Pathogens Pathways – riparian management III

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Foreword

The Pathogen Transmission Pathway Project was a three-year research project to investigate the pathways by which microbes move from farmed animals into water bodies. This was a follow-up to the fresh water microbiology research programme, which identified farmed livestock as an important source of microbial contamination of water.

The potential pathways for microbial movement are many and varied, and the project was carried out by a consortium of research providers: AgResearch, Environmental Science & Research Ltd (ESR), Landcare Research, Massey University, National Institute of Water and Atmospheric Research Ltd (NIWA), and Thinking Animals. This report is one of seven that covers the range of work carried out:

Pathogen Pathways · Direct deposition.
Pathogen Pathways · Riparian Management (II).
Pathogen Pathways · Riparian Management (III).
Pathogen Pathways · Soil Risk Index.
Pathogen Pathways · Contamination of water bodies by artificial drainage.
Pathogen Pathways · Update on groundwater contamination.
Pathogen Pathways · Best Management Practices.

The last of these publications summaries the work carried out and outlines some best management practises for farmers to use to mitigate microbial contamination of water bodies.

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1. Executive Summary

Objective 9 of the Pathogen Transmission Routes Research Programme (PTRRP) focused upon two areas of related research, with the following aims:

1. To quantify the generation and faecal contamination of surface runoff upon rolling dairy land.
2. The development of riparian management guidelines, with respect to faecal microbes.

Faecal contamination of surface runoff generated upon dairy pasture

This research was conducted in collaboration with Massey University with the details and results presented along with those from the closely aligned drainage studies, in an integrated report (Hedley et al. 2005). Three key findings arose from the surface runoff research and are summarised in this report, these were:

- Despite the presence of subsurface drains, appreciable surface runoff can be generated upon dairy pasture. For example, 46mm and 179mm of surface runoff were generated upon one study plot during 2003 and 2004, respectively. This compared with 258mm and 388mm of subsurface drainage from the same plots over 2003 and 2004 respectively.
- The surface runoff generated is contaminated by faecal microbes, with concentrations of *E. coli* and *Campylobacter* peaking at $> 10^5$ MPN 100 mL^{-1} and $> 10^3$ MPN 100 mL^{-1}, respectively, immediately following grazing. Peak *Campylobacter* concentrations in surface runoff, generated following the application of effluent, were also $> 10^3$ MPN 100 mL^{-1}.
- Information derived from the Ruakura experimental studies (Collins et al. 2004) suggests that riparian buffer strips would be effective at trapping most of the faecal microbes entrained within the surface runoff generated upon the Massey plots.

Riparian guidelines

Riparian management guidelines with respect to faecal microbes have been developed and are provided within this report. These consist of a qualitative component that discusses the variation in riparian buffer strip efficiency with a range of factors including slope angle, buffer width, soil type, and rate of surface runoff. In addition, quantitative guidelines for buffer design with respect to faecal bacteria are presented. These illustrate the estimated optimal buffer width for a range of slope angles, soil drainage properties and, degrees of bacterial attachment to other (e.g., soil and faecal material) particles. Important caveats are associated with the derivation of the quantitative guidelines that require the reported efficiencies to be treated as a best-case.

2. Introduction

Objective 9 of the Pathogen Transmission Routes Research Program (PTRRP) had two key aims:

1. Quantification of the generation and faecal contamination of surface runoff upon rolling dairy land underlain by subsurface artificial drains.
2. Continuation of the development of riparian management guidelines, with respect to faecal microbes.

3. The generation and faecal contamination of surface run off upon artificially drained dairy pasture

This component of objective 9 was conducted in collaboration with Massey University using the Dairy Farm Number 4 experimental plots. Details of this work, and findings from the closely aligned drainage studies are provided in the integrated final report (Hedley et al. 2005). Three key findings arose from the surface runoff research and are summarised below:

- Despite the presence of subsurface drains, appreciable surface runoff can be generated upon dairy pasture. For example, 46mm and 179mm of surface runoff were generated upon one study plot during 2003 and 2004, respectively. This compared with 258mm and 388mm of subsurface drainage from the same plots over the same periods.
- The surface runoff generated is contaminated by faecal microbes, with concentrations of *E. coli* and *Campylobacter* peaking at $> 10^5$ MPN 100 mL^{-1} and $> 10^3$ MPN 100 mL^{-1}, respectively, immediately following grazing. Peak *Campylobacter* concentrations in surface runoff, generated following the application of effluent, were also $> 10^3$ MPN 100 mL^{-1}.
- Information derived from the Ruakura experimental studies (Collins et al. 2004) suggests that riparian buffer strips would be effective at trapping most of the faecal microbes entrained within the surface runoff generated upon the Massey plots.

