The Effect of Cattle Grazing on Indicator Bacteria in Runoff From a Pacific Northwest Watershed[1]

M. D. JAWSON, L. F. ELLIOTT, K. E. SAXTON, AND D. H. FORTIER[2]

ABSTRACT

Total coliform (TC), fecal coliform (FC), and fecal streptococcal (FS) numbers were monitored for 3 years to determine the effect of grazing on the presence of these organisms in runoff from a cattle-grazed and a nongrazed watershed in the Pacific Northwest. The watersheds were characterized by winter precipitation and summer grazing. Weighted-average numbers of TC and FS in runoff did not appear to be appreciably different between the two watersheds during the study.

Numbers of TC in runoff from both watersheds routinely exceeded 10,000/100 mL. Prolonged absence of grazing animals did not seem to affect number of TC and FS in runoff from the check watershed. Each spring after a period of warm weather and prolonged absence of animals, there were increases in numbers of TC, FC, and FS in the runoff. There was some correlation between recentness of grazing and numbers of indicator bacteria in runoff. However, more than a year after animals were removed from the nongrazed check watershed FC numbers in runoff still exceeded 200/100 mL in many samples, and not until the following year did they drop to < 10/100 mL.

Sampling at several locations within the grazed watershed showed that sources of indicator bacteria were well distributed, and as a result were nonpoint after the initial runoff events. Thus, present FC recommendations developed for point-sources would not apply adequately to grazed land in the Pacific Northwest. Indicator bacteria as presently analyzed would not provide a basis for developing best management practices.

Additional Index Words: **fecal coliforms, fecal streptococci, total coliforms, pollution potential, best management practices.**

Jawson, M. D., L. F. Elliott, K. E. Saxton, and D. H. Fortier. 1982. The effect of cattle grazing on indicator bacteria in runoff from a Pacific Northwest watershed. J. Environ. Qual. 11:621-627.

Over 300 million ha of land in the United States is grazed annually (USDA, 1969, 1979). The influence of grazing on bacterial quality of downstream waters is not completely understood. Protection of downstream waters requires indicator bacterial data from contributing areas to evaluate best management practices. However, bacterial water quality standards were developed for point-sources (Table 1) and may not be applicable to nonpoint-source situations.

Several reports have provided some insight on bacterial water quality from grazed land. Runoff from a grazed area usually contains more sediment and indicator bacteria than a nongrazed area, but runoff from both areas may exceed recommended bacterial water quality standards (Doran and Linn, 1979; Schepers et al., 1980; Kunkle, 1970; Harms et al., 1975; Milne, 1976; Robbins et al., 1972). Stephenson and Street (1978) found maximum fecal coliform (FC) numbers in a southern Idaho stream occurred shortly after cattle were moved onto the grazing area. Fecal coliform counts in the stream increased from 0 to 2,500/100 mL and remained high for up to 3 months after the animals were removed. On the other hand, Buckhouse and Gifford (1976) simulated rain on small cattle-grazed and nongrazed plots in southern Utah and were unable to find significant differences in numbers of indicator bacteria in the runoff, although FC survived in cow dung longer than 18 weeks.

Doran and Linn (1979) concluded from a 3-year grazing study in Nebraska that the FC content of runoff from grazed land was the best indicator of bacterial quality. However, they showed that FC in runoff from the grazed and nongrazed areas usually exceeded recommended primary contact water quality standards. They showed that the FC/FS (fecal streptococcal) ratio and percentage of *Streptococcus bovis* were useful for evaluating livestock management practices to minimize bacterial contamination of pasture runoff, but concluded that recommended bacterial water quality standards developed for point-sources may be unsuitable for nonpoint sources.

Rychert and Stephenson (1981) found that many *Eschericia coli* isolated from an Idaho rangeland stream were atypical. They also found that *E. coli* concentrations in stream-bottom sediments were 2-760 times greater than in the overlying water. In an earlier study, Hendricks and Morrison (1967) showed that enteric bacteria may multiply in relatively clean water. These reports indicate there are questions about testing methods and interpreting results concerning indicator bacteria when dealing with nonpoint sources.

Geldreich (1976) discussed the behavior of indicator organisms from point-sources and the collection and use of FC and FS data. He concluded that FC/FS ratios > 1 in water indicate human fecal contamination, while ratios of 1.0 or less indicate domestic animal fecal contamination and those < 0.1, wild aimals. Geldreich cautioned that although fresh cattle manure has an average FC/FS ratio of about 0.2, prolonged sample storage or stream residence time can cause the ratio from this source to increase to as high as 3.0, since *S. bovis* and *S. equinus* die off rapidly under these conditions. He believes that FC/FS ratios developed from FC numbers below 100/100 mL are of limited usefulness. Geldreich also stated that *S. faecalis* var. liquifaciens should be

Table 1—Bacteriological water quality standards† (surface waters).

Water use	TC	FC
	per 100 mL	
Recreation		
Primary contact	1,000	200
Partial contact	5,000	1,000
Public water supply	10,000	2,000

† U.S. Department of Interior, 1968.

