WATER QUALITY OF MOUNTAIN WATERSHEDS

By

Samuel H. Kunkle

and

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HYDROLOGY PAPERS
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ABSTRACT

Water quality was investigated from April, 1964 to September, 1965 on mountain watersheds in the Colorado Front Range. The primary objective of the study was to assess water quality characteristics at varying natural flow regimes under conditions of limited land use. Ten stations, ranging in elevation from 7,600 to 9,790 feet, were sampled during the two runoff years. Samples were collected on a weekly to ten-day basis from May to September, and several times during the rest of the year. A total of 604 samples were taken. The parameters measured were: flow; water temperature; pH; turbidity; suspended sediment; dissolved solids; and total, coliform, fecal streptococcus (FS), and fecal coliform (FC) bacteria.

Statistical and graphical analyses indicated that the bacteria groups were closely related to the physical parameters of the stream and were especially dependent on the "flushing effect" of the runoff from snowmelt and rain, summer storms, or irrigation. The seasonal trend for the coliform, FC, and FS bacteria groups was similar: (1) low counts prevailed while the water was $0^{\circ}C$, although bacteria from all groups were isolated during winter; (2) high counts appeared during the rising and peak flows caused by June snowmelt and rain; (3) a short "post flush" lull in counts took place as runoff receded in early July; (4) high counts were found again in the July-August period of warmer temperatures and low flows; and (5) counts declined in September.

Coliforms fluctuated from 0 to about 300 colonies/100 ml depending on the site and season. The FC and FS ranged from 0 to about 75 colonies/100 ml. A few counts following summer storms and during extreme spring flooding rose to several thousand coliform colonies/100 ml and several hundred FC and FS. The FC, FS, and coliforms all clearly defined grazing-irrigation impact; the FC showed the "highest sensitivity" to such pollution. The coliforms rated slightly less, while the FS were the least sensitive.

A greater number of correlations were found among the physical factors during the high flow period of May-June in both years. Minimum pH values occurred near the peak flow with a total range of from 6.3 to 8.7 pH units observed. There was a 0.1 to 0.2 pH unit decrease per 1000 feet of elevation. Turbidity and suspended sediment were positively related to flow and to each other. An approximate 5:1 sediment-turbidity ratio was found. Maximum storm readings were 724 mg/l for sediment and 475 Hellige units (ppm SiO_2) for turbidity. Most of the sediment appeared to be from roads; the periodic sediment readings did not reflect a grazing-irrigation impact. Water temperatures ranged from 0 to $24^{\circ}C$. Dissolved solids ranged between 0 to 205 mg/l; no relations between dissolved solids and other physical or bacterial parameters were found.

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CHAPTER I

INTRODUCTION

Increasing demands on water supplies and growing concern for water quality require watershed managers to know more about the impact of land use on water. A large part of the water supply in many parts of the world comes from high elevation watersheds that are relatively unused at present. It is essential if we are to use these lands more intensively and at the same time maintain water quality at desired levels that we understand the impact of land use on water quality. The first step in such an understanding is a better knowledge of the natural characteristics of these water supplies. Such detailed information on the water quality of wildland mountain watersheds is sparse.

This study presents the results of the first two years of a long range study of the impact of land use on water quality from mountain watersheds. The objective of the first phase of this long range study was to assess water quality characteristics of high elevation watersheds at varying natural flow regimes under conditions of very limited land use. The paper is a condensation of a more complete presentation by Kunkle (1967). A review of literature of natural water quality and the impact of land use thereon is available from the Colorado State University Department of Recreation and Watershed Resources.

Emphasis is placed in this paper on the presentation in detail of the fluctuations and interrelations of the selected water quality parameters. To the extent possible, standard techniques were used in order that results could be compared and utilized wherever there is an interest in water quality of high elevation watersheds. The results are particularly pertinent to areas where snowmelt runoff is an important source of water supply.

CHAPTER II

RESEARCH DESIGN AND METHODS

Study Area

The study was conducted on the Little South Fork of the Cache la Poudre River (Fig. 1). This watershed is located on the northern boundary of Rocky Mountain National Park, approximately 70 air miles northwest of Denver, in north-central Colorado. The stream drains into the Cache la Poudre, which is a tributary of the South Platte River. The catchment is 105 square miles in area, ranging in elevation from 6,600 feet to approximately 13,000 feet. It is a reasonably typical forested watershed of the Rocky Mountains' eastern slope, being covered primarily by spruce-fir (17%), lodgepole pine (47%), ponderosa pine (10%), and aspen (1%) forest types. The alpine constitutes 17% of the total area and range and miscellaneous types account for the remaining 8%.

In a general way the watersheds in this study may be considered as representative of those mountainous areas where both air and water temperatures are low, the influence of man is minimal, and snowmelt runoff is a major contributor to streamflow. There are no permanent residences in the watershed. During the months of June, July, and August there are several hundred temporary residents in the 105 square mile area. These are concentrated at two camps in the center of the area. In addition there are three summer ranch operations. During the months of May through October there are approximately 2000 recreation visits by a combination of fishermen, hunters, picnickers, and sightseers.

Both domestic and wild animals graze in parts of the watershed. There are approximately 350 head of cattle (900 animal unit months) and 2,000 head of sheep (665 animal unit months) grazing during the summer months. The cattle are restricted to the meadows of the lower part of the watershed and the sheep are restricted to less than 1/2 of the alpine area. Elk, deer, mountain sheep, beaver, and many species of smaller mammals and birds inhabit the area.

Using Figure 1 as a guide, stations 1, 3, 4, and 8 receive the major part of the cattle and recreation use impact. Stations 2, 4, and 17 are essentially free of man's impact. Station 17 does include part of the alpine subjected to grazing by domestic sheep. Stations 10, 11, and 15 received only very slight impact by man during the period of study.

There are no industrial or commercial sources of pollution in the study watersheds.

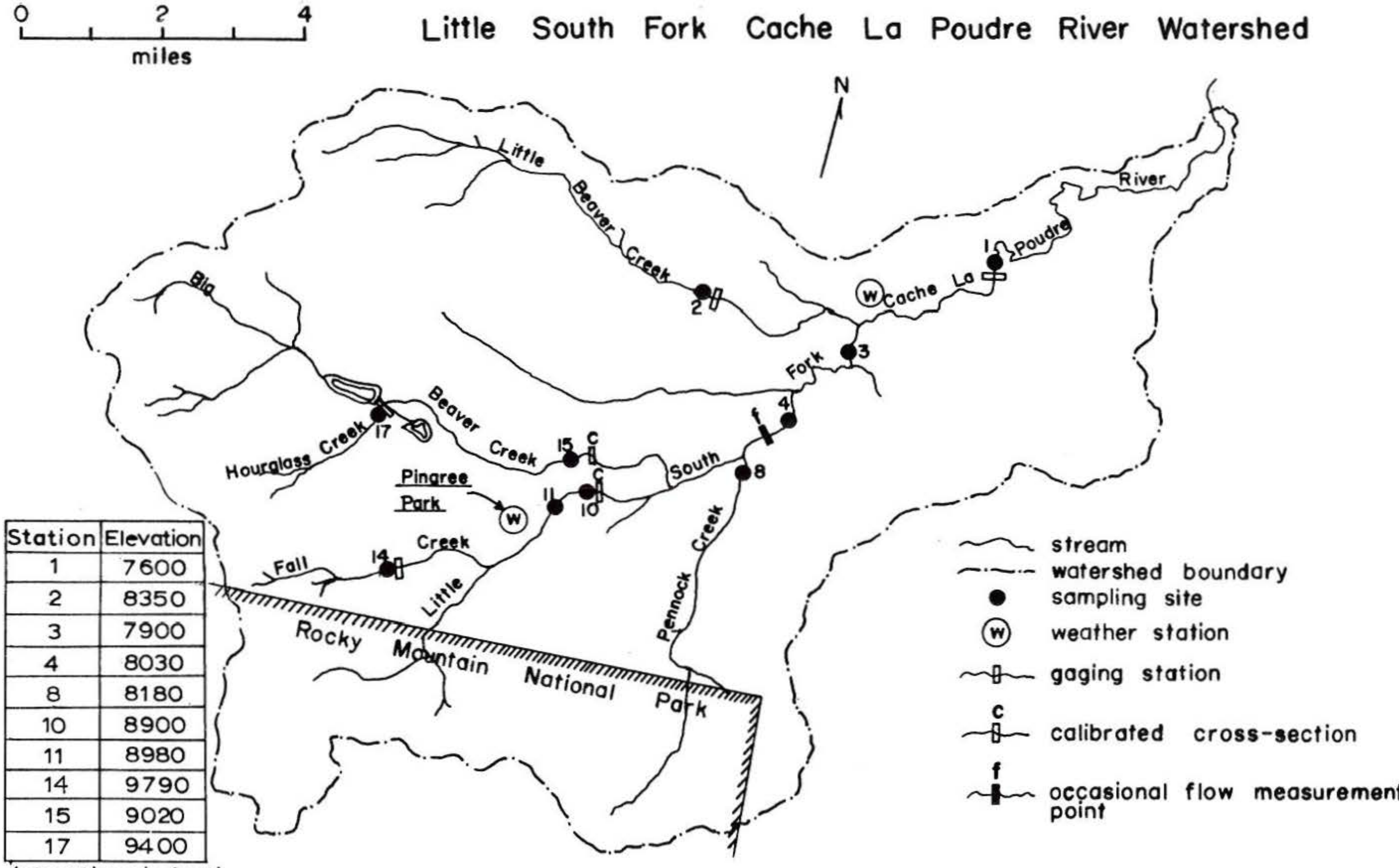
Colorado State University's Pingree Campus is located at Pingree Park on the study catchment. The Little South Watershed is being intensively studied as a "resource complex" with studies underway on wildlife, fishes, timber, geology, recreation, soils and climate in addition to water yields and quality. This watershed is described in detail in the watershed analysis of the drainage (Johnson et al., 1962). Laboratory and shop facilities are available. Weather instrumentation and stream gages are maintained cooperatively by the U. S. Geological Survey, the U. S. Forest Service, and the Department of Recreation and Watershed Resources of Colorado State University. Additional reaches of streams were calibrated where necessary for the study.

Sampling

The stream sampling network was designed to take samples at various elevations within both the montane and subalpine zones. Collection points were located at existing stream gage sites where possible (Fig. 1). Measurement of land treatment impact was a major consideration in sampling site location, and several stations were positioned to sample above and below land use, such as irrigation-grazing (Fig. 2) or campground utilization. Future land treatment was kept in mind and certain sites were located for ultimately recording the effect of increased logging, grazing, recreation, road building, home construction, or other land use expansions. Ten sites were sampled regularly. The sampling route was altered randomly to provide varied sampling times at an individual site.

The study was conducted during the period April, 1964 to September, 1965; two runoff years were observed. Samples were taken at least monthly during the March through November periods. Weekly samples were generally made from May until late summer, a period when stream flow is greatest and land use is most intensive. More frequent collections were made for certain occurrences, such as summer storms, concentrated tourist use, algae blooming, or the heavy peak flows of 1965 (Fig. 3). A four-day study under winter conditions was carried out in March of 1965.

A half-liter polyethylene bottle was used to collect water for the physical parameter analyses; the bottle was inserted in a "D-H 48 depth-integrating hand sampler" (Fig. 4), in order to attain a cross section of the stream-sediment load. Simultaneously 300 ml of water for bacteria analysis was collected in a second polyethylene bottle. This bottle was rinsed thoroughly in the stream prior to filling, and after sampling was transported on ice to the Fort Collins laboratory.



Station	Elevation
1	7600
2	8350
3	7900
4	8030
8	8180
10	8900
11	8980
14	9790
15	9020
17	9400

(elevations in feet)

Figure 1--Study area, showing sampling site locations.

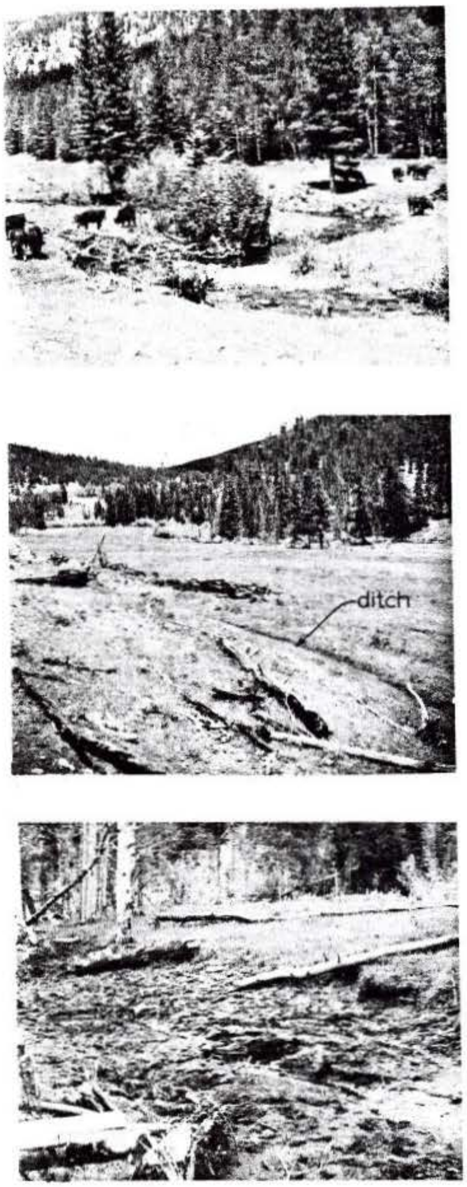


Figure 2--Cattle grazing on irrigated meadow, Pennock Creek (top). Irrigation water from ditch floods onto meadow (center). Irrigation water seeping and draining through cattle-disturbed area (bottom).

Temperature readings were made on site, using a pocket Taylor thermometer, precise to ca. ±0.5°C. Three Foxboro air and water thermographs were installed in late 1964 and used for the 1965 season at sites 1, 2, and 17. Measurement of pH was carried out on site by means of a battery-powered Beckman Model N pH meter, reading pH units to ±0.1 unit. Staff gage readings were taken at calibrated stations during the collection, for later conversion to flow data in cubic feet per second. In some locations staff gages had to be installed and the necessary calibration carried out, using a Gurley flow meter. On the smaller streams this technique produces results precise to ca. ±7%; on the larger streams, during heavy flows, calibrated cross sections would produce less accurate flow readings due to channel changes.

Laboratory Techniques

All bacteria determinations were made by the membrane filter technique (Fig. 5). Coliform counts were determined by following the Standard Methods procedure (American Public Health Association, 1960) for coliform isolation by the membrane filter technique. Fecal coliform concentrations were derived by utilizing m-Fecal Coliform Broth (Difco), with incubation in a water bath at 44.5°C (±0.5°) for 24 hours. Total bacterial counts were made by using m-Plate Count Broth (Difco), incubating plates at 35°C for 24 hours. The fecal streptococci (enterococci) determinations were made by employing m-Enterococcus Agar (Difco) instead of a liquid medium, incubating at 35°C for 48 hours. Further descriptions are given in Standard Methods. Coliform isolations were usually made from an aliquot of 10 ml. This volume provided ±10% accuracy, since each colony on the plate would represent 10 colonies/100 ml. Fecal coliform and fecal streptococcus isolations were made from 50 or 100 ml, so that each colony represented 2 or 1 colony/100 ml respectively.

Turbidity readings were made on a Hellige Turbidimeter, with values recorded in ppm "turbidity units" (based on SiO_2 concentrations). Suspended sediment values were derived gravimetrically by filtering a known volume of sample (ca. 400-500 ml) through a membrane filter. A Mettler Analytical Balance was utilized, and weights were determined to the nearest 0.1 mg, yielding results in mg/l suspended sediment (earlier in the study samples were filtered through fiberglass filters in Gooch crucibles, but the membrane filters were found to be less hygroscopic, very similar in porosity, and easier to weigh). Sediment results were probably precise to ca. ±5 mg/l.

Total dissolved solids determinations were found by evaporating 100 ml of filtrate (after sediment was removed) for 24 hours at 105°C in a pyrex container, weighing the residue, and reporting the results in mg/l TDS. At these very low concentrations, hygroscopic errors are important in that moisture could cause an error of 5 mg/l. In view of hygroscopic errors and the weighing accuracy, the dissolved solids results are probably precise to around ±7 mg/l. Weighing accuracy is extremely important in measurement of such low concentrations of dissolved solids. For example, a weighing error of only .0005 g for a 25 mg/l sample represents a 20% error. Use of membrane filters in place of the very hygroscopic Gooch crucibles helped reduce errors, but weighing discrepancies remained an obstacle to the collection of accurate low-concentration dissolved solids data.

Chemical tests were carried out on certain samples by the Soil Testing Laboratory, Colorado State University, using colorimetric techniques. Determinations included Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4, and NO_3.

Data Analysis Techniques

Each year's data were entered onto punch cards, for use in an IBM 1401 computer. In 1964, "mark sense" punch cards were employed in the field and laboratory, with observations and determinations marked directly by pencil onto specially prepared cards. The marks were machine read and converted to punches at the season's end. The mark sense cards were found to be unsatisfactory (pencil smudges for example caused much grief), and in 1965 the data were punched directly onto standard 80-space cards.

Data for each entire year were analyzed by sites for between-parameter correlations; the results were extremely poor. Several parameters were then put on plastic overlays and graphical comparisons were made. The relations between parameters in the spring to early summer period were seen to be different than the same relations in mid-to late summer. After numerous comparisons the season's data were separated by the convenient (and perhaps logical) breaking point--the peak of the hydrograph. Analysis

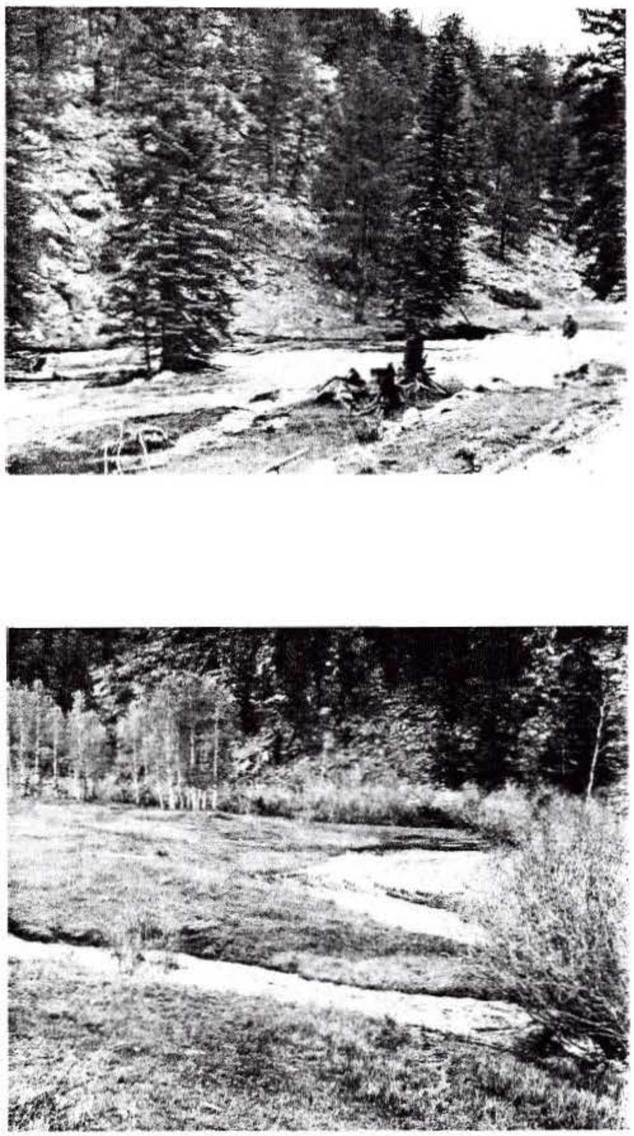


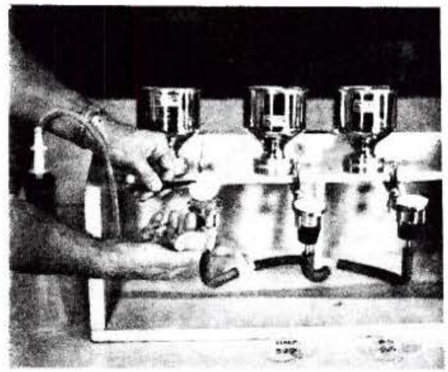
Figure 3--High flows of June, 1965 "flushing out" Pennock Creek (top) and cutting new channel in meadow of Little Beaver Creek (bottom).

Figure 4-- Wintertime collection of bacteria sample (top) and summer sediment collection with "depth-integrating" sediment sampler (bottom).

for correlations between parameters was once more carried out by sites for Time Period I (from spring melt until the peak flow) and Time Period II (from peak until autumn) separately. Much more frequent and higher correlations resulted. Graphical comparisons (using plastic overlays) were relied on heavily in nearly all analyses because of the obvious lack of linear correlations among parameters.

The Water Quality of the Area

The waters of the study catchment are exceptionally "pure" in comparison to many lower elevation areas. As seen in the chemical analyses of Appendix Table B, parts per million results of all the common chemical components are quite low. The pH values are near neutral, temperatures are cold, and the coloring is normally very light. Sediment is exceptionally low, except during storms or very early spring runoff. The runoff is largely from snowmelt sources with a high percentage of the yearly runoff occurring in the May-July melt period, as shown in the hydrographs of Figure 6.



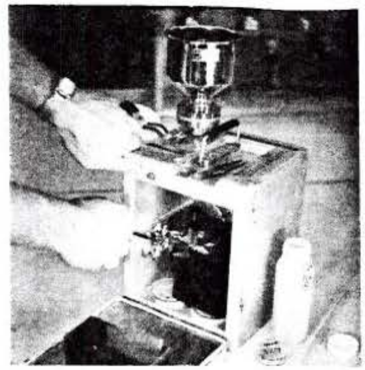


Figure 5-- Membrane filter apparatus: funnels, filter papers, and suction flask (top). Hand operated unit for field use (center). Autoclave for pipettes, funnels, and other supplies (bottom).

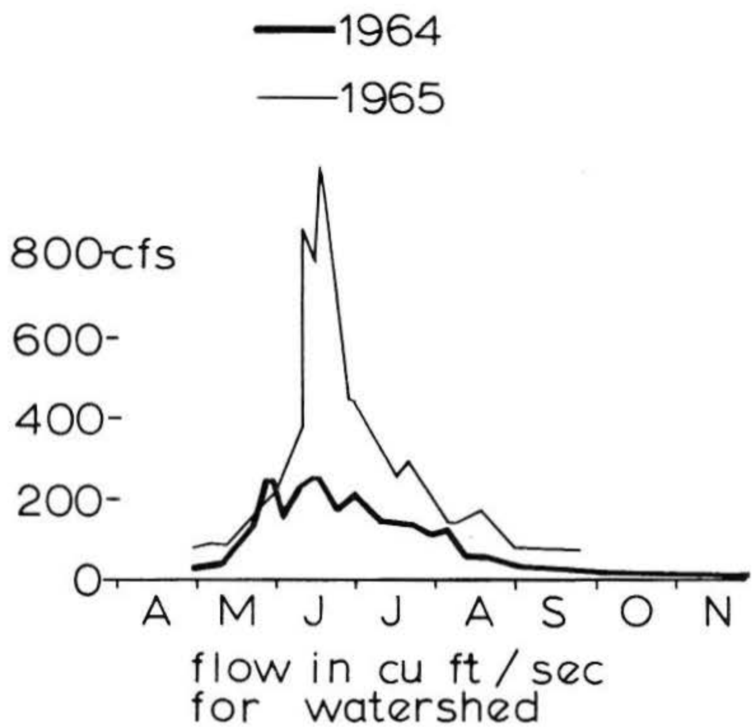


Figure 6--Hydrographs at lowest station on the watershed for runoff seasons of 1964 and 1965.

