A microbiological and chemical investigation of the effects of multiple use on water quality of high mountain watersheds
by Gary Kent Bissonnette

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Microbiology
Montana State University
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Abstract:
During the summers of 1969 and 1970 bacteriological determinations of coliform, enterococcal, and standard plate counts were performed on two high mountain drainage systems: Hyalite, a watershed open for public use and Mystic, a watershed that had been closed from 1917 until its opening for limited human activity in the spring of 1970.

The 1969 bacteriological results agreed with previous studies in that coliform densities were found to be greater in the closed watershed than found in the open watershed. In 1970 coliform densities decreased considerably to values that were quite similar to numbers observed in the open watershed. Coliform densities were found to be high in the South Fork of the Bozeman Creek in 1969, while these densities decreased considerably in 1970.

Chemical and physical analyses included air temperature, water temperature, pH, conductivity, turbidity, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, nitrite, nitrate, and orthophosphate. These analyses indicated that the chemical and physical make-up of the two drainages did not adequately account for differing bacterial densities.

Serological studies on Escherichia coli isolated from water and wild animal (bear and elk) fecal droppings indicated the strong, influence that wild game animals had on determining bacterial densities in the closed watershed.

It was concluded that the cause of significant changes in the closed watershed were a direct result of the influences of its main tributary, the South Fork. Wild game animal populations which inhabited the South Fork area in 1969 were the primary cause of the high bacterial contamination. The opening of the closed watershed for limited public use and an extensive logging operation in 1970 coincided with decreasing bacterial densities in this drainage. The influence exerted by the South Fork on bacterial numbers in the closed (Mystic) watershed was a result of its direct entrance into the Bozeman Creek below the Mystic reservoir.

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A MICROBIOLOGICAL AND CHEMICAL INVESTIGATION OF THE EFFECTS OF MULTIPLE USE ON WATER QUALITY OF HIGH MOUNTAIN WATERSHEDS

by

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A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

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in

Microbiology

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TABLE OF CONTENTS

	Page
VITA	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	xiii
ABSTRACT	xv
INTRODUCTION	1
LITERATURE REVIEW	5
DESCRIPTION OF THE STUDY AREA	14
METHODS AND MATERIALS	17
Sampling - Bacteriological	17
Standard Plate Count	18
Coliforms	18
Enterococci	20
Animal Dropping Examination from Closed Watershed	21
Serological Examination	22
Sampling - Chemical	24
Water Chemistry Analyses	24
RESULTS	26
Quantitative Bacteriological Studies of Water Samples	26

Page

Qualitative Bacteriological Studies of Water Samples. . . . 38

Coliforms. 38

Enterococci. 38

Seasonal Variation of Coliforms and Enterococci 38

Bacteriology of Animal Droppings. 43

Serology of Organisms Isolated from Water and Animal Droppings. 43

Physical and Chemical Results of Water Analyses 46

Statistical Results 75

DISCUSSION 77

SUMMARY. 87

APPENDIX 90

LITERATURE CITED 127

LIST OF TABLES

Table — Page

1. Comparison of Numbers of Bacteria Obtained From 8 Weekly Water Sample Collections at Different Sites in Mystic (closed) and Hyalite (open) Watersheds During the Summer of 1968. 27

2. Comparison of Numbers of Bacteria Obtained From 9 Weekly Water Sample Collections at Different Sites in Mystic (closed) and Hyalite (open) Watersheds During the Summer of 1969. 28

3. Comparison of Numbers of Bacteria Obtained From 13 Weekly Water Sample Collections at Different Sites in Mystic (closed) and Hyalite (open) Watersheds During the Summer of 1970. 29

4. Comparison of Numbers of Bacteria Obtained From Water Samples Collected at Different Sites in the South Fork of Mystic (closed) Watershed During the Summers of 1969 (7 weekly collections) and 1970 (13 weekly collections). 35

5. Percentage Distributions of Escherichia coli, Enteterobacter aerogenes, Intermediates, and Fecal Isolates Obtained at Different Sites. 39

6. Enterobacteria and Enterococci Found in Animal Droppings 44

7. Reactions of 86 E. coli Isolates With Polyvalent Antisera. 45

8. Reactions of Unheated E. coli Isolates With Individual A Antisera. 47

9. Reactions of Unheated E. coli Isolates With Individual B Antisera. 48

10. Reactions of Heated E. coli Isolates With Individual B Antisera. 49

11. Reactions of Unheated E. coli Isolates With Individual C Antisera. 50

Table Page

12. Reactions of Heated *E. coli* Isolates With Individual C Antisera 51

13. Comparison of Water Temperatures (C) Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds 52

14. Comparison of Air Temperatures (C) Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds 53

15. Comparison of pH Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds 54

16. Comparison of Conductivity @ 25 C (Micromhos) Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds 56

17. Comparison of Calcium and Magnesium Concentrations Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 (9 Weekly Collections). 57

18. Comparison of Sodium and Potassium Concentrations Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 (9 Weekly Collections) 58

19. Comparison of Major Anions Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 (9 Weekly Collections). 59

20. Comparison of Nitrate, Orthophosphate, and Turbidity Determinations Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 (9 Weekly Collections). . . . 60

21. Comparison of Water Temperature and Air Temperature Obtained at Different Sites in South Fork of Mystic Watershed During 7 Weekly Samplings in 1969 and 13 Weekly Samplings in 1970. 65

Table | Page

22. Comparison of pH and Conductivity Obtained at Different Sites in South Fork of Mystic Watershed During 7 Weekly Samplings in 1969 and 13 Weekly Samplings in 1970. 66

23. Comparison of Cation Concentrations Obtained at Different Sites in South Fork of Mystic (Closed) Watershed During the Summer of 1970 (8 Weekly Collections). 68

24. Comparison of Anion Concentrations and Turbidity Determinations Obtained at Different Sites in South Fork of Mystic (Closed) Watershed During the Summer of 1970 (8 Weekly Collections) 69

25. Comparison of Nitrate and Orthophosphate Concentrations Obtained at Different Sites in South Fork of Mystic (Closed) Watershed During the Summer of 1970 (8 Weekly Collections) 70

26. Correlation Coefficients for the Variables Indicated Below at P=0.05, Except Where * Indicates P=0.01. . . . 76

27. Number of Organisms per 100 ml in Water Samples Obtained from Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1969 91

28. Number of Coliforms per 100 ml Obtained From Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 92

29. Number of Enterococci per 100 ml Obtained From Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970. 93

30. Standard Plate Counts per ml (SPC/ml) of Water Samples Obtained From Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summers of 1969 (Incubated at 35 C for 48 hrs.) and 1970 (Incubated at 20 C for 5 Days) 94

Table | Page

31. Number of Coliforms per 100 ml, Enterococci per 100 ml, and Standard Plate Count per ml (SPC/ml) in Water Samples Obtained From the Mystic (M_3) and Hyalite (H_3) Diversion Dams and Settling Basin (SB) During January - May, 1970. 95

32. Number of Coliforms per 100 ml, Enterococci per 100 ml, and Standard Plate Count per ml (SPC/ml) in Water Samples Obtained From the Mystic (M_3) and Hyalite (H_3) Diversion Dams and Settling Basin (SB) During October - November, 1970 96

33. Number of Organisms per 100 ml in Water Samples Obtained in Different Sites From the South Fork of the Mystic (Closed) Watershed During the Summer of 1969. 97

34. Number of Coliforms per 100 ml in Water Samples Obtained From Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970 98

35. Number of Enterococci per 100 ml in Water Samples Obtained From Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970. 99

36. Standard Plate Counts per ml (SPC/ml) of Water Samples Obtained From Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summers of 1969 (Incubated at 35 C for 48 hrs.) and 1970 (Incubated at 20 C for 5 Days). 100

37. Water Temperatures (C) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1969 101

38. Water Temperatures (C) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970. 102

39. Air Temperatures (C) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1969. 103

Table | Page

40. Air Temperatures (C) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970. 104

41. pH Measurements at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1969. 105

42. pH Measurements at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970. 106

43. Conductivities (Micromhos) at 25 C for Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1969. 107

44. Conductivities (Micromhos) at 25 C for Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970. 108

45. Water Temperatures (C), Air Temperatures (C), and pH Measurements of Samples Obtained at the Mystic (M_3) and Hyalite (H_3) Diversion Dams and the Settling Basin (SB) During January - May, 1970 109

46. Water Temperatures (C), Air Temperatures (C), and pH Measurements of Samples Obtained at the Mystic (M_3) and Hyalite (H_3) Diversion Dams and Settling Basin (SB) During October - November, 1970 110

47. Water and Air Temperatures (C) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1969 111

48. Water Temperatures (C) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970. 112

49. Air Temperatures (C) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970. 113

Table | Page

50. pH Measurements and Conductivities (Micromhos) at 25 C From Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1969 . . 114

51. pH Measurements at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970. 115

52. Conductivities (Micromhos) at 25 C for Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970 116

53. Calcium and Magnesium Concentrations (mg/l) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 117

54. Calcium and Magnesium Concentrations (mg/l) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970. 118

55. Sodium and Potassium Concentrations (mg/l) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 119

56. Sodium and Potassium Concentrations (mg/l) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970. 120

57. Total Alkalinities (meq/l) and Turbidity (Jackson Turbidity Units) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970. 121

58. Total Alkalinities (meq/l) and Turbidity (Jackson Turbidity Units) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970. 122

59. Sulfate and Chloride Concentrations (mg/l) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 123

Table Page

60. Sulfate and Chloride Concentrations (mg/1) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970 124

61. Nitrate (mg/1 $N\text{-}NO_3^-$) and Orthophosphate (mg/1 PO_4^{-3}) Concentrations at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 125

62. Nitrate (mg/1 $N\text{-}NO_3^-$) and Orthophosphate (mg/1 PO_4^{-3}) Concentrations at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970. 126

LIST OF FIGURES

Figure		Page
1.	Map Showing Elevations and Sampling Sites of Mystic and Hyalite Watersheds.	15
2.	Bacteriological Profile of Bozeman (Mystic) Creek and Middle (Hyalite) Creek During the Summer of 1968	30
3.	Bacteriological Profile of Bozeman (Mystic) Creek and Middle (Hyalite) Creek During the Summer of 1969	31
4.	Bacteriological Profile of Bozeman (Mystic) Creek and Middle (Hyalite) Creek During the Summer of 1970	32
5.	Bacteriological Profile of the South Fork of Bozeman (Mystic) Creek During the Summer of 1969.	36
6.	Bacteriological Profile of the South Fork of Bozeman (Mystic) Creek During the Summer of 1970.	37
7.	Numbers of Coliforms and Enterococci Obtained at Bozeman (Mystic) Creek Diversion Dam (M_3) on 36 Sampling Dates in 1970	40
8.	Number of Coliforms and Enterococci Obtained at Middle (Hyalite) Creek Diversion Dam (H_3) on 36 Sampling Dates in 1970.	41
9.	Number of Coliforms and Enterococci Obtained at the Settling Basin (SB) on 36 Sampling dates in 1970.	42
10.	Chemical Profile of Average Calcium (mg/l) and Magnesium (mg/l) Concentrations of the Bozeman (Mystic) and Middle (Hyalite) Creeks During the Summer of 1970	61

Figure | Page

11. Chemical Profile of Average Conducitivity (Micromhos) and Total Alkalinity (meq/1) of the Bozeman (Mystic) and Middle (Hyalite) Creeks During the Summer of 1970 62

12. Chemical Profile of Average Turbidity (Jackson Turbidity Units) and Nitrate (mg/1 NO_3^- -N) Concentrations of the Bozeman (Mystic) and Middle (Hyalite) Creeks During the Summer of 1970 63

13. Chemical Profile of Average Orthophosphate (mg/1 PO_4^{-3}) Concentrations of the Bozeman (Mystic) and Middle (Hyalite) Creeks During the Summer of 1970. 64

14. Chemical Profile of Average Calcium (mg/1) and Magnesium (mg/1) Concentrations of the South Fork and its Tributaries During the Summer of 1970 71

15. Chemical Profile of Average Conductivity (Micromhos) and Total Alkalinity (meq/1) Concentrations of the South Fork and its Tributaries During the Summer of 1970 72

16. Chemical Profile of Average Turbidity (Jackson Turbidity Units) and Nitrate (mg/1 NO_3^- -N) Concentrations of the South Fork and its Tributaries During the Summer of 1970 73

17. Chemical Profile of Average Orthophosphate (mg/1 PO_4^{-3}) Concentrations of the South Fork and its Tributaries During the Summer of 1970. . . . 74

18. Drainage Systems of Mystic (Closed) and Hyalite (Open) Watersheds. 84

ABSTRACT

During the summers of 1969 and 1970 bacteriological determinations of coliform, enterococcal, and standard plate counts were performed on two high mountain drainage systems; Hyalite, a watershed open for public use and Mystic, a watershed that had been closed from 1917 until its opening for limited human activity in the spring of 1970.

The 1969 bacteriological results agreed with previous studies in that coliform densities were found to be greater in the closed watershed than found in the open watershed. In 1970 coliform densities decreased considerably to values that were quite similar to numbers observed in the open watershed. Coliform densities were found to be high in the South Fork of the Bozeman Creek in 1969, while these densities decreased considerably in 1970.

Chemical and physical analyses included air temperature, water temperature, pH, conductivity, turbidity, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, nitrite, nitrate, and orthophosphate. These analyses indicated that the chemical and physical make-up of the two drainages did not adequately account for differing bacterial densities.

Serological studies on Escherichia coli isolates from water and wild animal (bear and elk) fecal droppings indicated the strong influence that wild game animals had on determining bacterial densities in the closed watershed.

It was concluded that the cause of significant changes in the closed watershed were a direct result of the influences of its main tributary, the South Fork. Wild game animal populations which inhabited the South Fork area in 1969 were the primary cause of the high bacterial contamination. The opening of the closed watershed for limited public use and an extensive logging operation in 1970 coincided with decreasing bacterial densities in this drainage. The influence exerted by the South Fork on bacterial numbers in the closed (Mystic) watershed was a result of its direct entrance into the Bozeman Creek below the Mystic reservoir.

Chapter 1

INTRODUCTION

A large amount of the water supply for municipal, agricultural, industrial, and recreational purposes comes from high mountain watersheds that are relatively unused at present. With increasing demands for water, it is important that adequate knowledge of the natural characteristics of these supplies be obtained. High mountain watersheds, such as those in the northwestern United States, contain much of the water considered to be in a near virgin state. In the past, the principal investigations of water quality have been concerned with surface water that was considered to be definitely polluted; there is, however, limited knowledge concerning the composition of high quality waters. Perhaps more importantly, there is little known about what actually does constitute "high quality water."

Since there is increasing pressure for the use of watersheds for timber, mining, grazing, recreation, etc., it is of extreme importance to obtain a better knowledge of the natural characteristics of these water supplies. Specifically, a thorough knowledge of natural, pristine watersheds must be obtained in order to understand the impact of later land use on water quality.

Recently, much interest has developed concerning the impact of land use on water quality. In 1963, Teller [37] concluded that there was insufficient information to determine what the natural

quality of water should be, and to what extent fluctuations in bacterial numbers in a stream can be attributed to natural or man-made causes. Van Nierop[38] has shown that public use of reservoirs and municipal watersheds is possible without drastically affecting water quality, provided that proper sanitary practices are strictly observed. Carswell et al.[7] have examined the arguments both for and against the use of public watersheds for recreational purposes. In their study of five watersheds they concluded that little or no deterioration in bacterial water quality occurred when recreation was permitted in or around water supplies. Also, they state that even when a rise in indicator organisms did occur, the bacterial content was within limits that permit removal by existing water treatment technology. Geldreich[13] has examined bacteriological parameters which may be used in quantitating effects of recreational use of water supplies and has attempted to establish the sanitary significance of total coliforms, fecal coliforms, and fecal streptococci.

The subject of this thesis involves the study of two watersheds serving the city of Bozeman, Montana. Specifically, the investigation concerns water quality of two high mountain watershed areas: Middle Creek drainage (Hyalite), an open watershed that is used extensively for numerous recreational activities, and the Bozeman Creek drainage (Mystic) which has been closed to public entry from 1917 until the spring of 1970. In March of 1970, the Mystic watershed area was

opened for limited activities. This unique situation permits a comparison of the "natural quality" of two different sources of mountain water, i.e., a watershed used for recreation and a watershed protected from human use. In essence, this study allows for possible conclusions about the effect of man's activities, such as logging and recreation, on water quality. Equally important, it enables an evaluation of the effect of wild game animals on the composition of waters from high mountain elevations.

Statement of Purpose

In a previous study by Walter and Bottman,[39] results indicated that the Mystic area (closed watershed) had higher coliform and enterococcal counts than the Hyalite area (open watershed). In light of these findings, the purposes of the present study are many-fold:

1. To gain a better knowledge of what actually constitutes natural quality water of high elevation mountain watersheds, both chemically and bacteriologically.

2. To postulate a possible explanation as to the reason for the existence of higher bacterial numbers in the closed watershed.

3. To examine the possibility of tracing microbial pollution to its source by means of serological methods.

4. To gain an insight as to the effects of logging, recreation, and wild animals on water quality in mountain watersheds.

5. To determine whether there are statistical relationships between bacterial numbers and the physical and chemical aquatic environment in these two high elevation mountain watersheds.

Chapter 2

LITERATURE REVIEW

In determining quality of waters which normally contain low bacterial numbers it is of special importance to examine the relationships between bacteria and the physical and chemical environment. The determination of bacterial and chemical indicators of pollution in water has resulted in qualitative and quantitative standard methods.[1,10,23,35] The evaluation of results obtained by using these bacteriological methods has been extensively examined by a number of different researchers as described below.

Bacteria are introduced into waters both naturally and by man and his activities. The coliform organisms have been used as one of the primary indicators of pollution. According to the Standard Methods for the Examination of Water and Wastewater,[1] the coliform group includes all of the aerobic and facultatively anaerobic, Gram-negative, nonsporeforming, rod-shaped bacilli which ferment lactose with gas formation within 48 hours. These coliform organisms are present in soil, on plants, and in the feces of many warm-blooded animals. Schuettpelz[34] states that coliform bacteria have the following advantages for use as indicator organisms: (1) coliforms are constantly found in the human intestine in large numbers; (2) the fate of the coliform organism in water reasonably reflects that of pathogenic bacteria, although the coliform bacteria will normally

live longer than intestinal pathogens; (3) the coliform organism is easy to isolate and enumerate in the laboratory; and (4) coliforms are not normally pathogenic and are easy to handle. Schuettpelz further states that the specific group called fecal coliforms indicates a much better relation to true contamination than that of total coliforms. Geldreich et al.[12,13,15,17] states that fecal coliforms may be the best tool to detect evidence of fecal pollution from warm-blooded animals in polluted water. Kunkle[26] also concluded that the fecal coliform group was the best index for pollution surveillance in an agricultural watershed.

The use of enterococci as a bacterial pollution indicator has become accepted as a standard method. Winslow et al.,[40] as early as 1902, reported observing that streptococci were present consistently in the feces of all warm-blooded animals and in the water associated with such animal discharges. However, the true sanitary significance of fecal streptococci has been confused by controversies concerning procedures for quantitation, definition of the group, and differing concepts as to their occurrence in the water environment and in warm-blooded fecal discharges. Geldreich et al.[18] questions the sanitary significance of Streptococcus faecalis var. liquifaciens and atypical Streptococcus faecalis and implies that the detection of S. bovis and S. equinis, which are not found in human feces but are specific indicators of non-human animal pollution, may be a more sensitive test

of sanitary significance. It is also stated that a valuable application of the fecal streptococci indicator system is through fecal coliform to fecal streptococci ratios which would aid in the determination of sources of fecal discharge into streams. A high ratio indicates human origin, while a low ratio indicates animal origin.

The sanitary significance of fecal streptococci was also examined by Burman[6] who additionally submitted evidence of the relatively greater ability of fecal streptococci than Escherichia coli to survive in various natural and antagonistic environments. In a study concerning bacterial survivability by Benson[4] the results indicated that Streptococcus faecalis was as good, but not necessarily a better indicator of recent and dangerous pollution in a cold, fresh water environment. Halton et al.[25] also examined survivability of coliforms concluding that low sea water temperatures favor the survival of large numbers of E. coli.

Sources of bacterial indicators of pollution, such as coliforms and enterococci, are extremely diverse. Mundt[32] determined the presence of enterococci in a truly wild environment, the Great Smoky Mountains National Park. Enterococci were isolated from most specimens of bats and from carnivorous mammals, such as fox, bear, racoon, boar, and skunk. The distribution of coliform bacteria in the feces of such warm-blooded animals as humans, cows, pigs, sheep, chickens, turkeys, and ducks has been investigated by Geldreich et al.[15] Examination of wild animal fecal droppings (elk, moose, bear) by Goodrich et al.[24]

in a high mountain watershed indicated fecal pollution was primarily from a non-human source, including both fecal coliforms and fecal streptococci.

Bacterial indicators of pollution are also found in soil and on vegetation. Geldreich et al.[16] surveyed the fecal coli-aerogenes flora of soils from various geographical areas. The occurrence of enterococci on plant materials, in spite of their sanitary significance, indicated to Mundt et al.[33] that enterococci do occur naturally on plant surfaces in an agricultural and an inhabited environment, as well as in soils under cultivation or in the vicinity of cultivation. Geldreich et al.[17] conducted a study considering the sanitary significance of coliforms, fecal coliforms, and fecal streptococci isolated from a number of species of plants and a variety of samples of insects. Their findings supported the use of the fecal coliform test for surface water quality evaluations.

