U.S. Geological Survey Open-File Report 02-0330

Water and Sediment Study of the Snake River Watershed, Colorado,

Oct. 9-12, 2001

By

D.L. Fey, S.E. Church, D.M. Unruh, and D.J. Bove

U.S. Department of the Interior

U.S. Geological Survey

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Abstract

The Snake River watershed, located upstream from Dillon Reservoir in the central mountains of Colorado, has been affected by historical base-metal mining. Trout stocked in the Snake River for recreational purposes do not survive through the winter. Sediment cores analyzed by previous investigators from the reservoir revealed elevated concentrations of base metals and mercury. We collected 36 surface water samples (filtered and unfiltered) and 38 streambed-sediment samples from streams in the Snake River watershed. Analyses of the sediment and water samples show that concentrations of several metals exceed aquatic life standards in one or both media. Ribbon maps showing dissolved concentrations of zinc, cadmium, copper, and manganese in water (0.45-micron filtered and corrected for the ameliorating effect of hardness), and copper, cadmium, and zinc in sediment indicate reaches where toxic effects on trout would be expected and stream reaches where toxicity standards for rainbow, brown, and brook trout are exceeded.

Instantaneous loads for sulfate, strontium, iron, cadmium, copper, and zinc were calculated from 0.45-micron-filtered water concentrations and discharge measurements were made at each site. Sulfate and strontium behave conservatively, whereas copper, cadmium, and zinc are reactive. The dissolved copper load entering the reservoir is less than 20 percent of the value calculated from some upper reaches; copper is transferred to suspended and or streambed sediment by sorption to iron oxyhydroxides. Higher percentages of zinc and cadmium reach the reservoir in dissolved form; however, load calculations indicate that some of these metals are also precipitated out of solution. The most effective remediation activities should be concentrated on reducing the dissolved loads of zinc, cadmium, and copper in two reaches of lower Peru Creek between the confluence with the Snake River and Cinnamon Gulch.

We analyzed all streambed sediment for mercury and selected streambed-sediment and reservoir core samples for lead isotope signatures. Results indicate that the mercury anomaly in the reservoir sediment was not from any known source in the Snake River, Blue River, or Tenmile Creek watersheds. Its source remains an enigma.

Introduction

The Snake River drains the watershed east of Dillon Reservoir in Summit County, Colorado. It contains numerous inactive, historical hardrock mines (Wilson and LaRock, 1992; Munroe, 2000). Drainage from these mines and rainfall or snowmelt runoff from waste piles and altered rock in the drainage affects the water quality of the Snake River and some of its tributaries. The Snake River flows into Dillon Reservoir, a major recreational area, and a supplier of water to Denver. A previous study by Greve and others (2001) identified elevated levels of mining-related metals in Dillon Reservoir sediments. This report presents the results of sampling conducted over a four-day period October 9-12, 2001 during low flow. Sample localities are in figure 1. Thirty-six water samples and 38 streambed-sediment samples were collected. In addition, we present data from water samples collected hourly during the day at two localities to assess time-based variations in zinc concentrations. We also performed lead isotope analyses on samples obtained from Dillon Reservoir to determine whether the lead anomaly that occurred in conjunction with the mercury anomaly in the cores could be traced to any of the mines in the Snake River watershed.

Purpose and Scope

We collected water and streambed sediment samples from the Snake River watershed to assess the effect of past mining activities on the aquatic environment and on water quality in Dillon Reservoir and to assist the U.S. Forest Service in their assessment of Federal lands in the watershed. Past mining activity in the region has resulted in elevated metal anomalies in sediment from Dillon Reservoir, including copper, lead, zinc, and mercury. Metal concentrations in stream reaches are known to have adverse affects on Rainbow, Brook, and Brown Trout. This study assesses the possible effects of metals on trout survivability in the watershed.

Previous investigations

A number of studies of the study area and nearby basins have been made, including the geology (Lovering, 1935; Neuerberg, 1971), geochemistry (Theobald and others, 1963; Sullivan and others, 1998; Deacon and Driver, 1999), abandoned mines (Munroe, 2000), water quality (Greve and others, 2001), sediment quality (Apodaca and others, 1999), and biology (Chadwick Ecological Consultants, 1996). Reconnaissance geochemical sampling was conducted in the mid-1970s under the National Uranium Resource Evaluation (NURE) program (Planner and others, 1980; Hills and others, 1982).

Acknowledgements

We thank the U.S. Forest Service and the Army Corps of Engineers for partial support of this work. We also thank Greg O’Neill, Rick Neam, Ben Glass, and Pete Theodorakos for field assistance.

Geology

A summary of the geology of the Montezuma area is in figure 2. Emplacement of the Montezuma stock and associated dikes and small intrusive plugs was one of the primary factors causing extensive fracturing and mineralization in the Montezuma mining district. Heated, metal-bearing fluids formed economic mineral deposits and created a widespread area of hydrothermally altered rock, containing abundant disseminated pyrite. The Oligocene age Montezuma stock is composed primarily of quartz monzonite of the granite porphyry (Bookstrom and others, 1987). It intruded Precambrian age hornblende gneiss and schist. Faults, fractures, and pyrite-rich alteration associated with the stock extend into the surrounding Precambrian gneiss (Meyer and others, 1996).

Surficial exposures of the Montezuma stock extend south to the town of Montezuma. A band of highly altered and pervasively pyritic rock about 1 to 2 miles wide is superimposed on the southeast part

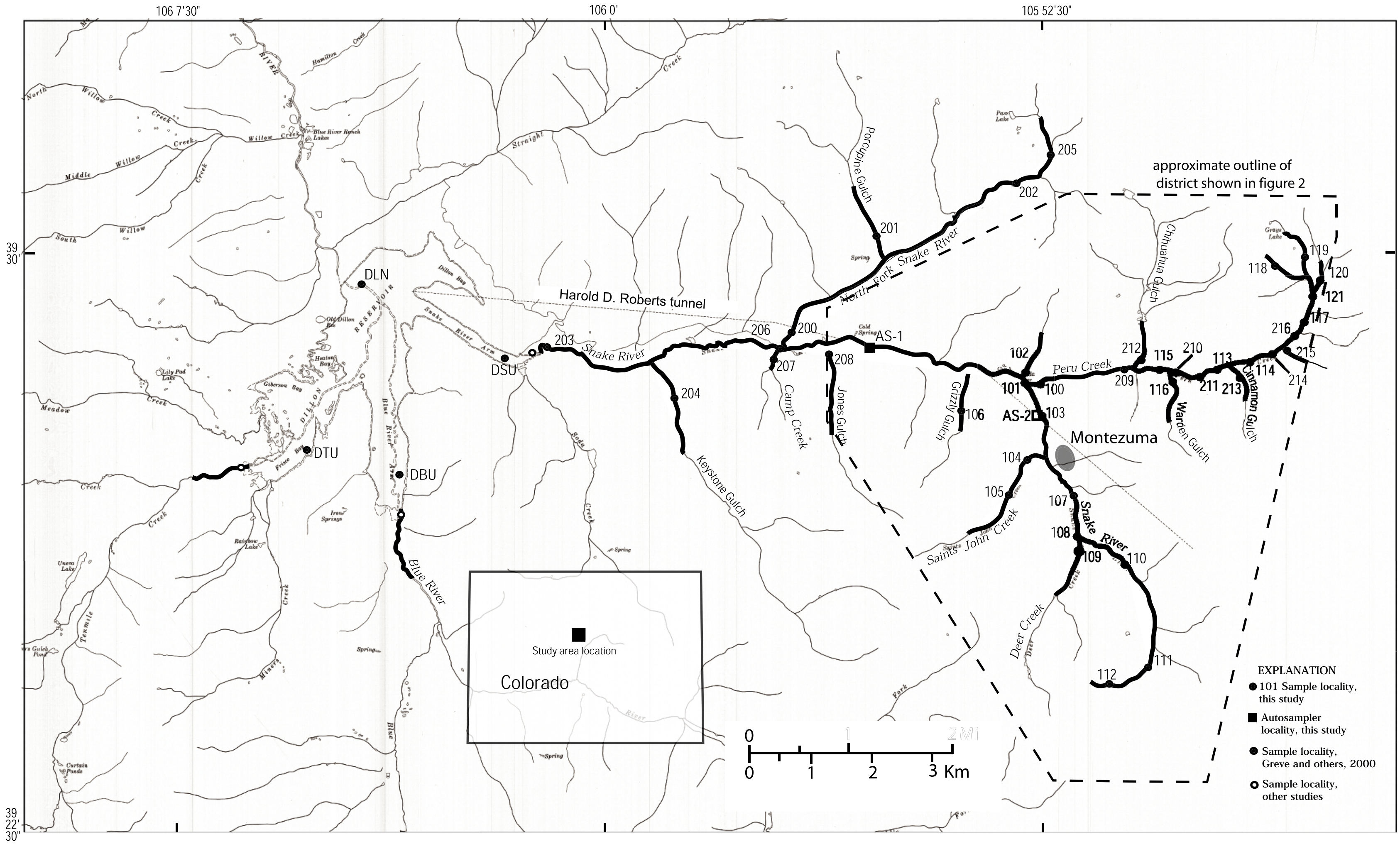

Figure 1. Locality map of streambed-sediment and water quality samples, and placement of autosamplers. Outline of geologic map of the Montezuma mining district shown as a dashed line (fig. 2).

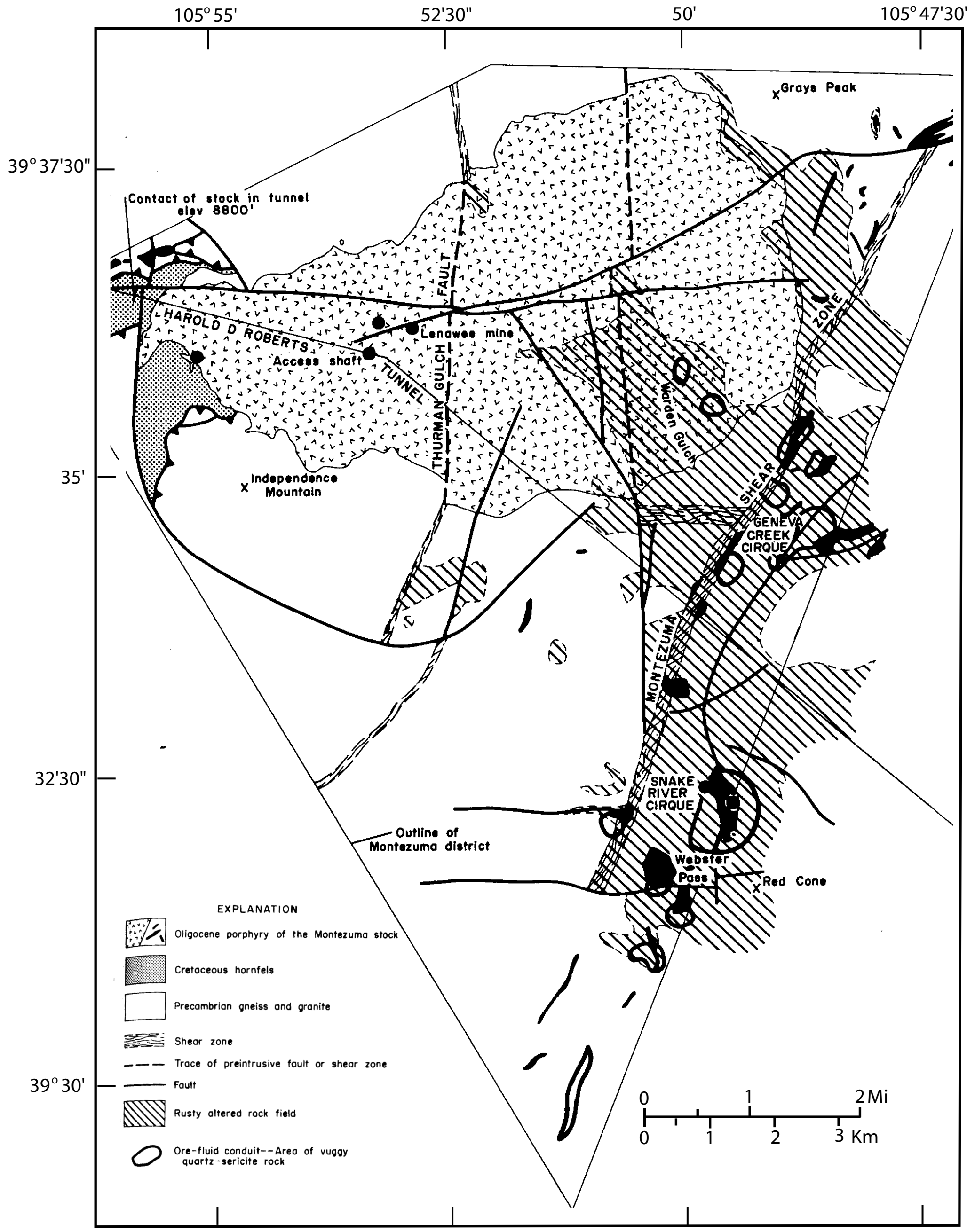

Figure 2. Generalized Geology of Montezuma District
(from Neuerberg and others, 1974)

of the stock (fig. 2). This band of altered rock follows along the Montezuma shear zone, and extends southward and eastward into the Precambrian rocks (Neuerberg, 1971a).

Pyrite, galena, and sphalerite are the major sulfide minerals in veins associated with the Montezuma stock and related intrusions. Chalcopyrite and copper sulphosalts are also common. Quartz, manganiferous carbonate, and barite occur as gangue minerals (Neuerberg, 1971a). Locally, molybdenite is also common. Ferricrete deposits are common in the areas underlain by and peripheral to altered rocks.

Intrusive History

A voluminous suite of granite porphyry intrusive bodies were emplaced between 45 and 35 Ma ago into Precambrian igneous and metamorphic rocks, along the north-central Colorado Mineral Belt from Empire to Climax (Bookstrom and others, 1987). Examples of these intrusions include the Montezuma stock and associated intrusions. The Fe, Cu, Zn, Pb, Ag, Au, and Mo-bearing hydrothermal systems of the Montezuma and surrounding area are related to intrusions of this suite of late Eocene-early Oligocene granitic intrusions. The 40 Ma Montezuma granite porphyry stock is the largest outcropping pluton in a northeast trending swarm of smaller stocks, plugs, cupolas and dikes. This swarm extends from near Breckenridge, northeastward to near Empire.

Hydrothermal Alteration and Mineralization

Hydrothermally altered rock and strongly pyritic zones are common throughout the Montezuma district. Zones of intensely altered rock show a strong spatial correlation with the Montezuma shear zone and especially within these granite-rhyolite porphyry intrusions (A. Bookstrom, U.S. Geological Survey, oral commun., 2001). A zone of potassic altered rock is only recognized locally in the Snake River cirque. This alteration assemblage is characterized by the recrystallization of the intrusive groundmass by quartz and potassic feldspar and stockwork quartz-magnetite-pyrite-molybdenite veinlets (Neuerberg and others, 1974). Phyllic alteration is concentrated mostly within and adjacent to the post-40 Ma granite-rhyolite porphyry intrusions. Pyrite within these rocks is typically fine-grained and abundant. Other sulfide minerals, including chalcopyrite, bismuthinite, molybdenite, and sphalerite, are rare. In some localities, the phyllic-altered rock is vuggy and quite permeable. These vuggy phyllic zones are commonly accompanied by quartz-pyrite veins and were postulated by Neuerberg and others (1974) to be major conduits of the complex hydrothermal system.

Propylitic altered rock is volumetrically abundant throughout the area and consists of chloritized biotite and partially sericitized plagioclase, with fine-grained pyrite, calcite, and locally minor sphalerite. These rocks are typically enriched in zinc as well as other chalcophile elements, largely associated with the abundance of fracture-filling veins. Zones of propylitic altered rock grade outward into weakly chloritic zones, in which biotite is altered to chlorite, and hematite is present along fractures.

The mineral deposits within the Montezuma district are predominantly polymetallic (Ag-Pb-Zn) vein deposits. The veins are localized in and around the margins of zones of hydrothermally altered rock and extend into regions of unaltered rock. Sulfide minerals in the veins include pyrite, galena, and sphalerite, generally with tetrahedrite and chalcopyrite and less commonly with silver and bismuth sulfosalts (Neuerberg, 1971a).

Minor molybdenite is disseminated in many of the rocks in the Montezuma area; in addition, it also present locally within vein and fracture fillings (Neuerberg and others, 1974). The disseminated molybdenite spatially corresponds to zones of more intensely altered rock and increases slightly in quantity toward the inner parts of the alteration zones.

Sample Collection

Streambed Sediment

We collected 38 streambed-sediment samples from the Snake River and its tributaries, including the North Fork Snake River, Peru Creek, Saints John Creek, Deer Creek, Keystone Gulch, Camp Creek, Jones Gulch, Grizzly Gulch, Porcupine Gulch, Thurman Gulch, Chihuahua Gulch, Warden Gulch, Cinnamon Gulch, and several unnamed small tributaries. Sample sites are located on the Montezuma, Keystone, Loveland Pass, Grays Peak, and Frisco, Colorado U.S. Geological Survey 1:24,000 topographic maps (fig. 1).

Streambed-sediment samples represent the integration of geologic materials exposed in the watershed upstream from the sample locality. Analyses of streambed sediment reflect the geochemistry of material eroded upstream of the sample site and of colloidal or iron oxyhydroxide material coating detrital grains. An integrated streambed-sediment sample was collected at each site by compositing 10 to 20 individual subsites within 15 m (50 ft) of the plotted sample locality; material collected was from the active channel alluvium. Each sample composite was sieved in the field through a 2 mm (10 mesh) stainless steel screen, and the minus-2-mm fraction retained; the larger size fractions were discarded.

Samples were air-dried in the laboratory, sieved to minus-80 mesh (<0.18 mm), and the minus-80-mesh fraction was ground to minus-150 mesh before analysis. The plus-80 mesh fraction was archived but not ground or analyzed.

Core Samples

Selected subsamples from Dillon Reservoir cores (labeled DLN, DBU, DSU, and DTU on figure 1) were analyzed for lead isotopes. The lead isotopic signature from the sediment in the core interval can be used as a tracer of different mineral deposits to help pinpoint the potential source of the mercury anomaly. The core samples are described in Greve and others (2001), and were subsequently provided for this study to address the potential source of the mercury anomaly in the core from near the dam in Dillon Reservoir.

Surface Water Samples

We collected 36 surface-water samples from the same sample localities where streambed sediment was collected, except where the site was dry (fig. 1). Samples were collected using a DH 81 sampler, and were width and depth integrated. Field parameters (pH, conductivity, and temperature) were recorded at each site; these data are in table A1. Four sample aliquots were collected: 1) unfiltered samples for total metal content (preserved with ultra-pure nitric acid); 2) samples filtered on-site through a syringe-mounted 0.45-micron filter for dissolved metal analysis (preserved with ultra-pure nitric acid); 3) samples filtered on-site through the same syringe-mounted filter for anion analysis (kept refrigerated and dark until analysis); and 4) samples filtered on-site (same syringe-mounted filter) and preserved with sodium dichromate in glass vials for mercury analysis.

Diel Zinc Concentrations in Surface Water Samples

At two separate localities, we installed automated water samplers to collect surface-water samples every hour during the day, typically 9:00 AM to 5:00 PM. Localities of the autosamplers (AS-1 and AS-2) on the Snake River above and below the confluence with Peru Creek (fig. 1). We collected these samples to monitor changes in zinc and sulfate concentration throughout the day over the sampling period. Weather conditions (subfreezing temperatures) prevented the deployment of the autosamplers overnight. The water samples collected during the day were processed that night. The samples were filtered (0.45 micron), and preserved using ultra-pure nitric acid for subsequent cation analysis.

Discharge Measurements

Discharge measurements were made at all water collection sites except one (SRP-118), in order to calculate metal loads at individual sites. Measurements were made with a pygmy-meter where flow was sufficient, or with a small portable weir and stopwatch where flow was very low. Discharge measurements are in table A1.

Sample Analysis

Streambed Sediment Total Digestion

The streambed-sediment samples were digested in a mixed four-acid media of HCl, HNO_3, $HClO_4$, and HF, and analyzed for 40 elements by inductively coupled plasma-atomic emission spectroscopy (ICP-AES; Briggs, 1996). This digestion procedure dissolves most minerals, including silicates, oxides and sulfides; resistant or refractory minerals such as zircon, chromite, and some tin oxides are only partially dissolved. Previous investigations using a variety of geologic materials confirm the completeness of the digestion (Church and others, 1987; Wilson and others, 1994). The data are in table A2.

Mercury in Sediment

Mercury analyses on the streambed-sediment samples were performed by cold vapor-atomic absorption spectrophotometry (O'Leary and others, 1996). The data are in table A2.

Lead Isotope Analyses

Selected streambed-sediment samples from the present study and selected core intervals from Dillon Reservoir (Greve and others, 2001) were analyzed for their lead isotope signatures. The data are in table 5. Four isotopes of lead exist in nature, three of which change directly as a function of time through the radioactive decay of uranium and thorium: ^{206}Pb is the daughter product of decay of ^{238}U, ^{207}Pb is the daughter product of decay of ^{235}U, ^{208}Pb is the daughter product of decay of ^{232}Th. However, ^{204}Pb has no radioactive parent. Thus, the isotopic composition of lead in rocks in the earth's crust (that is, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$) changes regularly with time as uranium and thorium undergo radioactive decay. During a mineral deposit-forming event, lead is separated from the parent uranium and thorium isotopes and the lead isotopic composition of the hydrothermal fluid is "frozen" into the sulfide minerals, usually in galena, within the mineral deposit. This mineral-deposit lead isotopic signature will eventually differ from that of the host rocks underlying a watershed because the lead in the host rocks continues to change with time whereas the lead in the mineral deposit remains fixed.

The samples were leached with a warm 2M HCl-1percent H_2O_2 solution, which dissolves galena and also releases metals (including lead) sorbed to colloidal phases and coatings on mineral grains. However, this digestion does not dissolve lead bound in silicate phases such as feldspars, thereby simplifying the assessment of the lead isotopic results. Approximately 0.5 µg of lead in solution is dried and processed twice through ion exchange columns. The sample was then loaded onto a rhenium filament and analyzed by thermal ionization mass spectroscopy (TIMS). Analytical methods and precision are in Unruh and others (2000). Analytical precision (95 percent confidence level) for the NBS standards 981 and 982 is approximately 0.6 percent for the $^{206}Pb/^{204}Pb$ value over the three-year period of analysis for these data depending upon the analytical instrument used. This means that the reported $^{206}Pb/^{204}Pb$ results for the unknown samples are thought to be accurate to about $\pm$ 0.013 (that is, 18.xxx $\pm$ 0.013). Results are reported in terms of the lead isotope ratio to ^{204}Pb, the isotope of lead that has no radioactive parent.

Water Samples

Filtered (0.45 micron), acidified water samples were analyzed by ICP-AES (Briggs and Fey, 1996) and by inductively coupled plasma-mass spectroscopy (ICP-MS; Lamothe and others, 1999) for 17 elements and sulfate. Data are in table A3; for some elements, reported values are from both ICP-AES (higher concentrations) and ICP-MS (lower concentrations). Unfiltered, acidified (total-recoverable) samples were also analyzed by ICP-AES and ICP-MS. The data are in table A4.

Filtered, unacidified water samples were analyzed for the anions fluorine, chlorine, nitrate, phosphate, and sulfate by ion chromatography (d'Angelo and Ficklin, 1996). The data are in table A1.

Filtered, sodium dichromate-preserved water samples were collected for mercury analysis. Only six water samples were analyzed and the data were at or below detection limit for the water method (0.005 ppt); the data are not presented.

Filtered, acidified water samples collected by the autosamplers were analyzed for major ions and trace elements by ICP-AES; the data are in table A5.

Quality Assurance and Quality Control

Field duplicate samples were collected for both streambed-sediment and stream-water samples, and field-prepared blanks were collected in the field, prepared with laboratory deionized water. Standard reference materials were analyzed with streambed-sediment samples, and reference water standards were analyzed with water samples. Quality control data for water analyses are in table A6 and quality control data for sediment analyses are in table A7. We reported values for Ba, Ca, Mg, Na, and Si in water by ICP-AES. Field duplicate analyses were generally within 5% of each other. Analyses of three standard reference waters were also withing 5% of published values for those elements (table A6). We reported values for Al, Cd, CO, Cu, Fe, Mn, Mo, Ni, Pb, SO4, Sr, Ti, and Zn in water by ICP-MS. The field duplicates measured by ICP-MS were also within 5% of each other, and the standard reference water sample analyses were also within 5% of published values. The data for streambed sediment analyses, in table A7, are similarly well constrained. Field duplicate and standard materials analyses are genenerally within the 5% limit. Uncertainty due to field sampling and analytical variation is quite small. A statistical analysis of data from solid material standards analyzed over three years is given in Fey and others (1999).

Results and Discussion

The analytical data from both water and streambed sediment are presented in this report in terms of their effect on different trout species. Results for dissolved cadmium, copper, lead, and zinc in tables A3 and A4 are as analyzed. Hardness-corrected effective concentrations were used to make the plots in the figures below. Hardness (as mg/L $CaCO_3$) was calculated from measured Ca and Mg concentrations:

$$\text{Hardness} = ((\text{Ca}/40.08)+(\text{Mg}/24.31))*100.1 \qquad 1$$

The median calculated hardness for the entire water data set is 58 mg/L.

Corrected effective concentrations of dissolved trace metals in water are discussed below and are calculated by subtracting the value calculated for the ameliorating effect of hardness on cadmium, copper, lead, and zinc from the observed value for that metal in water at each site. The equations for calculation of the hardness corrections are (USEPA, 1999, 2001):

Cadmium

$$Cd_{chronic} = e^{(0.758 * LN(Hardness) - 2.715} \qquad 2$$

$$Cd_{acute} = e^{(1.128 * LN(Hardness) - 3.6867} \qquad 3$$

Copper

$$Cu_{chronic} = e^{(0.8545 * LN(Hardness) - 1.702} \qquad 4$$

$$Cu_{acute} = e^{(0.9422 * LN(Hardness) - 1.700} \qquad 5$$

Lead

$$Pb_{chronic} = e^{(1.273 * LN(Hardness) - 4.705} \qquad 6$$

$$Pb_{acute} = e^{(1.273 * LN(Hardness) - 1.460} \qquad 7$$

Zinc, chronic and acute

$$Zn_{acute} = e^{(0.8473 * LN(Hardness) + 0.884}$$

Where hardness is the concentration calculated from equation 1 above in mg/L at each site. Values are calculated for acute effects, defined as death of half the exposed organism in a 96-hr period, or chronic effects, which are loss of full functionality resulting from cumulative effects of the metal in body tissue, ultimately resulting in death of the organism.