[1] Contribution of USDA-ARS in cooperation with the College of Agricultural Research Center, Washington State University, Pullman, WA 99164, and College of Agriculture, University of Idaho, Moscow, ID 83843. Scientific Paper no. 6070. Work partially supported under interagency agreement no. EPA-78-D-X0249 between the USDA-ARS and U.S. EPA. Received 4 Jan. 1981.

[2] Graduate Research Assistant, Washington State Univ. (formerly Soil Scientist, USDA-ARS); Microbiologist and Hydrologist, USDA-ARS, Pullman; and Agricultural Engineer, USDA-Bureau of Land Management, Coeur D'Alene, ID 83814 (formerly Agricultural Engineer, Univ. of Idaho); respectively.

considered ubiquitous because it can exist for extended periods in soil or water.

Data on indicator bacteria in runoff from grazed areas are limited, especially over extended periods and for summer-grazed areas with winter precipitation patterns. The objective of this study was to determine the indicator bacteria in runoff from a summer-grazed and a nongrazed watershed in the Pacific Northwest, both with "typical" management. The sources of indicator bacteria within the grazed watershed were also investigated.

MATERIALS AND METHODS

The study was initiated in the fall of 1976 (water year 1977) on a 21.5-ha grazed watershed and a 0.9-ha nongrazed (check) watershed in a 710-mm average annual rainfall zone (Fig. 1). Cattle were excluded from the check area by fencing it out of the grazed watershed the fall of 1976. There was a difference in slope between the grazed and check watersheds (Fig. 1); the lower portion of the grazed watershed had mild slopes of 4-8% with steep slopes of 15-25% in the upper portion. The check watershed was all mildly sloping. The complete site description, instrumentation, management, runoff sampling, and gauging were described by Fortier et al. (1980). Water years of 1 October-30 September were used for analysis. The grazed area was stocked annually with 45-55 cows plus 25-30 calves. Animals normally grazed from the latter part of May through mid-October. Very little runoff occurred during the grazing period.

During runoff events, streamflow was sampled hourly from each watershed with an automatic pumping sampler (sites 1 and 2, Fig. 1). Streamflow was measured with a broad-crested V-notch weir on the grazed watershed and with a small precalibrated flume on the check watershed. For some events during water years 1978 and 1979, runoff samples were obtained at several points within the grazed watershed (sampling point 1, main channel; point 3, main channel at pond; point 4, drainage from southwest half of watershed; point 5, drainage from north half of watershed) (Fig. 1) to determine if indicator bacterial sources could be defined within the watershed during an event. Bacteriological samples were collected in acid-rinsed (5*N* HCl followed by distilled-deionized water) plastic bottles after the samplers were automatically flushed. Periodic checks (using the methods employed for TC, FC, and FS) assured that the liter bottles were not contaminated before being filled. Refrigeration of the samples at the site was unnecessary because most runoff occurred during cool weather, and the samples were taken to the laboratory within 6-8 h after collection and cooled to 4°C. Bacterial analyses were completed within 24 h after sample collection. From late fall (November) through mid-spring (May) the grazed watershed normally had a small baseflow from a spring. Baseflow was checked for numbers of TC, FC, and FS once daily. This flow + runoff that was not of long-enough duration or intensity to be part of an event was classified as nonevent flow. All runoff during the drought 1977 water year was included within an event.

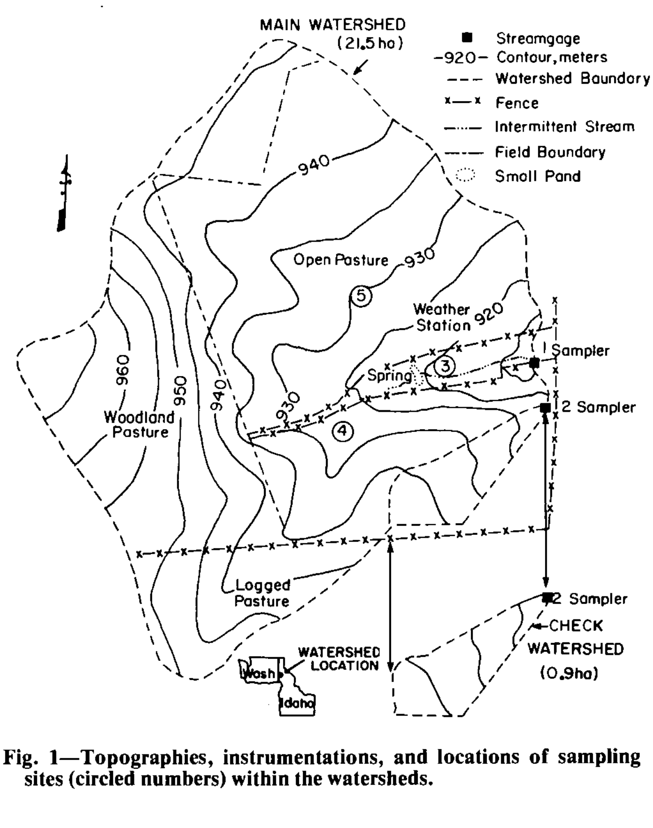

Fig. 1—Topographies, instrumentations, and locations of sampling sites (circled numbers) within the watersheds.

