Bottom Sediment: a Reservoir of *Escherichia coli* in Rangeland Streams

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Abstract

***Escherichia coli* concentrations of bottom sediment and overlying water were determined from a variety of streams in southwestern Idaho by a one-step most probable number technique. Results show *E. coli* concentrations of bottom sediments to be from 2 to 760 times greater than from the overlying water. *E. coli* concentrations of bottom sediment were found to be resuspended following disturbance simulation and a rainstorm event, contributing to pollution of the overlying waters. It is, therefore, suggested that microbial analysis of bottom sediments be considered a part of water-quality evaluations for rangeland streams.**

During the past decade, Federal legislative action has brought attention to sources of nonpoint pollution related to livestock grazing on public lands. Collectively, the National Environmental Policy Act of 1969, the Federal Water Pollution Control Act Amendments of 1972, and the Federal Land Policy and Management Act of 1976 have specified the need to establish criteria for identifying pollution sources and to improve environmental quality of streams through improved management.

To achieve the goals set forth in these acts, many research programs have been initiated to identify and document pollution sources. One of the findings has been the implication that livestock grazing on western rangeland watersheds is a source of bacterial pollution of streams (Darling and Coltharp 1973; Doty and Hookano 1974; Buckhouse and Gifford 1976; Skinner et al. 1974; Stephenson and Street 1978). Researchers have had difficulty, however, explaining variations in bacterial indicators occurring in many of the studies (Buckhouse and Gifford 1976; Darling and Coltharp 1973; Kunkle 1970; Skinner et al. 1974; Stephenson and Street 1978).

These variations can be characterized by two questions: (1) why do fecal coliform counts remain relatively high in some streams after livestock have been removed from the area, and (2) what is the source of sudden fecal coliform increases in stream runoff from rainstorms or snowmelt? Wildlife have been suggested as the source in question one (Fair and Morrison 1967; Stuart et al. 1971; Walter and Bottman 1967; Doran and Linn 1979), while for question two, Stephenson and Street (1978) suggest that fecal coliforms remain in soil and adjacent streambanks to be flushed into the streams during subsequent runoff.

In an attempt to more fully answer the above questions, we began a study in 1979 on southwestern Idaho rangeland, utilizing eight sampling sites on six separate shallow stream segments within varying land-use practices. Our objective was to evaluate stream bottom sediments as a possible reservoir of bacterial pollutants available to overlying surface waters via resuspension.

In previous work relating possible bacterial pollutants to stream bottom sediment, none of the studies have dealt with rangeland environments. In a study of the Greenwater River Watershed in Washington, Varness et al. (1978) found that concentrations of fecal coliforms increased dramatically during periods of human use. Since rainfall and surface runoff were minimal, they suggested that fecal coliforms might be surviving in sediments.

Matson et al. (1978) found mean fecal coliform counts in sediment to be 2,500 times greater than in the overlying water, upstream of a sewage treatment plant on the Shetucket River in northeastern Connecticut. Downstream of the treatment plant effluent discharge site, the fecal coliform counts for the sediment

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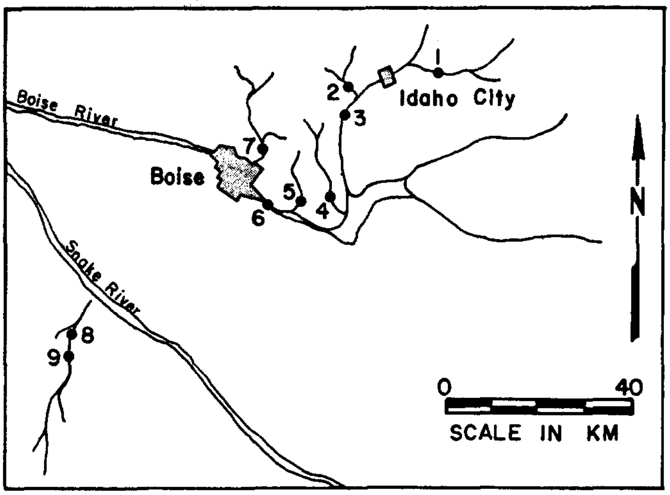

Fig. 1. *Location of sampling sites.*

Table 1. Stream characteristics of sampling sites at times samples were collected.

