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WATER-QUALITY BENEFITS OF HAVING CATTLE MANURE DEPOSITED AWAY FROM STREAMS

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Abstract
A series of runoff and infiltration studies with bovine feces placed 0·0, 0·61, 1·37, or 2·13 m from a collection point were used to assess effectiveness of vegetative filter strips. Effectiveness was evaluated on the ability of the separation distance to reduce the number of fecal coliform (FC) bacteria being transported from the manure to the edge of the plots. Bacterial transport was evaluated under conditions of variable distance, soil permeability, and rainfall intensity. The FC bacteria yields were 40–115 million at the edge of the manure pile. This is only 17% of the FC in the manure. FC concentrations and yields were further reduced as the separation increased. The analysis of data did not indicate significant differences of bacteria transport in relation to rainfall intensities of 5 cm/h versus 10 cm/h at the 0·61, 1·37, or 2·13 m distances.

Key words: Water quality, bacteria, cattle, manure, runoff, buffer strips, overland flow, fecal coliform.

INTRODUCTION

In the Pacific Northwest, rangelands provide water, forage, wildlife habitat, recreation, and timber. The major economic use of these rangelands is for livestock grazing. However, if cattle are not managed properly they can have adverse impacts on the bacteriological quality of streams to which they have access. Animal grazing is a major land use in the western US that can impact water quality. Bacterial contamination occurs when cattle manure is deposited in streams. Well planned grazing management can help maintain acceptable water quality.

Organisms from manure get into streams by two pathways. One is direct deposit from the animals as they drink, graze or otherwise spend time in and along the stream. The second pathway is to be carried from manure deposited away from the stream by runoff or overland flow. Overland flow carries indicator organisms if the rainfall lands on the animal feces or if runoff from adjacent land passes over the manure.

The objective of this study was to compare the bacterial contribution of bovine feces deposited near a stream, up to 2·13 m from the flowing water, to feces deposited directly in the stream as a source of bacterial pollution during rainfall and subsequent runoff.

Bacterial transport was evaluated in a laboratory equiped with an indoor programmable spray-type infiltrometer. The infiltrometer allowed for controlled replicated experiments. The indoor laboratory also allowed control over environmental factors that would have otherwise confounded the interpretation of the data.

Background

Bacteria from the enteric tract are used as the primary indicators of surface water-quality relative to water-based recreational uses. Though fecal coliforms (FC) and fecal streptococci (FS) are not pathogenic, they are easily analyzed and are the primary indicators of the potential presence of pathogens. Most bacterial water quality criteria are based on the concentrations of these organisms. The extent or severity of elevated bacterial indicator organisms in grazed rangeland streams is related to the number and size of cattle in the pasture, bacterial die-off rates, time since manure deposition, as well as the location where the fecal materal was deposited.

Importance of indicator organisms

Pathogenic organisms, when present in animal waste, can be transferred to humans via water (Diesch, 1970). As recreational use of rangeland streams increases, the possibility of contracting disease from the water will increase. Some potential diseases that can be transferred to humans from infected cattle are as follows: salmonellosis, leptospirosis, anthrax, tuberculosis, Johne's Disease, brucellosis, listeriosis, tetanus, tularemia, erysipelas, and colibacilosis (Azevedo & Stout, 1974). However, it must be remembered that FC and FS bacteria indicate the potential presence of disease causing organisms. Coliform tests were originally designed for public health reasons. They were used to test drinking water which may have been contaminated by contagious wastes from human beings. Since spe-

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cific disease causing organisms are very difficult to trap and culture, the benign but ubiquitous coliform groups were chosen. They are easy to detect, simple to culture, and indicative of fecal contamination from warm blooded animals.

A test designed to evaluate public water supplies potentially contaminated by wastes from human beings may not be directly applicable to wildland waters with potential ruminant fecal contamination. Bohn and Buckhouse (1985) have published a discussion of the uses, and possible abuses, of coliform bacteria as a wildland water-quality indicator. They were concerned with the possible shortcomings of coliform bacteria as a wildland water-quality indicator. They raised questions of the ability of pathogens to 'track' similarly to the coliform group in natural systems. It has also been recognized that fecal contamination originating from ruminants carries a reduced risk of disease transmission to humans compared with the same coliform concentrations that originate from other humans.

