

# Pathogen pathways – Riparian management II

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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 summarises 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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Phil Journeaux  
**Manager North Island Regions**  
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# 1. Executive Summary

Objective 5 of the Pathogen Transmission Routes Research Programme (PTRRP) focused upon three areas of related research:

- 1) Faecal contamination of surface runoff,
- 2) Riparian attenuation of faecal microbes, and
- 3) The drawing up of preliminary riparian management guidelines with respect to faecal microbes.

## ***Faecal Contamination of Surface Runoff***

Continuing work initiated under objective 2 of the PTRRP, a large-scale rainfall simulator (LRS) has been used to quantify the delivery of microbes to a hill-country stream via surface runoff. The LRS encompasses 1050 m<sup>2</sup> of a steep grazed hillside (18°) within the Whatawhata research station, west of Hamilton. Surface runoff generated by the LRS converges naturally and flows directly to a headwater stream. At the point of convergence, flow was measured and samples collected for *E. coli* analysis. Following the five experiments conducted under objective 2, a further six experiments have been conducted under objective 5. Together these 11 events encompass two simulated rainfall rates and variable antecedent soil moisture conditions. Additionally, they have been conducted between zero (stock still present) and 75 days after grazing by sheep, in both summer and winter.

The total number or load of bacteria washed across the outflow flume during an event varied between  $2 \times 10^8$  and  $6 \times 10^{11}$  MPN. Since the outflow drains into a headwater stream, these loads represent a substantial delivery ( $2 \times 10^5$  to  $6 \times 10^8$  MPN/m<sup>2</sup>) of *E. coli* direct to the stream network. Event mean concentrations varied between  $3 \times 10^3$  and  $6 \times 10^6$  MPN/100 mL. Both the load and event-mean concentration of bacteria declined exponentially with the time elapsed since the paddock was last grazed.

## ***Riparian Attenuation of Faecal Microbes***

Ongoing field studies (on the Ruakura farm campus, Hamilton) have continued to determine the ability of buffer strips to trap *Campylobacter* and *E. coli* washed in by surface runoff. Sloping grass plots (downslope length 5 m, width 2 m) were irrigated with clean water (using a sprinkler system) to generate steady surface runoff. Twenty litres of farm dairy effluent, artificially contaminated with *C. jejuni*, was then applied to the saturated surface, at the top of the plots, over 2-3 minutes. Irrigation with clean water was continued for 40-60 minutes. Both surface and subsurface outflow at the lower end of the plots was sampled for microbial analysis. Results using a fast flow rate under objective 5 have been combined with those from earlier experiments (objective 2) using intermediate and slow flow rates. Pooling these results shows that flow rate (or hydraulic loading) has a clear impact upon the recovery (the percentage of the applied microbe recovered in the outflow, i.e., the inverse of attenuation) of microbes. At low flow, microbial recovery is  $\leq 5\%$  (i.e., entrapment is  $\geq 95\%$ ) but at high flows, recovery ranges between 15% and 100%. This finding raises important implications for buffer strip design, particularly if appreciable faecal contamination is only delivered by surface runoff during large events. However, it is important to note that these results are specific to the Hamilton clay loam, a soil characterised by high bypass flow.

Grass plot experiments have also been undertaken upon a farm near Tirau in the Waikato. These plots are located upon an Allophonic Soil characterised by a predominance of flow

through the soil matrix. The Tirau soil therefore provides a clear contrast to the Hamilton clay loam (underlying the Ruakura site) with its high rates of bypass flow.

No clear difference in *E. coli* recovery was apparent between plots on the two differing soil types. This was probably due to the limited number of experiments conducted (two at Hamilton, and four at Tirau under the fast flow rate) and uncertainties associated with the experimental methodology. However, strong hydrological differences were apparent. For the same fast inflow rate, surface outflow on the Tirau soil was much lower than that of the Hamilton clay loam. Additionally, no subsurface flow was measured upon the Tirau plots, this contrasted with the large volumes recorded at Ruakura. These hydrological differences provide evidence (supporting that from other studies) that the Allophonic Soil at Tirau is likely to be much more efficient at attenuating microbes.

### ***Preliminary Riparian Guidelines***

Brief guidelines, as discussed in this report, have been established describing riparian buffer effectiveness with respect to faecal microbes. These account for variations in efficiency with slope, soil type and buffer width.

## 2. Delivery of faecal contamination to waterways by surface runoff – large scale rainfall simulator experiments

### 2.1 INTRODUCTION

To improve understanding of the delivery of microbes to waterways by surface runoff, five experiments were conducted under Objective 2 of the PTRRP using a large-scale rainfall simulator located upon hill-country pasture. The experiments aimed to quantify microbial delivery under heavy rainfall and examine the variation of delivery with stock history. Objective 5 has continued this series of experiments with a further six simulator runs being conducted. Together these 11 events (Table 1) encompassed two simulated rainfall rates and variable antecedent soil moisture conditions. Additionally, they have been conducted between zero (stock still present) and 75 days after grazing by sheep, in both summer and winter. The analysis reported here includes all 11 simulated events.

