Columbia Environmental Research Center

Selenium and other trace elements in water, sediment, aquatic plants, aquatic invertebrates, and fish from streams in southeastern Idaho near phosphate mining operations: May 2001.

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Abstract

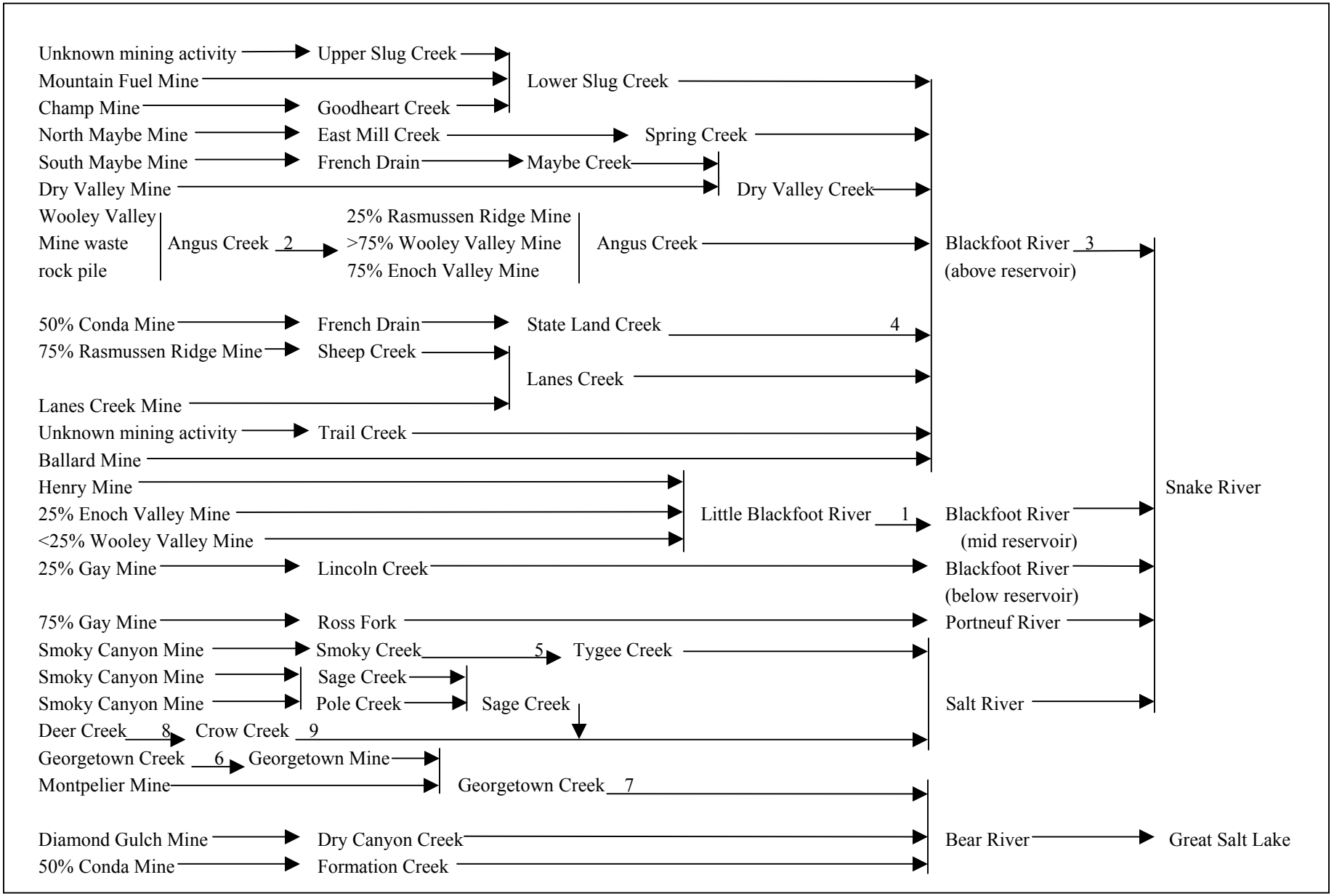
Nine stream sites in the Blackfoot River, Salt River, and Bear River watersheds in southeast Idaho were sampled in May 2001 for water, surficial sediment, aquatic plants, aquatic invertebrates, and fish. Selenium and other inorganic elements were measured in these aquatic ecosystem components, and a hazard assessment was performed on the data. Water quality characteristics such as pH, hardness, and specific conductance were relatively uniform among the nine sites examined. Of the aquatic components assessed, water was the least contaminated with selenium because measured concentrations were below the national water quality criterion of 5 µg/L at 8 of the 9 sites. In contrast, selenium and several inorganic elements were elevated in sediment, aquatic plants, aquatic invertebrates, and fish from several sites suggesting deposition in sediments and food web cycling through plants and invertebrates. Selenium was elevated to concentrations of concern in fish at eight sites (>4 microgram/gram [µg/g] in whole body). A hazard assessment of selenium in the aquatic environment suggested a moderate hazard at upper Angus Creek and Smoky Creek, and high hazard at Little Blackfoot River, Blackfoot River gaging station, State Land Creek, upper and lower Georgetown Creek, Deer Creek, and Crow Creek. The results of this study indicate that selenium concentrations from the phosphate mining area of southeast Idaho were sufficiently elevated in several ecosystem components to cause adverse effects to aquatic resources in southeastern Idaho.

Introduction

Phosphorus is present in economically mineable quantities in organic-rich black shales of the Permian Phosphoria Formation, which constitutes the Western Phosphate Field. There are four active open pit mines (Dry Valley Mine, Smoky Canyon Mine, Enoch Valley Mine, Rasmussen Ridge Mine) in the southeast Idaho Phosphate District that produce phosphate from the Meade Peak Phosphatic Shale Member, and 11 inactive mines (Gay Mine, Lanes Creek Mine, Conda Mine, Henry Mine, Ballard Mine, Mountain Fuel Mine, Champ Mine, North Maybe Mine, South Maybe Mine, Georgetown Canyon Mine, Wooley Valley Mine) in the Southeast Idaho Phosphate Resource Area (MW 1999). Most mining of these phosphatic shales is by open-pit or contour strip surface mining, and waste materials are generally deposited on the surface in tailings piles, ponds, landfills, and dumps. Many of the waste piles have drainage systems to move surface water and groundwater away from waste-rock piles. These drainage systems transfer leachates from mining areas to surface waters, eventually draining into tributaries, and later, rivers such as the Blackfoot, Salt, and Bear. Thus, water movement releases toxic inorganic elements to aquatic and terrestrial ecosystems.

The Blackfoot, Salt, and Bear river watersheds have several active and inactive phosphate mines that could adversely affect aquatic resources in tributaries of the Blackfoot, Salt, and Bear rivers (Figure 1). As early as 1970-1976 concerns were expressed about contamination of the Blackfoot River and its tributaries by inorganic elements released from phosphate mining (Platts and Martin 1978). Recent concerns about the potential impact on aquatic and terrestrial ecosystems from phosphate mining have been the subject of several reports (MW 1999, 2000, 2001a, 2001b, MWH 2002a, 2002b, Tetra Tech 2002a, 2002b). Several investigations by the U.S. Geological Survey (USGS) have reported the chemical composition of weathered and less-weathered strata of the Meade Peak Phosphoatic Shale (e.g., Desborough et al. 1999, Herring et al. 2000a, 2000b). Other USGS investigations have reported inorganic element

Figure 1. Diagram of surface water flow from phosphate mines (generalized to 25% increments) to drains, creeks, and rivers in southeastern Idaho. Numbers are sample locations: 1 Little Blackfoot River, 2 upper Angus Creek, 3 Blackfoot River gaging station, 4 State Land Creek, 5 Smoky Creek, 6 upper Georgetown Creek, 7 lower Georgetown Creek, 8 Deer Creek, 9 Crow Creek.



concentrations in aquatic bryophytes and terrestrial plants that were influenced by mining (Herring and Amacher 2001, Herring et al. 2001).

Release of toxic inorganic elements from phosphate mining in southeast Idaho and accumulation in the food chain has resulted in adverse biological effects. In recent years, seven horses in the Dry Valley and Woddall areas were euthanized, and 60-80 sheep died in the Caribou National Forest on the old Stauffer Mine site due to selenium poisoning according to toxicologist and veterinarian reports (Caribou County Sun 1999). Twenty-six dead sheep were found at the south end of Rasmussen Ridge Mine near a spring or seep at an overburden ore site. Elevated concentrations of selenium and other inorganic elements have been reported in samples of fish and aquatic invertebrates from streams below phosphate mining activities (MW 1999, 2001a, 2001b). Recent USGS reports suggest that selenium concentrations in fish and wildlife were sufficiently elevated to cause adverse effects in sensitive fish species (Piper et al. 2000, Hamilton et al. 2002, Hamilton and Buhl 2003).

The purpose of this study was to determine the concentrations of selenium and other inorganic elements in water, surficial sediment, aquatic plants, aquatic invertebrates, and fish from streams in southeast Idaho near phosphate mining operations. This information was used in a hazard assessment of the potential effects of selenium and other inorganic elements on aquatic resources in areas of the Blackfoot, Salt, and Bear river watersheds that are potentially impacted by phosphate mining.

Methods and Materials

Samples of water, surficial sediment, aquatic plants, aquatic invertebrates, and fish were collected from nine sites in the Blackfoot, Salt, and Bear river watersheds located in southeast Idaho (Figures 2 and 3, Table 1). Sample collection occurred in May 2001, and was a joint effort of the USGS Biological Resources Discipline and the U.S. Forest Service (USFS).

Site description

The collection sites were as follows:

1. The Little Blackfoot River (LiB) site was located on private property accessed with landowner permission (Walt Engeler, Henry, ID). The site was located about 1 kilometer (km) above its confluence with Blackfoot Reservoir and about 1 km southeast of State Highway 34. The sampling site was below the active Enoch Valley Mine and the inactive Henry and Wooley Valley mines. The land along the river was primarily open grassland with light grazing.

2. The upper Angus Creek (UAC) site was located about 2 km below the headwater seep in Little Long Valley accessed by Forest Route 205 (USFS map, Caribou National Forest, Montpelier and Soda Springs, Districts, 1988) and a mining road. The site was about 11 km above the confluence with the Blackfoot River. The sampling site was below the Wooley Valley Mine Unit 4 waste-rock pile. The land on either side of the creek was composed primarily of grassland habitat with sparse forbs and no grazing activity. Sample collection was in an open area of forbs, grass, and willows. The creek had been previously impacted by upslope runoff of water and sediment from Wooley Valley Mine Unit 4 waste-rock pile located about 2 km upstream.

3. The Blackfoot River gaging station (BGS) site was located at the crossing of the river by the private haul road and the railroad tracks, accessed from the Blackfoot River Road. The

Figure 2. Map of study area. Dots are general locations of sample sites. (Map source: modified from Herring et al. 2001).

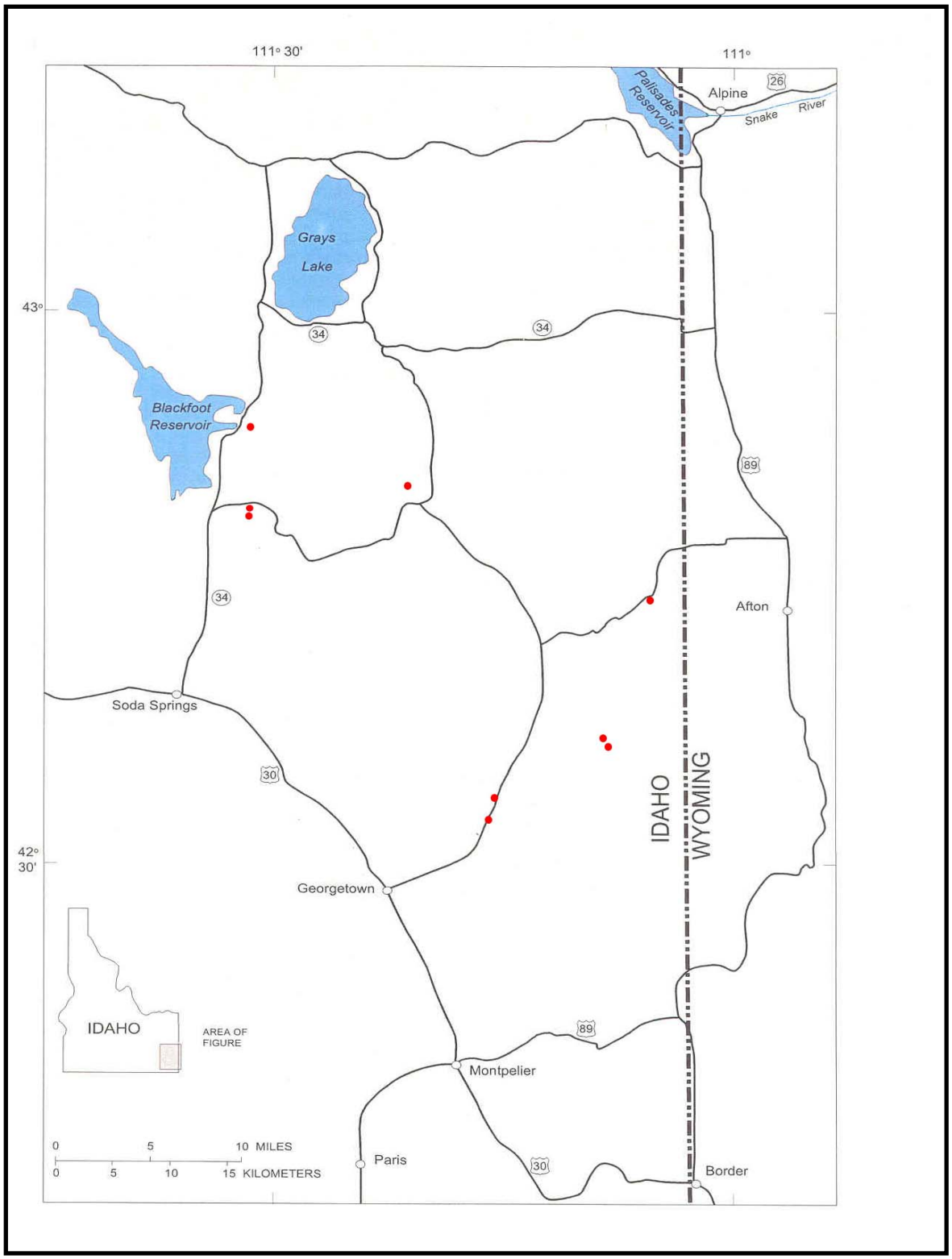
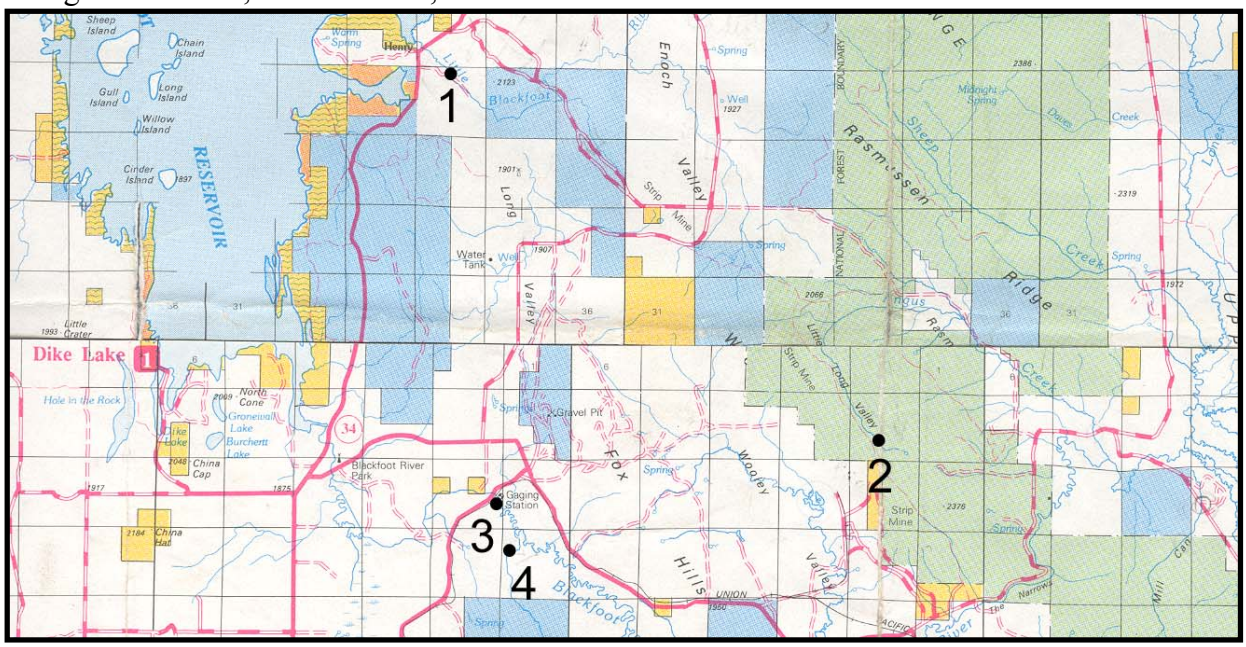


Figure 3. Map of sample sites: 1 Little Blackfoot River, 2 upper Angus Creek, 3 Blackfoot River gaging station, 4 State Land Creek, 5 Smoky Creek, 6 upper Georgetown Creek, 7 lower Georgetown Creek, 8 Deer Creek, 9 Crow Creek.