CHAPTER III

THE PHYSICAL PARAMETERS OF WATER QUALITY

Data relating each of the physical parameters of water quality--temperature, pH, turbidity, suspended sediment, and dissolved solids--to flow and the interrelationships of these physical factors with each other are presented in this chapter. The data are analyzed by two time periods: Time Period I is from initial melt runoff until peak flow; Time Period II is from peak flow until autumn. Extreme minimum and maximum values found for all parameters, by site, are presented by Kunkle (1967).

Temperature

Analysis of the data taken at sampling time shows almost no significant flow-water temperature correlations at the 95% level in all time periods of 1964-1965 (Table 1). Graphic comparisons of water temperature and flow data for the two years (Figs. 7 and 8) show the major difference in water temperature-flow relations in 1964 as opposed to 1965 to be: (1) the snow-supplied, peak June flows of 1964 were accompanied by rising water temperatures, whereas (2) the heavy rains of June, 1965 brought about peak flows during decreasing water temperatures. Late summer water temperatures rose in both years, as might be expected.

Water-air thermographs were in operation during 1965 at Stations 1, 2, and 17. Station 17 (Hourglass Creek) lies in a forested, subalpine area at an elevation of 9,400 feet, where snow melting in the immediate vicinity upstream provides the flow. Station 1 (main stem, Little South Fork) is located at the lower end of the watershed at 7,600 feet, below open meadows where the stream has meandered and been exposed to warming. Records from the thermographs at these stations indicate that daily maximum water temperatures in summer, 1965 occurred as much as three hours earlier in the day at the 9,500 foot elevation station (ca. 1200 to 1400 hr) as at the 7,600 foot station (ca. 1400 to 1600 hr).

An analysis of 5-day means (Figs. 9 and 10) reveals the relations between air and water temperatures. Although the air temperature graphs are not greatly different for the two stations, summer water temperature fluctuations at the higher station average about 3°C per day, while 5-6°C fluctuations are shown for the lower site. Daily minimum values of water temperature during the early summer months appear to be influenced by the proximity of the thermograph to the snowmelt source. At Station 17, near the melting snow, the daily minimum water temperatures in June-July, 1965 were often below the daily minimum air temperatures. At Station 1, where the water had been exposed to air temperatures for several hours, the daily minimum water temperatures during the same period were seldom below the daily minimum air temperatures.

The monthly temperature means for both thermograph sites appear in the Appendix, Figure A. The highest water temperature at sampling time encountered during the period of study was 17°C at Station 1 on August 18, 1964. The highest water temperature recorded on the continuous monitoring thermograph was 24°C at Station 1 on July 10, 1965.

Hydrogen Ion Activity (pH) Relations

Flow and pH

Distinct differences were observed between the two years of sampling in respect to pH-flow relations. Nearly all significant 95% pH-flow correlations occurred in 1965 (Table 1). The nine pH-flow correlations in both time periods of 1965 were all negative. In Figure 12, the negative pH-flow relationships for 1965 are graphically shown, with values of pH and flow for each site being compared. These graphs show for 1965:

1. some rise in pH at most sites during the early spring (April-May) melt period;
2. a drop in pH for most sites as runoff increases, with pH minimums occurring during the peak flows of June;
3. a general (not consistent) rise in pH for all sites as the summer continues into autumn.

The 1964 data do not present the distinct pH-flow relations observed in 1965; the graphs of pH-flow values (Fig. 11) for 1964 show:

1. minimum pH values during the first peak flows in June, at nearly all sites, similar to the trend for 1965 (low pH values also occurred in August at several stations).
2. fairly constant pH readings for much of the summer following the peak flows of June, without the general rise in pH shown in the 1965 data.

The only major similarity in pH values for both years was the occurrence of pH minimum values at or near the first large spring-early summer peak in flow. Individual sites varied widely in pH values, but the seasonal trend in pH, as described above for each year, was similar for nearly all stations on the watershed. The lowest pH observed during the two years was 6.3 (Station 1, August 4, 1964), and the highest pH recorded was 8.7 (Station 2, May 30, 1964).

TABLE 1--Significant correlations at 95% between flow and the other physical parameters.

Year	TP	Station	pH	Temperature	Turbidity	Suspended Sediment	Dissolved Solids
1964	I	11	+				
		8	-	+	+		
	II	4		+			
1965	I	11			+		
		10	-	-	+		
		4	-		+		
		3	-		+		
		1	-		+	+	
		17			+	+	
		15			+	+	
		2	-		+	+	
	II	11	-			+	-
		10	-			+	
		4				+	
		3			+	+	
		1				+	+
		17	-		+	+	
		15				+	
		2	-		+	+	+

TP = Time Period. Time Period I is from initial spring melt until peak flow; Time Period II is from peak flow until autumn.

+ = positive linear correlations

- = negative linear correlations

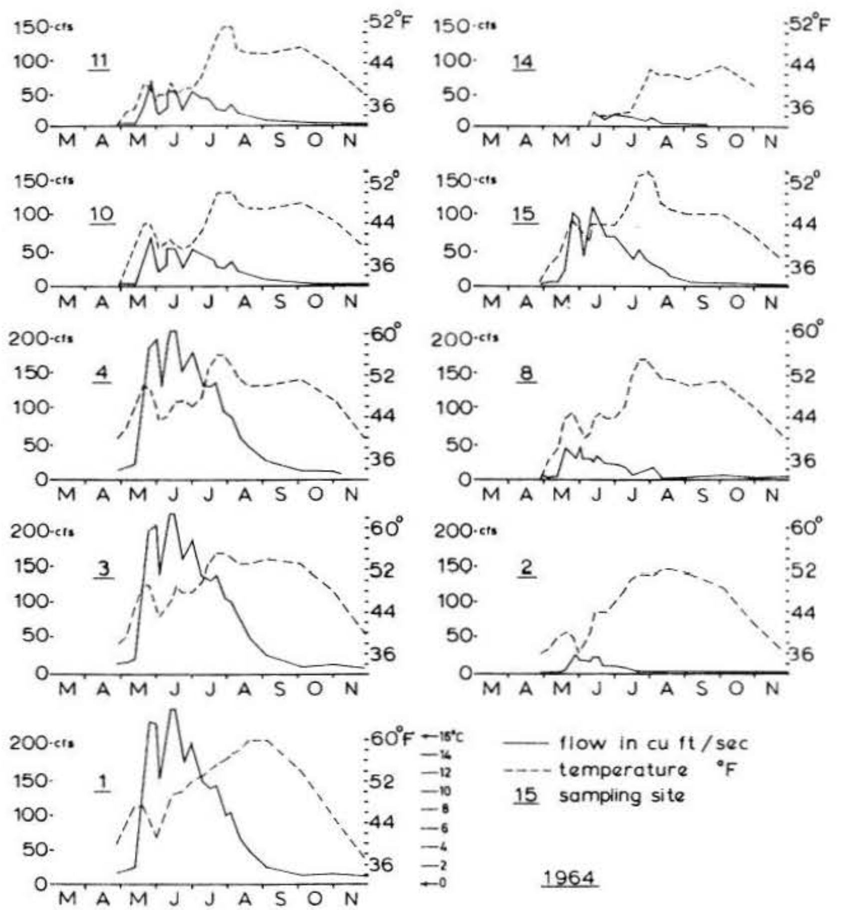


Figure 7--Flow and temperature observations for individual sampling sites during 1964. Temperature graphs represent moving means of three consecutive samples. Flows are values observed at sampling time.

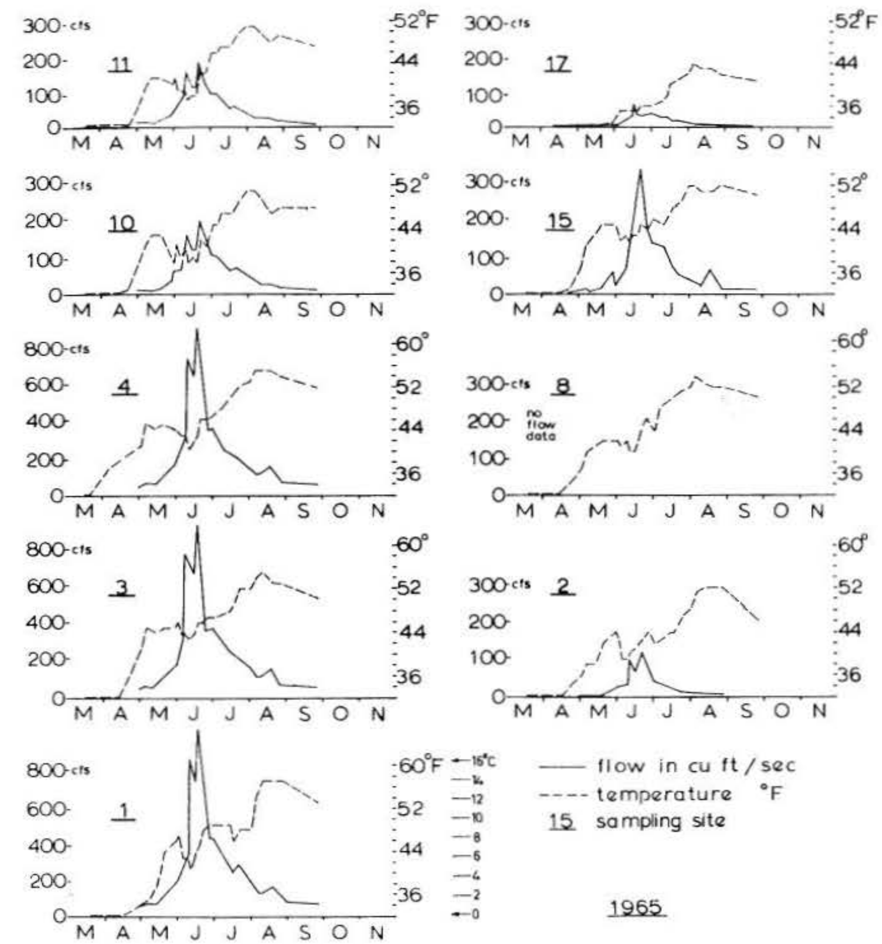


Figure 8--Flow and temperature observations for individual sampling sites during 1965. Temperature graphs represent moving means of three consecutive samples. Flows are values observed at sampling time.

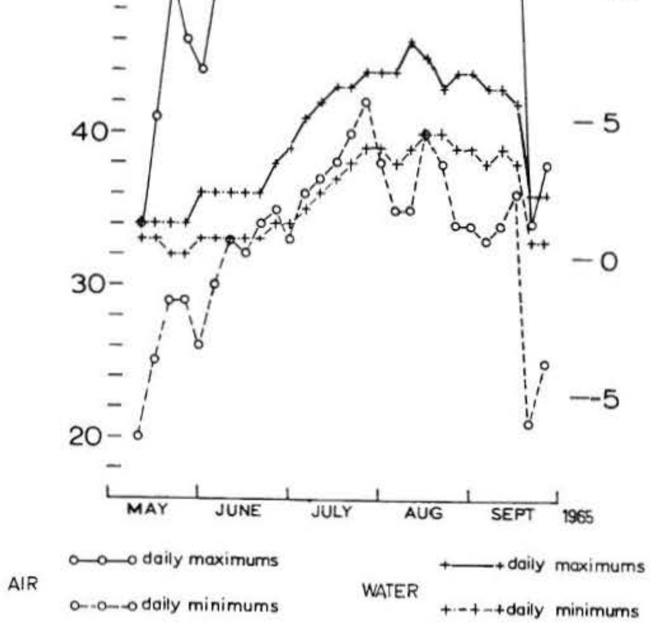


Figure 9--Daily maximum and minimum temperature values for water and air, plotted by 5-day means. Hourglass Creek.

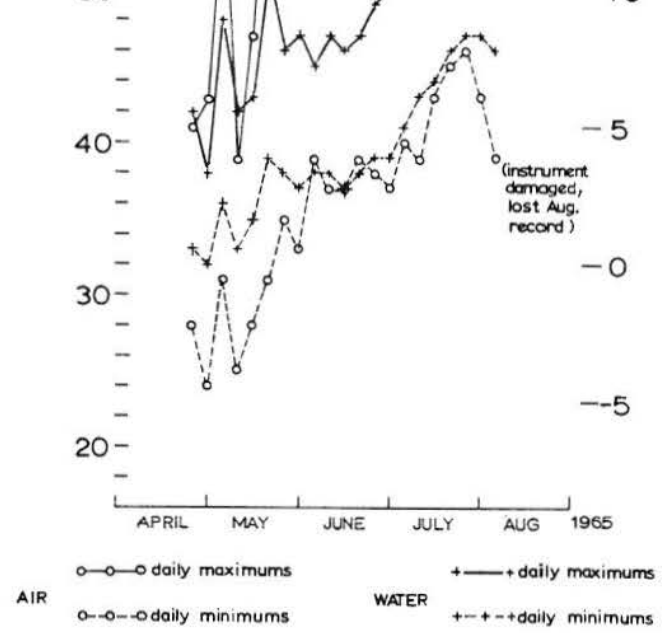


Figure 10--Daily maximum and minimum temperature values for water and air, plotted by 5-day means. Main stem.

Sediment, Turbidity, and pH

Spring to autumn pH and flow values were seen to be inversely related. Turbidity and suspended sediment on the other hand were positively related to flow, as seen in the Table 1 list of correlations. The pH-turbidity and pH-sediment correlations probably were significant due to the dependence of pH, turbidity, and sediment on the common factor, flow. It is also worth noting that the sediment of the watershed (mostly from roads) often had a pH of ca. 6.5. Perhaps in a year of heavy rains, such as 1965, sediment concentrations can lower pH.

Higher, turbid flows in 1965 apparently accentuated relationships among the physical factors, resulting in an increase of significant (95%) correlations. In Time Period I (from runoff initiation until peak flow) 1965, seven out of the nine sites showed significant pH-turbidity negative correlations, whereas the same time period in the much drier year of 1964 showed only two out of nine sites with significant pH-turbidity correlations. Time Period II (from peak flow until autumn low flows) exhibited a marked absence of pH-turbidity correlations in both years.

The pH-sediment relations appear very similar to the pH-turbidity relations described above: again the significant correlations commonly occurred only in the heavy flow period of 1965.

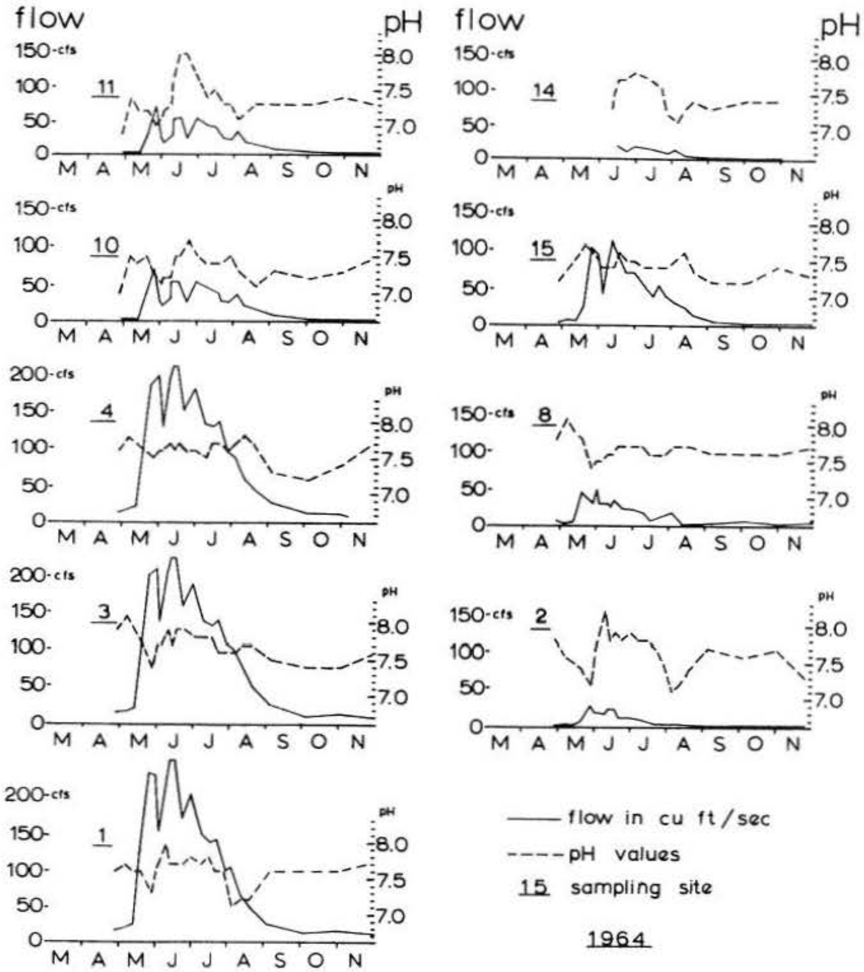


Figure 11--Flow and pH observations for individual sampling sites during 1964. Graphs of pH are moving means of three consecutive samples. Flows are values observed at sampling time.

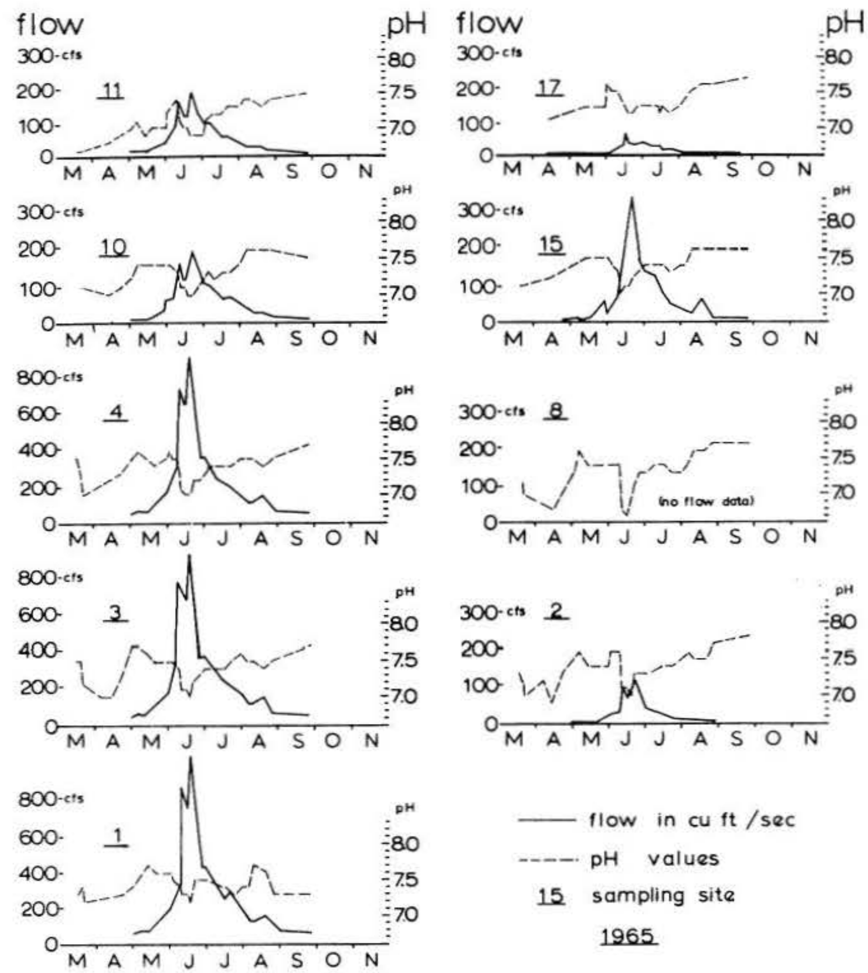


Figure 12--Flow and pH observations for individual sampling sites during 1965. Graphs of pH are moving means of three consecutive samples. Flows are values observed at sampling time.

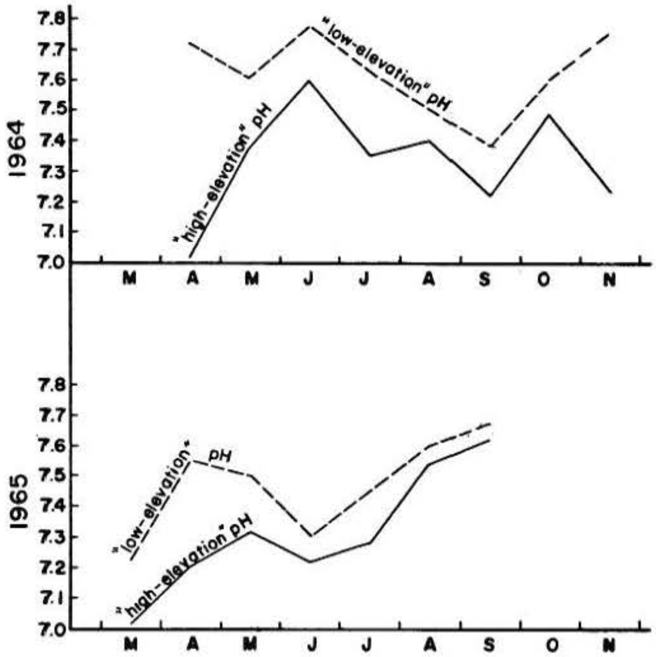


Figure 13--An elevation comparison of pH for both years, where "high elevation" values are an average of observations from Stations 10, 11, 15, 17 and 14 . "Low elevation" readings are an average of values from Stations 1, 2, 3, and 4.

Elevation and pH

There is indication that pH is somehow related to elevation. The 1964 and 1965 stream pH values from the sampling network averaged about a one-tenth to two-tenths pH unit decrease for each increase of 1000 feet elevation within the range of elevation sampled. This elevation-pH relation appears in Figure 13, where "high elevation" values from the watershed are compared with "low elevation" values. The pH readings from Stations 10 (8,900 feet), 11 (8,980 feet), 15 (9,020 feet), 17 (9,400 feet), and 14 (9,790 feet) are averaged to give the mean monthly "high elevation" pH value; the mean monthly "low elevation" pH reading is derived by averaging pH values from Stations 1 (7,600 feet), 2 (8,350 feet), 3 (7,900 feet), and 4 (8,030 feet). As seen in Figure 13, in every month of both years, the "low elevation" pH value exceeds the "high elevation" reading.

Paired Stations Comparison of pH

Two sampling sites at nearly the same elevation may have distinctly different pH values. A comparison of pH values for two sites--Stations 10 and 11--has been made. The two sampling sites are only one-quarter mile apart on the stream so that by taking samples from the two stations at nearly the same time, differences in flow, temperature, or time of day remain insignificant. The major differences apparent in the two stations are the physical features of the stream immediately above the sampling sites: Station 11 is located below a long, flat reach of meandering stream, whereas Station 10 (downstream from 11) lies below a stretch of rocky, steeper gradient, well-aerated stream.

TABLE 2--Comparison of "winter" pH values at sampling times for Stations 10 and 11, showing distinct difference in pH between the two stations.

Date	pH	
	Station 10	Station 11
Nov. 28, 1964	7.8	6.9
Mar. 18, 1965	7.1	6.4
Mar. 19, 1965	7.0	7.0
Mar. 20, 1965	7.1	6.6
Apr. 13, 1965	6.8	6.7
Apr. 22, 1965	7.5	7.3
Nov. 24, 1965	7.2	6.9
Nov. 25, 1965	7.2	6.9
"winter mean"	7.2	6.8

In Figure 14, moving means from each of the paired stations are shown. Station 11 (below the meanders) clearly had lower pH values than Station 10 (below the aerated reach) during the 1965 summer season, with exception of the rainy period in mid-June. Exact values used in deriving the graph are found in Appendix Table A.