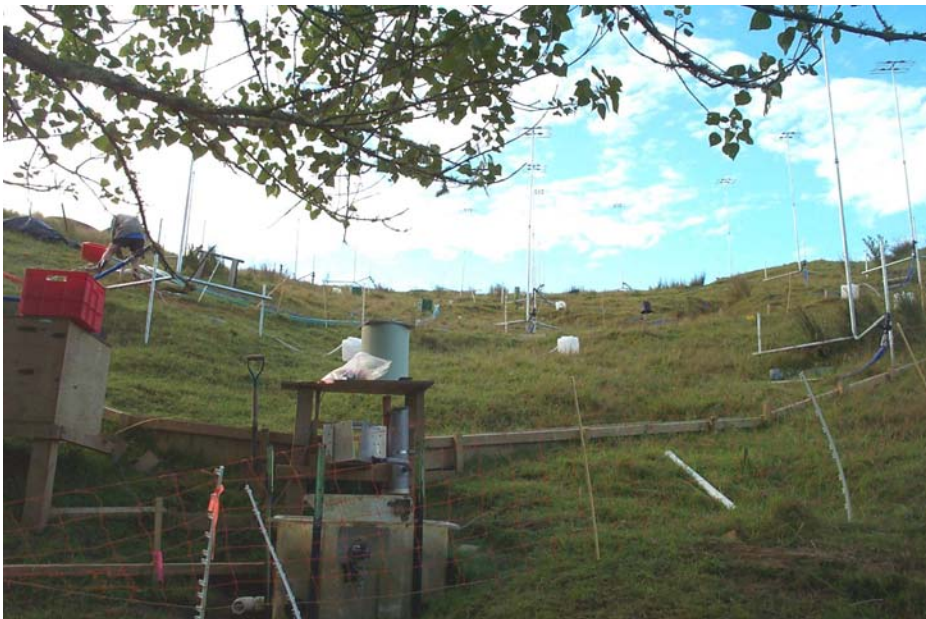
### 2.2 METHODOLOGY AND SITE DESCRIPTION

The large-scale rainfall simulator (Photograph 1) encompasses 1050 m<sup>2</sup> of a topographically-convergent hillslope in the Pukemanga catchment, within the Whatawhata Research Station, west of Hamilton. The simulator consists of 13 rainfall stands at 9 m spacing. Each stand consists of a 5 m high pole with four closely spaced upward-spraying sprinklers mounted on a frame. The design rainfall rate is 35 mm/hr, providing a total application rate of 10.2 L/s, applied over approximately one hour during each experiment. This application rate and duration corresponds approximately to an 8-year recurrence interval. By removing two sprinklers from each stand it was possible to halve the design rainfall rate, and, during objective 5, two experiments were conducted at this lower intensity. On occasion the simulator was run one day prior to an event in order to wet up the soil.

Mean slope angle at the site is 18°, and the hillside is underlain by a yellow-brown earth soil (Kaawa hill soil). Vegetation is predominantly ryegrass-clover. No artificial borders were used around the area encompassed by the simulator since surface runoff converged and flowed naturally into a headwater stream. A 10 m wide wing-wall dug 50 mm into the ground was used to guide the flow to a flume (Photograph 2) at the outlet of the simulator area. Flow rate was measured using a 25 L tipping bucket. Samples of the outflow were collected manually throughout an experiment and taken immediately to the laboratory for microbial (*E. coli*) analysis.



**Photograph 1:** The rainfall simulator and experimental site.



**Photograph 2:** The flume and catchment outlet.

**Table 1:** A description of the “11 rainfall simulator events”.

| Event | Load               | Conc.           | Days | Flow | 3d-rain | Graze | Stock |
|-------|--------------------|-----------------|------|------|---------|-------|-------|
| 1     | $9 \times 10^8$    | $6 \times 10^3$ | 42   | 14.1 | 15.8    | 4     | 49    |
| 2     | $4 \times 10^{11}$ | $3 \times 10^6$ | 0    | 13.7 | 70.2    | 7     | 130   |
| 3     | $2 \times 10^9$    | $1 \times 10^4$ | 55   | 12.9 | 34.3    | 3     | 130   |
| 4     | $6 \times 10^{11}$ | $6 \times 10^6$ | 0    | 9.9  | 7.2     | 3     | 412   |
| 5     | $2 \times 10^{10}$ | $1 \times 10^5$ | 14   | 20.5 | 53.6    | 3     | 412   |
| 6     | $4 \times 10^8$    | $5 \times 10^3$ | 75   | 6.8  | 6.5     | 3     | 340   |
| 7     | $5 \times 10^9$    | $2 \times 10^5$ | 0    | 2.4  | 0.0     | 3     | 225   |
| 8 *   | $1 \times 10^{11}$ | $7 \times 10^5$ | 2    | 18.4 | 50.5    | 3     | 225   |
| 9     | $2 \times 10^9$    | $7 \times 10^4$ | 13   | 2.1  | 0.0     | 3     | 225   |
| 10 *  | $4 \times 10^9$    | $5 \times 10^4$ | 28   | 7.8  | 31.5    | 3     | 225   |
| 11    | $2 \times 10^8$    | $3 \times 10^3$ | 43   | 5.4  | 31.6    | 3     | 225   |

