



The effects of heavy metals on the distribution and abundance of aquatic insects in the Boulder River, Montana
by William Michael Gardner

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Fish and Wildlife Management
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Abstract:

The effects of heavy metals on the distribution and abundance of aquatic insects in the Boulder River were studied during 1975 and 1976. On the upper Boulder River, concentrations of total zinc were highest at Station 2 below derelict mining and milling sites where they averaged 0.25 mg/l. The insect community at this station in August and September samples was 29, 81, and 45 percent lower in average total number, average total weight, and average number of subordinal taxa, respectively, than at Station 1 above the pollution sources. On the lower Boulder River, the highest average concentration of total zinc was 0.31 mg/l and occurred at Station 5 below the heavy metals laden floodplain. The insect community at this station in August and September samples was at least 30, 19 and 18 percent lower in average total number, average total weight, and average number of subordinal taxa, respectively, than at Stations 3 or 4 above it. The aquatic insect community at Station 5 was at least 62 and 69 percent lower in average total number and average total weight, respectively, than at Stations 6 through 8 below it. The number of subordinal taxa at Stations 5 and 6 were lower than at Stations 7 and 8.

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THE EFFECTS OF HEAVY METALS ON THE DISTRIBUTION
AND ABUNDANCE OF AQUATIC INSECTS IN THE
BOULDER RIVER, MONTANA

by

WILLIAM MICHAEL GARDNER

A thesis submitted in partial fulfillment
of the requirements for the degree

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in

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Approved:

William R. Gould
Chairperson, Graduate Committee

Jim Pachett
Head, Major Department

Henry L. Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

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ABSTRACT

The effects of heavy metals on the distribution and abundance of aquatic insects in the Boulder River were studied during 1975 and 1976. On the upper Boulder River, concentrations of total zinc were highest at Station 2 below derelict mining and milling sites where they averaged 0.25 mg/l. The insect community at this station in August and September samples was 29, 81, and 45 percent lower in average total number, average total weight, and average number of subordinal taxa, respectively, than at Station 1 above the pollution sources. On the lower Boulder River, the highest average concentration of total zinc was 0.31 mg/l and occurred at Station 5 below the heavy metals laden floodplain. The insect community at this station in August and September samples was at least 30, 19 and 18 percent lower in average total number, average total weight, and average number of subordinal taxa, respectively, than at Stations 3 or 4 above it. The aquatic insect community at Station 5 was at least 62 and 69 percent lower in average total number and average total weight, respectively, than at Stations 6 through 8 below it. The number of subordinal taxa at Stations 5 and 6 were lower than at Stations 7 and 8.

INTRODUCTION

Hardrock mining for metallic minerals in the Boulder River drainage was intensive in the late 1800's and early 1900's. Roby et al. (1960) summarized the extent of the mining for these minerals in Jefferson County and reported there had been at least 71 ore-producing mines and 15 mills in the upper Boulder and Elkhorn drainages. Presently, few mines are being worked in the drainage.

Mining has produced adverse effects on the Boulder River below the town of Basin. Appraisal of the water quality in the drainage by Braico and Botz (1974) revealed heavy metals from acid mine seeps and mill tailings were causing a "major water quality impairment." Sampling of the sediments in the river channel and floodplain disclosed high concentrations of zinc, copper and lead extending some 40 km downriver below the source areas (Vincent 1975). In the upper Boulder River, Nelson (1976) found depressed standing crops of trout and high mortalities of bioassayed eyed eggs and fingerling rainbow trout (*Salmo gairdneri*) associated with higher heavy metals concentrations in the river. Vincent (1975) partially attributed the low numbers of trout in the lower Boulder River to heavy metals pollution. A preliminary investigation of the aquatic insect fauna in the Boulder River indicated low number of mayfly species in areas of the river containing high concentrations of heavy metals (Vincent 1975).

The primary purpose of this investigation was to determine the effects of the heavy metals on the distribution and abundance of the aquatic insects in the Boulder River. A secondary purpose was to describe the concentrations of heavy metals occurring in the river year around. Field research was conducted from April 26, 1975 to October 10, 1976.

DESCRIPTION OF STUDY AREA

The Boulder River is located in Jefferson County, southwestern Montana. It originates on the east side of the Continental Divide at an elevation of 2,220 m and flows southwest for approximately 120 km to the Jefferson River near Cardwell, Montana. The drainage area is approximately 1,975 square km and is primarily underlain by the Boulder Batholith which is composed of quartz monzonite. The lower third of the drainage is composed of sedimentary rocks of Precambrian to Tertiary age (Roby et al. 1960). The river has an overall gradient of about 4.8 m per river kilometer. Major tributaries, in downriver progression, are: Lowland, Bison, Basin, Cataract and Muskrat Creeks and the Little Boulder River.

Average annual precipitation is approximately 90 cm at the town of Basin and 30 cm at the town of Boulder (North Boulder Drainage and Jefferson Conservation District 1975). Flows in the river depend primarily on snowpack in the mountains with a number of large springs adding to the river in the lower valley. The average discharge of the Boulder River near the town of Boulder for a 41-year period of record ending in 1972 was $206 \text{ m}^3/\text{min}$ (112 cfs), while the maximum and minimum discharges were 5,933 (3358 cfs) and $0 \text{ m}^3/\text{min}$, respectively (U.S. Geological Survey 1972). During 1975, the first year of this study, discharges were abnormally high. The maximum and minimum discharges for the period April 26 through September 31 were 5,972 (3377 cfs) and

94 m³/min (53 cfs), respectively. In 1976 maximum and minimum discharges for the period April 16 through October 31 were 3,080 (1760 cfs) and 95 m³/min (56 cfs), respectively (U.S. Soil Conservation Service 1976). The surface run-off patterns for both years are presented in Figure 1. The major use of water from the Boulder River below the town of Boulder is for the irrigation of alfalfa and hay meadows. In low water years, use is so intensive that irrigation diversions dewater about a 19 km reach in this section of river (North Boulder Drainage and Jefferson Conservation Districts 1975).

For this study, the river was considered to consist of two sections. The river lying above the town of Boulder was designated as the upper Boulder River. In this section the river had a narrow floodplain, a high elevation, and a steep gradient. Riparian vegetation primarily included willows, alder, conifers and, to a lesser extent, cottonwoods and aspen. Rainbow trout (*Salmo gairdneri*), brook trout (*Salvelinus fontinalis*), and mountain whitefish (*Prosopium williamsoni*) were the salmonids found in this study section.

The section of river lying below the town of Boulder was designated the lower Boulder River. This section of the river had a wider floodplain through which the river meandered, a lower elevation and a more gradual gradient. Riparian vegetation was primarily cottonwoods, aspen and willows. Brown trout (*Salmo trutta*) dominated the salmonid fauna in this section (Vincent 1975).