Procedures for TC, FC, and FS analyses were conducted according to the *Standard Methods* of the American Public Health Association (APHA, 1975). Portions of each water sample were filtered through sterile 0.45-membrane filters (Gelman Inc.)[3] and incubated in each of the following media: M-coliform broth (Baltimore Biological Laboratories Inc., BBL)[3] for total coliforms (TC), M-FC broth (BBL) for FC, and KF streptococcal broth (BBL) for FS. The average standard error of samples containing 20-100 colonies was ± seven colonies. One hundred replicate samples were randomly chosen to compute this average standard error. Doran and Linn (1979) presented evidence that PSE medium (Pfizer) recovers *S. bovis* better than KF streptococcal broth, so *Streptococcus* sp. recoveries by the two media were compared.

Weighted-average number of organisms/100 mL per event was calculated by dividing the total number of organisms delivered per event by the total amount of water delivered per event. The total number of organisms per event was determined by plotting the concentration of organisms in each hourly sample and integrating the time distribution.

WATER QUALITY DATA

General Comments

Precipitation received on the watersheds was 370 and 676 mm for water years 1977 and 1978, respectively. In water year 1979, 516 mm of precipitation fell during 1 October-5 July. Precipitation was not collected after study termination 5 July 1979; but weather records from nearby Potlatch, Idaho, showed 80 mm of precipitation fell from July through September, which would bring the total to about 600 mm for water year 1979. These amounts were below the 710-mm annual average (Fortier et al., 1980). Water year 1977 was extremely dry (precipitation was not collected in October 1976, but little occurred).

Indicator bacteria in runoff depended on event type and time of year. Runoff events in the Pacific Northwest last from a few hours to many days, with most longer events occurring during the winter. Indicator bacterial numbers in fall runoff caused by rain responded directly to changes in streamflow rates. However, there often was little or no change in indicator bacterial concentrations during events in the winter when runoff was generated by snowmelt or rainfall on frozen ground. During a mixed event (snowmelt and rainfall) on thawed ground, indicator bacterial concentrations usually responded directly to streamflow changes after snow thaw. In late winter or early spring, indicator bacterial concentrations responded to changes in runoff rate erratically, but in late spring they were more proportional to changes in streamflow.

[3] Trade names and company names are included for the benefit of the reader and do not imply endorsement or preferential treatment of the product by the U.S. Department of Agriculture.

Table 2—Water deliveries and bacterial concentrations for major events from the Rock Creek grazed watershed, 1977 water year.

Event dates	Water delivery	TC Weighted†-average	FC Maximum	FC Minimum	FC Weighted†-average	FS Maximum	FS Minimum	FS Weighted†-average	FC/FS	Event type
	m³	no.	no./100 mL							
16-19 Jan.	1,796	1.4×10^4	3.4×10^3	50	395	11.4×10^3	3.1×10^3	6.8×10^3	0.06	Snowmelt/rain
8-11 Feb.	105	2.0×10^5	6.0×10^3	500	3.3×10^3	6.0×10^3	500	3.3×10^3	1.00	Snowmelt/rain
28 Feb.-1 Mar.	25	3.4×10^4	128	4	72	470	33	250	0.30	Snowmelt/rain
7-10 Mar.	66	2.4×10^4	200	8	69	400	4	91	0.76	Rain/snow/rain
15-20 Mar.	52	5.6×10^3	96	4	31	84	6	31	1.00	Snowmelt/rain
27-28 Mar.	16	5.3×10^3	20	1	11	100	14	52	0.20	Snowmelt/rain
13-14 Apr.	5	3.1×10^6	1.3×10^3	36	710	20.5×10^3	520	8.3×10^3	0.09	Rain
2-4 May	3	3.2×10^6	8.0×10^3	520	3.7×10^3	1.6×10^4	790	8.5×10^3	0.40	Rain
17-18 May	12	3.0×10^5	410	20	177	4.4×10^3	400	1.6×10^3	0.10	Rain
26-27 May	4	1.0×10^6	1.1×10^3	10	290	6.6×10^3	200	2.5×10^3	0.10	Rain
4 June	0.2	8.8×10^6	4.0×10^4	1.7×10^4	2.6×10^4	1.8×10^6	8.5×10^5	1.4×10^6	0.02	Rain/cattle present
Annual concn†		4.0×10^3			521			6.2×10^3	0.08	
Total water delivery	2,084.2									

† Weighted by water volume.

Statistical analyses of the data were not possible because of the inherent differences between the grazed watershed and nongrazed check watershed, which resulted in water volume and time-distribution differences not amenable to statistical methods. The results obtained are presented as differences of observed trends that adequately define the conclusions.

Water Year 1977

There was little runoff from either the grazed or the nongrazed check watershed during the drought water year 1977 (Tables 2 and 3). In the runoff that occurred, maximum-minimum numbers of FC and FS from the watersheds appeared similar, as did the weighted-average numbers of TC, FC, and FS, because both watersheds were grazed the previous summer. The number of events and quantities of runoff were different between the two watersheds because slopes and contributing areas were different. Nonetheless, weighted-average concentrations of FC and FS for the entire water year appeared similar for the two watersheds. The annual weighted-average numbers are nearly identical to those for the 16-19 January event since this event accounted for 86 and 93% of the year's total runoff for the grazed and check watersheds, respectively. Cattle were put on the grazed watershed 3 d before the 4 June event and their presence was reflected by the highest numbers of TC, FC, and FS in runoff during this water year (no runoff occurred from the check watershed for this event). The FC/FS ratio (0.02) of this event was the lowest found during 1977. Runoff-event FC/FS ratios from both watersheds fluctuated with no apparent pattern or relationship to recentness of animal presence. It should be noted that in water years 1977, 1978, and 1979, several of the FC/FS ratios were developed using < 100 organisms/100 mL, which may be an invalid comparison (Geldreich, 1976).