*Notes:*Load the total number (MPN) of *E. coli* in the outflow over the duration of an experiment

Conc the event-mean concentration (MPN/100 mL)

Days the number of days elapsed since the paddock was last grazed

Flow the total flow passing over the outlet flume during an event (m<sup>3</sup>)

3d-rain the 3-day antecedent rainfall total (mm), and includes simulated rainfall used to wet-up the soil prior to an event

Graze the number of days that sheep grazed the paddock during the last grazing period

Stock is the number of sheep per hectare during the last grazing period

\* a reduced rainfall rate was applied over a period of two hours. In all other experiments, the design rainfall rate of 35 mm/hr was applied over one hour

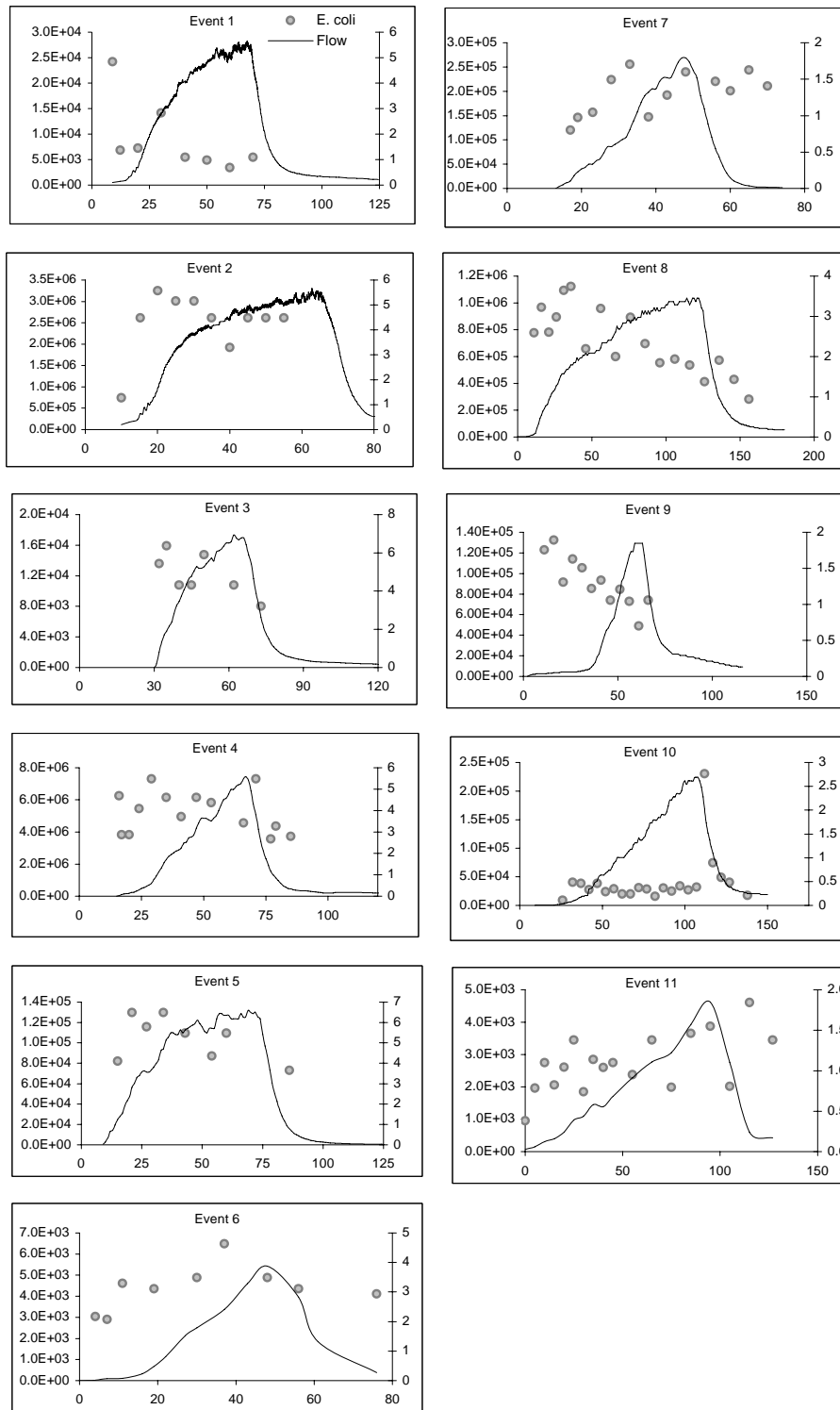
## 2.3 RESULTS

Total flow over each event varied markedly between events (Table 1), reflecting variation in antecedent soil moisture and the rate and duration of rainfall application. Time-series outflow and outflow *E. coli* concentrations for each event are shown in Figure 1. These often illustrate an initial flush of relatively high bacterial concentration, prior to the attainment of peak flow. This is followed by a gradual decline in concentration over the remainder of the event. The total number or load of bacteria washed across the outflow flume during an event varied between  $2 \times 10^8$  and  $6 \times 10^{11}$  MPN. Since the outflow drains into a headwater stream, these loads represent a substantial delivery ( $2 \times 10^5$  to  $6 \times 10^8$  MPN/m<sup>2</sup>) of *E. coli* direct to the stream network.

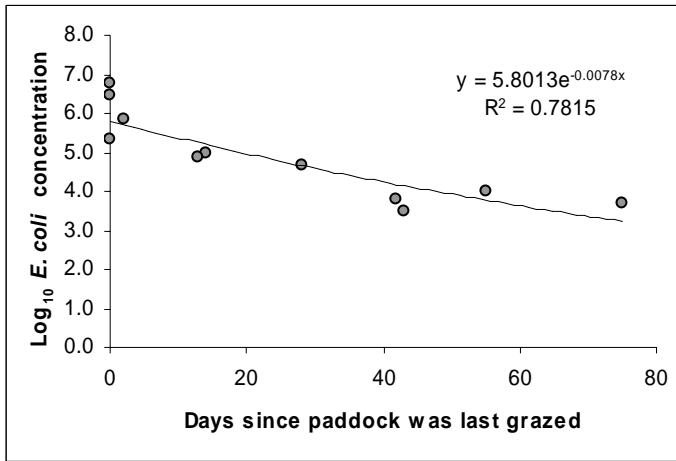