An important criterion for the existence of poor quality water is through the recovery of bacterial pathogens from supposedly high quality water. An investigation in a high quality mountain stream by Fair and Morrison[9] resulted in the isolation of enteric pathogens, specifically eleven isolates of the genus Salmonella and 51 isolates of organisms belonging to the Arizona group. The authors state that the isolation of potentially pathogenic bacteria in waters of remote mountain regions indicates that naturally occurring potable surface

water does not exist. They also postulate that the presence of these potentially pathogenic bacteria may be the result of contamination by wild or domestic animals in the watershed area.

Although coliform organisms indicate the possibility of the presence of pathogens, Gallagher and Spino[11] showed little apparent correlation between levels of total or fecal coliforms and the isolation of salmonellae. The authors reason that salmonellae are persistent under conditions which may be adverse to survival of fecal coliforms. In the Northwest Watershed Project[36] pathogenic enterobacteriaceae were found in 28% of the samples collected at the most downstream sampling station although the fecal coliform density was always less than 100/100 ml.

A common problem encountered in bacteriological studies of aquatic systems is to definitely identify the source of bacterial pollution. In recent years Glantz and others[19,20,21,22] have demonstrated the value of serological typing procedures for tracing the source of bacterial pollution. Specifically, Glantz[21] isolated different E. coli serogroups at various sampling points on a stream and used this information to trace these serogroups to their probable upstream source. Support of serological typing procedures for determining microbial pollution was also performed by Bissonnette et al.[5] in the examination of high mountain watersheds. Similar serological reactions were observed in E. coli isolates obtained both

from water and wild animal (bear and elk) fecal droppings in the watershed areas, indicating that the microbial pollution might possibly be traced to wild animals inhabiting the surrounding area of the streams.

Water quality in high elevation mountain watersheds is affected by recreation, grazing, and timber management. As these watersheds are developed for a variety of uses, water quality of the streams is commonly affected. However, there is a dearth of knowledge regarding cycles and variability of bacteria in mountain stream environments. Equally lacking is information concerning the relationships of the microbiology to physical and chemical environmental factors. Also, it is not clear whether the presence of coliforms encountered in water of normally good quality (such as high mountain streams) is in fact an indication of recent fecal contamination.

The environmental influences on stream microbial dynamics have been extensively examined by Morrison and Fair.[31] They determined the causes of variation in bacterial numbers of an unpolluted mountain stream, with emphasis upon the effects of selected chemical and physical variables. They concluded that summer rainstorms washing bacteria into the stream caused the greatest variations in bacterial numbers. Also, the chemical factors (pH, ammonia, and orthophosphate) varied with precipitation and therefore cannot be directly related to bacterial numbers. Differences in bacterial

numbers during the winter were attributed to small changes in water temperature in the 0 - 5.5 C range.

Proper sampling techniques and interpretation of data from high quality mountain water have been provided by Kunkle and Meiman.[28] They observed a daily cycle for indicator organisms; evening maximums in concentrations preceeded by afternoon minimums, while morning bacterial counts usually fell between the two. It was postulated that rising stream stages of early evening caused stream bank "flushing" to account for evening maximums. Also, maximum coliform and fecal coliform numbers were observed in the spring "flushing" or runoff period as well as during summer storm stages. Additionally, water temperature was inversely related to bacterial counts. High bacterial yields from a rural watershed were also attributed to storm runoff by Kunkle[26] in a Vermont stream study. Schuettpelz[34] found that coliform bacteria are especially common during periods following rainfall when there are large amounts of surface runoff. Geldreich et al.[14] have also examined the bacteriological aspects of storm water runoff and found similar results.

Kittrell and Furfari[29] postulated that physical characteristics of a stream may be a prime factor in determining coliform densities. They agree that high densities of coliform bacteria in streams usually follow runoff from rainfall. They also conclude that there is seasonal variance of coliform numbers with temperature, as well as the fact

that turbidity appears to affect rates of bacterial decrease through sedimentation. These authors place much emphasis on the presence or absence of riffle areas as being an important factor in stream self-purification, due to the action of attached predators.

A water quality investigation of mountain watersheds in Colorado by Kunkle and Meiman[27] indicated that physical parameters of the stream were closely related to bacterial numbers. Bacterial groups were especially dependent upon the "flushing" effect of the runoff from snowmelt and rain, summer storms, or irrigation. Observations of surface runoff during thunderstorms indicated most of the storm sediment was contributed by roads in the watershed area. Additionally, there was no indication that the level of human use in campgrounds, picnic areas, or cabin sites increased sediment in the streams. The authors observed numerous significant correlations of bacterial groups to pH, turbidity, and suspended sediment. The coliforms, fecal coliforms, and fecal streptococci were positively related to flow, turbidity, and suspended sediment and negatively related to pH at most sites on the watershed.

Interesting results were provided by Lee et al.[30] concerning a study of three northwestern United States watersheds. They observed that during periods of high flow, indicator organism densities were lower and that they reached their peaks during low flow. They concluded that, although some indicator organisms may be washing into the stream during times of runoff, the bacterial densities were

actually being diluted during periods of high streamflow. Additionally, peak turbidities occurred during times of high streamflow, but the indicator organism densities were low at this time. The dominant factor contributing to fecal coliform densities was attributed to the presence of a large animal population in all three watersheds.

Chapter 3

DESCRIPTION OF THE STUDY AREA

Two high mountain watersheds provide a major portion of the municipal water supply for the approximately 18,000 people of Bozeman, Montana. The watershed areas are located about ten miles south of the city (Figure 1). This study involves the examination of these two watersheds - an open watershed in the Hyalite area, and a closed watershed in the Mystic area.

Separated by a single mountain ridge, Bozeman Creek (Mystic) and Middle Creek (Hyalite) provide about 90% of Bozeman's water supply and are among the principal tributaries of the East Gallatin River.

The Hyalite reservoir receives water draining 5,760 acres and stores 8,000 acre-feet of water. The entire watershed covers 30,080 acres and is completely open to the public for recreational purposes, including boating, swimming, fishing, hunting, camping, and mechanized vehicular travel. Logging has been conducted in the area for several years.

With a total watershed area of 28,160 acres, the Mystic reservoir receives water from 2,880 acres and stores 675 acre-feet of water. This watershed has been closed to the public since 1917 but was opened to foot and horseback travel in March of 1970, as well as for camping, fishing, and hunting. However, extensive logging has taken place in

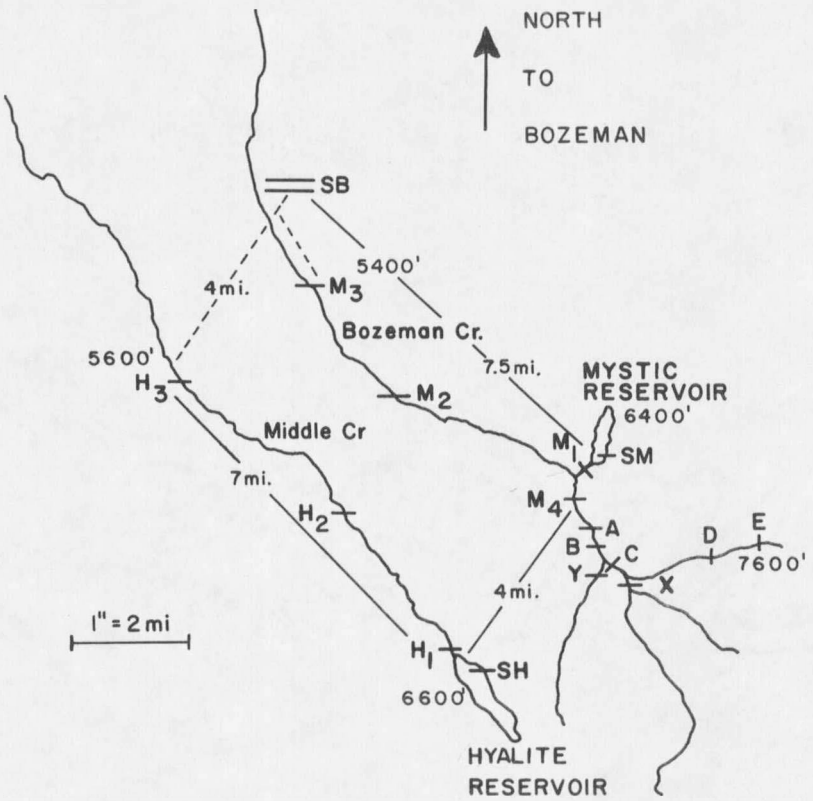


Figure 1. Elevations and Sampling Sites of Mystic (M) and Hyalite (H) Watersheds, Surface of Reservoir (S), Reservoir Outlet (1) Halfway Point (2), Diversion Dam (3), Settling Basin (SB), and the South Fork Sites: M_4, A, B, C, D, E, and South Fork Tributaries X and Y

recent years and mechanized vehicular travel is permitted for this purpose. Most of the present logging activity is in the South Fork of Bozeman Creek.

Being adjacent mountain watersheds, the Hyalite and Mystic streams are similar in many respects: viz., they originate in high elevation snowmelt areas, are impounded to form mountain reservoirs, and the water for the municipal water supply is drawn off at a diversion dam just before the stream leaves the mountain canyon and flows out onto the valley floor.

The various sampling sites of both watersheds are indicated in Figure 1 and are designated as follows:

Site SM - Surface of the Mystic reservoir

Site M_1 - Mystic reservoir outlet

Site M_2 - Halfway point of Bozeman Creek

Site M_3 - Diversion dam of Bozeman Creek

Site SH - Surface of the Hyalite reservoir

Site H_1 - Hyalite reservoir outlet

Site H_2 - Halfway point of Middle Creek

Site H_3 - Diversion dam of Middle Creek

Site SB - Settling basin

Sites M_4, A, B, C, D, E, X, and Y - sampling points on the South Fork drainage of Bozeman Creek.

Chapter 4

METHODS AND MATERIALS

Sampling - Bacteriological

Weekly samples were collected in two-liter sterile nalgene bottles from sites shown in Figure 1 during the summer months of 1969 and 1970. Additionally, periodic sampling of water from the two diversion dams and the settling basin was carried out from January 1970 through May 1970, as well as during October and November of 1970. The sampling of the ten sites in the Mystic and Hyalite watersheds (Figure 1) was performed on one day, while on the following day sampling was from eight sites on the South Fork drainage of Bozeman Creek. Routinely, the first sample was collected from the surface of Mystic reservoir about 9 a.m. and the others subsequently at about the same time on each occasion. The samples were always taken at the same sites in the stream. When sampling the South Fork area, the first sample was taken at site E and subsequently downstream to site M_4. The samples were returned by 1 p.m. to the University laboratory for testing and beginning of analyses. All samples were generally tested within four hours of collection. All samples were stored in a Coleman cooler immediately after collection and held at approximately 5-10 C until testing.

Standard Plate Count

The procedures recommended in the 1965 edition of Standard Methods for the Examination of Water and Wastewater[1] were followed. Dilutions used for inoculation of standard petri dishes (100 X 15 mm) included 10^{-2}, 10^{-1}, and 10^{0}. In addition, water and agar controls were prepared. The medium of choice was tryptone glucose extract (TGE) agar (Difco). After solidification of the agar, the plates were inverted and incubated at 35 C for 48 hr. during the summer of 1969 analysis and at 20 C for five days during the 1970 analysis. Plates were then counted with the aid of a New Brunswick Scientific Colony Counter and reported as SPC/ml.

Coliforms

The membrane filter technique as described in Standard Methods[1] was used in determining coliform numbers. All samples were thoroughly shaken before withdrawing 50, 10, or 1 ml of water for filtration. The 1 ml samples were placed in a 99 ml sterile phosphate buffer dilution blank before pouring through the sterile membrane filters (Millipore Filter type HAWG 047 SO with a pore size of 0.45 micron). After filtration, the membrane filter was aseptically rolled onto pads (Millipore) that had been previously saturated with 2.0 ml of m-coliform broth (BBL) in disposable 50 X 12 mm, sterile, plastic petri dishes (Falcon Plastics). Filter and water controls were also performed.

The dishes were inverted and incubated at 35 C for 40-48 hr. All organisms which produced a dark purple-green colony with a metallic sheen within the incubation period were considered to be members of the coliform group. A viewing scope and incident light were used to facilitate counting of the coliforms. These were reported as numbers of coliform bacteria/100 ml.

To confirm the presence of coliforms, green metallic colonies were transferred from the m-coliform medium to brilliant green lactose bile (BGLB) broth (Difco) and considered positive if gas was produced within 48 hr. at 35 C. One-half the number of metallic green colonies counted on the 10 or 50 ml plate, up to a five per plate maximum, were used to inoculate the BGLB broth. Tubes exhibiting gas production were then streaked for differentiation and isolation on eosin methylene blue (EMB) agar (Difco) plates, inverted, and incubated at 35 C for 24 hr. Representative colonies were then transferred to 0.5 ml sterile phosphate buffered water to form a dense suspension of cells. This was inoculated into EC medium (Difco) for incubation at 44 ± 0.1 C for 24 hr. and into IMViC media (Difco). Cultures producing gas from the EC medium were considered to be fecal coliform bacteria. The IMViC tests were all incubated at 35 C for the times required.[1] These tests allowed for differentiation among E. coli, Enterobacter (Aerobacter) aerogenes, and intermediates. Interpretation of results was determined according to Standard Methods.[1]

Enterococci

The membrane filter technique was also used in determining enterococcal counts as described in Standard Methods.[1] After filtration of the appropriate volume of water (100 to 500 ml), the membrane filters (Millipore) were aseptically placed in 60 X 15 mm disposable sterile, plastic petri dishes (Falcon) containing m-enterococcus agar (Difco). Filter and sterile water controls were also prepared. The plates were inverted and incubated at 35 C for 40-48 hr. Typical dark red to pink colonies were counted using a viewing scope and incident light. Counts were reported as numbers of enterococci/100 ml.

Representative colonies - one-half the number of colonies counted per plate, up to a five per plate maximum - were inoculated into 10 ml of ethyl violet azide (EVA) broth (Difco) and observed for a purple button and/or turbidity after 48 hr. of incubation at 35 C. Cultures giving positive reactions in EVA broth were streaked onto m-enterococcus agar for isolation, inverted, and incubated at 35 C for 48 hr.

Differentiation of enterococci to species was based on a schema presented by Ayres et al.[2] Isolated colonies from m-enterococcus agar were inoculated into 7 ml of peptone broth (Difco) and incubated for 5 days at 35 C. Production of ammonia from arginine was determined by the spot plate method using Nessler's reagent. If the test were negative, the culture was inoculated into 7 ml of lactose broth, consisting of nutrient broth (BBL), 0.5% yeast extract, 1% lactose

(Difco), and 0.0015% bromo cresol purple. Those cultures showing production of ammonia were inoculated onto tryptic soy agar (Difco) plates containing 1.5% gelatin (Difco) for 6 days, potassium tellurite agar plates for 48 hr. (TGE agar with the addition of 0.4% glucose and 0.04% potassium tellurite), mannitol broth for 48 hr. (nutrient broth with the addition of 0.5% yeast extract, 1% mannitol, and 0.0015% bromo cresol purple), 5% horse blood agar for 24 hr., and nutrient agar (Difco) slants for 24 hr. All were incubated at 35 C.

Animal Dropping Examination from Closed Watershed

Periodic sampling of animal droppings from bear, elk, moose, and deer were made in the closed Mystic area, especially in the South Fork drainage area. The use of trail bikes in 1969 enabled access into remote areas to obtain fresh droppings. Fecal samples were collected with sterile applicator sticks and placed in 35 ml vials containing four types of media respectively: BGLB broth for detecting coliform bacteria; azide dextrose broth (Difco) for enterococci; selenite broth (Difco) for isolating salmonellae, shigellae, and other Gram-negative enteric bacteria; and lactose broth for enrichment of enterobacteria. After overnight incubation at 35 C, the samples were subcultured into tubes of appropriate fresh media.

All BGLB broth tubes showing fermentation were streaked onto EMB agar for 48 hr. incubation at 35 C. The IMViC reactions were used for final identification and differentiation of the coliform organisms.

All azide dextrose broth tubes showing cloudiness were treated as previously described for enterococci beginning with isolation on m-enterococcus agar.

All selenite broth tubes showing marked turbidity were streaked onto both MacConkey (Difco) and EMB agar, inverted, and incubated at 35 C for 24 hr. Isolated colonies from MacConkey agar were transferred to Kliger iron agar (Difco) slants and examined after 12 and 24 hr. at 35 C incubation. Urea broth (Difco) was inoculated from Kliger iron agar and read at 8 and 24 hr. at 35 C incubation. Also, dulcitol broth (nutrient broth with 1% dulcitol and 0.0015% bromo cresol purple) and lysine decarboxylase medium (Difco) were inoculated and incubated at 35 C. Dulcitol broth tubes were read after 48 hr. and lysine decarboxylase after 24 hr.

All lactose broth tubes showing growth were first subcultured into selenite broth and subsequently treated as previously described with MacConkey agar, EMB agar, Kliger iron agar, urea broth, dulcitol broth, and lysine decarboxylase medium.

Serological Examination

Serological examination of E. coli from water samples and isolates from animal droppings (bear, elk, and moose) were performed during the summer of 1969. Additionally, suspected Salmonella and Shigella-like organisms isolated from animal droppings were also reacted with

corresponding antisera. The techniques used for the determination of E. coli OB and OK antigens were those advocated by the manufacturer of the antisera (Difco).

The E. coli cultures from both water and fecal samples were first transferred from stock culture agar to veal-infusion agar (Difco) slants for 24 hr. incubation at 35 C. Dense suspensions of E. coli were then prepared by mixing the growth from veal-infusion agar slants in 0.5 ml of 0.85% saline. Each suspension was tested using three polyvalent antisera (A, B, C) employing the slide agglutination technique. If agglutination occurred, a portion of the suspension was boiled for one hr. Both heated and unheated suspensions were tested on the OB and OK individual antisera (which comprised the polyvalent antiserum). The Difco antisera employed for E. coli are those shown in Tables 7, 8, 9, 10, 11, and 12.

A similar procedure was used for the serological examination of Salmonella and Shigella-like organisms. Sera employed for Salmonella were: Poly A-1; Group A Factor 2; Group B Factors 4, 5; Group C_1 Factor 7; Group C_2 Factor 8; Group D Factor 9; Group E_1 Factor 10; Group E_2 Factor 15; Group E_4 Factor 19; Group F Factor 11; Group G Factors 13, 22; Group H Factors 14, 24; Group I Factor 16; and Vi. Shigella sera employed were polygroups A, A_1, B, C, C_1, C_2, D, and Alkalescens-Dispar group.

Sampling - Chemical

The water remaining after performing the bacteriological tests was used for chemical analyses; however, an additional sample was also taken at each site for determining orthophosphate, total alkalinity, nitrate, and nitrite. This involved rinsing a 250 ml pyrex glass stoppered bottle in the water and then filling to overflow before inserting the stopper. Special precautions were taken so as to not enable the incorporation of gas bubbles within the bottles.

At the time of collection, water and air temperature were recorded. A portable Sargent-Welch pH meter was used with a thermocompensator for on-site pH readings. Additionally, conductivity measurements were recorded in the natural water at the time of collection or upon return to the laboratory using a Lab Line Lectro MHO-meter (Model MC-1, Mark IV).

Water Chemistry Analyses

In the laboratory, a 100 ml sample was taken from the glass bottle for a total alkalinity determination according to Standard Methods.[1] The remaining water in the glass bottles was then filtered through membrane filters (Millipore) and used for orthophosphate, nitrate, and nitrite determinations.

Total hardness, calcium, magnesium, chloride, sulfate, and

turbidity were also determined as described by the American Public Health Association.[1]

The colorimetric equipment used in the various analyses was either a Bausch and Lomb "Spectronic 20", Beckman Model B Spectrophotometer, or a Klett-Summerson colorimeter.

Potassium and sodium were determined by flame emission utilizing a Beckman DU Flame Spectrophotometer, following the procedures given in the Beckman Instruction Manual #334-A (March, 1957).

Total alkalinity, orthophosphate, nitrate, and nitrite determinations were made within 8 hr. after collection of samples. The remaining analyses were routinely performed within the following 72 hr.

Chapter 5

RESULTS

Quantitative Bacteriological Studies of Water Samples

The numbers of bacteria obtained from water samples collected during the summers of 1968, 1969 and 1970 from the Mystic and Hyalite watersheds are summarized in Tables 1, 2, and 3. Ranges and geometric means are given for coliform, enterococcal, and standard plate counts at each site. Geometric means were used in order to eliminate the large variations that occurred throughout the summer months. These geometric means were then used to produce a "bacteriological profile" of the streams (Figures 2, 3, and 4). These profiles were based on eight, nine, and thirteen weekly collections for the respective years.

During 1968 and 1969 no great difference was observed between the two watersheds with regard to standard plate counts. In 1970, a 5 to 10-fold increase in total organisms was obtained at each site. This increase can be attributed to incubating plates at 20 C for five days, whereas plates were incubated at 35 C for 48 hours during the 1968 and 1969 seasons. The lower temperature (20 C) was used after it had been determined that this procedure gave more realistic counts, since the water temperature of these mountain streams was quite cold. Once again, it was observed that the standard plate counts were essentially the same in both watersheds during 1970.