The "winter" samples of 1964-65 (Table 2) showed an even greater trend for lower pH values at Station 11 (below the meanders) than at Station 10. The 1964 summer season (Table A, Appendix) did not present a pH difference between the two sites, despite the consistent differences shown during other seasons.

Turbidity and Suspended Sediment

Turbidity-Sediment-Flow Relations

The bar graphs of turbidity, suspended sediment, and flow in Figures 15 and 16 show the positive relationship of these three factors in both years of sampling. Turbidity-sediment-flow relations--not concentrations--for both years were similar, and seasonal trends were much the same for the two years. The much larger runoffs of 1965 produced far higher sediment and turbidity concentrations, especially at the downstream sites. Note that a different scale was necessarily used for each year's graph, due to the great difference in values between years.

There is a tendency (with exceptions) for turbidity and sediment values to be greater at lower sites on the watershed. Stations at high elevations on the catchment (e. g., 14 and 17) have consistently low sediment yields, under present conditions. For reasons unknown, Little Beaver Creek (Station 2) had higher sediment yields, in both years than might be expected, compared to the other stations. Using regular non-storm samples during both years, the maximum sediment values (in mg/l) attained by each station (by number) were: 1, 118; 2, 178; 3, 184; 4, 207; 8, 120; 10, 219; 11, 84; 14, 9; 15, 85; and 17, 17. A few samples were collected during thunderstorms, and analysis showed a turbidity of 475 Hellige Units (ppm SiO_2) and a sediment concentration of 724 mg/l for one storm (Station 10) to be the maximum values found to date on the catchment.

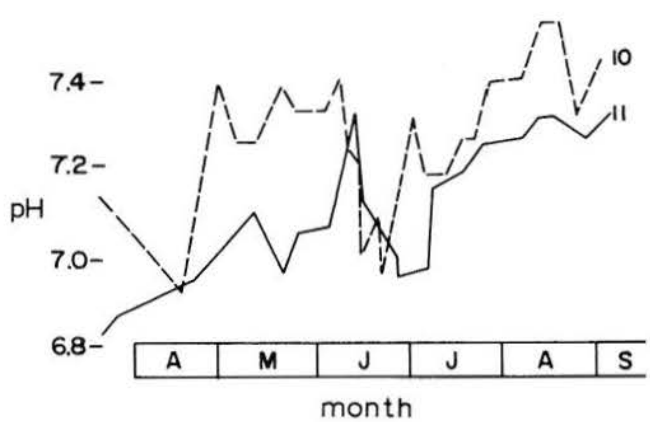


Figure 14--Spring and summer pH value comparison between Stations 10 and 11, 1965, using moving means of three consecutive samples.

Statistically, the turbidity-flow and sediment-flow relations are accentuated during greater flows, as in 1965. Every station analyzed[1] in 1965 showed significant (95%) positive turbidity-flow and/or sediment-flow correlations (Table 1); on the other hand, the 1964 data were almost entirely devoid of statistically significant turbidity-flow or sediment-flow correlations.

The bar graphs (Figs. 15 and 16) were constructed with the sediment scale five times that of the turbidity scale. A 5:1 ratio allows better graphical comparison. This sediment to turbidity ratio of 5:1 appears again in Figure 17, where data from the main stem stations of the Little South Fork, 1965, are used to present a scattergram of sediment vs. turbidity. Almost every point of the scatter falls to the left of a 1:1 ratio line, and the sediment-turbidity ratio is seen to be perhaps 4:1 or 5:1. In other words the Hellige turbidity unit values from our catchment should be multiplied by perhaps five to provide an estimate of sediment in mg/l.

The 1965 data also show a far greater number of turbidity-sediment (all positive) correlations than the 1964 data, as seen in Table 3.

TABLE 3--Significant turbidity-sediment correlations for sampling sites, by time periods, during both years. Time Period I is from initial spring melt until hydrograph peak; Time Period II is from peak until autumn.

TP	1964		1965	
	Station	Percent	Station	Percent
I	1	95	11	99
	2	99	4	95
			3	99
			1	99
			17	99
			15	95
			8	99
II	1	95	3	99
			1	99
			2	99

[1] Station 8 had no 1965 flow data and therefore was not included in this analysis.

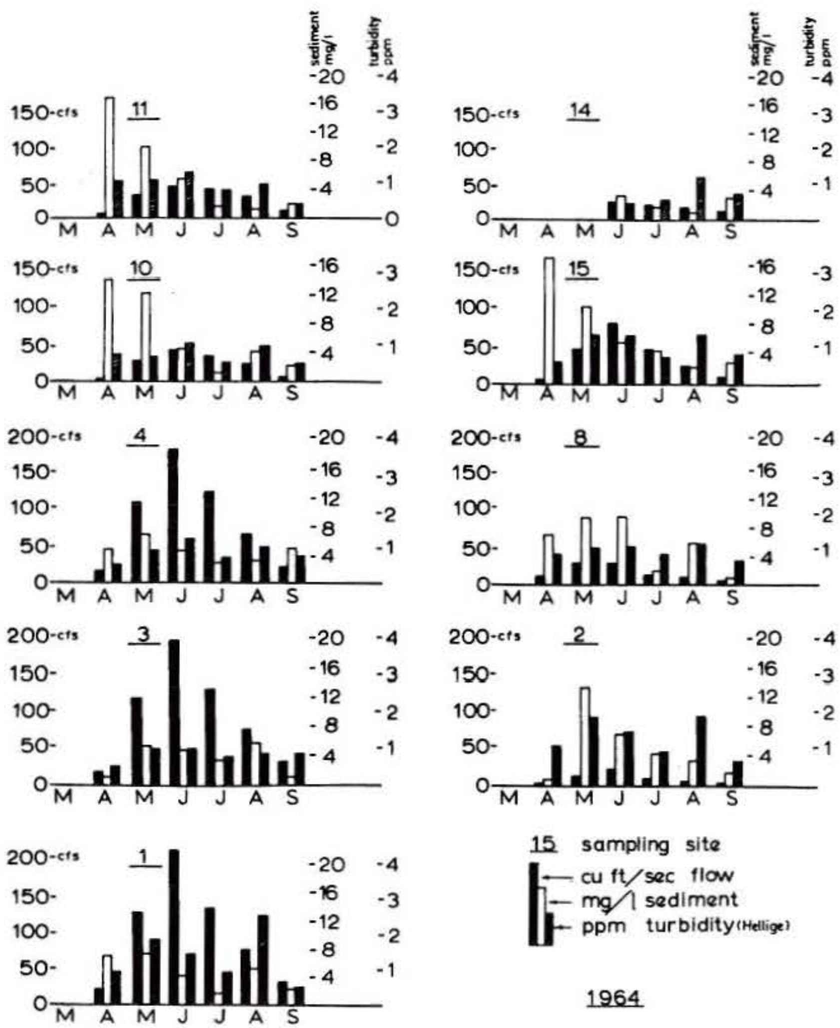


Figure 15--Turbidity, suspended sediment, and flow. Mean monthly values at each sampling site, 1964. (Note the difference in scale in Fig. 16).

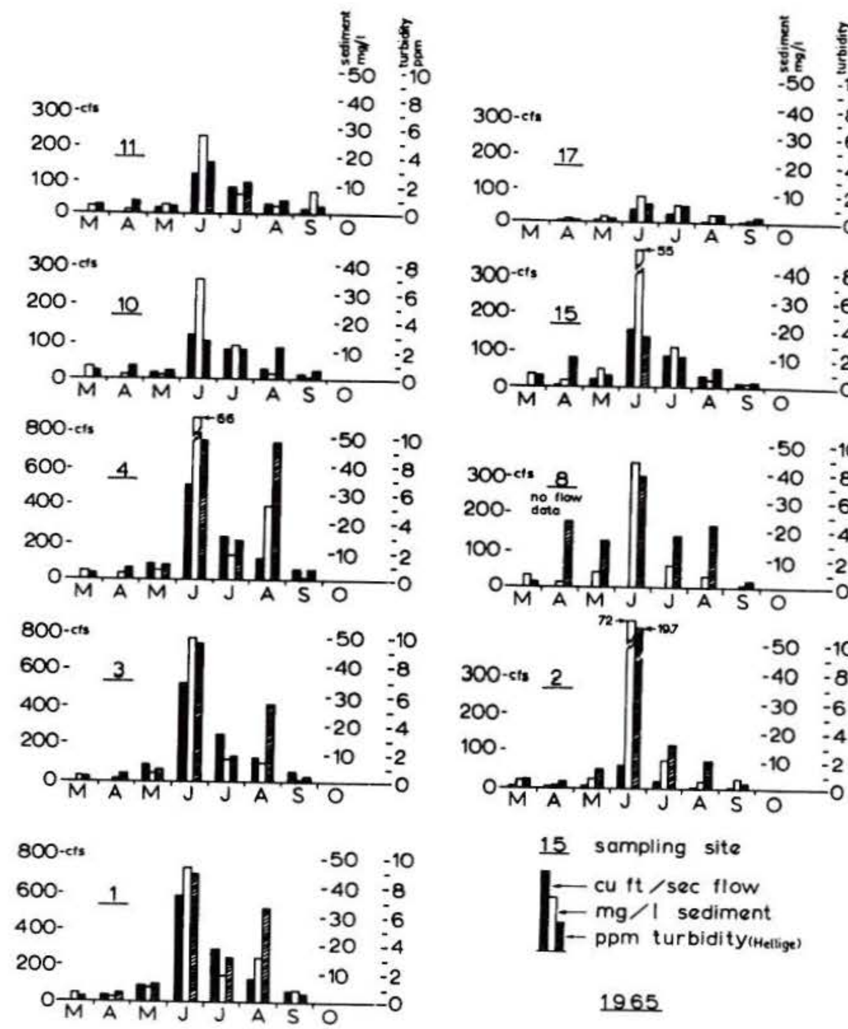


Figure 16--Turbidity, suspended sediment, and flow. Mean monthly values at each sampling site, 1965. (Note the difference in scale in Fig. 15).

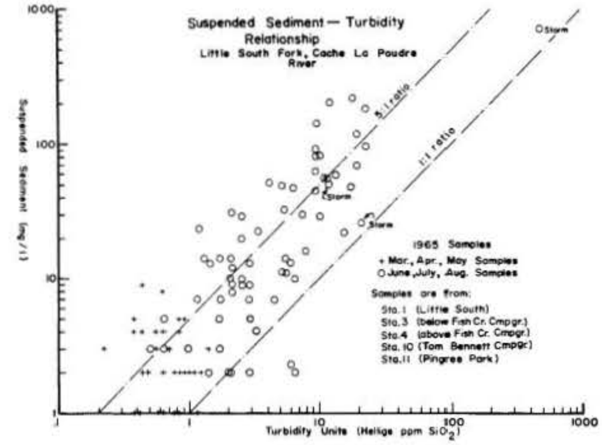


Figure 17--Suspended sediment vs. turbidity scattergram of values from sampling sites on the main stem of the Little South.

Impact of Land Use on Turbidity and Sediment

Large scale land use on the watershed was insignificant during 1964 and 1965. Sediment concentrations from storm runoff probably best describe land use impact (Table D, Appendix). Observation of surface runoff during thunderstorms indicated that roads probably contributed most of the storm sediment, while sheet erosion or gullying appeared to be very minor sources of sediment.

There was no indication (by routine sampling) that the level of human use in campgrounds, picnic areas, or cabin sites increased sediment in the streams. New roads, reservoir construction, and logging are potentially major sediment sources in the next few years.

Comparison was made of a pair of subwatersheds--Pennock Creek and Little Beaver Creek--where the former was grazed and irrigated, the latter not. The grazed catchment did not show higher sediment values than the natural watershed (Fig. 18). No significant amount of erosion was common on either drainage. By contrast, three bacteria pollution indicators distinctly showed land use impact on the grazed drainage (see Chapter IV).

Dissolved Solids Concentration

The bar graph presentation of the data (Fig. 19) shows no distinct seasonal trend for dissolved solids common to all sites on the catchment. The graphs show no apparent relation between dissolved solids concentrations and flow. Almost no statistically significant dissolved solids-flow correlations appear (Table 1). The comparisons of monthly mean values of dissolved solids with flow, temperature, coliforms, and pH made in Figures B to J, Appendix, show no relationship between dissolved solids and the other parameters. The dissolved solids graphs are quite erratic.

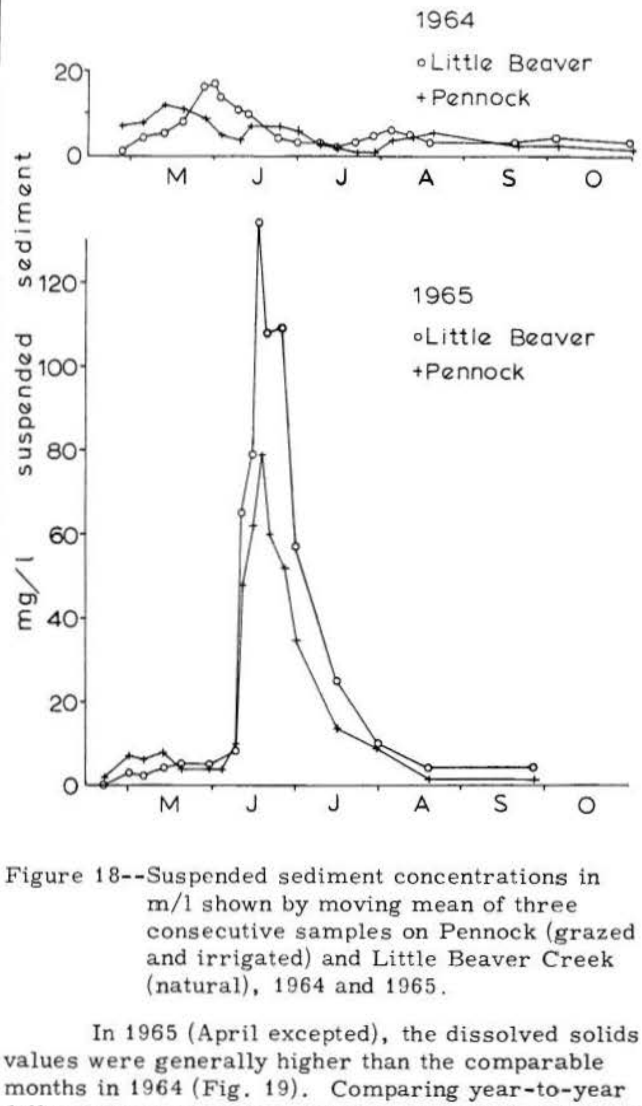


Figure 18--Suspended sediment concentrations in m/l shown by moving mean of three consecutive samples on Pennock (grazed and irrigated) and Little Beaver Creek (natural), 1964 and 1965.

In 1965 (April excepted), the dissolved solids values were generally higher than the comparable months in 1964 (Fig. 19). Comparing year-to-year differences of both flow and dissolved solids by using the graphs of Figures 6 and 19, it appears possible that the higher flows of 1965 contributed the increased dissolved solids concentrations of that year, in which case it might be inferred that dissolved solids on the watershed are derived more from surface sources than from ground water. The highest dissolved solids concentration was 205 mg/l at Station 8 on May 19, 1965; the lowest dissolved solids concentration observed was 0 mg/l at several stations during Time Period II, 1964.

Chemical tests were run for certain samples. These results appear in Table B, Appendix.

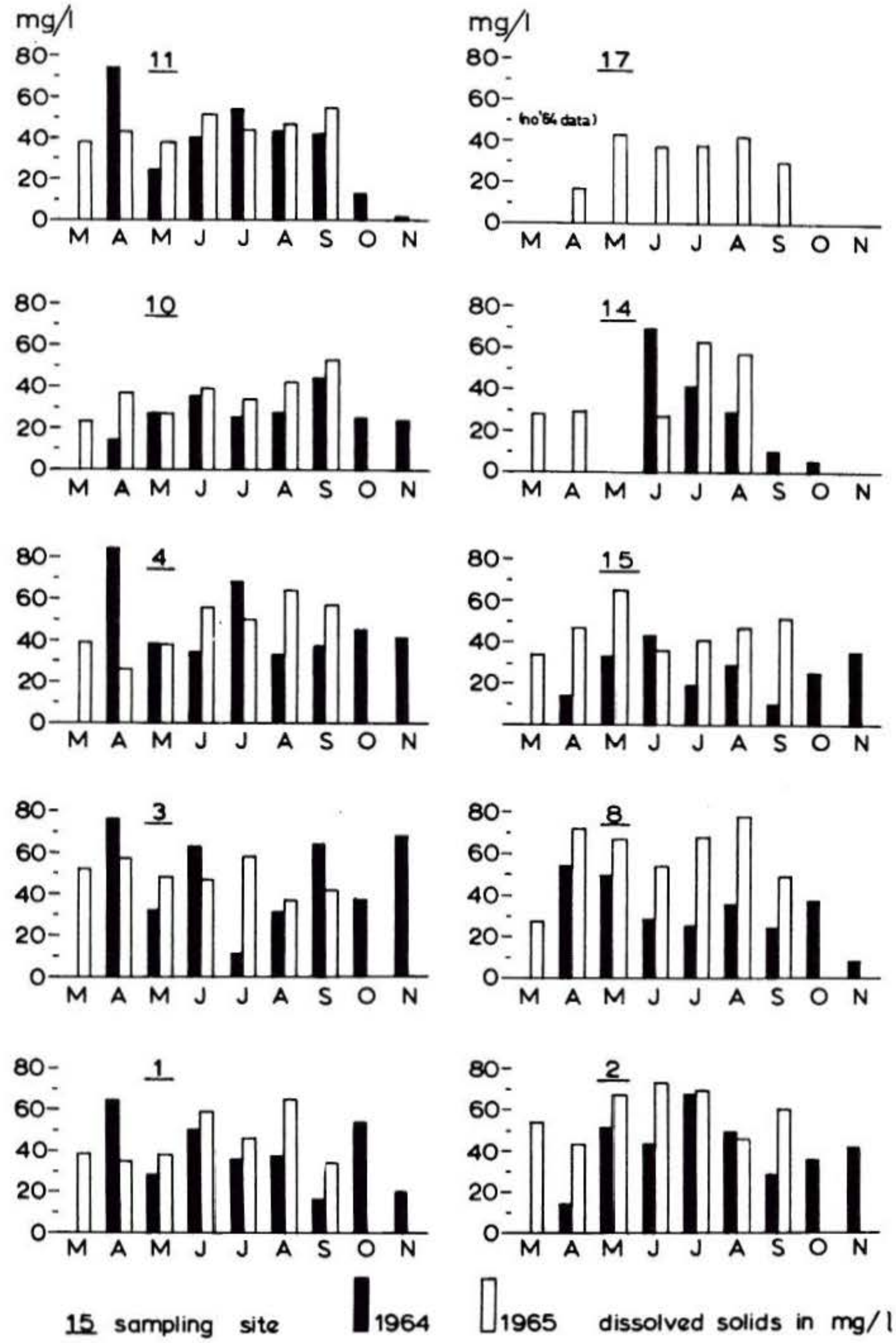


Figure 19--Comparison of the mean monthly dissolved solids concentrations for each sampling site during 1964 (black) and 1965 (white).

CHAPTER IV

THE BACTERIAL PARAMETERS OF WATER QUALITY

The bacterial parameter data from both sampling years are presented in this chapter showing mean values and ranges for the bacteria groups at each site, the distribution of bacteria concentrations area-wise on the catchment, the comparison of Time Period I to Time Period II values for each bacteria group, the interrelationship between bacteria groups, and land use impact on the bacteria counts. Linear correlations between the bacteria groups, by year, site, and time period appear in Figure 20. Total bacteria counts for 1964 appear in Table C, Appendix. Bacteria to physical parameter relations are presented primarily in Chapter V.

Ranges of Bacteria Concentrations

A frequency distribution of a site's bacteria concentrations by class intervals (Figs. 21 and 22) categorizes observations, showing the broad bacteria count distribution for each year of sampling. Such a breakdown depicts "typical" bacteria counts for a site during the year (usually different from the mean value), shows the range of concentrations pictorially, and facilitates site-to-site comparisons.

The Coliforms in 1964-65

In Figure 21, coliform classifications for all sites during 1964 and 1965 are presented, with class intervals of:

class a =	% samples	with	0-19	colonies/100 ml
" b =	"	"	20-49	"
" c =	"	"	50-99	"
" d =	"	"	100-299	"
" e =	"	"	≥300	"

The number of observations taken at each site appears in parentheses by each bar graph. The stations all had approximately equal numbers of observations (except Station 14), taken from the spring to autumn period. A greater number of observations were taken in late spring to early summer, making the histograms biased toward values of this period.

Station 14 is exceptional in having had only half as many observations as the other sites. In 1964, sampling was reasonably periodic at the site, but in 1965, heavy snows reduced spring sampling at this station; this reduced the number of zero or near zero concentrations of the springtime period and consequently made the station's distribution graphs biased in 1965. Probably the class "a" group for Station 14 should be a much larger percentage.

The most obvious feature presented by the Figure 21 graphs is the wide range of bacteria concentrations found at most sites. Only at very few sites (e. g. 17) did the observations fall predominantly

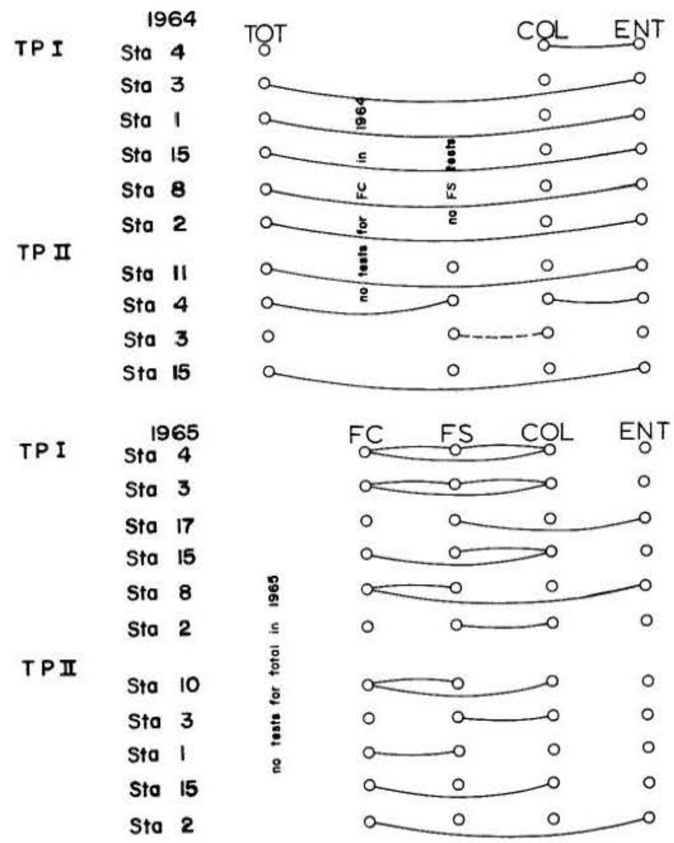


Figure 20--Correlations between bacteria groups, by year, site, and time period. Positive correlation at 95% = solid line; negative = dashed. Groups are: total, fecal coliforms (FC), fecal streptococci (FS), coliforms (COL), and the enterics (ENT).

into one or two classes; at most sites a wide range of values was common.