Transport

Total fecal output of cattle will range from 0·5–0·75 percent of body weight per day, on a dry weight basis (Julander, 1955; Larsen *et al.*, 1988). Based on a typical 12% solids, this is equivalent to 27–40 kg of manure per day for a 450 kg animal. Free-ranging cattle will defecate an average of 12 times per day (Hafez *et al.*, 1969; Arnold & Dudzinski, 1978). This is an average fecal output of 0·04–0·06% of the body weight per defecation or 2 to 3 kg of manure per defecation.

Hafez *et al.* (1969) found that fecal deposits from cattle were nonuniformly distributed throughout a pasture. This nonuniform distribution can result in approximately 0·4–2·0% of the area covered by fecal deposits annually. However, in certain areas, e.g. water troughs, gates, fence lines, and bedding areas, manure concentrations may be much higher (Johnson *et al.*, 1978).

A small fraction of the indicator bacteria in fecal material may remain viable for one grazing season or longer (Buckhouse & Gifford, 1976). Thus, there is a potential for bacterial contamination long after the cattle have been removed from the site. However, bacteria in fecal material have to reach the stream before downstream contamination can be measured. Bacteria from feces can reach a stream by either direct deposit or by overland transport from a runoff event.

Peak fecal coliform concentrations in streams are frequently related to runoff events (Stephensen & Street, 1978). The resulting high concentration of coliforms may come from resuspending bacteria associated with the stream bottom sediments as well as from runoff carried organisms. Sherer *et al.* (1988) found that when stream bottom sediments were disturbed by raking, from 1·8 to 760 million fecal coliform organisms per m^2 of stream bottom were resuspended. However, rainfall events large enough to cause runoff which causes bacteria to move or which stirs the stream bottom sediments are infrequent in semi-arid sites.

Johnstone-Wallace and Kennedy (1944) and Buckhouse and Gifford (1976) have shown that as grazing intensity increases, coliform counts in the stream increase. When cattle are present in riparian areas they can deposit fecal material directly into the stream. The majority of the bacteria in the deposited feces will settle to the stream bottom and begin a die-off process. Survivors can be resuspended at a later time (Biskie *et al.*, 1988).

Sherer *et al.* (1988) noted that when cattle had not had access to the stream for several months, bacterial counts were similar to an area protected from grazing. Following the removal of cattle, one to several months may be needed for coliform counts in a stream to return to background levels (Tiedemann *et al.*, 1987).

Runoff from snow melt or rainfall can carry viable bacteria from fresh manure into the stream. Doran and Linn (1979) found that runoff from a grazed pasture had coliform concentrations 5–10 times higher than from an ungrazed pasture. However, Buckhouse and Gifford (1976) utilized a small plot infiltrometer and concluded that bacteria did not travel farther than 1·0 m in a sandy loam range site in semi-arid southeastern Utah. The relationship of source, distance, and bacterial transport is complex in low rainfall rangeland environments. More information is needed before a quantitative relationship between individual management decisions and nonpoint water pollution impacts can be accurately predicted (Springer *et al.*, 1983).

Entrapment

There are few studies that deal quantitatively with buffer strip width and microbial entrapment that can be directly applied to rangeland grazing conditions. Doyle *et al.* (1975) studied forested buffer strips in controlling bacterial transport on a gravelly silt loam soil spread with 90 t/ha of dairy manure. They measured elevated bacterial concentrations at the edge of the manure application area, but observed no significant movement of bacteria beyond 3·8 m.

Glenne (1984) presented a model which simulated the generation of water pollution on three watersheds in northern Utah. He noted that buffer strips approximately 50 m and 90 m wide were needed to reduce bacterial concentrations by 90% on 10% and 20% slopes, respectively.

The relationship of buffer strips and total solids, nitrogen, and phosphorus reductions have been observed in other studies. Bingham *et al.* (1980) studied buffer strips designed to control sediment, phosphorus and nitrogen from poultry wastes spread on clay loam fields. They concluded that the buffer strips needed to be as wide as the spread width of manure, i.e. if manure was spread 13 m wide, at least 13 m of buffer strip was necessary.

Other researchers have evaluated vegetative filters and their effectiveness for livestock waste treatment.

Dickey and Vanderholm (1981) found that vegetative filters, up to 400 m in length, reduced nutrients and solids by as much as 80% from feedlot runoff. They also stated that bacterial concentrations in the feedlot runoff were not significantly reduced. Concentrations were as high as $1{\cdot}05 \times 10^7/100$ ml. It is evident that the role of buffer strips in reducing bacterial concentrations in streams to which grazing animals have access is poorly understood.

