



Chemical and physical findings from pollution studies on the East Gallatin River and its tributaries
by Raymond Arthur Soltero

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Botany

Montana State University

© Copyright by Raymond Arthur Soltero (1968)

Abstract:

A section of the East Gallatin River and its tributaries in the vicinity of Bozeman, Montana, were studied in an effort to determine, by chemical-physical means, the water quality at various points and to determine the effects of suspected pollutant sources on this system.

Comparison of the detailed chemical analyses at the upstream and downstream stations demonstrated that the tributaries contributed little if any pollution to the East Gallatin River. The major pollutant of the stream was found to be the Bozeman City Sewage effluent.

129
CHEMICAL AND PHYSICAL FINDINGS FROM POLLUTION STUDIES ON
THE EAST GALLATIN RIVER AND ITS TRIBUTARIES

by

RAYMOND ARTHUR SOLTERO

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

of

MASTER OF SCIENCE

in

Botany

Approved:

William G. Walter
Head, Major Department

John C. Wright
Chairman, Examining Committee

A. Goering
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

December, 1968

ACKNOWLEDGEMENTS

The author would like to express his gratitude to Dr. John C. Wright for the guidance in the materialization of this manuscript and his assistance throughout every phase of this study. Sincere thanks are also due to Drs. W. E. Booth and Don D. Collins for the time spent in reviewing the manuscript.

Thanks are given to Mrs. Jane Brunsvold for her assistance in the laboratory. Thanks are also due to Ted Ehlke, Lyle Hammer, and Bob Warren for their aid in the collection of field data. The cooperation extended by Mr. Carl Larson, Superintendent of the Bozeman City Sewage Treatment Plant for making available plant records was greatly appreciated.

Sincere thanks are due to my wife, Pam, for her patience, understanding, and encouragement during the course of this study.

This project was supported by Research Grant WP-00125 and Training Grant 5T1-WP-1 from the Division of Water Supply and Pollution Control.

TABLE OF CONTENTS

	Page
VITA	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	xi
ABSTRACT	xiii
INTRODUCTION	1
DESCRIPTION OF THE STUDY AREA	3
METHODS	7
Water Chemistry	7
Temperature	12
Hydrology	12
Morphometry	14
RESULTS.	15
Water Chemistry of Bozeman Creek and Bridger Creek	15
Water Chemistry of Rocky Creek and the East Gallatin River	17
Water Chemistry on Sampling Periods of 24-Hour Duration	36
Water Temperature	42
Hydrology	47
Statistical Analysis	47
DISCUSSION	54

TABLE OF CONTENTS - Continued

	Page
SUMMARY	61
APPENDIX	63
LITERATURE CITED	110

LIST OF TABLES

			Page
Table	I.	The date and the station at which 24-hour and single samples were taken during the summer (1967)	8
Table	II.	Average water chemistry for Bozeman Creek and Bridger Creek during the summer for the single sampling periods	16
Table	III.	The downstream distances from station 2 for the Rocky Creek and East Gallatin River sampling stations	19
Table	IV.	Average water temperatures ($^{\circ}\text{C}$) at the stations sampled during single sampling periods throughout the summer (1967)	46
Table	V.	Average discharge rates for Bridger Creek during the summer (1967)	49
Table	VI.	Average discharge rates for Bozeman Creek during the summer (1967)	50
Table	VII.	Average discharge rates for the sewage effluent during the summer (1967)	51
Table	VIII.	Average discharge rates for the East Gallatin River during the summer (1967)	52
Table	IX.	Water temperatures ($^{\circ}\text{C}$) at the stations sampled during single sampling periods throughout the summer (1967)	64
Table	X.	Dissolved oxygen concentrations (mg/l) at the stations sampled during single sampling periods throughout the summer (1967).	65
Table	XI.	pH measurements at the stations sampled during single sampling periods throughout the summer (1967)	66
Table	XII.	Total alkalinities (meq/l) at the stations sampled during single sampling periods throughout the summer (1967)	67

