Aquatic Health Status of the Upper Tenmile Creek Drainage, Montana 1997-2001. Impacts from Abandoned Mines and Municipal Water Diversions

Montana Fish, Wildlife & Parks

Aquatic Health Status of the Upper Tenmile Creek Drainage, Montana 1997-2001. Impacts from Abandoned Mines and Municipal Water Diversions

Prepared for:
Montana Department of Environmental Quality
Helena, Montana

Prepared by:
Don Skaar, Montana Fish, Wildlife & Parks
Daniel L McGuire, McGuire Consulting

May 2008

Table of Contents

List of Acronyms

AA	Atomic Absorption
DEQ	Montana Department of Environmental Quality
DOC	Dissolved organic content
DNRC	Montana Department of Natural Resources
EPT	Ephemeroptera, Plecoptera, Tricoptera
FWP	Montana Fish, Wildlife and Parks
HAB	Habitat measurements
HYDSIM	Hydraulic/habitat simulation
ICP	Inductively Coupled Plasma-Atomic Emission Spectroscopy
LC_{50}	Median Lethal Concentration
MDPHHS	Montana Department of Public Health and Human Services
MTI	Metals Tolerance Index
NPL	National Priorities List
PHABSIM	Physical Habitat Simulation System
RBP	Rapid Bioassessment Protocol
RHABSIM	Riverine Habitat Simulation
ROD	Record of Decision
SI	Suitability indices
SZF	stage of zero flow
USEPA	United State Environmental Agency
USFS	United Stated Forest Service
USGS	United State Geological Survey
VAFs	Velocity Adjustment Factors
WETP	Wetted Perimeter
WUA	weighted usable area
YOY	Young of year

List of Figures

List of Tables

Chapter 1
Introduction

1.1 The Impacted Resource

The upper Tenmile Creek drainage in west-central Montana is defined as that portion of the drainage upstream from the City of Helena Water Treatment plant (Figure 1-1). Mining and water diversions (described below in detail) are probably the two most significant human activities that have altered the aquatic communities in the drainage, but other activities have undoubtedly caused impacts as well. Logging has been conducted in certain parts of the drainage, primarily in the Ruby, Monitor, Lazyman and Minnehaha Creek drainages. Associated tree removal and machinery activity in the riparian areas of these drainages has the potential to impact aquatic biota, but this has not been investigated. Road building is probably the other major human-caused impact in the drainage, and although most of this has occurred in conjunction with logging and mining, there are also roads built for real estate development, home building purposes, and mine reclamation activities. Rain and snow runoff from roads can carry suspended sediments into waterways, and potentially impact biota.

1.1.1 Mining

The upper Tenmile Creek drainage was mined extensively from the 1870s through the 1930s, primarily for gold, lead, zinc, and copper (United States Environmental Protection Agency (USEPA) 2002). The watershed contains 150 abandoned or inactive mine sites (Figure 1-1), and the mining wastes at these sites consist primarily of waste rock and tailings. Many of the sites also have acid-rock or acid-mine drainage, where water emanating from underground workings or mining wastes is acidic and contains high levels of metals. In many cases, the acidic waters from these mine sites connect to surface waters, resulting in surface water contamination. Once in the water, a proportion of all of the metals will stay in solution where they may be taken up by aquatic biota, especially gill-breathing fish and insects. Other metals will fall out of solution into streambed sediments, and work their way into biota via the food chain.

1.1.2 Stream Diversions

The City of Helena has diverted water from the Tenmile Creek drainage since the 1800s. Approximately 70-80% of Helena's potable water comes from the watershed (USEPA 2002). The city withdraws water from one location on the mainstem of Tenmile Creek and at four locations on tributaries (Figure 1-1). The city also operates two storage reservoirs (Chessman and Scott). Scott Reservoir dams up Ruby Creek and stores the water from this drainage for release at times of the year when needed most. The released water flows downstream to the Tenmile mainstem diversion above Rimini where it is piped to the Treatment Plant at the mouth of the Canyon near US Highway 12. Chessman Reservoir dams up Beaver Creek and receives water from Banner Creek via a pipe and flume system. When water is needed from Chessman Reservoir, it is released down Beaver Creek and diverted near its mouth into the same pipe system that leads to the Treatment Plant. The other tributary diversions on Minnehaha Creek, Moose Creek, and Walker Creek are located near the mouths of those drainages, and diverted water is fed into the same pipe system that leads to the Treatment Plant.

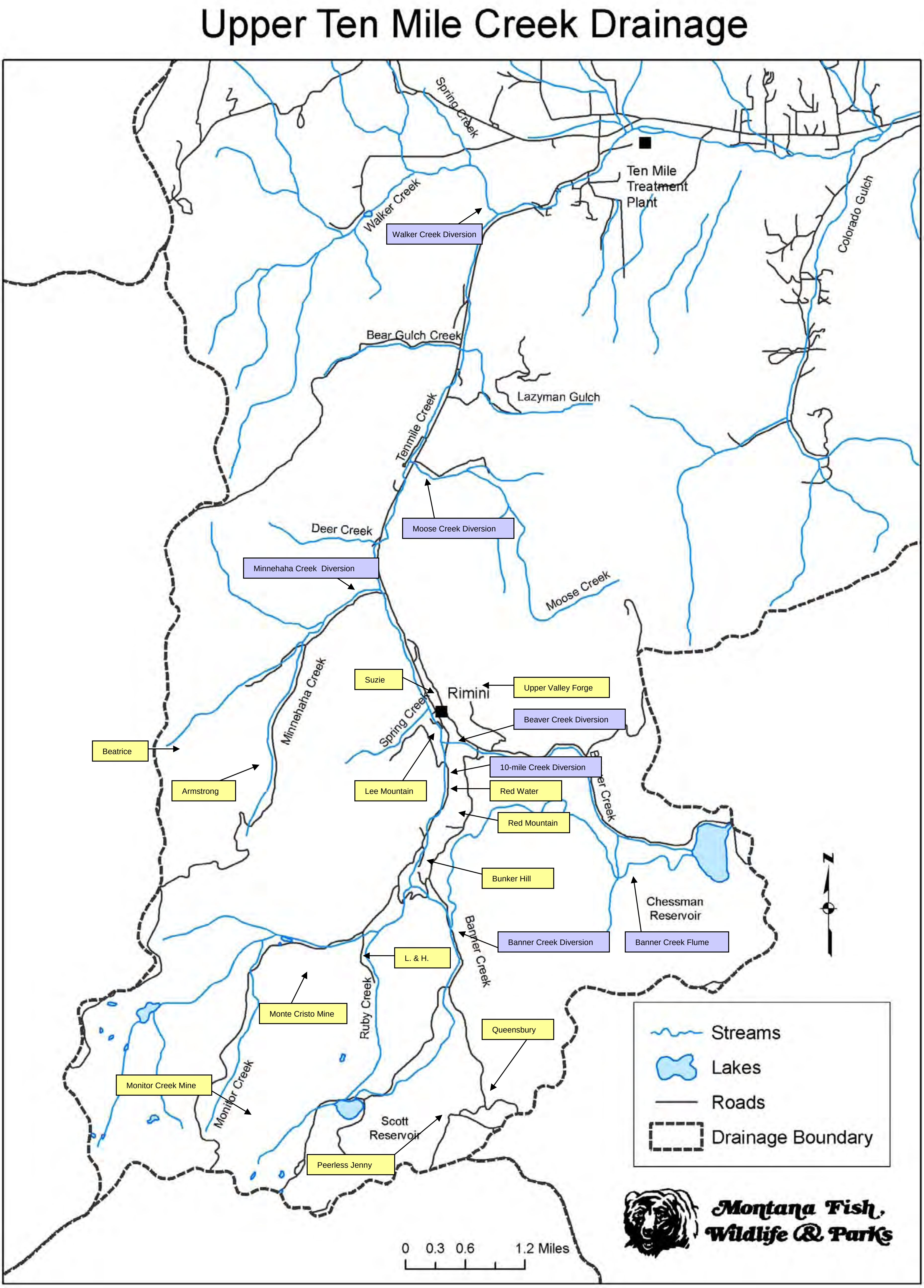


Figure 1-1

Locations of some of the mines that contribute metals to surface waters.

Location of stream diversion structures operated by the City of Helena.

The operation of this system has led to significant changes in the surface water hydrograph of the tributaries and mainstem relative to natural conditions. On the mainstem, most of the surface flow is diverted except during the months of snowmelt and spring rains (March-July). The result is that the flow in the mainstem of Tenmile Creek is much reduced for most of the year for the entire distance between the Rimini diversion and the Treatment Plant. Downstream of the Treatment Plant, some accretion of groundwater to the channel increases surface flows somewhat in most years. On the tributaries, the timing of withdrawals is similar, but since the diversions are near the mouths of the streams, there are relatively small stretches of stream that are seriously dewatered. The greater impact of these tributary diversions is due to the fact that the dams impede any upstream movement of fish into the drainages.

1.2 Scope of Work

This project was conducted from 1997-2001 to assess the extent to which metals contamination and water diversions impair aquatic life in the upper Tenmile Creek drainage. To accomplish this goal, we used a variety of methods and sampling approaches. To assess the nature and extent of metals contamination in the aquatic environment, we analyzed for metals in water, sediment, biofilm, aquatic insects and fish. We also used in-situ bioassays to determine the acute toxicity of these metals to fish at different sites. To assess the extent to which water withdrawls were harmful to aquatic life, we used Physical Habitat Simulation System (PHABSIM) and Wetted Perimeter (WETP) survey methodologies to estimate water needs for different lifestages of different trout species. Finally, we measured community composition and density of aquatic insects and fishes at various locations in the drainage and compared these parameters to reference sites with no water withdrawals or metals contamination.

At the conclusion of this report, we synthesize all of these data in an attempt to identify the extent to which differences in insect or fish communities among sites are due to the influence of metals contamination or dewatering. For the most part, the data collected in this study represent a “baseline” condition to the extent that it portrays conditions in the drainage prior to mine cleanup efforts under Superfund jurisdiction or modification of water diversion practices. The Upper Tenmile Creek area was first designated a Superfund site in the fall of 1999 and some limited emergency cleanup efforts at the Bunker Hill Mine began in 2000. However, most effort has been subsequent to issuance of the Record of Decision in 2002. Operation of the City water supply system has remained largely unchanged since this study began in 1997, although in 2003 the City announced the intention to reduce their dependence on surface water in the drainage and rely more on Missouri River water to meet their needs. This has not yet occurred however, as the City needs to raise considerable funding to accomplish this goal.

1.3 Study Design

The approach taken in this study was to establish sampling sites that would be reflective of mining conditions at that site or in the drainage upstream of that site. On the mainstem, ten sites were established (Figure 1-2 and Table 1-1). The Below Banner Creek site served as a “reference” site, but only to the extent that it was above the City Diversion and therefore represented conditions free from water diversions and mining activity in the Rimini vicinity. This site however, was downstream of some relatively minor mining activity that had occurred in the Banner Creek, Monitor Creek, and Ruby Creek watersheds. Further downstream, the Rimini site served as the location where impacts from mining and dewatering were anticipated to be at their worst. The mainstem sites downstream from Rimini were selected to show the attenuation or moderation of impacts from mining in the Rimini area. Mainstem sites were placed above and Below Minnehaha Creek to capture effects that might occur due to the impact of mining in that drainage. Below Minnehaha Creek, mining in the drainage has been relatively minor.

Four tributary sites were chosen for the study, with Moose Creek representing a true reference stream, as no mining or stream diversions occur in the drainage above the sample site. The other tributary sites were chosen as integrator sites, to the extent that they were intended to reflect mining impacts in those drainages. The sites on Monitor and Minnehaha creeks were at the lower end of their watersheds, and thus truly integrated the mining impacts; the site on Minnehaha Creek was also above the City Diversion, and thus dewatering was not a factor in influencing fish and insect populations at that location. The site on Banner Creek was also above the City Diversion, but because this diversion was fairly high in the watershed, it did not serve as an intergrator for the entire drainage.

1.4 References

U.S. Environmental Protection Agency. 2002. Record of Decision. Upper Tenmile Creek Mining Area Site. Lewis and Clark County, Montana.

Table 1-1 Sample Collection Sites used in this Study, 1997-2001.

Sample Site Name	Sampling effort	Latitude/Longitude	General Description of Lower End of Site
Tenmile Creek below Banner Creek	1,2,3,4,5,6,7	46.468620° 112.250404° (upper end) 46.469720 112.249875 (lower end)	Where Bunker Hill Mine waste reached creek
Tenmile Creek in Rimini	1,2,3,4,6,7	46.489923 112.249312 (upper end) 46.491337 112.251080 (lower end)	About 100 ft below bridge
Tenmile Creek near Sawmill	1,2,3,4,5,6,7	46.496871 112.254293 (upper end) 46.498897 112.255079 (lower end)	Where 10-Mile Creek abuts road
Tenmile Creek above Minnehaha Creek	1,7	46.505652 112.259786	About 100 ft above bridge
Tenmile Creek below Minnehaha Creek	1,2,3,5,6,7	46.508513 112.261446 (upper end) 46.509792 112.262652 (lower end)	Where 10-Mile Creek turns away from RR grade
Tenmile Creek above Moose Creek	1,2,7	46.521026 112.257147	Right channel of split channel area
Tenmile Creek at Moose Creek Campground	1,2,3,4,5,6	46.522593 112.256648 (upper end) 46.524660 112.256824 (lower end)	At United States Geologic Survey (USGS) gage house
Tenmile Creek below Moose Creek	7	46.529670 112.252214	Where 10-Mile Creek turns away from road
Tenmile Creek at Parrett's house	7	46.567930 112.219906	At Parrett's house
Tenmile Creek at Treatment Plant	1,2,3,4,5,6,7	46.569819 112.217520 (upper end) 46.571720 112.215678 (lower end)	At bridge
Monitor Creek	1,3,4,5,6	46.453839 112.283554 (upper end) 46.455926 112.281038 (lower end)	About 100 ft above confluence with 10-Mile Cr.
Banner Creek	1,3,4	46.456146 112.243283 (upper end) 46.457366 112.243466 (lower end)	At city diversion
Minnehaha Creek	1,3,4,5,6	46.506557 112.262751 (upper end) 46.507275 112.261506 (lower end)	At city diversion
Moose Creek	1,2,3,4,5,6,7	46.524582 112.253815	At city diversion
Walker Creek	7	46.561951 112.239391	At city diversion
Poison Creek	4	46.476934 112.245024 (upper end) 46.477161 112.245541(lower end)	100 ft below road crossing

Latitude/longitude coordinates for sites where fish density estimates were made indicate the upper and lower ends of the electrofishing section; otherwise the coordinates indicate the upper and lower extent of sampling for tissue, sediment or biofilm.

For sampling effort: 1=sediment metal analysis, 2=biofilm metal analysis, 3=insect metal analysis, 4=insect community composition, 5=fish metal analysis, 6=fish density estimates, 7=fish bioassays,

Upper Ten Mile Creek Drainage

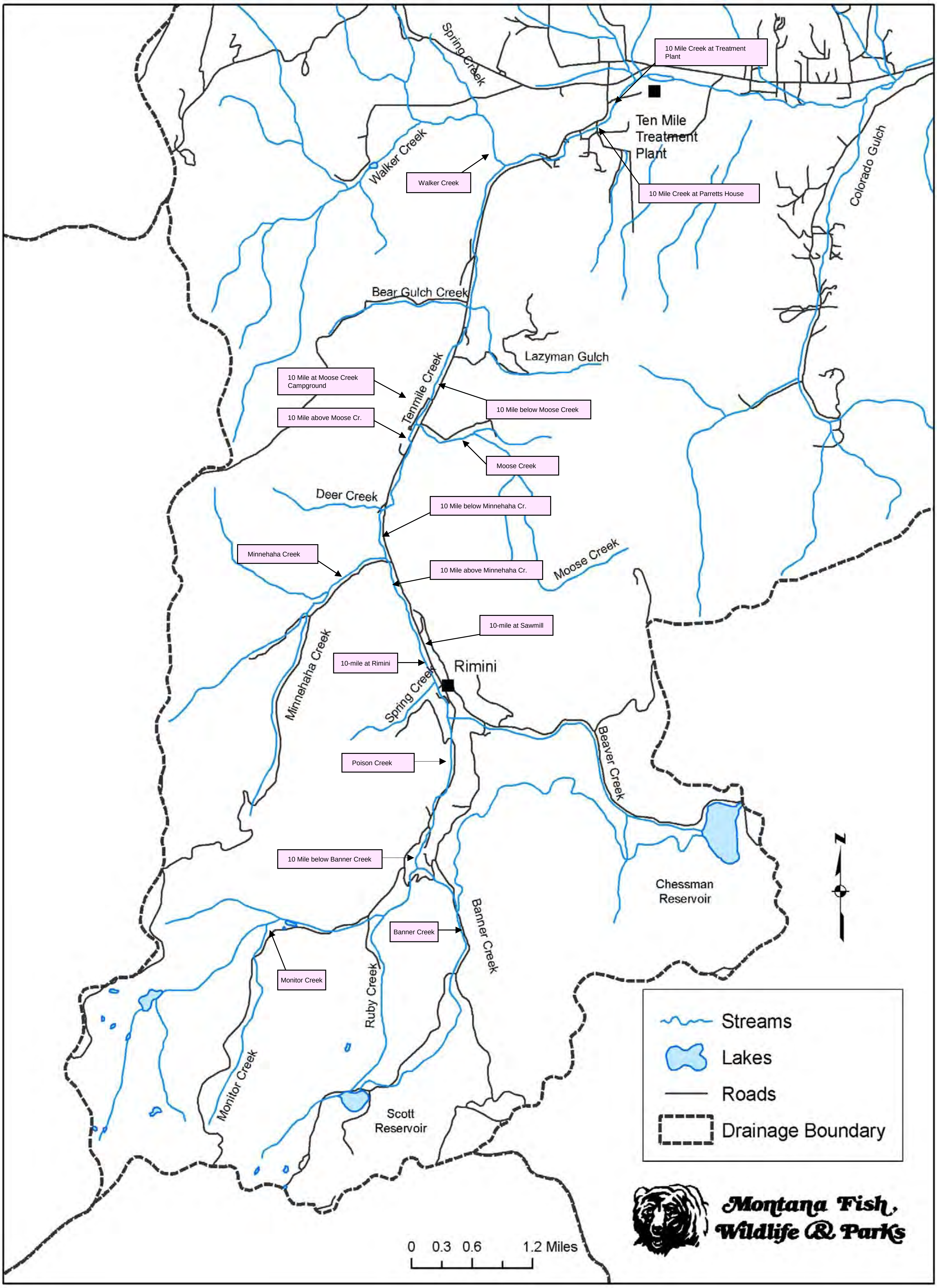


Figure 1-2
Locations and names of sample sites used in this study, 1997-2001.

Chapter 2
Trace Elements in Abiotic and Biotic Media

2.1 Purpose and Scope

Trace elements were measured in the biotic and abiotic media in the Tenmile Creek drainage to: 1) determine drainages and portions of drainages where mining has occurred and where trace element residues were elevated relative to reference drainages; 2) determine levels of trace elements in biota that might be considered harmful to the organisms; and 3) identify the extent to which food chain transfer and movement of trace elements may be occurring between trophic levels.

2.2 Methods and Materials

2.2.1 Sample Collection

The locations of sample sites are shown in Figure 1-2 and a description of each site along with latitude: longitude coordinates is provided in Table 1-1. Not all media were sampled at all sites, but within a site, all samples were taken within a section of stream approximately 400 meters in length.

2.2.1.1 Bed Sediment

Bed sediments were collected for trace element analysis using the methods and procedures of Dodge et al. (1997). In 1998, two bed sediment samples were collected from each of six mainstem sites and four tributary sites. In 1999, three samples were taken from each of the same sites as used in 1998, plus two additional mainstem sites. Sediments were collected from the surface of depositional areas along the streams. Acid-washed polypropylene scoops were used to collect the sediment. Sediments that appeared to be in a reduced state (darker color) were not sampled. Sediments were passed through a 63-μm filter, using stream water as a carrier, and stored in 500 mL plastic bottles.

2.2.1.2 Benthic Macroinvertebrates

Sampling procedures for benthic macroinvertebrates were designed to accomplish the following: 1) to collect immature insects close to the time of emergence, so as to assure collection of the largest possible individuals. In Tenmile Creek, this sampling occurred from late June to early August, depending on elevation; 2) to sample similar taxa at each site to allow for comparisons among sites; and 3) to sample insects from different feeding guilds. Therefore, collector-filterers were represented by the caddisfly *Arctopsyche grandis*; engulfers (predators) were represented by the stoneflies *Doronueria* sp. and *Drunella* sp.; collector-gatherers were represented by the mayflies *Ameletus* sp., *Baetis* sp. and *Heptageniidae;* scrapers were represented by the stonefly *Drunella* sp. and Heptageniid mayflies.

The insects were sampled with nylon-mesh kick nets from riffle areas of the sites. Sample collection continued until enough individuals were collected to provide sufficient mass for analysis. Animals were removed from the net with plastic forceps and placed in acid-rinsed plastic containers filled with site water. The taxa were held together in the containers; separate containers were not provided for individual species. The containers were placed on ice for six hours to allow the insects to depurate the contents of their digestive tracts. After this time, the water was drained and the insects immediately frozen.

In 2000, six mainstem sites and three tributary sites were sampled for insects from late June to mid-July. Densities and diversity were low and only one or two species were available in sufficient quantities to conduct metals analyses at any one site. Therefore, we sampled the same sites again in 2001, but from mid-July to early August. Collections were much more successful, and as many as four taxonomic groups were available at each site.

2.2.1.3 Biofilm

Biofilm consists of the organic/inorganic matrix of material attached to the large rocky substrate of streams. It is composed of fine sediment particles, bacteria, algae and moss and detritus. This was sampled in triplicate at each site. Biofilm was scrubbed off rocks with an acid-rinsed toothbrush and into a plastic tub. Large detritus, sediment particles larger than sand, and animal life were then removed. The remaining sample was transferred to acid-rinsed plastic bottles and refrigerated or frozen while awaiting analysis.

2.2.1.4 Fish

Fish were collected for tissue analysis using a backpack electroshocker. Standard procedures were followed to process all fish and fish tissues. Fish were anaesthetized with MS-222 to facilitate easy handling. Lengths and weights were measured on all fish. Tissues (gill arches, fillets and livers) were removed using acid-rinsed stainless steel or plastic instruments. While removing the livers, care was taken to avoid bursting the gall bladder and thus contaminating the sample. The tissues were placed in acid-rinsed vials and placed on ice for transport back to the laboratory where they were frozen while awaiting analysis.

2.2.2 Sample Preparation and Analysis

Sediment and biofilm samples brought in from the field were submitted directly to the laboratory for analysis, but the insect and fish tissue samples required some preparatory work. Insect samples were thawed and individuals were identified and sorted by species or genus. There were usually 20-50 individuals per group, although fewer individuals were needed for larger species such as *Arctopsyche grandis*. Ten individuals from each species or genus were measured for total length. Each insect sample was then rinsed with distilled water. For fish gill tissue, samples were thawed and lamellae were trimmed off all gill arches. Both gill and liver samples were pooled (typically from 2-6 individuals per site) in order to get the needed quantity of material for analysis.

Trace element analyses were performed by the Environmental Laboratory at the Montana Department of Public Health and Human Services (MDPHHS) in Helena, Montana. All sediment, biofilm, insect and fish samples were dried in an oven at $60^{o}C$, and then microwave-digested with acid in accordance with USEPA method 3051 (insect and fish livers were ground with mortar and pestle prior to microwave digestion). Samples were analyzed for metals and arsenic using Atomic Absorption (AA) and/or Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP) instrumentation and USEPA methods 200.7 and 200.9.

Quality assurance in the MDPHHS laboratory for all samples included analysis of spiked and duplicate samples (every 10th sample) and reference samples (every 25th sample).

2.3 Results

2.3.1 Bed Sediments

Sediment samples were collected from 10 sites in 1998 and 12 sites in 1999 (Table 2-1 and Table 2-2). In general, mean values from the 1999 data are probably more precise than the 1998 data because they are based on three samples rather than two. However, the results for selenium and cadmium in the 1998 samples were more useful than the 1999 samples due to lower detection levels.

The results are reflective of the large amount of mining and acid-mine drainage occurring in the immediate vicinity of Rimini. For the Tenmile Creek mainstem sites, concentrations of all metals but manganese increased markedly from the Below Banner Creek site to the Rimini site (based on the 1999 data). Rimini was the site where most metals and arsenic were found in the highest mean concentrations: aluminum (18,967 μg/g), arsenic (7,857 μg/g), copper (352 μg/g), iron (138,333 μg/g) and sodium (1,456 μg/g). The next location downstream (Sawmill) was highest for manganese (3,040 μg/g) and lead (1,860 μg/g), while the Above Minnehaha site was highest for calcium (9,217 μg/g), cadmium (19.0 μg/g) and zinc (5,837 μg/g). Magnesium reached its highest levels (6,013 μg/g) at the Below Minnehaha site.

With respect to the tributary sites (using the 1999 data), Minnehaha Creek was highest for arsenic and most metals (aluminum, cadmium, copper, lead and zinc). Moose Creek was also highest for several metals (calcium, iron, magnesium, manganese and sodium), which might be expected to be elevated in non-mining areas and due to natural erosional processes. Monitor Creek had a notably higher level of mercury (0.59 μg/g) than all tributary or mainstem sites, and this suggests that mercury might have been used for mining in that drainage.

The acidity of the water in Tenmile Creek is highest immediately below the Suzie Mine adit discharge (immediately upstream from our Rimini site), and the pH increases in the downstream direction below Rimini. The pH data are presented in more detail in Chapter 6, but measurements taken during bioassays (August 19, 1999) showed a pH of 4.66 at Rimini, 7.00 at Sawmill, 7.7 Above Minnehaha, 7.6 Below Minnehaha, 7.18 Above Moose Creek and 7.65 at the Treatment Plant. It would be expected that most of the metals would precipitate out of solution (at least partially) through this range of pH. The minimum pH value for complete precipitation as metal hydroxides was summarized by Kelly (1988) as follows: Fe (III) 4.3, Al 5.2, Pb (II) 6.3, Cu (II) 7.2, Zn (8.4), Fe (II) 9.5, Cd 9.7 and Mn (II) 10.6. Our bed sediment results were generally consistent with these pH thresholds for precipitation, and help explain much of the variation in trends of metals concentrations at varying distances downstream from Rimini.

Table 2-1 Trace Elements (µg/g Dry Wt) in Fine-Grained Sediments in the Tenmile Drainage, September 4, 1998.
Values are expressed as mean and (range) of 3 samples at each site. Non-detect values assumed to be half the level of detection when used to calculate a mean value.

Site	Al	As	Ca	Cd	Cu	Fe	Mg	Mn
Below Banner Creek	9815 (9130-10500)	389 (209-569)	4305 (4230-4380)	<2.00 (<2 - <2)	70.1 (67.4-72.7)	25900 (24800-27000)	2130 (2030-2230)	1940 (1920-1960)
Rimini	41850 (37800-45900)	8155 (7390-8920)	1520 (1220-1820)	<2.00 (<2 - <2)	588 (545-631)	117500 (111000-124000)	1130 (871-1390)	349 (271-428)
Sawmill	9170 (8340-10000)	4840 (3980-5700)	2465 (550-4380)	6.6 (2.5-10.7)	277 (265-288)	37650 (37600-37700)	3560 (3540-3580)	1041 (982-1100)
Above Minnehaha Cr	8480 (8300-8660)	4350 (3610-5090)	7000 (6600-7400)	14.4 (13.0-15.8)	246 (232-260)	32300 (30600-34000)	4185 (4060-4310)	1420 (1280-1560)
Moose Cr Campground	6850 (6700-7000)	1026 (262-1790)	5800 (5750-5850)	<2.00 (<2 - <2)	181 (163-200)	125000 (26000-224000)	3635 (3490-3780)	1225 (1140-1310)
Treatment Plant	44300 (11000-77600)	1349 (819-1880)	8080 (7600-8560)	9.8 (3.6-16.0)	227 (217-236)	25500 (21000-30000)	24550 (5100-44000)	2245 (2030-2460)
Moose Creek	8505 (7560-9450)	15.0 (12.3-17.7)	9390 (8990-9790)	<2.00 (<2 - <2)	26.3 (24.0-28.7)	181700 (29400-334000)	3890 (3630-4150)	2015 (1840-2190)
Minnehaha Creek	10305 (8710-11900)	46.8 (40.8-52.8)	4520 (3930-5110)	3.1 (<2 - 5.2)	222 (217-227)	19700 (16300-23100)	3285 (2950-3620)	1016 (662-1370)
Monitor Creek	5400 (5320-5480)	23.1 (22.8-23.3)	1315 (1260-1370)	<2.00 (<2 - <2)	24.4 (24.3-24.5)	13600 (13600-13600)	271 (249-293)	963 (955-970)
Banner Creek	8455 (7960-8950)	32.0 (30.3-33.7)	4665 (4550-4780)	<2.00 (<2 - <2)	53.8 (53.1-54.5)	24750 (24000-25500)	2350 (2310-2390)	2425 (2290-2560)

Table 2-1 (continued) Trace Elements in Fine-Grained Sediments in the Tenmile Creek Drainage, 1998. Values are expressed as mean and (range) of 3 samples at each site. Non-detect values assumed to be half the level of detection when used to calculate a mean value.

Site	Na	Pb	Se	Zn
Below Banner Cr	1120 (1040-1200)	670 (301-1040)	11.6 (11.4-11.8)	733 (702-763)
Rimini	1000 (830-1170)	1410 (1380-1440)	<0.05 (<0.05)	966 (902-1030)
Sawmill	3275 (3050-3500)	2610 (2170-3050)	10.6 (10.1-11.2)	1705 (1300-2110)
Above Minnehaha	5210 (4980-5440)	2530 2130-2930)	11.1 (10.9-11.3)	3040 (2900-3180)
Moose Cr Campground	2420 (2260-2580)	1570 (1380-1760)	3.5 (<2 - 6.00)	1945 (1830-2060)
Treatment Plant	3975 (3410-4540)	1182 (904-1460)	<2.00 (<2 - <2)	2885 (2300-3470)
Moose Creek	56.5 (17.2-95.7)	<5.00 (<5 - <5)	2.35 (2.1-2.7)	37.2 (32.9-41.6
Minnehaha Creek	2560 (2070-3050)	111 (107-116)	<2.00 (<2 - <2)	2015 (1660-2370)
Monitor Creek	446 (427-465)	72.5 (70.6-74.5)	<2.00 (<2 - <2)	315 (315-315)
Banner Creek	521 (491-552)	70.0 (67.8-72.3	<2.00 (<2 - <2)	510 (483-537)

Table 2-2 Trace Elements in Fine-Grained Sediments (µg/g Dry Wt) Measured at Various Sites in the Tenmile Creek Drainage, July 28 - August 10, 1999. Values are expressed as mean and (range) of 3 samples at each site, with the exception of Hg where sample size was one. Non-detected values were assumed to be half the level of detection when used to calculate a mean value.

Site	Al	As	Ca	Cd	Cu	Fe	Mg
Below Banner Creek	7720 (6590-9810)	87.9 (69.8-105)	4257 (3850-5020)	<6.0 (<6.0-<6.0)	51.9 (42.3-57.0)	18233 (16500-21600)	2343 (2080-2820)
Rimini	18967 (17900-20200)	7857 (6590-9390)	8593 (4080-12800)	<6.0 (<6.0-<6.0)	352 (341-359)	138333 (117000-154000)	4340 (3230-5580)
Sawmill	12067 (11400-12600)	3900 (3410-4710)	5593 (5290-5930)	18.4 (17.9-18.7)	320 (305-333)	51667 (45600-60900)	3390 (2920-3920)
Above Minnehaha Cr.	11533 (10900-12200)	1497 (1280-1650)	9217 (7900-9950)	19.0 (16.6-20.3)	254 (245-263)	38567 (34700-42200)	4497 (4100-4710)
Below Minnehaha Cr.	8720 (7660-10700)	519 (471-563)	8717 (8060-9940)	12.7 (11.3-14.8)	173 (166-185)	21100 (18400-25900)	6013 (5250-7360)
Above Moose Creek	6427 (5970-6980)	606 (536-709)	5940 (5510-6400)	17.1 (6.5-30.4)	188 (138-239)	19300 (17800-21600)	2863 (2660-3080)
Moose Cr. Campground	7243 (6980-7550)	596 (479-855)	5830 (5400-6050)	7.0 (5.9-8.3)	204 (176-231)	17800 (16500-19600)	3247 (2940-3660)
Treatment Plant	8243 (6820-9070)	368 (300-422)	8827 (7710-9450)	9.9 (9.6-10.1)	133 (122-146)	22933 (18100-25400)	4100 (3520-4510)
Banner Creek	8037 (7800-8180)	31.7 (30.7-33.0)	5903 (5500-6490)	<6.0 (<6.0-<6.0)	49.8 (49.0-50.5)	26100 (24200-27700)	2483 (2400-2600)
Monitor Creek	5570 (5510-5650)	24.2 (23.3-25.5)	1790 (1460-2160)	<6.0 (<6.0-<6.0)	27.1 (24.7-28.9)	11600 (11400-11800)	526 (469-588)
Moose Creek	9600 (8810-11100)	9.5 (<10.0-13.0)	11733 (11300-12400)	<6.0 (<6.0-<6.0)	23.8 (21.3-25.7)	38767 (36500-40400)	4023 (3830-4130)
Minnehaha Creek	10360 (4980-14700)	42.0 (24.9-52.1)	4190 (2370-5750)	27.2 (6.8-42.6)	207 (80.0-300)	15433 (10700-19400)	3073 (2180-3920)

Table 2-2 (continued) Trace Elements in Fine-Grained Sediments (µg/g Dry Wt) Measured at Various Sites in the Tenmile Creek Drainage, July 28 - August 10, 1999.

Site	Mn	Na	Pb	Se	Zn	Hg
Below Banner Creek	1180 (989-1420)	192 (157-226)	161 (136-190)	10.0 (9.9-10.0)	559 (452-702)	
Rimini	931 (830-1040)	1456 (337-2920)	873 (826-909)	<10.0 (<10.0-<10.0)	2497 (1920-2920)	0.14
Sawmill	3040 (2770-3220)	392 (365-410)	1860 (1570-2080)	<10.0 (<10.0-<10.0)	4110 (3770-4620)	0.24
Above Minnehaha Cr.	2307 (2080-2540)	1057 (781-1370)	512 (470-557)	<10.0 (<10.0-<10.0)	5837 (4660-6770)	0.16
Below Minnehaha Cr.	631 (473-903)	566 (448-768)	456 (389-505)	<10.0 (<10.0-<10.0)	1115 (976-1390)	0.15
Above Moose Creek	858 (743-1030)	687 (627-773)	418 (391-465)	<10.0 (<10.0-<10.0)	1169 (866-1380)	0.33
Moose Cr. Campground	742 (312-1490)	519 (389-637)	632 (580-721)	<10.0 (<10.0-<10.0)	1280 (1230-1330)	0.20
Treatment Plant	1380 (1020-1640)	873 (684-1060)	327 (281-388)	<10.0 (<10.0-<10.0)	2317 (1750-2780)	0.18
Banner Creek	2363 (1880-2650)	281 (231-343)	55.6 (50.7-58.9)	10.0 (9.9-10.0)	507 (474-535)	0.13
Monitor Creek	679 (521-846)	299 (215-409)	86.3 (85.0-87.0)	9.9 (9.7-9.9)	300 (235-345)	0.59
Moose Creek	2720 (2440-2940)	816 (726-862)	6.7 (<10.0-10.1)	<10.0 (<10.0-<10.0)	39.1 (34.0-43.0)	0.06
Minnehaha Creek	743 (534-859)	402 (224-507)	111 (54.3-149)	<10.0 (<10.0-<10.0)	2000 (880-2850)	0.16

2.3.2 Biofilm

Biofilm samples were collected in 1999 and analyzed for a smaller suite of trace elements (As, Al, Cd, Cu, Pb, Zn) and at fewer sites than the sediments. The Rimini site had higher levels of arsenic (15,717 μg/g), aluminum (27,000 μg/g), copper (2,420 μg/g) and lead (1,673 μg/g) than the other eight sites (Table 2-3). The Below Minnehaha site had the highest levels of cadmium (73.4 μg/g) and zinc (21,433 μg/g). The Moose Creek site served as a reference site, and was also the only tributary sampled. The biofilm in Moose Creek had substantially lower levels of all trace elements than the mainstem sites, with the exception of aluminum.

2.3.3 Benthic Macroinvertebrates

Sampling and analysis of metals in immature aquatic insects was more thorough in 2001 than in 2000, when a greater number of insect species were analyzed for a greater number of trace elements. Selenium and cadmium were found in the lowest concentrations, typically in the low to sub-μg/g range, whereas iron and calcium were found at the highest concentrations, reaching a peak at greater than 10,000 μg/g at the Rimini site (Tables 2-4 and 2-5). Generally speaking, *Arctopsyche* (net-spinning caddisfly) and *Doronueria* (predatory stonefly) had lower levels of most metals than did *Drunella* (predators or scrapers) or the mayfly mix (collector-gatherers or scrapers). The metals for which this trend was most pronounced were copper, manganese, lead and zinc.

On the mainstem of Tenmile Creek, three types of patterns of trace element accumulation were seen (Figure 2-1). In the case of arsenic, concentrations rose markedly from Below Banner Creek to Rimini and then decreased quickly downstream, only to increase again between Below Minnehaha and Moose Creek Campground. Concentrations of lead followed the same general pattern, although the magnitude of difference between the site with the highest levels (Rimini) and the lowest levels (Treatment Plant) were much less for lead than it was for arsenic. The pattern for zinc was much different. The increase from Below Banner to Rimini was much more subtle than for the other two metals, as was the subsequent drop in concentrations at stations downstream of Rimini.

The trends on the tributaries are easiest to put in perspective relative to Moose Creek, the reference site. This site is at the lower end of a drainage which has had no mining and this is reflected in the concentrations of all trace elements and major ions in the water. Some of the major ions, which normally occur as a result of rock weathering and soil erosion (sodium, calcium, aluminum and iron) were similar in concentration to those found at most of the other sites sampled in this study. Most of the trace elements that are typically enriched in surface waters as a result of mining (arsenic, cadmium, copper, manganese, lead, zinc) were much lower in Moose Creek than in the other sites in the Tenmile drainage (Parrett and Hetinger 2000). This trend was generally seen in the concentrations in aquatic insects as well. For example, levels of Fe, Mg, and Na in *Doronueria* were similar to most other sites, whereas Cu, Cd, Pb and Zn were generally much lower than the other sites (Table 2-5).

Table 2-3 Concentration of Trace Elements (µg/g Dry Wt) in Biofilm Sampled from August 5-13, 1999 at Various Sites in the Tenmile Creek Drainage. N=3 for All Sites. Values Represent Mean and Range.

Site	As	Al	Cd	Cu	Pb	Zn
Below Banner Creek	116 (105-123)	7400 (7100-7760)	8.55 (7.43-9.14)	47.5 (38.8-52.9)	264 (254-271)	598 (494-652)
Rimini	15717 (13300-17910)	27000 (25900-28300)	56.1 (55.2-56.6)	2420 (2300-2580)	1673 (1610-1770)	3606 (3440-3710)
Sawmill	3348 (3227-3580)	13533 (12600-14500)	52.2 (47.0-57.8)	878 (815-912)	527 (508-548)	12467 (11300-13600)
Below Minnehaha Cr	832 (784-892)	7970 (7460-8400)	73.4 (69.1-79.7)	366 (351-391)	205 (195-217)	21433 (21000-22700)
Above Moose Creek	560 (492-657)	4130 (3700-4630)	25.7 (19.8-30.2)	201 (190-219)	158 (150-164)	4757 (3700-4630)
Moose Cr Campground	538 (290-668)	4387 (3320-5250)	28.7 (9.7-42.7)	195 (83.9-277)	214 (192-229)	3590 (1480-5450)
Treatment Plant	200 (177-213)	6100 (4800-6990)	26.2 (13.1-32.9)	145 (92.5-181)	149 (136-158)	3743 (2270-4550)
Moose Creek	19.9 (4.5-27.7)	7183 (7010-7510)	5.63 (4.4-6.3)	34.5 (17.7-43.8)	1.74 (<2-3.21)	120 (45.1-159)

Table 2-4 Trace Elements in Immature Aquatic Insects (µg/g Dry Wt) in the Tenmile Creek Drainage, June 27- July 13, 2000.

Site	Taxon	As	Cd	Cu	Pb	Zn
Below Banner Creek	*Ameletus* sp.	5.95	15.7	22.7	5.42	1590
Below Banner Creek	*Doronueria* sp.	0.96	2.13	46.6	1.15	380
Rimini	*Baetis* sp.	620	13.8	151	53.5	1680
Sawmill	*Baetis* sp	66.3	14.0	69.0	12.5	2800
Sawmill	*Doronueria* sp.	10.9	2.23	64.4	2.13	560
Below Minnehaha Creek	*Doronueria* sp.	3.74	4.66	95.9	1.29	759
Moose Creek Campground	*Doronueria* sp.	4.22	5.17	98.4	1.2	711
Treatment Plant	*Doronueria* sp	1.46	2.96	46.2	0.91	371
Moose Creek	*Ameletus* sp	2.36	1.35	17.7	0.42	112
Moose Creek	*Doronueria* sp	0.28	<0.20	30.2	<0.20	200
Banner Creek	*Ameletus* sp	4.54	20.9	26.0	2.05	1690
Banner Creek	*Doronueria* sp	0.3	1.23	51.9	<0.20	241
Monitor Creek	*Doronueria* sp	0.65	3.0	52.0	0.4	372

Table 2-5 Trace Elements in Immature Aquatic Insects (µg/g Dry Wt) in The Tenmile Creek Drainage, July 10 - August 3, 2001.
Sample size is indicated when it consisted of less than 10 individuals. For the taxa, *Arctopsyche=Arctopsyche grandis*; *Drunella* sp. includes *D. coloradensis, D. doddsi* and *D. spinifera*; *Doronueria* species were not identified; Mayfly mix included animals in the genera of *Ameletus, Baetis* and the family Heptageniidae.