Site	Date (1979)	Flow m^3/s	Avg. width (m)	Avg. depth (m)
1	8/2	0.14	2.4	0.2
2	8/2	0.11	3.6	0.2
3	8/2	0.34	4.8	0.3
4	6/11	<0.1	0.9	0.1
	6/19	<0.1	0.9	0.1
	6/25	<0.1	0.8	<0.1
	7/12	<0.1	0.5	<0.1
	8/2	<0.1	0.3	<0.1
5	6/11	<0.1	0.9	0.1
6	8/2	45.0	25.0	1.2
7	8/13	0.3	3.0	0.2
8	5/21	1.3	3.0	0.5
9	5/21	1.3	3.0	0.5
	7/12	0.2	2.5	0.3
	7/24	0.2	2.2	0.3
	8/9	0.1	2.0	0.2

averaged only 230 times greater than for the overlying water. The downstream sampling site had a higher mean water velocity, lower organic content, and a larger mean particle size, which, in part, explained the lower ratios of indicator organisms.

Van Donsel and Geldreich (1971) recovered 100 to 1,000 times more fecal coliforms in river mud than in the overlying water. Gerba and McLeod (1976) determined that estuarine sediment may contain up to a 70 times greater concentration of fecal coliforms than the overlying water. The presence of sediment was found to increase the survival of *Escherichia coli* in sea water. Faust et al. (1975) found that montmorillinite clay enhanced the survival of *E. coli* in an estaurine environment. Greater than 80% of indicator organisms (fecal streptococci and fecal coliforms) were directly associated with suspended sediments in Upper Chesapeake Bay (Sayler et al. 1975). Dredging in the Mississippi River released sediment-bound fecal coliforms into the water (Grimes 1975).

These studies have demonstrated that a definite relationship exists between elevated *E. coli* concentrations and bottom sediments, as compared with those in the overlying waters in large rivers and estuaries. In this study, we attempted to show that these relationships also exist in western rangeland streams and should be a part of rangeland water-quality evaluations.

Site Characteristics

The study sites selected for this investigation (Fig. 1) are located along the Boise and Snake River systems, two of the major drainages in southern Idaho. Except for the Boise River site (No. 6), all sites were selected in areas where livestock are grazed in the drainage area directly upstream. Figure 1 gives the relative location of each site and Table 1 gives stream characteristics. Site-use descriptions are given in Tables 2 and 3.

The rangeland streams used in this study can generally be characterized as intermittent, often with extreme variations in temperature and flow. Streambeds range from bedrock to deep alluvium of varied size fractions, with alluvial channels far more numerous than bedrock channels. The channel segments at the study sites are all alluvial, with textures ranging from silt to coarse sand.

Methods

Water and sediments were sampled using sterile, wide-mouth

Table 2. *E. coli* concentrations in bottom sediment and overlying water during spring and early summer, 1979.

Date	Sample	Site No.	Site use	*E. coli*/ml	*E. coli* bottom sediment/water ratio	*E. coli*/g sediment
May 21	sediment	9	1*	6.1	31	65
	water	9		0.2	—	—
July 12	sediment	9		4.5	10	310
	water	9		0.45	—	—
May 21	sediment	8		33.0	37	204
	water	8		0.9	—	—
June 11	sediment	5	2*	813.3	145	8579
	water	5		5.6	—	—
June 11	sediment	4		97.8	51	617
	water	4		1.9	—	—
June 19	sediment	4		263.0	11	2097
	water	4		23.0	—	—
June 25	sediment	4		594.0	43	3694
	water	4		13.8	—	—
July 12	sediment	4		73.0	3	4563
	water	4		24.0	—	—

*Site use description
1. Irrigated pasture; winter livestock feeding.
2. Heavily grazed; livestock and big game.

Table 3. *E. coli* concentrations in bottom sediment and overlying water and sediment organic carbon percentages during summer, 1979.

