IMPACTS OF DIRECT FAECAL INPUTS AND EFFLUENT MANAGEMENT PRACTICES ON MICROBIAL WATER QUALITY

R W Muirhead and R M Monaghan

AgResearch, Invermay, Private Bag 50034, Mosgiel 9053, New Zealand. E-mail: richard.muirhead@agresearch.co.nz

Abstract

Contact recreation is an important community value for many streams and rivers. It is important that the faecal microbial content of streams flowing from agricultural catchments be maintained below guideline values, particularly under base-flow conditions, when contact recreation is most likely to occur. Here we present a model framework that tested the effectiveness of 6 on-farm management strategies on the faecal microbial concentration of water leaving a farm. Continuous inputs, such as effluent treatment pond discharges, increased the expected median concentrations of *E. coli* in the stream. Sporadic inputs, such as direct faecal inputs to the stream or losses from effluent irrigation systems, increased the upper percentiles of expected *E. coli* concentrations. Overall, our modelling analysis suggests that the implementation of currently available good environmental practices (GEPs) should minimise the impact of FIO losses to the water flowing through a farm during base-flow conditions.

Introduction

New Zealanders enjoy fishing and swimming in streams and rivers. The maintenance of stream water quality that is suitable for contact recreation is thus an important community and cultural value in many catchments. It is important that streams flowing out of agricultural catchments meet faecal microbial guidelines under base-flow conditions, as this is when most contact recreation occurs. The New Zealand Dairy Industry Environmental Strategy aims for all water leaving a farm to meet contact recreation water quality guidelines (Anon, 2006).

Our ability to predict the effectiveness of different mitigation options at meeting desired water quality in streams is weak (McDowell *et al*., 2008). Typically effectiveness of good environmental practices (GEPs) is to initially calculate annual losses from a farm in the absence of GEPs, then determine the subsequent reduction in loss following implementation of a given GEP (Monaghan *et al*., 2008). It has been determined however, that annual losses of faecal indicator organisms (FIOs) from a catchment are dominated (95%) by sporadic storm-flow events (Kay *et al*., 2007; Davies-Colley *et al*., 2008). Mitigation options, such as fencing off streams to prevent direct inputs, would appear to be ineffective in reducing FIO losses as they typically only represent 1% of the annual load (Muirhead *et al*., 2008). There is experimental evidence however, that shows that direct inputs do have an impact on stream water quality during base-flow conditions (Davies-Colley *et al*., 2004).

We propose that evaluation of the effectiveness of GEPs to reduce farm losses of FIOs needs to be conducted separately for base- and storm-flow conditions. As a rule of thumb; base-flow conditions are important for the recreational use of the stream channel, whereas storm-flow is important for the water body that the stream empties into. The New Zealand Contact Recreational Microbial Water Quality Guidelines are set as 95th percentile values (MfE, 2003). Therefore, any model framework developed to assess the performance of on-farm mitigations will need to generate 95th percentile values (not just average values) that can be compared to the guidelines. We demonstrate this using a risk modelling framework to quantify the effectiveness of farm-scale FIO-GEPs to achieve water quality targets under base-flow conditions in a stream.

Methods

The model is based on a representative dairy farm in the Bog Burn catchment, Southland, New Zealand (Monaghan *et al*., 2007), and is structured as a 230 ha farm with a single stream (median flow 158 L s^{-1}) flowing through the farm. The calculations are based on steady state conditions with inputs and outputs averaged over a day; variations from day to day are considered through the Monte Carlo process (Vose, 1996). The model inputs upstream of the farm are flow rate, stream *E. coli* concentration, length of stream running through the farm, and the in-stream *E. coli* attenuation rate. The daily loads of *E. coli* from the farm were calculated as the expected value multiplied by a frequency, which represents the number of days per year losses are expected. Running the model 5000 times generates a distribution of the expected downstream concentrations that could be sampled by a long-term water quality monitoring protocol.

The modelled sources of *E. coli* from within the farm system included direct inputs from animal access to streams and four different systems for managing farm dairy effluent (FDE). FDE is generated from the wash down of the hard standing areas where the cows wait prior to milking and the milking parlour.

Streams do not flow through all of the paddocks of a farm, so direct inputs from animal access to the stream were modelled assuming the cows would only be in a paddock with direct access 25% of the time. It was also assumed that the cows would cross the stream to reach 10% of the paddocks on the farm. The effect of both direct inputs, from stream access and crossings, were combined as it was considered unlikely that a farmer would fence off a stream and not provide a bridge for the stream crossing.