Different species of trout have different biologic toxicity thresholds, that is different concentrations of specific metals cause measurable biologic toxic effects in different species of trout.

Rainbow Trout are generally more sensitive to metals than either Brook or Brown Trout. Furthermore, different life stages also respond differently to toxic metals. New trout fry are the most sensitive and adults the least (Mayer and Ellersieck, 1986). Horn (2001) compiled the toxicity data for different species of trout from the literature. The data are expressed as threshold values for water having a hardness of <50 mg/L (table 1). We used these data to calibrate the probable toxicity of different metals for each species of trout.

Results for metals in streambed sediment are expressed in terms of hazard quotients (MacDonald and others, 2000). Two values are recommended: the Threshold Effect Concentration (TEC), that is the value below which harmful effects are unlikely to be observed, and the Probable Effects Concentration (PEC), that is the concentration above which harmful effects are likely to occur (table 2). PEC values have been used to prepare the streambed-sediment hazard quotient maps; ratios greater than 1 indicate a potential effect on aquatic life through dietary exposure. Values of less than 0.1 indicate no probable affect to aquatic life. Standard breaks have been plotted for each metal shown. No sediment quality standards have been recommended for manganese, iron, or aluminum.

Table 1. Biological Thresholds or Toxicity Criteria for Trout[1]
[Hardness <50 mg/L; concentrations in μg/L (ppb); --, no criteria determined]

	Rainbow Trout		Brown Trout		Brook Trout	
Trace Element	Chronic	Acute	Chronic	Acute	Chronic	Acute
Aluminum	87	750	87	750	87	750
Cadmium	1.4	1.9	1.4	4.09	2.4	3.6
Copper	19	54	30.8	57	12.9	104
Lead	5.6	1,170	45	--	57	3,362
Manganese	790	3,320	2,700	3,770	1,360	5,120
Zinc	47	321	200	550	853	--

[1]Data compiled by Horn (2001); sources of data are extensively referenced therein.

Table 2. Consensus-Based Sediment Quality Guidelines[1]
[Shaded concentrations used to calculate toxicity quotients for streambed sediment]

Element	TEC (ppm)	PEC (ppm)	No. of cases tested	Percentage found to be toxic
Arsenic	9.79	33.0	150	74.1
Cadmium	0.99	4.98	347	80.4
Copper	31.6	149	347	82.3
Lead	35.8	128	347	81.6
Mercury	0.18	1.06	79	34.3
Zinc	121	459	347	81.6

[1]Data from MacDonald and others (2000).

Effects of Changes in pH

Many of the trace elements plotted in figs. 4-17 are readily sorbed from the aqueous or dissolved phase by iron and aluminum colloids. Sulfate, (fig. 3) however, is not sorbed and behaves generally conservatively, meaning that there are no instream processes, other than dilution, that substantially affect the concentration of sulfate in stream water. Sulfate is typically a good proxy for the total contribution from oxidation of pyrite from hydrothermally altered zones and of weathered sulfide minerals from mine waste. Sulfate concentrations are highest in reaches affected by hydrothermal alteration zones and where there are inactive historical mines. Downstream from its confluence with Peru Creek, the sulfate concentration in the Snake River decreases, and in the North Fork of the Snake River (outside of the alteration zone), it is less than 30 mg/L.

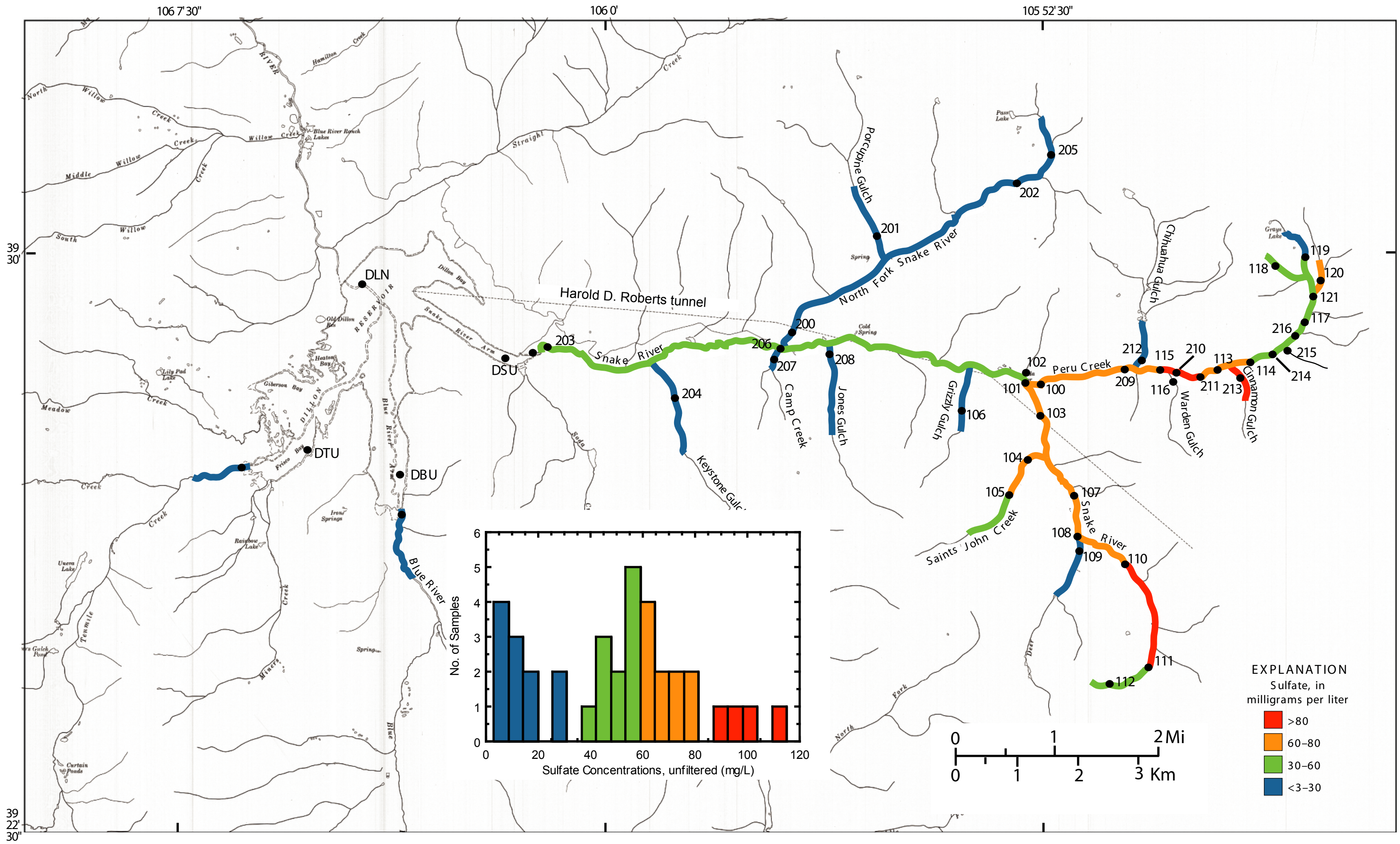

Figure 3. Ribbon map and histogram showing distribution of concentration data for sulfate in stream water, Snake River watershed. Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

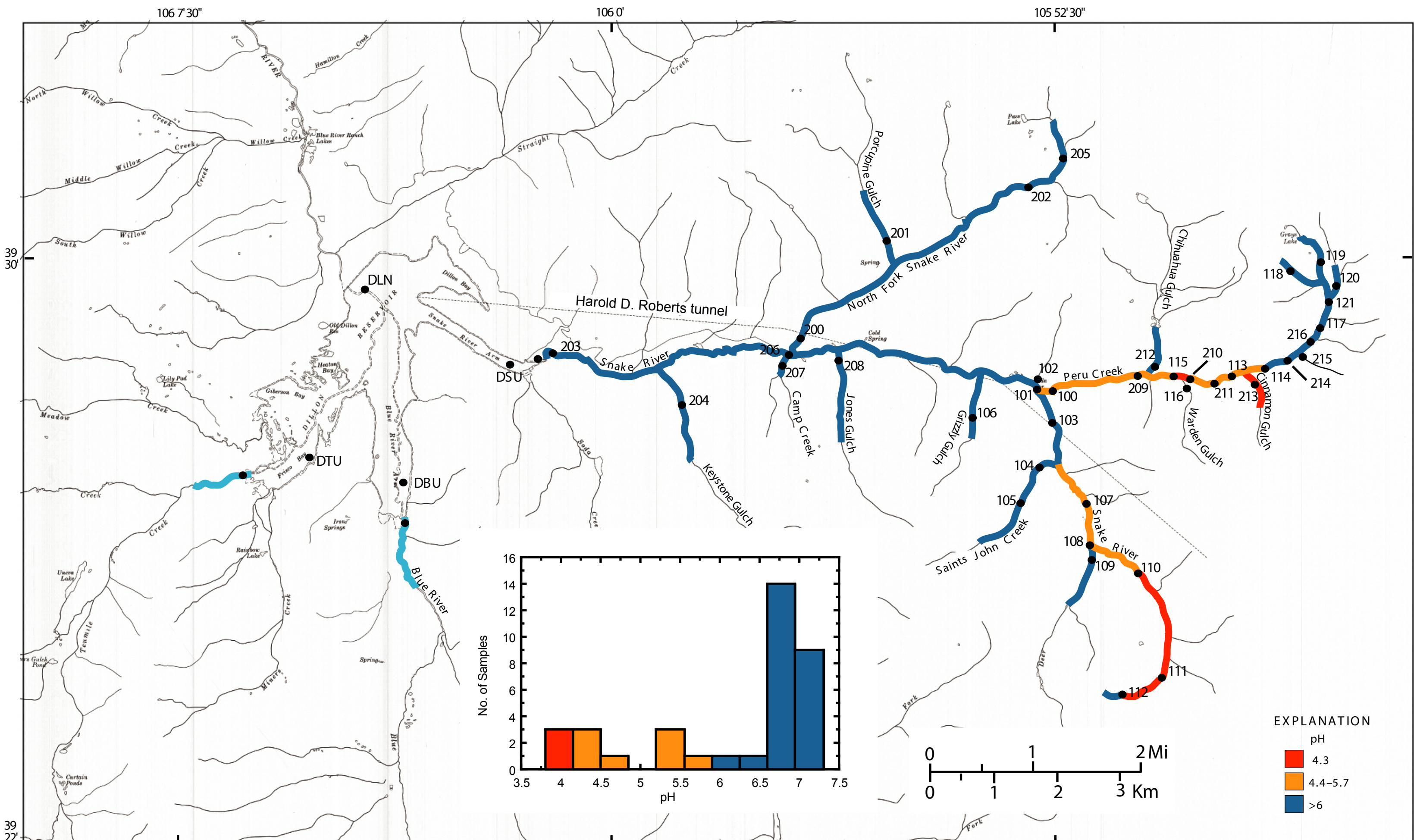

Figure 4. Ribbon map and histogram showing distribution of pH in stream water, Snake River watershed. Data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

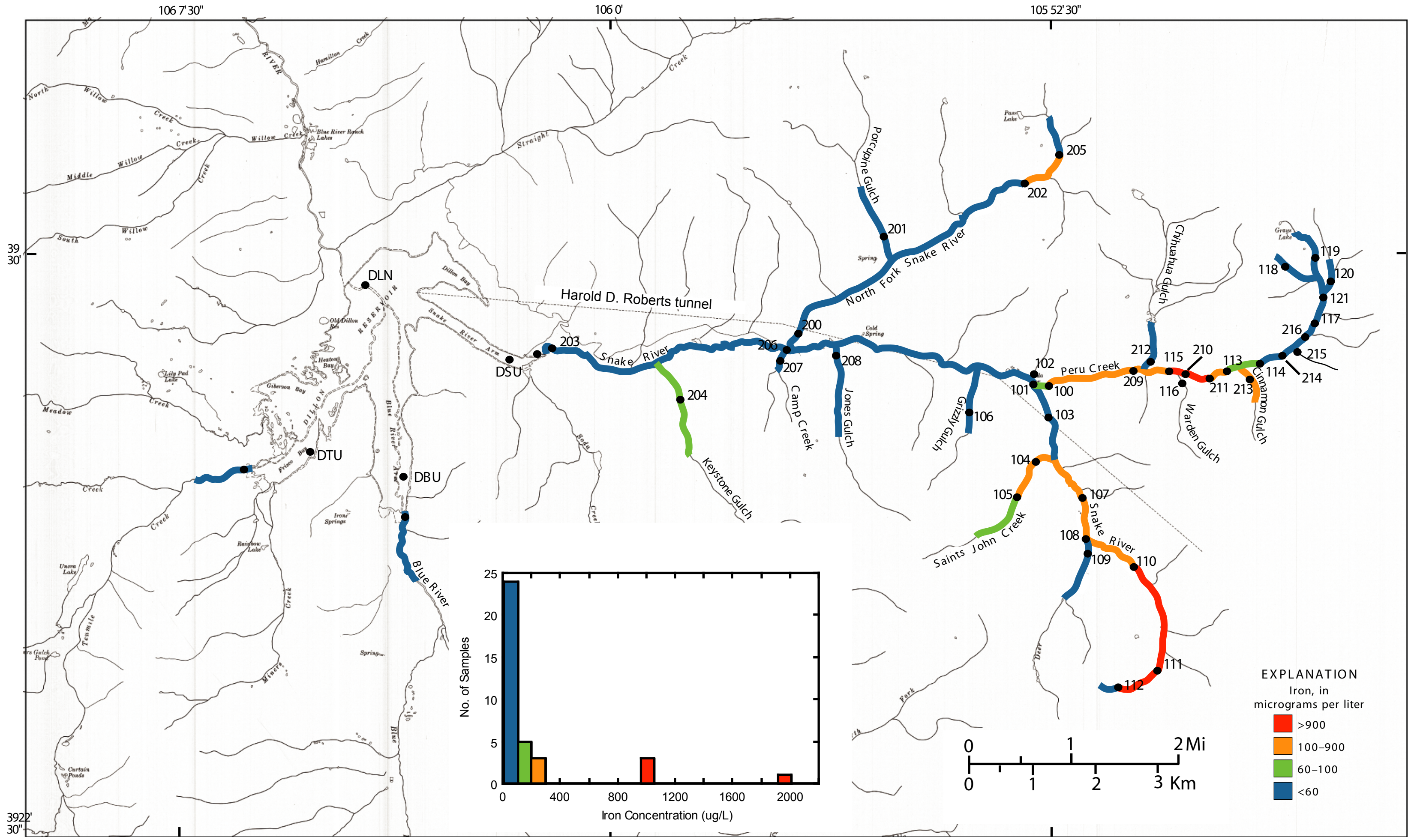

Figure 5. Ribbon map and histogram showing distribution of concentration data for iron in stream water, Snake River watershed. Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

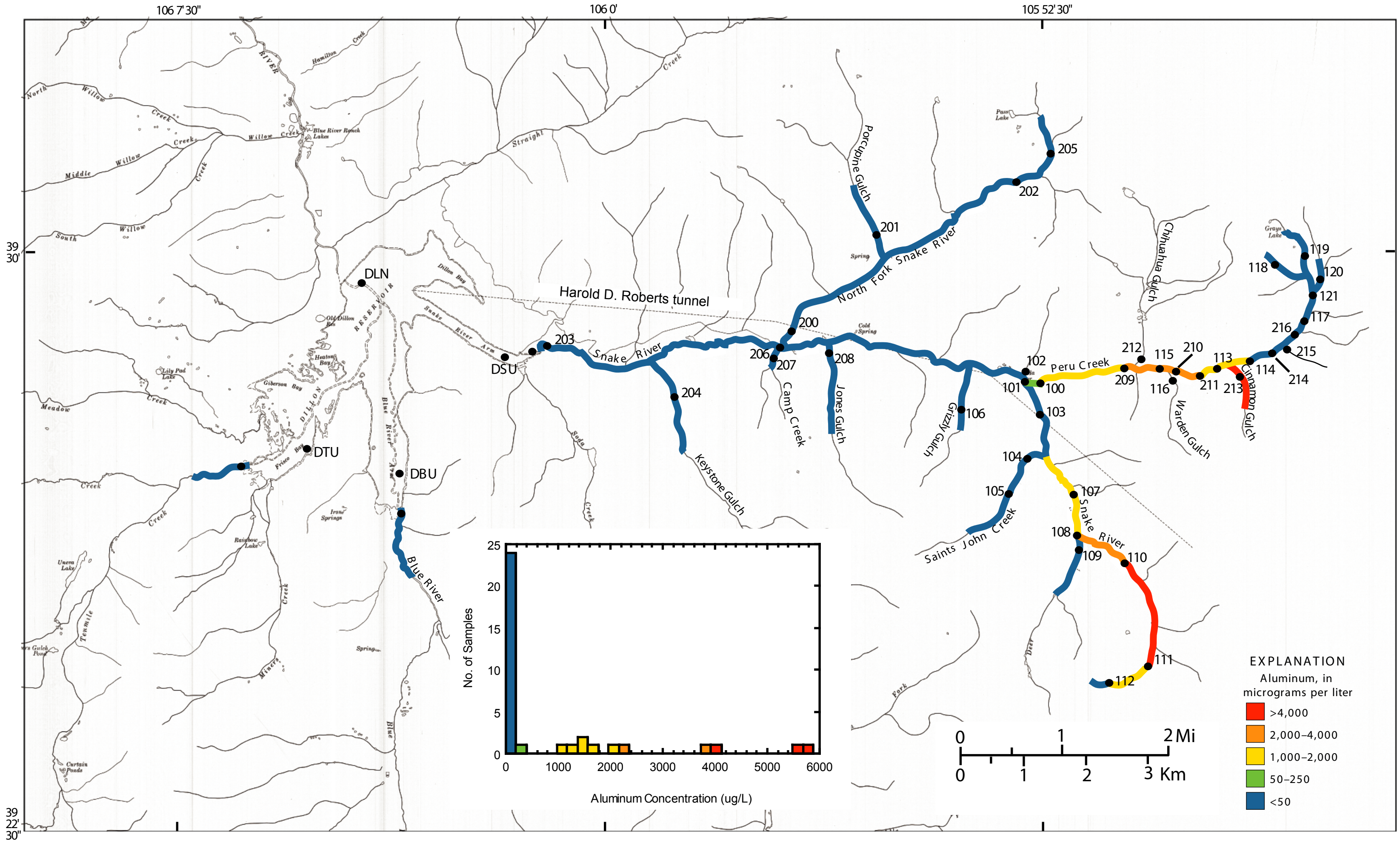

Figure 6. Ribbon map and histogram showing distribution of concentration data for aluminum in stream water, Snake River watershed. Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

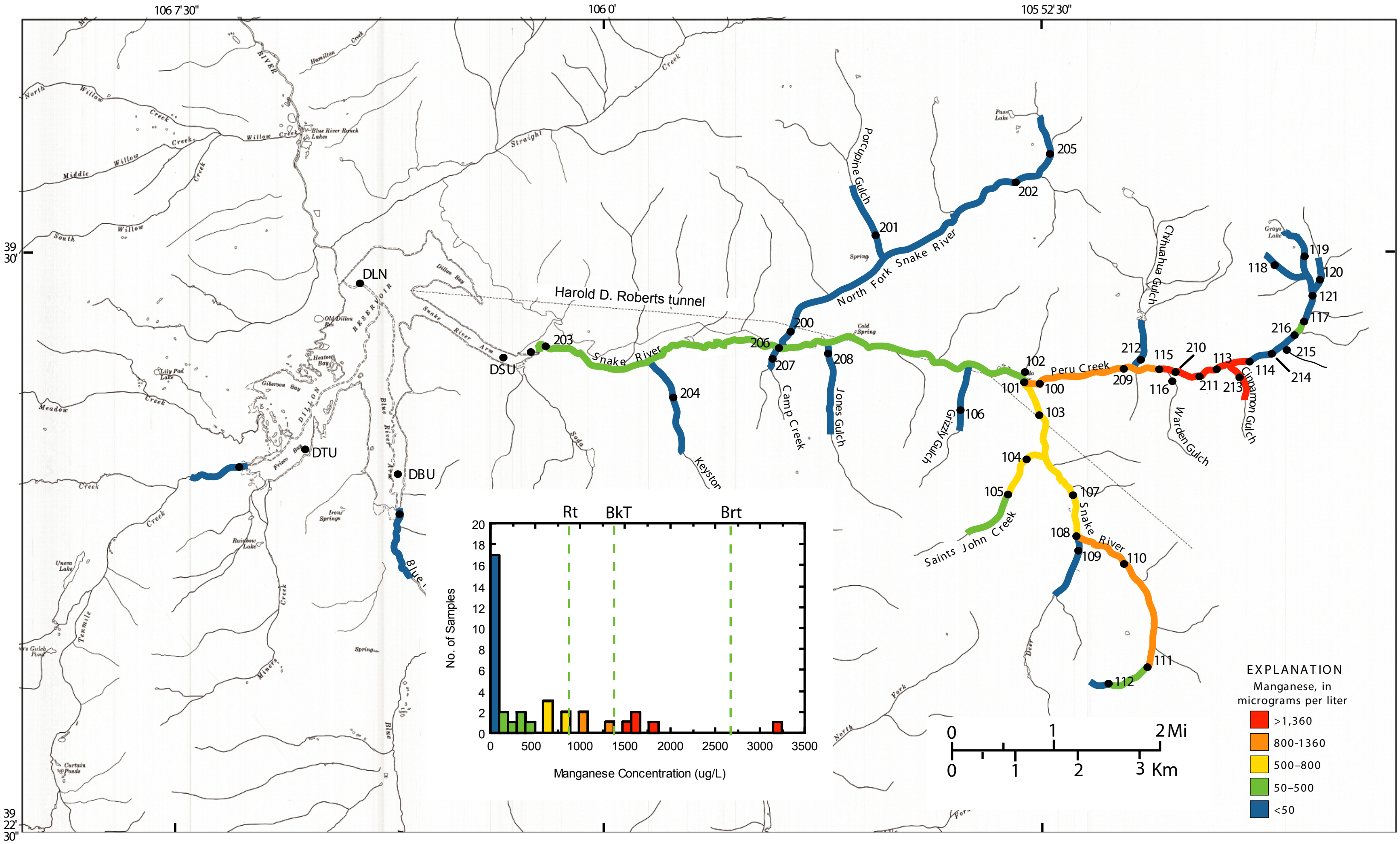

Figure 7. Ribbon map and histogram showing distribution of concentration data for manganese in stream water, Snake River watershed. Chronic toxicity values (green) for rainbow (RT), brown (BrT), and brook trout (BkT) are from table 1; data from Horn (2001). Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

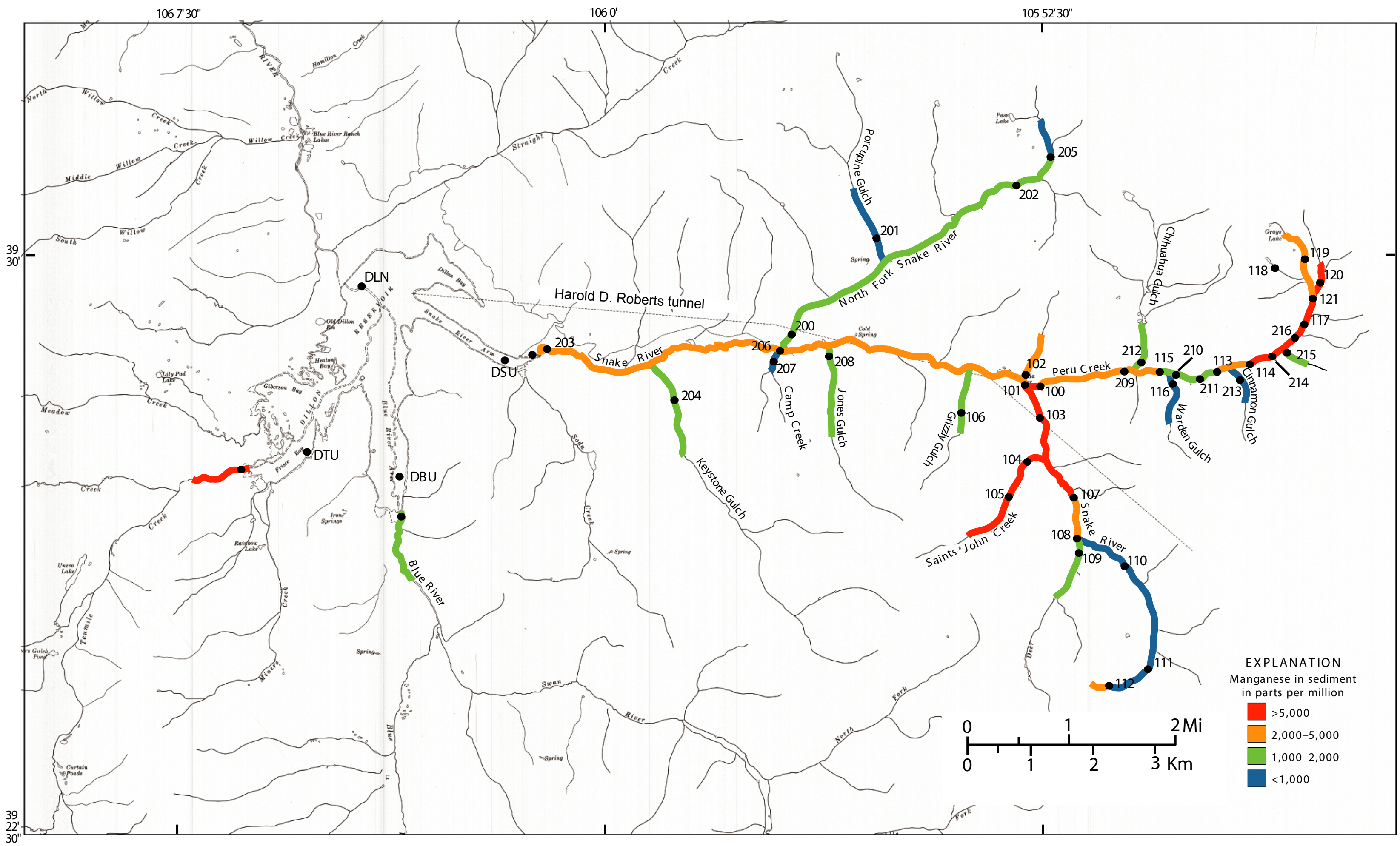

Figure 8. Ribbon map showing conentrations of manganese in streambed sediment, Snake River watershed. Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