The coliform "profiles" for 1968 and 1969 indicate greater numbers

Table 1. Comparison of Numbers of Bacteria Obtained from 8 Weekly Water Sample Collections at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1968

	MYSTIC		HYALITE	
SITE*	RANGE	GEOMETRIC MEAN	RANGE	GEOMETRIC MEAN
		COLIFORMS/100 ML		
S	0-570	26	0-4600	5
1	0-160	12	10-80	18
2	0-280	76	8-130	42
3	67-540	227	6-220	63
SB	10-270	35		
		ENTEROCOCCI/100 ML		
S	0-13	5	0-16	2
1	0-15	2	0-3	1
2	3-38	12	3-24	10
3	9-87	27	5-26	13
SB	3-116	13		
		**SPC/ML @ 35 C		
S	32-6190	291	31-450	199
1	14-325	82	27-415	95
2	42-640	93	34-151	88
3	51-294	102	49-159	82
SB	10-283	85		

* S = surface of reservoir; 1= reservoir outlet; 2= halfway point
3 = diversion dam

**SPC = Standard Plate Count

Table 2. Comparison of Numbers of Bacteria Obtained From 9 Weekly Water Sample Collections at Different Sites in Mystic (closed) and Hyalite (open) Watersheds During the Summer of 1969.

	MYSTIC		HYALITE	
SITE*	RANGE	GEOMETRIC MEAN	RANGE	GEOMETRIC MEAN
		COLIFORMS/100 ML		
S	0-170	7	0-60	1
1	0-70	1	0-60	2
2	40-540	121	10-130	65
3	90-930	217	10-310	63
SB	0-200	25		
		ENTEROCOCCI/100 ML		
S	0-998	6	0-48	1
1	0-3	1	0-2	1
2	1-135	15	4-65	13
3	4-117	32	4-99	39
SB	1-101	19		
		**SPC/ML @ 35 C		
S	39-860	144	65-8000	447
1	3-62	23	10-5870	69
2	15-308	77	26-1560	113
3	29-277	76	26-760	124
SB	26-446	136		

* S = surface of reservoir; 1 = reservoir outlet; 2 = halfway point 3 = diversion dam

**SPC = Standard Plate Count

Table 3. Comparison of Numbers of Bacteria Obtained From 13 Weekly Water Sample Collections at Different Sites in Mystic (closed) and Hyalite (open) Watersheds During the Summer of 1970

	MYSTIC		HYALITE	
SITE*	RANGE	GEOMETRIC MEAN	RANGE	GEOMETRIC MEAN
		COLIFORMS/100 ML		
S	0-1300	7	0-230	36
1	0-200	8	0-100	13
2	0-270	41	10-220	56
3	10-390	91	10-290	85
SB	10-350	69		
		ENTEROCOCCI/100 ML		
S	0-179	9	0-71	5
1	0-18	3	0-17	2
2	1-87	14	0-141	12
3	0-140	23	10-239	23
SB	1-71	15		
		**SPC/ML @ 20 C		
S	190-3200	936	170-3800	667
1	30-4100	294	0-2500	373
2	300-2400	781	80-6500	563
3	370-5600	1033	230-2100	656
SB	150-4100	797		

* S = surface of reservoir; 1 = reservoir outlet; 2 = halfway point
3 = diversion dam

** SPC = Standard Plate Count

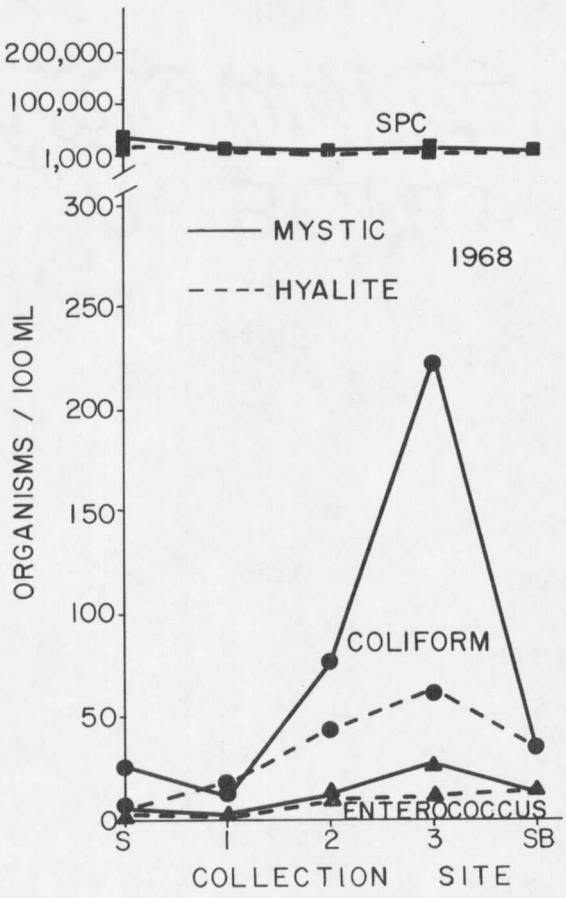


Figure 2. Bacteriological Profile of the Bozeman (Mystic) Creek and Middle (Hyalite) Creek Showing Geometric Means of Organisms/100 ml. SPC (■), Coliform (●), and Enteroccus (▲) Counts Geometrically Averaged From Eight Weekly Collections During the Summer of 1968

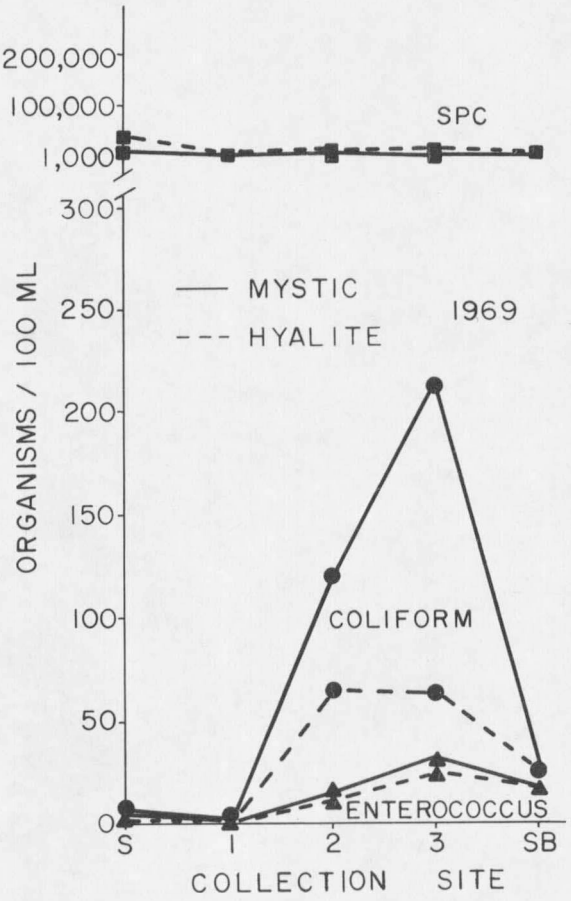


Figure 3. Bacteriological Profile of the Bozeman (Mystic) Creek and Middle (Hyalite) Creek Showing Geometric Means of Organisms/100 ml. SPC (■), Coliform (●), and Enterococcus (▲) Counts Geometrically Averaged From Nine Weekly Collections During the Summer of 1969

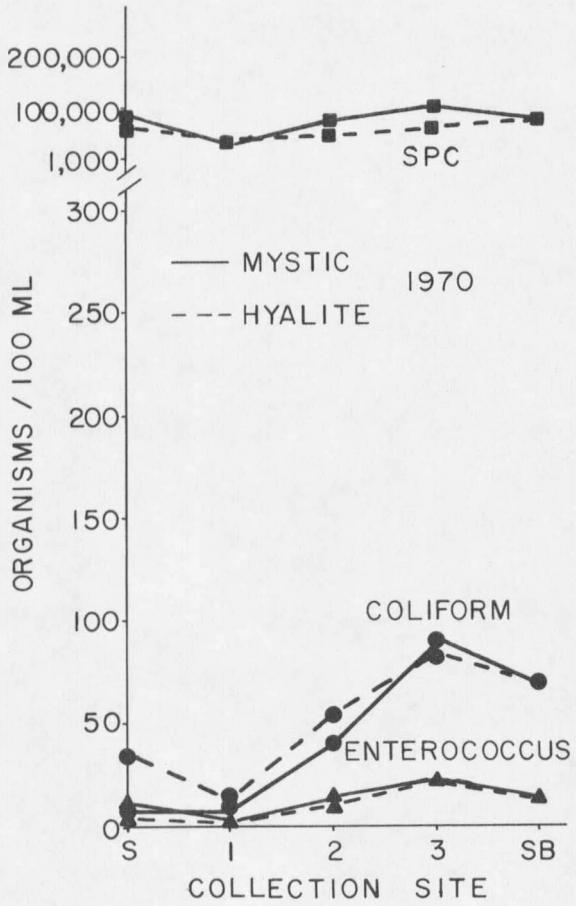


Figure 4. Bacteriological Profile of the Bozeman (Mystic) Creek and Middle (Hyalite) Creek Showing Geometric Means of Organisms/100 ml. SPC (■), Coliform (●), and Enterococcus (▲) Counts Geometrically Averaged From Thirteen Weekly Collections During the Summer of 1970

at the halfway point and diversion dam (sites 2 and 3) in the Mystic (closed) watershed than found in the Hyalite (open) watershed. Additionally, the coliform numbers increase as the water flows downstream from the spillway resulting in geometric means of over 200/100 ml in Mystic compared to about 65/100 ml in Hyalite at the diversion dams (site 3). Essentially, the geometric means were approximately equal at the surfaces (site S) and spillways (site 1) of both watersheds; however, the halfway point (site 2) and diversion dam (site 3) of Mystic gave higher counts. Comparison of the two curves (Figures 2 and 3) for each watershed indicates excellent correlation for all stream sites.

The coliform profile for the Hyalite area in 1970 (Figure 4) is similar to those for 1968 and 1969. In contrast, the Mystic area shows a decrease in coliform numbers at site 3. Whereas the geometric means were over 200 coliforms/100 ml at the Mystic diversion dam in 1968 and 1969, the 1970 mean is about half or 91/100 ml. In addition, there is a definite decrease at site 2, even below that in the open watershed (56/100 ml) as compared to the closed Mystic watershed (41/100 ml).

Examination of the enterococcal counts in 1968 and 1969 also reveals a similar picture of greater contamination in the closed Mystic area, although not as profound as the coliform profile. The contamination once again increased in both watersheds as the water

flowed downstream. An adequate explanation of this increase has yet to be determined. The enterococcal counts in 1970 were nearly identical at all sites in both watersheds.

In 1969, a study of the South Fork (Figure 1) was undertaken to determine the water quality of the major tributary of Bozeman Creek draining the upper basin of the Mystic watershed. The ranges and geometric means for bacteriological counts during 1969 and 1970 are shown in Table 4. The bacteriological profiles for the two years (Figures 5 and 6) reflect essentially straight lines for the standard plate counts.

The coliform profiles were quite different. In 1969, the geometric means progressed from a low at E (62/100 ml) to a peak at C (219/100 ml) and subsequently decreased in numbers as the water flowed downstream to M_4 (146/100 ml). In 1970, there was a definite decrease in coliform densities with a minimum of 22/100 ml at E and only 49/100 ml at C, representing a fourfold decrease at the latter site.

In 1970, samples were taken from two small tributaries (designated as sites X and Y in Figure 1) of the South Fork in hope of determining what effect they might have on resulting bacterial densities further downstream in the South Fork. The geometric mean at X was 20 coliforms/100 ml and at Y was 52 coliforms/100 ml. A proper interpretation of these results is not yet possible.

The enterococcal profiles of the South Fork were essentially the

Table 4. Comparison of Numbers of Bacteria Obtained From Water Samples Collected at Different Sites in the South Fork of Mystic (Closed) Watershed During the Summers of 1969 (7 Weekly Collections) and 1970 (13 Weekly Collections)

1969 DETERMINATION

SITE	Coliforms/100 ml Range	Coliforms/100 ml Geometric Mean	Enterococci/100 ml Range	Enterococci/100 ml Geometric Mean	*SPC/ml @ 35C Range	*SPC/ml @ 35C Geometric Mean
E	10-100	50	7-35	15	1-25	8
D	20-160	72	12-57	36	6-40	22
C	100-450	219	2-70	17	17-22	21
B	120-480	203	3-60	14	8-25	14
A	70-370	167	1-69	21	12-43	19
M_4	60-430	146	1-81	21	14-35	21

1970 DETERMINATION

SITE	Coliforms/100 ml Range	Coliforms/100 ml Geometric Mean	Enterococci/100 ml Range	Enterococci/100 ml Geometric Mean	*SPC/ml @ 20C Range	*SPC/ml @ 20C Geometric Mean
Y	0-240	52	1-88	10	90-780	329
X	0-270	20	0-56	8	73-850	189
E	0-800	22	0-199	12	76-3260	266
D	0-3000	38	0-300	8	85-7500	329
C	0-1210	49	0-239	11	92-4380	329
B	0-470	39	0-151	9	99-1810	317
A	0-900	35	0-159	9	118-3390	346
M_4	0-700	43	0-83	11	109-2260	376

* SPC = Standard Plate Count

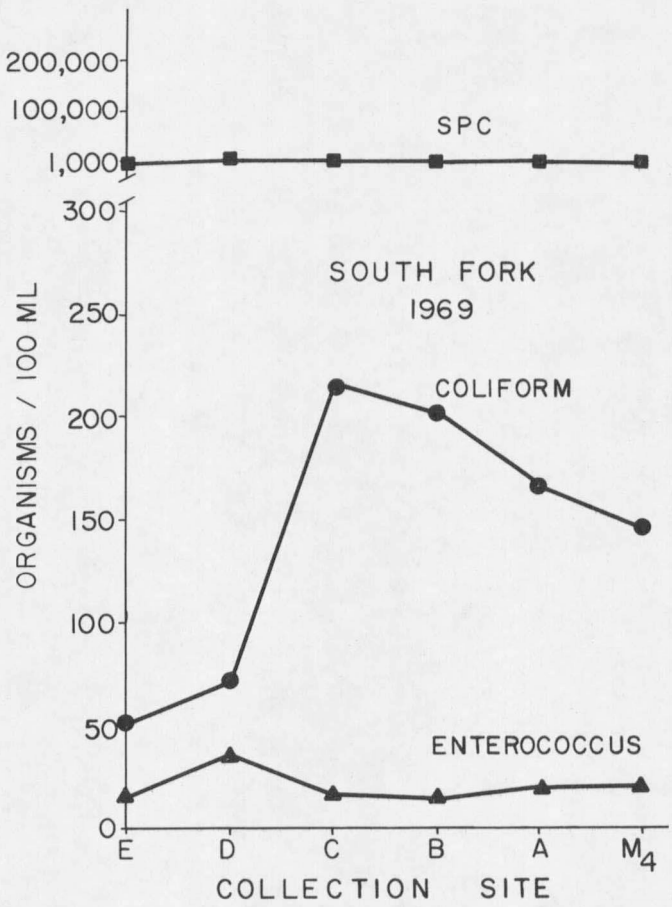


Figure 5. Bacteriological Profile of the South Fork of Bozeman (Mystic) Creek During the Summer of 1969 Showing Geometric Means of Organisms/100 ml. SPC (■), Coliform (●), and Enterococcus (▲) Counts Geometrically Averaged From Seven Weekly Collections at Sites E Through M_4 as Shown in Figure 1

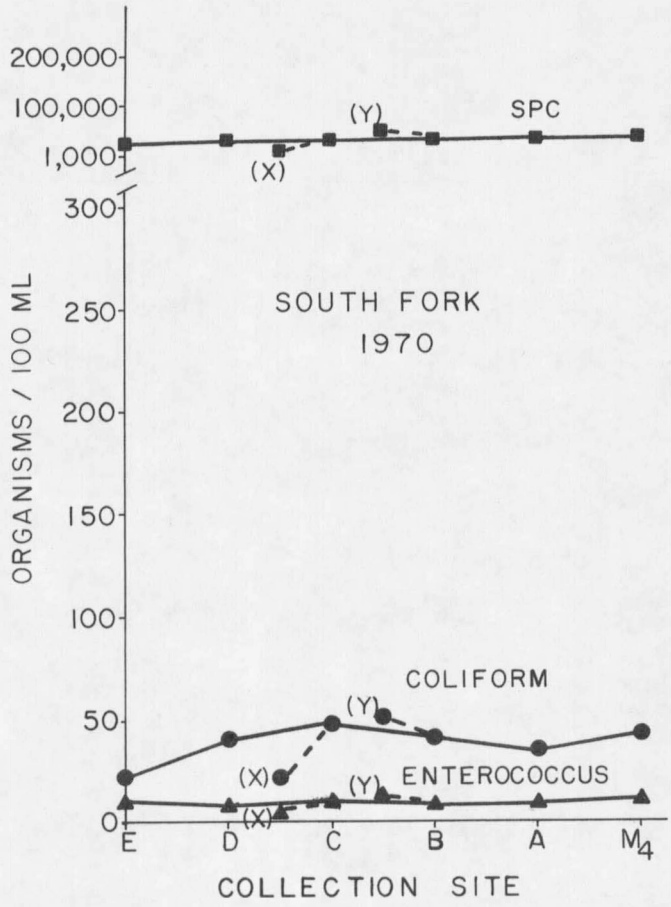


Figure 6. Bacteriological Profile of the South Fork of Bozeman (Mystic) Creek During the Summer of 1970 Showing Geometric Means of Organisms/100 ml. SPC (■), Coliform (●), and Enterococcus (▲) Counts Geometrically Averaged From Thirteen Weekly Collections at Sites E Through M_4 and Sites X and Y (Tributaries of the South Fork) as Shown in Figure 1

same in 1969 and 1970. However, a slight peak was observed at D (36/100 ml) in 1969. No peaks were observed in 1970, the profile being basically a straight line.

Qualitative Bacteriological Studies of Water Samples

Coliforms. A comparison of the differentiated coliform bacteria obtained from the two watersheds in 1968, 1969, and 1970 is shown in Table 5. The percentage of Escherichia coli was higher in Mystic than Hyalite for all three years. Also, the percentages of fecal coliforms were higher in the Mystic area. An even greater percentage of fecal coliforms was obtained from the South Fork area than from the lower Bozeman Creek in 1969 and 1970.

Enterococci. Differentiation of the enterococci to species resulted in the following: Streptococcus faecium, S. faecium var. durans, S. faecalis var. liquefaciens, and S. bovis. Most of the enterococci were found to be S. faecalis var. liquefaciens.

Seasonal Variation of Coliforms and Enterococci

In an effort to determine bacterial fluctuations with seasons, sampling was performed periodically during all of 1970 at both diversion dams and the settling basin. The coliform and enterococcal counts obtained on 36 sampling dates during 1970 are presented in Figures 7, 8, and 9. Highest coliform densities were generally obtained from early August to mid-October at all three sites. A smaller peak

Table 5. Percentage Distributions of Escherichia coli, Enterobacter aerogenes, Intermediates and Fecal Isolates Obtained at Different Sites

DETERMINATION	Mystic	Hyalite	Settling Basin	South Fork
	SUMMER 1968			
Escherichia coli	33	25	46	-
Enterobacter aerogenes	23	43	0	-
Intermediates	44	32	54	-
Fecal origin	32	29	46	-
	SUMMER 1969			
Escherichia coli	47	38	31	41
Enterobacter aerogenes	42	41	46	46
Intermediates	11	21	23	13
Fecal Origin	64	52	38	70
	SUMMER 1970			
Escherichia coli	35	12	31	47
Enterobacter aerogenes	10	24	4	15
Intermediates	55	64	65	38
Fecal origin	42	29	48	54

- not determined

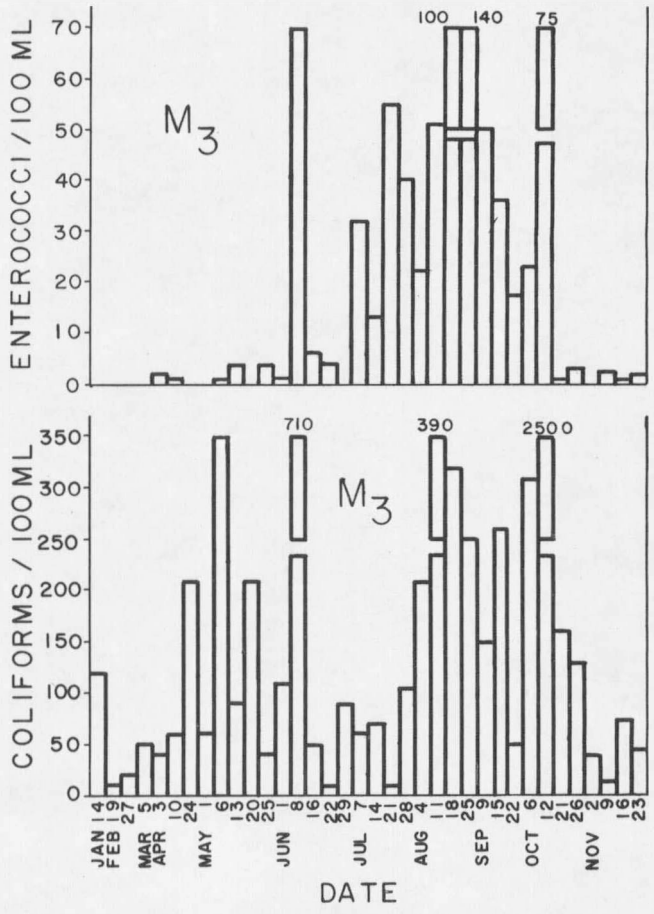


Figure 7. Numbers of Coliforms/100 ml and Enterococci/100 ml of Water Obtained at the Bozeman (Mystic) Creek Diversion Dam (M_3) on 36 Sampling Dates in 1970