The four FDE management systems modelled were:

- a two-pond (anaerobic/aerobic) system that discharged directly to the stream (Hickey *et al*., 1989);
- an advanced pond system (APS; Craggs *et al*., 2004) that also discharged directly to the stream;
- a high application rate irrigation system that applied FDE to land on a daily basis and;
- a low application rate FDE land application system, with 60 days pond storage available (deferred irrigation strategy).

The high application rate FDE system had no storage facility, and therefore fresh effluent was irrigated to the pasture daily. Under this FDE system, effluent losses to the stream were modelled to occur when the volume of effluent applied each day exceeded the soil water deficit (Houlbrooke *et al*., 2004a; Monaghan *et al*., 2007; Muirhead *et al*., 2010). The FDE irrigation area was assumed to be highly connected to the stream due to the extensive artificial drainage networks in this catchment (Monaghan *et al*., 2007).

The Deferred irrigation system included a 60 day storage pond to store effluent when the soils were too wet to absorb the applied FDE. Ideally, the storage system should allow the FDE to be applied when soil conditions are more favourable. However, losses of FDE to the stream from this system was modelled to occur when the volume of effluent applied each day exceeded the water holding capacity of the soils *and* the storage pond was full (Houlbrooke *et al*., 2004b; Houlbrooke *et al*., 2006; Muirhead *et al*., 2010). A detailed description of the model framework is available in Muirhead *et al*. (2011).

Results and Discussion

The effect of the four different effluent systems on downstream *E. coli* concentrations was modelled both with and without direct animal inputs to the stream (Figure 1). The distribution of the input *E. coli* concentrations in the up-stream water entering the farm is also shown for comparison. This upstream distribution was chosen to represent a situation where all farms upstream were already complying with the dairy industry water quality targets (Anon, 2006).

Model outputs indicated that the two-pond effluent treatment system produced the highest down-stream *E. coli* concentrations. This finding is not surprising as these systems have long been identified as a major source of stream contamination (Hickey *et al*., 1989; Wilcock et al., 1999). The Advanced Pond System (APS) is an upgrade of the two-pond system that significantly (two orders of magnitude; Craggs *et al*., 2004) reduces *E. coli* concentrations in the discharge. As expected, this improved effluent treatment system substantially reduced expected downstream *E. coli* concentrations.

The high application rate effluent system produced a large spread in predicted downstream *E. coli* concentrations (Figure 1). There was little direct loss of applied effluent over most of the milking season due to adequate soil water deficits. This system, therefore, did not greatly affect median downstream concentrations. Large losses were predicted to occur when soil water deficits were low as irrigation was modelled to occur each day. Under a worst case scenario it has been demonstrated that most of the applied volume of effluent can potentially be lost via artificial drainage networks such as found in the Bog Burn catchment (Houlbrooke *et al*., 2004a; Monaghan *et al*., 2007). Given the possibility all effluent applied from the high application rate system could be lost, it is not surprising that the modelled 95th percentile values are as high as those modelled for the two-pond system (Figure 1).

The low application rate effluent system also included a 60-day storage pond to defer irrigation until soil water deficits enabled effluent to be applied without exceeding the soil saturation point (Houlbrooke *et al*., 2004b). When the storage pond is full, effluent has to be irrigated even under unfavourable conditions, which in practice leads to some FDE being lost to streams each year. When storage ponds are full and it is necessary to apply FDE to wet soils, then low application rate system losses are less than those from the high application rate systems (Houlbrooke *et al*., 2006; Muirhead *et al*., 2010). The combined effect of storage and low application rate system resulted in a significant reduction in the modelled 90th and 95th percentiles of the low application rate/deferred irrigation system relative to the high application rate system (Figure 1B).

Direct inputs of FIOs had very little effect on the median stream concentrations, which is not surprising as the inputs were modelled to occur on <25% of the days. On the specific days when direct inputs are assumed to occur, the loads are high (Davies-Colley *et al*., 2004; Muirhead *et al*., 2008), as illustrated by the high 90th and 95th percentile values (Figure 1A). The effect of direct animal inputs to the stream was most pronounced for those treatments that had the greatest effect on water quality, i.e. the APS and low application rate effluent systems.