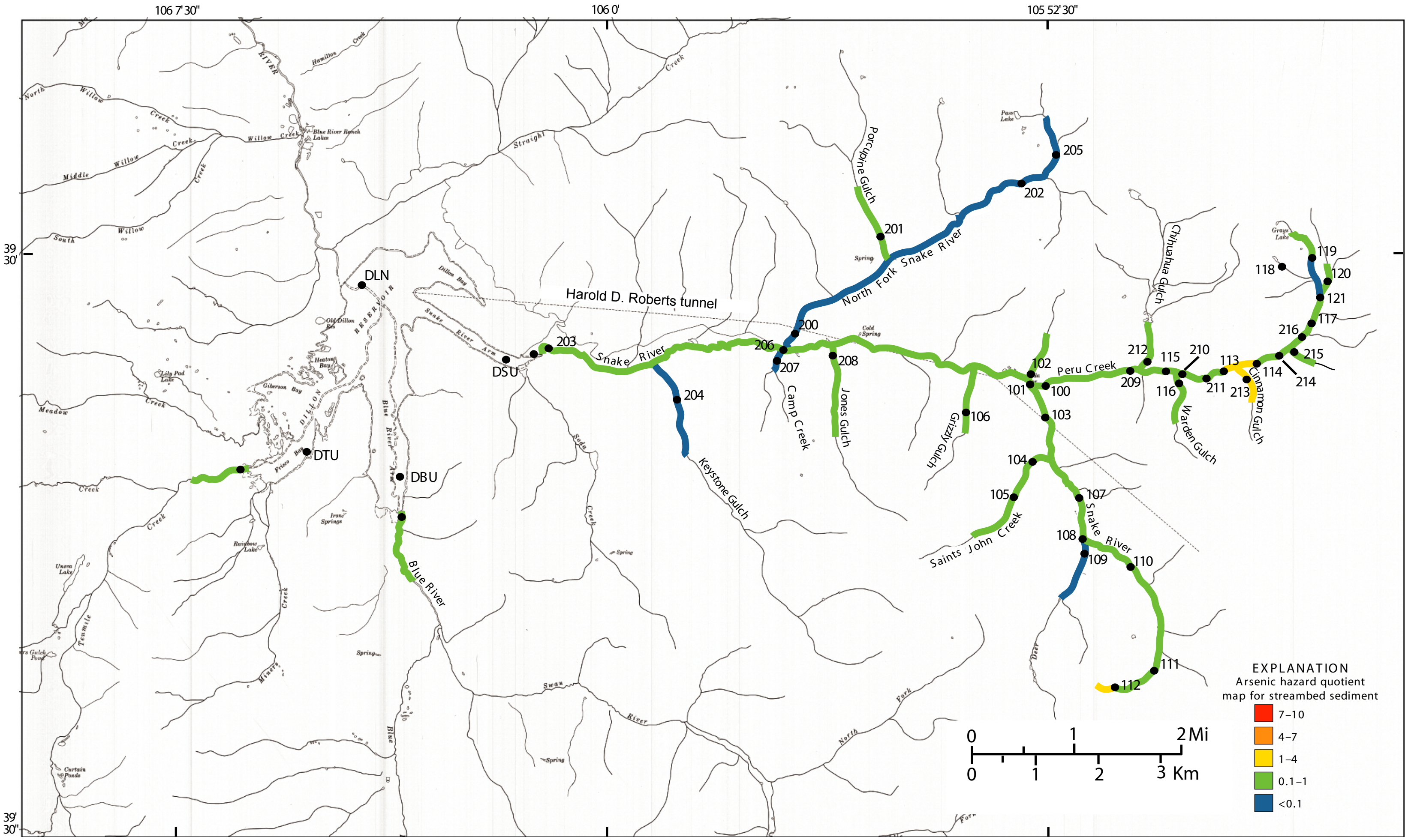

Figure 9. Arsenic hazard quotient map from streambed-sediment data, Snake River watershed. Concentation data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

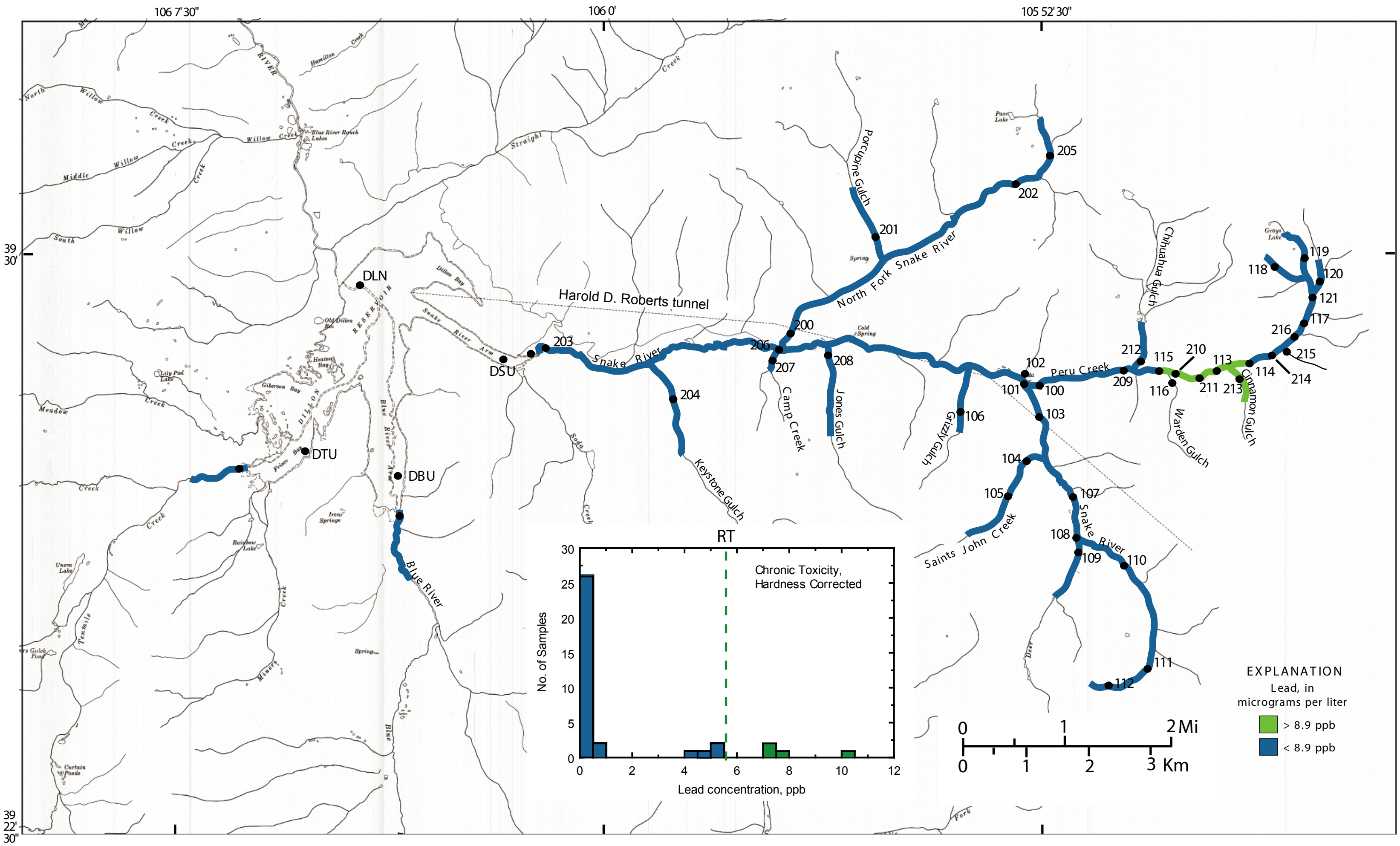

Figure 10. Ribbon map and histogram showing concentrations of dissolved lead (0.45 micron filtered water), corrected for amelioration by hardness, Snake River watershed. Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999). Chronic toxicity values (green) for rainbow trout (RT) are from table 1; data from Horn (2001).

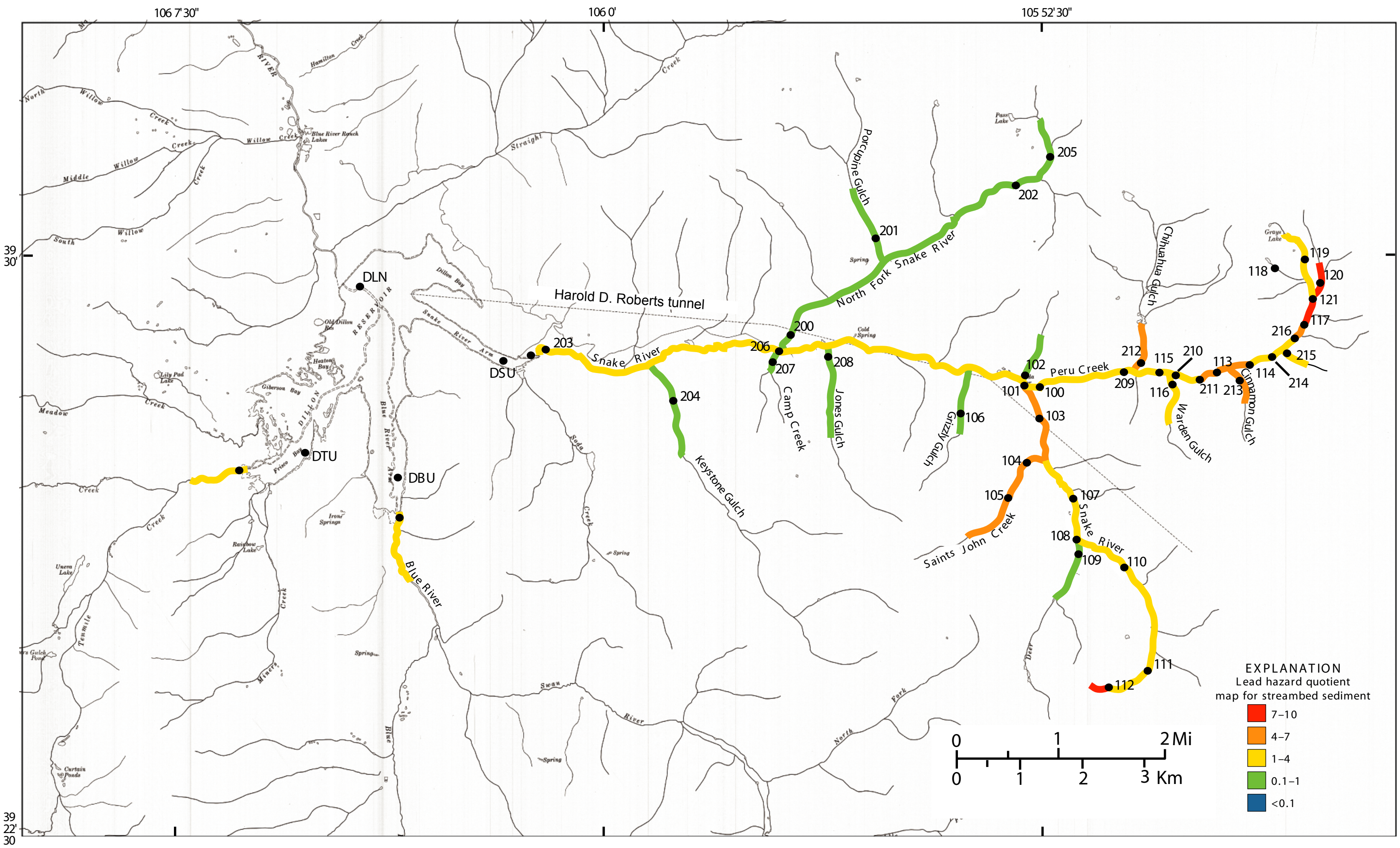

Figure 11. Lead hazard quotient map from streambed-sediment data, Snake River watershed. Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

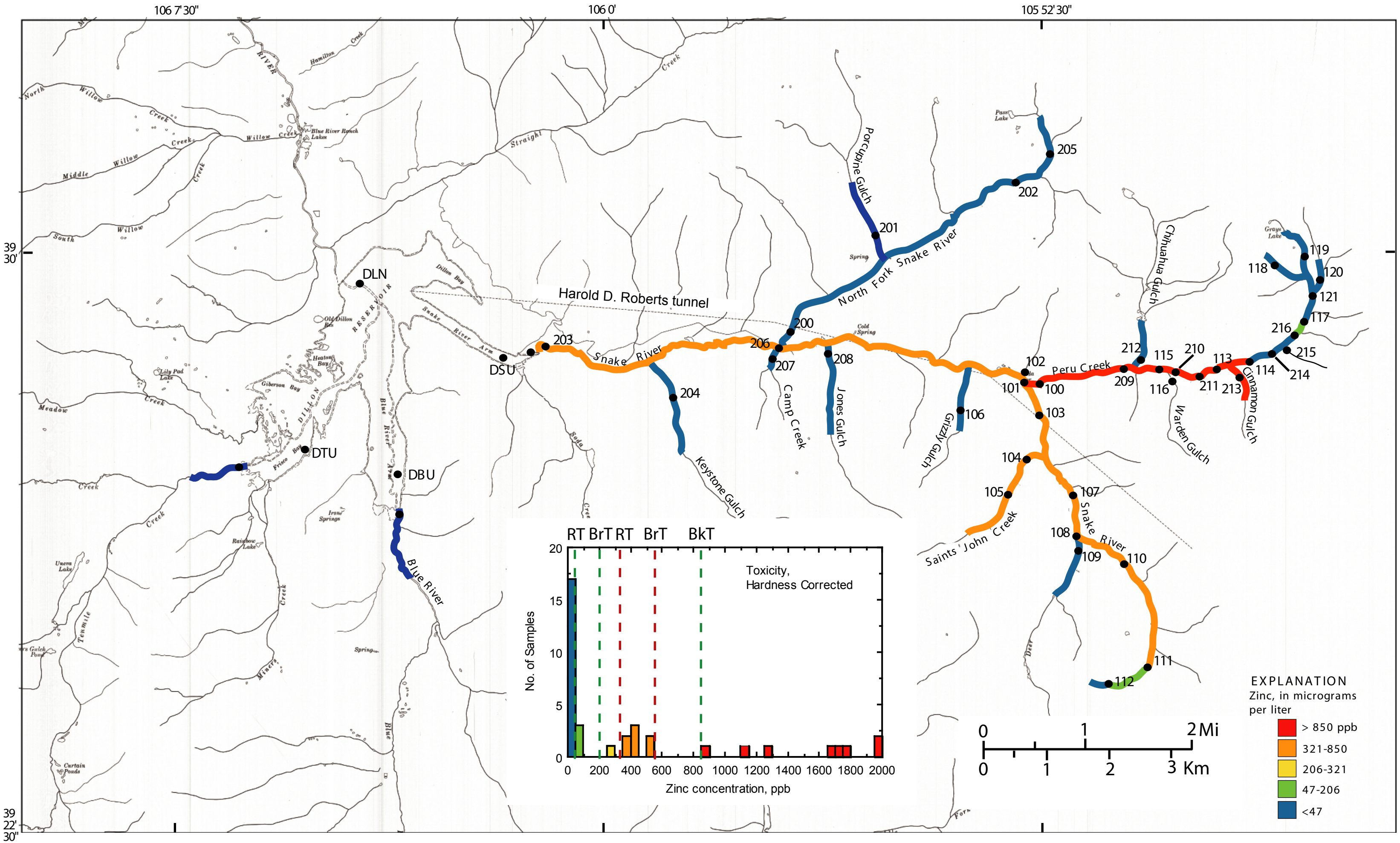

Figure 12. Ribbon map and histogram of dissolved zinc concentrations (0.45 micron filtered water), corrected for amelioration by hardness, showing chronic (green) and acute (red) toxicity criteria for rainbow (RT), brown (BrT), and brook trout (BkT) from table 1; data from Horn (2001). Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

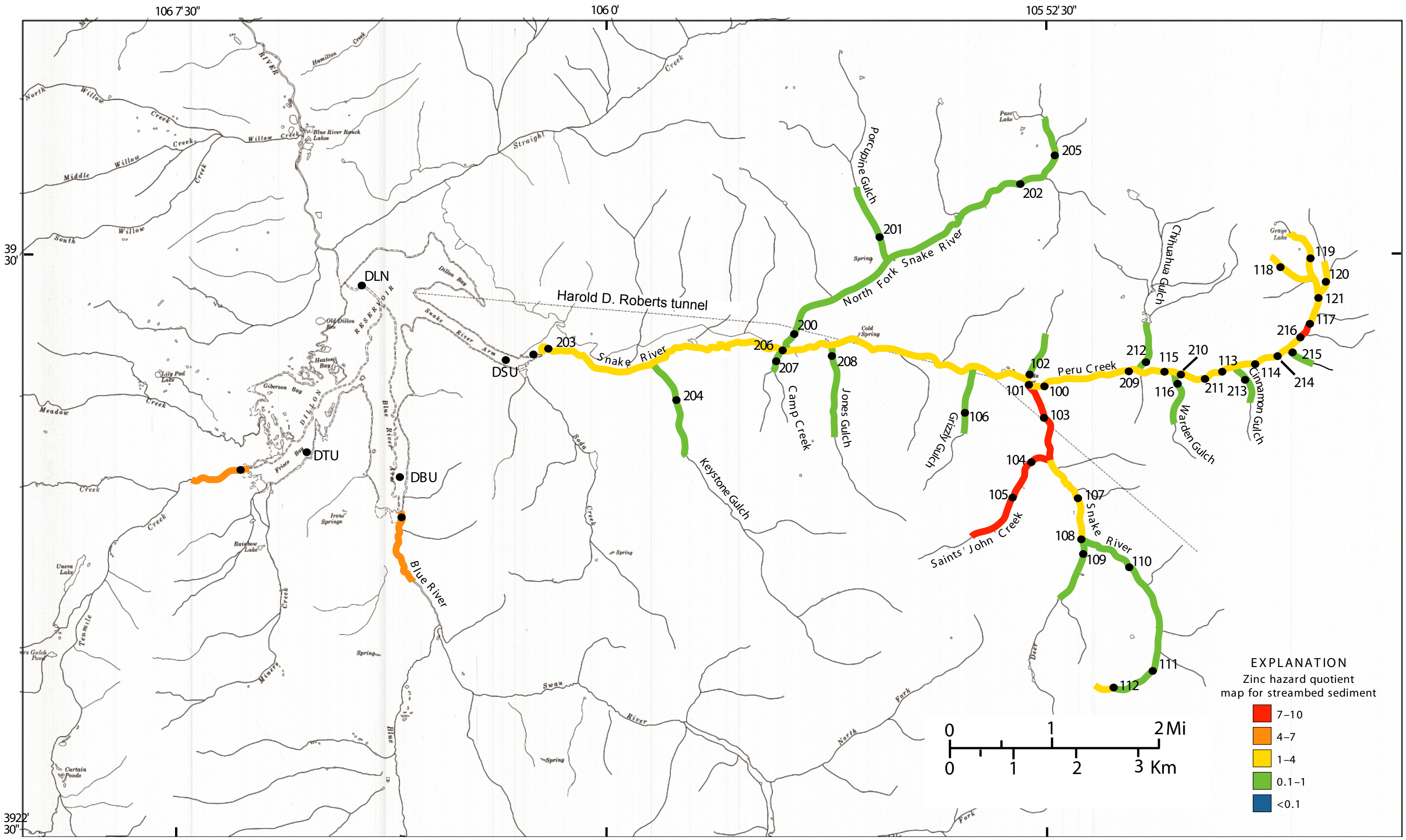

Figure 13. Zinc hazard quotient map from streambed-sediment data, Snake River watershed. Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

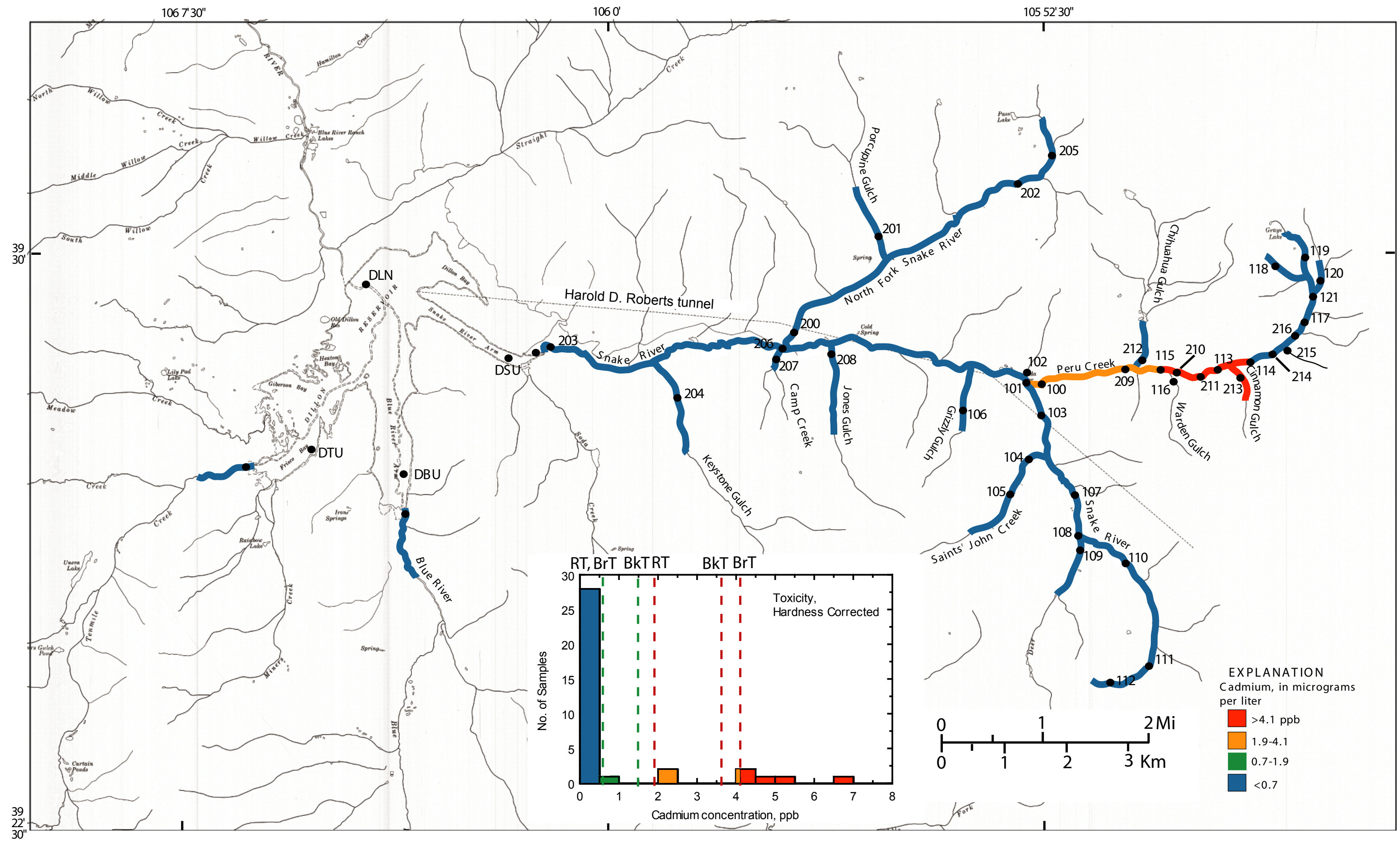

Figure 14. Ribbon map and histogram of dissolved cadmium concentrations (0.45 micron filtered water), correceted for amelioration by hardness, showing chronic (green) and acute toxicity (red) criteria for rainbow (RT), brown (BrT), and brook trout (BkT) are from table 1; data are from Horn (2001). Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

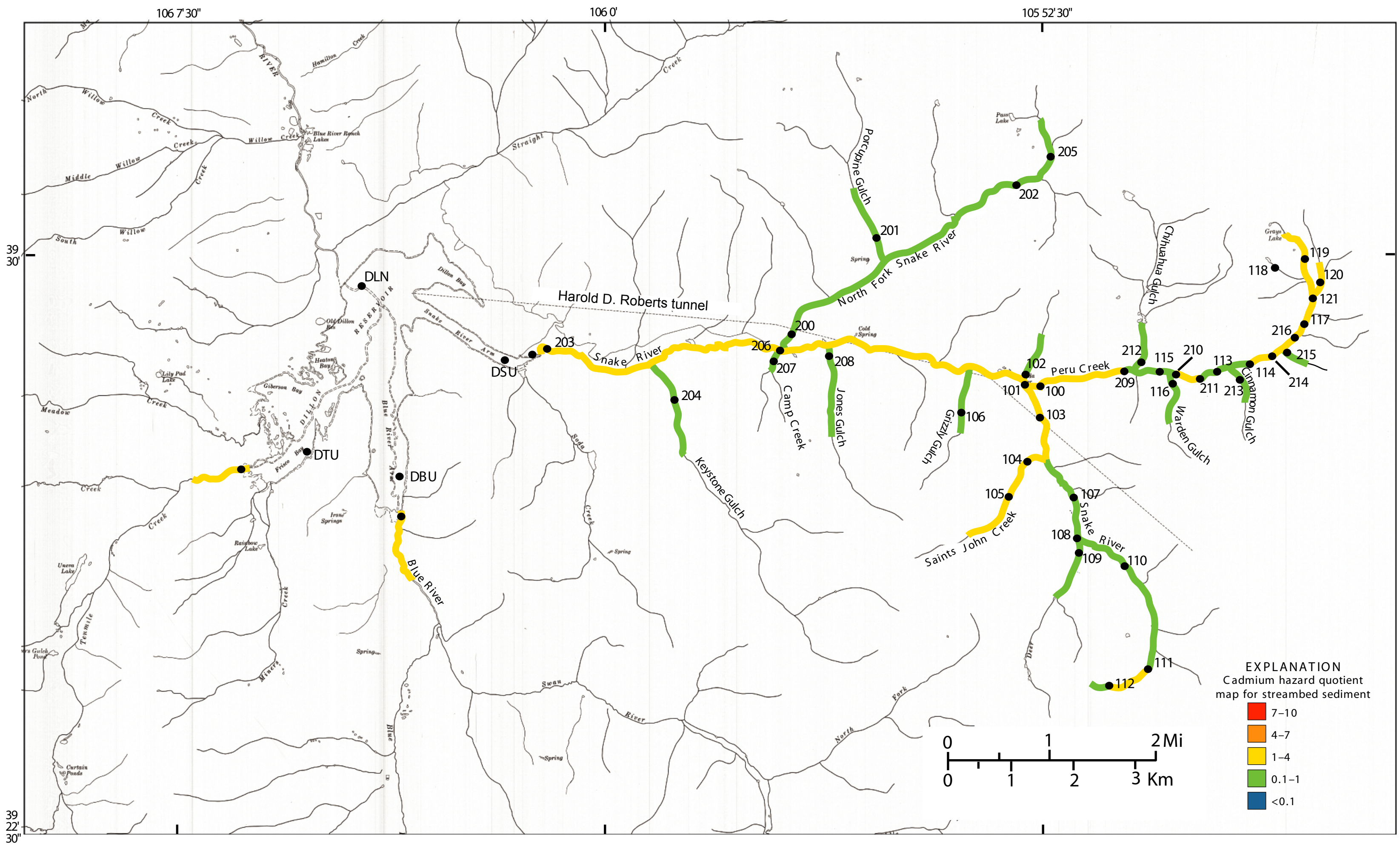

Figure 15. Cadmium hazard quotient map from streambed-sediment data, Snake River watershed. Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

