Chapter 4 - Inorganic Water Chemistry of the Boulder Creek Watershed, Colorado, During High-Flow and Low-Flow Conditions, 2000

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Abstract

Spatial and temporal variability of major and trace constituents in the Boulder Creek Watershed, Colorado were determined on a suite of water samples collected during high and low flow in the year 2000. Field parameters and inorganic water analyses are reported for twenty-nine sites including sixteen stream sites, twelve tributaries/inflows, and Saint Vrain Creek. The most upstream site was above the town of Eldora, and the most downstream site was at the confluence of Boulder Creek and Saint Vrain Creek. Most dissolved constituents display similar downstream variations with relatively low concentrations in the upper 30 kilometers section (above the mouth of Boulder Canyon), an increase in concentration in the reach between the mouth of Boulder Canyon and the Boulder 75th Street Wastewater Treatment Plant (WWTP), and a further increase in solute concentrations in the lower reach. Alkalinity, calcium, chloride, magnesium, silica, sodium, and sulfate are the dominant dissolved constituents in Boulder Creek, accounting for over 90 percent of the mass of dissolved inorganic constituents. The relative proportion of these constituents varied during high and low flow and from the upper sampling sites to the lower sites. Most constituents were higher in concentration during low flow than during high flow. The rare earth element patterns of the effluent from the Boulder 75th Street WWTP and the first Boulder Creek sampling site downstream of the inflow of the effluent contain a peak in gadolinium.

Using the low-flow results, preliminary interpretations of the sources of solutes and the processes controlling their downstream variations are discussed. Interpretations are based on geochemical modeling results and identification of geochemical signatures. In the upper part of the watershed, above the range front, natural weathering of crystalline bedrock appears to be the primary source of solutes. Historical mining, the towns of Eldora and Nederland, and road runoff did not appear to have a major effect on Boulder Creek during the samplings. The chemistry of Boulder Creek in the reach between the range front and the Boulder 75th Street WWTP appears to be dominated by ground-water inflows that have interacted with sedimentary bedrock. Anthropogenic sources of some solutes cannot be ruled out. During the low-flow sampling, effluent from the WWTP accounted for 77 percent of the flow of Boulder Creek at the next downstream site. The large percentage of flow and the high concentrations of most constituents make the Boulder effluent the largest loading inflow to Boulder Creek. Because of numerous potential sources of solutes and various in-stream processes downstream of the WWTP, differentiating between anthropogenic and natural sources of solutes is difficult solely using the inorganic data set. Wastewater treatment plant effluent from Erie, Lafayette, Louisville, and Superior, agriculture diversion ditch return flow, and ground water also enter Boulder Creek.

INTRODUCTION

Spatial and temporal variability of major and trace constituents in the Boulder Creek Watershed were determined on a suite of water samples collected during high- and low-flow in the year 2000. Stream chemistry is controlled by