In 1964, many sites at both the higher (Stations 10, 11, and 15) and lower (Stations 1, 3, and 4) elevations showed similar distributions of bacteria counts in the "a-e" class breakdown. Distribution by classes was similar for 1964 and 1965, although lower sites (1, 3, and 4) showed fewer observations in class "a" in 1965 (i.e., less "zero" counts were isolated).

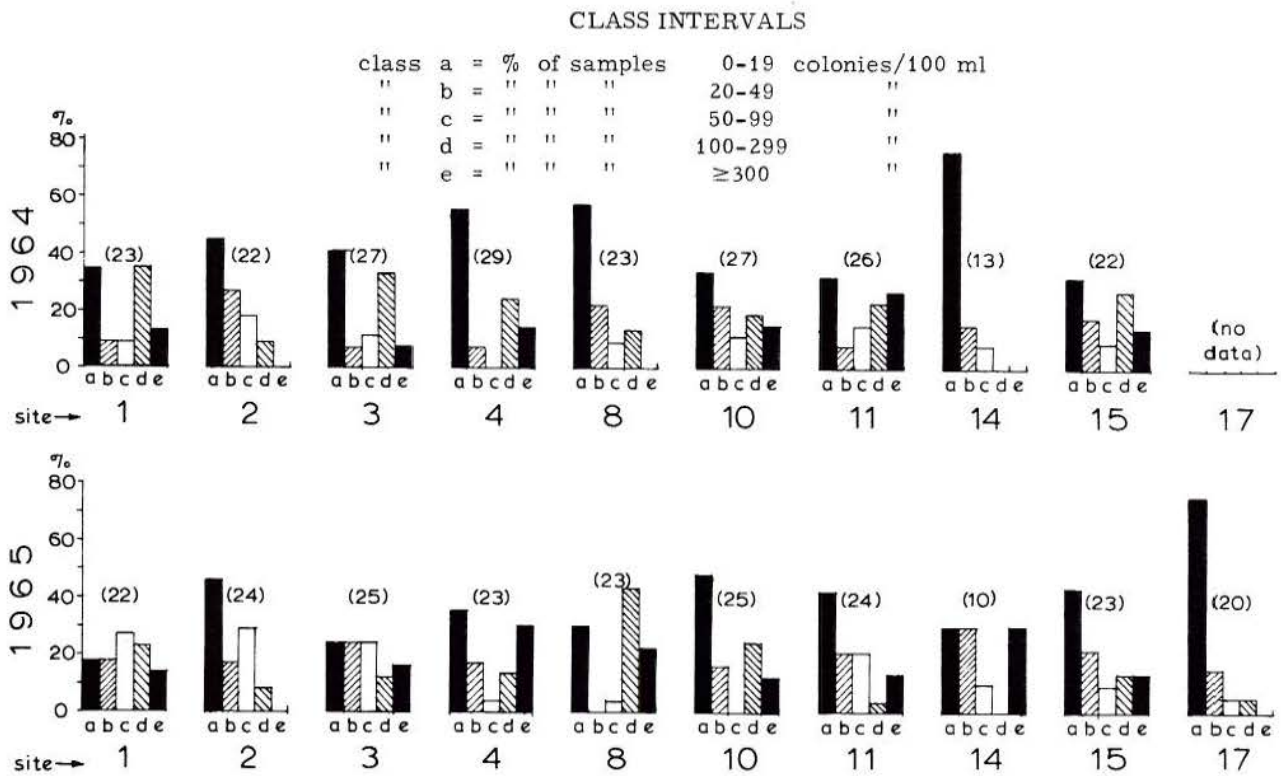


Figure 21--Coliform frequency distribution at sampling sites in 1964 and 1965 by class intervals a-e. Numbers in parentheses are numbers of observations for each site.

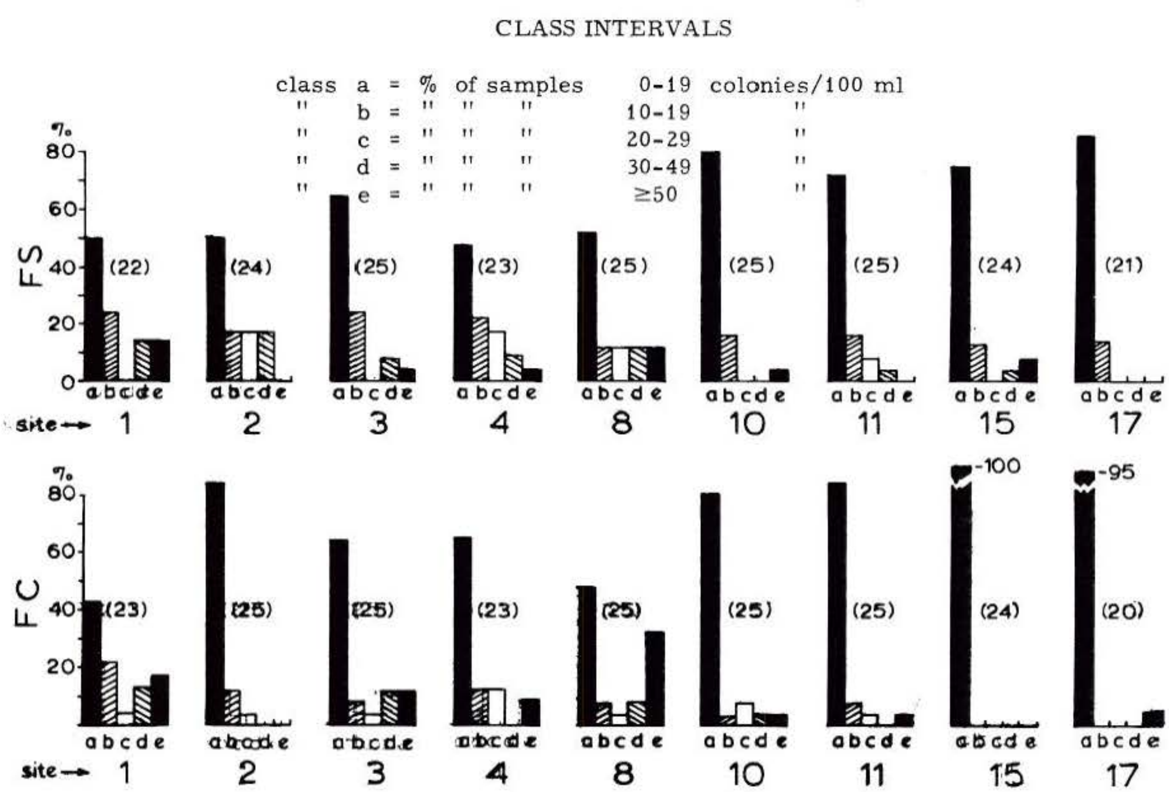


Figure 22--Fecal streptococcus (FS) and fecal coliform (FC) frequency distribution at sampling sites during 1965 by class intervals a-e. Numbers in parentheses are numbers of observations for each site.

Stations 2, 14 (in 1964), and 17 showed a highly skewed distribution toward classes "a" and "b"; this skew toward lower concentrations is predictable for such high elevation or "virgin" sites.

The 1965 results for Station 8 seem to depict grazing impact (higher percentage of classes "d" and "e"), but the same number of observations in 1964 failed to show the contamination.

Total Bacteria in 1964

Total bacteria counts for 1964 presented an extremely wide range of values, from several million colonies per 100 ml down to occasional counts of less than ten thousand colonies per 100 ml. These erratic data are difficult to interpret and the observations taken no doubt do not fully describe total bacteria counts that occurred on the watershed. Rather than present maps or frequency diagrams as with the other bacteria groups, the actual values for total bacteria, by station and date, appear in the Appendix, Table C.

Fecal Coliforms and Fecal Streptococci in 1965

The FC and FS bacteria, occurring less commonly than the coliforms, were isolated in much lower concentrations. Classification of FC and FS bacteria into a frequency distribution (or class intervals) therefore requires a class breakdown utilizing lower values than those used for the coliforms. The following intervals are used for the graphs of Figure 22:

class	a =	% samples	with	0-9	colonies/100 ml
"	b =	"	"	10-19	"
"	c =	"	"	20-29	"
"	d =	"	"	30-49	"
"	e =	"	"	≥ 50	"

A definite skew to the left (toward zero) appears in most of the individual bar graphs, despite the lower values comprising the class intervals; this emphasizes the preponderance of zero to very low FC and FS isolations. There were predominantly lower class "a" occurrences at several stations. Extremely low counts of FC and FS bacteria typify high elevation or backcountry sites. Observations of FS bacteria were spread among all the frequency intervals "a-e" at many lower stations on the drainage, without the left hand skew; this FS frequency distribution perhaps bears greater resemblance to the coliform distribution than to the FC.

For both FC and FS bacteria the upper elevation to lower elevation comparison is fairly distinct. Many more zero counts occurred in streams at higher elevations than in streams lower on the watershed (the coliforms did not show a distinct difference).

Land use impact (grazing-irrigation) at Station 8 appears clearly in the FC graph, not so distinctly on the FS. The increase in higher concentrations ("d" and "e" class occurrences) apparently followed the Station 8 flow down into the main stem; higher percentages in classes "d" and "e" showed up at Stations 4, 3, and 1 (see also the section on "Impact," this chapter).

Wintertime isolations of bacteria in March, 1965, under ice-covered conditions, exhibited counts usually close to zero for all three bacteria groups (Appendix, Table E). Isolated winter samples of FS displayed readings as high as 40 for unknown reasons. The FC concentrations were nearly always zero; the highest FC isolation was only 6 colonies/100 ml.

Distribution of Bacteria on the Watershed

Areal distribution of bacteria count observations on the watershed is shown for both years of observation in Figures 23, 24, and 25. The year 1965 had a more distinctive and seemingly "logical" pattern of bacteria count distribution than the year 1964, in regard to patterns of land use. Time Period II was more comparable between the two years than Time Period I.

1964

Time Period I (TP I) mean coliform counts in 1964 were higher than Time Period II (TP II) means at many sites on the catchment (Fig. 23). Station 8 was a notable exception to this trend; during both 1964 and 1965 the site had higher TP II than TP I coliform concentrations. This station is exceptional, being irrigated by water spreading and grazed by about 75 head of cattle during the summer.

The 1964 mean coliform count was especially high at Stations 11 and 15 in TP I (Fig. 23); these stations did not have higher counts than other stations in TP II of the same year, nor did they have higher counts than other sites in either time period of 1965. It is possible that either (1) local contamination occurred at or above these stations in 1964 only, or (2) the TP I 1964 coliforms in question were not of fecal origin.

The areal pattern of coliform count distribution in Time Period II 1964 (Fig. 23), on the other hand, more clearly approximates the pattern of both time periods in 1965 (Figs. 24 and 25).

1965

The two time periods of 1965 had similar coliform mean counts, unlike the marked difference between time periods observed in 1964. The fecal coliforms (FC) did not show this similarity between time periods, and higher concentrations of FC were common to TP II at most sites. The "flushing" flows of TP I apparently increased coliform counts but not so much FC counts, whereas FC concentrations were possibly increased by the TP II impact of lower dilutions, warmer temperatures, continued grazing, or other factors. Examples of higher FC counts in TP II are seen at Stations 1, 2, 3, and 8 (Fig. 25).

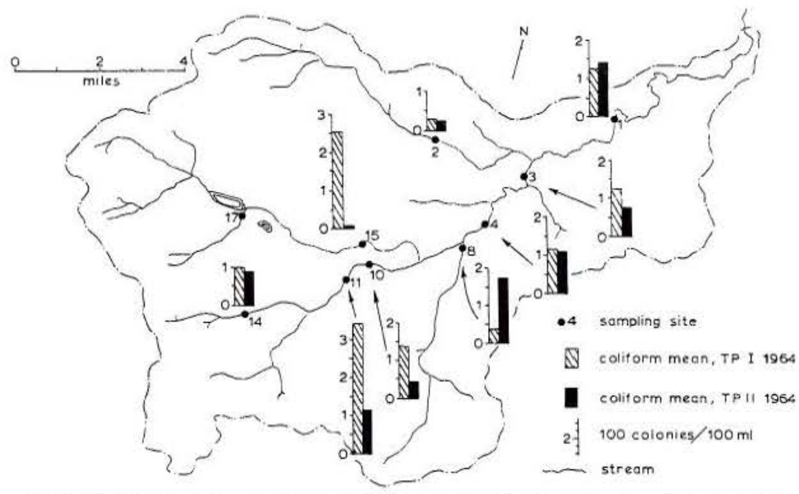


Figure 23--Coliform means by time periods for sampling sites in 1964, where Time Period I (TP I) is from spring melt until peak flow, Time Period II (TP II) from peak flow until autumn.

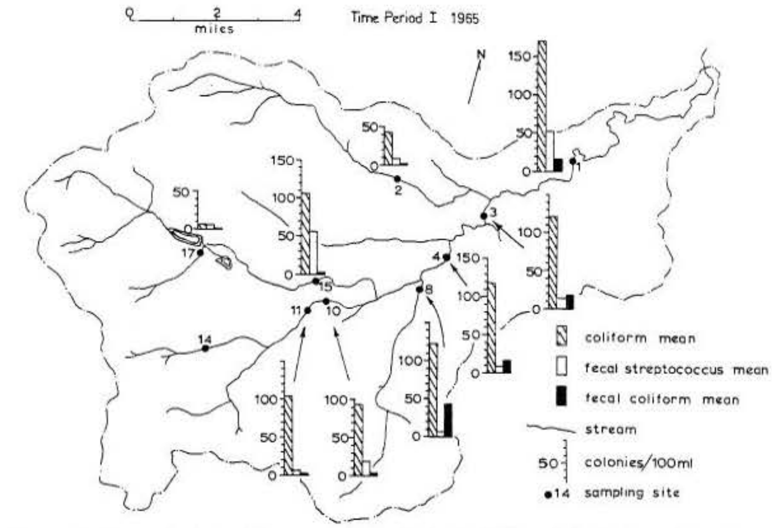


Figure 24--Means for bacterial groups in Time Period I, 1965, at individual sampling sites on watershed.

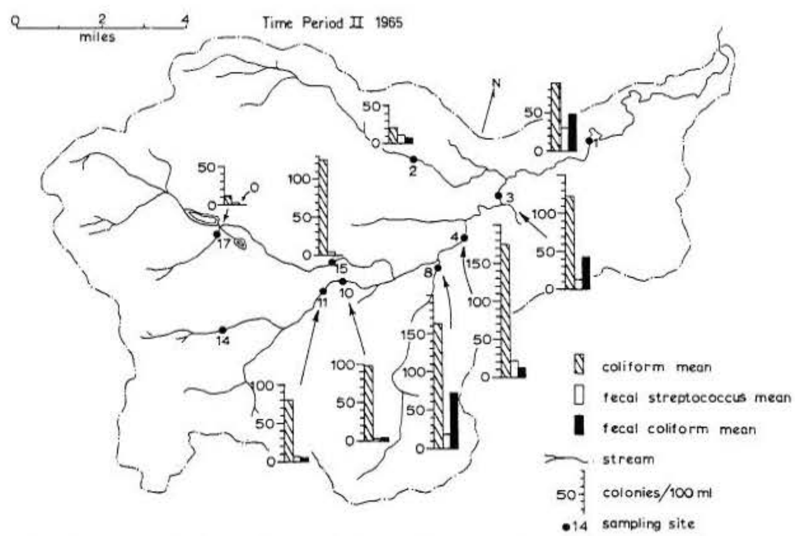


Figure 25--Means for bacterial groups in Time Period II, 1965, at individual sampling sites on watershed.

Relations Between Bacteria Groups

A broad comparison of bacteria counts reveals great year-to-year differences in bacteria group interrelationships. The between-groups correlations, by year, station, and time period appear in Figure 20; the connecting lines represent 95% correlations.

The 1964 Relations Between Bacteria Groups

The 1964 observations showed consistent correlations only between the total bacteria group and the enterics. Total bacteria and the coliforms had no correlations for 1964, while other between-bacteria group correlations were too infrequent to have meaning (Fig. 20). Total bacteria-enterics positive correlations (95%) were numerous, appearing at five stations in Time Period I, three in Time Period II. After 1964, total bacteria counts were discontinued with the fecal coliform test being initiated in spring, 1965. The 1964 coliform correlations with other bacteria groups were very sporadic. Coliform count graphical presentation appears in Chapter V.

The 1965 Relations Between Bacteria Groups

Bacteria indicator groups from many of the sampling sites were positively correlated with each other in 1965, somewhat more frequently in Time Period I than in Time Period II (Fig. 20).

During both time periods of 1965, positive correlations between coliform organisms and both the fecal coliforms (FC) and fecal streptococci (FS) appeared at numerous stations, as shown in Figure 20. Time Period I displayed these correlations more frequently than Time Period II. Since FC or FS counts were not determined in 1964 (except FS for TP II), coliform-FC or coliform-FS data cannot be compared for the two years. Graphical illustration of the coliform counts, by stations, appears in Chapter V, where the coliform-flow relationship is presented. Similar presentation of FC and FS for 1965 appears in Figure 26. The broad seasonal trend for all three organism groups (coliforms, FC, FS) was similar: low winter counts, higher concentrations during the high flows of June, a short "post-flush" period of low bacteria counts often in mid-summer, higher concentrations once again in the warmer late summer, and finally declining counts as autumn begins. Such a positive relationship between organisms suggests mutual dependence of the groups on flow and temperature (see Chapter V).

Enteric bacteria--those organisms also appearing on the m-Endo plates with the coliforms but not having the coliform color--were enumerated in both years. Since total bacteria were not tabulated in 1965, it is not possible to see if significant enteric-total correlations would be found, as in 1964. In 1965, the enterics were not consistently correlated to any other bacteria groups. The enterics showed no obvious relations to the coliforms. Very often, enterics were numerous on a plate having no coliforms, or a plate heavy in coliform colonies was devoid of enterics.

A positive relationship between fecal coliforms and fecal streptococci occurred at five of the nine stations in 1965 (Fig. 20). The relationship between the two bacteria groups is shown graphically in Figure 26. The FS attained higher counts in spring and early summer at most stations, whereas the FC reached maximums later, often in June-July. Both were possibly dependent on flow and temperature (see Chapter V).

The FC-FS relationship may also be described in terms of the FC/FS ratio. This ratio has been under investigation by the U. S. Public Health Service for use as a pollution indicator, where the FC/FS value would indicate the contamination source--for example, whether human or cattle (Geldreich, Clark, and Huff, 1964). Values of FC/FS for the Little South Watershed in 1965 (Fig. 26) were:

1. commonly less than one during the spring (April-May) period of slight warming but small flows;
2. greater than unity during the early June "flush" at many (not all) sites;
3. much higher, reaching maximums of over twenty during the peak flows of June to the somewhat lower flows of July;
4. lower during August and September generally, although FS counts remained high at certain sites (remember that FC/FS ratios do not depend on the concentrations of either bacteria group per se, only on the relationship between the two);
5. again, less than unity during the autumn, at most sites.

Land Use Impact on Bacteria Counts

Grazing-Irrigation Impact: Pennock-Little Beaver

The combined impact of grazing and irrigation of a mountain meadow on water quality was observed by comparing a pair of similar sub-watersheds from the study area--one with approximately the lower half grazed and irrigated by surface spreading in summer (Pennock Creek), the other essentially "natural" (Little Beaver).

A comparison of suspended sediment for the two streams did not show higher values for the grazed drainage, i. e., the analyses of sediment (or turbidity) did not detect the land use impact (Fig. 16, Chapter III). Despite no significant sediment differences between the two streams, all three bacteria groups clearly defined the grazing-irrigation impact in 1965 (Table 4); nearly every observation showed higher coliform counts on the grazed catchment than

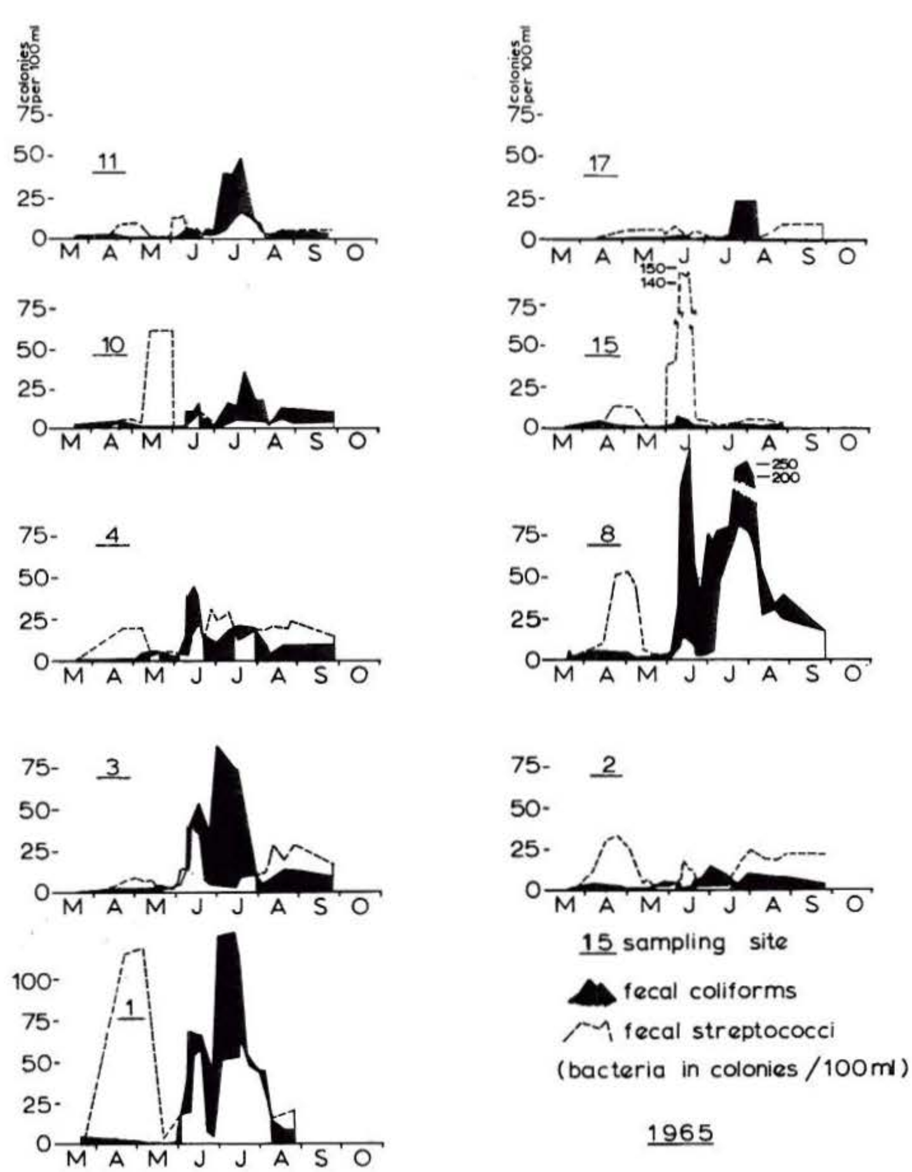


Figure 26--Moving means (three consecutive samples) for fecal streptococcus and fecal coliform bacteria concentrations, by stations, 1965.

on the ungrazed. The much drier year of 1964 did not show such distinct differences between watersheds in coliform counts. The other bacteria groups--fecal coliforms and fecal streptococci--were not in use in 1964.