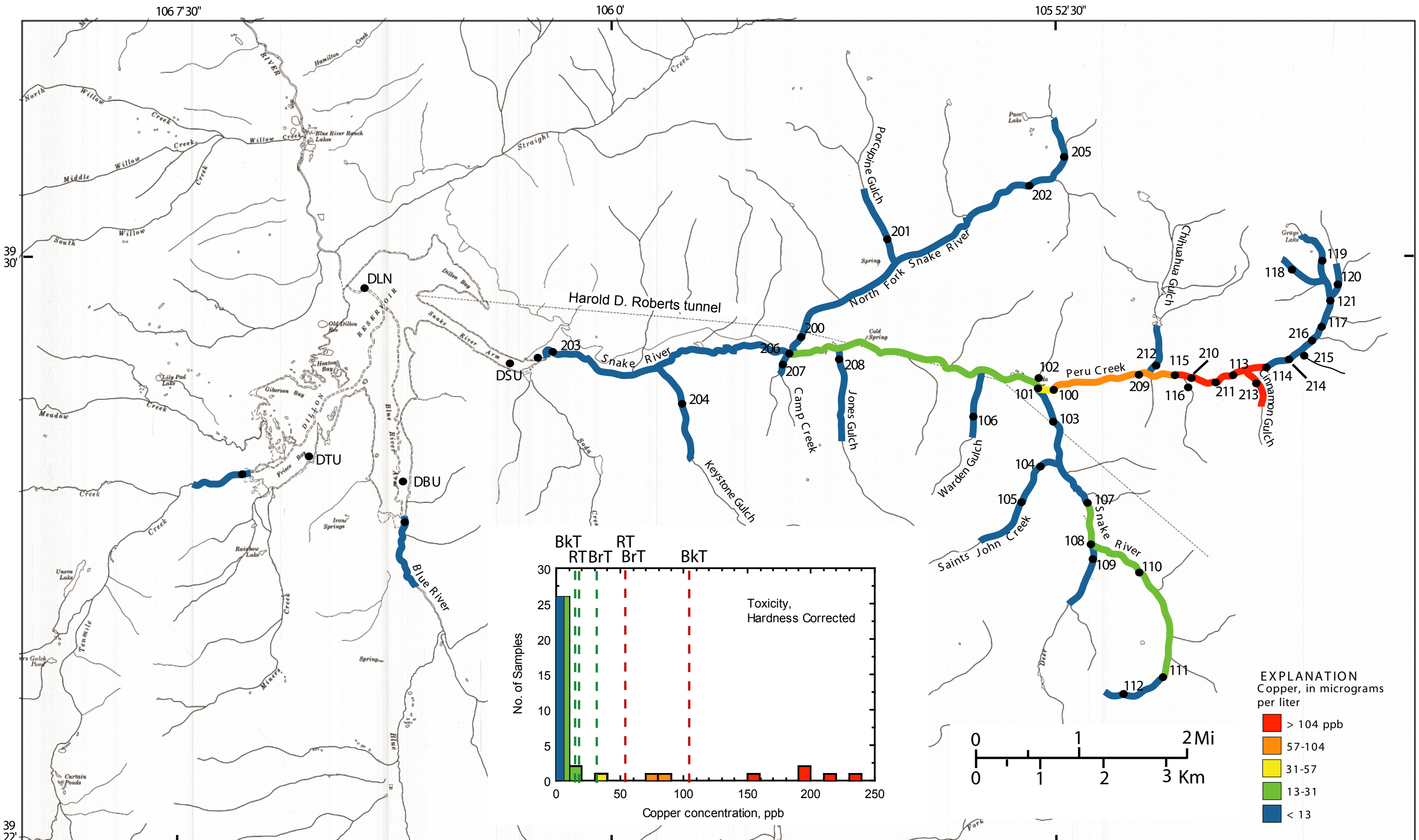

Figure 16. Ribbon map and histogram of dissolved copper (0.45 micron filtered water), corrected for amelioration by hardness, showing chronic (green) and acute toxicity (red) criteria for rainbow (RT), brown (BrT), and brook (BkT) are from table 1; data are from Horn (2001). Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

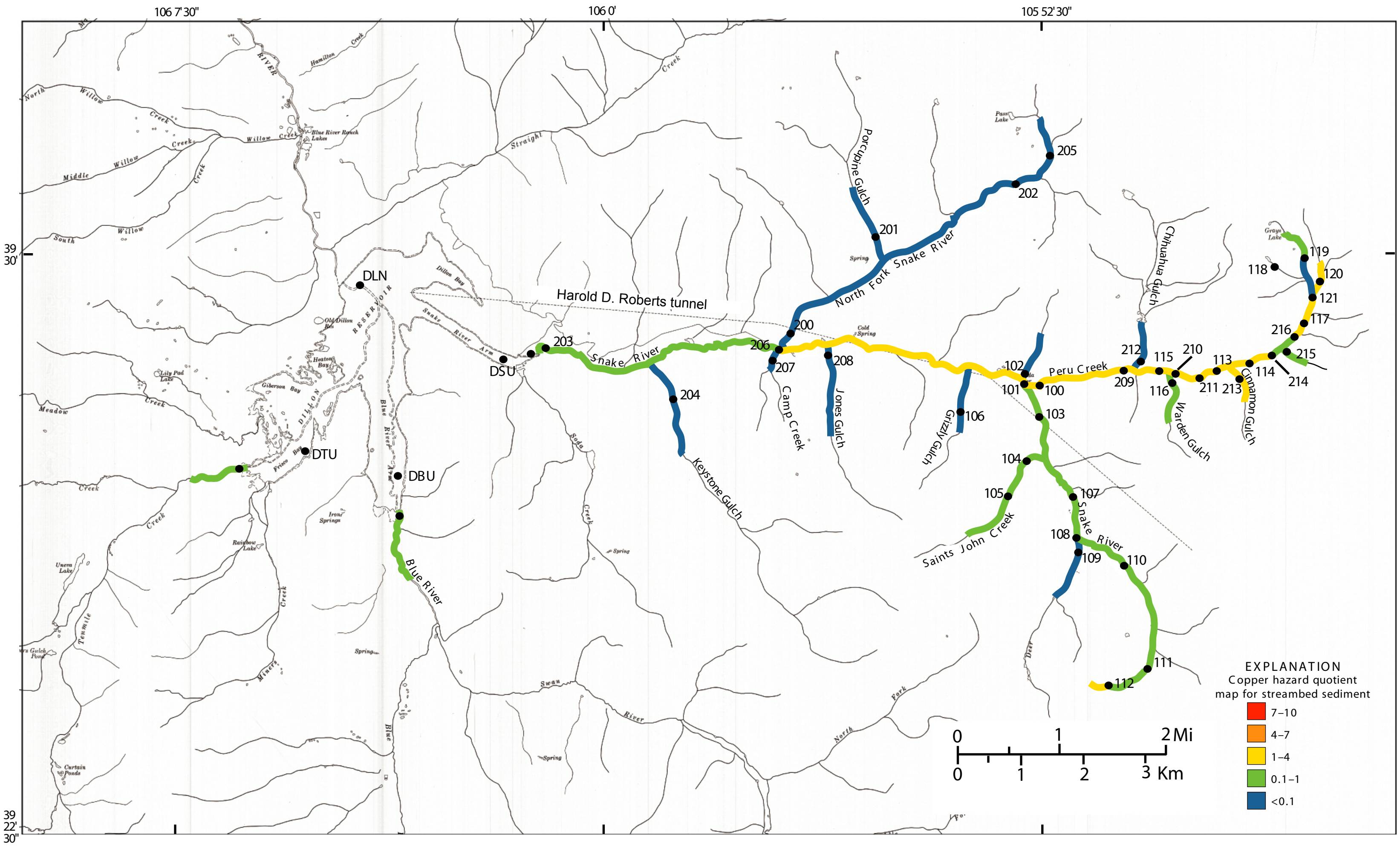

Figure 17. Copper hazard quotient map from streambed-sediment data, Snake River watershed. Concentration data from the mouth of the Blue River and Tenmile Creek are from Deacon and Driver (1999).

The dissolved concentration of many of the trace elements, however, is pH dependent. Thus, the pH of the stream is the dominant controlling factor of the distribution of metals in the dissolved or colloidal phase. Sorption curves for many of these trace elements are functions of pH (fig. 7.5; Smith, 1999). In figure 4, pH is plotted in three discrete intervals. Trout avoid streams where the water has a pH less than 6 and will not survive in waters where the pH is less than 5 (Mayer and Ellersieck, 1986). Thus, only the North Fork of the Snake River and the Snake River downstream of the confluence with Saints John Gulch provide suitable aquatic habitat for trout during low flow.

Iron

Iron colloids begin to form at about pH 3-3.5 (Smith, 1999). The upper reach of the Snake River above site 110 and Cinnamon Gulch are two reaches where iron colloids are being actively precipitated in the stream (fig. 5). Settling of these iron colloids to the streambed represent the primary process of removal of dissolved metals from the stream. This process is dramatically shown by the elevated concentrations of iron in Peru Creek downstream from Cinnamon Gulch (between sites 115 and 211, fig. 5). Iron concentrations in the streams drop dramatically as pH increases to near neutral. In stream reaches where the pH is greater than 6, dissolved iron concentrations are usually less than 60 µg/L. Saints John Creek is an exception. Trout survival in reaches where dissolved iron is high is also limited by pH.

Aluminum

Aluminum colloids precipitate between a pH of 5-5.5 (Smith, 1999). The values reported in Table 1 are for toxicity of dissolved aluminum. Dissolved aluminum is below the chronic toxicity standard for aluminum in near-neutral waters throughout much of the Snake River basin. The upper reach of the Snake River, above the confluence with Saints John Creek, and Peru Creek from the confluence with the Snake River to the confluence of Cinnamon Gulch, have pH in the range where aluminum colloids are being precipitated (fig. 6). Toxicity of aluminum to trout is greatest when aluminum colloids are freshly precipitated. Comparison of 0.45-micron-filtered aluminum with total-recoverable aluminum (tables A3 and A4) shows that aluminum is being precipitated in Peru Creek between sites 100 and 113, and the upper Snake River above site 103. Thus, the Peru Creek reach from site 100 to the confluence with Cinnamon Gulch, and the Snake River upstream from Saints John Creek would not support trout because of the toxic effect of aluminum colloids on the respiratory system. In addition, aluminum is suspected to be toxic when dissolved aluminum exceeds 300-400 µg/L (Cleveland and others, 1986; Mount and others, 1988). Aluminum concentrations for the above reaches are all above 1,000 µg/L.

Manganese

Dissolved manganese concentrations are high in water and low in streambed sediment where stream pH is low (figs. 7 and 8), that is, in Peru Creek from its confluence with the Snake River to the confluence with Cinnamon Gulch, in Cinnamon Gulch, and in the Snake River above site 110. Dissolved manganese concentrations decrease as a pH increases. Dissolved manganese concentrations exceed the chronic toxicity threshold for Brown Trout in Cinnamon Gulch, for Brook Trout in Peru Creek between the confluences of Warden and Cinnamon Gulches (red, fig. 7), and for Rainbow Trout in Peru Creek downstream of Warden Gulch and in the upper Snake River upstream from the confluence with Deer Creek. The highest concentrations of manganese in streambed sediment occur upstream of Cinnamon Gulch in Peru Creek, in Saints John Creek, and in the reach of the Snake River upstream from the confluence with Peru Creek (fig. 8). Manganese entering Peru Creek from near Cinnamon Gulch is the source of much of the manganese load. Although the drainage from the Pennsylvania mine was dry and not sampled, diffuse flow from the mine area appears to be the major source of many metals (see discussion on loads, below).

Arsenic

Arsenic is readily sorbed by iron colloids at pH values greater than 3 (Smith, 1999). Arsenic concentrations were not detected in water (detection limit of 1 μg/L) and, with the exception of the reach in Peru Creek near Cinnamon Gulch, have hazard quotients for arsenic in streambed sediment either in the <0.1 or in the 0.1-1 range (fig. 9) indicating that there is no expected effect from dietary exposure to arsenic. Arsenic concentrations in this watershed have no substantive effect on aquatic life in the Snake River basin.

Lead

Dissolved lead concentrations are elevated (up to 10 µg/L) only in those reaches where pH is relatively low (between 3.8 and 5.5). Only the Peru Creek reach upstream from site 100 to the confluence with Cinnamon Gulch, Cinnamon Gulch, and the upper Snake River upstream from site 110 have measurable lead concentrations. In these reaches, the dissolved lead concentration exceeds the chronic threshold for Rainbow Trout (fig. 10). However, these reaches are unsuitable for trout habitat because they are outside the pH range for suitable trout habitat. We conclude that dissolved lead is not a limitation on trout survivability.

Hazard quotients for lead in streambed sediment are in the range of 1-4 in Peru Creek downstream of the confluence with Cinnamon Gulch and the Snake River (fig. 11). The dietary exposure of lead to trout in the Snake River and all of the tributaries, except for Peru Creek and in reach 107 downstream from the confluence with Deer Creek, are above those that are likely to show harmful dietary effects in trout. In the North Fork of the Snake River and many of the lower tributaries, the hazard quotient is less than 1. Studies of the effect of lead on chronic toxicity in Brook Trout via the food web (periphton-invertebrates-trout), as measured by accumulation in liver tissue in fish from the Animas River watershed in southwestern Colorado, indicate that lead is not very efficiently transferred to higher tropic levels (Besser and others, 2001). We have indicated possible dietary pathway effects on trout in reaches where the hazard quotient exceeds 4 (fig. 11). Lead concentrations in water and sediment do not appear to effect the survival of trout species in the Snake River basin.

Zinc

The different species of trout have varying biological thresholds for toxicity to dissolved zinc (table 1). These different biological threshold values are indicated on the histogram in fig. 12 for 0.45-micron filtered zinc after correction for hardness. Dissolved zinc concentrations in the North Fork of the Snake River and many of the lower tributaries have hardness-corrected concentrations that are below those values (table 1) that would place Brook or Brown Trout populations at risk (reaches shown in blue). In the upper reaches of Peru Creek, some reaches have concentrations that are above the chronic threshold for Rainbow Trout (green; fig. 12). Peru Creek from Cinnamon Gulch downstream to the confluence with the upper Snake River exceeds the acute toxicity threshold for all trout species. Dissolved, hardness corrected concentrations of zinc in lower Saints John Gulch, the upper Snake River, and the mainstem of the Snake River exceed the acute toxicity threshold for Rainbow Trout. Upper Saints John Gulch has dissolved zinc concentrations that exceed the chronic toxicity threshold for Brown and Rainbow Trout. The North Fork of the Snake River and many of the lower tributaries have concentrations of dissolved zinc that do not have any effect on trout populations. Dissolved zinc is a limiting factor in the survivability of all species of trout in much of the watershed.

Zinc is sorbed least effectively by iron colloids so zinc will persist in the dissolved form after the iron colloids have effectively been removed from suspension in the river/lake system by precipitation to the streambed or lake sediment (Smith, 1999; fig. 7.5). The hazard quotients determined from streambed sediment (fig. 13) are highest in Saints John Creek and the reach of the upper Snake River immediately downstream to the confluence with Peru Creek. The hazard quotient for zinc in streambed sediment of the Snake River from Dillon Reservoir to the confluence with Peru Creek, and all of Peru Creek, is in the range of 1-4, indicating that there is an expected chronic effect from dietary exposure to zinc. Studies of food web pathways for zinc in Brook Trout from the Animas River watershed indicate that zinc is not very effectively concentrated in fish liver via the dietary pathway (Besser and others, 2001). The effect of dietary exposure of trout to zinc may be much less important than that of dissolved zinc in limiting trout survivability.

Cadmium

The different species of trout have varying biological thresholds for toxicity to dissolved cadmium (table 1). Both the chronic and acute threshold values are indicated on the histogram (fig. 14). Dissolved cadmium in Peru Creek between the Warden and Cinnamon Gulch confluences (sites 115 to 114; fig. 14) exceeds the acute toxicity standard for all three trout species. Between Warden Gulch and the confluence with the upper Snake River (sites 100-115; fig. 14), dissolved cadmium concentrations exceed the acute threshold for Rainbow Trout. At the sample from the mixing zone (site 101), dissolved cadmium concentrations exceed the chronic toxicity threshold for both Rainbow and Brown Trout. However, in the lower tributaries, the North Fork of the Snake River and the mainstem of the Snake River, dissolved cadmium concentrations do not appear to affect trout survivability at low flow.

The hazard quotient for cadmium in streambed sediment (fig. 15) is in the range of 1-4 for much of the habitable reaches of the Snake River. Besser and others (2001) demonstrated that cadmium is most readily bioaccumulated via the food web in livers of Brook Trout in the Animas River watershed Colorado, suggesting that dietary accumulation of cadmium would be expected to have an effect on the survival of all trout species in the mainstem of the Snake River.

Copper

The different species of trout have varying biological thresholds for toxicity to dissolved copper (table 1). Both the chronic and acute threshold values are shown in the histogram (fig. 16). Concentrations of dissolved copper, corrected for the effect of hardness, exceed the acute toxicity standard for all three trout species in Peru Creek between the confluences of Warden and Cinnamon Gulches (sites 115-114; fig. 16). Downstream from Warden Gulch to the confluence with the upper Snake River, dissolved concentrations of copper exceed the acute toxicity threshold for both Brook and Rainbow Trout whereas in the mixing zone (site 101) they exceed the chronic toxicity thresholds for all trout species. In the upper Snake River, upstream from the confluence with Deer Creek, and in the mainstem of the Snake River between the confluence of Peru Creek and the North Fork, dissolved concentrations of copper, corrected for hardness, exceed the chronic thresholds for both Brook and Rainbow Trout. In the North Fork of the Snake River and in the Snake River downstream from this confluence, as well as in many of the lower tributaries, dissolved concentrations of copper, corrected for hardness, does not effect survivability of any of the three trout species. Dissolved copper probably limits the survivability of trout in part of the watershed.

In streambed sediment (fig. 17), the hazard quotient values are in the range of 1-4 for all of Peru Creek and for the reach of the Snake River upstream from the confluence with the North Fork to the confluence with Peru Creek. Downstream from the confluence with the North Fork to Dillon Reservoir and upstream from the confluence with Peru Creek, streambed sediment hazard quotient values for copper are less than 1 indicating little probably dietary effect of copper on trout survivability. Upstream of the confluence of the North Fork, however, dietary uptake of copper would have a chronic effect on trout survival. Besser and others (2001) have shown that copper is bioaccumulated about as efficiently as cadmium via the food web. Copper, via the food web route, is probably a limiting factor for trout survival in the Snake River basin.

Summary of the Effects of Trace Metals on Trout Survivability

Table 3 is a summary of stream reaches with expected effects on Rainbow, Brook, and Brown Trout. R203 is the Snake River from site 203 to 206; R206 is Snake River from 206 to 101, R103 is from site 103 to the confluence with Saints John Creek, R107-108 is the upper Snake River between the confluence of Saints John Creek and Deer Creek, R110 is the upper Snake River upstream from Deer Creek, Peru Creek is divided into two reaches, one from site 101 to site 114 and a second upstream from site 114, North Fork of the Snake River is from site 200 to 205, and lower tributaries include those tributaries to the Snake River downstream from site 101. The effects listed are C, expected chronic effects for that species, A, acute effects for that species (from water exposure), and F, expected effects through the food web (from sediment exposure). Avoidance by fish is also noted for pH, and aluminum. Zinc would be expected to produce effects in many reaches for all three species except the lower tributaries, Deer Creek, and the North Fork Snake River. Peru Creek is affected by all the listed elements for all three species except lead where only the chronic toxicity threshold for dissolved lead is exceeded for Rainbow Trout. Several stream reaches have possible dietary pathways from exposure to lead in sediment. Cadmium would be expected to produce effects for some trout species in Peru Creek but has possible dietary exposure for all species in the Snake River, Saints John Creek, and lower Peru Creek. Dissolved copper would be expected to produce chronic effects for both Brook and Rainbow Trout in the Snake River between 206 and 101, and for Brown Trout in the mixing zone downstream from the confluence with Peru Creek. Dissolved copper in lower Peru Creek would be expected to produce acute effects on all three species of trout at different sections. Aluminum would be expected to produce acute effects for Peru Creek between 101 and 114 and is controlled by pH, which also limits suitable trout habitat in the upper Snake River and Peru Creek. Manganese would be expected to produce chronic effects in the upper Snake River above site 110, and Peru Creek above site 101 for all three species, and in reach 103-108 for Rainbow trout.

Table 3. Summary of effects of metals in stream reaches on Rainbow Trout, Brown Trout, and Brook Trout

[Av, fish avoid; N.S., not suitable aquatic habitat; A, exceeds acute toxicity; C, exceeds chronic toxicity; F, dietary exposure possible pathway for metal accumulation.]

Rainbow Trout

Stream Reach	pH	Al	Mn	Cd	Cu	Pb	Zn
Snake River R203	--	--	--	F	--	--	A, F
Snake River R206	--	--	--	F	C, F	--	A, F
Snake River 103	--	--	--	AF	--	F	A, F
Snake River 107-108	Av	N.S.	--	--	--	--	A, F
Snake River R110	N.S.	N.S.	C	--	C	--	A
Saints John Creek R104-105	--	--	--	F	--	F	A, F
Deer Creek R109	--	--	--	--	--	--	--
Peru Creek R100-113	Av	N.S.	C	A, F	A, F	C, F	A, F
Peru Creek R114-119	--	--	--	F	F	F	F
North Fork Snake River	--	--	--	--	--	--	--
Lower Tributaries	--	--	--	--	--	--	--

Brown Trout

Stream Reach	pH	Al	Mn	Cd	Cu	Pb	Zn
Snake River R203	--	--	--	F	--	--	C, F
Snake River R206	--	--	--	F	F	--	C, F
Snake River 103	--	--	--	F	--	F	C, F
Snake River 107-108	Av	N.S.	--	--	--	--	C, F
Snake River R110	N.S.	N.S.	--	--	--	--	C, F
Saints John Creek R104-105	--	--	--	F	--	F	C, F
Deer Creek R109	--	--	--	--	--	--	--
Peru Creek R100-113	Av	N.S.	--	C, F	A, F	F	A, F
Peru Creek R114-119	--	--	--	F	F	F	F
North Fork Snake River	--	--	--	--	--	--	--
Lower Tributaries	--	--	--	--	--	--	--

Brook Trout

Stream Reach	pH	Al	Mn	Cd	Cu	Pb	Zn
Snake River R203	--	--	--	F	--	--	F
Snake River R206	--	--	--	F	C, F	--	F
Snake River R103	--	--	--	F	--	F	F
Snake River 107-108	Av	N.S.	--	--	--	--	F
Snake River R110	N.S.	N.S.	--	--	--	--	--
Saints John Creek R104-105	--	--	--	F	--	F	F
Deer Creek R109	--	--	--	--	--	--	--
Peru Creek R100-113	Av	N.S.	C	C, A, F	A, F	F	C, F
Peru Creek R114-119	--	--	--	F	--	F	F
North Fork Snake River	--	--	--	--	--	--	--
Lower Tributaries	--	--	--	--	--	--	--

Metal Loads

Instantaneous metal loads in water can be determined at each sampling point by multiplying the discharge by the total-recoverable concentration. Table A4 shows the calculated loads for sulfate, strontium, copper, cadmium, and zinc. Comparing the sulfate loads at sites 203 (Dillon Reservoir inlet), 206, and 101 shows that sulfate is conserved from the confluence with Peru Creek downstream to the reservoir. Contributions from tributary sites 204, 207, 208, and 106 (between 10 and 40 kg/day) add small amounts to the overall load of around 2,600 kg/day. Since the load between sites 206 and 203 changes very little, and the load at site 200 (North Fork Snake River) is about 110 kg/day, the majority of the sulfate load comes from Peru Creek and the upper Snake River upstream from the Peru Creek confluence. Table A4 shows that 1,516 kg/day comes from Peru Creek and 1,137 kg/day comes from the Snake River above Peru Creek. Added together, this gives a sulfate load of 2,653 kg/day, which is nearly identical to that measured at site 203. The sum of the contributions throughout the watershed is equal to the load observed at the inlet to the reservoir within analytical error. We conclude that sulfate is not reacting instream and leaving the water column. Sulfate has been shown to behave conservatively in other streams in other mining-impacted watersheds (Schemel and others, 2000).

Comparison of calcium and strontium loads from the watershed with the load entering Dillon Reservoir shows that they also behave conservatively. The load expected at site 203 from the summation of the loads from upstream sources matches the load determined from the concentration and discharge at that site.

