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Impact of agricultural practices and river catchment characteristics on river and bathing water quality

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Abstract The objective was to investigate the potential risk of faecal indicator organism (FIO) bacteriological contamination of river catchments and coastal bathing waters from farm management practices and to develop practices to reduce the risk. A risk assessment on 117 farms was carried out in two river catchments in south-west Scotland. Manure storage facilities, farming practices, field conditions and catchment characteristics were assessed. River samples at 33 locations were regularly taken and analysed for FIOs. Available manure storage capacity and farm management practices are inadequate on a high proportion of farms and FIO contamination of watercourses was likely the result of effluent transported into watercourses due to non-collection or poor containment. In addition, surface run-off or leaching following land application of manure or intensive stocking in adverse conditions was a high risk on up to 50% of farms. The concentrations of FIOs in the streams of two sub-catchments with high livestock intensity was 4 to 8 times higher compared to the two sub-catchments which had a low livestock intensity. The majority of potential risks of agricultural pollution to watercourses may be eliminated through improved manure and dirty water management, forward planning of manure spreading activities and improved operational procedures.
Keywords Agriculture; diffuse pollution; livestock; manure; rivers

Introduction

Eighty-five per cent of Scotland's 60 identified bathing waters passed the EC Bathing Water Directive's mandatory standard in 2001 (SEPA, 2001). 20 samples are taken at each bathing water throughout the bathing season (1 June to mid-September) to assess the level of pass for each identified bathing water. Mandatory limits as defined in EEC Directive 76/160 concerning the quality of bathing water are 2,000 faecal coliforms per 100 ml and 10,000 total coliforms per 100 ml (in 95% of samples).

Sewage effluent from combined sewer outfalls was, by far, the main cause of polluted coastal waters. However on-going remedial action to reduce sewage pollution may be insufficient to guarantee a mandatory pass in parts of Ayrshire due to a possible contribution of faecal indicator organism (FIO) bacteria from agricultural manure run-off (SEPA, 2000). Recent studies in Ayrshire (Wyer *et al*., 1999) using regressional techniques have shown that non-point sources of faecal pollution from predominantly pastoral agricultural land may be a major component of river bacterial concentrations.

Large volumes of livestock manures and dirty water are generated on livestock farms and these materials can contain large numbers of FIO microorganisms, including many potential pathogens (Kearney *et al*., 1993). The main pathways by which animal FIOs can get into watercourses are discussed by Mawdsley *et al*. (1995) and Hooda *et al*. (2000). Pathways include livestock excretion while drinking in or crossing watercourses, or contaminated runoff from slurry stores, middens and farmyards etc. running directly into watercourses. Runoff or sub-surface drainage from fields onto which manure has been applied, either by direct animal excretion or by farm manurial practices are other potential sources. Diffuse pollution of FIO via the field drainage and runoff, particularly from areas intensively grazed or after slurry application (Joy *et al*., 1998) can be a source of faecal micro-organisms with concentrations in excess of 10^4 coliforms per litre of drainage.

Agricultural manures (livestock slurries and solid farmyard) are valuable fertilisers and soil conditioners but are also potential sources of water pollution if poorly managed (SOAEFD, 1997). With increasing economic and environmental pressures on farm businesses, it is essential to maximise the fertiliser value of manure, whilst taking action to prevent or minimise the risk of pollution.

A total of 379 water pollution events caused by agriculture in Scotland during 2000 were reported by SAPG (2001) and the main source of pollution (40% of incidents) was livestock manures and slurries. The apparent inability of manure collection and storage systems to cope with the volumes of waste produced, and the landspreading of livestock slurries on land at or near water saturation was the main cause of water pollution. It has been projected that diffuse agricultural pollution will be the most significant cause of poor river quality in Scotland by 2010, if appropriate action is not taken soon to turn this situation around (SEPA, 1999).