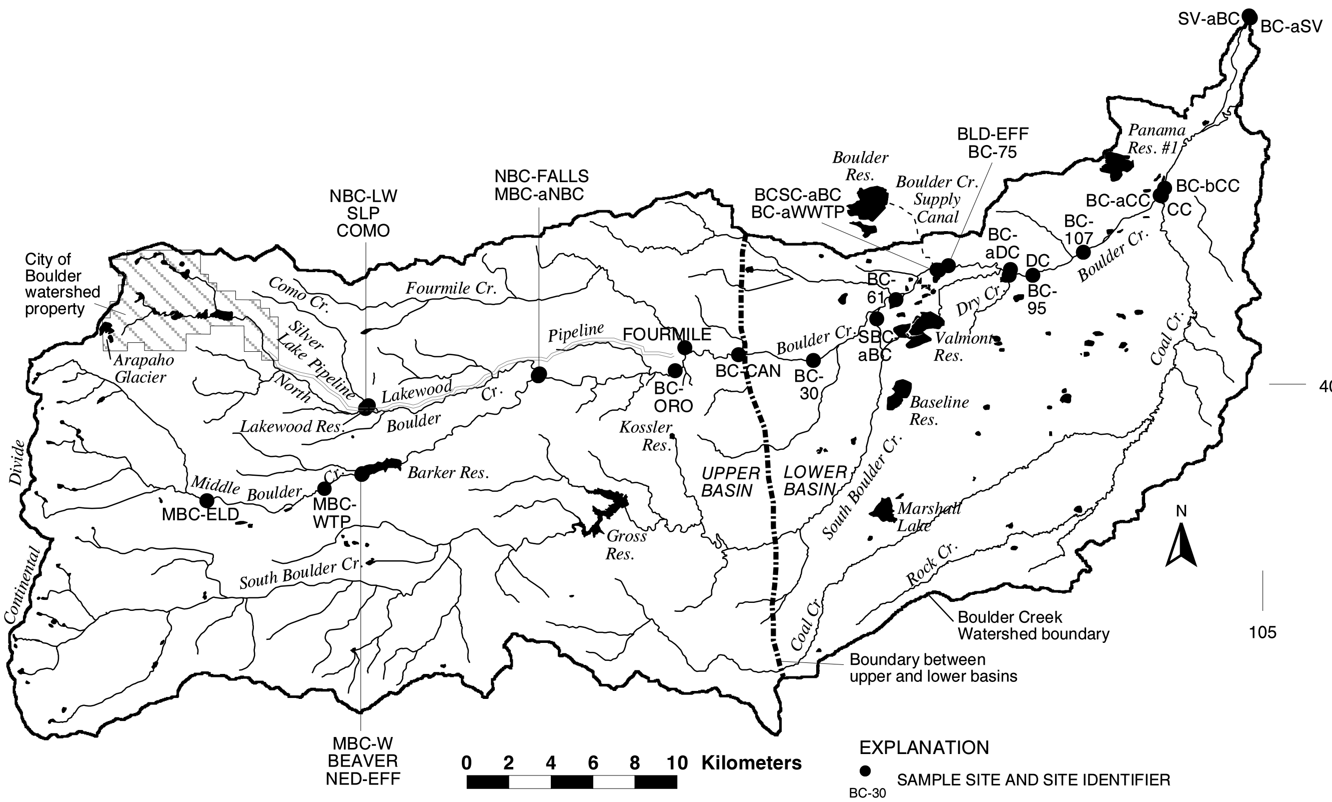

Figure 4.1. Map of Boulder Creek Watershed and sampling sites.

natural and anthropogenic inputs, as well as chemical reactions that influence the fate and transport of these inputs. Detailed water-quality sampling of Boulder Creek, including the main stem and major inflows, is required to determine the sources and sinks of chemical constituents. The relative importance of different sources is likely to vary seasonally, such that high- and low-flow sampling are essential components in the characterizing of the watershed. Twenty-nine sites along Boulder Creek, Colorado, including sixteen stream sites, twelve inflows and Saint Vrain Creek, were sampled over a three-day period for each sampling (fig. 4.1). The purpose of this chapter is to present results of determinations of field parameters and major and trace inorganic constituents.

METHODS OF STUDY

Water-Quality Sampling

Water-quality samples were collected during high and low flow along the main stem of Boulder Creek and its major inflows. Field measurements at the sampling sites included air and water temperature, dissolved oxygen, pH, and specific conductance. Dissolved oxygen, specific conductance, and temperature measurements were made by immersing probes directly into the source. Measurements for pH were made on unfiltered water samples pumped from the creek or tributary through an acrylic plastic flow-through cell containing a thermometer, pH electrode, and test tubes containing calibrating solutions. At each site the pH electrode was calibrated using two buffers, which bracketed the measured pH, thermally equilibrated with the sample water.

Water-quality samples were collected using a depth-integrated sampler following the equal-width-increments method (Edwards and Glysson, 1988), unless the discharge was too great to safely wade the width of the creek. In these situations a plastic bucket was pulled across the width of the creek to integrate the sample. Water quality samples for major, minor, and trace element determinations were filtered with a 142-mm diameter, 0.1-µm pore-size tortuous path, filter membrane. Anion samples were filtered and not acidified, cation samples were filtered and acidified with concentrated nitric acid, and samples for iron speciation were filtered and acidified with six-molar hydrochloric acid. Total-recoverable samples were unfiltered aliquots from the same sample-collection bottle as the filtered samples, which were acidified with concentrated nitric acid. All filtration was performed on site except for samples NED-EFF, SLP, MBC-WTP and BLD-EFF, which were filtered at the laboratory from a one-gallon grab sample. Samples from NED-EFF and BLD-EFF were filtered with cartridge-style, 0.45-µm pore-size filters. Possible contamination of samples was minimized by using new, acid- and deionized-water-washed bottles. Each container was rinsed on-site three times with sample water prior to filling.

