Evaluation of the Effects of Edge-of-Field Grass and Shrub Filter Strips on Fecal Coliform Bacteria Transport in an Agricultural Setting

Results of Phase II of the Tillamook Buffer Strip Effectiveness Project

FINAL REPORT

Prepared for
Tillamook Estuaries Partnership
by
E&S Environmental Chemistry, Inc.

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DEFINITIONS

Buffer Strip: a distance of varying width from a stream bank in which mechanical manure application is prohibited. A buffer is required by the State of Oregon as part of a farm's Water Quality Management Plan. The North Coast Basin Agricultural Water Quality Management Area Plan states that a "buffer or equally effective pollution control application should be established adjacent to waters of the state to minimize soil and manure transport to waters of the state". Exclusion of livestock grazing from a buffer area is not required by the Plan.

Riparian Buffer Zone: the area between the active stream channel and upland vegetation which generally contains unique native vegetation. The riparian zone serves several functions, including stream shading, bank stabilization, large wood recruitment, and surface water runoff infiltration. Under the North Coast Basin Agricultural Water Quality Management Area Plan, livestock can have limited access to riparian areas. The plan also states that a healthy riparian zone should have the following characteristics: "a diverse assortment of plants, trees, shrubs/groundcover, in two or more vertical layers. Riparian areas should be dominated by native species with a diverse age class distribution. Where suitable, conifers are the preferred dominant tree species. Vegetation should cover approximately 90% of the soil surface, with less than 10% bare soil or impervious surfaces".

Vegetated Filter Strip: As used in this document, a vegetated filter strip refers to a strip of land of varying width adjacent to a pasture, planted in pasture grasses and native shrubs and/or trees, and fenced to exclude livestock and grazing. A vegetated filter strip is generally installed between grazed pasture and stream. Mechanical manure application is prohibited in the vegetated filter strip. For a detailed description of a vegetated filter strip see the "Site Construction, Instrumentation, and Maintenance" section of this document.

EXECUTIVE SUMMARY

It is of critical importance to water quality that we determine edge-of-field vegetated filter strip widths and treatment characteristics that will effectively remove fecal coliform bacteria (FCB) from runoff water following land application of dairy manure. An additional consideration is the reluctance of some farmers to install vegetative filter strips that are larger than is necessary to accomplish water quality protection goals. Vegetated filter strip size requirements for protection of water quality have typically been established by political process, not scientific merit, and it has been unclear what degree of treatment we could expect. An experimental treatment system in Tillamook, Oregon, was used to test the fecal coliform bacteria removal efficiencies of edge-of-field vegetated filter strips of various sizes and configurations during nine rainstorms. The experimental system at the primary site consisted of 23 treatment cells, each about 14 m across and 30 m from top to bottom. Cells were vegetated with different filter strip widths (0, 1, 3, 8, 15, 25 m), each located along the lower edge of the cell. They were constructed with different configuration (even and corrugated surfaces) and slope (gentle, moderate, steep), including several replicates. Edge-of-field vegetative filter strip areas in this study were intended to represent areas adjacent to manure-treated pasture. They did not include any representation of additional processing of bacteria in runoff that might occur adjacent to a stream in the riparian zone.

Midway through the project, a second experimental site was established on a farm southwest of Tillamook, near the Tillamook River. Soils at this site were heavier, due to a lower sand and higher silt content. As a consequence, infiltration of rainfall/runoff at this silty soil site was lower than infiltration at the primary treatment site.

Runoff samples were collected and analyzed for fecal coliform bacteria concentration and runoff volume at the primary treatment site during seven rainstorms during the 2004-2005 water year. During the previous year, one storm had been sampled to determine the background storm flux of bacteria from the experimental cells in the absence of manure application, and a second storm had been sampled subsequent to manure application. Half of the sampled storms over the course of the study included more than 8 cm of rain, with a maximum of 20 cm.

On average, more than 99% of the rainfall infiltrated the loamy soils of the primary treatment site, without generating surface or shallow (< 15 cm) runoff, based on measured quantities of precipitation and shallow runoff. Soil moisture was not measured. The observed

high infiltration rates had a substantial influence on the flux of bacteria from manure-treated pasture to the edge-of-field ditchline.

Concentrations of FCB were high in runoff from the zero filter strip cells (experimental cells that received manure application immediately adjacent to the ditchline, with no vegetated filter strip). Most zero filter strip runoff samples had FCB concentration higher than the 200 cfu/100 ml guideline for contact recreation. The median FCB concentration in runoff from the zero filter strip cell in the gentle slope (3.8%) experimental area was 16,500 cfu/100 ml. In contrast, only 10% of the runoff samples collected from the cells having vegetated filter strips exhibited FCB concentrations > 200 cfu/100 ml, and the median concentration for all cells containing filter strips was only 6 cfu/100 ml. In the absence of vegetated filter strips, the flux of FCB from pasture to edge of field was higher, on average, by about two orders of magnitude as compared with manure-treated pasture that lacked any filter strip. Thus, manure spreading in advance of rainstorms resulted in substantial contamination of runoff in the absence of a vegetated filter strip. However, the presence of a filter strip of any size, from 1 m to 25 m, in most cases reduced the median FCB concentration in runoff by more than 99%. There was a general pattern (not statistically significant; p $ 0.065) of higher FCB concentration in runoff from the shorter vegetated filter strip cells (1 m and 3 m), as compared with longer filter strips (8 m, 15 m, 25 m), but any potential improvement in bacterial removal efficiency with increasing filter strip size was minimal.

Three storms were sampled at the silty soil site during the 2004-2005 water year. Limited data suggested lower infiltration and greater bacterial flux from manure-treated pasture to simulated stream for the short (1 m and 3 m) experimental vegetated filter strip cells, as compared with results from the primary study area, which was characterized by higher sand content in the loamy soils.

This study evaluated the bacterial removal effectiveness of edge-of-field filter strips vegetated with grasses and shrubs. It did not involve investigation into riparian function or the extent to which woody riparian vegetation influences water quality via functions related to stream shading, bank stability, filtration of nutrients and sediments, or large wood recruitment. With respect to bacterial removal from runoff, however, vegetated edge-of-field filter strips, on average, reduced the flux of bacteria from manure-treated pasture by about two orders of magnitude, as compared with pasture that lacked filter strips.

These results suggest that installation of a vegetated filter strip on loamy soils dramatically reduced the bacterial contamination of runoff water from manure-treated pasturelands, but the size of the vegetated filter strip was not an important determinant of bacterial removal efficiency. In general, FCB flux was lowest in the experimental area that had highest soil sand content and associated infiltration. Generally higher FCB fluxes were observed for 1 m and 3 m vegetated filter strips as compared with longer filter strips in the study area that had lowest soil sand content and associated lower infiltration of rainfall and higher runoff. These limited data suggest that FCB contamination of runoff from manure-treated pasturelands may be disproportionately associated with heavier soils that exhibit lower infiltration and generate larger volumes of runoff. Field observations and consideration of runoff volumes collected in this study suggest that overland sheet flow did not occur during any of the sampled rainstorms. Thus, the principal bacterial removal mechanisms were probably related more to soil properties than to vegetation. Additional research will be required to quantify the relationships among soil texture, filter strip size, and bacterial removal efficiency. Filter strip size regulations for riparian buffers that do not consider such differences may not be efficient or effective in reducing bacterial contamination of runoff.

INTRODUCTION

Numerous studies have evaluated the extent to which agricultural practices such as cattle grazing and manure application impact the microbiological quality of runoff water (see reviews of Castelle et al. 1994 and Wenger 1999). Quantification of impacts is difficult, however, in part because the extent of bacterial pollution is related to climatological and hydrological factors such as rainfall amount and intensity and temperature, as well as microbial die-off in the interim between fecal deposition/application and the occurrence of a runoff-generating storm event. The quantity of bacteria present and available for transport in runoff is a complex function of numerous inter-related variables that include initial bacteria deposition rate, soil conditions, temperature, sunlight, and organic matter (Gerba et al. 1975). As a consequence of the uncertainties in correlating manure application with the quality of runoff water, available empirical data frequently exhibit apparent contradictions (Edwards et al. 1997).

Tiedemann et al. (1988) found that the concentrations of fecal coliform bacteria (FCB) in streams in Oregon were associated with grazing strategy. Average FCB concentrations exceeded 1000 cfu/100 ml in some streams that passed through grazing lands.

Manure spreading on pasturelands is a common practice among dairy farmers in the north coastal region of Oregon. Subsequent surface runoff during rainstorms can contaminate stream and estuarine resources with enteric bacteria (Entry et al. 2000). Because the regional climate is moist and cool, and therefore conducive to bacterial survival, and because relatively frequent large rainstorms (> 10 cm) can result in locally saturated soil conditions, the movement of bacteria from pasture to surface water is an important environmental concern. These same fresh and estuarine surface waters are used for recreational activities, and therefore high concentrations of fecal bacteria pose a health risk. Fecal contamination of the estuary causes periodic closure of oyster harvesting in portions of Tillamook Bay.

FCB are commonly used as an indication of bacterial pathogen contamination. Their presence implies the potential presence of microorganisms that are pathogenic to humans (Entry et al. 2000). FCB are enteric to homeothermic animals, and their presence in runoff water suggests fecal pollution. It is generally accepted that FCB will be affected in soil and water in the same manner as human pathogenic bacteria (Greenberg et al. 1992, Toranzos and McFeters 1997, Entry et al. 2000). FCB concentrations typically decline substantially when transported through soil, suggesting that FCB transport from pasture to surface water occurs mainly by surface or macropore flow (Kunkle 1970, Huysman and Verstraete 1993, Howell et al. 1996, Abu-Ashour et al. 1998).

Most pathogenic bacteria are removed from drainage water within the soil profile. For example, Gerba et al. (1975) found that about 95% of *Escherichia coli* are filtered out of soil leachate within the top 4 cm of the soil profile. Long-distance transport can occur, however, due to the presence of soil macropores, cracks, or fissures (Abu-Ashour et al. 1994, McMurry et al. 1998).

The recommended FCB standards for surface waters for designated recreational water use have been 200 cfu/100 ml for primary and 1,000 cfu/100 ml for secondary (partial) contact recreation (USDI 1968, Edwards et al. 1997). The U.S. Environmental Protection Agency required that FCB concentrations not exceed 200 cfu/100 ml for bathing water and contact recreation, and 14 cfu/100 ml for shellfish harvesting water (USEPA 1976). The state of Oregon has shifted to a bacterial standard for fresh water contact recreation based on *E. coli* concentration (126 counts/100 ml for 30-day log mean, with maximum of five samples and no sample higher than 406 counts/100 ml). For the estuary, and associated shellfish production, the FCB standard applies.

Buffers are strips of land maintained in vegetation and managed for the control of pollutant transport in runoff from cultivated fields or pasture to surface water. Pollution control is achieved through natural processes that occur in or on the soil and vegetative surfaces and prevent or retard leaching or overland transport of pollutants (i.e., pathogens, nutrients, toxics, organic materials) from the terrestrial to the aquatic environment. For this study, we investigated pollution control provided by filter strips vegetated with grasses and shrubs.

According to current conceptual models of pollutant transport, vegetated filter strips can reduce the movement of bacteria from pasture to surface water. Although these functions are well-established, the degree to which they can be enhanced by the installation of larger vegetated filter strips has not been experimentally quantified (Dosskey 2000).

It is of critical importance that we determine edge-of-field vegetated filter strip widths and configurations that will protect water quality, as well as agricultural livelihoods. Large Federal programs have been established (e.g., CRP, EQUIP) to encourage farmers to convert some of their cultivated streamside areas to vegetated filter strips, but it remains unclear what degree of pollution reduction we can expect (Dosskey 2000). It is important to identify management procedures that reduce runoff of FCB from pastureland, and also to determine the extent to which farmers can trade such things as vegetated filter strip width for slope steepness or soil texture. This research will help to provide the foundation for determining which factors are most important and which combination of factors will optimize protection of water quality while optimizing vegetated filter strip width.

Few studies have been conducted to examine the removal of FCB in vegetated filter strips, although somewhat more information is available regarding removal of sediment and nutrients (Wenger 1999). Many agencies throughout the United States rely primarily on a combination of political acceptability and assumed aquatic resource functional value to establish vegetated filter strip size standards appropriate for riparian buffers (Castelle et al. 1992, 1994). In order to adopt an approach that is more firmly rooted in science, it is necessary for scientists to provide resource managers with information on specific vegetated filter strip functionality under varying conditions and settings.

In our experience, many agricultural landowners do not believe that land management on their farms adversely impacts water quality. These landowners generally are not convinced that streamside fencing and establishment of riparian vegetated filter strips will improve water quality. If we can show clear and unambiguous proof of the effectiveness of edge-of-field vegetated filter strips for water quality protection in an agricultural setting, many of these landowners may be more willing to install vegetated filter strips and fencing. This will not only help reduce fecal bacteria contamination, but the development of natural vegetation will also provide stream shading and reduce erosion, sedimentation, and nutrient enrichment, and will have positive impacts on stream and riparian habitat health.

Subsequent to manure spreading on pastureland, the quantity of FCB that move downslope from the application area will depend on the attraction of bacteria to soil particles and the rainfall duration and intensity. A variety of factors affect the adsorption of bacteria to soil, including bacterial secretion of adhesive substances, pH, temperature, moisture, and soil cation exchange capacity and organic content (Reddy et al. 1981, Moore et al. 1988).

Research has been conducted elsewhere regarding the effectiveness of vegetated filter strips in filtering pollutants from agricultural runoff, mostly focused on nutrient and sediment removal. Relatively little research has been conducted on FCB removal and little of that has been conducted in a hydrogeomorphic setting such as is found in Pacific NW coastal areas.

Edwards et al. (1997) treated experimental pasture plots near Lexington, KY with cattle manure and then applied simulated precipitation. On average, 7.4 cm of precipitation was required to generate runoff from the plots. Runoff as a proportion of total simulated rainfall averaged only 1.8%. Initial concentrations of FCB in runoff were as high as 2 x 10^7 cfu/100 ml. Nevertheless, no FCB was detected in runoff that had traversed vegetated filter strip zones of 6.1, 12.2, and 18.3 m width. This 100% removal of FCB from runoff after a vegetated filter strip of 6.1 m was attributed by Edwards et al. (1997) to high infiltration of simulated precipitation into the soil profile. In contrast, studies by Chaubey et al. (1995), Coyne et al. (1995), and Walker et al.(1990) concluded that vegetated zones were relatively ineffective in removing FCB from runoff. Young (1980), Coyne et al. (1995, 1998) and Walker et al. (1990) concluded that 10 m grass filter strips reduced FCB concentration by only up to about 70% in runoff from pasturelands where poultry or dairy waste had been applied. They further concluded that 10 m grass filter strips were often not adequate in meeting water quality standards for FCB in runoff. Results of a modeling study by Walker et al. (1990) suggested that vegetated filter strip strips alone would not be sufficient for reducing FCB concentrations to low enough levels to meet water quality goals. However, the model COLI involved a number of untested assumptions regarding the bacterial die-off rate.