In addition to a distinct coliform count difference between the grazed and ungrazed drainages, the fecal coliform (FC) and fecal streptococci (FS) counts also emphasized the land use pattern. The moving mean values of FC and FS bacteria in Figure 27 show consistently higher values on the grazed (Pennock) creek as opposed to the ungrazed stream (Little Beaver). The bacteria concentrations of all three groups attained higher values in July and August (Figs. 27 and 28), a period of low flows and warmer water temperatures when grazing and irrigation probably had the largest effect.

The ratio of fecal coliforms to fecal streptococci (FC/FS) ranged from less-than-1 to 4.5 on the natural catchment but less than 1 to a maximum of 44 on the grazed-irrigated watershed. The average 1965 FC/FS ratios were 1.3 for the natural as opposed to 7.6 for the grazed watershed, neglecting samples where either FC or FS was zero.

The "ability to detect cattle pollution" is evaluated for each indicator group--coliforms, FC, and FS--as well as for the FC/FS ratio, by comparing yearly means of each bacteria group for the grazed as opposed to the ungrazed catchments. This grazed-to-natural comparison or "impacted: natural" factor is presented in Table 5. The fecal coliform (FC) group shows the highest value or greatest sensitivity to this type of pollution; for the FC group the grazed

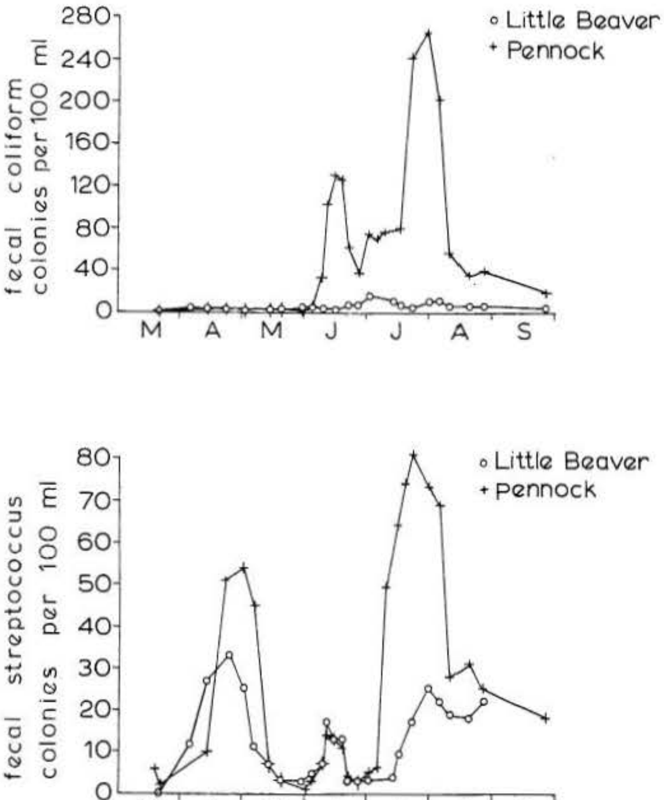


Figure 27--Fecal coliform (top) and fecal streptococcus (bottom) concentrations in colonies/100 ml shown by moving means of three consecutive samples for Pennock Creek and Little Beaver Creek during 1965.

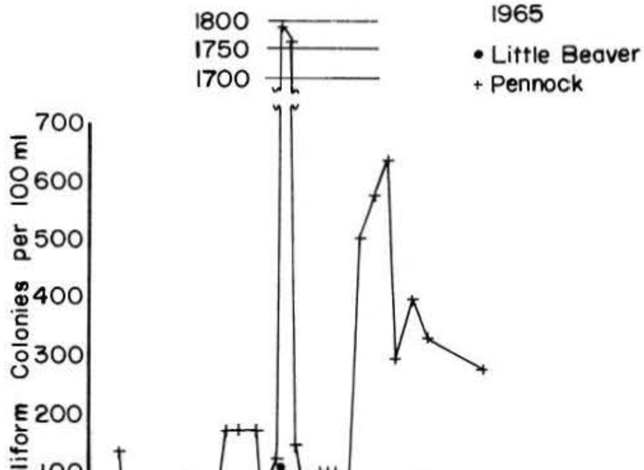


Figure 28--Coliform concentrations in colonies/100 ml on Pennock Creek and Little Beaver Creek, 1965. Values are moving means of three consecutive samples.

watershed's mean is 16.1 times greater than the ungrazed. The high sensitivity of the FC group increases the "rating" of the FC/FS indicator as well (FC being the numerator), as shown in Table 5. The coliforms rate somewhat less sensitive, while the FS group is ranked least perceptive as a pollution detector.

Grazing-Irrigation Impact:
Pennock-Main Stem

The irrigation-grazing impact appears once more in Figure 29, where FC/FS ratios from the grazed and irrigated Pennock Creek drainage are compared again--this time to ratios from sites along the main stem of the Little South Fork (Stations 1, 3, 4, 10, and 11, averaged). Grazing above the main stem stations was less intensive in relation to flow volumes. Figure 29 shows FC/FS ratios greater for Pennock than for the main stem during the entire season. A definite rise of FC/FS values appeared on Pennock during the June-July "flushing" period of peak flows, while the main stem values remained much lower; actual levels of FC/FS reached 22.0 on Pennock, only 5.4 on the main stem. As flows receded, FC/FS ratios for Pennock decreased, but still remained twice as high as values for the main stem stations.

TABLE 4--Mean values for 1965, number of observations, and range of values encountered for Little Beaver and Pennock bacteria samples. Significant differences between the two stations indicated.

	Mean	n	Range	Significant level of difference
COLIFORMS				
Little Beaver	37.3	28	0-240	90%
Pennock	120.8	28	0-1390	
FECAL COLIFORMS				
Little Beaver	4.2	24	0-22	99%
Pennock	67.7	24	0-500	
FECAL STREPTOCOCCUS				
Little Beaver	14.2	24	0-46	90%
Pennock	24.1	24	0-150	
FC/FS RATIO				
Little Beaver	1.3	-	-	-
Pennock	7.6	-	-	

Other Considerations of Grazing Impact

In Figure 26, the FC-FS interrelationships are shown; very possibly the figure also shows land use impact. Areas above Stations 8, 4, 3, and 1 were grazed most heavily, while on areas above Stations 10 and 11 grazing was less common, and Stations 2, 15, and 17 had little or no grazing effect by cattle. The relationship of FC to FS counts, seen in Figure 26, bears resemblance to the grazing intensity patterns, with heavily grazed stations generally showing higher FC/FS ratios.

In the time period means of Figures 24 and 25, a distinct difference is seen for the fecal coliform counts in regard to the location of a sampling station respective to intensity of land use impact. In both time periods, higher elevation stations such as 17, 15, 10, and 11 were clearly lower in FC bacteria concentrations than Pennock Creek (8) or the main stem stations below Pennock (1, 3, and 4). This pattern was also exhibited by FS counts in TP II, but not distinctly in TP I.

TABLE 5--Grazed site to natural site factors (Pennock: Little Beaver) for the bacteria indicator groups used in 1965.

Bacteria Group	"grazed : natural" factor
Coliform	3.2
Fecal coliform	16.1
Fecal streptococcus	1.7
FC/FS ratio	5.8

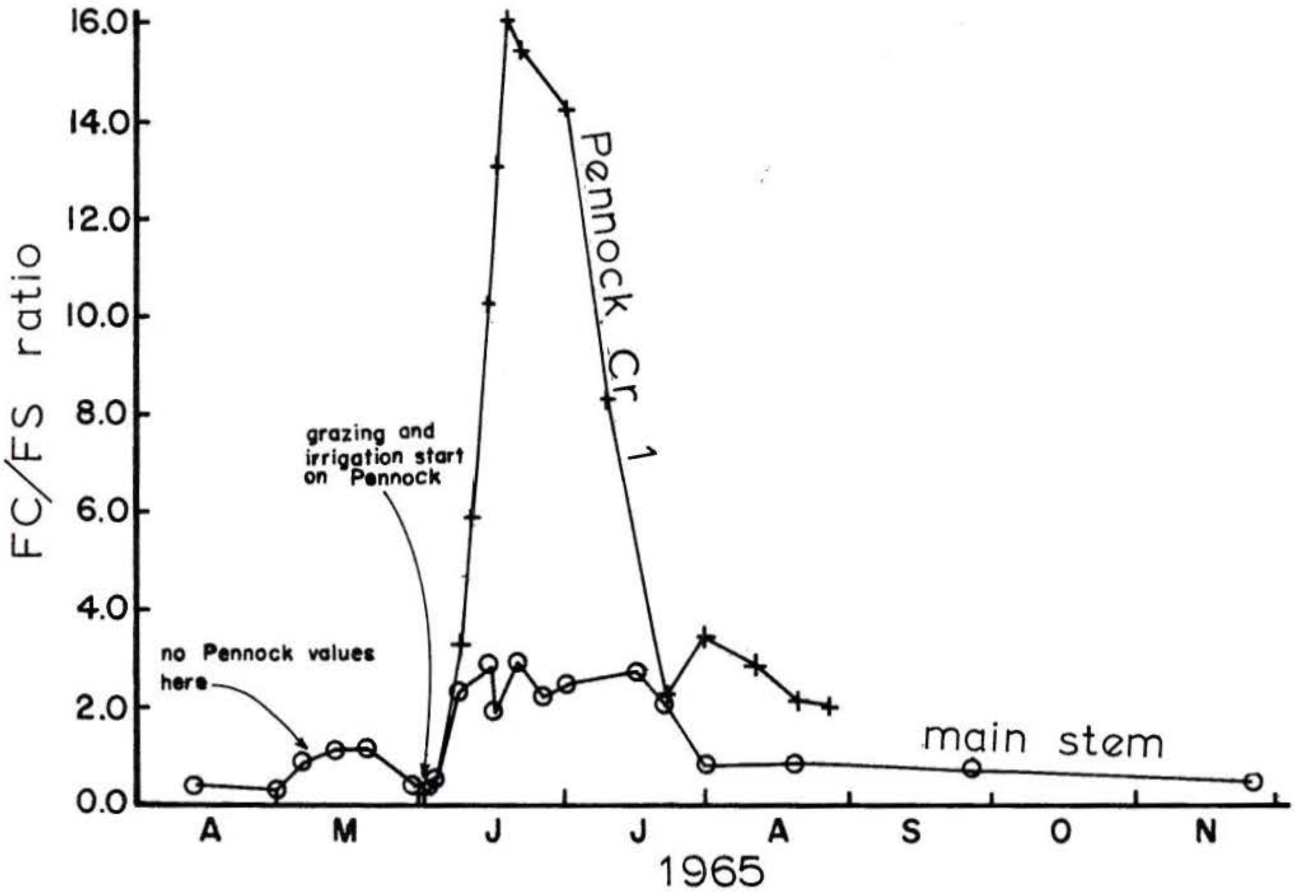


Figure 29--Fecal coliform/fecal streptococcus ratios for heavily grazed Station 8 (Pennock) compared to values for the main stem stations. Main stem ratios are an average for Stations 1, 3, 4, 10, and 11.

CHAPTER V

THE PHYSICAL TO BACTERIAL RELATIONSHIPS

Relations between the bacterial and physical parameters are presented in this chapter by comparing the bacteria data of Chapter IV to the basic physical parameter data presented in Chapter III. Additional information in the Appendix includes storm values (Table D), winter values (Table E), and comparison of the coliform bacteria to the physical parameters (Fig. B through J).

Statistical and graphical analyses indicate that the bacteria groups investigated were related to the physical parameters of the stream. Significant (95%) linear correlations were found between the bacteria groups and many of the physical factors. Table 6 is a broad tabulation of these significant correlations, all sampling sites pooled together. Tables 7, 8, and 9 are detailed breakdowns of Table 6.

The tabulation of Table 6 is separated into "Time Periods I and II", the former covering the period from initial spring melting until the peak flow (which normally is in mid-June), the latter extending from the peak flow until autumn. In the Rocky Mountains, Time Period I is the time of maximum flows, but perhaps more important it is a period of rising stages, when stream channel and meadow "flushing out" occurs. During both sampling years in Time Period I, significant correlations between the bacteria groups and flow, pH, turbidity, and sediment were common (Table 6). Conversely, Time Period II exhibited a scant number of bacteria to physical parameter correlations. Comparison of the two time periods suggests that higher bacteria concentrations accompany the rising stages, larger flows and flushing effects.

TABLE 6--Summary tabulation of significant (95%) correlations between bacteria groups and temperature (tp), flow (fl), pH, turbidity (tu), suspended sediment (ss), and dissolved solids (ds), all sites pooled together, in 1964 and 1965 time periods.

TP (both years)		tp		fl		pH		tu		ss		ds	
		+	-	+	-	+	-	+	-	+	-	+	-
I	Coliforms			4			3	5		4	1		1
	Total bacteria*			1			1	2		1		2	
	Enterics	1		2			3	3		3		2	
	Fecal Coliforms*		1	5			4	6		3			
	Streptococcus*			2			4	4		4		1	
	Totals	1	1	14			15	20		15	1	5	1
II	Coliforms				1		1						
	Total bacteria*									1		1	
	Enterics			1			2	1		1			2
	Fecal Coliforms*												
	Streptococcus	1			1	1	1	1	1		1	1	
	Totals	1		1	2	1	4	2	1	2	1	2	2

*indicates one year of sampling only.

Other observations also indicate a positive bacteria-flow relation. Significant coliform-flow correlations (95%) were far more common in the year 1965--a very wet year--than in the drier year of 1964. Bacteria counts for all groups were observed to increase drastically during the rising stages of summer storm runoff, then drop below pre-storm values temporarily during the reclining limb of the storm hydrograph. High bacteria concentrations associated with grazing and irrigation impact (see Chapter IV) likely depend on the "flushing effect" of flooding: shortly after irrigation ceased (with cattle remaining) bacteria counts decreased markedly. These examples all point to a strong, positive bacteria-flow relationship.

It is notable that the larger flows and higher bacteria concentrations of certain sites (particularly lower on the catchment) did not necessarily produce more bacterial-physical parameter correlations of significance. Small streams containing few bacteria by comparison (e. g. Sta. 2) had as many significant (95%) bacterial-physical correlations as larger, "more polluted" sites.

The significant correlations of bacteria groups to pH, turbidity, and suspended sediment were numerous as seen in Table 6, however it must be remembered that these same physical parameters were also highly correlated to flow (Table 1, Chapter III). This suggests a mutual dependency of all physical parameters as well as the bacteria groups on the key factor, flow.

The temperature data were essentially not correlated statistically to any of the bacteria group data. Partial correlations were carried out for the combined Time Period I plus Time Period II season, to remove the effect of flow and determine if thereby the bacteria-temperature correlations would improve. The correlations did not improve. The rise in bacteria common in late summer suggests a bacteria dependence on temperature but this has not been verified statistically in this study.

Relations of Coliforms to the Physical Parameters

Statistical Analysis

The coliforms were the only bacteria tested in all time periods of both years. Significant correlations between the coliforms and all physical parameters appeared much more frequently in the rainy 1965 sampling season than in drier 1964, more frequently in Time Periods I than in Time Periods II, suggesting a strong dependence of coliform counts (as other bacteria) on stream flow and precipitation. A summary of the coliform to physical parameter correlations appears by years and time periods in Table 7.

Positive coliform-sediment and coliform-turbidity correlations appeared only in 1965, Time Period I--the "wettest" time period of both years--indicating that flushing by rain increased sediment and bacteria concentrations simultaneously.

Statistically, coliform-pH negative relations were more frequent in 1965 than in 1964. No coliform-temperature relations were indicated by the statistics. "Partial correlations," designed to remove the effect

TABLE 7--Tabulation of correlations at the 95% confidence level between coliforms and temperature (tp), flow (fl), pH, turbidity (tu), suspended sediment (ss), and dissolved solids (ds), by site, time period, and year.

Year	TP	Station	tp	fl	pH	tu	ss	ds
1964	I	1		+				
		3		+				
		11					-	
	II	3		-				
		4		-				
1965	I	1			-	+	+	
		2		+	-	+	+	
		3			-	+	+	
		4		+		+	+	
		10						-
		15				+		
	II	1			-			

of flow and thereby reveal a better coliform-temperature correlation, did not indicate a coliform dependence on temperature. Relations between coliforms and dissolved solids were not apparent.

Graphical Analysis

Graphs for coliforms and flow are shown by individual sites for 1964 (Fig. 30) and 1965 (Fig. 31). The graphical analysis agrees with the statistical analysis in most respects. In both years Time Period I coliform graphs for most sites follow an upward trend as spring "flushing" occurs (note scale differences between graphs for each year). In Time Period II, where coliform-flow correlations were not found statistically, coliform count graphs bear no resemblance to the hydrograph. Early in TP II (July), many stations showed what might be termed a "post-flushing" lull in coliform counts, at the time when stream flows began to decrease. During the late summer portion of TP II, when warmer water temperatures and small flows prevailed, coliform counts attained new highs--even peak values at some sites.

In Chapter II, it was shown that pH attained lowest values near the peak of the hydrograph (Figs. 11 and 12). The correlation of coliforms to flow was positive for TP I. It then is logical that negative coliform-pH correlations appeared in TP I (1965), since coliform counts increased as pH dropped. The lack of significant pH-coliform correlations in TP I, 1964 appears to be due to the far lower flows of that year, which probably caused smaller fluctuations of all parameters.

Comparing the coliform graphs of Figures 30 and 31 to the temperature graphs of the same sites in Figures 7 and 8, no very obvious relationship appears. The coliforms are also compared to the physical parameters in the Appendix, Figures B through J. The coliforms reached a peak near the hydrograph peak and again in late summer at many stations, with low values occurring during the "post-flush" period in mid-summer. The water temperature at individual sites essentially followed a steady increase throughout the summer.

The enteric bacteria--those organisms appearing on the m-Endo plates with the coliforms but not having a coliform golden color--were enumerated in 1964 and 1965. Fluctuations of enterics were extremely high, making analysis of limited numbers of observations very difficult. Correlations found between enterics and the physical factors are presented in Table 6; these correlations are similar to those shown (in the same table) by the other bacteria groups.

Relations of Total Bacteria to the Physical Parameters

Tests for total bacteria were conducted during the 1964 season only. Correlations found between 1964 total bacteria and physical parameter data were not numerous (Table 6). A positive total bacteria relationship to flow, sediment, and dissolved solids, and a negative relation to pH, is suggested by a small number of significant correlations; this indicates that many of the relations between coliforms and physical parameters might also hold true between total bacteria and the physical parameters.

The extremely large fluctuations of total bacteria counts makes analysis difficult (and perhaps meaningless) unless observations are numerous. It is not meaningful to graph the 1964 weekly observations, therefore they appear in Table C, Appendix. Comparison of total bacteria observations to flow shows no distinct relationship between the two. Likewise a comparison of total bacteria counts to other physical parameters shows no consistent relationships. Again, the large fluctuations in bacteria concentrations necessitate very frequent sampling if meaningful results are to be obtained.

Relations of Fecal Coliforms to the Physical Parameters

Tests were conducted for the fecal coliforms in 1965, in place of the total bacteria tests. The fecal coliform counts for individual sites, compared to the physical parameters showed the significant (95%) correlations in Table 8.

The fecal coliforms were clearly related to certain physical parameters in Time Period I. It is very striking that Time Period II had no correlations at the 95% confidence level. The fecal coliform-physical parameter relations were essentially the same as coliform relations to the physical parameters, although FC counts were commonly only about 1/4 or 1/3 as high as the coliform values.

Comparison of the fecal coliforms (FC) graphically to flow in Figure 32 shows a trend very similar to that of the coliforms in Figure 31, namely: (1) a spring rise in concentrations during the "flushing" of rising stages, followed by (2) a "post-flush lull" in counts, after the hydrograph peak, and finally (3) a July-August peak in concentrations during the warm water and lower flow period.

Relationship of the fecal coliforms to flow is not fully understood but the data indicate that the "flushing effect" of rising stages in flow is most important in increasing bacteria counts--probably more important than the volume of flow per se.

Partial correlations were carried out on the fecal coliforms--as with coliforms and the FS--to remove the effect of flow and thereby test the temperature-fecal coliform correlations; no improvement in correlations resulted.

In comparing the fecal coliform graphs (Fig. 32) to pH values (Fig. 11, Chapter III) for 1965, an inverse relationship is evident in Time Period I, while no relationship is seen for TP II. This agrees with statistical findings.

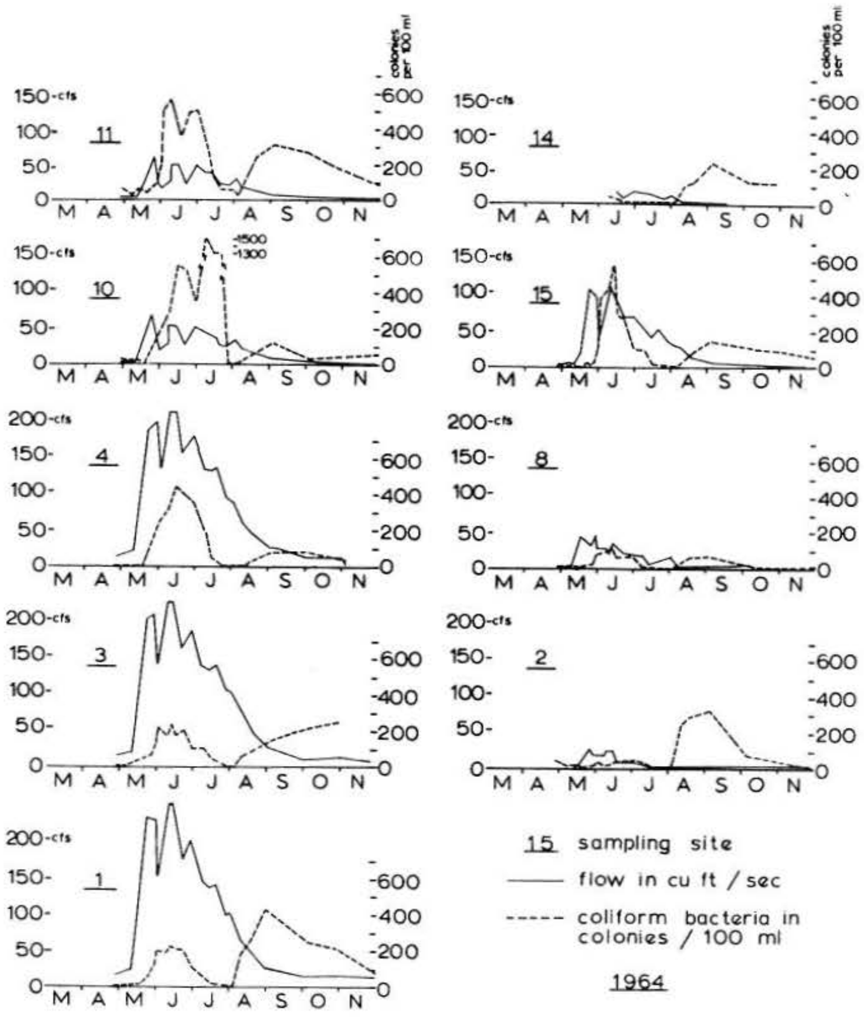


Figure 30--Coliform-flow relationships in 1964. Coliform points are moving means of three consecutive values. Flows are actual values at time of sampling.