The result of comparing loads for copper is different. The measured load at site 203 is 0.98 kg/day. This is less than the load of 1.5 kg/day at site 206, four miles upstream, and less than the 1.5 kg/day measured at site 101, just downstream from the confluence of the Snake River with Peru Creek. Copper is reacting instream, probably sorbing to amorphous colloidal iron. The pH in this reach is 6.9, and the iron concentrations are less than 100 ppb, indicating that iron has precipitated out of the water column (upstream at sites 115 and 210 the iron concentration is about 1,000 ppb) and become incorporated into the streambed sediment. This phenomenon is reflected by the iron in the streambed sediment at site 210 of 9.7 percent. Using the above numbers, about 0.5 kg/day (1 lb/day) of copper is being lost to the streambed in the reach between site 101 and site 203. Above the confluence with Peru Creek at site 103, the copper load in the Snake River is only 75 percent of the copper load measured upstream. Along Peru Creek, similar attenuation of total-recoverable copper is seen. Between sites 210 and 209, a distance of 0.75 miles, the copper load decreases from 2.80 to 1.60 kg/day. About 1.2 kg/day (2.6 lbs/day) copper is lost to streambed sediment in this reach.

Comparing loads and concentrations for copper of the filtered 0.45-micron fraction and the unfiltered fraction, one might expect to see a difference between copper concentrations in the two fractions at the sampling sites, since some copper is assumed to become sequestered in the colloidal phase. However, the concentrations and calculated loads at most sites are nearly the same. Filtering with a 0.45-micron filter does not actually define the dissolved fraction, however, since colloidal material can still pass through this size filter (colloids range in size from 0.001 to 1 micron). Thus, the filtered and unfiltered fractions may contain nearly the same concentrations of copper (as well as zinc or cadmium). The 0.45-micron filtrate is what is required by the State of Colorado to meet water quality standards for aquatic life, and it is convention to collect this fraction. There is, however, a difference between filtered and unfiltered analyses for iron and aluminum, as these metals tend to form oxyhydroxide colloids that agglomerate and can reach sizes greater than 0.45 micron.

Some reaches of Peru Creek seem to show a gain in copper load. Between sites 209 and 100, a distance of 1.3 miles, the load increases from 1.60 to 2.22 kg/day. It appears that a source between the two sites provides a contribution of at least 0.62 kg/day copper. However, the conservative element strontium also shows an increase, about 20 percent, and the measured load for sulfate changes by 18 percent. This indicates that the measured discharges may have relatively large errors, and that the increase in copper loading may be an artifact of this measurement error. However, the increase in the copper load is greater than 20 percent; it is about 40 percent, meaning that there is still at least a 20 percent increase in copper load in this reach. Even with uncertainty in the discharge measurements, there still appears to be a source adding at least 0.31 kg/day to the reach.

Zinc and cadmium loads also demonstrate the transfer of metal to the streambed. The zinc load at site 203 is 29.4 kg/day (65 lbs/day), and at site 101 it is 40 kg/day (88 lbs/day). Downstream from the confluence of Peru Creek with the Snake River to Dillon Reservoir, around 11 kg/day zinc is lost to the streambed. The three streambed-sediment samples comprising this reach all had about 1,500 ppm zinc. Uncertainties in discharge measurements result in some substantial errors in the calculated results, but by using the conservative species strontium and sulfate to monitor the discharge changes, one can determine whether a particular metal is lost or gained in separate reaches.

As was the case with copper above, there is an increase in the zinc load between sites 209 and 100. The load changes from 23 to 30 kg/day zinc, an increase of 30 percent. Allowing for discharge and/or analytical error, there is a source of zinc between these two sites providing a contribution of at least 5 kg/day.

Whereas concentration maps identify reaches with elevated water concentrations, load calculations provide a way to compare contributions from different sources in the watershed. Tributaries with high concentrations of metals may or may not have a major effect on the concentration of a trace element in the main stream. For example, the metal concentrations measured in Cinnamon Gulch were the highest in the study, and exceed toxicity standards by many times, but the discharge is only 0.0014 m^3/s, and so the load from Cinnamon Gulch cannot be significant enough to influence concentrations in Peru Creek in a major way (the discharge of Peru Creek near here was 0.121 m^3/s). The concentrations of zinc and copper in Peru Creek rise dramatically between sites 114 and 113, as do the loads. Between sites 114 and 113, the zinc load in Peru Creek increases from 0.9 kg/day to over 18 kg/day, and the copper load increases from 0.01 to 2.32 kg/day. The loads from Cinnamon Gulch are so small (0.23 and 0.03 kg/day respectively) that another source must be responsible for these increased metal loads. This is most likely drainage coming from the Pennsylvania mine area.

Table 4. Summary of metal loads in selected reaches between sample localities relative to the loads at the confluence of Peru Creek with the Snake River

[Loads expressed as percent of load measured at site 101. Negative values indicate loss to colloids that settle out to the streambed.]

	Saints John Creek	Upper Snake River	Cinnamon Gulch 213	Peru Creek 100-209	Peru Creek 209-115	Peru Creek 115-210	Peru Creek 210-211	Peru Creek 211-113	Peru Creek 113-114
Zn	7	14	1	18	6	-19	26	1	43
Cd	6	17	1	17	4	-20	30	3	50
Cu	1	8	2	41	-18	-61	45	-14	150

Table 4 shows the loads of three metals, zinc, cadmium, and copper for nine reaches in the study area, relative to the load measured just below the confluence of Peru Creek with the Snake River (site 101). The loads calculated for Saints John Creek are from site 104, and the loads from the upper Snake River are calculated from site 107. Note that the copper load at site 110 is 30 percent higher than at site 103 (table A4). This is reflective of loss of copper in water between sites 110 and 103. Cinnamon Gulch load contributions to Peru Creek, relative to site 100, are minimal.

The calculations for reaches along Peru Creek reflect some major increases in loads as well as one reach where sorption to the streambed is removing metals from the water column. These values would represent the percent contributions of each reach relative to the site at the bottom of the subbasin were it not for reactive processes. Since copper, cadmium, and zinc are reactive, the concentrations measured at the downstream sites of the subbasins may be less than the concentrations should be if the metals were conservative. Therefore, the percent numbers in the rows may add to more than 100 percent. The numbers do show the relative contributions of the individual reaches to the Snake River watershed. In Peru Creek, reaches 100-209, 210-211, and 113-114 (below the Pennsylvania mine), there are major increases in metal loadings, due to sources other than the measured inflows to Peru Creek. These reaches merit closer investigation. One reach, Peru Creek 115-210 showed a substantial decrease in metal loadings.

Discussions with personnel from Arapahoe Basin (Alan Henceroth, oral commun., 2002) indicate that the proposed withdrawal of water from the North Fork for snow-making will not exceed 0.5 cfs. We have shown throughout this paper that water and sediment from the North Fork of the Snake River at low flow contain no significant metal load. Given the conditions at low flow measured in this study, that is with the Snake River discharge at the gage downstream from the confluence of the North Fork measured at 27.5 cfs (table A1), withdrawal of a maximum of 0.5 cfs of water from the North Fork of the Snake River for snow making would result in an increase in concentration of dissolved metals in the main stem of the Snake River below the confluence with the North Fork of less than 2 percent at low flow as long as the flow at the gage (09047500) was more than 25 cfs. That change would not result in substantial changes in toxicity to trout in the mainstem of the Snake River downstream from the confluence with the North Fork of the Snake River.

Mercury

Mercury concentrations were determined in streambed sediment to determine the contribution of mercury from the Snake River basin to Dillon Reservoir. Mercury was detected at a concentration above crustal abundance (0.086 ppm; Fortescue, 1992) in six sites (fig. 18) in Chihuahua Gulch, where soil mercury anomalies have been reported by Neuerberg (1971b), and the upper reaches of Peru Creek and the Snake River. The Snake River Basin is not a significant source of mercury into Dillon Reservoir under the conditions when we sampled in the watershed. Mercury concentrations in streambed sediment are similar to those measured the Blue and Tenmile drainages (Deacon and Driver, 1999).

Lead Isotopic Results

Lead isotopic data from streambed- and lake-sediment samples from the Snake River watershed (table 5) show a wide range in compositions. Samples from Deer Creek (SRP-109) and the North Fork of the Snake River (SRP-200) have lower lead concentrations and elevated lead isotopic compositions (fig. 19A; $^{206}Pb/^{204}Pb$ of 18.7 and 19.0 respectively) indicating a lead isotopic signature characteristic of Precambrian unmineralized rock (Church and others, 1993). In contrast, analyses of the Tertiary Montezuma stock, three galena samples from the Montezuma mining district, and the Waldorf mine in the next drainage to the east (Stein, 1985) have $^{206}Pb/^{204}Pb$ that lie on a Tertiary-age array in figure 19B. This array is distinctive from the older, unmineralized rock in the headwaters of the Snake River. Veinlets sampled from altered rock in the headwaters have a lead isotopic composition that matches that of the underlying Montezuma stock of Oligocene age (Stein, 1985). Data from streambed sediment from Peru Creek and from downstream in the Snake River arm of Dillon Reservoir plot close to the isotopic composition of the two galena samples from mines in the Montezuma district (table 5). The lead isotopic composition of samples from the Snake River above the confluence with Saints John Creek and at the mouth of the Snake River agree well with data from the arm of the Snake River in Dillon Reservoir. This lead isotopic composition is less radiogenic (lower $^{206}Pb/^{204}Pb$; fig. 20) than that in all of the intervals we analyzed from the Dillon Reservoir core near the dam (Greve and others, 2001).

Data from sediment from both the Tenmile Creek arm and the Blue River arm of Dillon Reservoir do not plot near those of the Snake River (fig. 19B). However, the average compositions of lead from the three intervals in the Dillon Reservoir core not associated with the mercury anomaly (fig. 20) plot within a small cluster along a mixing line between lead isotopic data from sediment from the Snake River arm

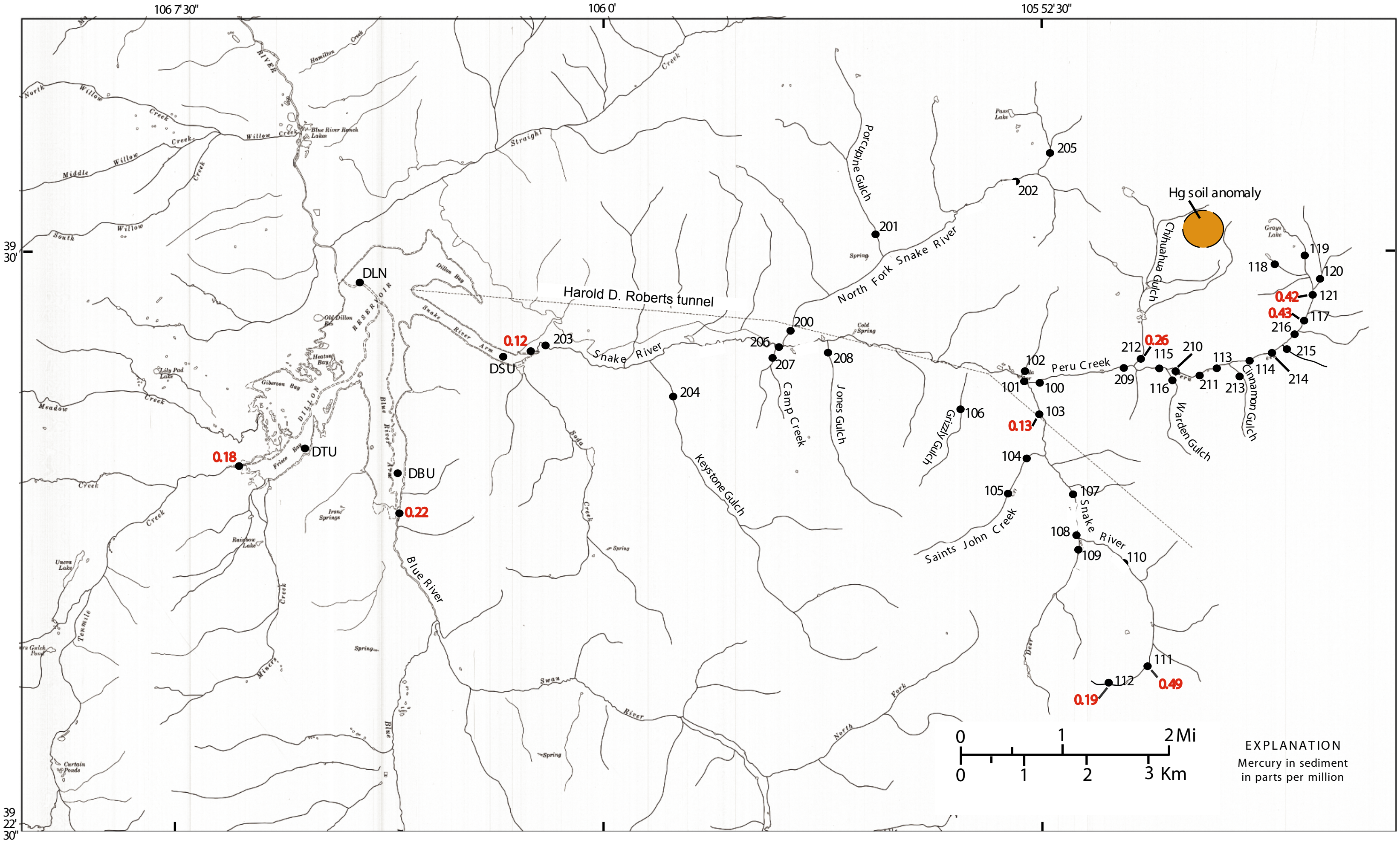

Figure 18. Mercury concentrations determined in six streambed-sediment samples, Snake river watershed. Mercury at all other sites was below the limit of detection (0.02 ppm). Concentration data from the mouth of the Blue River, Snake River, and Tenmile Creek are from Deacon and Driver (1999). Mercury soil anomaly after Neuerberg (1971b).

Table 5. Lead isotopic analyses of selected samples from the Snake River watershed and Dillon Reservoir

[*Data from Stein (1985), analytical errors area comparable to those in this study, values in italics are calculated from published results.]

Dillon Reservoir Sample Depth (in cm)	Site	$^{206}Pb/^{204}Pb$		$^{207}Pb/^{204}Pb$		$^{208}Pb/^{204}Pb$		$^{207}Pb/^{206}Pb$		$^{208}Pb/^{206}Pb$	
DLN (0-1;1-2;2-3)	Samples from Lake Dillon near dam	18.339	± 0.011	15.567	± 0.014	38.498	± 0.047	0.84886	± 0.00026	2.0993	± 0.0013
DLN (6-7;7-8;8-9)		18.383	± 0.011	15.563	± 0.014	38.500	± 0.047	0.84661	± 0.00028	2.0944	± 0.0013
DLN (12-13)	Hg anomaly	18.434	± 0.012	15.588	± 0.014	38.604	± 0.047	0.84560	± 0.00026	2.0942	± 0.0013
DLN (16-17;17-18)		18.339	± 0.013	15.564	± 0.015	38.491	± 0.049	0.84866	± 0.00027	2.0988	± 0.0013
DTU (0-2;2-4)	Tenmile Creek arm of Lake Dillon	18.409	± 0.011	15.562	± 0.014	38.454	± 0.046	0.84537	± 0.00025	2.0889	± 0.0013
DSU (0-2;2-4)	Snake River arm of Lake Dillon	18.174	± 0.011	15.542	± 0.014	38.523	± 0.047	0.85517	± 0.00026	2.1197	± 0.0013
DBU (0-1;1-2;2-3)	Blue River arm of Lake Dillon	18.452	± 0.012	15.585	± 0.015	38.450	± 0.048	0.84465	± 0.00027	2.0838	± 0.0013
SRP-110	Snake River upstream from Deer Creek confluence	18.272	± 0.014	15.572	± 0.016	38.734	± 0.051	0.85222	± 0.00029	2.1198	± 0.0014
SRP-109	Deer Creek	18.742	± 0.011	15.615	± 0.014	38.905	± 0.047	0.83320	± 0.00027	2.0759	± 0.0013
SRP-100	Peru Creek	18.113	± 0.011	15.544	± 0.014	38.543	± 0.046	0.85817	± 0.00026	2.1279	± 0.0013
SRP-200	North Fork of Snake River	19.024	± 0.012	15.648	± 0.014	39.170	± 0.048	0.82255	± 0.00025	2.0590	± 0.0013
SRP-203	Snake River upstream from Lake Dillon	18.235	± 0.011	15.555	± 0.014	38.596	± 0.047	0.85299	± 0.00027	2.1165	± 0.0013
HS-82-8*	Montezuma Stock	18.406		15.596		38.902		*0.84733*		*2.1135*	
HS-82-49*	Montezuma Stock	18.542		15.607		38.972		*0.84171*		*2.1018*	
HS-82-32-GN*	Waldorf mine	18.185		15.572		39.051		*0.85631*		*2.1195*	
HS-82-53-GN*	Climax-Geneva Gulch	18.473		15.585		38.885		*0.84366*		*2.1050*	
HS-82-29-GN*	St. Johns mine	17.958		15.552		38.454		*0.86602*		*2.1413*	
HS-82-33-GN*	Mozart mine	18.024		15.565		38.544		*0.86357*		*2.1385*	

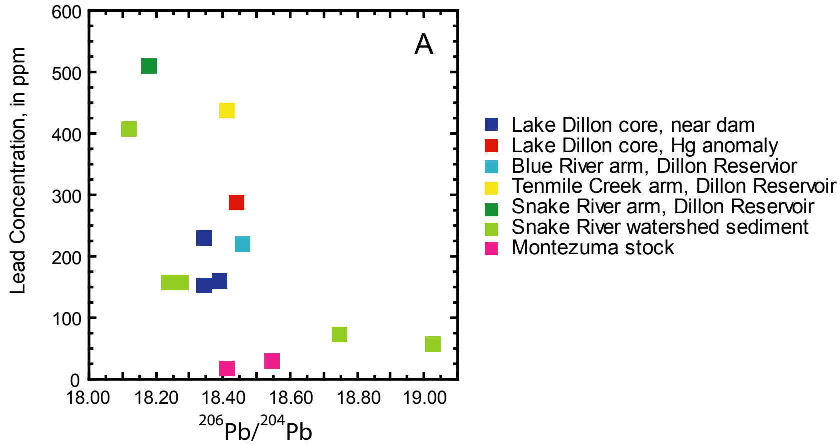

Figure 19. A. Lead isotopic ratio $^{206}Pb/^{204}Pb$ versus concentration for selected samples from Snake River watershed, Blue River, Tenmile Creek and Dillon Reservoir core determined in this study. Data from the Montezuma stock from Stein (1985).

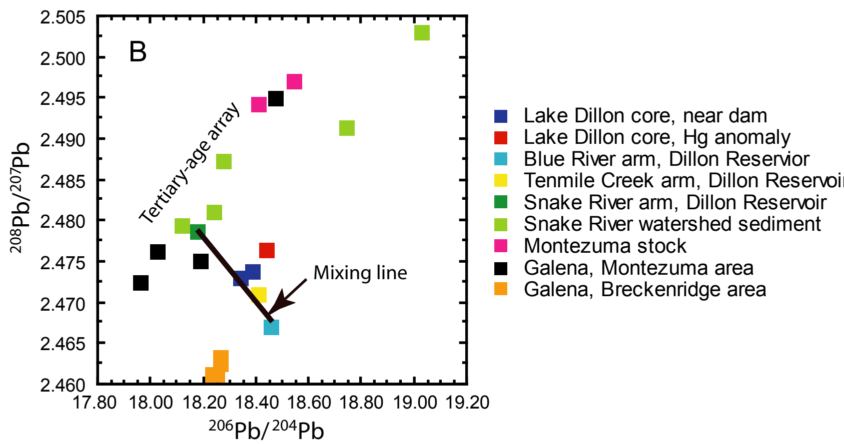

Figure 19. B. Lead isotopic ratio diagram showing the data from streambed sediment and lake sediment (this study), from galena from the Montezuma mining district and the Montezuma stock (Stein, 1985), from galena from the Breckenridge mining district (Delevaux and others, 1966). The lead isotopic signatures of rocks and galena associated with the Montezuma stock lie along a Tertiary array and are distinctive from the signature of the Precambrian basement rocks. Rocks from the Tenmile and Blue River drainages have a different lead isotopic signature. A mixing line between the lead isotopic data from sediment from the Snake River arm of Dillon Reservoir, the lead isotopic data from sediment from the Tenmile Creek and the Blue River arms pass through the composition of normal lake sediment from the core near the dam in Dillon Reservoir (fig. 20) showing that the three samples represent good mixtures of lead from the three drainage basins. The lead isotopic signature of the core containing the mercury anomaly contains a more radiogenic lead isotopic signature indicating that there is a higher concentration of lead from the old Precambrian rocks in this interval. However, the lead isotopic signature cannot be produced by mixing lead and other base metals from either the Breckenridge or Montezuma mining districts if the measured lead isotopic compositions are representative of the bulk of the ore in these districts.

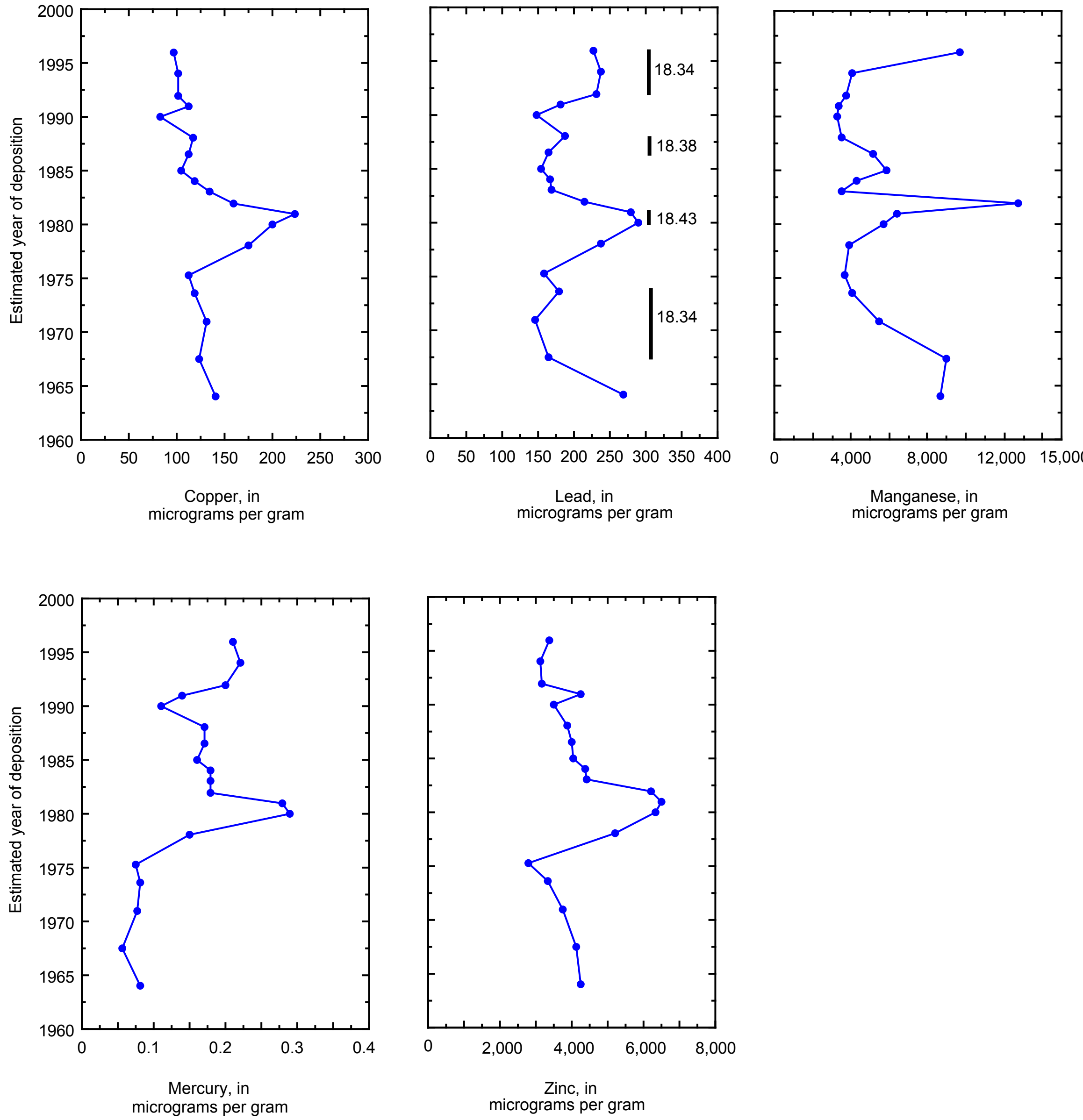

Figure 20. Copper, lead, manganese, mercury, and zinc concentration profiles versus estimated year of deposition for samples from Dillon Reservoir core (from Greve and others, 2001). The $^{206}Pb/^{204}Pb$ data determined in the core intervals (table 5) are indicated on the lead concentration diagram. Note that the lead isotopic signature of the interval containing the high mercury anomaly has a higher $^{206}Pb/^{204}Pb$ value than that from the other three intervals.

with sediment from the Blue River and Tenmile Creek arms (fig 19B). The lead isotopic data from the sediment containing high mercury in the Dillon Reservoir core does not plot along this line. Rather, it has a radiogenic contribution from the older crystalline rocks.

The lead isotopic signature of samples from both the Climax porphyry molybdenum and the Breckenridge mining districts plot along the older array (^{206}/Pb/^{204}Pb from the Climax deposit is in the range of 17.60-17.63; Stein, 1985) and are not shown on figure 19B. The lead isotopic signature from both the Breckenridge mining district and the Climax porphyry molybdenum deposits appear to have a composition that is not sufficiently radiogenic to match that of the mercury anomaly in Dillon Reservoir. Soil mercury anomalies from Chihuahua Gulch (fig. 18), a tributary of Peru Creek (Neuerberg; 1971a), which we might suspect would have a lead isotopic composition like that represented by Peru Creek (^{206}Pb/^{204}Pb of 18.11) would also be ruled out by the lead isotopic data.