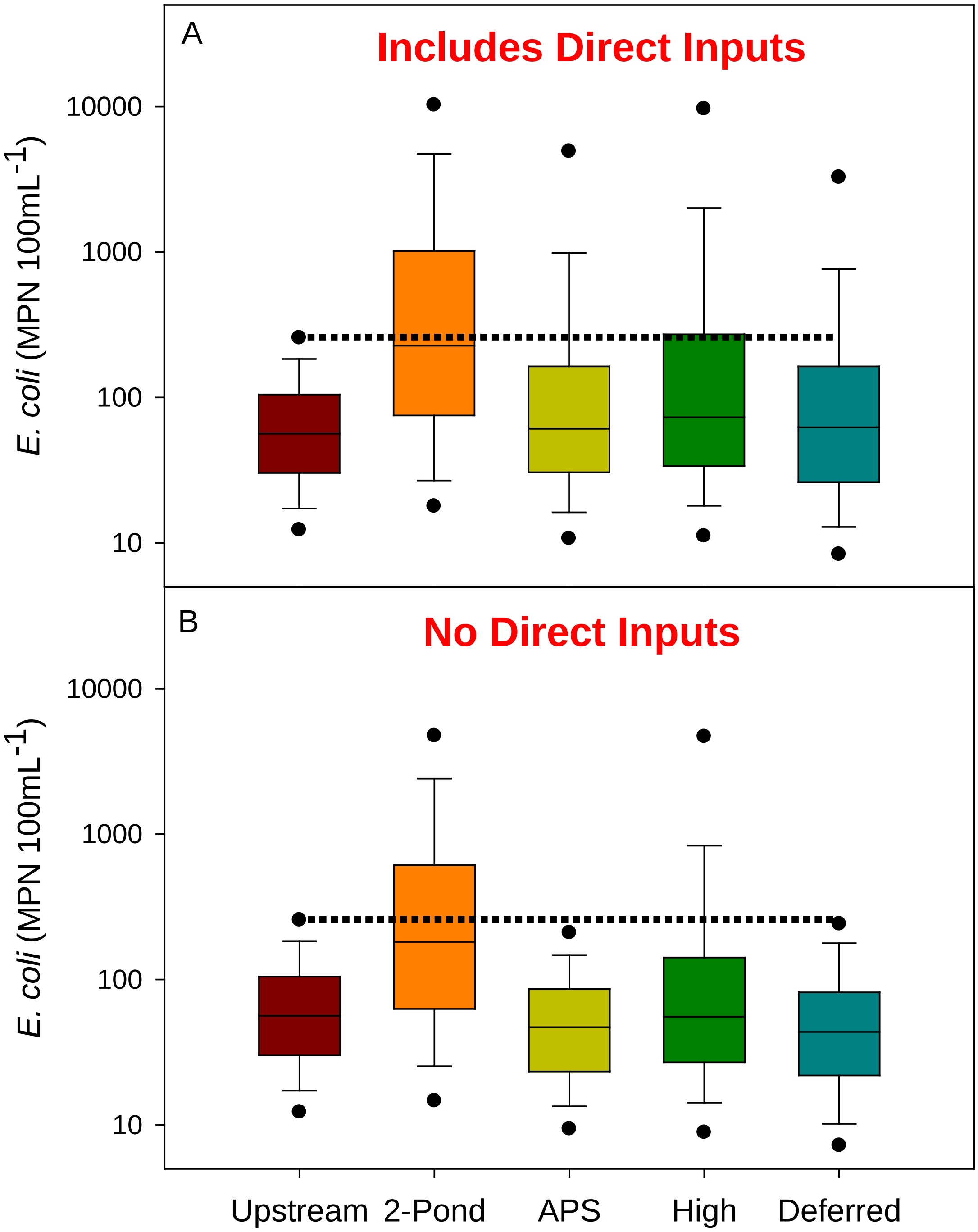

Figure 1: Modelled daily *E. coli* concentrations upstream and downstream of the farm under contrasting scenarios for the management of farm dairy effluent, (A) with and (B) without direct animal access to the stream. Horizontal line is the median, boxes are the 25th to 75th percentile, whiskers the 10th and 90th percentile and points the 5th and 95th percentile values. The dotted line represents the 95th percentile water quality guideline value of 260 *E. coli* 100 mL^{-1}.

With no direct animal inputs, and either assuming an APS or a deferred FDE irrigation system, daily inputs to the stream are effectively zero. Downstream concentrations of *E. coli* therefore default to the upstream distribution (Figure 1B).

Of the effluent management scenarios evaluated, only two predicted that downstream distribution of *E. coli* concentrations would still meet Contact Recreational Water Quality Guidelines based on the 95th percentile value (MfE, 2003). These included the advanced pond system (APS) and the low application rate plus storage systems where no direct animal access to the stream was assumed. Of these two FDE systems, the low application rate system would be preferred by many farmers as it is more cost effective than the APS system and it will help reduce losses of other potential pollutants contained within the FDE such as N and P (Monaghan *et al*., 2008).

Conclusions

This analysis indicates that implementation of some currently available GEPs can help to ensure that *E. coli* discharges from farms during base-flow conditions are minimised. Therefore, if the water entering a farm achieves the water quality standards, the water leaving the farm should still achieve the standards. This modelling analysis needs to be confirmed with field measurements. Future work should focus on how to implement good environmental practice on farms and the development of new mitigations targeting FIO losses from farms during storm-flow conditions.

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