LIST OF TABLES - Continued

			Page
Table	XIII.	Conductivities (micromhos) at 25°C for the stations sampled during single sampling periods throughout the summer (1967)	68
Table	XIV.	Chloride concentrations (mg/l Cl ⁻) at the stations sampled during single sampling periods throughout the summer (1967)	69
Table	XV.	Fluoride concentrations (mg/l F ⁻) at the stations sampled during single sampling periods throughout the summer (1967)	70
Table	XVI.	Turbidity (Standard Jackson Units) at the stations sampled during single sampling periods throughout the summer (1967)	71
Table	XVII.	Sulfate concentrations (mg/l SO ₄ ⁼) at the stations sampled during single sampling periods throughout the summer (1967)	72
Table	XVIII.	Total carbon concentrations (mg/l C) at the stations sampled during single sampling periods throughout the summer (1967)	73
Table	XIX.	Total organic carbon concentrations (mg/l C) at the stations sampled during single sampling periods throughout the summer (1967)	74
Table	XX.	Soluble organic carbon concentrations (mg/l C) at the stations sampled during single sampling periods throughout the summer (1967)	75
Table	XXI.	Total nitrogen concentrations (mg/l N-NH ₃) at the stations sampled during single sampling periods throughout the summer (1967)	76
Table	XXII.	Total soluble nitrogen concentrations (mg/l N-NH ₃) at the stations sampled during single sampling periods throughout the summer (1967)	77

LIST OF TABLES - Continued

		Page
Table XXIII.	Free ammonia concentrations (mg/1 N-NH ₃) at the stations sampled during single sampling periods throughout the summer (1967).	78
Table XXIV.	Nitrate concentrations (mg/1 N-NO ₃ ⁻) at the stations sampled during single sampling periods throughout the summer (1967)	79
Table XXV.	Nitrite concentrations (mg/1 N-NO ₂ ⁻) at the stations sampled during single sampling periods throughout the summer (1967).	80
Table XXVI.	Total phosphate concentrations (mg/1 P-PO ₄ ^{III}) at the stations sampled during single sampling periods throughout the summer (1967).	81
Table XXVII.	Soluble inorganic and organic phosphate concentrations (mg/1 P-PO ₄ ^{III}) at the stations sampled during the single sampling periods throughout the summer (1967)	82
Table XXVIII.	Soluble inorganic phosphate concentrations (mg/1 P-PO ₄ ^{III}) at the stations sampled during the single sampling periods throughout the summer (1967)	83
Table XXIX.	Calcium concentrations (meq/1) at the stations sampled during 8/8/67 - 9/12/67 for the single sampling periods	84
Table XXX.	Magnesium concentrations (meq/1) at the stations sampled during 8/8/67 - 9/12/67 for the single sampling periods	85
Table XXXI.	Sodium concentrations (meq/1) at the stations sampled during 8/8/67 - 9/12/67 for the single sampling periods	86
Table XXXII.	Potassium concentrations (meq/1) at the stations sampled during 8/8/67 - 9/12/67 for the single sampling periods	87

LIST OF TABLES - Continued

	Page
Table XXXIII.	Silica concentrations (mg/l SiO ₂) at the stations sampled during 7/25/67 - 9/12/67 for the single sampling periods 88
Table XXXIV.	5-day B.O.D. (mg/l D.O.) at the stations sampled during 8/8/67 - 9/12/67 for the single sampling periods 89
Table XXXV.	Dissolved oxygen concentrations (mg/l) at the stations sampled during 24-hour sampling periods throughout the summer (1967). 90
Table XXXVI.	pH measurements at the stations sampled during 24-hour sampling periods throughout the summer (1967) 92
Table XXXVII.	Total alkalinities (meq/l) at the stations sampled during 24-hour sampling periods throughout the summer (1967) 94
Table XXXVIII.	Conductivities (micromhos) at 25°C at the stations sampled during 24-hour sampling periods throughout the summer (1967). 96
Table XXXIX.	Total carbon concentrations (mg/l C) at the stations sampled during 24-hour sampling periods throughout the summer (1967) 98
Table XXXX.	Total organic carbon concentrations (mg/l C) at the stations sampled during 24-hour sampling periods throughout the summer (1967) 100
Table XXXXI.	Total nitrogen concentrations (mg/l N-NH ₃) at the stations sampled during 24-hour sampling periods throughout the summer (1967) 102
Table XXXXII.	Total phosphate concentrations (mg/l P-PO ₄ [≡]) at the stations sampled during 24-hour sampling periods throughout the summer (1967) 104

LIST OF TABLES → Continued

	Page
Table XXXXIII. Water temperatures ($^{\circ}\text{C}$) at the stations sampled during 24-hour sampling periods throughout the summer (1967)	106
Table XXXXIV. Flow times (minutes) between the stations sampled during 24-hour sampling periods throughout the summer (1967)	108
Table XXXXV. Mean depths between the stations sampled during 24-hour sampling periods throughout the summer (1967)	109