Diel Zinc Variation in Water

The autosampler at site AS-1 collected hourly water samples from the Snake River below Peru Creek during the four days of sampling upstream. The autosampler at site AS-2 collected hourly samples from the Snake River above Peru Creek during the two days we collected samples from the basin. The standard deviation of the zinc concentration throughout each day was less than 5 percent; the standard deviation of the daily mean zinc concentration was slightly higher, but still less than 5 percent (table A6). The variation in zinc concentration at site AS-2 was slightly higher, but still only 5 percent. In other words, there was no diel zinc variation at the sampling stations for the period October 9-12 when we sampled. These results indicate that the other metal concentrations probably had little or no diel variation as well, so that the concentration-based hazard quotient maps are a good representation for conditions during the sampling period. Sampling of the watershed during the day for a 4-day period is sufficient to demonstrate that concentrations of metals in water have met the criteria for exceedence of the acute toxicity standard for aquatic life.

Conclusions

Our analysis of the sediment and water data collected at low flow on Oct. 9-12, 2001 have shown that concentrations of zinc in water, corrected for the ameliorating effect of hardness, exceeded the acute toxicity criteria for rainbow trout and the chronic criteria (Horn, 2001) for brown trout in the mainstem of the Snake River, Peru Creek, and many of the upper tributaries affected by historical mining in the watershed. Dissolved concentrations of copper and cadmium, corrected for the ameliorating effect of hardness, exceeded the chronic or acute toxicity criteria (Horn, 2001) for all species of trout in Peru Creek between the confluence of the Snake River and Cinnamon Gulch as well as for Cinnamon Gulch itself. Dietary exposure of aquatic life to zinc and cadmium, and, to a lesser extent, to copper and lead would be expected to affect survivability of trout in the watershed. The low pH range in some reaches as well as the concentrations of colloidal aluminum and dissolved manganese also limit trout habitat in the watershed. Since brook and brown trout are apparently less sensitive than rainbow trout (Horn, 2001), stocking efforts in the Snake River possibly would be more effective if either of the more tolerant trout species were stocked.

Load calculations clearly indicate that the lower reach of Peru Creek (between sites 100 and 209), and the reach between site 21 upstream from Warden Gulch to site 114 upstream from Cinnamon Gulch are the primary reaches where metal loads increase and are added to Peru Creek. Primary targets for remediation should target identified mining sources draining into these reaches of Peru Creek. Other sources of metals in the watershed are minor by comparison with the contributions from these two reaches. Load calculations indicate that the proposed withdrawal of water from the North Fork of the Snake River for snowmaking by Arapahoe Basin should have a minor affect on the dissolved concentrations of metals in water in the mainstem of the Snake River and would not significantly affect survivability of trout in this reach assuming that our data are typical of low-flow conditions when the withdrawals would occur.

The mercury and associated base metal anomaly in the core from near the dam in Dillon Reservoir (Greve and others, 2000) has a radiogenic lead isotopic signature and does not match that of any of the mining districts where lead isotopic data are available in the Snake River, Blue River or Tenmile Creek watersheds. A cloud burst in the headwaters of one of the three drainages where there is a large amount of altered Precambrian rock appears to be the most likely source, but evaluation of the stream-flow data from the gages in the three watersheds does not provide definitive data in the 1979-1981 timeframe that would point to an event within one of the three watersheds. Major mining districts, that is the Montezuma mining district in the Snake River watershed, the Breckenridge mining district in the Blue River watershed, and the Climax mine in the Tenmile Creek watershed can be ruled out by the lead isotopic data. The source of the mercury anomaly remains an enigma.

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Appendix 1. Field numbers, location descriptions, sample localities, discharge, conductivity, pH, temperature, sulfate, fluorine, chlorine, nitrate and phospate concentrations of filtered water samples, Snake River watershed, Summit County, Colorado Oct 9-12, 2001

U.S. Geological Survey Open-File Report 02-0330
by D.L Fey, S.E. Church, D.M. Unruh, and D.J. Bove

Field Number	Location description	Latitude	Longitude	Discharge ft3/s	Discharge m3/s	Conduct-ivity uS/cm	pH	Temp deg C	SO4 icp-aes mg/L	SO4 icp-ms mg/L	SO4 IC mg/L	Fluorine mg/L	Chlorine mg/L	Nitrate mg/L	Phosphate mg/L
SRP-100	Peru Creek above confluence w/ Snake	39.59813	105.86885	10	0.283	175	4.4	4.3	71	73	97	0.36	0.22	1.13	0
SRP-101	Snake River below Peru Creek	39.59817	105.87610	17.2	0.487	172	6.9	4	69	62	88	0.23	0.33	1.11	0
SRP-102	Thurman Gulch above Peru Creek (sediment only)	39.59926	105.87490	-	-	-	-	-			-	-	-	-	-
SRP-103	Snake River above Peru Creek	39.59011	105.87067	7.88	0.223	179	6.8	0.4	63	65	80	0.19	0.48	1.05	0
SRP-104	Saints John Creek below wetland	39.58076	105.87483	2.08	0.0589	227	6.6	1.4	66	63	87	0.08	0.33	0.92	0.02
SRP-105	Saints John Creek above wetland	39.57606	105.87820	2.25	0.0637	200	6.6	1.1	55	57	69	0.07	0.30	1.07	0
SRP-106	Grizzly Gulch below Hunkidori Mine	39.59245	105.89297	0.556	0.0157	106	6.6	1.4	14	12	15	0.06	0.24	1.30	0
SRP-107	Snake River above Montezuma	39.57440	105.86293	5.19	0.147	150	5.7	1.5	59	62	76	0.31	0.31	0.91	0
SRP-108	Snake River below conf. W/ Deer Creek	39.56424	105.86097	2.93	0.0830	162	4.8	1.8	61	63	86	0.37	0.27	0.94	0
SRP-109	Deer Creek above Snake River conf.	39.56273	105.86038	1.96	0.0555	100	6.6	0	15	18	16	0.06	0.26	1.25	0.02
SRP-110	Upper Snake above Deer Creek	39.55948	105.84885	3.46	0.0980	283	3.8	1.7	97	96	160	0.58	0.43	0.74	0
SRP-111	Upper Snake below upper wetland	39.53748	105.84097	0.312	0.00883	153	4	2.3	42	56	79	0.19	0.20	0.65	0.09
SRP-112	Upper Snake above upper wetland	39.53220	105.84962	0.013	0.00037	117	6.1	6.9	42	39	49	0.05	0.10	0.65	0
SRP-113	Peru Creek above Cooper Mountain tribs	39.60072	105.82073	4.27	0.121	192	5.2	3.5	81	74	120	0.4	0.25	3.32	0
SRP-114	Peru Creek below Pennsylvania mine	39.60228	105.81192	3.42	0.0969	134	6.9	3.4	47	52	56	0.14	0.18	1.61	0
SRP-115	Peru Creek above Cooper Mountain tribs	39.59980	105.83715	4.67	0.132	233	4.3	1.6	98	88	150	0.46	0.32	1.37	0.49
SRP-116	Warden Gulch above Peru Creek (sediment only)	39.59819	105.83473	-	-	-	-	-			-	-	-	-	-
SRP-117	Peru Creek above Shoe Basin Mine	39.61135	105.79699	1.34	0.0379	170	6.7	1.7	58	53	73	0.17	0.16	1.64	0
SRP-118	Upper Horseshoe Basin Lake outlet (water only)	39.62338	105.80667		N/A	151	7	1	57	54	74	0.15	0.16	2.46	0
SRP-119	Peru Creek above Falls Gulch	39.62213	105.79788	0.334	0.00946	107	7.1	2.1	30	26	33	0.12	0.17	1.38	0
SRP-120	trib to Peru Creek	39.61673	105.79510	0.392	0.0111	244	7	1.9	87	78	115	0.19	0.49	2.30	0
SRP-121	Peru Creek below National Treasury Mine	39.61636	105.79546	1.27	0.0360	179	7	1	62	56	80	0.18	0.20	1.51	0
SRP-200	North Fork Snake River at Keystone	39.60810	105.94057	6.21	0.176	109	6.3	3.7	7.1	10	7.4	0.12	7.22	2.33	0
SRP-201	Porcupine Gulch, North Fork Snake River	39.62730	105.91591	2.63	0.0745	66	7.3	3	3.9	7	3.7	0.11	0.17	1.29	0.02
SRP-202	North Fork Snake River, below Arapahoe Basin	39.64055	105.87809	2.77	0.0874	165	6.8	3.7	13	12	14	0.1	23.10	2.72	0
SRP-203	Snake River inlet into Dillon Reservoir	39.60571	106.00918	26.9	0.762	148	6.8	1.1	43	46	49	0.17	2.70	1.02	0
SRP-204	Keystone Gulch above Snake River	39.59405	105.97288	2.65	0.0750	84	7	2.4	4.3	3	4.2	0.09	0.36	0.60	0
SRP-205	North Fork Snake River, above Arapahoe Basin	39.64639	105.86812	0.69	0.020	134	7	0.6	5.1	4	3.1	0.1	10.90	0.86	0
SRP-206	Snake River below gaging station in Keystone	39.60545	105.94345	27.5	0.779	134	6.9	4.1	43	46	51	0.17	2.10	1.07	0.07
SRP-207	Camp Creek next to Timber Lodge	39.60400	105.94447	0.38	0.011	113	7.1	1.4	11	8	10.9	0.11	0.94	0.69	0
SRP-208	Jones Gulch	39.60361	105.92979	1.32	0.0374	110	7.2	0.9	14	16	15	0.07	0.64	1.55	0
SRP-209	Peru Creek below Chihuahua Gulch	39.60051	105.84699	7.84	0.222	184	5.4	1.1	77	70	114	0.38	0.23	3.14	0
SRP-210	Peru Creek above Warden Gulch	39.59987	105.83386	5.77	0.163	233	4.4	2.4	100	99	153	0.5	0.30	1.28	0
SRP-211	Peru Creek below Cooper Mountain tribs	39.59960	105.82533	4.35	0.123	184	5.5	4.2	19	78	111	0.41	0.24	1.58	0
SRP-212	Chihuahua Gulch above Peru Creek	39.60164	105.84397	1.25	0.0354	111	6.8	1.2	33	29	37	0.07	0.22	1.46	0
SRP-213	Cinnamon Gulch above Peru Creek	39.59970	105.81767	0.051	0.0014	275	4.1	0	113	115	183	0.55	0.33	1.16	0.05
SRP-214	Peru Creek above Pennsylvania Mine	39.60393	105.80679	2.55	0.0722	134	6.8	2.4	49	44	58	0.13	0.20	1.65	0
SRP-215	trib to Peru Creek , above Cinnamon Gulch (sediment only	39.60416	105.80371	-	-	-	-	-			-	-	-	-	-
SRP-216	Peru Creek below Shoe Basin Mine	39.60672	105.80108	1.61	0.0456	148	6.8	2.5	53	55	64	0.14	0.26	1.68	0

Appendix 2. Major and trace element data from streambed sediment,
Snake River watershed, Summit County, Colorado, Oct 9-12, 2001

U.S. Geological Survey Open-File Report 02-0330
by D.L Fey, S.E. Church, D.M. Unruh and D.J. Bove

Field No	Al %	Ca %	Fe %	K %	Mg %	Na %	P %	Ti %	Ag ppm	As ppm	Ba ppm	Be ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Li ppm
SRP-100	7.3	0.91	6.7	2.6	0.47	1.3	0.17	0.31	10	12	930	3	8	240	35	52	350	19	140	14
SRP-101	6.6	1.1	7.8	2.3	0.57	1.3	0.15	0.29	20	24	670	3	10	230	32	58	350	19	150	18
SRP-102	7.2	2.1	4.5	2.1	0.66	1.8	0.20	0.37	< 2	11	620	2	4	140	10	20	25	20	100	28
SRP-103	6.3	1.6	6.3	1.9	0.88	1.3	0.11	0.29	16	19	230	3	15	130	45	68	100	16	67	15
SRP-104	6.7	2.5	6.0	1.9	1.2	1.8	0.09	0.32	11	18	920	2	18	84	24	70	42	18	50	12
SRP-105	6.8	2.9	7.9	1.5	1.4	1.8	0.09	0.44	20	22	620	2	19	91	51	75	60	20	51	13
SRP-106	6.9	2.5	5.8	1.8	1.1	1.8	0.18	0.43	< 2	18	660	2	4	180	17	65	13	19	110	18
SRP-107	6.9	1.8	6.6	2.0	1.2	1.4	0.12	0.37	< 2	10	780	2	5	130	44	97	69	18	73	17
SRP-108	7.0	2.1	6.6	1.9	1.3	1.5	0.14	0.38	< 2	15	690	2	4	97	37	98	46	17	54	17
SRP-109	7.5	3.1	5.0	1.8	1.9	1.9	0.16	0.50	< 2	< 10	670	2	3	110	29	120	18	18	62	21
SRP-110	6.1	0.54	12	2.3	0.72	0.80	0.13	0.23	< 2	13	800	2	5	120	36	76	58	19	65	11
SRP-111	3.7	0.34	28	0.96	0.33	0.39	0.11	0.11	2	13	640	1	11	26	110	16	85	12	20	6
SRP-112	8.0	2.1	4.6	2.4	1.5	1.4	0.23	0.49	18	120	2000	2	5	100	20	110	360	21	65	22
SRP-113	7.9	0.56	6.8	3.2	0.81	0.93	0.17	0.31	5	36	1100	3	5	180	18	94	380	25	110	17
SRP-114	7.2	0.78	5.3	2.8	0.68	1.2	0.21	0.33	< 2	15	1200	3	12	390	22	93	160	21	230	22
SRP-115	7.2	0.64	7.3	2.9	0.68	1.1	0.18	0.30	7	28	1100	2	5	240	24	76	200	21	140	18
SRP-116	6.4	0.83	3.3	2.9	0.40	1.5	0.09	0.24	< 2	12	720	2	2	97	3	32	31	17	64	7
SRP-117	7.6	0.60	5.2	2.5	0.65	0.88	0.17	0.33	4	16	2100	5	13	170	43	81	180	18	130	19
SRP-119	7.8	0.88	4.4	3.3	0.87	0.98	0.24	0.37	< 2	18	1100	3	8	150	20	76	39	22	89	22
SRP-120	7.1	0.72	5.8	2.6	0.67	0.94	0.20	0.38	4	22	1800	4	12	210	38	91	170	19	140	20
SRP-121	7.1	0.72	6.1	3.1	0.66	0.92	0.18	0.32	2	< 10	1100	3	10	210	25	110	30	22	130	17
SRP-200	6.9	1.1	5.8	2.4	0.75	1.4	0.16	0.27	< 2	< 10	820	2	3	540	24	120	15	20	290	16
SRP-201	6.6	1.2	4.8	2.9	0.60	1.7	0.18	0.30	< 2	14	920	2	3	690	17	76	15	22	370	14
SRP-202	6.9	1.1	4.7	2.6	0.75	1.5	0.13	0.29	< 2	< 10	820	2	3	230	16	80	18	19	140	17
SRP-203	6.7	1.2	4.1	2.4	0.70	1.5	0.10	0.25	< 2	12	1200	2	6	160	25	70	130	17	90	16
SRP-204	6.9	3.0	6.4	1.7	1.7	2.2	0.12	0.49	< 2	< 10	660	2	3	180	27	110	5	18	110	15
SRP-205	6.5	1.2	4.2	2.7	0.68	1.6	0.13	0.28	< 2	< 10	780	2	2	350	14	91	15	19	210	16
SRP-206	6.8	1.4	7.0	2.4	0.69	1.4	0.17	0.36	8	18	1500	2	9	300	37	77	160	19	190	15
SRP-207	6.9	1.5	3.6	2.4	0.93	1.7	0.09	0.30	< 2	< 10	760	2	3	220	14	73	20	18	130	15
SRP-208	7.1	2.5	8.0	1.9	1.4	1.6	0.16	0.47	< 2	18	810	2	4	480	40	110	14	22	280	17
SRP-209	7.2	0.92	6.2	2.6	0.52	1.5	0.16	0.31	7	14	930	3	5	230	20	49	270	20	150	16
SRP-210	6.7	0.56	9.7	2.5	0.57	0.96	0.17	0.24	6	20	920	2	6	170	32	63	240	19	98	15
SRP-211	7.8	0.63	6.6	3.0	0.72	0.96	0.20	0.33	6	28	1200	3	5	300	20	97	340	23	170	17
SRP-212	6.9	1.3	5.6	2.5	0.54	1.6	0.17	0.32	< 2	11	770	2	4	170	16	39	30	19	120	17
SRP-213	7.2	0.68	5.9	3.0	0.87	0.68	0.19	0.38	6	38	1300	2	4	150	15	100	150	22	83	11
SRP-214	6.8	0.86	5.4	2.6	0.64	1.1	0.25	0.41	< 2	20	1300	4	10	580	22	95	130	20	360	20
SRP-215	7.9	0.43	4.4	3.1	0.76	0.76	0.16	0.29	< 2	18	870	3	3	170	13	90	48	24	100	22
SRP-216	7.7	0.77	4.8	2.7	0.68	1.2	0.20	0.34	< 2	11	1300	4	14	360	25	88	200	21	230	24

Appendix 2. Major and trace element data from streambed sediment, Snake River watershed, Summit County, Colorado, Oct 9-12, 2001
continued

U.S. Geological Survey Open-File Report 02-0330
by D.L Fey, S.E. Church, D.M. Unruh and D.J. Bove

Field No	Mn ppm	Mo ppm	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Sn ppm	Sr ppm	Th ppm	V ppm	Y ppm	Yb ppm	Zn ppm	Hg ppm
SRP-100	4400	7	41	120	22	410	11	< 5	270	36	120	54	5	950	0.07
SRP-101	5600	4	18	120	25	550	12	8	330	26	130	54	4	1600	0.09
SRP-102	2000	5	67	69	12	74	11	5	430	36	99	38	3	430	0.04
SRP-103	6600	2	< 4	66	32	810	14	6	380	29	94	33	3	3700	0.13
SRP-104	11000	3	< 4	37	35	520	17	< 5	350	19	110	32	3	4100	0.04
SRP-105	8000	< 2	< 4	48	38	540	21	10	360	22	150	48	4	3300	0.08
SRP-106	1300	3	47	95	26	78	16	< 5	320	52	130	39	3	410	0.03
SRP-107	2000	2	27	75	37	180	17	6	250	32	120	36	3	820	0.03
SRP-108	1600	< 2	25	58	36	140	17	< 5	240	26	110	28	2	410	0.03
SRP-109	1300	< 2	30	61	42	74	22	< 5	270	25	130	32	3	260	0.02
SRP-110	460	4	24	72	28	160	13	6	200	29	80	15	1	150	0.04
SRP-111	230	4	< 4	39	28	180	12	8	100	5	53	12	< 1	130	0.49
SRP-112	3400	< 2	26	56	59	1200	20	6	510	15	120	26	2	740	0.19
SRP-113	2400	4	38	95	30	570	15	8	220	23	90	25	2	520	0.05
SRP-114	7500	4	< 4	200	54	350	12	5	240	43	95	57	3	1400	0.04
SRP-115	1800	4	40	130	28	420	14	7	230	26	92	30	2	520	0.06
SRP-116	620	2	61	42	13	280	8	< 5	320	18	54	13	1	180	0.02
SRP-117	6500	10	6	150	55	1200	12	6	250	15	92	120	6	1800	0.43
SRP-119	2600	3	32	81	35	280	14	< 5	300	15	89	25	2	850	0.03
SRP-120	5700	4	9	140	55	940	13	< 5	260	23	110	71	4	1700	0.05
SRP-121	4200	< 2	20	120	46	240	13	< 5	220	36	100	35	2	1100	0.42
SRP-200	1300	3	37	270	30	61	23	6	220	160	97	86	8	120	<0.02
SRP-201	590	3	46	340	20	48	12	< 5	200	210	100	63	3	87	0.09
SRP-202	1100	2	51	110	28	69	15	< 5	260	46	88	38	3	170	<0.02
SRP-203	2400	< 2	32	83	33	160	12	< 5	260	34	81	38	3	1500	0.02
SRP-204	1100	< 2	43	99	40	17	22	< 5	300	54	160	42	4	110	<0.02
SRP-205	660	2	50	180	25	45	12	< 5	220	86	86	48	3	100	<0.02
SRP-206	4200	4	35	150	30	390	14	5	370	67	130	54	4	1600	0.06
SRP-207	790	< 2	42	110	31	32	14	< 5	280	48	80	32	2	240	<0.02
SRP-208	1400	< 2	41	250	39	58	27	5	310	150	180	80	7	210	0.02
SRP-209	2400	6	52	120	20	320	12	5	300	24	120	45	4	680	0.06
SRP-210	1800	4	32	98	25	500	12	5	200	26	72	25	2	520	0.06
SRP-211	1800	5	40	160	29	520	14	10	210	34	96	35	2	570	0.06
SRP-212	1400	5	66	81	19	720	12	210	340	27	110	41	4	270	0.26
SRP-213	670	< 2	42	79	27	580	14	17	230	22	97	19	2	240	0.05
SRP-214	5800	3	15	290	49	300	13	7	230	52	110	81	4	1700	0.05
SRP-215	1900	5	44	79	30	220	14	6	180	22	78	17	1	260	0.06
SRP-216	9900	4	< 4	200	58	450	13	5	240	36	94	70	4	1900	0.07

Appendix 3. Major and trace element data for 0.45-micron filtered water, Snake River watershed, Summit County, Colorado, Oct 9-12, 2001

U.S. Geological Survey Open-File Report 02-0330
by D.L Fey, S.E. Church, D.M. Unruh and D.J. Bove

Field Number	River	Location description	Discharge cubic m/s	Al ug/L ICP-MS	Ba ug/L ICP-AES	Ca ug/mL ICP-AES	Cd ug/L ICP-MS	Co ug/L ICP-MS	Cu ug/L ICP-MS	Fe ug/L ICP-MS	Mg ug/mL ICP-AES	Mn ug/L ICP-MS	Mo ug/L ICP-MS
SRP-100	Peru creek	Peru Creek above confluence w/ Snake	0.283	1380	31	18	5.11	3.37	91.4	108	4.3	1020	0.01
SRP-101	Snake River	Snake River below Peru Creek	0.487	217	30	19	3.47	3.37	44.3	68	4.7	791	0.20
SRP-103	Snake River	Snake River above Peru Creek	0.223	15.4	25	19	1.90	3.96	2.0	50	4.8	616	0.22
SRP-104	Saints John Creek	Saint John's Creek below wetland	0.0589	8.86	33	30	1.35	0.52	0.74	154	5.1	635	0.26
SRP-105	Saints John Creek	Saint John's Creek above wetland	0.0637	9.23	16	26	1.30	0.45	0.71	10	4.3	285	0.30
SRP-106	Grizzly Gulch	Grizzly Gulch below Hunkidori Mine	0.0157	1.32	7.8	14	0.02	0.01	< 0.5	10	2.0	0.5	0.66
SRP-107	Snake River	Snake River above Montezuma	0.147	1120	22	12	2.08	6.74	9.3	218	4.5	685	0.01
SRP-108	Snake River	Snake River below conf. W/ Deer Creek	0.0830	2160	24	12	2.28	7.95	11.3	212	4.7	793	0.22
SRP-109	Deer Creek	Deer Creek above Snake River conf.	0.0555	4.20	15	13	0.04	0.03	0.50	10	2.4	11.3	0.31
SRP-110	Snake River	Upper Snake above Deer Creek	0.0980	5660	29	9.8	2.56	15.8	20.0	1010	6.3	1350	0.01
SRP-111	Snake River	Upper Snake below upper wetland	0.00883	1260	34	9.0	0.48	6.44	1.7	2010	3.8	387	0.01
SRP-112	Snake River	Upper Snake above upper wetland	0.00037	6.11	37	14	0.09	0.03	2.0	10	2.8	22.7	0.01
SRP-113	Peru creek	Peru Creek above Cooper Mountain tribs	0.121	1660	37	19	7.34	3.72	225	90	5.4	1600	0.01
SRP-114	Peru creek	Peru Creek below Pennsylvania mine	0.0969	14.4	42	15	0.35	0.06	0.86	10	3.8	61.5	0.01
SRP-115	Peru creek	Peru Creek above Cooper Mountain tribs	0.132	3920	36	19	7.68	6.08	164	1000	5.4	1620	0.01
SRP-117	Peru creek	Peru Creek above Shoe Basin Mine	0.0379	36.5	49	20	0.84	0.07	1.5	50	4.7	85.7	0.01
SRP-118	trib to Peru Creek	Upper Horseshoe Basin Lake outlet (water only)	N/A	21.5	8.5	19	0.12	0.36	0.85	10	4.1	47.3	0.01
SRP-119	Peru creek	Peru Creek above Falls Gulch	0.00946	2.33	32	13	0.05	0.01	1.1	10	2.8	2.6	0.46
SRP-120	trib to Peru Creek	trib to Peru Creek	0.0111	2.40	84	32	0.12	0.04	< 0.5	10	6.8	4.5	0.01
SRP-121	Peru creek	Peru Creek below National Treasury Mine	0.0360	36.3	53	21	1.10	0.09	1.4	10	5.0	138	0.01
SRP-200	Snake River	North Fork Snake River at Keystone	0.176	3.48	18	12	0.05	0.02	< 0.5	10	2.3	2.7	1.55
SRP-201	Porcupine Gulch	Porcupine Gulch, North Fork Snake River	0.0745	4.24	15	9.3	0.01	0.01	< 0.5	10	1.6	0.4	0.85
SRP-202	Snake River	North Fork Snake River, below Arapahoe Basin	0.0874	7.58	32	14	0.02	0.14	0.54	150	3.0	57.7	0.85
SRP-203	Snake River	Snake River inlet into Dillon Reservoir	0.762	20.1	28	18	1.53	1.46	5.1	10	3.7	384	0.62
SRP-204	Keystone Gulch	Keystone Gulch above Snake River	0.0750	3.68	20	11	0.01	0.03	< 0.5	80	2.7	7.5	0.47
SRP-205	Snake River	North Fork Snake River, above Arapahoe Basin	0.020	4.51	61	12	0.01	0.04	0.50	10	3.5	3.4	0.94
SRP-206	Snake River	Snake River below gaging station in Keystone	0.779	17.5	26	17	1.78	1.60	8.0	10	3.6	401	0.62
SRP-207	Camp Creek	Camp Creek next to Timber Lodge	0.011	5.11	16	14	0.02	0.04	0.61	50	3.3	17.4	0.45
SRP-208	Jones Gulch	Jones Gulch	0.0374	1.76	14	15	0.03	0.03	< 0.5	10	2.6	0.3	0.67
SRP-209	Peru creek	Peru Creek below Chihuahua Gulch	0.222	2070	30	18	5.03	3.41	82.3	156	4.5	1010	0.01
SRP-210	Peru creek	Peru Creek above Warden Gulch	0.163	3930	31	18	8.35	6.86	207	979	5.4	1830	0.01
SRP-211	Peru creek	Peru Creek below Cooper Mountain tribs	0.123	1410	37	18	7.05	3.58	206	120	5.1	1510	0.01
SRP-212	Chihuahua	Chihuahua Gulch above Peru Creek	0.0354	2.31	22	15	0.01	0.03	< 0.5	52	2.5	3.6	0.55
SRP-213	Cinnamon Gulch	Cinnamon Gulch above Peru Creek	0.0014	5880	30	17	9.69	11.8	245	241	6.0	3240	0.01
SRP-214	Peru creek	Peru Creek above Pennsylvania Mine	0.0722	14.2	45	17	0.39	0.08	0.95	56	4.1	83.2	0.01
SRP-216	Peru creek	Peru Creek below Shoe Basin Mine	0.0456	26.2	47	18	0.64	0.10	1.9	10	4.4	135	0.01