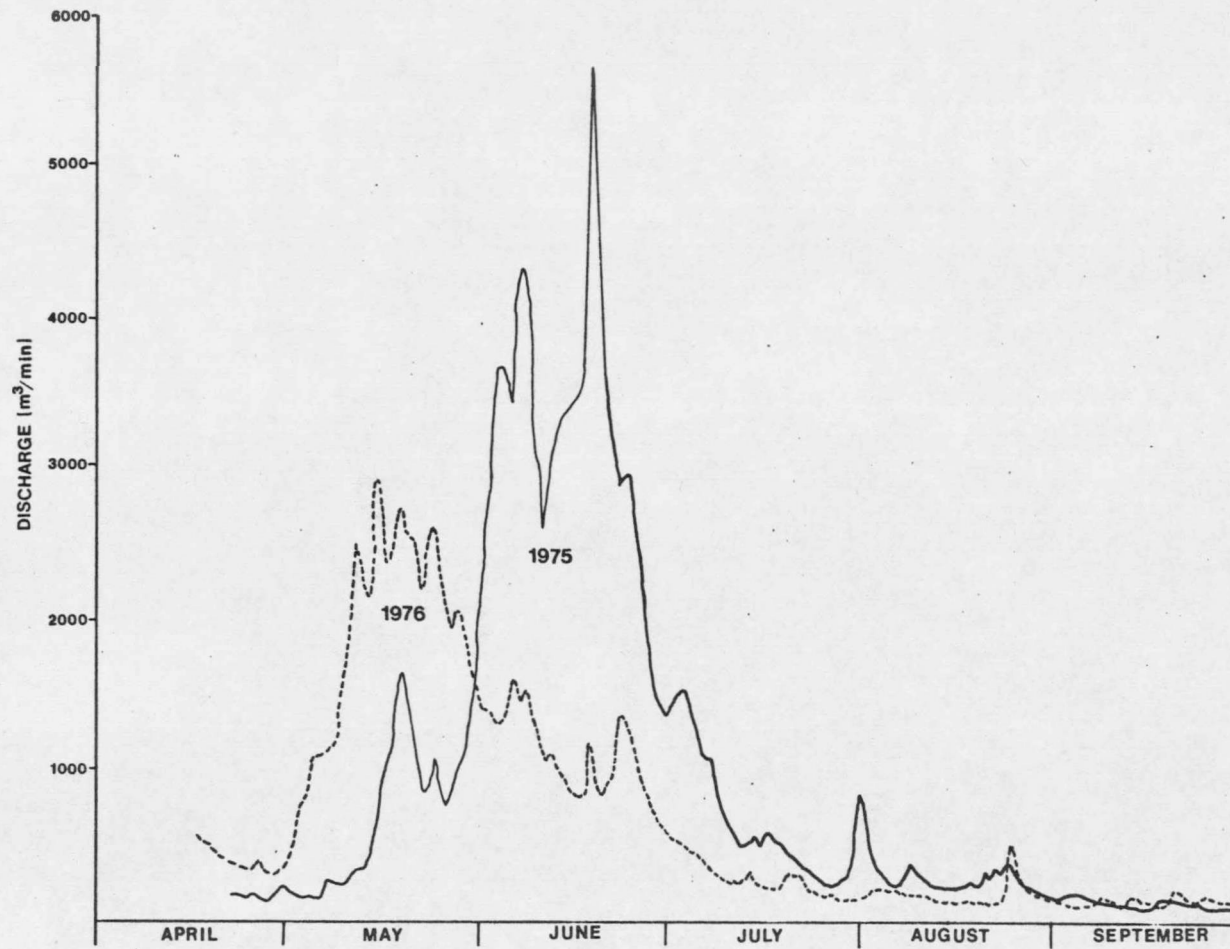


Figure 1. Hydrographs of the Boulder River for 1975 and 1976 at the USGS gaging station 6 km downriver from the town of Boulder. (U.S. Soil Conservation Service 1976).

Nine stations were established in the study area (Figure 2). The locations and distances from the mouth of the river and between stations are given in Appendix Table 1.

Water quality and aquatic insects were sampled at eight sites (Stations 1-8), and water quality only at one additional site (Station 1-A). Stations 1 and 2 served to assess the combined effects of Basin, Cataract, and High Ore Creeks on the upper Boulder River. Bottom types at these stations were comprised of boulders and large cobbles interspaced with large gravel. Station 1-A functioned to delineate the combined heavy metals load of Basin and Cataract Creeks on the water quality of the river from that contributed by High Ore Creek.

Six water quality and aquatic insect sampling stations were installed on the lower Boulder River. Stations 3 and 4 were used to investigate the influence of the Little Boulder River. Stations 5, 6, 7, and 8 were located at approximately equal interstational distances downriver from Station 4 to ascertain the persistence and effect of the heavy metals in the lower reach of the river. Bottom types at these stations were predominantly small cobble and large gravel interspaced with small gravel and sand. Because the habitats in the sections on the upper and lower Boulder River were different, only intra-sectional comparisons could be made.

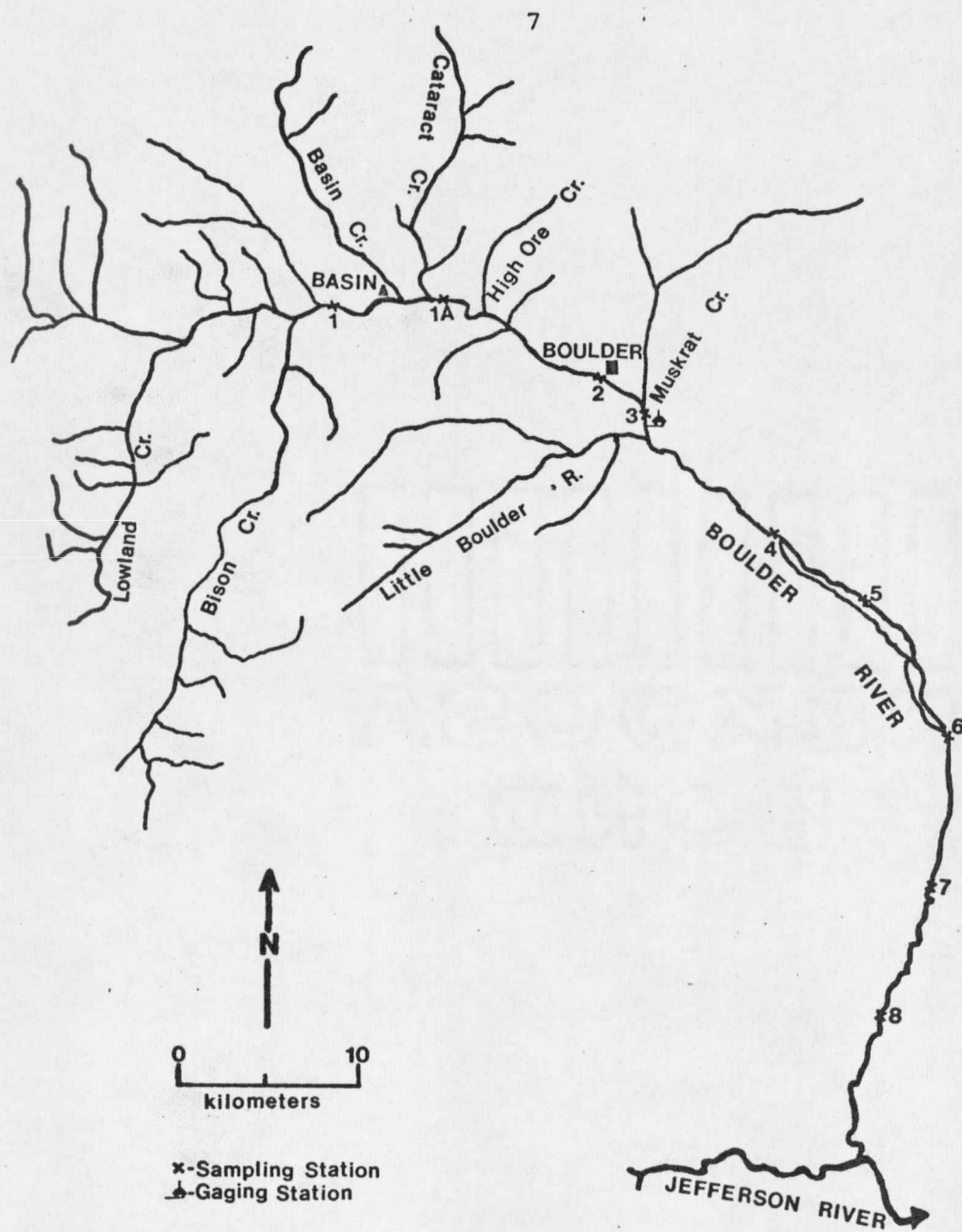


Figure 2. Map of the study area showing the location of sampling stations

METHODS

Chemical and physical parameters were measured monthly, when possible, except during July through September when dissolved oxygens were measured twice monthly and maximum-minimum temperatures were recorded at least two times a month. The pH, conductivity, and alkalinity of water samples were determined within 12 hours of collection. Samples were kept cool during the interim. The pH was determined using a Beckman Expandomatic pH meter. Conductivity was measured on a Yellow Springs Instrument conductivity bridge, and alkalinity was determined potentiometrically. Calcium and magnesium concentrations were determined by atomic absorption spectrophotometry and hardness was then calculated from these concentrations. The range in water temperature at each station was monitored with a Taylor maximum-minimum thermometer. Dissolved oxygen was assessed by a modified azide-Winkler method using Hach Chemical Company reagents. Discharge measurements were determined with a Gurley-type AA current meter using single point velocity measurements made approximately every 0.6 m on a transect across the channel.