LIST OF FIGURES

	Page
Figure 1. Map of the upper East Gallatin River system showing location of study area and stations.	4
Figure 2. Average conductance at 25°C and total alkalinity at the Rocky Creek and East Gallatin River stations during the summer for the single sampling periods.	20
Figure 3. Average % O ₂ saturation and dissolved oxygen concentration at the Rocky Creek and East Gallatin River stations during the summer for the single sampling periods.	21
Figure 4. An example of a 5-day B.O.D. at the Rocky Creek and East Gallatin River stations during a single sampling period (8/22/67)	23
Figure 5. Average concentrations of the major metallic cations at the Rocky Creek and East Gallatin River stations during 8/8/67 - 9/12/67 for single sampling periods.	24
Figure 6. Average concentrations of the major anions at the Rocky Creek and East Gallatin River stations during the summer for the single sampling periods.	26
Figure 7. Average concentrations of the various carbon fractions at the Rocky Creek and East Gallatin River stations during the summer for the single sampling periods	28
Figure 8. Average of the inorganic nitrogen fractions at the Rocky Creek and East Gallatin River stations during the summer for the single sampling periods.	30
Figure 9. Average of the organic nitrogen fractions at the Rocky Creek and East Gallatin River stations during the summer for the single sampling periods.	31
Figure 10. Average of the various phosphate fractions at the Rocky Creek and East Gallatin River stations during the summer for the single sampling periods.	33

LIST OF FIGURES - Continued

	Page
Figure 11. Average silica concentrations at the Rocky Creek and East Gallatin River stations during the summer for the single sampling periods	35
Figure 12. Mean turbidity at the Rocky Creek and East Gallatin River stations during the summer for the single sampling periods	37
Figure 13. Example of pH curves for the East Gallatin River over a 24-hour period (8/15-16/67).	38
Figure 14. Average conductance at 25°C during the summer for the 24-hour sampling periods	40
Figure 15. The net rate of change in dissolved oxygen in the river reaches during a 24-hour sampling period (8/1-2/67)	41
Figure 16. The rate of change in total carbon in the river reaches during a 24-hour sampling period (8/29-30/67)	43
Figure 17. The rate of change in total nitrogen in the river reaches during a 24-hour sampling period (8/1-2/67)	44
Figure 18. The rate of change in total phosphate in the river reaches during a 24-hour sampling period (8/1-2/67)	45
Figure 19. Mean water temperature at the stations sampled during 24-hour sampling periods throughout the summer	48
Figure 20. Average current velocity for reaches 7-11 on each 24-hour sampling date	53

ABSTRACT

A section of the East Gallatin River and its tributaries in the vicinity of Bozeman, Montana, were studied in an effort to determine, by chemical-physical means, the water quality at various points and to determine the effects of suspected pollutant sources on this system.

Comparison of the detailed chemical analyses at the upstream and downstream stations demonstrated that the tributaries contributed little if any pollution to the East Gallatin River. The major pollutant of the stream was found to be the Bozeman City Sewage effluent.

INTRODUCTION

Water from streams and lakes in mountainous districts may be relatively free from organic impurities but usually contains varying concentrations of dissolved inorganic salts, while water from lowland rivers and lakes near population centers may be highly polluted. Pollution, in this sense of the word, is anything that renders the water impure or alters the originality of the water in any way.

The growing scarcity of water sources and the ever increasing usage of water for domestic and industrial purposes have been primarily the reasons for the great interest in pollution problems.

The East Gallatin River at Bozeman, Montana provides an excellent opportunity for the study of stream pollution. The major pollutant is the sewage outfall of the Bozeman City Sewage Treatment Plant. This plant is of the primary treatment type, treating an average of 3.5 million gallons per day of raw sewage. Although the sewer system is not of the combined type, during and after heavy storms there is an increase of flow into the plant. During the study period the sewage outfall comprised from 1.4% to 11.8% of the total stream flow.

A slaughter house and stockyards are located upstream from the sewage effluent, both of which are other sources of possible pollution to this river system. The slaughter house discharges unmarketable animal material into the water while the stockyards place the manure pilings from their pens along the stream banks, which when eroded, dump overlying waste material directly into Rocky Creek. Other additional sources of possible pollution are located on the tributaries, Bozeman

Creek and Bridger Creek, which were also sampled in the course of the study.