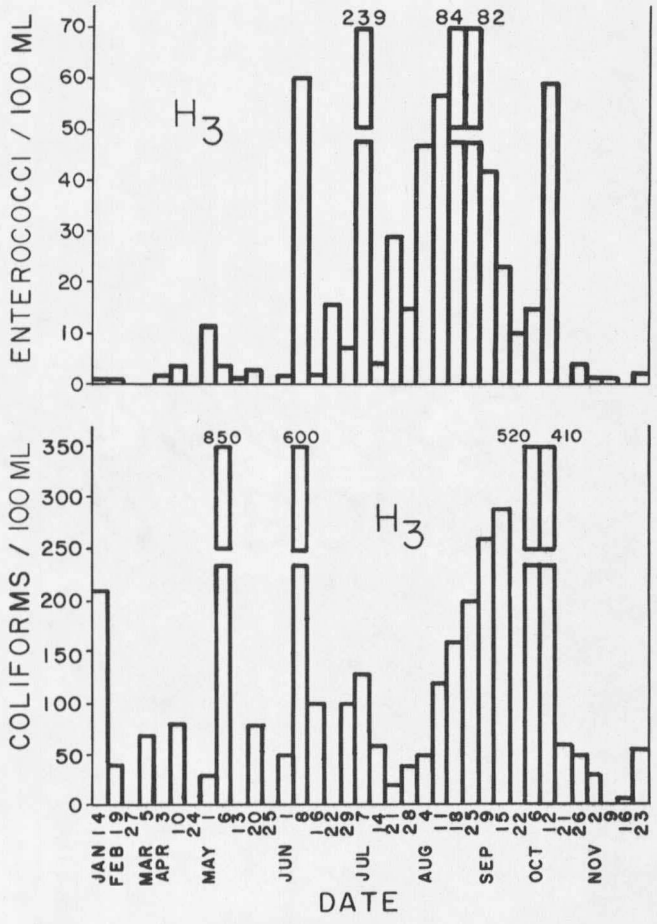


Figure 8. Numbers of Coliforms/100 ml and Enterococci/100 ml of Water Obtained at the Middle (Hyalite) Creek Diversion Dam (H_3) on 36 Sampling Dates in 1970

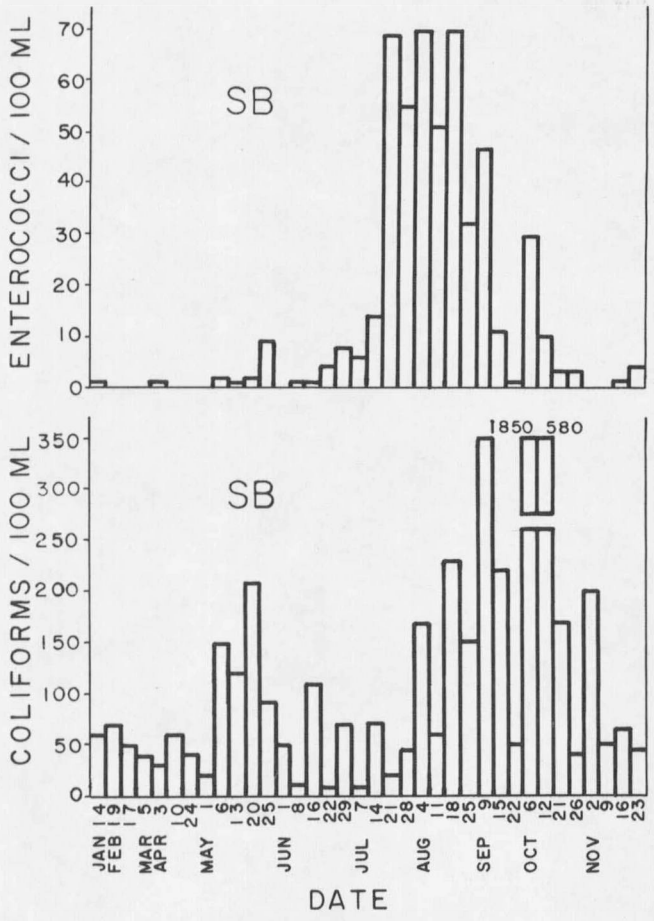


Figure 9. Numbers of Coliforms/100 ml and Enterococci/100 ml of Water Obtained at the Settling Basin (SB) on 36 Sampling Dates in 1970

period is indicated from early May to mid-June. Lowest coliform numbers occurred from October through April and mid-June to early August. The enterococci reached only one peak density in early July and remained high until early October. From mid-October through June, enterococci remained quite low.

Bacteriology of Animal Droppings

Animal droppings from elk, moose, bear, deer, and horse were collected from the closed Mystic area, especially in the South Fork drainage area. Different genera of Gram-negative organisms including Escherichia, Enterobacter, Proteus, Salmonella-like, and Shigella-like as well as various streptococcal species were isolated from these fecal droppings and differentiated using physiological tests (Table 6).

Serology of Organisms Isolated from Water and Animal Droppings

Serological procedures were performed on water and fecal dropping isolates of Escherichia, Salmonella-like, and Shigella-like organisms obtained during 1969. None of the Salmonella-like nor the Shigella-like organisms reacted with the sera employed.

According to the IMViC results, of 202 coliforms isolated during the summer of 1969, 86 were classified as E. coli. Upon serological examination of these 86 strains, 39 agglutinated with one of the polyvalent antisera and nine cross-reacted among the antisera (Table 7).

The resultant reactions of unheated cultures with individual OB

Table 6. Enterobacteria and Enterococci Found in Animal Droppings

ENTEROBACTERIA

ORIGIN	Escherichia coli	Enterobacter aerogenes	Intermediates	Proteus	Salmonella-Like	Shigella-Like	Providencia
Elk	X	X	X	X	X	X	X
Moose		X					X
Bear	X	X	X				X
Deer	X	X	X				X
Horse	X	X		X	X		X

ENTEROCOCCI

ORIGIN	Streptococcus faecium	Streptococcus faecium var. durans	Streptococcus faecalis var. liquifaciens	Streptococcus faecalis
Elk	X	X	X	X
Moose		X		
Bear	X			
Deer	none			
Horse	X	X		

Table 7.* Reactions of 86 *E. coli* Isolates with Polyvalent Antisera

Polyvalent Antisera

	A	B	C
A	6% A: 1302, 1516, 1520	6% AB: 1315, 1318, 1522	2% AC: 1125
B	50% B: 814, 937, 985, 1059, 1061, 1066, 1067, 1068, 1072, 1073, 1074, 1076, 1222, 1224, 1370, 1422, 1423, 1424, 1426, 1427, 1518, 1519, 1521, 1525		6% BC: 1275, 1428, 1527
C	25% C: 801, 805, 972, 1223, 1274, 1279, 1280, 1297, 1429, 1517, 1524, 1526		

Additional cross reactions

A B C 1271, 1273 5%

* Data in these tables are presented in a "Punnette square" fashion. Antisera used are shown vertically and horizontally. Culture numbers are displayed at the intersection of sera with which the culture reacted. Homologous reactions are located on the outside diagonal while cross reactions occur within the system. NR = no reaction.

antisera comprising the polyvalent A set are indicated in Table 8. The B antigen masks the O antigen and is inactivated by boiling for one hour. The O antigen is heat stable. It was noted that none of the heated cultures reacted with individual A antisera.

The resultant reactions of unheated and heated cultures with individual OB antisera comprising the polyvalent B set are shown in Tables 9 and 10. Clustering of serotypes can be observed in various sections of these tables, e. g., a large cluster was found with O119:B14. Several unexplainable cross reactions were also observed.

The results of reacting unheated and heated cultures with individual OK antisera comprising the polyvalent C set are given in Tables 11 and 12. A distinctly predominant clustering was observed with antiserum O18:B21.

Physical and Chemical Results of Water Analyses

Air and water temperatures for the summers of 1968, 1969, and 1970 shown in Tables 13 and 14 revealed no significant differences between the Mystic and Hyalite watersheds.

The pH of the two streams (Table 15) was very similar in both 1968 and 1969; however, the pH values in 1970 showed a decrease at all sites in both watersheds.

Chemical analyses indicated greater concentrations of most ions in the Mystic water than in the open watershed, while the settling

Table 8.* Reactions of Unheated *E. coli* Isolates With Individual A Antisera

	0111:B4	055:B5	0127:B8	026:B6
0111:B4	NR	1520 (Elk)	NR	NR
055:B5		1516 (Elk)	1522 (Elk)	NR
0127:B8			NR	NR
026:B6				NR

Additional Cross Reactions

1271 (M_4) – all four antisera

1273 (M_4) – 0111:B4, 055:B5, 026:B6

Table 9.* - Reactions of Unheated *E. coli* Isolates with Individual B Antisera

	086:B7	0119:B14	0124:B17	0125:B15	0126:B16	0128:B12
086:B7	NR	1066(B) 1426(Bear)	NR	1522(Elk)	NR	1315 (SH)
0119:B14		985(H_3) 1073(C) 1059(M_4) 1074(C) 1061(M_4) 1076(D) 1067(B) 1224(Elk) 1072(C)	1068(B) 1518(Elk) 1519(Elk)	1527(Elk)	NR	937(Elk) 1370(A)
0124:B17			1422(Bear) 1423(Bear)	NR	NR	NR
0125:B15				NR	NR	NR
0126:B16					NR	NR
0128:B12						1275(A) 1318(H_3)

Additional Cross Reactions

814(M_4) - 0119:B14, 0124:B17, 0128:B12
1222(Elk) - 0119:B14, 0126:B16, 0128:B12
1271(M_4) - all six antisera
1273(A) - all six antisera
1424(Bear) - 0119:B14, 0124:B17, 0125:B15
1427(Bear) - 0119:B14, 0124:B17, 0125:B15, 0126:B16
1428(Bear) - all six antisera
1521(Elk) - 0119:B14, 0124:B17, 0125:B15

Table 10.* Reactions of Heated *E. coli* Isolates with Individual B Antisera

	086:B7	0119:B14	0124:B17	0125:B15	0126:B16	0128:B12
086:B7	NR	NR	NR	NR	NR	NR
0119:B14		1059(M_4) 1066(B) 1067(B)	NR	NR	NR	NR
0124:B17			814(M_4) 1423(Bear) 1424(Bear)	NR	NR	NR
0125:B15				NR	NR	NR
0126:B16					NR	NR
0128:B12						1318(H_3)

Additional Cross Reactions

1521 (Elk) - 0125:B15, 0126:B16, 0128:B12
1525 (Elk) - 086:B7, 0119:B14, 0124:B17, 0128:B12

Table 11.* Reactions of Unheated E. coli Isolates With Individual C Antisera

	018:B21	020:B7	020:84B	028:B18	044:K74	0112:B11
018:B21	801(M_1) 805(M_2) 972(SB) 1223(Elk) 1274(A) 1275(A) 1279(B) 1280(B) 1429(Bear) 1526(Elk)	NR	NR	1524(Elk)	NR	NR
020:B7		NR	NR	NR	1297(M_2)	NR
020:84B			NR	NR	NR	NR
028:B18				NR	NR	NR
044K74					NR	NR
0112:B11						1428(Bear)

Additional Cross Reactions

1271(M_4) – 020:B7, 020:84B, 028:B18, 0112:B11
1273(A) – 020:B7, 020:84B, 028:B18, 0112:B11
1527(Elk) – 018:B21, 020:84B, 028:B18

Table 12.* Reactions of Heated E. coli Isolates With Individual C Antisera

	018:B21	020:B7	020:84B	028:B18	044:K74	0112:B11
018:B21	801(M_1) 972(SB) 1280(B) 1527(Elk)	NR	NR	NR	NR	NR
020:B7		NR	NR	NR	NR	NR
020:84B			NR	NR	NR	NR
028:B18				NR	NR	NR
044:K74					NR	NR
0112:B11						1297(M_2)

Additional Cross Reactions

1125 (C) – all six antisera
1428 (Bear) – all six antisera
1429 (Bear) – all six antisera
1517 (Elk) – all six antisera

Table 13. Comparison of Water Temperatures (C) Obtained at Different Sites in Mystic (closed) and Hyalite (open) Watersheds

	MYSTIC		HYALITE	
SITE*	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
		SUMMER 1968		
S	11.0-19.0	16.4	13.5-18.0	15.3
1	8.0-16.0	10.7	7.5-10.0	9.1
2	7.5-11.5	8.8	8.0-13.0	10.1
3	8.0-12.0	9.2	9.0-14.0	10.3
SB	9.0-12.0	10.6		
		SUMMER 1969		
S	11.0-21.0	16.8	8.0-22.0	16.1
1	7.0-13.0	10.2	7.5-13.0	9.5
2	7.5-10.5	8.6	8.0-13.0	10.3
3	7.0-10.0	9.0	8.0-14.0	10.6
SB	8.0-13.0	10.6		
		SUMMER 1970		
S	7.5-21.0	16.1	6.5-18.2	14.4
1	5.0-13.0	9.0	5.0-11.1	8.5
2	5.1-10.1	7.5	5.5-14.3	10.1
3	6.5-11.7	7.9	6.2-13.8	10.2
SB	6.2-11.2	8.6		

* S = surface of reservoir; 1 = reservoir outlet; 2 = halfway point; 3 = diversion dam

Table 14. Comparison of Air Temperatures (C) Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds

	MYSTIC		HYALITE	
SITE*	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
		SUMMER 1968		
S	8.5-23.0	14.3	10.0-27.0	12.5
1	8.0-25.0	13.9	11.0-25.0	17.1
2	6.0-22.0	14.6	10.0-24.0	17.4
3	11.0-28.5	17.3	11.5-26.0	19.0
SB	9.0-25.0	17.2		
		SUMMER 1969		
S	6.0-23.0	16.7	11.0-23.0	18.3
1	8.0-19.0	15.2	10.5-21.5	16.1
2	8.5-19.5	15.7	10.5-23.5	16.4
3	8.0-20.5	16.3	10.0-26.0	17.5
SB	13.0-24.0	18.2		
		SUMMER 1970		
S	9.5-26.5	17.5	9.6-28.7	20.5
1	10.0-27.8	15.2	9.9-24.3	18.4
2	11.4-30.2	17.5	11.5-27.7	18.9
3	13.5-32.6	19.1	11.5-28.6	20.9
SB	7.8-34.8	19.6		

* S = surface of reservoir; 1 = reservoir outlet; 2 = halfway point; 3 = diversion dam

Table 15. Comparison of pH Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds

	MYSTIC		HYALITE	
SITE*	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
		SUMMER 1968		
S	7.4-8.6	7.8	7.0-9.9	7.6
1	6.5-8.2	7.3	6.7-8.1	7.3
2	7.6-8.3	8.0	6.9-8.1	7.4
3	7.6-8.3	8.0	7.0-8.2	7.5
SB	7.4-8.0	7.6		
		SUMMER 1969		
S	7.9-9.2	8.5	8.2-10.0	9.0
1	7.2-8.5	7.8	7.4-8.5	7.9
2	7.9-8.5	8.2	7.8-8.6	8.0
3	8.0-8.6	8.3	7.8-8.5	8.1
SB	7.6-8.2	7.8		
		SUMMER 1970		
S	6.8-9.9	7.8	7.1-9.1	7.6
1	6.6-8.6	7.2	6.3-8.7	6.9
2	6.9-9.0	7.4	6.5-8.3	7.0
3	7.3-8.2	7.6	6.6-8.0	7.1
SB	6.9-7.8	7.3		

* S = surface of reservoir; 1 = reservoir outlet; 2 = halfway point; 3 = diversion dam

basin showed intermediate values reflecting the mixture of the two (Tables 16, 17, 18, 19, and 20). Calcium was the dominant cation followed by magnesium, sodium, and potassium. The dominant anion was bicarbonate, followed by sulfate and chloride.

Chemical profiles of calcium, magnesium, bicarbonate, conductivity, nitrate, turbidity, and orthophosphate in the two watersheds are shown in Figures 10, 11, 12, and 13. Greater concentrations of calcium, magnesium, bicarbonate, and conductivity were found in the closed watershed when compared to the Hyalite area. Also, the concentrations of these constituents increased as the water flowed downstream. The nitrate profile was essentially the same in both areas. Turbidity and orthophosphate profiles reflect considerable variation. Orthophosphate was nearly identical in concentration at the spillways of both reservoirs; however, the concentration was greater at the halfway point in Mystic (0.33 mg/1) when compared to the halfway point in Hyalite (0.26 mg/1).

Chemical analyses were also performed on eight weekly water collections obtained from the South Fork drainage area in 1970. Only water temperature, air temperature, pH, and conductivity determinations were made in 1969. Ranges and means for these factors in 1969 and 1970 are shown in Tables 21 and 22. The water temperatures for the South Fork sites were quite cold with an approximate range of 4-8 C. The

Table 16. Comparison of Conductivity @ 25 C (Micromhos) Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds

	MYSTIC		HYALITE	
SITE*	RANGE	ARITHMETIC MEANS	RANGE	ARITHMETIC MEANS
		SUMMER 1969		
S	167-194	175	60-99	75
1	180-230	205	69-84	73
2	193-234	215	103-146	117
3	212-229	221	104-150	120
SB	118-215	146		
		SUMMER 1970		
S	125-162	149	51-66	58
1	145-189	168	51-72	60
2	142-190	166	70-113	93
3	149-217	179	70-110	96
SB	103-189	141		

* S = surface of reservoir; 1 = reservoir outlet; 2 = halfway point; 3 = diversion dam

Table 17. Comparison of Calcium and Magnesium Concentrations Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 (9 Weekly Collections)

	MYSTIC		HYALITE	
SITE*	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
		CALCIUM (mg/l)		
S	15.6-23.6	17.4	4.7-7.7	5.5
1	18.6-21.5	19.9	4.9-7.3	6.1
2	18.2-25.7	22.0	7.7-13.5	10.5
3	21.8-27.1	24.3	7.8-13.6	11.3
SB	13.4-20.0	16.4		
		MAGNESIUM (mg/l)		
S	0.6-5.1	4.3	1.1-2.2	1.6
1	4.7-6.6	5.5	0.9-1.9	1.4
2	4.3-7.5	5.9	1.8-3.7	2.8
3	5.9-7.8	6.6	2.2-3.7	3.0
SB	3.3-5.4	4.3		

*S = surface of reservoir; 1 = reservoir outlet; 2 = halfway point; 3 = diversion dam

Table 18. Comparison of Sodium and Potassium Concentrations Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 (9 Weekly Collections)

	MYSTIC		HYALITE	
SITE*	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
		SODIUM (mg/l)		
S	3.7-4.8	4.1	0.6-3.1	1.3
1	2.8-4.8	3.8	0.6-1.3	0.9
2	1.6-2.7	2.1	0.7-2.4	1.4
3	1.4-3.1	2.3	1.1-2.4	1.6
SB	1.4-2.2	1.8		
		POTASSIUM (mg/l)		
S	0.9-2.0	1.7	1.0-3.9	1.8
1	1.1-1.8	1.5	1.2-1.8	1.3
2	1.2-2.0	1.7	1.0-1.8	1.4
3	1.4-2.4	1.9	1.0-2.0	1.5
SB	1.1-2.0	1.5		

* S = surface of reservoir; 1 = reservoir outlet; 2 = halfway point; 3 = diversion dam

Table 19. Comparison of Major Anions Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 (9 Weekly Collections)

	MYSTIC		HYALITE	
SITE*	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
		BICARBONATE (meq/l)		
S	1.23-1.40	1.29	0.47-0.62	0.54
1	1.37-1.49	1.43	0.45-0.68	0.55
2	1.56-1.78	1.68	0.66-1.11	0.90
3	1.79-1.97	1.88	0.70-1.00	0.90
SB	1.16-1.53	1.33		
		SULFATE (mg/l)		
S	8.3-16.0	12.2	1.5-8.2	4.7
1	10.6-17.8	12.9	1.1-8.5	4.3
2	6.5-11.9	8.5	2.3-10.0	5.0
3	5.7-12.0	8.2	2.3-10.0	5.5
SB	3.9-12.0	6.8		
		CHLORIDE (mg/l)		
S	0.03-0.73	0.30	0.01-0.25	0.12
1	0.09-0.40	0.19	0.01-0.30	0.11
2	0.10-0.40	0.22	0.00-0.21	0.10
3	0.03-0.40	0.17	0.05-1.00	0.23
SB	0.01-0.45	0.19		

* S = surface of reservoir; 1 = reservoir outlet; 2 = halfway point; 3 = diversion dam

Table 20. Comparison of Nitrate, Orthophosphate, and Turbidity Determinations Obtained at Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970 (9 Weekly Collections)

	MYSTIC		HYALITE	
SITE*	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
	NITRATE (mg/l $N\text{-}NO_3^-$)			
S	0.01-0.14	0.05	0.00-0.15	0.05
1	0.01-0.15	0.05	0.00-0.12	0.05
2	0.01-0.16	0.05	0.01-0.16	0.06
3	0.01-0.18	0.06	0.01-0.16	0.06
SB	0.00-0.15	0.06		
	ORTHOPHOSPHATE (mg/l PO_4^{-3})			
S	0.11-0.56	0.29	0.10-0.23	0.15
1	0.21-0.32	0.27	0.22-0.35	0.28
2	0.27-0.45	0.33	0.22-0.35	0.26
3	0.20-0.40	0.27	0.17-0.35	0.26
SB	0.21-0.32	0.26		
	TURBIDITY (Jackson Turbidity Units)			
S	0-41	15	0-60	16
1	0-35	13	0-27	6
2	0-53	12	0-29	9
3	0-33	11	0-29	12
SB	0-27	9		

* S = surface of the reservoir; 1 = reservoir outlet; 2 = halfway point; 3 = diversion dam