Appendix 3. Major and trace element data for 0.45-micron filtered water, Snake River watershed, Summit County, Colorado, Oct 9-12, 2001
continued
U.S. Geological Survey Open-File Report 02-0330
by D.L Fey, S.E. Church, D.J. Bove and D.M. Unruh

Field Number	River	Na ug/mL ICP-AES	Ni ms ICP-MS	Pb ug/L ICP-MS	Si ug/mL ICP-AES	Sr ug/L ICP-MS	Ti ug/L ICP-MS	Zn ug/L ICP-MS	SO4 ug/mL ICP-MS	SO4 load kg/day	Sr load kg/day	Zn load kg/day	Cd load kg/day	Cu load kg/day	Fe load kg/day
SRP-100	Peru creek	2.1	8.3	6.8	5.2	157	1.5	1360	73	1785	3.84	33.25	0.125	2.23	2.64
SRP-101	Snake River	2.3	8.3	2.7	5.3	121	1.8	962	62	2609	5.09	40.48	0.146	1.86	2.86
SRP-103	Snake River	2.3	9.4	0.4	5.3	73.7	1.3	608	65	1252	1.42	11.71	0.037	0.04	0.96
SRP-104	Saints John Creek	2.0	2.6	2.6	3.6	65.3	2.3	499	63	321	0.33	2.54	0.007	0.004	0.78
SRP-105	Saints John Creek	1.5	1.8	0.79	3.4	53.5	1.4	388	57	314	0.29	2.14	0.007	0.00	0.06
SRP-106	Grizzly Gulch	1.6	0.3	0.05	3.8	55.0	1.0	3.8	12	16	0.07	0.01	0.000	0.00	0.01
SRP-107	Snake River	2.3	14.4	1.4	6.1	70.0	1.3	501	62	787	0.89	6.36	0.026	0.12	2.77
SRP-108	Snake River	2.2	15.3	1.0	6.4	64.6	5.6	512	63	452	0.46	3.67	0.016	0.08	1.52
SRP-109	Deer Creek	1.5	0.3	0.2	2.8	44.0	2.1	5.5	18	86	0.21	0.03	0.000	0.00	0.05
SRP-110	Snake River	3.0	26.8	6.1	10	65.9	2.3	588	96	813	0.56	4.98	0.022	0.17	8.55
SRP-111	Snake River	2.1	9.9	1.6	5.6	48.7	2.1	114	56	43	0.04	0.09	0.000	0.00	1.53
SRP-112	Snake River	0.80	1.6	0.3	2.9	51.7	1.7	84.9	39	1	0.00	0.00	0.000	0.00	0.00
SRP-113	Peru creek	1.9	13.5	9.4	4.2	196	2.3	1780	74	774	2.05	18.61	0.077	2.35	0.94
SRP-114	Peru creek	1.4	2.1	0.2	2.7	186	2.4	111	52	435	1.56	0.93	0.003	0.01	0.08
SRP-115	Peru creek	2.2	12.1	7.5	6.1	171	0.9	1800	88	1004	1.95	20.53	0.088	1.87	11.40
SRP-117	Peru creek	1.1	5.2	1.5	2.0	260	1.5	132	53	174	0.85	0.43	0.003	0.00	0.16
SRP-118	trib to Peru Creek	1.4	2.3	0.1	2.2	156	0.7	13.2	54	N/A	N/A	N/A	N/A	N/A	N/A
SRP-119	Peru creek	0.80	0.7	0.3	1.3	218	0.01	15.0	26	21	0.18	0.01	0.000	0.00	0.01
SRP-120	trib to Peru Creek	1.3	0.9	0.2	2.0	415	0.7	24.3	78	75	0.40	0.02	0.000	0.00	0.01
SRP-121	Peru creek	1.2	6.9	1.1	2.1	270	0.5	149	56	174	0.84	0.46	0.003	0.00	0.03
SRP-200	Snake River	4.2	0.4	0.2	3.0	94.3	0.8	4.3	10	152	1.43	0.07	0.001	0.00	0.15
SRP-201	Porcupine Gulch	1.5	0.3	0.2	2.8	57.2	0.4	4.0	7	45	0.37	0.03	0.000	0.00	0.06
SRP-202	Snake River	11	0.5	0.1	2.4	146	0.6	12.9	12	91	1.10	0.10	0.000	0.00	1.13
SRP-203	Snake River	3.2	4.0	0.4	4.6	114	0.5	466	46	3028	7.51	30.68	0.101	0.34	0.66
SRP-204	Keystone Gulch	2.1	0.3	0.1	4.4	61.0	0.1	1	3	19	0.40	0.01	0.000	0.00	0.52
SRP-205	Snake River	7.1	0.4	0.3	2.2	120	0.01	2.9	4	7	0.21	0.01	0.000	0.00	0.02
SRP-206	Snake River	2.9	4.3	0.3	4.5	111	0.4	515	46	3096	7.47	34.66	0.120	0.54	0.67
SRP-207	Camp Creek	3.0	0.5	0.1	4.5	109	0.01	12.0	8	8	0.10	0.01	0.000	0.00	0.05
SRP-208	Jones Gulch	2.1	0.3	0.3	4.4	75.5	0.4	4.7	16	52	0.24	0.02	0.000	0.00	0.03
SRP-209	Peru creek	2.0	7.9	6.2	5.3	153	0.7	1200	70	1343	2.93	23.02	0.096	1.58	2.99
SRP-210	Peru creek	2.1	14.3	9.8	6.0	177	1.0	2080	99	1394	2.49	29.29	0.118	2.92	13.79
SRP-211	Peru creek	1.7	13.5	9.2	4.2	192	0.9	1850	78	829	2.04	19.66	0.075	2.19	1.28
SRP-212	Chihuahua	1.4	0.4	0.1	2.2	128	0.3	3.3	29	89	0.39	0.01	0.000	0.00	0.16
SRP-213	Cinnamon Gulch	2.5	26.4	12.2	8.6	175	1.1	2080	115	14	0.02	0.25	0.0012	0.03	0.03
SRP-214	Peru creek	1.4	2.2	0.58	2.4	199	0.4	116	44	274	1.24	0.72	0.002	0.01	0.35
SRP-216	Peru creek	1.2	3.4	0.74	2.1	231	0.7	171	55	217	0.91	0.67	0.003	0.01	0.04

Appendix 4. Major and trace element data for unfiltered water
and calculated instantaneous metal loads
Snake River watershed, Summit County, Colorado, Oct 9-12, 2001

U.S. Geological Survey Open-File Report 02-0330

by D.L Fey, S.E. Church, D.M Unruh and D.J. Bove

Field Number	River	Location description	Discharge cubic m/s	Al ug/L ICP-MS	Ba ug/L ICP-AES	Ca ug/mL ICP-AES	Cd ug/L ICP-MS	Co ug/L ICP-MS	Cu ug/L ICP-MS	Fe ug/L ICP-MS	Mg ug/mL ICP-AES	Mn ug/L ICP-MS	Mo ug/L ICP-MS
SRP-100	Peru creek	Peru Creek above confluence w/ Snake	0.283	2100	24	14	4.92	3.32	90.6	191	3.3	910	< 0.2
SRP-101	Snake River	Snake River below Peru Creek	0.487	67.5	22	15	3.54	3.32	35.8	10	3.5	774	< 0.2
SRP-103	Snake River	Snake River above Peru Creek	0.223	1510	19	15	1.89	3.60	6.0	289	3.6	569	0.20
SRP-104	Saints John Creek	Saint John's Creek below wetland	0.0589	128	36	24	1.72	0.68	1.4	471	3.9	728	0.23
SRP-105	Saints John Creek	Saint John's Creek above wetland	0.0637	108	11	21	1.40	0.46	1.2	117	3.3	286	0.26
SRP-106	Grizzly Gulch	Grizzly Gulch below Hunkidori Mine	0.0157	5.41	5.4	11	0.02	0.01	< 0.5	10	1.5	1.4	0.64
SRP-107	Snake River	Snake River above Montezuma	0.147	2340	20	11	1.99	6.21	9.5	374	3.5	644	< 0.2
SRP-108	Snake River	Snake River below conf. W/ Deer Creek	0.0830	3100	17	9.6	2.20	7.40	11.1	447	3.5	748	0.26
SRP-109	Deer Creek	Deer Creek above Snake River conf.	0.0555	11.9	12	10	0.03	0.04	0.51	64	1.8	19.3	0.26
SRP-110	Snake River	Upper Snake above Deer Creek	0.0980	5500	23	7.9	2.54	14.8	19.4	1060	4.8	1260	< 0.2
SRP-111	Snake River	Upper Snake below upper wetland	0.00883	1200	26	7.0	0.47	6.04	1.7	2150	2.9	362	< 0.2
SRP-112	Snake River	Upper Snake above upper wetland	0.00037	20.9	30	11	0.11	0.04	3.1	10	2.1	29.8	0.22
SRP-113	Peru creek	Peru Creek above Cooper Mountain tribs	0.121	1960	27	14	7.38	3.58	222	277	4.0	1540	< 0.2
SRP-114	Peru creek	Peru Creek below Pennsylvania mine	0.0969	44.4	38	13	0.35	0.06	1.2	10	3.0	61.4	< 0.2
SRP-115	Peru creek	Peru Creek above Cooper Mountain tribs	0.132	4340	23	14	7.80	6.04	165	1600	4.0	1630	< 0.2
SRP-117	Peru creek	Peru Creek above Shoe Basin Mine	0.0379	216	36	16	0.89	0.07	2.7	10	3.5	87.0	< 0.2
SRP-118	trib to Peru Creek	Upper Horseshoe Basin Lake outlet	N/A	59.1	15	16	0.11	0.35	0.90	10	3.2	46.0	< 0.2
SRP-119	Peru creek	Peru Creek above Falls Gulch	0.00946	2.23	24	10	0.05	0.01	< 0.5	10	2.2	2.3	0.61
SRP-120	trib to Peru Creek	trib to Peru Creek	0.0111	1.74	59	25	0.12	0.03	< 0.5	10	4.9	4.4	< 0.2
SRP-121	Peru creek	Peru Creek below National Treasury Mine	0.0360	196	39	17	1.10	0.08	2.1	10	3.9	132	< 0.2
SRP-200	Snake River	North Fork Snake River at Keystone	0.176	11.4	14	9.9	0.03	0.03	< 0.5	10	1.7	3.6	1.69
SRP-201	Porcupine Gulch	Porcupine Gulch, North Fork Snake River	0.0745	4.97	10	7.3	0.01	0.01	< 0.5	10	1.2	0.4	0.78
SRP-202	Snake River	North Fork Snake River, below Arapahoe Basin	0.0874	43.9	26	11	0.02	0.16	0.66	386	2.2	58.8	0.82
SRP-203	Snake River	Snake River inlet into Dillon Reservoir	0.762	543	20	13	1.55	1.33	14.9	128	2.8	361	0.58
SRP-204	Keystone Gulch	Keystone Gulch above Snake River	0.0750	28.6	14	8.4	0.01	0.05	< 0.5	93	2.0	10.9	0.42
SRP-205	Snake River	North Fork Snake River, above Arapahoe Basin	0.020	60.2	44	9.5	0.01	0.09	0.53	139	2.6	8.6	0.82
SRP-206	Snake River	Snake River below gaging station in Keystone	0.779	846	18	12	1.76	1.51	22.4	139	2.7	389	0.62
SRP-207	Camp Creek	Camp Creek next to Timber Lodge	0.011	91.8	13	11	0.04	0.10	1.2	260	2.5	24.2	0.40
SRP-208	Jones Gulch	Jones Gulch	0.0374	2.23	11	12	0.03	0.02	< 0.5	10	2.0	0.3	0.68
SRP-209	Peru creek	Peru Creek below Chihuahua Gulch	0.222	2680	23	14	4.94	3.38	83.5	317	3.4	996	0.23
SRP-210	Peru creek	Peru Creek above Warden Gulch	0.163	4060	23	14	8.38	6.48	199	1380	4.1	1840	< 0.2
SRP-211	Peru creek	Peru Creek below Cooper Mountain tribs	0.123	1780	26	14	6.85	3.30	199	254	3.8	1420	< 0.2
SRP-212	Chihuahua	Chihuahua Gulch above Peru Creek	0.0354	5.59	20	12	0.01	0.03	< 0.5	50	1.9	4.6	0.52
SRP-213	Cinnamon Gulch	Cinnamon Gulch above Peru Creek	0.0014	5470	24	14	9.45	11.1	233	220	4.5	3040	< 0.2
SRP-214	Peru creek	Peru Creek above Pennsylvania Mine	0.0722	54.0	29	13	0.39	0.07	1.3	10	3.0	83.5	< 0.2
SRP-216	Peru creek	Peru Creek below Shoe Basin Mine	0.0456	124	35	14	0.66	0.10	2.3	10	3.3	137	< 0.2

Appendix 4. Major and trace element data for unfiltered water
and calculated instantaneous metal loads
Snake River watershed, Summit County, Colorado, Oct 9-12, 2001
continued

U.S. Geological Survey Open-File Report 02-0330
by D.L Fey, S.E. Church, D.M Unruh and D.J. Bove

Field Number	River	Na ug/mL ICP-AES	Ni ug/L ICP-MS	Pb ug/L ICP-MS	Si ug/mL ICP-AES	Sr ug/L ICP-AES	Ti ug/L ICP-MS	Zn ug/L ICP-MS	SO4 ug/mL ICP-MS	SO4 load kg/day	Sr load kg/day	Zn load kg/day	Cd load kg/day	Cu load kg/day	Fe load kg/day	Mn load kg/day
SRP-100	Peru creek	1.6	8.0	7.0	4.0	146	1.8	1240	62	1,516	3.57	30.32	0.120	2.22	4.67	22.25
SRP-101	Snake River	1.8	8.4	0.74	3.8	120	0.01	951	58	2,440	5.05	40.02	0.149	1.51	0.42	32.57
SRP-103	Snake River	1.8	8.9	2.8	4.2	75.1	1.9	582	59	1,137	1.45	11.21	0.036	0.12	5.57	10.96
SRP-104	Saints John Creek	1.7	2.7	12.7	2.8	64.3	6.4	548	58	295	0.33	2.79	0.009	0.01	2.40	3.70
SRP-105	Saints John Creek	1.3	1.9	4.4	2.7	56.2	3.1	390	53	292	0.31	2.15	0.008	0.01	0.64	1.57
SRP-106	Grizzly Gulch	1.4	0.3	0.1	2.9	54.0	1.2	3.8	12	16	0.07	0.01	0.000		0.01	0.00
SRP-107	Snake River	1.8	13.1	0.98	4.8	70.5	1.4	446	55	699	0.90	5.66	-	0.12	4.75	8.18
SRP-108	Snake River	1.8	14.8	1.1	4.9	65.5	1.2	459	58	416	0.47	3.29	0.016	0.08	3.21	5.36
SRP-109	Deer Creek	1.5	0.4	0.4	2.2	44.8	1.8	4.4	15	72	0.21	0.02	0.000	0.00	0.31	0.09
SRP-110	Snake River	2.4	25.6	1.3	7.7	67.2	2.1	550	88	745	0.57	4.66	0.022	0.16	8.98	10.67
SRP-111	Snake River	1.7	9.5	1.6	4.3	49.2	2.2	113	50	38	0.04	0.09	0.000	0.00	1.64	0.28
SRP-112	Snake River	0.82	1.7	3.1	2.2	50.7	1.3	84.5	38	1	0.00	0.00	0.000	0.00	0.00	0.00
SRP-113	Peru creek	1.5	13.2	9.8	3.2	194	2.0	1740	68	711	2.03	18.19	0.077	2.32	2.90	16.10
SRP-114	Peru creek	1.2	2.0	1.7	2.1	184	1.9	105	48	402	1.54	0.88	0.003	0.01	0.08	0.51
SRP-115	Peru creek	1.5	11.8	8.8	4.6	169	0.8	1800	84	958	1.93	20.53	0.089	1.88	18.25	18.59
SRP-117	Peru creek	1.10	5.5	2.4	1.6	266	0.5	140	52	170	0.87	0.46	0.003	0.01	0.03	0.28
SRP-118	trib to Peru Creek	1.3	2.2	0.1	1.7	156	0.3	10.6	52	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SRP-119	Peru creek	0.84	0.4	0.07	1.0	218	0.01	13.3	26	21	0.18	0.01	0.000		0.01	0.00
SRP-120	trib to Peru Creek	1.0	0.9	< 0.05	1.6	420	0.4	21.8	74	71	0.40	0.02	0.000		0.01	0.00
SRP-121	Peru creek	1.1	7.0	2.2	1.7	270	0.1	154	55	171	0.84	0.48	0.003	0.01	0.03	0.41
SRP-200	Snake River	3.3	0.4	0.2	2.3	97.5	1.2	2.2	7	106	1.48	0.03	0.000		0.15	0.05
SRP-201	Porcupine Gulch	1.2	0.2	< 0.05	2.1	57.9	0.01	0.01	3	19	0.37	0.00	0.000		0.06	0.00
SRP-202	Snake River	8.1	0.6	0.3	1.8	144	1.8	13.0	11	83	1.09	0.10	0.000	0.00	2.91	0.44
SRP-203	Snake River	2.4	3.8	1.9	3.5	117	0.2	447	39	2,568	7.70	29.43	0.102	0.98	8.43	23.77
SRP-204	Keystone Gulch	1.6	0.3	0.1	3.4	59.3	1	0.7	2	13	0.38	0.00	0.000		0.60	0.07
SRP-205	Snake River	5.4	0.4	0.4	1.7	121	2.7	2	4	7	0.21	0.00	0.000	0.00	0.24	0.01
SRP-206	Snake River	2.2	4.1	2.1	3.4	119	0.01	496	40	2,692	8.01	33.38	0.118	1.51	9.36	26.18
SRP-207	Camp Creek	2.2	0.6	0.3	3.5	111	5.1	18.4	9	9	0.11	0.02	0.000	0.00	0.25	0.02
SRP-208	Jones Gulch	1.7	0.3	0.06	3.4	76.1	0.01	2	12	39	0.25	0.01	0.000		0.03	0.00
SRP-209	Peru creek	1.5	7.9	24.0	4.1	154	0.6	1200	67	1,285	2.95	23.02	0.095	1.60	6.08	19.10
SRP-210	Peru creek	1.7	13.4	11.2	4.5	181	0.6	1990	91	1,282	2.55	28.03	0.118	2.80	19.43	25.91
SRP-211	Peru creek	1.4	12.6	9.9	3.2	191	0.3	1670	69	733	2.03	17.75	0.073	2.11	2.70	15.09
SRP-212	Chihuahua	1.2	0.3	0.08	1.7	132	0.2	2	30	92	0.40	0.01	0.000		0.15	0.01
SRP-213	Cinnamon Gulch	2.1	25.5	12.4	6.5	174	0.6	1880	102	12	0.02	0.23	0.001	0.03	0.03	0.37
SRP-214	Peru creek	1.1	2.1	0.54	1.8	202	0.2	116	44	274	1.26	0.72	0.002	0.01	0.06	0.52
SRP-216	Peru creek	1.0	3.3	1.3	1.6	239	0.01	161	49	193	0.94	0.63	0.003	0.01	0.04	0.54

Appendix 5. Major and trace element data **[lat 39.60510; long 105.91825]**
ICP-AES results for autosampler at site AS-1
Snake River watershed, Summit County, Colorado
U.S. Geological Survey Open-File Report 02-0330
by D.L Fey, S.E. Church, D.M. Unruh and D.J. Bove

[samples filtered through 0.45-micron filter]

field number	date	time of day	Al ug/mL	B ug/L	Ba ug/L	Be ug/L	Ca ug/mL	Cd ug/L	Co ug/L	Cr ug/L	Cu ug/L	Fe ug/mL	K ug/mL	Li ug/L	Mg ug/mL
11009011200	October 9 2001	12.00	0.018	< 10	27	< 10	18	< 10	< 10	< 10	17	< 0.05	0.96	< 10	4.2
11009011300	October 9 2001	13.00	0.019	< 10	25	< 10	18	< 10	< 10	< 10	18	< 0.05	0.99	< 10	4.1
11009011400	October 9 2001	14.00	0.019	< 10	28	< 10	18	< 10	< 10	< 10	20	0.09	0.94	< 10	4.3
11009011500	October 9 2001	15.00	0.018	< 10	30	< 10	19	< 10	< 10	< 10	17	< 0.05	0.95	< 10	4.2
11009011600	October 9 2001	16.00	0.014	18	28	< 10	18	< 10	< 10	< 10	14	< 0.05	0.95	< 10	4.2
11009011700	October 9 2001	17.00	0.023	< 10	27	< 10	181	< 10	< 10	< 10	18	0.06	0.95	< 10	4.2
11010010930	October 10 2001	9.50	< 0.01	< 10	27	< 10	20	< 10	< 10	< 10	13	< 0.05	1.07	< 10	4.2
11010011030	October 10 2001	10.50	< 0.01	< 10	26	< 10	19	< 10	< 10	< 10	11	< 0.05	1.00	< 10	4.2
11010011130	October 10 2001	11.50	< 0.01	< 10	28	< 10	19	< 10	< 10	< 10	11	< 0.05	1.07	< 10	4.1
11010011230	October 10 2001	12.50	< 0.01	< 10	33	< 10	20	< 10	< 10	< 10	11	< 0.05	1.05	< 10	4.2
11010011330	October 10 2001	13.50	< 0.01	< 10	26	< 10	20	< 10	< 10	< 10	10	< 0.05	1.05	< 10	4.2
11010011430	October 10 2001	14.50	< 0.01	< 10	32	< 10	21	< 10	< 10	< 10	13	< 0.05	1.08	< 10	4.2
11010011530	October 10 2001	15.50	< 0.01	< 10	28	< 10	20	< 10	< 10	< 10	21	< 0.05	1.07	< 10	4.3
11010011630	October 10 2001	16.50	< 0.01	< 10	26	< 10	19	< 10	< 10	< 10	10	< 0.05	1.03	< 10	4.2
11011010900	October 11 2001	9.00	0.021	< 10	26	< 10	19	< 10	< 10	< 10	20	< 0.05	1.09	< 10	4.3
11011011000	October 11 2001	10.00	0.017	< 10	26	< 10	19	< 10	< 10	< 10	16	< 0.05	1.05	< 10	4.2
11011011100	October 11 2001	11.00	0.015	< 10	28	< 10	18	< 10	< 10	< 10	15	< 0.05	0.94	< 10	4.0
11011011200	October 11 2001	12.00	0.016	< 10	27	< 10	17	< 10	< 10	< 10	12	< 0.05	0.96	< 10	4.0
11011011300	October 11 2001	13.00	0.016	< 10	26	< 10	18	< 10	< 10	< 10	13	< 0.05	0.96	< 10	4.0
11011011400	October 11 2001	14.00	0.017	< 10	26	< 10	18	< 10	< 10	< 10	13	< 0.05	0.96	< 10	4.0
11011011500	October 11 2001	15.00	0.019	< 10	27	< 10	18	< 10	< 10	< 10	14	0.07	0.96	< 10	4.2
11011011600	October 11 2001	16.00	0.022	< 10	27	< 10	19	< 10	< 10	< 10	12	< 0.05	0.92	< 10	4.1
11011011700	October 11 2001	17.00	0.017	< 10	27	< 10	19	< 10	< 10	< 10	11	< 0.05	0.91	< 10	4.2
11011011800	October 11 2001	18.00	0.019	< 10	26	< 10	19	< 10	< 10	< 10	11	0.05	0.96	< 10	4.4
11012011000	October 12 2001	10.00	0.022	< 10	24	< 10	18	< 10	< 10	< 10	10	< 0.05	1.12	< 10	4.0
11012011100	October 12 2001	11.00	0.026	< 10	27	< 10	18	< 10	< 10	< 10	13	< 0.05	1.17	< 10	4.1
11012011200	October 12 2001	12.00	0.021	< 10	27	< 10	18	< 10	< 10	< 10	13	< 0.05	1.10	< 10	4.1
11012011300	October 12 2001	13.00	0.024	< 10	26	< 10	18	< 10	< 10	< 10	11	< 0.05	1.01	< 10	4.1
11012011400	October 12 2001	14.00	0.021	< 10	27	< 10	19	< 10	< 10	< 10	11	< 0.05	1.04	< 10	4.1
11012011500	October 12 2001	15.00	0.023	< 10	26	< 10	18	< 10	< 10	< 10	11	< 0.05	0.94	< 10	4.1
11012011600	October 12 2001	16.00	0.022	< 10	27	< 10	19	< 10	< 10	< 10	9	< 0.05	0.99	< 10	4.2
11012011700	October 12 2001	17.00	0.023	< 10	27	< 10	19	< 10	< 10	< 10	11	< 0.05	0.96	< 10	4.2