Both the loads and event mean concentrations of bacteria (Table 1) correlate with the recent stock history prior to each experiment (Figures 2 and 3). Events undertaken immediately following sheep removal (or whilst sheep were still present) gave an event-mean concentration of between  $2 \times 10^5$  and  $6 \times 10^6$  MPN/100 mL. Concentrations then declined exponentially with the time elapsed since the paddock was last grazed (Figure 2). A similar exponential decline in event load was observed with the time elapsed since the last period of grazing (Figure 3).

Multiple Regression was used to attempt to develop a statistical model with which to predict event load and event-mean concentration. In addition to the number of days elapsed since grazing, total flow, the 3-day antecedent rainfall, the number of animals and their duration of grazing were all examined as independent variables, in an interactive stepwise selection procedure. The strength of relationships was assessed using the coefficient of determination

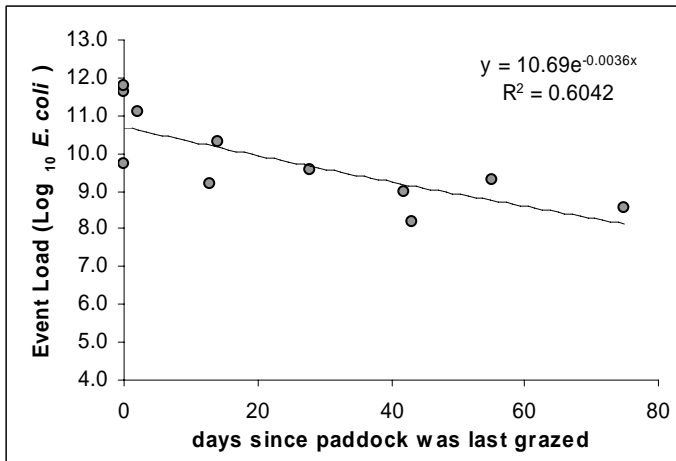
( $r^2$ ), expressed as percentage and adjusted for degrees of freedom. In the prediction of event-mean concentration, ‘time elapsed since grazing’ alone was the strongest predictor ( $r^2=0.78$ ; Figure 2). That is, the addition of the other independent variables made no improvement to the model fit. For the prediction of event load, the combination of two independent variables – ‘time elapsed since grazing’ and ‘total flow’ explained 67% of the observed variance. The addition of other variables made no improvement to the model fit.



**Figure 1:** Time-series outflow (L/s, 2<sup>nd</sup> Y axis) and outflow *E. coli* concentration (MPN/100 mL, Y axis) for the 11 rainfall simulator events. Units of time are minutes after rainfall began.