Coyne et al. (1995) applied poultry manure to 9 m grass filter strip test plots and applied artificial rain to the plots. FCB concentrations were reduced by 74% and 43% in the two strips studied, but still exceeded the primary contact standard (200 cfu/100 ml) in all samples. Karr and Schlosser (1977) reported the results of a 1973 study that documented FCB reductions by 87% for a 60 m grass filter strip. Gilfillen (1994) found 90% bacterial reduction with a 9 m filter strip. However, Young et al. (1980) found only 69% reduction with 27 m grass filter strips on 4% slope, and effluent concentrations at the bottom of the filter strips were near 10^6 cfu/100 ml. Schellinger and Claussen (1992) found that total coliform and fecal streptococci bacteria were also reduced about 70% in a grass filter used to treat dairy barnyard runoff.

Coyne et al. (1998) incorporated poultry manure into experimental plots, buffered by 4.5 m and 9.0 m grass filter strips. Simulated rain studies were used to investigate FCB removal on silt loam soil of 9% slope. Average FCB trapping efficiency was 75% in the 4.5 m grass filter strip strips and 91% in the 9.0 m grass filter strips. Most of the bacterial trapping was attributed to infiltration. Nevertheless, flows-weighted FCB concentrations in filter strip runoff, when it occurred, were still 1,000 times higher than the 200 cfu/100 ml water quality standard. Even lower values for FCB trapping efficiency (43% and 74%) were reported by Coyne et al. (1995) below a 9 m grass filter strip. It is important to note, however, that simulated rain was applied at a high rate (6.4 cm/hr), and it was continued until runoff had occurred from the filter strips for one hour (Coyne et al. 1995, 1998). Similarly, the study reported by Young et al. (1980) involved rainfall simulation at a very high rate (6.35 cm of rain over 1.2 hours on each of two occasions separated by 24 hours).

The pattern and intensity of rainfall are important in the determination of vegetated filter strip effectiveness. In general, wider filter strips will likely be needed in areas that experience seasonal periods of high storm intensity (Wenger 1999), such as are common in the Pacific NW. Wenger (1999) recommended that filter strips should be designed to effectively handle runoff from a one-year storm event, with allowance for exceptional events. Soils characteristics are important in regulating infiltration rates, the extent of overland flow, runoff detention time, and other factors that influence the removal efficiencies of edge-of-field vegetated filter strips.

Past research has been inconclusive in determining transport distances needed to filter or kill bacteria in runoff. Some researchers have suggested that survival is influenced by variables such as sunlight, pH, temperature, soil type, organic matter concentration, and predator organisms. Reviews by Castelle et al. (1994) and Wenger (1999) have not found consistent data on the pollutant removal efficiencies of varying vegetated filter strip size, especially for bacteria. Dosskey (2000) concluded that substantial gaps remain in our knowledge of the pollutant control functions of edge-of-field vegetated filter strips, in particular their magnitude compared to functions within the agricultural conditions that they replace. We believe that one major reason that past vegetated filter strip effectiveness studies have been inconclusive has been that they examined few (often two) transport distances. We examined in this project the bacteria removal efficiencies of six vegetated filter strip widths. It is the distribution of response across these different sizes that is of interest. We also examined the influence of differences in slope and soil texture.

The results of past research were fairly consistent in suggesting that wider vegetated filter strips in general provided more effective nutrient, sediment, and bacteria removal than narrow filter strips. However, in searching the scientific literature, we have found no published research that:

1. quantifies removal efficiencies as a function of vegetated filter strip width or slope in a hydrogeomorphic setting such as we have in the Pacific Northwest Coast region; or
2. examines and/or quantifies the relationships (and trade-offs) among vegetated filter strip size, slope, and manure management (spreading setbacks, time of spreading in advance of storm), not just in the Pacific Northwest, but anywhere.

Thus, there is a great deal of information suggesting that vegetated filter strips can be effective in some instances for protecting water quality, but quantitative data are rare and inconsistent. In particular, little information is available regarding removal of fecal bacteria from runoff. We are unaware of any available data that provide quantitative information regarding how large vegetated filter strips must be to effectively remove bacteria on soils of different textures or slope classes. Conditions are somewhat unique along the Pacific NW coast because of the heavy rainfall commonly encountered (individual storms frequently > 10 cm of rain). However, quantitative information is not just lacking for the coastal Pacific NW; it is not available anywhere. At this point, there are no unambiguous data to show to landowners that clearly demonstrate that a certain size of vegetated filter strip will dramatically reduce the extent to which their activities directly cause a deterioration of water quality. There are also insufficient data on which to base streamside buffer policy, especially with respect to FCB.

This information is needed as a foundation for management decisions regarding vegetated filter strip width recommendations, and is also needed in order to convince landowners that the considerable effort and expense required to install fenced edge-of-field filter strips on their property (and the associated loss of productive land if filter strips are not grazed) will in fact improve water quality. Availability of such information will likely result in more streamside fencing in the region and beyond. In the process, aquatic ecosystem recovery will be enhanced through direct effects on water quality and through development of natural streamside vegetation and its beneficial effects on a wide variety of parameters, such as stream temperature and sedimentation.

This project was structured to occur in stages. The Phase I effort involved the design, construction, and testing of the treatment system. Results were reported by E&S Environmental Chemistry, Inc. (2004). During the first storm sampled and analyzed for bacteria in runoff, no manure was applied to any of the cells; for the second storm, manure was applied to each cell except the two controls prior to the beginning of the storm. Both of these experiments were designed, in part, to evaluate comparability of experimental cells and runoff collection capabilities prior to conducting Phase II of the research program. Phase II work, which is the subject of this report, involved additional experiments to quantify the effects of such factors as vegetated filter strip size, slope, and topography on bacterial removal efficiencies during seven storms of differing sizes and intensities during the 2004-2005 water year.

The major objective of this study was to quantify the concentration in runoff and flux of FCB from agricultural fields treated with dairy cow manure, with and without edge-of-field filter strips. We examined FCB transport across vegetated filter strips of various sizes on fields of various slope classes to determine the effectiveness of filter strips in reducing bacterial movement as compared with unbuffered, manure-treated pastureland. We did not attempt to evaluate any additional influence on bacteria transport that might occur in conjunction with riparian processes along receiving waters located below the experimental pasture area. Those riparian processes might include additional processing of bacteria, as well as contribute to ecosystem functions associated with stream shading, bank stability, filtration of nutrients and sediment, and large wood recruitment.

METHODS

Experimental Design

Principal Experimental Site

We conducted a series of experiments over a two-year period to quantify the FCB removal efficiencies of edge-of-field vegetated filter strips during nine rainstorms. The work was conducted in Tillamook, on the northern coast of Oregon. Five rivers drain the adjacent Coast Range Mountains and flow into Tillamook Bay. Dairy farming is important to the local economy and constitutes a major land use throughout the lower Tillamook Basin.

The experimental system on the principal experimental site was located midfield on the sloping pasture land and consisted of 23 treatment cells, each about 14 m across and 30 m from top to bottom. Cells were vegetated with mixed pasture grasses and a variety of native shrubs and sedges within different vegetated filter strip widths (0, 1, 5, 8, 15, 25 m), and were constructed with different configuration (even and corrugated surfaces) and slope (gentle, moderate, steep). Trees were not planted in the filter strips, but would not have been expected to impact bacterial removal. A sample collection system was installed with which to consecutively collect at the base of each treatment cell, samples from 10 locations, each integrated over the course of a portion of a rainstorm. Each cell consisted of a simulated pasture area, which was periodically mowed; a simulated vegetated filter strip, which was planted with typical pasture grasses and streamside native shrub species and then left undisturbed; and a simulated stream (ditch line). Each cell was hydrologically isolated by ditching and berm installation. Soils in the

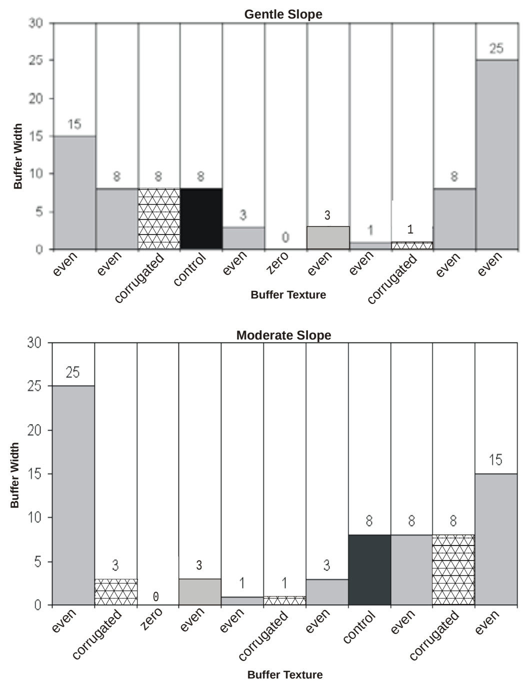


Figure 1. Configuration of established treatment cells for the experiments on two slope classes (gentle and moderate). There is also one vegetated filter strip cell on steep ground (~12% slope). Each cell is divided into simulated pasture (white) and filter strip (shaded), with a ditch to represent the stream along the base of each cell. The control cells do not receive manure treatment. All other cells receive manure application along a 3 m strip across the pasture/filter strip interface in advance of rainstorms. Cross-hatched filter strips have corrugated surfaces; all others have smooth surfaces. The 3 m and 8 m filter strips are replicated in the gentle slope class and the 3 m filter strip is replicated in the moderate slope class. Cells are labeled from left to right G1 to G11 in the gentle slope class and M1 to M11 in the moderate slope class.

project area are Quillayute silt loams. They are very dark gray to black, very strongly acidic soils with numerous very fine pores and abundant roots (Bowlsby and Swanson 1964).

The main experimental treatment area was located just west of the Grange building on the eastern side of Tillamook. The fields at this site had not been heavily grazed or treated with manure for several years prior to initiation of this study. Two sets of experimental cells were constructed, one on a gentle slope (3.8%) and the other on a moderate slope (7.0%), selected to correspond with most of the dairy pasture lands in north coastal areas. Each set included 10 experimental cells and one control cell (Figure 1). In addition, one cell was established on steep ground (12% slope), with an 8 m vegetated filter strip. Three of the cells were replicated for width in the gentle and moderate slope cell sets, and there were two control cells which received no manure treatment. For some of the cells, filter strips were installed in which furrows were constructed to produce a corrugated ground surface perpendicular to the drainage pattern to enhance drainage water infiltration. Treatment cells were situated to avoid monotonic changes in filter strip size across the study area in the event that there were any consistent changes in soil characteristics. In addition, cells were situated to place those that would be directly compared side by side. The overall pattern of placement facilitated manure application, which occurred at the pasture/filter strip interface in conformance with normal farm practice. Replicated plots were not located in proximity.

All treatment plots were constructed to allow runoff collection to be spatially and temporally replicated to allow statistical analysis of results. Cells were hydrologically isolated from each other. At the downhill end of each cell was a ditch, dug perpendicular to the length of the cell. Near the center of the ditch we installed two (1.2 m long each) gutter systems, separated into compartments (alternating 5, 10, and 15 cm in width), each connected below to a runoff collection tube. These collected overland flow and shallow groundwater (# 15 cm) flow that drained from the treatment cell and associated vegetated filter strip during rainstorms within the middle one third of the filter strip width, thereby avoiding collection of runoff near either of the sides (which could be affected by lateral flow towards or away from the cell). Initially, the water collection ability of each of the three compartment sizes was evaluated during two rainstorms. Based on these data, it was decided to collect samples using the medium (10 cm) and large (15 cm) compartments. In advance of each storm, 10 compartments (two - 10 cm wide and eight - 15 cm wide) in each cell were selected for sampling and each was connected to a 0.9 L sample bottle. At the top of each cell was a drainage ditch to divert any uphill runoff towards the sides and away from the treatment area. The experimental area was fenced to exclude livestock. Topography had been modified two years earlier using heavy equipment to provide consistent surfaces and to prevent excessive channelization of runoff within a given cell.

It is expected that all experimental cells received the same amount of rainfall during a given storm (measured by a rain gauge on the site), with no additional runoff originating from out-of-cell. Each cell received equal amounts of manure during each experiment. No manure applications had occurred for at least three years prior to initiation of this research. We do not expect to have lingering effects of treatment from previous years. Fecal bacteria generally decline to below detectable levels within about 60 days of manure application (Stoddard et al. 1998). Lingering effects from previous manure applications within a given year mimic typical agronomic practices and therefore did not affect our ability to quantify differences in effectiveness of vegetated filter strips of different sizes. The pasture soil was loosened two years prior to sampling most of the experimental rainstorms. This action, and the lack of livestock compaction of soil, may have influenced the amount of infiltration of precipitation that occurred during the experiments.

The runoff collection system allowed quantification of runoff volume collected from each cell, estimation of total surface and near-surface discharge from each cell throughout the duration of each storm, and subsampling for bacterial analyses. This design allowed quantification of precipitation input; infiltration rate; discharge to simulated stream via overland flow and shallow (~ 15 cm) groundwater flow; bacterial concentrations (cfu/100 ml) in runoff; bacterial flux (e.g., cfu/storm/m); and bacterial removal efficiency (percent removed, normalized to zero filter strip treatment) under differing experimental treatments.

Silty Soil Site

In October, 2004, five additional runoff collection cells were temporarily installed on a farm adjacent to the lower Tillamook river, near its confluence with Bewley Creek. This site was selected because it contains heavier soils, and therefore was expected to have lower infiltration of storm precipitation, resulting in additional runoff. The cells installed at the heavier soil site were as follows: control (no manure); zero filter strip; and 3, 5, 8 m vegetated filter strips. Each cell consisted of about 27 to 30 m of pasture, bordered on the uphill side by a road, above the runoff collection ditch. The size of this runoff-generating area was similar to that of the original study area on soils containing more sand. Designated vegetated filter strip areas contained pasture grasses. Manure was spread in advance of three rainstorms along a 3 m wide strip at the pasture/filter strip interface of each cell in the same manner as at the original study site. Cows had recently grazed the field prior to initiation of sampling but were excluded during the study. Cow pies uphill from the sampling and treatment areas were removed by shovel prior to the first manure application.

