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Bacteriological Aspects of a Mountain Watershed

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Abstract

Numbers of fecal coliforms and fecal streptococci increased during the winter in a stream near a ski area. These numbers returned to background levels within a month after the ski area closed for the year. As the pollution events continued with time, the day of the week on which maximal numbers were obtained changed. Maximum numbers of these bacteria were seen in the afternoons when pollution was occurring. Minimum numbers were found in the morning.

Fecal coliforms and fecal streptococci were enumerated in a stream above and below the ski area for three summers. Statistically significant differences in the numbers of these organisms occurred between the months studied, depending upon whether the statistics were run upon numbers per 100 mL or upon numbers passing a point per second.

INTRODUCTION

There has been quite a bit of study concerned with the bacteriology of streams in the western United States. The grazing of livestock has been shown to cause increases in indicator bacteria in streams (Morrison and Fair, 1966; Kunkel and Meiman, 1967; 1968, Stuart *et al.*, 1971; Buckhouse and Gifford, 1976; Jahn *et al.*, 1978; Stephenson and Street, 1978; Doran and Linn, 1979; Jawson *et al.*, 1982). Recreational activities may have beneficial effects by decreasing the amount of pollution by causing wildlife to leave an area (Stuart *et al.*, 1971; Varness *et al.*, 1978). In another study by Gary (1982), it was found that recreational use of a campground that had proper sanitation facilities did not cause pollution of surface water.

Increased numbers of bacteria have been found in sediments (van Donsel and Geldreich, 1971; Hendricks, 1971; Grimes, 1975). Beaver ponds may aid in the settling of bacteria into sediments (Skinner *et al.*, 1984). Also, moss beds may act as traps for these organisms (Gary and Adams, 1985). Settled bacteria may be resuspended into the water column by increased flow due to rainfall and snowmelt, and by human and animal activities (Varness *et al.*, 1978; Grimes, 1975; Stephenson

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and Rychert, 1982). Also, coliform organisms may grow in algal mats and be released into the water column (McFeters *et al.*, 1978).

Some study has occurred on the Nash Fork Watershed in the Snowy Range Mountains of Wyoming. Skinner *et al.*, (1974) studied the bacteriology of streams during the summer in this watershed. Gary and Adams (1985) studied the sediments in this watershed, and Hussey *et al.* (1986) reported upon the changes in the bacteriology of these waters between the summers of 1971 and 1972 and 1982. This paper reports upon studies that have been done during the winter and in a different way of calculating data.

MATERIALS AND METHODS

The wastes from a ski lodge were treated in an aeration chamber and the effluent was released to a holding pond. The ability to chlorinate was incorporated into the waste-processing system between the aeration unit and the holding pond; however, chlorination was not used during the study period. The aeration chamber was enclosed in an attempt to maintain a constant temperature, although no heat was purposefully added to the system. The holding pond was designed to have no release of an effluent to a receiving stream. The ultimate fate of the contents of the holding pond was to be either removal by a commercial waste hauler or evaporation of the liquid during the summer. The pond was frozen over during most of the study period.

Two sampling sites were established on a stream in the proximity of the ski resort. One site was selected above the ski area as close to the area as possible where there appeared to be minimal effect by humans. The sample site below the ski area was chosen at a point at which visual observation of a muddy tributary indicated that complete mixing of the effluent would have occurred.

Triplicate water samples for bacterial analysis were collected at the two sampling sites on the stream at various times from October 1975 through May 1976. Samples were collected from the stream at roughly two-week intervals at 1 P.M. from October 6, 1975, until May 29, 1976. In addition, samples were collected at one-day intervals at 1 P.M. for a total of seven days during the months of November through March. Moreover, during these months, samples were collected one day each month at bihourly intervals from 7 A.M. until 9 P.M. The effluent of the treatment facility was sampled in February, through April. When the effluent from the waste treatment was sampled, it was, in most cases, sampled in triplicate. The triplicate samples were taken in series as quickly as possible. The samples were collected aseptically in sterile 1-L wide-mouth screw-capped polypropylene bottles. The samples were iced and transported to the laboratory in Laramie for analysis. Samples were processed within 6 h of collection.

During the summers, single samples were collected weekly as a matter of convenience in the morning at the previously established sites. Fecal coliforms and fecal streptococci were enumerated by membrane filtration procedures.

In some cases data were analyzed two ways. First, all values were analyzed on an organism per 100 mL basis. Second, stream flow for each sampling time was recorded and calculations were carried out to determine organisms flowing past a point per second by the following equation:

$$\frac{\text{Organisms}}{\text{Second}} = \frac{\text{Organisms}}{100\ \text{mL}} \times \frac{1000\ \text{mL}}{\text{L}} \times \frac{28.3\ \text{L}}{\text{Cubic Foot}} \times \frac{\text{Flow (cubic feet)}}{\text{Second}}$$

Bacteriological data were analyzed using analysis of variance and Duncan's new multiple range tests (Steel and Torrie, 1960).

RESULTS

Water temperatures on October 6 were 5°C. These temperatures fell to 1°C by November 8 and were below 1°C until April. The water temperatures then rose to 4°C by the end of the study period. The water temperature above the ski area was usually 0.1–0.2°C colder than that below the ski area.

When samples taken at biweekly intervals were analyzed, it was found that the maximum number of indicator bacteria occurred at the end of March (Table I). The numbers of both groups of indicator bacteria had returned to background levels by early May, approximately one month after the ski area closed for the year. This demonstrated that the pollution disappeared from the water column rapidly after the pollution events ceased and that use of the ski area had no lasting effect upon the bacterial water quality of the receiving stream. Numbers of fecal coliforms above the ski area never exceeded 1 per 200 mL of water. The fecal streptococci at this site had a maximum of 39 cells per 100 mL in February and were not higher than below the ski area during the year ($p = 0.01$).