Water-Quality Analyses

All reagents were of a purity at least equal to the reagent-grade standards of the American Chemical Society. Double-distilled de-ionized water and re-distilled acids using a sub-boiling purification technique (Kuehner and others, 1972) were used in all preparations. For inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled plasma-optical emission spectroscopy (ICP-OES), external standards, blanks, sample dilutions, and spiking solutions were made with commercial trace analysis grade elemental standards. Mercury standards were prepared gravimetrically from semi-conductor grade 99.9995 percent purity $HgCl_2$. For ion chromatography (IC) determinations, standards were prepared from compounds of the highest commercially available purity. USGS standard reference water samples (SRWS) and National Institute of Standards and Technology (NIST), formerly National Bureau of Standards, standard reference materials were used as independent quality control standards. Samples were diluted as necessary to bring the analyte concentration within the optimal range of the method. For elemental analyses, several dilutions of each sample were analyzed to check for concentration effects on the analytical method.

Trace metal concentration determinations for dissolved samples were performed using a Perkin Elmer Sciex Elan 6000 ICP-MS using a method similar to that described in Garbarino and Taylor (1979). Elements analyzed by this method included aluminum, antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, cerium, cesium, chromium, cobalt, copper, lead, lithium, manganese, molybdenum, nickel, the rare earth elements (cerium, dysprosium, erbium, europium, gadolinium, holmium, lanthanum, lutetium, neodymium, praseodymium, samarium, terbium, thulium, and ytterbium), rhenium, rubidium, selenium, strontium, tellurium, thallium, thorium, uranium, vanadium, yttrium, zinc, and zirconium. Mercury concentrations were determined by the method described in Roth (1994) using a PS Analytical Merlin Cold Vapor-Atomic Fluorescence Spectrometer System. Major cations (calcium, magnesium, potassium, and sodium) and silica for dissolved samples were determined using a Leeman Labs – Direct Reading Echelle (DRE) ICP-OES. Major cations, silica and trace elements (aluminum, arsenic, barium, boron, beryllium, cadmium, chromium, cobalt, copper, lead, lithium, manganese, nickel, selenium, strontium, vanadium, and zinc) for total recoverable samples were determined using a Leeman Labs - DRE ICP-OES. Major cations were analyzed using the radial view while the axial view was used for trace elements Iron redox species were determined using a modification of the FerroZine colorimetric method (Stookey, 1970; To and others, 1999) with a Hewlett Packard 8453 diode array UV/VIS spectrophotometer. Concentrations of major anions were determined by ion chromatography (Brinton and others, 1995) using a Dionex 2010i ion chromatograph with 10-µL and 50-µL sample loops. Alkalinity (as HCO_3^-) was determined using an Orion 960 autotitrator and standardized H_2SO_4 (Barringer and Johnsson, 1989).

Calibration curves were constructed by using standards within each set of analyses. Standard reference water samples 67, 69, T115, T143, T153, and T159 were used to check the analytical methods for major and trace metals for those analytes determined by ICP-OES. Standard reference water samples T135, T147, T149, T157, NIST 1643b, NIST 1643d, and PPREE1 and SCREE1 (Verplanck and others, 2001) were used as quality control checks for ICP-MS analyses. Quality control for the determination of mercury concentrations was monitored using USGS SRWS Hg7, Hg14, Hg15, and Hg22, all at a dilution of 1/100. Standard reference water samples M136, M140, and M150 were used to check the analytical methods for major anions. The quality-control data are presented in tables 4.1 to 4.4. Mercury detection limits (table 4.4) were determined using the method described by Skogerboe and Grant (1970) at the 97.5 percent confidence level.