Soil particle size distribution, determined by the pipette method, is given in Table 1 for each slope class and soil type. Soils on the principal experimental site were classified as silt loams (gentle and step slope areas) and loams/silt loams (moderate slope area). Soils at the heavy soil site were also classified as silt loams, but had lower percent sand and higher percent silt, especially in comparison with the gentle and moderate slope classes at the principal experimental site.

Table 1. Particle size distribution for soils at each of the experimental sites.

	Percent Soil Particle Size			
Filter Strip Type	Sand (50 :m – 2 mm)	Silt (2 – 50 :m)	Clay (< 2 :m)	Soil Texture
Principal Experimental Site				
Gentle slope	33.8	56.4	9.8	silt loam
Moderate slope	35.0	50.0	15.0	loam/silt loam
Steep slope	24.8	58.6	16.6	silt loam
Heavy (Silty) Soil Site				
Moderate slope	22.7	64.7	12.7	silt loam

Site Construction, Instrumentation, and Maintenance

One recording rain gauge was installed at the primary experimental site. It was used to quantify precipitation amounts subsequent to, and during, sampled storms.

Uphill treatment areas were planted in 2002 with a typical mixture of pasture grasses and clover. Filter strips were planted with a mixture of pasture grasses, clover, sedges, and native shrubs (red ozier dogwood, ninebark, Indian plum, nootka rose, serviceberry, Oregon grape, salal, huckleberry) to simulate the shrub component of common streamside planting mixes in the north coast region. However, trees were not planted and we did not expect that they would have influenced bacterial removal within the period of time of this study. Treatment areas (uphill from each respective vegetated filter strip) were mowed periodically throughout the growing season during the study to simulate grazing. Vegetated filter strip areas were left undisturbed. Mole trapping was conducted periodically.

The experimental site was fenced and two gates were installed. Treatment cells were established within the three selected slope classes. Earth moving was completed with the use of heavy equipment to yield cells of consistent slope (± 0.3%) and even topography within each slope class. Runoff from a road culvert located near the top of the experimental area was routed via buried 8" plastic pipe to the bottom of the area. Corrugations were added by hand to a subset of the cells (Figure 1), with mounds and ditches alternating approximately every 20 cm. The relief was about 15 cm from top to bottom of the corrugations. These corrugations were expected to force greater infiltration of runoff water through soils within these cells. After construction of the corrugations, disturbed areas were reseeded and planted. Metal sampling gutters were installed at the base of each cell.

Manure Application

Thirty five gallons (132.5 L) of manure was applied in advance of each rainstorm across a 35-ft (10.8 m) width of each treatment cell. The manure loading rate uphill from the simulated stream was 1 gal per linear ft (12.27 L/m), or 0.1 gal per ft^2 (4.07 L/m^2). Manure loading generally employed what would approximate agronomic rates. Manure was applied to treatment areas at and above the interface between pasture and filter strip, in advance of each storm initiation. On the zero filter strip treatment cells, we spread manure close to the boundary between simulated pasture and stream, and collection gutters were covered during manure application. Manure was applied to each of the experimental cells, except the controls, in advance of eight predicted rainstorms (one in Year 1 and seven in Year 2). In most cases, the storm began within about 24 hours of manure spreading. Fresh manure scrapings (in thick liquid form) were obtained from the dairy barn in close proximity to the experimental site and spread immediately.

The manure application area was situated at the pasture/filter strip interface on each cell. Thus, for each of the two zero filter strip cells, manure was applied to within a few cm of the simulated streambank (water collection gutter and ditchline). For other treatment cells, manure was applied at varying distances (1, 3, 8, 15, 25 m) from the simulated streambank. The two control cells received no manure application at any time during the study.

Manure was applied consistently across each application area in a manner that was comparable from cell to cell. Application was accomplished using a modified hand-pushed lawn fertilizer spreader. Several passes were made across each application area to achieve uniformity of manure application rate.

Sample Collection and Field Processing

Sample bottles were attached to the gutter collection systems in advance of rainstorms. Bacteria samples were collected during and after rainstorms and aliquots (generally n=10) of pooled samples were transferred to new sterile bottles (125 ml) or sterilized bottles (using an autoclave). Samples were generally collected at approximately 24-hour intervals and pooled samples were transported to the analytical laboratory for processing. Samples were labeled uniquely with site identifier and date in the field. An additional lab number was added to each aliquot. Samples were processed for bacteria at Kilchis Dairy Herd Services (KDHS) in Bay City (in close proximity to the experimental site). About 10% of the samples analyzed were allocated to QA/QC, and these included field duplicates of pooled samples and blanks. QA/QC samples were used to quantify sampling and analytical variability.

Two storms were sampled during the winter season of 2003-2004. The first storm was sampled in January to determine baseline levels of FCB, in the absence of manure spreading. Such baseline bacteria could be due, for example, to feces from pasture fauna, especially rodents, gulls, and moles, or to soil bacteria that could be inadvertently classified as FCB. The subsequent storm during Year 1 and seven storms during Year 2 (2004-2005) were sampled following application on each cell (except controls) of fresh dairy cow manure on each treatment area.

During each storm, runoff samples were collected at the primary experimental site on one to five occasions, depending on storm size and duration, from gutter sampling compartments that intercepted runoff from the ground surface and the top 6 inches (15 cm) of soil along a known length of simulated streambank. Typically, 3.5 to 4.5 ft (1 to 1.4 m) of pasture runoff was intercepted during a given storm within the middle 50% of each cell using the metal collection gutters. If one or more sample bottles malfunctioned (i.e., flooded, disconnected) then appropriate adjustments were made in the database in order to quantify the length of pasture that had been intercepted for runoff during that sampling period.

At the heavy soil site, 60 cm of pasture runoff was intercepted at the base of each cell. Four storms were sampled at this site. Results from samples collected at the heavy soil site were directly compared to results obtained from comparable vegetated filter strips at the primary site which contained more sand in the soil.

The average runoff was calculated during each storm for each of the slope classes, based on all treatment cells included within that slope class. There were 11 cells in each of the gentle and moderate slope classes, and one cell in the steep slope class at the primary experimental site. Five cells were installed at the heavy soil site. The bacteria flux during each storm was calculated for each cell by multiplying the average runoff volume for the cell slope class by the total measured bacteria amount in the combined runoff collected from each cell.

Analytical Methodologies

All samples were analyzed for FCB at the Kilchis Dairy Herd Services laboratory in Bay City, typically within six hours of collection. The KDHS is directed by Dr. Mark Wustenberg and Judy Wustenberg and is certified for coliform bacteria presence/absence determinations for drinking water. The laboratory staff work closely with the local dairy industry and have been involved in educational efforts concerning herd management and implementation of Best Management Practices.

Within KDHS, the equipment is maintained and monitored to public health certification standards. Fecal coliform bacteria are determined using the membrane filter technique described in Standard Methods for the Examination of Water and Wastewater (APHA 1995).

The KDHS provided the sample collection crew with unmarked, clean sterile nalgene screw top bottles. The sampling crew attached a label at the time of sample collection. This label contained a code to identify the slope class, then a two-number code to identify the cell number, followed by a two-number code to identify the sampling round.

QA/QC analyses included blanks and field splits. Results of field splits were averaged for most analyses.

On the E&S Environmental Chemistry, Inc. chain of custody record form there is information to determine sample name, date, time of day, bottles, test requested, and comments. When the samples were delivered to the laboratory, a second chain of custody form was started for use in the lab. On this was noted the name of who collected the samples and the date and time the samples were delivered to the laboratory. The person who received the samples signed them in and recorded the date and time. This form also identified the project name and number and contained the sample date and number.

The laboratory also utilized a worksheet which showed who collected, analyzed, and counted the plates and the three dates for these activities. On the worksheet, there was a sample site number, identifying number, volume of sample water filtered, plate count, and calculated cfu/100 ml. Information from these worksheets was transferred to a results form. This showed the sample identification and the resulting plate count. This form was reviewed and the reviewer signature was noted. The calculations were rechecked by E&S staff prior to entering the data into the database.

Data Analysis

Each experiment yielded results for multiple vegetated filter strip sizes and slopes. Data were evaluated for within- and between-cell differences in bacterial removal efficiency. Replicate samples (10 per cell) were pooled to reduce laboratory costs. Data were analyzed to quantify the relationships between vegetated filter strip size and pollutant removal efficiencies for each slope class. The removal efficiency of each filter strip type was normalized by the measured flux from the treatment cells with no filter strip (zero filter strip cells). Pollutant removal efficiencies were calculated and reported for each filter strip treatment type, including averaged replicates.

Regression curves were used to smooth scatter plots of mean concentrations of bacteria versus width for the cells within each of three experiments: Gentle Slope Class, Moderate Slope Class, and Gentle Slope Class on Silty Soils. The regression curves were obtained by fitting models for the mean concentration (μ) on width (w) of the form:

$$\mu = \alpha \exp(\beta \mathrm{w}) + \gamma$$

where

$\gamma =$ lower asymptote corresponding to no application of bacteria

$\alpha + \gamma =$ intercept corresponding to no vegetated filter strip

$\beta =$ slope parameter

with the slope of the regression curve satisfying

$$\frac{d\mu}{dw} = \beta(\mu - \gamma)$$

That is, the slope of the regression curve is proportional to the distance of the mean from the lower asymptote.

The NLMIXED procedure in SAS was used for fitting the models. The Poisson distribution and parameter constraints: $\alpha \geq 0$,and $\beta \leq 0$, were specified. The resulting regression curves will then be non-increasing as vegetated filter strip width is increased.

Quality Control

Quality Assurance Objectives

The overall quality assurance objectives for the project were to implement quality control requirements for laboratory analysis that would provide data that could be used to achieve the program objectives, and to follow procedures that would provide data of known quality in terms of completeness, representativeness, and comparability.

Data quality was evaluated with respect to completeness and results of replicated measurements. Completeness is defined as the percentage of reportable analyses out of the total number of possible analyses. The laboratory completeness objective for samples received intact from the field was expected to be 95% to 100%. There were occasions when portions of the sampling ditches collapsed and flooded some of the sample bottles. There were also occasions when one or more sample bottles became disconnected from the sampling gutter or otherwise failed to collect sufficient water for analysis. Such situations reduced the sampling completeness. The field sampling completeness objective was expected to be 90%. The actual completeness statistics realized for this study were 100% for the laboratory and 94% for the field sampling (Table 2). Field sampling completeness was higher than 95% for most treatment types. The exceptions were the longer vegetated filter strips on the heavy soil site. These cells experienced more frequent flooding of collection ditches during periods of heavy rainfall.

Comparability of data collected during this program to other data is provided by specifying standard procedures for sample collection and analysis, and by using defined standard methods for laboratory analyses. Quality assurance objectives are outlined in Table 3.

Relative error and absolute error were calculated for results of duplicate analysis (field splits) of FCB. For FCB duplicate pairs (n=39), the median absolute error (concentration difference between Sample A and Sample B) was 80 cfu/100 ml. Relative error (RE) was expressed as:

$$RE = \frac{|C_1 - C_2|}{(C_1 + C_2)/2} \ \chi \ 100$$

The median relative error (MRE) was 46.5%. A total of 38.5% of the duplicate pairs had RE of 75% or greater. For the duplicate sample pairs that had FCB $ 200 cfu/100 ml (16 pairs), the MRE was 21.6%, and a total of 15% of those had RE of 75% or greater. Comparative results of duplicate pair analyses are shown in Figure 2.

Table 2. Completeness achieved for field sampling during manure treatment storms (storms #2 through 9).				
Vegetated Filter Strip Size (m)	Cell	Number of Sampling Rounds	Samples Successfully Analyzed	
			Number	Percent
Gentle Slope Class				
Control	G4	21	18	86
25	G11	21	20	95
15	G1	21	20	95
8	G2, G10	42	42	100
3	G5, G7	42	38	90
1	G8	21	21	100
Zero	G6	21	21	100
Moderate Slope Class				
Control	M8	21	21	100
25	M1	21	20	95
15	M11	21	19	90
8	M9	21	20	95
3	M4, M7	42	41	98
1	M5	21	21	100
zero	M3	21	21	100
Steep Slope Class				
8	S1	21	20	95
Moderate Slope Class on Heavy Soils				
Control	C1	11	11	100
8	C5	11	6	55
3	C4	11	8	73
1	C3	11	8	73
zero	C2	11	10	91

Table 3. Laboratory methods and quality assurance objectives for fecal coliform bacteria.	
Method	SM9221 (ALPHA 9221E)
Reporting Unit	MPN/100 ml
Target Detection Limit	1/100 ml
Completeness Objective (Lab)	95%
Completeness Objective (Field)	80%