Date	Sample	Site No. and use	*E. coli*/ml	*E. coli* bottom sediment/water ratio	*E. coli*/g sediment	% organic carbon
July 24	sediment	9 } 1*	165.0	127	802	4.3
	water	9	1.3	—	—	—
August 9	sediment	9	152.0	760	655	4.9
	water	9	0.2	—	—	—
August 2	sediment	4 } 2*	137.0	17	3702	7.7
	water	4	7.9	—	—	—
August 2	sediment	1 } 3*	1.9	>10	27	3.1
	water	1	<0.18	—	—	—
August 2	sediment	3	2.8	>15	49	0.7
	water	3	<0.18	—	—	—
August 2	sediment	2	1.5	8	205	0.6
	water	2	0.18	—	—	—
August 2	sediment	6 } 4*	0.5	>2	167	0.7
	water	6	<0.18	—	—	—

*Site use description
1. Irrigated pasture; winter livestock grazing
2. Forested; big game; moderate livestock grazing.
3. Heavily grazed; livestock and big game.
4. Mostly urban; some grazing.

bottles, with sediment samples taken at 1 to 2-cm depths. Serial 10-fold dilutions were made of sediment and water samples with 0.1% peptone and the *E. coli* MPN (most probable number, 5 tubes/dilution) was determined in TMS medium, according to the recovery procedure of Dufour and Marino (1978). The TMS medium ingredients are: mannitol, 5g; tryptone, 20g; NaCl, 5g; salicin, 0.5 g; tryptophane, 1 g; Triton X-100, 1 ml; distilled water, 1 liter; pH 7.0. The MPN tubes were incubated for 2 hours at 35° C, then for 22 hours at 44.5° C. Gas positive tubes were tested for indole production by adding 10 drops of Kovac's reagent, with gas positive/indole positive tubes used to compute the MPN. The TMS medium represents a modification of medium A-1 (Andrews and Presnell 1972), which provides for greater recovery of *E. coli* than the 72-hour APHA procedure (American Public Health Association 1976). All sediment MPN values represent the mean of triplicate sediment sample MPN's.

Stream bottom disturbance was simulated by raking an area of about 4 m^2 with a lawn rake for about 30 sec. This vigorous action gave rapid, uniform dispersion of the bottom material for about 20 meters downstream. Surface water samples were then collected from the plume at 10-sec intervals at a static point 5 to 10-m below the disturbance site, as the plume moved downstream. The *E. coli* MPN was then determined, as previously described, along with the suspended sediment concentration (American Public Health Association 1976).

All samples were kept on ice until taken to the laboratory, where they were assayed within 24 hours after collection.

Results and Discussion

Table 2 shows that for each stream examined, the *E. coli* counts for the sediment, though varied, on a volume basis are higher than for the overlying water. These variations may reflect input (e.g., fecal loading from increased grazing), survival, bottom sediment disturbance, and possibly transient multiplication of the microorganisms. The latter possibility is suggested, particularly by the increase of *E. coli* per gram of sediment, on the Highland Valley site between June 11 and July 12. The cattle grazing intensity remained constant during this time and all large game animals had moved out to higher, more isolated back country by June 1.

Table 3 shows that sediment-to-water ratios of *E. coli* concentrations continued to increase in the sediment during the latter part of the summer. There was also a positive relationship ($r = 0.82$) between the organic matter content and the *E. coli* concentration in the sediment of the six stream sites studied. Since the number of samples evaluated was small, this relationship was not statistically significant. Rabbit Creek, Grimes Creek, Mores Creek, and the Boise River (Site Nos. 1, 2, 3, and 6, respectively) are streams that flow from watersheds with moderate to low levels of grazing. One would not expect a strong correlation between organic matter content of bottom sediment and *E. coli,* unless fecal coliforms were deposited in the sediment; i.e., in streams located in the more heavily grazed watersheds. However, animals such as deer, elk, and rodents, and the activity of humans may be a source of organic input to streams where there is no grazing close by. From our preliminary data, and that reported by Gerba and McLeod (1976), bottom sediment organic matter seems to play a significant role relative to fecal coliform survival.

Figures 2 and 3 present *E. coli* and suspended solid concentrations from disturbance simulations. These indicate an increase in the *E. coli* concentration of the overlying downstream water when the bottom sediment is sufficiently disturbed. These results compare favorably with results from the model developed by Matson et al. (1978), which indicated the potential for resuspension of *E. coli* in the water column with an increase in river discharge (i.e., disturbance of the bottom sediment).