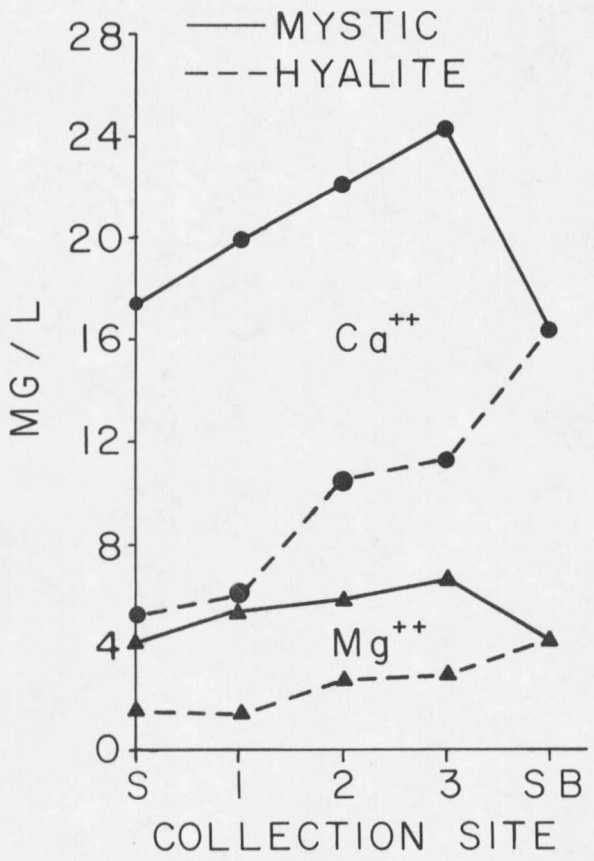


Figure 10. Chemical Profile of Average Calcium (● mg/l) and Magnesium (▲ mg/l) Concentrations Obtained From Ten Weekly Collections at Different Sites on the Bozeman (Mystic) and Middle (Hyalite) Creeks During the Summer of 1970

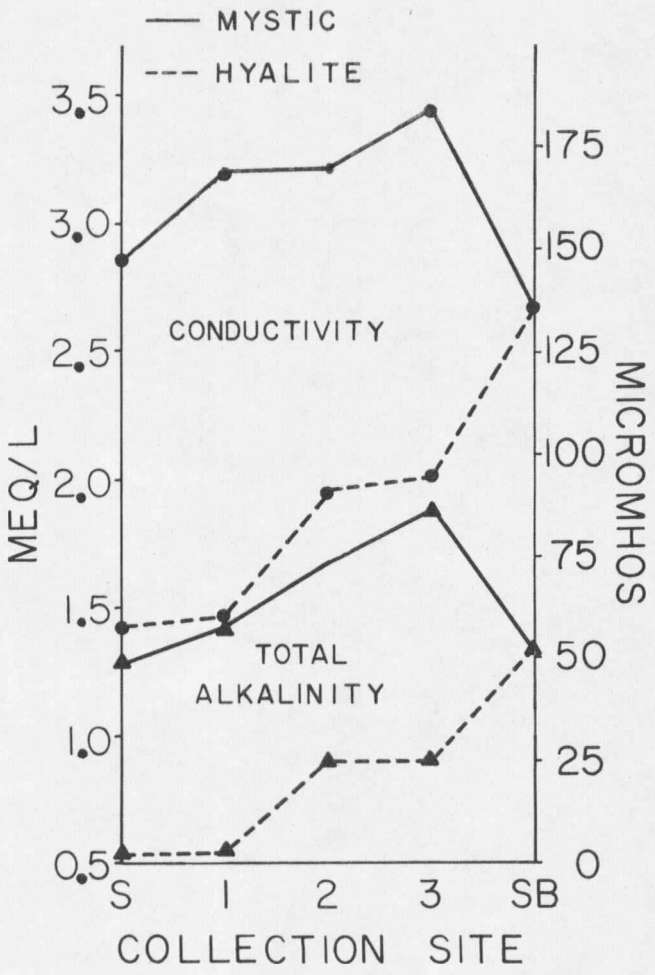


Figure 11. Chemical Profile of Average Conductivity (● micromhos) and Total Alkalinity (▲ meq/1) Concentrations Obtained From Ten Weekly Collections at Different Sites on the Bozeman (Mystic) and Middle (Hyalite) Creeks During the Summer of 1970

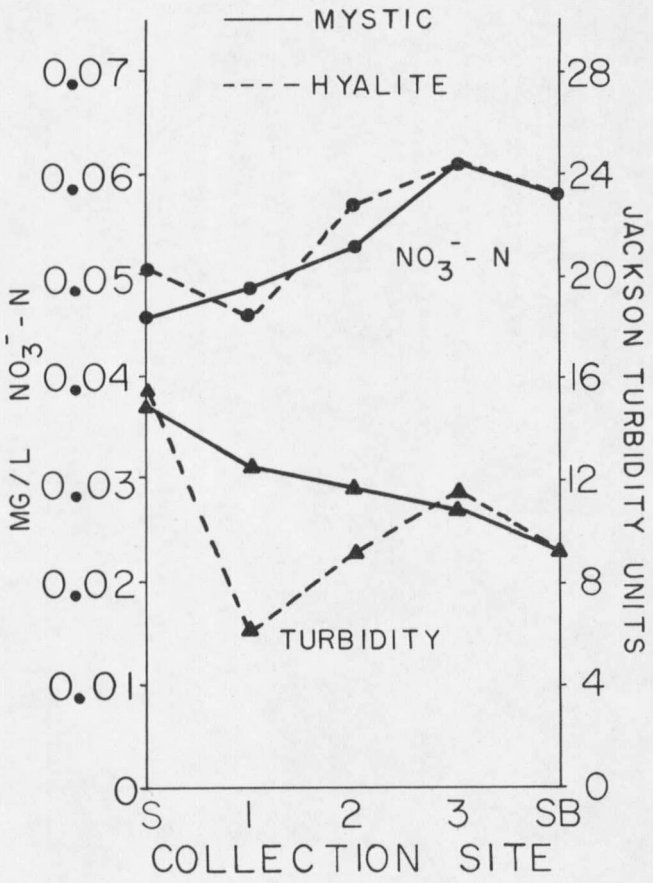


Figure 12. Chemical Profile of Average Turbidity (▲Jackson Turbidity Units) and Nitrate (● mg/l NO_3^- -N) Concentrations Obtained From Ten Weekly Collections at Different Sites on the Bozeman (Mystic) and Middle (Hyalite) Creeks During the Summer of 1970.

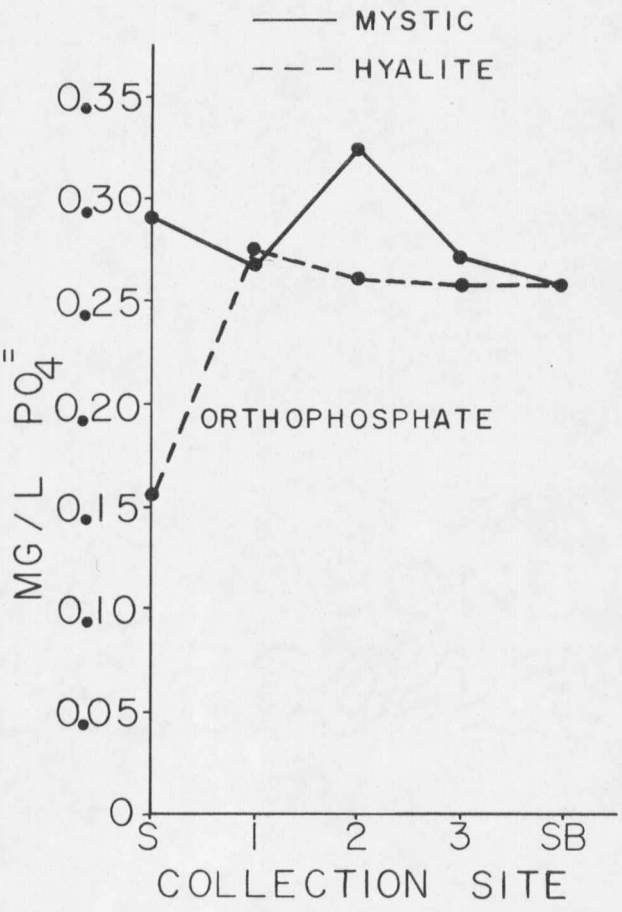


Figure 13. Chemical Profile of Average Orthophosphate (● mg/l PO_4^{-3}) Concentrations Obtained From Five Weekly Collections at Different Sites on the Bozeman (Mystic) and Middle (Hyalite Creeks) During the Summer of 1970

Table 21. Comparison of Water Temperature and Air Temperature Obtained at Different Sites in South Fork of Mystic Watershed During 7 Weekly Samplings in 1969 and 13 Weekly Samplings in 1970

	WATER TEMPERATURE (C)		AIR TEMPERATURE (C)	
SITE	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
		SUMMER 1969		
E	4.5-6.0	5.3	11.0-20.0	15.7
D	5.0-7.0	5.7	12.0-20.0	15.5
C	5.0-7.0	6.0	12.0-21.0	16.5
B	5.0-7.0	6.5	13.0-22.5	18.4
A	6.0-8.0	7.5	13.5-24.0	19.6
M_4	7.0-9.0	8.4	15.0-24.0	20.1
		SUMMER 1970		
Y	2.4-7.0	4.5	3.9-24.0	12.9
X	0.9-5.0	3.6	0.7-21.0	12.7
E	1.2-4.9	3.5	1.5-16.0	10.2
D	1.6-5.8	3.9	0.0-19.1	10.7
C	1.7-7.0	4.4	1.8-23.2	13.5
B	2.2-7.0	4.5	3.9-24.0	12.9
A	2.3-8.0	5.4	7.5-24.7	17.6
M_4	3.5-8.1	5.9	8.3-26.2	18.2

Table 22. Comparison of pH and Conductivity Obtained at Different Sites in South Fork of Mystic Watershed During 7 Weekly Samplings in 1969 and 13 Weekly Samplings in 1970

	pH		CONDUCTIVITY @ 25 C (micromhos)	
SITE	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
		SUMMER 1969		
E	7.5-7.8	7.7	52-63	57
D	7.7-7.9	7.9	63-77	69
C	7.4-7.9	7.7	61-76	67
B	6.9-8.1	7.5	63-76	70
A	7.2-8.3	7.4	73-78	76
M_4	6.7-8.6	7.4	71-76	75
		SUMMER 1970		
Y	6.4-7.3	6.7	60-67	63
X	6.3-7.2	6.6	51-57	54
E	6.3-7.7	6.6	40-63	50
D	6.4-7.5	6.8	52-76	62
C	6.4-7.7	6.8	52-64	57
B	6.3-7.6	6.9	55-63	59
A	6.4-7.8	7.0	59-72	65
M_4	6.2-7.7	6.8	58-70	65

pH values were fairly constant at all sites; however, a noticeable decrease was observed for all sites during 1970.

The dominant cation in the South Fork stream was calcium, followed by lesser amounts of magnesium, sodium, and potassium, respectively (Table 23). The dominant anion was bicarbonate with smaller concentrations of sulfate and chloride (Table 24). However, it should be noted that the concentrations of these ions are several-fold less than that found in the Bozeman Creek.

Profiles of calcium, magnesium, bicarbonate, and conductivity are shown in Figure 14 and 15. Calcium concentrations range from a low of 4.5 mg/1 at E to a maximum of 6.3 mg/1 at site A. Magnesium concentrations range from a low of 1.1 mg/1 at E and gradually increases to a maximum of 1.7 mg/1 at M_4.

Bicarbonate and conductivity profiles gave basically the same curve (Figure 15). Bicarbonate concentrations range from a low of 0.45 meq/1 at the upper most site, E, to a maximum of 0.59 meq/1 at M_4. The lowest conductivity mean also appeared at site E (50 micromhos) with the maximum attained at M_4 (65 micromhos).

Turbidity readings (Figure 16) remained constant throughout all the sampling sites. Minute fluctuations in nitrate concentrations were observed (Table 25).

Orthophosphate concentrations were quite constant at all sites in the South Fork (Figure 17); however, these concentrations were

Table 23. Comparison of Cation Concentrations Obtained at Different Sites in South Fork of Mystic (Closed) Watershed During the Summer of 1970 (8 Weekly Collections)

	CALCIUM (mg/l)		MAGNESIUM (mg/l)	
SITE	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
Y	5.3-6.5	5.9	1.3-2.5	1.8
X	4.2-4.9	4.6	0.2-1.6	1.1
E	3.9-4.9	4.5	0.6-1.7	1.1
D	5.5-6.6	6.0	0.8-1.7	1.3
C	4.6-5.8	5.3	0.8-2.0	1.3
B	5.2-5.7	5.4	1.3-2.0	1.6
A	5.9-6.5	6.3	1.0-2.2	1.7
M_4	5.9-6.5	6.2	1.2-2.2	1.7
	SODIUM (mg/l)		POTASSIUM (mg/l)	
Y	1.4-2.5	1.9	1.0-2.1	1.8
X	0.8-1.2	1.5	1.3-2.1	1.9
E	0.7-1.7	1.1	1.1-2.0	1.7
D	0.6-1.9	1.2	1.1-2.0	1.7
C	1.1-1.7	1.3	1.4-2.1	1.9
B	1.1-5.5	2.0	1.4-2.1	1.8
A	1.1-1.9	1.6	1.5-2.2	1.9
M_4	1.2-1.9	1.6	1.5-2.4	1.9

Table 24. Comparison of Anion Concentrations and Turbidity Determinations Obtained at Different Sites in South Fork of Mystic (Closed) Watershed During the Summer of 1970 (8 Weekly Collections)

	BICARBONATE (meq/l)		SULFATE (mg/l)	
SITE	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
Y	0.55-0.68	0.61	2.0-7.3	4.1
X	0.43-0.53	0.47	1.7-6.3	4.2
E	0.40-0.49	0.45	1.5-6.8	4.0
D	0.48-0.58	0.52	2.5-9.0	5.0
C	0.47-0.58	0.50	2.5-6.3	4.5
B	0.48-0.57	0.53	2.4-6.0	4.2
A	0.54-0.64	0.58	2.3-6.9	4.2
M_4	0.54-0.67	0.59	2.1-9.3	4.6
	CHLORIDE (mg/l)		TURBIDITY (Jackson Turbidity Units)	
Y	0.03-0.79	0.19	0-29	10
X	0.05-0.30	0.18	0-29	9
E	0.05-0.23	0.13	0-29	12
D	0.01-0.20	0.15	0-29	12
C	0.06-0.40	0.17	0-29	11
B	0.01-0.50	0.20	0-29	10
A	0.01-0.49	0.19	0-29	11
M_4	0.05-0.81	0.36	0-31	11

Table 25. Comparison of Nitrate and Orthophosphate Concentrations Obtained at Different Sites in South Fork of Mystic (Closed) Watershed During the Summer of 1970 (8 Weekly Collections)

	NITRATE (mg/l $N\text{-}NO_3^-$)		ORTHOPHOSPHATE (mg/l PO_4^{-3})	
SITE	RANGE	ARITHMETIC MEAN	RANGE	ARITHMETIC MEAN
Y	0.03-0.08	0.05	0.29-0.57	0.44
X	0.01-0.07	0.04	0.37-0.52	0.45
E	0.02-0.07	0.04	0.35-0.55	0.45
D	0.01-0.08	0.04	0.43-0.60	0.48
C	0.01-0.07	0.03	0.39-0.51	0.43
B	0.01-0.07	0.04	0.36-0.49	0.42
A	0.01-0.07	0.04	0.36-0.53	0.43
M_4	0.01-0.12	0.05	0.40-0.49	0.42

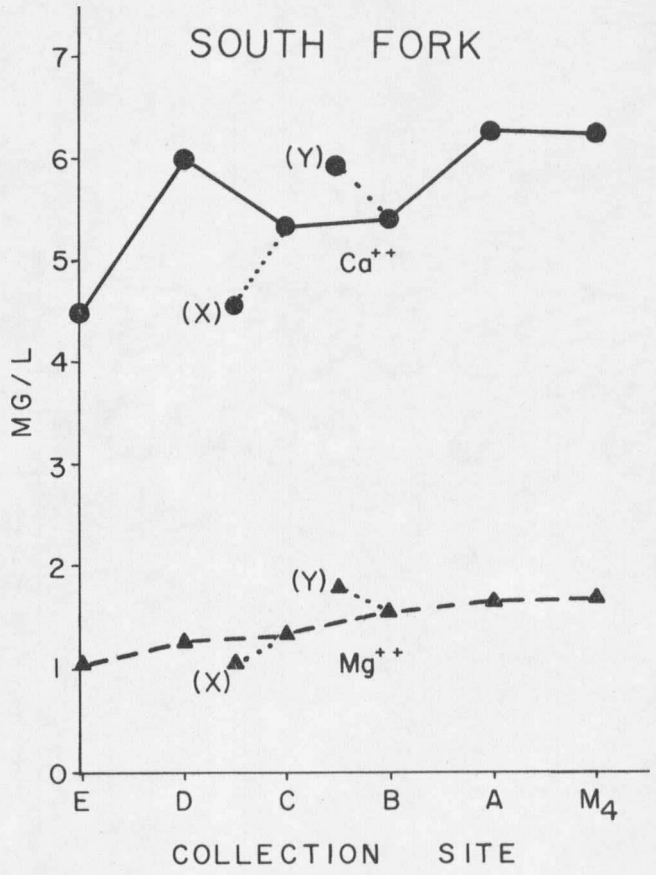


Figure 14. Chemical Profile of Average Calcium (● mg/1) and Magnesium (▲ mg/1) Concentrations Obtained From Eight Weekly Collections at Different Sites on the South Fork (and its Tributaries X and Y) of Bozeman Creek During the Summer of 1970

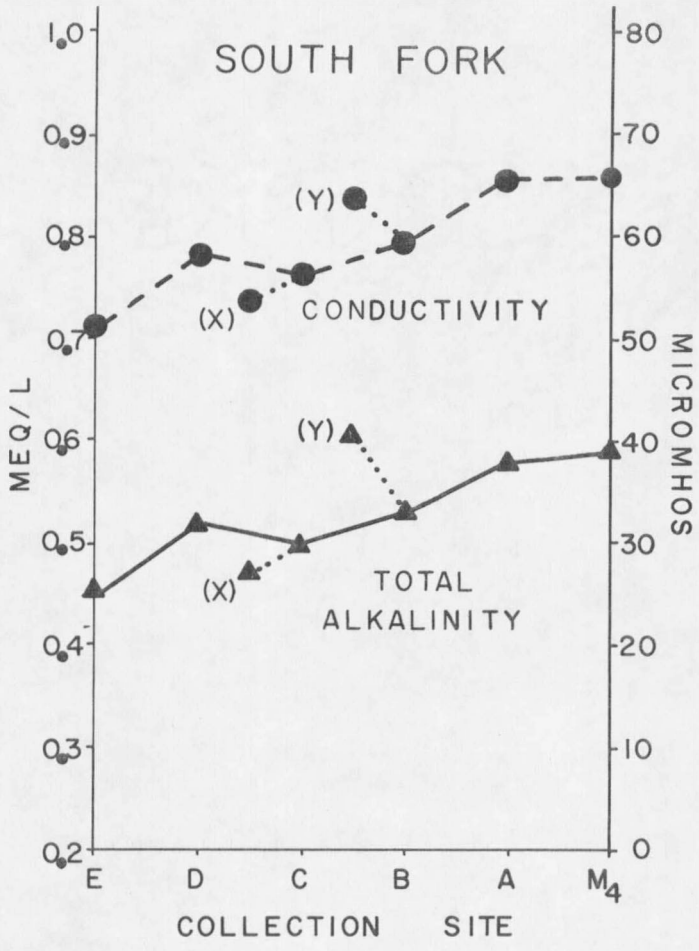


Figure 15. Chemical Profile of Average Conductivity (● micromhos) and Total Alkalinity (▲meq/l) Concentrations Obtained From Eight Weekly Collections at Different Sites on the South Fork (and its Tributaries X and Y) of Bozeman Creek During the Summer of 1970

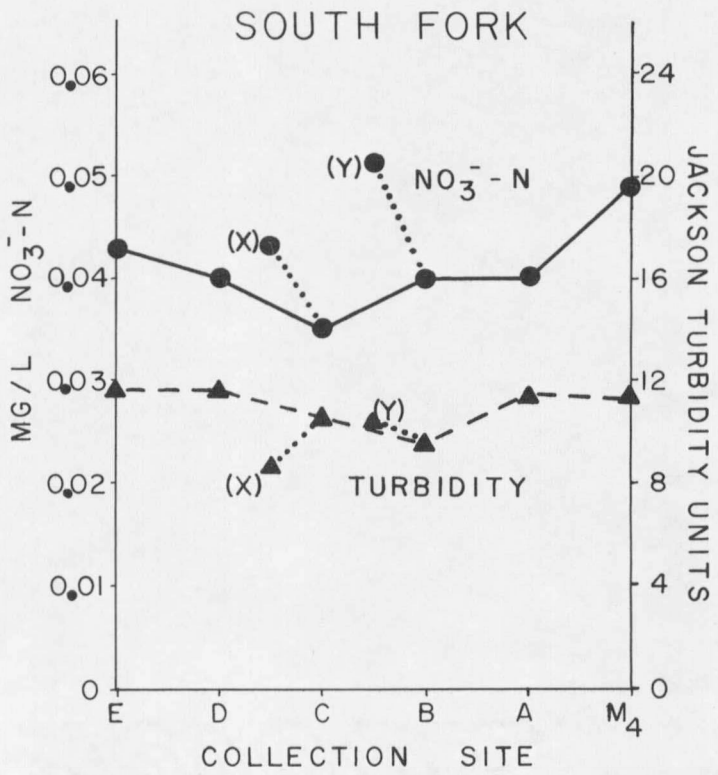


Figure 16. Chemical Profile of Average Turbidity (▲ Jackson Turbidity Units) and Nitrate (● mg/l NO_3^- -N) Concentrations Obtained From Eight Weekly Collections at Different Sites on the South Fork (and its Tributaries X and Y) of Bozeman Creek During the Summer of 1970

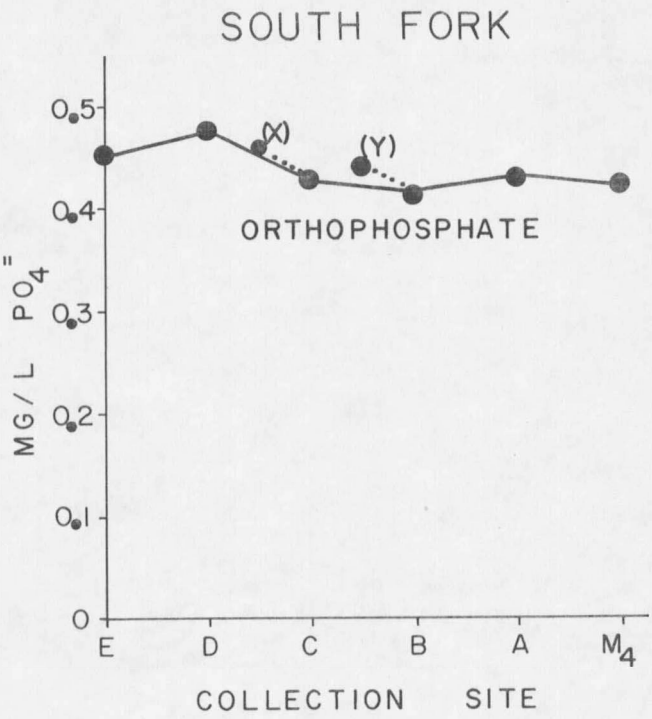


Figure 17. Chemical Profile of Average Orthophosphate (● mg/l PO_4^{-3}) Concentrations Obtained From Five Weekly Collections at Different Sites on the South Fork (and its Tributaries X and Y) of Bozeman Creek During the Summer of 1970

higher in this area (0.425 mg/1 at M_4) than found in Bozeman Creek (0.325 mg/1).