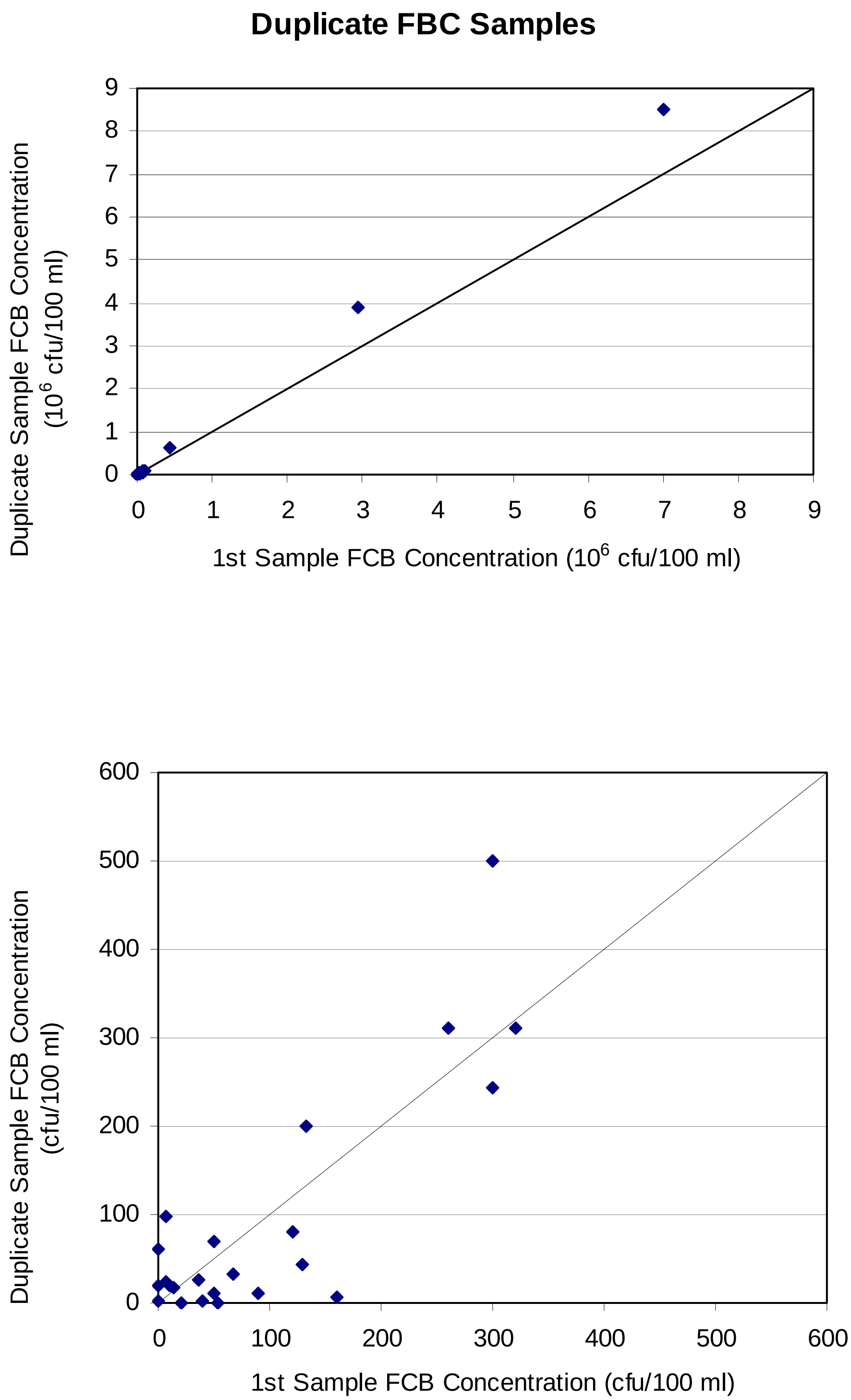


Figure 2. Results of analyses of sample duplicate pairs (field splits). Results for those sample pairs having bacteria concentration less than 600 cfu/100 ml are shown in the bottom panel. Results for all samples (up to 8.4 x 10^6 cfu/100 ml) are shown in the top panel.

Sample Custody and Documentation Procedures

Sample bottles were labeled with indelible ink. Sample identification included the year, month, day and station code. This information was recorded on a multi part chain of custody record along with information about the desired analyses and the identity of the sample collector. A field log book was kept in which station codes, date and time of sampling, and all field data were recorded. Notes on any unusual conditions at the sample sites or any circumstances that may have caused deviation from normal procedures was also recorded in the field data book. Document control procedures included the following:

- Records are clear, comprehensive, and written in indelible ink.
- Corrections to data sheets and logbooks are made by drawing a single line through the error and initialing and dating the correction.
- Before release of data, records are cross checked for consistency between sample tags, custody records, bench sheets, personal and instrument logs, and other relevant data.

Documents are archived in the project records according to the contract requirements.

Data Reduction and Validation

Laboratory data reduction and validation were performed according to standard Quality Assurance plans. Data were reported as hard copy delivered by the laboratory to E&S Environmental Chemistry. Field data were recorded in a field notebook, examined for internal consistency, and reported. All data were entered into a computer database in a format compatible with Excel for Windows. Prior to data analysis and interpretation, all data entered into the database were validated. Tests included evaluation of blanks, split samples, and outlier analysis.

Technical Advisory Committee

A Technical Advisory Committee was established for this project. It was comprised of representatives from the Oregon Department of Environmental Quality, Oregon Department of Agriculture, OSU Extension Service, Tillamook County Creamery Association, and Tillamook Estuaries Partnership. This committee assisted with periodic review of progress in developing this project, and their contribution is appreciated.

RESULTS

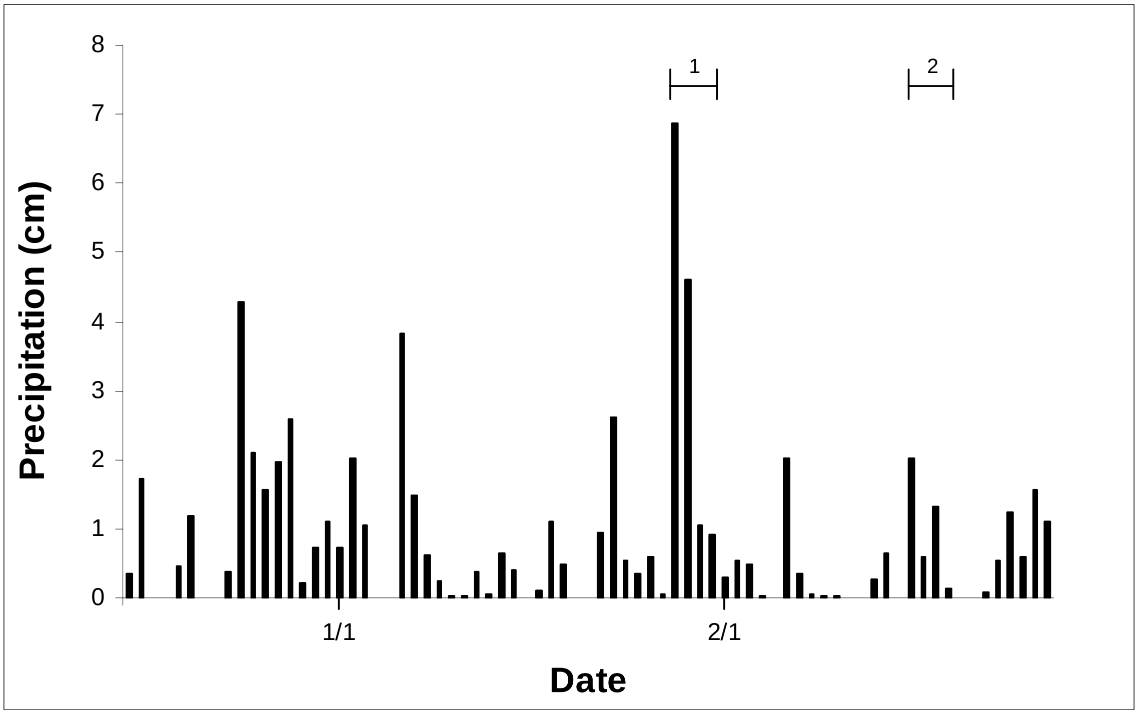
Precipitation and Runoff

Two storms were sampled during the 2004 water year and seven storms were sampled during the 2005 water year, including several of the largest storms of the year. Precipitation amounts received during the sampled storms are given in Table 4. Figure 3 shows the precipitation amounts received throughout the study period and indicates storm sampling periods. We sampled several large storms; five included more than 7.5 cm (3 inches) of rain, and the largest included 20.4 cm (8 inches) of rain.

The flux of precipitation to the experimental cells during each storm is given in Table 4. During about half of the sampled storms, the amount of rainfall received by each cell (from the uppermost end of the cell to the downhill end where runoff was collected) exceeded about 1,000 L upslope of each meter of simulated stream. Infiltration of precipitation was high. For example, during the first storm, 2.6 L of runoff water per meter of pasture/stream interface was collected, on average, from the experimental cells despite the large size of this storm (13.2 cm of precipitation). Similarly, during subsequent storms, only from 0.3 to 2.3 L of runoff water per meter of simulated pasture/stream interface was collected, on average, from each cell in the gentle slope class (Table 5). Runoff volumes were consistently lower at the moderate slope loamy site and higher at the silty soil site.

Table 4. Precipitation amounts received during each of the storms sampled for runoff water quality.

Storm	Precipitation (cm)	Precipitation Flux to Each Experimental Cell per Unit Pasture Length (L/m)
1	13.4	1584
2	4.1	480
3	10.7	1269
4	4.5	537
5	3.3	387
6	9.6	1145
7	20.4	2407
8	6.7	788
9	8.1	954



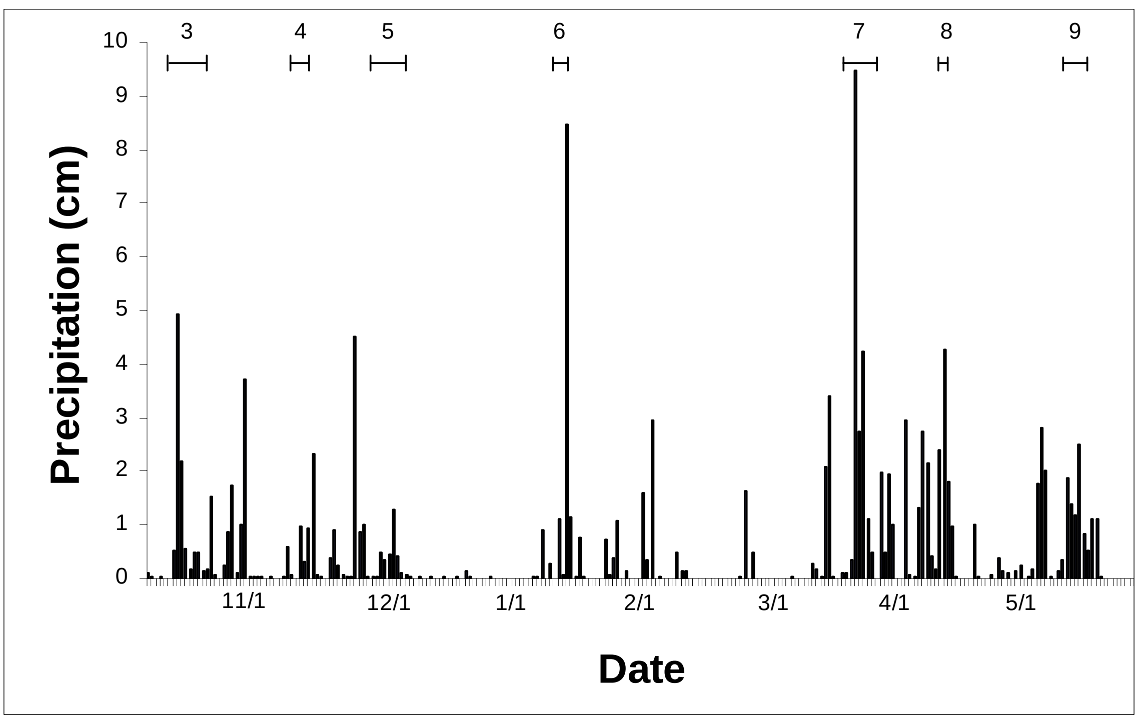


Figure 3. Precipitation amounts received during the two years of study. Monitored storms are indicated with storm numbers (1-9) and the period of storm monitoring is indicated with brackets. The top panel provides data for Year 1 (2003-2004) and the bottom panel for Year 2 (2004-2005)

Table 5. Runoff by site and storm.										
Site	Percent Sand in Topsoil	Storm Runoff (L/m)[1]								
		Storm								
		1	2	3	4	5	6	7	8	9
Silty soil site	22.7				1.89	10.72		4.96		
Gentle slope site	33.8	3.40	0.49	0.40	0.67	2.26	0.92	1.55	0.72	0.34
Moderate slope site	35.0	1.84	0.27	0.35	0.65	1.08	0.45	1.04	0.71	0.27

[1] Liters of runoff water collected per meter of simulated stream.

Storms also varied in intensity, with maximum 1-hr precipitation amounts ranging from 0.18 cm during Storm 5 to 1.30 cm during Storm 6 (Table 6). More than half of the storms had maximum 4-hr precipitation amounts more than 2 cm.

Table 6. Maximum precipitation intensity values recorded for each of the sampled storms		
Storm	Maximum Precipitation Intensity	
	1 hr Period	4 hr Period
1	0.66	2.31
2	0.48	1.45
3	0.94	2.57
4	0.89	1.30
5	0.18	0.46
6	1.30	2.71
7	0.63	2.66
8	0.74	2.63
9	0.37	1.00

Percent runoff was calculated from the experimental estimates of average runoff collected per meter of pasture length as a percentage of the precipitation input to the treatment cells. Percent runoff in the gentle slope class was, on average, less than 0.6%. In other words, more than 99.4% of the precipitation to the treatment cells infiltrated into the soil without generating surface or shallow (< 15 cm) runoff (Table 7). On the moderate slope class, the percent runoff values were even lower. Both field observations during periods of sample collection and examination of estimated runoff amounts during the sampled storms (Table 4) suggest that overland flow did not occur to any extent during this study.

Table 7. Percent runoff, calculated as a percentage of precipitation, by site and storm.										
Site	Percent Sand in Topsoil	Percent Runoff* (%)								
		Storm								
		1	2	3	4	5	6	7	8	9
Gentle slope site	33.8	0.21	0.10	0.03	0.12	0.58	0.08	0.06	0.09	0.04
Moderate slope site	35.0	0.12	0.06	0.03	0.12	0.28	0.04	0.04	0.09	0.03

* Percent runoff calculated based on estimated runoff from treatment cells divided by estimated precipitation

Storm Treatments

Baseline Storm (without manure application)

The baseline storm was very large, and caused flooding of Highway 101 in Tillamook. A total of 5.3 inches (13.2 cm) of rainfall was recorded at the experimental site, over a period of 4 days. We experienced flooding of the sampling ditches at the base of several of the lower treatment cells in the moderate slope class. Additional ditching was done during and subsequent to that storm to minimize this problem in the future. Baseline bacteria concentrations were generally very low. For most cells, on most sample occasions, there were no bacteria measured in the runoff. Only 2 samples were collected that contained in excess of 200 cfu/100 ml. The average concentration of FCB measured from each cell, throughout the duration of the first storm was 11 cfu/100 ml or less for 19 of the 23 experimental cells. Only cells G1, G4, M10, and M11 experienced higher average FCB concentrations. For 19 of 23 treatment cells, the average background bacteria flux throughout the duration of the storm was less than 500 cfu per linear meter of simulated streambank, and the median value was 47 cfu/m.

Manure Application Storms

A total of 680 gallons (2,575 L) of fresh dairy cow manure was applied to the pasture areas of the treatment cells generally one to several days in advance of initiation of each of the eight manure application storms. The manure was obtained as fresh scrapings from the floor of Joe Oldenkamp’s dairy barn, with a thick liquid consistency. Bacteria measurements indicated an average FCB concentration of about 26×10^6 cfu/100 ml for the manure. Thus, the bacteria loading on each of the treatment cells was about 1.2 billion cfu upslope from each linear foot (3.9×10^9 cfu/m) of simulated streambank.