**Figure 2:** The decline in event-mean concentration with the time elapsed since the last grazing period.



**Figure 3:** The decline in event load with the time elapsed since the last grazing period.

## 3. Riparian Attenuation of Faecal Microbes

### 3.1 INTRODUCTION

There is a widespread perception that fencing to exclude livestock from stream channels and a proportion of riparian land is likely to be the most effective measure in reducing faecal contamination by grazing cattle. Not only does this prevent the deposition of faecal material directly to streams and near channel contributing areas, but also the dense vegetation associated with riparian buffer strips (RBS) reduces the momentum of overland flow, promoting entrapment of faecal material (and other particulates). However, although many studies of sediment and nutrient entrapment in RBS have been conducted, understanding of microbial processes within them is poor, limiting evaluation of their effectiveness. To improve understanding, MAF Policy funded an initial field study of riparian attenuation of faecal microbes during the financial year 2001/02 (Collins et al. 2002), followed by a second study under Objective 2 of the PTRRP (Collins et al. 2003). Both these studies were conducted upon experimental plots established at the Ruakura farm campus, Hamilton. Objective 5 of the PTRRP has extended the Ruakura experimental work further, addressing one specific objective:

- (a) To complete an assessment of the impact of flow rate upon microbial attenuation through conducting “fast flow” experiments, providing a comparison with results from earlier Ruakura experiments run at “intermediate” and “slow” flow rates.

The Ruakura plots are underlain by a Hamilton clay loam, characterised by high bypass flow (McLeod et al. 2003). Bypass flow occurs when water (and entrained contaminants) flow through soil cracks, and worm and root holes, rather than through the small soil pores of the matrix. As a consequence there is likely to be limited beneficial interaction (e.g., filtration of microbes) with the soil. Riparian attenuation is therefore likely to vary with soil type and in order to develop riparian guidelines that are widely applicable, further experiments have been conducted upon an Allophonic Soil on a farm at Tirau in the Waikato. This soil has developed in loamy volcanic tephra and is characterised by low bypass flow, with a matrix thought to be very efficient at filtering pathogens. It therefore provides a clear contrast with the clayey Hamilton soil, facilitating a second objective within the riparian attenuation study.

- (b) To determine the impact of a contrasting soil type upon microbial attenuation.

### 3.2 METHODOLOGY

The study objectives were achieved through a series of plot experiments that involved the flushing of liquid dairy farm effluent into sloping grass strips, by surface runoff generated by a sprinkler. Surface and subsurface outflows at the lower end of a plot were sampled for microbial analysis during each experiment. This information, coupled with a known input of microbes to each plot, enables attenuation of *Campylobacter* and *E. coli* to be quantified.

### 3.3 EXPERIMENTAL DESIGN

#### 3.3.1 Ruakura Plots

Experimental plots have been established for earlier RBS studies (Collins et al. 2002, 2003) on the Ruakura campus farm, Hamilton. Two of these plots were used during this latest study. The plots lie on a sloping paddock (8-12°) underlain by a Hamilton clay loam soil, and have not been grazed since October 2001. The plots are 2 m wide and 5 m long. During the

experiments one of the plots had short grass (7-10 cm) to simulate recently grazed pasture, while the other had long grass (30-37 cm) to simulate a grass buffer strip.

Each plot was bound along its sides by sheet metal inserted approximately 5 cm into the soil, to minimise lateral flow of water out the plot. At the lower end of each plot a trough was dug. Sheet metal was pushed horizontally into the exposed soil face, along the width of the plot, approximately 5 cm below the soil surface. Foam sealant was applied from the sheet metal upwards to just below the ground surface, across the width of the plot. This allowed collection of surface flow. The metal sheet overhung open plastic piping into which flowed surface runoff generated on the plot. This piping sloped laterally so that runoff flowed out of the lower end. At a depth of about 30 cm (corresponding to a clay-rich layer that impeded vertical movement of water) a second sheet metal strip was pushed horizontally into the exposed soil face, along the width of the plot. The metal strip overhung plastic piping and this design collected subsurface runoff draining out of the exposed soil face between depths of 5 and 30 cm. Water was applied to the top of each plot using a “sprinkler” which comprised a hosepipe, to which was attached a closed plastic tube that lay across the top of a plot. Ten holes were drilled in the plastic tube to ensure an even application of water to the plot. A water meter was attached to the hosepipe to determine input rates. The water supply was subject to changes in pressure. Effluent was obtained from a local dairy farm, and stored overnight at 10°C. A strain of *C. jejuni*, isolated from dairy land drainage sediments, was added to the effluent.

### 3.3.2 Tirau Plots

Four plots (two short grass, two long grass) were also established at the Tirau study site, on an 8-10° slope, using the same experimental design as that adopted for the Ruakura experiment. However, since the Tirau site is a privately owned farm (as distinct from the research farm at Ruakura), it was not acceptable to introduce *Campylobacter* to the effluent. Instead, samples were analysed for *E. coli* only.

