exhibited higher faecal indicator concentrations than expected with faecal streptococci particularly prominent (i.e. farm 1 6.4×10^{3} $100ml^{-1}$ (n=13), farm 2 4.66×10^{4} $100ml^{-1}$ (n=22) and farm 3 1.17×10^{4} $100ml^{-1}$n=10).

DISCUSSION AND CONCLUSIONS

These results confirm the significance of farm hardstanding drainage on stream water quality in this dairy farming area. The effect of farm 2, in particular, on the high flow water quality in the adjacent stream, which had a peak discharge of approximately 1 cumec, is marked with a 385% increase in faecal coliform flux before and after the hardstanding input. This illustrates the effects of a hardstanding area on stream water quality within a small catchment. Farm 3 hardstandings were the sole source of the faecal indicators observed at the monitoring point approximately 50 m from the hardstanding area. The geometric mean (GM) values of this sampling location are indicative of the quality produced by mixed roof and hardstanding drainage (i.e. TC high flow GM = 2.05×10^{5}, FC high flow GM = 1.67×10^{5}, FS high flow = 2.20×10^{4})

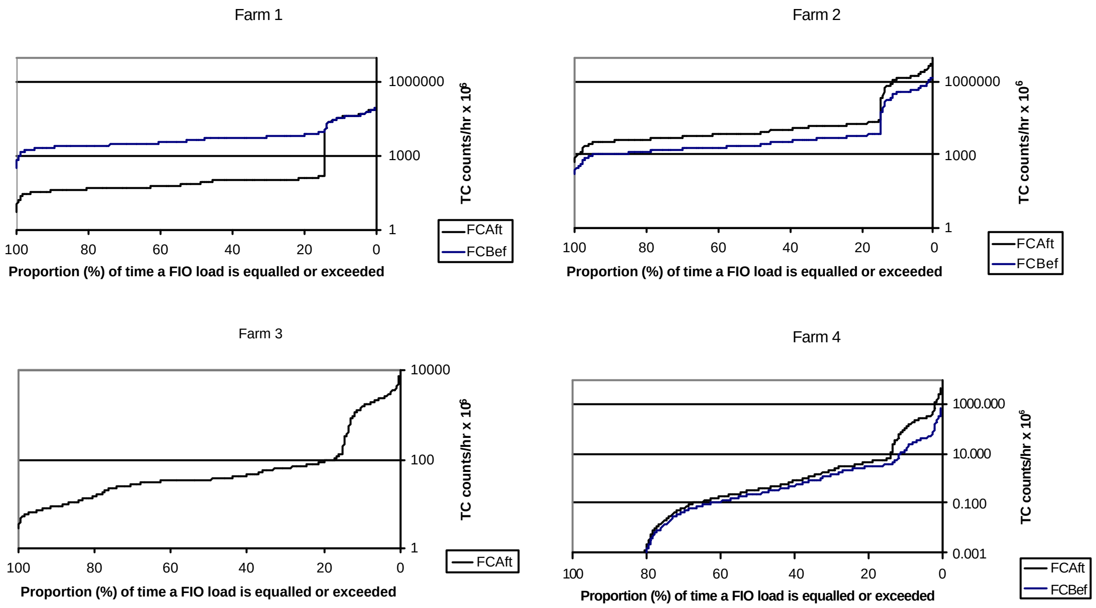

Figure 3 Faecal coliform load-duration curves for each of the four farms.

Table 4 Faecal indicator flux characteristics at the four study farms

	farm 1	farm 2	farm 3	farm 4
Total measured discharge in cubic metres	30,054	301,055	312	124
Percentage increase in total coliform after/before	109	375	NA	529
Percentage increase in faecal coliform after/before	66	385	NA	662
Percentage increase in faecal streptococci after/before	183	164	NA	286
Total coliform % high flow delivery before	59.43	93.95	NA	99.93
Total coliform % high flow delivery after	99.55	95.65	99.65	99.98
Faecal coliform % high flow delivery before	63.52	96.76	NA	99.94
Faecal coliform % high flow delivery after	99.08	97.29	99.90	99.99
Faecal streptococci % high flow delivery before	93.38	96.64	NA	99.99
Faecal streptococci % high flow delivery after	99.37	95.24	99.93	99.99

The effect of stock removal from farm 4 immediately prior to the sampling is clearly evident in lower faecal indicator concentrations observed at this site (i.e. TC high flow GM = $4.40x10^4$ $100ml^{-1}$ FC high flow GM = $5.48x10^4 100ml^{-1}$, FS high flow = $2.47x10^3 100ml^{-1}$). However, the impacts, in terms of percentage elevations in faecal indicator concentrations in the field margin drainage ditch receiving the hardstanding drainage, are still greater than for any of the other sites, due to the relatively low faecal indicator concentrations upstream of this input.