Since most pollutions that are found in aquatic systems are of a chemical or physical nature, chemical analyses supplemented by physical determinations must in part play a vital role in the detection and estimation of the degree of pollution.

The purpose of the present investigation was to conduct several routine chemical-physical analyses in an attempt to obtain information pertaining to stream quality at the various points sampled. Twenty-four hour sampling periods were also carried out to determine what chemical and physical effects the sewage outfall had on the East Gallatin River.

DESCRIPTION OF THE STUDY AREA

The East Gallatin River is formed by the union of Rocky Creek and Bozeman Creek and flows in a northwesterly direction along the northern margin of Bozeman, a city of some 20,000 people.

The average discharge from this river was 84.7 cfs ($2.40 \text{ m}^3/\text{sec.}$) for a 22 year period (1939-1961). The discharge normally fluctuates between a fall minimum of approximately 18 cfs ($0.51 \text{ m}^3/\text{sec.}$) and a spring maximum of 189 cfs ($5.35 \text{ m}^3/\text{sec.}$). Maximum recorded discharge was 1,230 cfs ($35.14 \text{ m}^3/\text{sec.}$) on June 4, 1953 and the minimum was 12 cfs ($0.34 \text{ m}^3/\text{sec.}$) on December 9, 1944 and March 24-26, 1955. The drainage area of this river comprises 148 sq. mi. (384.82 km^2) at an elevation of about 4,701 ft. (1,433.23 m) above mean sea level.

The East Gallatin River is a permanent stream approximately 37 miles (59.58 km) long. It varies from 7 ft. (2.13 m) to 30 ft. (9.15m) in width during low water and varies in depth from a few inches in the riffles to more than 6 ft. in a few pools. The principal natural source of the water is springs and surface runoff from the surrounding mountainous terrain. The flow is augmented, however, by the Bozeman City Sewage Treatment Plant and by Bridger Creek.

The river is of the calcium-magnesium-bicarbonate type, with silica, sodium, and potassium present in small concentrations.

Twelve permanent stations were established during the course of the study (see Figure 1). Station 1 was located on Bozeman Creek 3.7 miles (5.96 km) above its confluence with Rocky Creek.