The weighted-average FC, FS, and TC concentrations in runoff showed a gradual decline from January through March for both watersheds. However, after warm weather in April and May, there was a trend for an increase in weighted-average numbers of FC, FS, and TC in runoff from the grazed watershed. This trend was observed even though all grazing animals were removed in October 1976 and evidence of or the presence of wild animals was rarely observed on the watersheds. Also, the FC/FS ratios were not characteristic of wild animal fecal contamination (Geldreich, 1976). There were no events from the check watershed during this period, so it was not possible to determine if the apparent increase in indicator bacteria occurred on it during the 1977 water year.

Water Year 1978

Maximum-minimum and weighted-average numbers of FC and FS were greater in runoff from the grazed than from the check watershed for the first events of November and December in water year 1978 (Tables 4 and 5). This trend was not apparent for TC numbers. After the 5-9 January event, FS numbers in

Table 3—Water deliveries and bacterial concentrations for major events from the Rock Creek check watershed, 1977 water year.

Event dates	Water delivery	TC Weighted†-average	FC Maximum	FC Minimum	FC Weighted†-average	FS Maximum	FS Minimum	FS Weighted†-average	FC/FS	Event type
	m³	no./100 mL								
16-19 Jan.	206	5.8×10^3	2.6×10^3	100	500	1.4×10^4	3.5×10^3	6.2×10^3	0.08	Snowmelt/rain
8-10 Feb.	12	2.5×10^4	700	280	110	6.6×10^3	3.4×10^3	4.9×10^3	0.02	Snowmelt/rain
8-9 Mar.	2	2.4×10^4	200	20	90	1.0×10^3	500	750	0.12	Rain/snow/rain
19 Mar.	1	1.5×10^4	130	60	200	210	120	160	1.25	Rain
Annual concn†		7.0×10^3			473			6.1×10^3	0.08	
Total	221									

† Weighted by water volume.

Table 4—Water deliveries and bacterial concentrations for major events from the Rock Creek grazed watershed, 1978 water year.

Event dates	Water delivery	TC Weighted†-average	FC Maximum	FC Minimum	FC Weighted†-average	FS Maximum	FS Minimum	FS Weighted†-average	FC/FS	Event type
	m^3	no./100 mL								
					1977					
30 Oct.-2 Nov.	16	3.7×10^5	8.1×10^4	1.4×10^3	1.8×10^4	1.9×10^5	2.8×10^3	4.6×10^4	0.39	Rain
8 Nov.	23	6.8×10^5	1.3×10^5	4.4×10^4	7.4×10^4	7.7×10^5	2.7×10^6	6.3×10^5	0.12	Pond draining
13-16 Nov.	26	1.9×10^5	3.0×10^4	800	9.0×10^3	4.5×10^4	1.4×10^3	1.1×10^4	0.90	Rain
25-30 Nov.	304	5.2×10^5	2.6×10^4	1.3×10^3	1.0×10^4	1.5×10^4	3.3×10^3	8.5×10^3	1.18	Snowmelt/rain
1-4 Dec.	172	1.6×10^5	2.0×10^4	400	8.0×10^3	3.0×10^4	4.0×10^3	1.2×10^4	0.67	Snowmelt/rain
6-7 Dec.	107	2.2×10^5	1.4×10^4	460	8.0×10^3	2.5×10^4	2.6×10^3	1.2×10^4	0.67	Snowmelt/rain
10-15 Dec.	6,718	1.6×10^5	2.0×10^4	200	3.8×10^3	1.2×10^4	700	3.8×10^3	1.00	Rain
					1978					
5-9 Jan.	5,875	3.2×10^4	1.0×10^3	40	250	2.1×10^3	180	340	0.74	Snowmelt/limited rain
3-7 Feb.	6,699	2.0×10^5	305	1	170	540	50	200	0.85	Snowmelt/rain
26 Feb.-2 Mar.	1,418	2.2×10^4	300	15	70	300	15	110	0.91	Snowmelt/rain
8-9 Mar.	1,068	1.1×10^4	120	30	60	130	45	80	0.75	Rain
12-15 Mar.	1,152	8.4×10^3	170	30	40	170	40	75	0.53	Snowmelt
1-7 Apr.	1,519	7.6×10^4	2.2×10^3	20	250	2.5×10^3	20	620	0.40	Rain/sleet/snow
16 Apr.	123	1.1×10^5	2.7×10^3	12	630	9.7×10^3	50	3.4×10^3	0.19	Snow/hail/rain
27-28 Apr.	166	8.9×10^4	6.2×10^3	160	1.0×10^3	6.2×10^3	160	2.4×10^3	0.42	Rain
15-16 May	113	4.9×10^5	1.1×10^4	70	5.4×10^3	1.4×10^4	300	7.3×10^3	0.74	Rain
4 July	6	5.6×10^6	2.0×10^5	1.9×10^5	1.9×10^5	6.7×10^5	5.7×10^5	6.0×10^5	0.31	Rain/cattle present
Annual concn†		77.0×10^4			1.5×10^3			2.2×10^3	0.68	
Total	25,505									
Base-flow	12,098	2.3×10^4			150			420	0.36	