Site	Taxon	Length, mm (range)	Al	As	Cd	Ca	Cu	Fe	Mg	Mn	Pb	Se	Na	Zn
Below Banner Cr (N=5)	*Arctopsyche*	19.4 (17.5-22.0)	687	4.3	4.8	1360	7.56	458	2100	75.0	5.60	0.8	2100	228
Below Banner Cr	*Drunella* sp.	12.4 (10.5-13.5)	1290	80.4	15.9	2670	69.4	1840	2920	266	54.9	0.21	2070	2830
Below Banner Cr	Mayfly mix	5.5 (4.0-7.0)	1590	19.2	28.4	3460	27.7	2190	2740	150	29.4	0.9	1350	2510
Below Banner Cr (N=7)	*Doronueria* sp.	24.7 (22.5-32.0)	706	6.2	4.2	4170	89.9	213	2090	73.6	4.8	0.62	4200	712
Rimini	*Drunella* sp.	11.9 (11.0-13.0)	1130	423	13.6	2530	122	7490	2190	101	33.4	3.46	1850	1850
Rimini	Mayfly mix	8.0 (6.5-16.5)	3310	878	29.6	5750	118	13200	4010	161	121	1.24	1600	3370
Rimini	*Doronueria* sp.	14.5 (13.0-16.0)	1220	109	9.10	15800	85.3	2270	3610	97.0	19.5	1.00	994	786
Sawmill	*Drunella* sp.	12.5 (11.5-13.5)	723	324	8.40	1960	93.9	1950	2160	164	80.1	1.85	7440	2850
Sawmill	*Doronueria* sp.	28.9 (21.0-31.5)	299	35.7	4.40	3090	90.3	284	2130	43.1	13.6	1.18	4980	664
Below Minnehaha Cr	*Drunella* sp.	12.1 (9.0-16.0)	462	10.4	9.30	1180	71.5	400	1900	220	15.4	1.68	4880	1240
Below Minnehaha Cr	Mayfly mix	7.1 (6.0-8.5)	701	10.7	17.9	3610	46.3	581	2410	98.7	7.80	1.51	1330	3220
Below Minnehaha Cr (N=6)	*Doronueria* sp.	27.3 (22.0-38.0)	229	2.00	7.00	3760	74.4	139	2000	56.8	1.30	1.11	1900	703
Moose Cr Camp (N=4)	*Arctopsyche*	22.4 (21.5-23.0)	438	16.1	4.00	964	17.6	485	1600	70.9	6.50	1.31	7230	274
Moose Cr Campground	*Drunella* sp.	11.3 (9.0-15.0)	409	40.1	15.1	2030	74.3	829	2220	220	22.2	1.33	6080	2410
Moose Cr Campground	Mayfly mix	6.4 (5.5-7.5)	939	75.2	20.5	4720	70.6	12.2	2870	164	25.2	1.93	1380	3400
Moose Cr Campground	*Doronueria* sp.	25.2 (14.5-37.0)	242	2.50	5.00	4520	80.4	169	2180	76.1	2.03	1.11	4700	589
Minnehaha Cr	*Arctopsyche*	19.9 (18.0-21.5)	373	0.9	18.3	820	34.1	288	1420	94.1	2.20	2.20	5940	445
Minnehaha Cr	Mayfly mix	4.6 (3.5-5.5)	1550	4.40	61.2	4790	123	1290	3950	123	6.30	3.00	1880	6840
Moose Creek (N=4)	*Arctopsyche*	19.7 (17.0-22.0)	546	0.6	<0.5	1430	5.43	1030	1840	507	<1.00	0.90	3230	112
Moose Creek	*Drunella* sp.	12.5 (11.5-13.5)	794	1.30	2.20	3020	21.8	1440	3170	581	<1.00	2.04	3480	262
Moose Creek	Mayfly mix	12.5 (5.0-16.5)	1180	3.30	3.10	4400	31.3	2830	2790	438	0.60	1.80	4020	226
Moose Creek (N=6)	*Doronueria* sp.	22.7 (21.5-24.0)	251	0.7	0.2	2430	29.9	355	2060	183	0.2	0.63	4430	180
Monitor Creek	*Arctopsyche*	15.9 (14.0-19.0)	1170	1.00	5.40	1440	29.8	553	2200	116	9.90	0.71	9760	289
Monitor Creek	*Doronueria* sp.	21.9 (17.0-30.5)	415	0.6	5.00	4770	74.4	229	2510	70.0	4.10	1.12	5700	560
Banner Creek	*Arctopsyche*	17.6 (15.0-19.5)	906	1.80	11.2	1760	22.9	886	2830	289	6.00	2.20	5330	426
Banner Creek	Mayfly mix	7.7 (4.0-16.0)	2330	12.0	31.3	4720	37.2	4600	3650	714	38.5	2.20	1570	2520

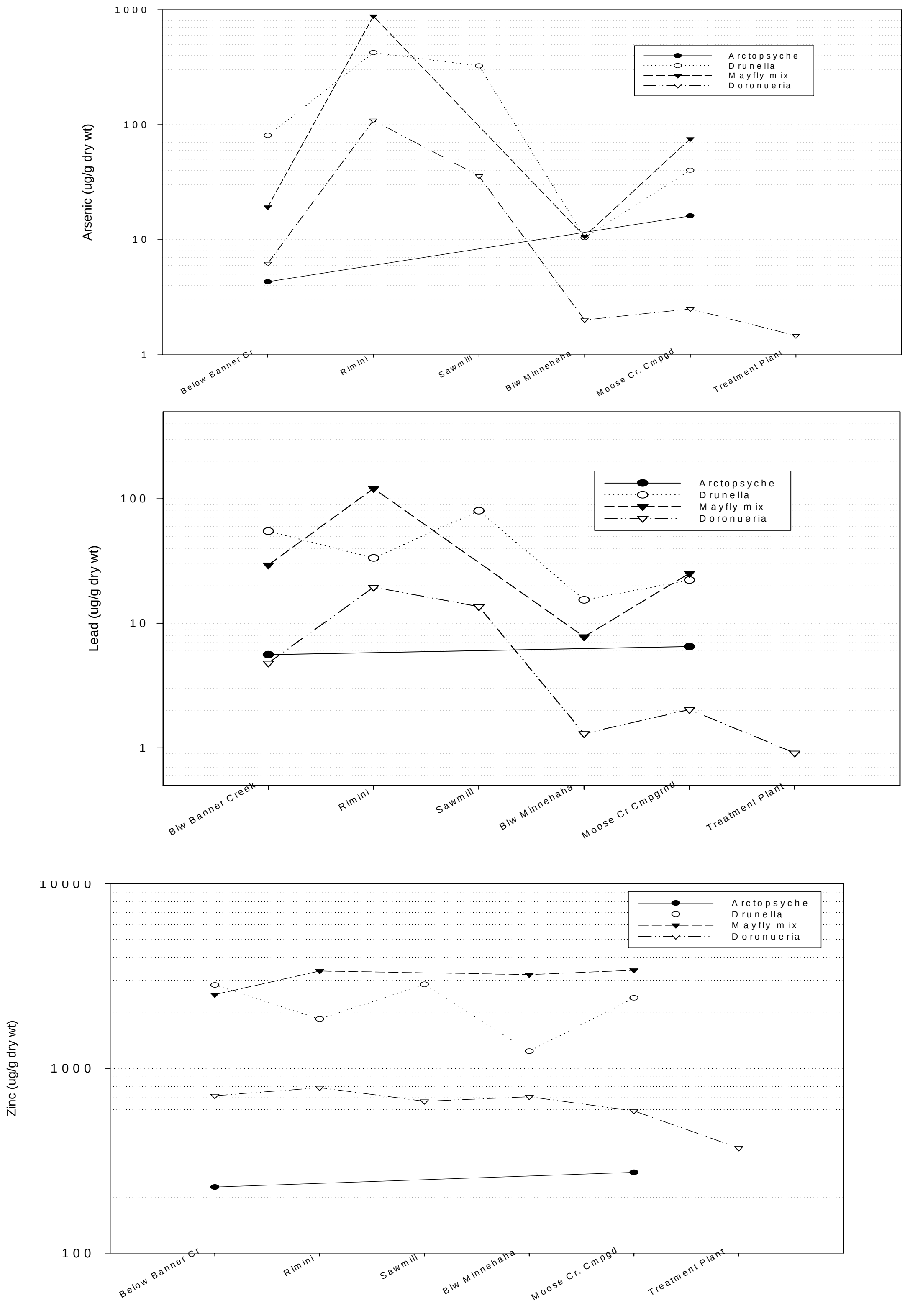


Figure 2-1 Concentrations of Zinc, Lead, and Arsenic in Insects at Tenmile Creek Mainstem Sites.

Of the tributary sites, Minnehaha Creek showed the greatest amount of trace element enrichment in the insects. *Doronueria* were not sampled at the Minnehaha Creek site, but *Arctopsyche* can be used to compare Minnehaha to the other tributary sites. Levels of copper and zinc in *Arctopsyche* were highest at the Minnehaha site, whereas Monitor Creek had the highest levels of lead.

2.3.4 Fish

Trace element residues in brook trout (*Salvelinus fontinalis*) tissues were elevated at sites where mining and/or acid mine drainage had occurred. For livers in fish at the mainstem sites, levels of arsenic, lead and zinc were highest at the Sawmill site, while levels of copper were highest at the Below Minnehaha site and levels of cadmium were highest at the Moose Creek Campground site (Table 2-6). The high mean value for arsenic at the Moose Creek Campground is due to one extraordinarily high value (19.9 μg/g) that maybe contaminated sample. On the tributaries, livers from brook trout in Minnehaha Creek were considerably more enriched with all trace elements than the other tributary sites. Livers from Monitor Creek had higher levels of all trace elements, with the exception of arsenic, than the reference site (Moose Creek).

The pattern of residue accumulation in gills of brook trout at mainstem sites was similar to livers in terms of the site with the highest concentrations for arsenic, cadmium, copper and zinc (Table 2-7). Lead was markedly different however, being highest in gills Below Banner Creek, while livers were highest at the Sawmill site. On the mainstem, the Sawmill site was highest for arsenic, copper and zinc in gills, while the Moose Creek Campground was highest for cadmium, magnesium and sodium. The Below Banner Creek site was highest for aluminum, calcium and lead. On the tributaries, Minnehaha Creek was highest for arsenic, copper and zinc, while Monitor Creek was highest for cadmium, sodium and lead. Moose Creek was highest for only aluminum and calcium.

Analysis of trace element residues in whole fish (brook trout) samples showed that calcium, sodium, and magnesium were found in much higher concentrations than all other elements measured, with Monitor Creek being highest for Na and Ca, and Moose Creek highest in Mg (Table 2-8). For elements that have been shown to be enriched in fish gills and livers in the vicinity of Rimini, there was no similar trend in whole fish on the mainstem. Zinc was highest at the sawmill site (521 μg/g). While copper and lead were highest below Minnehaha Creek (7.2 μg/g respectively), and cadmium was highest at the treatment plant (4.2 μg/g). For these same elements at the tributary sites, Minnehaha had the highest levels.

A limited number of elements were analyzed in brook trout fillets, and only at mainstem sites (Table 2-9). Arsenic, lead, and copper were highest at the Moose Creek campground (0-29 μg/g 3.3 μg/g and 15 μg/g respectively), while zinc was highest at the sawmill sit (67 μg/g). Mercury was not found at the detection level (0.033 μg/g) in fish at any site.

Distinct patterns of accumulation were evident when comparing the trace elements in the various fish tissues (Figure 2-2). For arsenic, tissue concentrations ranging from highest to lowest were gills>livers>fillets. For cadmium, gills had higher levels than livers for all but two sites, but both of these tissues typically had much higher concentrations than did whole body measurements (Figure 2-2). For copper, livers had markedly higher concentrations than gills, whole body and

Table 2-6 Metal Residues (µg/g Dry Wt) in Livers of Brook Trout in the Tenmile Creek Drainage. For calculating means, censored values (<) were assigned a value one half the of the detection level.

Site	Date sampled	Total length (mm) Mean (range)	Weight (g) Mean (range)	N	As	Cd	Cu	Pb	Zn
Below Banner Creek	8/2/2001	202 (197-211)	89.7 (87-92)	3	0.47	7.8	116	0.29	131
Below Banner Creek	8/2/2001	189 (184-195)	80.7 (78-83)	3	0.36	9.6	93.8	0.29	112
Below Banner Creek	8/2/2001	165 (153-180)	46.7 (37-62)	4	0.52	8.1	108	0.22	143
			Mean=		**0.45**	**8.5**	**105.9333**	**0.2666667**	**128.66667**
Sawmill	8/1/2001	195 (190-199)	75.3 (65-84)	3	3.18	14.9	246	1.1	261
Sawmill	8/1/2001	171 (163-182)	55.7 (49-67)	3	1.8	18.6	233	0.77	404
Sawmill	8/1/2001	158 (151-163)	39.0 (34-44)	4	1.75	16.6	277	0.96	481
			Mean=		**2.243333**	**16.7**	**252**	**0.9433333**	**382**
Below Minnehaha Cr	8/1/2001	200 (188-220)	87.7 (72-115)	3	1.47	20.7	279	1.26	330
Below Minnehaha Cr	8/1/2001	165 (157-173)	53.7 (45-64)	3	1.31	18.3	253	0.78	300
Below Minnehaha Cr	8/1/2001	151 (145-155)	39.5 (34-47)	4	1.63	20.5	257	0.58	362
			Mean =		**1.47**	**19.83333**	**263**	**0.8733333**	**330.66667**
Moose Cr. Campground	8/1/2001	205 (200-209)	93.7 (85-106)	3	1.3	41.4	254	1.03	213
Moose Cr. Campground	8/1/2001	171 (156-183)	61.0 (42-82)	3	1.41	33.3	255	1	214
Moose Cr. Campground	8/1/2001	145 (131-155)	30.8 (24-37)	5	19.9	22.8	184	0.5	225
			Mean =		**7.536667**	**32.5**	**231**	**0.8433333**	**217.33333**
Treatment Plant	8/2/2001	209 (190-228)	107 (80-133)	2	0.39	19.1	145	0.37	171
Treatment Plant	8/2/2001	174 (167-181)	60.5 (49-72)	2	0.48	15.1	181	0.24	197
Treatment Plant	8/2/2001	130 (119-145)	43 (22-78)	3	0.69	10.5	154	<0.20	185
			Mean =		**0.52**	**14.9**	**160**	**0.203**	**184.33333**
Minnehaha Creek	8/29/2001	151 (143-159)	32.8 (26.0-42.1)	3	0.91	50.1	228	<0.30	478
Minnehaha Creek	8/29/2001	140 (138-142)	27.5 (25.1-30.3)	3	0.59	33.4	146	0.31	273
Minnehaha Creek	8/29/2001	131 (126-136)	21.8 (14.1-28.2)	6	1.02	29.6	215	1.82	300
			Mean =		**0.84**	**37.7**	**196.3333**	**0.76**	**350.33333**
Monitor Creek	8/2/2001	155 (152-158)	37.3 (35-40)	3	<0.20	20.2	91.2	0.29	117
Monitor Creek	8/2/2001	143 (134-151)	25.3 (23-28)	3	<0.20	30.3	134	0.78	152
Monitor Creek	8/2/2001	127 (123-129)	20.2 (19-22)	4	<0.20	15.4	70.4	<0.20	115
			Mean =		**0.1**	**21.96667**	**98.53333**	**0.39**	**128**
Moose Creek	8/29/2001	154 (147-158)	35.2 (26.5-41.2)	3	0.33	0.23	21.2	<0.20	156
Moose Creek	8/29/2001	141 (139-142)	28.4 (25.5-32.7)	3	0.42	0.45	24.3	<0.20	137
Moose Creek	8/29/2001	126 (116-132)	19.7 (13.9-22.0)	6	0.35	0.32	28	<0.20	112
			Mean =		**0.366667**	**0.333333**	**24.5**	**0.1**	**135**

Table 2-7 Metal Residues (µg/g Dry Wt) in Gills of Brook Trout in the Tenmile Creek Drainage.
For Calculating Means, Censored Values (<) were Assigned a Value One Half the of the Detection Level.

Site	Date sampled	Total length (mm) Mean (range)	Weight (g) Mean (range)	N	Al	As	Ca	Cd
Below Banner Creek	08/02/01	202 (197-211)	89.7 (87-92)	3	48.7	0.80	13800	7.80
Below Banner Creek	08/02/01	189 (184-195)	80.7 (78-83)	3	21.4	0.60	15100	14.4
Below Banner Creek	08/02/01	165 (153-180)	46.7 (37-62)	4	<20	0.35	16800	13.1
Sawmill	08/01/01	195 (190-199)	75.3 (65-84)	3	21.8	2.86	13000	31.3
Sawmill	08/01/01	171 (163-182)	55.7 (49-67)	3	<20	4.20	4880	28.4
Sawmill	08/01/01	158 (151-163)	39.0 (34-44)	4	29.3	5.20	16700	33.4
Below Minnehaha Cr	08/01/01	200 (188-220)	87.7 (72-115)	3	<20	1.80	21500	30.7
Below Minnehaha Cr	08/01/01	165 (157-173)	53.7 (45-64)	3	<40	1.90	14300	39.2
Below Minnehaha Cr	08/01/01	151 (145-155)	39.5 (34-47)	4	<40	3.70	14100	36.6
Moose Cr. Campground	08/01/01	205 (200-209)	93.7 (85-106)	3	21.4	3.40	18600	24.8
Moose Cr. Campground	08/01/01	171 (156-183)	61.0 (42-82)	3	<20	1.80	14800	21.3
Moose Cr. Campground	08/01/01	145 (131-155)	30.8 (24-37)	5		4.40		23.7
Treatment Plant	08/02/01	209 (190-228)	107 (80-133)	2	<20	0.40	16900	15.8
Treatment Plant	08/02/01	174 (167-181)	60.5 (49-72)	2	<20	0.80	16900	19.5
Treatment Plant	08/02/01	130 (119-145)	43 (22-78)	3	<20	2.50	10800	20.0
Minnehaha Creek	08/29/01	151 (143-159)	32.8 (26.0-42.1)	3	90.5	1.46	13200	25.7
Minnehaha Creek	08/29/01	140 (138-142)	27.5 (25.1-30.3)	3	<200	3.0	9700	23.4
Minnehaha Creek	08/29/01	131 (126-136)	21.8 (14.1-28.2)	6	<100	1.56	9000	19.6
Monitor Creek	08/02/01	155 (152-158)	37.3 (35-40)	3	<50	<1.00	8250	21.7
Monitor Creek	08/02/01	143 (134-151)	25.3 (23-28)	3	<100	<2.00	4620	28.9
Monitor Creek	08/02/01	127 (123-129)	20.2 (19-22)	4	<50	<1.00	10200	25.4
Moose Creek	08/29/01	154 (147-158)	35.2 (26.5-41.2)	3	224	1.10	14900	<0.50
Moose Creek	08/29/01	141 (139-142)	28.4 (25.5-32.7)	3	173	<1.00	10900	<0.50
Moose Creek	08/29/01	126 (116-132)	19.7 (13.9-22.0)	6	148	1.00	7110	<0.50

Table 2-7 (continued) Metal Residues in Gills of Brook Trout in the Tenmile Drainage. For Calculating Means, Censored Values (<) were Assigned a Value One Half the of the Detection Level.

Site	Cu	Mg	Na	Pb	Se	Zn
Below Banner Creek	3.30	856	6700	3.48	<50	105
Below Banner Creek	3.50	975	8530	12.8	<50	126
Below Banner Creek	3.30	857	8320	0.90	<50	179
Sawmill	10.3	891	7360	4.60	<50	395
Sawmill	6.80	766	6760	3.60	<50	515
Sawmill	9.00	792	7540	5.40	<50	627
Below Minnehaha Cr	5.30	1390	8820	3.53	<50	464
Below Minnehaha Cr	6.00	616	8110	2.26	<50	444
Below Minnehaha Cr	7.10	<1000	8290	2.56	<50	509
Moose Cr. Campground	10.7	1280	9100	<10	<50	276
Moose Cr. Campground	4.50	863	8270	<10	<50	236
Moose Cr. Campground	1.60			1.83		326
Treatment Plant	6.80	1100	7830	1.62	<50	170
Treatment Plant	3.80	1100	7830	0.9	<50	185
Treatment Plant	9.30	<500	8070	1.30	<50	193
Minnehaha Creek	8.2	<1000	9030	2.3	<50	445
Minnehaha Creek	14.9	<2000	7880	3	<50	503
Minnehaha Creek	7.80	<1000	6860	1.76	<50	336
Monitor Creek	8.50	<1000	8780	4.04	<50	119
Monitor Creek	6.90	<1500	10100	2.18	<50	135
Monitor Creek	6.30	<1500	9290	1.70	<50	150
Moose Creek	3.90	<1000	8550	1.18	<50	123
Moose Creek	4.80	<1000	8080	1.12	<50	139
Moose Creek	5.40	<1000	7600	1.0	<50	135

Table 2-8 Trace Element Residues (µg/g Dry Wt) in Whole Fish Samples of Brook Trout in the Tenmile Drainage. Each fish was analyzed individually. Values for each element are the mean (range).

Site	Date sampled	Total length (mm) Mean (range)	Weight (g) Mean (range)	N	Al	As	Ca	Cd
Below Banner Creek	8/2/2001	52	1.4	1	190	<20	17300	2.3
Sawmill	8/1/2001	56.2 (52-64)	1.5 (1.1-2.4)	5	61.6 (<10-126)	<12 (<10-<20)	17100 (15200-17900)	2.6 (2.3-3.2)
Below Minnehaha Cr	8/1/2001	56.7 (51-59)	1.9 (1.7-2.2)	4	129 (62.7-222)	<20 (<20)	15325 (13900-16700)	3.6 (3.3-3.8)
Moose Cr. Campground	8/1/2001	64.2 (60-67)	2.9 (2.4-3.4)	5	32.5 (<10-79.8)	<10 (<10)	19320 (16400-22900)	2.2 (<2-3.3)
Treatment Plant	8/2/2001	64.6 (60-74)	3.0 (2.3-3.4)	5	26.1 (13.6-36.7)	<20 (<20)	16120 (15200-18200)	4.2 (2.2-5.6)
Minnehaha Creek	8/29/2001	56.2 (53-62)	1.5 (1.2-2.2)	5	153 (75-275)	<20 (<20)	19160 (13900-22700)	4.7 (3.7-5.7)
Monitor Creek	8/2/2001	68.6 (65-75)	3.1 (2.6-4.0)	5	61.8 (25.2-106)	<20 (<20)	22400 (17100-25300)	1.7 (<2-2.3)
Moose Creek	8/29/2001	70.4 (68-72)	3.6 (3.1-3.9)	5	48.3 (35.1-77.7)	<20 (<20)	19040 (16800-20900)	<2.0 (<2)

Table 2-8 (continued) Trace Element Residues in Whole Fish Samples of Brook Trout in the Tenmile Drainage.

Site	Cu	Mg	Na	Pb	Se	Zn
Below Banner Creek	4.2	1310	5020	<10	<20	232
Sawmill	4.6 (<2-6.1)	1127 (955-1200)	4496 (4050-4940)	6.3 (<10-11.7)	<20 (<20)	499 (473-544)
Below Minnehaha Cr	7.2 (5.6-9.4)	1198 (1080-1390)	4617 (3980-5040)	13.0 (<10-22.1)	<20 (<20)	521 (416-612)
Moose Cr. Campground	3.8 (2.8-4.8)	1142 (998-1250)	4114 (3270-4710)	<8.0 (<2-<10)	<20 (<20)	451 (363-551)
Treatment Plant	4.0 (2.0-6.3)	1134 (1080-1200)	4218 (3890-4480)	<8.0 (<2-<10)	<20 (<20)	378 (326-439)
Minnehaha Creek	7.6 (4.9-13.8)	1230 (1100-1310)	4806 (4450-5500)	<8.4 (<2-<10)	<20 (<20)	391 (334-444)
Monitor Creek	3.1 (2.3-4.4)	1230 (1150-1270)	4966 (4690-5220)	<6.8 (<2-<10)	<20 (<20)	182 (157-208)
Moose Creek	<2.0 (<2)	1244 (1220-1260)	4172 (3990-4300)	<2.0 (<2)	<20 (<20)	116 (87.7-100)

Table 2-9 Trace Element Residues (µg/g Wet Wt) in Fillets of Brook Trout (Skin Left On) in the Tenmile Creek Drainage, November 5, 1998. All individual fish from a site combined into one composite sample for analysis.

Site	Total length, range (in)	N	As	Pb	Cu	Hg	Zn
Below Banner Creek	6.3-8.8	17	0.06	1.2	1	<0.033	31
Below Banner Creek (duplicate)	6.3-8.8	17	0.06	0.85	1.1	<0.033	34
Sawmill	5.2-6.9	18	0.2	0.53	0.63	<0.033	67
Moose Creek Cmpgrnd	5.9-7.1	12	0.29	3.2	15	<0.033	64
Moose Creek Cmpgrnd	7.3-10.5	9	0.17	3.3	2.4	<0.033	40
Treatment Plant	5.9-8.9	19	0.12	0.41	0.79	<0.033	34

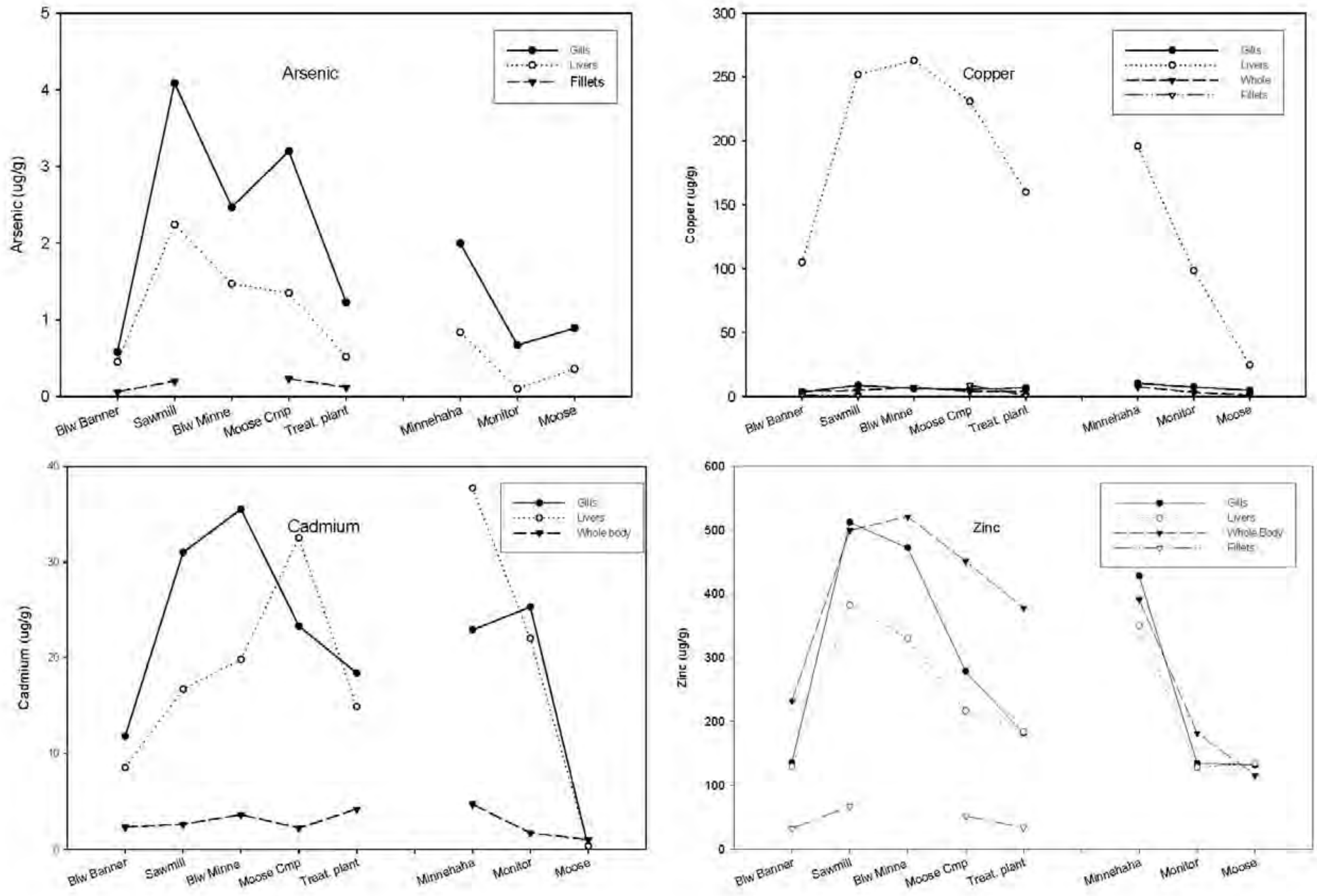


Figure 2-2 Trace Element Concentrations (µg/g) in Brook Trout Tissues.

fillets. For zinc, whole bodies and gills typically had the highest concentrations, followed closely by livers; all three of these tissues had much higher levels than found in fillets. These differences are related to the patterns of fate and transport of the elements in the fish bodies (Sorenson 1991).

2.4 Discussion

2.4.1 Trophic Level Comparisons

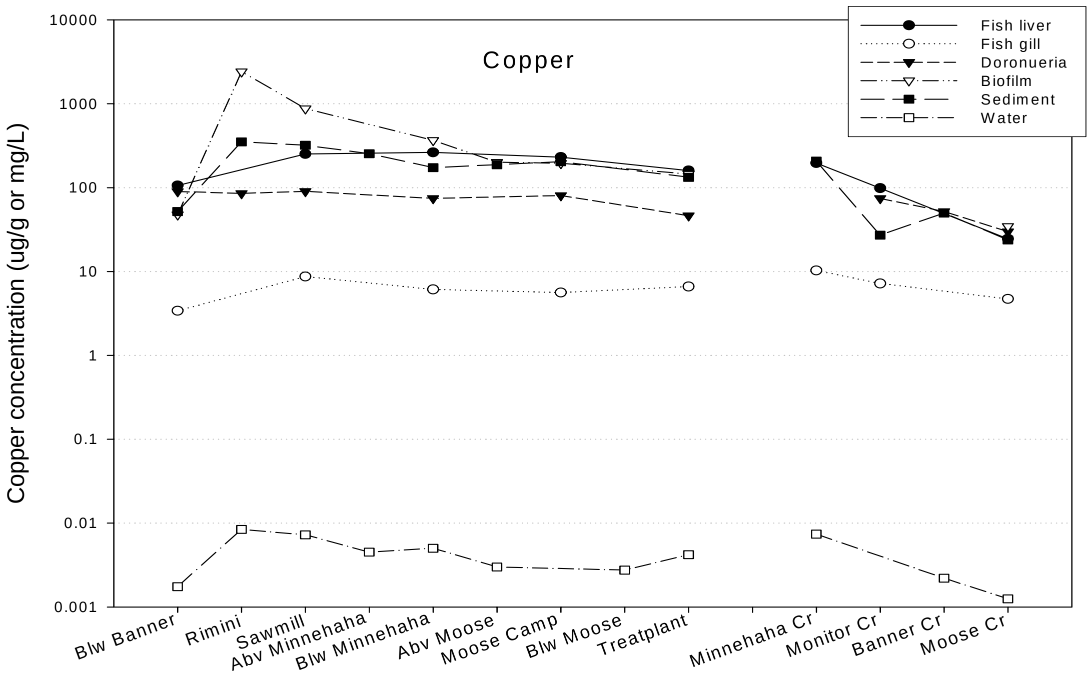
Concentrations of trace elements in water (Table 2-10) were compared with concentrations in sediments and biota (Tables 2-1 through 2-9) in order to examine the potential for bioconcentration, bioaccumulation and trophic transfer of the trace elements. The results showed some notable and unique patterns for each element (Figures 2-3 and 2-4). The tendency of these elements to bioconcentrate (uptake directly from water) in fish was determined through the ratio of the level of the element in fish gills to the level in water. In the case of zinc, levels in the gills (on a part-per-million basis) were no more than 1 to 2 orders of magnitude greater than water, and at some sites were actually lower. Levels of arsenic were typically about two orders of magnitude higher in gills than in water, while this difference increased with copper (three orders of magnitude difference) and was greatest with cadmium where the gills had typically about four orders of magnitude higher levels than in water.

Levels of metals in the livers were close to and slightly lower than in the gills with the exception of copper. For copper, levels were more than an order of magnitude higher in the livers than in the gills, showing a significant tendency for fish livers to sequester the metal there. The tendency for livers to bioaccumulate metals can also be evaluated by a comparison of the ratio of the trace element in liver to the concentration in bed sediment. Maret and Skinner (2000) did such a comparison for largescale suckers and mountain whitefish in the Clark Fork-Pend Oreille River drainages. They found that cadmium had the highest ratio (liver:sediment) of around 3, while copper had a ratio slightly higher than 1.0. The ratio of zinc was about 0.8, while arsenic was much lower (about 0.04), and lead was lowest (0.006). In this study, the ratios were strikingly similar: cadmium—2.0, copper—1.53, zinc—0.61, arsenic—0.008 and lead—0.002.

2.4.2 Implications for Fish Health

For the purposes of this study, it is desirable to understand the effect of trace elements on fish, in terms of both acute and chronic toxicity. Acute mortality effects were studied by using in-situ bioassays (Chapter 6), whereas sub-chronic effects such as growth were not studied directly, but are of interest. To this end, tissue residue data from this study were compared to the results of laboratory studies found in the literature that have evaluated growth response in relation to levels of trace elements in one or more tissues. This approach does not always yield reliable conclusions, because as Hansen et al (2000) cautioned, critical body residue approaches to biomonitoring may be misleading because residues are dependent on exposure duration, a variable that typically is unknown in field settings. In addition, the age (and size), pre-exposure, and route of exposure (diet vs. water) may influence the response of the organism in terms of mortality, growth, and physiological function and may also therefore influence tissue residues.

With these considerations in mind, literature sources were selected for comparison only if: 1) the species were the same as those found in the Tenmile drainage; 2) the exposure was lengthy (28



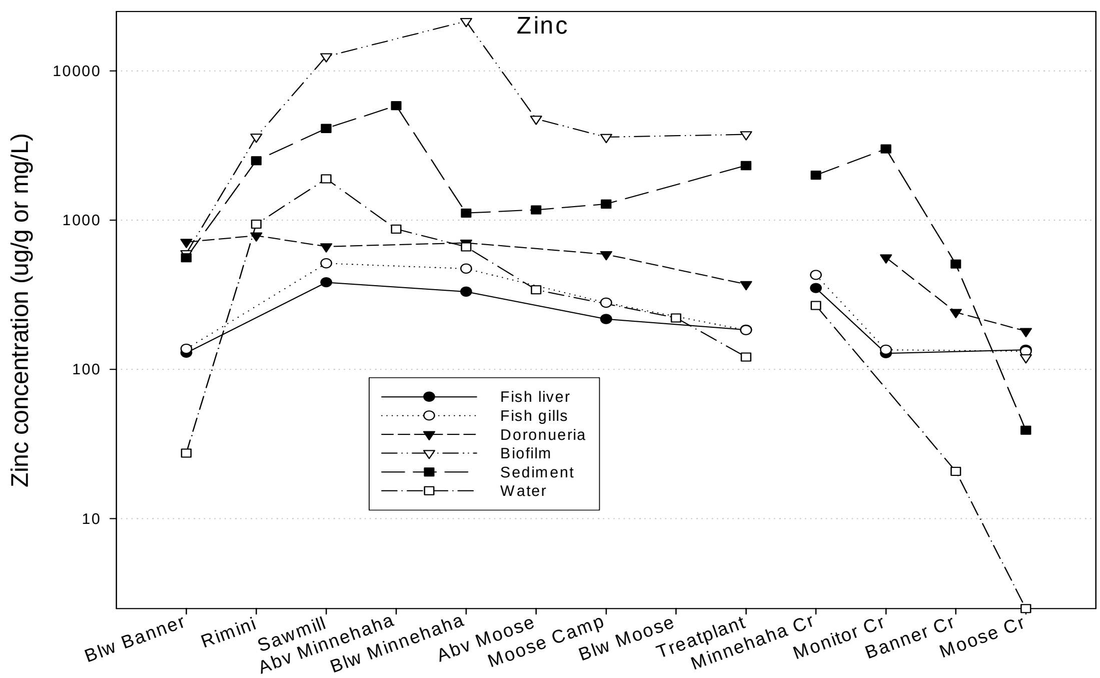


Figure 2-3 Concentrations of Copper and Zinc in Abiotic and Biotic Media in the Tenmile Drainage, 1999-2001.
[Data used for these figures include fish tissue (2001), *Doronueria* (2001, except Treatment Plant and Monitor Creek, 2000), biofilm and sediments (2001), and water (any or all of the years 1999-2001)]

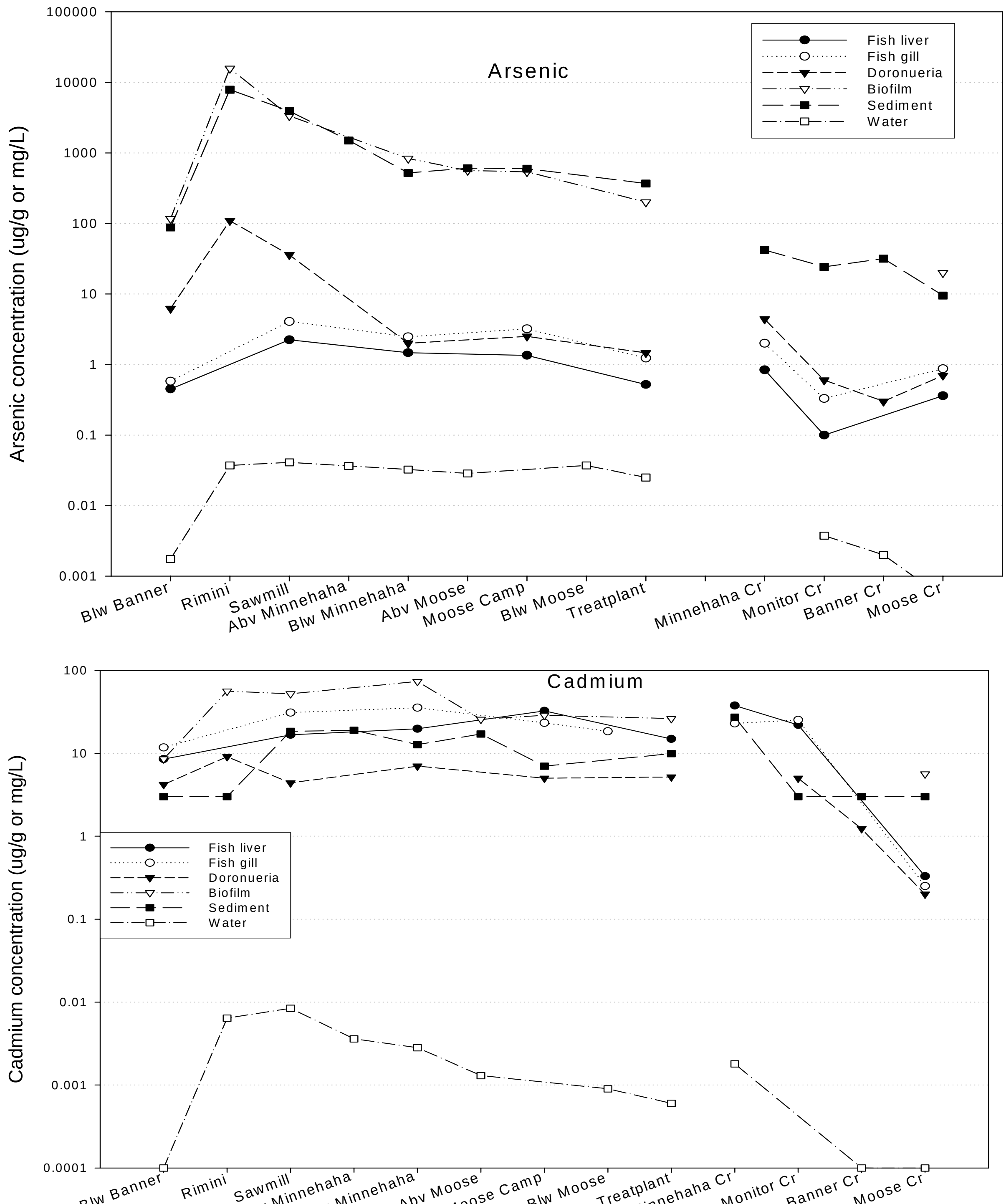


Figure 2-4 Concentrations of Cadmium and Arsenic in Abiotic and Biotic Media in the Tenmile Drainage, 1999-2001.
[Data used for these figures include fish tissue (2001), *Doronueria* (2001, except Treatment Plant and Monitor Creek, 2000), biofilm and sediments (2001), and water (any or all of the years 1999-2001)]

Table 2-10 Trace Element Concentrations in Surface Waters of Tenmile Creek Drainage, Late June through October During the Years 1997- 2001. Asterisks (*) indicate data are collected by the USGS (Parrett and Hettinger, 2000 for 1997 data and the online water quality database for 1998-2001 data); all other data are from this study (Chapter 6). Tot. Rec. = Total recoverable.

			Mean (range) concentration (µg/L) of constituent								
Year	**Dates**	**N**	**Arsenic Tot. rec.**	**Cadmium Tot.rec.**	**Cadmium filtered**	**Copper Tot.rec.**	**Copper Filtered**	**Lead Tot.rec.**	**Lead Filtered**	**Zinc Tot.rec.**	**Zinc. Filtered**
Tenmile Creek below Banner Creek											
1999	Aug 19- Aug 27	2		0.1 (<0.2- <0.2)	0.15 (<0.2-0.2)	2.5 (2-3)	2.0 (2-2)	0.5 (<1-<1)	0.5 (<1-<1)	28.0 (25-31)	23.0 (22-24)
2000	Jul 18- Jul 20	2	1.75 (<1-3)	0.1 (<0.2- <0.2)	0.1 (<0.2- <0.2)	1.0 (1-1)	1.0 (1-1)	0.5 (<1-<1)	0.5 (<1-<1)	29.5 (29-30)	32.0 (30-34)
Tenmile Creek above City Diversion											
1997*	Aug 25 Oct 7	2	6.5 (5-8)	1.75 (1.7-1.8)	1.75 (1.7-1.8)	23.5 (10-37)	7.5 (7-8)	6.5 (6-7)	1.5 (<3-<3)	450 (440-460)	430 (420-440)
1999*	Jun 29 Aug 19	2	6.5 (4-9)	0.5 (<1-<1)	0.5 (<1-<1)	7.1 (6.4-7.8)	6.05 (5.2-6.9)	4.0 (2.9-5.1)	1.5 (1-2)	164 (149-179)	152 (135-169)
2000*	Aug 3	1	7.0	0.7	0.6	4.4	3.8	3.29	<1	139	136
2001*	Aug 6 Sep 27	2	8.0 (8-8)	1.27 (1.2-1.34)	1.14 (1.11-1.18)	4.95 (3.7-6.2)	4.3 (2.8-5.8)	2.7 (2.7-2.7)	0.80 (.65-.96)	245.5 (224-267)	231 (215-247)
Tenmile Creek below Spring Creek (in Rimini)											
1997*	Aug 26- Oct 7	2	116.5 (63- 170)	16.7 (3.4-30.0)	15.0 (3-27)	110.5 (51-170)	54.0 (39-69)	13.0 (8-18)	3.25 (<3-5)	1830 (560-3,100)	1750 (500-3000)
2001*	Aug 6- Sep 27	2	37 (32-42)	6.39 (4.58-8.19)	6.06 (4.23-7.9)	8.4 (7.8-9.0)	5.3 (4.6-6.0)	4.21 (3.1- 5.33)	0.72 (0.6- 0.84)	939 (598-1280)	910 (610-1210)
Tenmile Creek at Sawmill											
1999	Aug 19- Aug 27	2		12.0 (10.8-13.2)	11.5 (10.8-12.2)	10.5 (10-11)	6.5 (6-7)	1.25 (<1-2)	0.5 (<1-<1)	2215 (2200-2230)	2195 (2170-2220)
2000	Jul 18- Jul 20	2	41.0 (37-45)	4.8 (4.6-5.0)	4.9 (4.7-5.1)	4.0 (4-4)	1.0 (1-1)	0.75 (<1-1)	0.5 (<1-<1)	1565 (1340-1790)	1465 (1310-1620)
Tenmile Creek above Minnehaha Creek											
1999	Aug 19- Aug 27	2		4.4 (4-4.8)	4.45 (4.1-4.8)	6.0 (6-6)	5.0 (5-5)	0.5 (<1-<1)	0.5 (<1-<1)	994 (948-1040)	971 (943-1000)
2000	Jul 18- Jul 20	2	36.5 (36-37)	2.8 (2.4-3.2)	2.85 (2.5-3.2)	3.0 (2-4)	6.0 (1-11)	0.5 (<1-<1)	0.5 (<1-<1)	745.5 (601-890)	727 (585-869)

Table 2-10 (continued) Trace Element Concentrations in Surface Waters of Tenmile Creek Drainage, Late June through October During the Years 1997- 2001. Asterisks (*) indicate data are collected by the USGS (Parrett and Hettinger, 2000 for 1997 data and the online water quality database for 1998-2001 data); all other data are from this study (Chapter 6). Tot. Rec. = Total recoverable.