Figure 3 clearly illustrates the bactericidal nature of the hardstanding inputs from farm 1 during low flow conditions when dairy parlour washings were evident at the monitoring point. The downstream faecal indicator concentrations observed at this site were lower than other 'background' concentrations observed in this investigation. Under high flow events, i.e. in the 15% to zero section on the delivery duration curve in Figure 3, the effects of the disinfectant is lost.

Perhaps the most surprising result of this investigation was the recording of elevated faecal streptococci concentrations in roof drainage at three of the four farms. This may be due an avian source and/or enhanced survival of the faecal streptococci in a hostile roof environment. To put these data into context, both the EU and WHO have suggested revised standards for recreational waters involving a new faecal streptococci (the term intestinal enterococcci is used in both documents) standard of 95 percentile compliance with 200 faecal streptococci cfu.$100ml^{-1}$. Using $\log_{10}$ standard deviation for faecal streptococci in surface waters which was used to underpin the WHO risk analysis i.e. a $\log_{10}$ value of 0.8103 (Kay *et al.*, 1996), would imply a geometric mean value of approximately 30 faecal streptococci .$100ml^{-1}$ (i.e. $3.0x10^1 100ml^{-1}$). Even the cleanest site (i.e. farm 4), produces a faecal streptococci concentration in roof drainage an order of magnitude higher than this (i.e. $4.82x10^2$ $100ml^{-1}$). It is also interesting to note that, in all cases, the faecal streptococci concentration in roof drainage water was higher than the coliform indicators and, for the two sites with significant stream flows (farms 1 and 2), the faecal streptococci concentration in the roof drainage was higher or comparable to the stream concentrations under high flow conditions when >95% of the faecal streptococci flux was taking place.

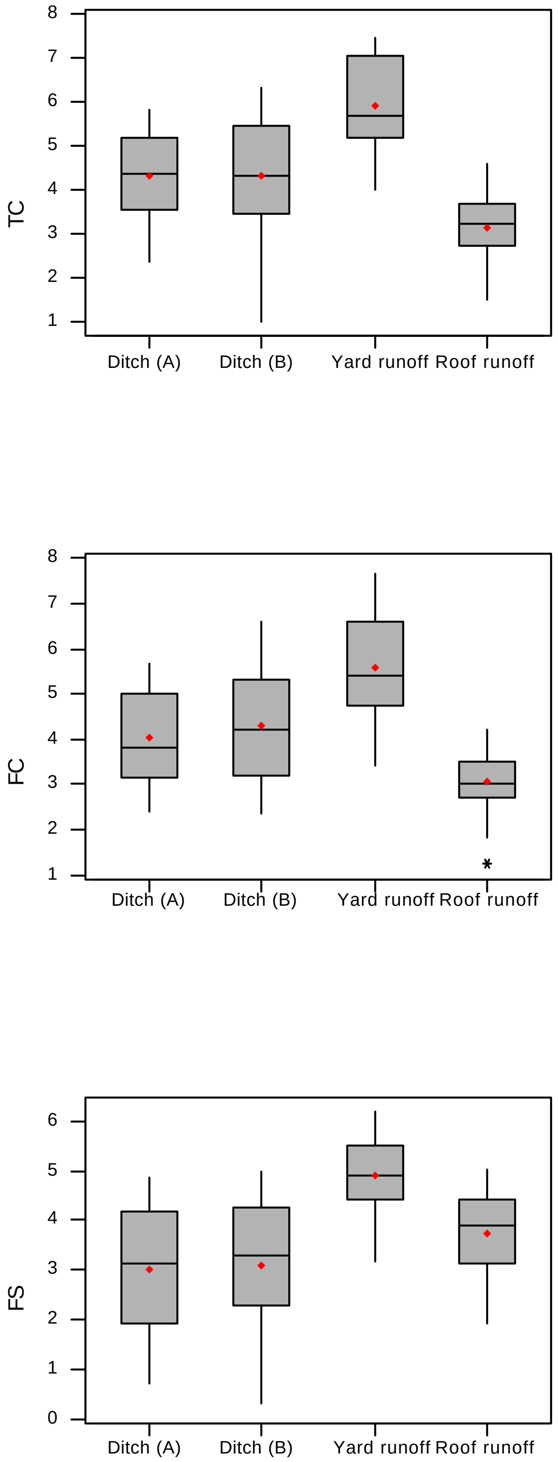

Figure 4 Geometric mean (dot) 50 percentiles (box) and range (line) for $\log_{10}$ faecal indicator concentrations (TC, FC and FS) for all samples taken from upstream (ditch A) downstream (ditch B) hardstanding (yard runoff) and roof runoff

Given the likely tightening of Directive 76/160/EEC (CEC, 1976) bathing water microbiological standards with the introduction of the criteria in CEC (2002), (i.e. producing a new mandatory standard roughly equivalent to the current recommended Guide criteria), there is a clear and growing imperative to ensure appropriate remediation of diffuse sources of pollution. The raw data presented here are now being further analysed better to define the discrete contribution of farm hardstanding areas, to bathing beach compliance along the Ayrshire coast.

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