Water samples for heavy metal analyses were collected in one liter polyethylene bottles, acidified with 5 ml of distilled, concentrated nitric acid, and analyzed within six months of collection. Concentrations of total recoverable zinc, iron, copper, lead, cadmium, and silver, in samples taken from April 1975 through April 1976,

determined by personnel at the Montana Department of Health and Environmental Sciences, Water Quality Bureau, Helena, by atomic absorption spectrophotometry. From May 1976 to October 1976, the investigator measured only total recoverable zinc concentrations in water samples by atomic absorption spectrophotometry at Montana State University.

Aquatic insects were sampled monthly, when possible, using artificial substrates similar to Hester-Dendy samplers (APHA 1971) but with seven 12.2 x 12.2 cm plates giving total surface area of 0.2 m² per sampler. Plates were spaced 0.56 cm apart to ensure that larger insect forms could colonize the sampler. Four samplers were used at each station and were placed at the downriver end of riffles at sites with visually similar current velocities and depths. Each sampler was positioned with plates parallel to the flow and anchored to the channel bottom. Aquatic insects were collected after a colonization period of approximately 30 days.

The material on each sampler was scraped into a separate jar containing an identifying label and 10% Formalin. Samples were taken to Montana State University where they were individually washed on a US Series Number 30 screen. The aquatic insects from each sample retained by the screen were removed and identified to the lowest taxon practical (usually genus) using Ward and Whipple (1959) and Pennak (1953) and the numbers in each taxon recorded. The wet weight and

percent composition by number and weight were determined for each order and major subordinal taxon from samplers collected in August and September 1975 and 1976. The wet weight was obtained by blot drying the insects with absorbent paper towels and weighing them to the nearest hundredth of a gram on a Mettler Instruments Corporation type H-16 analytical balance. The percent composition by number and percent composition by weight of a taxon is the average number or wet weight of that taxon in a sample divided by the average total number or total wet weight of all insects in that sample, expressed as a percentage. Periodic kick samples were taken to investigate the distribution of *Pteronarcys californica* and one field bioassay was conducted on this species to test its resistance to heavy metals.

Regression analyses were performed on selected chemical and physical parameters using the multiple linear regression computer program of "Ministat" at Montana State University's statistical laboratory. Output from this program included a correlation coefficient (r). An r -value of 0.7 or greater was deemed a strong correlation.

RESULTS

Chemical and Physical

General Limnological Measurements

Values of all chemical and physical parameters, other than heavy metals, measured on each collection date are presented in Appendix Tables 2-11. The average values and ranges of these measurements at each station are given in Table 12.

The average and range of these measurements at stations on the upper Boulder River (Stations 1, 1-A, and 2) were similar except in flows and suspended solids. The relatively low conductivity, alkalinity, calcium, magnesium and hardness values recorded at all stations are the results of the igneous geochemical nature of the upper drainage basin. The highest temperatures recorded in the upper Boulder River occurred during late July to mid-August. The dissolved oxygen values in this section of the river never declined below 83% of saturation and averaged above 100%. Average seasonal discharge was approximately 40% greater at Station 2 than at Station 1 because of the entry of four major tributaries between these two stations. Concentrations of suspended solids were highest in the upper Boulder River during spring run-off and were dominantly comprised of the decayed granitic country rock. The higher values of suspended solids at Station 1-A may have been partially due to the numerous derelict mines and milling sites.

Table 12. Average Values and Ranges (in parentheses) of Chemical and Physical Characteristics other than Heavy Metals, from 20 Monthly Samples at Stations on the Boulder River during 1975 and 1976

Characteristic	Stations								
	1	1-A	2	3	4	5	6	7	8
pH	7.6 (7.2- 8.2)	7.6 (7.1- 8.3)	7.7 (7.2- 8.2)	7.6 (7.2- 8.0)	7.6 (7.2- 8.2)	7.6 (7.1- 8.0)	7.7 (7.2-8.2)	7.8 (7.3-8.5)	8.0 (7.4-8.5)
Conductivity (µmhos/cm)	132 (87-174)	127 (77-165)	136 (80-180)	155 (88-214)	160 (90-235)	173 (97-235)	206 (107-340)	224 (115-384)	255 (141-404)
Alkalinity (mg/l CaCO ₃)	40.6 (17.5-55.0)	37.7 (16.5-50.5)	39.1 (16.0-53.0)	47.4 (20.0-62.0)	49.0 (21.0-65.0)	52.5 (23.5-67.5)	70.4 (27.0-122.0)	74.3 (32.0-140.0)	87.8 (38.5-140.0)
Calcium (mg/l)	14.0 (8.5-19.1)	13.5 (7.7-18.3)	14.5 (8.0-23.8)	16.8 (9.0-28.5)	17.0 (9.5-25.1)	17.4 (10.5-25.5)	22.1 (11.5-35.0)	24.9 (13.0-41.0)	29.1 (15.5-42.0)
Magnesium (mg/l)	2.7 (1.7-4.0)	2.8 (1.5-3.9)	3.1 (1.5-4.2)	3.6 (2.0-4.8)	3.8 (2.0-5.8)	4.1 (2.3-6.1)	5.1 (2.4-8.3)	5.8 (3.0-10.5)	6.8 (3.5-11.5)
Hardness (mg/l CaCO ₃)	44.6 (28.2-64.2)	45.2 (25.4-61.8)	48.8 (26.2-65.5)	56.2 (30.7-106.2)	58.3 (32.0-86.6)	62.7 (35.7-88.8)	76.4 (38.6-121.7)	85.8 (44.8-145.2)	100.8 (53.1-152.4)
Temperature ¹ (C)	12.5 (3-21)	--	14.0 (4-22)	15.0 (5-22)	15.0 (5-22)	16.0 (5-23)	16.5 (6-23)	16.5 (5-24)	16.5 (6-23)
Dissolved Oxygen ² (mg/l)	10 (8-13)	--	10 (8-14)	11 (8-13)	11 (7-13)	10 (7-14)	10 (7-14)	10 (7-15)	10 (7-14)
Discharge ³ (m ³ /min)	123 (60-199)	--	172 (73-214)	197 (110-265)	243 (146-318)	212 (65-360)	209 (63-352)	233 (92-355)	296 (167-430)
Suspended Solids (mg/l)	26 (0-189)	40 (0-256)	27 (0-116)	33 (0-170)	43 (0-224)	65 (0-470)	67 (0-546)	48 (1-394)	36 (1-166)

¹ From 9 measurements made twice monthly from late July to October

² From 14 measurements made twice monthly from July to October

³ From 7 measurements made August, September and November 1975 and July-October 1976

existing in this vicinity, and the activities of an open-pit silica mine located about 1 km above the sampling site.

The pH, conductivity, alkalinity, calcium, magnesium and hardness values in the lower Boulder River (Stations 3-8) generally increased with a downriver progression. Conductivity, alkalinity, calcium, magnesium, and hardness values in the lower Boulder River were higher than in the upper section because of the sedimentary geochemical nature of the lower drainage and the contribution of several large springs in the lower stretch of the section. As in the upper Boulder River, the highest temperatures occurred in late July to mid-August. The dissolved oxygen level never declined below 80% of saturation and averaged above 100%. The average and minimum seasonal discharge measurements were lower at Stations 5, 6, and 7 than at Station 4 because of irrigation withdrawal. The average and minimum flows at Stations 7 and 8 were higher than at Station 6 because of irrigation return water and the contribution from large springs 6 km above Station 8. The maximum suspended solids loads at all of the stations in the lower Boulder River occurred during May and June when surface run-off was high. The higher maximum and average suspended solids concentrations at Stations 5 and 6 are the result of poor channel stability as evidenced by channel braiding and shifting immediately above and below Station 5. After the spring run-off subsided, the suspended solids loads decreased to minimal values except after heavy precipitation.