Year	Dates	N	Arsenic Tot. rec.	Cadmium Tot.rec.	Cadmium filtered	Copper Tot.rec.	Copper Filtered	Lead Tot.rec.	Lead Filtered	Zinc Tot.rec.	Zinc. Filtered
Tenmile Creek below Minnehaha Creek											
1999	Aug 19-Aug 27	2		2.9 (1.8-4)	2.65 (1.9-3.4)	7.0 (5-9)	4.5 (4-5)	0.5 (<1-<1)	0.5 (<1-<1)	655 (434-876)	635 (428-842)
2000	Jul 18-Jul 20	2	32.5 (32-33)	2.75 (2.6-2.9)	2.60 (2.5-2.7)	3.0 (3-3)	1.0 (1-1)	0.5 (<1-<1)	0.5 (<1-<1)	668.5 (620-717)	664.5 (612-717)
Tenmile Creek above Moose Creek											
1999	Aug 19-Aug 27	2		1.45 (1.4-1.5)	1.3 (1.2-1.4)	4.0 (4-4)	5.5 (4-7)	0.5 (<1-<1)	0.5 (<1-<1)	377 (340-414)	346 (331-361)
2000	Jul 18-Jul 20	2	28.5 (28-29)	1.15 (1.0-1.3)	1.1 (0.9-1.3)	2.0 (2-2)	1.0 (1-1)	0.5 (<1-<1)	0.5 (<1-<1)	306.5 (262-351)	299 (256-342)
Tenmile Creek near Rimini (Moose cr. Gage)											
1997*	Aug 27-Oct 8	2	28.5 (27-30)	2.8 (2.8-2.8)	2.65 (2.6-2.7)	52.5 (17-88)	18.75 (<1-37)	7.0 (6-8)	1.5)<3-<3)	595 (550-640)	555 (540-570)
Tenmile Creek below Moose Creek											
1999	Aug 19-Aug 27	2		1.05 (0.8-1.3)	0.60 (0.1-0.7)	4.0 (4-4)	3.5 (3-4)	0.5 (<1-<1)	0.5 (<1-<1)	249.5 (247-252)	245.5 (241-250)
2000	Jul 18-Jul 20	2	37.0 (36-38)	0.75 (0.6-0.9)	0.7 (0.6-0.8)	1.5 (1-2)	1.0 (1-1)	0.75 (<1-1)	0.75 (<1-1)	192.5 (166-219)	179 (150-208)
Tenmile Creek at Treatment Plant											
1997*	Aug 27-Oct 8	2	19.0 (19-19)	1.1 (0.9-1.3)	0.9 (0.7-1.1)	28.0 (10-46)	8.0 (2-16)	2.25 (<3-3)	1.5 (<3-<3)	240 (160-320)	225 (140-310)
1999	Aug 19-Aug 27	2		0.6 (0.5-0.7)	0.55 (0.5-0.6)	5.0 (5-5)	4.0 (4-4)	0.5 (<1-<1)	0.5 (<1-<1)	148 (134-162)	140.5 (109-172)
2001*	Aug 7	1	25	0.61	0.57	3.8	3.3	<1.0	0.11	94.0	97.7
Monitor Creek at Mouth											
1997*	Aug 25-Oct 6	2	1.5 (<3-<3)	0.2 (0.2-0.2)	0.15 (0.1-0.2)	6.25 (<1-12)	2.75 (<1-5)	4.25 (<3-7)	1.5 (<3-<3)	50 (<100-<100)	50 (<100-<100)

days or longer); 3) the size of fish was similar to those chosen for tissue analysis in this study; and 4) tissue residue data were available for livers or whole bodies (Table 2-11). Gill tissue was also analyzed in this study, but was not used for this comparison because concentrations of trace elements in gills typically reflect only very recent exposure history, whereas livers and whole bodies are more reflective of long-term exposure.

For the fish collected and analyzed in this study, duration of exposure can probably be accurately estimated in some instances but not others. For the whole-body measurements of trace elements in fry (1-3 g), it may be assumed that the fry have drifted downstream somewhat between the time they emerged from the gravels and the time they were captured for this study. For the tributary sites where the fish were captured above barriers (Moose and Minnehaha), it is probably safe to assume that they were exposed to the contaminated water, food and sediment of those streams as portrayed in Tables 2-1 through 2-5 of this report. This was probably the case in Monitor Creek as well, although there is no barrier on that stream and because the collection site for the fry was only about 100 feet above the confluence with Tenmile Creek it is possible that some of the fry may have moved up into Monitor Creek during their short lives. On the mainstem, the single fry sampled at the Below Banner Creek site may have drifted from further upstream in the mainstem or in Ruby or Monitor Creek, so the exposure history is somewhat uncertain. As discussed in Chapter 3, the acutely toxic conditions at the Sawmill site suggest that at least some of the fry found there may have drifted downstream from above the mainstem diversion at Rimini during high water the previous spring. Fry collected below Minnehaha Creek could possibly have been a combination of fry born in the stream near or upstream of this site as well as some drifting out of Minnehaha Creek. Fry collected at the Moose Creek Campground were likely born in the mainstem near or upstream of this site. Fry collected at the Treatment plant were likely born in the mainstem near or upstream of the site or possibly in Walker Creek. The exposure history for the larger fish (20-107 g) is probably similar to the fry although less certain, except for those tributary situations with barriers, which prevent upstream movement of fish. Nonetheless, even for the larger fish at each site, some of which were mature and in pre-spawning condition, large scale movements were not expected because suitable spawning habitat seemed to exist at all sites.

Only three studies were found in the literature that exposed trout to arsenic under conditions that are judged to be similar to Tenmile Creek (Table 2-11). Dixon and Sprague (1981) found no change in the weight of 0.44 g rainbow trout fry with whole-body levels of 16.4 ug/g, whereas McGeachy and Dixon (1990) found decreases in body weight of rainbow trout with whole-body levels of 6.8-12 μg/g. In addition, the Hansen et al (2004) study found growth effects on rainbow trout fry following exposure to a metal mixture, but the authors found that the growth effects were best correlated with arsenic exposure. The rainbow trout (2.9 g) had 20.3-26.6 μg/g arsenic on a whole-body basis. Unfortunately, in our study the detection level for arsenic was between 10 and 20 μg/g. At the Sawmill site, which is the site with the greatest exposure to arsenic (based on liver tissue data), it was not detected at a level of 10 ug/g in rainbow trout fry samples with weights between 1.1-2.4 g. Without knowing the actual arsenic levels in these fish, it is impossible make a useful comparison to the published studies. Even so, the 10 μg/g detection level falls in between the level of effect from McGeachy and Dixon of 6.8 μg/g and the no effect level of Dixon and Sprague (16.4 μg/g), making it even more difficult to interpret.

Table 2-11. Summary of studies relating levels of trace elements in tissues to growth or mortality effects in salmonids. The response listed in the table was either the lowest level of exposure leading to a significant decrease in growth or the highest level of exposure leading to no significant change in growth. If residues were reported as wet-weight, they were converted here to dry weight assuming 75% moisture. Values followed by an asterisk mean that the value was estimated from a graph in the publication.

Species	Lifestage	Weight (g) of control fish	Exposure duration	Diet/ water exposure	Response	Tissue	Trace element concentration (µg/g dry wt)					Reference
							As	Cd	Cu	Pb	Zn	
Mixture of trace elements												
RBT	eyed egg to fry	0.85 g	80 d post-hatch	both	44-52% decreased weight	whole-body	6.0	0.48	31.2	1.92	144	Woodward et al 1994
LL	newly hatched to fry	0.57 g	88 d	both	50-53% decreased weight	whole body	2.8-3.2	0.5-0.75	20.8-32.8	2-3.6		Woodward et al 1995
RBT	newly hatched to fry	1.41 g	88 d	both	41-43% decreased weight	whole body	2.4-2.8					Woodward et al 1995
RBT	newly hatched to fry	1.41 g	88 d	both	41-43% decreased weight	liver	3.0-3.6					Woodward et al 1995
RBT	eyed egg to fry	2.9 g	67 d	diet	19-30% decreased weight	whole body	20.3-26.6	0.09		0.57-0.86	445-530	Hansen et al 2004
RBT	eyed egg to fry	2.9 g	67 d	diet	19-30% decreased weight	liver	12.3-28.7	0.08		0.3-0.43	111	Hansen et al 2004
Arsenic												
RBT	fry	0.44g	21 d	water	no change in weight	whole body	16.4					Dixon and Sprague 1981
RBT	juvenile	10.4-26.0g	77 d	water	33-24% decreased weight at 5 & 15^{o}C	whole body	12-6.8					McGeachy and Dixon 1990
Cadmium												
RBT	fry	2.79 g	30 d	water	no change in weight	liver		17.3				Hollis et al 2001

Table 2-11 (continued). Summary of studies relating levels of trace elements in tissues to growth or mortality effects in salmonids. The response listed in the table was either the lowest level of exposure leading to a significant decrease in growth or the highest level of exposure leading to no significant change in growth. If residues were reported as wet-weight, they were converted here to dry weight assuming 75% moisture. Values followed by an asterisk mean that the value was estimated from a graph in the publication.

Species	Lifestage	Weight (g) of control fish	Exposure duration	Diet/ water exposure	Response	Tissue	Trace element concentration (µg/g dry wt)					Reference
							As	Cd	Cu	Pb	Zn	
RBT	juvenile	12-15 g	30 d	diet	no change in weight	liver		10.8*				Baldisserotto et al 2005
RBT	adult	628 g	178 d	water	no change in weight	liver		18*				Giles 1988
EBT	juvenile	174 g	266 d	water	17-40% increased mortality in male spawners	liver		10				Benoit et al 1976
RBT	juvenile	12-15 g	30 d	diet	no change in weight	whole body		16.0*				Baldisserotto et al 2005
RBT	fry	2.79 g	30 d	water	no change in weight	whole body		4.64				Hollis et al 2001
EBT	Fry	1.38 g	74 d	Water	58% decreased weight	Whole body		1.26				Benoit eat al 1976
Copper												
RBT	juvenile	63 g	28 d	diet	no change in weight	whole body			21.0			Kamunde et al 2001
RBT	juvenile	19.9 g	28 d	water	26% mortality & 56% decreased weight	whole body			5.6*			Kamunde et al 2005
RBT	fry	0.50 g	56 d	water	22% decreased weight	whole body			9.5*			Hansen et al 2002

Table 2-11 (continued). Summary of studies relating levels of trace elements in tissues to growth or mortality effects in salmonids. The response listed in the table was either the lowest level of exposure leading to a significant decrease in growth or the highest level of exposure leading to no significant change in growth. If residues were reported as wet-weight, they were converted here to dry weight assuming 75% moisture. Values followed by an asterisk mean that the value was estimated from a graph in the publication.

Species	**Lifestage**	**Weight (g) of control fish**	**Exposure duration**	**Diet/ water exposure**	**Response**	**Tissue**	**Trace element concentration (µg/g dry wt)**					**Reference**
							As	Cd	Cu	Pb	Zn	
RBT	fry	0.58 g	60 d	water	45% decreased weight	whole body			8.57			Marr et al 1996
RBT	Fry	13.9 g	168 d	diet	no change in weight	liver			1,643		86	Lanno et al 1985
RBT	juvenile	63 g	28 d	diet	no change in weight	liver			401			Kamunde et al 2001
RBT	juvenile	20.2 g	42 d	both	no change in weight	liver			732		78	Miller et al 1993
EBT	yearling-adult	173 g	24 months	water	no change in weight	liver			238			McKim and Benoit 1974
RBT	juvenile	19.9 g	28 d	water	26% mortality & 56% decreased weight	liver			152*			Kamunde et al 2005
Lead												
EBT	egg-fry (third generation fish)	1.17 g	12 weeks	water	25% decreased weight	whole body				20.1		Holcombe et al 1976
EBT	fry-juvenile	312 g	65 weeks	water	34% of fish with scoliosis	liver				50		Holcombe et al 1976
Zinc												
EBT	yearling-adult	102 g	24 weeks	water	no change in weight	liver					350*	Holcombe et al 1979

For cadmium, three studies were found for whole-body tissue levels in rainbow trout, although only two of the studies used similar-sized fish to those in Tenmile Creek . No change in weight was documented at 4.64 µg/g in 2.79 g rainbow trout (Nollis et al 2001), although growth reductions were found in 1.38 g rainbow trout with 1.26 µg/g cadmium (Benoit et al 1976). In this study, Minnehaha Creek had the highest levels of cadmium (4.7 µg/g) in whole body fry weighing 1.5 g, which when compared to the two studies above suggests growth effects based on one study but not the other. For liver tissue, Minnehaha Creek was again the highest with a mean (range) of 37.7 µg/g (29.6-50.1) in fish weighing 22-33 g. These levels are far above the no effect levels shown in Table 2-11 which range from 10.8-18 µg/g, but because there are no low-effect studies to compare to, it is not possible to say if growth effects might be expected in Minnehaha Creek. Levels of 18 µg/g were also exceeded at three other sites—Below Minnehaha Creek, Monitor Creek and Moose Creek Campground. In the Benoit et al (1976) study they found an increase in mortality of male spawning brook trout (174 g) with liver levels of 10 µg/g. Fish from most of the sites in this study had higher levels of liver cadmium than 10 µg/g, but no observations of spawning fish were made to corroborate or refute the Benoit study.

Copper is the metal most studied with regard to associating tissue levels with growth effects. Because effects of copper have been shown to be size dependent, with younger fish more sensitive (Chapter 6 this study), studies referenced in Table 2-11 with fry similar in size to those in this study show growth effects at levels ranging from 8.57-9.5 µg/g on a whole-body basis. To this list should be added the Woodward et al studies (1994,1995), which were studies of metal mixtures, although copper was believed to be the element causing growth effects at levels ranging from 20.8-32.8 µg/g. In this study, whole body copper levels exceed the 8.57 level in some individual fish in Minnehaha Creek and Tenmile Creek below Minnehaha Creek. For livers, studies showing no changes in weight had copper levels ranging from 732-1643 µg/g for fish in the size range used in this study. The Kamunde et al (2005) study showed decreased weight and increased mortality when livers had 152 µg/g, but because many of the fish in this groups were dying, one must question the ability of the fish in this study to have normal physiological function or feeding behavior. Therefore, we are more trusting of the range of 732-1643 µg/g being reflective of no-effect levels. In this study, the highest single liver copper value was 279 µg/g, far below the no effect levels of the studies cited in Table 2-11.

Few studies exist for examining the effects of lead on trout. Holcombe et al (1976) found reduced growth at whole body lead levels of 20.1 µg/g, far above all fish in this study except for Minnehaha Creek where lead levels in one fish sample were 22.1 µg/g. For livers, Holcombe found an increase in levels of scoliosis where lead levels were 50 µg/g. In this study, the highest levels were also in Minnehaha Creek but only 1.82 µg/g.

Holcombe et al (1979) reported that 102 g rainbow trout accumulated zinc to about 350 µg/g in liver tissue without any effect on growth. In this study, the livers of generally smaller brook trout (14-115 g) had similar or slightly higher levels of zinc in one tributary (Minnehaha Creek, mean level of 350 µg/g) and two mainstem sites (Sawmill site—mean concentration of 382 µg/g and below Minnehaha Creek—mean concentration of 331 µg/g). Given how close the zinc levels in fish in Tenmile Creek are to this no-effect level, and the lack of other relevant studies for comparison, there is no compelling reason to think zinc is affecting growth. Hansen et al

(2004) reported growth effects were seen at 111 μg/g in 2.9 g rainbow trout, but the authors felt that the growth effects were most likely due to arsenic exposure.

2.4.3 Implications for Human Health

The U.S. EPA guidance (USEPA 2000) on fish consumption advisories was used to evaluate the degree to which fish contaminated with trace elements in Tenmile Creek might pose a human health risk. In this study, brook trout fish fillets were analyzed for arsenic, copper, lead, mercury, and zinc (Table 2-9). Of these elements, the EPA offers consumption advice for only mercury and arsenic. Cadmium was not analyzed in the muscle of brook trout in the Tenmile Creek drainage, but given its presence in fish livers and whole bodies, it is possible that it might accumulate to levels of concern for human consumption.

The EPA risk assessment for arsenic is based on inorganic arsenic, the toxic form of this metalloid. The organic forms of arsenic are considered non-toxic. In this study, total arsenic was measured, and not the inorganic and organic components. MacIntosh et al (1997) reports that only 1.5% of arsenic in fish is inorganic, and so the total arsenic values in this study can be multiplied by 0.015 to get the estimated concentration of inorganic arsenic. In this study the highest concentration of total arsenic was 0.29 μg/g in 5.9-7.1 inch brook trout fillets at the Moose Creek Campground (Table 2-9). The estimated concentration of inorganic arsenic is 0.29 x 0.015 = 0.0045 μg/g. EPA consumption advice for this is "unrestricted consumption" for non-cancer endpoints (>16 meals/month) and 12 meals/month for cancer endpoints (assuming a 1 in 100,000 increased cancer risk).

Methylmercury is the toxic form of mercury, and in fish 90% or greater is in this form (ATSDR 1999, USEPA 2001). In this study, total mercury was measured, and it is assumed for the purposes of this discussion that it was entirely methylmercury. In the Tenmile drainage, mercury was not detected at a level of 0.033 μg/g in brook trout muscle at any site. The EPA consumption advice for non-cancer endpoints for this level of mercury is 16 meals/month. There are no cancer endpoints for mercury.

2.5 Summary

The effort to relate tissue residues of trace elements in trout in Tenmile Creek to residue levels causing growth effects in laboratory studies did not yield definitive conclusions. The detection levels of arsenic in this study were too high to allow a good comparison to the laboratory studies, but the available data suggests that arsenic is not causing growth effects in trout anywhere in the Tenmile Creek drainage. The comparisons for cadmium provide the strongest indication that tissue levels in some Tenmile Creek (especially Minnehaha Creek) drainages may be high enough to cause decreased growth. This conclusion is based on the whole-body levels of cadmium being above levels of effect from one literature source; the liver concentrations of cadmium were also much higher in some Tenmile fish than laboratory studies showing no-effects, but no lab studies were available to indicate a liver concentration that would affect growth. For copper some fish in Minnehaha Creek and Tenmile Creek below Minnehaha creek may be impacted based on whole-body residue comparisons. However, copper levels in liver tissue at all sites were far below levels of effect reported in the literature. Levels of zinc do not appear to be high enough to suggest growth effects, although only one study was available for comparison. The impact of lead is not clear, because while levels in whole bodies in Minnehaha

Creek were as high as one lab study showing growth effects, liver levels were far below those causing scoliosis in another study.

The risk to humans from exposure to arsenic and mercury as a result of consuming fish in the Tenmile Creek drainage appears to be negligible. Allowable consumption rates of 12-16 meals/month for these fish is a level of consumption that seems very unlikely to be occurring, especially for the extended period of exposure (70 years) that the risk calculations are based upon.

2.6 References

Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicological Profile for Mercury. U.S. Dept. of Health and Human Services. 676 pp.

Baldisserotto B, MJ Chowdhury, CM Wood. 2005. Effects of dietary calcium and cadmium on cadmium accumulation, calcium and cadmium uptake from water, and their interactions in juvenile trout. Aquatic Toxicology 72: 99-117.

Benoit, D.A., E.N. Leonard, G.M. Christensen and J.T. Fiandt. 1976. Toxic effects of cadmium on three generations of brook trout (Savelinus fontinalis). Trans. Amer. Fish. Soc. 105: 550-560.

Dixon, DG and JB Sprague. 1981. Acclimation-induced changes in toxicity of arsenic and cyanide to rainbow trout, *Salmo gairdneri* Richardson. J. Fish Biol 18: 579-589.

Dodge, KA, MI Hornberger, and EV Axtman. 1997. Water-quality, bed-sediment, and biological data (October 1995 through September 1996) and statistical summaries of data for streams in the Upper Clark Fork River Basin, Montana. U.S. Geological Survey, Open-file report 97-552. Helena, Montana. 91 pp.

Giles M. 1988. Accumulation of cadmium by rainbow trout, Salmo gairdneri, during extended exposure. Can. J. Fish. Aquat. Sci. 45: 1045-1053.

Hansen JA, J Lipton, PG Welsh, J Morris, D Cacela and MJ Suedkamp. 2002. Relationship between exposure duration, tissue residues, growth, and mortality in rainbow trout (Oncorhynchus mykiss) juveniles sub-chronically exposed to copper. Aquatic Toxicology 58: 175-188.

Hansen, JA, J Lipton, PG Welsh, D Cacela and B MacConnell. 2004. Reduced growth of rainbow trout (Oncorhynchus mykiss) fed a live invertebrate diet pre-exposed to metal-contaminated sediments. Environmental Toxicology and Chemistry 23: 1902-1911.

Holcombe, GW, DA Benoit, EN Leonard, and JM McKim. 1976. Long-term effects of lead exposure on three generations of brook trout (Salvelinus fontinalis). J. Fish. Res. Board Can: 33: 1731-1741.

Holcombe, GW, DA Benoit and EN Leonard. 1979. Long-term effects of zinc exposures on brook trout (Salvelinus fontinalis). Trans. Amer. Fish. Soc. 108:76-87.

Hollis L, C Hogstrand and CM Wood. 2001. Tissue-specific cadmium accumulation, metallothionein induction, and tissue zinc and copper levels during chronic sublethal cadmium exposure in juvenile rainbow trout. Arch. Environ. Contam. Toxicol. 41: 468-474.

Kamunde CN, M Grosell, JNA Lott, CM Wood. 2001. Copper metabolism and gut morphology in rainbow trout (Oncorhynchus mykiss) during chronic sub-lethal dietary copper exposure. Can J Fish Aquat. Sci. 58: 293-305.

Kamunde CN, S Niyogi, and CM Wood. 2005. Interaction of dietary sodium chloride and waterborne copper in rainbow trout (Oncorhynchus mykiss): copper toxicity and sodium and chloride homeostasis. Can. J. Fish. Aquat. Sci. 62: 390-399.

Kelly, M. 1988. Mining and the freshwater environment. Elsevier Applied Science. New York and London. 231 pp.

Lanno RP, SJ Slinger and JW Hilton. 1985. Maximum tolerable and toxicity levels of dietary copper in rainbow trout (Salmo gairdneri Richardson). Aquaculture 49: 257-268.

MacIntosh DL, PL Williams and DJ Hunter. 1997. Evaluation of a food frequency questionnaire-food composition approach for estimating dietary intake of inorganic arsenic and methylmercury. Cancer Epidemiol. Biomarkers Prev. 6: 1043-1050.

Maret, TR and KD Skinner. 2000. Concentrations of selected trace elements in fish tissue and streambed sediment in the Clark Fork-Pend Oreille and Spokane River basins, Washington, Idaho and Montana, 1998. U.S. Geological Survey, Water Resources Investigations report 00-4159, 26 pp.

Marr, JCA, J Lipton, D Cacela, JA Hansen, HL Bergman, JS Meyer and C. Hogstrand. 1996. Relationship between copper exposure duration, tissue copper concentration, and rainbow trout growth. Aquatic Toxicology 36: 17-30.

McGeachy, SM and DG Dixon. 1990. Effect of temperature on chronic toxicity of arsenate to rainbow trout (Oncorhynchus mykiss). Can,. J. Fish. Aquat. Sci. 47: 2228-2234.Miller, P.A., R. P. Lanno, M.E. McMaster and DG Dixon. 1993. Relative contributions of dietary and waterborne copper to tissue copper burdens and waterborne-copper tolerance in rainbow trout (Oncorhynchus mykiss). Can. J. Fish. Aquat. Sci 50: 1683-1689.

McKim, JM and DA Benoit. 1974. Duration of toxicity for establishing “No effect” concentrations for copper with brook trout (Salvelinus fontinalis). J. Fish. Res. Board Can 31: 449-452.

Miller, P.A., R. P. Lanno, M.E. McMaster and DG Dixon. 1993. Relative contributions of dietary and waterborne copper to tissue copper burdens and waterborne-copper tolerance in rainbow trout (Oncorhynchus mykiss). Can. J. Fish. Aquat. Sci 50: 1683-1689.

Parrett, C. and P.S. Hettinger. 2000. Streamflow and water-quality characteristics in the upper Tenmile Creek watershed, Lewis and Clark County, West-Central Montana. U.S. Geological Survey. Water Resources Investigations Report 00-4129.

Sorensen, EM. 1991. Metal poisoning in fish. CRC Press, Boca Raton, Florida. 374 pp.

U.S. EPA. 2000. Guidance for assessing chemical contaminant data for use in fish advisories. Volume 2. Risk assessment and fish consumption limits.Third Edition. EPA 823-B-00-008.

U.S. EPA. 2001. Water Quality Criterion for the Protection of Human Health: Methylmercury. Final. EPA-823-R-01-001.

Chapter 3
Fish Populations Surveys

3.1 Purpose and Scope

Surveys to determine fish species occurrence and abundance are crucial to any comprehensive assessment of the aquatic health of a waterbody. Prior to the surveys reported here, work by the Helena Ranger District of the Helena National Forest had determined the species occurrence in many of the streams in the drainage, including the finding that there were no cutthroat trout in the upper drainage (Archie Harper, United Stated Forest Service (USFS), personal communication). But it wasn't until the work of this study that an effort was made to estimate densities of salmonids in the fish-bearing streams in the drainage.

Our surveys had two objectives: 1) Estimate densities of salmonids in all drainages where they occur; and 2) estimate densities in mining-impacted as well as mining-unimpacted reaches in the mainstem of Tenmile Creek.

3.2 Methods and Materials

A total of ten sites were chosen for the purpose of estimating salmonid densities (Table 3-1). Four tributary sites were chosen: three were on streams having had previous mining activity (Monitor, Banner and Minnehaha creeks), while one served as a reference—meaning having had no mining activity (Moose Creek). In the case of Moose, Banner and Minnehaha creeks, the downstream end of the sampling reach was at the City of Helena diversion. On Monitor Creek, the downstream end of the sampling reach was about ¼ mile above the confluence with Tenmile Creek. Six mainstem sites were chosen, and although it was not possible to find a reference site on the mainstem, the uppermost site (Tenmile below Banner Creek) was upstream from all of the major mining areas (including Lee Mountain, Red Mountain, Red Water, Suzie). The rest of the mainstem sites were all downstream of the aforementioned mines, beginning with Tenmile at Rimini, which had its upstream end of the sampling reach about 100 feet upstream of the Suzie Mine adit discharge. Other mainstem sites--proceeding in a downstream direction--were Tenmile at Sawmill (near Chessman Reservoir turnoff), Tenmile below Minnehaha Creek, Tenmile above Moose Creek Campground, and Tenmile at Water Treatment Plant.

All sampling was done with a backpack electroshocker unit, equipped with a Coffelt BP-6 Rectifier generating a straight DC current. The length of stream sampled varied, but ranged from 420-742 feet of stream length. Density estimates were determined using a two- or three-pass depletion method (Seber and LeCren 1967, Zippen 1958). Block nets were positioned at the upper and lower ends of the sample sections to prevent escape of fish. Fish captured on each pass were held in separate live cars, and when processed were measured for length and weight.

Table 3-1 Summary of Electrofishing Surveys to Estimate Fish Densities (+ SE) in the Upper Tenmile Creek Drainage. EBT= Eastern Brook Trout, RBT= Rainbow Trout, All=both trout species.

Site	Length (ft)	Date	Species	Size range (in)	Number/ 1000 ft	Pounds/ 1000 ft	Number/ acre	Pounds/acre
Monitor Creek	544	9/1/98	EBT	1.8-6.7	187±2	7.29±0.09	1776 ± 21	69.3 ± 0.8
Monitor Creek	544	9/14/99	EBT	1.8-5.6	116±8	2.32±0.16	1102 ± 77	22.0 ± 1.5
Minnehaha Cr.	600	8/25/98	EBT	1.8-6.2	344±13	11.0± 0.4	2055 ± 76	65.8 ± 2.4
Minnehaha Cr.	600	8/24/99	EBT	1.9-7.6	248± 11	7.46± 0.32	1479 ± 63	44.5 ± 1.9
Moose Creek	500	8/21/98	EBT	1.7-7.9	192± 7	9.22± 0.36	1707 ± 66	81.9 ± 3.2
Moose Creek	500	8/17/99	EBT	1.9-8.2	123± 7	4.79± 0.29	1092 ± 66	42.6 ± 2.6
10-Mile blw Banner Cr.	420	8/21/98	EBT	2.3-8.5	143±32	14.0±3.1	448 ± 100	43.9 ± 9.8
10-Mile blw Banner Cr.	420	8/30/99	EBT	2.4-8.3	119 ± 9	8.93 ± 0.65	372 ± 27	27.9 ± 2.0
10-Mile at Rimini	700	8/26/98	EBT	1.9-2.5	10	0.1	36.6	0.5
10-Mile at Rimini	700	8/27/99	EBT		0	0	0	0
10-Mile at sawmill	765	9/1/98	EBT	1.8-8.1	57.1 ± 4.7	3.03 ± 0.25	186 ± 15	9.9 ± 0.8
10-Mile at Sawmill	738	9/7/99	EBT	1.1-8.1	84.3 ± 11.2	2.02 ± 0.26	274 ± 36	6.6 ± 0.9
10-Mile blw Minnehaha Cr.	600	9/10/99	EBT	1.6-7.5	160 ± 7	7.84 ± 0.34	611 ± 27	29.9 ± 1.3
10-Mile at Moose Cr.	742	8/20/98	EBT RBT All	2.0-8.8 6.4-8.4 2.0-8.8	360 ± 8 12.1 ± 0.3 372 ± 8	14.4 ± 0.3 1.85 ± 0.01 16.4 ± 0.3	1081 ± 23 36.4 ± 0.8 1118 ± 23	43.2 ± 0.9 5.57 ± 0.03 49.2 ± 1.0
10-Mile at Moose Cr.	742	8/25/99	EBT RBT All	2.2-7.5 3.9-9.4 2.2-9.4	395 ± 11 32.3 ± 0.3 424 ± 10	14.2 ± 0.4 1.78 ± 0.02 15.7 ± 0.4	1185 ± 34 97.2 ± 0.8 1274 ± 31	42.7 ± 1.2 5.3 ± 0.04 47.1 ±1.1
10-Mile at Treat. Plant	670	8/25/98	EBT RBT All	2.4-9.9 1.7-9.0 1.7-9.9	123 ± 38 32.4 ± 5.7 149 ± 27	9.0 ± 2.8 3.08 ± 0.54 11.8 ± 2.2	360 ± 111 94.7 ± 17 436 ± 80	26.3 ± 8.1 9.0 ± 1.6 34.4 ± 6.3
10-Mile at Treat. Plant	670	9/3/99	EBT RBT All	2.2-8.7 1.6-9.7 1.6-9.7	157 ± 5 95.5 ± 10.6 249 ± 9	6.58 ± 0.20 4.58 ± 0.51 11.0 ± 0.4	458 ± 14 279 ± 31 729 ± 26	19.2 ± 0.6 13.4 ± 1.5 32.1 ± 1.1

3.3 Results

3.3.1 Species Occurrence

With regard to salmonids, brook trout were found in all drainages and at all sites except for Banner Creek. Rainbow trout (*Oncorhynchus mykiss*) were found only on the mainstem at the Treatment Plant and above Moose Creek Campground. The source of this species is probably Walker Creek, which has a private pond high in the drainage that has been stocked in the past with rainbow trout. One brown trout (*Salmo trutta*) was captured at the Treatment Plant in 1998. The only non-salmonid species encountered was the mottled sculpin (*Cottus bairdii).* There were only two sites at which the presence/absence was recorded in 1998 and 1999. They were found at the Tenmile Creek below Banner Creek site and not in Monitor Creek. Follow-up sampling of all the other sites in 2004 revealed that they were not present at any of the tributary sites, but were present in Tenmile Creek below Minnehaha, at Moose Creek Campground, and at the Treatment Plant.

3.3.2 Density Estimates of Salmonids

Densities and biomass of salmonids were greater in 1998 than 1999 at all sites except Tenmile at Sawmill and Tenmile below Minnehaha (which was only sampled in 1999) (Table 3-1). This was true, whether expressed on a lineal basis (number or pounds per 1000 feet) or aerial basis (number or pounds per acre). With respect to the tributaries, Minnehaha Creek was higher in numbers and biomass than either Monitor Creek or Moose Creek. The numbers and biomass of trout in Monitor Creek were similar to those in Moose Creek, but generally slightly lower.

Differences in biomass and numbers of trout at mainstem sites were much more variable than in the tributaries. The site least impacted by elevated concentrations of metals in the water was Tenmile below Banner Creek. This site had densites and biomass levels similar to the three lowest sites on the mainstem (below Minnehaha creek, at Moose Creek, and at the Treatment Plant. This is contrasted with the much lower numbers and biomass found at the sites At Rimini and Sawmill (Figure 3-1).

3.3.3 Demographics of Salmonids Populations

The age composition of trout species was approximated using length-frequency analysis (Table 3-2). This analysis was probably quite accurate for the age 0 fish, as the mode and entire range of length of this age group showed almost total separation from age 1 fish. The mode of age 1 fish was also typically distinct, but the distribution of the larger fish of this age group almost always overlapped to some degree with the age 2 and older fish. Therefore, the separation of age 1 and 2+ fish in this table is only an approximation.

Some of the demographic characteristics were almost certainly due to habitat features. For example, the relatively low percentage of age 0 brook trout at Below Banner Creek relative to other mainstem sites was probably due to the fact that the site was high gradient with large boulder substrate and little holding water for small fish. Conversely, the Moose Creek site was a very small narrow channel with few places for large fish to reside, and this is reflected in the low percentage (8%) of age 2 and older brook trout.

The interpretation of the impact of toxic metals on the age composition of both trout species is aided by bioassays conducted during this study (see Chapter 6). These bioassays showed that very small age 0 fish (about 0.4 grams) are much more sensitive to zinc and cadmium than are larger-sized fish, and this sensitivity is most acute in the Rimini area where these metals are at their highest concentrations in the water.

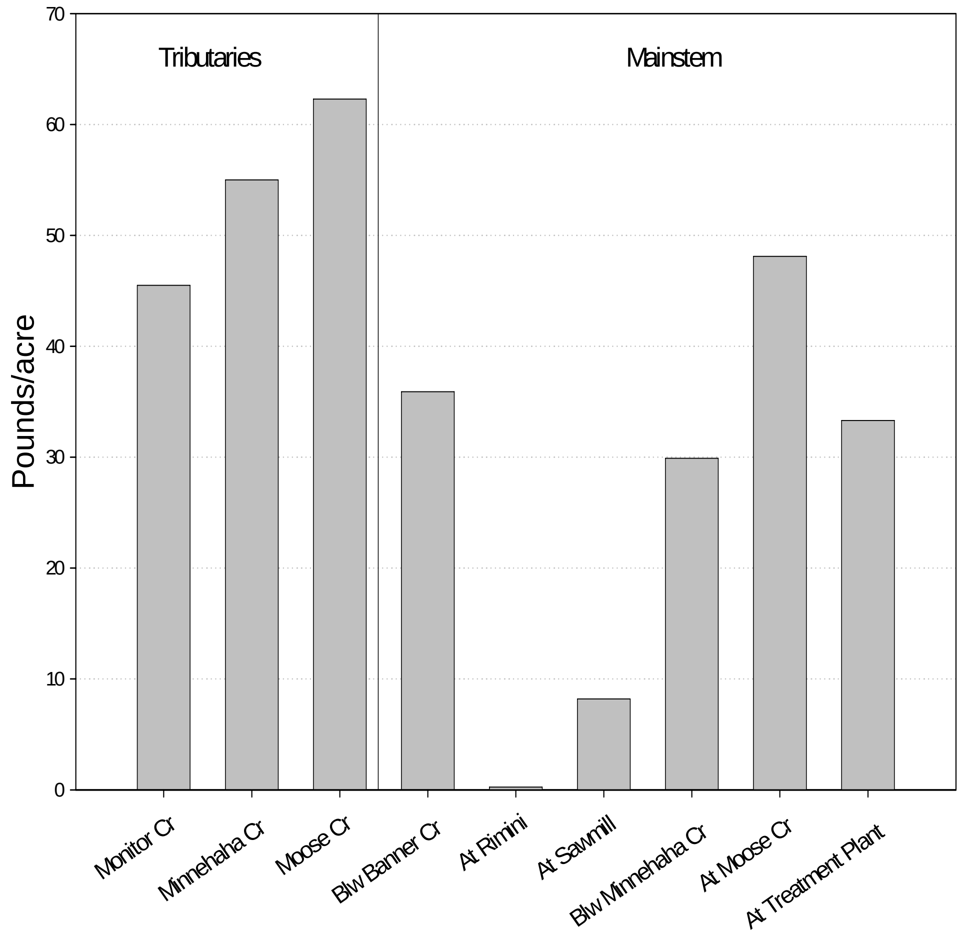


Figure 3-1 Average Number of Pounds/Acre of all Trout Species for Years 1998 and 1999.

Table 3-2 Approximate Age Composition of Trout Species at Sample Sites in 1998 and 1999.

	Brook Trout			**Rainbow trout**		
Site	Age 0	Age 1	Age 2 and older	Age 0	Age 1	Age 2 and older
Mainstem sites						
Blw Banner Creek	17	39	44	--	--	--
Rimini*	100	0	0	--	--	--
Sawmill	64	29	7	--	--	--
Blw Minnehaha**	48	45	7	--	--	--
Moose Cr Cmpgrnd	59	34	7	0	55	45
Treatment Plant	56	33	11	29	19	52
Tributaries						
Monitor Creek	35	42	23	--	--	--
Minnehaha Creek	25	49	26	--	--	--
Moose Creek	44	48	8	--	--	--

*Fish captured in 1998 only
**Sampled in 1999 only

For this reason, the high percentage of age 0 brook trout at Rimini and the Sawmill (100 and 64% respectively) relative to other mainstem sites, suggests that these fish may have drifted into these sites from Tenmile Creek above the City diversion after they had grown larger than the most sensitive size. The distribution of age classes of rainbow trout may also be a reflection of the effect of toxic metals, but for different reasons. Since many of the rainbow trout in the mainstem presumably come from Walker Creek (low in the drainage), the lack of age 0 rainbows upstream of Walker Creek (0% at the Moose Creek Campground) may simply reflect their tendency not to move great distances upstream. However, the fact that there are larger, probably mature, rainbow trout at the Campground site suggests that this species may spawn in the area, but that the fry do not survive the metals exposure (see discussion in Chapter 6).

3.4 References

Seber, G.A.A. and E.D. LeCren. 1967. Estimating population parameters from catches large relative to the population. Journal of Animal Ecology 36: 631-643.

Zippen, C. 1958. The removal method of population estimation. Journal of Wildlife Management 22:82-90.

Chapter 4
Aquatic Macroinvertebrate Survey

4.1 Introduction

The upper Tenmile Creek Drainage was added to the Superfund National Priorities List (NPL) in October 1999 due to metals contamination from historic mining and milling. State and Federal agencies are conducting numerous investigations to determine the degree and extent of metals impacts to streams in the drainage. As part of this effort, Montana Fish, Wildlife and Parks (FWP) evaluated aquatic macroinvertebrate communities in the drainage.

This report presents and evaluates macroinvertebrate data collected from ten sites during the summers of 1997, 1998, and 1999. The objectives of this study are to (1) provide a current assessment of biotic condition at each stream site, (2) describe the degree and probable causes of biological impairment, and (3) develop a baseline for future monitoring.

4.2 Rationale

Aquatic macroinvertebrate communities consist primarily of immature insects, including stoneflies (Plecoptera), caddisflies (Trichoptera), mayflies (Ephemeroptera), true flies (Diptera), beetles (Coleoptera) and others. These organisms are important components of aquatic ecosystems and form energy links between primary producers (algae), organic inputs to the stream, and fish. Macroinvertebrates are good indicators of environmental conditions due to their limited mobility, predictable associations with specific habitats, and differential tolerances to pollution. Evaluating the biological integrity of this assemblage can provide an assessment of environmental quality and can be used to identify limiting factors, for detecting impacts from physical alterations, sediment deposition, nutrients and toxicants, and to document successful mitigation of environmental degradation. Biological integrity has been defined as "the capability of supporting and maintaining a balanced, integrated, adaptive community having species composition, diversity and functional organization comparable to that of natural habitat of the region" (Karr and Dudley 1981).

4.3 Site Descriptions

Upper Tenmile Creek is located approximately 20 miles southwest of Helena, Montana. The Rimini Mining District includes more than 20 inactive and abandoned hard rock mining and milling sites. Aquatic macroinvertebrates were collected from five tributaries and five mainstem sites on Upper Tenmile Creek (Figure 1-2). Sampling locations were designated:

Monitor Creek	at road crossing
Banner Creek	above diversion
Poison Creek (kick samples only)	at road crossing
Minnehaha Creek	above diversion
Moose Creek	above diversion
Tenmile Creek below Banner Cr.	above Bunker Hill Mine slump
Tenmile Creek at Rimini	at lowermost bridge
Tenmile Creek at Sawmill (1999 only)	adjacent to Chessman Reservoir road
Tenmile Creek above Moose Creek.	at Moose Creek campground
Tenmile Creek	at Treatment Plant

4.4 Methods

4.4.1 Field Work

Field work was conducted by Don Skaar and Kurt Hill (FWP). Dan McGuire (McGuire Consulting) assisted in site selection and sampling during 1997. Samples were collected during mid-summer (generally in August) of 1997, 1998, and 1999. On each date, three Hess samples (0.1 m^2) were collected from coarse cobble substrates in riffle or run habitats at each site except Poison Creek. Hess samples were not collected from Poison Creek due to large substrates and insufficient flow. The first Hess samples collected for this study (Monitor Creek, 1997) appeared to contain too few organisms to allow a meaningful analysis. Consequently, a multiple-habitat, traveling kick sample (Bukantis 1996) was also collected at each site. Kick samples covered a large but variable area (generally in excess of 4 m^2) and were of sufficient duration to insure the collection of several hundred organisms. Sampling duration varied from 2 to 7 minutes.

4.4.2 Laboratory Analysis

Samples were processed by Dan McGuire. All macroinvertebrates were removed and identified from Hess samples. Rapid Bioassessment Protocol (RBP) III sorting methodology (Plafkin et al. 1989) was used to obtain an ~300 organism subsample from each kick-net collection. Macroinvertebrates were identified to taxonomic levels specified in Montana's RBP protocols (Bukantis 1996), usually genus or species.

4.4.3 Data Analysis

The standard Montana Department of Environmental Quality (DEQ) RBP assessment for mountain streams incorporates seven metrics. This multiple-metric approach quantifies attributes of community composition, structural, and functional organization into a single number estimate of biological integrity (Table 4-1). Each metric receives a score ranging from 0 (severely impaired) to 3 (nonimpaired). Scores for all metrics were totaled and biological integrity was expressed as a percentage of the maximum possible score.

Table 4-1 Macroinvertebrate-Based Bioassessment Metrics and Scoring Criteria for Mountain Streams in Montana (Bukantis 1996): RBP- 300 Organism Subsamples from Kick Samples.

Metric	Score: 3	2	1	0
Taxa Richness	>28	28-24	24-19	<19
EPT Richness	>19	19-17	17-15	<15
Biotic Index	<3	3-4	4-5	>5
% Dominant Taxon	<25	25-35	35-45	>45
% EPT	>70	70-55	55-40	<40
% Collectors (Gather +Filterer)	<60	60-70	70-80	>80
% (Scrapers+Shredders)	>55	55-40	40-25	<25

Bioassessment scores are computed as follows: 1) compute metrics, 2) determine score from criteria table, 3) sum scores for all metrics, 4) express total as percentage of maximum possible score.

Suggested water quality use support/standards violation thresholds (Bukantis 1996).

Full support--standards not violated	>75%
Partial support--moderate impairment	25-75%
Nonsupport--severe impairment	<25%

Several other metrics that provide insight to metals related impacts are presented in this report. Tolerance values and functional designations used in metric calculations were those compiled by Bukantis (1996). Statistical analyses (ANOVA and posthoc Student-Newman-Kuels) were used to help interpret data.

<u>RBP mountain streams ecoregion metrics</u>
Taxa Richness
EPT Richness
Biotic Index
% Dominant Taxon
% EPT
% Collectors (gathers + filterers)
% Scrapers + Shredders
<u>Additional Metrics used to evaluate impacts in the Tenmile Creek Drainage</u>
Community density (Hess samples only- $0.1m^2$)
Ephemeroptera density
Ephemeroptera richness
Metals Tolerance Index

4.4.4 Results and Discussion

4.4.4.1 Streamflow

Stream discharge is an important factor influencing benthic communities. Mean daily streamflow for Tenmile Creek near Rimini are presented in Figure 4-1. Streamflows were highest in 1997 and lowest in 1999. Extremes in discharge are of particular consequence to macroinvertebrates. Lower Moose Creek appeared to suffer seasonal dewatering (United States Geological Survey (USGS) noted no visible surface flow in Moose Creek on September, 6, 1998). While complete dewatering was not documented at other study area sites, flows of less than 2 cfs were common (Table 4-2).