Statistical Results

In order to determine the degree of linear association between two variables, a statistical examination using correlation coefficients was employed. Using all the data obtained in 1969 and 1970, it was found that there was a significant positive correlation between numbers of coliforms and enterococci ($r=0.125$; $P=0.05$). When these data were subdivided into individual sampling areas (i.e., Mystic, Hyalite, and South Fork), this strongly positive relationship was upheld.

A positive correlation between numbers of enterococci and water temperature ($r=0.203$; $P=0.01$) resulted when all data for 1969 and 1970 were used. Although coliforms did not show significant correlation with water temperature, it was noted that most of the coefficients were negative rather than positive.

Positive correlation ($r=0.623$; $P=0.01$) was observed between numbers of coliforms and standard plate counts when 1970 data were used, as well as positive correlation between numbers of enterococci and standard plate counts ($r=0.182$; $P=0.05$).

Table 26 summarizes several significant correlations obtained from data in 1970. It should be noted that the majority of correlations are distributed in the Hyalite area.

Table 26. Correlation Coefficients for the Variables Indicated Below at P = 0.05, Except Where * Indicates P = 0.01

Variables and Sampling Area	r	N
Mystic		
Coliforms vs. Standard Plate Count	0.485*	41
Coliforms vs. Sulfate	0.399*	41
Hyalite		
Coliforms vs. Conductivity	0.342	41
Coliforms vs. Total Alkalinity	0.312	41
Coliforms vs. Total Hardness	0.327	41
Coliforms vs. Turbidity	0.342	41
Enterococci vs. Conductivity	0.302	41
Enterococci vs. Total Alkalinity	0.475*	41
Enterococci vs. Total Hardness	0.465*	41
Enterococci vs. Chloride	0.541*	41
Enterococci vs. Nitrate	0.357	41
South Fork		
Coliforms vs. Enterococci	0.754*	82
Coliforms vs. Standard Plate Count	0.813*	82
Enterococci vs. Standard Plate Count	0.699*	82
Standard Plate Count vs. Turbidity	0.248	82

Chapter 6

DISCUSSION

The bacteriological results of 1968 and 1969 corroborate earlier findings by Walter and Bottman[39] in that numbers of coliforms and enterococci were observed to be higher in water from the closed area (Mystic) than in water from the open watershed (Hyalite). However, Figure 4 illustrates that different results were obtained in 1970, since the coliform and enterococcal counts were nearly identical at all sites in both watersheds. A comparison of the coliform and enterococcal profiles for 1968, 1969, and 1970 in the Hyalite area gave essentially the same picture; therefore it was possible to use Hyalite as a "control system." The most significant difference occurred with the coliforms in the Mystic watershed during 1970, indicating that some change had occurred in the closed watershed.

Examination of the 1969 data from the South Fork of Bozeman Creek indicated extremely high coliform counts. The maximum geometric mean of approximately 220 coliforms/100 ml was observed at collection site C. At site M_4, a short distance above the convergence of the South Fork with Bozeman Creek, the coliform counts were observed to be almost 150 coliforms/100 ml, several times greater than at the spillway of the Mystic reservoir. Further downstream, the coliform geometric mean was found to be approximately 125 organisms/100 ml at the diversion dam. These findings seemed to indicate that the South Fork was

the major cause of the high coliform counts in the Mystic watershed.

The 1970 data further substantiated the hypothesis that the South Fork was the prime contributor in resulting coliform counts in the closed Mystic watershed. In 1970, coliform geometric means at the halfway point and diversion dam of the Mystic watershed reached only about 40 and 90 coliforms/100 ml, respectively. These numbers are less than in previous years. Low counts in the Mystic stream were reflected by low coliform numbers in the South Fork of Bozeman Creek in 1970 (Figure 6). Site M_4 of the South Fork had a geometric mean of only 40 coliforms/100 ml, approximately four times less than the previous year. Thus, it seemed that the South Fork drainage area was the key contributing factor to resulting bacterial densities in Bozeman Creek.

A possible explanation of the high coliform counts in the Mystic area during 1968 and 1969 is that this area had been a game reserve since it was closed to public entry until the spring of 1970. This hypothesis is supported by Forest Service browse transects which indicate that there were more big game animals in the Mystic drainage than in the Hyalite area. (Personal communication with Ross MacPherson, District Ranger). Specifically, this large concentration of about 300-500 elk and other big game animals was found in the South Fork drainage system prior to its limited opening in 1970.

Table 5 presents information supporting the notion that the South

Fork area may contain greater numbers of animals. In all three years it can be seen that E. coli isolates make up the larger percentage of coliforms in the Mystic than in the Hyalite waters. Also, the fecal coliforms make up the larger percentage of coliforms in the closed watershed in all three years. Perhaps more importantly, it can be seen that the fecal coliforms were found at a greater percentage in the South Fork area than in the Bozeman Creek, and this suggests that a large big game animal population did, in fact, exist. Further evidence indicating that animals contribute to the bacteriological counts is found in Table 6. As can be seen, many of the indicator organisms found in water samples were also isolated from animal droppings in the area.

Additional evidence of animal contribution to fecal coliform densities in the South Fork and Bozeman Creek is noted from the serological study. In this examination, an attempt was made to apply serological methods as a means of determining the source of greater pollution observed in Mystic as compared to Hyalite in 1969. Only 16 of the most common pathogenic E. coli antisera were used in this effort. Since approximately 50 percent of the isolates did not react with any of these sera, the more than 100 other available sera will have to be used to complete this study. No suitable explanation can be found to account for the various cross-reactions observed.

Tables 9, 10, 11, and 12 show that there are common E. coli

serotypes found both in water and fecal samples. For example, Table 11 illustrates a definite clustering of isolates in serotype 018:B21. Sampling sites from which serotype 018:B21 was isolated include various collections on the South Fork, Bozeman Creek, settling basin, and bear and elk fecal droppings. Serotype 0119:B14 shows similar results (Table 9).

The fact that common serotypes were found in both water and fecal samples further confirms that belief that big game animals in the South Fork area are a significant cause of the bacterial densities observed in the lower Bozeman Creek.

A suitable explanation of the lower coliform counts in the Bozeman Creek during 1970 than in previous years must be found. Since the South Fork also exhibited a great decrease in coliform densities, it appears that the answer should be found in this area. The best explanation appears to be that the wild animal population in the South Fork had been decreased. In the spring of 1970, the Mystic area was opened for limited public use. Possibly, this entrance of human activity forced the animals from their normal habitat in the South Fork area. Additionally, extensive logging practices had taken place in 1970 in the South Fork drainage area. The combination of sudden human activity and logging of the natural wild animal habitat surely would cause movement of animals from the South Fork area of the Mystic watershed. The decrease in animal numbers in this area is amply reflected

in declining coliform densities in the South Fork and Bozeman Creek in 1970.

In hope of finding a reason for the higher counts in the closed watershed than in the open watershed, chemical analyses were conducted during the summer of 1970. Bozeman Creek was found to be richer in regard to most chemical factors. This would seem to indicate that the chemistry of the Mystic water was the reason for the greater coliform densities than found in the open Hyalite watershed. However, it should be realized that the greatest coliform densities are found in the South Fork drainage system, where the chemical make-up of the water is even less rich than Middle Creek. Therefore, it is reasoned that the chemistry of the two watersheds is not the prime controlling factor in determining bacterial numbers in the closed watershed.

The oligotrophic properties of the South Fork, in combination with extremely low water temperatures, is not conducive to bacterial growth. However, the bacteriological pollution probably enters directly from fecal droppings in this area. In contrast, the open Hyalite watershed does not contain such great numbers of wild animals due to the presence of considerable human activity. Both the bacterial densities and chemical concentrations are less in the Hyalite water.

The hypothesis that the richer chemistry in the Mystic water is the sole reason for the higher coliform counts in this watershed is further rejected by the fact that the overall bacterial densities

(standard plate count) of the two streams are nearly the same. More importantly, the fact that the Mystic coliform counts showed a decrease in 1970 to nearly the same values as Hyalite additionally counters the hypothesis of using chemistry as the only explanation. Again, the overall data seem to indicate that animals in the South Fork area are the prime cause of high coliform densities in the closed watershed.

The computerized statistical analysis, using correlation coefficients, has indicated several interesting relationships concerning the bacterial, chemical, and physical environment. The significantly positive correlation between numbers of coliforms and enterococci obtained in this study lends support to the use of enterococci as possible indicators of pollution.

The strongly positive correlation between numbers of enterococci and water temperature indicates that increasing water temperature is possibly associated with rising enterococcal densities. Figures 7, 8, and 9 support these findings: the periodic sampling of the diversion dams and settling basin during all months of 1970 indicates that enterococci reach only one peak period of high density. These high densities are obtained in the summer months from July through September, corresponding to highest water temperatures during the year.

Coliforms did not show any significant positive correlation to water temperature, in fact most correlations appeared to be negative. Figures 7, 8, and 9 illustrate that coliforms reach two peak densities:

the largest peak occurring from August through October and a smaller one from May to mid-June. The high peak in the late summer possibly can be attributed to rain storms washing bacteria from the banks into the streams. Additionally, the water is quite low at this time of the year, thereby giving greater numbers of coliforms per unit volume of water. The smaller peak from May to mid-June is harder to explain. This period encompasses the latter half of spring run-off and the rainy season which may contribute to increasing numbers of coliforms. However, to positively designate spring run-off and abundance of rainfall as the cause of this peak period is not entirely possible: other unknown factors may contribute to this occurrence.

The statistical results also show that the majority of significant correlations occur in the Hyalite waters (Table 26). Indicator organisms were found to be significantly correlated with conductivity, total alkalinity, total hardness, turbidity, chloride, and nitrate in the Hyalite area. The number and degree of correlations in the Mystic and South Fork waters were found to be considerably less.

It should be emphasized that the various statistically significant correlations found between the bacteriological, chemical and physical environments are not meant to express cause and effect relationships. It is not possible to conclude that increasing bacterial numbers are a direct result of a particular increase in some chemical entity. However, the fact that various significant correlations were observed

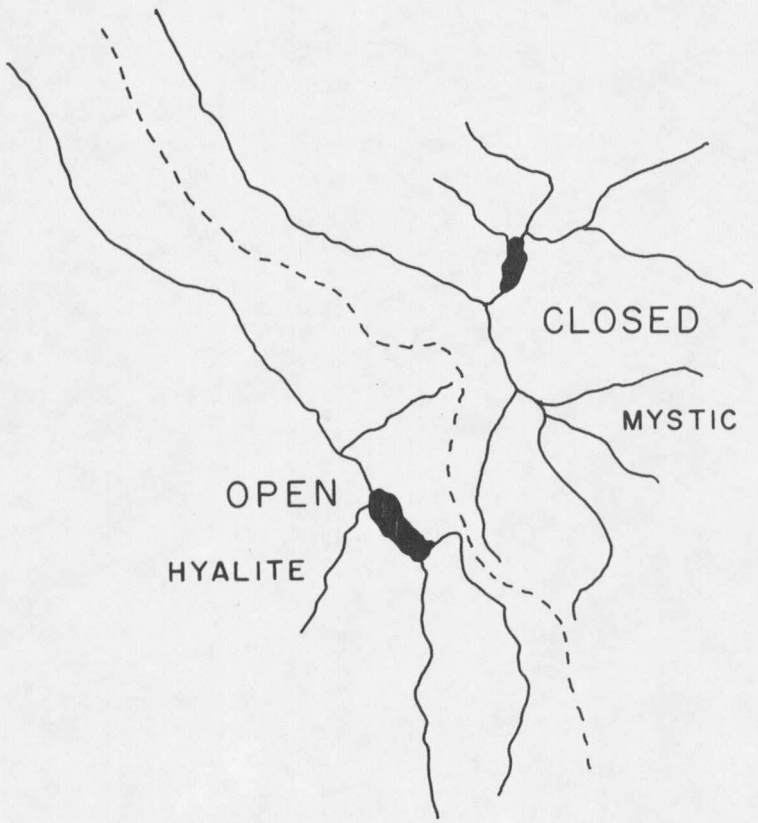


Figure 18. Drainage Systems of Mystic (Closed) and Hyalite (Open) Watersheds. Broken Line Indicates Mountain Range Between Two Watersheds

is of interest in itself. At this time, a proper interpretation of these statistical analyses is not possible.

Another factor that should be examined is that the drainage system of the two watersheds differ considerably (Figure 18). It can be seen that the high country of the Hyalite watershed is drained by streams which enter directly into the Hyalite reservoir; therefore, any significant bacterial pollution contributed from these streams would be diluted by a large volume of water contained in the reservoir. The Mystic reservoir also has high country stream contributions; however it is important to notice that the South Fork enters directly into the Bozeman Creek, below the Mystic reservoir. As a result, any bacterial contribution from the South Fork would directly affect the water quality of Bozeman Creek. Indeed, this direct effect of the South Fork appears to be the major controlling factor of the bacteriological water quality of the Bozeman Creek.

It is of major importance to incorporate these findings and conclusions in an effort to obtain a better understanding of what actually constitutes "natural quality water" of high elevation mountain watersheds, both chemically and bacteriologically. It was found that the open watershed contained better quality water than in the closed watershed in terms of chemistry and bacteriology. The South Fork waters have shown high bacterial contamination; however, the chemical make-up of this water is of very high quality. The opening of the Mystic watershed

in early 1970 for limited use, in addition to an expanded logging operation, has coincided with an unexpected decrease of bacterial contamination in the area. Keeping these facts in mind, it is quite simple to realize the difficulty and complexity of understanding what actually does constitute "natural quality water".

With the increasing concern for the preservation of our natural environment, it is quite unique that the results of this study have shown that human activity has coincided with lowered bacterial pollution in the studied waters. As a result, it seems that in the future careful consideration should be given as to the advisability of closing high mountain municipal watersheds to public entry.

Chapter 7

SUMMARY

During the summers of 1969 and 1970 bacteriological determinations of coliform, enterococcal, and standard plate counts were performed on two high mountain drainage systems: Hyalite, a watershed open for public use and Mystic, a watershed that had been closed from 1917 until its opening for limited human activity in the spring of 1970.

The 1969 bacteriological results agreed with previous studies in that coliform densities were found to be greater in the closed watershed than found in the open watershed, while no great differences were observed with regard to enterococcal densities or standard plate counts. The geometric mean at the most downstream sampling site in the Mystic watershed (diversion dam) in 1969 was over 200 coliforms/100 ml while it was about 60 coliforms/100 ml for a comparable site in the Hyalite watershed. In 1970 coliform densities in the closed drainage decreased considerably to values that were quite similar to numbers observed in the open watershed (91 coliforms/100 ml at the Mystic diversion dam and 85 coliforms/100 ml at the Hyalite diversion dam).

The 1969 bacteriological results from the South Fork of Bozeman Creek indicated a high coliform density with a geometric mean of about 150 coliforms/100 ml at a sampling site a short distance from its convergence with Bozeman Creek. In 1970 the coliform density decreased to 40 coliforms/100 ml at this site.

In 1970 the study was expanded to include a water chemistry analysis of the waters from both watersheds. Analyses included air temperature, water temperature, pH, conductivity, turbidity, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, nitrate, nitrite, and orthophosphate. These analyses indicated that the chemical make-up of the two drainages did not adequately account for differing bacterial densities. Highest coliform counts were found in the South Fork waters; however, these waters contained the least concentrations of various chemical entities.

Serological studies were conducted on Escherichia coli isolates obtained from water and wild animal (bear and elk) fecal droppings in the closed watershed. The finding of common serotypes of E. coli isolates from both water and animal fecal droppings indicates the strong influence that wild game animals had on determining bacterial densities in the closed watershed.

It was concluded that the cause of significant changes in the closed watershed were a direct result of the influences of its main tributary, the South Fork. Wild game animal populations which inhabited the South Fork area in 1969 were the primary cause of the high bacterial contamination. The opening of the closed watershed for limited public use and an extensive logging operation in 1970 coincided with decreasing bacterial densities in the closed watershed since it is possible that human influence forced the game animals out of

their natural habitat in the South Fork area. The influence exerted by the South Fork on bacterial numbers in the closed (Mystic) watershed was a result of its direct entrance into the Bozeman Creek below the Mystic reservoir. No such influence of high country tributaries were observed in the open watershed since the tributaries entered directly into the Hyalite reservoir.

APPENDIX

Table 27. Number of Organisms per 100 ml in Water Samples Obtained From Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1969

COLIFORMS/100 ml

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
7/7	0	20	40	90	40	0	20	130	310
7/14	10	70	120	170	60	50	10	100	80
7/21	20	0	50	110	0	0	0	120	20
7/28	20	0	540	360	200	60	60	110	200
8/4	-	-	-	-	-	-	-	-	-
8/11	10	0	100	240	20	0	0	60	30
8/18	10	20	400	930	80	20	10	30	300
8/25	170	10	230	370	140	0	10	10	10
9/27	10	0	40	100	160	0	10	110	30

ENTEROCOCCI/100 ml

7/7	0	0	1	4	1	0	0	4	22
7/14	2	1	1	8	8	1	0	5	4
7/21	13	1	9	29	18	2	1	11	16
7/28	5	1	48	75	55	0	0	28	50
8/4	998	2	55	86	74	48	0	30	72
8/11	14	2	135	80	101	1	2	65	99
8/18	4	1	23	47	22	1	1	9	40
8/25	18	3	51	117	36	14	0	27	46
9/27	6	1	8	14	7	0	0	4	4

- not determined

Table 28. Number of Coliforms per 100 ml Obtained From Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
6/16	70	110	70	50	110	140	80	70	100
6/22	0	20	0	10	10	10	0	10	10
6/29	0	0	0	90	70	0	100	100	100
7/7	0	40	30	60	10	230	20	40	130
7/14	0	10	80	70	70	0	0	20	60
7/21	1300	0	40	10	20	20	10	40	20
7/28	10	0	50	104	44	40	6	30	42
8/4	0	20	270	210	170	200	100	90	50
8/11	110	0	140	390	60	110	30	60	120
8/18	0	150	110	320	230	200	10	220	160
8/25	0	0	140	250	150	180	10	110	200
9/9	200	200	50	150	350	30	90	140	260
9/15	-	-	-	260	220	-	-	-	290
9/22	10	0	110	50	50	30	0	40	110

- not determined

Table 29. Number of Enterococci per 100 ml Obtained From Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
6/16	0	4	1	6	1	3	0	0	2
6/22	1	18	1	4	4	42	2	1	16
6/29	6	0	1	0	8	5	2	7	7
7/7	-	14	83	32	6	-	11	141	239
7/14	-	12	27	13	14	20	1	1	4
7/21	179	0	44	55	69	22	1	7	29
7/28	24	1	35	40	55	4	1	12	15
8/4	16	3	8	22	70	70	2	14	47
8/11	36	0	31	51	51	0	4	58	57
8/18	24	1	25	100	71	2	0	41	84
8/25	162	0	87	140	32	4	0	33	82
9/9	1	3	38	50	47	0	17	56	42
9/15	-	-	-	36	11	-	-	-	23
9/22	0	2	10	18	1	0	3	14	10

- not determined

Table 30. Standard Plate Counts per ml (SPC/ml) of Water Samples Obtained From Different Sites in Mystic (Closed) and Hyalite (Open) Watersheds During the Summers of 1969 (Incubated at 35 C for 48 hrs.) and 1970 (Incubated at 20 C for 5 days)

	SITE								
	1969								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
7/7	39	41	72	30	26	89	10	26	760
7/14	61	53	195	203	155	368	11	83	50
7/21	158	10	57	60	42	429	16	52	32
7/28	395	53	90	76	167	1680	46	104	135
8/4	810	3	15	35	38	1480	123	38	26
8/11	86	29	138	124	145	73	106	172	120
8/18	44	62	308	277	446	534	297	325	562
8/25	860	20	37	29	64	8000	5870	1560	278
9/27	68	13	56	85	142	65	19	80	89
	1970								
6/16	2560	4100	2400	5600	3330	3800	1800	780	920
6/22	670	990	690	810	470	1360	810	950	1190
6/29	1000	1910	1080	1740	4100	780	890	950	620
7/7	-	-	-	-	-	-	-	-	-
7/14	1110	60	300	600	810	190	230	250	330
7/21	3140	70	1010	1370	330	330	460	350	690
7/28	1030	90	990	460	610	910	310	520	840
8/4	190	240	320	610	690	700	570	770	670
8/11	390	30	500	370	150	430	200	260	290
8/18	590	210	650	980	740	170	900	440	710
8/25	580	80	300	470	230	600	0	80	230
9/9	3200	1300	1670	1900	3490	800	2500	6500	2100
9/15	-	-	-	1490	520	-	-	-	650
9/22	910	920	1840	1740	1560	1380	670	690	740

Table 31. Number of Coliforms per 100 ml, Enterococci per 100 ml, and Standard Plate Count per ml (SPC/ml) in Water Samples Obtained From the Mystic (M_3) and Hyalite (H_3) Diversion Dams and Settling Basin (SB) During January - May, 1970

	COLIFORMS/100 ml			ENTEROCOCCI/100 ml			SPC/ml @35° C		
DATE	M_3	H_3	SB	M_3	H_3	SB	M_3	H_3	SB
1/14	120	210	60	0	1	1	33	70	23
2/19	10	40	70	0	1	0	19	15	9
2/27	20	0	50	0	0	0	-	-	-
3/5	50	70	40	0	0	0	15	50	11
4/3	40	20	30	2	2	1	26	20	9
4/10	60	80	60	1	4	0	58	280	13
4/24	210	0	40	0	0	0	36	70	21
5/1	60	30	20	0	12	0	25	42	11
5/6	350	850	150	1	4	2	61	172	87
5/13	90	70	120	4	1	1	30	41	23
5/20	210	80	210	0	3	2	117	122	111
5/25	40	0	90	4	0	9	80	40	52
6/1	110	50	50	1	2	0	48	17	30
6/8	710	600	10	71	60	1	86	163	40

- not determined

Table 32. Number of Coliforms per 100 ml, Enterococci per 100 ml, and Standard Plate Count per ml (SPC/ml) in Water Samples Obtained From the Mystic (M_3) and Hyalite (H_3) Diversion Dams and Settling Basin (SB) During October – November, 1970.