Heavy Metals Measurements

The values of total recoverable zinc, iron, copper, and lead measured in samples taken from established stations throughout this study are presented in Appendix Tables 13-16. Analyses for zinc were continued after terminating those for the other heavy metals because of the following reasons: (1) zinc was present in relatively high concentrations in the floodplain sediments (Vincent 1975) and in the water; (2) it was the most soluble of the heavy metals measured (Stumm and Morgan 1970; Hawkes and Webb 1962), and therefore potentially the most toxic; and (3) there was a strong correlation between values of total zinc and other heavy metals (Table 17). Consequently, by monitoring only the total zinc concentrations, inferences could be made about the concentrations of other heavy metals. Total cadmium and silver were also measured in initial samples but concentrations were usually below the detection limits of the atomic absorption spectrophotometer unit, therefore, attempts to measure these heavy metals were discontinued. The concentrations of heavy metals are reported as total recoverable metals (TRM), and are a measure of both the toxic and non-toxic species.

The average values and ranges of total zinc, iron, copper, and lead measured at each station are given in Table 18. The average and maximum value of each heavy metal generally increased with downriver progression on the upper Boulder River. Values of total zinc in individual samples at Station 1 never exceeded those at Station 1-A or 2,

Table 17. Correlation Coefficients (r) from Linear Regressions of Heavy Metals against Selected Measurements

Regression	N	r-value
Total zinc versus total iron, copper and lead at all stations.	124	0.862
Total zinc versus total iron at all stations	124	0.758
Total zinc versus total copper at all stations	124	0.804
Total zinc versus total lead	124	0.740
Total zinc versus suspended solids at Station 1	19	0.608
Total zinc versus suspended solids at Station 1-A	19	0.688
Total zinc versus suspended solids at Station 2	19	0.146
Total zinc versus suspended solids at Station 3	19	0.600
Total zinc versus suspended solids at Station 4	19	0.733
Total zinc versus suspended solids at Station 5	19	0.771
Total zinc versus suspended solids at Station 6	19	0.859
Total zinc versus suspended solids at Station 7	18	0.859
Total zinc versus suspended solids at Station 8	19	0.880
Total iron versus suspended solids at Station 1	13	0.517
Total iron versus suspended solids at Station 1-A	13	0.881
Total iron versus suspended solids at Station 2	13	0.601
Total iron versus suspended solids at Station 3	13	0.816
Total iron versus suspended solids at Station 4	13	0.795
Total iron versus suspended solids at Station 5	13	0.690
Total iron versus suspended solids at Station 6	13	0.817
Total iron versus suspended solids at Station 7	13	0.766
Total iron versus suspended solids at Station 8	13	0.798

Table 18. Average Values and Ranges (in parentheses) of Heavy Metals Concentrations expressed as mg/l Total Recoverable Metals from 14 Samples collected at Stations on the Boulder River during 1975 and 1976 (Analyses performed by Montana Public Health Service)

Metal	1	1-A	2	3	4	5	6	7	8
Zn	0.01 (<.01-0.05)	0.12 (0.06-0.25)	0.25 (0.07-0.80)	0.22 (0.11-0.40)	0.22 (0.14-0.49)	0.31 (0.14-0.75)	0.27 (0.07-1.00)	0.21 (0.05-0.72)	0.14 (0.02-0.43)
Fe	0.68 (0.22-1.80)	0.81 (0.18-2.00)	0.98 (0.21-2.60)	1.25 (0.28-4.20)	1.30 (0.30-4.80)	1.68 (0.30-5.20)	1.28 (0.27-2.50)	1.07 (0.30-2.80)	0.90 (0.15-2.20)
Cu	<.01 (<.01-0.02)	0.03 (<.01-0.09)	0.04 (<.01-0.10)	0.04 (<.01-0.13)	0.04 (<.01-0.15)	0.06 (<.01-0.24)	0.06 (<.01-0.34)	0.04 (<.01-0.22)	0.03 (<.01-0.07)
Pb	<.01 (<.01)	<.01 (<.01-0.05)	0.02 (<.01-0.09)	0.02 (<.01-0.12)	0.03 (<.01-0.10)	0.05 (<.01-0.19)	0.04 (<.01-0.24)	0.02 (<.01-0.12)	0.02 (<.01-0.07)

and only once during both years did a sample value of total zinc at Station 1-A exceed that at Station 2 (Appendix Tables 13-16). The particularly weak correlation between total zinc and suspended solids at Station 2 (Table 17) is not understood.

Although the average value of total iron was highest at Station 2, the only time when the individual measurements were higher than at Station 1 was during periods of high flow (Appendix Tables 13-16 and Figure 1). At low flows the total iron values were essentially equal at Stations 1, 1-A, and 2. Total iron values in the upper Boulder River were not closely associated with suspended solids at Stations 1 and 2 (Table 17). Average values of total copper and lead were greater at Station 2 than at the other stations on the upper Boulder River (Table 18). However, the differences between stations in these heavy metals were not as great as with zinc and iron. The values for total copper and lead for each sampling period at Station 2 usually equaled or exceeded that of Stations 1 and 1-A (Appendix Tables 13-16).

The values of total zinc measured at supplementary sites are given in Appendix Table 19. Table 20 implicates Basin Creek and the milling site at Basin, Cataract, and High Ore Creeks as major contributors of total zinc, and therefore probably other heavy metals, to the upper Boulder River. The concentration of total zinc entering the river from High Ore Creek was approximately seven times that from any of the other sources. However, the average low flow of High Ore Creek

Table 20. Concentrations of Zinc expressed as mg/l Total Recoverable Metals in Water Samples from Established Stations and Selected Tributaries on the Upper Boulder River

Date	St. 1 (above Basin Crk)	Basin Creek	Cataract Creek	St. 1-A (below Cataract)	High Ore Creek	St. 2 (below High Ore)
4/26/75	<.01	0.20	0.54	0.14	3.90	0.44
5/11/	<.01	0.31	0.66	0.20	5.70	0.30
6/10/	<.01	0.11	0.25	0.09	4.20	0.16
5/13/76	0.01	0.09	0.19	0.06	3.25	0.09
6/16/	<.01	0.14	0.22	0.08	1.50	0.11
7/12/	<.01	0.10	0.30	0.08	2.10	0.14
8/ 6/	<.01	0.11	0.40	0.08	2.25	0.15
9/ 2/	<.01	0.14	0.45	0.11	4.70	0.20
10/ 6/	<.01	0.15	0.51	0.11	3.50	0.24

was approximately $3.4 \text{ m}^3/\text{min}$ (2 cfs), compared to the average low flow of Basin and Cataract Creeks each of which was approximately $17 \text{ m}^3/\text{min}$ (10 cfs). Consequently, the impact of total zinc from Basin and Cataract Creeks and the milling site at Basin combined was similar to that of High Ore Creek alone.

In the lower Boulder River the average and maximum values of heavy metals were generally intermediate at Stations 3 and 4, highest at Station 5, from which they declined downriver to Station 8 where the lowest levels were recorded (Table 18). Point measurement of total zinc were generally similar at Stations 3 and 4 during low flows and slightly higher at Station 4 during high flows. The Little Boulder River, which enters between Stations 3 and 4, did not appear to reduce the zinc concentrations at Station 4, even though its low flows were usually about 10% of the Boulder River's flow. The highest total zinc concentrations in the lower Boulder River were usually encountered at Station 5. Between Stations 4 and 5, the floodplain and channel sediments had the highest recorded heavy metals concentrations in the Boulder River drainage (Vincent 1975), and the river had poor channel stability. The correlations of total zinc vs. suspended solids in the lower Boulder River increase in a downriver progression (Table 17) suggesting more of the zinc at and below Station 4 is originating from the floodplain sediments. The sharp decline in total zinc values between Stations 7 and 8 showed the effect of the large ($51 \text{ m}^3/\text{min}$)

spring entering the river about 6 km above Station 8. The water from the spring contained a high alkalinity which probably caused some precipitation of zinc; also the volume of the spring water may have had a substantial dilution effect on the total zinc concentrations.