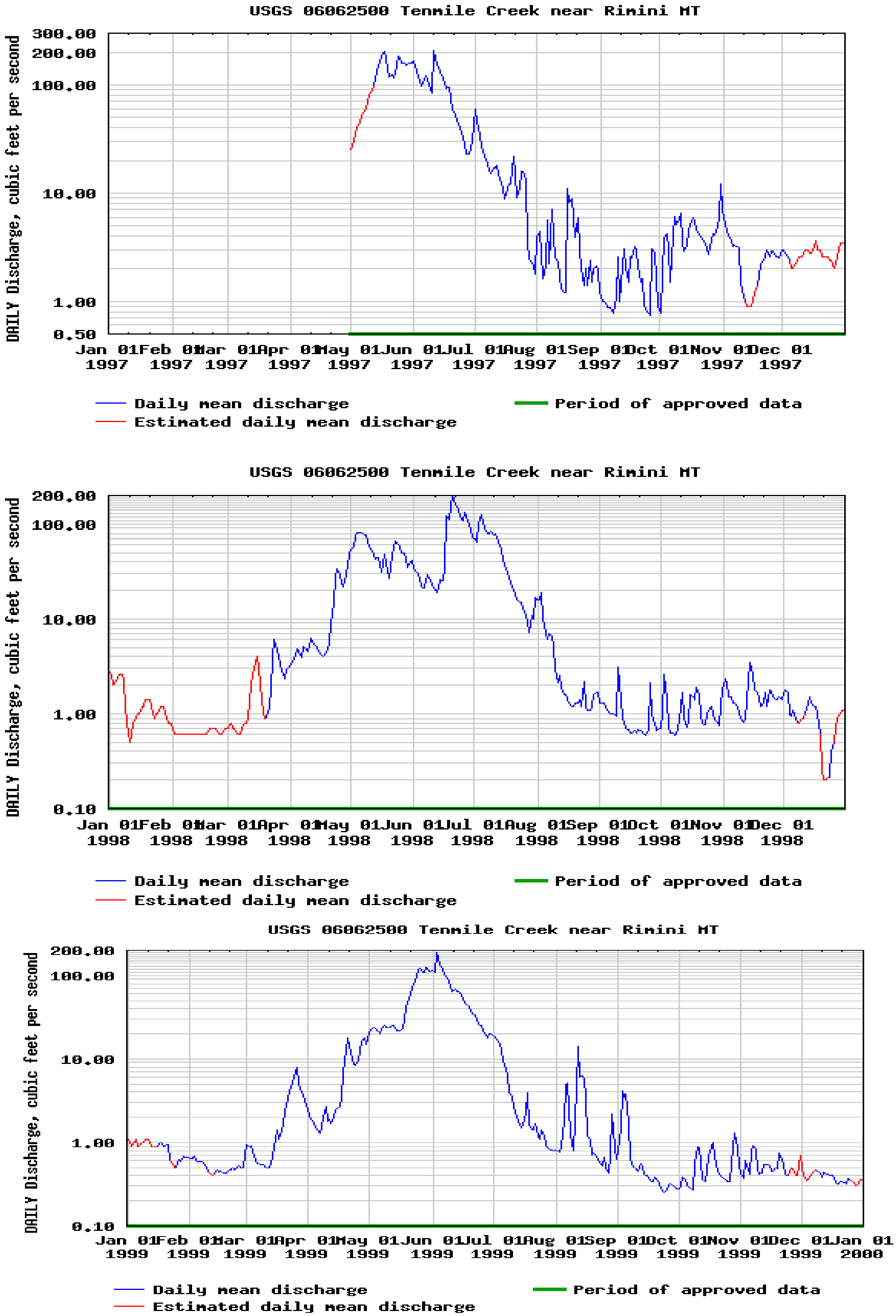


Figure 4.1 Daily Streamflow on Tenmile Creek Near Rimini, 1997, 1998, and 1999. Graphs courtesy of U.S. Geological Survey.

Table 4-2 The Number of Days when Stream Discharge Exceeded 100 Cfs or was Below 2 cfs in Tenmile Creek at the Moose Creek Campground (USGS Gage 06062500) from May Through September 1997-1999.

	Discharge (cfs)			
Year	**<1**	**<2**	**>100**	**>200**
1997	0	10	32	2
1998	0	18	15	0
1999	23	38	14	0

4.4.4.2 RBP Bioassessment

Single traveling kicknet samples were collected at each site during August of 1997, 1998, and 1999. When possible, approximately 300 organism subsamples were used to evaluate biointegrity using DEQ's RBP protocols. For RBP analyses, Montana streams have been grouped into three primary physiographic regions: mountains, foothills and valleys, and plains (Bahls et al. 1992). Metrics and scoring criteria have been developed for each ecoregion (Bukantis 1996). Data from the Tenmile Creek Drainage were evaluated using the mountain ecoregion criteria (Table 4-1).

Based on standard mountain ecoregion criteria, biointegrity estimates ranged from 0 to 100% (Table 4-3). Values for most sites were greater than 75% and were classified as nonimpaired. Two sites on Tenmile Creek (Rimini and Sawmill) and Poison Creek were exceptions. Tenmile at Rimini was classified as nonimpaired during 1997 and 1998 but was moderately impaired in 1999. Tenmile at Sawmill was classified as moderately impaired in 1999, the only year it was sampled. Poison Creek was severely impaired on all dates.

Table 4-3 Macroinvertebrate-Based RBP Assessments at Ten Locations in the Tenmile Creek Drainage, Lewis & Clark County, Montana August, 1997-1999. Standard Montana Mountain Stream Assessment (300 Organism Kicknet Subsamples).

Site:	**Monitor Cr.**			**Banner Cr.**			**Poison Cr.**			**Minnehaha Cr.**			**Moose Cr.**		
Metric values year:	**1997**	**1998**	**1999**	**1997**	**1998**	**1999**	**1997**	**1998**	**1999**	**1997**	**1998**	**1999**	**1997**	**1998**	**1999**
TAXA RICHNESS	37	44	33	37	37	39	3	3	12	29	33	32	34	40	39
EPT RICHNESS	23	31	23	25	26	25	1	3	5	22	24	22	19	19	18
BIOTIC INDEX	1.1	2.02	1.54	1	1.23	1.11	5.8	0.71	3.38	1.4	1.59	1.87	2.85	2.48	2.34
% DOMINANT TAXON	11	21	36	17	16	20	95	43	54	28	28	52	22	13	11
% EPT	82	65	90	91	85	93	3	100	21	94	90	89	59	63	57
% COLLECTORS (gather+filterer)	22	50	18	14	17	15	95	0	58	19	17	14	52	59	55
% (SCRAPERS+SHREDDERS)	59	33	61	74	69	70	3	43	37	69	69	76	35	25	20
Metric scores															
TAXA RICHNESS	3	3	3	3	3	3	0	0	0	3	3	3	3	3	3
EPT RICHNESS	3	3	3	3	3	3	0	0	0	3	3	3	2	2	2
BIOTIC INDEX	3	3	3	3	3	3	0	3	2	3	3	3	3	3	3
% DOMINANT TAXON	3	3	1	3	3	3	0	1	0	2	2	0	3	3	3
% EPT	3	2	3	3	3	3	0	3	0	3	3	3	2	2	2
% COLLECTORS (gather+filterer)	3	3	3	3	3	3	0	3	3	3	3	3	3	3	3
% (SCRAPERS+SHREDDERS)	3	1	3	3	3	3	0	1	0	3	3	3	1	1	0
TOTAL SCORE	21	18	19	21	21	21	0	11	5	20	20	18	17	17	16
PERCENT BIOINTEGRITY	1	0.86	0.905	1	1	1	0	0.52	0.2381	0.95	0.95	0.86	0.81	0.81	0.76

Table 4-3 (continued) Macroinvertebrate-Based RBP Assessments at Ten Locations in the Tenmile Creek Drainage, Lewis & Clark County, Montana. August, 1997-1999. Standard Montana Mountain Stream Assessment (300 Organism Kicknet Subsamples).

Site:	10mile blw Banner			10mile @ Rimini			10mile @ mill			10mile @ Moose			10mile @ treatment		
Metric values year:	**1997**	**1998**	**1999**	**1997**	**1998**	**1999**			**1999**	**1997**	**1998**	**1999**	**1997**	**1998**	**1999**
TAXA RICHNESS	39	36	36	31	29	21			21	30	22	32	37	35	33
EPT RICHNESS	26	24	23	20	18	10			13	23	17	20	28	23	21
BIOTIC INDEX	1.9	1.8	1.57	1.2	1.48	2.33			2.4	1.8	1.77	2.11	2.68	2.09	3.23
% DOMINANT TAXON	14	17	15	15	34	30			21	21	29	28	17	28	21
% EPT	70	80	75	82	77	64			59	93	98	90	68	79	58
% COLLECTORS (gather+filterer)	40	27	34	15	27	31			39	45	43	45	57	38	58
% (SCRAPERS+SHREDDERS)	39	44	42	66	63	48			39	28	51	48	37	54	34
Metric scores															
TAXA RICHNESS	3	3	3	3	3	1			1	3	1	3	3	3	3
EPT RICHNESS	3	3	3	3	2	0			0	3	2	3	3	3	3
BIOTIC INDEX	3	3	3	3	3	3			3	3	3	3	3	3	2
% DOMINANT TAXON	3	3	3	3	2	2			3	3	2	2	3	2	3
% EPT	2	3	3	3	3	2			2	3	3	3	2	3	2
% COLLECTORS (gather+filterer)	3	3	3	3	3	3			3	3	3	3	3	3	3
% (SCRAPERS+SHREDDERS)	1	2	2	3	3	1			1	1	2	2	1	2	1
TOTAL SCORE	18	20	20	21	19	12			13	19	16	19	18	19	17
PERCENT BIOINTEGRITY	0.86	0.95	0.952	1	0.9	0.57			0.619	0.9	0.76	0.9	0.86	0.905	0.81

In fact, Poison Creek was almost devoid of aquatic life. During 17 minutes of kicknet sampling only 119 macroinvertebrates (85 Chironomidae) were collected from Poison Creek.

These results may under estimate metals pollution at some sites in the Tenmile Creek Drainage. RBP analyses were designed primarily to evaluate nonpoint-source nutrient and sediment pollution rather than toxic pollution. Since RBP analyses do not include a measure of community density, the increased sampling effort (4 to 7 minutes vs. ~1 minute for most streams) needed to collect approximately 300 organisms may have masked impacts manifest as low macroinvertebrate densities. Without replication, the RBP analyses provide a screening level assessment of general environmental condition.

4.4.4.3 Hess Sample Assessments

Three Hess samples were collected at eight sites in the Tenmile Creek Drainage each summer (Data not present). Tenmile Creek at Mill was sampled only in 1999 and was excluded from statistical analyses (Appendix A).

4.4.4.4 Community Composition (Figure 4-2)

The composition of macroinvertebrate assemblages reflected differences in water quality, geology, and trophic condition among sites. Mayflies and stoneflies were the most abundant macroinvertebrates at headwater sites (Monitor, Banner, and Minnehaha creeks and Tenmile Creek below Banner) while mayflies and caddisflies predominated in the lower portion of the study area (Tenmile at Moose and Treatment Plant).

Moose Creek supported a much different macroinvertebrate assemblage than other streams in the drainage. Dipterans and caddisflies were the most abundant macroinvertebrates at this site, which was more productive and had more fine sediments than other streams in the drainage. Tanytarsini chironomids, which are intolerant of metals (Clements 1991, Wiederholm 1984), were the most numerous macroinvertebrates in Moose Creek. An increase in chironomid relative abundance during the three-year monitoring period appeared to be flow related.

Tenmile Creek at Rimini supported an unstable community with variable macroinvertebrate assemblages each year. Stoneflies accounted for 64% of the fauna during 1997 but declined to only 7% by 1999. Mayflies were the most abundant group in 1998 (46%) but were absent in 1999. Metals tolerant chironomids (Diamesinae and Orthocladinae) comprised 60% of the sparse macroinvertebrate fauna at this site in 1999.

4.4.4.5 Community Density (Figure 4-3)

Aquatic macroinvertebrates can be eliminated, or greatly reduced in abundance, by severe metals pollution (i.e. Poison Creek). Community densities were relatively low throughout the Tenmile Creek Drainage and were particularly low in Tenmile Creek at the Rimini and Sawmill sites (Table 4-4). Mean density estimates ranged from 190/m^2 in Tenmile Creek at Rimini to 1,630/m^2 in Moose Creek. Moose Creek had significantly higher densities (P = 0.05) than all

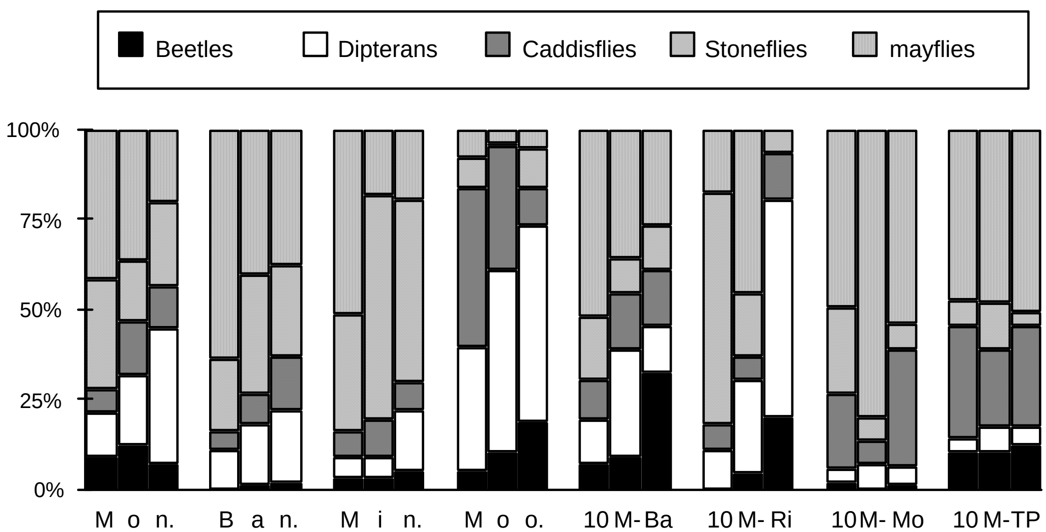


Figure 4-2 Relative Abundance of Macroinvertebrate Orders at Eight Sites in the Tenmile Creek Drainage: 1997-1999.

sites except Minnehaha Creek (Appendix A). Macroinvertebrate densities at Rimini were significantly lower than at all other sites in the drainage. The 1999 density estimate for Tenmile Creek at Sawmill (210/m^2) was similar to the mean density at Rimini.

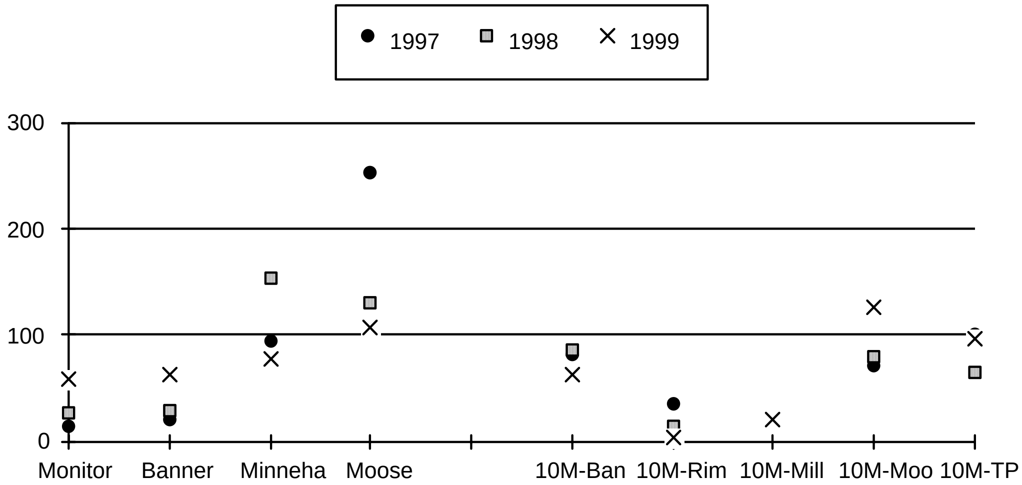


Figure 4-3 Mean Aquatic Macroinvertebrate Community Density at Nine Sites in the Tenmile Creek Drainage: 1997-1999.

Table 4-4 Aquatic Macroinvertebrate Data: Mean Community Metric Values At Nine Sites in the Tenmile Creek Drainage: N= 3 Hess Samples (0.1m^2) Per Site.

1997 station: metric	Monitor Creek	Banner Creek	Minnehaha Creek	Moose Creek	10mile Banner	10mile Rimini		10mile Moose	10mile WTP	mean
TOTAL ORGANISMS	14.7	21.3	94.3	251.7	81.7	35.7		72.3	101	84.09
TAXA RICHNESS	7.3	8.3	20.7	22.3	20.3	11		21.3	21	16.53
EPT RICHNESS	5.7	7.3	15.3	12.7	14.3	9.3		17.3	15.7	12.20
BIOTIC INDEX	2.01	1.01	1.21	3.07	1.06	1.46		1.67	1.5	1.62
% DOMINANT TAXON	0.3	0.27	0.3	0.35	0.25	0.36		0.25	0.26	0.29
% COLLECTORS (gather+filter)	0.31	0.18	0.12	0.44	0.21	0.16		0.33	0.33	0.26
% SCRAPERS + SHREDDERS	0.6	0.75	0.76	0.5	0.6	0.57		0.5	0.62	0.61
% EPT	0.7	0.9	0.9	0.57	0.8	0.85		0.9	0.86	0.81
SHANNON DIVERSITY	2.41	2.7	3.29	3.02	3.57	2.81		3.65	3.55	3.13
EPT/(EPT + Chironomidae)	0.76	0.97	0.95	0.62	0.87	0.85		0.97	0.097	0.76
% COLLECTOR-GATHERERS	0.31	0.11	0.12	0.13	0.21	0.15		0.29	0.2	0.19
% SHREDDERS	0.33	0.18	0.29	0.21	0.04	0.36		0.21	0.06	0.21
% SCRAPERS	0.28	0.58	0.46	0.29	0.57	0.21		0.3	0.56	0.41
% FILTERERS	0	0.07	0	0.31	0	0.01		0.03	0.13	0.07
% PREDATORS	0.08	0.07	0.12	0.06	0.19	0.27		0.17	0.05	0.13
EPHEMEROPTERA DENSITY	6	14	49	19	42	6		38	48	27.75
EPHEMEROPTERA TAXA	3	4.7	6.7	4.7	6.7	3.3		7.7	7	5.48
% CHIRONOMIDAE	0.23	0.03	0.05	0.34	0.12	0.15		0.03	0.02	0.12
METALS TOLERANCE INDEX	1.72	1.15	0.95	1.7	1.34	1.43		1.6	2.11	1.50

Table 4-4 (continued) Macroinvertebrate Data: Mean Community Metric Values At Nine Sites in the Tenmile Creek Drainage: N= 3 Hess Samples ($0.1m^2$) Per Site.

1998 station: metric	Monitor Creek	Banner Creek	Minnehaha Creek	Moose Creek	10mile Banner	10mile Rimini		10mile Moose	10mile WTP	mean
TOTAL ORGANISMS	27.3	30	153.7	129.7	85.7	15.3		80	64.7	73.30
TAXA RICHNESS	16	14.3	26	17.3	21	10		13.3	20	17.24
EPT RICHNESS	11.3	10.3	18	9	14	7.3		12	14.3	12.03
BIOTIC INDEX	1.88	1.67	1.66	3.75	2.7	2.3		1.38	2.02	2.17
% DOMINANT TAXON	0.18	0.24	0.35	0.4	0.19	0.25		0.31	0.22	0.27
% COLLECTORS (gather+filter)	0.43	0.18	0.14	0.48	0.52	0.35		0.35	0.49	0.37
% SCRAPERS + SHREDDERS	0.37	0.68	0.68	0.46	0.3	0.47		0.53	0.39	0.49
% EPT	0.68	0.81	0.9	0.41	0.62	0.71		0.97	0.83	0.74
SHANNON DIVERSITY	3.69	3.43	3.4	2.77	3.91	3.05		2.98	3.73	3.37
EPT/(EPT + Chironomidae)	0.91	0.86	0.97	0.45	0.7	0.76		1	0.94	0.82
% COLLECTOR-GATHERERS	0.4	0.18	0.12	0.15	0.5	0.33		0.34	0.47	0.31
% SHREDDERS	0.2	0.32	0.53	0.22	0.02	0.09		0.03	0.09	0.19
% SCRAPERS	0.16	0.36	0.15	0.24	0.28	0.38		0.5	0.3	0.30
% FILTERERS	0.02	0	0.02	0.32	0.02	0.01		0.01	0.03	0.05
% PREDATORS	0.21	0.15	0.18	0.06	0.19	0.18		0.12	0.12	0.15
EPHEMEROPTERA DENSITY	10	12	28	5	31	7		67	31	23.88
EPHEMEROPTERA TAXA	5.7	4.3	6	3	6.3	4.3		8	7	5.58
% CHIRONOMIDAE	0.07	0.14	0.03	0.49	0.27	0.23		0.004	0.05	0.16
METALS TOLERANCE INDEX	1.79	1.62	1.37	2.14	3.15	2.95		1.16	2.38	2.07
1999 station: metric	**Monitor Creek**	**Banner Creek**	**Minnehaha Creek**	**Moose Creek**	**10mile Banner**	**10mile Rimini**	**10mile Mill**	**10mile Moose**	**10mile WTP**	**mean**
TOTAL ORGANISMS	57.7	62	77.7	108.3	63.3	5	20.7	126	96.3	68.56
TAXA RICHNESS	18.3	23.7	25	20.7	16.3	2.7	9	19.7	18	17.04
EPT RICHNESS	11.3	17.3	17	10	12.3	0.7	5.7	14.7	13	11.33
BIOTIC INDEX	1.74	1.79	2.09	3.74	1.36	3.81	2.5	1.01	2.26	2.26
% DOMINANT TAXON	0.23	0.23	0.25	0.39	0.28	0.53	0.29	0.33	0.22	0.31
% COLLECTORS (gather+filter)	0.37	0.15	0.28	0.35	0.32	0.69	0.46	0.2	0.36	0.35
% SCRAPERS + SHREDDERS	0.46	0.66	0.5	0.54	0.44	0	0.3	0.73	0.61	0.47
% EPT	0.63	0.79	0.8	0.3	0.77	0.19	0.56	0.94	0.84	0.65
SHANNON DIVERSITY	3.55	3.93	3.92	3.02	3.31	1.3	2.88	3.03	3.39	3.15
EPT/(EPT + Chironomidae)	0.78	0.89	0.85	0.41	0.93	0.42	0.69	0.97	0.95	0.77
% COLLECTOR-GATHERERS	0.36	0.14	0.27	0.32	0.31	0.69	0.46	0.14	0.35	0.34
% SHREDDERS	0.17	0.37	0.39	0.49	0.03	0	0.05	0.05	0.05	0.18
% SCRAPERS	0.29	0.29	0.11	0.05	0.41	0	0.25	0.69	0.56	0.29
% FILTERERS	0	0.01	0.01	0.03	0.02	0	0	0.06	0.004	0.01
% PREDATORS	0.18	0.19	0.22	0.11	0.23	0.31	0.24	0.07	0.03	0.18
EPHEMEROPTERA DENSITY	12	23	15	5	17	0	5	68	49	21.56
EPHEMEROPTERA TAXA	5.7	7	6.7	2.7	6.7	0	2.7	7.7	5.7	4.99
% CHIRONOMIDAE	0.2	0.1	0.14	0.45	0.04	0.5	0.24	0.03	0.05	0.19
METALS TOLERANCE INDEX	1.27	1.93	1.51	3.45	1.69	5.44	3.7	2.17	2.8	2.66

Table 4-4 (continued) Macroinvertebrate Data: Mean Community Metric Values At Nine Sites in the Tenmile Creek Drainage: N= 3 Hess Samples (0.1m²) Per Site.

1997-1999 Average station: metric	Monitor Creek	Banner Creek	Minnehaha Creek	Moose Creek	10mile Banner	10mile Rimini	10mile Mill	10mile Moose	10mile WTP	mean
TOTAL ORGANISMS	33.23	37.77	108.57	163.23	76.90	18.67	20.70	92.77	87.33	71.02
TAXA RICHNESS	13.87	15.43	23.90	20.10	19.20	7.90	9.00	18.10	19.67	16.35
EPT RICHNESS	9.43	11.63	16.77	10.57	13.53	5.77	5.70	14.67	14.33	11.38
BIOTIC INDEX	1.88	1.49	1.65	3.52	1.71	2.52	2.50	1.35	1.93	2.06
% DOMINANT TAXON	0.24	0.25	0.30	0.38	0.24	0.38	0.29	0.30	0.23	0.29
% COLLECTORS (gather+filter)	0.37	0.17	0.18	0.42	0.35	0.40	0.46	0.29	0.39	0.34
% SCRAPERS + SHREDDERS	0.48	0.70	0.65	0.50	0.45	0.35	0.30	0.59	0.54	0.50
% EPT	0.67	0.83	0.87	0.43	0.73	0.58	0.56	0.94	0.84	0.72
SHANNON DIVERSITY	3.22	3.35	3.54	2.94	3.60	2.39	2.88	3.22	3.56	3.19
EPT/(EPT + Chironomidae)	0.82	0.91	0.92	0.49	0.83	0.68	0.69	0.98	0.66	0.78
% COLLECTOR-GATHERERS	0.36	0.14	0.17	0.20	0.34	0.39	0.46	0.26	0.34	0.30
% SHREDDERS	0.23	0.29	0.40	0.31	0.03	0.15	0.05	0.10	0.07	0.18
% SCRAPERS	0.24	0.41	0.24	0.19	0.42	0.20	0.25	0.50	0.47	0.32
% FILTERERS	0.01	0.03	0.01	0.22	0.01	0.01	0.00	0.03	0.05	0.04
% PREDATORS	0.16	0.14	0.17	0.08	0.20	0.25	0.24	0.12	0.07	0.16
EPHEMEROPTERA DENSITY	9.33	16.33	30.67	9.67	30.00	4.33	5.00	57.67	42.67	22.85
EPHEMEROPTERA TAXA	4.80	5.33	6.47	3.47	6.57	2.53	2.70	7.80	6.57	5.14
% CHIRONOMIDAE	0.17	0.09	0.07	0.43	0.14	0.29	0.24	0.02	0.04	0.17
METALS TOLERANCE INDEX	1.59	1.57	1.28	2.43	2.06	3.27	3.70	1.64	2.43	2.22

4.4.4.6 Taxa Richness (Figure 4-4)

Macroinvertebrate taxa richness is probably the best single measure of a stream's environmental health. While any environmental stress may cause the loss of a few species, toxic pollutants cause the greatest reductions in this metric. Within the Tenmile Creek Drainage, taxa richness was highest in Minnehaha Creek (mean = 23.9) and lowest in Tenmile Creek at Rimini (mean = 7.9). Taxa richness was significantly lower at Rimini than at any other site included in the analysis (Tenmile Creek at Sawmill had low taxa richness (9.0) during 1999).

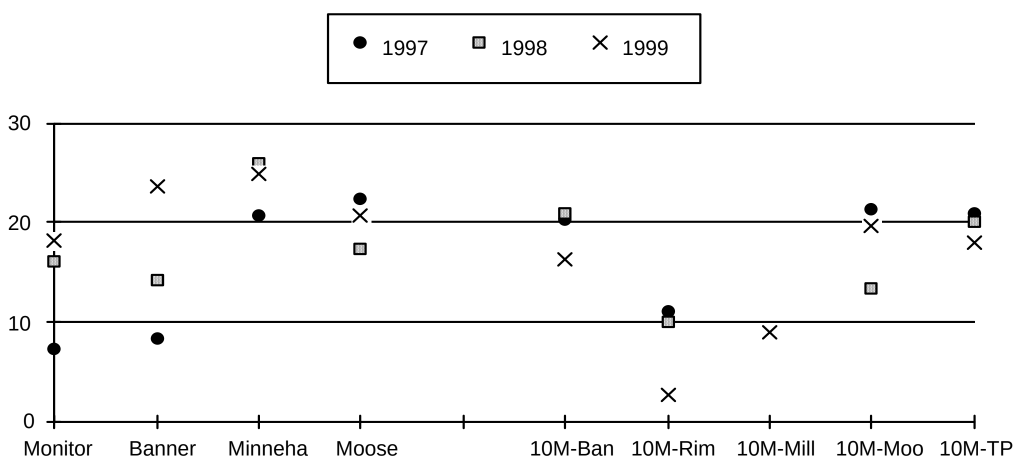


Figure 4-4 Mean Aquatic Macroinvertebrate Taxa Richness at Nine Sites in the Tenmile Creek Drainage: 1997-1999.

Relatively few taxa were collected in Hess samples from Monitor and Banner creeks during 1997. However, these data may reflect, at least in part, the effects of sampling low density populations rather than water quality problems. Based on multiple habitat kick samples, taxa richness was actually quite high at these sites during 1997 (Table 4-3).

4.4.4.7 EPT Richness (Figure 4-5)

This metric summarizes species richness of mayflies, stoneflies, and caddisflies and is a good indicator of metals pollution. Many species in these groups are among the first to be eliminated by metals toxicity (Winner et al. 1980). Minnehaha Creek supported significantly more Ephemeroptera, Plecoptera, Tricoptera (EPT) taxa (mean 16.8) than Tenmile at Rimini (5.8), Monitor (9.4), Moose (10.6) and Banner (11.7) creeks. Mean EPT richness was significantly lower in Tenmile at Rimini than at all other sites.

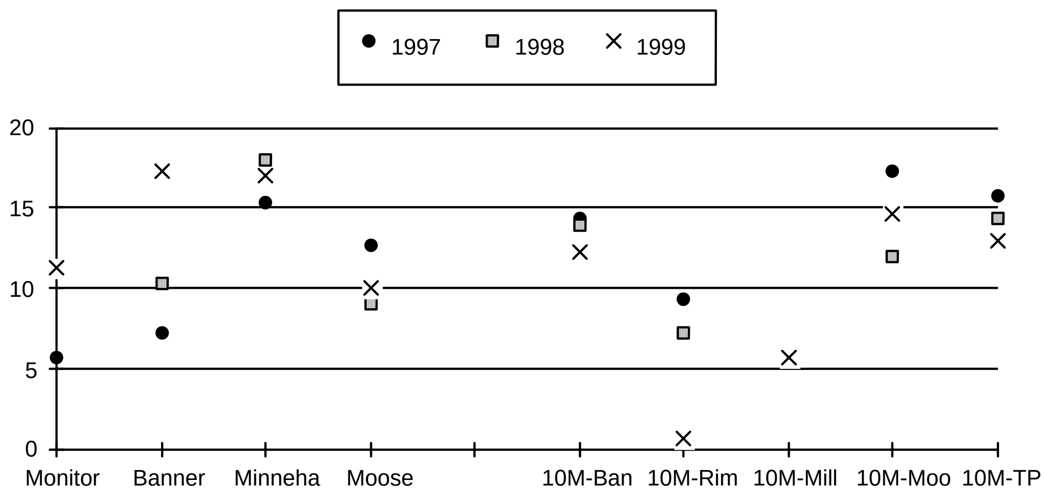


Figure 4-5 Mean EPT Taxa Richness at Nine Sites in the Tenmile Creek Drainage: 1997-1999.

4.4.4.8 Metals Tolerance Index (MTI) (Figure 4-6)

The metals tolerance index (McGuire 1993) is based on indicator species with values ranging from 0 (a highly intolerant community) to 10 (a community highly tolerant of metals). Mean MTI values ranged from 1.3 for Minnehaha Creek to 3.3 for Tenmile Creek at Rimini. MTI values for Tenmile Creek at Rimini increased from 1.4 in 1997, to 3.0 in 1998, to 5.4 in 1999. For all sites combined, MTI values increased each year and were significantly lower in 1997 than during subsequent years.

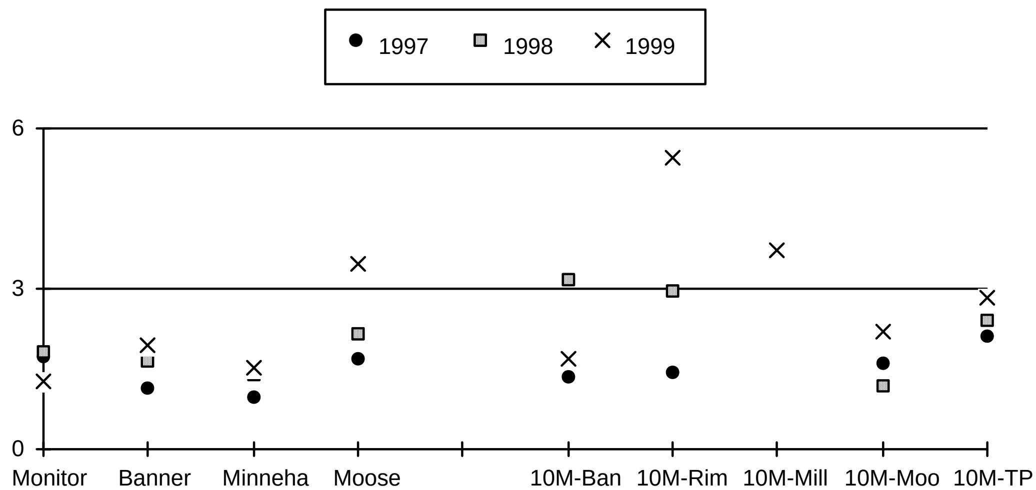


Figure 4-6 Mean Aquatic Macroinvertebrate Metals Tolerance Index Values at Nine Sites in the Tenmile Creek Drainage: 1997-1999.

4.4.4.9 Biotic Index (Figure 4-7)

The biotic index was developed to provide a measure of organic and nutrient pollution (Hilsenhoff 1987) and has been adapted for use in Montana streams (McGuire 1992). This index has a theoretical range of 0 to 10 with higher values indicating increased organic pollution or trophic status. Biotic index values were significantly higher for Moose Creek (mean = 3.5) than any other site in the study area. These values reflect the higher productivity associated with the sedimentary geology in the Moose Creek Basin.

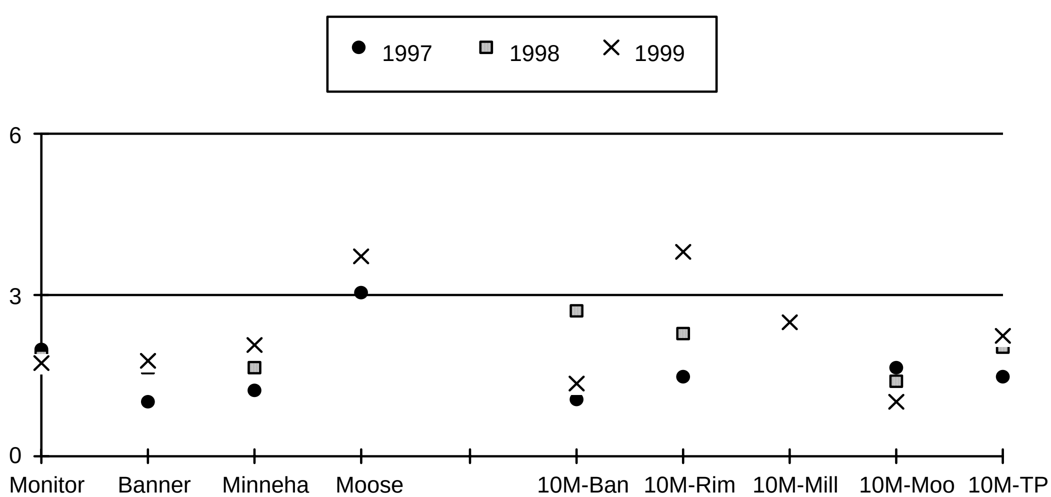


Figure 4-7 Mean Aquatic Macroinvertebrate Biotic Index Values at Nine Sites in the Tenmile Creek Drainage: 1997-1999.

4.4.4.10 Mayfly Species Richness and Density (Figures 4-8 and 4-9)

Mayflies are among the most sensitive macroinvertebrates to metals pollution (Clements 1991). Mayfly densities and species richness clearly showed an impact in Tenmile Creek at Rimini. Mayflies were significantly less abundant at Rimini (44/m^2) than at any other site on Tenmile Creek (301 to 431/m^2). Mayfly species richness had a similar pattern. Tenmile Creek at Moose Creek, at the Treatment Plant, and below Banner Creek had significantly more mayfly species than did Tenmile Creek at Rimini. Mayfly density was significantly higher in Minnehaha Creek (mean 578/m^2) than at any other site. Other tributaries had lower mayfly densities and species richness. Densities were not significantly different between Tenmile at Rimini and Monitor, Moose, and Banner creeks.

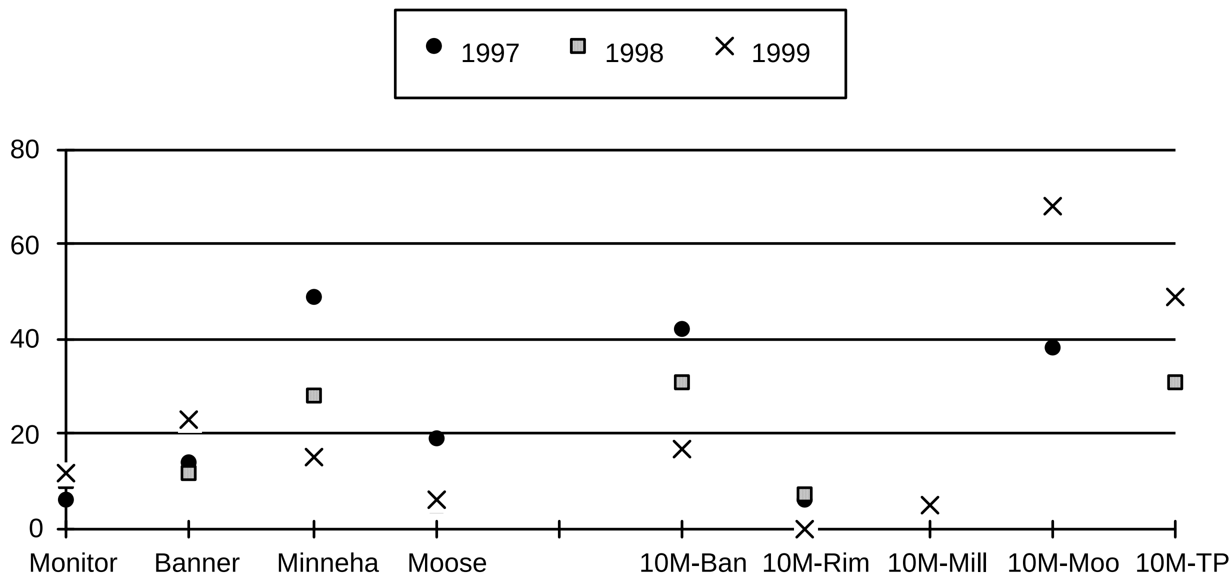


Figure 4-8 Mean Mayfly Density at Nine Sites in the Tenmile Creek Drainage: 1997-1999.

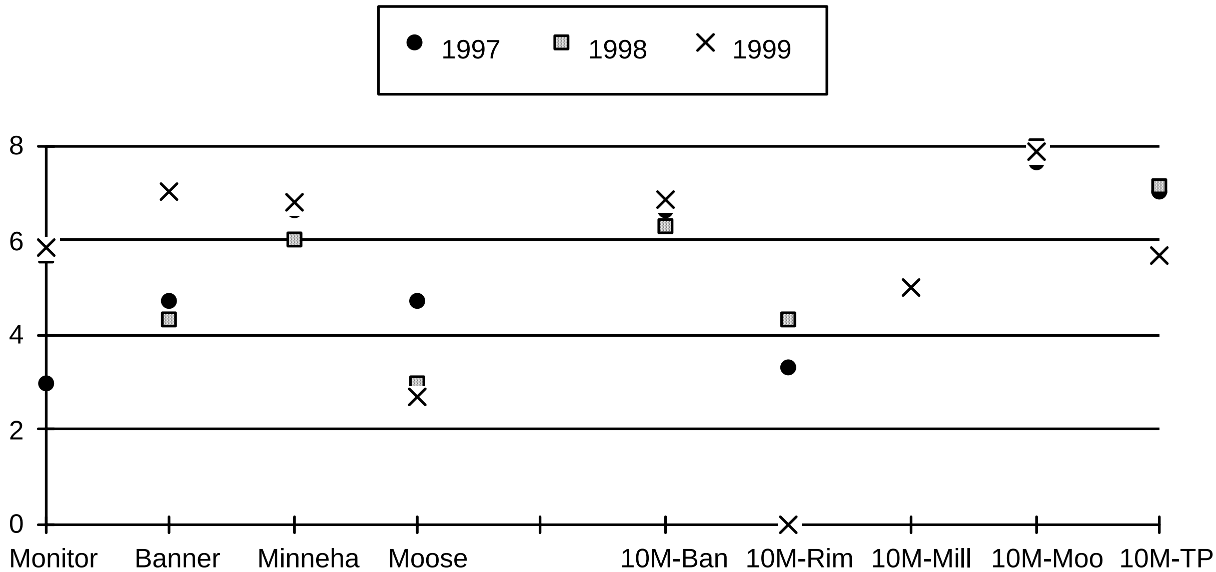


Figure 4-9 Mean Mayfly Species Richness at Nine Sites in the Tenmile Creek Drainage: 1997-1999.

4.5 Conclusions

Tenmile Creek was clearly impacted by metals pollution at the Rimini and Sawmill sites. These sites supported unstable macroinvertebrate assemblages that were characterized by low community density, taxa richness, Shannon diversity, percent EPT (mayflies, stoneflies and caddisflies), mayfly density, and number of mayfly species. The degree of impact varied by year and was most severe in 1999. Poison Creek was the only tributary site that was severely impaired by metals and practically devoid of macroinvertebrates. Metals-related impacts were not clearly indicated at other sites in the drainage.

Chapter 5
Procedures Used to Determine Instream Flow Requirements of Trout

5.1 Purpose and Scope

The suitability of Tenmile Creek for aquatic life is significantly impaired due to water withdrawals for agricultural and domestic uses. In the upper Tenmile drainage (above the Helena Water Treatment Plant), the vast majority of all withdrawals are by the City of Helena, which diverts water out of four tributaries (Banner, Moose, Minnehaha and Walker creeks) and the mainstem of Tenmile Creek near Rimini. Although the City withdraws water at all times of year, the greatest impacts to aquatic life are probably during the July-October period after the high spring runoff flows have subsided and water use by the City is at its highest. In most years, flows during the late summer drop below 1 (cfs), as measured at the USGS gage station near the Moose Creek campground. In severe drought years, such as 2000, the discharge dropped to zero at the Water Treatment Plant and several stretches upstream. In addition to reducing the amount of habitat available to aquatic life, withdrawals during the summer can lead to dangerously high water temperatures and/or dangerously low levels of dissolved oxygen. Withdrawals during the winter are not accompanied by temperature and oxygen problems, but there are potential impacts from ice. If low flows during the winter accelerate the buildup of ice, fish can be crushed by moving ice, or trapped when the steam freezes solid, or stranded in side channels if ice formation blocks water flow.

Because these water withdrawals are probably harmful to the aquatic life in Tenmile Creek, we initiated a study to determine the quantity and quality of instream habitat for trout as a function of streamflow. We used two established techniques for estimating habitat availability as a function of flow: the WETP method and the PHABISM method. The findings from this study will give the USEPA resource managers a valuable tool for weighing remedial alternatives in terms of their ability to enhance conditions for aquatic life in Tenmile Creek.

5.2 Methods

5.2.1 Physical Habitat Simulation System

We used the PHABSIM system to quantify habitat availability for brook and rainbow trout in Tenmile Creek. PHABSIM is a collection of computer models and analytical procedures that was developed by the U.S. Fish and Wildlife Service to relate changes in discharge to changes in physical habitat availability for fish. Several assumptions of PHABSIM were articulated by Bovee (1982), and include: 1) each fish species exhibits preferences within a range of habitat conditions that it can tolerate; 2) these ranges can be defined for each species; and 3) the area of stream providing these conditions can be quantified as a function of discharge and channel structure. For this study, the preferences for both fish species (called suitability indices) were taken from literature sources. There were nine suitability indices for each species, derived from an individual index for depth, velocity and substrate for each of the three lifestages (fry, juvenile and adult). In order to calculate the portion of the stream channel providing these preferred conditions, we used a three-step procedure which is based on measurements collected along strategically placed transects which are assumed to represent the longitudinal distribution of habitat in the stream. The first step in the procedure is to characterize the habitat in the stream in terms of habitat types (pools, runs and riffles) and then choose transects that will be representative of each habitat type. The second step is to simulate hydraulic conditions (depth, velocity, substrate) at points along the transects as a function of flow. The third step is to assign values to points along the transects, which are based on the preference curves of the fish species. These values are summed, and the resulting total is called weighted usable area (WUA), which is a numeric expression of the suitability of the stream for a fish species. The procedures used to accomplish each step are described in detail below.