	COLIFORMS/100 ml			ENTEROCOCCI/100 ml			SPC/ml @ 20 C		
DATE	M_3	H_3	SB	M_3	H_3	SB	M_3	H_3	SB
10/6	310	520	1850	23	15	30	2440	2120	3570
10/12	2500	410	580	75	59	10	4700	4250	3500
10/21	160	60	170	1	0	3	TNTC*	3500	3690
10/26	130	50	40	3	4	3	5900	2590	1880
11/2	40	30	200	0	1	0	3500	2700	2700
11/9	15	0	50	2	1	0	2900	1440	1360
11/16	76	7	63	1	0	1	1380	2600	870
11/23	45	33	45	2	2	4	1260	460	260

* TNTC = too numerous to count

Table 33. Number of Organisms per 100 ml in Water Samples Obtained in Different Sites From the South Fork of the Mystic (Closed) Watershed During the Summer of 1969

	COLIFORMS/100 ml						
			SITE				
DATE	*M_4-reg.	M_4	A	B	C	D	E
7/15	1230	430	230	190	160	-	-
7/22	70	110	70	120	100	20	10
7/29	1310	170	240	290	140	40	70
8/5	-	60	140	480	450	80	40
8/14	410	190	140	140	310	90	70
8/19	90	140	160	130	170	150	100
8/26	410	310	370	200	170	160	80
	ENTEROCOCCI/100 ml						
7/15	4	1	1	3	2	-	-
7/22	6	9	8	9	11	57	10
7/29	45	30	29	27	25	12	7
8/5	135	32	32	28	30	22	12
8/14	142	81	69	60	70	56	35
8/19	55	27	42	14	23	50	21
8/26	56	41	25	20	33	52	17

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 34. Number of Coliforms per 100 ml in Water Samples Obtained From Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970

		SITE						
DATE	*M_4-reg.	M_4	A	B	C	D	E	X	Y
6/19	20	40	50	0	20	0	0	-	-
6/24	0	0	0	0	20	10	0	-	-
7/1	10	30	20	10	20	0	0	0	20
7/8	30	0	0	10	0	10	0	0	0
7/15	20	14	0	30	20	26	8	6	20
7/22	150	700	900	470	1210	3000	800	270	120
7/29	38	110	84	72	62	88	50	30	38
8/5	350	124	78	118	204	58	46	26	64
8/12	180	88	70	110	78	154	164	44	86
8/20	130	120	140	170	70	30	50	50	120
8/25	-	220	260	150	180	170	160	80	160
9/9	-	40	70	130	70	120	130	60	160
9/22	-	100	110	120	60	90	110	20	240

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 35. Number of Enterococci per 100 ml in Water Samples Obtained From Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970

			SITE						
DATE	*M_4-reg.	M_4	A	B	C	D	E	X	Y
6/19	1	0	0	0	0	0	0	-	-
6/24	0	1	0	0	0	4	12	-	-
7/1	6	2	0	0	0	2	0	0	1
7/8	5	4	2	2	3	4	3	5	3
7/15	12	5	3	2	8	2	28	15	3
7/22	71	70	159	151	206	300	199	27	88
7/29	28	25	16	9	14	4	12	8	25
8/5	26	29	15	15	23	17	10	17	15
8/12	15	27	28	16	12	11	9	27	9
8/20	26	54	31	37	28	20	8	38	57
8/25	-	54	38	27	29	26	14	20	22
9/9	-	83	88	151	239	21	8	56	28
9/22	-	6	7	8	8	6	10	5	5

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 36. Standard Plate Counts per ml (SPC/ml) of Water Samples Obtained From Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summers of 1969 (Incubated at 35 C for 48 hrs.) and 1970 (Incubated at 20 C for 5 days)

			SITE						
			1969						
DATE	*M_4-reg.	M_4	A	B	C	D	E	X	Y
7/15	53	35	32	25	-	-	-	-	-
7/22	17	18	12	11	21	18	15	-	-
7/29	56	14	13	18	18	19	6	-	-
8/5	22	23	12	14	22	6	1	-	-
8/14	110	34	26	16	17	39	25	-	-
8/19	40	17	16	10	18	32	8	-	-
8/26	30	21	43	8	21	40	11	-	-
			1970						
6/19	840	740	310	380	400	230	820	-	-
6/24	380	210	260	260	160	120	120	-	-
7/1	540	1040	-	310	630	1400	700	370	730
7/8	-	180	160	160	-	220	150	120	90
7/15	120	109	254	133	153	85	76	79	123
7/22	390	2260	3390	1760	4380	7500	3260	850	780
7/29	230	660	600	640	400	390	260	250	730
8/5	280	140	118	99	92	116	107	73	181
8/12	210	190	140	157	94	105	112	76	166
8/20	410	210	218	310	216	320	271	175	500
8/25	270	159	192	164	162	122	115	106	163
9/9	3900	-	-	-	-	-	-	-	-
9/22	-	1920	1850	1810	1480	1600	510	750	1310

-not determined
*M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 37. Water Temperatures (C) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1969

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
7/7	13.0	12.0	8.0	9.0	8.0	12.0	7.5	8.0	8.5
7/14	16.5	7.0	8.5	8.5	10.0	15.5	8.0	9.5	9.5
7/21	21.0	8.0	7.5	9.5	11.5	18.0	8.5	9.0	9.5
7/28	19.0	7.0	8.0	9.0	10.0	19.0	8.5	11.0	12.0
8/4	21.0	10.0	10.5	10.0	13.0	22.0	10.5	13.0	13.5
8/11	20.0	13.0	10.5	10.0	11.0	18.0	11.0	11.5	11.5
8/18	11.0	10.5	8.0	8.0	11.0	8.0	8.0	9.0	9.0
8/25	19.0	13.0	9.0	10.0	13.0	20.0	13.0	13.0	14.0
9/27	11.0	11.0	7.5	7.0	8.0	12.0	10.5	9.0	8.0

Table 38. Water Temperatures (C) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
6/16	7.5	5.0	5.1	6.5	6.2	6.5	5.0	5.5	6.2
6/22	16.3	6.0	6.1	7.4	8.1	12.5	5.0	7.2	9.0
6/29	15.2	6.7	5.1	7.9	8.0	12.7	6.0	7.0	8.2
7/7	17.0	6.2	7.3	8.3	9.0	15.5	7.5	9.1	10.1
7/14	16.6	7.1	7.0	8.2	8.6	14.5	8.0	9.9	10.8
7/21	20.2	7.8	8.1	9.5	10.4	12.0	7.9	10.5	11.3
7/28	17.5	8.8	8.0	8.8	10.1	16.3	9.3	11.8	12.9
8/4	19.0	10.7	8.0	8.9	9.7	18.2	10.0	11.1	11.7
8/11	18.2	11.5	7.6	8.1	10.3	17.2	10.5	12.0	12.0
8/18	17.9	12.7	7.2	7.0	9.1	16.5	10.7	10.9	10.5
8/25	21.0	13.0	10.1	11.7	11.2	17.9	11.1	14.3	13.8
9/9	13.9	13.0	8.7	8.3	8.7	13.4	10.9	11.9	10.8
9/15	-	-	-	2.9	5.0	-	-	-	5.2
9/22	9.0	8.1	9.1	6.8	6.4	-	-	-	-

- not determined

Table 39. Air Temperatures (C) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1969

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
7/7	16.5	16.0	17.0	19.0	18.0	11.0	11.0	10.5	11.0
7/14	15.5	15.5	19.0	18.0	19.5	21.5	18.0	19.5	19.0
7/21	18.0	19.0	18.5	20.5	23.0	17.5	17.5	16.5	17.5
7/28	14.0	13.0	13.0	15.0	16.0	22.5	16.0	18.5	22.0
8/4	23.0	16.5	18.5	20.5	24.0	23.0	21.5	23.5	26.0
8/11	20.0	18.0	19.5	15.0	17.0	19.0	18.0	18.5	18.0
8/18	19.0	12.5	10.5	12.0	15.0	16.5	11.0	10.5	10.0
8/25	18.0	18.0	16.5	18.5	18.0	22.0	21.0	20.0	22.0
9/27	6.0	8.0	8.5	8.5	13.0	12.0	10.5	10.5	12.0

Table 40. Air Temperatures (C) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
6/16	11.0	11.0	12.6	13.5	12.8	10.5	9.9	11.5	14.9
6/22	25.5	24.2	23.6	27.5	26.4	24.1	24.0	25.0	25.2
6/29	15.2	16.4	15.0	18.6	19.0	15.6	13.8	14.6	21.5
7/7	20.5	17.0	21.5	22.2	21.5	21.3	22.0	21.0	24.6
7/14	14.2	11.7	14.8	15.5	17.9	18.1	18.5	18.5	20.5
7/21	19.1	17.7	22.6	21.6	21.5	22.0	19.2	19.9	21.9
7/28	19.2	14.5	18.3	23.8	20.8	23.6	18.1	18.1	22.1
8/4	18.1	12.8	13.2	20.3	20.6	25.5	24.2	19.7	26.0
8/11	18.2	11.6	18.3	20.6	24.7	26.6	19.4	21.7	24.1
8/18	17.4	11.9	12.5	15.5	22.5	20.0	17.4	17.4	23.2
8/25	26.5	27.8	30.2	32.6	34.8	28.7	24.3	27.7	28.6
9/9	9.5	11.0	11.4	12.0	16.0	9.6	10.0	11.5	11.5
9/15	-	-	-	8.1	8.2	-	-	-	8.0
9/22	12.8	10.0	13.9	15.4	7.8	-	-	-	-

- not determined

Table 41. pH Measurements at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1969

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
7/7	7.95	7.90	8.15	8.20	7.65	8.22	7.58	7.89	7.95
7/14	8.10	7.20	7.95	8.25	7.60	9.10	7.40	7.80	7.80
7/21	9.05	7.90	8.30	8.35	7.75	9.60	8.30	8.20	8.45
7/28	9.00	7.90	8.55	8.60	8.20	9.70	8.10	8.60	8.45
8/4	9.00	7.70	8.15	8.00	7.75	10.00	7.80	8.40	8.00
8/11	9.10	8.15	8.40	8.40	7.75	10.00	8.10	8.30	8.20
8/18	8.30	8.10	8.15	8.15	7.90	9.20	8.15	8.00	8.40
8/25	9.20	8.45	8.05	8.35	7.90	10.00	8.45	8.15	8.30
9/27	-	-	-	-	-	-	-	-	-

- not determined

Table 42. pH Measurements at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
6/16	6.80	6.60	7.10	7.30	7.30	7.20	7.00	7.00	7.10
6/22	8.10	7.30	7.70	7.90	7.30	8.00	6.90	7.10	-
6/29	7.90	7.50	7.20	7.30	7.10	7.10	6.90	7.30	7.10
7/7	8.10	7.90	8.50	8.05	7.80	7.50	8.70	7.70	8.00
7/14	8.10	7.40	7.60	7.90	7.50	7.75	7.80	7.40	6.60
7/21	8.70	7.40	7.90	7.90	7.55	7.60	7.45	7.80	7.45
7/28	8.70	7.70	8.40	8.20	7.80	8.70	8.20	8.30	8.00
8/4	8.60	7.02	7.80	7.70	7.20	8.20	7.20	7.50	7.80
8/11	8.85	7.30	9.00	7.70	7.60	9.10	6.30	7.80	7.90
8/18	9.37	7.10	6.90	7.65	6.85	8.27	6.65	6.48	7.06
8/25	9.91	6.77	7.23	7.53	7.09	8.02	6.41	6.78	7.00
9/9	8.76	8.51	7.40	7.48	7.18	7.66	7.41	6.90	6.98
9/15	-	-	-	7.58	7.40	-	-	-	7.26
9/22	8.94	8.62	7.62	7.32	7.21	7.49	7.02	6.96	-

- not determined

Table 43. Conductivities (Micromhos) at 25 C for Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1969

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
7/28	170	230	224	222	215	60	70	118	114
8/4	170	211	208	212	118	72	69	105	103
8/11	167	197	211	212	117	69	69	103	109
8/18	170	202	222	225	125	72	71	112	114
8/25	182	210	234	229	138	99	77	118	128
9/27	194	180	193	229	165	81	84	146	150

Table 44. Conductivities (Micromhos) at 25 C for Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
6/16	152	170	154	149	189	64	67	113	110
6/22	157	182	142	168	180	61	72	92	95
6/29	155	163	162	158	105	59	55	69	70
7/7	125	166	155	156	124	60	59	76	79
7/14	156	169	156	172	118	53	51	73	74
7/21	160	189	180	202	141	59	53	84	84
7/28	141	185	165	169	136	51	57	91	92
8/4	148	175	188	213	151	53	58	101	109
8/11	162	178	190	217	157	56	65	105	108
8/18	142	162	180	198	150	55	61	93	96
8/25	153	151	156	159	103	56	54	95	97
9/9	143	149	163	188	148	66	64	110	110
9/15	-	-	-	181	137	-	-	-	107
9/22	149	145	167	178	135	65	68	107	109

- not determined

Table 45. Water Temperatures (C), Air Temperatures (C), and pH Measurements of Samples Obtained at the Mystic (M_3) and Hyalite (H_3) Diversion Dams and the Settling Basin (SB) During January - May, 1970

	WATER TEMPERATURE			AIR TEMPERATURE			pH		
DATE	M_3	H_3	SB	M_3	H_3	SB	M_3	H_3	SB
1/14	0.5	0.5	0.5	4.5	6.0	3.5	9.3	9.1	8.4
2/19	0.5	0.5	0.5	5.0	3.0	3.5	8.7	8.5	8.4
2/27	0.5	0.5	0.5	1.5	2.0	0.0	8.6	8.1	8.6
3/5	0.5	0.5	0.5	3.5	1.0	0.5	9.2	7.8	7.9
4/3	1.0	1.0	1.0	8.0	9.5	9.0	8.1	8.0	7.8
4/10	2.5	3.0	2.5	3.5	3.5	4.5	8.5	8.4	8.0
4/24	4.0	4.5	2.0	9.0	11.0	8.5	8.6	8.5	8.7
5/1	6.5	7.0	2.5	9.0	9.5	7.5	8.8	8.5	8.0
5/6	2.5	2.0	2.5	6.0	4.0	10.0	8.7	8.5	7.9
5/13	2.0	1.0	2.0	2.5	1.5	2.0	8.5	8.1	8.7
5/20	3.5	3.5	4.0	9.5	11.0	9.0	8.3	8.0	8.5
5/25	3.5	2.0	4.0	10.0	6.5	8.5	8.2	8.2	7.9
6/1	3.5	3.0	4.0	9.5	8.5	9.5	7.7	8.0	7.7
6/8	5.5	5.0	6.5	16.0	13.0	17.0	7.8	7.2	7.1

Table 46. Water Temperatures (C), Air Temperatures (C), and pH Measurements of Samples Obtained at the Mystic (M_3) and Hyalite (H_3) Diversion Dams and Settling Basin (SB) During October - November, 1970

	WATER TEMPERATURE			AIR TEMPERATURE			pH		
DATE	M_3	H_3	SB	M_3	H_3	SB	M_3	H_3	SB
10/6	2.7	3.4	5.0	-0.5	-1.2	-0.4	8.17	7.69	7.58
10/12	2.9	3.6	4.2	0.7	0.6	1.4	7.91	7.68	7.84
10/21	4.5	3.2	4.5	2.0	7.5	6.5	8.03	7.80	7.73
10/26	1.0	1.5	2.0	-2.0	-1.0	-0.5	8.03	7.88	7.79
11/2	0.0	0.0	1.0	-2.0	-2.5	-1.0	8.09	7.90	7.83
11/9	3.5	4.0	2.5	8.5	9.0	9.5	8.29	8.28	7.93
11/16	-	-	-	-	-	-	8.11	8.01	7.92
11/23	0.0	0.0	0.5	-9.0	-6.0	-8.0	8.15	7.91	8.00

- not determined

Table 47. Water and Air Temperatures (C) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1969

DATE	*M_4-reg.	M_4	A	B	C	D	E
			WATER TEMPERATURE				
			SITE				
7/15	5.5	-	-	7.0	6.0	-	-
7/22	8.5	7.0	6.0	5.0	5.0	7.0	6.0
7/29	6.0	9.0	8.0	7.0	7.0	6.5	6.0
8/5	8.5	9.0	8.0	7.0	6.0	5.5	5.0
8/14	6.5	8.5	8.0	6.5	6.0	5.0	5.0
8/18	5.5	8.0	7.0	6.0	5.5	5.0	4.5
8/26	7.5	9.0	8.0	7.0	6.5	5.5	5.0
			AIR TEMPERATURE				
			SITE				
7/15	17.0	-	-	15.5	15.0	-	-
7/22	18.5	15.0	13.5	13.0	12.0	12.0	13.0
7/29	12.5	15.0	15.0	15.0	15.0	15.0	13.0
8/5	16.0	20.5	21.0	22.0	17.0	15.5	19.5
8/14	16.0	22.0	22.0	18.5	17.5	17.0	18.0
8/18	9.0	24.0	24.0	22.0	18.0	13.5	11.0
8/26	15.5	24.0	22.0	22.5	21.0	20.0	20.0

- not determined

* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 48. Water Temperatures (C) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970

			SITE						
DATE	*M_4-reg.	M_4	A	B	C	D	E	X	Y
6/19	3.4	4.8	4.6	2.6	2.5	2.5	2.2	-	-
6/24	4.1	5.5	4.9	3.9	3.8	3.7	3.4	-	-
7/1	4.6	4.8	4.8	4.2	4.0	3.5	3.4	3.4	4.1
7/8	4.5	6.1	5.6	4.9	5.1	4.9	4.5	4.0	4.8
7/15	4.6	9.3	8.0	7.0	7.0	4.3	4.1	5.0	7.0
7/22	6.3	5.2	5.1	4.7	4.9	4.8	4.6	4.0	4.7
7/29	5.3	8.1	6.7	5.7	6.0	5.0	4.4	4.8	6.0
8/5	4.6	6.6	7.0	6.0	6.1	5.8	4.9	4.8	5.1
8/12	4.8	6.0	5.9	4.9	4.8	4.6	4.0	3.9	4.6
8/20	3.5	5.5	5.0	4.4	4.4	4.1	3.6	3.8	4.3
8/25	-	7.2	6.0	5.0	5.0	4.6	3.8	3.9	4.7
9/9	-	3.8	4.4	2.6	1.7	1.7	1.6	0.9	2.4
9/22	-	3.5	2.3	2.2	1.8	1.6	1.2	1.6	2.4

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 49. Air Temperatures (C) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970