When samples were taken each day for a week, the highest numbers of fecal coliforms and fecal streptococci were found on Monday in February and on Sunday in March, with lower counts being seen the other days (Table II). Normal operation of the ski area was Wednesday through Sunday; the area was closed Monday and Tues-

TABLE I
Numbers of indicator bacteria in biweekly samples below a ski area

Date	Fecal coliforms[a]	Fecal streptococci[a]
2-14	−0.08[b]	1.09
2-28	−0.18	1.22
3-13	—[c]	0.48
3-27	3.85	3.85
4-9	2.76	2.95
4-24	1.04	2.00
5-8	0.18	1.23

[a] No fecal coliforms were found before 2-14 or after 5-8; fecal streptococci had a log mean below 0.7 for these dates.
[b] Values presented are log means of three samples.
[c] No fecal coliforms detected.

day. However, the area was open on the Monday in February when the high bacterial numbers were observed because it was Presidents' Day. Visual observation determined that the holding pond was close to overflowing on this day and may have overflowed.

The results of bihourly samples taken in February and March are presented in Table III. Maximum numbers of both organisms were found at 5 P.M. in February and at 1 P.M. in March. Numbers at all other times were generally higher in March than they were in February. Minimum numbers of these organisms were always found in the early morning.

TABLE II
Numbers of indicator bacteria in daily samples in a stream associated with a ski area

	Fecal coliforms		Fecal streptococci	
Day	February	March	February	March
Monday	2.45[a]	0.80	2.45	0.91
Tuesday	1.11	−0.30	1.33	1.12
Wednesday	0.07	—[b]	1.18	0.90
Thursday	−0.48	−0.77	1.50	1.05
Friday	−0.48	−0.49	1.58	1.03
Saturday	0.08	—	1.09	0.48
Sunday	−0.48	2.90	1.14	2.86

[a] Values presented are log means of three samples.
[b] None detected.

TABLE III
Numbers of indicator bacteria in bihourly samples in a stream associated with a ski area

	Fecal coliforms		Fecal streptococci	
Time	February	March	February	March
7 A.M.	0.00[a]	1.63	0.94	1.58
9 A.M.	0.00	1.36	0.83	1.54
11 A.M.	−0.76	2.19	0.57	2.37
1 P.M.	−0.17	3.85	1.22	3.85
3 P.M.	0.78	3.53	1.90	3.75
5 P.M.	2.31	2.90	2.34	3.27
7 P.M.	2.16	3.68	2.21	3.60
9 P.M.	1.97	3.55	1.93	3.44

[a] Values presented are log means of three samples.

Samples were collected for three summers above and below the ski area. Low levels of indicator bacteria were found in these studies (Table IV). When analysis of variance was run on numbers per 100 mL, no significant differences were seen in the numbers of fecal coliforms above or below the ski area ($p = 0.05$). In contrast, when the analysis was made on the basis of numbers per second for this organism, the value in July was significantly higher than the other months above the

TABLE IV
Comparison of numbers of fecal coliforms per 100 mL with numbers passing a point per second

		Fecal coliforms		Fecal streptococci	
Site	Month	Per 100 mL	Per second	Per 100 mL	Per second
Above ski area	June	−0.17[a,b]	4.42	0.80	5.25
	July	1.16	5.10[c]	0.83	4.92
	August	0.64	4.41	1.59	5.32
	September	−0.16	3.24	1.44	4.87
Below ski area	June	−0.23	4.34	0.72	5.16
	July	1.21	5.13	1.05	5.14
	August	1.08	4.83	1.74	5.45
	September	1.05	4.55	1.41	4.92

[a] Values presented are log means.

[b] Data for 1971 and 1972 were used from Skinner *et al.* (1974) with permission from the American Society of Agronomy (*Journal of Environmental Quality*).

[c] Values with the same symbol or no symbol indicate no significant differences between months, p = 0.05.

ski area (p = 0.05). Below the ski area the value in July was significantly higher than the values found in June and September but not August (p = 0.05). When fecal streptococci were analyzed on the basis of numbers per 100 mL the highest number were found in August both above and below the ski area (p = 0.05). This analysis on the basis of cells per second revealed no differences in any month above the ski area while the most cells were found in August below the ski area (p = 0.05).

DISCUSSION

It is evident from the data presented that a breach in the waste treatment system of the ski area occurred. Possible explanations of what happened are that the holding pond overflowed or that a broken pipe between the aeration chamber and the holding pond, observed after the spring thaw, was the source. At any rate, the level of the indicator bacteria in the water column below the ski area dropped quickly after pollution ceased, indicating that the bacteria either washed out, died, or were deposited into the sediments. The last possibility may have some merit since Gary and Adams (1985) found higher numbers of fecal coliforms in the sediment below the ski area in May than during the rest of the summer. Number of fecal coliforms in this latter study numbered less than one per gram (wet weight) of sediment in July and August. Thus even in these sediments the organisms did not last long.

The number of organisms passing a point per second may be a useful concept, particularly in pristine mountain watersheds. As flow slows down both by time and distance, one would expect suspended cells to settle into bottom sediments. This calculation might be used to assess the total numbers of indicator bacteria coming downstream that could impact a certain location. Further research is needed to elucidate the importance of this calculation.

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