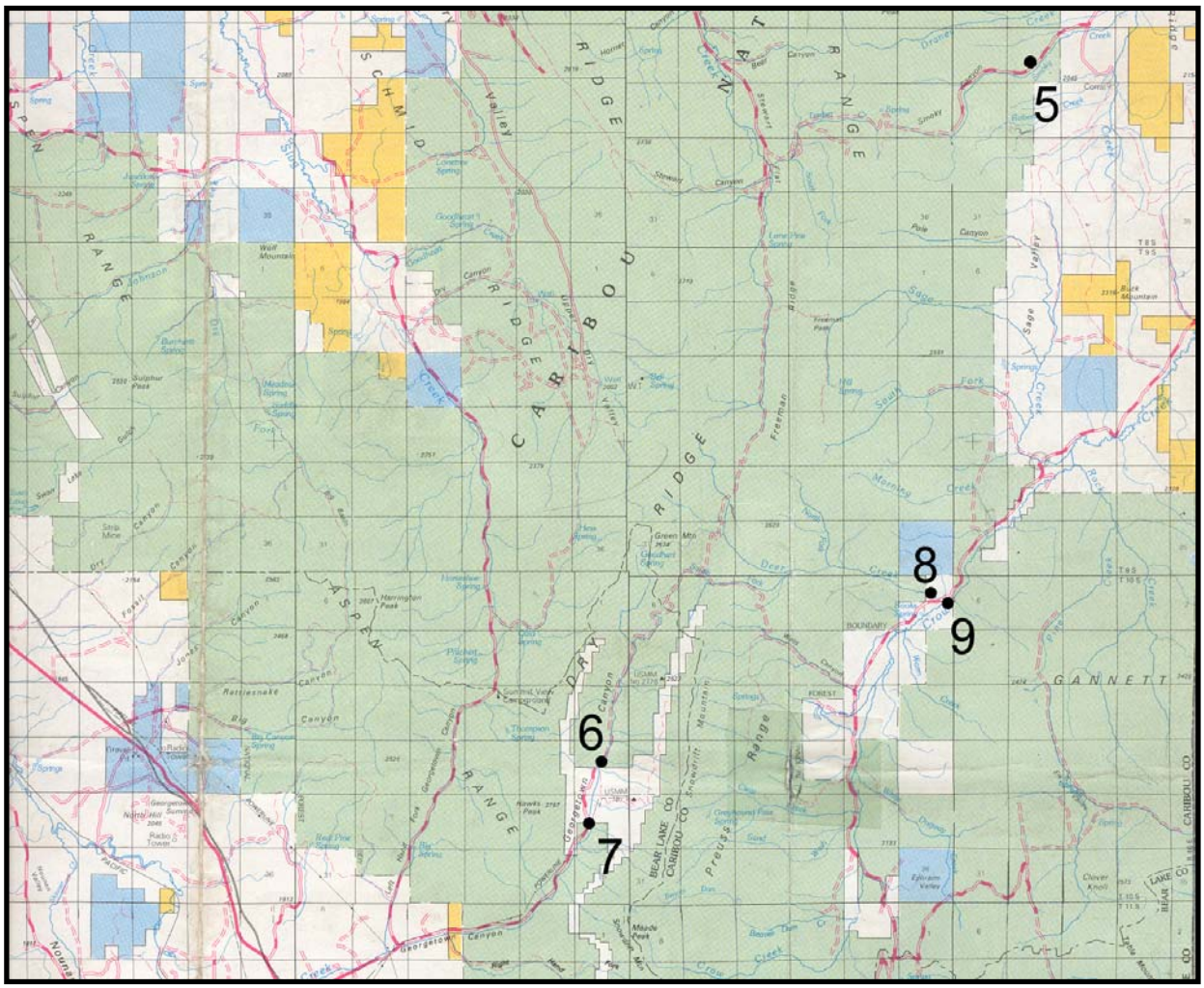

5
8
9
6
7
SCHMID RIDGE
CARIBOU RIDGE
ASPEN RANGE
GEORGETOWN RANGE
DRY CANYON
GANNETT
BEAR LAKE CO
CARIBOU CO

Table 1. Universal transverse mercator (UTM) and latitude and longitude of nine sites sampled in southeastern Idaho.

Site name & ID	UTM[1]	Latitude/Longitude[2]
Little Blackfoot River (LiB)	12T 0457496 4749940	N42º54'10.16" W111º31'14.28"
Upper Angus Creek (UAC)	12T 0466344 4743342	N42º50'37.85" W111º24'42.70"
Blackfoot River at gaging station (BGS)	12T 0458641 4740223	N42º48'55.38" W111º30'21.22"
State Land Creek (SLC)	12T 0459050 4738945	N42º48'14.02" W111º30'02.87"
Smoky Creek (SC)	12T 0491433 4729808	N42º43'21.57" W111º06'16.68"
Upper Georgetown Creek (UGC)	12T 0478733 4709432	N42º32'20.08" W111º15'32.34"
Lower Georgetown Creek (LGC)	12T 0476665 4705101	N42º29'59.45" W111º17'02.36"
Deer Creek (DC)	12T 0488906 4714371	N42º35'00.98" W111º08'06.70"
Crow Creek (CC)	12T 0489089 4713340	N42º34'27.56" W111º07'58.60"

[1]UTM: Garmin GPS III Plus, Garmin International, Olathe, KS.

[2]Converted from UTM to latitude/longitude using the conversion program from National Geodetic Survey at www.ngs.noaa.gov (conversions provided by Mark Huebner, USGS, Menlo Park, CA).

site was located about 20 m upstream of the haul road and railroad tracks. The sampling site was below several active and inactive mines (Figure 1). The land on either side of the river was composed of grass and sagebrush and had moderate grazing.

4. The State Land Creek (SLC) site was located about 1.2 km from the private haul road at a point near the USGS gaging station, accessed from the Blackfoot River Road. The site was approximately 0.5 km above the confluence with the Blackfoot River. The sampling site was below the inactive Conda Mine. Sample collection was in a generally open area of forbs, grass, and spare pine trees with some grazing.

5. The Smoky Creek (SC) site was located in Smoky Canyon about 1.5 km inside the USFS boundary on Forest Route 110. The site was in the road right-of-way, and about 3 km above the confluence with Tygee Creek, which flows into the Salt River. The sampling site was not impacted by mining activity. The land around the stream was primarily riparian with numerous beaver ponds above and below the collection site. The roadway bordered one side of the creek and the opposite side was heavily forested. No grazing was evident.

6. The upper Georgetown Creek (UGC) site was located adjacent to the public parking lot located just inside of the USFS boundary and about 0.5 km above the abandoned mine processing plant in Georgetown Canyon (Forest Route 102) and within the Georgetown Canyon Mine area. The site was approximately 15 km above the confluence with the Bear River. The sampling site was below the inactive Georgetown Mine. The site was in the road right-of-way next to the public parking lot. The land on either side of the road was ungrazed, riparian habitat.

7. The lower Georgetown Creek (LGC) site was located about 5 km downstream of the upper Georgetown Creek site and below the abandon mine processing plant, but within the Georgetown Canyon Mine area. The sampling site was below the inactive Georgetown and Montpelier mines. The site was in the road right-of-way. The roadway bordered one side of the stream and the opposite stream bank bordered a steep forested slope. No grazing was evident.

8. The Deer Creek (DC) site was located on private land (accessed with owner permission) adjacent to Forest Route 111 and about 0.5 km upstream of its confluence with Crow Creek, which flows into the Salt River. The sampling site was not impacted by mining activity, but the upper portion of the Deer Creek watershed has outcroppings of Phosphoria (Figure 2 in Tetra Tech 2002a). The land along the stream was primarily riparian with some forbs, shrubs, and grass. Sample collection was upstream of roadway influences. The area had light grazing.

9. The Crow Creek (CC) site was located on USFS land adjacent to Forest Service Route 111 and upstream of the confluence of Deer Creek and an in-stream crossing. The sampling site was not impacted by mining activity, but the upper portion of the Crow Creek watershed has outcroppings of Phosphoria (Figure 2 in Tetra Tech 2002a). The sampling site was not impacted by mining activity, but the land along the stream was primarily riparian with some shrubs nearby and light camping activity.

Sample collection

Samples of water, surficial sediment, aquatic plants, aquatic invertebrates, and fish were collected at each of nine stream sites. Water sample bottles were conditioned by immersion in site water three times. Water samples were collected by grab sampling. At a mobile laboratory, water was filtered through a 0.45 µm polycarbonate filter using standard sampling techniques. A 200-ml sample of each filtered water was collected in an acid-cleaned polyethylene bottle for

analysis of selenium concentrations and a second filtered water sample collected for analysis of inorganic element concentrations. Water samples for selenium analysis were acidified with ultrapure hydrochloric acid (HCl) and those for inorganic elements were acidified with ultrapure nitric acid (HNO_3). A reagent blank was collected for analysis of selenium and inorganic element concentrations and consisted of deionized water from a mobile laboratory combined with the acid preservative. All samples for selenium and other inorganic element analyses were stored frozen.

Two sediment samples were collected at each site using a plastic scoop to gently acquire surficial sediments including detritus, but not pebbles or plant material. The scoop and acid-cleaned sample container were rinsed in ambient water for sufficient time to condition the equipment to ambient conditions prior to sample collection. After sediments settled, excess water was discarded and the sample stored frozen. One sample was used for analysis of selenium and mercury concentrations, and a second sample used for analysis of inorganic element concentrations.

Submerged aquatic plants (white-water buttercup, *Ranunculus longirostris*) were collected by hand from each site. The sample consisted of leaf whorls removed from stems using plastic or stainless steel forceps. Additional samples of leaves and stems (minus roots) were collected at the Little Blackfoot River and Crow Creek sites for comparison with leaf-only samples. At the upper Georgetown Creek site no white-water buttercup could be found, so a different submerged macrophyte was collected (Hypericum). Two plant samples were collected from each site, squeezed to remove excess water, weighed, bagged in Whirl-Pak bags, labeled, and stored frozen. One composite sample was analyzed for selenium concentration and the other sample analyzed for inorganic element concentrations.

Aquatic invertebrates were sieved from bed substrate materials collected either by D-frame kick nets or by removing large stones with attached invertebrates. Substrate was placed in large polypropylene trays and invertebrates separated from substrate using forceps or glass tubes with suction bulbs. Invertebrate samples were separated by taxa group and weighed by taxa group. One half of the weight of each taxa group was combined as a composite invertebrate sample. One composite sample was analyzed for selenium concentration and the other sample analyzed for inorganic element concentrations.

Fish were collected by electrofishing with a Coffelt Mark-10 electroshocker provided and operated by the USFS, Caribou National Forest, Soda Springs, ID. The anode and cathode wands were rinsed in ambient water for sufficient time to condition the equipment to ambient conditions. Fish samples were collected from each site, euthanized with MS-222 (tricaine methanesulfonate), identified to species if possible, measured for total length and weight, bagged in Whirl-Pak bags, labeled with identification information, and stored frozen. When possible, one or more fish of each species from each site was analyzed for selenium concentrations in whole body and other fish of the same species from the same site analyzed for inorganic element concentrations in whole body. A specimen of some species was retained to confirm identification. Year class information was not collected.

Water quality analyses and flow measurement

Water samples (~1 l) at each site were collected and analyzed for general water quality characteristics in a mobile laboratory according to standard methods (APHA et al. 1995). Site water was analyzed *in situ* for the following general water quality characteristics: conductivity,

pH, temperature, dissolved oxygen, and percent saturation of dissolved oxygen. Flow measurements were taken using a global flow probe (FP101), except at the Blackfoot River gaging station. At the gaging station, the flow was recorded from the USGS web site (USGS gage 1306000, Blackfoot River above reservoir near Henry, Idaho; http://waterdata.usgs.gov/nwis/discharge).

Immediately after arrival of the site water at the mobile laboratory, the following water quality characteristics were measured in unfiltered water: conductivity, pH, alkalinity, hardness, calcium, magnesium, and temperature. A subsample of 200 ml water was collected and stored at 4ºC with no preservative, and transported to the Columbia Environmental Research Center Field Research Station, Yankton, SD, for analysis of sulfate and chloride. A second subsample of 125 ml water was collected, acidified with 0.5 ml concentrated sulfuric acid (H_2SO_4), and transported to Yankton for analysis of ammonia concentrations. All water quality characteristics were measured according to standard methods (APHA et al. 1995), except ammonia and chloride. Ammonia was measured using ion-selective electrodes and following the procedures for low concentration measurements of the electrode manufacturer (Orion Research 1990, 1991, ATI Orion 1994). Chloride was measured by the mercuric nitrate titration method (Hach Company 1997).

Inorganic element analysis

Water, surficial sediment, aquatic plants, aquatic invertebrates, and fish were analyzed for selenium concentrations by atomic absorption spectroscopy graphite furnace (AA-GF) at the Research Triangle Institute (RTI), Research Triangle Park, NC. Analyses incorporated appropriate quality assurance/quality control (QA/QC) procedures such as standardizing equipment with certified reference material, determination of limit of detection, analysis of reagent blanks, duplicate samples, certified reference materials, and spiked samples. Analysis of selenium concentrations was based on U.S. Environmental Protection Agency (USEPA) method 7740 (USEPA 1983). Results were reported on a dry weight basis for analysis of sediment, aquatic plant, aquatic invertebrate, and fish samples.

Water, surficial sediment, aquatic plants, aquatic invertebrates, and fish were analyzed for mercury concentrations by cold vapor atomic absorption at the RTI. Analyses incorporated the appropriate QA/QC described above. Analysis of mercury was based on USEPA method 7174A (USEPA 1983). Results are reported on a dry weight basis for analysis of sediment, aquatic plant, aquatic invertebrate, and fish samples.