5.2.1.1 Selecting Representative Habitat Types for Hydraulic and Habitat Simulation

Habitat surveys were conducted in September 1997 in three areas of Tenmile Creek between the City Diversion and the Treatment Plant: 1) within the town of Rimini; 2) at the Moose Creek Campground; and 3) at the Treatment Plant (Figure 5-1). These areas were collectively deemed to be representative of the entire stretch of stream between the City Diversion and the Treatment Plant, in terms of channel gradient and channel width. Ten transects were spaced equally along the length of stream in each section. Habitat measurements were taken along each transect, and each transect was characterized according to the general habitat type: pool, run, riffle. Results are shown in Table 5-1.

Table 5-1 Results of Measurements Taken During Habitat Surveys.

Section	Section length (ft)	% Riffles	% Pools	% Runs
Rimini	700	88.5	0	11.5
Moose Cr. Cmpgrnd	742	76.3	0	23.7
Treatment Plant	670	81.0	0	19.0

We then selected nine transects for hydraulic and habitat simulation—in groups of three at three different sites. The transects are shown below in Table 5-2 and Figure 5-1. The percentage of riffles was 33%, considerably lower than the 76-88% in the habitat transects. This under-representation of riffles was done primarily for the practical reason that simulating conditions in riffles on Tenmile Creek is difficult and subject to much error due to the low discharges. However, the riffles that we did select ultimately yielded reliable simulations. The ramification of using a disproportionately low percentage of riffles for the simulations was that it probably yielded results that overestimated the amount of brook trout habitat and underestimated rainbow trout habitat.

5.2.1.2 Hydraulic Simulation Procedure

At each transect, water surface elevations were measured at four different discharges (shown in Table 5-2). At the second highest discharge (25-35 cfs), depth, velocity, and substrate measurements were taken at 0.5 ft intervals across the wetted channel. These flows (called calibration flows) were then used for hydraulic and habitat simulations. The simulations were performed using Riverine Habitat Simulation (RHABSIM), a model developed by Thomas Payne and Associates, Arcata CA, which is a Windows-based version of PHABSIM. The log-log linear regression method IFG4 in the HYDSIM module was used to simulate water surface elevations at discharges from 40%-250% of the range of calibration flows. The velocity simulation algorithm that was used to simulate velocities in individual cells was based on the 1-velocity set calibration approach where a Manning's N value was computed for each cell.

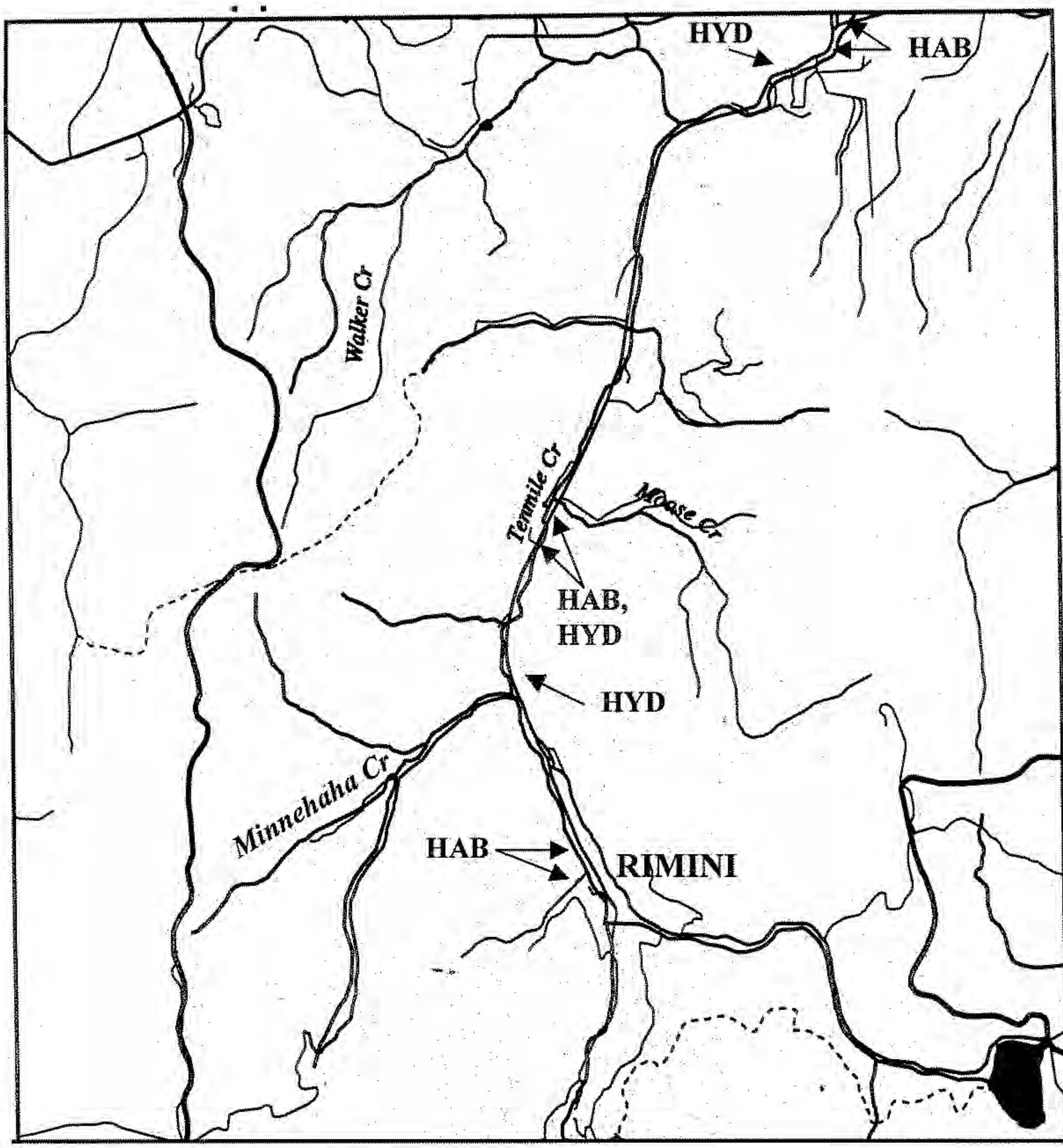


Figure 5-1 Sites within the Tenmile Watershed where Data was Collected Along Transects for Habitat Measurements (HAB) or for Hydraulic/Habitat Simulation (HYD).

Table 5-2 Results of Measurements Taken for Hydraulic/Habitat Simulation.

Site	Transect	Calibration flows (cfs)	Habitat type	Dominant/sub-dominant substrate
Parrett's bridge	T-1	1.5, 13, 35, 81	Run	Cobble/boulder
Parrett's bridge	T-2	1.5, 13, 35, 81	Riffle	Cobble/boulder
Parrett's bridge	T-3	1.5, 13, 34, 81	Run	Cobble/boulder
Campground	T-4	1.3, 7.0, 25, 81	Run	Cobble/boulder
Campground	T-5	1.3, 7.2, 28, 81	Riffle	Cobble/boulder
Campground	T-6	1.3, 7.6, 28, 81	Run	Cobble/gravel
Below Minnehaha Cr.	T-7	0.9, 6.0, 34, 65	Riffle	Cobble/boulder
Below Minnehaha Cr.	T-8	0.9, 6.0, 31, 65	Run	Cobble/boulder
Below Minnehaha Cr.	T-9	0.9, 6.0, 33, 65	Run	Cobble/boulder

Results of simulation went well. For some transects, hydraulic controls were evident downstream, and had to be used as the stage of zero flow (SZF) in order to optimize the log-log stage/discharge regressions. In several transects, the best regression was obtained by leaving out the highest calibration flow. In two of the nine transects, the Velocity Adjustment Factors (VAFs) were marginally outside of the recommended range. Manning's values were all within the acceptable range, and in only one case was the default value changed. Simulated flows were all lower than the discharge at which velocities were measured in individual cells, and therefore there were no simulations made in dry cells.

5.2.1.3 Habitat Simulation Procedures

Suitability indices (SI) for all brook trout lifestages were taken from Chapman (1995); rainbow trout fry SI values were taken from Raleigh (1984), while rainbow trout juvenile and adult SI values came from values developed by Ken Bovee (USGS, pers. comm.) for the South Platte River, Colorado. Suitability for a given cell was calculated by multiplying the suitability values for depth, velocity and substrate. WUA curves were generated for each lifestage at flows ranging from 0.6 to 24 cfs.

WUA curves were adjusted for the relative space needs of the different lifestages. Fish need progressively more space as they grow older. This is partly because the fish physically occupy more space as they grow older, but also because of space requirements that arise from feeding hierarchies that become established. WUA values for fry were multiplied by 5 and juvenile values multiplied by 1.5 to reflect these changing space needs. This is a normalization process that makes the curves for the different lifestages directly comparable, so that a unit of WUA from each curve provides the same amount of habitat for the same number of fish. This normalization procedure also effectively converts the WUA curves to density curves, although it is not known how many units of WUA are needed for one fish.

Time-series simulations were also conducted using the following reasoning and assumptions. It was assumed that habitat was fully utilized when fish were fry. Different mortality rates were then applied to fish in these habitats for three years as the fish matured to an adult (1 year as a fry and 2 years as a juvenile). Because of the adjustment already made for relative space needs, it was assumed (for model purposes) that 1 unit of WUA was equivalent to 1 fish. For example, if brook trout fry started with 1000 WUA, this is equivalent to 1000 fish. Then, if we assumed survival rates between the three years of 10%, 40% and 40%, the number of fish surviving to each year would be 100, 40 and 16, respectively. These numbers are subject to change if the available habitat is insufficient to hold that number of survivors. For example, if 100 fish could survive their first year, but only 90 units of juvenile habitat was available, then it is assumed that the other 10 fish would die or emigrate from the study section.

5.2.2 WETP Method

The WETP method is widely used by FWP to derive low flow recommendations for rivers and streams. "WETP" is defined as the distance along the bottom and sides of the channel cross-section that is in contact with water. The principle of this method was described well by Nelson (1980) who said: "As the flow in a stream channel increases, the WETP also increases, but the rate of gain of WETP is not constant throughout the entire range of flows. Starting at zero flow, the WETP increases rapidly for small increases in flow up to the point where the stream channel nears its maximum width. Beyond this break or inflection point, the increase of WETP is less rapid as flow increases. The instream flow recommendation is selected at or near this inflection point."

The method is based primarily on the assumption that food supply is a major factor influencing a stream's carrying capacity (pounds of fish a stream can support). The principle food for trout in Montana streams is aquatic invertebrates, which are primarily produced in stream riffles. The method assumes that fish production is related to food production, which in turn is related to the WETP in riffle areas. Measurements of WETP are therefore taken primarily in riffle areas.

In this study, the same nine transects being used for WUA simulations were used for WETP calculations. WETP values were calculated for each transect and at different flows using the RHABSIM hydraulic simulation procedure. This procedure is very similar to the FWP WETP Program, in that water surface elevations are derived from a log/log stage-discharge relationship. Therefore, the WETP values from the RHABSIM procedure should be very similar to those that would be generated if we had used the WETP program.

5.3 Results

5.3.1 Weighted Usable Area Approach

WUA values for individual transects were pooled for further analysis. For rainbow trout fry, discharges of 3-4 cfs appeared to provide the most WUA (Figure 5-2). Suitable habitat for juveniles increased with discharge, and the maximum WUA was at some flow higher than 24 cfs (our highest simulated flow). Adult WUA was less than juveniles at all flows, but increased with discharge in an almost linear fashion.

Fry seek fairly shallow water with some current. As flows increase in Tenmile from 0.6-4 cfs, the depth increases toward optimal depths, while the suitability of velocities are still high. Above 4 cfs, depths continue to increase (as does their suitability in most cases), but velocities quickly become so high that the suitability drops for the fry. Overall suitability therefore drops. Juvenile rainbow trout can tolerate faster and deeper water than the fry, and therefore the WUA continues to increase with discharge. However, as flows approach and exceed 20 cfs, velocities in some places start to become too fast, and the overall suitability starts to level off. Adult rainbow trout WUA increased with discharge because they can tolerate higher velocities than the younger fish. The reason there is less adult habitat than juvenile habitat at all flows is that the adults need deeper water, over 1.5 ft to be optimal, and this is in short supply at the discharges being simulated.

The curves for the different lifestages of brook trout are quite unlike the rainbow trout curves (Figure 5-3). Brook trout fry and juveniles have relatively small WUA at all discharges. Adult brook trout habitat is greater than the other lifestages at all flows, and peaks at about 5 cfs. The reason that the fry and juvenile WUA is so low and unresponsive to changes in flow is that these lifestages prefer shallow water with very low velocities. Therefore, their usable habitat is primarily along the stream margins, areas that remain low velocity at all discharges. Adult brook trout prefer much deeper water, but not water with high velocities. Therefore, as flows increase to 5 cfs, WUA increases as depths increase, and velocities are still not too fast. Above 5 cfs, velocities become too swift and suitability drops.

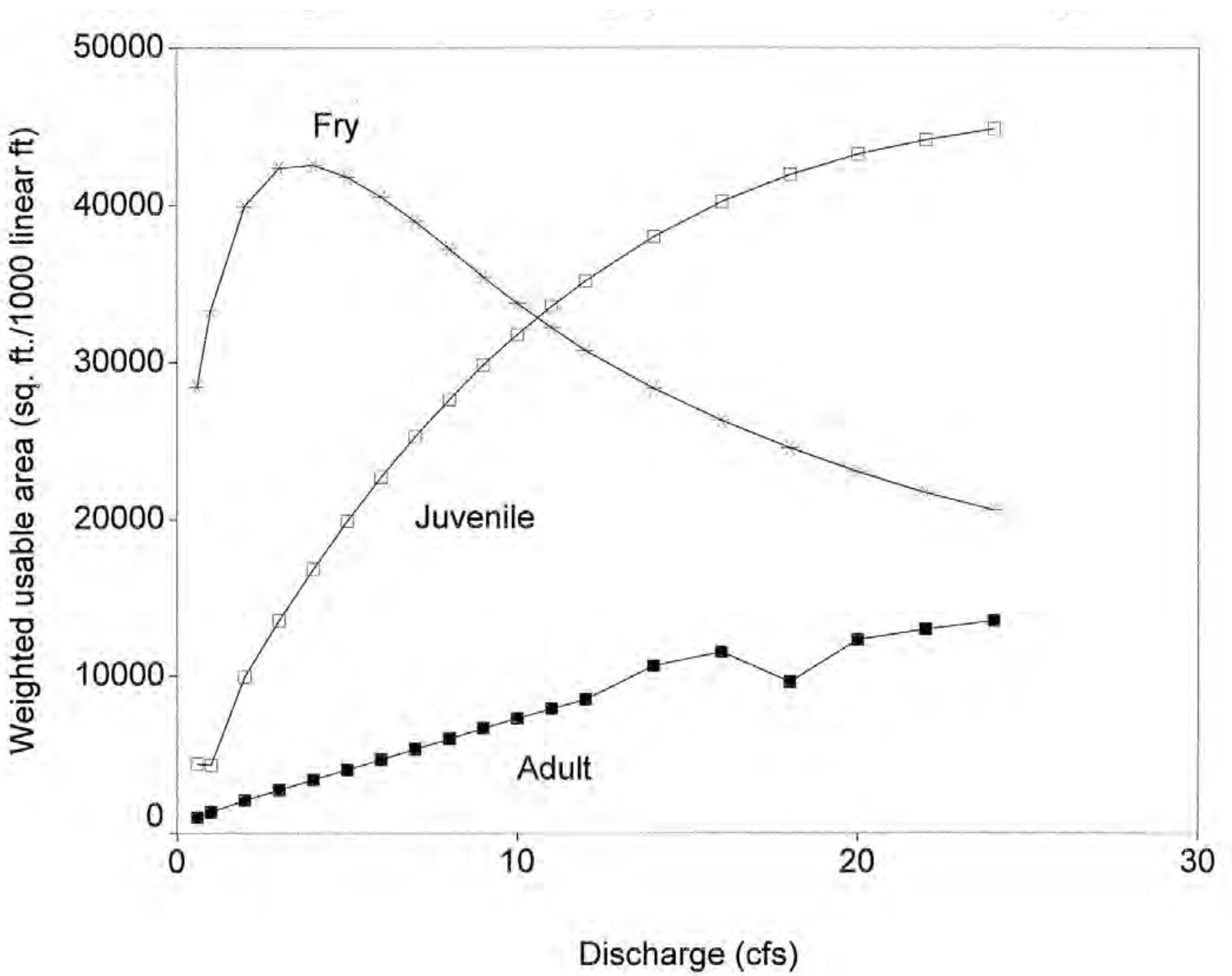


Figure 5-2 WUA/Discharge Plots for Rainbow Trout Lifestages.

These suitability curves seem reasonable from the perspective of my subjective judgment. Tenmile Creek generally seems to be more suited for rainbow trout. The high gradient of the stream in most places looks like rainbow trout water, and this impression is particularly true at higher discharges, which are accompanied by higher velocities.

In order to compare the WUA curves for the different lifestages in Figures 5-2 and 5-3, they were adjusted for relative space needs (Figures 5-4 and 5-5). An examination of the curves makes it clear that conditions in Tenmile Creek are most suited to rainbow trout fry. This assessment is based on the fact that their WUA is between 110-220,000 at all discharges, far above the WUA for all other rainbow and brook trout lifestages. Also evident is the fact that rainbow trout fry have more WUA at all flows than do rainbow juveniles, which in turn have more WUA than adults. On the other hand, brook trout adults have more WUA than fry at most flows, and both of these lifestages have considerably more WUA than the brook trout juveniles. This is an important distinction, because when these curves are subjected to time series analysis, the species that will have the most survivors to adulthood is the one for which there will be enough habitat available to hold the cohort as it grows older.

The time-series analysis uses the relative space curves as if they were density curves for the purpose of following the survival of different cohorts. This analysis has considerable uncertainty associated with it, because we have no empirical information from Tenmile Creek to tell us what the survival rates are between successive lifestages. Therefore, the Handbook of Freshwater Fishery Biology (Carlander 1969) was consulted to determine typical survival rates for these species, and it was decided to simulate survival in the first year (from fry to the first year juvenile stage) under high level (25%) and low level (10%) scenarios. Because survival tends to be more stable after the first year in resident freshwater salmonid populations, the survival estimates for the 2nd and 3rd years of life were assumed to be 40% for both years and for both scenarios.

The step-by-step procedure that was used to calculate survival between the lifestages is shown in Figures 5-6 through 5-8, using rainbow trout as an example. In step 1, the values on the WUA curve for fry were multiplied by 25%, and the resulting curve (shown with open circles) was then compared to the WUA curve for juveniles, which portrays the maximum number of fry that can survive the first year and remain in this stream. If more fry survive than the habitat can support, they will die or emigrate. Therefore, the survival after the first year will be the lesser of the two curves. Step 2 shows how this selection is made. The number of surviving fry will be described by the juvenile WUA curve where it is lower than the 25% curve, and by the 25% curve where it is lower than the juvenile WUA curve. Step 2 also shows the estimate of survival from the first year juvenile stage to the second year stage. In this case, the resulting values (described by the juvenile x 40% curve) are all below the juvenile WUA curve. Step 3 shows the application of 40% survival again to reflect survival between 2nd year juveniles and adults. In this case, the resulting curve (lower curve with open circles) has some overlap with the adult WUA curve, and the final survival curve will be the lesser of the two curves.

This three-step procedure was used for both low and high survival scenarios and for both brook and rainbow trout. In both scenarios at flows above 1 cfs, there are more adult rainbow trout produced than brook trout. The only time more brook trout are produced than rainbows is with the 25% first-year survival scenario and at flows less than 2 cfs (Figure 5-9).

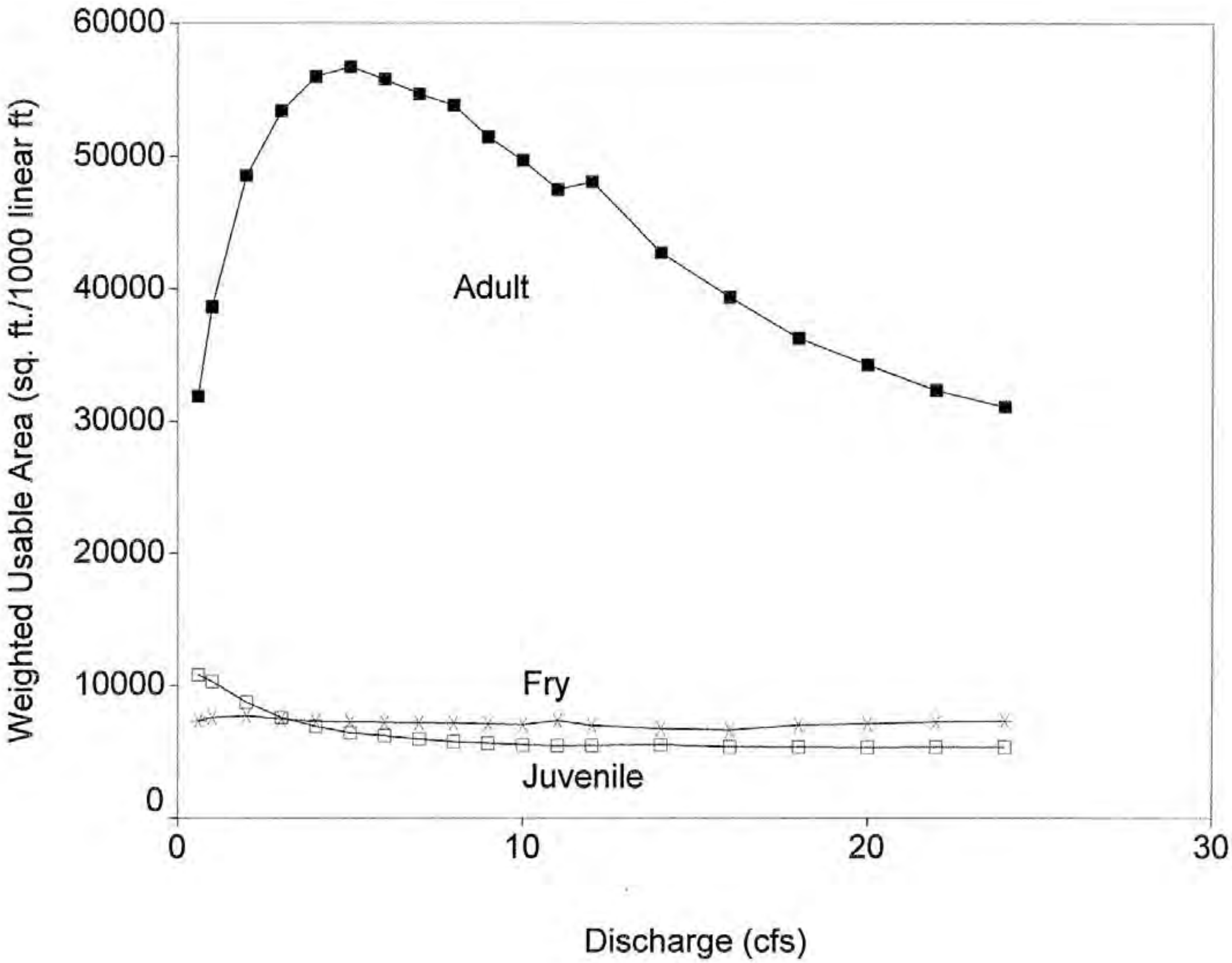


Figure 5-3 WUA/Discharge Plots for Brook Trout Life Stages.

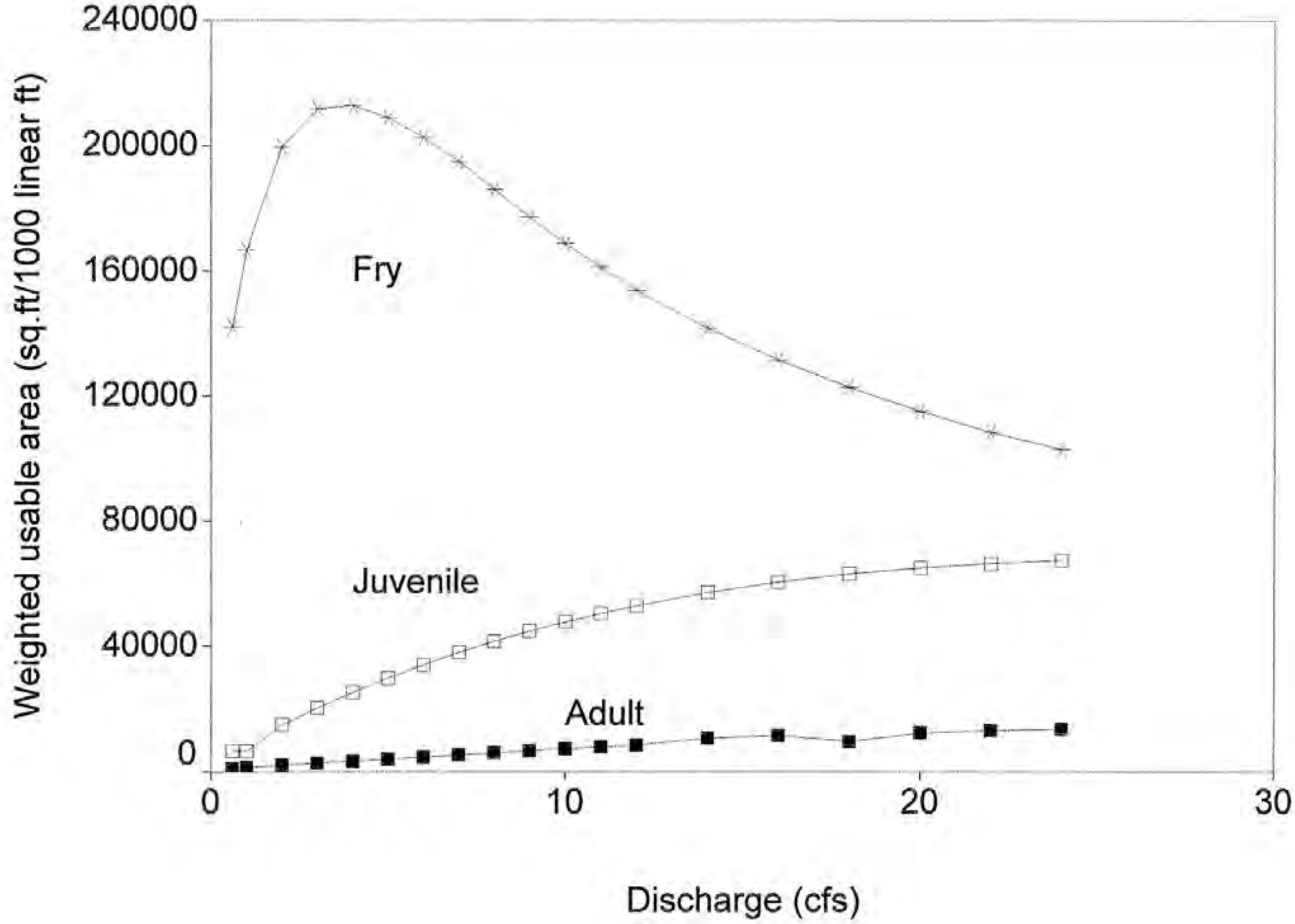


Figure 5-4 WUA/Discharge Plots for Rainbow Trout Life Stages Adjusted for Relative Space Needs.

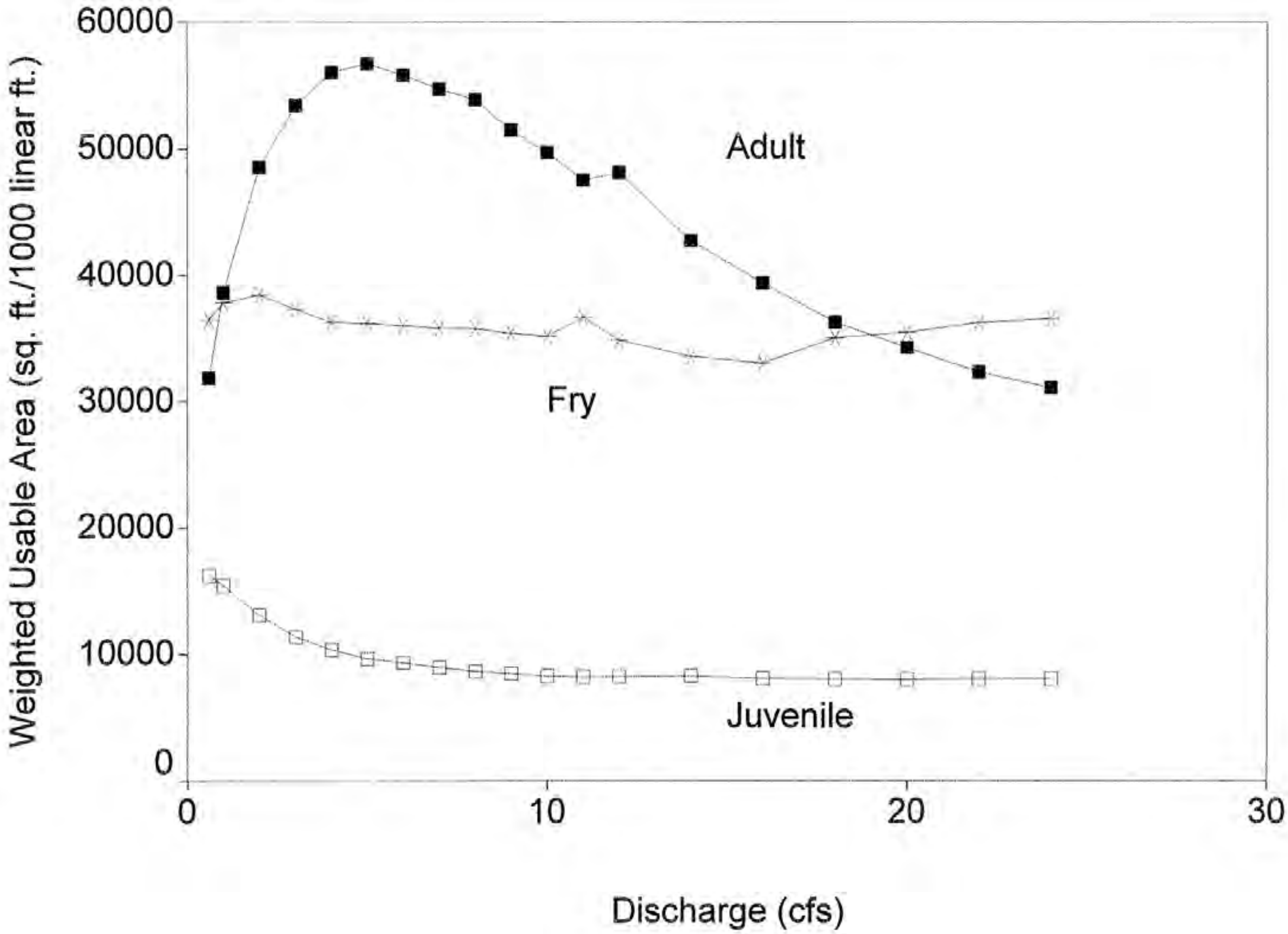


Figure 5-5 WUA/Discharge Plots for Brook Trout Lifestages Adjusted for Relative Space Needs.

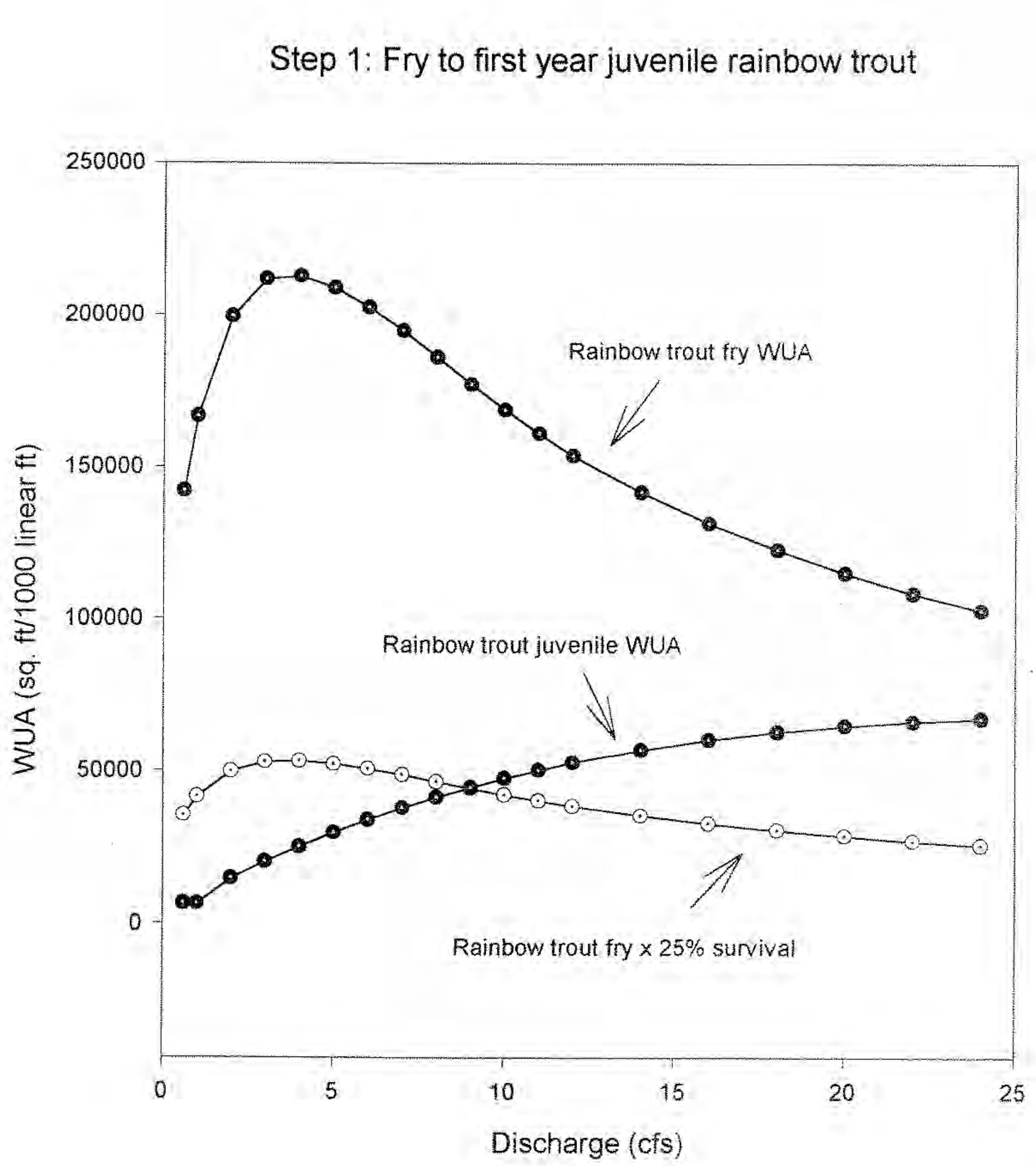


Figure 5-6 Survival of Rainbow Trout as Influenced by Habitat Availability.

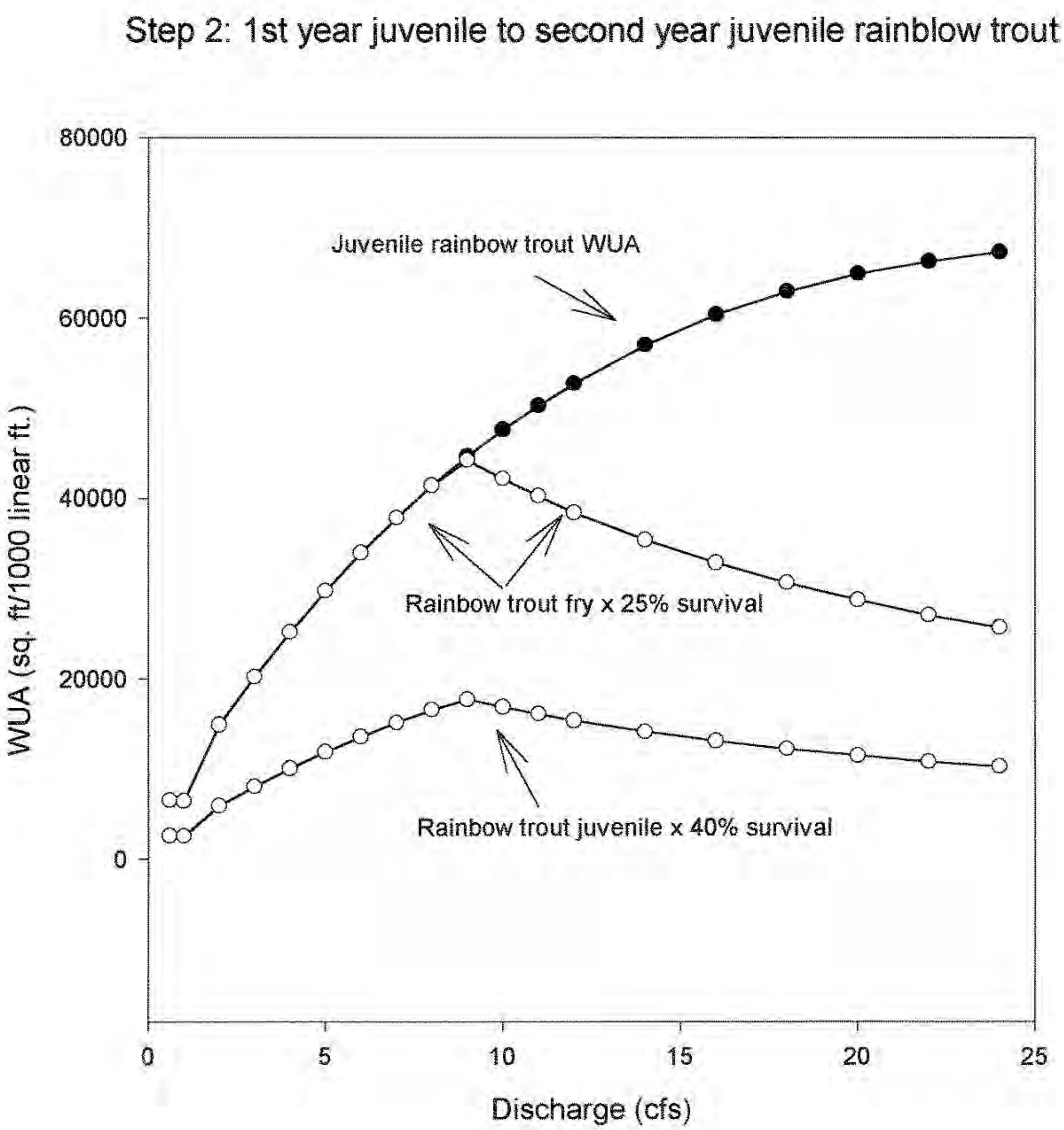


Figure 5-7 Survival of Rainbow Trout as Influenced by Habitat Availability.

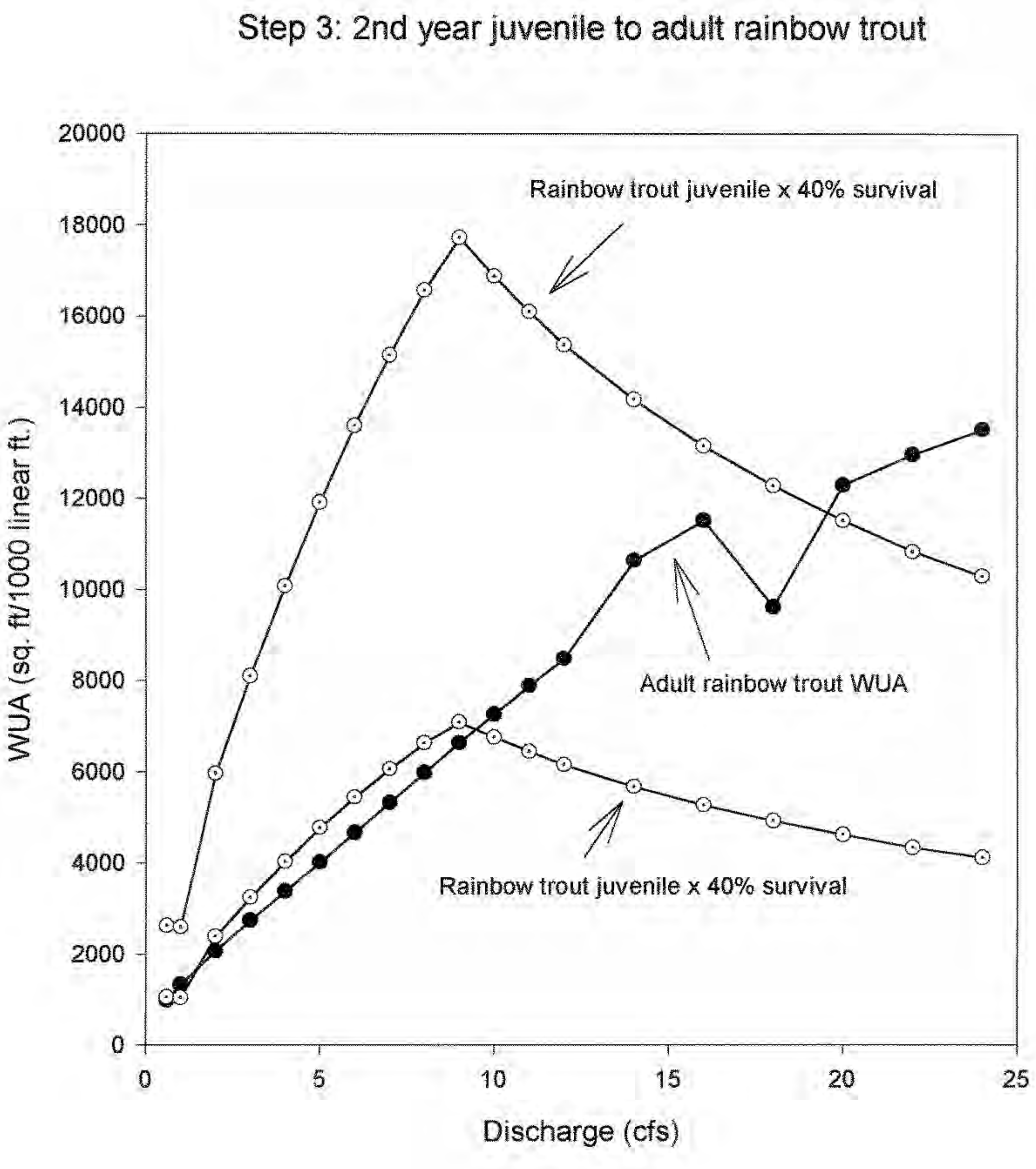


Figure 5-8 Survival of Rainbow Trout as Influenced by Habitat Availability.