Bacteria Concentrations in Pasture Runoff

Primary Experimental Site

Concentrations of bacteria were often high in the runoff from the zero filter strip cells. Over the course of the eight treatment storms included in this study, 90% of the samples from the zero filter strip cell on the gentle slope (n=21) had FCB concentration > 200 cfu/100 ml; the median FCB concentration was 16,500 cfu/100 ml. Similarly, 67% of the samples from the zero filter strip cell in the moderate slope class (n=21) had FCB > 200 cfu/100 ml, and the median FCB concentration was 620 cfu/100 ml (Table 8). In marked contrast, less than 26% of the samples collected from any of the various filter strip sizes had FCB > 200 cfu/100 ml (10% overall for all filter strip sizes combined). The median FCB concentration for all cells containing vegetated filter strips was 6 cfu/100 ml, and none of the filter strip cells had median FCB concentration greater than 29 cfu/100 ml (Table 8).

Table 9 gives the volume-weighted average concentration of FCB measured in runoff from each of the cells during each of the storms. Storm #1 received no manure application. As a result, FCB concentrations were uniformly low. For the subsequent eight storms that did include manure application in advance of the storm, the volume-weighted average FCB concentration of runoff was high in each of the zero filter strip cells. Median values for the zero filter strip cells across storms 2 through 9 were 5,896 (gentle slope), 786 (moderate slope), and 7,289 cfu/100 ml (moderate slope silty soil). Thus, manure spreading in advance of the storms resulted in very high concentrations of FCB in runoff water in the absence of a vegetated filter strip. Volume-weighted average FCB concentrations were much lower (# 34 cfu/100 ml) in all cells that contained filter strips. There was little indication that average concentrations were dramatically higher in cells having shorter filter strips as compared with cells having longer filter strips. Similarly, results for the background storm (#1, no manure application) were generally similar to average results for the storms that did involve manure application (storms 2 through 9, Tables 8-10).

Heavy Soil (Silty) Site

Fewer storms were sampled and fewer samples collected at the silty site as compared with the various slope classes at the principal study site. Concentrations of bacteria were generally high in the runoff from the zero filter strip cell at the silty site. Eight of ten samples collected from the zero filter strip cell had FCB concentration higher than 200 cfu/100 ml (Table 8). The median FCB concentration was 10,600 cfu/100 ml. Results for the 8 m vegetated filter strip were similar to results from the control (no manure application), suggesting little movement of FCB across the filter strip from this cell. However, the shorter (3 m and 1 m) vegetated filter strips showed generally higher FCB concentrations (median values of 74 and 113 cfu/100 ml, respectively) than did the 8 m filter strip cell and the control cell. About 25% (3 m vegetated filter strip) and 38% (1 m vegetated filter strip) of the samples from these cells had FCB concentration in runoff higher than 200 cfu/100 ml (Table 8).

Table 8. Median and quartile values of the measured concentration of fecal coliform bacteria and percent of runoff samples that exceeded FCB concentration of 200 cfu/100 ml.							
Sample Type[1]	Vegetated Filter Strip Size (m)	n	Bacteria Concentration (cfu/100 ml)			Percent of Samples Exceeding 200 cfu/100 ml	Cells Included
			Percentile				
			25	50	75		
Gentle Slope Class							
Reference Storm (Storm #1)	variable	26	0	0	2	4	G7, G8, G10, G11, G1, G2, G4, G5, G6
Control	8	18	0	9	25	6	G4
Treatment	25	20	0	0	4	5	G11
Treatment	15	20	0	2	15	20	G1
Treatment	8[2]	42	0	0	28	12	G2, G10
Treatment	3[2]	38	1	29	198	26	G5, G7
Treatment	1	21	0	10	73	14	G8
Treatment	zero	21	3100	16500	95000	90	G6
Moderate Slope Class							
Reference Storm (Storm #1)	variable	19	0	6	10	0	M1, M3, M4, M5, M7, M8, M9, M11
Control	8	21	0	0	3	5	M8
Treatment	25	20	0	3	28	10	M1
Treatment	15	19	0	0	10	5	M11
Treatment	8	20	0	0	0	0	M9
Treatment	3[2]	41	0	7	25	7	M7, M4
Treatment	1	21	0	0	13	0	M5
Treatment	zero	21	150	620	1900	67	M3
Steep Slope Class							
Reference Storm (Storm #1)	8	3	0	0	0	0	S1
Treatment	8	20	0	1	13	15	S1
Moderate Slope Class on Silty Soils							
Control	8	11	8	32	74	0	C1
Treatment	8	6	11	22	47	0	C5
Treatment	3	8	17	74	188	25	C4
Treatment	1	8	36	113	403	38	C3
Treatment	zero	10	633	10600	37825	80	C2

[1] Reference storm (Storm #1) did not include manure treatment on any cells. Treatment cells include all cells that received manure application (all except control cells, during storms 2 through 9).

[2] Cells that contained the 3 m vegetated filter strip on both gentle and moderate slopes and the 8 m vegetated filter strip on the gentle slope class were replicated. Therefore, approximately twice as many samples were collected from these vegetated filter strip types as compared with others.

Table 9. Volume-weighted average concentration of bacteria at experimental cells during each storm.[1]

Vegetated Filter Strip Size (m)	Volume-Weighted Average Bacteria Concentration[2] (cfu/100 ml)										
	Storm #										
	1	2	3	4	5	6	7	8	9	Ave[3] (2-9)	Median[3] (2-9)
Gentle Slope Class											
Control	262	0	2,300	0	4	4	24	8	282	328	6
25	2	0	0	0	8	3	19	0	6	4	1
15	15	0	1,760	178	131	ND[4]	0	0	0	296	0
8	6	0	335	15	24	0	1	0	20	48	10
3	0	1	1,055	49	19	0	10	290	998	303	34
1	6	0	3,470	11	13	0	8	9	314	478	10
Zero	0	99	528,000	2,194	3,129	470	665,975	108,481	8,664	164,627	5,896
Moderate Slope Class											
Control	0	0	10	0	9	0	0	1	3	3	1
25	6	0	12,900	30	8	4	0	0	91	1,629	6
15	116	0	4,150	9	12	1	1	3	1	522	2
8	0	0	0	0	5	3	2	0	0	1	0
3	1	4	52	18	15	10	3	3	370	59	16
1	7	0	13	0	9	0	5	7	31	8	6
Zero	9	0	1,600	702	495	3,152	72	871	9,175	2,008	786
Gentle Slope Class on Silty Soils											
Control				113	6		2			40	6
8				9	6		ND			8	8
3				68	11		1			27	11
1				705	15		9			243	15
Zero				52,469	7,289		181			19,980	7,289

[1] Storm #1 involved no manure application
[2] ND indicates that bacteria concentration was not determined
[3] The average and median values were computed for the storms that involved manure application (#2-9)
[4] Not determined

Table 10. FCB concentrations in runoff samples calculated as the percent of the FCB concentration measured in the zero filter strip cell appropriate to each site during that sampling period.

Site	Vegetated Filter Strip Size	n	FCB Concentration as Percent of Concentration at Zero Filter Strip Cell			Percent of Samples Greater than 1%
			25	50	75	
Gentle Slope	1	19	0.00	0.10	0.75	11
	3	34	0.00	0.05	2.51	29
	8	38	0.00	0.00	0.39	16
	15	18	0.00	0.00	0.32	17
	25	18	0.00	0.00	0.00	6
	Control	16	0.00	0.05	0.54	6
Moderate Slope	1	19	0.00	0.00	0.82	21
	3	37	0.00	0.89	3.00	46
	8	18	0.00	0.00	0.00	11
	15	17	0.00	0.00	1.04	29
	25	17	0.00	0.48	1.05	29
	Control	19	0.00	0.00	0.07	5
Silty Soil	1	8	0.52	0.93	2.82	50
	3	8	0.12	0.17	0.94	25
	8	6	0.02	0.09	0.13	17
	Control	10	0.05	0.17	1.82	30

Bacteria Concentrations as Percentage of Results for Cells Having No Vegetated Filter Strip

FCB concentrations in each of the vegetated filter strip cells were also examined as a percentage of the FCB concentration measured in the zero filter strip cell in the same slope class during that sampling period. These calculated values indicate the extent to which each of the vegetated filter strip sizes reduced FCB concentration in runoff as compared with what the FCB concentration would be expected to have been in the absence of a vegetated filter strip. The results of these calculations indicate that the presence of a vegetated filter strip of any size, from 1 to 25 m, generally reduced the median FCB concentration of runoff by more than 99%. The 75th percentile value was # 1% for all cells except the 3 m vegetated filter strip on the gentle slope site (2.5%), the 3 m vegetated filter strip on the moderate slope site (3.0%), and the 1 m vegetated filter strip on the silty soil site (2.8%, Table 10). In general, a higher percentage of the runoff samples from the shorter filter strips (1 m and 3 m) exhibited FCB concentration greater than 1% of the concentration measured in the zero filter strip cell (Table 10). This suggests that the longer filter strips may have done a better job of reducing FCB concentration in runoff, but such improvements (if they occurred) were minimal.

Bacteria Loads per Unit Pasture Length

Transport of bacteria from agricultural land to a drainage system is not only a function of the bacterial concentration in runoff (Tables 8 and 9), but also of the amount of runoff (Table 5). We therefore calculated the water flux from the pasture to the water collection system during each storm. Because runoff was collected from a known cross sectional pasture length of each cell during each sampling period, it was possible to estimate the total volume of runoff from each cell during each storm, and therefore to compute estimates of the average volume of runoff from each cell per meter of pasture length during the course of each storm (Table 5). These estimates of water flux were combined with discharge-weighted average FCB concentrations (Table 9) to yield estimates of bacterial load per unit pasture length from each experimental cell during each storm. These values are given in Appendix A for each of the nine storms. Results are summarized in Table 11.

There was considerable variation from storm to storm in the FCB load delivered from a given treatment cell (Table 11). Loads were very high from the zero filter strip cells, often exceeding 10,000 cfu/m during an individual storm in the gentle slope class. Loads from vegetated filter strip cells were typically lower by two orders of magnitude. FCB loads were much lower in the moderate slope class because FCB concentrations and runoff volumes were both lower than was found in the gentle slope class.

We found variability in the estimates of bacterial flux (cfu per meter of pasture length intercepted) from cells of differing vegetated filter strip sizes within a given storm (Table 11). During some storms, the cells having longer vegetated filter strips and/or the control cell (no manure application) exhibited higher FCB flux than did the cells having shorter vegetated filter strips (Table 11). It is important to note, however, that FCB flux was generally much higher in the zero filter strip cells than in any of the buffered cells. There are many possible reasons for the observed variability in FCB flux among cells containing varying filter strip sizes. These include, for example, bacteria contributed by pasture fauna, the influence of flow through lateral macropores (for example associated with mole tunnels), and sampling or analytical error. But there was no indication that FCB flux varied consistently as a function of vegetated filter strip size.

Table 11. Calculated bacterial flux, in cfu per meter of pasture length intercepted, for each experimental cell throughout the duration of each storm.

Vegetated Filter Strip Size[1]	Reference Storm 1	Manure Treatment Storms									
		2	3	4	5	6	7	8	9	Ave[2]	Median[2]
Gentle Slope Class											
0	0	484	2,106,720	14,676	70,704	1,653	10,322,607	781,062	29,459	1,665,928	50,082
1	197	0	13,845	75	293	5,074	120	63	1,068	2,567	207
3*	13	4	1,684	330	419	2,817[3]	83	110	1451	862	375
8*	217	0	1337	101	552	8,100	9	0	70	1,271	86
15	522	0	7,022	1,192	2,960	ND	6	0	0	1,597	6
25	11	0	0	0	174	2,932	295	0	20	428	97
Control	8,905	0	9,177	0	91	1,155	374	57	958	1,476	232
Moderate Slope Class											
0	164	1	5,584	4,561	5,348	14,276	750	6,182	24,313	7,627	5,466
1	134	0	45	0	98	0	53	51	83	41	48
3*	24	10	2,880	118	167	45	33	22	982	532	82
8	0	0	0	0	56	14	20	0	0	11	0
15	2,126	0	14,484	61	130	3	13	20	3	1,839	17
25	113	0	45,021	195	90	20	0	0	241	5,696	55
Control	0	0	35	0	101	2	0	7	9	19	5
Steep Slope Class											
8	0	14	5,313	224	46	2	1,153	7	0	845	30
Silty Soil											
0				991,668	781,419		8,983			594,023	781,419
1				13,331	1,636		448			5,138	1,636
3				1,293	1,143		26			821	1,143
8				166	602		ND			384	384
Control				2,137	594		100			944	594

1 Vegetated filter strip sizes that were replicated (indicated with asterisk) are expressed as the average of the two replicates.
2 Average or median of all manure treatment storms (storms 2 through 9)
3 Storm flux for the 3 m vegetated filter strip during storm 6 was calculated using data from only one of the two 3 m vegetated filter strip cells

Effectiveness of Surface Corrugation as a Vegetated Filter Strip Treatment

At the onset of this study, we wished to ascertain whether shorter vegetated filter strips could be made to be more effective in removing fecal bacteria from agricultural runoff. We hypothesized that contouring of the ground surface might increase runoff infiltration, and therefore bacterial removal efficiency. To test this possibility, we installed at the beginning of the study surface corrugations (~ 15 cm from top to bottom of alternating mounds and trenches) in two experimental cells in the gentle slope class (1 and 8 m vegetated filter strip) and three experimental cells in the moderate slope class (1, 3, and 8 m vegetated filter strip).

Results for bacterial concentrations (cfu/100 ml) were compared between each corrugated cell and its respective smooth cell of the same size on the same slope class. There was no indication that installation of such surface treatments increased bacterial removal efficiency (Figure 4). This result was likely due to the high rate of infiltration observed for the smooth vegetated filter strip cells; any further increase in infiltration attributable to surface contouring was insignificant.