Water, surficial sediment, aquatic plant, aquatic invertebrate, and fish samples were analyzed for inorganic element concentrations (aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, strontium, vanadium, and zinc) by inductively-coupled plasma (ICP) spectrophotometry. Analyses were conducted by the RTI and incorporated appropriate QA/QC described above. Analysis of inorganic elements by ICP was based on USEPA method 6020 (USEPA 1983), except arsenic analysis which was method 7060A (USEPA 1983). Results were reported on a dry weight basis for analysis of sediment, aquatic plant, aquatic invertebrate, and fish samples.

Statistical analyses

Data were analyzed (SAS 2002) to determine the relation among various measures made

during the study. Pearson correlation analyses were used to test for relations among water quality characteristics, and selenium concentrations in water, sediment, aquatic plant, aquatic invertebrate, and fish. For fish residue data for each sample location, the geometric mean was used in correlation analyses with other variables.

The nonparametric Friedman test (Conover 1980) ranked the streams from highest inorganic concentrations to lowest for each ecosystem component (water, sediment, plant, invertebrate, and fish). Significant differences (P=0.05) among streams were determined with Friedman's multiple comparison test.

Results

Water quality

Water quality characteristics were relatively uniform among the sites, with two exceptions (Table 2). Crow Creek had elevated chloride, and Little Blackfoot River had elevated sulfate and slightly elevated chloride relative to the other seven sites. The nine sites were well oxygenated at the time of sampling (Table 2).

Inorganic elements

The results of QA/QC sample analysis by AA-GF at RTI for the determination of selenium concentrations are given in Table 3. The procedure blank had background concentration less than the LOD, which indicated no contamination from reagents or sample handling. The percent relative standard deviation (duplicate preparation and analysis) ranged from <LOD to 11%, which indicated consistent sample handling during preparation, digestion, and analysis. Percent recovery of selenium from certified material ranged from 83 to 108%, which indicated the digestion and analysis procedure accurately measured selenium concentrations. Percent recovery of selenium from samples spiked before digestion ranged from 80 to 110%, which indicated the digestion procedure did not alter the amount of spiked selenium in the sample, i.e., suggested no loss of selenium during digestion.

The results of QA/QC sample analysis by ICP for inorganic element concentrations are given in Table 4. In general the LOD, procedural blanks, relative standard deviation of duplicate preparation and analysis, and spike recoveries were comparable to those in the selenium analysis. Percent relative standard deviations for duplicate analysis of selected samples seemed elevated (i.e., >30%) in water for zinc, in sediments for molybdenum, in plants for manganese, in invertebrates for boron, and in fish for aluminum (Table 4). Measurement of inorganic elements in reference materials (% recovery of reference material) was outside the normal range of recovery (i.e., ~80 to ~120%) in sediments for aluminum, barium, cadmium, chromium, lead, magnesium, strontium, and vanadium, in plants for aluminum, in invertebrates for mercury, and in fish for mercury. Measurement of recovery of spiked elements in samples was outside the normal range of recovery (i.e., ~80% to 120%) in sediments for aluminum and iron, and in invertebrates for manganese. There was no consistent pattern for percent relative standard deviations, percent recovery of reference material, or percent recovery of digested spikes. In general, concentrations of inorganic elements were relatively low, which may have contributed to the variability in the analysis of duplicate samples.

Table 2. Water quality characteristics measured in water from nine sites in southeastern Idaho. n=1; <: below limit of measurement.

Measure	Site[1]								
	LiB	UAC	BGS	SLC	SC	UGC	LGC	DC	CC
pH	7.6	8.2	8.5	8.0	7.9	8.2	8.2	8.4	8.7
Conductivity (μmhos/cm)	880	610	390	600	590	500	620	530	1,050
Hardness (mg/L as $CaCO_3$)	344	227	174	206	203	201	184	212	220
Calcium (mg/L)	83	66	50	60	53	60	50	56	61
Magnesium (mg/L)	33	15	12	14	17	12	14	18	16
Alkalinity (mg/L as $CaCO_3$)	238	175	166	193	186	185	176	207	200
Chloride (mg/L)	60	4	3	12	4	<2	<2	2	173
Sulfate (mg/L)	113	54	10	11	14	18	8	6	19
Un-ionized ammonia (mg/L NH_3-N)	<0.001	0.001	0.004	<0.001	<0.001	<0.001	<0.001	0.001	0.003
Total ammonia (mg/L as N)	<0.01	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02
Dissolved oxygen (mg/L)	6.7	8.9	9.3	8.2	9.3	10.2	10.7	10.8	10.5
% Saturation dissolved oxygen	69	79	99	73	79	81	93	100	116
Discharge (cfs)	1.95	0.58	54	0.07	0.60	4.97	24.84	2.74	13.75

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.

Table 3. Quality assurance and quality control measures of selenium analysis of water, sediment, aquatic plants, aquatic invertebrates, and fish from nine sites in southeastern Idaho. n=1 for water, sediment, aquatic plants, and aquatic invertebrates; n=2 for fish (mean and standard error in parentheses); <: less than.

	Ecosystem component				
Measure	Water	Sediment	Aquatic Plant	Aquatic Invertebrate	Fish
Limit of detection (LOD) (µg/L or µg/g)	2	0.5	0.5	0.5	0.5
Procedural blank	<LOD	<LOD	<LOD	<LOD	<LOD
% RSD[1]	<LOD	11	2.3	7.0	4.8 (2.0)
% Recovery of reference material	89[2]	83[3]	NR[4,5]	108[6]	108[6]
% Recovery of digested spike	93	82	80	84	110 (4)

[1]%RSD: percent relative standard deviation for duplicate preparation and analysis.
[2]Leeman Labs commercial standard solution (lot number 480801).
[3]National Institute of Standards and Technology (NIST) standard reference material 2709 (San Joaquin soil; 1.57 µg/g).
[4]NR: not reported.
[5]NIST standard reference material 1547 (peach leaves, 0.12 µg/g).
[6]National Resource Council of Canada standard reference material TORT-2 (lobster hepatopancreas, 5.63 µg/g).

Table 4. Quality assurance and quality control measures of analyses of inorganic elements in water (W), sediment (S), aquatic plants (P), aquatic invertebrates (I), and fish (F) from nine sites in southeastern Idaho. n=1 for water, sediment, aquatic plants, and aquatic invertebrates; n=2 for fish (mean and standard error in parentheses); <: less than.

	LOD[1]				% RSD[2]				
Element	W (µg/L)	S (µg/g)	P, I, F (µg/g)	Procedural blank	W	S	P	I	F
Aluminum	5	2	1	<LOD	0	4.0	15.0	4.4	33.6 (29.2)
Arsenic	2	0.5	0.5	<LOD	<LOD	28.9	<LOD	14.2	15.3 (3.2)
Barium	1	0.2	1	<LOD	3.2	2.4	1.2	0.3	18.2 (10.0)
Beryllium	1	0.02	0.03	<LOD	<LOD	5.0	<LOD	<LOD	<LOD
Boron	1	2	0.5	3	0.1	10.3	9.6	47.8	<LOD
Cadmium	1	0.5	0.1	<LOD	<LOD	0.4	1.5	5.8	<LOD
Chromium	1	0.2	0.1	<LOD	<LOD	2.9	9.6	1.9	<LOD
Copper	1	0.2	0.1	<LOD	<LOD	0.9	1.3	4.1	5.6 (0.6)
Iron	10	10	5	<LOD	2.2	2.1	8.6	0.5	26.8 (25.8)
Lead	5	2	0.5	<LOD	<LOD	12.5	<LOD	<LOD	<LOD
Magnesium	10	10	5	<LOD	1.5	2.6	0	7.4	2.9 (2.8)
Manganese	1	1	0.3	<LOD	0.9	4.1	32.3	1.2	12.4 (11.0)
Mercury	-	0.1	0.05	<LOD	0	2	<LOD	<LOD	4.8 (1.4)
Molybdenum	1	1	1	<LOD	2.7	178	6.2	<LOD	<LOD
Nickel	2	1	0.1	<LOD	3.0	3.8	17.5	6.6	<LOD
Strontium	1	0.5	0.1	<LOD	1.5	7.2	0	1.7	9.2 (0.5)
Vanadium	1	0.3	0.1	<LOD	1.4	4.4	5.7	6.5	<LOD
Zinc	1	5	1	<LOD	69	0.8	0	7.8	0.8 (0.6)

Table 4. Continued.

Element	% Recovery of reference material					% Recovery of digested spike				
	W[3]	S[4]	P[5]	I[6]	F[6]	W	S	P	I	F
Aluminum	100	23	67	NG	NG	104	32	96	81	100 (0)
Arsenic	102	82	<LOD	97	97	117	101	101	92	106 (4)
Barium	107	36	82	NG	NG	109	94	96	88	102 (1)
Beryllium	98	NG[7]	<LOD	<LOD	NG	101	97	93	87	100 (2)
Boron	99	NG	81	NG	NG	102	91	92	85	98 (0)
Cadmium	99	176	<LOD	94	96	99	100	89	84	96 (2)
Chromium	105	45	<LOD	79	79	106	97	94	87	102 (1)
Copper	102	99	88	94	95	106	96	99	94	108 (1)
Iron	96	83	NG	86	87	102	50	87	80	98 (3)
Lead	99	68	<LOD	<LOD	<LOD	100	99	89	83	96 (1)
Magnesium	97	73	82	NG	NG	101	80	93	83	96 (1)
Manganese	104	87	83	94	92	107	79	93	61	102 (1)
Mercury	90	101	<LOD	129	130	93	104	106	111	111 (1)
Molybdenum	99	NG	NG	109	116	102	83	89	83	95 (0)
Nickel	99	86	<LOD	82	84	99	100	91	85	98 (1)
Strontium	103	39	89	88	88	105	92	91	88	98 (2)
Vanadium	103	48	NG	95	95	107	96	94	88	102 (1)
Zinc	100	79	91	95	97	100	100	93	88	97 (0)

[1]LOD: limit of detection.
[2]%RSD: percent relative standard deviation for duplicate preparation and analysis.
[3]Leeman Labs commercial standard solution (lot number 480801).
[4]National Institute of Standards and Technology (NIST) standard reference material 2709 (San Joaquin soil).
[5]NIST standard reference material 1547 (peach leaves).
[6]National Resource Council of Canada standard reference material TORT-2 (lobster hepatopancreas).
[7]NG: not given.

Water

Selenium concentrations in water from eight sites were less than the LOD (<2 µg/L), but elevated at upper Georgetown Creek, which contained 11 µg/L (Table 5). Concentrations of inorganic elements in water were generally similar among the nine sites (Table 6). Although upper Georgetown Creek water contained elevated selenium, it was not among the highest in other inorganic element concentrations, except for strontium (third highest). Relative to the other sites, Smoky Creek water contained the highest concentrations of aluminum, boron, and iron and the second highest magnesium and strontium. Little Blackfoot River water contained the highest magnesium and strontium, second highest zinc, and third highest boron and iron. State Land Creek water contained the highest barium and zinc and second highest manganese. Because a large number of inorganic element concentrations in water were below the limit of detection, no ranking of streams was done.

Sediment

Selenium concentrations in surficial sediment were relatively low at Blackfoot River gaging station, Angus Creek, Smoky Creek, Little Blackfoot River (≤2 µg/g), moderately elevated at the State Land Creek and Crow Creek (2.1 µg/g), and elevated at Deer Creek and upper Georgetown Creek (4.5 µg/g) and lower Georgetown Creek (7.5 µg/g) (Table 5).

Concentrations of inorganic elements in surficial sediments followed a slightly different pattern than selenium in sediments (Table 7). State Land Creek sediment contained the highest concentrations of arsenic, barium, beryllium, boron, iron, and manganese, and second highest aluminum and copper. Upper Georgetown Creek sediment contained the highest concentrations of chromium, copper, and lead, and the second highest boron, nickel, and vanadium. Upper Angus Creek sediment contained the highest aluminum, beryllium, and molybdenum, and second highest copper, iron, and manganese. Based on the Friedman test, the streams were ranked from highest inorganic element concentrations in sediment (with selenium in the dataset) to lowest as follows (streams with lower case letters in common are not significantly different): UGC_a, DC_a, SLC_a, SC_{ab}, UAC_{ab}, LGC_{ab}, CC_b, LiB_c, BGS_c. Based on selenium concentrations alone, the streams from highest concentration to lowest were: LGC, UGC, DC, CC, SLC, LiB, UAC, SC, BGS. Disparities in order between the two approaches occurred for lower Georgetown Creek, Smoky Creek, and Crow Creek.

Significant correlations between sediment and water were found for manganese and strontium (Table 8).

Aquatic plants

Selenium concentrations in aquatic plants were relatively low at lower Georgetown Creek and Little Blackfoot River (1.6-1.8 µg/g), intermediate at Smoky Creek, upper Angus Creek, upper Georgetown Creek, State Land Creek, Deer Creek, and Crow Creek (2.5-4.6 µg/g), and high at Blackfoot River gaging station (7.2 µg/g) (Table 5). Selenium concentrations in plants at Blackfoot River gaging station (7.2 µg/g) and lower Georgetown Creek (1.6 µg/g) seemed inconsistent with selenium concentrations in sediments at those two sites (1.0 µg/g and 7.5 µg/g, respectively). Lower Georgetown Creek contained the highest selenium concentration in sediment of all the sites, and the lowest selenium concentration in plants.

Upper Georgetown Creek plants contained the highest concentrations of boron, cadmium,

Table 5. Selenium concentrations (µg/L for water and µg/g dry weight for sediment, aquatic plants, and aquatic invertebrates) in water, sediment, aquatic plants, and aquatic invertebrates from nine sites in southeastern Idaho. Concentrations in parentheses are for leaves and stems. n=1; <: less than limit of detection.

Ecosystem component	Site[1]								
	LiB	UAC	BGS	SLC	SC	UGC	LGC	DC	CC
Water	<2	<2	<2	<2	<2	11	<2	<2	<2
Sediment	1.8	1.2	1.0	2.1	1.2	4.5	7.5	4.5	2.1
Aquatic plant	1.8 (2.0)	2.8	7.2	4.3	2.5	3.7	1.6	4.3	4.6 (3.1)
Aquatic invertebrate	5.4	5.0	10.8	9.7	4.1	9.3	7.8	8.7	6.7

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.

Table 6. Inorganic element concentrations (µg/L) in water from nine sites in southeastern Idaho. n=1; <: less than limit of detection.

	Site[1]								
Element	LiB	UAC	BGS	SLC	SC	UGC	LGC	DC	CC
Aluminum	19	16	13	10	38	17	15	23	15
Arsenic	<2	<2	<2	<2	<2	<2	<2	<2	<2
Barium	39	28	63	70	28	42	39	34	68
Beryllium	<1	<1	<1	<1	<1	<1	<1	<1	<1
Boron	26	16	20	20	29	9	15	17	28
Cadmium	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	<1	<1	<1	<1	<1	<1	<1	<1	<1
Copper	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron	28	12	12	22	110	14	<10	34	<10
Lead	<5	<5	<5	<5	<5	<5	<5	<5	<5
Magnesium	32,200	14,600	11,400	13,400	16,900	12,400	14,000	16,700	16,300
Manganese	19	90	35	64	7	2	1	16	13
Mercury	<0	<0	10	<0	<0	<0	<0	<0	<0
Molybdenum	1	<1	<1	1	<1	<1	<1	2	<1
Nickel	3	2	<2	3	<2	<2	<2	<2	<2
Strontium	737	180	192	190	380	331	127	102	282
Vanadium	2	<1	2	1	<1	<1	2	2	4
Zinc	8	7	6	10	4	5	7	7	4

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.