Total iron, copper, and lead all basically followed the same patterns in magnitude and chronology exhibited by total zinc. The correlation coefficients for the regressions of total iron vs. suspended solids at the stations located on the lower Boulder River were all strong except at Station 5, and no apparent pattern with a downriver progression was noticed (Table 17).

Figure 3 shows the average total zinc concentrations in the Boulder River at low and high flows. At low flows, the total zinc concentrations in the Boulder River increased from Station 1 to Station 2 and persisted at approximately that level to Station 5 or 6 after which the concentrations declined. At high flows the total zinc concentrations increased from Station 1 to Stations 5 or 6, thereafter declining rapidly.

The average concentrations of total zinc appeared to be slightly higher during 1975 than in 1976 at all stations with the exception of the control, Station 1 (Table 21). This difference between years was most apparent during low flows at Station 2 (Figure 3). During 1975 there was severe flooding of High Ore Creek at a large tailings area.

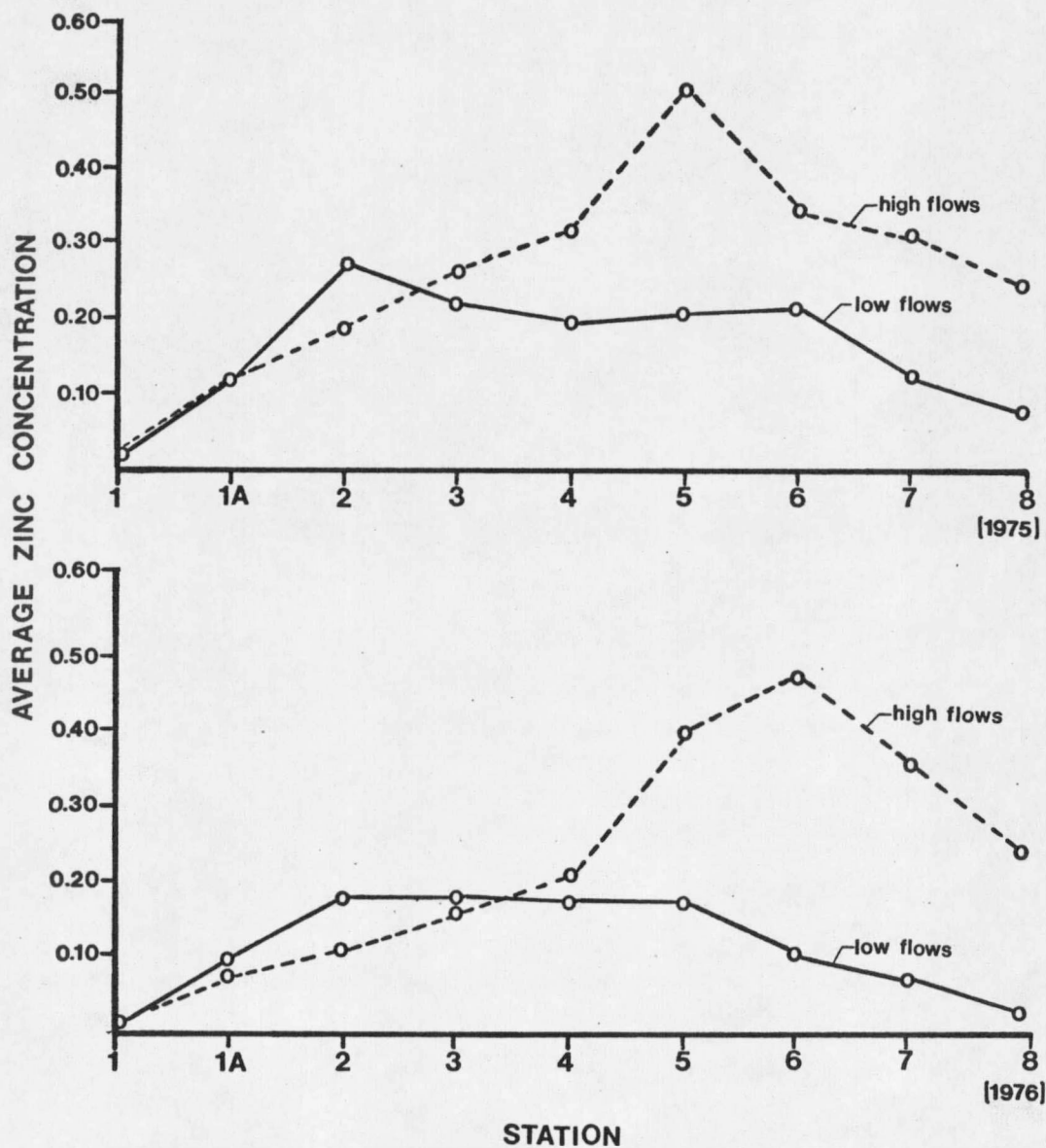


Figure 3. The average zinc concentration expressed as mg/l total recoverable metals (TRM) at sampling stations on the Boulder River during low flows ($350 \text{ m}^3/\text{min}$ or less) and high flows ($1000 \text{ m}^3/\text{min}$ or greater) in 1975 and 1976. Each point on figure is the average of four measurements.

Table 21. Average Values and Ranges (in parentheses) of 19 Samples of Zinc Concentrations expressed as mg/l Total Recoverable Metals from Stations on the Boulder River from April 1975 to October 1976

Year	Station								
	1	1-A	2	3	4	5	6	7	8
1975	0.01 (<.01-0.05)	0.14 (0.09-0.20)	0.35 (0.11-0.80)	0.27 (0.13-0.40)	0.27 (0.14-0.49)	0.39 (0.18-0.73)	0.31 (0.14-0.46)	0.24 (0.10-0.41)	0.17 (0.03-0.28)
1976	0.01 (<.01-0.05)	0.12 (0.06-0.25)	0.17 (0.09-0.30)	0.18 (0.11-0.24)	0.18 (0.09-0.34)	0.27 (0.14-0.75)	0.26 (0.07-1.00)	0.21 (0.05-0.72)	0.13 (0.02-0.43)

This probably caused the higher average total zinc concentrations recorded at Station 2 during 1975.

Aquatic Insects

The average and range of aquatic insect numbers in each subordinal taxon collected from samplers recovered on each sampling date are given in Appendix Tables 22-29. The wet weights of aquatic insects sampled in August and September 1975 and 1976 are also presented in Appendix Tables 22, 23, 28, and 29. The aquatic insects collected belong to eight orders with Trichoptera, Diptera, Plecoptera, and Ephemeroptera comprising 45, 30, 15, and 9% of the total numbers collected, respectively. Forty-eight subordinal taxa were identified and their distribution throughout the area sampled is given in Appendix Table 30. Eleven of these were numerically dominant forms.

A summary of selected compositional measurements for the sampled aquatic insect communities at the ordinal and subordinal taxa levels during months of equitable sampling success are given in Tables 31, 32, and 33, respectively. Relationships in these samples were indicative of trends present for all the samples collected during the study.