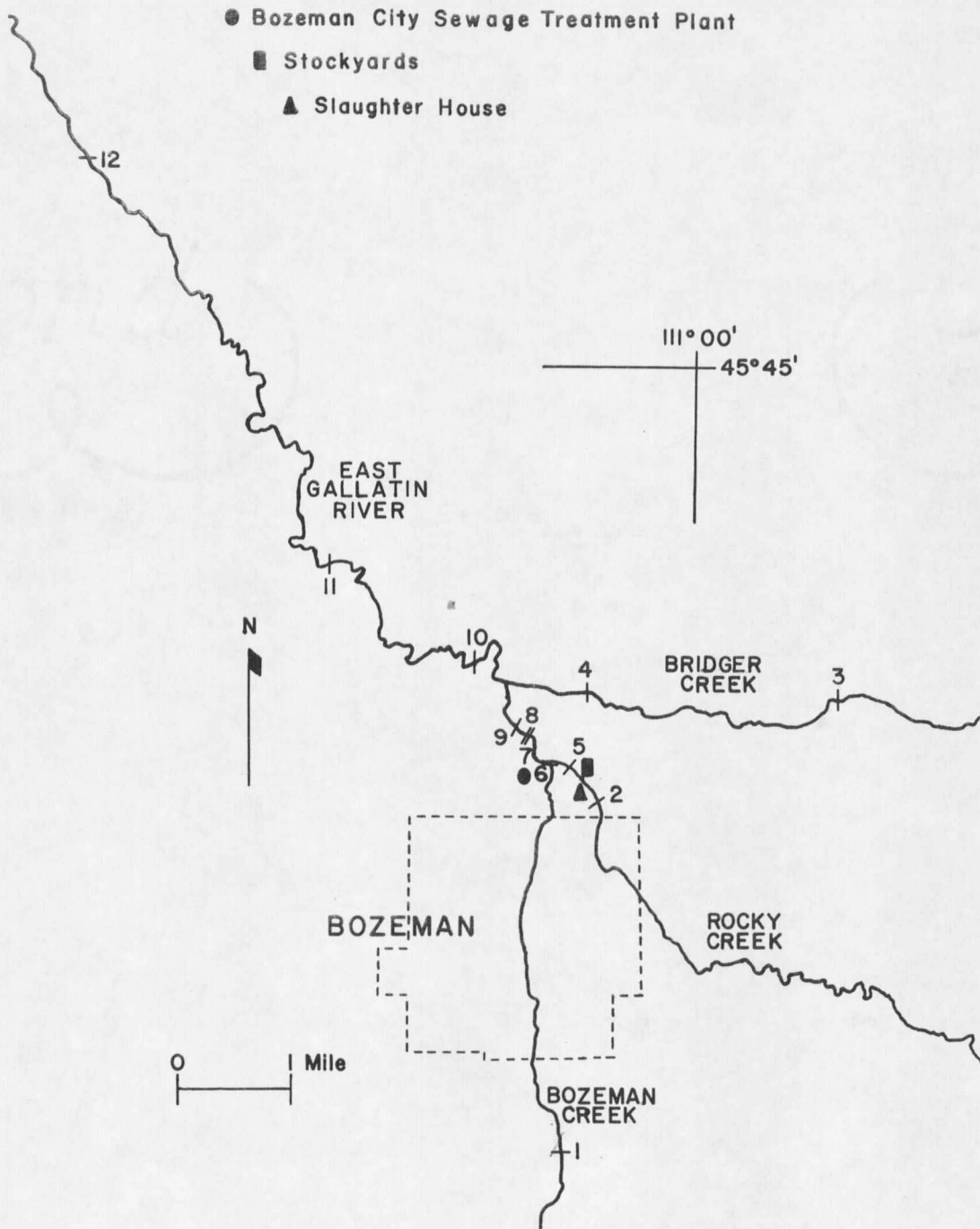


Figure 1. Map of the upper East Gallatin River system showing location of study area and stations

Station 2 was established on Rocky Creek 0.9 miles (1.45 km) upstream from the sewage effluent, 0.4 miles (0.64 km) from the stockyards and 0.2 miles (0.32 km) from the slaughter house.

Station 3 was situated on Bridger Creek 3.4 miles (5.48 km) upstream from its confluence with the East Gallatin River.

Station 4 was also situated on Bridger Creek 0.6 miles (0.97 km) from its confluence with the river. This union with the East Gallatin River is also 0.6 miles (0.97 km) below the sewage outfall.

Station 5 was located on Rocky Creek just downstream from the stockyards, 0.2 miles (0.32 km) from the slaughter house and 0.2 miles (0.32 km) from its confluence with Bozeman Creek.

Station 6 was established on Bozeman Creek about 50 ft. (15.24 m) above its confluence with Rocky Creek. The confluence is 0.4 miles (0.64 km) above the sewage outfall.

Station 7 was situated on the East Gallatin River approximately 100 ft. (30.49 m) upstream from the sewage effluent.

Station 8 was the sewage effluent itself, 0.4 miles (0.64 km) by underground cement pipe from the treatment plant area.

Station 9 was located in the area where the sewage outfall became completely mixed with the rest of the river, 0.3 miles (0.48 km) downstream from the sewage outfall.

Station 10 was established 1.4 miles (2.25 km) downstream from station 9.

Station 11 was situated 2.5 miles (4.02 km) below station 10.

Station 12 was established 6.3 miles (10.15 km) downstream from station 11 and 10.5 miles (16.89 km) from the sewage outfall.

The stream bottom types at these various stations consisted mainly of large to small cobbles and coarse to fine gravel.

METHODS

Water samples and field measurements were taken at the various stations at weekly intervals, when possible, throughout the duration of the study.

Table I shows the date and the station at which 24-hour and single samples were taken. Diurnal sampling at stations 7, 8, 9, 10, and 11 commenced at 0600 hours and proceeded through 0600 hours the following day. Sample collections were made every three hours except between 2400 hours and 0600 hours when samples were not taken. The single samples were generally collected at all stations. Sampling began at 0600 hours and was complete by 0800 hours that same day.

All samples were obtained by lowering an 8 liter polyethylene bucket over the side of a bridge into the middle of the stream. This container was rinsed well with the surface water before a sample was taken. Upon collection, one 300 ml and one-1 liter aliquots were collected in Pyrex glass-stoppered bottles. These storage bottles were rinsed twice before being filled with the water sample.