4. Riparian Management Guidelines

4.1 INTRODUCTION

Results from the PTRRP and elsewhere have shown that the entrapment efficiency of a riparian buffer strip (RBS) can vary markedly and is strongly dependent upon local, site-specific factors. In order to aid the interpretation of this information, a review of information has been conducted and a set of quantitative riparian guidelines has been developed.

4.2 REVIEW OF INFORMATION

Whilst numerous studies have been conducted to investigate RBS performance with respect to sediment and nutrients, very little information exists with respect to microbes. To date very few papers on this topic have been published in the international literature and, those that have, typically do not examine the variation of efficiency with a range of factors. Additionally, work conducted under this program represents the only study undertaken within New Zealand. Given the general scarcity of information, a review of information has been conducted that encompasses key findings not only with respect to faecal microbes, but sediment and particulate nutrients as well. Justification for this is twofold:

1. Microbes can become attached to soil particles and when they do so their short-term fate within a RBS will reflect that of the particle they are adhered to;

2. Some individual bacteria (e.g., *E. coli*) are comparable in size to clay-sized particles.

4.2.1 Slope

A composite of data from studies conducted using differing methods at varying locations suggests that slope angle is a key factor in determining sediment entrapment within RBS (Dillaha et al. 1989; Magette et al. 1989; Peterjohn and Correll 1984; Young et al. 1980). Stronger evidence is provided by the work of Dillaha et al. (1988) who compared sediment removal under differing slopes with all other factors constant, deriving an inverse relation between slope angle (6° - 9°) and sediment entrapment (50% - 90%). Whilst no equivalent data is yet available for microbes (i.e., studies upon variable slope angles have not been conducted), the plot studies at Ruakura and Tirau (Collins et al. 2004) have shown, upon a slope of 8°, that microbial entrapment occurs provided flow rates are not excessive. Studies elsewhere indicate that there is likely to be an optimum range of slope angle at which RBS attenuate both sediment and microbes.

On steep hill-country, convergence of surface and subsurface flows occurs upon the hillside, often leading to the development of wetlands that drain directly to the stream network. These are permanently (or near-permanently) saturated features that respond rapidly to rainfall with high discharge velocities and channelised flow. Typically, outflow rates from these wetlands far exceed those generated upon the Ruakura plots at which little or no microbial entrapment was shown to occur (Collins 2004). Establishing RBS at the lower end of these wetlands is, therefore, unlikely to trap microbes in surface runoff, particularly during storm events. Cattle are not attracted to the larger and deeper of these wetlands, presumably for fear of entrapment. However, the smaller and shallower of these wetlands have been shown to attract cattle for lush grazing and considerable faecal material has been observed to be deposited directly upon them (Collins 2004). Consequently, fencing to exclude cattle from the smaller wetlands is likely to reduce their levels of faecal contamination and, therefore, those of the stream network.

Apart from the prevention of stock access to streams, the primary role of RBS is the entrapment of pollutants washed in by surface runoff. Consequently, they can be bypassed upon flat or gently sloping land where the vertical movement of pollutants down through the soil horizons dominates. Additionally, in order to reduce surface ponding and aid infiltration, low-lying pastoral land (particularly that under dairying) is likely to be underlain by artificial drainage that feeds a network of open drains discharging directly into streams. Subsurface drains have been shown to be susceptible to high levels of faecal contamination (Hedley et al. 2005; Ross and Donnison 2003). The key hydrological pathway on this land is, therefore, a vertical one, causing pollutants including a proportion of faecal microbes to pass beneath any RBS. Muscott et al. (1993), in a comprehensive review of the role of buffer zones in improving water quality, note the minimal impact RBS can have upon artificially drained land. Where this is the case, mitigation is likely to be better focused upon the treatment of drain flows, for example, through the construction of treatment wetlands (Tanner et al. 2005).

It is important to note, however, that studies have shown that a significant volume of surface runoff can be generated upon drained land (Houlbrooke et al. 2004; Hedley et al. 2005). Typically, this generation occurs where soils remain heavy and imperfectly drained despite the presence of artificial drains. At such locations, RBS are likely to be a worthwhile mitigation measure (see Section 3).

4.2.2 Buffer Width

Data from studies comparing multiple width buffers in the same location (Dillaha et al. 1988; Dillaha et al. 1989; Magette et al. 1989; Peterjohn and Correll 1984; Young et al. 1980, Mander et al. 1997; Vought et al. 1994) have shown that sediment and total phosphorus entrapment (removal rates between 53% and 98%) increase with increasing buffer width (4.6 m to 27 m). Additionally, Young et al. (1980) observed a linear decrease in total coliform concentration with increasing (0-25m), cropped buffer width. Results from the earlier Ruakura plots studies (Collins et al. 2002) showed that increasing plot length (equivalent to buffer width):

1. Decreased peak flow.
2. Increased the time taken for peak microbial concentration in outflow to occur.
3. Decreased peak microbial concentrations.