In the upper Boulder River, the sampled aquatic insect community at Station 2 was 29, 81, and 45% lower than at Station 1 in average total number, average total weight, and average number of subordinal taxa, respectively (Table 31). The lower average total number at

Table 31. Selected Community Measurements of Aquatic Insects Sampled at Stations on the Boulder River for August and September 1975 and 1976.*

Order	Characteristic	Station							
		1	2	3	4	5	6	7	8
Ephemeroptera	Average number/sampler	50	23	63	110	27	4	3	84
	Average weight (gms)/4 samplers	0.43	0.11	0.52	0.93	0.11	0.05	0.01	0.03
	Average number of taxa/4 samplers	5	2	2	2	2	1	1	2
	Percent composition by number	22.4	14.8	17.0	28.0	8.0	1.0	t	t
	Percent composition by weight	12.3	15.5	18.5	23.0	4.0	1.0	t	3.0
Plecoptera	Average number/sampler	18	15	70	69	100	222	96	49
	Average weight (gms)/4 samplers	3.20	0.23	1.46	1.94	1.69	6.13	2.96	1.91
	Average number of taxa/4 samplers	6	4	5	5	4	4	4	5
	Percent composition by number	10.0	13.0	20.0	20.0	38.0	26.0	20.0	9.0
	Percent composition by weight	56.3	26.3	38.0	42.8	50.0	48.3	32.8	11.0
Trichoptera	Average number/sampler	61	7	22	20	63	673	387	829
	Average weight (gms)/4 samplers	0.52	0.01	0.04	0.07	0.69	10.55	5.75	15.59
	Average number of taxa/4 samplers	5	3	5	4	4	6	6	7
	Percent composition by number	19.0	7.0	9.0	9.0	30.0	63.0	63.0	81.0
	Percent composition by weight	17.3	1.5	1.0	1.5	34.3	50.5	66.3	87.0
Diptera	Average number/sampler	119	133	187	118	34	49	97	110
	Average weight (gms)/4 samplers	0.34	0.52	1.38	1.90	0.29	0.08	0.08	0.25
	Average number of taxa/4 samplers	3	3	4	4	3	2	2	4
	Percent composition by number	43.5	67.0	57.0	46.0	12.0	11.0	20.0	9.0
	Percent composition by weight	14.0	56.3	42.5	33.0	21.0	1.0	1.0	3.0
Others	Average number/sampler	3	0	1	1	0	0	4	6
	Average weight (gms)/4 samplers	0.04	0	0	0	0	0	0.01	0.08
	Average number of taxa/4 samplers	3	0	2	1	0	0	1	3
	Percent composition by number	1.4	0	t	t	0	0	t	t
	Percent composition by weight	t	0	t	t	0	0	t	t
Totals	Average number/sampler	251	178	343	318	224	948	583	1078
	Average weight (gms)/4 samplers	4.53	0.86	3.40	4.84	2.76	16.81	8.82	17.85
	Average number of taxa/4 samplers	22	12	18	16	13	13	14	21

*The t signifies less than 1% in number and/or weight.

Table 32. Average Number (AN) and Average Weight (AW, gms/4 samplers) of the Predominant Subordinal Taxa Sampled for August and September 1975 (upper row) and 1976 (lower row) at Stations on the Boulder River*

Taxon	Station															
	1		2		3		4		5		6		7		8	
	AN	AW	AN	AW	AN	AW	AN	AW	AN	AW	AN	AW	AN	AW	AN	AW
<i>Ephemera</i>	36	0.50	5	0.03	40	0.51	41	0.45	4	0.01	3	0.01	--	--	--	--
	23	0.15	2	0.01	37	0.37	42	0.42	10	0.04	2	0.02	--	--	--	--
<i>Baetis</i>	5	0.06	21	0.12	15	0.08	100	0.79	13	0.06	4	0.06	t	t	1	0.01
	25	0.06	27	0.04	40	0.07	88	0.22	39	0.10	2	t	7	0.01	29	0.07
<i>Pteronarcella</i>	4	0.09	4	0.06	27	0.63	25	0.76	55	0.52	76	1.90	16	0.30	16	0.34
	9	0.26	15	0.33	63	1.97	99	2.83	158	2.36	413	8.75	169	3.42	31	0.84
<i>Pteronarcys</i>	1	3.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	1	2.23	--	--	--	--	--	--	--	--	--	--	t	0.06	t	0.49
<i>Isoperla</i>	2	0.02	t	t	2	0.01	3	0.01	2	0.01	2	0.01	t	t	12	0.04
	6	0.02	4	t	8	0.02	18	0.07	10	0.01	8	t	1	t	25	0.06
<i>Arcynoptera</i>	t	t	--	--	t	t	1	0.03	6	0.34	12	1.00	15	1.05	7	0.61
	1	0.03	--	--	t	0.02	1	0.03	3	0.15	8	0.58	14	1.00	15	1.27
<i>Acroneuria</i>	1	0.19	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	t	0.48	t	0.01	t	0.15	--	--	--	--	--	--	--	--	--	--
<i>Hydropsyche</i>	16	0.13	4	t	1	t	1	t	42	0.32	123	0.65	225	1.91	481	4.78
	62	0.68	1	t	1	t	7	0.08	53	0.41	640	7.72	352	3.11	784	12.07
<i>Brachycentrus</i>	4	0.08	1	0.01	t	t	3	0.02	20	0.22	354	3.10	83	3.61	56	0.65
	10	0.02	1	t	4	0.04	16	0.04	20	0.39	268	8.97	35	0.60	230	5.58
<i>Lepidostoma</i>	44	0.05	3	0.02	6	t	3	t	4	0.01	14	0.08	7	t	4	0.03
	9	t	2	t	25	0.03	15	0.01	8	0.07	18	0.11	10	0.09	17	0.15
<i>Simulium</i>	13	0.06	10	0.03	27	0.09	31	0.10	t	t	--	--	t	t	2	0.01
	4	0.01	1	t	1	0.01	16	0.06	3	t	2	t	19	0.02	3	0.01
Chironomidae	97	0.05	200	0.09	306	0.17	146	0.08	41	0.01	109	0.07	176	0.09	192	0.19
	29	0.01	19	0.01	28	0.02	6	t	2	t	9	t	39	0.04	70	0.06
<i>Atherix</i>	32	0.25	10	0.13	44	0.78	30	0.82	6	0.02	t	t	t	t	t	t
	65	0.34	43	0.50	36	1.67	51	2.68	28	0.48	2	0.07	--	--	1	0.02

* Hyphens indicate zero counts and t signifies trace amounts

Table 33. Percent Composition by Number (PCN) and Percent Composition by Weight (PCW) of the Predominant Subordinal Taxa Sampled for August and September 1975 (upper row) and 1976 (lower row) at Stations on the Boulder River*

Taxon	Station															
	1		2		3		4		5		6		7		8	
	PCN	PCW	PCN	PCW	PCN	PCW	PCN	PCW	PCN	PCW	PCN	PCW	PCN	PCW	PCN	PCW
<i>Ephemerella</i>	15	44	4	10	9	20	12	17	2	t	t	t	--	--	--	--
	10	3	1	1	13	6	11	8	3	1	t	t	--	--	--	--
<i>Baetis</i>	2	3	5	16	2	3	18	19	6	2	t	t	t	t	t	t
	10	2	25	4	12	1	24	3	8	2	t	t	1	t	2	t
<i>Pteronarcella</i>	2	2	4	16	6	27	9	29	18	25	13	31	3	4	1	3
	5	5	13	28	19	41	25	48	45	56	38	42	24	35	3	4
<i>Pteronarcys</i>	1	48	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	1	41	--	--	--	--	--	--	--	--	--	--	t	t	t	t
<i>Isoperla</i>	1	1	1	1	t	1	1	1	1	t	t	t	t	t	1	t
	3	t	4	t	3	t	6	2	4	t	1	t	t	t	2	t
<i>Arcynopteryx</i>	t	t	--	--	t	t	t	t	6	36	3	20	2	14	t	6
	t	t	--	--	t	1	t	1	1	t	2	4	3	7	1	6
<i>Acroneuria</i>	t	9	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	t	13	t	1	t	t	--	--	--	--	--	--	--	--	--	--
<i>Hydropsyche</i>	6	6	1	1	t	t	t	t	17	15	10	7	30	17	40	42
	12	18	1	1	t	t	2	1	18	11	33	23	43	29	51	47
<i>Brachycentrus</i>	1	5	1	1	t	t	t	t	11	14	40	37	22	29	6	6
	7	t	1	t	2	1	6	1	8	11	19	28	6	6	20	25
<i>Lepidostoma</i>	15	2	4	t	1	t	2	t	3	1	3	2	t	2	t	t
	4	t	1	t	9	t	5	t	3	t	2	t	2	t	1	t
<i>Simulium</i>	3	4	2	3	4	4	5	2	t	t	--	--	t	t	t	t
	1	t	1	t	t	t	3	1	1	t	t	t	6	t	1	t
Chironomidae	33	3	64	14	63	7	42	3	28	t	25	1	33	1	18	1
	9	t	12	t	10	t	1	t	t	t	1	t	7	t	6	t
<i>Atherix</i>	13	8	8	32	9	34	8	24	3	2	t	t	t	t	t	t
	22	11	32	61	12	38	12	35	7	15	t	t	--	--	t	t

*Hypens indicate zero counts and t signifies trace amounts.