† Weighted by water volume.

the runoff from the two watersheds appeared similar for the remainder of the water year. There may have been a trend for weighted-average numbers of FS to be higher in runoff from the check watershed during April and May. The weighted-average concentration of FS for the year appeared about the same for both watersheds (2,230 vs. 2,452/100 mL). The weighted-average concentration of FC for the year appeared higher from the grazed watershed than the check (over 20 times greater), while there was a similar trend for TC (seven times greater). Cattle were removed from the grazed watershed 3 d before the October 30–November 2 event, and maximum-minimum and weighted average FC and FS numbers in the runoff reflected the recent grazing. The pond and/or the sediment in the channel between the pond and the sampler apparently served as a reservoir for indicator organisms, as evidenced by the high numbers of TC, FC, and FS during the pond draining in 8 November (Table 4).

Generally, weighted-average numbers of FC and FS in nonevent flow from the grazed watershed were lower than those in the event flow. The year's average FC and FS numbers were much less for nonevent compared with event flow.

The FC/FS ratios in runoff from the grazed watershed were higher than those from the check watershed

Table 5—Water deliveries and bacterial concentrations for major events from the Rock Creek check watershed, 1978 water year.

Event dates	Water delivery	TC Weighted†-average	FC Maximum	FC Minimum	FC Weighted†-average	FS Maximum	FS Minimum	FS Weighted†-average	FC/FS	Event type
	m^3	no./100 mL								
					1977					
25-27 Nov.	15	7.0×10^5	560	30	210	8.2×10^3	4.2×10^3	5.9×10^3	0.04	Snowmelt/rain
1-3 Dec.	15	2.5×10^5	290	10	130	1.3×10^4	1.7×10^3	7.4×10^3	0.02	Snowmelt/rain
6-7 Dec.	4	3.1×10^5	70	30	50	1.1×10^4	4.3×10^3	8.4×10^3	0.01	Snowmelt/rain
10-16 Dec.	143	1.2×10^5	2.0×10^3	2	100	5.4×10^3	100	2.5×10^3	0.04	Rain
					1978					
5-9 Jan.	89	2.6×10^4	110	10	30	400	90	220	0.14	Snowmelt/limited rain
2-8 Feb.	82	1.5×10^4	35	<1	10	550	15	100	0.10	Snowmelt/rain
26 Feb.-1 Mar.	7	2.5×10^4	5	<1	5	20	10	20	0.25	Snowmelt/rain
8-9 Mar.	10	1.6×10^4	4	<1	4	56	5	30	0.13	Rain
12-15 Mar.	6	1.4×10^4	5	<1	10	30	10	20	0.50	Snowmelt
1-7 Apr.	24	2.1×10^5	164	5	40	5.6×10^3	200	2.4×10^3	0.02	Rain/sleet/snow
16 Apr.	2	1.5×10^5	36	32	35	1.3×10^4	4.6×10^3	1.0×10^4	0.003	Snow/hail/rain
27-28 Apr.	4	1.4×10^5	400	50	200	1.9×10^4	4.1×10^3	1.1×10^4	0.02	Rain
15-16 May	6	4.8×10^5	250	132	160	2.0×10^4	1.5×10^4	1.7×10^4	0.003	Rain
Annual concn†		11.0×10^4			64			2.5×10^3	0.03	
Total	407									

† Weighted by water volume.

Table 6—Water deliveries and bacterial concentrations for major events from the Rock Creek grazed watershed, 1979 water year.