## 3.4 EXPERIMENTAL PROCEDURE

Two sets of experiments (Table 2) were conducted to address the objectives of the study. During each set, experiments were conducted on two (Ruakura) or four (Tirau) plots.

**Table 2:** Overview of the 2 sets of experiments.

| Expt. | Num | R/T | Purpose                 | Date     | Q_In        | Q_Out     |
|-------|-----|-----|-------------------------|----------|-------------|-----------|
| 1     | 2   | R   | Objective A (flow)      | 15/10/03 | 12.9 – 13.3 | 3.5 – 8.4 |
| 2     | 4   | T   | Objective B (soil type) | 11/02/04 | 11.5 -12.6  | 2.4 – 4.7 |

Notes:

Num                                   the number of individual plots used in each set  
R/T                                       the location (Ruakura or Tirau)  
Q\_In and Q\_out                       (surface plus subsurface) give the range of input and output flows (L/min) from the plots under each set of experiments

### 3.4.1 Experiment 1

Experiment 1 involved the application of effluent to two of the Ruakura plots. The inflow rate of water was about 13 L/minute, sufficient to saturate the soil and generate overland flow. Additionally, this rate provided a contrast to the slow (5-6 L/min) and intermediate (10 L/min) rates applied during objective 2. The outflow rate was steady and similar to that seen during heavy rainfall. Once the plots had attained a hydrological steady state by pre-watering, the hosed water was temporarily stopped and 20 L of dairy effluent was applied to

each plot using watering cans fitted with a distributor to ensure an even application. Effluent was applied evenly across the width, and 0-30 cm above the top end, of each plot, over a period of c. 2 minutes, the time taken for the sprinklers to apply 20 L of water. This practise minimised the changes in outflow from a plot whilst the hosed input of water was temporarily stopped. Once effluent application was completed, the water supply was turned back on. The plastic pipe (attached to the hosepipe) was placed above the band of effluent enabling surface runoff to wash down through the effluent. Water was applied for 40 minutes. Surface and subsurface outflow from the lower end of each plot was measured at designated intervals using a graduated plastic container held beneath the collection pipe. One-litre samples of outflow were also collected at designated intervals for microbial analysis. Samples of background outflow (prior to the addition of effluent), and of the effluent, were also taken for microbial analysis. All samples were placed in a chilly bin and transported to the laboratory within one hour of collection. Analysis was completed within six hours of collection.

### 3.4.2 Experiment 2

Experiment 2, conducted upon the Tirau plots, used the same procedure as that for experiment 1, with the application of a fast inflow rate of 13 L/min to four plots.

### 3.4.3 Microbial Analysis

#### *E. coli* Analysis

*E. coli* were analysed using a commercial MPN technique involving Colilert and Quantitray™ (IDEXX, USA). Trays were incubated at 35°C for 24 hours and *E. coli* identified under UV light (366 nm). The concentration of *E. coli* was determined from MPN probability tables supplied by the manufacturer.

#### *Campylobacter* Analysis

Samples were analysed for *C. jejuni* using a 5-tube (i.e., 5 tubes per dilution) two-stage MPN technique (MIRINZ Manual 2001). A ten-fold dilution series was inoculated into *Campylobacter* medium. The concentration of confirmed *Campylobacter* in the original sample was determined by reference to five-tube MPN probability tables.

## 3.5 RESULTS

### 3.5.1 Objective A

*To determine the impact of flow rate upon microbial attenuation – Experiment 1.*

Both concentrations of *E. coli* and *Campylobacter* in plot surface outflow during experiment 1 exhibited an initial peak, within 10 minutes of effluent application, followed by a gradual decline (1-2 orders of magnitude) for the remaining 40 minutes of the experiment. This pattern is consistent with an initial first flush, followed by the depletion of a finite store of faecal material. It is also a pattern consistent with earlier experiments conducted during objective 2 of the PTRRP.

Microbial recovery (the percentage of the applied microbes recovered in the outflow, i.e., the inverse of attenuation) and outflow data from experiment 1 has been pooled with that from earlier experiments. These combined results (Figures 4 and 5) show that flow rate has a clear impact upon microbial recovery, with a relationship evident between percent recovery and outflow rate, for both *E. coli* and *Campylobacter*. At low flow microbial recovery is less than 5% but at high flows, ranges between 15% and 100%. The relationship between flow rate and microbial recovery raises important implications for buffer strip design, particularly if appreciable faecal contamination is only delivered by surface runoff during large events.

However, it is important to note that this relationship is specific to the Hamilton clay loam, a soil characterised by high bypass flow.

### 3.5.2 Objective B

Application of a fast flow rate to the Tirau plots (11.5-12.6 L/min) resulted in *E. coli* recovery rates of 40%, 41%, 47%, and 96% respectively for each of the four plots. Concentrations in outflow peaked between 5 and 10 minutes after effluent application, and declined steadily thereafter for the remainder of the experiment (Figure 6).