All three effects indicate that the longer plot length (5m versus 1m) led to a greater entrapment of microbes, although this wasnÊt directly quantified.

4.2.3 Soil Type

Soil drainage properties influence RBS performance. Free draining soils minimise the generation of surface runoff, both on the hillside and within a buffer. Under these conditions RBS entrapment may be high relative to the amount of material washed in. However, if surface runoff generation is too infrequent then it is questionable whether buffer strips are a cost-effective mitigation measure.

Poorly drained clay-rich soils promote the generation of surface runoff and, provided flow rates are not excessive, RBS are likely to trap faecal microbes. However, strongly weathered clay soils with a well-developed coarse structure are characterised by macropores (e.g., cracks and worm holes) that promote rapid vertical flows that bypass the soil matrix, providing little attenuation of microbes. The Hamilton clay loam underlying the Ruakura experimental site also exhibited high rates of bypass flow that reduced the microbial trapping efficiency of overlying grass strips (Collins et al. 2003). Alluvial soils with a lot of gravel and sand (often known as Àdroughty soilsÊ are not common but are used for dairying) and without much silty matrix are well drained and the generation of surface runoff is low. However, such soils do not attenuate microbes well. Alluvial Soils developed in younger, loamy material as well as soils derived from volcanic material (Allophanic and Pumice Soils) have a porous nature without a well-developed soil structure. As a consequence these soils promote infiltration over surface runoff and are effective at filtrating percolating microbes, McLeod et al. (2001).

Because of the shallow depth of soils upon steep slopes, generation of surface runoff can be significant, often converging and flowing at high velocity. However, steep slopes with soils developed in loamy volcanic material (e.g., Allophanic and Pumice soils) will provide good infiltration, reducing the generation of surface runoff. Such soils also provide for good filtration of microbes transported in subsurface flows. Clay soils with structural cracks and soils with mechanical cracks arising from slope instability will favour vertical movement of water over generation of surface runoff. However, rapid flow of microbes through the soil to depth without adequate remediation of microbes may result.

4.3 ESTIMATED OPTIMAL RBS WIDTH AND PERFORMANCE WITH RESPECT TO FAECAL BACTERIA

The studies within this research programme coupled with others reported in the international literature provide a useful guide to the optimal design of RBS with respect to faecal microbes. However, it is not possible to derive quantitative guidelines from this work alone that are widely applicable across pastoral land within New Zealand. To do so requires field studies to be undertaken across the whole range of soils, slope angles, buffer types, and magnitude of rainfall events found within New Zealand. Instead, quantitative guidelines for RBS with respect to faecal bacteria have been derived from those reported for sediment attenuation (Collier et al. 1995) that, in turn were derived from a detailed modelling study (section 4.3.1). This extrapolation of the sediment guidelines to faecal bacteria required that some assumptions were made with respect to the state in which bacteria are transported in surface runoff (section 4.3.2).

4.3.1 Model simulation of sediment entrapment

Full details of the sediment modelling approach are provided by Collier et al. (1995), with a brief summary provided here. The modified CREAMS model of Cooper et al. (1992) was run for each of the major soil groups of New Zealand assuming pastoral land and a grass buffer strip. Input data for these soils was obtained from existing site descriptions and databases. Model simulations were run using a minimum of 10 years of climate data to ensure that the model predictions reflected long-term average buffer effectiveness, rather than that of a specific rainfall event only. For each soil group, simulations were conducted that encompassed numerous combinations of slope angle, hill slope length and buffer width, whilst assuming for each case that the buffer was characterised by a very dense vegetative cover. The simulations accounted for the influence of soil particle size: RBS are best able to remove coarse particles (e.g., sand sized) from surface runoff, with a larger reduction in surface runoff transport energy being required to deposit smaller clay-sized particles within the strip.

4.3.2 Application to Faecal Microbes

A current lack of understanding of the form in which faecal microbes are transported in surface runoff limits our ability to predict buffer effectiveness for bacteria with certainty. If, for example, bacteria are transported singularly, un-attached, and free-floating in surface runoff, then they are likely to be trapped with a similar efficiency to clay particles. This is because clay particles and bacteria are similar in size, with clay particles being < 2 µm and bacteria ranging between 0.3 and 2 µm; *E. coli* are 1-2 µm. However, if bacteria are transported in clumps, adhered to faecal material or soil particles, then they are likely to be trapped with a greater efficiency that is broadly comparable to that of soil particles larger than clay. The proportions of free-floating to attached bacteria in surface runoff may vary with a range of factors including the type of faecal material, soil type, amount of bare soil and the characteristics of a rainfall event.