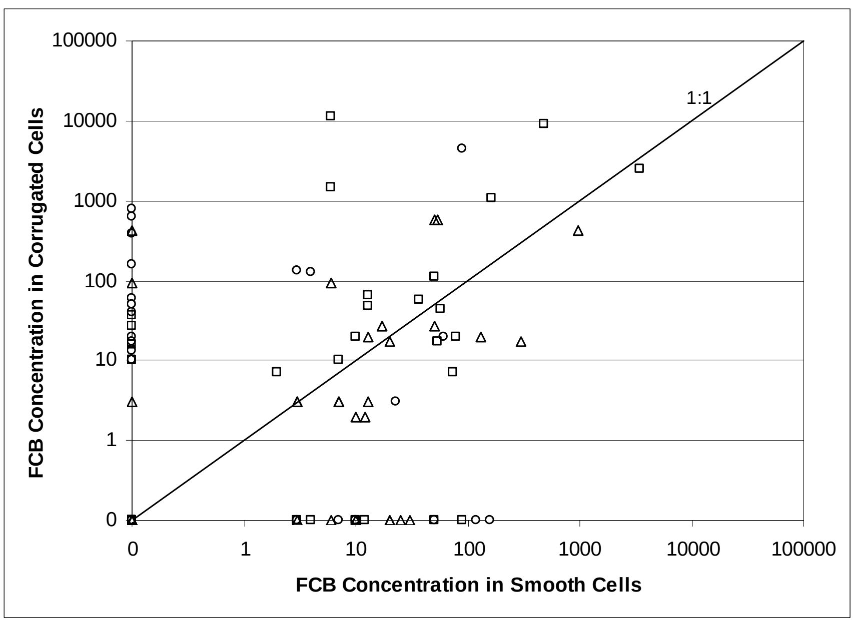


Figure 4. Comparison between FCB concentration in pasture runoff collected at the base of vegetated filter strips that had been installed with corrugated surface contouring compared with results from vegetated filter strips of the same size that had not been corrugated. Data points are coded according to vegetated filter strip size: 1 m as squares, 3 m as triangles, and 8 m as circles. A 1:1 line is added.

Variables Influencing Bacteria Movement

Slope

At the beginning of this study, we anticipated that FCB concentrations in runoff would generally be higher on steeper slopes, for a given vegetated filter strip size. The data were not in agreement, however, with this expected result. Only the 8 m vegetated filter strip was represented on three different slope classes (3.8%, 7%, 12%). The median FCB concentration measured in these three slope classes were similar (0, 0, and 1 cfu/100 ml, respectively), as were the 75th percentile values (28, 0, and 13 cfu/100 ml; Table 8). In fact, the 75th percentile FCB concentration was highest for the gentle slope class, in direct opposition to the anticipated result. The number of samples that exceeded 200 cfu/100 ml was generally comparable between the gentle slope and steep slope 8 m vegetated filter strip cells (12% and 15%, respectively; Table 8). Furthermore, in almost all cases of comparison between gentle and moderate slope results, the gentle slope class cells exhibited higher 75th percentile FCB concentrations and percent of samples exceeding 200 cfu/100 ml than did moderate slope cells having the same vegetated filter strip size (Table 8).

Soil Texture

One possible explanation for the general tendency of vegetated filter strip cells on the gentle slope class to yield equal or higher FCB concentrations in runoff as compared with comparable cells on the moderate slope class could be the looser texture and higher sand content of soils in the moderate slope experimental area (Table 1). These soil differences were reflected in runoff volumes collected, which tended to be lower for the moderate slope cells than for the gentle slope cells (Table 5).

Based on quartile values presented in Table 8, there was also some evidence that FCB transport may have occurred more readily at the heavy (silty) soil site as compared with either the gentle or moderate slope class at the primary experimental site. In general, quartile FCB concentration values were highest at the silty soil site. Such comparisons must be made with caution, however, because there was a substantial difference in the number of storms sampled and samples collected at the various sites (Table 8). A more appropriate comparison is shown in Table 12, which only includes occasions which were successfully sampled at all three locations (gentle and moderate slopes at the primary experimental site and moderate slope at the silty soil

Table 12. Comparison of FCB concentration in pasture runoff among three experimental treatment areas for sampling occasions during which all three were sampled.						
Vegetated Filter Strip Size	Treatment Area	Experimental Cell	FCB Concentration			Percent of Samples Exceeding 200 cfu/100 ml
			Percentile			
			25	50	75	
Zero	Moderate Slope	M3	151	360	950	60
	Gentle Slope	G6	3,225	14,350	216,250	100
	Silty Soil	C2	633	10,600	37,825	80
1 m	Moderate Slope	M5	0	8	52	0
	Gentle Slope	G8	7	44	58	0
	Silty Soil	C3	36	113	403	38
3 m	Moderate Slope	M4	7	10	45	14
		M7	0	0	10	0
	Gentle Slope	G5	52	87	190	29
		G7	5	13	75	0
	Silty Soil	C4	45	80	205	29

site). For the 1 m and 3 m vegetated filter strip cells, FCB concentrations were generally lowest at the site having the highest sand content in the soil (moderate slope site), and FCB concentrations were generally highest at the site having the lowest sand content (silty soil site).

Precipitation Patterns

We compared FCB concentrations within each experimental cell with two variables that reflected precipitation amount and two variables that reflected precipitation intensity. The variables selected for analysis were as follows:

- cumulative precipitation amount during the sampling interval
- cumulative precipitation amount since manure spreading
- maximum 1-hr precipitation amount within the sampling interval
- maximum 4-hr precipitation amount within the sampling interval

In general, there was not a clear relationship between FCB concentration in pasture runoff and any of these precipitation variables. However, there was a tendency towards lower FCB concentration when precipitation amount or intensity was low. FCB concentrations were more variable when precipitation amount or intensity was higher. Results of this analysis are shown in Figures 5 and 6, which depict combined results for the shorter vegetated filter strips (1 m and 3 m) on the gentle and moderate slope classes at the primary experimental treatment site. FCB concentrations higher than 500 cfu/100 ml were generally restricted to sampling occasions that included more than about 4 cm of precipitation during the sampling interval (Figure 5) and that had a 4-hr precipitation intensity greater than about 0.5 cm (Figure 6).

Based on the observation that high FCB concentrations in the vegetated filter strip cells generally occurred when the maximum 4-hr precipitation amount exceeded 0.5 cm, an analysis was conducted to examine the relationship between vegetated filter strip size and FCB concentration in runoff for only those samples that were collected subsequent to a sampling interval that had a maximum 4-hr precipitation total greater than 0.5 cm. Results of this analysis are shown in Table 13. At the gentle slope site, 75th percentile FCB concentrations were generally higher at the shorter vegetated filter strip cells. Such a pattern was not evident at the moderate slope site (Table 13). For the zero filter strip cell on the gentle slope class, there was a general pattern of increasing FCB concentration with increasing precipitation amount and intensity (Figure 7).

Table 13. FCB concentration quartile values for runoff samples collected subsequent to sampling intervals that had maximum 4-hr precipitation intensity greater than 0.5 cm.

Vegetated Filter Strip Size (m)	n	Percentile		
		25	50	75
Gentle Slope Cells				
1	19	0	5	70
3	28	0	25	220
8	33	0	0	7
15	15	0	0	4
25	15	0	0	0
Control	15	0	10	44
Moderate Slope Cells				
1	17	0	0	6
3	33	0	10	30
8	15	0	0	0
15	14	0	0	10
25	15	0	0	25
Control	16	0	0	1

FCB concentration as a percent of the concentration measured in the zero filter strip cell for the same sampling occasion and slope class (Table 10) was recalculated after subsetting the data to only include samples having 4-hr maximum precipitation greater than 0.5 cm. Results again suggested a general pattern of somewhat higher FCB concentrations in shorter vegetated filter strip cells (Table 14).

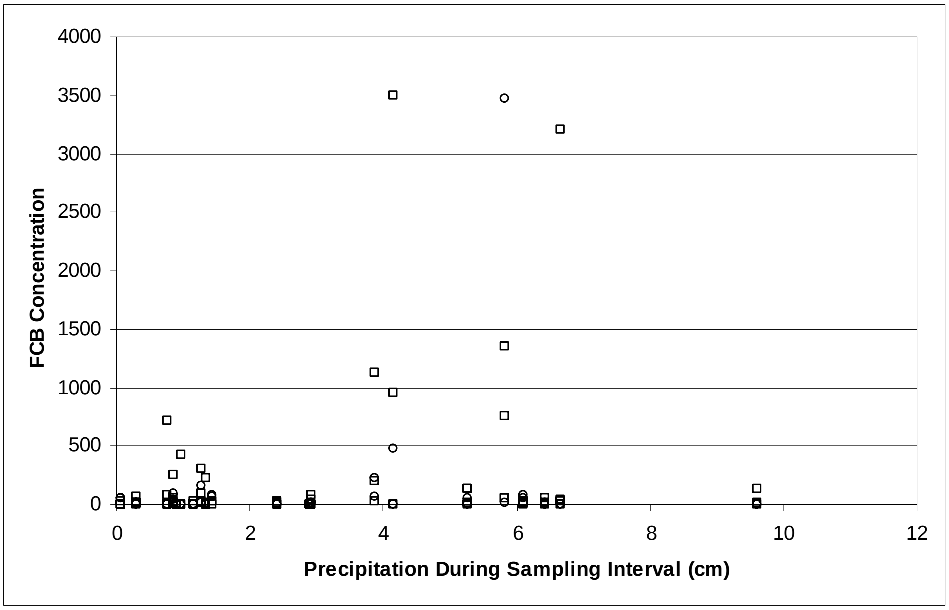


Figure 5. FCB concentration measured in runoff compared with precipitation amount. Included are samples collected from the 1 m and 3 m vegetated filter strip cells on the gentle and moderate slope classes during the storms that followed manure application (storms 2-9). The precipitation volume is that recorded during the runoff sampling interval.

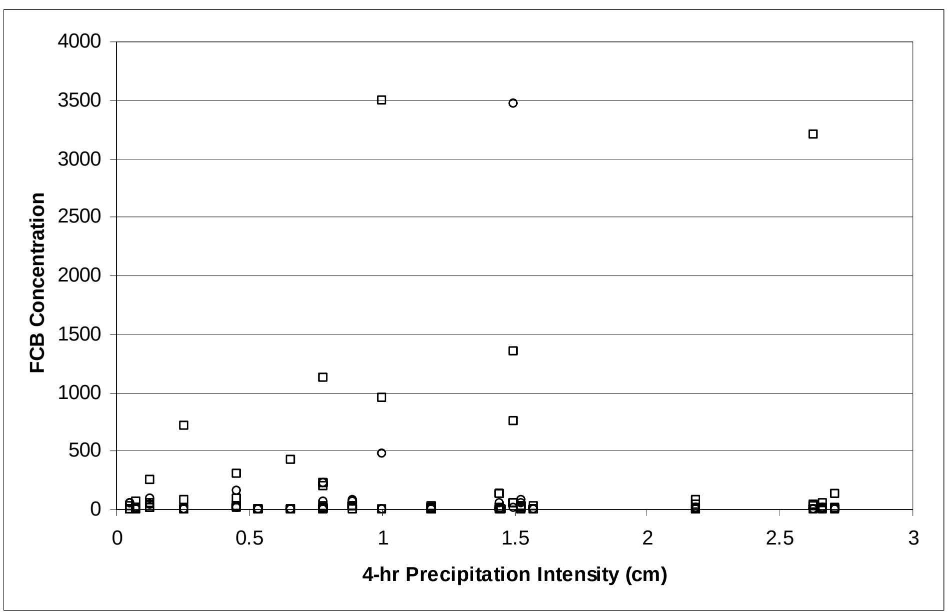


Figure 6. FCB concentration measured in runoff compared with maximum precipitation intensity. Included are samples collected from the 1 m and 3 m vegetated filter strip cells on the gentle and moderate slope classes during the storms that followed manure application (storms 2-9). The maximum precipitation intensity is the maximum amount of precipitation recorded during any one continuous 4 hr period within the runoff sampling interval.

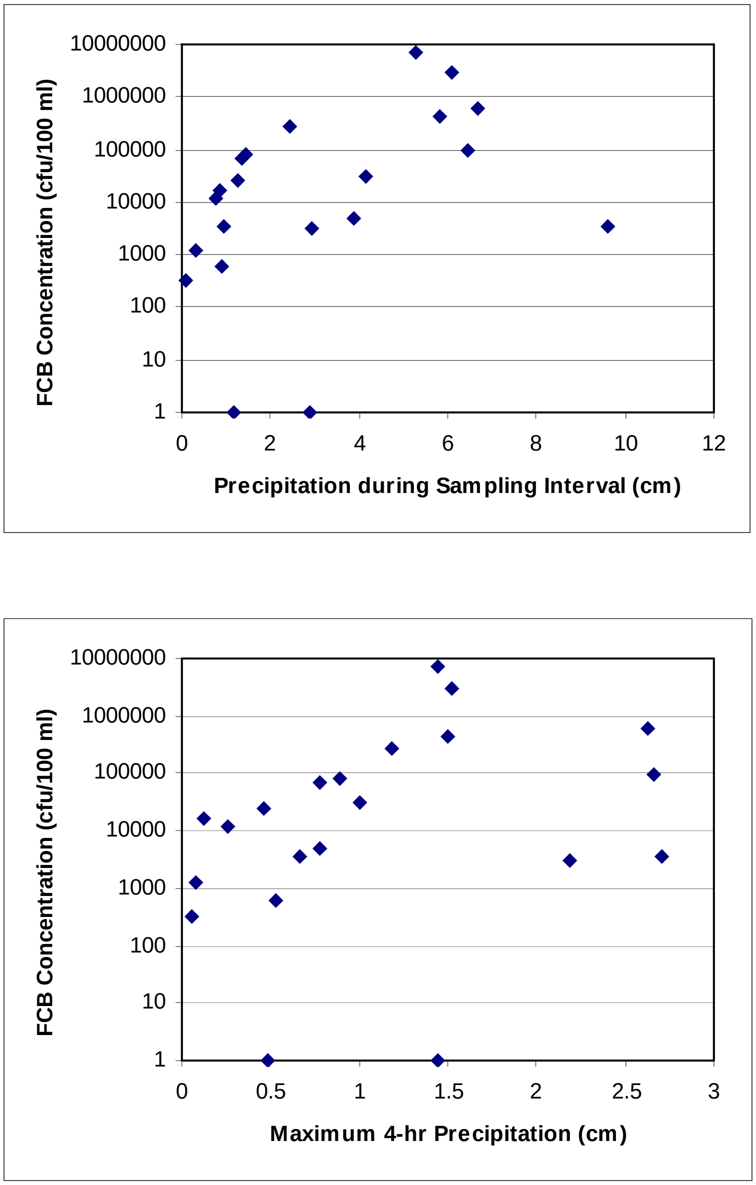


Figure 7. Relationships between FCB concentration in runoff from the zero filter strip cell on the gentle slope class and precipitation patterns. The top panel compares FCB concentration with the precipitation recorded during the sampling interval. The bottom panel compares FCB concentration with the maximum precipitation amount recorded during any continuous 4 hr period within the sampling interval.