The EU Water Framework Directive (2000/60/EEC) was agreed in 2000 and under it, a comprehensive and co-ordinated programme is to be implemented to protect and improve the water environment in Scotland. This Directive will establish a system of river basin management and will identify measures to deal with diffuse pollution.

The objective of this study (reported more fully in Aitken *et al.*, 2001) was to investigate the potential risk of FIO contamination of watercourses from farm management practices in the River Irvine and Water of Girvan catchments and to develop recommendations and mitigation techniques to reduce the risk.

Methods

One hundred and twenty-eight farmers and waste contractors were surveyed and a risk assessment of 117 farms was carried out in two river catchments in Ayrshire, south-west Scotland. Waste storage facilities, waste management practices and operational performances, farming practices, field conditions and risks to watercourses were assessed on each farm. SOAEFD (1997) highlights potential environmental problems associated with agriculture practices and provides a practical guide to farmers in ways of eliminating or minimising problems. Farmer and contractor knowledge and compliance with good practices as given in SOAEFD (1997) was assessed. GIS datasets were used to carry out a risk assessment based on elevation, slope angle, soil type, and land-use.

The River Irvine and Water of Girvan and their tributaries were assessed along their lengths, at a series of sampling points, to monitor populations of *E. coli* and enterococcal organisms. Additionally, two sub-catchments representing high input (more intensive and higher stocking rate, mainly dairying) and low input (more extensive, lower stocking rate) agriculture were identified along each river for further detailed examination. River samples at 33 locations were regularly taken and analysed for FIOs to determine the key elements which contribute to faecal pollution.

Results and discussion

Catchment characteristics

The River Irvine catchment, which includes the catchments of the River Garnock and Lugton Water, occupies an area of 706 km^2 in North Ayrshire and contains approximately 530 farms. The Water of Girvan catchment occupies an area of 252 km^2 in South Ayrshire and contains approximately 100 farms. Both catchments discharge their riverine water to designated coastal bathing waters which have a poor record of compliance with the Bathing Water Directive (BWD). Irvine bathing water has only complied with the BWD four times over the period 1988 to 2001 while Girvan has complied in six years (SEPA, 2001). River concentrations of faecal coliforms close to the mouth of the River Irvine during periods of high flow can be greater than 20,000 per 100 ml (SEPA, 2001).

The climate is predominantly mild windy oceanic and average annual precipitation is 1,000 to 1,200 mm rising to 2000 mm in the upper headwaters of the catchments. The main agricultural land use is improved grassland (70% and 44% of the River Irvine and Water of Girvan catchment areas respectively) and rough grazing (21% and 50% of each area). Predominant agriculture in both catchments is milk, beef and sheep production, resulting in above national average stocking densities. The River Irvine and Water of Girvan catchments contain 2% of the total agricultural land area of Scotland and 17% of the total number of dairy cows (Table 1). Livestock farming in both catchments therefore has considerable socio-economic importance in Ayrshire as has tourism which in turn is influenced by an expectation of good quality rivers and beaches.

In terms of daily production of *E. coli,* the livestock in the River Irvine catchment produce the equivalent *E. coli* loading of untreated sewage from 1,400,000 people while in Girvan catchment the livestock *E. coli* production is equivalent to 900,000 people.

Over the River Irvine catchment during the bathing season (May to September) average overall grazing intensities of adult livestock are 1.3 dairy cattle, 0.8 beef cattle and 2.0 sheep per hectare. The equivalent figures for the Water of Girvan catchment are 1.3 dairy cattle, 1.0 beef cattle and 2.6 sheep per hectare.

Both catchments have a high percentage (greater than 60%) of imperfectly and poorly drained soils on largely sloping land under high rainfall which will restrict the vertical drainage, so that the dominant pathway for rain falling on their surface is lateral, as surface, or sub-surface runoff. In such situations the response to rainfall at a catchment outlet will be rapid and little water will be retained within the catchment following rainfall events.