METHODS

The experiments reported in this paper were conducted in a laboratory environment. The use of a programmable spray-type infiltrometer enabled precise control of the rainfall application rate, ambient temperature and the slope under which the various experiments were conducted. The indoor laboratory was maintained at 21°C. Wind affects were eliminated. Logan (UT, USA) city water supply was used to operate the infiltrometer. The small amount of chlorine present, was considered inconsequential.

Dairy cattle fecal material was used as a source of bacteria. All of the fecal material that was used in these studies was collected at the beginning of the experiment from a local dairy, mixed, and frozen into 1135 cm^3 packets weighing approximately 1·2 kg. This procedure was adopted to minimize the daily bacterial variation that exists in bovine feces. Each week a sample of the fecal material was tested to ensure that bacterial numbers remained constant. Each fecal sample was placed on a new piece of sod, to avoid contamination from the previous fecal deposit. The drainage troughs were cleaned at the end of each run by using chlorine bleach and rinsing with 10% solution of $Na_2S_2O_3$.

Since it was expected that the infiltration rate would be a major factor determining bacteria movement, grass sod was placed on two different underlying soil types. The first soil type (sand) was used to simulate a highly permeable medium with high infiltration rates. A second, less permeable condition was simulated by placing plastic beneath the sod. This second physical arrangement was used to simulate frozen or other impermeable soil conditions. Rainfall intensities of 5 cm/h and 10 cm/h were used.

Four distances — 0·0, 0·61, 1·37, and 2·13 m, were chosen to determine the impact of distance on bacterial removal as a result of overland flow. These are the distances from the edge of the manure to the collecting point. The sod covered plot lengths were 0, 0·61, 1·37 and 2·13 m. The zero distance was used to determine the release rate from the fecal deposits.

Four plot frames were built. Each plot frame was constructed from 4·4 cm × 19 cm boards. These frames were 0·44 m wide and 2·5 m long. A layer of gravel approximately 2·5 cm thick covered by 11 cm of sand was placed over hardware cloth in order to provide a porous medium through which water could percolate. A drainage trough at the lower end of each frame collected runoff water. Freshly harvested, lawn-grade Kentucky bluegrass (*Poa pratensis*) nursery sod was placed on top of the sand. The frames were placed on a bench to maintain a slope of 5%.

The plots were sprinkled with the infiltrometer at the rate being studied in that day's experiment for 20 min before adding fecal material. This allowed plots to become saturated and infiltration rates to equilibrate. Runoff samples were collected prior to adding manure to define background bacterial concentrations.

Manure, after thawing at room temperature, was spread in a band, approximately 15 cm × 44·5 cm × 2·5 cm across the upper end of the plots. The infiltrometer was shut off for approximately 2 min while the manure was being added.

After fecal material was added, each plot was sprinkled for an additional 30 min, at 5 or 10 cm/h, with runoff samples collected at 10, 20, and 30 min to determine overland bacterial movement. After collection, the runoff water was stored on ice in sterile whirl-pak bags and tested for fecal coliform bacterial concentrations using the membrane filter technique (APHA, 1985). After incubation, the fecal coliform colonies were counted and the results converted to number of bacteria per milliliter.

The statistical design to analyze the resulting data was a split-plot, repeated measures design. The whole plot factors were soil type and rainfall intensity. The split-plot factor was distance down the sod surface. The repeated measures were the samples collected through time (e.g. 10, 20, and 30 min). There were 16 treatments from different combinations of soil type, rainfall intensity, and distance. There were seven replications of each treatment resulting in 112 total plots.

RESULTS AND DISCUSSION

Background FC concentrations were measured prior to loading manure on the plots. The background fecal coliform counts ranged from 0 to 300 FC/ml, with an average of 9 FC/ml.

The manure samples were checked for FC concentrations each day prior to loading the plots. The average concentration was $5{\cdot}6 \times 10^5$/g with a standard error of $2{\cdot}4 \times 10^5$/g. Thus, 669 million FC organisms were loaded onto the plots. This is the number of FC that would have entered the stream had this amount of manure been directy deposited into the stream.