Table 7. Inorganic element concentrations (µg/g dry weight) in sediment from nine sites in southeastern Idaho. n=1; <: less than limit of detection.

	Site[1]								
Element	LiB	UAC	BGS	SLC	SC	UGC	LGC	DC	CC
Aluminum	8,400	13,700	7,400	13,200	9,900	11,600	8,000	11,800	9,700
Arsenic	6	10	4	13	10	11	9	12	10
Barium	78	111	90	25	111	132	113	228	153
Beryllium	0.5	0.9	0.3	0.9	0.5	0.7	0.4	0.6	0.5
Boron	8	16	10	20	18	18	14	18	16
Cadmium	1.5	2.3	1.5	2.7	4.6	4.9	6.0	5.1	2.2
Chromium	22	24	17	28	40	46	45	39	22
Copper	10	21	8	21	21	23	18	18	11
Iron	9,600	21,300	8,000	21,600	18,500	16,800	10,000	16,900	12,300
Lead	12	13	7	10	10	16	10	12	15
Magnesium	3,600	6,600	2,800	4,500	7,400	6,000	7,200	6,400	5,000
Manganese	76	2,800	790	3,400	1,700	870	270	2,000	1,180
Mercury	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1
Molybdenum	<1	4.7	<1	<1	<1	2	1	3.5	<1
Nickel	15	28	11	34	40	41	36	42	19
Strontium	146	39	93	63	101	93	94	46	100
Vanadium	15	22	18	28	42	43	47	33	19
Zinc	135	93	40	132	191	210	234	269	128

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.

Table 8. Significant (P<0.05) Pearson correlation coefficients for various aquatic ecosystem components and inorganic elements (standard symbols in table).

Ecosystem component	Ecosystem component							
	Sediment		Aquatic plant		Aquatic invertebrate		Fish	
Water			Ba	0.74				
	Mn	0.73					Mn	0.83
	Sr	0.82			Sr	0.69		
							Zn	0.70
Sediment							Al	0.67
			Be	-0.89				
			Cd	0.76				
			Cr	0.82				
							Cu	-0.72
							Mn	0.78
			Ni	0.88				
					Zn	0.80		
Aquatic plant					Se	0.70	Se	0.69
					Mn	0.94		
Aquatic invertebrate							Ba	0.69
							Se	0.82
							Sr	0.71

chromium, copper, magnesium, strontium, and vanadium, and the second highest arsenic (Table 9). Other sites that contained elevated inorganic concentrations in plants include Deer Creek and State Land Creek, whereas lower Georgetown Creek and Crow Creek tended to have low concentrations relative to the other sites. Based on the Friedman test, the streams were ranked from highest inorganic element concentrations in aquatic plants (with selenium in the dataset) to lowest as follows (streams with lower case letters in common are not significantly different): DC_a, UGC_{ab}, SLC_{bc}, SC_{bc}, BGS_{bcd}, UAC_{bcd}, LiB_{cd}, LGC_{cd}, CC_d. Based on selenium concentrations alone, the streams from highest concentration to lowest were: BGS, CC, SLC, DC, UGC, UAC, SC, LiB, LGC. Disparities in order between the two approaches occurred for Deer Creek, Smoky Creek, Blackfoot River gaging station, and Crow Creek.

Significant correlations were observed between aquatic plants and water for barium (Table 8). Four elements in sediment were significantly correlated with those in aquatic plants: beryllium, cadmium, chromium, and nickel. Selenium concentrations in aquatic plants were not significantly correlated with those in sediments (r= -0.37, P=0.32, n=9), which was probably due to the inconsistent selenium concentrations between aquatic plants and sediments at the Blackfoot River gaging station and lower Georgetown Creek.

Aquatic invertebrates

Selenium concentrations in aquatic invertebrates were relatively low at Smoky Creek, upper Angus Creek, and Little Blackfoot River (4.1-5.4 µg/g), intermediate at Crow Creek, lower Georgetown Creek, and Deer Creek (6.7-8.7 µg/g), and high at upper Georgetown Creek, State Land Creek, and Blackfoot River gaging station (9.3-10.8 µg/g) (Table 5). Selenium concentrations in invertebrates were significantly correlated with selenium concentrations in aquatic plants (r=0.70, P=0.04, n=9), but not with sediments (r=0.27, P=0.48, n=9).

Each of the nine sites contained the highest concentration of one or more elements, but no one site contained consistently elevated inorganic element concentrations (Table 10). Invertebrates from the Blackfoot River gaging station contained the highest concentrations of aluminum, boron, iron, and manganese. Invertebrates from upper Angus Creek contained the highest concentrations of arsenic, copper, and magnesium, and the second highest concentrations of barium, cadmium, and strontium. Based on the Friedman test, inorganic element concentrations (with selenium in the dataset) in invertebrates in the nine streams were not significantly different from each other.

Only one inorganic element concentration in water was significantly correlated with those in aquatic invertebrates: strontium (Table 8). Zinc was the only element in sediment significantly correlated with those in aquatic invertebrates (Table 8). Manganese was the only element in aquatic plants significantly correlated with those in aquatic invertebrates (Table 8).

Fish

Nine fish species were collected at the nine stream sites, but no one species was collected at all nine sites (Table 11). Fish collected included cutthroat trout (*Oncorhynchus clarki*), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), mottled sculpin (*Cottus bairdi*), longnose dace (*Rhinichthys cataractae*), speckled dace (*Rhinichthys osculus*), redside shiner (*Richardsonius balteatus*), an unknown minnow, and an unknown chub. The most commonly collected fish were cutthroat trout (four sites) and mottled sculpin (four sites). Only one fish

Table 9. Inorganic element concentrations (µg/g dry weight) in aquatic plants from nine sites in southeastern Idaho. Concentrations in parentheses are for leaves and stems. n=1; <: less than limit of detection.

	Site[1]								
Element	LiB	UAC	BGS	SLC	SC	UGC	LGC	DC	CC
Aluminum	2,470 (2,600)	2,030	2,010	1,600	1,300	1,620	630	2,050	470 (260)
Arsenic	1 (1)	2	2	1	1	2	<0.5	3	2 (1)
Barium	29 (31)	38	124	103	33	44	25	72	64 (51)
Beryllium	<0.03 (<0.03)	0.04	0.07	0.04	0.05	<0.03	0.06	0.06	<0.03 (<0.03)
Boron	12 (17)	12	9	13	9	15	10	12	9 (41)
Cadmium	1 (1)	3	1	2	3	4	3	3	2 (2)
Chromium	5 (6)	5	6	5	9	10	7	9	3 (2)
Copper	4 (4)	9	4	8	4	14	2	5	3 (4)
Iron	2,350 (3,650)	2,070	1,730	2,000	2,050	1,760	960	2,330	530 (370)
Lead	<0.5 (<0.5)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5 (<0.5)
Magnesium	3,520 (3,360)	2,730	3,040	3,280	5,300	6,910	3,740	3,390	3,160 (3,640)
Manganese	440 (390)	5,090	10,400	6,070	1,240	412	77	3,800	3,350 (2,680)
Mercury	<0.5 (<0.5)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05 (<0.05)
Molybdenum	<1 (<1)	<1	<1	2	<1	<1	<1	3	<1 (<1)
Nickel	6 (6)	4	4	7	9	8	8	9	5 (4)
Strontium	89 (99)	70	52	40	93	120	34	52	68 (60)
Vanadium	6 (7)	5	7	6	6	8	7	8	3 (2)
Zinc	130 (100)	38	27	53	92	67	260	75	53 (58)

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.

Table 10. Inorganic element concentrations (µg/g dry weight) in aquatic invertebrates from nine sites in southeastern Idaho. n=1; <: less than limit of detection.

	Site[1]								
Element	LiB	UAC	BGS	SLC	SC	UGC	LGC	DC	CC
Aluminum	360	1,030	1,790	390	1,380	1,270	270	660	1,540
Arsenic	6	6	2	5	3	2	3	3	4
Barium	28	91	80	104	24	15	18	23	37
Beryllium	<0.03	<0.03	0.06	<0.03	0.06	0.06	<0.03	<0.03	0.07
Boron	3	1	5	1	3	3	2	1	2
Cadmium	0.1	4	1	1	4	16	1	2	3
Chromium	1	2	4	1	9	7	3	3	4
Copper	21	61	17	29	19	25	19	21	20
Iron	360	850	1,630	400	1,590	1,320	450	750	1,380
Lead	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Magnesium	1,600	1,960	1,200	1,490	1,660	1,410	1,660	1,540	1,350
Manganese	38	500	1,330	580	320	100	130	580	730
Mercury	0.09	<0.05	0.06	0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Molybdenum	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nickel	1	2	3	2	4	4	3	3	4
Strontium	230	140	9	77	18	14	9	8	23
Vanadium	1	2	4	1	6	6	3	3	4
Zinc	86	120	110	130	170	300	370	290	220

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.

Table 11. Selenium concentrations (µg/g dry weight) in whole-body fish from nine sites in southeastern Idaho. n=1.

	Site[1]								
Species	LiB	UAC	BGS	SLC	SC	UGC	LGC	DC	CC
Brook trout	-[2]	-	-	-	-	9.8	6.7[3] 6.9[4]	-	-
Cutthroat trout	-	6.6	12.2	-	5.0[3] 3.5[4]	-	-	9.3[3] 11.0[4]	-
Brown trout	-	-	-	-	-	-	-	-	9.7
Mottled sculpin	-	6.2	12.3	-	-	-	-	12.0	8.2
Longnose dace	-	-	10.9	-	-	-	-	-	10.8[3] 13.4[4]
Speckled dace	5.8	-	-	15.2	-	-	-	-	-
Redside shiner	-	-	13.6	-	-	-	-	-	-
Other	9.8[5]	-	11.1[6]	-	-	-	-	-	-
Geometric mean	7.6	6.4	12.0	15.2	4.2	9.8	6.8	11.5	10.4

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.
[2]-: Not collected.
[3]Young of year.
[4]Subadult.
[5]Unknown minnow.
[6]Unknown chub.

species was collected at each of four sites in spite of substantial electrofishing effort: speckled dace at State Land Creek, cutthroat trout at Smoky Creek, and brook trout at upper and lower Georgetown Creek.

Geometric mean selenium concentrations in whole-body fish were relatively low at Smoky Creek, upper Angus Creek, and lower Georgetown Creek (4.2-6.8 µg/g), intermediate at Little Blackfoot River, upper Georgetown Creek, and Crow Creek (7.7-10.4 µg/g), and high at Deer Creek, Blackfoot River gaging station, and State Land Creek (11.5-15.2 µg/g) (Table 11). Selenium concentrations in fish were significantly correlated with selenium concentrations in aquatic plants (r=0.69, P=0.04, n=9), and aquatic invertebrates (r=0.82, P=0.006, n=9), but not in sediments (r= -0.04, P=0.92, n=9). Young-of-year and subadults of cutthroat trout and longnose dace were collected at four sites (Table 11). In general, selenium concentrations in young-of-year fish were similar to those in subadult fish.

State Land Creek seemed to consistently have the highest concentrations of inorganic elements in fish, whereas upper Georgetown Creek contained the lowest concentrations (Tables 12 and 13). Fish from the State Land Creek contained the highest concentrations of arsenic, barium, iron, magnesium, mercury, and zinc, and the second highest aluminum, cadmium, manganese, and strontium. Based on the Friedman test using the geometric mean inorganic element concentrations in fish, the streams were ranked from highest inorganic element concentrations (with selenium in the dataset) to lowest as follows (streams with lower case letters in common are not significantly different): SLC_a, UAC_{ab}, LiB_{abc}, CC_{abc}, BGS_{abc}, SC_{bc}, LGC_{bcd}, DC_{cd}, UGC_d. Based on selenium concentrations alone, the streams from highest concentration to lowest were: SLC, BGS, DC, CC, UGC, LiB, LGC, UAC, SC. Disparities in order between the two approaches occurred for upper Angus Creek, Deer Creek, and upper Georgetown Creek.

Significant correlations were observed for two inorganic element concentrations in water and fish: manganese and zinc (Table 8). Three elements in sediment were significantly correlated with those in fish: aluminum, copper, and manganese (Table 8). Two elements in aquatic invertebrates were significantly correlated with those in fish: barium and strontium (Table 8).

Streams

There were no significant differences among the streams based on inorganic element concentrations including selenium in sediment, aquatic plant, aquatic invertebrate, and fish (but not water) using the Friedman test. However, there were significant differences among streams based on selenium concentrations alone in water, sediment, plant, invertebrate, and fish using the Friedman test. Streams were ranked from highest selenium concentration to lowest as follows (streams with lower case letters in common are not significantly different): UGC_a, SLC_a, BGS_a, DC_{ab}, CC_{ab}, LGC_{abc}, LiB_{bc}, UAC_c, SC_c. Testing the same rankings based on selenium concentrations, but without the water component (only upper Georgetown Creek water contained measurable selenium in water), streams were ranked from highest selenium concentration to lowest as follows (streams with lower case letters in common are not significantly different): SLC_a, BGS_a, DC_a, UGC_{ab}, CC_{ab}, LGC_{abc}, LiB_{bc}, UAC_c, SC_c. Only the position of upper Georgetown Creek in the ranking changed between the two approaches.

Table 12. Inorganic element concentrations (µg/g dry weight) in whole-body fish from nine sites in southeastern Idaho. n=1; <: less than limit of detection.

	Site[1] and Species									
Element	LiB Speckled dace	LiB Unknown minnow	UAC Cutthroat trout	UAC Mottled sculpin	BGS Cutthroat trout	BGS Mottled sculpin	BGS Longnose dace	BGS Unknown chub	BGS Redside shiner	SLC Speckled dace
Aluminum	33	180	210	210	41	140	69	54	9	101
Arsenic	5	5	4	5	4	5	5	5	4	6
Barium	10	8	6	5	3	10	15	6	5	30
Beryllium	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Boron	<0.5	<0.5	0.8	0.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cadmium	<0.1	<0.1	0.5	0.3	<0.1	<1	0.3	<0.1	<1	1.1
Chromium	0.2	0.6	0.6	0.7	0.2	13	0.3	0.3	0.2	0.6
Copper	7.9	6.6	8.2	3.0	4.7	3	8.8	13.1	3.5	4.1
Iron	110	230	210	170	83	210	110	95	56	180
Lead	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Magnesium	1,400	1,380	1,260	1,750	1,310	1,410	1,340	1,360	1,190	2,140
Manganese	16	11	46	70	20	49	30	28	12	34
Mercury	0.31	0.21	0.07	0.08	0.16	0.07	0.21	0.09	0.13	0.26
Molybdenum	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nickel	<0.1	<0.1	0.2	<0.1	<0.1	2.1	<0.1	<0.1	<0.1	<0.1
Strontium	110	85	22	42	14	44	38	25	29	80
Vanadium	<0.1	0.3	0.3	1.2	<0.1	1.0	<0.1	<0.1	<0.1	<0.1
Zinc	287	198	132	69	119	118	157	86	156	302

Table 12. Continued.