The average total length of watercourse running alongside or next to land used for farm manure application was 1.24 km (range 0.1 km to 3.2 km) on dairy farms. For beef farms an average of 0.93 km (range 0.03 km to 3.3 km) of watercourses bounded or ran alongside land used for manure application. The percentage of farmers who reported a watercourse adjacent to some of their land used for waste application was very high (90 and 93% for dairy and beef farms respectively).

A risk assessment of each catchment for manure applications based on elevation, slope angle, soil type, and land-use was carried out. Four categories were mapped for each catchment viz. unsuitable for manure application, low risk of pollution, moderate and high risk of pollution. Unsuitable land was defined as any area with a gradient greater than 15° and/or peaty soil and/or land use other than grass and arable land. The potentially suitable land remaining was divided into the following three categories based on a run-off risk: low risk (slope 0–3°), moderate risk (slope 3–7°), and high risk (slope 7–15°). These data demonstrate that 38% of the total land area in the River Irvine catchment is unsuitable for manure application while 2% of the total area is a high risk, 19% a medium risk and the remainder (41%) is a low risk.

Table 1 Total numbers of each livestock in each catchment. The number in each catchment is given as a percentage of the total livestock numbers in Scotland

Catchment	**Total livestock numbers**		
	Dairy cattle	Beef cattle	Sheep
River Irvine	32,279 (15%)	13,266 (3%)	124,059 (3%)
Water of Girvan	4,061 (2%)	4,855 (1%)	86,673 (2%)

Manure characteristics

Agricultural manures (solid and slurries) are valuable organic fertilisers and soil conditioners but may be sources of FIO pollution to watercourses if poorly managed. Seepage from fresh manure can contains 10^6 per litre of both total coliforms and faecal streptococci.

The total annual amount of farm manure collected, stored and later landspread from winter housing is 562,000 tonnes in the River Irvine catchment and 87,000 t in the Water of Girvan catchment. The waste excreted directly onto fields by livestock during the grazing season (April–September) is 437,000 t (Irvine) and 90,000 t (Girvan). During the bathing season (May–September), 24% and 36% of stored slurry and 11 and 21% of "solid" farmyard manure is spread on farmland in the Water of Girvan and River Irvine catchments respectively.

Farm manure management practices

An adequate available waste storage capacity will allow a farmer to delay spreading slurry until soil and weather spreading conditions are suitable. However 21% of farms had less storage than 1 month of the farm's waste production. The equivalent figures for 1–2 months were 18%; 2–3 months, 10%; 3–4 months, 12% and 4–5 months, 9%. 29% of farms had more than 5 months storage available. In addition over 50% of farms had inadequate or unsatisfactory waste storage facilities (in terms of water pollution risks) (Table 2).

Rainwater and wash water draining into the slurry storage system unnecessarily increased volumes of farm manure requiring storage and land application by 44%. The majority of farms can reduce collected waste by up to 1,000 m^3 per year through water diversion and thereby save costs. Average annual wash water used per dairy farm enterprise was calculated as 538 m^3. It was common for part of the wash water volume to be discharged either directly or via a water tank overflow to a drain and watercourse creating a risk of FIO contamination. In addition, a large area of many farm steadings contaminated the rainfall by FIOs in the farmyard, which was then not collected, resulting in a further risk of FIO contamination of watercourses. The average annual volume of contaminated rainfall originating from roofs was 3,119 m^3 per farm.

Only 12% of farms had a Farm Waste Management Plan (FWMP) as recommended in SOAEFD (1997). The vast majority of farmers use a manure exclusion zone, 4–5 m in width, adjacent to watercourses in order to protect water quality. This width is lower than the recommended 10 metres given in the PEPFAA code to reduce water pollution risks. 5% of River Irvine catchment's farmers and 16% of Water of Girvan catchment's farmers apply farm manures to steeply sloping ground. 8% of River Irvine catchment's farmers apply manures to very poorly drained land. Manure application to steeply sloping or very

Table 2 Frequency of different waste storage systems on beef farms surveyed in the River Irvine catchment, average volume and adequacy (%)