Station 2 was primarily because of the lower number of ephemeropterans and trichopterans. The reduction in Ephemeroptera at Station 2 was primarily due to lower numbers of *Ephemerella* which occurred in densities at an average of 3 individuals per sampler at Station 2 and 30 individuals per sampler at Station 1. (Table 32). All subordinal taxa of trichopterans were found in lower numbers at Station 2.

The lower average total weight at Station 2 resulted from lower weights in all orders except Diptera (Table 31). The lower average number of subordinal taxa was primarily because of fewer subordinal taxa in Plecoptera and Ephemeroptera (Table 31).

The percent composition of trichopterans by number and the percent composition of plecopterans and trichopterans by weight were lower at Station 2 than at Station 1, whereas, the reverse was true for Diptera (Table 31). Declines in *Hydropsyche* and *Lepidostoma* were responsible for the lower percent composition by number and weight of trichopterans at Station 2 (Table 33). The 30% decrease in percent composition by weight of Plecoptera was chiefly caused by the absence of *Pteronarcys*, a large aquatic insect (Table 33). The absence of this form from Station 2 was verified from three seasonal kick-samples. In supplemental kick-sampling on the Clark Fork River drainage between Butte and Missoula, *Pteronarcys* was virtually nonexistent in the upper 100 km of the river below the heavy metals sources, but was present in substantial numbers in Flint and Rock Creeks, unpolluted tributaries

in this area, and in the Clark Fork River below Rock Creek. Boland (1968), in an investigation of untreated waste waters from the Anaconda Company mines and mills, found a similar distribution of *Pteronarcys* in the Clark Fork River.

One field bioassay was conducted with *Pteronarcys* nymphs 2-5 cm in length. Twenty nymphs in plastic screen cages were placed at both Station 1 and Station 2 for four days. The total zinc values reached a maximum of 0.01 mg/l at Station 1 and ranged from 0.11 to 0.23 mg/l at Station 2. Survival was one hundred percent at both stations. From field and lab bioassays, Nehring (1976) concluded this genus was tolerant of concentrations of zinc, copper, and lead in excess of those recorded in the upper Boulder River. Therefore, it appeared that *Pteronarcys* avoided Station 2 where total zinc concentrations were much lower than those reported as lethal to this genus.

The increases in percent composition by number and weight for Diptera at Station 2 was related to the predominance of chironomids and *Atherix*, respectively (Table 33). These dipteran forms together comprised 58 and 54% of the composition by number and weight, respectively, of all the aquatic insects at this station. At Station 1 these two taxa together represented 39 and 11% of the composition by number and weight, respectively.

While the measured characteristics of the aquatic insect community at Station 1 were similar between years, the average total

weight at Station 2 was 135% greater in 1976 than 1975 (Table 34). Increases in *Pteronarcella* and *Atherix* were the two genera that accounted for most of this increase (Tables 32 and 33).

In the lower Boulder River, the lowest average total number and lowest average total weight of aquatic insects occurred at Station 5 (Table 31). Average total number, average total weight, and average number of subordinal taxa of the aquatic insect community at Station 5 were at least 30 and 19 and 18% lower, respectively, than at Station 3 or 4. The lower average total number and average total weight at Station 5 was primarily the result of at least a 57% reduction in average number and a 79% reduction in average weight of both ephemeropterans and dipterans. In Ephemeroptera, *Ephemerella* was collected at Station 5 at an average density of 7 individuals per sampler, and at Station 3 or 4 at an average density of at least 38 individuals per sampler (Table 32). The dipterans *Atherix* and Chironomidae were collected at Station 5 at an average density of 17 and 21 individuals per sample, respectively, and at Station 3 or 4 at an average density of at least 40 and 76 individuals per sampler, respectively (Table 32). The higher numbers of *Ephemerella*, *Atherix*, and Chironomidae at Stations 3 and 4 may in part be a response to the municipal sewage outfall located approximately 5 km above Station 3. Ramamoorthy and Kushner (1975) found the highest binding capacity of selected heavy metals occurred in water heavily polluted with sewage. The considerable

Table 34. Wet Weights of Aquatic Insects (gms/4 samplers) from Stations on the Boulder River for Selected Sampling Periods.

Weights	Station							
	1	2	3	4	5	6	7	8
<u>1975</u>								
August weights	1.61	0.74	2.25	4.26	2.37	9.90	10.23	12.79
September weights	7.64	0.29	2.43	2.30	0.73	4.15	4.90	9.04
Average weights	4.63	0.52	2.34	3.28	1.55	7.03	7.56	10.92
<u>1976</u>								
August weights	2.98	1.37	5.87	8.42	5.23	43.21	13.36	31.94
September weights	6.00	1.06	3.12	4.58	2.82	9.97	6.79	17.64
Average weights	4.49	1.22	4.50	6.50	4.03	26.59	10.08	24.79
Percent increase from 1975 to 1976	-8	+135	+92	+98	+160	+278	+33	+127

increases in average number and average weight of trichopterans at Station 5, did not compensate for the loss of ephemeropterans and dipterans.

Although the average total weight of aquatic insects was similar at Stations 3 and 4, the total weight for each sampling period was generally higher at Station 4 (Table 31). This may have been due to a moderating effect of the Little Boulder River entering between the two stations.

The percent composition by number and weight of Ephemeroptera at Station 5 decreased at least 9 and 14.5%, respectively, from that at Stations 3 or 4 (Table 31). For the dipterans these same parameters decreased at least 34 and 12% at Station 5, respectively. These decreases were due to lower numbers of *Ephemerella*, *Atherix* and Chironomidae at Station 5 (Table 32). The reverse was true for Trichoptera and to a lesser extent, Plecoptera. At Station 5 Trichoptera and Plecoptera combined, comprised 39 and 45% more of the ordinal percent composition by number and weight, respectively, than at Stations 3 and 4 (Table 31). These differences were the result of the increase in relative abundance of *Hydropsyche*, *Brachycentrus* and *Pteronarcella* (Table 33).

The average total number and average total weight of aquatic insects at Station 5 were at least 62 and 69% lower, respectively, than at Stations 6 through 8 (Table 31). The lower average total number and

average total weight at Station 5 were primarily caused by lower numbers of trichopterans and/or plecopterans. The average total number and average total weight at Station 7 were lower than at Station 6 probably as a result of partially sedimented samplers at Station 7 in 1976.

From Stations 5 through 8 the percent composition by number and weight of Ephemeroptera and Diptera generally decreased, whereas, Trichoptera increased (Table 31). *Ephemereilla* and *Atherix* were the subordinal taxa accounting for the decrease and *Hydropsyche* and *Brachycentrus* accounted for the increases between stations (Table 33). Figure 4 indicates this predominance of *Hydropsyche* and *Brachycentrus* in the lower Boulder River below Station 5.

The sampled aquatic insect communities at all stations on the lower Boulder River, with the exception of Station 7, were 92% or greater in total weight during 1976 than in 1975 (Table 34). The percent composition by number and weight of *Pteronarcella* at Stations 3 through 7 increased at least 13 and 11%, respectively, in 1976, thus accounting for much of the increases in the average total weight between years (Table 33). The increases in total weights at Station 8 were explained by the 11 and 5 and 14 and 19% increases in the percent composition by number and weight of *Hydropsyche* and *Brachycentrus*, respectively, in 1976 (Table 33).