Water Chemistry

After returning to the laboratory, the one-liter sample was filtered through "Millipore" filters with a pore size of 0.8 microns. After filtering, the samples were placed back in the Pyrex glass-stoppered bottles, which had been rinsed with a small quantity of the filtrate.

Table I. The date and the station at which 24-hour and single samples were taken during the summer (1967).

DATE	24-HOUR SAMPLES	SINGLE SAMPLES
	Stations	Stations
6/13/67	—	1-2, 5-8, 10-11
6/20/67	—	1-12
6/27/67	—	1-8, 10-12
7/11/67	—	1-12
7/18-19/67	7-11	—
7/25/67	—	1-2, 5-12
8/1-2/67	7-11	—
8/8/67	—	1-12
8/15-16/67	7-11	—
8/22/67	—	1-2, 5-12
8/29-30/67	7-11	—
9/12/67	—	1-12

— Samples were not collected.

The electrical resistance of each sample was measured with a YSI Conductivity Bridge (Model 31). An Industrial Instruments (Model CEL 4) dipping cell was used with the YSI Conductivity Bridge. The cell constant of the dipping cell was approximately 2.1 throughout the study.

The specific conductance of the water at 25°C was computed from the observed resistance which was corrected for temperature and cell resistance.

Measurements of the hydrogen ion concentrations were made with a Beckman Expanded Sclae pH meter (Model 76).

Total alkalinity, Biochemical Oxygen Demand (B.O.D.), chloride, fluoride, nitrite, total and soluble nitrogen, total, soluble and inorganic phosphate, silica, sulfate, and turbidity determinations were made as described by the American Public Health Association (1965). Ammonia was determined by the phenoxide and hypochlorite method as described by Charlot (1964). The colorimetric equipment used in the various analyses was either a Bausch and Lomb "Spectronic 20" or a Klett-Summerson colorimeter.

Nitrate determinations were made according to the method of West and Lyles as described in *Analytica Chimica Acta* (1960).

Total carbon, total organic carbon and soluble organic carbon were determined by a Beckman Laboratory Carbonaceous Analyzer, following the procedure given in the Beckman Bulletin #1307-6A (February, 1965). Total inorganic carbon was also computed from pH, temperature, and total alkalinity, using the formulae derived by

Saunders et al. (1962).

Calcium, potassium, and sodium were determined by flame emission with a Beckman DU Flame Spectrophotometer, following the procedures given in the Beckman Instruction Manual #334-A (March, 1957), and magnesium was determined by atomic absorption spectroscopy using the Beckman Spectrophotometer.

Bicarbonate ion was determined as described by Hutchinson (1957).

The Precision Galvanic Cell Oxygen Analyser was used for the determination of dissolved oxygen as described in Precision Scientific Company Bulletin #TS-68850. The Oxygen Analyser was calibrated by allowing the electrode system equilibrate in a sample of known oxygen content. The Alsterberg modification of the Winkler technique (APHA, 1965) was the chemical test used to determine the dissolved oxygen of the standardizing sample.

Upon attaining a water sample from the stream the probe was immersed in the sample and gently swirled for several minutes. The meter current and temperature were recorded and the dissolved oxygen of the sample was obtained from a nomograph supplied with the instrument. A nomograph was also used for calculating the percentage saturation of oxygen in the water sample as described by Mortimer (1956).

All of the above mentioned analyses were run on the single samples within 30 hours after field collection. Free ammonia, total alkalinity, total carbon, total and soluble organic carbon, total and soluble nitrogen, nitrate, nitrite, total, soluble, and inorganic

phosphate, and pH determinations were made within 5 hours after collection.

In the sampling periods of 24-hour duration determinations of temperature; dissolved oxygen, conductivity, pH, total alkalinity, total carbon, total organic carbon, total nitrogen, and total phosphate were made at 3 hour intervals.

The net changes in total carbon, total nitrogen, total phosphate, and dissolved oxygen were computed by the upstream-downstream method (Odum, 1956; Wright et al, 1967).

For each 24-hour sampling period a series of graphs were produced by first plotting the total carbon, total nitrogen, total phosphate, or dissolved oxygen concentrations at station 7 as the ordinate against the time of collection as the abscissa. At each successive station, carbon, nitrogen, phosphate, or dissolved oxygen concentrations were displaced to the left by a time interval equivalent to the flow time from station 7 to the station whose data was being plotted.

The vertical distance between the two curves will give the net change in concentration of the substance (total carbon, total nitrogen, total phosphate, or dissolved oxygen) during the time required for it to flow through the reach.