Waste store type	% of farms	Average volume (m3)	Adequacy (%)
Uncontained midden	56	344	0
Contained midden	28	297	93
Compound	5	388	100
Field heap	7	189	67
Slurry reception tank	21	201	89
Non steel tank, above ground	19	453	90
Non steel tank, below ground	37	131	88
Steel tank, above ground	21	722	90
Steel tank, below ground	9	30	75
Earth walled lagoon, unlined	2	992	100
Dirty water tank	7	12	50

poorly drained land is a very high-risk situation and likely to result in water pollution. Typical manure application rates were 19 to 28 m^3 per hectare.

Contractors are employed for slurry application on 50% of farms in the River Irvine catchment and 34% of farms in the Water of Girvan catchment. A total slurry volume of 446,000m^3 is applied by contractors to *c*. 11,000 ha of land in both catchments. The majority of this slurry is applied from January to April with 16% of the total between May and September in the River Irvine and 6% in the Water of Girvan catchments.

Farmer and contractor awareness

SOAEFD (1997) highlights potential environmental problems associated with agriculture practices and provides a practical guide to farmers in ways of eliminating or minimising problems. 43% of farmers and 75% of waste contractors surveyed were unaware of this pollution prevention advice and government code of good agricultural practice. Although a large percentage of farms claimed to use their common sense and experience to minimise the risk of pollution problems, there was considerable evidence that watercourses were being put at risk of FIO contamination on some farms.

Contractors are engaged for slurry application on up to 50% of farms in the Irvine catchment and 38% in the Girvan catchment but are not generally aware of Farm Waste Management Planning (FWMP) and current Codes of Practice on landspreading. Out of a sample of 12 major agricultural contractors only one was aware of FWMPs. On 42% of farms some form of risk assessment was carried out prior to land spreading, usually by the contractor. The majority do not apply slurry immediately adjacent to watercourses but a number of contractors thought that exclusion zones were not necessary. This lack of awareness gives cause for concern.

Risk assessment

A risk assessment of manure pollution was carried out for each catchment. Risks of discharges of effluents and FIOs into watercourses were found on over 50% of farms. These mainly arose from the leakage from uncontained middens, poorly designed or mismanaged waste storage facilities, high level slatted courts, and run-off from self-feed silage aprons, farmyards and cow tracks. Although the seepage from middens with stored and composted FYM can be relatively low in FIO, the fresh manure and other sources of seepage contaminated with raw slurry are high and would normally contain about 10^6 of each of total coliforms and faecal streptococci per litre (Hojovec, 1990; Moore *et al*., 1995).

Diffuse discharges of FIO, via run-off and field drainage, particularly from areas of poorly managed slurry application and intensive grazing, were another potential source of FIO. Survey data indicated that 9% of farmers spread manures in conditions likely to result in run-off (e.g. very poorly drained or steeply sloping soils). On 19% of dairy farms, grazing animals have regular access to watercourses and on 13% of these farms, animals regularly cross watercourses on a daily basis. Defecation directly into the water or nearby can contaminate water with loading in excess of 10^5 coliforms per gram of faecal material.

Septic tanks are used on practically all farms to treat farmhouse wastes. The majority of systems are old with 82% potentially discharging directly to watercourses. Connection of other farm building drainage to the septic tank system occurs on some farms thus reducing the septic tank's effectiveness and increasing the potential risk of discharge of faecal material to watercourses. Septic tanks also commonly occur with non-agricultural dwellings and buildings in rural Ayrshire.