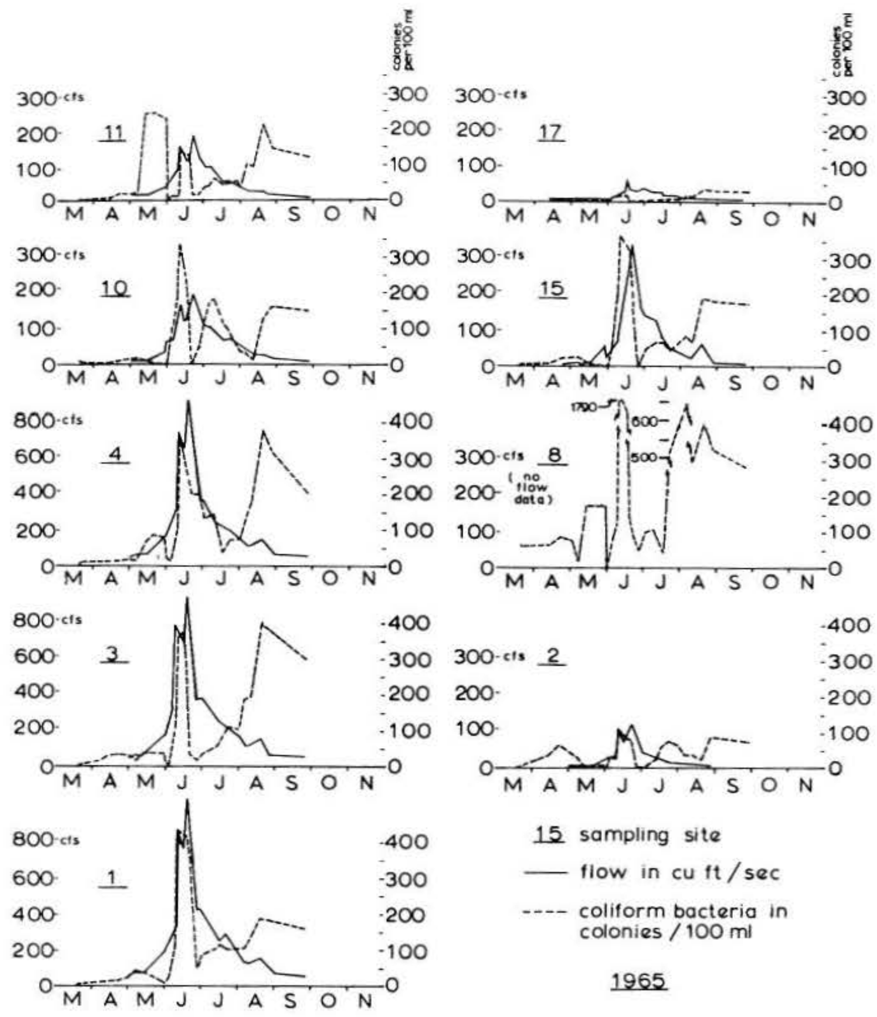


Figure 31--Coliform-flow relationships in 1965. Coliform points are moving means of three consecutive values. Flows are actual values at time of sampling.

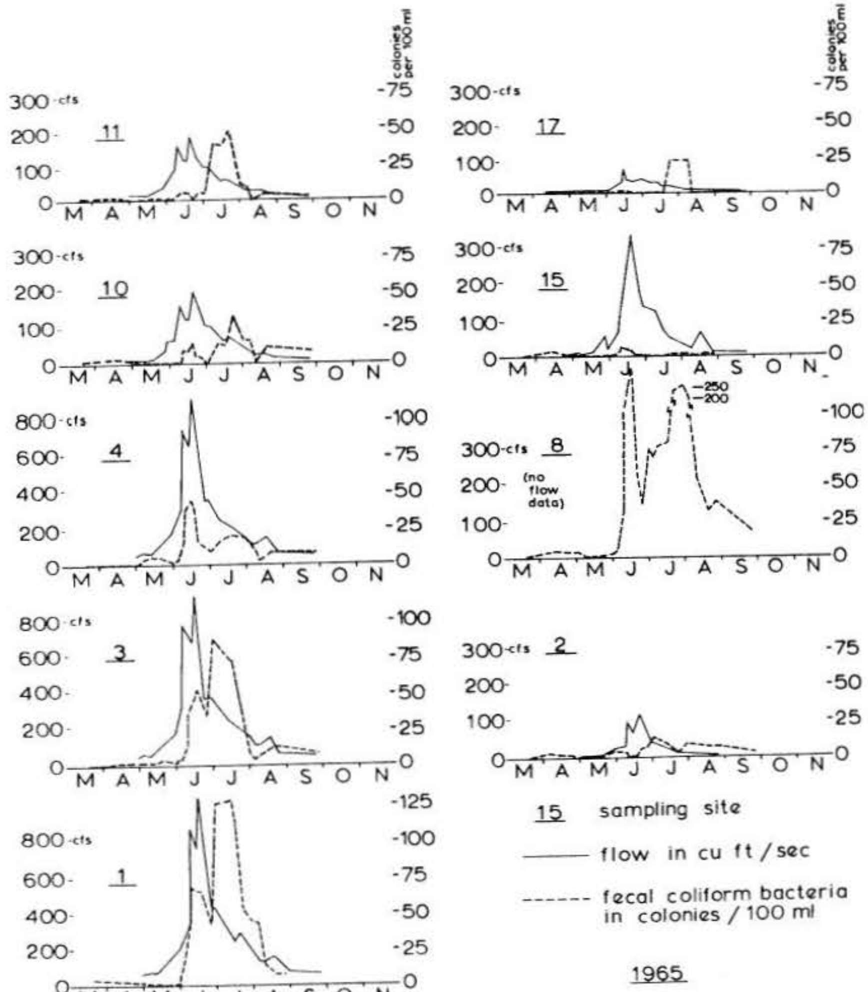


Figure 32--Fecal coliform-flow relationships in 1965. Values of FC are moving means of three consecutive samples. Flows are actual values at time of sampling.

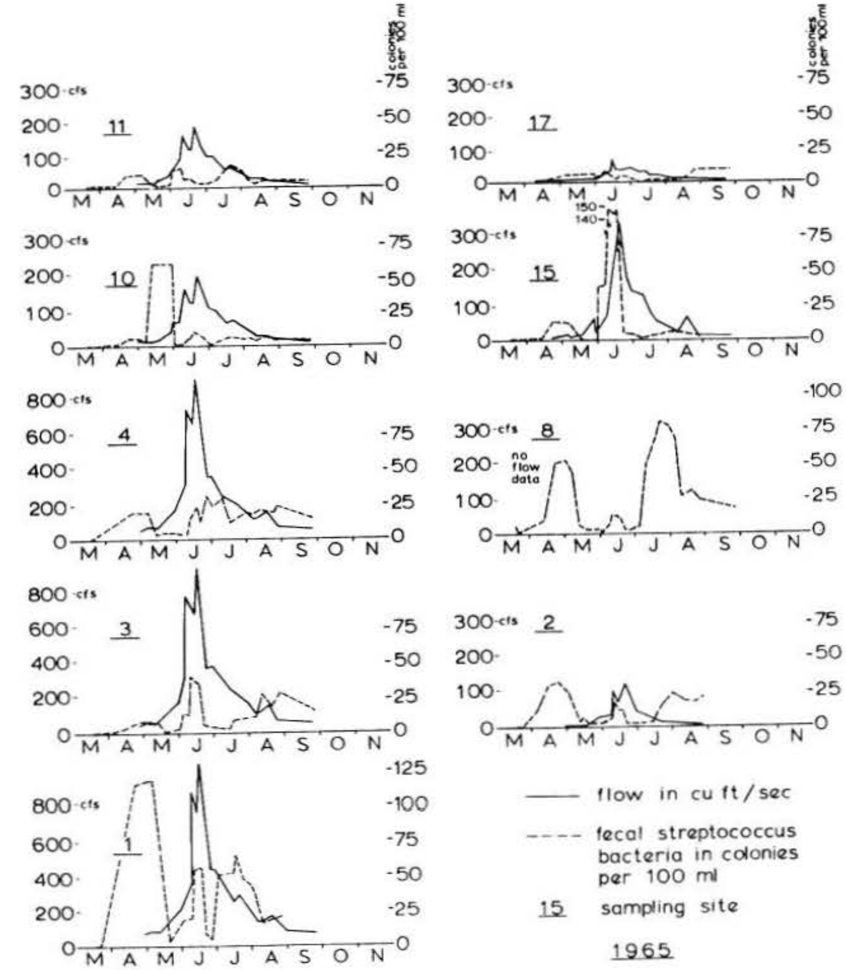


Figure 33--Fecal streptococcus-flow relationships in 1965. Values of FS are moving means of three consecutive samples. Flows are actual values at time of sampling.

TABLE 8--Tabulation of correlations at the 95% confidence level between fecal coliforms and temperature (tp), flow (fl), pH, turbidity (tu), suspended sediment (ss), and dissolved solids (ds), by site and time period during 1965.

TP	Station	tp	fl	pH	tu	ss	ds
I	11		+		+	+	
	10	-	+	-	+		
	4		+	-	+		
	3		+	-	+	+	
	1		+				
	15				+		
	8			-	+	+	
II -- no correlations at 95% confidence level							

No fecal coliform-water temperature relationship is found by comparing the FC (Fig. 32) graphs to values of temperature (Fig. 8, Chapter III) for 1965. Possibly bacteria changes lag behind changes in temperature, but this study could not measure such a lag.

The many fecal coliform-turbidity correlations are likely a factor of mutual dependence on flow, although it remains to be clearly determined if bacteria are increased by the sediment increases per se, i.e. if the bacteria are attached to or "riding with" the sediment.

Relations of Fecal Streptococci to the Physical Parameters

Tests for the fecal streptococci (the enterococci) were carried out for Time Period II in 1964 and the entire season of 1965. The fecal streptococcus counts for individual sites, when compared to the physical parameters, yield the significant correlations of Table 9.

The fecal streptococci (FS) were related to pH, turbidity and suspended sediment, very much like the FC and coliform bacteria. Time Period II was also nearly devoid of significant correlations.

Comparing the fecal streptococci graphically to flow in Figure 33, a trend similar to that of the coliforms (Fig. 31) and FC (Fig. 32) appears with one major exception--the early spring period of April and May shows higher than would be expected FS counts at many stations. This is the same period during which coliform and FC counts were commonly near zero. The rise in FS concentrations during the "flushing" of rising water in June and the "post flush lull" of late June-early July is very much like the FC and coliform trends. The late summer rise in concentrations also is in evidence, although perhaps not as clearly as in the case of the other two indicator groups. The reason for the late winter or early spring concentrations of FS bacteria--from the same sampling that produced near zero FC and coliform bacteria counts--is not known (Appendix, Table E).

Partial correlations carried out on the fecal streptococci, to remove the effect of flow and thereby increase the temperature-fecal coliform correlations, were of no value; the r values remained basically the same.

Comparing the fecal streptococci (Fig. 33) to pH values (Fig. 11, Chapter III) for 1965 shows an inverse relation in Time Period I, while Time Period II shows no such relation, substantiating the statistical results of Table 9.

The comparison of FS to water temperatures (Fig. 8, Chapter III) for 1965 shows no relationship, in agreement with statistical findings.

As with coliforms and FC, several FS-turbidity and FS-sediment correlations were found. The mutual dependence of both the bacteria and sediment on flow is thought to be the reason for the bacteria-sediment and turbidity correlations.

The fecal streptococcus counts were low, comparable in intensity to the FC counts and much below the values found for coliforms.

TABLE 9--Tabulation of correlations at the 95% confidence level between fecal streptococci and temperature (tp), flow (fl), pH, turbidity (tu), suspended sediment (ss), and dissolved solids (ds), by site and time period, 1964 and 1965.

Year	TP	Station	tp	fl	pH	tu	ss	ds
1964	I		No samples					
	II	10			-	+		
1965	I	11						+
		4		+	-	+	+	
		3			-	+	+	
		8			-	+	+	
		2		+	-	+	+	
	II	4						+
		8	+					
		2		-	+	-	-	

CHAPTER VI

DISCUSSION AND IMPLICATIONS

General Comments

The results of the study are discussed in this chapter by describing possible significance of the data, pointing out shortcomings of the study, comparing results with those of other investigators, and speculating on reasons certain results were or were not obtained. Not every subject of the preceding chapters is mentioned again; only those aspects are discussed where additional explanation or comment is thought to be of value.

Daily cycles of all parameters of the stream environment no doubt occur, depending ultimately on energy input of solar radiation. These hourly fluctuations of environmental or water quality parameters are especially distinct in small streams, where a smaller volume of flow is influenced by radiation, weather changes, land use impact and other factors. Water temperatures on the watershed can fluctuate 8-11°C (15-20°F) daily during summer according to the recorded temperature data, causing difficulty in interpretation of water temperature data between sites sampled at various times of the day.

While the study was not specifically designed to investigate diurnal fluctuation of water quality parameters, these variations must be taken into account during data analysis. The sampling route was varied in an attempt to avoid sampling an individual site always at the same time of the day. If a site is so located on the sampling network that it is usually sampled in mid-day, the site's data would be biased in regard to temperature, pH, flow, and to an unknown extent bacteria concentrations. Two sites on the network, consistently sampled at markedly different times of the day, are possibly biased in opposite directions making realistic comparison between the sites difficult. Comparisons between sites have nonetheless been made, but the following limitations imposed on the data must be recognized: (1) because of accessibility problems, all streams could not be sampled at approximately the same time; (2) daily and hourly fluctuations of water quality parameters on the watershed are too inadequately understood for correction factors to be applied; and (3) weather fluctuations, which affect stream environment, were not recorded in the subwatersheds.

Water Temperature

Analysis of instantaneous water temperatures from sampling times is problematic for the reasons discussed above. Ideally, temperature data should be taken by recording thermometers at all stations. As noted by Macon (1959), the duration and fluctuation of temperature is often of more concern to the aquatic biologist than the actual level attained. Thermograph data could improve analysis by supplying temperature information in terms of degree-hours of heat supplied to a stream, for a designated period of time prior to sampling. Studies are now underway utilizing recording temperature data.

Vegetation alteration, for purposes of improving water yield and timing, may increase stream temperatures. It is not known to what extent water temperature increases in mountainous areas affect counts of coliforms, fecal coliforms, or fecal streptococci. During later stages of this study, after land treatment is implemented, temperature increase effects will be studied.

At high elevation sites, parameters of water quality probably depend very much on available heat. Water temperature is likely the key limiting factor to biologic productivity in cold, high elevation streams. The question arises as to what degree low bacteria counts at cold sites (e. g. 14, 17) are due to limited land use, to what extent due to lack of heat. It has been demonstrated by Morrison and Fair (1966) that coliforms exhibit a very low survival rate in ice, although in winter certain organisms survive in ice and snow along streambanks. It seems logical that fecal organism counts would be higher in a warmer, lower-elevation stream environment where conditions are favorable for survival and possibly reproduction. Wintertime isolations of bacteria in March, 1965, under iced-over conditions, showed very low or zero bacteria counts. Greenberg (1964) believes stream temperature to be the single most important factor of plankton production in his study area. Other studies by Potter (1963), Burman (1961), and Morita and Haight (1964) point to a strong temperature-organism relationship.

Hydrogen Ion Activity (pH)

The major similarity in pH data for the two study years was the occurrence of pH seasonal minimums near the season's peak flow in June. Analysis has found sediment load material in the area slightly acidic, a fact that might partially explain the inverse relation between pH and flow values in June. Photosynthesis is known to increase pH values (Palmer, 1962). It seems logical that under turbid conditions less light would result in less photosynthesis and consequently in lower pH values, in agreement with the data found. Stream "buffering" (Ruttner, 1964) is also changed by addition of sediment to a stream.

The year 1965 had many more correlations between pH values and other parameters than the year 1964. Sediment loads were much higher during peak flows, a factor that should intensify the inverse relationship between flow and pH values. In 1965, rain-on-snow produced the heavy runoff, as opposed to the smaller 1964 snowmelt runoff. The heavy washing of rain over thawed soils may partially explain the lower pH values. Goldman and Wetzel (1963) found an inverse relationship between rainfall and pH. "Pure" rainwater, according to Junge (1963), may vary widely in pH values, from 3.0 to 8.0. It is not known how the pH of rain compares to the pH of snowmelt water in the study area.

Most water quality parameters (if not all) were related to flow in the study area. It seems reasonable that increased flows might emphasize relations between two factors, such as pH and coliforms, where both are dependent on flow. The heavy rains of 1965 probably intensified all the pH relations while the low flows of 1964 de-emphasized them.

The pH-suspended sediment and pH-turbidity negative relations found were much like the pH-flow relations. The effect of turbid water on photosynthesis and consequently on pH was mentioned. The slightly acidic sediment possibly helped reduce pH values, producing the strong inverse pH-sediment correlations of 1965 (when sediment loads were high).

Powers (1929) determined that a general decrease in pH accompanies elevation increases in the Smoky Mountains. He referred to the process of "ageing" as water travels further downstream, pH increasing. The results of 1964-65 appear in agreement with Powers' findings.

It is recommended by most investigators not to transport samples to the laboratory, rather analyze for pH on site. During the study, "drifting" of the pH meter was common, due to temperature differences, dryness of the electrode, and other factors. Expensive repairs, because of transportation and handling in the remote study area, were often needed. On-site pH measurements seemed to cause more serious errors, all factors considered, than the errors made by brief transport of a cooled, completely-filled sampling bottle to the field laboratory, where pH measurements were possible under ideal conditions.

Turbidity, Suspended Sediment and Dissolved Solids

Land modification on the study area during 1964-65 was negligible. It is not surprising that turbidities were low. Regular sampling, as conducted in 1964-65, was adequate for attaining general values of sediment encountered, but as noted by Swenson (1964) 90% of a stream's sediment may discharge in 10-12 days and as much as one half of the year's sediment may occur in one storm. The validity of collecting samples periodically is open to serious questioning, once intensive land use is under way.

The conversion of periodic sediment sampling values to soil loss figures is not meaningful. Taking samples during all storms would be preferable, but storms habitually ignore the investigator's field schedule and are not sampled. The best sampling method may be use of a series of automatic-suspended sediment samplers, as described by the U. S. Interagency Committee on Water Resources (1961). These samplers could be mounted at a series of stages in the stream, collected after a storm occurs, and reinstalled for future storms. Wherever possible, storms could be sampled by hand, for comparison to automatic sampler values. Heidel (1956) observed peak concentrations of suspended sediment to lag behind the peak of a storm hydrograph. This presents a problem in use of automatic suspended sediment samplers, which collect on the rising stage only. Perhaps a device could be arranged to make possible sampling on the falling stage. Sediment collectors or "splitters" may also be attached to weirs, to take a constant sample of sediment, should a weir be located below a treatment area.

The 5:1 sediment-turbidity ratio of Figure 17 represents values of the calibration period, giving no assurance that the same ratio will occur after treatment. The time-consuming sediment determinations might be partially replaced by convenient turbidity analyses, should it be found that the 5:1 ratio is valid throughout the entire range of values encountered. The large scatter, however, indicates accuracy would be low if such a technique were used.

Certain investigators have assumed the sediment-turbidity ratio to be 1:1, calculating soil loss from treated areas accordingly. Results from this study indicate the danger in applying such relationships indiscriminately. If turbidity is used strictly as a relative tool for comparing types of land use, actual values of sediment are not of great interest.

Color in water affects turbidity readings very much. Streams in the study area have a slight brown, probably organic coloring in spring. To what extent turbidities are affected by the coloring is not presently known. Much of the study area's turbidity may also be due to colloidal material.

The measurement of very small concentrations of dissolved solids is not accurate with normal laboratory equipment, because of weighing errors, limitations on the volume that can be evaporated and weighed, and hygroscopic errors. Measurement of conductance is worthwhile if the investigator understands how much of the dissolved solids concentration is inorganic.

Bacteria Variation

Stream bacteria data interpretation is made difficult by the tremendous hour-to-hour, perhaps minute-to-minute variability in bacteria concentrations. Seasonal fluctuations in bacteria counts are shown by data of the study to be very large; periods of intensive sampling have demonstrated that hourly variations in bacteria counts must also be great. Because a "recording bacteriograph" is yet unavailable, interpretation must be made of individual observations. In studying the bacteria frequency distribution histograms of Figures 21 and 22, one must recognize the limitations placed on the data by the large daily bacteria count variations. The individual observations are from various hours of the day.

At what time of the day are bacteria counts usually highest? What changes in concentrations occur due to organism deaths, multiplication, sedimentation or other factors? How much variation takes place daily? Many questions concerning bacteria variations are unanswered.

Bacteria Source

The pollution indicators used in the study--coliforms, fecal coliforms, and fecal streptococci--all exhibited similar seasonal trends in concentrations. Conversely, total bacteria counts did not follow the seasonal pattern shown by the three indicator groups. The similarity for all three pollution indicators suggests a common bacteria source, while lack of similarity in seasonal trends between total bacteria and the three pollution groups implies different bacteria sources for the total bacteria counts. Although no proof is given that fecal material is the primary source of the pollution indicators, comparison of grazed to ungrazed areas (Chapter IV) gives strong evidence that in certain streams cattle are probably the principal source of coliform, FC, and FS bacteria.

The fecal coliform counts were very low at high elevation, essentially unused sites, such as Station 17. "Background" counts of fecal coliforms, viz. those occurring naturally in the stream, likely depend on the physical environment of the stream, for example water temperature and dissolved solids. Perhaps the low counts at high elevation sites is as much a factor of cold water temperatures as a factor of "virginity" or lack of use, of the land. Geldreich, Huff, Bordner, Kabler, and Clark (1962) maintain that fecal coliforms of surface waters are derived largely, if not completely, from fecal pollution of animal origin.

Fair points out (1963) that the coliforms are probably not entirely of fecal origin. The occurrence of frequent coliform counts at sites where contamination is very improbable suggests that coliforms are of non-fecal as well as fecal sources.

The FC/FS Ratio

Use of the FC/FS ratio as a method of distinguishing human from animal pollution on the Little South watershed is still questionable. The coliform, FC, and FS bacteria all indicated stream contamination by cattle in grazed areas. As summarized in the Table 5 (Chapter IV) comparison of the three groups, the FC group rates "most sensitive" to cattle pollution, the heavily grazed watershed containing 16 times higher FC concentrations than the lightly grazed one. The FS group is "least sensitive" of the three, the heavily grazed watershed showing less than twice the concentrations of the lightly grazed one. These distinct contrasts between FC and FS "sensitivity" make it obvious that the FC/FS ratios, FS being the denominator, must at times be large on the grazed stream. Studies by the PHS Taft Sanitary Engineering Center describe use of the FC/FS ratio to determine human pollution, whereby the smaller FC/FS ratios (less than ca. 1.0) would represent domestic livestock, the larger ratios, human (Geldreich, Clark, and Huff, 1964). According to such a hypothesis, the results shown in Figure 29 would necessarily be rated as "human contamination," despite the apparent fact that the cause must be cattle pollution; cattle are nonchalantly defecating in the stream while no apparent human pollution is occurring. In comparing results of this study with results reported by other investigators, such as the Taft Center, it must be remembered that environmental conditions in the cold, "pure" mountain streams of the study area are drastically different from those found in warmer, "contaminated," low elevation streams. No specific study of wildlife impact was carried out during the two year study. In certain areas of the watershed, such as the Little Beaver drainage, herds of elk (up to ca. 50) and scattered groups of deer probably affect the water quality--to what degree is not known.

Stream "Flushing"

As shown in Chapter V, bacteria concentrations in the stream may depend on the "flushing" effect of rising spring flows. Bacteria counts are also observed to increase drastically during the rising limb of storm hydrographs. In the case of irrigation, a similar flushing of bacteria into the stream apparently takes place. The rainy year of 1965 exhibited much higher bacteria counts than drier 1964. All evidence implies a strong dependence of bacteria concentrations on "flushing." Morrison and Fair (1966), studying a Colorado watershed north of the study area, also found evidence that surface runoff washes bacteria directly into the stream. They found increases in bacteria concentrations during summer storm runoff, however, they found a reduction in bacteria concentrations near the hydrograph peak, possibly due to dilution. During rising stages of the spring runoff, they surmised that water washes material into the stream and picks up foreign material from stream banks.