Element	Site[1] and Species							
	SC Cutthroat trout (YOY)	SC Cutthroat trout (Subadult)	UGC Brook trout (Subadult)	LGC Brook trout (YOY)	LGC Brook trout (Subadult)	DC Cutthroat trout (YOY)	DC Cutthroat trout (Subadult)	DC Mottled sculpin
Aluminum	85	93	78	36	143	65	61	56
Arsenic	4	4	3	4	4	4	4	5
Barium	2	2	1	<1	2	2	2	5
Beryllium	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Boron	1	<0.5	<0.5	3	1	1	<0.5	<0.5
Cadmium	0.5	0.3	1.4	0.4	0.8	0.2	0.1	<0.1
Chromium	0.6	0.8	0.5	0.2	2.2	0.3	0.5	0.5
Copper	3.9	4.4	2.7	3.9	3.1	3.4	3.8	3.1
Iron	150	160	99	62	160	110	110	85
Lead	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Magnesium	1,300	1,270	970	1,240	1,130	1,300	1,420	1,340
Manganese	19	31	6	3	7	13	18	56
Mercury	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	0.07	<0.05
Molybdenum	<1	<1	<1	<1	<1	<1	<1	<1
Nickel	<0.1	0.2	<0.1	<0.1	0.8	<0.1	<0.1	<0.1
Strontium	33	28	21	67	38	8	10	21
Vanadium	0.1	0.2	0.2	<0.1	1.5	<0.1	<0.1	2.1
Zinc	147	119	80	104	103	122	130	67

Table 12. Continued.

Element	Site[1] and Species: CC Brown trout (Subadult)	CC Mottled sculpin	CC Longnose dace (YOY)	CC Longnose dace (Adult)
Aluminum	97	110	44	75
Arsenic	4	6	4	5
Barium	2	6	8	14
Beryllium	<0.03	<0.03	<0.03	<0.03
Boron	<0.5	<0.5	1.5	<0.5
Cadmium	0.2	0.2	0.2	0.2
Chromium	0.7	0.7	0.1	0.4
Copper	3.7	3.3	5.2	6.4
Iron	110	130	81	110
Lead	<0.5	<0.5	<0.5	<0.5
Magnesium	1,170	1,420	1,200	1,400
Manganese	38	55	13	31
Mercury	0.08	0.07	0.09	0.21
Molybdenum	<1	<1	<1	<1
Nickel	0.1	<0.1	<0.1	<0.1
Strontium	13	87	33	56
Vanadium	0.3	2.1	<0.1	<0.1
Zinc	138	81	124	144

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.

Table 13. Geometric mean of inorganic element concentrations (µg/g dry weight) in whole-body fish from nine sites in southeastern Idaho. <: less than limit of detection.

	Site[1]								
Element	LiB	UAC	BGS	SLC	SC	UGC	LGC	DC	CC
Aluminum	77	210	45	10	89	78	71	60	77
Arsenic	5	5	4	6	4	3	4	4	5
Barium	9	5	7	30	2	1	2	3	6
Beryllium	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Boron	<0.5	1	<0.5	<0.5	1	<0.5	1	1	2
Cadmium	<0.1	0.4	0.3	1.1	0.4	1.4	0.6	0.1	0.2
Chromium	0.4	0.6	0.5	0.6	0.7	0.5	0.7	0.4	0.4
Copper	7.2	5.0	5.6	4.1	4.1	2.7	3.5	3.4	4.5
Iron	160	190	100	180	160	99	98	100	100
Lead	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Magnesium	1,390	1,490	1,320	2,140	1,290	970	1,180	1,380	1,290
Manganese	13	56	25	34	24	6	4	32	30
Mercury	0.26	0.07	0.12	0.26	0.05	<0.05	<0.05	0.07	0.10
Molybdenum	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nickel	<0.1	0.2	2.1	<0.1	0.2	<0.1	0.8	<0.1	0.1
Strontium	96	31	28	80	30	21	51	15	38
Vanadium	0.3	0.6	1.0	<0.1	0.1	0.2	1.5	2.1	0.8
Zinc	240	96	120	300	130	80	100	94	120

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.

Discussion

Water

Upper Georgetown Creek contained substantially elevated selenium concentrations in water, whereas the other eight sites contained concentrations below the limit of detection. Selenium in upper Georgetown Creek was substantially higher than the current national water quality criterion for the protection of aquatic life of 5 µg/L (USEPA 1987).

A recent workshop on selenium aquatic toxicity and bioaccumulation was held to discuss the technical issues underlying the federal freshwater aquatic life chronic criterion for selenium (USEPA 1998a) and concluded that water was a poor choice for a criterion for selenium. Even though there has been a substantial number of papers calling for a water criterion of 2 µg/L (reviewed by Hamilton and Lemly, 1999), there was also a substantial number of examples of aquatic situations where water borne selenium concentrations of 2-4 µg/L have allowed selenium accumulation in the food chain to approach concentrations near or above the proposed dietary toxic threshold of 3 µg/g for fish (Lemly 1993, 1996b, Hamilton 2002). This scenario seems to be occurring at several sites in the current study.

Most of the nine stream sites contained inorganic element concentrations in water that were below the limit of detection. Consequently, no one stream stood out as being impacted by water borne inorganic elements other than upper Georgetown Creek, which contained 11 µg/L selenium.

Judging the health of a stream based only on water borne inorganic element concentrations should be done cautiously. Water concentrations of inorganic elements are generally the basis of water quality standards issued by the U.S. Environmental Protection Agency (USEPA 1998b, 1999). However, investigations have indicated that dietary routes of exposures of inorganic elements were important in discerning effects on biota (reviewed in Hamilton and Hoffman 2002). For example, Kiffney and Clements (1993) reported that monitoring concentrations of cadmium, copper, and zinc in aquatic invertebrates was a better indicator of element bioavailability in the Arkansas River of Colorado, which was impacted by acid mine drainage, than inorganic element concentrations in water. Butler et al. (1994) reported two examples of low selenium concentrations in water, yet elevated concentrations in aquatic invertebrates from the Uncompahgre Valley: Horsefly Creek (<1 µg/L, 6.1 µg/g, respectively) and South Fork (<1 µg/L, 4.8 µg/g, respectively). Stephens et al. (1992) reported four examples from the Green River valley: Sheppard Bottom pond 5 (3-4 µg/L, 4.4-8.9 µg/g, respectively), Desilting Basin (3-5 µg/L, 3-9 µg/g, respectively), Big Island Pond (2-5 µg/L, 5-6 µg/g, respectively), and Felters, Shoveler, and Pintail ponds (1-5 µg/L in adjacent waters, 6-11 µg/g, respectively). Birkner (1978) reported two examples from the Grand Valley: Mac Mesa Reservoir (2.2 µg/L, 7.7 µg/g, respectively), and Highline Reservoir (4.2 µg/L, 7.7 µg/g, respectively), as well as four other locations in Colorado and two in Wyoming. Similar examples were reported in Peltz and Waddell (1991) and Hamilton et al. (1996, 2001a, 2001b).

Comparison to other Idaho water data

The Idaho Mining Association Selenium Subcommittee (Selenium Subcommittee) investigated concentrations of selenium, cadmium, manganese, nickel, vanadium, and zinc in water from numerous sites in the Southeast Idaho Phosphate Resource Area during 1998-2000 and concluded that selenium was the major contaminant of potential concern (MW 1999, 2000, 2001a, 2001b). In May 1998, selenium concentrations in water at 12 of 37 stream sites exceeded

the USEPA criteria of 5 µg/L, whereas in September 1998 only one stream, East Mill Creek (32 µg/L), exceeded the USEPA criteria (MW 1999).

Selenium concentrations in water at sites sampled by Montgomery Watson (MW) in May 1998 that were located close to our sites included the following: <1 µg/L in the Little Blackfoot River (designated ST043), 3 µg/L in Angus Creek (ST129; about 2 km below our site), 7 µg/L in the Blackfoot River at the gaging station (ST019), 9 µg/L in State Land Creek (ST071; about 2 km upstream of our site), 1 µg/L in Smoky Creek (ST173), and 6 µg/L in Georgetown Creek (ST196; about 6 km below our LGC site) (MW 1999). Deer Creek (ST193; about 5 km above our site) was snow covered in May, and Crow Creek was not selected for sampling by MW in 1998. Most of these sites contained selenium concentrations less than in the September sampling (MW 1999). Overall, our selenium concentrations in water were lower than those measured in 1998 by MW, except at upper Georgetown Creek.

In May 1999 MW conducting additional water sampling, but only one site was close to the sites in the current study. They reported 8.2 µg/L at the Blackfoot River gaging station (MW 1999), whereas in September 1999 they reported <1 µg/L selenium in water at the Blackfoot River gaging station, Little Blackfoot River, Angus Creek, and Smoky Creek (MW 2001a). They did not sample other sites in 1999 that were close to those in the current study.

Selenium concentrations in water at sites sampled by MW in May 2000 that were close to our sites included the following: <1 µg/L in the Little Blackfoot River (designated ST043), 2 µg/L in Angus Creek (ST129), 4 µg/L in the Blackfoot River at the gaging station (ST019), 10 µg/L in State Land Creek (ST071), 7 µg/L in Georgetown Creek (ST199), and 18 µg/L downstream Georgetown Creek (ST197) (MW 2001b). Deer Creek (ST193) and Crow Creek were not selected for sampling by MW in 2000. Overall, our selenium concentrations in water were lower than those measured in 2000, except at upper Georgetown Creek. The high selenium concentration in State Land Creek water reported by MW was probably due to selenium loading from two unnamed tributaries downstream of waste rock dumps (ST073 and ST074 were separate tributaries and each contained 160 µg/L selenium, MW 2001b).

In 2001, Tetra Tech collected water samples for analysis of elemental concentrations at 31 sites in the Blackfoot, Bear, and Salt river watersheds in May, June, and September 2001, and six of those sites were close to the locations sampled in the present study (Tetra Tech 2002a). Tetra Tech reported similar selenium concentrations as those in the present study for Little Blackfoot River (close to our site), State Land Creek (about 4 km upstream of our site), middle Angus Creek (about 3 km downstream of our site), Smoky Creek (close to our site), Deer Creek (close to our site), and Crow Creek (close to our site) (Tetra Tech 2002a). They reported 1.9 µg/L in May, 1.5 µg/L in June, and 2.0 µg/L in September in Georgetown Creek, which was similar to our lower Georgetown Creek site (<2 µg/L), but lower than our upper Georgetown Creek site (11 µg/L). This difference in selenium concentrations suggests relatively high variability in selenium concentrations due to dilution from surface and ground water sources. Overall, Tetra Tech (2002a) reported that most selenium loading of watersheds was occurring in the Blackfoot River watershed, less loading in the Salt River watershed coming mostly from Sage Creek with lesser amounts from Deer Creek and Crow Creek, and lower loading in the Bear River watershed coming from Georgetown Creek and Montpelier Creek. They also reported that chronic selenium criteria was exceeded at least once in Georgetown Creek, Sage Creek, East Mill Creek, Spring Creek, Maybe Creek, Dry Valley Creek, Trail Creek, State Land Creek, and the Blackfoot River. Much of the selenium in those surface waters came from elevated selenium

concentrations in seeps, ponds, and drains associated with waste rock piles (MWH 2002a).

In a follow-up study in May 2002, Tetra Tech sampled water at 10 sites they previously sampled in 2001, but only two were close to those in the present study (Tetra Tech 2002b). They reported selenium concentrations in water were 3.0 µg/L at State Land Creek and 2.0 µg/L at Georgetown Creek (about 7 km downstream of LGC), which were higher than concentrations we found. They attributed the higher selenium concentrations and selenium loading in the streams they monitored to the higher snowmelt runoff. They also concluded that selenium loading occured primarily in the spring and was associated with spring runoff.

Sediment

Selenium concentrations in surficial sediment from Blackfoot River gaging station, Angus Creek, Smoky Creek, and Little Blackfoot River were 1.0-1.2 µg/g, which were above the value that Presser et al. (1994) and Moore et al. (1990) used (0.5 µg/g) as a reasonable selenium concentration in sediment to represent the threshold between uncontaminated, background conditions and environments with elevated selenium concentrations. Selenium in surficial sediment from State Land Creek, Crow Creek, Deer Creek, and upper and lower Georgetown Creek were elevated suggesting a substantial contamination concern.

Elevated selenium in sediments is an important consideration in assessing the health of aquatic ecosystems and has been considered as a federal criterion for selenium in a workshop on selenium aquatic toxicity and bioaccumulation (USEPA 1998a). However, the workshop participants concluded that the sediment compartment was a poor choice for a criterion. Two papers have proposed the use of a sediment-based criterion for selenium expressed on a particulate basis, such as sediment selenium concentration or a measure of the organic content of sediment (Canton and Van Derveer 1997, Van Derveer and Canton 1997). Hamilton and Lemly (1999) reviewed these two papers and pointed out how they incorrectly interpreted contaminant survey reports as being exposure-response studies, did not acknowledge the importance of the water borne entry of selenium in aquatic food webs, overlooked key studies from the extensive body of selenium literature, and failed to consider the off-stream consequences of proposing high in-stream selenium standards.

Surficial sediments from upper Georgetown Creek, State Land Creek, and upper Angus Creek tended to have the highest concentrations of several inorganic elements. Generally elevated inorganic elements in sediments from upper and lower Georgetown Creek, Deer Creek, State Land Creek, Smoky Creek, and Angus Creek probably were more stressful to biota than those in sediments from Little Blackfoot River and Blackfoot River at gaging station.

The sediment component of aquatic ecosystems is an important pathway of inorganic element movement through the food web (Seelye et al. 1982). Sediments represent the most concentrated pool of inorganic elements in aquatic environments, and many types of aquatic organisms ingest sediment during the foraging process (Luoma 1983). Fish can ingest inorganic elements from sediment and detritus (Kirby et al. 2001a, 2001b). For example, Campbell (1994) reported that in lakes and ponds contaminated by inorganic elements, bottom feeding redear sunfish (*Lepomis microlophus*) significantly accumulated cadmium, nickel, copper, lead, and zinc, whereas predatory largemouth bass (*Micropterus salmoides*) significantly accumulated cadmium and zinc, and omnivorous bluegill (*Lepomis macrochirus*) significantly accumulated only copper. Others have reported similar findings (Delisle et al. 1977, Van Hassel et al. 1980, Ney and Van Hassel 1983). Dallinger and Kautzky (1985) and Dallinger et al. (1987) concluded

that sediments were an important link in the contamination of food webs with inorganic elements and in the resultant adverse effects in fish.

Specific to selenium, Woock (1984) demonstrated in a cage study with golden shiner (*Notemigonus crysoleucas*) that fish in cages with access to bottom sediments accumulated more selenium than fish held in cages suspended about 1.5 m above the sediments. This study revealed that effects in fish were linked to selenium exposure via sediment, benthic invertebrates, or detritus, or a combination of sediment components. A similar finding was presented by Barnhart (1957) who reported that "numerous species of game fish" lived at least 4 months when held in a livebox, which limited access to food organisms and sediment, but fish lived less than 2 months when released in selenium-contaminated Sweitzer Lake, CO. The highly toxic nature of benthic invertebrates from selenium-contaminated Belews Lake, NC, was reported by Finley (1985) in an experiment where bluegill died in 17 to 44 days after being fed Hexagenia nymphs containing 13.6 µg/g wet weight selenium. Elevated selenium in sediments at North Pond at Walter Walker State Wildlife Area near Grand Junction, CO (geometric mean 25.1 µg/g in 1996 and 38.9 µg/g in 1997) were associated with elevated selenium in the food chain, and increased mortality of larval endangered razorback sucker (*Xyrauchen texanus*) in two 30-day water and dietary exposure studies (Hamilton et al. 2001a, 2001b).