Watercourse analysis

The water analysis demonstrated the relationship between livestock systems and river water quality and provided quantitative *E. coli* data. In general, average values for total

Table 3 *E. coli* numbers (cfu/100 ml) in river waters from 2 livestock dominated agricultural sub-catchments

Sub-catchment	Minimum number	Maximum number	Median number
River Irvine	1.0×10^2	1.5×10^5	5.0×10^3
Water of Girvan	0.4×10^2	1.2×10^5	1.7×10^3

Based on 209 samples (Irvine), 70 samples (Girvan), taken during the period August to November 2000

coliforms, in the whole Girvan catchment (2.4×10^4 colony forming units (cfu)/100 ml), were approximately half of that found in the Irvine basin (4.7×10^4 cfu/100 ml). The concentrations of *E. coli* recorded during the summer and autumn of 2000 were high (Table 3).

Bacterial concentrations observed at the sample points within the area of lower intensity land-use in the River Irvine basin were, on average, about 25% of those observed in the chosen area of higher intensity land-use. Likewise, bacterial concentrations observed at the sample points within the area of lower intensity land-use in the Water of Girvan basin were, on average, about 12% of those observed in the chosen area of higher intensity land-use. The highest numbers of *E. coli* in the streams occurred during and after high rainfall. During very high flows, 10^9 cfu per second were flowing down the stream in a sub-catchment of the River Irvine. This sub-catchment is predominantly a livestock farming area with very little input of untreated or treated human effluent.

Land with high stocking densities is likely to be associated with increased proximity and access of livestock to streams resulting in increased ingress of *E. coli* and faecal *enterococ*-*c*i into water courses either by direct defecation, or entry via field drains, or by increased surface run-off during heavier rain events. Subsurface drainage from a grazing field during June contained 8,840 to 32,500 *E.coli* cfu per 100 ml compared to <100 *E. coli* cfu per 100 ml from a neighbouring grass silage field. This agrees with results reported by Doran and Linn (1979) who found five to ten times higher bacterial concentrations in water run-off from a grazed compared to a non-grazed area.

The temporal variations in faecal indicators in this study suggests that if data from one sampling point were found to be high or low on a particular date, then all of the points on the profile were likely to follow this trend. This trend was attributed to the effect of precipitation over the entire catchment area. Sampling on rainy days, when the rivers were in spate, and hence more turbulent and turbid with re-suspended material, was associated with increased faecal indicators levels compared with samples of clearer less turbid waters. Results also indicated that faecal indicator levels tended to increase the further downstream the samples were taken.

These data contrast with data from the River Esk in the East of Scotland where livestock enterprises are less common. Here, *E. coli* exceeded 1000 cfu/100 ml in only 21% of water samples taken over a similar period, compared with 80% (River Irvine) and 57% (River Girvan).

Mitigation techniques

A number of potential risks to bathing water quality may be eliminated through improved slurry/dirty water management, forward planning of land spreading activities and improved operational procedures. Where a potential risk to bathing water was identified, the majority of farmers could significantly reduce the risk of water pollution by FIOs through limited expenditure and good management practice.

There is a strong requirement to further promote good agricultural practices and the PEPFAA Code in both catchments. On a limited number of farms a substantial investment will be required to remove or remedy a significant risk of pollution from storage facilities.

It was clearly apparent that under current economic conditions, money for this form of investment is not available.

The main operational techniques which farmers and contractors can use to mitigate against the risk of FIO contamination of watercourses in the Ayrshire catchments are as follows:

- Prevent contamination of clean water from roof and yard systems, with dirty water, to allow recycling or direct discharge of clean water to watercourses.
- Reduce volumes of dirty water by increased use of roofed areas for waste storage, feeding and standing stock.
- Minimise volumes of contaminated water by using low volume wash equipment.
- Regularly inspect, repair and maintain storage structures and associated equipment and ensure contingency plans are available to all staff in the event of system failure.
- Prepare and use a Farm Waste Management Plan and always apply manure or contaminated water in accordance with the Code of Good Agricultural Practice.
- Ensure rural septic tanks are designed for their particular use and are correctly installed and monitored.
- Site water troughs and feeding areas well away from watercourses and avoid regular stock movement on tracks where run-off to watercourses is likely and, where possible, prevent stock from standing in watercourses while drinking.
- Ensure good waste management operations by training staff to appropriate competence standards in the use of equipment and in the landspreading of wastes.