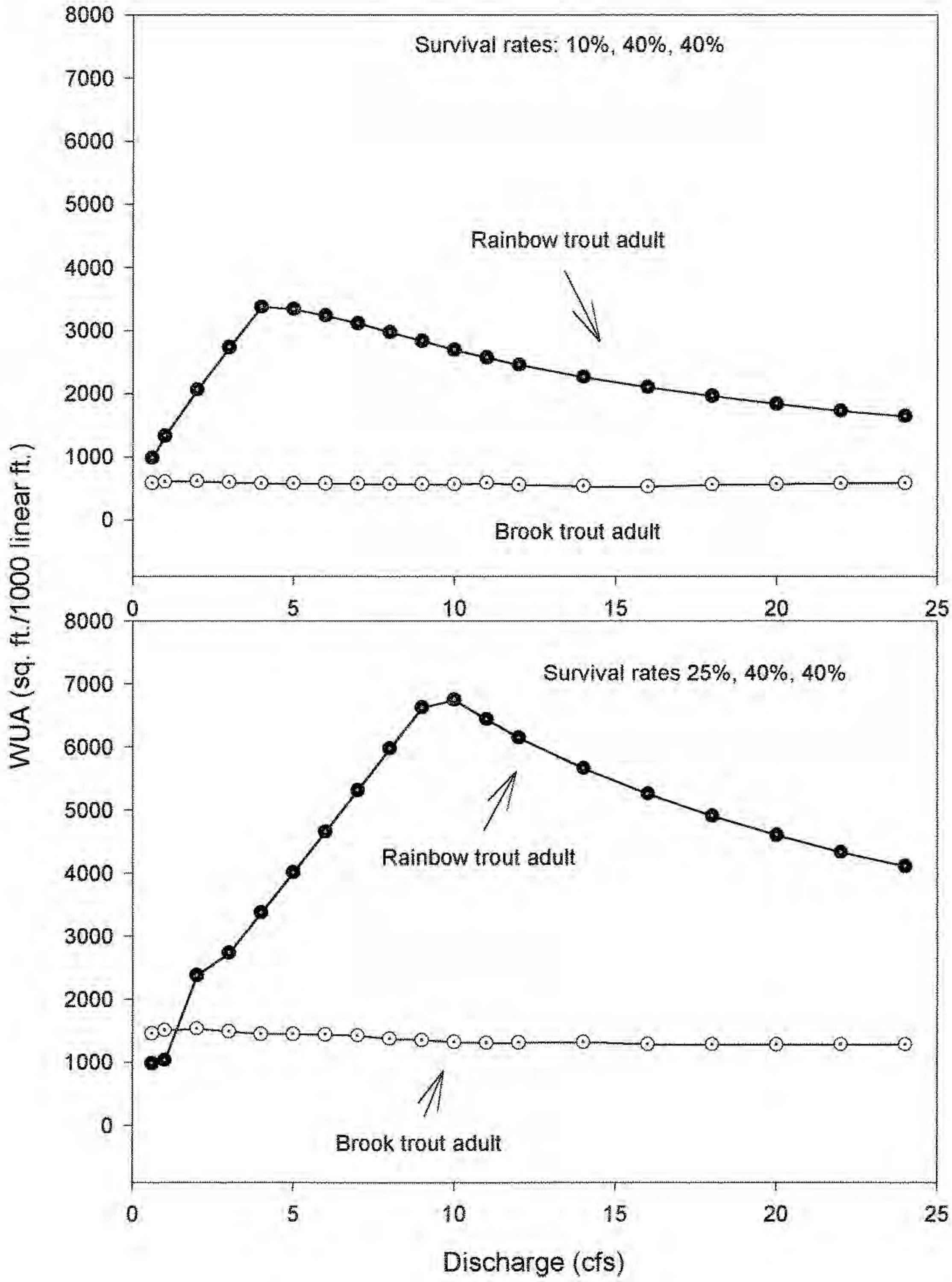


Figure 5-9 Survival of Adult Brook and Rainbow Trout.

These plots show clearly that rainbow trout habitat (and presumably the population) will increase in response to increased flows. When the survival curves for adult rainbow trout under both scenarios are plotted on the same graph, it can be seen that the optimal flow lies somewhere between 4 and 10 cfs (Figure 5-10).

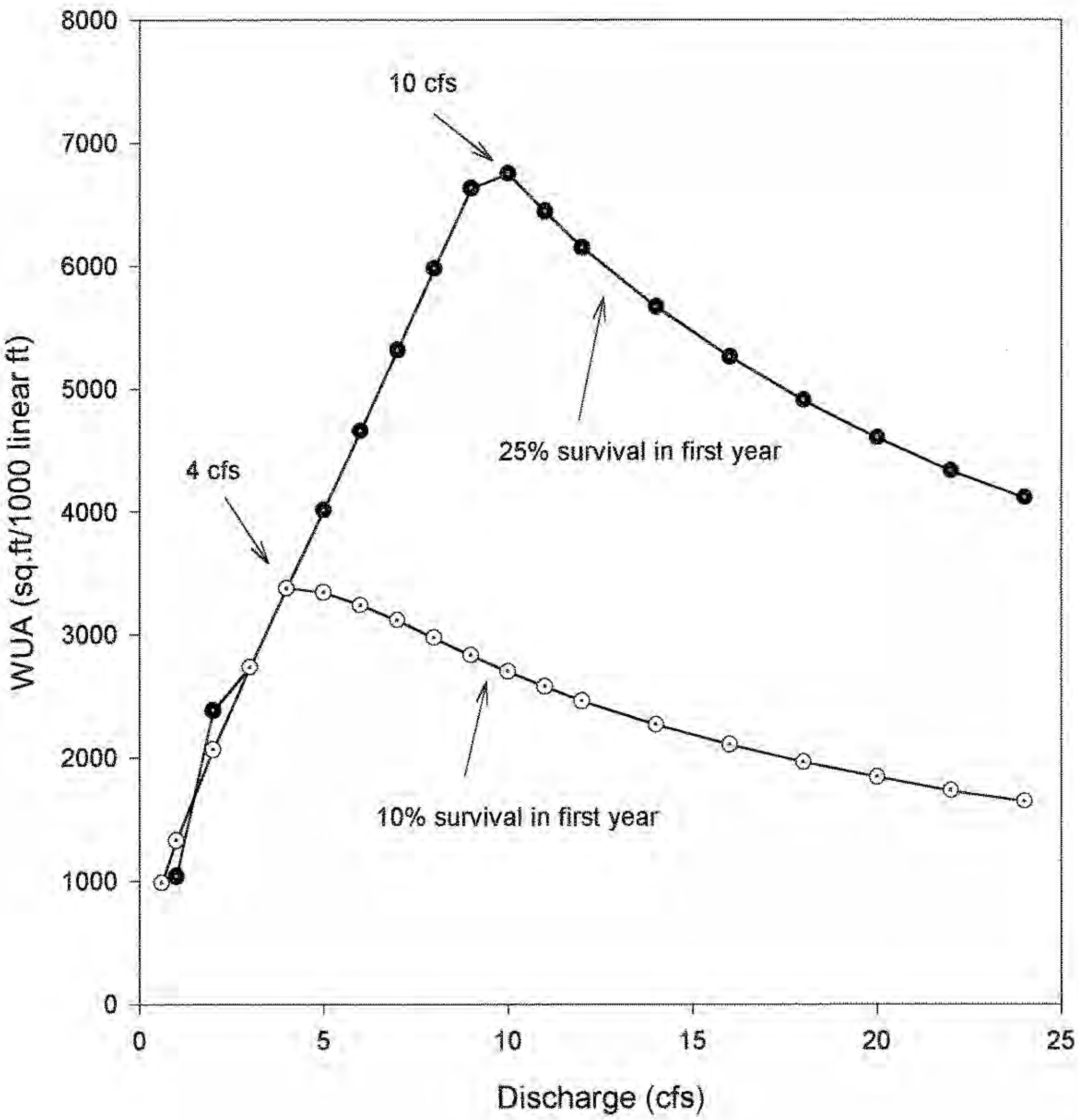


Figure 5-10 Survival of Adult Rainbow Trout.

5.3.2 WETP Approach

Calculations of WETP were generated with the RHABSIM simulations for individual transects. WETP values were combined for all nine transects (n=9) and for the riffles alone (n=3) (Figure

5-11). In both plots, WETP continued to increase with increasing discharge up to the maximum flow (34 cfs) that was simulated.

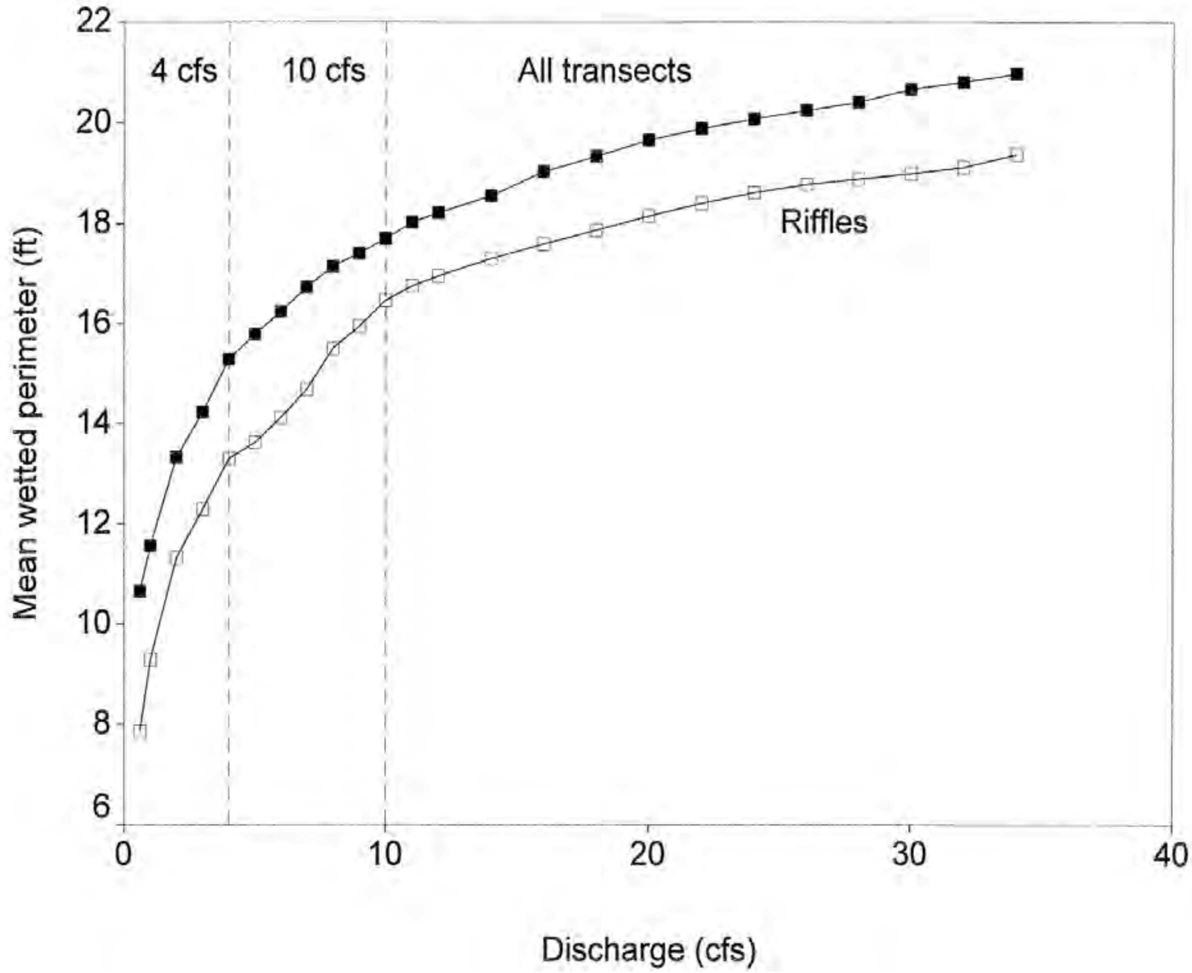


Figure 5-11 WETP for Upper Tenmile Creek.

However, the flow at which the increase in WETP started to decline (the inflection point) was at 4 cfs for both plots. The inflection point was more pronounced in the riffles, and there was a second, although less obvious inflection point in the riffles at about 10 cfs. Montana Fish, Wildlife and Parks uses riffles in their WETP method to establish instream flow requests. This is because riffles become exposed more quickly than pools as water levels drop, and they serve as the most important food-producing areas of a stream. We believe that the flood of 1981 has contributed greatly to the shape of this curve. The 1981 flood greatly widened the stream in most places, and today the stream appears to have established a new, smaller channel within the one created by the flood. Therefore, we suspect that the inflection point at 10 cfs is the point where water reaches the streambanks of the channel created in 1981, while the inflection point at 4 cfs represents the "banks" of this new channel.

5.4 Discussion and Conclusion

In order to make recommendations about minimum or optimum flows for trout in Tenmile Creek, it is necessary to integrate the results from the WETP and weighted usable area approaches. This is difficult however, because the models are different in the kinds of information they provide about the suitability of a stream for fish. The WETP method indirectly measures the amount of food producing streambottom that exists for fish. This method is also designed to recommend minimum flows, with the inflection point in the WETP curve designating the minimum flow. The WUA approach is a direct measure of habitat suitability for fish and does not lend itself as conveniently to determining a minimum flow, because there is no assurance that there will be an inflection point in the habitat/flow curves.

Results from the weighted usable area approach suggests that trout survival will benefit greatly if flows in Tenmile Creek are kept higher than current levels, which frequently drop below 1 cfs in late summer. Even though survival of adult brook trout is largely unaffected by discharge, survival of adult rainbow trout shows a positive, and nearly linear increase with discharge. This suggests that trout biomass will increase in Tenmile Creek as flows increase from 0.6-4 cfs. It is less certain whether trout biomass will increase between 4 and 10 cfs. If first year survival of rainbow trout is only 10%, then 4 cfs provides the peak WUA, and if first year survival is 25%, then WUA will continue to increase up to 10 cfs. Above 10 cfs, WUA will decrease for both survival scenarios. The WETP analysis shows that food production will increase rapidly as flow goes from 0.6-4 cfs, increase less quickly between 4 and 10 cfs, and then level off significantly above 10 cfs.

Both methods suggests that increasing flows from 0.6 to 4 cfs in the stretch of Tenmile Creek between the City Diversion in Rimini and the water Treatment Plant will greatly benefit trout from the standpoint of increased habitat, survival and food production. In the flow range of 4 to 10 cfs, conditions are probably optimal for trout. Habitat and survival may or may not increase through this flow range, although space for food production does increase about 25%. Flows above 10 cfs will probably not benefit trout production, because space for food production increases slowly and habitat suitability and survival actually decreases.

5.5 References

Bovee, K.D. 1982. A Guide to Stream Habitat Analysis Using the Instream Flow Incremental Methodology, IFIP #12. U.S. Fish and Wildlife Service, Washington, D.C. FWS/OBS-82/26. 250 pp.

Carlander, K.D. 1969. Handbook of Freshwater Fishery Biology. Life History Data on Freshwater Fishes of the United States and Canada, Exclusive of the Perciformes. Volume One. Iowa State University Press, Ames, Iowa. 752 pp.

Chapman, D. 1995. Assessment of injury to fish populations: Clark Fork River NPL Sites, Montana. In Appendices A-H. Aquatic Resources Injury Assessment Report. State of Montana, Natural Resource Damage Program.

Nelson, F. 1980. Guidelines for using the WETP Computer Program of the Montana Department of Fish, Wildlife and Parks. Montana Department of Fish, Wildlife and Parks, Bozeman. 28 pp. plus appendices.

Raleigh, R.F., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. Habitat Suitability Information: Rainbow Trout: U.S. Fish and Wildlife Service, Washington, D.C. GWS/OBS-82/10.60. 64 pp.

Chapter 6
Use of *In-Situ* Bioassays to Determine Lethal Thresholds of Zinc and Cadmium to Rainbow and Brook Trout

6.1 Purpose and Scope

Fish population surveys in the Tenmile Creek drainage revealed a distribution pattern for rainbow trout that was quite unlike that of brook trout. Adult and juvenile rainbow trout were found in Walker Creek and the mainstem from the Treatment Plant upstream to the Moose Creek Campground. Rainbow trout young of year (YOY) were found sparingly at the Campground, and in greater numbers downstream at the Treatment Plant. Brook trout were found in all tributaries sampled except Banner Creek. In the mainstem, all life stages were numerous in all reaches sampled upstream from the Treatment Plant with the exception of a zone between the town of Rimini and Minnehaha Creek (see Chapter 3 for more details).

This "hole" in the distribution of both species near Rimini suggests strongly that it is due, at least in part, to metals toxicity and/or avoidance. The differences in distribution between the two species could be due to differences in sensitivity to the metals, or it could be due to differences in times when the most sensitive lifestage (post-emergent fry) are exposed to water-borne metals. To test the hypothesis that metals are responsible for these distribution patterns, we conducted *in-situ* bioassays at various spots along Tenmile Creek, to determine lethal thresholds for brook and rainbow trout.

6.2 Methods and Materials

Young-of-the-year brook and rainbow trout were exposed to Tenmile Creek water at various sites and times to determine their susceptibility to metals in stream water. Three primary considerations were used to design the study. First was the fact that previous studies have shown that salmonids are most sensitive to metals when they are in the post-emergent fry lifestage. For rainbow trout, the most sensitive size has been determined to be at a weight of about 0.4 g (USEPA 2001a). In the Tenmile Creek drainage, brook trout fry are likely to emerge from the gravels in April-May, while rainbow trout are probably emerging in July. A second consideration is that the concentrations of metals in the Tenmile Creek mainstem are lowest during runoff in May (due to the diluting effects of snowmelt) and highest once the stream returns to baseflow (August-February). Bioassays were therefore scheduled for the June-August period, when both species of fish would be at or near their most sensitive size and would be exposed to the full range of metals concentrations. Accordingly, bioassays were conducted in June 1999, July 2000 and August 1999. The June 1999 bioassays exposed brook trout at their most sensitive size (presumed to be close to 0.4 g) to the high-flow conditions of runoff, while the July and August bioassays exposed slightly larger brook trout (1-3 g) to conditions closer to baseflow. Bioassays in July 2000 were also used to test rainbow trout at the time when it was estimated they had just emerged from the gravels and were close to the 0.4 g stage. The third design consideration for the bioassays was the trend for metals concentrations in the mainstem to be highest near Rimini and decrease in a downstream direction (Cleasby and Nimick 2002).

Because of this, eight sites along the mainstem were chosen for bioassays in order to expose the fish to a wide range of metal concentrations.

All fish used for the bioassays had previous exposure to very low levels of metals, and were thus considered to be metals-naïve. Brook trout were collected from “Control” streams (Moose Creek or Walker Creek) with the use of a backpack electroshocker. Rainbow trout were obtained from the Big Springs State Fish Hatchery. All fish were acclimated to control site water for at least 24 hours prior to testing. Fish were not fed during acclimation or testing phases, but were probably consuming natural food that drifted into the cages.

During the tests, all fish were held in cages that were 10x10x12-inch chambers with a wooden frame, constructed with 1/8-inch nylon mesh panels on all but one side. The cages had Styrofoam collars to provide floatation and to keep one side of the cage above the water surface. This was a solid wood-covered side that was a hinged lid and allowed access to the fish.

Fish were exposed to site water for 96 hours (or 192 hours in one series of exposures). Cages were checked daily for mortalities. All fish were measured for length and weight when they were found dead each day or at the end of the test. In all tests, dissolved metals (0.45 µm filtration) were measured at each site at the beginning of the exposures and when all fish died or after 96-hours, whichever was earlier. Total recoverable metals were measured once at each site. Alkalinity, hardness, pH and dissolved oxygen were measured daily at each site. Water temperatures were recorded with a hand-held thermometer during the daily visits to each site. Continuous measurements were taken with Onset Stowaway recorders during all series of bioassays with the exception of the series on June 15-19, 1999. Dissolved organic content (DOC) was measured at select sites in each of the years 1999 and 2000.

Water quality measurements were taken at two sites on Tenmile Creek (Rimini and at the Moose Creek gage) in 2000 in order to describe the diel cycle of dissolved zinc. An automatic pumping sampler was used to collect water samples every half hour for a 24-hour period at each site. At intervals no longer than six hours, selected samples were filtered (0.1 µm filtration) for later analysis of zinc. An automatic recording Hydrolab was also deployed to record water temperature, pH, specific conductance, and dissolved oxygen levels every half hour.

6.3 Results

6.3.1 Brook Trout Bioassays (1999)

Brook trout were exposed to waters of the Tenmile Creek drainage on three occasions: June 15-19, June 24-28 and August 19-27. Walker Creek served as the control site during the exposures in June, while both Walker Creek and Moose Creek were control sites in August. During June 15-19, when the brook trout averaged from 0.25-0.26 g, the mortality after 96 hours on Tenmile Creek at Rimini was 85%. For the tests on June 24-28, the fish had grown slightly to where the average weight was 0.45-0.63g. The 96-hour mortality was 100% at the Above Moose Creek site, followed by 83% at Rimini and 8% at the Treatment Plant (Table 6-1). In August, the brook trout were averaging 1.81-3.10 g. Exposures were conducted for 192 hours, although only one additional fish died between 96 and 192 hours of exposure for all sites. After 192 hours, the only site with complete mortality was Rimini. Partial mortalities ranging between 10 and 30% were observed at the Sawmill, Above Minnehaha and Above Moose Creek. No mortalities were

Table 6-1 Results of *In-Situ* Fish Bioassay Tests in Tenmile Creek in 1999 and 2000, Showing Length and Weight of Fish and the Survival at Various Sites.
EBT= Eastern Brook Trout; RBT=Rainbow Trout.

Site of exposure	Species	Source of fish	Date test began/ ended	Length, mm (mean ± S.D., range)	Weight, g (mean ± S.D., range)	# fish at start of exposure	Number of survivors at:					
							24h	48h	72h	96h	120h	144h 168h 192h
10-Mile at Rimini	EBT	Walker Cr	06/15/99 06/19/99	31.9 ± 2.4 (30-37)	0.26 ± 0.07 (0.2-0.4)	13	3	2	2	2*		
Walker Cr.	EBT	Walker Cr	06/15/99 06/19/99	32.6 ± 3.6 (29-38)	0.25 ± 0.10 (0.1-0.4)	14	14	14	14	14		
10-Mile at Rimini	EBT	Walker Cr	06/24/99 06/28/99	40.2 ± 3.8 (34-48)	0.59 ± 0.14 (0.4-0.9)	12	8	2	2	2*		
10-Mile abv Moose Cr.	EBT	Walker Cr	06/24/99 06/28/99	36.5 ± 2.2 (33-41)	0.45 ± 0.07 (0.4-0.6)	12	3	0	0	0*		
10-Mile at TreatPlant	EBT	Walker Cr	06/24/99 06/28/99	41.7 ± 3.6 (36-47)	0.53 ± 0.13 (0.3-0.7)	12	11	11	11	11		
Walker Cr.	EBT	Walker Cr	06/24/99 06/28/99	42.8 ± 2.9 (39-47)	0.63 ± 0.15 (0.4-0.9)	12	12	12	12	12		
10-Mile blw Banner Cr.	EBT	Walker Cr	08/19/99 08/27/99	64.8 ± 7.9 (53-79)	2.47 ± 0.84 (1.3-4.2)	10	10	10	10	10	10	10
10-Mile at Rimini	EBT	Walker Cr	08/19/99 08/20/99	65.0 ± 7.4 (53-74)	3.10 ± 0.88 (2.0-4.5)	10	0	--	--	--*	--	--
10-Mile at Rimini	EBT	Moose Cr	08/19/99 08/20/99	63.8 ± 5.6 (56-74)	3.03 ± 0.79 (2.1-4.4)	10	0	--	--	--*	--	--
10-Mile at Sawmill	EBT	Walker Cr	08/19/99 08/27/99	63.2 ± 8.9 (46-74)	2.22 ± 0.89 (0.9-3.6)	11	10	10	10	10	9	9
10-Mile abv Minnehaha	EBT	Walker Cr.	08/19/99 08/27/99	67.3 ± 7.4 (56-76)	2.76 ± 0.95 (1.6-4.4)	10	10	9	8	7	7	7
10-Mile blw Minnehaha	EBT	Walker Cr	08/19/99 08/27/99	68.1 ± 9.7 (53-76)	2.78 ± 1.21 (1.3-5.5)	10	10	10	10	10	10	10
10-Mile abv Moose Cr	EBT	Walker Cr	08/19/99 08/27/99	63.0 ± 4.8 (56-71)	2.15 ± 0.50 (1.5-3.2)	10	10	10	10	10	10	10
10-Mile abv Moose Cr	EBT	Moose Cr	08/19/99 08/27/99	65.0 ± 4.6 (58-71)	2.34 ± 0.56 (1.5-3.2)	10	10	9	9	9	9	9
10-Mile blw Moose Cr.	EBT	Walker Cr	08/19/99 08/27/99	65.0 ± 8.4 (53-79)	2.47 ± 1.03 (1.4-4.6)	10	10	10	10	10	10	10
10-Mle at TreatPlant	EBT	Walker Cr	08/19/99 08/27/99	65.8 ± 6.1 (56-74)	2.47 ± 0.68 (1.4-3.0)	10	10	10	10	10	10	10
Moose Cr.	EBT	Moose Cr	08/19/99 08/27/99	59.4 ± 7.1 (48-71)	1.81 ± 0.56 (0.9-2.6)	10	10	10	10	10	10	10
Walker Cr.	EBT	Walker Cr	08/19/99 08/27/99	66.8 ± 8.6 (51-81)	2.55 ± 0.88 (1.1-4.2)	10	10	10	10	10	10	10

Table 6-1 (continued) Results of *In-Situ* Fish Bioassay Tests in Tenmile Creek in 1999 and 2000, Showing Length and Weight of Fish and the Survival at Various Sites.
EBT= Eastern Brook Trout; RBT=Rainbow Trout.

Site of exposure	Species	Source of fish	Date test began/ ended	Length, mm (mean ± S.D., range)	Weight, g (mean ± S.D., range)	# fish at start of exposure	Number of survivors at:					
10-Mile blw Banner Cr.	RBT	Lewistown Hatchery	07/18/00 07/22/00	38.2 ± 3.7 (32 – 46)	0.44 ± 0.15 (0.21 – 0.78)	25	25	24	24	24		
10-Mile at Rimini	EBT	Walker Creek	07/18/00 07/22/00	54.9 ± 6.7 (44 – 66)	1.53 ± 0.54 (0.60 – 2.50)	21	19	16	11	11*		
10-Mile at Rimini	RBT	Lewistown Hatchery	07/18/00 07/22/00	38.7 ± 4.2 (30 – 47)	0.55 ± 0.20 (0.21 – 0.99)	25	12	2	0	0*		
10-Mile at Sawmill	RBT	Lewistown Hatchery	07/18/00 07/22/00	37.1 ± 3.1 (31 – 44)	0.48 ± 0.12 (0.29 – 0.76)	25	9	0	0	0*		
10-Mile abv Minnehaha Cr	RBT	Lewistown Hatchery	07/18/00 07/22/00	38.3 ± 3.6 (34 – 44)	0.50 ± 0.16 (0.30 –0.76)	25	7	0	0	0*		
10-Mile blw Minnehaha Cr	RBT	Lewistown Hatchery	07/18/00 07/22/00	39.2 ± 3.4 (34 - 45)	0.52 ± 0.14 (0.33 – 0.82)	25	9	0	0	0*		
10-Mile abv Moose Creek	RBT	Lewistown Hatchery	07/18/00 07/22/00	36.7 ± 3.3 (31 – 45)	0.39 ± 0.11 (0.27 – 0.66)	25	22	18	18	18*		
10-Mile abv Moose Creek	EBT	Walker Creek	07/18/00 07/22/00	56.5 ± 6.7 (47 - 71)	1.45 ± 0.55 (0.72 – 2.83)	20	20	20	20	20		
10-Mile blw Moose Creek	RBT	Lewistown Hatchery	07/18/00 07/22/00	36.7 ± 4.9 (28 – 44)	0.45 ± 0.16 (0.20 – 0.77)	25	17	16	16	16*		
Moose Creek	RBT	Lewistown Hatchery	07/18/00 07/22/00	36.8 ± 3.3 (31 - 40)	0.37 ± 0.11 (0.21 - 0.61)	25	25	25	25	25		
Moose Creek	EBT	Walker Creek	07/18/00 07/22/00	59.1 ± 7.5 (46 – 71)	1.60 ± 0.59 (0.70 – 2.68)	20	20	20	20	20		
10-Mile at Parrett's	RBT	Lewistown Hatchery	07/18/00 07/22/00	37.0 ± 6.9 (32 – 43)	0.33 ± 0.20 (0.26 – 0.78)	25	24	24	24	24		

*Significantly different mortality rate (P<0.05) from control based on binomial probability distribution**.**

observed at the Below Banner Creek, Below Minnehaha, Below Moose Creek, the Treatment Plant, and the Control sites (Table 6-1).

The concentration of many water quality constituents was influenced greatly by the surface discharge. During June, snowmelt runoff had crested and was beginning to fall: the discharge on June 15 on Tenmile Creek at Rimini was about 52 cfs, falling to around 35 cfs on June 19 and 23 cfs on June 24 (Table 6-2). By the time of the August bioassays, all mainstem water was being diverted into the City of Helena diversion upstream of Rimini. The source of water at the site of the Rimini bioassays was from the Banks spring creek, Suzie Mine adit, groundwater discharge from the Lee Mountain mine, and other unknown sources. The surface water discharge at the Rimini site on August 19 was 0.51 cfs, falling to 0.3 cfs on August 20.

Concentrations of metals in water on Tenmile Creek were typically highest at Rimini and decreased in a downstream direction (Table 6-3). Along the Tenmile mainstem sites, concentrations were lower in June during snowpack runoff than during low flows in August. For example, the concentration of total recoverable zinc at Rimini increased from 157 µg/L on June 19 to 241 µg/L on June 24 and finally to 3.39 mg/L on August 20. This pattern was seen at the other sites where sampling was done in both June and August. Tenmile below Banner Creek had lower levels of metals than all other mainstem sites in August, and the concentrations were all below aquatic life standards. The tributary sites (Moose and Walker creeks) had very low levels of metals, and aluminum and zinc were the only metals that were found at levels above detection.

Water temperatures during the June 15-19 bioassays ranged from 47-64ºF, based on only two manual measurements at each site. Continuous recorders were used during the June 24-28 bioassays, and the mean and mean daily maximum temperatures ranged between 8.9-13.0ºCand 11.0-15.3ºC respectively, for all four sites (Table 6-4). During the August tests, mean and mean daily maximum temperatures ranged between 12.2-16.8^{o}C and 13.6-21.6ºC respectively. The Treatment Plant was the only site where temperatures exceeded 20º, and the single highest temperature recorded at this site was 23.2^{o}.

Dissolved oxygen was measured at the beginning and end of each bioassay test at each site. Dissolved oxygen ranged from 9.2-10.2 mg/L during the June 15-19 tests, and between 8.9-10.6 mg/L during the June 24-28 tests (Table 6-2). Oxygen values were lower during the August 19-27 bioassays, ranging from a low of 6.8 mg/L at Walker Creek to a high of 8.9 mg/L at Walker Creek and Tenmile Creek at the Sawmill. All oxygen measurements were made during daylight hours (0915-1610), and it is likely that if measurements were taken during the hours of darkness the oxygen levels would have been lower.

DOC was measured because it can bind metals and reduce their toxicity. During the August 1999 bioassays, the sites with the highest DOC (> 4 mg/L) were the tributaries (Walker and Moose creeks) and Tenmile below Banner Creek. The Tenmile mainstem from Rimini on down were much lower in DOC, presumably because the source of water for this stretch of stream was all groundwater (Table 6-2).

The pH of the water was strongly influenced by discharge. During the high water in June, the pH at all sites ranged from 7.25 to 8.05 (Table 6-2). In August, the pH above the City Diversion

Table 6-2 Water Quality Data Collected During *In-Situ* Fish Bioassay Tests on Tenmile Creek in 1999.

Site	Date	Time	Temp (°F)	pH (s.u.)	Alkalinity (mg/L as $CaCO^3$)	Hardness (mg/L as $CaCO^3$)	Calcium (mg/L)	Magnesium (mg/L)	Calcium/ Magnesium Ratio	Dissolved oxygen (mg/L)	Discharge (cfs)	DOC (mg/L)
10-Mile at Rimini	6/15/1999	1120	47	7.35		11	3.9	0.8	4.9	10	51.53	
Walker Creek	6/15/1999	1145	54	7.92		30	10.2	2.2	4.6	10.2		
10-Mile at Rimini	6/19/1999	1400	56	7.39		14	4.6	1	4.6	9.3	34.93	
Walker Creek	6/19/1999	1530	64	7.84		34	11.6	2.6	4.5	9.2		
Walker Creek	6/24/1999	1700	63	8.03	42		10.4	2.5	4.1	8.9		
10-Mile at Treatment Plant	6/24/1999	1715	60	7.73	18		6.6	1.6	4.1	9.3		
10-Mile above Moose Creek	6/24/1999	1735	50	7.18	16		5.8	1.4	4.1	10.1		
10-Mile at Rimini	6/24/1999	1750	48	7.42	12		4.2	1	4.2	10.6	23.32	
10-Mile at Rimini	6/26/1999	1605	52									
10-Mile above Moose Creek	6/26/1999	1620	54									
Walker Creek	6/26/1999	1640	58									
10-Mile at Treatment Plant	6/26/1999	1655	58									
Walker Creek	6/27/1999	1735	59									
10-Mile at Rimini	6/27/1999	1755	52									
10-Mile at Treatment Plant	6/27/1999	1815	59									
10-Mile at Rimini	6/28/1999	1430	52	7.25	14	16				10.2		
10-Mile above Moose Creek	6/28/1999	1500	57	7.29	14	18				9.8		
10-Mile at Treatment Plant	6/28/1999	1530	58	7.68	32	26				9.7		
Walker Creek	6/28/1999	1600	58	8.05	42	38				9.7		
10-Mile at Rimini	8/19/1999	1315	59	4.66	3	70	19.6	6.4	2.1	7.5	0.51	0.993
10-Mile below Banner Creek	8/19/1999	1355	55	7.33	10	16	3.9	0.8	4.9	8.4		4.03
10-Mile at Sawmill	8/19/1999	1415	63	7	12	84	23.5	7.5	3.1	8		1.58
10-Mile above Minnehaha	8/19/1999	1440	63	7.7	22	70	20.5	6	3.4	8.1		1.77
10-Mile below Minnehaha	8/19/1999	1455	63	7.66	30	70	19.5	5.5	3.5	8.1		2.25
10-Mile above Moose Creek	8/19/1999	1510	63	7.18	28	50	15.6	3.9	4	8.1		2.04
Moose Creek	8/19/1999	1520	58	7.74	78	74	22.8	4.7	4.9	8.6		4.65
10-Mile below Moose Creek	8/19/1999	1535	64	7.45	32	44	14.7	3.4	4.3	8.1		1.9
Walker Creek	8/19/1999	1610	65	8.18	84	78	23.5	5.1	4.6	8.4		8.8
10-Mile at Treatment Plant	8/19/1999	1630	66	7.65	44	56	16.9	3.6	4.7	8.1		2.89
10-Mile at Rimini	8/20/1999	1320	64	5.15	6	78				7.4	0.3	
10-Mile below Banner Creek	8/23/1999	915	50	7.33	14	12				8		
10-Mile at Sawmill	8/23/1999	945	54	6.9	14	98				8.9		

Table 6-2 (continued) Water Quality Data Collected During *In-Situ* Fish Bioassay Tests on Tenmile Creek in 1999.

Site	Date	Time	Temp (^oF)	pH (s.u.)	Alkalinity (mg/L as $CaCO^3$)	Hardness (mg/L as $CaCO^3$)	Calcium (mg/L)	Magnesium (mg/L)	Calcium/ Magnesium Ratio	Dissolved oxygen (mg/L)	Discharge (cfs)	DOC (mg/L)
10-Mile above Minnehaha	8/23/1999	1020	56	7.4	30	82				8.7		
10-Mile at Treatment Plant	8/23/1999	1100	62	7.51	48	56				8.1		
Walker Creek	8/23/1999	1135	57	8.07	94	86				8.9		
Moose Creek	8/23/1999	1205	52	8	84	82				8.8		
10-Mile below Moose Creek	8/23/1999	1220	59	7.36	35	56				8.6		
10-Mile above Moose Creek	8/23/1999	1240	56	7.01	30	64				7.6		
10-Mile below Minnehaha	8/23/1999	1300	58	6.7	26	82				7.7		
10-Mile at Sawmill	8/24/1999											
10-Mile below Banner Creek	8/24/1999											
10-Mile at Treatment Plant	8/27/1999	950	61	7.3	48	60				7.6		
Walker Creek	8/27/1999	1040	60	7.15	100	90				6.8		
10-Mile below Moose Creek	8/27/1999	1110	56	7.03	38	56				8.6		
Moose Creek	8/27/1999	1135	53	7.6	88	78				8.8		
10-Mile above Moose Creek	8/27/1999	1200	56	6.95	31	58				7.5		
10-Mile below Minnehaha	8/27/1999	1240	66	7.44	28	84				7.5		
10-Mile above Minnehaha	8/27/1999	1300	64	7.6	24	92				8.2		
10-Mile at Sawmill	8/27/1999	1334	69	6.95	14	116				7.8		
10-Mile below Banner Creek	8/27/1999	1400	60	7.4	16	16				8.2		

Table 6-3 Metals Concentration Data Collected During *In-Situ* Fish Bioassay Tests on Tenmile Creek In 1999. Tot=Total Recoverable, Filt=Filtered

Site	Date	Time	Al-Tot (mg/L)	Al-Filt (mg/L)	Cd-Tot (mg/L)	Cd-Filt (mg/L)	Cu-Tot (mg/L)	Cu-Filt (mg/L)	Pb-Tot (mg/L)	Pb-Filt (mg/L)	Zn-Tot (mg/L)	Zn-Filt (mg/L)
10-Mile at Rimini	6/15/1999	1120										
Walker Creek	6/15/1999	1145										
10-Mile at Rimini	6/19/1999	1400		0.08		<0.001		0.008		<0.001		0.157
Walker Creek	6/19/1999	1530										
Walker Creek	6/24/1999	1700	0.19	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005
10-Mile at Treatment Plant	6/24/1999	1715	0.29	0.04	<0.001	<0.001	0.006	0.004	0.002	<0.001	0.183	0.158
10-Mile above Moose Creek	6/24/1999	1735	0.36	0.06	<0.001	<0.001	0.12	0.008	0.005	<0.001	0.278	0.23
10-Mile at Rimini	6/24/1999	1750	0.34	0.08	<0.001	<0.001	0.011	0.009	0.002	<0.001	0.231	0.241
10-Mile at Rimini	6/26/1999	1605										
10-Mile above Moose Creek	6/26/1999	1620										
Walker Creek	6/26/1999	1640										
10-Mile at Treatment Plant	6/26/1999	1655										
Walker Creek	6/27/1999	1735										
10-Mile at Rimini	6/27/1999	1755										
10-Mile at Treatment Plant	6/27/1999	1815										
10-Mile at Rimini	6/28/1999	1430	0.19	0.08	<0.001	<0.001	0.007	0.005	0.003	0.002	0.267	0.249
10-Mile above Moose Creek	6/28/1999	1500	0.18	0.06	<0.001	<0.001	0.006	0.005	0.003	<0.001	0.257	0.235
10-Mile at Treatment Plant	6/28/1999	1530	0.14	0.03	<0.001	<0.001	0.005	0.004	0.011	0.011	0.178	0.158
Walker Creek	6/28/1999	1600	0.11		<0.001		<0.001		<0.001		<0.005	
10-Mile at Rimini	8/19/1999	1315	0.66	0.07	0.0292	0.0293	0.029	0.021	0.013	0.004	3.45	3.41
10-Mile below Banner Creek	8/19/1999	1355	0.11	0.04	<0.0002	0.0002	0.002	0.002	<0.001	<0.001	0.025	0.024
10-Mile at Sawmill	8/19/1999	1415	0.13	0.01	0.0132	0.0122	0.011	0.006	0.002	<0.001	2.2	2.17
10-Mile above Minnehaha	8/19/1999	1440	0.05	0.01	0.0048	0.0048	0.006	0.005	<0.001	<0.001	1.04	1
10-Mile below Minnehaha	8/19/1999	1455	0.04	<0.01	0.0018	0.0019	0.005	0.004	<0.001	<0.001	0.434	0.428
10-Mile above Moose Creek	8/19/1999	1510	0.03	<0.01	0.0015	0.0014	0.004	0.004	<0.001	<0.001	0.34	0.331
Moose Creek	8/19/1999	1520	0.06	<0.01	0.0002	<0.0002	0.002	0.002	<0.001	<0.001	<0.005	<0.005
10-Mile below Moose Creek	8/19/1999	1535	0.02	<0.01	0.0013	0.001	0.004	0.003	<0.001	<0.001	0.252	0.241

Table 6-3 (continued) Metals Concentration Data Collected During *In-Situ* Fish Bioassay Tests on Tenmile Creek in 1999. Tot=Total Recoverable, Filt=Filtered

Site	Date	Time	Al-Tot (mg/L)	Al-Filt (mg/L)	Cd-Tot (mg/L)	Cd-Filt (mg/L)	Cu-Tot (mg/L)	Cu-Filt (mg/L)	Pb-Tot (mg/L)	Pb-Filt (mg/L)	Zn-Tot (mg/L)	Zn-Filt (mg/L)
Walker Creek	8/19/1999	1610	0.03	<0.01	<0.0002	<0.0002	0.004	0.003	<0.001	<0.001	<0.005	<0.005
10-Mile at Treatment Plant	8/19/1999	1630	0.03	<0.01	0.0007	0.0006	0.005	0.004	<0.001	<0.001	0.134	0.109
10-Mile at Rimini	8/20/1999	1320	0.73	0.05	0.0282	0.0285	0.029	0.016	0.014	<0.001	3.46	3.39
10-Mile below Banner Creek	8/23/1999	915										
10-Mile at Sawmill	8/23/1999	945										
10-Mile above Minnehaha	8/23/1999	1020		<0.01		0.0031		0.005		<0.001		0.875
10-Mile at Treatment Plant	8/23/1999	1100		<0.01		0.0006		0.003		0.001		0.137
Walker Creek	8/23/1999	1135		<0.01		0.0002		0.002		0.002		<0.005
Moose Creek	8/23/1999	1205		<0.01		<0.0002		0.001		<0.001		<0.005
10-Mile below Moose Creek	8/23/1999	1220		<0.01		0.001		0.002		<0.001		0.246
10-Mile above Moose Creek	8/23/1999	1240		<0.01		0.0016		0.002		<0.001		0.375
10-Mile below Minnehaha	8/23/1999	1300		<0.01		0.0015		0.003		<0.001		0.402
10-Mile at Sawmill	8/24/1999		0.01		0.0082			0.006	<0.001		2.25	
10-Mile below Banner Creek	8/24/1999		0.04		<0.0002			0.003	<0.001		0.037	
10-Mile at Treatment Plant	8/27/1999	950	<0.01	<0.01	0.0005	0.0005	0.005	0.004	<0.001	<0.001	0.162	0.172
Walker Creek	8/27/1999	1040	0.02	<0.01	0.0003	<0.0002	0.004	0.004	<0.001	<0.001	<0.005	<0.005
10-Mile below Moose Creek	8/27/1999	1110	0.02	<0.01	0.0008	0.0007	0.004	0.004	<0.001	<0.001	0.247	0.25
Moose Creek	8/27/1999	1135	0.02	<0.01	<0.0002	<0.0002	0.002	0.003	<0.001	<0.001	<0.005	<0.005
10-Mile above Moose Creek	8/27/1999	1200	0.02	0.02	0.0014	0.0012	0.004	0.007	<0.001	<0.001	0.414	0.361
10-Mile below Minnehaha	8/27/1999	1240	0.03	<0.01	0.004	0.0034	0.009	0.005	<0.001	<0.001	0.876	0.842
10-Mile above Minnehaha	8/27/1999	1300	0.02	<0.01	0.004	0.0041	0.006	0.005	<0.001	<0.001	0.948	0.943
10-Mile at Sawmill	8/27/1999	1334	0.07	0.01	0.0108	0.0108	0.01	0.007	0.001	<0.001	2.23	2.22
10-Mile below Banner Creek	8/27/1999	1400	0.15	0.04	<0.0002	<0.0002	0.003	0.002	<0.001	<0.001	0.031	0.022

Table 6-4 Summary of Water Temperature Data Collected on Tenmile Creek with Stowaway Automatic Recorders, 1999 and 2000.