During our investigation, the only significant increase in streamflow from the watershed study sites occurred on August 13, during a short duration rainfall event. Cottonwood Creek (Site No. 7) was the only readily accessible site (Figure 1) with a continuous recorder. It is mostly urban with some grazing. Figure 4 illustrates the stream hydrograph and the rainfall record for August 13, at this site. The times at which samples were collected are indicated on the hydrograph, as are the *E. coli* concentrations of the samples and the corresponding suspended sediment concentrations. Between the first and last sampling, as the suspended sediment concentration increased, the *E. coli* concentration increased 10-fold. However, between the first and second sampling, the *E. coli* concentration decreased slightly, while the suspended sediment concentration increased 12-fold. As seen in Figure 4, the second sample was taken at the beginning of an increase in streamflow, after a sudden decrease. The peak streamflow between samples two and three probably supplied sufficient energy to disturb enough additional bottom sediment to cause resuspension of more *E. coli.*

Results from this naturally occurring event compared favorably

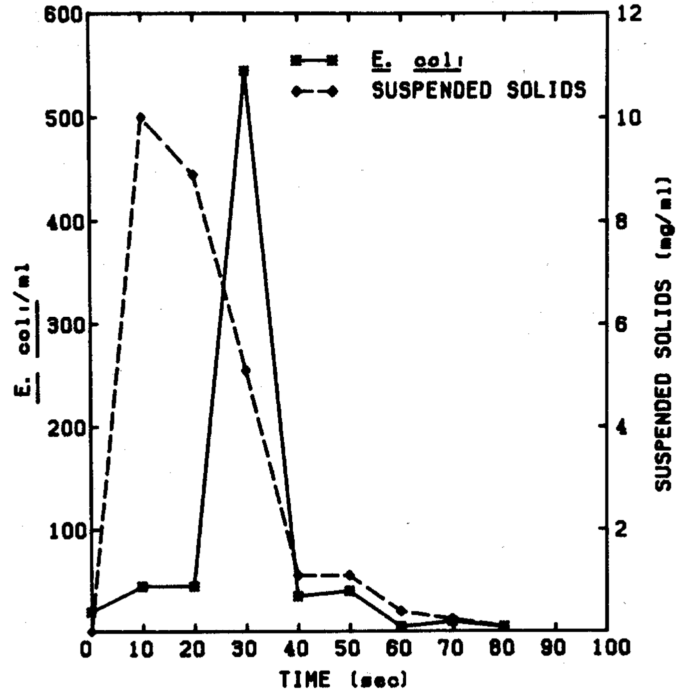

Fig. 2. *Disturbance simultion, June 19, 1979, Highland Valley Creek (Site No. 4).*

with the simulated disturbance tests, and were what we would have predicted. However, we have yet to investigate layering associated with the bottom sediment, microbiological adsorption incorporated within, and the energy required to cause resuspension.

Saunders (1967), in a theoretical study of the growth kinetics of attached stream bacteria ("bottom slime"), listed three factors that influence break-up of the bottom mass: (1) degree of utilization of absorbed nutrients and decomposed cell materials; (2) formation of gas bubbles; and (3) stream turbulence.

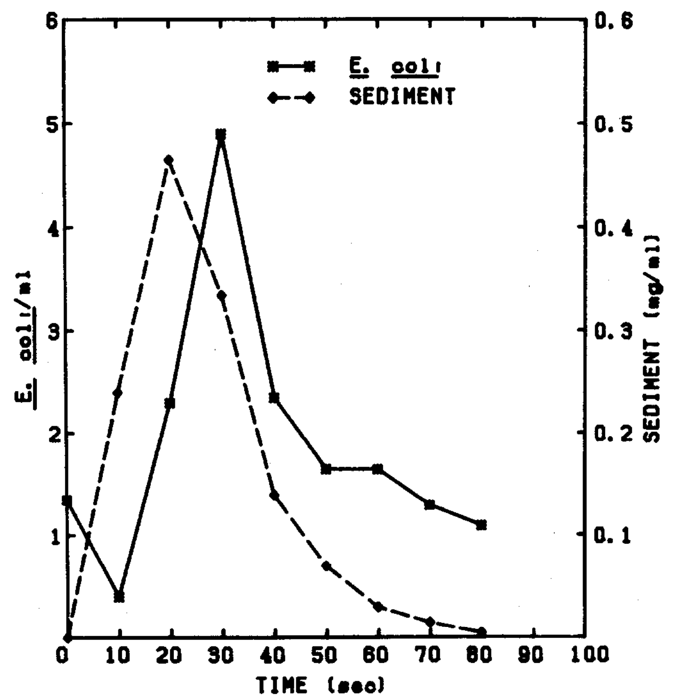

Fig. 3. *Disturbance simulation, July 24, 1979, Reynolds Creek-056 site (Site No. 9).*