Comparison to other Idaho sediment data

MW (1999) evaluated selenium concentrations in sediment at sites in September 1998 that were close to our sites included: 1.3 µg/g in the Little Blackfoot River (designated ST043), 0.5 µg/g in Angus Creek (ST129), 0.9 µg/g in the Blackfoot River at the gaging station (ST019), 9.4 µg/g in State Land Creek (ST071), 1.0 µg/g in Smoky Creek (ST173), 2.6 µg/g in Georgetown Creek (ST196), and 0.95 µg/g Deer Creek (ST193). In contrast, our State Land Creek site (2.1 µg/g) was a substantial distance downstream of their site (ST071, 9.4 µg/g) and sediment-bound selenium might not have reached the lower creek area, due to numerous depositional areas above our site. Likewise, our selenium concentrations in sediments at the two Georgetown Creek sites (4.5 - 7.5 µg/g) were substantially higher that that reported by MW (1999) (ST196, 2.6 µg/g), which may have been due to their downstream site location. In contrast, the other Georgetown Creek site sampled by MW (1999) was located above the Georgetown Mine and contained only 0.34 µg/g selenium in sediment. Their site on Deer Creek (ST193, 0.95 µg/g) was near the mined area, but also was high elevation and high stream gradient, which may have reduced deposition of selenium in sediments, whereas our site was located closer to depositional areas near the mouth of Deer Creek (4.5 µg/g).

MW (2001a) reported selenium concentrations in sediment at sites in September 1999 at Little Blackfoot River (ST043, 1.6 µg/g), upper Angus Creek (ST129, 1.0 µg/g), Blackfoot River gaging station (ST019, 1.1 µg/g), State Land Creek (ST070, 2.1 µg/g), and Smoky Creek (ST170, 1.1 µg/g) that were similar to those in the present study. The closeness of selenium concentrations in sediments to those in the present study was because MW had shifted the location of several stations relative to the sites sampled in 1998. The only disparity occurred in sediment selenium concentrations in Georgetown Creek where MW (2001a) reported 6.9 µg/g at ST197, which was close to our UGC site (4.5 µg/g), and 1.2 µg/g at ST199, which was close to our LGC site (7.5 µg/g). One other possible disparity occurred in Angus Creek where MW (2001a) reported 5.1 µg/g in sediment collected downstream of the sediment pond (ST130) and about 2 km above our site (1.2 µg/g).

MW (1999) monitored 54 sites in September 1998 and 11 contained selenium concentrations of 2-4 µg/g in sediment including Slug Creek, Dry Valley Creek, Rasmussen Creek (tributary to Angus Creek), and East Mill Creek, whereas State Land Creek contained sediment values greater than 4 µg/g. Overall, the elevated concentrations of selenium and other inorganic elements in sediments from several streams in the Blackfoot, Salt, and Bear river watersheds in the present study coincides with reports by others (MW 1999, 2001a, Hamilton et al. 2002, Hamilton and Buhl 2003) and suggested widespread contamination of the aquatic environment by phosphate mining.

Aquatic plants

No guidelines were found that propose toxicity threshold concentrations for selenium in aquatic plants that might be considered hazardous to aquatic organisms. However, most domestic animals exhibit signs of selenium toxicity on terrestrial vegetative diets containing ≥3-5 µg/g natural selenium (NRC 1980, Eisler 1985, Olson 1986). Selenium concentrations in aquatic plants from lower Georgetown Creek and Little Blackfoot River were 1.8 µg/g or less, which was similar to the lower range of concentrations in the previous studies (Hamilton et al. 2002, Hamilton and Buhl 2003), and thus, this concentration might be considered near background. By comparison, selenium concentrations in aquatic plants at Smoky Creek, upper Angus Creek, upper Georgetown Creek, State Land Creek, Deer Creek, and Crow Creek were relatively elevated, and those at Blackfoot River gaging station were elevated.

Substantial accumulation of selenium has been reported in aquatic macrophytes by Saiki (1986), Schuler et al. (1990), Gutenmann et al. (1976), and Barnum and Gilmer (1988) in selenium-contaminated environments. Submerged macrophytes provide a substrate upon which periphyton and some macroinvertebrates colonize, and which benthic invertebrates and some aquatic and semi-aquatic birds and mammals feed. Although fish typically do not feed on macrophytes, when macrophytes die, they become an important contributor to the detrital food chain. Detritus has been reported to contain highly elevated selenium concentrations in selenium-contaminated environments (9.8-440 µg/g, Saiki 1986; 7-22 µg/g, Saiki et al. 1993; 36-307 µg/g, Saiki and Lowe 1987), whereas reference areas contained 1 µg/g or less (Saiki and Lowe 1987). Benthic invertebrates readily accumulate selenium from detritus (Alaimo et al. 1994), which in turn is bioaccumulated by predators such as fish and waterbirds. Saiki et al. (1993) concluded that high concentrations of selenium in aquatic invertebrates and fish in selenium-contaminated areas of central California were the result of food-chain transfer from selenium-enriched detritus rather than other pathways. Thus, aquatic plants with elevated selenium concentrations from several of the stream sites in the present study were probably contributing to the selenium transfer in the aquatic food web and sediments.

Inorganic elements accumulate in aquatic plants both from water column uptake (Bryson et al. 1984, Devi et al. 1996) and sediment uptake (Cherry and Guthrie 1977, Dallinger and Kautzky 1985, Dallinger et al. 1987). The significant correlation coefficients between surficial sediments and aquatic plants for several inorganic elements (beryllium, cadmium, chromium, and nickel) suggested a strong interconnectedness in some element cycles. Although selenium in aquatic plants was not significantly correlated with selenium in sediments in the present study (r= -0.37, P=0.32), it was significant in two previous studies (r=0.96, P=0.0001, Hamilton et al. 2002; r=0.97, P=0.0001, Hamilton and Buhl 2003).

Uptake of inorganic elements by aquatic plants alone might seem unimportant; however,

inorganic elements in dead plant material can play an important role in the movement of elements and energy through the detrital food web to aquatic invertebrates and fish. Although few herbivores feed on aquatic plants directly, when rooted aquatic plants die, their biomass constitutes greater than 90% of the detrital food chain, whereas the remaining 10% is from algal detritus and animal detritus (Teal 1962, Mann 1972). Much of the nutritional content in detritus comes from microbe enrichment and metabolic products, which add proteins and amino acids to detritus (Odum and de la Cruz 1967, Foda et al. 1983). Although not sampled in the present study, periphyton (composed of diatoms, green algae, and cyanobacteria) are another source of nutrients and inorganic elements for grazing aquatic invertebrates and contributor to the detrital food web (Allan 1995). Uptake of inorganic elements by periphyton could have also contributed to elevated elements in sediments and aquatic invertebrates, especially in western streams where aquatic macrophytes might be limited. Plant litter and other coarse debris that enter a stream are a major source of energy that fuels higher trophic levels (Allan 1995).

Comparison to other Idaho aquatic plant data

MW (2001a) measured selenium concentrations in macrophytes collected in September 1999, but only two sites were close those in the present study. They reported 4.2-4.6 µg/g at the Blackfoot River gaging station (ST019), whereas we found 7.2 µg/g. At Angus Creek (ST129) they reported 1.4-1.7 µg/g, whereas we found 2.8 µg/g. They reported 3.3, 5.1, and 9.2 µg/g in periphyton collected downstream of the sediment pond (ST130) on Angus Creek about 2 km above our site.

MW (2001b) measured selenium concentrations in macrophytes collected in May 2000, but only two sites were close to those in the present study. They reported 2.2-2.8 µg/g at the Blackfoot River gaging station (ST019), whereas we found 7.2 µg/g. At Angus Creek (ST129) they reported 0.6-2.2 µg/g, whereas we found 2.8 µg/g. They reported 8.4, 9.6, and 11 µg/g in submergent macrophytes collected downstream of the sediment pond (ST130) on Angus Creek.

Selenium concentrations in aquatic plants in the present study exceeded the typical background concentration in submerged macrophytes (<1.5 µg/g) (USDOI 1998). Likewise, selenium concentrations in terrestrial plants collected from selenium-impacted riparian sites such as upper Angus Creek (ST130) contained 0.9-1.1 µg/g (MWH 2002b), and in grasses (64 µg/g), forbs (78 µg/g), and shrubs (11 µg/g) in riparian areas next to Maybe Creek (TRC Environmental 1999), a tributary of Dry Valley Creek. These concentrations were above the typical selenium concentrations in terrestrial plants from nonseleniferous soils (<0.25 µg/g) (USDOI 1998).

Elevated selenium and other inorganic elements in aquatic plants have been found in several sites in the Blackfoot River watershed. A native bryophyte that was collected from a seep in 2000 at the base of the Wooley Valley Phosphate Mine Unit 4 waste-rock pile in the headwater area of Angus Creek contained very elevated concentrations of several inorganic elements including cadmium (160 µg/g), cobalt (180 µg/g), chromium (210 µg/g), manganese (33,000 µg/g), nickel (2,000 µg/g), vanadium (1,000 µg/g), zinc (11,000 µg/g), and selenium (750 µg/g) (Herring et al. 2001). This site and others on Angus Creek were previously monitored for inorganic element accumulation in late spring and late summer 1999 using an introduced bryophyte, *Hygrohypnum ochraceum* (Herring et al. 2001). The same elements that were present in the native bryophyte also accumulated in the introduced bryophyte, but selenium was the most enriched of the elements measured.

MW (2001a) reported selenium concentrations in periphyton collected from artificial substrates placed in streams between September and October 1999. Elevated selenium concentrations were found in the Blackfoot River (3.0 µg/g), Angus Creek (3.3-9.2 µg/g), Spring Creek (4.2-7.5 µg/g), and very high values in East Mill Creek (12-25 µg/g). MW (2001b) reported selenium concentrations in periphyton collected from artificial substrates placed in streams between May and June 2000, but fewer streams than investigated in MW (2001a). Elevated selenium concentrations were found in the Blackfoot River (4.3 µg/g) and Angus Creek (6.0 µg/g).

Submerged macrophytes were collected in September 1999 from numerous stream sites in the Blackfoot River watershed and analyzed for selenium concentrations (MW 2001a). They reported several samples with elevated concentrations ranged from 3.2 to 4.8 µg/g, 10 samples with high concentrations ranged from 5.1 to 8.8 µg/g, and one site, East Mill Creek, with very high concentrations ranging from 31 to 46 µg/g. Submerged macrophytes collected by MW (2001b) in May 2000 contained similar selenium concentrations as in the September 1999 collection.

Taking the periphyton, plankton, and submerged macrophyte data together, the elevated selenium concentrations demonstrated that aquatic plants were accumulating selenium from both water and sedimentary sources in the Blackfoot River watershed. MW (2001a, 2001b) acknowledged that submerged aquatic plants were efficient accumulators of selenium. Their values were similar to data in the present report and previous studies (Hamilton et al. 2002, Hamilton and Buhl 2003). Aquatic plants, i.e., periphyton, plankton, submerged macrophytes, are the foundation of the food web including detritus. As such, they are the first link in the bioaccumulation of selenium to higher trophic consumers such as aquatic invertebrates and fish.

Aquatic invertebrates

Selenium concentrations in aquatic invertebrates from Smoky Creek and upper Angus Creek (4.1-5.0 µg/g) were the lowest of the sites investigated, but were above the proposed dietary selenium threshold of 3 µg/g for fish. Several other studies summarized in Hamilton (2002) have reported that dietary selenium concentrations of 4 to 6 µg/g have caused adverse effects in larval fish. Consequently, the moderate dietary selenium concentrations in Little Blackfoot River, Crow Creek, and lower Georgetown Creek (5.4-7.8 µg/g), and the elevated concentrations in Deer Creek, upper Georgetown Creek, State Land Creek, and Blackfoot River gaging station (8.7-10.8 µg/g) were of concern to the health of fishery resources and species that use these resources.

Although upper Angus Creek and Little Blackfoot River contained relatively low selenium concentrations in water, surficial sediments, and aquatic plants, selenium concentrations in aquatic invertebrates were elevated. Benthic invertebrates can be efficient accumulators of selenium and can retain elevated concentrations over long time periods. For example, Maier et al. (1998) reported that aquatic invertebrates contained selenium concentrations of 1.7 µg/g at pretreatment of a watershed with selenium fertilizer, and elevated concentrations during post-treatment monitoring: 4.7 µg/g at 11 days, 4.0 µg/g at 2 months, 5.0 µg/g at 4 months, 4.2 µg/g at 6 months, 4.3 µg/g at 8 months, and 4.5 µg/g at 11 months.

Much of the selenium concentrations in invertebrates likely came from the food web transfer from detritus, which have been reported as the important route of uptake by aquatic invertebrates and fish (Maier and Knight 1994, Lemly 1993, 1996b). Three investigations have

reported high correlations between selenium concentrations in sediment and benthic invertebrates (r=0.94, Zhang and Moore 1996; r=0.87, Malloy et al. 1999 and Hamilton et al. 2001b), which suggested that selenium concentrations in invertebrates were linked with sedimentary selenium. Recently, Peters et al. (1999) reported that two benthic organisms, a eunicid polychaete and a bivalve mollusk, accumulated selenium directly from spiked sediments. In our study, the linkage between selenium concentrations in invertebrates, sediment, and plants, was supported by the significant correlation between aquatic invertebrates and aquatic plants in the present study (r=0.70) and previous studies (r=0.91, P=0.0001, Hamilton et al. 2002; r=0.74, P=0.04, Hamilton and Buhl 2003). Bioaccumulation of selenium through the food web from invertebrates to higher trophic organisms such as fish have been reported by several investigators (Sandholm et al. 1973, Finley 1985, Bennett et al. 1986, Dobbs et al. 1996, Hamilton et al. 2001a, 2001b).

The lack of significant differences, based on the Friedman test, among streams using inorganic element concentrations in aquatic invertebrates suggested that no one stream might be exerting, in general, a greater stress on invertebrates than the others. Nevertheless, aquatic invertebrates in the streams sampled were somewhat enriched. Other investigators have reported enrichment of aquatic invertebrates with inorganic elements in contaminated aquatic environments (Cherry and Guthrie 1977, Patrick and Loutit 1978, Furr et al. 1979, Dallinger and Kautzky 1985, Dallinger et al. 1987), and adverse effects on fish (Woodward et al. 1995, Farag et al. 1998, 1999). Kiffney and Clements (1993) reported that benthic invertebrates readily accumulated cadmium, copper, and zinc in a stream impacted by acid mine drainage, and the accumulation was strongly linked with element concentrations in *aufwuchs* (defined as biotic and abiotic materials accumulating on submerged surfaces).

Comparison to other Idaho aquatic invertebrate data

MW (2001a) measured selenium concentrations in aquatic invertebrates collected in September and October 1999, but only two sites were close those in the present study. They reported 5.0 µg/g at the Blackfoot River gaging station (ST019), whereas we found 10.8 µg/g. At Angus Creek (ST129) they reported 6.2 µg/g, whereas we found 5.0 µg/g. In contrast, they reported 12 µg/g in invertebrates collected below the sediment pond on Angus Creek and about 2 km upstream of our site.

MW (2001b) measured selenium concentrations in aquatic invertebrates collected in May and June 2000, but only two sites were close those in the present study. They reported 4, 12, and 20 µg/g at the Blackfoot River gaging station (ST019), whereas we found 10.8 µg/g. At Angus Creek (ST129) they reported 1, 10, and 37 µg/g, whereas we found 5.0 µg/g. In contrast, they reported 12, 20, and 22 µg/g in invertebrates collected below the sediment pond on Angus Creek.