Table 14. FCB concentrations in runoff samples, calculated as the percent of the FCB concentration measured in the zero filter strip cell appropriate to each site during that sampling period. Only samples having maximum 4-hr precipitation greater than 0.5 cm are included.

Site	Vegetated Filter Strip Size	n	FCB Concentration as Percent of Concentration at Zero Filter Strip Cell			Percent of Samples Greater than 1%
			25	50	75	
Gentle Slope	1	14	0.00	0.01	0.58	14
	3	24	0.00	0.01	0.42	17
	8	28	0.00	0.00	0.01	7
	15	13	0.00	0.00	0.00	8
	25	13	0.00	0.00	0.00	8
	Control	11	0.00	0.00	0.48	9
Moderate Slope	1	14	0.00	0.00	0.43	14
	3	27	0.00	0.29	2.81	41
	8	13	0.00	0.00	0.00	8
	15	12	0.00	0.01	1.41	17
	25	13	0.00	0.00	0.54	15
	Control	14	0.00	0.00	0.02	0
Silty Soil	1	4	0.75	1.19	4.33	50
	3	3	0.06	0.13	0.15	0
	8	2	0.00	0.01	0.01	0
	Control	5	0.17	0.21	2.31	40

DISCUSSION

Zero Filter Strip Treatment Cells

Runoff from the manure-treated cells that contained no filter strip (zero filter strip cells) had very high concentrations of FCB. Median values for the gentle slope cell and for the silty soil site cell both exceeded 10,000 cfu/100 ml. Median FCB concentration in the zero filter strip cell on the moderate slope class was lower (620 cfu/100 ml), but still more than three times the freshwater health guideline. More than two-thirds of the storm runoff samples collected in all three of these areas (gentle slope, moderate slope, silty soil) had FCB > 200 cfu/100 ml, and the majority of samples collected at the gentle slope site and silty soil site had FCB > 1,000 cfu/100 ml (Table 8). These data confirm the expected extensive contamination of drainage water subsequent to manure spreading in the absence of a vegetated filter strip. Clearly, it is important to maintain some level of vegetated filter strip to minimize this contamination.

Vegetated Filter Strip Cells

All cells containing vegetated filter strips exhibited much lower FCB concentrations in runoff than did the respective zero filter strip cell in the same slope class. Median values of all filter strip cells in all three study areas were less than about 1% of median values for the respective zero filter strip cells (Table 10). A major factor in the reduction of bacteria in all the vegetated filter strips as compared with the zero buffer cells was the fact that there was little or no surface runoff, and that only a small percentage of precipitation was captured by the samplers. High infiltration rates were apparently more important for removing bacteria from runoff than filter strip width or surface roughness. Lack of grazing undoubtedly led to reduced soil compaction, which may have increased the soil infiltration rate, thereby contributing to a reduced probability of runoff.

Based on examination of median and 75th percentile results of measured FCB concentrations in runoff, and also the percent of samples exceeding 200 cfu/100 ml (Table 8), it appears that manure application to cells that contained vegetated filter strips may have resulted in higher FCB concentrations as compared with reference conditions (storm #1 results and control cells). This pattern was observed most strongly for the silty soil site, less clearly for the gentle slope site, but not at all for the moderate slope site. This pattern of higher FCB concentration in manure-treated cells containing vegetated filter strips as compared with cells not treated with manure appeared to be especially evident in the cells having shorter vegetated filter strips (1 and 3 m). The pattern was less clear for cells containing longer filter strips (8, 15, 25 m).

Our results indicate that all vegetated filter strips were extremely successful in removing FCB from runoff (Tables 8-11). There was limited evidence that the shorter vegetated filter strips (1 m and 3 m) may have been slightly less efficient at removing FCB from runoff as compared with the longer vegetated filter strips (8-25 m). Such an effect, if it occurred, was not statistically significant. For the gentle slope class, the one-sided P value comparing mean values with square root transformations was nearly significant ($P = 0.065$). For the moderate slope class, the P value was 0.7. Bacteria concentration data are given in Figure 8 as smoothed mean values across all treatment storms for each experimental cell, including replicates. The regression model was

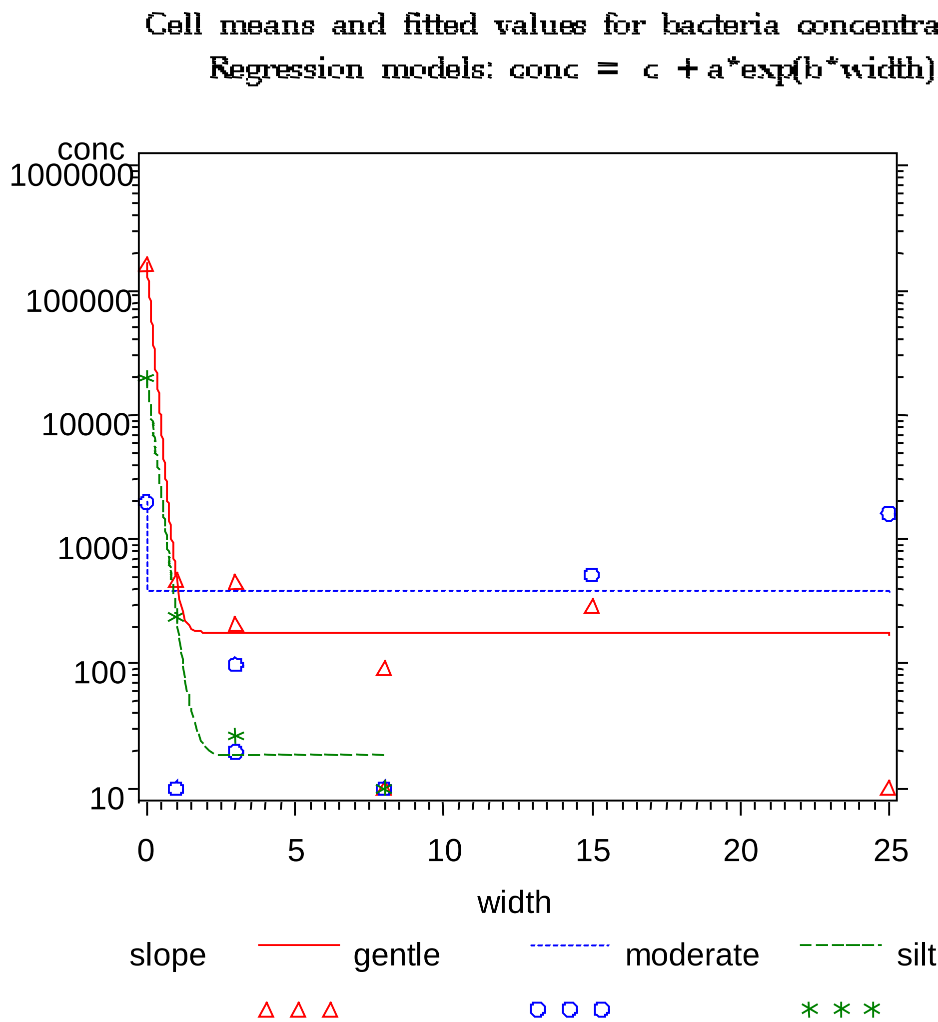


Figure 8. Cell means and fitted values for bacteria concentration by soil slope and texture class, using the regression model: bacteria concentration = C + a*exp (b*width)

selected to satisfy the property of giving a non-increasing curve. Thus, we imposed the constraint that bacteria concentration could not increase with increasing vegetated filter strip size. The lower asymptote corresponded to a cell with no manure treatment and the slope of the regression curve was proportional to the distance of the mean concentration from the lower asymptote. For all three soil/slope classes, the smoothed function reached the background value (bacteria concentration without manure application) at a vegetated filter strip size shorter than about 2 m.

On loamy soils such as those that occur on the farms that were the site of this study, our results suggest that infiltration of precipitation is very high (typically > 99%; Table 7), and therefore FCB flux in runoff from pasture to stream was low where there were vegetated filter strips, even filter strips as short as 1 m. In the absence of vegetated filter strips, however, the flux of FCB from pasture to stream was higher, on average, by about two orders of magnitude (Table 11). During many storms, the FCB flux from pasture lacking a vegetated filter strip exceeded 10,000 cfu per km of stream length, which could have a substantial impact on the FCB concentration in streamwater passing through manure-treated pastureland. In contrast, FCB flux from cells that contained vegetated filter strips was almost uniformly low.

On soils that exhibited lower infiltration of precipitation, there was greater opportunity for movement of FCB from pasture to simulated stream. This pattern was evident in our experimental data even though there were relatively small differences in texture among the soil types found at our experimental sites (Table 1). It is likely that FCB flux from heavy soils, that is those having much lower infiltration than we found in this study, is considerably higher than was found for our study areas. It is therefore possible that FCB flux from pasturelands in the Tillamook Basin that do have vegetated filter strips may be disproportionately associated with those areas that exhibit heavy soils and consequent low infiltration.

Most of the precipitation at the experimental sites infiltrated the soil, generating very little runoff. Three storms were sampled that had more than 10 cm of precipitation. Despite the large size of these storms, less than 1% of the precipitation contributed shallow runoff (Table 7). Runoff was several times higher at the silty soil site (Table 7), and this might explain the somewhat higher concentrations of FCB measured in the short vegetated filter strip cells of the silty soil site as compared with the sites having higher soil sand content (Table 8). Runoff was generally lowest at the moderate slope site, and this site also exhibited the lowest concentrations and loads of FCB from the short vegetated filter strip treatment cells.

FCB fluxes from the experimental treatment cells containing vegetated filter strips were generally low, even in treatment cells having vegetated filter strips as short as 1 m. We attribute this finding to the high infiltration of precipitation even during very large rainstorms in these loamy soils. Furthermore, our data suggest that the concentrations and fluxes of FCB in runoff may vary with soil texture, such that heavier soils yield more FCB than soils containing greater quantities of sand.

In the cells that contained short vegetated filter strips (1 and 3 m), FCB concentrations in runoff generally exceeded 200 cfu/100 ml only when the 4-hr precipitation intensity exceeded 0.5 cm or when the cumulative precipitation during the sampling interval exceeded 4 cm (Figures 5 and 6). The zero filter strip cells also showed a relationship between FCB in runoff and either the 4 hr precipitation intensity or the cumulative precipitation during the sampling interval, although the FCB concentrations were much higher. In the case of no vegetated filter strip, a 4-hr precipitation intensity above 1 cm or a cumulative precipitation amount during the sampling interval above 4 cm was generally required to yield FCB concentration in runoff above 100,000 cfu/100 ml (Figure 7).

Background Concentrations of FCB

In general, storm runoff samples collected from cells that did not receive manure application in advance of the storm contained low concentrations of FCB. This was the case across all treatment cells sampled in storm #1. It was also the case for the control cells established on the gentle and moderate slope classes at the primary treatment site and on the heavy soil site. These control cells received no manure application during the course of the study. During storm #1, 75% of the samples collected on both the gentle and moderate slope classes had FCB concentration less than 10 cfu/100 ml (Table 8). Results for the first storm clearly showed that FCB contamination of runoff was minimal in the absence of manure spreading, even with the occurrence of a very large storm. Over 4.5 inches (11.4 cm) of rain was recorded over a period of 48 hours during that storm. The observed low contamination of runoff in the absence of manure application is an important finding, and helped to simplify the calculations required to determine the impacts of manure spreading with differing vegetated filter strip treatments. Similarly, the 75th percentile values for FCB concentration in the control cells during storms 2 through 9 for both the gentle and moderate slope classes were 25 cfu/100 ml or less (Table 8). A somewhat higher 75th percentile value was found for the silty soil site (74 cfu/100 ml), but this could have been due to cattle grazing that occurred in that area shortly before installation of that site. In contrast, the primary experimental site had not been grazed for more than three years prior to initiation of the study.

However, despite the observed general pattern of low FCB concentration in the absence of manure application, this finding was not universally applicable. One sample collected during storm #1 on the gentle slope class and one sample collected from a control cell in each of the gentle and moderate slope classes exhibited high FCB concentration (> 200 cfu/100 ml). One of those samples exceeded the secondary health standard of 1,000 cfu/100 ml.

Several earlier studies also found that FCB concentration in storm runoff can exceed both the primary and secondary contact standards downslope from fields that have not recently been grazed and have not received manure application (Doran and Linn 1979, Doran et al. 1981, Jawson et al. 1982, Edwards et al. 1997). Substantial populations of enteric bacteria have been observed in both soils and streamwater in areas that have not been affected by livestock or human activities (Gary et al. 1985, Niemi and Niemi 1991). It therefore seems that background concentrations of FCB can, and occasionally do, exceed water quality standards. One likely cause of these occasional high FCB concentrations in our study in cells that did not receive manure application was the common occurrence of moles, voles (and perhaps other rodents), and gulls in pasturelands used for this study. Alternatively, this could have been the result of some mechanism that facilitated bacteria transported laterally between cells. Gentle-sloped control cells had higher concentrations of bacteria than the steeper controls, and this is consistent with the possibility that lateral transport of bacteria occurred on some occasions because the gentler slopes would have less downslope energy for transport.

In view of this finding that high FCB concentrations occasionally occur in the absence of manure application, the small percentage of samples that exhibited high FCB concentrations in the various vegetated filter strip treatments must be viewed with caution (Tables 8 and 9). For example, it is unlikely that results for the 1 to 25 m vegetated filter strip cells in the moderate slope class actually experienced enhanced FCB transport in comparison with the control cell. In fact, the highest FCB concentrations were found in the cell on this slope class that contained the longest vegetated filter strip (25 m; Table 8).

Additional Considerations

The study design did not include aspects of riparian systems; the vegetated filter strips were installed in sloping pasture land, and there was not a stream at the downhill end. In essence, we tested the extent to which the installed vegetated filter strips removed bacteria from runoff before it reached the riparian zone. Some additional processing of the runoff may, in fact, occur within the riparian zone before the runoff enters the stream. It was not considered necessary, in this study, to attempt to quantify that. We would not have been able to find a stretch of riparian system that was sufficiently homogeneous that it would have been comparable from treatment cell to treatment cell.

The study design also differed somewhat from standard agricultural practice in that simulated pastures did not have cows on them during the study. The simulated pasture areas were not grazed because we wanted experimental manure loading to be identical from cell to cell.