The amount of runoff from each of the experimental plots was measured 3, 10, 20 and 30 min after the manure was added. Table 1 summarizes these measurements for the various plot lengths, soil permeabilities and simulated rainfall intensities. Analysis of variance for infiltration rates shows a significant difference $P < 0{\cdot}001$) between permeable (sand) and less permeable (plastic underlain) soil types. Alternatively, the Student–Newman–Kuels multiple comparison test indicated no significant difference in infiltration for permeable and less permeable soil types

Table 1. Runoff rates measured after various intervals of simulated rainfall (average seven trials)

Soil type[a]	Rainfall intensity (cm/h)	Buffer length (m)	Runoff rate (ml/min); Interval after manure applied to plot			
			3 min	10 min	20 min	30 min
Permeable	5·2	0	16	32	34	36
Permeable	5·1	0·61	47	102	116	141
Permeable	5·7	1·37	91	218	256	288
Permeable	5·3	2·13	157	339	369	402
Impermeable	5·1	0	18	36	41	44
Impermeable	5·0	0·61	109	190	210	220
Impermeable	5·4	1·37	172	356	399	417
Impermeable	5·1	2·13	295	585	642	652
Permeable	10·0	0	59	81	75	71
Permeable	9·9	0·61	184	246	322	286
Permeable	10·0	1·37	142	303	385	446
Permeable	10·2	2·13	311	557	651	684
Impermeable	9·8	0	70	83	75	78
Impermeable	9·9	0·61	266	401	421	438
Impermeable	10·1	1·37	519	854	884	894
Impermeable	9·8	2·13	597	1323	1377	1457

[a]Permeable soil simulated by a sand layer beneath the sod. Impermeable simulated by a plastic layer beneath the sod and the underlying sand.

Table 2. Summary of fecal coliform concentrations after various intervals of simulated rainfall (average of seven trials)

Soil type	Rainfall intensity (cm/h)	Buffer (m)	Fecal coliform concentrations (no./ml); Interval after manure applied to plot		
			10 min	20 min	30 min
Permeable	5·2	0	63538	51444	37134
Permeable	5·1	0·61	1185	4542	5309
Permeable	5·7	1·37	23	168	232
Permeable	5·3	2·13	1	257	605
Impermeable	5·1	0	47134	31877	27277
Impermeable	5·0	0·61	461	4758	4986
Impermeable	5·4	1·37	166	1066	2325
Impermeable[a]	5·1	2·13	64	642	914
Permeable	10·0	0	69181	47230	39039
Permeable	9·9	0·61	3502	3913	3610
Permeable	10·0	1·37	884	1016	629
Permeable	10·2	2·13	14	226	154
Impermeable	9·8	0	47348	27205	25562
Impermeable	9·9	0·61	6655	4161	2765
Impermeable	10·1	1·37	828	1768	1370
Impermeable[a]	9·8	2·13	192	627	639

[a]Represents the average of six trials.

at the 5 cm/h rainfall intensity. However, there was a significant difference between permeable and less permeable soil types at the 10 cm/h rainfall intensity.

Fecal coliform concentrations were determined after 10, 20 and 30 min of sprinkling. Those data are summarized in Table 2. The one-way analysis of variance of the fecal coliform concentration data indicate a significant difference for the variables distance ($P < 0{\cdot}001$), distance–soil interaction ($P = 0{\cdot}002$), time ($P < 0{\cdot}001$), and distance–time interaction ($P < 0{\cdot}001$). There were no significant differences in fecal coliform counts between the 0·61, 1·37, and 2·13 m buffer distances.

An analysis of the distance–time interaction using the Student–Newman–Kuels mean separation test ($P < 0{\cdot}5$), indicated that the zero distance is significant different from the 0·61, 1·37, and 2·13 m distances. A significant reduction of bacterial concentrations at the edge of the manure covered area (no buffer, zero distance) occurred over time.

Tables 3 and 4 were generated to provide an estimate of the amount of runoff from the various plots and in turn to calculate the total number of FC escaping from the plots. The first and most dramatic observation is that even when there was no buffer between the manure and the edge of the plot, FC numbers

Table 3. Runoff volumes calculated for various time periods during four intervals of simulated rainfall (average of seven trials)