The data of both years show a "post-flush" lull in bacteria concentrations during the receding flow period following the season's peak flow. Foreign material is apparently washed into streams from land surface and streambanks during rising stages by the high velocity waters. This leaves streambeds essentially "clean" up to the height of the peak flow. The low counts during the following receding flows are possibly due to: (1) a lack of "contaminated" streambanks, (2) the still large volume of water, causing great dilution, and (3) high velocities, creating an unfavorable environment for bacteria reproduction on the stream bottom.

The few storms sampled also exhibited a "post-flush" lull in bacteria counts, during the receding limb of the storm hydrograph.

Late Summer Bacteria Rises

Morrison and Fair (1966) found that during periods of stable streamflow, in the absence of precipitation, bacterial numbers are directly related to the wetted perimeter and velocity of the stream and indirectly related to the cross-sectional area. In periods of low flows, the wetted perimeter would be large in relation to the cross-sectional area, causing high bacteria counts. This hypothesis agrees with findings on the Little South, where late summer bacteria counts are high at most sites. The "wetted perimeter-cross-sectional area hypothesis" probably also needs a factor for temperature as noted by Morrison and Fair.

CHAPTER VII

SUMMARY

A study was made during 1964-65 to determine water quality characteristics of high elevation watersheds at varying natural flow regimes. The results are believed to be applicable in a general way to mountain watersheds where both air and water temperatures are low, the influence of man and domestic livestock is minimal, and snowmelt runoff is a major contributor to streamflow. Based on 604 sampling events the following was found:

1. All evidence points to a strong, positive bacteria to flow relationship. High bacteria concentrations associated with grazing and irrigation impact appear to depend on the "flushing effect" of the flooding. This flushing effect also occurs during spring snowmelt and summer storm runoff periods. Bacteria-physical parameter correlations were far more common in 1965--a very wet year--than in the drier year of 1964.

2. The broad seasonal trend for the coliform, fecal coliform (FC) and fecal streptococcus (FS) bacteria groups was similar: (1) low winter counts prevailed while the water was 0°C; (2) high concentrations appeared during the peak flows of June; (3) a short "post-flush" lull in counts took place as the hydrograph declined in mid-summer; (4) high concentrations were found again in the late summer period of warmer temperature and low flows; and (5) counts declined with the arrival of autumn. The FS differed somewhat from the other two indicator groups by having higher counts in the period of moderate flows and cold water in April-May.

3. Concentrations of bacteria from wintertime sampling during ice-covered conditions of March, 1965 were low, however, bacteria of all three indicator groups were found. FC and FS counts for the period were all less than 10 colonies/100 ml. Most sites showed coliform counts of 0-20 colonies/100 ml; one site showed a 140 colonies/100 ml concentration.

4. A wide range of bacteria concentrations was common to most sites. Disregarding sporadic, exceptionally high counts, coliforms fluctuated from zero to about 300 colonies per 100 ml , depending on the site and season. FC and FS fluctuated less, from zero to around 75 colonies per 100 ml , not including occasional, exceptionally high counts. The high elevation sites usually exhibited near zero counts of FC and FS and low values for coliforms (less than 40), while downstream sites showed much higher counts of all three indicator organisms. Total bacteria counts (1964 only) presented a range of values of from several million colonies per 100 ml to occasional concentrations of less than ten thousand colonies per 100 ml.

5. The coliforms, FC, and FS were positively related to flow, turbidity, and suspended sediment and negatively related to pH at most sites on the watershed. A mutual dependency of the physical parameters and bacteria groups on the key factor, streamflow, was suggested.

6. All three bacteria groups clearly defined the grazing-irrigation impact in 1965 on Pennock Creek--a small stream running through a meadow. The FC showed the highest value, or "greatest sensitivity," displaying an impacted watershed mean 16.1 times greater than that of the control. The coliforms rated much less sensitive (3.2), while the FS group was ranked "least perceptive" as a pollution detector, showing an impacted watershed mean only 1.7 times greater than the control.

7. Higher, more turbid flows accentuated relationships among the physical parameters of water quality in 1965 as compared to 1964. A greater number of correlations were found in the period from the initial spring melt until peak flow than from the peak flow until autumn in both years of observation.

8. Water temperature values at the time of sampling ranged from 0 to 17°C. Recording thermographs gave a maximum value of 24°C. This occurred at the lowest site on the watershed.

9. Minimum pH values were found near the peak flows of both years. Within the range of elevation sampled, pH decreased 0.1 to 0.2 units per each 1000 foot elevation increase. Total range of pH for all samples was from 6.3 to 8.7.

10. Turbidity and suspended sediment were positively correlated to flow and to each other. Maximum readings were 724 mg/l for sediment and 475 Hellige Units for turbidity, during a summer storm runoff period. The sediment to turbidity ratio was about 5:1.

11. Dissolved solids ranged between 0 and 205 mg/l; no relations between dissolved solids and the other physical parameters were found.

REFERENCES

American Public Health Association. 1960. Standard methods for the examination of water, sewage, and industrial wastes. 11th ed. American Public Health Association, New York. 626 p.

Burman, N. P. 1961. Some observations on coli-aerogenes bacteria and streptococci in water. J. Appl. Bacteriol. 24:368-376.

Fair, Jerrell F. 1963. An application of a modified membrane filter technique for the demonstration of enteric pathogens in raw surface waters. M. S. Thesis, Colorado State University, Fort Collins. 96 p.

Geldreich, E. E., H. F. Clark, and C. B. Huff. 1964. A study of pollution indicators in a waste stabilization pond. J. Water Pollution Control Federation 36:1372-1379.

Geldreich, E. E., C. B. Huff, R. H. Bordner, P. W. Kabler, and H. F. Clark. 1962. The faecal coli-aerogenes flora of soils from various geographical areas. J. Appl. Bacteriol. 25:87-93.

Goldman, C. R., and R. B. Wetzel. 1963. A study of the primary productivity of Clear Lake, Lake County, California. Ecology 44:283-294.

Greenberg, A. E. 1964. Plankton of the Sacramento River. Ecology 45:40-49.

Heidel, S. G. 1956. The progressive lag of sediment concentration with flood waves. Amer. Geophys. Union, Trans. 37:56-66.

Junge, C. E. 1963. Air chemistry and radioactivity. Academic Press. New York. 351 p.

Kunkle, S. H. 1967. Water quality of a mountain watershed in Colorado. M. S. Thesis, Colorado State University, Fort Collins. 139 p.

Macon, T. T. 1959. The temperature of a small stony stream. Hydrobiologia. 12:89-106.

Morita, R. Y., and R. D. Haight. 1964. Temperature effects on the growth of an obligate psychrophilic marine bacterium. Limnol. Oceanog. 9:103-106.

Morrison, S. M., and J. F. Fair. 1966. Influence of environment on stream microbial dynamics. Hydrology Paper No. 13. Colorado State University, Fort Collins. 21 p.

Palmer, M. C. 1962. Algae in water supplies; an illustrated manual on the identification, significance, and control of algae in water supplies. U. S. Public Health Serv., Div. Water Supply and Pollution Control, Cincinnati, Ohio. 88 p.

Potter, L. F. 1963. Planktonic and benthic bacteria of lakes and ponds, p. 148-166. In H. Heukelekian and N. C. Dondero (ed.) Principles and applications in aquatic microbiology (Rudolfs Research Conference, 1963, Rutgers, the State University, New Brunswick, N. J., Proc.) John Wiley and Sons, Inc., New York.

Powers, E. B. 1929. Fresh water studies I. The relative temperature, oxygen content, alkali reserve, the carbon dioxide tension and pH of the waters of certain mountain streams at different altitudes in the Smoky Mountain National Park. Ecology 10:97-111.

Ruttner, Franz. 1963. Fundamentals of limnology. 3d ed. University of Toronto Press, Toronto. 295 p.

Swenson, H. A. 1964. Sediment in streams. J. Soil Water Conserv. 19:223-226.

U. S. Interagency Committee on Water Resources. 1961. The single-stage sampler for suspended sediment. Report No. 13. Subcommittee on Sedimentation. U. S. Govt. Print. Off., Washington, D. C. 105 p.

APPENDIX CONTENTS

APPENDIX

TABLES AND FIGURES

TABLE A-- Comparison of the pH values at sampling times during the spring-summer season at Stations 10 and 11, showing the difference in pH for 1965 between the two stations. No difference between the two stations is evident in 1964.

1964			1965		
Sample	Station 10	Station 11	Sample	Station 10	Station 11
April			March		
28	7.0	6.9	18	7.1	6.4
May			19	7.0	7.0
5	7.9	7.8	20	7.1	6.6
10	7.3	6.9	April		
19	7.3	6.9	13	6.8	6.7
26	7.2	7.2	22	7.5	7.3
30	6.9	7.2	May		
June			1	7.3	6.9
2	7.4	7.2	6	7.3	6.7
9	7.1	7.6	13	7.5	7.2
13	8.0	8.3	19	7.4	7.2
16	7.5	8.1	29	7.4	6.4
23	7.5	7.5	June		
30	7.5	7.5	1	7.5	7.5
July			4	7.3	7.6
8	7.2	7.3	9	7.2	7.0
14	7.5	7.6	11	6.9	6.7
21	7.6	7.1	15	7.1	7.2
28	7.4	7.0	18	6.9	7.0
August			21	7.1	6.4
4	7.9	7.2	26	7.4	7.2
11	7.4	7.5	July		
18	7.1	7.3	1	7.2	7.2
September			5	7.2	7.0
4	7.3	7.1	9	7.3	7.4
October			16	7.3	7.1
3	7.1	7.6	22	7.3	7.3
31	7.6	7.5	30	7.5	7.4
			August		
			5	7.7	7.4
			10	7.7	7.3
			19	7.4	7.3
			26	7.6	7.7
			September		
			26	7.6	7.5
Annual mean	7.40	7.38	Annual mean	7.30	7.09

TABLE B-- Parts per million of chemical components for selected samples throughout both sampling seasons, showing general range of concentrations common on the watershed.

Station	Date	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3
1	6-13-64	4.0	3.6	2.0	0.0	0.0	12.2	4.0	7.4	0.6
1	6-23-64	2.0	7.3	0.0	0.0	2.4	9.8	4.0	14.0	0.0
1	7-28-64	2.0	8.5	0.0	0.0	0.0	12.2	4.0	6.6	0.0
1	8-11-64	4.0	12.2	0.0	0.0	0.0	14.6	4.0	7.4	0.6
1	3-18-65	4.0	4.9	0.0	0.0	4.8	17.1	4.0	19.8	1.3
2	3-18-65	2.0	7.3	0.0	0.0	2.4	22.0	4.0	13.2	0.3
8	3-18-65	2.0	8.5	0.0	0.0	4.8	14.6	6.0	9.1	0.3
14	3-19-65	2.0	6.1	0.0	0.0	0.0	17.1	4.0	4.1	0.8
15	3-19-65	2.0	9.7	0.0	0.0	4.8	14.6	2.0	9.9	0.0
1	3-19-65	2.0	6.1	0.0	0.0	2.4	22.0	4.0	8.2	0.0
1	5-1-65	4.0	4.9	2.8	1.0	0.0	31.7	6.0	18.9	1.4
1	5-19-65	4.0	6.1	2.8	1.0	0.0	29.3	8.0	46.1	1.4
1	6-15-65	2.0	10.9	2.0	1.0	0.0	14.6	6.0	12.5	1.1
1	6-26-65	2.0	6.1	2.0	1.0	0.0	12.2	4.0	4.6	1.1
1	7-1-65	2.0	4.9	1.5	1.0	0.0	12.2	4.0	23.9	1.1
1	7-16-65	4.0	2.4	1.5	1.0	0.0	19.5	8.0	4.7	1.1

TABLE C--Total bacteria observations in thousand colonies per 100 ml for main stem stations, 1964.

Date	Station						Date	Station			
	11	10	4	3	1	Main Stem $\bar{x}$		2	8	14	15
4-28	13,000	130	20	110	30	2,658	4-28	10	150	-	5,000
5-5	360	30	20	50	20	96	5-5	20	30	-	-
5-12	300	120	120	20	60	124	5-12	-	-	-	-
5-19	400	650	450	20	180	340	5-19	280	220	-	600
5-26	-	550	400	260	790	500	5-26	450	630	-	10,000
5-30	350	120	80	550	500	320	5-30	60	40	-	1,200
6-2	500	160	60	2	100	164	6-2	200	80	-	10
6-9	30	20	10	0*	-	15	6-9	0	20	70	40
6-13	4,000	-	4,000	30	20	2,012	6-13	10	80	30	60
6-16	70	-	-	340	50	153	6-16	40	860	170	880
6-23	160	110	7,000	80	180	1,506	6-23	30	120	120	30
6-30	400	-	120	ca. 110	-	210	6-30	100	250	350	500
7-8	880	280	40	50	0*	250	7-8	20	1,700	-	100
7-14	480	200	90	450	130	270	7-14	900	60	270	550
7-21	180	400	3,000	300	1,000	976	7-21	4,000	20,000	-	-
7-28	20	100	20	-	190	82	7-28	8,000	0	40	50
8-4	60	200	80	330	520	238	8-4	350	70	120	200
8-11	420	60	130	450	100	232	8-11	800	190	-	530
8-18	170	10,000	80	20	670	2,188	8-18	80	250	350	-
9-4	20	500	70	430	20	208	9-4	100	500	140	650
10-3	210	80	120	40	1,200	330	10-3	3,000	450	130	500

* "Zero counts" actually mean the count is less than 10,000, since each colony on the plate represents 10,000 colonies/100 ml, due to the dilution used.

TABLE D -- Samples collected during summer storms, showing turbidity, suspended sediment, temperature, and dissolved solids values.

Date	Station	Time	Turb.	SS	Temp.	DS
Storm Samples, 1964						
7-21-64	11	1750	5.00	void	40	68
7-21-64	15	1800	0.77	13	38	40
7-21-64	10	1810	0.62	8	41	16
7-21-64	14	1850	0.56	void	38	120
7-21-64	11	1920	0.44	10	41	28
8-2-64	11	1533	65.00	233	54	0
8-2-64	11	1550	16.50	54	54	0
8-2-64	11	1558	6.00	15	54	1
8-2-64	11	1626	0.56	8	54	1
8-2-64	11	1645	0.70	8	54	0
Storm Samples, 1965						
6-16-65	15	1450	2.90	34	--	48
6-16-65	17	1550	2.90	59	--	68
6-16-65	10	1630	1.20	24	--	61
6-16-65	8	1710	11.00	95	--	74
6-16-65	4	1720	11.00	57	--	38
6-16-65	11	1836	3.30	52	--	52
6-16-65	17	1900	3.30	102	--	12
6-16-65	15	1920	0.65	68	--	46
6-16-65	10	1930	9.55	93	--	2
6-16-65	8	1950	46.00	596	--	88
7-22-65	10	1310	475.00	724	52	52
7-22-65	11	1300	12.00	50	52	27

TABLE E-- Samples collected during "winter," iced-over conditions of March, 1965. Values by stations for pH, turbidity, suspended sediment, dissolved solids, coliforms, fecal streptococcus and fecal coliforms.

Date	Station	Time	pH	Turb.	SS	DS	COLI	FS	FC
Winter Samples									
3-16-65	1	0915	7.3	0.05	2	63	--	--	--
3-16-65	2	1230	7.3	0.22	6	50	--	--	--
3-16-65	2	1400	7.3	0.01	5	34	--	--	--
3-16-65	3	1430	7.5	0.18	1	47	--	--	--
3-16-65	4	1500	7.5	0.28	4	50	--	--	--
3-18-65	14	0730	7.1	0.45	9	29	0	4	--
3-18-65	10	0835	7.1	0.63	8	15	10	0	--
3-18-65	15	0900	7.1	0.56	10	29	0	0	--
3-18-65	1	1340	7.5	0.50	3	10	0	0	--
3-18-65	2	1410	7.0	0.50	4	53	0	0	--
3-18-65	3	1420	7.4	0.22	3	61	0	0	--
3-18-65	4	1440	7.0	0.56	4	65	0	0	--
3-18-65	8	1530	7.1	0.38	4	29	140	6	--
3-18-65	11	1530	6.4	0.44	4	53	0	0	--
3-19-65	14	0710	7.1	0.62	3	35	0	0	--
3-19-65	15	0820	7.0	0.50	2	34	0	0	--
3-19-65	10	0810	7.0	0.84	2	28	0	0	--
3-19-65	11	0920	7.0	0.77	2	35	0	2	--
3-19-65	1	1300	7.5	0.63	2	50	0	0	--
3-19-65	2	1340	7.4	1.50	1	56	0	0	--
3-19-65	3	1350	7.4	0.77	1	31	0	0	--
3-19-65	4	1400	7.4	0.50	3	17	0	0	--
3-19-65	8	1450	7.3	0.56	4	25	0	0	--
3-20-65	14	0630	7.4	0.62	4	21	10	0	0
3-20-65	10	0745	7.1	0.56	3	25	10	0	6
3-20-65	15	0800	7.2	1.60	2	39	12	0	0
3-20-65	11	0800	6.6	0.63	2	27	4	2	4
3-20-65	4	1540	6.7	0.50	2	34	24	2	0
3-20-65	3	1550	7.8	0.63	4	67	14	0	0
3-20-65	2	1600	6.6	0.91	3	58	6	0	0
3-20-65	1	1640	6.7	0.44	4	28	6	0	4
3-20-65	8	1000	6.5	0.50	--	--	26	0	2

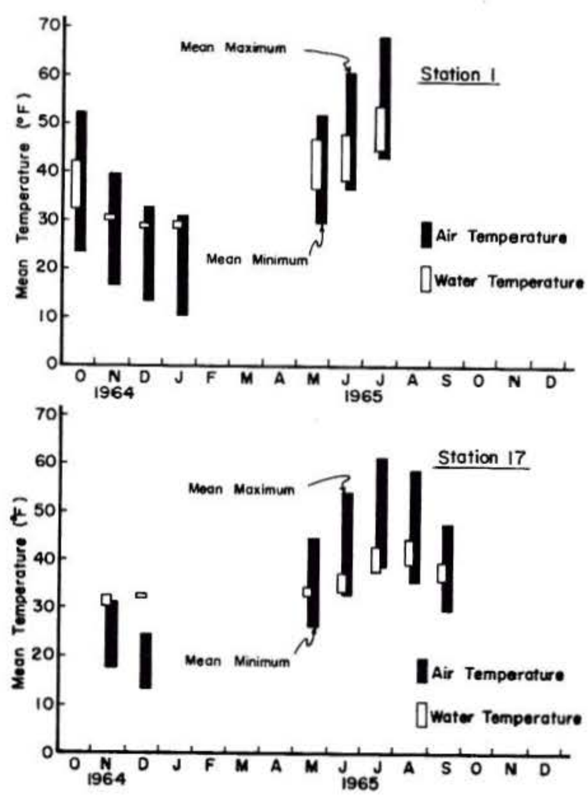
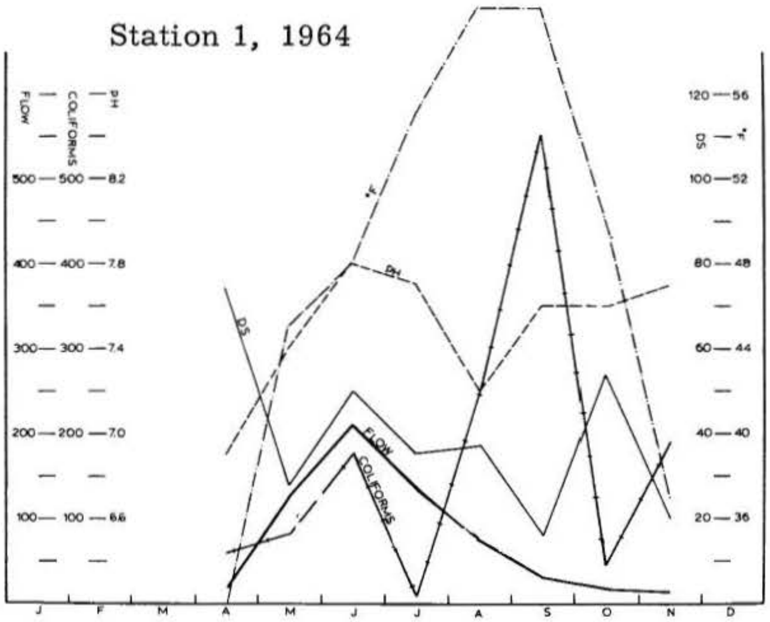


Figure A-- Mean monthly maximum and minimum air and water temperatures during 1964-1965 at Stations 1 and 17.

Station 1, 1964



Station 1, 1965

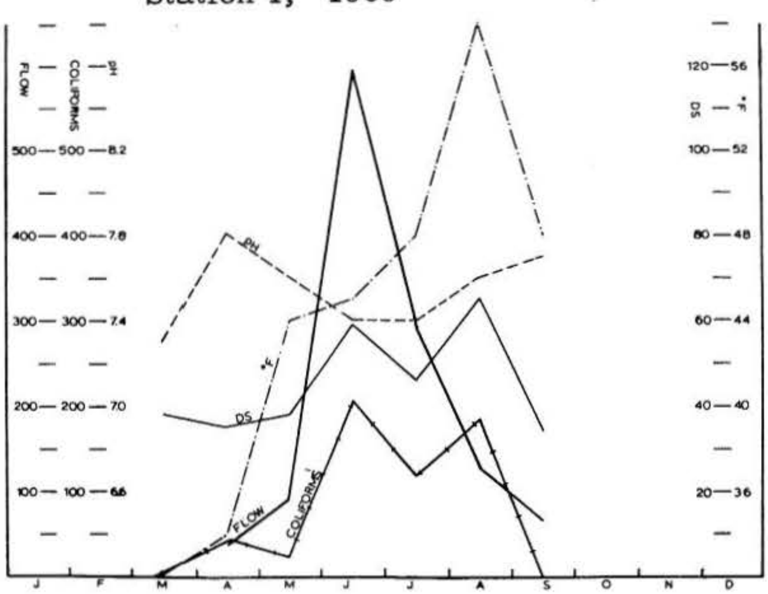
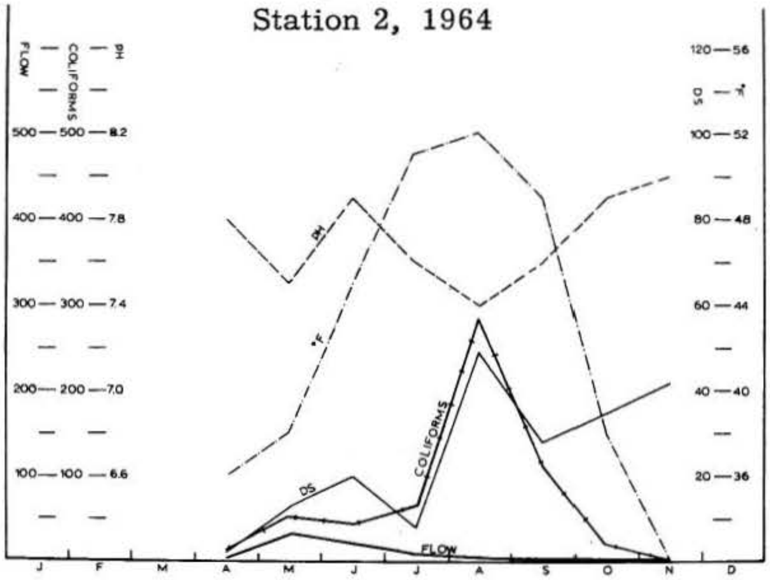


Figure B-- Monthly mean values plotted for flow, pH, temperature, dissolved solids, and coliform bacteria for Station 1, 1964 and 1965.