The net changes in concentration per unit area per minute of total carbon and etc. were computed according to equation 1:

$$C = \frac{h (c_1 - Rc_2)}{t} \quad (1)$$

Where:

C = net change in concentration per unit area per minute,
g/m²/min.

h = average depth of the reach, m.

c₁ = upstream concentration, g/m³.

c₂ = downstream concentration, g/m³.

R = ratio obtained from dividing the discharge (cfs) at the upper
station of the reach by the discharge (cfs) at the lower one.

t = flow time, min.

Temperature

The temperature of the sample upon collection was measured with the Precision Galvanic Cell Oxygen Analyser which had a thermistor attachment. The thermistor used with the Oxygen Analyser had an accuracy within 0.1°C.

Hydrology

Discharge measurements on the East Gallatin River were obtained from the rating table for the gauging station maintained by the U. S. Geological Survey 500 ft. below the confluence of Rocky Creek and Bozeman Creek.

Vertical staff gauges were installed at station 4 on Bridger Creek and station 6 on Bozeman Creek. The average stream velocity was

computed by obtaining sufficient point velocities. The average velocity multiplied by the cross-sectional area was used for computing the total discharge. Velocity measurements were determined by using a Gurley Current Meter (No. 622).

The above procedure was repeated numerous times for various stream stages. The stage record was then transformed to a discharge record by calibration.

The sewage discharge measurements were made by means of a free flow discharge Parshall 12" flume and a float level recorder located at the Bozeman City Sewage Treatment Plant.

Rate of flow between consecutive stations on the East Gallatin River was determined by introducing an appropriate quantity of fluorescent dye (rhodamine-B) in the main current of the stream at an upstream station. At the downstream station the water was pumped through a Turner Fluorimeter (Model 110) which was equipped with a Rustrak recorder and continuous flow cell to determine the passage of the peak dye concentration. The elapsed time for the dye to flow from the upstream station to the downstream station was considered to be the flow time.

This procedure was repeated for several different river stages. Flow times were plotted against the river stage during that period and flow times for water levels between those measured were obtained from the graphs.

Morphometry

Aerial photographs were measured for the lengths and widths used in calculating the area of the different river reaches. Average depths were computed according to equation 2:

$$h = \frac{d (t)}{A} \quad (2)$$

Where:

h = average depth of the reach, m.

d = discharge, m³/min.

t = flow time, min.

A = area of the reach, m².

The average current velocity was determined by dividing the flow time between two stations into the length of the reach.

RESULTS

Water Chemistry of Bozeman Creek and Bridger Creek

The average results of the water chemistry of Bozeman Creek and Bridger Creek for single sampling periods are recorded in Table II. This table includes both the inorganic and organic fractions that were analyzed.

Upon examination of the various cations found in both drainage systems, calcium was found to be dominant with magnesium, sodium, and potassium following in that order. Potassium is usually the least dominant cation in natural waters because of several processes which remove it from solution.

Bicarbonate and sulfate were less concentrated in Bozeman Creek than in Bridger Creek, but in both creeks the dominance order of the anions was the same, bicarbonate being most dominant, then sulfate, chloride, and fluoride.

The carbon determinations showed inorganic carbon to be higher in Bridger Creek. Soluble organic carbon was approximately the same for both streams (4-5 mg/l C). A decline in particulate carbon was noted at both stations 4 and 6.

Soluble organic nitrogen was higher than any of the other nitrogen fractions analyzed in Bozeman and Bridger Creeks. The mean particulate nitrogen differed from 0.24 mg/l at station 4 to 0.65 mg/l at station 1. Nitrates were consistently higher than free ammonias and nitrites which were essentially void in each creek.

Table II. Average water chemistry for Bozeman Creek and Bridger Creek during the summer for the single sampling periods.