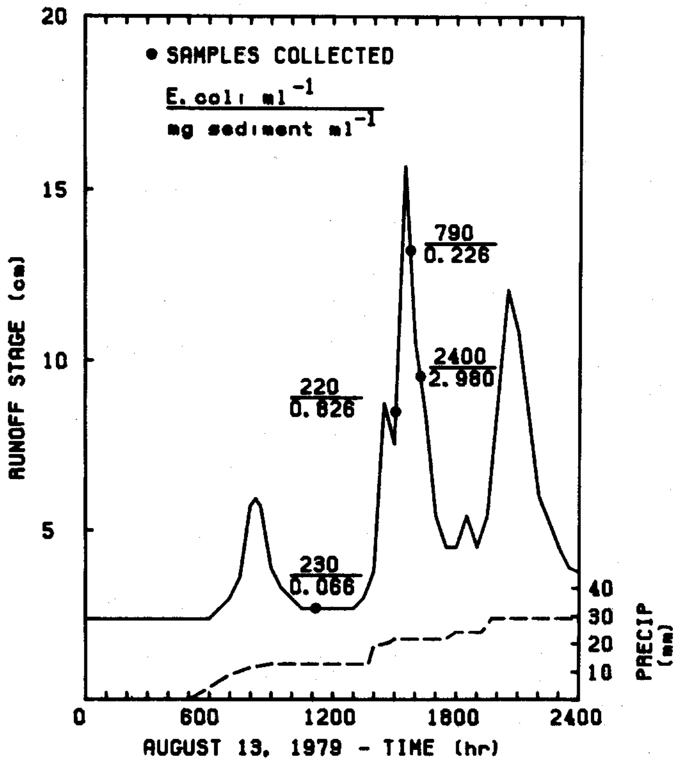

Fig. 4. *August 13, 1979, Cottonwood Creek Hydrograph (Site No. 7).*

Although we have not yet studied the dynamics of sediment fecal coliforms in detail, we are presently evaluating more storm runoff events to clarify the effect of stream dynamics on *E. coli* adsorption and release.

Summary and Conclusions

Variation in concentrations of bacterial indicators from streams have previously been recognized (Darling and Coltharp 1973; Stephenson and Street 1978; and Kunkle 1970). These variations occur as elevated counts in streams following removal of livestock from the grazed allotments, and increased counts during stream runoff from rainstorm and snowmelt. In an attempt to explain these phenomena, the results of our investigation show *E. coli* concentrations of bottom sediment of streams to be 2 to 760 times greater than that of the overlying water. Data obtained from disturbance simulations and from a rainstorm event indicate that *E. coli* concentration of bottom sediments are resuspended and could substantially contribute to pollution of the overlying waters.

We, therefore, suggest that the elevated fecal coliform indicator counts reported by the above authors are mostly the result of resuspension of the stream bottom sediment and organic matter, rather than from a source extraneous to the stream at the time of increased runoff. We further suggest that the organic matter content of the sediment may have a critical influence on the survival and/or multiplication of the bacteria.

Because of these results, microbiological analysis of stream bottom sediments should probably be considered a part of stream water-quality evaluations. The bottom sediment mass may be a significant reservoir of fecal microorganisms, when the contributing watershed is not grazed, or during the post-grazing period. Even minor disturbances of the organic bottom mass, at the stream-sediment interface, can cause resuspension of the *E. coli* or other indicators, thereby increasing the possibility of pollution of the overlying water body.

As rangeland management plans are revised, methods are being developed for identifying and controlling nonpoint sources of pollution. Waterborne indicators should not be the sole criterion for determining potential non-point sources of pollution, since many viable organisms are deposited in the bottom sediments. When stream samples are analyzed for indicator microorganisms, results may be misleading unless stream bottom sediment is also analyzed.

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