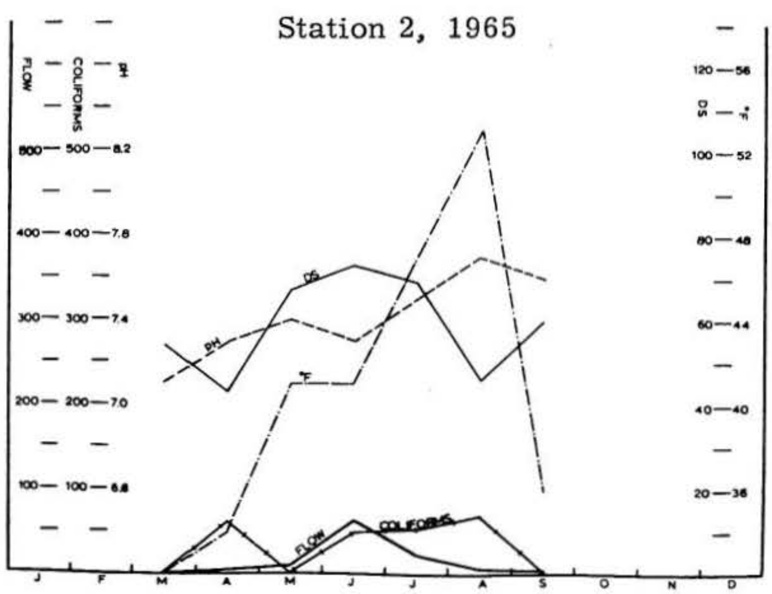
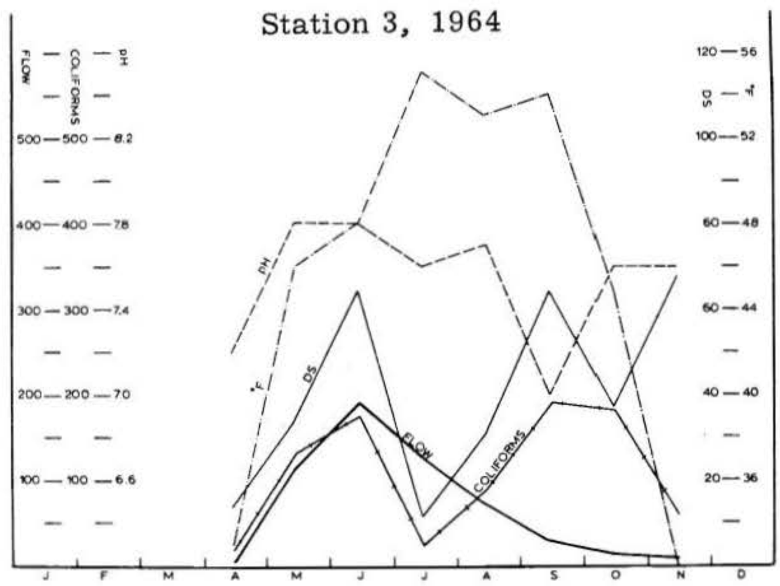


Figure C-- Monthly mean values plotted for flow, pH, temperature, dissolved solids, and coliform bacteria for Station 2, 1964 and 1965.



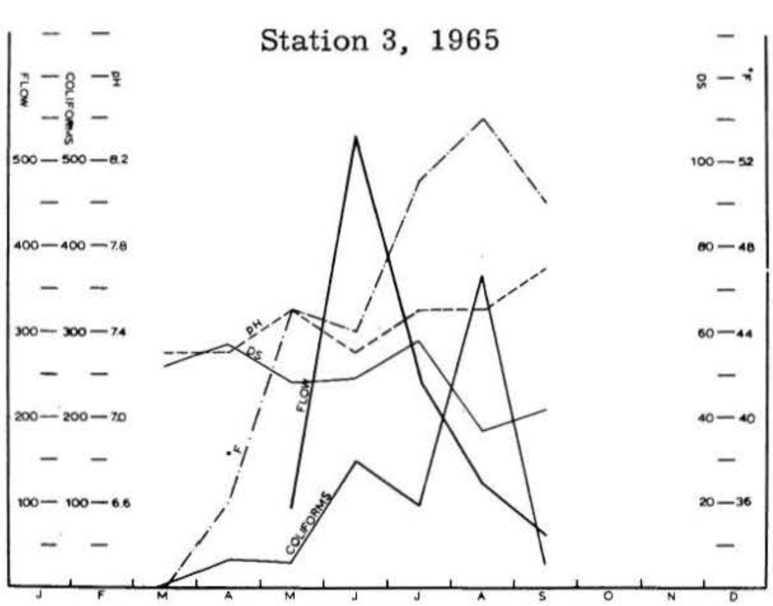
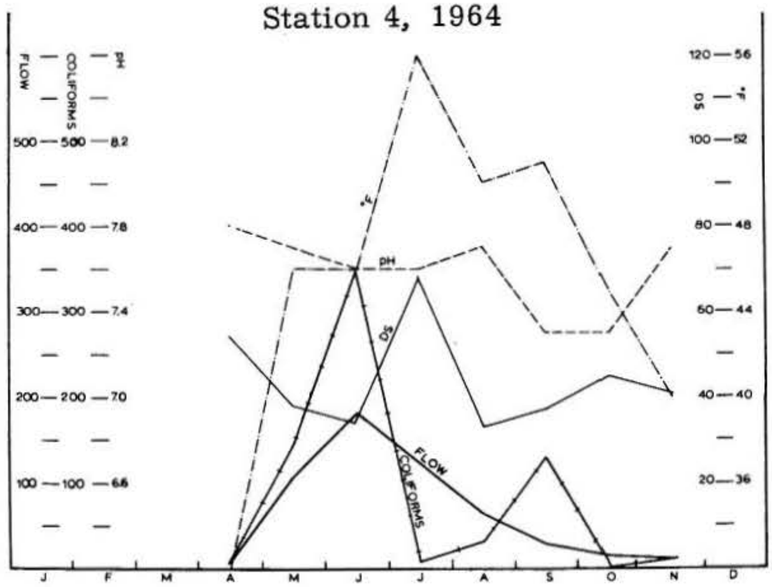


Figure D-- Monthly mean values plotted for flow, pH, temperature, dissolved solids, and coliform bacteria for Station 3, 1964 and 1965.



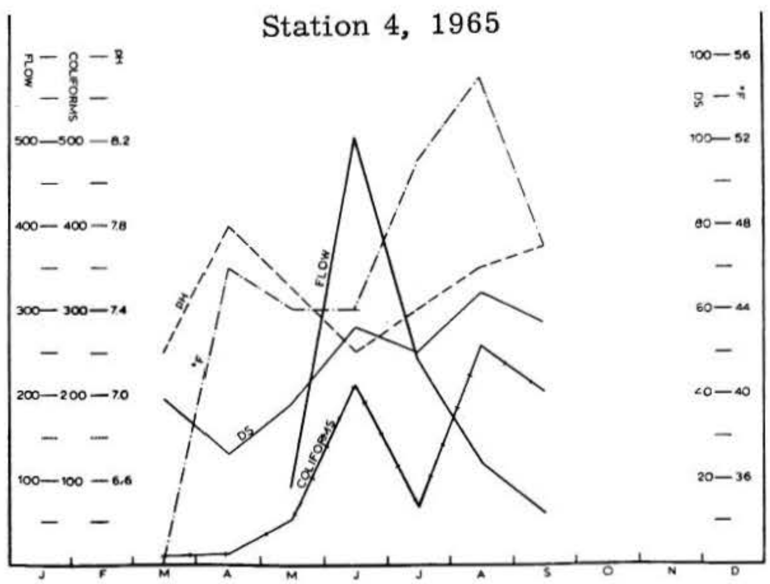
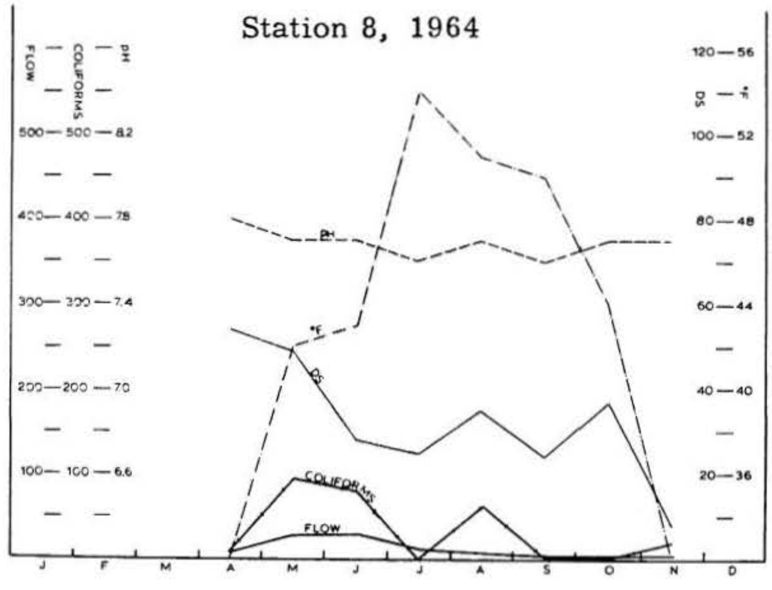


Figure E-- Monthly mean values plotted for flow, pH, temperature, dissolved solids, and coliform bacteria for Station 4, 1964 and 1965.

Station 8, 1964



Station 8, 1965

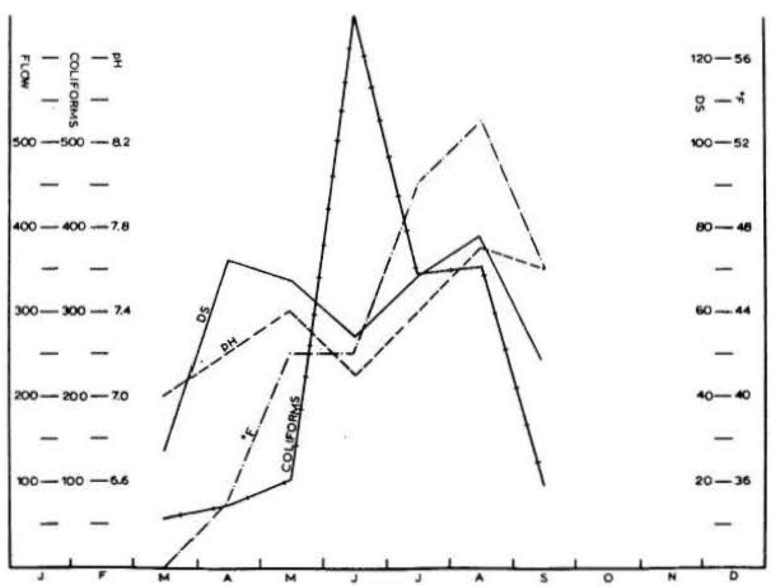
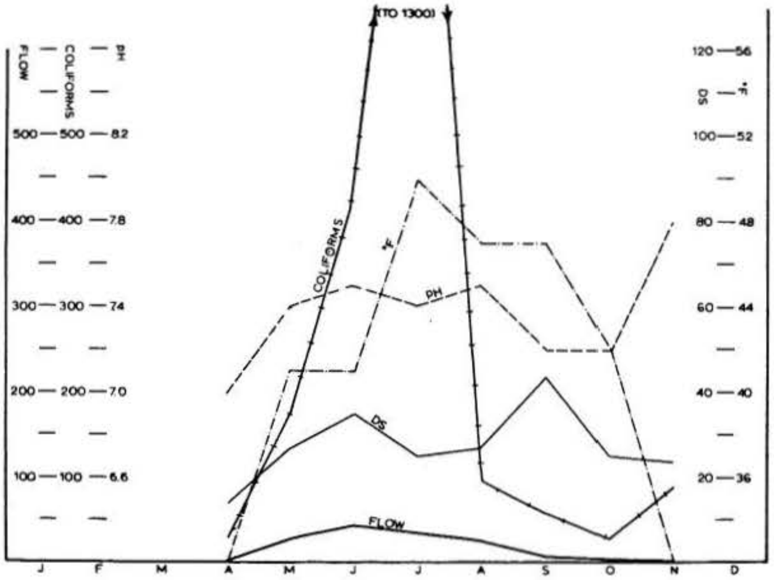


Figure F-- Monthly mean values plotted for flow, pH, temperature, dissolved solids, and coliform bacteria for Station 8, 1964 and 1965.

Station 10, 1964



Station 10, 1965

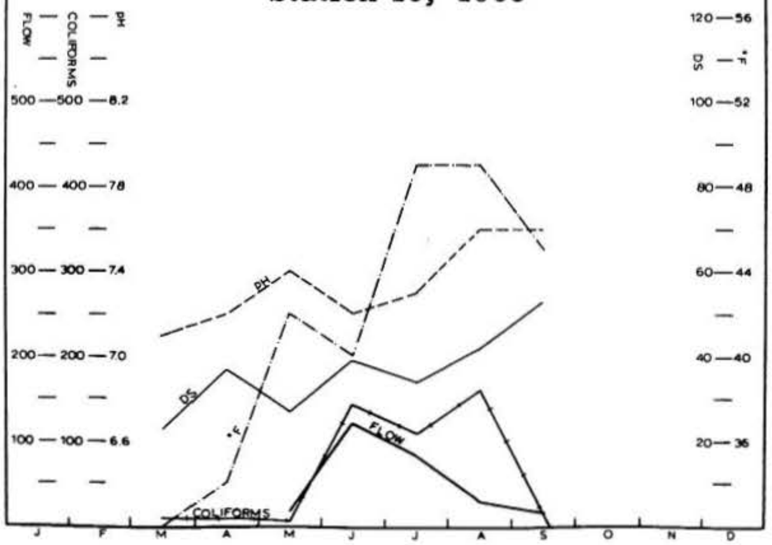
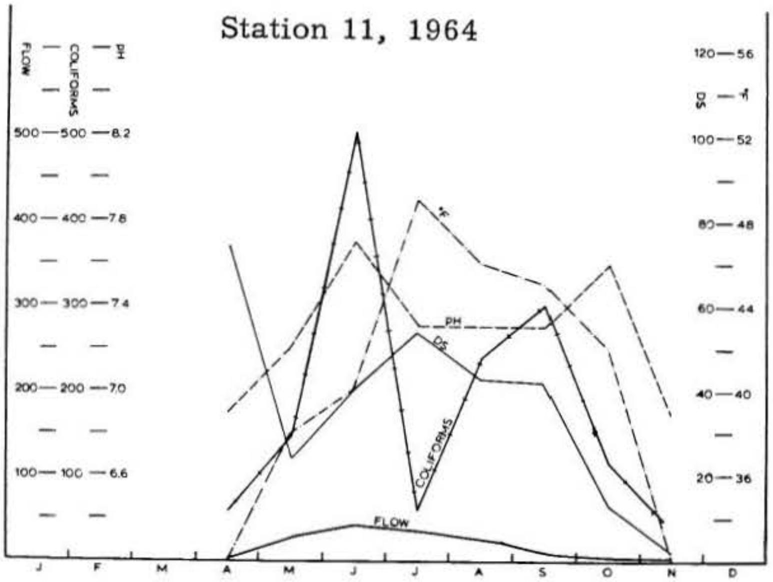


Figure G--Monthly mean values plotted for flow, pH, temperature, dissolved solids, and coliform bacteria for Station 10, 1964 and 1965



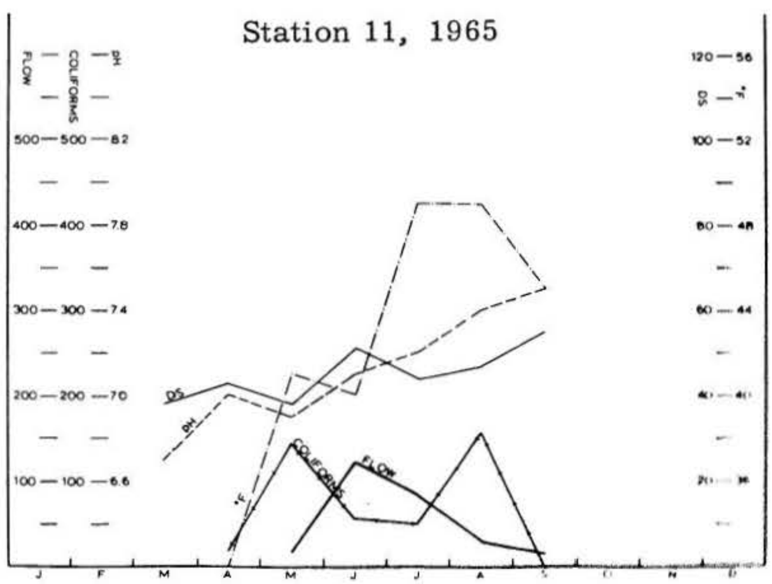
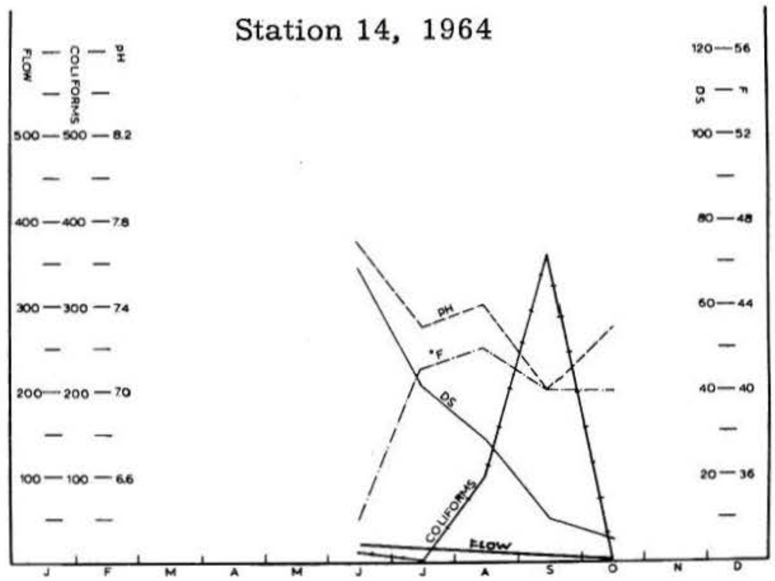


Figure H--Monthly mean values plotted for flow, pH, temperature, dissolved solids, and coliform bacteria for Station 11, 1964 and 1965



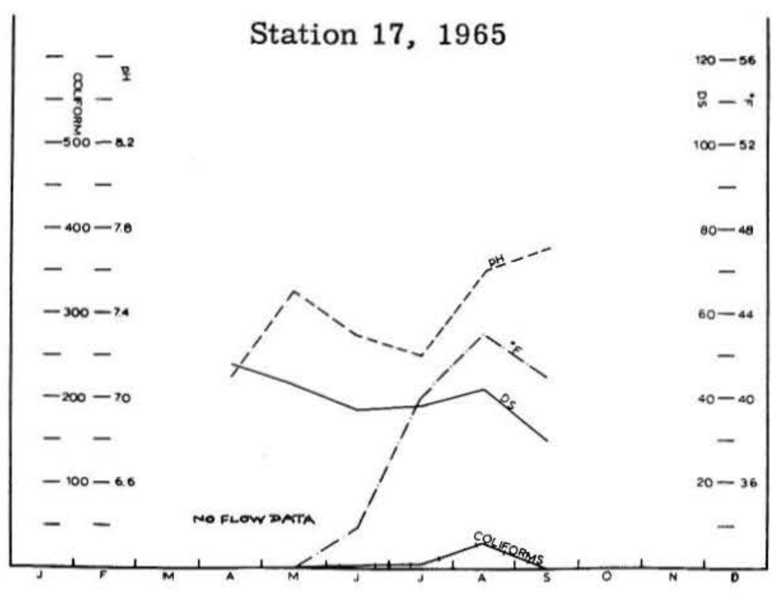
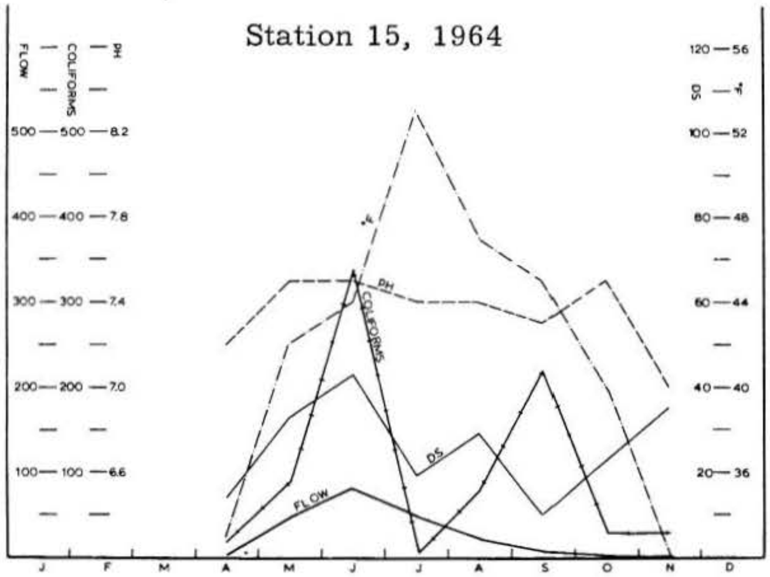


Figure I--Monthly mean values plotted for flow, pH, temperature, dissolved solids, and coliform bacteria for Station 14, 1964 and Station 17, 1965



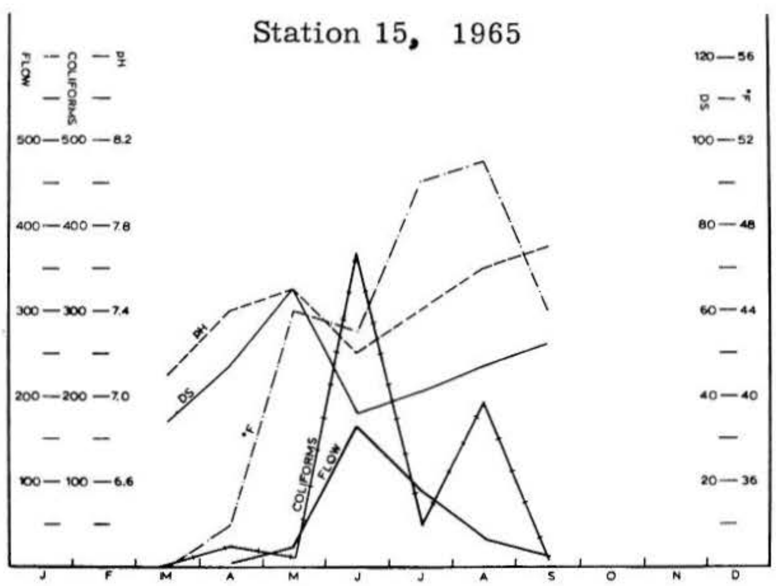


Figure J--Monthly mean values plotted for flow, pH, temperature, dissolved solids, and coliform bacteria for Station 15, 1964 and 1965

Key Words: Water Quality, Hydrology, Mountain Watersheds, Bacteria.

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Abstract - Cont'd.
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Abstract - Cont'd.
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