Soil type	Rainfall intensity (cm/h)	Buffer length (m)	Fecal coliform concentrations (no./ml); Interval after manure applied to plot			
			0–6·5 min	6·5–15 min	15–25 min	25–30 min
Permeable	5·2	0	0·10	0·27	0·34	0·18
Permeable	5·1	0·61	0·31	0·86	1·16	0·71
Permeable	5·7	1·37	0·59	1·85	2·56	1·44
Permeable	5·3	2·13	1·02	2·88	3·69	2·01
Impermeable	5·1	0	0·12	0·30	0·42	0·22
Impermeable	5·0	0·61	0·71	1·61	2·09	1·10
Impermeable	5·4	1·37	1·12	3·02	3·99	2·09
Impermeable	5·1	2·13	1·91	4·97	6·42	3·26
Permeable	10·0	0	0·38	0·69	0·75	0·36
Permeable	9·9	0·61	1·20	2·06	3·22	1·43
Permeable	10·0	1·37	0·92	2·58	3·85	2·23
Permeable	10·2	2·13	2·02	4·73	6·51	3·42
Impermeable	9·8	0	0·46	0·71	0·75	0·39
Impermeable	9·9	0·61	1·73	3·41	4·21	2·19
Impermeable	10·1	1·37	3·37	7·26	8·84	4·47
Impermeable	9·8	2·13	3·88	11·24	13·77	7·29

Table 4. Number of fecal coliform organisms running off the plots during various intervals of simulated rainfall (average of seven trials)

Soil type	Rainfall intensity (cm/h)	Buffer length (m)	Fecal coliform numbers in runoff (millions); Interval after manure applied to plot			
			0–15 min	15–25 min	25–30 min	Total
Permeable	5·2	0·00	23·61	18·19	7·08	48·88
Permeable	5·1	0·61	1·84	6·43	4·08	12·34
Permeable	5·7	1·37	0·04	0·58	0·44	1·06
Permeable	5·3	2·13	0·02	2·09	2·50	4·61
Impermeable	5·1	0·00	20·24	14·13	6·11	40·49
Impermeable	5·0	0·61	1·06	10·39	5·73	17·18
Impermeable	5·4	1·37	0·73	4·25	4·97	9·95
Impermeable[a]	5·1	2·13	0·32	3·91	3·19	7·41
Permeable	10·0	0·00	75·61	36·70	14·77	127·09
Permeable	9·9	0·61	16·14	14·88	3·68	34·70
Permeable	10·0	1·37	5·34	6·81	2·56	14·71
Permeable	10·2	2·13	0·18	1·98	0·76	2·92
Impermeable	9·8	0·00	55·97	20·18	10·16	86·30
Impermeable	9·9	0·61	39·93	17·21	6·27	58·49
Impermeable	10·1	1·37	10·31	18·29	6·34	34·94
Impermeable[a]	9·8	2·13	3·64	9·36	4·84	17·84

[a]Represents the average of six trials.

escaping were reduced from 669 million to less than 115 million, an 83% reduction. If there was 1·37 m or more of buffer strip between the edge of the plots, sampling point, and the manure, the FC reductions were 95% or greater. These data while not appropriate for predicting FC concentrations in streams passing through grazed rangeland areas do clearly document the advantages to be achieved by having manure deposited other than directly into the stream. Off-stream watering devices or watergaps that preclude animals depositing manure directly into streams can dramatically reduce the presence of manure borne bacteria in the stream.

SUMMARY AND CONCLUSIONS

This experiment measured the overland flow component of two simulated sod covered soil types, porous and impervious (simulated frozen) soil. This study dealt with the delivery of bacteria to the stream. Also, this study only dealt with the overland flow component of runoff and did not address interflow contributions.

This study indicates that during those times of the year when infiltration rates are high, the hazard of elevated FC concentrations decreases. Approximately 2·2 million FC were delivered to the collection point from fecal deposits placed 2·13 m away under high infiltration and rainfall intensity conditions. Approximately 13·7 million FC were delivered to the collection point from deposits placed 2·13 m away under reduced infiltration (simulated frozen ground) conditions.

The results of this experiment indicate that bovine feces landing near a stream have a much smaller potential for a water quality impact, as measured by FC contribution, than does manure landing directly in the stream indicating a dramatic impact of even a narrow, 0·61 m, buffer strip. The number of bacteria escaping during a 30-min rainfall event when the manure was placed out of the stream but within 0·61 m was 83% less than if the manure had landed in the stream. Bacterial loads were reduced by 95% if 2·13 m of separation between the feces and collection point were maintained.

Analyses of the data indicated that the two rainfall intensities had no significant effect on fecal coliform concentrations. However, there was a significant difference ($P<0{\cdot}001$) with respect to distance. The Student-Newman-Kuels mean separation test ($P<0{\cdot}5$) showed that the bacteria numbers at the 0·0 m distance were significantly higher than those at 0·61, 1·37, and 2·13 m distances. However, there were no significant differences between 0·61, 1·37, or 2·13 m distances.

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