No clear difference in *E. coli* recovery (40%-96% at Tirau; 41% and 100% at Hamilton) was apparent between plots on the two differing soil types. This was probably due to the limited number of experiments conducted and uncertainties associated with the experimental methodology. Clearer evidence of a difference in soil processes between the two sites is provided by the hydrological data. Under fast flow at Ruakura (Hamilton clay loam) outflow rates were 3.5-8.4 L/min and included a substantial subsurface contribution. At Tirau, for the same inflow rate, surface outflows were 2.4-4.7 L/min, and no subsurface flow was recorded on any of the four plots. These hydrological differences provide some evidence that the Allophonic Soil is devoid of bypass flow and is better suited for soaking up both water and microbes.

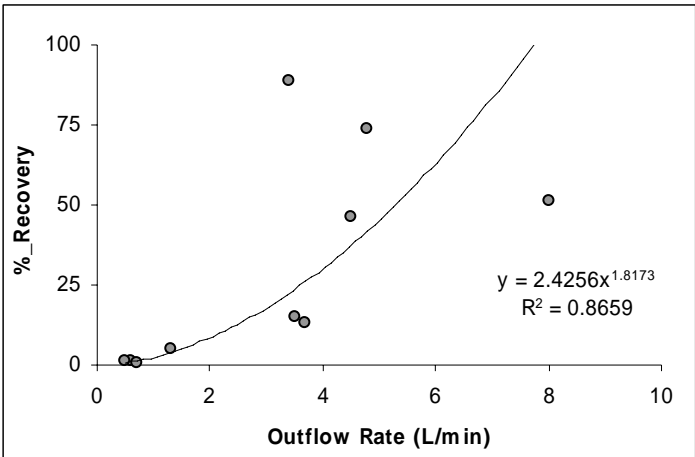


Figure 4: The relationship between the percent recovery of applied Campylobacter and outflow rate.

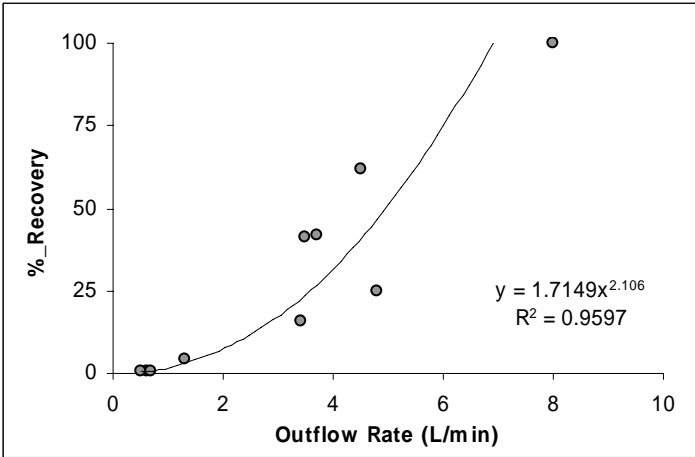
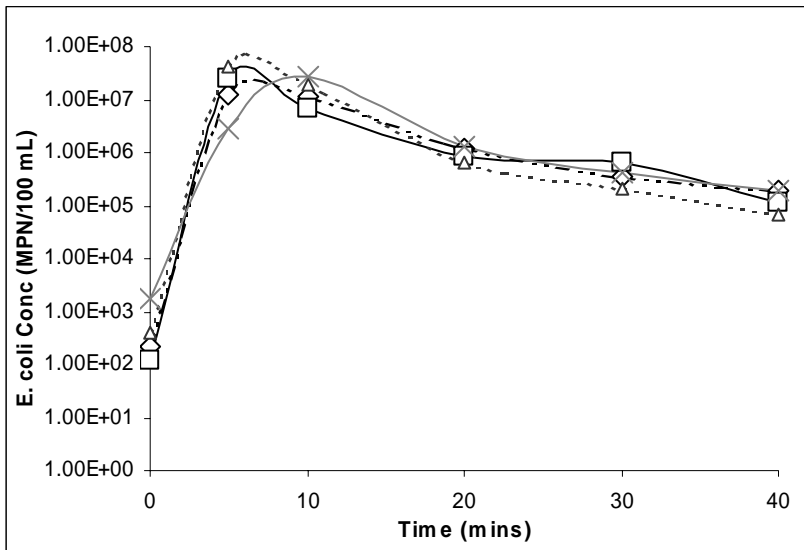


Figure 5: The relationship between the percent recovery of applied *E. coli* and outflow rate.