Site	Date	Mean (°C)	Range (°C)	Mean daily maximum (°C)
10-Mile at Rimini	June 24-28, 1999	8.9	5.5-11.7	11.0
10-Mile above Moose Cr. Gage	June 24-28, 1999	9.6	5.8-13.4	12.8
10-Mile at Treatment Plant	June 24-28, 1999	11.5	7.4-14.8	14.3
Walker Creek	June 24-28, 1999	13.0	9.2-17.0	15.3
10-Mile below Banner Cr.	August 19-27, 1999	12.2	9.2-15.3	14.2
10-Mile at Rimini	August 19-27, 1999	13.9	9.8-19.1	18.5
10-Mile above Moose Cr. Gage	August 19-27, 1999	13.8	10.1-18.9	18.1
10-Mile below Moose Cr. Gage	August 19-27, 1999	13.5	10.0-18.3	17.4
10-Mile at Treatment Plant	August 19-27, 1999	16.8	12.1-23.2	21.6
Moose Creek	August 19-27, 1999	12.0	9.5-14.0	13.6
Walker Creek	August 19-27, 1999	15.2	11.7-18.8	17.5
10-Mile below Banner Creek	July 18-22, 2000	12.5	10.3-16.4	15.0
10-Mile at Rimini	July 18-22, 2000	14.2	10.9-20.1	18.4
10-Mile at Sawmill	July 18-22, 2000	13.8	12.0-16.5	15.7
10-Mile above Minnehaha Cr.	July 18-22, 2000	15.5	11.7-23.4	20.8
10-Mile below Minnehaha Cr.	July 18-22, 2000	14.5	11.5-20.2	18.6
10-Mile above Moose Cr. Gage	July 18-22, 2000	13.2	10.3-18.3	17.1
10-Mile at Parrett's	July 18-22, 2000	17.6	14.3-24.1	21.6

at the Below Banner Creek site was 7.33-7.4. Because all mainstem water was then diverted at the City diversion, the pH at the Rimini site was strongly influenced by the quality of the adit discharge water in the Rimini area. At the Rimini site, the pH ranged from 4.66-5.15, which then increased immediately to 6.9-7.0 at the next station downstream (Sawmill). All mainstem sites downstream of the Sawmill had pHs above 7.0, with the exception of one measurement at the Below Minnehaha site.

Water hardness was also strongly influenced by the changing discharge. In June the dilute snowmelt resulted in hardness values of 11-26 mg/L on the Tenmile mainstem sites, while Walker Creek had values somewhat higher (34-38 mg/L)(Table 6-2). In August at lower flows, all sites except the Below Banner Creek site had hardness values that ranged between 44-116 mg/L. The below Banner Creek site had hardness values from 12-16 mg/L. Calcium and magnesium were analyzed separately because calcium is believed to be the hardness cation most responsible for protection against metals. During the spring runoff period in June, the ratios all ranged between 4.1 - 4.9. On August 19, the calcium: magnesium ratios at the sites with no or little mining impact (Moose Creek, Walker Creek and Tenmile below Banner) were between 4.6 - 4.9. The water at the Rimini site, which consisted of spring creek water, groundwater discharge water and adit discharge water, had a Ca:Mg ratio of 3.1, which then increased slowly with each downstream site until a value of 4.7 was reached at the Treatment Plant. The significance of the different ratios is that if two sites had identical hardness and metals values, the one with the higher Ca:Mg ratio would be less toxic to fish.

6.3.2 Brook and Rainbow Trout Bioassays (2000)

The rainbow trout used for the bioassays ranged from 0.33-0.55 g, while the brook trout had mean weights ranging from 1.45-1.60 g. All rainbow trout died within 48 hours in the cages placed in Tenmile Creek at Rimini, the Sawmill, above Minnehaha, and below Minnehaha (Table 6-1). Some fish survived 96 hours of exposure at the other mainstem sites Above Moose Creek (28% mortality), Below Moose Creek (36% mortality), Parrett's House (4% mortality), and Below Banner Creek (4%). No mortality was observed at the control site (Moose Creek). For the brook trout (which were larger than the rainbows), mortality was partial at Rimini (52%), and no mortality was observed at the Above Moose Creek site or the control site on Moose Creek.

Discharge was not measured at any of the bioassay sites during the exposures, but the measurements from the USGS gage at Moose Creek provide a good general portrayal of flows between Rimini and the Treatment Plant because the mainstem and tributaries in this stretch were all being diverted into the City waterline. Mean daily flows at the gage dropped from 0.31 cfs on July 18 to 0.20 cfs on July 22.

Concentrations of metals in water were lower on the mainstem sites during these exposures than they had been in August 1999, although the general pattern of metals decreasing in a downstream direction below Rimini was similar. Levels of dissolved (filtered) aluminum, cadmium and copper were highest at Rimini, although the Sawmill site had the highest concentrations of dissolved zinc: 1.31-1.62 mg/L at the Sawmill versus 0.82-1.63 mg/L at Rimini (Table 6-5). Dissolved arsenic was unique in that levels were highest at a point farther downstream (Above Minnehaha and Below Moose Creek sites) than for the other trace elements.

Mean water temperatures during the July 18-22 exposures were below 15^{o}C at all mainstem sites except for Tenmile above Minnehaha Creek and Tenmile Creek at Parrett's house (Table 6-4), where the mean temperatures were 15.5º and 17.6º, respectively. These two sites were also the only sites where the daily mean maximum was over 20º (20.8º for Above Minnehaha and 21.6º for Parrett's) while all other sites were below 18.6º. The single highest temperature recorded at Parrett's was 24.1º, while it got as high as 23.4º above Minnehaha.

Dissolved oxygen levels were measured during the midday period (1000-1500 hr) on three separate days at each site. Measurements were also taken near sunrise (0500-0705) on July 22 in order to evaluate the degree to which a dissolved oxygen sag develops during the night. With the exception of Tenmile at Parrett's, all sites had dissolved oxygen levels between 6.9 and 9.0 mg/L, even during the early morning hours (Table 6-6). Oxygen levels at Parrett's were 7.9 mg/L on July 20, but dropped to 3.5 mg/L at 0645 on July 22 and 3.6 mg/L later that morning at 1030. The reason for this was that the stream at this site was going dry over the course of the bioassay exposures, and by July 22, only a small trickle (ca 5 gallons/minute) was flowing. The oxygen demand of the biotic community was probably responsible for these low levels.

Table 6-5 Metals Concentration Data Collected During *In-Situ* Fish Bioassay Tests on Tenmile Creek in 2000. Tot=Total Recoverable, Filt=Filtered

Site	Time	Date	Al-Tot (mg/L)	Al-Filt (mg/L)	As-Tot (mg/L)	As-Diss (mg/L)	Cd-Tot (mg/L)	Cd-Filt (mg/L)	Cu-Tot (mg/L)	Cu-Filt (mg/L)	Pb-Tot (mg/L)	Pb-Filt (mg/L)	Zn-Tot (mg/L)	Zn-Filt (mg/L)
10-Mile blw Banner	1115	7/18/2000	0.09	0.01	<0.001	<0.001	<0.0002	<0.0002	0.001	0.001	<0.001	<0.001	0.029	0.03
Moose Creek	1200	7/18/2000	0.01	<0.01	<0.001	0.031	<0.0002	<0.0002	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005
10-Mile at Parrets	1240	7/18/2000	0.1	<0.01	0.027	0.026	0.0008	0.0004	0.002	0.001	<0.001	<0.001	0.107	0.094
10-Mile blw Moose	1300	7/18/2000	0.03	<0.01	0.038	0.035	0.0006	0.0006	0.002	0.001	0.001	0.001	0.166	0.15
10-Mile abv Moose	1320	7/18/2000	0.01	<0.01	0.028	0.028	0.001	0.0009	0.002	0.001	<0.001	<0.001	0.262	0.256
10-Mile blw Minnehaha	1345	7/18/2000	<0.01	<0.01	0.032	0.031	0.0026	0.0025	0.003	0.001	<0.001	<0.001	0.62	0.612
10-Mile abv Minnehaha	1410	7/18/2000	0.01	0.01	0.036	0.035	0.0024	0.0025	0.002	0.001	<0.001	<0.001	0.601	0.585
10-Mile at Mill	1428	7/18/2000	0.05	<0.01	0.045	0.029	0.0046	0.0047	0.004	0.001	0.001	<0.001	1.34	1.31
10-Mile at Rimini	1500	7/18/2000	0.09	0.01	0.042	0.014	0.0041	0.0038	0.008	0.011	0.002	<0.001	0.795	0.818
10-Mile blw Banner	1000	7/20/2000	0.08	0.01	0.003	0.003	<0.0002	<0.0002	0.001	0.001	<0.001	<0.001	0.03	0.034
Moose Creek	1025	7/20/2000	0.03	<0.01	<0.001	<0.001	<0.0002	<0.0002	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005
10-Mile at Parrets	1040	7/20/2000	0.01	<0.01	0.025	0.025	0.0007	0.0006	0.002	0.001	<0.001	<0.001	0.141	0.171
10-Mile blw Moose	1100	7/20/2000	0.01	<0.01	0.036	0.034	0.0009	0.0008	0.001	0.001	<0.001	<0.001	0.219	0.208
10-Mile abv Moose	1120	7/20/2000	0.01	<0.01	0.029	0.025	0.0013	0.0013	0.002	0.001	<0.001	<0.001	0.351	0.342
10-Mile blw Minnehaha	1140	7/20/2000	0.03	<0.01	0.033	0.031	0.0029	0.0027	0.003	0.001	<0.001	<0.001	0.717	0.717
10-Mile abv Minnehaha	1200	7/20/2000	0.01	<0.01	0.037	0.035	0.0032	0.0034	0.003	0.011	<0.001	<0.001	0.89	0.869
10-Mile at Mill	1230	7/20/2000	0.02	<0.01	0.037	0.033	0.005	0.0051	0.004	0.001	<0.001	<0.001	1.79	1.62
10-Mile at Rimini	1245	7/20/2000	0.11	<0.01	0.054	0.014	0.0081	0.0078	0.009	0.011	0.006	<0.001	1.54	1.48
10-Mile at Rimini	1015	7/21/2000	0.12	0.02	0.045	0.013	0.0085	0.0083	0.01	0.011	0.004	<0.001	1.61	1.63
10-Mile at Parrets	1030	7/22/2000	0.02	<0.01	0.03	0.039	0.0008	0.0008	0.003	0.001	<0.001	<0.001	0.204	0.2
10-Mile blw Moose	1120	7/22/2000	0.01	<0.01	0.038	0.037	0.0006	0.0005	0.002	0.001	<0.001	<0.001	0.164	0.154
Moose Creek	1140	7/22/2000	0.01		<0.001		<0.0002		<0.001		<0.001		<0.005	
10-Mile abv Moose	1215	7/22/2000	0.01	<0.01	0.029	0.027	0.0009	0.0009	0.001	0.001	0.001	<0.001	0.279	0.27
10-Mile at Rimini	1255	7/22/2000	0.07	0.02	0.025	0.015	0.0041	0.0046	0.008	0.011	0.006	0.001	0.88	0.84
10-Mile blw Banner	1320	7/22/2000	0.07	0.01	0.002	0.002	<0.0002	<0.0002	0.001	0.001	<0.001	<0.001	0.026	0.033

Several other water quality parameters were measured at each site (Table 6-6). The pH levels were lowest at the Rimini site, ranging from 6.04-6.69. All other sites had slightly higher pH levels, ranging from 6.81-7.81. DOC was measured on July 19 at all sites, and Tenmile below Banner Creek had the highest levels at 2.53 mg/L; all other sites had values between 1.28-1.76 mg/L. Water hardness was lowest at the two uppermost sites: Tenmile below Banner site (20 mg/L as $CaCO_3$) and the Rimini site (36-46 mg/L). Downstream sites on the mainstem had higher levels, ranging from 62-88 mg/L, with the exception of the Below Moose site which had levels from 42-50 mg/L.

6.3.3 Metals Toxicity in Relation to Water Quality Standards

The task of identifying the individual metal(s) causing mortality to trout in the bioassays is made difficult by the fact that the metals concentrations in water show a strong tendency to co-vary among sites. As mentioned earlier, all metals (with the exception of arsenic) are highest in the Rimini-Sawmill area and decrease in concentration in a downstream direction. Therefore, rather than using correlative techniques to determine the metals causing toxicity, we chose to compare ambient water quality conditions during our bioassays in 2000 to acute aquatic water quality standards (Montana Numeric Water Quality Standards, 2002). The presumption is that the higher the concentration of a metal relative to its standard, the more likely it is to impart toxic effects. On July 18, 2000 zinc and cadmium were the only metals with ratios above 1.0 at more than one site; zinc had the highest ratios by far (0.8-16.2), followed by cadmium (<0.01-5.03). Copper had a ratio of 2.06 at Rimini, but was no higher than 0.16 at any other site (Table 6-7).

Because of the high ratios, zinc and cadmium were assumed to be responsible for most of the toxicity to fish. However, the ratios were not constant at each site, and changed with discharge. This was due to the fact that both water hardness and metals concentrations were lower at higher discharges than they were at lower discharges. Water samples collected during this study and in 1997 by Parrett and Hettinger (2000) can be used to show these differences. In May 1997, conditions were typical for the snowmelt runoff period: the discharge on May 15 was 103 cfs in Rimini, 135 cfs at the Moose Creek Campground gage, and 177 cfs at the Treatment Plant.

Levels of hardness were at or below 16 mg/L at all sites. On this date, the ratio of dissolved (filtered) zinc to the water quality standard was close to 4 for all sites, while the similar ratio for cadmium was close to 2 at all sites (Figures 6-1 and 6-2). Most significantly though, the ratio stayed fairly constant at all sites, due to the dilution of adit water in Rimini by the snowmelt and the high velocities necessary to carry the metals downstream. Parrett and Hettinger sampled the same three sites at on August 26, 1997, when most water was being diverted at the City Diversion, but not at the tributary diversions at Moose, Minnehaha and Walker creeks. On this day, the flow at Rimini was 0.39 cfs, at the Moose Creek Campground gage it was 2.22 cfs and at the Treatment Plant it was 5.2 cfs. Hardness levels had risen to 50-81 mg/L. At this time, the ratio for zinc was nearly 31 at Rimini and decreased to just under 2 at the Treatment Plant. Cadmium showed a similar pattern, dropping from about 16 in Rimini to 0.5 at the Treatment Plant. This steep drop in ratios from Rimini to the Treatment Plant was also seen during our bioassay tests on July 18, 2000. On this day, the flow at the Moose Campground gage was 0.31 cfs. Flows were not measured at any other sites that day, but no water was getting past the City Diversion in Rimini or any of the tributary diversions. All flows in Tenmile below the City Diversion were due to

Table 6-6 Water Quality Data Collected During *In-Situ* Fish Bioassay Tests on Tenmile Creek in 2000.

Site	Date	Time	Temp (°C)	Dissolved oxygen (mg/L)	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	pH (s.u.)	Calcium (mg/L)	Magnesium (mg/L)	Calcium/ Magnesium Ratio	DOC (mg/L)
10-Mile blw Banner	7/18/2000	1115	11.8	6.9	20	12	7.3				
Moose Creek	7/18/2000	1200	11.9	8.1	82	86	7.81				
10-Mile at Parrets	7/18/2000	1240	17	7.8	64	46	7.66				
10-Mile blw Moose	7/18/2000	1300	16	8.6	42	34	7.59				
10-Mile abv Moose	7/18/2000	1320	15.7	7.8	62	28	6.93				
10-Mile blw Minnehaha	7/18/2000	1345	16.7	8.1	62	22	7.03				
10-Mile abv Minnehaha	7/18/2000	1410	17.6	8.4	82	28	7.67				
10-Mile at Mill	7/18/2000	1428	17.7	7.9	88	14	7				
10-Mile at Rimini	7/18/2000	1500	18	7.8	36	10	6.69				
10-Mile blw Banner	7/19/2000							5.4	1.1	4.9	2.53
10_mile at Rimini	7/19/2000							13.2	4.1	3.2	1.28
10-Mile at Mill	7/19/2000							25.2	8	3.2	1.34
10-Mile abv Minnehaha	7/19/2000							22.3	6.6	3.4	1.46
10-Mile blw Minnehaha	7/19/2000							21.9	6.1	3.6	1.76
10-Mile abv Moose	7/19/2000							16.9	4.1	4.1	1.6
10-Mile blw Moose	7/19/2000							16.1	3.6	4.5	1.66
10-Mile at Parrets	7/19/2000							20	4.2	4.8	1.56
10-Mile blw Banner	7/20/2000	1000	11.5	7.2	20	14	7.3				
Moose Creek	7/20/2000	1025	11.7	8.1	84	86	7.77				
10-Mile at Parrets	7/20/2000	1040	16.8	7.9	66	46	7.66				
10-Mile blw Moose	7/20/2000	1100	16.3	8.4	44	34	7.61				
10-Mile abv Moose	7/20/2000	1120	16.1	7.9	64	28	6.89				
10-Mile blw Minnehaha	7/20/2000	1140	16.9	8.2	62	24	7.07				
10-Mile abv Minnehaha	7/20/2000	1200	17.5	8.3	80	30	7.67				
10-Mile at Mill	7/20/2000	1230	17	7.8	86	14	7.04				
10-Mile at Rimini	7/20/2000	1245	17.5	7.8	38	10	6				
10-Mile at Rimini	7/21/2000	1015	14.9	8	46	10	6.04				
10-Mile blw Banner	7/22/2000	500	10	9							
10-Mile at Mill	7/22/2000	520	11	7.9							
10-Mile at Rimini	7/22/2000	535	11	7.9							
10-Mile abv Minnehaha	7/22/2000	545	11	7.8							
10-Mile blw Minnehaha	7/22/2000	555	11	7.9							
10-Mile abv Moose	7/22/2000	615	11	7.4							

Table 6-6 (continued) Water Quality Data Collected During *In-Situ* Fish Bioassay Tests on Tenmile Creek in 2000.

Site	Date	Time	Temp (°C)	Dissolved oxygen (mg/L)	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	pH (s.u.)	Calcium (mg/L)	Magnesium (mg/L)	Calcium/ Magnesium Ratio	DOC (mg/L)
10-Mile blw Moose	7/22/2000	630	11	7.5							
10-Mile at Parrets	7/22/2000	645	15	3.5							
Moose Creek	7/22/2000	705	9	8							
10-Mile at Parrets	7/22/2000	1030	16.1	3.6	66	50	7.09				
10-Mile blw Moose	7/22/2000	1120	15.7	8.9	50	40	7.56				
Moose Creek	7/22/2000	1140	12.4	8.7	86	90	8				
10-Mile abv Moose	7/22/2000	1215	12.7	7.8	56	30	6.81				
10-Mile at Rimini	7/22/2000	1255	20.5	8	36	10	6.83				
10-Mile blw Banner	7/22/2000	1320	14.1	8.5	18	16	7.76				

Table 6-7 Comparison of Filtered Metals Concentrations on Tenmile Creek Measured on July 18, 2000.

Site	Hardness (mg/L as $CaCO_3$)	Water Concentration (ug/L)						Ratio of water concentration to hardness-adjusted acute water quality standard					
		Al	As	Cd	Cu	Pb	Zn	Al	As	Cd	Cu	Pb	Zn
Below Banner Creek	20	0.01	<0.001	<0.0002	0.001	<0.001	0.03	.01	<.01	<.01	0.26	<.07	0.81
Rimini	36	0.01	0.014	0.0038	0.011	<0.001	0.818	.01	.04	5.03	2.06	<.04	16.2
Sawmill	88	<0.01	0.029	0.0047	0.001	<0.001	1.31	<.01	.09	2.51	0.08	<.01	12.2
Above Minnehaha Cr	82	0.01	0.035	0.0025	0.001	<0.001	0.585	<.01	.07	1.43	0.09	<.02	5.78
Below Minnehaha Cr	62	<0.01	0.031	0.0025	0.001	<.0001	0.612	<.01	.09	1.91	0.11	<.02	7.66
Above Moose	62	<0.01	0.028	0.0009	0.001	<0.001	0.256	<.01	.08	0.69	0.11	<.02	3.20
Below Moose	42	<0.01	0.035	0.0006	0.001	0.001	0.150	<.01	.09	0.68	0.16	.04	2.61
At Parrett's	64	<0.01	0.026	0.0004	0.001	<0.001	0.094	<.01	.08	0.30	0.11	<.02	1.15

inflow from the Moore and Banks spring creeks as well as Suzie Mine adit discharge, Lee Mountain adit seepage, and groundwater seepage along the stream down to the Treatment Plant. Flows on this day actually ceased somewhere between the Parrett's house and the Treatment Plant. Hardness values at all sites ranged from 36-82 mg/L. Under these conditions, the ratios for both zinc and cadmium showed steep drops between Rimini and Parrett's house, with the cadmium ratios dropping from 5.0 at Rimini to 0.3 at Parrett's and the zinc dropping from 16.2 to 1.1 (Figures 6-1 and 6-2).

The mortality of both species of trout was positively related to the zinc ratio. For rainbow trout (weighing between 0.33-0.55 g), partial (<100%) mortalities were observed when ratios were between 2 and 4, while 100% mortalities were reached when ratios exceeded 6.5 (Figure 6-3). For similarly-sized brook trout (0.25-0.63 g), the results were similar but less clear, because a ratio of 4.2 yielded a mortality rate of 85%, while a ratio of 4.7 had only 9% mortality (Figure 6-4). Ratios of 6.6 and 7.2 had mortality rates of 83 and 100%, respectively. The larger brook trout (1.45-3.1 g) were clearly more tolerant of the zinc. Ratios between 9.9-22.9 yielded mortality rates ranging from 18-48%, while a ratio of 36.6 resulted in a 100% kill (Figure 6-5).

6.3.4 Diel Zinc Cycles

The diel variation in dissolved zinc concentrations showed a similar pattern at the two sites, in that concentrations dropped quickly and briefly to the minimum level in mid-afternoon, while the maximum level was part of a plateau of values that was reached in the late night-early morning hours. At the USGS gage near Moose Creek, the zinc level reached a minimum of 0.12 mg/L at 1500 hours and a maximum level of 0.24 at 0300 hours (Table 6-8). At the Rimini site, the minimum level measured was 1.64 mg/L at 1600 hrs and the maximum was 2.71 mg/L at 0600 hrs (Table 6-9). At the USGS gage, this maximum "plateau" consisted of measurements that ranged from 0.23-0.24 mg/L from 0100 to 0700 hrs, while at Rimini, the concentration was 2.7-2.71 mg/L from 0400 to 0800 hrs.

The trend in temperature and pH were generally the inverse of that shown for zinc (Figure 6-6 and 6-7). At the Moose Creek gage, maximum and minimum temperatures were reached at 1530 and 0800 hrs, respectively, while high and low pH values were reached at 1600 and between 2130-0030 hrs, respectively. At Rimini, temperature was highest at 1600 and lowest at 0830, while pH was highest between 1130-1200 and lowest between 0630-0730.

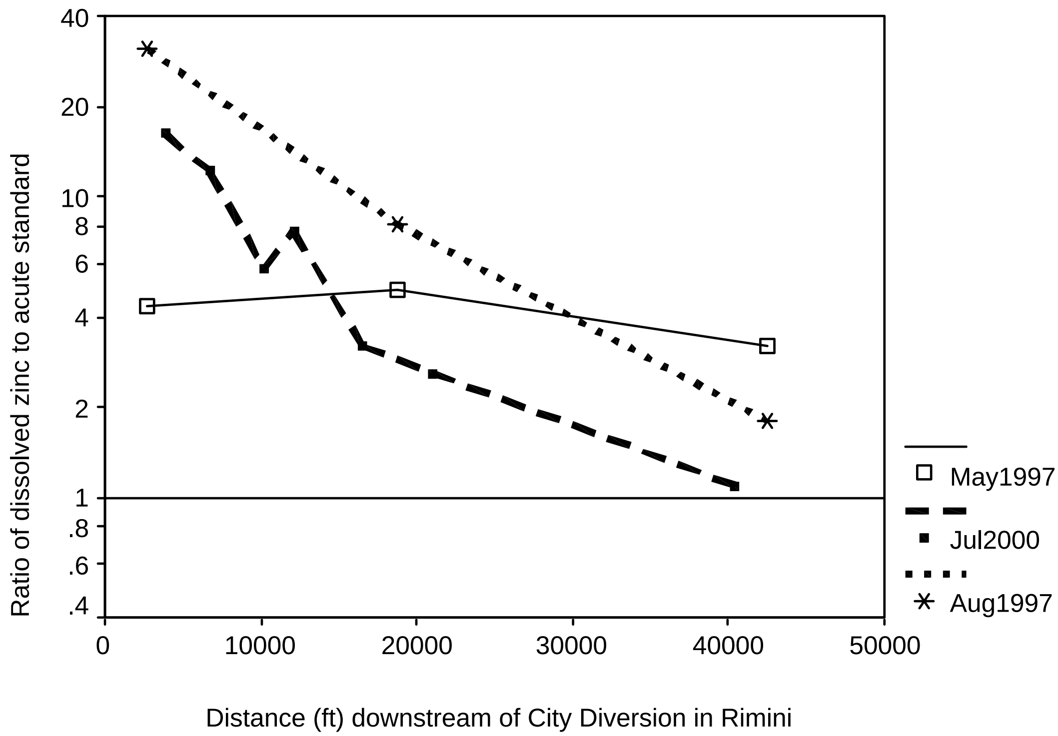


Figure 6-1 Ratio of dissolved zinc in water to the acute aquatic life water quality standard at different times and sites in Tenmile Creek.

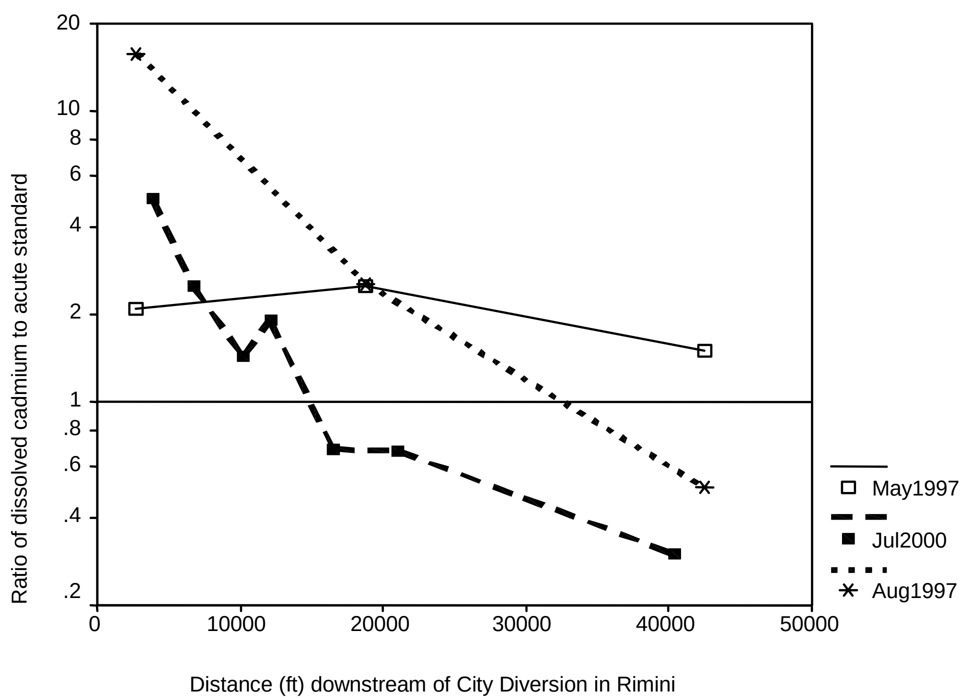


Figure 6-2 Ratio of dissolved cadmium ion in water to the acute aquatic life water quality standard at different times and sites in Tenmile Creek.

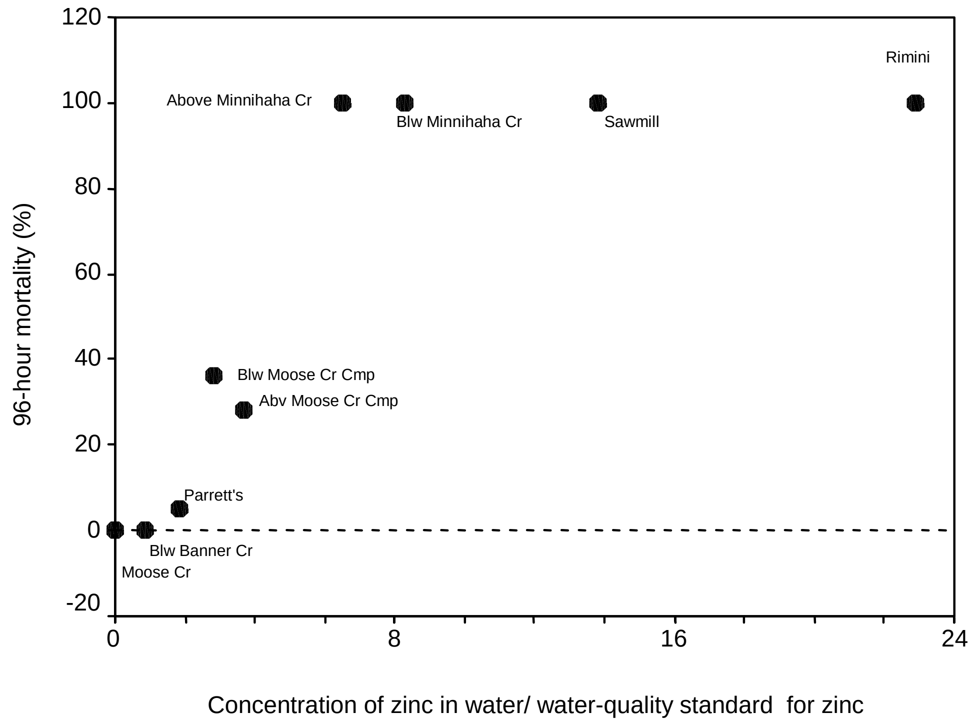


Figure 6-3 Toxicity of Tenmile Creek water to rainbow trout (0.33-0.55g).

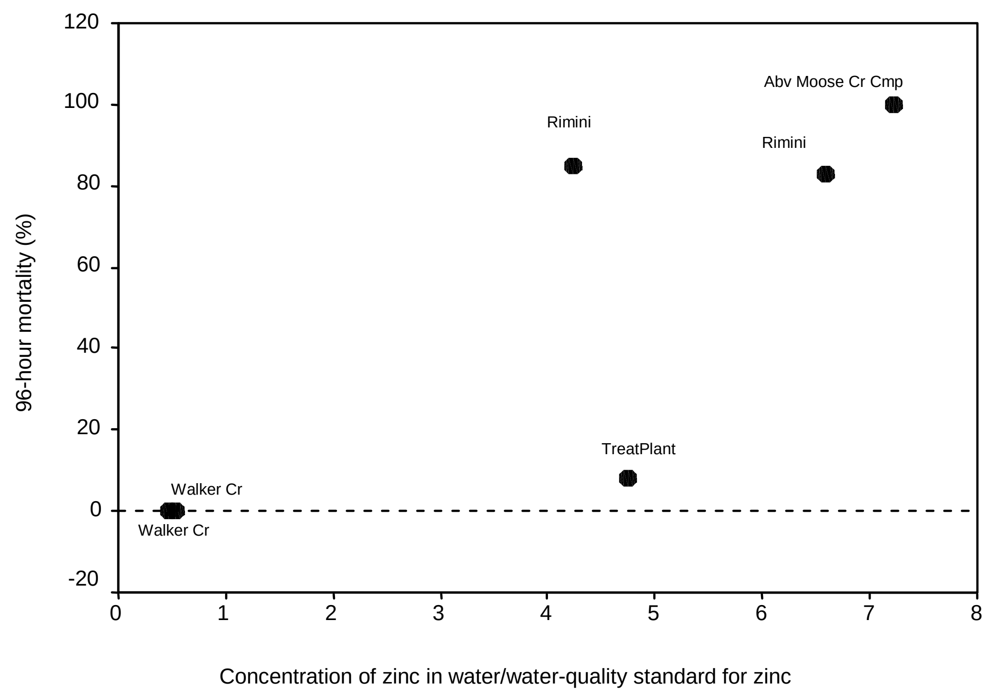


Figure 6-4 Toxicity of Tenmile Creek water to brook trout (0.25-0.63g).

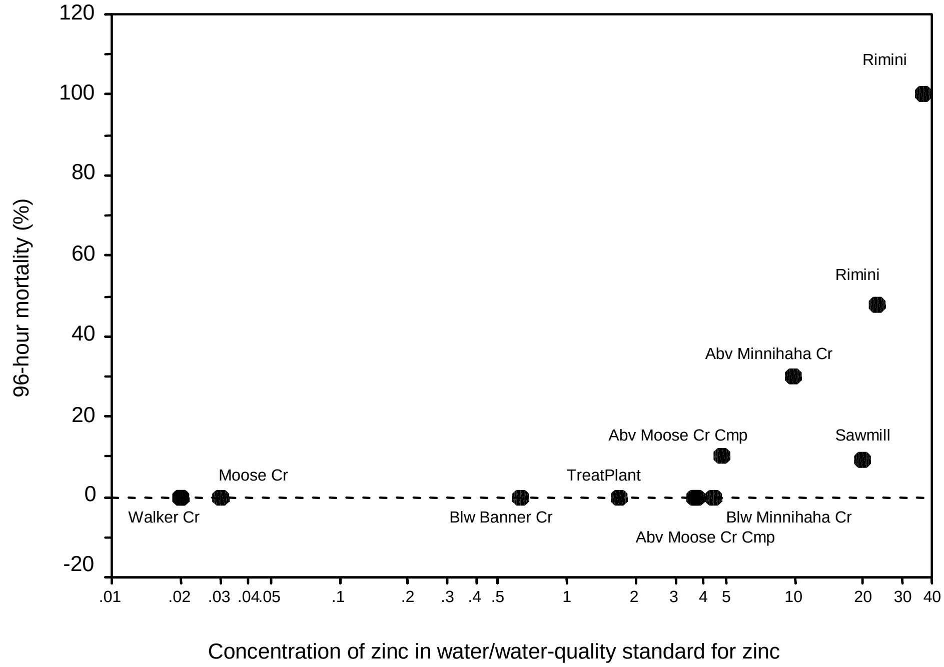


Figure 6-5 Toxicity of Tenmile Creek water to brook trout (1.45-3.1g).

Table 6-8 Results of Water Quality Sampling on Tenmile Creek at the USGS Moose Creek Gage to Describe the Diel Pattern of Zinc Concentrations.

Date MMDDYY	Time HHMMSS	Zinc-Filtered (0.1 um)	Temp (^oC)	Dissolved Oxygen (% saturation)	Dissolved Oxygen (mg/L)	Specific Conductance (uS/cm)	pH (s.u.)
91300	110000	0.2	9.9	98.1	9.38	164	7.13
91300	113000		10.43	99.5	9.4	162	7.18
91300	120000		11.14	100.7	9.35	161	7.23
91300	123000		12.56	105.4	9.48	161	7.31
91300	130000	0.16	14.57	109.9	9.46	162	7.4
91300	133000		16.03	112.1	9.35	162	7.46
91300	140000		17.32	112.6	9.14	162	7.51
91300	143000		18.44	114.7	9.1	162	7.57
91300	150000	0.12	19.2	116.4	9.09	162	7.63
91300	153000		19.55	116.5	9.04	162	7.65
91300	160000		19.4	115.6	8.99	162	7.67
91300	163000		18.79	111.9	8.82	161	7.6
91300	170000	0.14	18.1	106.8	8.54	161	7.5
91300	173000		17.31	103.1	8.38	161	7.36
91300	180000		16.42	98	8.11	161	7.25
91300	183000		15.61	95.8	8.06	161	7.19
91300	190000	0.19	14.88	93.5	7.99	160	7.14
91300	193000		14.31	91.4	7.91	160	7.1
91300	200000		13.79	89.4	7.82	160	7.06
91300	203000		13.29	88	7.79	160	7.04
91300	210000	0.21	12.78	87.3	7.82	160	7.02
91300	213000		12.35	87.8	7.94	160	7.01
91300	220000		11.96	87.6	7.99	160	7.01
91300	223000		11.63	87.5	8.04	160	7.01
91300	230000	0.22	11.33	87.6	8.11	160	7.01
91300	233000		11.06	87.4	8.14	160	7.01
91400	0		10.82	87.4	8.18	160	7.01
91400	3000		10.6	85.4	8.04	125	7.01
91400	10000	0.23	10.4	85.6	8.09	125	7.02
91400	13000		10.2	85.5	8.13	125	7.02
91400	20000		10.01	85.5	8.16	125	7.02
91400	23000		9.83	85.7	8.21	126	7.02
91400	30000	0.24	9.68	85.7	8.24	126	7.02
91400	33000		9.54	85.7	8.27	126	7.02
91400	40000		9.41	85.7	8.3	126	7.03
91400	43000		9.28	85.7	8.32	127	7.03
91400	50000	0.23	9.17	85.8	8.35	127	7.03
91400	53000		9.05	85.9	8.39	127	7.03
91400	60000		8.93	86	8.42	127	7.03

Table 6-8 (continued) Results of Water Quality Sampling on Tenmile Creek at the USGS Moose Creek Gage to Describe the Diel Pattern of Zinc Concentrations.

91400	63000		8.8	86.1	8.46	128	7.03
91400	70000	0.23	8.68	86.3	8.5	128	7.03
91400	73000		8.58	87.1	8.6	128	7.04
91400	80000		8.54	89.4	8.83	129	7.07
91400	83000		8.56	91.6	9.05	129	7.11
91400	90000	0.21	8.63	93.2	9.19	129	7.14
91400	93000		8.75	94.7	9.31	129	7.16
91400	100000		9.03	96.8	9.45	129	7.21
91400	103000		9.5	99.3	9.59	129	7.25
91400	110000	0.19	10.03	100.3	9.57	129	7.27
91400	113000		10.54	100.3	9.46	129	7.23

Table 6-9 Results of Water Quality Sampling on Tenmile Creek at the Rimini Site to Describe the Diel Pattern of Zinc Concentrations.

Date MMDDYY	Time HHMMSS	Zinc-filtered (0.1 um)	Temp (^oC)	Dissolved oxygen (% saturation)	Dissolved oxygen (mg/L)	Specific conductance (uS/cm)	pH (s.u.)
91400	133000		18.2	118.2	9.32	213	6.73
91400	140000	1.77	18.76	116.4	9.08	214	6.72
91400	143000		19.32	116	8.94	214	6.73
91400	150000		19.73	115.3	8.82	214	6.71
91400	153000		20.18	112.6	8.53	213	6.72
91400	160000	1.64	20.46	111.3	8.39	212	6.69
91400	163000		20.42	110.2	8.31	211	6.68
91400	170000		19.41	109.8	8.45	211	6.68
91400	173000		17.74	104.7	8.33	210	6.69
91400	180000	1.81	16.89	106.9	8.66	208	6.72
91400	183000		16.29	105	8.62	207	6.72
91400	190000		15.68	105.8	8.79	205	6.72
91400	193000		15.13	104	8.74	204	6.73
91400	200000	2.04	14.61	100.3	8.53	203	6.72
91400	203000		14.12	99.6	8.56	203	6.72
91400	210000		13.65	96.2	8.36	203	6.72
91400	213000		13.16	97.4	8.55	202	6.72
91400	220000	2.32	12.72	97.8	8.67	202	6.72
91400	223000		12.33	97.5	8.72	201	6.71
91400	230000		11.97	97	8.74	200	6.71
91400	233000		11.68	97.8	8.88	200	6.7
91500	0	2.46	11.42	97.9	8.94	199	6.69
91500	3000		11.18	98	9	200	6.68
91500	10000		11.01	99	9.13	201	6.67
91500	13000		10.83	98.5	9.12	201	6.66
91500	20000	2.52	10.65	98.3	9.14	202	6.66

Table 6-9 Results of Water Quality Sampling on Tenmile Creek at the Rimini Site to Describe the Diel Pattern of Zinc Concentrations.

Date MMDDYY	Time HHMMSS	Zinc-filtered (0.1 um)	Temp (°C)	Dissolved oxygen (% saturation)	Dissolved oxygen (mg/L)	Specific conductance (uS/cm)	pH (s.u.)
91500	23000		10.46	99.3	9.27	203	6.66
91500	30000		10.3	99.1	9.28	203	6.65
91500	33000		10.14	98.9	9.31	206	6.65
91500	40000	2.7	9.99	98.5	9.29	208	6.64
91500	43000		9.83	99	9.38	209	6.64
91500	50000		9.7	99.2	9.43	209	6.63
91500	53000		9.56	99.7	9.5	210	6.63
91500	60000	2.71	9.46	99.4	9.5	211	6.63
91500	63000		9.31	99.8	9.57	212	6.62
91500	70000		9.19	99.4	9.57	212	6.62
91500	73000		9.07	100.1	9.66	212	6.62
91500	80000	2.7	8.97	101.6	9.83	212	6.63
91500	83000		8.95	103.8	10.04	212	6.64
91500	90000		8.94	105.1	10.17	211	6.64
91500	93000		8.99	105.8	10.23	211	6.66
91500	100000	2.48	9.3	107.5	10.32	210	6.67
91500	103000		10.07	109	10.27	210	6.67
91500	110000		11.4	111.5	10.18	211	6.68
91500	113000		12.98	113.7	10.02	211	6.74
91500	120000	1.98	14.52	115.6	9.85	211	6.74
91500	123000		16.01	116.3	9.6	212	6.73

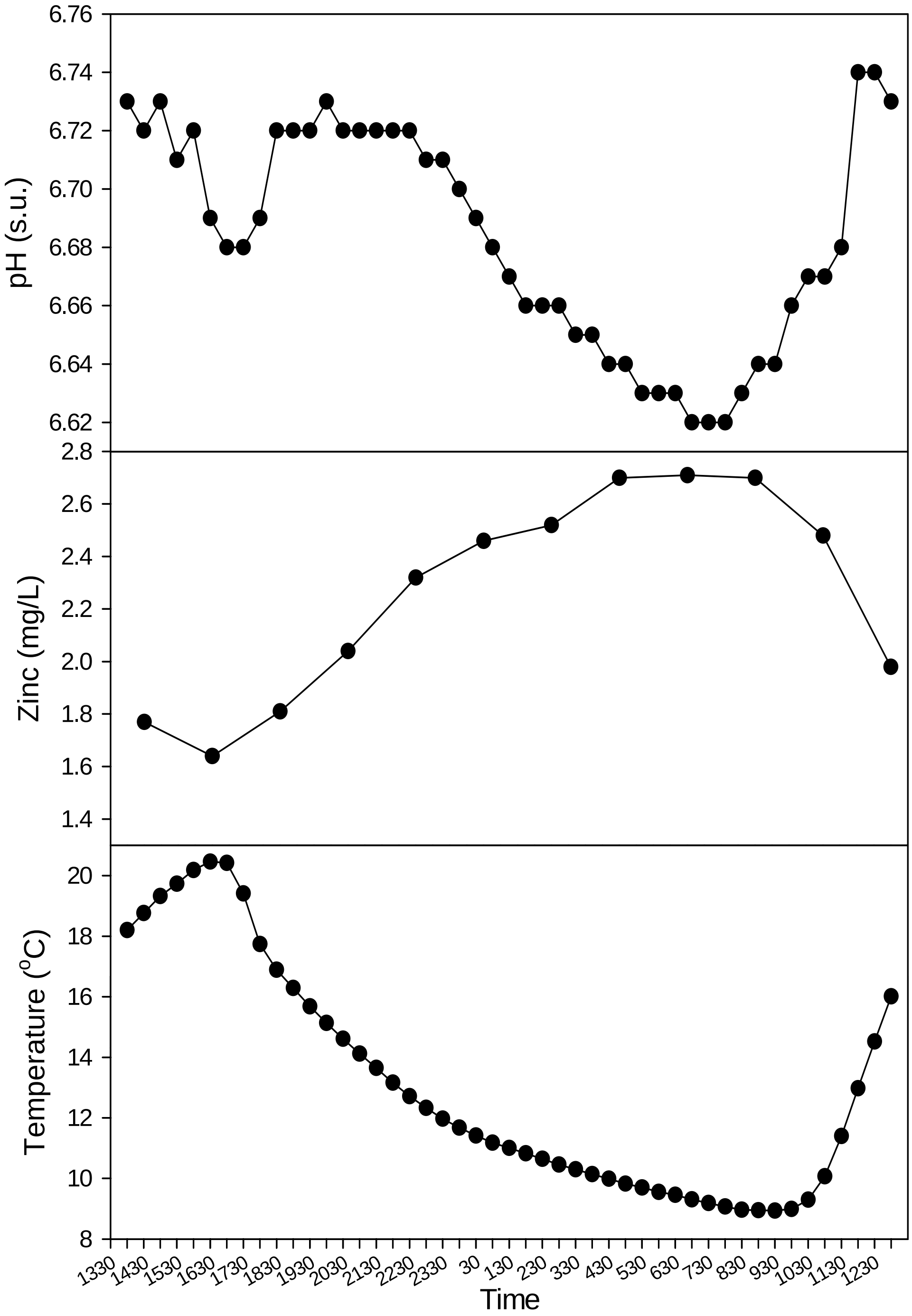


Figure 6-6 Diel trends in water temperature, zinc, and pH on Tenmile Creek at Rimini, September 14-15, 2000.