		TC	FC			FS				
Event dates	Water delivery	Weighted†-average	Maximum	Minimum	Weighted†-average	Maximum	Minimum	Weighted†-average	FC/FS	Event type
	m³	no./100 mL								
					1978					
4 Nov.	1	1.5×10^6	3.1×10^4	1.1×10^4	2.7×10^4	8.1×10^4	2.9×10^4	6.2×10^4	0.43	Rain
17 Nov.	6	3.1×10^5	4.2×10^4	1.0×10^4	2.5×10^4	9.8×10^4	1.3×10^4	7.2×10^4	0.34	Rain
30 Nov.-4 Dec.	66	3.8×10^4	1.7×10^3	240	800	7.3×10^3	1.1×10^3	4.6×10^3	0.17	Snowmelt
11 Dec.	97	3.0×10^4	760	260	500	2.2×10^4	210	6.5×10^3	0.09	Snowmelt/rain
23-24 Dec.	68	2.3×10^4	3.8×10^3	300	1.1×10^3	1.4×10^3	700	1.0×10^3	1.10	Snowmelt
					1979					
6-7 Feb.	51	1.0×10^5	400	76	300	8.0×10^3	208	6.3×10^3	0.04	Snowmelt
9-14 Feb.	12,523	5.9×10^4	1.4×10^3	30	200	6.6×10^4	164	2.4×10^3	0.08	Snowmelt
18-20 Feb.	1,255	1.8×10^4	450	14	80	2.5×10^3	170	500	0.16	Snowmelt/rain
25-28 Feb.	5,012	7.9×10^3	392	2	70	3.0×10^3	40	1.2×10^3	0.06	Snowmelt/rain
4-8 Mar.	4,968	5.6×10^3	220	12	60	1.2×10^3	32	400	0.15	Rain
15-18 Mar.	1,066	3.8×10^4	118	18	50	1.2×10^3	88	400	0.13	Rain
27-28 Mar.	532	2.7×10^4	300	50	100	3.6×10^3	128	1.0×10^3	0.10	Rain
2-4 Apr.	1,001	1.1×10^4	65	20	40	600	70	200	0.20	Snowmelt/rain
6-10 Apr.	2,510	1.0×10^4	435	10	90	1.5×10^3	40	400	0.23	Rain
12-13 Apr.	675	2.6×10^3	160	2	300	360	10	200	1.50	Rain
16-17 Apr.	632	1.1×10^4	270	10	90	2.5×10^3	70	700	0.13	Rain
23-24 Apr.	624	2.6×10^4	500	50	200	2.0 × 1;³	52	700	0.29	Rain
4-9 May	3,927	3.8×10^4	6.5×10^3	220	1.2×10^3	1.5×10^4	150	2.1×10^3	0.58	Rain
Annual concn†		3.2×10^4			260			1.5×10^3	0.17	
Total	35,014									
Base-flow	5,618	5.6×10^3			120			420	0.19	

† Weighted by water volume.

(Tables 4 and 5). Most ratios generated from the check watershed were likely invalid due to FC numbers of < 100/100 mL. The ratio data are difficult to interpret because of the increased number of indicator bacteria present in the spring runoff.

Water Year 1979

The precipitation pattern during water year 1979 was different from the previous 2 years. Precipitation, after the first two events in November, fell as snow until late February, so the majority of the events, including the largest, were generated from snowmelt rather than rainfall as in the previous 2 years. Generally, weighted-average and maximum-minimum concentrations of indicator bacteria in the runoff from the grazed watershed tended to be lower than was the case for water year 1978, likely because the majority of the runoff occurred after February from snowmelt (Table 6). Numbers of FC from the grazed watershed appeared higher than from the check watershed. The pond was not drained in water year 1979 because it was essentially dry when the animals were removed. Cattle were removed from the grazed watershed 4 d before the 4 November event. Bacterial weighted-average and maximum-minimum numbers in runoff from the grazed watershed were high from the two November events and dropped fairly rapidly thereafter. The spring increase in average weighted numbers of FC and FS in runoff from the grazed watershed did not occur until the 4-9 May event and was not as great as in the two previous years (Table 6). The weather was much cooler through March and April than the two previous years, but warmed before the 4-9 May event. Weighted-average numbers of TC and FS from the grazed and check watersheds appear similar when similar events are compared (Tables 6 and 7). When the annual weighted-average concentrations of FS and TC are compared between the two watersheds, there appears to be no difference.

Concentrations of FC in runoff from the check watershed were low, and for the first time did not exceed, at any time, recommended standards for primary contact (Tables 1 and 7). The ratios from the check watershed are probably meaningless. The low FC numbers in the runoff from the check watershed resulted from the relative absence of FC and the persistence of FS on the check watershed. The FC/FS ratios from the grazed watershed appeared similar to the other 2 years of study.

Sources of FC and FS Within the Grazed Watershed

The sources of FC and FS within the grazed watershed appeared to be nonpoint after the stream channel and/or pond were flushed by the initial fall events, such as shown for November and December 1977 (Table 8). Thereafter there appeared to be no pattern associated with numbers of FC or FS in runoff within the watershed. The pond-draining data of 8 Nov. 1977 showed indicator bacteria were concentrated in the pond and/or stream channel, and that these areas could be a major reservoir for the organisms during the initial events in the fall of the year. However, it was not possible to determine the individual contributions to indicator bacterial load from the pond (sampling point 3), streambed (sampling point 1), or recent animal grazing (8 Nov. 1977; Table 8).

The increase in FC and FS in runoff from the grazed watershed after warm, spring weather was also shown within the watershed when the 4 May 1979 sampling was compared with earlier events in 1979 (Table 8). The FC/FS ratios from individual sites (3, 4, 5) within the

Table 7—Water deliveries and bacterial concentrations for major events from the Rock Creek check watershed, 1979 water year.