The priority now for all relevant organisations (government, regulators, farmers' unions, and farm advisers) is to effectively communicate these good agricultural practices and mitigation techniques to farmers and contractors.

Conclusions

Agricultural manures (livestock slurries and farmyard manures) are valuable fertilisers and soil conditioners, but are also potential sources of water pollution by faecal indicator organisms (FIO) to rivers and bathing waters if poorly managed. FIOs from farms can enter watercourses by:

- Faecal contaminated effluent transported into watercourses by non-collection, no containment or poor storage facility (i.e. leakage).
- Surface run-off or leaching following land application of manure or intensive stocking in adverse conditions (e.g. steeply sloping fields with high rainfall during and following land application).

There was a wide variability in concentration of FIOs in streams, primarily related to rainfall, water flows and farming practices. Although sewage effluent is currently the main cause of polluted coastal waters in Scotland, on-going remedial action to reduce sewage pollution will increase the relative importance of the contribution from livestock farming. The importance of this will increase further due to suggested changes to existing water quality standards for coastal waters now being made by the EC and WHO. The need to address all possible sources of water pollution will require a fully integrated river catchment management approach to ensure river and bathing water protection.

More attention to specific farm operational methods and in some cases, the maintenance and provision of appropriate facilities, could significantly reduce pollution risk in vulnerable catchments. A significant improvement in river water quality could be made by offering supportive advice to farmers on strategic and technical issues in the form of a programme of appraisal, agreement and implementation of remedial actions with follow up monitoring. It must be recognised that it will be difficult to achieve these measures in the current economic climate of UK farming.

If cost-effective and operationally acceptable methods can be identified and promoted, serious consideration of appropriate economic and advisory support methods for some farmers will be required in order to fully protect river and bathing water quality. This can be achieved on farms by furthering the process of awareness, education of the significance of related farm processes and to reinforce and in some cases initiate a long-term action programme to reduce pollution risk. There is also a need to further the partnership approach that has already been established in Scotland between all relevant organisations (government, regulators, farmers, farmers' unions, farm advisers environmental agencies and environmental researchers) to implement these action programmes.

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References

Aitken, M., Merrilees, D. and Duncan, A. (2001). *Impact of Agricultural Practices and Catchment Characteristics on Ayrshire Bathing Waters*. Report for Scottish Executive Central Research Unit.

Doran, J.W. and Linn, D.M. (1997). Bacteriological quality of runoff water from pastureland. *Applied Environmental Microbiologist*, **37**, 985–991.

Hojovec, J. (1990). *Hygienic aspects of slurry storing*. In. Influence of animal manure handling and utilisation systems on animal and human health. FAO network, Bologna, Italy.

Hooda, P.S., Edwards, A.C., Anderson, H.A. and Miller, A. (2000). A review of water quality concerns in livestock farming areas. *Science of the Total Environment*, **250**, 143–167.

Joy, D.M., Lee, H., Reaume, C.M., Whiteley, H.R. and Zelin, S. (1998). Microbial contamination of subsurface drainage water from field application of liquid manure. *Canadian Agricultural Engineering*, **40**(3), 153–160.

Moore, J.A., Gamroth, M.J., Skarda, S.M. and Niswander, S.F. (1995). Treating dairy flush water in a constructed wetlands. *Proceedings of the 7th International symposium on Agricultural and food processing wastes. Chicago, USA*.

SAPG (2001). *Pollution Review*. Scottish Agricultural Pollution Group, No 14. SEPA, Stirling.

SEPA (1999). *Improving Scotland's Water*. Scottish Environmental Protection Agency, Stirling.

SEPA (2001). *Scottish Bathing Waters 2001*. Scottish Environmental Protection Agency, Stirling.

SOAEFD (1997). *Prevention of Environmental Pollution from Agricultural Activity*. A Code of Good Practice. SEERAD, Edinburgh.

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