Selenium concentrations in aquatic invertebrates in the present study exceeded the typical background concentration in aquatic invertebrates (<2 µg/g) (USDOI 1998). Likewise, selenium concentrations in terrestrial invertebrates collected from selenium-impacted riparian sites such as upper Angus Creek (ST130) contained 1.6, 2, and 6 µg/g (MWH 2002b), which was above the typical selenium concentrations in terrestrial invertebrates (<1.5 µg/g) (USDOI 1998).

Elevated selenium concentrations in aquatic invertebrates were reported in two previous studies in the Blackfoot River watershed (Hamilton et al. 2002, Hamilton and Buhl 2003), and by others. Elevated selenium concentrations have been reported in benthic invertebrates collected from ponds (110-390 µg/g) and a lotic area (14 µg/g) of Maybe Creek, a tributary of

Dry Valley Creek (TRC Environmental 1999). Benthic invertebrate samples collected from various sites in Blackfoot Reservoir contained ≤2 µg/g in September 1999, except for three samples, which contained selenium concentrations of 3.8, 4.6, and 10 µg/g (MW 2001a). However, in the May 2000 sampling, 8 of 12 samples from Blackfoot Reservoir contained a geometric mean selenium concentration of 7.8 µg/g (range 5.3 to 12 µg/g; MW 2001b).

Benthic invertebrates collected in September 1999 from numerous stream sites in the Blackfoot River watershed contained low selenium concentrations in 5 of 26 samples (3.0 to 4.6 µg/g), moderately elevated concentrations in 5 samples (5.0 to 15 µg/g), and highly elevated concentrations at East Mill Creek (72 µg/g) (MW 2001a). In the May 2000 sampling, low selenium concentrations occurred in 11 of 42 samples (3.0 to 4.9 µg/g), 17 samples contained moderately elevated concentrations (5.0 to 37 µg/g), and East Mill Creek contained 100, 120 and 170 µg/g (MW 2001b).

The large number of samples with substantial selenium concentrations in aquatic invertebrates from the Blackfoot, Salt, and Bear river watersheds above the proposed toxic threshold of 3 µg/g for fish suggested that benthic invertebrate populations were highly contaminated with selenium. Similar to aquatic plants, benthic invertebrates also demonstrated that selenium accumulation was occurring. Aquatic invertebrates are an important link in the food web, and as such, they allow higher trophic consumers like predatory aquatic invertebrates and fish to bioaccumulate selenium.

Fish

Selenium concentrations in fish from the nine sites, based on geometric mean values, followed the same pattern of accumulation as in aquatic plants and aquatic invertebrates, but not surficial sediments. The similarity in selenium accumulation between aquatic ecosystem components also paralleled the significant correlations between selenium concentrations in fish, aquatic plants, and aquatic invertebrates, which demonstrated the interconnectedness of the aquatic ecosystem components. This accumulation pattern was supported in reviews of the selenium literature (Maier and Knight 1994, Lemly 1993, 1996b).

State Land Creek contained the highest selenium concentrations in whole-body fish and also the highest inorganic element concentrations based on the Friedman test. There seemed to be no parallel accumulation between selenium concentrations and concentrations of inorganic elements in fish from the other streams, especially for Deer Creek, upper Georgetown Creek, Little Blackfoot River, and upper Angus Creek. Consequently, State Land Creek seemed to standout as a potentially highly impacted stream.

In contrast, elevated selenium concentrations in fish from Blackfoot River gaging station, Deer Creek, Crow Creek, and upper Georgetown Creek were cause for concern in spite of lower rankings in the Friedman test based on inorganic element concentrations (except for Crow Creek, which had a similar rank position).

This scenario of selenium being a more important contaminant than other inorganic elements in the present study has occurred in other contaminant investigations. For example, Furr et al. (1979) examined contaminated food chains in coal ash settling basins and concluded that only selenium was of concern to biota. Other investigations reaching similar conclusions were reported by Sorensen (1988), Lemly (1985), Saiki and Lowe (1987), Nakamoto and Hassler (1992), Gillespie and Baumann (1986), Bryson et al. (1984), MW (1999), and Hamilton et al. (2001a, 2001b).

A workshop on selenium aquatic toxicity and bioaccumulation concluded that the tissue-based criterion might be the best approach for a national criterion because tissue residues accounted for selenium's biogeochemical pathways by integrating the route, duration, and magnitude of exposure, chemical form, metabolic transformations, and modifying biotic and abiotic factors (USEPA 1998a). A recent paper gave the rationale for a tissue-based criterion for selenium in fish (Hamilton 2002). That paper proposed a national criterion of 4 µg/g in whole body based on the review of several laboratory and field studies. This concentration was the same as the whole-body toxicity threshold for fish proposed earlier by Lemly (1993, 1996b) and similar to the threshold of 4.5 µg/g proposed by Maier and Knight (1994). Other papers have proposed selenium toxicity thresholds of 6 µg/g for coldwater anadromous fish and 9 µg/g for warm water fish (DeForest et al. 1999, Brix et al. 2000). The approach, information, and conclusions presented in DeForest et al. (1999) and Brix et al. (2000) have been reviewed and problems in their interpretation and conclusions have been discussed in Hamilton (2003). DeForest et al. (1999) and Brix et al. (2000) used selective data to propose high toxicity thresholds for selenium in whole-body and diet of fish, cited older selenium literature containing errors, excluded data from publications based on minor justifications, and overlooked key studies from the extensive selenium literature.

Based on a whole-body toxicity threshold of 4-4.5 µg/g, the geometric mean selenium concentrations in fish from Smoky Creek, Angus Creek, and lower Georgetown Creek (range 4.2-6.8 µg/g) would probably have some effects on early life stages of sensitive species. Fish in Little Blackfoot River and upper Georgetown Creek (7.6-9.8 µg/g) contained selenium concentrations above the 4-4.5 µg/g threshold value, thus suggesting possible effects in sensitive fish species in these streams. Elevated whole-body residues of selenium in fish from Crow Creek, Deer Creek, Blackfoot River gaging station, and State Land Creek (10.4-15.2 µg/g) suggested sensitive and moderately sensitive fish are probably being adversely affected by selenium exposure.

Comparison to other Idaho fish data

MW (2001a) measured selenium concentrations in fish collected in September 1999, but only two sites were close to those in the present study. They reported 10.0 µg/g (converted from 2.8 µg/g wet weight in unidentified forage fish) at the Blackfoot River gaging station (ST019), whereas we found 12.0 µg/g. At Angus Creek (ST129) they reported 3.4 µg/g (converted from 0.74 µg/g wet weight in unidentified forage fish), whereas we found 6.4 µg/g. In contrast, they reported 7.1 µg/g (converted from 1.7 µg/g wet weight) collected below the sediment pond on Angus Creek. For other sites, nine of 13 forage fish samples contained elevated selenium concentrations in fish (5.2 to 8.3 µg/g, after conversion to dry weight using the percent moisture given for each sample), and two samples contained high selenium concentrations of 10 and 12.9 µg/g (MW 2001a).

MW (2001b) measured selenium concentrations in fish collected in May 2000, but only two sites were close to those in the present study. They reported 5.1, 6.2, and 10.0 µg/g (assuming dry weight) in unidentified forage fish (they collected two redside shiner and one sucker species, but did not match the species with the residue) at the Blackfoot River gaging station (ST019), whereas we found 12.0 µg/g. At Angus Creek (ST129) they reported 4.2, 7.4, and 37 µg/g (assuming dry weight) in cutthroat trout, whereas we found 6.4 µg/g. For other sites, 13 of 36 samples of forage fish collected in the Blackfoot River watershed in May 2000

contained selenium concentrations of 5.0 to 9.4 µg/g, and 13 samples contained concentrations of 10 to 37 µg/g (MW 2001b).

Elevated selenium concentrations in fish were reported in two previous studies in the Blackfoot River watershed (Hamilton et al. 2002, Hamilton and Buhl 2003), and by others. Rich and Associates (1999) reported concentrations of inorganic elements in cutthroat trout, rainbow trout, brook trout, sculpin species, dace species, and redside shiner collected from Dry Valley Creek immediately upstream of the Blackfoot River, and Dry Valley Creek directly below Maybe Creek. They concluded that selenium and other elements (cadmium, copper, lead, vanadium, and zinc) were probably causing stress in fish populations in Dry Valley Creek.

Selenium concentrations in whole-body salmonids collected in September 1999 from Blackfoot Reservoir and the mainstem and tributaries of the Blackfoot River were elevated in 21 of 50 samples (4.2 to 9.7 µg/g) and high in 7 samples (12 to 31 µg/g) (converted to dry weight using the appropriate percent moisture from MW 2001a, and whole-body using a factor of 1.667, Lemly and Smith 1987). For salmonids collected in May 2000 from various locations in the Blackfoot River, selenium concentrations in whole-body were elevated in 13 of 27 samples (5.2 to 9.2 µg/g) and high in 12 samples (10 to 48 µg/g) (converted to dry weight using the appropriate percent moisture from MW 2001b, and whole-body using a factor of 1.667, Lemly and Smith 1987). These selenium residues in forage fish and salmonids were substantially above background concentrations in fish from laboratory and field investigations, which are typically 1-2 µg/g (Maier and Knight 1994; Hamilton et al. 2000). More importantly, the selenium residues were above those reported to cause adverse effects in early life stages of fish, including salmonids (4-5 µg/g; Hamilton et al. 2000). In particular, selenium residues of 5.2 µg/g in rainbow trout were associated with reduced survival (Hunn et al. 1987), and 3.8-4.9 µg/g in chinook salmon (*Oncorhynchus tshawytscha*) were associated with reduced survival and growth (Hamilton et al. 1986, Hamilton and Wiedmeyer 1990). Older life stages typically are more tolerant of contaminant stresses than are early life stages (Rand and Petrocelli 1985), thus effects in adults such as mortality and growth may not be as readily apparent as effects in early life stages. However, effects on adults could occur through reduced reproductive success.

Based on the above discussion, selenium contamination of the Blackfoot River and its tributaries is most likely adversely affecting aquatic resources, especially early life stages of fish. Thurow et al. (1981) reported that 13 fish species used the Blackfoot River and its tributaries, and that the indigenous cutthroat trout was the dominant species. They noted that cutthroat trout used several tributaries, as well as the main stem river and the Blackfoot Reservoir during their life cycle. Thurow et al. (1981) acknowledged the potential for mining activities to cause negative effects on trout and others species, primarily from erosion, sedimentation, and nutrient loading from phosphorous, but did not specifically mention impacts from inorganic elements. Selenium is also probably impacting fisheries in the tributaries of the Salt and Bear river watersheds.

The large number of samples in the present study with substantial selenium concentrations above the proposed toxic whole-body threshold of 4 µg/g suggested that fish populations have accumulated elevated selenium concentrations similar to aquatic plants and benthic invertebrates. Thus, forage fish and salmonids probably pose a hazard from dietary selenium toxicity to predatory fish and fish-eating wildlife.

Other considerations

One concern may be the presence of elevated selenium residues in fish from the Blackfoot River and tributaries of the Salt and Bear rivers without readily apparent biological effects. However, data in the current study and studies by others (Rich and Associates 1999, MW 1999, 2000, 2001a, 2001b) were from contaminant surveys and not biological effects studies. No biological or behavioral effects such as survival, growth, reproduction, diversity, population structure, community structure, predator/prey interactions, or other biological effects were measured. Secondly, residues measured in fish were for adults or subadults. This life stage is generally less sensitive to the effects of environmental contaminants than are early life stages (Rand and Petrocelli 1985). The third consideration was the movement of fish in the Blackfoot, Salt, and Bear river watersheds or in any open river system. Adverse effects on a demographically-open fish population in a section of the river with contaminant impacts would be difficult to detect and must be confirmed with detailed biological studies because of immigration of individuals from the portion of the population in non-affected river reaches or tributary streams. The review by Skorupa (1998) addresses this concern succinctly and stated, "It is common for instream studies to report the counterintuitive combination of abnormally elevated levels of selenium in fish tissue associated with what is viewed as a normally abundant and diverse fish fauna." Papers that seem to have reached this unproven conclusion include Canton and Van Derveer (1997), Van Derveer and Canton (1997), and Kennedy et al. (2000). These papers tended to conclude that the toxic thresholds for selenium derived from laboratory studies or field studies in closed basins, i.e., demographically closed populations, do not apply to stream studies. Effects of selenium on species or populations of fish in the lake and reservoir studies were substantiated with appropriate biological tests, whereas stream or river investigations typically have not incorporated appropriate biological tests (Hamilton and Palace 2001).

Monitoring of fish populations in rivers is an insensitive measure of contaminant effects unless substantial effort is made to assess the health of the fish community. This assertion was addressed by the USEPA in their guidelines for deriving water quality criteria. Stephan et al. (1985) stated that, "The insensitivity of most monitoring programs [for number of taxa or individuals] greatly limits their usefulness for studying the validity of [water quality] criteria because unacceptable changes can occur and not be detected. Therefore, although limited field studies can sometimes demonstrate that criteria are under protective, only high quality field studies can reliably demonstrate that criteria are not under protective [i.e., overprotective]."

Claim of no biological effects in stream or river studies cannot often be confirmed without appropriate biological effects tests. Statements of no biological effects in streams or rivers without appropriate testing fall into the null fallacy trap: (1) There is no evidence for adverse effects, versus (2) There is evidence for no adverse effects (J. Skorupa, USFWS, personal communication). The null fallacy occurs when statement 1 (a null finding) is given equal weight as statement 2 (a positive finding). What often is overlooked is that a null finding usually implies a lack of positive evidence in both directions -- for effects or for absence of effects. The null fallacy is just one of several errors in logic found in scientific dialogues (Sagan 1996).

MW (2001b) acknowledged that higher than expected selenium concentrations in forage fish from a reference site on Spring Creek above influences of East Mill Creek were probably due to the mobility of fish. Forage fish in the upper Spring Creek contained selenium concentrations of 10, 12, and 22 µg/g. However, in spite of high selenium residues in whole-

body forage fish collected in May 2000, MW (2001b) stated that, "There is no evidence of forage fish in the Blackfoot Reservoir being impacted by either selenium or cadmium." Likewise, MW (2001a) reported elevated selenium concentrations in forage fish collected in September 1999, yet stated that, "Evaluation of forage fish data show no evidence that this medium is impacted in the reservoir." Because no biological effects were assessed in fish collections in September 1999 or May 2000, their statements were unsupported.

Hazard assessment

Lemly (1995) presented a protocol for aquatic hazard assessment of selenium, which was formulated primarily in terms of the potential for food-chain bioaccumulation and reproductive impairment in fish and aquatic birds. The protocol incorporated five ecosystem components including water, sediment, benthic invertebrates, fish eggs, and bird eggs. Each component was given a numeric score based on the degree of hazard: 1, no identifiable hazard (no toxic threat is identified and selenium concentrations are not elevated in any ecosystem component); 2, minimal hazard (no toxic threat identified but concentrations of selenium are slightly elevated in one or more ecosystem components [water, sediment, benthic invertebrates, fish eggs, bird eggs] compared to uncontaminated reference sites); 3, low hazard (a periodic or ephemeral toxic threat that could marginally affect the reproductive success of some sensitive species, but most species will be unaffected); 4, moderate hazard (a persistent toxic threat of sufficient magnitude to substantially impair but not eliminate reproductive success; some species will be severely affected whereas others will be relatively unaffected); 5, high hazard (an imminent, persistent toxic threat sufficient to cause complete reproductive failure in most species of fish and aquatic birds). The final hazard characterization was determined by adding the individual scores and comparing the total to the following evaluation criteria: 5, no hazard; 6-8, minimal hazard; 9-11, low hazard; 12-15, moderate hazard; 16-25, high hazard.