		TC	FC			FS				
Event dates	delivery	Weighted†-average	Maximum	Minimum	Weighted†-average	Maximum	Minimum	Weighted†-average	FC/FS	Event type
	m^3	no./100 mL								
					1978					
3-4 Dec.	10	6.9×10^4	12	4	8	2.0×10^3	500	1.5×10^3	0.005	Snowmelt
11 Dec.	19	3.1×10^4	<1	<1	<1	2.5×10^3	800	1.5×10^3	0.003	Snowmelt/rain
23-24 Dec.	11	2.1×10^4	<1	<1	<1	1.8×10^3	1.1×10^3	1.5×10^3	0.002	Snowmelt
					1979					
6-7 Feb.	3	5.4×10^4	<1	<1	<1	3.8×10^3	2.7×10^3	3.6×10^3	0.006	Snowmelt
9-15 Feb.	170	2.3×10^4	12	<1	2	5.2×10^3	180	1.3×10^3	0.002	Snowmelt
17-20 Feb.	12	7.4×10^3	<1	<1	<1	520	140	360	0.006	Snowmelt/rain
25-28 Feb.	42	9.0×10^3	4	<1	2	2.0×10^3	160	830	0.005	Snowmelt/rain
4-7 Mar.	16	3.7×10^3	6	<1	2	1.1×10^3	170	450	0.007	Rain
27-28 Mar.	6	1.6×10^3	4	<1	2	6.6×10^3	1.8×10^3	4.4×10^3	0.001	Rain
2-4 Apr.	5	8.0×10^3	2	<1	<1	340	110	320	0.006	Snowmelt/rain
6-9 Apr.	15	2.1×10^4	20	<1	13	1.2×10^3	160	640	0.020	Rain
12-13 Apr.	4	2.9×10^3	<1	<1	<1	2.0×10^3	510	1.8×10^3	0.005	Rain
16-17 Apr.	4	3.1×10^4	5	<1	3	2.0×10^3	450	1.8×10^3	0.005	Rain
24 Apr.	7	4.0×10^4	2	<1	<1	2.3×10^3	450	1.5×10^3	0.001	Rain
4-6 May	44	1.2×10^5	30	<1	13	7.9×10^3	200	3.6×10^3	0.004	Rain
Annual concn†		3.3×10^4			4			1.5×10^3	0.003	
Total	370									

† Weighted by water volume.

watershed show the same variations as noted from the main sampling site (1).

The KF streptococcal broth gave higher FS numbers than the PSE medium. Doran and Linn (1979) indicated PSE medium was better on the basis of *S. bovis* recovery. In this study, we rarely dealt with runoff from fresh manure deposition, so *S. bovis* was generally not a significant proportion of the FS population.

Table 8—Concentration means of indicator bacteria in runoff from various points within the grazed watershed in 1977, 1978, and 1979.

Date	Sampling site	FC†	FS†	FC/FS
		no./100 mL		
8 Nov. 1977	1	78,000	715,000	0.11
	3	900	3,700	0.24
6 Dec. 1977	1	11,000	75,000	0.44
	3	12,800	20,000	0.64
	4	10,000	28,000	0.36
	5	18,400	23,000	0.80
13 Dec. 1977	1	800	2,700	0.30
	3	480	5,400	0.09
	4	300	3,100	0.10
	5	1,700	7,400	0.23
15 Mar. 1978	1	155	150	1.03
	3	90	150	0.60
	4	30	215	0.14
	5	50	105	0.48
13 Feb. 1979	1	230	460	0.50
	3	36	600	0.06
	4	56	680	0.08
	5	32	620	0.05
27 Feb. 1979	1	40	370	0.11
	3	1	370	--
	4	1	370	--
	5	1	210	--
6 Apr. 1979	1	205	1,170	0.18
	3	130	830	0.16
	4	160	600	0.27
	5	550	970	0.57
4 May 1979	1	5,300	12,000	0.44
	3	2,400	15,000	0.16
	4	2,230	20,000	0.11
	5	50	100	0.50

† Averages of duplicate samples.

DISCUSSION

Geldreich (1981) addressed problems associated with determining water quality by indicator organisms. He pointed out that assessing the microbial hazards from nonpoint-sources will require different approaches than for point-sources, and that we may have to test for the pathogens themselves. This study showed that TC and FS numbers in runoff from the grazed and check watersheds did not relate well to recentness of animal grazing. When weighted-average concentrations of TC and FS for each year were compared, there appeared to be little difference between the two watersheds. The highest weighted-average levels of TC, FC, and FS in runoff occurred during the two events when animals were present. However, there are many examples during the study when numbers of TC and FC exceeded recommended water quality standards developed for point-sources (Table 1). Many of these cases occurred long after animals were taken from the area. At this juncture, it would be difficult to assume that these levels of organisms, developed for point sources, would assess the pollution potential of runoff from such a nonpoint source.

The numbers of FC in runoff did relate to the recentness of cattle grazing. However, after warm weather, FC numbers appeared to increase in runoff from the grazed watershed in the spring months long after the animals were removed. While FC did increase slightly in the spring on the check watershed the year following cattle exclusion for the watershed (1978 water year), FC persistence was not nearly as great as FS. Nonetheless, FC numbers in runoff from the check watershed were not consistently $<200/100$ mL until water year 1979. Also, ratios of FC to FS from the check watershed were lower than from the grazed watershed during the second and third year of study because the FC organisms did not appear to persist as long as the FS. The persistence of FS observed in this study precluded the use of FC/FS ratios as a measure of animal fecal pollution. Additionally, many of the ratios were developed from numbers < 100/100 mL, and it is also possible that there was a contribution from wildlife that lowered the ratio. However, a larger increase in FC corresponding to that seen on the grazed watershed would have been expected on the check watershed had wildlife, and not greater FS persistence compared with FC, been the main source of difference in FC/FS ratios between the watersheds. Geldreich (1976) pointed out that FS can survive on vegetation, which may have been one source of these organisms in this study. Hunt et al. (1979) observed similar patterns and behavior by FC and FS with an overland-flow grass treatment of waste-water effluent, and they questioned the use of present indicator organisms and standards for nonpoint systems. Van Donsel et al. (1967) also noted seasonal variations in survival of indicator organisms in soil.