Appendix 5. Major and trace element data
ICP-AES results for autosampler at site AS-1
Snake River watershed, Summit County, Colorado
continued
U.S. Geological Survey Open-File Report 02-0330
by D.L Fey, S.E. Church, D.M. Unruh and D.J. Bove
[samples filtered through 0.45-micron filter]

field number	date	time of day	Mn ug/L	Mo ug/L	Na ug/mL	Ni ug/L	P ug/L	Pb ug/L	Si ug/mL	Sr ug/L	Ti ug/L	V ug/L	Zn ug/L	Zn statistics for AS-1	
11009011200	October 9 2001	12.00	680	< 20	2.3	16	< 50	< 50	5.1	125	< 50	< 10	750	daily mean	761
11009011300	October 9 2001	13.00	670	< 20	2.3	13	< 50	< 50	5.0	124	< 50	< 10	746	daily std dev	17
11009011400	October 9 2001	14.00	690	< 20	2.3	100	< 50	< 50	5.1	127	< 50	< 10	788	%RSD	2.2
11009011500	October 9 2001	15.00	680	< 20	2.2	13	< 50	< 50	5.2	127	< 50	< 10	767		
11009011600	October 9 2001	16.00	680	< 20	2.3	15	< 50	< 50	5.0	124	< 50	< 10	746		
11009011700	October 9 2001	17.00	680	< 20	2.2	17	< 50	< 50	5.2	126	< 50	< 10	771		
11010010930	October 10 2001	9.50	730	< 20	2.6	< 10	< 50	< 50	5.1	135	< 50	< 10	730	daily mean	719
11010011030	October 10 2001	10.50	720	< 20	2.5	< 10	< 50	< 50	5.1	135	< 50	< 10	731	daily std dev	18
11010011130	October 10 2001	11.50	710	< 20	2.7	< 10	< 50	< 50	5.1	135	< 50	< 10	725	%RSD	2.5
11010011230	October 10 2001	12.50	710	< 20	2.6	< 10	< 50	< 50	5.1	137	< 50	< 10	734		
11010011330	October 10 2001	13.50	710	< 20	2.7	< 10	< 50	< 50	5.2	138	< 50	< 10	724		
11010011430	October 10 2001	14.50	700	< 20	2.7	< 10	< 50	< 50	5.1	138	< 50	< 10	711		
11010011530	October 10 2001	15.50	710	< 20	2.7	< 10	< 50	< 50	5.2	136	< 50	< 10	719		
11010011630	October 10 2001	16.50	690	< 20	2.6	< 10	< 50	< 50	5.1	132	< 50	< 10	678		
11011010900	October 11 2001	9.00	680	< 20	2.7	11	< 50	< 50	5.4	141	< 50	< 10	802	daily mean	741
11011011000	October 11 2001	10.00	670	< 20	2.5	13	< 50	< 50	5.3	139	< 50	< 10	792	daily std dev	34
11011011100	October 11 2001	11.00	630	< 20	2.2	11	< 50	< 50	4.9	130	< 50	< 10	744	%RSD	4.5
11011011200	October 11 2001	12.00	640	< 20	2.3	10	< 50	< 50	4.9	130	< 50	< 10	738		
11011011300	October 11 2001	13.00	630	< 20	2.3	10	< 50	< 50	4.9	133	< 50	< 10	731		
11011011400	October 11 2001	14.00	630	< 20	2.4	12	< 50	< 50	5.0	138	< 50	< 10	732		
11011011500	October 11 2001	15.00	650	< 20	2.3	49	< 50	< 50	5.0	134	< 50	< 10	744		
11011011600	October 11 2001	16.00	610	< 20	2.3	< 10	< 50	< 50	5.0	128	< 50	< 10	708		
11011011700	October 11 2001	17.00	590	< 20	2.3	14	< 50	< 50	5.1	123	< 50	< 10	695		
11011011800	October 11 2001	18.00	640	< 20	2.5	15	< 50	< 50	5.3	124	< 50	< 10	719		
11012011000	October 12 2001	10.00	600	< 20	2.5	13	< 50	< 50	4.8	128	< 50	< 10	652	daily mean	680
11012011100	October 12 2001	11.00	620	< 20	2.6	14	< 50	< 50	5.0	130	< 50	< 10	707	daily deviatio	26
11012011200	October 12 2001	12.00	620	< 20	2.4	15	< 50	< 50	5.0	126	< 50	< 10	706	%RSD	3.8
11012011300	October 12 2001	13.00	620	< 20	2.4	12	< 50	< 50	5.1	130	< 50	< 10	712		
11012011400	October 12 2001	14.00	620	< 20	2.5	11	< 50	< 50	4.9	130	< 50	< 10	668		
11012011500	October 12 2001	15.00	600	< 20	2.3	11	< 50	< 50	4.8	127	< 50	< 10	655		
11012011600	October 12 2001	16.00	610	< 20	2.3	10	< 50	< 50	4.9	127	< 50	< 10	656		
11012011700	October 12 2001	17.00	620	< 20	2.3	12	< 50	< 50	5.0	127	< 50	< 10	682		

Appendix 5. Major and trace element data **[lat 39.59011; long 105.87067]**
ICP-AES results for autosampler at site AS-2
Snake River watershed, Summit County, Colorado
U.S. Geological Survey Open-File Report 02-0330
by D.L Fey, S.E. Church, D.M. Unruh, and D.J. Bove

field number	date	time of day	Al ug/mL	B ug/L	Ba ug/L	Be ug/L	Ca ug/mL	Cd ug/L	Co ug/L	Cr ug/L	Cu ug/L	Fe ug/mL	K ug/mL	Li ug/L	Mg ug/mL
21010011000	October 10 2001	10.00	0.024	< 10	26	< 10	19	< 10	< 10	< 10	< 10	0.06	0.95	< 10	4.8
21010011100	October 10 2001	11.00	0.015	< 10	24	< 10	19	< 10	< 10	< 10	< 10	0.07	0.92	< 10	4.7
21010011200	October 10 2001	12.00	0.017	< 10	29	< 10	20	< 10	< 10	< 10	< 10	< 0.05	0.98	< 10	4.7
21010011300	October 10 2001	13.00	0.016	< 10	28	< 10	19	< 10	< 10	< 10	< 10	< 0.05	0.96	< 10	4.6
21010011400	October 10 2001	14.00	0.017	< 10	23	< 10	18	< 10	< 10	< 10	< 10	0.05	0.96	< 10	4.6
21010011500	October 10 2001	15.00	0.015	< 10	22	< 10	19	< 10	< 10	< 10	< 10	0.05	0.96	< 10	4.6
21010011600	October 10 2001	16.00	0.019	< 10	23	< 10	19	< 10	< 10	< 10	< 10	0.07	0.92	< 10	4.6
21010011700	October 10 2001	17.00	0.020	< 10	23	< 10	19	< 10	< 10	< 10	< 10	0.08	0.96	< 10	4.6
21011011000	October 11 2001	10.00	< 0.01	< 10	27	< 10	23	< 10	< 10	< 10	< 10	< 0.05	1.10	< 10	4.8
21011011100	October 11 2001	11.00	< 0.01	< 10	28	< 10	23	< 10	< 10	< 10	< 10	< 0.05	1.20	< 10	4.9
21011011200	October 11 2001	12.00	< 0.01	< 10	28	< 10	23	< 10	< 10	< 10	< 10	< 0.05	1.10	< 10	4.9
21011011300	October 11 2001	13.00	< 0.01	< 10	27	< 10	20	< 10	< 10	< 10	< 10	< 0.05	0.98	< 10	4.7
21011011400	October 11 2001	14.00	< 0.01	< 10	23	< 10	19	< 10	< 10	< 10	< 10	< 0.05	1.10	< 10	4.7
21011011500	October 11 2001	15.00	< 0.01	< 10	25	< 10	21	< 10	< 10	< 10	< 10	< 0.05	0.99	< 10	5.0

field number	date	time of day	Mn ug/L	Mo ug/L	Na ug/mL	Ni ug/L	P ug/L	Pb ug/L	Si ug/mL	Sr ug/L	Ti ug/L	V ug/L	Zn ug/L	Zn statistics for AS-2	
21010011000	October 10 2001	10.00	600	< 20	2.3	14	< 50	< 50	5.3	75	< 50	< 10	525	daily mean	498
21010011100	October 10 2001	11.00	600	< 20	2.2	17	< 50	< 50	5.4	74	< 50	< 10	525	daily std dev	23
21010011200	October 10 2001	12.00	600	< 20	2.3	16	< 50	< 50	5.4	74	< 50	< 10	523	%RSD	4.7
21010011300	October 10 2001	13.00	580	< 20	2.2	15	< 50	< 50	5.3	73	< 50	< 10	499		
21010011400	October 10 2001	14.00	580	< 20	2.3	14	< 50	< 50	5.2	72	< 50	< 10	482		
21010011500	October 10 2001	15.00	590	< 20	2.2	15	< 50	< 50	5.2	72	< 50	< 10	473		
21010011600	October 10 2001	16.00	600	< 20	2.1	14	< 50	< 50	5.3	72	< 50	< 10	479		
21010011700	October 10 2001	17.00	580	< 20	2.2	14	< 50	< 50	5.3	71	< 50	< 10	477		
21011011000	October 11 2001	10.00	560	< 20	2.8	7	< 50	< 50	5.5	91	< 50	< 10	547	daily mean	528
21011011100	October 11 2001	11.00	560	< 20	2.9	9	< 50	< 50	5.7	92	< 50	< 10	556	daily std dev	26
21011011200	October 11 2001	12.00	560	< 20	2.6	7	< 50	< 50	5.9	92	< 50	< 10	502	%RSD	5.0
21011011300	October 11 2001	13.00	570	< 20	2.8	10	< 50	< 50	5.5	84	< 50	< 10	492		
21011011400	October 11 2001	14.00	640	< 20	2.6	10	< 50	< 50	5.4	80	< 50	< 10	522		
21011011500	October 11 2001	15.00	740	< 20	2.5	11	< 50	< 50	5.4	80	< 50	< 10	546		

Appendix 6. Quality Control analyses for water analyses

Snake River watershed, Summit County, Colorado, ICP-MS

U.S. Geological Survey Open-File Report 02-0330

by D.L Fey, S.E. Church, D.M. Unruh and D.J. Bove

	Field No	Al ug/L	Cd ug/L	Co ug/L	Cu ug/L	Fe ug/L	Mn ug/L	Mo ug/L	Ni ug/L	Pb ug/L	SO4 mg/L	Sr ug/L	Ti ug/L	Zn ug/L
Det. Limit		< 0.1	< 0.02	< 0.02	< 0.5	< 50	< 0.01	< 0.2	< 0.1	< 0.05	< 2	< 0.5	< 0.1	< 0.5
Filtered Sample	SRP-104FA	8.86	1.35	0.52	0.74	154	635	0.26	2.6	2.6	63	65.3	2.3	499
Field Duplicate	SRP-104dFA	8.84	1.35	0.52	0.88	112	622	0.24	2.5	2.0	62	65.4	2.5	495
Unfiltered Sample	SRP-104UA	128	1.72	0.68	1.4	471	728	0.23	2.7	12.7	58	64.3	6.4	548
Field Duplicate	SRP-104dUA	70.1	1.64	0.58	1.1	328	680	0.21	2.5	7.7	59	64.4	3.0	520
Filtered Sample	SRP-210FA	3930	8.35	6.86	207	979	1830	< 0.2	14.3	9.8	99	177	1.0	2080
Field Duplicate	SRP-210dFA	4010	8.48	7.04	208	1030	1960	< 0.2	14.2	9.6	99	177	1.0	2130
Unfiltered Sample	SRP-210UA	4060	8.38	6.48	199	1380	1840	< 0.2	13.4	11.2	91	181	0.6	1990
Field Duplicate	SRP-210dUA	4150	8.14	6.42	199	1280	1800	< 0.2	13.3	10.6	91	177	0.7	1990
Filtered Sample	SRP-213FA	5880	9.69	11.8	245	241	3240	< 0.2	26.4	12.2	115	175	1.1	2080
Field Duplicate	SRP-213dFA	5670	9.56	11.7	248	238	3230	< 0.2	26.6	12.3	112	173	1.4	2030
Unfiltered Sample	SRP-213UA	5470	9.45	11.1	233	220	3040	< 0.2	25.5	12.4	102	174	0.6	1880
Field Duplicate	SRP-213dUA	5560	9.50	11.2	235	223	3080	< 0.2	25.6	12.3	104	175	0.9	1880
Filtered Sample	SRP-119FA	2.33	0.05	< 0.02	1.1	< 50	2.6	0.46	0.7	0.3	26	218	< 0.1	15.0
Analytical Duplicate	SRP-119FA	2.52	0.06	0.02	1.3	< 50	2.7	< 0.2	0.7	0.3	27	216	0.4	15.9
Filtered Sample	SRP-200FA	3.48	0.05	0.02	< 0.5	< 50	2.7	1.55	0.4	0.2	10	94.3	0.8	4.3
Analytical Duplicate	SRP-200FA	3.71	0.02	0.02	< 0.5	< 50	2.8	1.29	0.4	0.2	9	95.1	2.4	3.3
Unfiltered Sample	SRP-119UA	2.23	0.05	< 0.02	< 0.5	< 50	2.3	0.61	0.4	0.07	26	218	< 0.1	13.3
Analytical Duplicate	SRP-119UA	2.40	0.05	0.02	< 0.5	< 50	2.4	< 0.2	0.4	0.06	28	215	< 0.1	13.9
Unfiltered Sample	SRP-200UA	11.4	0.03	0.03	< 0.5	< 50	3.6	1.69	0.4	0.2	7	97.5	1.2	2.2
Analytical Duplicate	SRP-200UA	10.8	< 0.02	0.03	< 0.5	< 50	3.7	1.20	0.4	0.2	7	96.5	1.8	2.0
Field Blank, Filtered	SRP-150FA	< 0.1	< 0.02	< 0.02	< 0.5	< 50	0.1	< 0.2	< 0.1	0.2	< 2	< 0.5	2.1	2
Field Blank, Filtered	SRP-151FA	0.98	< 0.02	< 0.02	< 0.5	< 50	0.2	< 0.2	< 0.1	0.1	< 2	< 0.5	< 0.1	0.6
Field Blank, Filtered	SRP-250FA	0.88	< 0.02	< 0.02	< 0.5	< 50	0.2	< 0.2	< 0.1	0.2	3	< 0.5	0.7	1
Field Blank, Filtered	SRP-251FA	1.02	< 0.02	< 0.02	< 0.5	< 50	0.1	0.20	< 0.1	0.3	3	< 0.5	0.1	2.6
Field Blank, Unfiltered	SRP-150UA	< 0.1	0.02	< 0.02	< 0.5	< 50	0.08	< 0.2	< 0.1	0.05	< 2	< 0.5	2.0	0.8
Field Blank, Unfiltered	SRP-151UA	0.47	< 0.02	< 0.02	< 0.5	< 50	0.1	< 0.2	< 0.1	0.1	< 2	< 0.5	< 0.1	< 0.5
Field Blank, Unfiltered	SRP-250UA	< 0.1	< 0.02	< 0.02	< 0.5	< 50	< 0.01	< 0.2	< 0.1	< 0.05	< 2	< 0.5	< 0.1	< 0.5
Field Blank, Unfiltered	SRP-251UA	1.36	< 0.02	< 0.02	< 0.5	< 50	0.1	0.22	< 0.1	0.08	< 2	< 0.5	< 0.1	< 0.5
NIST-1640-set 1		48.8	23.4	21.6	86.1	< 50	121	45.0	28.3	27.6	13	118	0.3	58.0
NIST-1640-set 2		48.4	23.5	20.3	83.8	< 50	122	46.6	27.2	28.4	12	126	< 0.1	54.8
NIST-1640-set 3		51.3	24.2	21.0	88.4	< 50	126	47.7	28.5	28.2	11	130	< 0.1	56.3
NIST-1640 avg		49.5	23.7	21.0	86.1		123.0	46.4	28.0	28.1	12.0	124.7	0.3	56.4
NIST-1640 true		52	22.8	20.3	85.2	34.3	121.5	46.8	27.4	27.9		124		53.2
% Difference		-4.8%	3.9%	3.3%	1.1%		1.2%	-0.8%	2.2%	0.6%		0.5%		6.0%
NIST-1643d set 1		123	6.52	27.3	22.0	121	39.0	114	61.7	18.0	2	298	0.1	74.8
NIST-1643d set 2		121	6.43	25.3	21.0	103	38.7	117	58.3	18.3	< 2	299	< 0.1	70.7
NIST-1643d set 3		127	6.60	26.5	22.0	119	41.5	120	60.6	17.9	< 2	306	< 0.1	74.0
NIST-1643d avg		123.7	6.5	26.4	21.7	114.3	39.7	117.0	60.2	18.1	2.0	301.0	0.1	73.2
NIST-1643d true		128	6.47	25	20.5	91.2	37.7	113	58.1	18.2		295		72.5
% Difference		-3.4%	0.7%	5.5%	5.7%	25.4%	5.4%	3.5%	3.6%	-0.7%		2.0%		0.9%
T-161 set 1		58.6	18.4	13.4	22.5	59	37.9	17.9	30.4	16.8	6	53.0	1.6	45.2
T-161 set 2		56.0	18.1	12.1	21.3	< 50	37.6	16.1	27.8	16.9	3	54.0	1.4	41.1
T-161 avg		57.3	18.3	12.8	21.9		37.8	17.0	29.1	16.9	4.5	53.5	1.5	43.2
T-161 true		32.4	17.5	12.5	22	61.7	37.4	18.9	29	16.5		54.2		40.6
% Difference		72.8%	3.4%	-3.2%	-3.2%		0.5%	-14.8%	-4.1%	2.4%		-0.4%		1.2%

Appendix 6. Quality Control analyses for water analyses
Snake River watershed, Summit County, Colorado, ICP-AES
continued

U.S. Geological Survey Open-File Report 02-0330
by D.L Fey, S.E. Church, D.M. Unruh and D.J. Bove

	Field No	Ba ppb	Ca ppm	Mg ppm	Na ppm	Si ppm
detection limit		5	1	1	1	1
Filtered Sample	SRP-104FA	33	30	5.1	2.0	3.6
Field Duplicate	SRP-104dFA	34	30	5.0	1.9	3.6
Unfiltered Sample	SRP-104UA	36	24	3.9	1.7	2.8
Field Duplicate	SRP-104dUA	24	23	3.8	1.5	2.8
Filtered Sample	SRP-210FA	31	18	5.4	2.1	6.0
Field Duplicate	SRP-210dFA	30	18	5.4	2.0	5.9
Unfiltered Sample	SRP-210UA	23	14	4.1	1.7	4.5
Field Duplicate	SRP-210dUA	23	14	4.1	1.6	4.5
Filtered Sample	SRP-213FA	30	17	6.0	2.5	8.6
Field Duplicate	SRP-213dFA	30	18	6.0	2.7	8.7
Unfiltered Sample	SRP-213UA	24	14	4.5	2.1	6.5
Field Duplicate	SRP-213dUA	32	15	4.6	2.1	6.6
Field Blank, Filtered	SRP-150FA	< 5	< 1	< 1	< 1	< 1
Field Blank, Filtered	SRP-151FA	< 5	< 1	< 1	< 1	< 1
Field Blank, Filtered	SRP-250FA	< 5	< 1	< 1	< 1	< 1
Field Blank, Filtered	SRP-251FA	< 5	< 1	< 1	< 1	< 1
Field Blank, Unfiltered	SRP-150UA	7.9	< 1	< 1	< 1	< 1
Field Blank, Unfiltered	SRP-151UA	< 5	< 1	< 1	< 1	< 1
Field Blank, Unfiltered	SRP-250UA	6.3	< 1	< 1	< 1	< 1
Field Blank, Unfiltered	SRP-251UA	< 5	< 1	< 1	< 1	< 1

	Ba ppb	Ca ppm	Mg ppm	Na ppm	Si ppm
NIST-1643d set 1	505	30	8.1	21	2.8
NIST-1643d set 2	504	31	8.1	21	2.8
NIST-1643d avg	504.5	30.5	8.1	21	2.8
NIST-1643d true	506	31	8.0	22	-
% Difference	-0.3%	-1.6%	1.3%	-4.5%	-
WRD-T-151 set 1	40	36	17	53	0.69
WRD-T-151 set 2	42	37	17	51	0.68
WRD-T-151avg	41.0	36.5	17.0	52	0.7
WRD-T-151true	41	37.9	17.5	55	0.67
% Difference	0.0%	-3.7%	-2.9%	-5.5%	2.2%
WRD-T-153 set 1	186	27	8.8	28	2.6
WRD-T-153 set 2	186	27	8.7	27	2.6
WRD-T-153avg	186.0	27.0	8.8	28	2.6
WRD-T-153true	184	28	8.7	29	2.7
% Difference	1.1%	-3.6%	0.6%	-5.2%	-3.7%

Appendix 7. Quality Control analyses for sediment samples from the Snake River watershed, Summit County, Colorado

U.S. Geological Survey Open-File Report 02-0330

by D.L Fey, S.E. Church, D.M. Unruh, and D.J. Bove

Field No	Al %	Ca %	Fe %	K %	Mg %	Na %	P %	Ti %	Ag ppm	As ppm	Au ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Eu ppm
SRP-200	6.9	1.1	5.8	2.4	0.75	1.4	0.16	0.27	< 2	< 10	< 8	820	2	< 10	3	540	24	120	15	3
SRP-200d	6.6	1.1	5.6	2.3	0.73	1.4	0.15	0.26	< 2	< 10	< 8	800	2	< 10	3	560	22	110	18	3
SRP-205	6.4	1.2	4.4	2.6	0.68	1.5	0.13	0.30	< 2	< 10	< 8	780	2	< 10	3	340	14	97	23	2
SRP-205d	6.5	1.2	4.2	2.7	0.68	1.6	0.13	0.28	< 2	< 10	< 8	780	2	< 10	2	350	14	91	15	3
SRM 2704	6.1	2.6	4.0	2.0	1.2	0.60	0.10	0.28	< 2	49	< 8	410	2	< 10	5	52	16	140	94	< 2
SRM 2704	6.2	2.6	3.9	2.0	1.2	0.60	0.10	0.27	< 2	14	< 8	400	2	< 10	4	48	17	130	86	< 2
average	6.2	2.6	4.0	2.0	1.2	0.6	0.10	0.28		32		405	2		4.5	50	17	135	90	
NIST certified value	6.11	2.60	4.11	2.00	1.20	0.55	0.10	0.46	< 2	23.40	-	414	-	-	3	72	14	135	99	-
percent difference	0.7%	0.0%	-3.9%	0.0%	0.0%	9.1%	0.0%	-40%		35%		-2.2%			30%	-31%	18%	0.0%	-9%	
SRM 2709	7.3	1.9	3.5	2.0	1.5	1.2	0.06	0.33	< 2	20	< 8	900	4	< 10	2	38	12	120	40	< 2
SRM 2709	7.5	1.9	3.5	2.0	1.5	1.2	0.06	0.33	< 2	20	< 8	900	4	< 10	2	37	18	130	36	< 2
average	7.4	1.9	3.5	2.0	1.5	1.2	0.06	0.33		20		900	4		2	38	15	125	38	
NIST certified value	7.50	1.89	3.50	2.03	1.51	1.16	0.06	0.34	< 2	18	-	968	4.2	-	< 2	42	13	130	35	< 2
percent difference	-1.3%	0.5%	0.0%	-1.5%	-0.7%	3.4%	0.0%	-3%		13%		-7.0%				-11%	15%	-3.8%	9%	
SRM 2711	6.3	2.8	2.8	2.4	1.0	1.2	0.08	0.26	4	92	< 8	680	2	< 10	34	63	5	42	110	< 2
SRM 2711	6.7	2.9	3.0	2.5	1.1	1.2	0.09	0.28	4	110	< 8	700	2	< 10	36	66	9	46	120	< 2
average	6.5	2.9	2.9	2.5	1.1	1.2	0.09	0.3		101		690	2.0		35	65	7	44	115	
NIST certified value	6.53	2.88	2.89	2.45	1.05	1.14	0.086	0.31	4.6	105	-	726	-	-	42	69	10	47	114	1.1
percent difference	-0.5%	-1.0%	0.3%	0.0%	0.0%	5.3%	-1.2%	-13%		-4%		-5.0%			-17%	-7%	-30%	-6.4%	1%	

Field No	Ga ppm	Ho ppm	La ppm	Li ppm	Mn ppm	Mo ppm	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Sn ppm	Sr ppm	Ta ppm	Th ppm	U ppm	V ppm	Y ppm	Yb ppm	Zn ppm
SRP-200	20	< 4	290	16	1300	3	37	270	30	61	23	6	220	< 40	160	< 100	97	86	8	120
SRP-200d	19	< 4	310	15	1300	< 2	39	290	28	57	23	5	210	< 40	170	< 100	95	89	7	120
SRP-205	19	< 4	200	16	710	2	51	180	26	49	12	< 5	200	< 40	83	< 100	91	47	3	120
SRP-205d	19	< 4	210	16	660	2	50	180	25	45	12	< 5	220	< 40	86	< 100	86	48	3	100
SRM 2704	15	< 4	31	48	570	4	32	29	45	170	12	9	130	< 40	8	< 100	95	22	2	450
SRM 2704	15	< 4	28	48	550	4	26	27	44	140	11	9	130	< 40	9	< 100	94	21	2	390
average	15		30	48	560	4	29	28	45	155	12	9	130		9		95	22	2	420
NIST certified value	15	-	29	50.0	555	-	-	-	44	161.0	12.0	-	130	-	9	3	95	-	-	438
percent difference	0.0%		1.7%	-4.0%	0.9%				0.9%	-4%	-4%		0%		-8%		-1%			-4%
SRM 2709	15	< 4	25	55	550	3	35	18	79	16	12	< 5	230	< 40	12	< 100	120	16	2	100
SRM 2709	16	< 4	23	56	550	3	38	18	84	17	12	< 5	230	< 40	14	< 100	120	16	2	110
average	16		24	56	550	3	37	18	82	17	12		230		13		120	16	2.0	105
NIST certified value	14	-	23	55	538	2	-	-	88	18	12	-	231	-	11	-	82	18	1.6	106
percent difference	10.7%		4.3%	0.9%	2.2%				-7.4%	-8%	0%		0%		20%		46%			-1%
SRM 2711	15	< 4	41	27	630	< 2	49	31	21	1000	10	< 5	250	< 40	14	< 100	83	26	2	340
SRM 2711	16	< 4	40	28	650	< 2	49	32	22	1200	10	6	260	< 40	18	< 100	86	28	3	350
average	16		41	28	640		49	32	22	1100	10	6	255		16		85	27	3	345
NIST certified value	15	-	40	-	638	1.6	-	31	21	1162	9	-	245	-	13.6	-	82	25	2.70	350
percent difference	3.3%		1.3%		0.3%				2.4%	-5%	11%		4%		18%		3%			-1%