STATION	1	3	4	6
Ca ⁺⁺ (meq/l)	1.48	1.83	1.85	1.67
Mg ⁺⁺ (meq/l)	1.15	1.17	1.39	1.32
Na ⁺ (meq/l)	0.16	0.68	0.51	0.25
K ⁺ (meq/l)	0.07	0.04	0.04	0.08
HCO ₃ ⁻ (meq/l)	2.38	3.32	3.32	2.71
SO ₄ ⁻² (meq/l)	0.19	0.32	0.34	0.20
Cl ⁻ (meq/l)	0.03	0.04	0.04	0.04
F ⁻ (meq/l)	less than 0.01 for all stations			
Inorganic Carbon (C) (mg/l)	24.70	37.00	39.70	33.30
Soluble Organic C (mg/l)	4.80	5.00	4.80	4.30
Particulate C (mg/l)	2.80	2.30	0.90	1.90
N-NO ₃ ⁻ (mg/l)	0.20	0.41	0.33	0.31
N-NO ₂ ⁻ (mg/l)	less than 0.01 for all stations			
N-NH ₃ (mg/l)	0.11	0.02	0.04	0.07
Soluble Organic N-NH ₃ (mg/l)	0.95	1.40	1.49	1.20
Particulate N-NH ₃ (mg/l)	0.65	0.46	0.24	0.51
Inorganic P-PO ₄ ⁻³ (mg/l)	0.36	0.12	0.11	0.39
Soluble Organic P-PO ₄ ⁻³ (mg/l)	0.01	0.08	0.03	0.15
Particulate P-PO ₄ ⁻³ (mg/l)	0.23	0.21	0.17	0.32
Silica (mg/l)	20.60	10.50	9.50	22.00
Dissolved Oxygen (mg/l)	9.26	9.53	9.41	9.48
% O ₂ Saturation	70.50	73.80	73.60	73.10
Conductance (micromhos)	247.40	340.70	343.50	284.70
pH Ranges	8.14	8.25	8.29	8.18

The average of the phosphate analyses showed inorganic phosphate and particulate phosphate to be lower in Bridger Creek. Mean soluble organic phosphate values for Bozeman Creek varied from 0.01 mg/l at station 1 to 0.15 mg/l at station 6, with Bridger Creek values falling within these limits.

Silica concentrations were higher in Bozeman Creek. This apparently was due to the flowing of these waters over a basic igneous area. The lower silica content of Bridger Creek was attributed to its drainage basin being primarily sedimentary.

The dissolved oxygen content of both systems was usually greater than 9.0 mg/l with an oxygen saturation of about 73%.

The mean specific conductance and pH range was usually greater in Bridger Creek than in Bozeman Creek.

An examination of the concentrations of the various chemical fractions at both the upstream and downstream stations indicates that there was no gross addition of pollution to either of the systems at the time of the study.

Water Chemistry of Rocky Creek and the East Gallatin River

In the following section, many of the graphs may have both solid and broken line curves. The solid lines represent the concentration of chemical factors in the length of Rocky Creek and the East Gallatin River that was sampled. Broken lines indicate the contributions from the major tributaries of the East Gallatin River system at appropriate

points. Station 2 was selected as the starting point (0 miles) in making graphs. The downstream distances of the remaining Rocky Creek and East Gallatin River stations from station 2 are recorded in Table III.

The average specific conductance and total alkalinity for Rocky Creek and the East Gallatin River during the study period are shown in Figure 2. An increase in the conductance and total alkalinity was noted within 0 to 0.4 miles, then a definite decrease between 0.4 and 0.9 miles. The decline was primarily due to the dilution effect of Bozeman Creek (station 6). Another increase in conductance and alkalinity was observed from 0.9 to 1.2 miles because of the added enrichment of the sewage outfall. Alkalinity and conductance both decreased within 1.2 to 2.6 miles downstream from station 2 which was attributed to the dilution effect from Bridger Creek (station 4). Between 2.6 miles and 11.4 miles there was a slight rise in both conductance and alkalinity.

Figure 3 shows the mean % O_2 saturation and dissolved oxygen for the single sampling periods during the summer. Fluctuations are noticed from 0 to 0.9 miles, the highest O_2 saturation being at 0.4 miles and a dissolved oxygen high near 9.1 mg/l between 0.4 and 0.9 miles. A decline in O_2 saturation and dissolved oxygen was noted from 0.9 to 2.6 miles and then a gradual increase of the two between 5.1 and 11.4 miles.

As can be seen from Figure 3, the greatest oxygen depletion was in the vicinity of the sewage effluent. This demand for oxygen was of such magnitude that the stream at 11.4 miles had still not regained its original O_2 concentration. If it were not for the highly oxygenated

Table III. The downstream distances from station 2 for the Rocky Creek and East Gallatin River sampling stations.

STATION	DISTANCE (miles)
2	0
5	0.4
7	0.9
9	1.2
10	2.6
11	5.1
12	11.4