The results of sampling various points within the grazed watershed indicated the pond and/or the stream channel were reservoirs of indicator bacteria only briefly during the first one or two small events. Stephenson and Rychert (1982) pointed out that sediment in rangeland streams can be a source of *E. coli.* Generally, the data indicate that the sources of indicator organisms within the grazed watershed were nonpoint.

While FC numbers in runoff from a grazed area may be useful for assessing environmental impact, present point standards may be inappropriate. In many cases FC numbers in runoff exceeded recommended standards months after cattle were removed. The literature indicates that bacterial pathogens generally do not persist for an extended period after fecal deposition (Elliott and Ellis, 1977). If this is so, specific pathogens may have to be determined directly, as Geldreich (1981) proposed, to fully assess limits for health hazards from nonpoint sources.

ACKNOWLEDGMENT

The authors acknowledge and are grateful for the technical assistance of Mary Ann Nagle.

LITERATURE CITED

1. American Public Health Association. 1975. Standard methods for the examination of water and waste water. 14th ed. APHA Publications, New York.
2. Buckhouse, J. C., and G. F. Gifford. 1976. Water quality implications of cattle grazing on a semiarid watershed in southeastern Utah. J. Range Manage. 29:109–113.
3. Doran, J. W., and D. M. Linn. 1979. Bacteriological quality of runoff water from pastureland. Appl. Environ. Microbiol. 37: 985–991.
4. Elliott, L. F., and J. R. Ellis. 1977. Bacterial and viral pathogens associated with land application of organic wastes. J. Environ. Qual. 6:245–251.
5. Fortier, D. H., M. Molnau, and K. E. Saxton. 1980. Sediment from a small summer grazed watershed. p. 790–801. *In* Proc. Natl. Watershed Management Symp., Am. Soc. Civ. Eng., Boise, Idaho. July 21–23, 1980. ASCE, New York.
6. Geldreich, E. E. 1976. Fecal coliform and fecal streptococcus density relationships in waste discharges and receiving waters. Crit. Rev. Environ. Control 6:349–369.
7. Geldreich, E. E. 1981. Current status of microbiological water criteria. ASM News. 47:23–27.
8. Harms, L. L., P. Middaugh, J. N. Dornbush, and J. R. Andersen. 1975. Bacteriological quality of surface runoff from agricultural lands. Part II. Water Sewage Works 122:71–73.
9. Hendricks, C. W., and S. M. Morrison. 1967. Multiplication and growth of selected enteric bacteria in clear mountain stream water. Water Res. 1:567–576.
10. Hunt, P. G., R. E. Peters, T. C. Sturgis, and C. R. Lee. 1979. Reliability problems with inicator organisms for monitoring overland flow treated waste water effluent. J. Environ. Qual. 8:301–304.
11. Kunkle, S. H. 1970. Concentrations and cycles of bacterial indicators in farm surface runoff. p. 49–60. *In* Proc. Conf. Agric. Waste Manage., Cornell Univ., Ithaca, N.Y. Jan. 1970.
12. Milne, C. M. 1976. Effect of a livestock wintering operation on a western mountain stream. Trans. ASAE 19:749–752.
13. Robbins, J. W. D., D. H. Howells, and G. J. Kris. 1972. Stream pollution from animal production units. J. Water Pollut. Control Red. 44:1536–1544.
14. Rychert, R. C., and G. R. Stephenson. 1981. Atypical *E. coli* in streams. Appl. Environ. Microbiol. 41:1276–1278.
15. Schepers, J. S., E. J. Vavricka, D. R. Andersen, H. D. Wittmus, and G. E. Schuman. 1980. Agricultural runoff during a drought period. J. Water Pollut. Control Fed. 52:711–719.
16. Stephenson, G. R., and L. V. Street. 1978. Bacterial variations in streams from a southwest Idaho rangeland watershed. J. Environ. Qual. 7:150–157.
17. Stephenson, G. R., and R. C. Rychert. 1982. Bottom sediment: a reservoir of Escherichia coli in rangeland streams. J. Range Manage. 35:119–123.
18. U.S. Department of Agriculture. 1969. Annual grazing statistical report. USDA Forest Service. Stock no. 0-280-916/FS-330. U.S. Government Printing Office, Washington, D.C.
19. U.S. Department of Agriculture. 1979. Agricultural statistics, 1979. Stock no. 001-000-04069-3. U.S. Government Printing Office, Washington, D.C.
20. U.S. Department of Interior. 1968. Federal water pollution control administration. Report of the Committee on Water Quality Criteria. U.S. Government Printing Office, Washington, D.C.
21. Van Donsel, D. J., E. E. Geldreich, and N. A. Clarke. 1967. Seasonal variations in survival of indicator bacteria in soil and their contribution to storm-water pollution. Appl. Microbiol. 15:1362–1370.