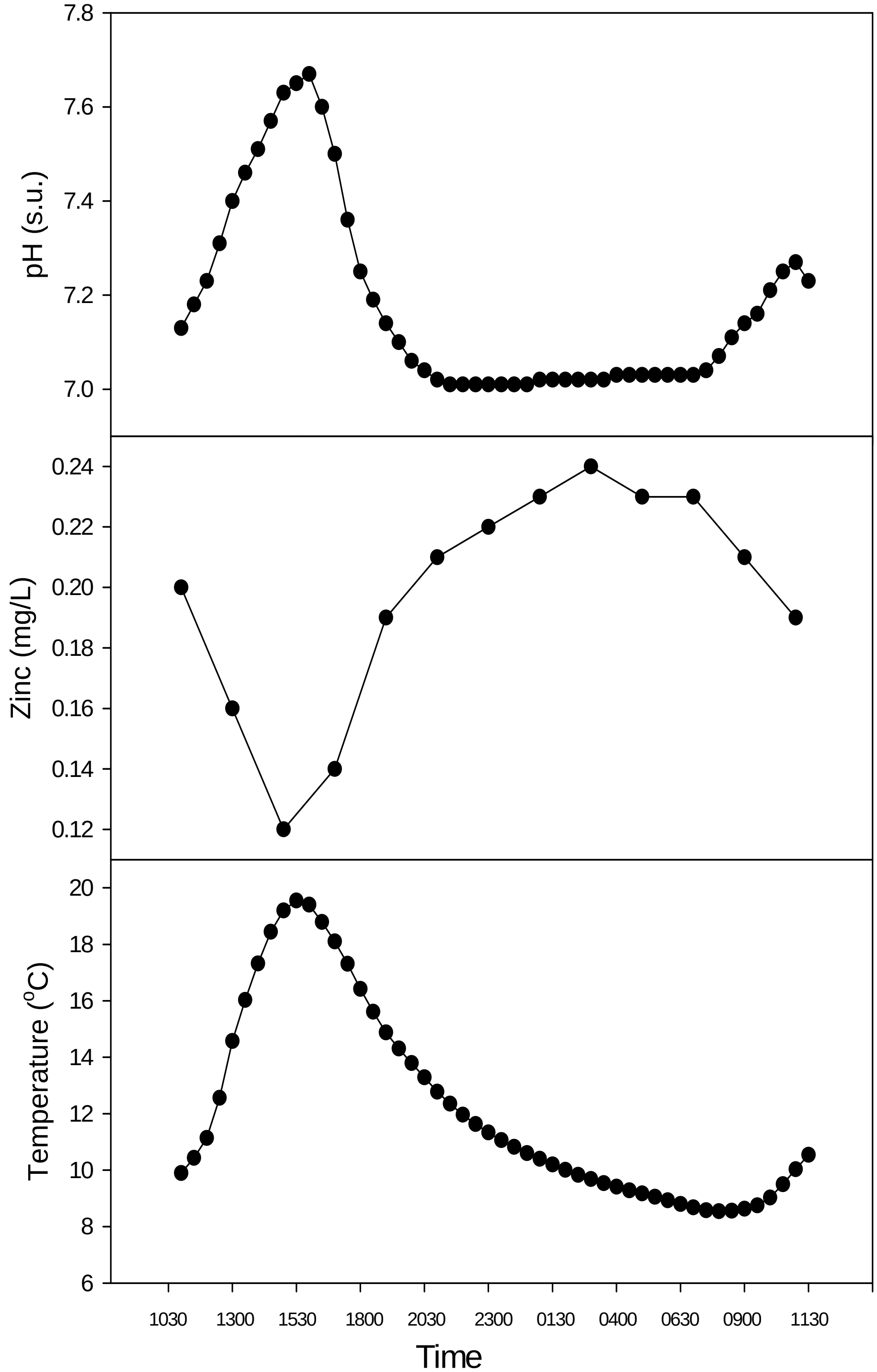


Figure 6-7 Diel trends in water temperature, zinc, and pH on Tenmile Creek at Moose Creek gage, September 13-14, 2000.

6.4 Discussion

The bioassay test results showed a strong relationship between dissolved zinc concentration and mortality rates in trout. The tests also demonstrated that post-emergent rainbow and brook trout (0.2-0.6 g) have a similar tolerance for the conditions in Tenmile Creek, but that older young-of-the-year brook trout (1.4-3.1 g) are more tolerant. When these findings are evaluated with respect to the periods of spawning and incubation for these species, some important implications can be seen. Water samples taken during spring runoff (May 1997 by the USGS and in June 1999 in this study) showed that the zinc ratios are not highly variable among the sites measured between Rimini and the Treatment Plant and ranged between 3.2-7.2. Water samples taken later in the summer (July 2000 and August 1999) show that the variability increases, due to the zinc ratios increasing in the Rimini/Sawmill area (as high as 36.6), and decreasing in the area below the Moose Creek Campground (as low as 1.1). This change in the ratios may mean that survival of emergent fry will be different for the two species. For the brook trout, which are emerging during the spring runoff period, the ratios of 3.2-7.2 probably bracket the ratios that cause 0 and 100% mortality in acute exposures. It seems reasonable to expect that in years where runoff yields high discharges, the ratios will be lower than in years with low discharges. In high discharge situations, the ratios may be pushed close to or below the 3.2 ratio, resulting in few, if any, mortalities. Conversely, in low discharge years, the ratios would push more toward 7.2, and produce many mortalities. For the rainbow trout, which are emerging during July, ratios are likely to always be lethal in the mainstem above Minnehaha Creek, and not likely to be lethal near the Treatment Plant.

It is important to reiterate that only metal-naïve fish were used in the bioassays, and therefore the results from the tests should only be assumed to apply to naïve fry that drift into the contaminated portion of Tenmile Creek from upstream or from tributaries (a notable exception to this is Minnehaha Creek, which is high in zinc and undoubtedly flushes out many acclimated brook trout fry to the mainstem during high flows). In reality, any brook trout born and residing in the stream between Rimini and the Treatment Plant is likely to develop some level of acclimation to the metals, and these fish might be expected to suffer fewer mortalities than were seen in the bioassays.

During the bioassay tests there were several water quality parameters other than metals that may have been stressors on the fish and could have affected the results. The USEPA criterion for pH for freshwater aquatic life is 6.5-9.0, and the station at Rimini was the only one that had values outside this range. During bioassays in August 1999, the pH ranged from 4.66-5.15 and during July 2000 it ranged from 6.04-6.83. It is unlikely the pH values even as low as 4.66 were causing mortality because Daye and Garside (1975) demonstrated in the laboratory that brook trout were not killed by low pH until levels dropped to between 3.2-3.8.

Dissolved oxygen is another water quality parameter that reached levels that might have been stressful to fish. The USEPA Water Quality Criteria (Chapman 1986) is 4.0 mg/L as a one-day minimum value for coldwater species older than 30 days. The document states “If the period of exposure to low dissolved oxygen concentrations is limited to less than 3.5 days, concentrations of dissolved oxygen of 3 mg/L or higher should produce no direct mortality of salmonids.” This statement is based, in part, on the Downing and Merkens (1957) study which reported 100% mortality of brook trout after a 3.5-day exposure to dissolved oxygen concentrations of 1.3 and

2.4 mg/L at 10º and 20ºC, respectively. The corresponding levels that resulted in no mortality were 1.9 and 2.7 mg/L. None of the bioassay sites had oxygen levels lower than these mortality thresholds; the lowest oxygen level measured was 3.5 mg/L at Parrett's in July 2000. Only 1 of 25 fish died at this site, and based on the references cited above, it would not be expected that oxygen levels at the site would cause any mortalities.

The water temperatures may have been high enough to be stressful, but not lethal, to fish at three sites: the Treatment Plant in 1999 and Above Minnehaha and at Parrett's in 2000. Cherry et al. (1977) determined experimentally that juvenile brook trout prefer water temperature of 15.5-16.8ºC, and can withstand temperatures as high as 24º for seven days without dying. During the August 1999 bioassays, mean daily temperatures were still lower than or equal to the preferendum at all sites. The Treatment Plant site had the highest mean daily maximum (21.6º) and single point maximum (23.2º). In 2000, the mean daily and single point maximum temperatures at Parrett's were 21.6º and 24.1º, while at the Above Minnehaha site they were 20.8º and 23.4º. With respect to the effects of elevated temperatures on rainbow trout, Hokanson et al. (1977) exposed juvenile trout to fluctuating water temperatures (simulating the diel pattern found in natural streams) and found that maximum growth occurred when temperatures averaged 15.5º. Growth declined slowly up to a mean temperature of 21º, and above this temperature the growth declined quickly. Hokanson et al. also tested fish under constant temperature conditions, and found that all fish could survive for 101 hours at 24.5º, but the upper incipient lethal temperature was determined to be 25.6º. Since the maximum temperatures at the Parrett and Above Minnehaha sites were 24.1º and 23.6º, they would not be expected to contribute to mortality at those sites.

Three water quality parameters (temperature, pH, dissolved oxygen) have been identified that may have been stressors at bioassays sites, but were not likely to be lethal in and of themselves. Conceivably however, they could have exacerbated the stress from metals exposure and caused an increase in mortalities over what would be expected from metals alone. The only sites that had high levels of mortalities along with these non-metal stressors were Rimini (stressed by pH, mortality rates of 100% for the largest brook trout in August 1999 and the rainbow trout in July 2000), and Above Minnehaha Creek (stressed by temperatures, mortality rate of 100% for rainbow trout in July 2000). If the pH and temperature were contributing to mortalities at these sites, then it might be expected that they would show up as outliers on the plots of Zn ratios vs. mortality. In the case of rainbow trout in July 2000 (Figure 6-3), the 100% mortality at Rimini can be safely attributed to metals, because two other sites with non-metal stressors also had 100% mortality and lower zinc ratios. The Above Minnehaha Creek site was not bracketed by other sites with 100% mortality and we can therefore not confidently attribute all mortalities to metals alone. The same problem exists for interpreting the 100% mortality of large brook trout at Rimini in 1999 (Figure 6-5), where all other sites had both lower zinc ratios and lower mortality rates.

The role of diel metals cycling in the toxicity to fish is unknown. For example, it is not known whether metals have to be higher than a lethal threshold for 24 hours per day, or if it dips below a lethal threshold for a brief time, if that somehow provides a certain protection to the fish. Further experimentation is required to assess the importance of diel metal cycling on fish survival.

The results and interpretations of this study are in general agreement with the conclusions reached by EPA (2001b). They conducted toxicity tests on rainbow and brook trout using a mobile laboratory, and were able to generate LC_{5O}(Median Lethal Concentration) values. Any subsequent investigation of the toxicity of Tenmile water to fish should be first become familiar with the results of the EPA study.

6.5 References

Chapman, G. 1986. Ambient Water Quality Criteria for Dissolved Oxygen. U.S. Environmental Protection Agency. 46 pp. USEPA 440/5-86-003.

Cherry, D.S., K.L. Dickson, J.Cairns, Jr., and J.R. Stauffer. 1977. Preferred, avoided, and lethal temperatures of fish during rising temperature conditions. J. Fish. Res. Bd. Canada. 34(2): 239-246.

Cleasby, T.E. and D.A. Nimick. 2002. Streamflow, water quality, and quantification of metal loading in the upper Tenmile Creek watershed, Lewis and Clark County, west-central Montana, September 1998. U.S. Geological Survey. Water Resources Investigations Report 02-4072.

Daye, P.G. and E.T. Garside. 1975. Lethal levels of pH for brook trout, Salvelinus fontinalis (Mitchill). Can. J. Zool. 53: 639-641.

Downing, K.M. and J.C. Merkens. 1957. The influence of temperature on the survival of several species of fish in low tensions of dissolved oxygen. Ann. Appl. Biol. 45: 261-267.

Hokanson, K.E.F., C.F. Kleiner, and T.W. Thorslund. 1977. Effects of constant temperatures and diel temperature fluctuations on specific growth and mortality rates and yield of juvenile rainbow trout, Salmo gairdneri.

Montana Numeric Water Quality Standards. Circular WQB-7. 2002. Montana Department of Environmental Quality, 37 pp.

Parrett, C. and P.S. Hettinger. 2000. Streamflow and water-quality characteristics in the upper Tenmile Creek watershed, Lewis and Clark County, west-central Montana: U.S. Geological Survey Water Resources Investigations Report 00-4129, 71 p.

U.S. Environmental Protection Agency. 2001a. Ecological Risk Assessment. Clark Fork River Operable Unit. Milltown Sediments/Clark Fork River Superfund Site. USEPA Region VIII, Denver, CO.

U.S. Environemental Protection Agency. 2001b. Aspects of remedial action cleanup objectives for the Upper Tenmile Creek Mining District, Rimini, Montana. Aquatic Toxicity of Mine Effluents within the Upper Tenmile Creek Mining District, Montana. Integrated Laboratory Systems, Inc. EPA Region VIII ESAT. Denver, CO.

Chapter 7
Conclusions and Recommendations

7.1 Conclusions

This study found numerous sites where aquatic life was judged to be impaired from exposure to metals, water withdrawals, or both (Table 7-1). On the mainstem, the highest levels of impairment due to both water withdrawals and metals occurred in the close vicinity of Rimini. This is not surprising, given that the City Diversion on the mainstem was built upstream of the mining sites in Rimini explicitly to avoid the poor water quality. Therefore, most times of year there is very little water allowed past the diversion that can dilute the contaminated mine water.

Those mainstem sites judged to be most impaired because of metals (receiving a +++ rating) had clearly diminished or altered insect or fish populations as well as water that was acutely toxic to fish. Lower levels of metals impairment (+ or ++) were assigned based on the results from fish bioassays or metals concentrations in biotic or abiotic media. The highest level of impairment due to water withdrawals was assigned in those situations where the stream was totally dry or reduced to a trickle during late summer, and the quantity and suitability of the habitat for aquatic life was seriously diminished. The high impairment ratings for water withdrawals on the tributaries were due to the fact that the City captures the entire flow of these tributaries during the late summer. Fortunately, these diversions are at the lower end of these drainages, so that the length of dewatered stream is minimal. On the other hand, the placement of the diversions essentially precludes the use of the tributaries by fish in the mainstem.

The dewatering of the streams, especially in the mainstem, compounds the toxic effects of the metals, because with less water the concentration of metals increases in the water column. Depending on the location, dewatering can also lead to high water temperatures and low dissolved oxygen at levels that can be harmful to the fish. Allowing some water to flow past these diversions during the late summer period would not only provide more usable habitat for benthic macroinvertebrates and fish, but also dilute metals and reduce stressful conditions.

Table 7-1 Summary Assessment of the Impacts of Metals Contamination and Dewatering on Aquatic Life in the Tenmile Creek Drainage, 1997-2001. For impairment status, sites are assigned a level of impairment: none, +, ++, and +++, relative to unimpacted sites (Moose Creek for metals evaluation, Monitor Creek for water withdrawls evaluation). The data which were used to make a judgment of impairment due to metals included metals concentrations in abiotic and biotic media, fish and benthic macroinvertebrates community characterization, and fish bioassays. Judgments of impairment due to water withdrawls were based on observations of flows during late summer.

Site	Indications of impairment from metals	Indications of impairment due to water withdrawls
Mainstem Sites		
Below Banner Creek		
At Rimini	+++	+++
At Sawmill	+++	++
Above Minnehaha Creek	++	++
Below Minnehaha Creek	++	+
Above Moose Creek	++	++
At Moose Creek Gage	+	+
Below Moose Creek	+	+
At Treatment Plant	+	+
Tributary Sites		
Monitor Creek	+	
Banner Creek	+	+
Poison Creek	+++	
Minnehaha Creek	++	+++
Moose Creek		+++
Walker Creek		+++

7.2 Recommendations

7.2.1 Augmenting Flows

Major improvements to aquatic life communities in the Tenmile Creek drainage would be realized if flows to the creek were augmented during late summer periods and releases of acid water and metals from mines sites were reduced. This two-pronged approach to improving water quality was part of the proposed remedy for the Upper Tenmile Creek Mining Area Superfund Site and described by the USEPA in the Record of Decision (ROD) (USEPA 2002). The ROD set the cleanup levels for surface waters to be the lower of either the human health or aquatic life standards for metals. If standards cannot be met, then the USEPA will consider the possibility of waiving the standards. In such an event, significant gains could still be realized by improving water quality simply to the point where acutely toxic conditions for fish do not occur. This study identified a level of zinc in the water that would eliminate these toxic conditions. This level was a ratio of 3.2 (ambient zinc: hardness-adjusted acute aquatic life zinc standard). This study also identified 4-10 cfs as optimal discharges that would provide for sustainable populations of aquatic insects and all lifestages of brook and rainbow trout. If mining areas could be cleaned up to achieve an instream zinc ratio of 3.2 and if instream flows could be provided by the City during late summer, then it should be possible to have self-sustaining and functioning aquatic life communities at all sites.

Achieving these instream flow needs may not be financially or politically feasible for the City of Helena. If so, an alternative approach should be considered. It is called the 6th Diversion option, and would involve building a new diversion near the Treatment Plant on Tenmile Creek. Some of the water that is currently diverted at Rimini would then be allowed to flow downstream and would be diverted near the Treatment Plant. This would improve the instream flows for over six miles of stream. Some of the issues associated with this idea have been addressed, and are presented in Appendix B.

A third option for augmenting instream flows would be to provide emergency releases of water for a short duration from a diversion(s) during late summer periods of critically low flows. Under this scenario, the City could potentially release water from the City Diversion on the mainstem or from any tributary diversions downstream. This approach was taken by the City of Helena in 2001, where they provided 75 gallons per minute from the Minnehaha Creek diversion for over three weeks. This was enough water to maintain flowing water through pools that had become stagnant.

7.2.2 Monitoring

This study has provided regulatory agencies (USEPA & DEQ) with a characterization of the response of the aquatic community to the mine pollution and dewatered stream conditions during the period 1997-2001, a period pre-dating most of the cleanup efforts in the drainage. These "baseline" conditions provide a valuable set of information from which to compare future changes brought about by cleanup efforts. The best way to measure changes in the aquatic community is through routine monitoring. The changes seen during monitoring should serve as the ultimate measure of success from mine cleanup and water augmentation efforts. Table 7-2 provides a suggested monitoring scheme.

Table 7-2 Summary of Suggested Monitoring to Assess Aquatic Life Health.

Type of Monitoring	Locations	Frequency of Monitoring
Fish populations	Mainstem—Below Banner Creek, Rimini, Sawmill, Moose Creek Cmpgrnd, Treatment Plant	Every 3 years
Benthic Macroinvertebrate populations	Mainstem—Below Banner Creek, Rimini, Sawmill, Moose Creek Cmpgrnd, Treatment Plant	Every 5 years
Fish bioassays	Mainstem—Below Banner Creek, Rimini, Treatment Plant	Every 3 years
Fish tissue analysis for metals	Mainstem—Below Banner Creek, Rimini, Sawmill, Moose Creek Cmpgrnd, Treatment Plant; Tributary—Moose Creek	Every 5 years
Dissolved oxygen, water temperature	Mainstem—Rimini, Moose Creek Cmpgrnd, Treatment Plant	Yearly, during late summer low flow periods

7.3 References

U.S. Environmental Protection Agency. 2002. Record of Decision. Upper Tenmile Creek Mining Area Site. Lewis and Clark County, Montana.

Chapter 8
Acknowledgements

Many people contributed to the helping make this project a success. Kurt Hill (FWP) was critical in the success of this project and assisted with all phases of sample collection and laboratory preparation of tissue samples. Denise Martin (DEQ) helped secure funding. Mike Bishop (USEPA) helped provide guidance throughout the study, and assisted with the siphon project on Minnehaha Creek. Jesse Aber (Montana Department of Natural Resources and Conservation (DNRC)) assisted many times with fieldwork and also with the siphon project. Members of the Tenmile Watershed group were always supportive of our work and provided useful feedback on our activities. David Nimick (USGS) kindly lent equipment to us to conduct the diel metal measurements. Tim Burton, John Rundquist, and Leonard Willet (City of Helena) graciously provided water during the 2001 siphon test, and provided the necessary information to research the 6th diversion option. Jim Beck (DNRC) and Tom Cleasby and Chuck Parrett (USGS) helped with fieldwork and evaluating the 6th Diversion option. Nancy Podolinsky (FWP) helped with report preparation and formatting.

Appendix A
Tenmile Creek Drainage Macroinvertebrate Data Statistical Analyses

SPSS 6.1 for the Power Macintosh

1. Community Density

***ANALYSIS OF VARIANCE *** by YEAR by SITE UNIQUE sums of squares. All effects entered simultaneouslySum of Mean Sig

Source of Variation	Squares	DF	Square	F	of F
Main Effects	142620.653	9	15846.739	4.718	.000
YEAR	1686.111	2	843.056	.251	.779
SITE	140934.542	7	20133.506	5.995	.000
2-Way Interactions	59121.667	14	4222.976	1.257	.268
Explained	201742.319	23	8771.405	2.612	.003
Residual	161207.333	48	3358.486		
Total	362949.653	71	5111.967		

72 cases were processed. 0 cases (.0 pct) were missing.

Multiple Range Tests: Student-Newman-Keuls test with significance level .05

SITE:	10M-Rim	Monitor	Banner	10M-Ban	10M-TP	10M-Moo		Minne	Moose
Mean:	18.7	33.1	37.8	76.9	87.3	93.0	108.6	163.2	

****

(*) Indicates no significant differences

YEAR	1997	1998	1999
Mean	84	73	69

****

- No two groups are significantly different at the .050 levels

C-2 TAXA RICHNESS

* * * A N A L Y S I S O F V A R I A N C E * * * by YEAR by SITE
UNIQUE sums of squares. All effects entered simultaneously

	Sum of		Mean		Sig
Source of Variation	Squares	DF	Square	F	of F
Main Effects	1511.250	9	167.917	8.916	.000
YEAR	27.028	2	13.514	.718	.493
SITE	1484.222	7	212.032	11.25	.000
2-Way Interactions	903.194	14	64.514	3.426	.001
Explained	2414.444	23	104.976	5.574	.000
Residual	904.000	48	18.833		
Total	3318.444	71	46.739		

72 cases were processed. 0 cases (.0 pct) were missing.

Multiple Range Tests: Student-Newman-Keuls test with significance level .05

SITE:	10M-Rim	Monitor	Banner	10M-Moo		10M-Ban	10M-TP	Moose	Minne
Mean:	7.9	13.9	15.4	18.1	19.2	19.7	20.1	23.9	

****

(*) Indicates no significant differences

YEAR	1997	1998	1999
Mean	16.5	17.3	18.0

****

- No two groups are significantly different at the .050 levels

C-3 EPT TAXA RICHNESS

* * * A N A L Y S I S O F V A R I A N C E * * * by YEAR by SITE

UNIQUE sums of squares. All effects entered simultaneously

		Sum of		Mean			Sig
Source of Variation	Squares	DF	Square	F	of F		
Main Effects	766.986	9	85.221	11.19	.000		
YEAR	.444		2	.222		.029	.971
SITE	766.542	7	109.506	14.3	.000		
2-Way Interactions	438.000	14	31.286	4.11	.000		
Explained		1204.986		23	52.391	6.88	.000
Residual	365.333	48	7.611				
Total		1570.319		71	22.117		

72 cases were processed. 0 cases (.0 pct) were missing.

Multiple Range Tests: Student-Newman-Keuls test with significance level .05

SITE:	10M-Rim	Monitor	Moose	Banner	10M-Ban	10M-TP	TM-Moo	Minne
Mean:	5.8	9.4	10.6	11.7	13.6	14.3	14.7	16.8

****

(*) Indicates no significant differences

YEAR	1999	1198	1997
Mean	12.0	12.0	12.2

****

- No two groups are significantly different at the .050 levels

C-4 EPT RELATIVE ABUNDANCE

* * * A N A L Y S I S O F V A R I A N C E * * * by YEAR by SITE

UNIQUE sums of squares. All effects entered simultaneously

		Sum of		Mean			Sig
Source of Variation	Squares	DF	Square	F	of F		
Main Effects	21096.972		9	2344.108		18.98	.000
YEAR	2880.361		2	1440.181		11.66	.000
SITE	18216.61		7	2602.373		21.07	.000
2-Way Interactions	6615.639		14	472.546	3.827	.000	

Explained		27712.611		23	1204.896	9.758	.000
Residual	5926.667		48	123.472			
Total		33639.278		71	473.793		

72 cases were processed. 0 cases (.0 pct) were missing.

Multiple Range Tests: Student-Newman-Keuls test with significance level .05

SITE:	Moose	10M-Rim	Monitor	10M-Ban	Banner	10M-TP	Minne	TM-Moo
Mean:	42.4	58.6	67.3	73.1	83.4	84.2	86.7	93.8

****

(*) Indicates no significant differences

YEAR	1999	1198	1997
Mean	65.7	74.3	81.1

****

(*) Indicates no significant differences

C-5 METALS TOLERANCE INDEX

* * * A N A L Y S I S O F V A R I A N C E * * * by YEAR by SITE
UNIQUE sums of squares. All effects entered simultaneously

		Sum of		Mean			Sig
Source of Variation	Squares	DF	Square	F	of F		
Main Effects	39.738	9	4.415		17.09	.000	
YEAR	12.753	2	6.376		24.68	.000	
SITE	26.985	7	3.855		14.92	.000	
2-Way Interactions	26.475	14	1.891		7.321	.000	
Explained		66.213	23	2.879		11.14	.000
Residual	12.398	48	.258				
Total		78.612	71	1.107			

72 cases were processed. 0 cases (.0 pct) were missing.

(Metals tolerance index continued)
Multiple Range Tests: Student-Newman-Keuls test with significance level .05

SITE:	Minne	Banner	Monitor	10M-Moo		10M-Ban	Moose	10M-TP	10M-Rim
Mean:	1.27	1.56	1.59	1.65	2.06	2.43	2.43	3.28	

****

(*) Indicates no significant differences

YEAR	1997	1198	1999
Mean	1.50	2.07	2.53

****

(*) Indicates no significant differences

C-6 BIOTIC INDEX

* * * A N A L Y S I S O F V A R I A N C E * * * by YEAR by SITE
UNIQUE sums of squares. All effects entered simultaneously

		Sum of		Mean			Sig
Source of Variation	Squares	DF	Square	F	of F		
Main Effects	36.732	9	4.081		15.24	.000	
YEAR	5.282		2	2.641		9.86	.000
SITE	31.450	7	4.493		16.77	.000	
2-Way Interactions	12.582	14	.899		3.356	.001	
Explained		49.314	23	2.144		8.006	.000
Residual	12.855	48	.268				
Total		62.169	71	.876			

72 cases were processed. 0 cases (.0 pct) were missing.

Multiple Range Tests: Student-Newman-Keuls test with significance level .05

SITE:	10M-Moo		Banner	Minne	10M-Ban	Monitor	10M-TP	10M-Rim	Moose
Mean:	1.35	1.48	1.66	1.71	1.88	1.93	2.52	3.52	

****

(*) Indicates no significant differences

YEAR	1997	1198	1999
Mean	1.62	2.17	2.22

****

- No two groups are significantly different at the .050 levels

C-7 MAYFLY DENSITY

* * * A N A L Y S I S O F V A R I A N C E * * * by YEAR by SITE
UNIQUE sums of squares. All effects entered simultaneously

		Sum of		Mean			Sig
Source of Variation	Squares	DF	Square	F	of F		
Main Effects	22251.2	9	2472.4	14.69	.000		
YEAR	272.3		2	136.2		.81	.451
SITE	21978.9	7	3139.8	18.65	.000		
2-Way Interactions	5478.8	14	391.3		2.33	.015	
Explained		27730.0	23	1205.6	7.16	.000	
Residual	8080.0	48	168.3				
Total		35810.0	71	504.4			

72 cases were processed. 0 cases (.0 pct) were missing.

Multiple Range Tests: Student-Newman-Keuls test with significance level .05

SITE:	10M-Rim	Monitor	Moose	Banner	10m-Ban	10M-Moo		10M-TP	Minne
Mean:	4.4	9.2	9.7	16.3	30.1	30.7	43.1	57.8	

****

(*) Indicates no significant differences

YEAR	1999		1198	1997
Mean	23.8	23.8		27.9

****

- No two groups are significantly different at the .050 levels

C-8 MAYFLY SPECIES RICHNESS

* * * A N A L Y S I S   O F   V A R I A N C E * * * by YEAR by SITE
UNIQUE sums of squares. All effects entered simultaneously

		Sum of		Mean			Sig	
Source of Variation	Squares	DF	Square	F	of F			
Main Effects	193.7		9	21.5		12.1	.000	
YEAR	1.44		2	2.72		.41	.668	
SITE	192.2		7	27.5		15.4	.000	
2-Way Interactions	66.3		14	4.74		2.67	.006	
Explained		260.0		23	11.3		6.34	.000
Residual	85.3		48	1.78				
Total		345.3		71	4.86			

72 cases were processed. 0 cases (.0 pct) were missing.

Multiple Range Tests: Student-Newman-Keuls test with significance level .05

SITE:	10M-Rim	Moose	Monitor	Banner	Minne	10M-Ban	10M-TP	10M-Moo
Mean:	2.6	3.4	4.7	5.3	6.4	6.6	6.6	7.7

****

(*) Indicates no significant differences

YEAR	1999	1198	1997
Mean	5.2	5.5	5.5

****

- No two groups are significantly different at the .050 levels

SPSS 6.1 for the Power Macintosh

Appendix B
FWP Position Paper on the “6th Diversion”

Instream flows and water quality could be improved by changing the location of the City of Helena’s mainstem diversion from its current location above Rimini downstream to a spot closer to the Treatment Plant. This additional diversion site would become the “6th diversion” in the drainage for the City of Helena. In an effort to establish the feasibility of a Sixth Diversion, MFWP gathered information to try to address three major issues and questions identified by the City. These questions are:

1. Where will the diversion be located, and how will it be constructed?
2. Will the water the City releases from upstream diversions actually make it to the new diversion?
3. What will the concentration of arsenic in the water be at the point of diversion?

Possible Sites for 6th Diversion and Other Thoughts on Construction

In mid-October 2001, Don Skaar and Jim Beck (DNRC) did some preliminary surveying of possible sites for a 6th Diversion. Because the objective of this project is to provide instream flows for the maximum distance possible, efforts were focused near the confluence of Walker Creek We confined our search to the 160 acre parcel owned by the City of Helena which includes the Walker Creek diversion and confluence (see enclosed map).

Several areas were ruled out as potential sites because there was not enough space between the stream and road to build an intake structure. From the point where Tenmile Creek enters the City property and for a distance of about 350 feet downstream, the road runs too close to the stream to build a diversion. From this point (which is about 150 ft above the footbridge) downstream to 85 feet below the Walker Creek confluence, the stream is far enough away from the road to allow placement of a diversion structure. One negative aspect of building a diversion in this area is that the existing City pipeline is on the south side of the Rimini road. Therefore, to hook into the City line, the pipe from the diversion would have to be trenched through the road. While this is possible, it is less than ideal in terms of access for future maintenance.

Sites farther downstream were also investigated, due to the desire to extend the zone of flow augmentation, but also because a site slightly more distant from the road was felt to be better from a security standpoint. Up to a distance of about 500 feet below Walker Creek, the stream abuts the road, and placement of a diversion would not be practical. However, there is another site (the preferred site) that appears to be suitable at about 600 feet below Walker Creek where the stream turns away from the road. Sites farther downstream were not investigated, due to the anticipated flow losses (see below) and the fact that as the stream gets farther away from the road, the costs of an access road will rise accordingly. The preferred site is also desirable because at this point the City Pipeline has shifted to the north side of the Rimini Road, and hooking up the 6th Diversion pipe would not involve trenching through the road.

Jim Beck wrote a letter about the preferred site. This site is located on a straight stretch of stream at the tailout of a pool. Using the location and grade line of the City pipeline, he estimated that the length of diversion pipe that would be necessary to carry 5 cfs (using a 12 inch diameter PVC pipe) to the City line would be about 400 feet long. From the preferred site, this would require laying the pipe through a part of the old railroad grade and out into the open field to the east of the stream. The costs he has indicated are only for the construction of the intake structure and placement and hookup of the pipeline. Tasks for which he has not assigned costs include building a separate structure to house a weir to measure flow, and construction of a dam in the stream just downstream from the diversion.

The issue of the dam needs more discussion. It is my wish that the dam be of a low profile and not a barrier to fish passage. This means building a lower profile structure than the one at the City Diversion in Rimini. Ideally, this structure would be a concrete sill, dug into the streambed, with the top elevation of the sill being close to the lowest point in the streambed. To the top of the sill would be attached a collapsible dam that could be raised in low flows and lowered in high flows. This design would provide for fish passage and would allow bedload to pass by the structure during high flows rather than settling out upstream of the structure. Whatever design we use, it is important to keep in mind that it has to be designed so that it can pass small amounts of flow during the late summer. This diversion would function to allow the City to recover the water that they release from diversions farther upstream. There will be some water already in the channel that should be allowed to pass. Furthermore, when the "EPA water" (stored in Chessman but swapped for Scott water) becomes a reality, there will be additional flows that must be passed by this structure.

Discharge Measurements Relevant to the Positioning of the 6th Diversion

The USGS has made three sets of gain/loss discharge measurements on Tenmile Creek between the City Diversion at Rimini and the Treatment Plant during low flow periods from 1998-2000 (Figure B-1) The gain/loss measurements involved taking discharge measurements at numerous locations on the stream over a short period of time during a single day. The USGS also observed and estimated flows that were zero or close to zero on August 14, 2000. In addition, the USGS and FWP conducted a fourth, shorter set of gain/loss measurements from Walker Creek to the Treatment Plant on November 15, 2001. Several observations can be made from these data:

1. Discharge peaked somewhere near the confluence with Walker Creek during all three of the gain/loss measurements in 1998, 1999, and 2000.

2. The discharge on the mainstem at Walker Creek was always higher than at the City Diversion during the gain/loss measurements in 1998, 1999, and 2000. There were inflows from Moose and Walker creeks during the 1999 measurements, but if these inputs are removed, there was still an increase in flow moving downstream.

3. The gain/loss measurements done in 1998, 2000, and 2001 all had maximum discharges less than 1.5 cfs, and all showed a trend toward a slight reduction in flow between Walker Creek and the County bridge (mile 7.0).

4. Flows at the County Bridge in 1998 and 2000 were still higher than flows at the City Diversion.

5. The site of the preferred 6th Diversion is approximate mile 6.65. Flows there on November 15, 2001 were about 10% less than at the Walker Creek confluence.

6. Flow observations made on August 14, 2000 probably represent the lowest (or close to the lowest) discharge conditions for Tenmile Creek during the years 1997-2001. These measurements showed that water was still flowing at the ford area below Walker Creek (approximate mile 6.8). This is about 900 feet downstream from the preferred diversion site.

In conclusion, it appears that there will always be water at the preferred 6th Diversion site, and about 90% of the flow accretion below the City Diversion in Rimini (the Moore and Banks spring creeks, Suzie adit water, Lee Mountain seepage, and unidentified groundwater discharge between Rimini and Walker Creek) will make it as far as the 6th Diversion. These accretion flows should provide enough buffer to guarantee that all augmented flow (from any of the three diversions—Moose, Minnehaha and Rimini) will be recoverable at the 6th Diversion.

Potential Arsenic Concentrations At 6th Diversion on Tenmile Creek

I have previously used output from several computer models to make the judgment that the optimal discharge for brook and rainbow trout in the upper Tenmile Creek lies somewhere between 4 and 10 cfs. For the ensuing discussion, I will use 4 cfs as the desired condition in the stream, and I will estimate the arsenic concentrations in Tenmile Creek at the point of the 6th Diversion at flow increments up to 4 cfs.

Several sources of water quality data were consulted, including Parrett and Hettinger (2000) who sampled the drainage at numerous times and locations in 1997, Nimick (unpublished) who did a tracer study in the drainage in 1998, Skaar (unpublished) who conducted bioassays on fish and took numerous water quality samples in 2000, and CDM (2001) who took samples in 2000. In the following analysis, only measurement taken from June through October were used, and then only if flows were below the following levels at the following sites: 10 cfs at the Tenmile diversion above Rimini, 1.2 cfs on Tenmile Creek at the Water Treatment Plant, 3.9 cfs at the Minnehaha Creek diversion, and 2.45 cfs at the Moose Creek diversion. There were 5 water quality samples available from Moose Creek and Tenmile at the Treatment Plant, 6 from Minnehaha Creek, and 12 from Tenmile Creek at the City Diversion.

Assumptions made:

1. Arsenic concentrations in Tenmile Creek at the point of the 6th diversion were assumed to be similar to those recorded for Tenmile Creek at the Treatment Plant in late summer or fall when all tributary flow is diverted and all water is from accretion. This concentration was 21.3 µg/L.

2. When arsenic concentrations measured at Moose and Minnehaha creeks were below detection, the concentration was assumed to be half the detection limit. The resulting

mean arsenic concentration from these streams was 3.0 µg/L from Minnehaha and 1.2 µg/L from Moose.

3. The discharge from Moose and Minnehaha creeks was assumed (for the purposes of this analysis) to be 0.44 and 0.51 cfs, respectively. These flows represent the lowest monthly mean flows as estimated by Parrett and Hettinger.

4. Arsenic concentrations at the Tenmile Diversion above Rimini are 6 µg/L based on the mean value of the measurements used.

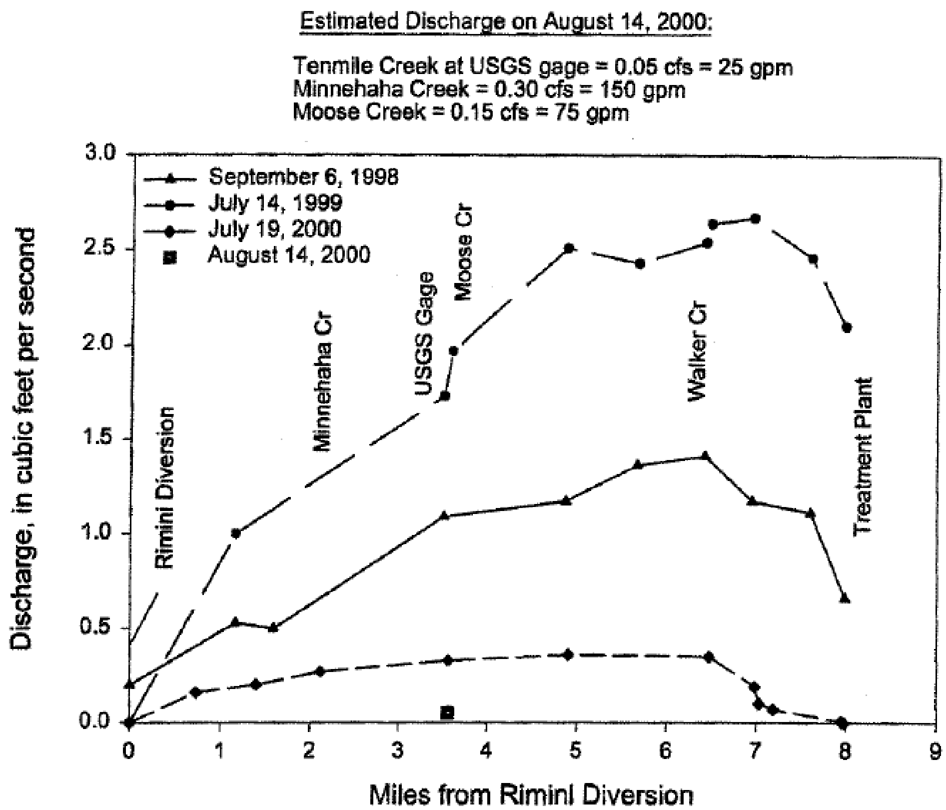


Figure B-1 Discharge measurements made by USGS personnel and provided courtesy of Chuck Parrett, Helena USGS office.

For the data displayed in the table below, I simply calculated what the addition of waters from the Moose and Minnehaha Creek diversions would do to the arsenic concentrations of Tenmile Creek at the point of the 6th Diversion. Results show that at the accretion flow of 0.5 cfs, the addition of 0.95 cfs from Moose and Minnehaha creeks will result in an arsenic concentration at the 6th Diversion of 8.8 µg/L. When accretion flows are raised to 1.0 cfs, the 6th Diversion arsenic level rises to 12 µg/L, slightly above the new proposed EPA human health standard of 10 ug/L. At accretion flows of 1.5 cfs, the resulting arsenic level is 13.9 µg/L. Flows higher than this were not calculated, because it is doubtful that accretion flows ever get higher than 1.5 cfs during dry, late summer conditions.

Conditions in 10-mile at Treatment plant (accretion flows w/o contribution from Moose, Minnehaha or Tenmile diversions) +	Conditions in Moose and Minnehaha Creek =	Estimated conditions at 6th diversion
0.5 cfs @ 21.3 µg/L	0 cfs @ 2.17µg/L	0.5 cfs @ 21.3 µg/L
0.5 cfs @ 21.3µg/L	0.95 cfs @ 2.17 µg/L	1.45 cfs @ 8.8 µg/L
1.0 cfs @ 21.3µg/L	0.95 cfs @ 2.17 µg/L	1.95 cfs @ 12.0 µg/L
1.5 cfs @ 21.3µg/L	0.95 cfs @ 2.17 µg/L	2.45 cfs @ 13.9 µg/L

To get flows to the desired 4 cfs in late summer, it will probably be necessary to allow some water to bypass the City Diversion at Rimini. Additional calculations are therefore needed. Let it be assumed that flows in Moose and Minnehaha creeks are always 0.95 cfs and flows at the 6th Diversion are always 4.0 cfs. We will vary the accretion flows between 0.5 cfs and 1.5 cfs, and make up the difference with water from the City Diversion at Rimini. Results are displayed below and show that accretion flows up to about 1.25 cfs can diluted with water from all three diversions and still meet the new arsenic standard of 10 µg/L.

Conditions in Tenmile At Treatment Plant (Accretion flows) +	Conditions in Moose and Minnehaha Cr +	Conditions of water bypassing the City Diversion =	Estimated conditions at 6th diversion
0.5 cfs @ 21.3 µg/L	0.95 cfs @ 2.17 µg/L	2.55 cfs @ 6 µg/L	4.0 cfs @ 7.0 µg/L
1.0 cfs @ 21.3 µg/L	0.95 cfs @ 2.17 µg/L	2.05 cfs @ 6 µg/L	4.0 cfs @ 8.9 µg/L
1.25 cfs @ 21.3 µg/L	0.95 cfs @ 2.17 µg/L	1.80 cfs @ 6 µg/L	4.0 cfs @ 9.9 µg/L
1.5 cfs @ 21.3 µg/L	0.95 cfs @ 2.17 µg/L	1.55 cfs @ 6 µg/L	4.0 cfs @ 10.8 µg/L

To summarize, it can be seen that during the late summer months (July-October), if the operating constraint was put on the 6th Diversion that it could not divert water containing arsenic higher than the new proposed standard, then this could be accomplished with a mix of Minnehaha, Moose and Tenmile water as long as the accretion flows did not exceed 1.25 cfs. If the water at the diversion in Rimini was diverted into the City pipe, and not used for instream flow augmentation, then accretion flows would have to be allowed to drop close to 0.5 cfs before augmentation by Moose and Minnehaha in order to avoid exceeding the proposed water quality standard.

To put this kind of flow augmentation scheme to work, it will be necessary to iron out the operational details. One possible operational scenario is as follows:

1. Each year after spring runoff, the Tenmile Gage at the Moose Creek Campground is closely monitored.

2. As soon as the discharge at the gage drops below 4 cfs, then water from Moose and/or Minnehaha creeks will be released to make up the difference. These flows will be recaptured at the 6th Diversion.

3. As the flows in the mainstem continue to drop and the augmented water from Moose/Minnehaha can no longer keep flows at 4 cfs, then water is released from the City Diversion at Rimini. This water is also recovered at the 6th Diversion.

4. As accretion flows as well as flows in Moose and Minnehaha drop even further during the late fall and winter, the releases from the City Diversion will have to be adjusted accordingly.

5. In the spring, as runoff begins, and flows exceed 4 cfs at the gage, augmentation from the City Diversion will be reduced, followed by reductions at Moose and Minnehaha. The intake at the 6th Diversion will then be closed until after runoff when the cycle will begin anew. This scenario would require that some discharge-measuring device (weir) be retrofit to the gateslot at the City Diversion.