Furthermore, cows would cause compaction which could have altered drainage water flowpaths in an unquantifiable way. However, the absence of cows did not affect our ability to evaluate the relative effectiveness of cells containing vegetated filter strips of varying sizes. Each cell was treated in a similar manner. In order to replicate these results in a farm setting, it might be necessary to fence the vegetated filter strips, as grazing and associated soil compaction might impact vegetated filter strip effectiveness.

On average, the presence of a vegetated filter strip reduced the flux of FCB from the manure-treated pasture by two orders of magnitude, as compared with pastures that lacked a vegetated filter strip. The actual amount of manure loading was arbitrary, although we targeted agronomically-acceptable loading levels. The presence of any additional manure loading above the manure spread on the cells for the experiments would have been inconsequential (as long as each cell received the same loading prior to a given storm). Furthermore, most dairy farmers in this region do not pasture their animals during the storm-prevalent months (approximately October to April). Vegetated filter strips were therefore evaluated as to their effectiveness in removing organisms from manure land spreading operations during the wet season. Nevertheless, we cannot discount the possibility that soil compaction from grazing might affect infiltration and runoff rates.

Implications of this Research

We observed substantial differences in the quality of runoff water with and without vegetated filter strips. This research clearly demonstrated the importance of vegetated filter strips in reducing the contamination of runoff with FCB subsequent to manure spreading. We did not attempt to evaluate any effects that might accompany periodic grazing of vegetated filter strip areas.

This work demonstrated that, on average, more than 99% of the FCB in runoff was removed by vegetated filter strips of any size, from 1 to 25 m. However, it appeared that sites containing heavier soil exhibited lower infiltration of precipitation and greater FCB transport as compared with sites containing higher sand content in soil. Additional research will be required to determine the prevalence in the Tillamook Basin of soils having low infiltration, and the relationships between soil texture, associated infiltration, and FCB contamination of runoff from pastures treated with manure. Although short (1 and 3 m) vegetated filter strips removed FCB from runoff as well, or nearly as well, as longer (8-25 m) vegetated filter strips, there may be other environmental benefits associated with longer vegetated filter strips. These were not investigated in this study.

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APPENDIX A

Bacteria Flux Calculations for Each Storm

Storm 1

Gentle Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
G1	549	3572	0.2	76.7	46.6	522
G2	742	5821	0.1	100.0	58.2	433
G3	180	2339	0.1	120.0	19.5	262
G4	9392	3586	2.6	115.0	31.2	8905
G5	26	3507	0.0	120.0	29.2	25
G6	0	2844	0.0	120.0	23.7	0
G7	0	3566	0.0	73.3	48.6	0
G8	140	2416	0.1	115.0	21.0	197
G9	0	2502	0.0	100.0	25.0	0
G10	0	2968	0.0	120.0	24.7	0
G11	18	5267	0.0	113.3	46.5	11
					Average = 34.0	

Moderate Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
M1	119	1933	0.1	80.0	24.2	113
M2	6	608	0.0	53.3	11.4	18
M3	140	1580	0.1	56.7	27.9	164
M4	61	2391	0.0	81.7	29.3	47
M5	88	1208	0.1	66.7	18.1	134
M6	42	392	0.1	60.0	6.5	195
M7	0	270	0.0	26.7	10.1	0
M8	0	152	0.0	31.7	4.8	0
M9	0	186	0.0	28.3	6.6	0
M10	3400	1000	3.4	23.3	42.9	6256
M11	2149	1860	1.2	88.3	21.1	2126
					Average = 18.4	

Steep Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
S1	0	3932	0.0	95.0	41.4	0

Storm 2

Gentle Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
G1	0	78	0.0	140	0.6	0
G2	0	230	0.0	125	1.8	0
G3	640	462	1.4	140	3.3	679
G4	0	358	0.0	140	2.6	0
G5	0	1746	0.0	140	12.5	0
G6	437	442	1.0	140	3.2	484
G7	6	364	0.0	140	2.6	8
G8	0	260	0.0	140	1.9	0
G9	0	386	0.0	130	3.0	0
G10	0	2182	0.0	140	15.6	0
G11	0	1040	0.0	140	7.4	0
					Average = 4.9	

Moderate Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
M1	0	348	0.0	110	3.2	0
M2	0	302	0.0	110	2.7	0
M3	0	87	0.0	115	0.8	1
M4	8	266	0.0	115	2.3	8
M5	0	666	0.0	110	6.1	0
M6	14136	650	21.7	120	5.4	5872
M7	10	232	0.0	110	2.1	11
M8	0	110	0.0	125	0.9	0
M9	0	32	0.0	120	0.3	0
M10	0	126	0.0	125	1.0	0
M11	0	588	0.0	125	4.7	0
					Average = 2.7	

Steep Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
S1	18	1196	0.0	130	9.2	14

Storm 3

Gentle Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
G1	22246	1264	17.6	140	9.0	7022
G2	750	112	6.7	140	0.8	2673
G3	188	313	0.6	140	2.2	239
G4	1242	54	23.0	140	0.4	9177
G5	2808	208	13.5	140	1.5	5387
G6	2259840	428	5280.0	140	3.1	2106720
G7	10062	1324	7.6	140	9.5	3032
G8	32202	928	34.7	140	6.6	13845
G9	4428	180	24.6	140	1.3	9815
G10	0	1210	0.0	140	8.6	0
G11	0	122	0.0	140	0.9	0
					Average = 3.99	

Moderate Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
M1	74304	576	129.0	140	4.1	45021
M2	5452	940	5.8	140	6.7	2024
M3	33600	2100	16.0	140	15.0	5584
M4	216	408	0.5	140	2.9	185
M5	23	180	0.1	140	1.3	45
M6	0	236	0.0	140	1.7	0
M7	79	158	0.5	140	1.1	175
M8	30	296	0.1	140	2.1	35
M9	0	86	0.0	140	0.6	0
M10	1026	270	3.8	140	1.9	1326
M11	5312	128	41.5	140	0.9	14484
					Average = 3.49	

Steep Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
S1	7489	296	25.3	140	2.1	5313

Storm 4

Gentle Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
G1	713	400	1.8	132.5	3.0	1192
G2	143	1664	0.1	140	11.9	57
G3	200	418	0.5	140	3.0	320
G4	0	230	0.0	140	1.6	0
G5	986	1536	0.6	140	11.0	429
G6	11934	544	21.9	140	3.9	14676
G7	431	1248	0.3	140	8.9	231
G8	148	1320	0.1	140	9.4	75
G9	51	552	0.1	140	3.9	62
G10	314	1462	0.2	140	10.4	144
G11	0	906	0.0	140	6.5	0
					Average = 6.7	

Moderate Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
M1	171	570	0.3	70	8.1	195
M2	176	1760	0.1	70	25.1	65
M3	351	50	7.0	140	0.4	4561
M4	266	736	0.4	140	5.3	235
M5	0	734	0.0	140	5.2	0
M6	0	296	0.0	70	4.2	0
M7	0	678	0.0	70	9.7	0
M8	0	798	0.0	140	5.7	0
M9	0	202	0.0	140	1.4	0
M10	35	390	0.1	140	2.8	58
M11	43	460	0.1	140	3.3	61
					Average = 6.5	

Steep Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
S1	310	526	0.6	140	3.8	224

Clay Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
C1	816	722	1.1	55	13.1	2137
C2	559322	1066	524.7	60	17.8	991668
C3	10200	1446	7.1	60	24.1	13331
C4	878	1284	0.7	60	21.4	1293
C5	94	1076	0.1	60	17.9	166
					Average = 18.9	

Storm 5

Gentle Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
G1	6260	4780	1.3	140	34.1	2960
G2	3755	8271	0.5	140	59.1	1026
G3	5300	1298	4.1	137	9.5	9228
G4	57	1412	0.0	140	10.1	91
G5	1136	3367	0.3	140	24.1	763
G6	60130	1922	31.3	140	13.7	70704
G7	155	4723	0.0	137	34.5	74
G8	238	1834	0.1	140	13.1	293
G9	2624	784	3.3	140	5.6	7564
G10	156	4550	0.0	137	33.2	77
G11	123	1601	0.1	140	11.4	174
					Average = 22.6	

Moderate Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
M1	151	1810	0.1	140	12.9	90
M2	139	3520	0.0	140	25.1	43
M3	6660	1345	5.0	140	9.6	5348
M4	338	1320	0.3	140	9.4	276
M5	164	1801	0.1	140	12.9	98
M6	110	942	0.1	140	6.7	126
M7	40	758	0.1	140	5.4	57
M8	220	2355	0.1	140	16.8	101
M9	53	1030	0.1	140	7.4	56
M10	207	1067	0.2	140	7.6	209
M11	77	638	0.1	140	4.6	130
					Average = 10.8	

Steep Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
S1	52	723	0.1	112	6.5	46

Clay Slope Class						
Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
C1	259	4678	0.1	59	79.3	594
C2	386190	5298	72.9	59	89.8	781419
C3	1037	6794	0.2	47	144.6	1636
C4	779	7305	0.1	56	130.4	1143
C5	247	4401	0.1	48	91.7	602
					Average = 107.2	

Storm 6

Gentle Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
G1	ND					
G2	0	2696	0.0	140	19.3	11978
G3	13	258	0.1	140	1.8	1146
G4	10	260	0.0	140	1.9	1155
G5	ND					
G6	1750	372	4.7	140	2.7	1653
G7	0	634	0.0	140	4.5	2817
G8	0	1142	0.0	140	8.2	5074
G9	0	864	0.0	140	6.2	3839
G10	0	950	0.0	140	6.8	4221
G11	23	660	0.0	140	4.7	2932
					Average = 6.22	

Moderate Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
M1	20	460	0.0	140	3.3	20
M2	20	1758	0.0	140	12.6	5
M3	10400	330	31.5	140	2.4	14276
M4	87	534	0.2	140	3.8	73
M5	0	558	0.0	140	4.0	0
M6	43	872	0.0	140	6.2	22
M7	13	364	0.0	140	2.6	16
M8	3	684	0.0	140	4.9	2
M9	10	320	0.0	140	2.3	14
M10	0	678	0.0	140	4.8	0
M11	3	416	0.0	140	3.0	3
					Average = 4.53	

Steep Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
S1	3	378	0.0	140	2.7	2

Storm 7

Gentle Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
G1	17	4756	0.0	140	34.0	6
G2	29	5302	0.0	140	37.9	8
G3	27	1460	0.0	140	10.4	29
G4	67	278	0.2	70	4.0	374
G5	170	1496	0.1	105	14.2	176
G6	11548000	1734	6659.7	112.5	15.4	10322607
G7	200	2278	0.1	140	16.3	136
G8	118	1512	0.1	140	10.8	120
G9	191	994	0.2	140	7.1	298
G10	10	1754	0.0	140	12.5	9
G11	210	1102	0.2	140	7.9	295
					Average = 15.5	

Moderate Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
M1	0	1844	0.0	140	13.2	0
M2	6	3940	0.0	140	28.1	2
M3	1280	1774	0.7	140	12.7	750
M4	63	1078	0.1	140	7.7	61
M5	63	1236	0.1	140	8.8	53
M6	10	1362	0.0	140	9.7	8
M7	3	682	0.0	140	4.9	5
M8	0	1126	0.0	140	8.0	0
M9	23	1192	0.0	140	8.5	20
M10	23	912	0.0	140	6.5	26
M11	10	808	0.0	140	5.8	13
					Average = 10.4	

Steep Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
S1	1620	1124	1.4	140	8.0	1153

Clay Slope Class						
Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
C1	95	4694	0.0	57.5	81.6	100
C2	2590	1430	1.8	45	31.8	8983
C3	117	1296	0.1	30	43.2	448
C4	3	576	0.0	13.75	41.9	26
C5	ND					
					Average = 49.6	

Storm 8

Gentle Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
G1	0	1390	0.0	140.0	9.9	0
G2	0	1094	0.0	140.0	7.8	0
G3	220	888	0.2	140.0	6.3	178
G4	25	314	0.1	93.3	3.4	57
G5	3420	594	5.8	93.3	6.4	4145
G6	735500	678	1084.8	103.3	6.6	781062
G7	60	1828	0.0	140.0	13.1	24
G8	80	912	0.1	140.0	6.5	63
G9	40	952	0.0	140.0	6.8	30
G10	0	1136	0.0	140.0	8.1	0
G11	0	370	0.0	93.3	4.0	0
					Average = 7.2	

Moderate Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
M1	0	1224	0.0	140.0	8.7	0
M2	0	2064	0.0	140.0	14.7	0
M3	12800	1470	8.7	140.0	10.5	6182
M4	10	548	0.0	140.0	3.9	13
M5	70	978	0.1	140.0	7.0	51
M6	0	298	0.0	93.3	3.2	0
M7	50	1132	0.0	140.0	8.1	31
M8	10	1070	0.0	140.0	7.6	7
M9	0	310	0.0	86.7	3.6	0
M10	10	242	0.0	86.7	2.8	29
M11	10	356	0.0	46.7	7.6	20
					Average = 7.1	

Steep Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
S1	10	862	0.0	140	6.2	7

Storm 9

Gentle Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
G1	0	1166	0.0	140	8.3	0
G2	250	1218	0.2	140	8.7	70
G3	0	66	0.0	70	0.9	0
G4	310	110	2.8	140	0.8	958
G5	1120	98	11.4	70	1.4	3886
G6	37950	438	86.6	140	3.1	29459
G7	3720	436	8.5	140	3.1	2901
G8	710	226	3.1	140	1.6	1068
G9	8900	66	134.8	70	0.9	45848
G10	150	738	0.2	140	5.3	69
G11	30	504	0.1	140	3.6	20
					Average = 3.4	

Moderate Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
M1	420	462	0.9	140	3.3	241
M2	420	350	1.2	70	5.0	318
M3	74500	812	91.7	140	5.8	24313
M4	30	190	0.2	140	1.4	42
M5	60	192	0.3	140	1.4	83
M6	0	28	0.0	70	0.4	0
M7	1160	160	7.3	140	1.1	1921
M8	10	286	0.0	140	2.0	9
M9	0	270	0.0	140	1.9	0
M10	0	10	0.0	70	0.1	0
M11	10	930	0.0	140	6.6	3
					Average = 2.65	

Steep Slope Class

Cell	Total CFU	Total Water Vol. (ml)	Vol_weighted Ave (cfu/ml)	Pasture Length Intercepted (cm)	Average Vol. Per Unit Pasture Length (ml/cm)	Bacteria Flux (cfu/m)
S1	0	212	0.0	140	1.5	0