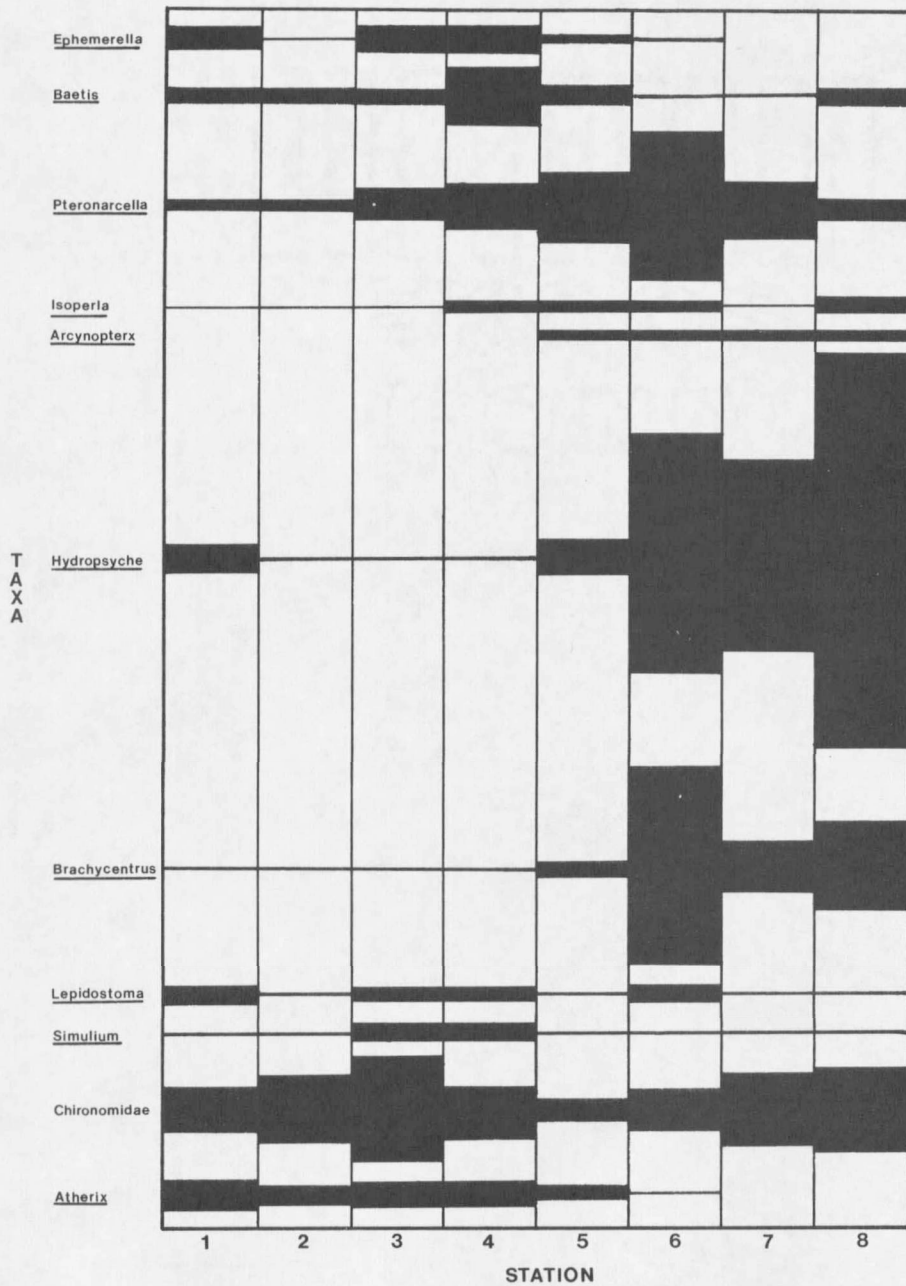


Figure 4. Distribution and abundance (average number per sampler) of predominant subordinal taxa collected during August and September 1975 and 1976.

SUMMARY AND DISCUSSION

Heavy metals were considered to be the major factor causing the severe depression of the aquatic insect community at Station 2. The measured chemical and physical characteristics of the upper Boulder River were largely similar except for heavy metals concentrations. Higher concentrations of heavy metals and lower average total number, weight, and number of subordinal taxa of aquatic insects occurred at Station 2. Vandenberg (1974) also found a severe reduction in total number of individuals and total number of taxa in areas of a stream receiving high concentrations of heavy metals. Taxa apparently sensitive to concentrations of heavy metals found in the upper river were

Pteronarcys which was present at Station 1 in moderate numbers and was never collected at Station 2, and *Ephemerella* which occurred only in substantially reduced numbers at Station 2. Warnick and Bell (1969) and Nehring (1976) concluded *Ephemerella subvaria* and *E. grandis*, respectively, were the most sensitive of the insects tested in their heavy metals bioassays. The increase in total weight of the benthos at Station 2 during 1976 occurred in conjunction with a decrease in heavy metals concentrations further suggesting heavy metals depressed the aquatic insect community at this station. Trout populations near Station 2 also appeared to be adversely affected by heavy metals.

Nelson (1976) found a lower rainbow trout population in the vicinity

of Station 2 as compared to that found in the vicinity of Station 1. He also reported eyed egg and fingerling survival were lower in the vicinity of Station 2 as compared to the vicinity of Station 1. He related these findings to the higher concentrations of heavy metals in the former area.

On the lower Boulder River, heavy metals possibly depressed the aquatic insect community at Station 5. In this section most chemical and physical characteristics generally increased in downriver progression. However, the highest concentrations of heavy metals were measured at Station 5 where the lowest average total numbers and weights and a low number of subordinal taxa occurred. A municipal sewage effluent and the addition of water containing a higher alkalinity, Muskrat Creek, may have mitigated the toxic effects of heavy metals on the biota at Stations 3 and 4.

Heavy metals may have had a mildly adverse effect on the aquatic insect communities at Station 6 through 8. *Hydropsyche* and *Brachycentrus* were dominant forms in this area of the lower river and ephemeropterans were virtually absent. *Hydropsyche betteni* is known to be tolerant to heavy metals (Warnick and Bell 1969). Boland (1968) found greater numbers of Hydropsychidae in areas receiving either periodic or chronic heavy metals pollution.

The heavy metals apparently affecting the insect communities most severely were copper and zinc. Copper is known to be highly toxic

to some insects (Nehring 1976; Warnick and Bell 1969). Zinc was present at high levels, is relatively stable, and therefore potentially lethal.

Major sources of zinc to the upper Boulder River were the tailings site at the town of Basin and Basin, Cataract, and High Ore Creeks. The highest concentrations in this section of the river occurred during low flows when the relative contributions of the heavy metals sources were greater. Jones (1958) described a similar pattern for the concentrations of zinc in a stream which received effluents from a mine tailings site.

In the lower Boulder River, the major sources of zinc were from the upper Boulder River and the erosion of the floodplain sediments near Station 5. The highest recorded concentrations of total zinc in the lower river occurred during high flows when zinc-laden floodplain sediments were eroded.

Since High Ore Creek was identified as the greatest contributor of total zinc to the upper Boulder River, efforts should be concentrated on the rehabilitation of this drainage. The creek should be diverted around the tailings area at the Comet Mine site by enlarging and lining the existing diversion channel and directing ground water away with the installation of a cut-off wall.

Increased channel stability is recommended to lessen the impact from the erosion of the floodplain sediments at Station 5.

Revegetation of the floodplain will increase channel stability. This has occurred apparently in an area above Station 3 (Mr. Heide, personal communication).

Special precautions should be taken to ensure the construction of Interstate Highway 15 through the Boulder Canyon does not result in increased velocities in the lower river. Higher velocities could increase the erosion of the heavy metals laden sediments and their effects on the biota.