To attempt to capture this uncertainty, the bacteria guidelines make use of a breakdown of the modelled sediment buffer efficiencies with the clay content of the (modelled) eroded soil (Low = ” 10% clay; Medium = ” 30% clay; High = ” 60% clay). For the bacteria guidelines, the percent clay content (of the sediment guidelines) was assumed to represent the percent of free-floating bacteria, whilst the percent of soil particles greater than clay-sized represented the percent of bacteria transported in an attached form. So, for example, if the original sediment guidelines reported a buffer efficiency of 80% for a soil with high (60%) clay content, then - for all other factors being equal - this same 80% efficiency was assumed to apply to and represent a situation whereby 60% of bacteria were transported unattached, and 40% attached. Use of this approach therefore derived a range of optimal buffer widths and associated efficiencies, for a set of site characteristics, including the degree of bacterial attachment.

The quantitative guidelines for buffer design with respect to faecal bacteria are presented in Table 1. These illustrate the optimal buffer width for each combination of slope, soil drainage and bacterial attachment, where the optimal is defined as giving the best return in terms of efficiency for the amount of land given over to the buffer.

Important caveats are associated with the derivation of these guidelines that require the reported efficiencies to be treated as a Âbest-caseÊ These caveats are as follows:

1. The proportion of bacteria transported as unattached in the derivation of Table 1 was assumed to range between 10% and 60%. In reality, however, this figure may, at least on occasion, be higher than 60%, reducing buffer efficiency. For example, Muirhead et al. (2005) report attachment rates of *E. coli* to sediment of < 25%.

2. Whilst some bacteria may approximate a clay particle in size, other bacteria and all viruses (25-350 nm) are considerably smaller. Unless a large proportion of these smaller microbes attach to other particles their entrapment efficiencies will be lower than those reported in Table 1. Furthermore, bacteria are less dense than mineral clays and hence, even if they are of comparable size, are less likely to deposit within a buffer, assuming all other factors are equal.

3. Results from the PTRRP (Collins et al. 2004) have shown that microbes trapped in a RBS can be remobilised in a subsequent rainfall event some days later. These guidelines do not account for survival and re-mobilisation.

4. The guidelines report long-term average efficiencies over numerous rainfall events of different magnitude and frequency. Efficiency will, therefore, be considerably lower in

large rainfall events. Conversely, efficiency will be higher for low magnitude rainfall events.

Table 1: Estimated optimal width and efficiency for RBS with respect to faecal bacteria. Buffer width is given as a percentage of hill slope length. Buffer efficiency is expressed as a percentage reduction, and represents a Âbest-caseÊestimate of average efficiency.

Slope	Soil Drainage Rate	Bacterial Attachment	Buffer Width	Buffer Efficiency	Notes
Flat to Undulating	Low <1-4 mm/h	High: ≈ 90%	1	95	On well-drained soils, RBS may not be warranted since vertical movement of water and microbes dominates. In addition, such land often has artificial subsurface drains. High intensity rainfall, however, can generate significant surface runoff on poor or imperfectly drained soil, even with artificial drainage.
		Medium: ≈ 70%	5	90	
		Low: ≈ 40%	9	80	
	Medium 5-64 mm/h	High	1	95	
		Medium	2	90	
		Low	4	80	
	High 65->250 mm/h	High	1	95	
		Medium	1	95	
		Low	3	85	
Rolling to Moderately Steep	Low	High	2	90	Generally, these are the most appropriate slope angles for RBS since sufficient surface runoff is generated, and as spatially diffuse sheet flow rather than concentrated in rivulets or channels.
		Medium	7	70	
		Low	15	50	
	Medium	High	1	95	
		Medium	4	80	
		Low	11	55	
	High	High	1	95	
		Medium	2	85	
		Low	4	60	
Moderately Steep to Very Steep	Low	High	5	45	RBS efficiency can be limited by topographical convergence of surface runoff, causing channelised flow. Buffers may need to extend some distance upslope, following flow pathways. Exclusion of stock from critical source areas (e.g., wetlands, flow pathways) is an important mitigation measure.
		Medium	15	30	
		Low	30	20	
	Medium	High	3	60	
		Medium	7	50	
		Low	13	35	
	High	High	3	75	
		Medium	4	70	
		Low	11	50	

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