**Figure 6:** Outflow (surface runoff) *E. coli* concentrations over time upon the four Tirau plots.

## 4. Preliminary Riparian Management Guidelines

### 4.1 INTRODUCTION

Results from the PTRRP and elsewhere have shown that a range of factors influences the performance of RBS with respect to the entrapment of faecal microbes. Entrapment efficiency of a RBS can vary markedly and is strongly dependent upon local, site-specific factors. In order to aid the interpretation of this information, a set of riparian guidelines has been developed. Currently these are brief and preliminary in nature. However, it is proposed that further development of them occurs during year 3 (objective 9) of the PTRRP to provide a more comprehensive set of management guidelines.

### 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 only five papers on this topic have been found in the international literature, and these do not examine the variation of efficiency with a given factor. Additionally, work conducted under this program represents the only study undertaken within New Zealand. Given the general scarcity of information, this review also encompasses key findings with respect to sediment and particulate nutrients. 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 mirror that of the particle they are adhered to.
- 2) Whilst entrapment efficiencies for sediment (and particulate P) cannot be directly transferred to microbes (since at least some microbes are likely to be transported unattached) the relative impact of a range of factors upon sediment entrapment may be broadly applicable to microbes.

#### 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 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, 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 (Collins 2004) far exceed those generated upon the Ruakura plots at which little or no microbial entrapment was shown to occur. Establishing RBS at the lower end of these wetlands is, therefore, unlikely to trap microbes in surface runoff, particularly during storm events. Some, limited, field evidence supports this assertion (Collins 2002).

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.

The primary role of RBS is the entrapment of pollutants washed in by surface runoff. Consequently, they are generally likely to 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 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 (Ross and Donnison 2003). Furthermore, studies within the Toenepi catchment, Waikato, have shown that the loss of nitrogen at the catchment outlet can be accounted for by the sum of all drainage inputs to the stream network (R. Wilcock, pers. comm.). In other words, the presence of RBS at Toenepi would generally be ineffectual at attenuating nitrogen delivery to waterways. It is likely that this also applies to the entrapment of faecal microbes, although, in contrast to soluble nitrogen, filtration probably attenuates microbes as they infiltrate down through the soil horizons. This process, however, differs from entrapment within buffer strips. Muscott et al. (1993) in a comprehensive review of the role of buffer zones in improving water quality, also note the minimal impact RBS have upon artificially drained land. Ongoing studies from the PTRRP at Massey University have, however, shown that surface runoff can be generated upon drained land. Work proposed for next year plans to quantify the importance of this relative to drainage water, under varying rainfall rates.

#### **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. 1987; 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 (0-25 m), 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 (5 m versus 1 m) led to a greater entrapment of microbes, although this wasn't directly quantified due to the high level of uncertainty associated with the 3-tube MPN technique that was used.

#### **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 as to 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, such soils can also be 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 exhibited high rates of bypass flow that reduced the microbial trapping efficiency of overlying grass strips (Collins et al. 2003). In contrast, Allophonic Soils are characterised by good drainage (little or no bypass flow) and, effective filtration of infiltrating microbes, McLeod et al. (2001).

Filter strips are best able to remove coarse particles from overland flow, with a larger reduction in transport energy being required to deposit clay-sized particles within a strip (Collier et al. 1995). Whilst *E. coli* may be approximately as large as a clay particle, most other bacteria and viruses are considerably smaller. Their entrapment within a RBS may therefore require either low flow rates or attachment to soil particles.

#### 4.2.4 Table of Guidelines

Using the review of information provided in sections 4.2.1–4.2.3, a preliminary table of riparian efficiency has been drawn up (Table 3).

**Table 3:** Preliminary Table of RBS efficiency.

| Slope Angle                               | Relative RBS Efficiency                                                                                                                                                                                                                                                                                                                                     | Notes                                                                                                                           |
|-------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| Flat to gently sloping land often drained | Generally, RBS may not be effective since vertical movement of water and pollutants dominates. High intensity rainfall, however, can generate substantial surface runoff and faecal loads. <u>Average Efficiency</u> ; although this rating remains uncertain until ongoing studies are complete.                                                           | Poorly, imperfectly drained soil is often artificially drained.                                                                 |
| Rolling land                              | Efficiency rating encompasses <u>low through to high</u> , and is dependent upon buffer width and soil type. Allophonic Soils are effective in attenuating faecal microbes and, in combination with the dense vegetation of an RBS, provide a high efficiency of attenuation. High bypass flow soils limit RBS effectiveness to average, or low efficiency. | Efficiency also varies with flow rate, which is a function of rainfall, antecedence, slope, and soil.                           |
| Steep land                                | <u>Low efficiency</u> , limited by topographical convergence that provides high flow velocities and channelised flow. For buffers to be effective they are likely to need to extend some distance upslope, following flow pathways. Exclusion of stock from critical source areas (e.g., wetlands, flow pathways) is an appropriate mitigation measure.     | Stock are wary of large deep wetlands. Fencing of smaller shallower wetlands may, however, yield improvements in water quality. |

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