Lemly (1996a) modified his protocol for use with four ecosystem components due to the difficulty in collecting residue information for all five components in an assessment, and adjusted the final ecosystem-level hazard assessment to the following four-component evaluation criteria: 4, no hazard; 5-7, minimal hazard; 8-10, low hazard; 11-14, moderate hazard; 15-20, high hazard. Table 14 gives the hazard term and corresponding selenium concentration range for each of the four ecosystem components in the four-component model (Lemly 1996a).

These protocols have been used to assess the selenium hazard to aquatic ecosystems at Ouray NWR, UT (Lemly 1995, 1996a), the Animas, LaPlata, and Mancos rivers in the San Juan River basin (Lemly 1997), three Wildlife Management Areas in Nevada (Lemly 1996a), and

Table 14. Aquatic ecosystem components and selenium concentrations posing various hazards based on Lemly (1996a).

	Hazard														
	None			Minimal			Low			Moderate			High		
Ecosystem component	Conc.	Lemly[1] score	Modified score	Conc.	Lemly[1] score	Modified score	Conc.	Lemly[1] score	Modified score	Conc.	Lemly[1] score	Modified score	Conc.	Lemly[1] score	Modified score
Water (µg/L)	<1	1	1	1-2	2	2	2-3	3	3	3-5	4	4	>5	5	5
Sediment (µg/g)	<1	1	1	1-2	2	2	2-3	3	3	3-4	4	4	>4	5	5
Benthic invertebrate (µg/g)	<2	1	2	2-3	2	4	3-4	3	6	4-5	4	8	>5	5	10
Fish eggs (µg/g)	<3	1	3	3-5	2	6	5-10	3	9	10-20	4	12	>20	5	15
Sum		4	7		8	14		12	21		16	28		20	35
Final hazard (Lemly[1])	4			5-7			8-10			11-14			15-20		
Final hazard (Modified)			7			8-13			14-20			21-27			28-35

[1]Lemly 1996a.

three sites near Grand Junction, CO (Hamilton et al. 2001a, 2001b). Stephens et al. (1997) and Engberg et al. (1998) have reported hazard classification schemes that were similar to Lemly (1995, 1996a).

The selenium hazard protocols give equal weight to each component (Lemly 1995, 1996a). However, there may be the need to give more weight to the biological components: benthic invertebrates, fish eggs, and bird eggs (written communication, H. Ohlendorf, 1996). Ohlendorf suggested a multiplication factor of two for the score for benthic invertebrate information and a factor of three for the score for fish eggs and bird eggs. Similar concerns have been raised by a USGS scientist (written communication, M. Sylvester, Menlo Park, CA, 2002), and a USFWS Environmental Contaminant Specialist (written communication, B. Osmundson, Grand Junction, CO, 2001). The weighting of the three biological components seems justified based on the repeated expression of their importance in the selenium literature (reviews by Lemly 1985, 1993, Maier and Knight 1994, Presser et al. 1994, Hamilton and Lemly 1999, Hamilton 2002, 2003).

Incorporating these factors into the protocol using the offset summation approach results in modified final hazard characterizations for the four-component protocol of 7, no hazard; 8-13, minimal hazard; 14-20, low hazard; 21-27, moderate hazard, and 28-35, high hazard (Table 14). The offset summation is explained as follows: for the low hazard column, Lemly (1996a) gives a score of 3 for each of the four components being evaluated (water, sediment, benthic invertebrate, and fish eggs), which results in a summed score of 12 (Table 14). However, if in an environmental situation all measured selenium concentrations of the four components fell into the "low" column, the additive effect of the combined low exposures would most likely result in a "moderate" final hazard to biota. Thus, Lemly (1996a) set the final hazard range for a "low" final hazard at 8-10, instead of closer to the summed total of 12. This offsetting of the final hazard total seems biologically reasonable and is referred to here as the offset summation approach. Similar offsets for other final hazards are given in Table 14. For the five-component protocol, the modified final hazard characterization would be 10, no hazard; 11-19, minimal hazard; 20-28, low hazard; 29-38, moderate hazard, and 39-50, high hazard. This modified hazard assessment was used in two previous investigations in the Blackfoot River watershed (Hamilton et al. 2002, Hamilton and Buhl 2003).

In the present study, fish eggs were not collected. In the hazard assessment, we converted the geometric mean whole-body concentrations of selenium in fish to fish eggs concentrations using the conversion factor based on Lemly (1995, 1996a), who reported: whole-body $\times$ 3.3 = fish egg. The hazard assessment for the nine sites is given in Table 15.

The two sites with minimal to moderate selenium concentrations in most aquatic ecosystem components had moderate overall hazard rating: Angus Creek and Smoky Creek. Although selenium concentrations were none or minimal in water and sediment at Little Blackfoot River and Blackfoot River gaging station, they were elevated in benthic invertebrates and whole body residues converted to fish egg concentrations, resulting in an overall high hazard rating. Selenium concentrations in water or sediment were in the none or low categories at State Land Creek and Crow Creek, but high in benthic invertebrates and whole-body residues. Thus these two sites received high final hazards. Upper and lower Georgetown Creek and Deer Creek consistently contained elevated selenium concentrations in sediment, invertebrates, and whole-body residues, thus resulting in an overall high hazard rating. Using the original Lemly (1996a)

Table 15. Hazard assessment of selenium at nine sites in southeastern Idaho using modified scores.

Site[1] and ecosystem component	Selenium concentration[2]	Evaluation by component		Total for the site	
		Hazard	Score	Score	Hazard
LiB					
Water	<2	None	1		
Sediment	1.8	Minimal	2	28	High
Benthic invertebrate	5.4	High	10		
Fish eggs[3]	25.1	High	15		
UAC					
Water	<2	None	1		
Sediment	1.2	Minimal	2	26	Moderate
Benthic invertebrate	5.0	Moderate	8		
Fish eggs	21.1	High	15		
BGS					
Water	<2	None	1		
Sediment	1.0	Minimal	2	28	High
Benthic invertebrate	10.8	High	10		
Fish eggs	39.6	High	15		
SLC					
Water	<2	None	1		
Sediment	2.1	Low	3	29	High
Benthic invertebrate	9.7	High	10		
Fish eggs	50.2	High	15		
SC					
Water	<2	None	1		
Sediment	1.2	Minimal	2	23	Moderate
Benthic invertebrate	4.1	Moderate	8		
Fish eggs	13.9	Moderate	12		
UGC					
Water	11	High	5		
Sediment	4.5	High	5	35	High
Benthic invertebrate	9.3	High	10		
Fish eggs	32.3	High	15		
LGC					
Water	<2	None	1		
Sediment	7.5	High	5	31	High
Benthic invertebrate	7.8	High	10		
Fish eggs	22.4	High	15		

Table 15. Continued.

Site[1] and ecosystem component	Selenium concentration[2]	Evaluation by component		Total for the site	
		Hazard	Score	Score	Hazard
DC					
Water	<2	None	1		
Sediment	4.5	High	5	31	High
Benthic invertebrate	8.7	High	10		
Fish eggs	38.0	High	15		
CC					
Water	<2	None	1		
Sediment	2.1	Low	2	28	High
Benthic invertebrate	6.7	High	10		
Fish eggs	34.3	High	15		

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.

[2]Selenium concentrations in µg/L for water, µg/g for sediment, benthic invertebrates, and fish eggs.

[3]Fish eggs: fish egg values converted from whole-body residues using: whole-body × 3.3 = fish egg (Lemly 1995, 1996a).

approach, Little Blackfoot River, Blackfoot River gaging station, State Land Creek, and Crow Creek would have received moderate final hazards in spite of the high score for benthic invertebrates and fish eggs (converted from whole-body residues).

Based on the final hazard score (in parentheses) the streams can be listed from highest selenium hazard to lowest as follows: UGC (35), DC (31), LGC (31), SLC (29), BGS (28), LiB (28), CC (28), UAC (26), SC (23). This ranking is very similar to the results of the Friedman test using the ranked selenium concentrations: UGC_a, SLC_a, BGS_a, DC_{ab}, CC_{ab}, LGC_{abc}, LiB_{bc}, UAC_c, SC_c. The largest major disparity seemed to occur in the ranking of lower Georgetown Creek. Thus, the selenium hazard protocol seems to be a useful tool in assessing the differences among sites due to the comparable outcome of statistical approach such as the Friedman test.

Reports by MW (1999, 2000, 2001a, 2001b) do not present hazard assessments. However, the data evaluations of the various aquatic ecosystem components for water, sediment, submerged macrophytes, benthic invertebrates, forage fish and salmonid fillets, tend to suggest no major impacts from selenium and other elements, with the exception of creeks influenced directly by phosphate mining.

A preliminary assessment of selenium hazard in the Caribou National Forest was conducted using selenium residue data in water and fish collected from 1997-1998 (Lemly 1999). Lemly (1999) concluded that there was a high potential for toxic impacts occurring in fish and wildlife associated with the Blackfoot River, its tributaries, and tributaries of the Salt and Bear rivers. The results of the present study and two previous studies add substantially more support to the premise that selenium concentrations in several aquatic ecosystem components were sufficiently elevated to cause adverse effects to aquatic resources and terrestrial species that utilize these resources in the Blackfoot River watershed.

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Appendix 1. Wet weight (g) of aquatic plants from nine sites in southeastern Idaho submitted for either selenium analysis (Se) or inorganic element analysis (ICP).

	Analysis	
Site[1]	Se	ICP
LiB	8.33	7.08
LiB[2]	10.95	11.77
UAC	7.43	10.46
BGS	5.45	6.13
SLC	6.14	8.05
SC	5.45	8.64
UGC	3.15	3.57
LGC	5.88	5.81
DC	5.78	6.83
CC	9.33	8.66
CC[2]	5.00	3.79

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.
[2]Leaves and stems.

Appendix 2. Wet weight (g) of aquatic invertebrates from nine sites in southeastern Idaho submitted for either selenium analysis (Se) or inorganic element analysis (ICP).

Site[1]	Chemical analysis	Composite weight	Aquatic invertebrate type							
			Gammaridae	Caddisfly	Mayfly	Damselfly	Beetle larvae	Stonefly	Dragonfly	Diter a
LiB	Se	5.20	0.89	0.13	0.06	4.12	-	-	-	-
	ICP	4.40	1.23	0.05	0.07	3.05	-	-	-	-
UAC	Se	7.55	4.99	1.04	1.52	-	-	-	-	-
	ICP	6.58	3.73	1.31	1.54	-	-	-	-	-
BGS	Se	3.31	-	2.40	0.38	-	-	-	0.53	-
	ICP	3.04	-	2.52	0.26	-	-	-	0.26	-
SLC	Se	8.48	2.09	5.43	-	-	0.11	-	0.85	-
	ICP	8.08	2.30	4.71	-	-	0.16	-	0.91	-
SC	Se	6.00	-	1.33	3.91	-	-	0.76	-	-
	ICP	6.25	-	1.07	4.45	-	-	0.73	-	-
UGC	Se	9.69	-	-	8.10	-	0.51	1.08	-	-
	ICP	7.59	-	-	6.45	-	0.40	0.74	-	-
LGC	Se	8.91	-	4.07	0.50	-	-	4.34	-	-
	ICP	9.24	-	4.09	0.48	-	-	4.67	-	-
DC	Se	10.09	-	2.52	1.75	-	2.30	1.82	-	1.70
	ICP	10.13	-	2.35	1.56	-	2.64	2.66	-	0.92

Appendix 2. Continued.

Site [1]	Chemical analysis	Composite weight	Aquatic invertebrate type							
			Gammaridae	Caddisfly	Mayfly	Damselfly	Beetle larvae	Stonefly	Dragonfly	Diptera
CC	Se	9.84	-	0.77	6.87	-	0.54	0.49	-	1.17
	ICP	10.77	-	0.78	7.67	-	0.50	0.56	-	1.26

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.

Appendix 3. Total length (mm), weight (g), and use (selenium analysis [Se], inorganic element analysis [ICP], or archive [A]) of fish from nine sites in southeastern Idaho.

Site[1]	Species	Total length	Weight	Use
LiB	Speckled dace	67	3.46	Se
		56	1.65	Se
		68	3.14	Se
		55	1.64	ICP
		54	1.44	ICP
		42	0.74	ICP
		58	2.14	A
	Unknown minnow	79	4.83	Se
		73	3.96	Se
		82	6.12	ICP
		92	8.40	A
UAC	Cutthroat trout	88	6.53	Se
		80	4.80	Se
		86	5.98	ICP
		68	2.93	ICP
	Mottled sculpin	74	5.10	Se
		67	3.44	ICP
BGS	Cutthroat trout	107	10.79	Se
		115	14.75	Se
		153	34.14	ICP
	Mottled sculpin	90	9.84	Se
		68	4.24	Se
		56	2.50	Se
		80	7.14	ICP
		71	4.54	ICP
		55	2.25	ICP
	Longnose dace	105	11.79	Se
		84	6.73	Se
		89	7.11	ICP
		65	3.31	ICP
		97	9.68	A

Appendix 3. Continued.

Site[1]	Species	Total length	Weight	Use
BGS	Unknown chub	173	59.54	Se
		170	59.77	ICP
		183	72.72	A
	Redside shiner	80	6.08	Se
		67	2.93	Se
		78	5.23	ICP
		69	3.61	ICP
		45	0.79	A
		44	0.85	A
SLC	Speckled dace	78	3.13	Se
		54	1.43	Se
		61	1.65	ICP
		64	1.73	ICP
SC	Cutthroat trout	48	0.96	Se
		48	1.11	Se
		58	1.53	ICP
		50	1.15	ICP
		109	9.16	Se
		92	7.08	Se
		120	17.22	ICP
UGC	Brook trout	165	42.92	Se
		106	13.24	Se
		88	6.04	Se
		157	37.71	ICP
		188	78.07	ICP
LGC	Brook trout	49	1.08	Se
		46	0.82	Se
		48	1.05	ICP
		115	15.92	Se
		91	7.20	Se
		118	17.58	ICP
	Rainbow trout	106	12.21	Se

Appendix 3. Continued.

Site[1]	Species	Total length	Weight	Use
DC	Cutthroat trout	72	3.57	Se
		74	3.70	Se
		75	3.75	Se
		85	5.29	ICP
		83	4.85	ICP
		118	13.79	Se
		102	8.60	ICP
	Mottled sculpin	88	9.66	Se
		64	3.41	Se
		77	5.95	ICP
		75	5.27	ICP
		66	3.44	A
CC	Brown trout	150	37.97	Se
		168	51.18	Se
		169	50.54	ICP
	Mottled sculpin	93	13.73	Se
		71	6.93	Se
		100	13.44	ICP
		71	5.08	ICP
	Longnose dace	44	0.75	Se
		47	0.92	Se
		45	0.85	Se
		41	0.61	ICP
		41	0.61	ICP
		43	0.75	ICP
		34	0.37	A
		117	19.21	Se
		85	4.76	Se
		91	6.87	ICP
		95	15.31	ICP

[1]LiB: Little Blackfoot River, UAC: upper Angus Creek, BGS: Blackfoot River gaging station, SLC: State Land Creek, SC: Smoky Creek, UGC: upper Georgetown Creek, LGC: lower Georgetown Creek, DC: Deer Creek, CC: Crow Creek.