	SITE								
DATE	*M_4-reg.	M_4	A	B	C	D	E	X	Y
6/19	9.9	18.0	18.9	10.0	11.2	6.2	5.0	-	-
6/24	24.0	24.8	24.2	15.2	15.6	12.7	9.7	-	-
7/1	16.2	15.0	15.0	12.5	14.3	11.5	14.0	13.2	14.1
7/8	21.5	18.1	18.5	14.9	17.4	19.1	15.1	18.0	14.8
7/15	12.6	24.5	24.7	24.0	23.2	14.6	12.9	21.0	24.0
7/22	19.9	10.3	10.7	8.3	9.8	7.9	7.1	9.4	9.8
7/29	13.5	20.4	23.6	15.3	18.1	13.4	16.0	18.7	14.0
8/5	10.1	20.8	17.5	15.2	15.3	10.4	13.9	13.7	14.2
8/12	11.0	22.3	19.5	14.7	15.4	14.2	12.8	13.7	13.4
8/20	6.0	17.1	17.4	12.7	13.2	11.6	11.2	12.4	13.2
8/25	-	26.2	20.3	16.4	16.6	13.5	11.6	15.5	16.1
9/9	-	8.3	11.2	5.0	1.8	0.0	2.2	0.7	3.9
9/22	-	11.4	7.5	3.9	4.0	3.9	1.5	3.0	4.0

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 50. pH Measurements and Conductivities (Micromhos) at 25 C From Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1969

			pH				
			SITE				
DATE	*M_4-reg.	M_4	A	B	C	D	E
7/15	7.70	6.72	7.20	6.95	7.40	-	-
7/22	8.05	8.05	8.10	8.05	7.95	7.90	7.80
7/29	8.25	8.60	8.30	8.15	7.90	7.65	7.60
8/5	7.80	8.05	7.95	7.65	7.75	7.85	7.70
8/14	7.75	7.90	7.90	7.80	7.65	7.95	7.80
8/19	8.50	7.90	7.85	7.65	7.75	7.95	7.65
8/26	7.75	7.60	7.65	7.35	7.55	7.70	7.50
			CONDUCTIVITY				
			SITE				
7/22	-	76	73	72	72	77	63
7/29	79	75	78	76	76	73	55
8/5	71	76	77	69	65	69	55
8/14	70	75	75	70	64	65	59
8/19	72	75	77	68	61	65	58
8/26	76	72	74	63	62	63	52

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 51. pH Measurements at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970

			SITE						
DATE	*M_4-reg.	M_4	A	B	C	D	E	X	Y
6/19	6.90	6.40	7.20	6.75	6.85	6.70	6.30	-	-
6/24	7.20	7.00	6.90	7.10	7.60	7.40	7.70	-	-
7/1	7.10	6.65	6.80	7.00	7.65	7.55	7.50	-	7.30
7/8	7.85	7.50	7.80	7.35	7.45	7.05	6.40	6.70	6.95
7/15	7.40	7.70	7.65	7.30	7.05	7.55	7.30	7.20	7.25
7/22	7.60	6.80	7.40	7.30	7.00	7.30	7.40	7.00	7.00
7/29	8.30	7.20	7.20	7.60	6.70	7.10	7.20	6.50	7.25
8/5	7.20	7.45	7.60	7.50	7.00	7.10	7.60	6.65	6.75
8/12	8.60	7.19	6.95	6.45	6.50	6.55	6.40	6.55	6.52
8/20	6.71	7.49	6.84	6.35	6.71	6.53	6.39	6.31	6.55
8/25	-	6.21	6.83	6.72	6.54	6.43	6.41	6.43	6.49
9/9	-	7.60	7.00	6.81	6.81	6.97	6.67	6.69	6.62
9/22	-	6.81	6.42	6.86	6.43	6.47	6.33	6.51	6.52

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 52. Conductivities (Micromhos) at 25 C for Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970

			SITE						
DATE	*M_4-reg.	M_4	A	B	C	D	E	X	Y
6/19	76	67	72	61	64	76	40	-	-
6/24	62	58	59	55	59	67	49	-	-
7/1	58	64	64	63	58	73	51	54	60
7/8	66	63	64	59	57	70	53	57	61
7/15	67	67	69	62	60	65	50	57	63
7/22	71	65	65	57	57	57	63	52	61
7/29	69	69	70	62	59	62	50	57	65
8/5	64	70	69	62	59	62	54	57	67
8/12	67	64	64	60	54	57	51	53	65
8/20	67	65	65	59	55	57	48	52	64
8/25	-	65	64	58	56	57	49	51	65
9/9	-	62	64	59	53	55	48	53	64
9/22	-	62	60	55	52	52	45	51	60

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 53. Calcium and Magnesium Concentrations (mg/1) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
				CALCIUM (mg/1)					
				SITE					
7/7	16.7	21.5	18.2	21.8	13.4	4.9	5.5	7.7	12.6
7/14	15.6	19.8	19.9	23.0	14.8	4.9	5.0	8.0	7.8
7/21	16.6	20.1	21.2	22.6	14.4	4.7	4.9	9.4	9.0
7/28	17.4	20.8	21.9	24.2	15.8	4.8	5.7	10.3	11.5
8/4	16.2	19.2	22.8	25.1	16.9	5.6	6.2	11.2	11.8
8/11	15.8	19.7	22.6	25.0	17.1	5.7	6.5	11.9	12.3
8/18	23.6	20.0	25.7	27.1	20.0	5.7	7.1	11.4	11.8
8/25	16.6	19.4	24.3	25.6	16.9	5.9	6.5	11.3	11.1
9/22	18.3	18.6	21.7	24.6	17.9	7.7	7.3	13.5	13.6
				MAGNESIUM (mg/1)					
				SITE					
7/7	5.1	6.6	5.8	6.0	3.7	1.9	1.1	2.4	3.5
7/14	4.7	5.2	5.7	6.3	3.3	1.6	0.9	1.8	2.2
7/21	4.6	5.9	6.0	7.2	4.7	1.4	1.2	2.3	2.4
7/28	4.1	5.0	5.5	6.9	4.4	1.2	1.2	2.5	2.3
8/4	5.1	5.9	6.0	6.5	3.8	2.2	1.6	3.2	3.5
8/11	5.1	5.7	7.5	7.8	5.4	1.8	1.9	3.7	3.7
8/18	0.6	4.8	4.3	5.8	4.9	1.2	1.5	2.7	3.1
8/25	4.0	5.4	6.3	6.9	4.2	1.1	1.5	3.1	2.8
9/22	5.0	4.7	6.1	5.9	4.2	1.6	1.7	3.3	3.3

Table 54. Calcium and Magnesium Concentrations (mg/1) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970

CALCIUM (mg/1)

			SITE						
DATE	*M_4-reg.	M_4	A	B	C	D	E	X	Y
7/15	5.8	6.0	6.3	5.7	5.4	6.4	4.3	4.9	5.7
7/22	6.2	5.9	6.3	5.3	5.8	6.6	3.9	4.2	5.8
7/29	6.1	6.5	6.2	5.2	5.4	6.3	4.8	4.8	6.3
8/5	6.0	6.3	6.3	5.4	5.8	6.1	4.6	4.8	5.7
8/12	6.2	6.5	6.1	5.2	5.0	5.8	4.4	4.6	5.4
8/20	6.6	6.1	5.9	5.4	4.6	5.7	4.2	4.6	5.9
8/25	-	6.2	6.5	5.5	5.5	5.7	4.8	4.2	6.2
9/22	-	6.3	6.4	5.7	5.0	5.5	4.9	4.6	6.5

MAGNESIUM (mg/1)

			SITE						
7/15	1.7	1.9	1.7	1.3	1.2	1.5	1.2	1.3	1.3
7/22	1.7	1.8	1.8	1.5	1.2	1.2	0.7	1.2	1.5
7/29	1.9	1.9	1.7	1.6	1.3	1.1	0.7	0.7	1.4
8/5	2.6	2.2	2.2	2.0	2.0	1.7	1.5	1.4	2.5
8/12	2.1	1.7	2.1	1.9	1.7	1.5	1.2	1.6	2.5
8/20	1.5	1.2	1.8	1.5	1.0	0.8	0.9	0.8	1.7
8/25	-	1.9	1.3	1.3	0.8	1.4	1.7	0.2	1.9
9/22	-	1.3	1.0	1.5	1.1	1.2	0.6	1.6	1.5

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 55. Sodium and Potassium Concentrations (mg/l) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
				SODIUM (mg/l)					
				SITE					
7/7	3.9	3.3	1.6	1.4	1.6	0.6	0.6	0.7	1.6
7/14	3.7	2.8	1.7	2.1	1.6	0.7	0.6	1.1	1.3
7/21	3.7	3.3	1.9	2.3	1.4	0.7	0.7	1.1	1.1
7/28	3.7	3.2	1.9	1.9	1.9	0.7	0.6	1.1	1.3
8/4	4.0	3.7	2.4	2.1	1.6	1.3	0.7	1.3	1.6
8/11	4.5	4.8	2.3	2.8	1.9	3.1	1.3	1.7	1.7
8/18	4.8	4.5	2.1	2.4	2.1	1.3	1.0	2.4	1.7
8/25	4.5	4.6	2.3	3.1	1.9	2.3	1.3	1.5	1.9
9/22	4.2	4.2	2.7	2.5	2.2	1.5	1.3	1.8	2.4
				POTASSIUM (mg/l)					
				SITE					
7/7	2.1	1.6	1.6	1.8	1.8	1.5	1.3	1.5	2.0
7/14	1.9	1.6	1.6	1.6	1.6	1.5	1.4	1.5	1.5
7/21	1.7	1.5	1.6	1.6	1.5	1.4	1.4	1.3	1.4
7/28	2.0	1.6	1.6	1.8	1.7	1.6	1.5	1.4	1.8
8/4	1.7	1.7	2.0	2.1	1.5	1.5	1.3	1.5	1.5
8/11	1.5	1.4	1.9	2.1	1.3	3.9	1.2	1.2	1.3
8/18	2.0	1.4	2.0	2.4	2.0	2.0	1.8	1.8	1.9
8/25	0.9	1.1	1.2	1.4	1.1	1.0	1.2	1.0	1.0
9/22	1.6	1.8	1.8	1.9	1.5	1.6	1.3	1.8	1.4

Table 56. Sodium and Potassium Concentrations (mg/l) at Different Sites in the South Fork of the Mystic (Closed) Watershed during the Summer of 1970

				SODIUM (mg/l)					
				SITE					
DATE	*M_4-reg.	M_4	A	B	C	D	E	X	Y
7/15	1.6	1.4	1.1	1.1	1.1	0.6	0.7	0.8	1.4
7/22	1.4	1.2	1.5	5.5	1.2	1.9	0.7	1.6	1.6
7/29	1.9	1.6	1.6	1.2	1.1	0.7	1.1	1.3	1.6
8/5	1.9	1.3	1.5	1.3	1.1	0.9	1.1	1.2	1.6
8/12	2.4	1.9	1.9	1.9	1.5	1.7	1.7	1.9	2.5
8/20	2.1	1.9	1.9	1.7	1.7	1.7	1.3	1.5	2.1
8/25	-	1.9	1.7	1.7	1.7	1.4	1.4	1.9	2.1
9/22	-	1.6	1.4	1.3	1.1	0.9	1.0	1.3	1.8
				POTASSIUM (mg/l)					
				SITE					
7/15	1.8	1.9	1.8	1.7	1.8	1.8	1.8	1.9	2.0
7/22	1.8	1.9	2.0	1.9	2.1	1.8	1.7	2.1	1.9
7/29	2.1	2.1	2.0	2.1	2.1	2.0	1.9	2.1	2.1
8/5	1.9	1.9	1.9	1.8	2.1	1.9	2.0	2.0	1.8
8/12	1.7	1.5	1.7	1.8	1.6	1.4	1.5	1.8	1.9
8/20	2.3	2.4	2.2	1.9	2.0	1.7	1.9	2.0	1.9
8/25	-	1.5	1.5	1.4	1.4	1.1	1.1	1.3	1.0
9/22	-	1.7	1.6	1.8	1.9	1.9	1.8	1.9	1.6

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 57. Total Alkalinities (meq/1) and Turbidity (Jackson Turbidity Units) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

	TOTAL ALKALINITIES (meq/1)								
	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
7/14	1.23	1.37	1.56	1.79	1.16	0.50	0.53	0.66	0.70
7/21	1.29	1.46	1.63	1.80	1.23	0.47	0.45	0.73	0.80
7/28	1.27	1.49	1.65	1.90	1.20	0.52	0.51	0.83	0.86
8/4	1.36	1.42	1.67	1.88	1.31	0.60	0.54	1.02	1.00
8/11	1.30	1.44	1.78	1.97	1.39	0.54	0.56	0.98	1.00
8/18	1.25	1.40	1.73	1.92	1.53	0.57	0.60	0.95	0.95
8/25	1.24	1.43	1.76	1.97	1.32	0.49	0.56	0.92	0.98
9/22	1.40	1.42	1.67	1.80	1.48	0.62	0.68	1.11	-
	TURBIDITY (Jackson Units)								
	SITE								
7/7	2	6	0	2	12	60	0	12	24
7/14	0	4	0	0	0	0	0	0	0
7/21	14	4	0	10	12	11	6	0	6
7/28	0	0	0	0	0	0	0	0	0
8/4	14	22	12	8	6	12	10	11	16
8/11	0	0	12	12	0	0	0	0	0
8/18	41	22	16	17	22	14	6	14	19
8/25	23	19	12	16	4	2	6	16	10
9/22	41	35	53	33	27	31	27	29	29

- not determined

Table 58. Total Alkalinities (meq/1) and Turbidity (Jackson Turbidity Units) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970

TOTAL ALKALINITIES (meq/1)

DATE	*M_4-reg.	M_4	SITE A	B	C	D	E	X	Y
7/22	0.63	0.67	0.56	0.55	0.50	0.48	0.40	0.45	0.55
7/29	0.64	0.58	0.56	0.55	0.49	0.52	0.43	0.46	0.57
8/5	0.69	0.58	0.54	0.48	0.47	0.49	0.49	0.45	0.63
8/12	0.59	0.58	0.54	0.51	0.47	0.54	0.43	0.43	0.63
8/20	0.59	0.54	0.62	0.53	0.49	0.52	0.44	0.50	0.60
8/25	-	0.57	0.64	0.54	0.52	0.58	0.45	0.48	0.68
9/22	-	0.60	0.58	0.57	0.58	0.52	0.49	0.53	0.60

TURBIDITY (Jackson Units)

			SITE						
7/15	0	29	27	12	10	8	10	10	12
7/22	2	2	6	2	1	29	10	0	0
7/29	0	0	0	0	0	0	0	0	0
8/5	19	0	4	6	17	10	12	10	16
8/12	0	0	0	0	0	0	0	0	0
8/20	16	12	16	16	14	10	16	10	11
8/25	-	16	10	12	14	12	16	10	16
9/22	-	31	29	29	29	27	29	29	27

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 59. Sulfate and Chloride Concentrations (mg/l) at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

	SULFATE (mg/l)								
	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
7/7	14.0	14.2	8.8	8.7	7.8	7.8	6.1	6.2	10.0
7/14	14.3	17.8	11.9	12.0	12.0	8.2	8.5	10.0	9.2
7/21	11.3	12.5	6.6	5.7	3.9	1.5	1.1	2.3	2.3
7/28	16.0	15.3	10.6	-	8.1	6.0	5.9	7.3	7.3
8/4	8.3	11.0	6.5	6.5	4.7	3.1	2.5	3.1	3.3
8/11	10.1	11.0	6.9	6.5	5.3	3.3	3.3	4.5	4.7
8/18	10.1	10.6	6.7	7.2	5.5	2.7	2.5	2.5	2.8
8/25	11.7	12.0	7.3	7.8	5.3	3.7	3.3	3.3	4.0
9/22	14.2	12.0	11.1	11.1	8.7	5.5	5.5	5.8	5.8
	CHLORIDE (mg/l)								
	SITE								
7/7	0.20	0.15	0.25	0.15	0.15	0.10	0.10	0.00	1.00
7/14	0.40	0.40	0.40	0.40	0.45	0.25	0.30	0.10	0.15
7/21	0.73	0.24	0.33	0.17	0.37	0.20	0.21	0.21	0.11
7/28	0.38	0.20	0.38	-	0.21	0.19	0.02	0.19	0.20
8/4	0.11	0.15	0.17	0.15	0.19	0.03	0.18	0.11	0.19
8/11	0.13	0.09	0.15	0.11	0.01	0.08	0.01	0.01	0.11
8/18	0.35	0.13	0.10	0.03	0.19	0.01	0.15	0.01	0.05
8/25	0.39	0.29	0.10	0.21	0.03	0.07	0.02	0.19	0.07
9/22	0.03	0.11	0.13	0.17	0.07	0.13	0.01	0.09	0.17

- not determined

Table 60. Sulfate and Chloride Concentrations (mg/l) at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970

SULFATE (mg/l)

		SITE							
DATE	*M_4-reg.	M_4	A	B	C	D	E	X	Y
7/15	7.6	6.6	5.4	5.9	6.2	7.0	6.7	7.4	6.2
7/22	1.1	3.3	2.3	3.7	5.5	9.0	1.5	1.7	2.1
7/29	6.9	9.3	6.9	5.5	6.3	6.7	6.8	6.3	7.3
8/5	2.7	2.8	2.7	2.8	3.0	2.5	2.5	2.8	2.5
8/12	3.7	3.7	4.0	3.5	2.8	2.5	1.7	2.0	2.0
8/20	2.1	2.1	2.4	2.4	2.5	3.1	2.8	3.1	2.5
8/25	-	3.7	3.7	3.9	3.9	3.8	3.7	4.9	4.3
9/22	-	5.3	6.0	6.0	5.3	5.5	6.0	5.5	6.0

CHLORIDE (mg/l)

		SITE							
7/15	0.90	0.25	0.15	0.50	0.40	0.45	0.15	0.30	0.20
7/22	0.11	0.75	0.49	0.39	0.20	0.19	0.23	0.25	0.15
7/29	0.11	0.81	0.51	0.40	0.28	0.20	0.23	0.31	0.13
8/5	0.04	0.23	0.23	0.06	0.07	0.15	0.08	0.15	0.79
8/12	0.02	0.08	0.10	0.01	0.08	0.01	0.05	0.05	0.09
8/20	0.17	0.40	0.01	0.20	0.12	0.01	0.10	0.10	0.03
8/25	-	0.31	0.02	0.01	0.14	0.06	0.09	0.10	0.07
9/22	-	0.05	0.03	0.03	0.06	0.13	0.09	0.15	0.11

- not determined

* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

Table 61. Nitrate (mg/l $N\text{-}NO_3^-$) and Orthophosphate (mg/l PO_4^{-3}) Concentrations at Different Sites in the Mystic (Closed) and Hyalite (Open) Watersheds During the Summer of 1970

NITRATE (mg/l $N\text{-}NO_3^-$)

	SITE								
DATE	SM	M_1	M_2	M_3	SB	SH	H_1	H_2	H_3
7/7	0.14	0.15	0.16	0.18	0.15	0.15	0.10	0.16	0.16
7/14	0.07	0.07	0.07	0.07	0.12	0.12	0.12	0.12	0.16
7/21	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.01	0.01
7/28	0.02	0.01	0.04	-	0.01	0.01	0.01	0.01	0.01
8/4	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01
8/11	0.02	0.05	0.03	0.05	0.04	0.03	0.03	0.04	0.04
8/18	0.02	0.03	0.03	0.04	0.03	0.01	0.02	0.03	0.02
8/25	0.05	0.05	0.04	0.06	0.06	0.05	0.05	0.08	0.06
9/22	0.08	0.06	0.08	0.05	0.09	0.07	0.06	0.07	-

ORTHOPHOSPHATE (mg/l PO_4^{-3})

	SITE								
8/4	0.56	0.24	0.45	0.23	0.31	0.12	0.27	0.24	0.17
8/11	0.16	0.29	0.29	0.40	0.23	0.13	0.23	0.23	0.25
8/18	0.11	0.27	0.26	0.20	0.23	0.09	0.22	0.22	0.27
8/25	0.15	0.32	0.35	0.30	0.32	0.23	0.35	0.35	0.35
9/22	0.48	0.21	0.27	0.22	0.21	0.20	0.31	0.27	-

- not determined

Table 62. Nitrate (mg/l $N\text{-}NO_3^-$) and Orthophosphate (mg/l PO_4^{-3}) Concentrations at Different Sites in the South Fork of the Mystic (Closed) Watershed During the Summer of 1970

NITRATE (mg/l $N\text{-}NO_3^-$)

DATE	*M_4-reg.	M_4	SITE A	B	C	D	E	X	Y
7/15	0.03	0.12	0.04	0.04	0.06	0.03	0.03	0.04	0.03
7/22	0.01	0.01	0.01	0.02	0.01	0.08	0.06	0.06	0.07
7/29	0.01	0.02	0.02	0.03	0.02	0.01	0.02	0.01	0.03
8/5	0.02	0.04	0.01	0.01	0.01	0.01	0.02	0.01	0.03
8/12	0.03	0.06	0.03	0.04	0.03	0.03	0.03	0.06	0.05
8/20	0.03	0.05	0.06	0.04	0.03	0.04	0.05	0.05	0.05
8/25	-	0.04	0.06	0.05	0.05	0.05	0.06	0.05	0.06
9/22	-	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.08

ORTHOPHOSPHATE (mg/l PO_4^{-3})

			SITE						
8/5	0.43	0.43	0.43	0.41	0.39	0.44	0.43	0.47	0.29
8/12	0.41	0.41	0.43	0.42	0.42	0.46	0.50	0.47	0.44
8/20	0.44	0.37	0.41	0.40	0.41	0.44	0.44	0.44	0.40
8/25	-	0.49	0.53	0.49	0.51	0.60	0.55	0.52	0.49
9/22	-	0.40	0.36	0.36	0.41	0.43	0.35	0.37	0.57

- not determined
* M_4-reg. = sample taken the previous day while sampling the main Bozeman Creek

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