Data for all samples with complete analyses were checked using the computer program WATEQ4F (Ball and Nordstrom, 1991) for charge imbalance (C.I.) using the following calculation:

$$\text{C.I. (percent)} = \frac{100 * (\text{sum cations - sum anions})}{(\text{sum cations} + \text{sum anions}) \div 2}$$

The sum anions and sum cations are the summation of the anions and cations in milliequivalents per liter (meq/L). The percent charge imbalance was low (< 10 percent) for most samples (tables 4.5 and 4.6). Dilute headwaters samples collected during high-flow had charge imbalances that were greater because of analytical imprecisions when determining concentrations at or near the detection limits.

RESULTS

Analytical results are tabulated in tables 4.5 and 4.6. Sample sites are listed in downstream order starting with the most upstream Middle Boulder Creek site (MBC-ELD). Sites not located on the mainstem of Middle Boulder Creek-Boulder Creek are listed below the mainstem sites in downstream order of where they flow into Boulder Creek. Sampling sites are shown in figure 4.1 and described in table 1.1 of Murphy and others (2003), and discharge measurements are tabulated in table 1.2.

Results less than the detection limit are identified in the tables using the less than symbol (<) preceding the detection limit. Parameters that were not determined for a particular sample are identified by dashes (--) within the table. If concentrations of trace elements were at least 3 times the detection limit by ICP-OES, good agreement between ICP-OES and ICP-MS results was observed (fig. 4.2). Field blanks are included in the bottom line of the high- and low-flow data tables.

For the upper portion of Boulder Creek (above the mouth of Boulder Canyon at 36.7 kilometers), bicarbonate, calcium, chloride, magnesium, silica, sodium, and sulfate are the dominant dissolved constituents, accounting for 97 and 94 percent of dissolved inorganic constituents at BC-CAN during high- and low-flow, respectively. The order of descending concentrations (in millimoles per liter) during high flow was bicarbonate, calcium, sodium, silica, chloride, magnesium, and sulfate, and during low flow was bicarbonate, calcium, sodium, chloride, silica, magnesium, and sulfate For the lower portion of Boulder Creek (below BC-CAN), bicarbonate, calcium, chloride, magnesium, silica, sodium and sulfate were still the dominant dissolved constituents, accounting for 98 and 92 percent of dissolved inorganic constituents during high- and low-flow

Table 4.1. Results of standard reference water samples used in the ICP-OES analyses of Boulder Creek water samples

[mg/L, milligrams per liter; --, element not analyzed; MPV, most probable value; <, less than; ND, not determined in standard]

	HIGH-FLOW					LOW-FLOW				MPV					
	SRWS69 (mg/L)	T115 (mg/L)	T143 (mg/L)	T153 (mg/L)	T159 (mg/L)	SRWS67 (mg/L)	SRWS69 (mg/L)	T153 (mg/L)	T159 (mg/L)	SRWS67 (mg/L)	SRWS69 (mg/L)	T115 (mg/L)	T143 (mg/L)	T153 (mg/L)	T159 (mg/L)
Al	0.52	<0.08	<0.08	<0.08	<0.08	<0.08	0.67	<0.08	<0.08	0.018	0.62	0.014	0.015	0.001	0.028
As	<0.02	<0.02	<0.02	<0.02	<0.02	<0.03	<0.03	<0.03	0.033	0.018	0.012	0.040	0.022	0.035	0.032
B	0.11	0.091	0.026	0.096	0.022	0.035	0.12	0.11	0.028	ND	ND	0.099	0.035	0.099	0.026
Ba	0.038	--	0.089	0.2	0.04	--	0.037	--	0.039	0.219	0.043	0.250	0.082	0.184	0.038
Be	0.035	0.059	0.007	<0.0001	0.011	0.051	0.034	<0.0001	0.011	0.044	0.032	0.054	0.009	ND	0.011
Ca	50	55	57	28	26	44	50	29	26	ND	ND	51	54	28	26
Cd	<0.001	0.013	0.02	0.016	0.026	0.01	<0.001	0.017	0.026	0.01	0.001	0.014	0.0191	0.016	0.024
Co	0.01	0.014	0.015	<0.001	0.011	0.013	0.015	0.001	0.014	0.011	0.014	0.0154	0.017	ND	0.0133
Cr	0.001	0.036	0.036	0.014	0.028	0.03	0.003	0.015	0.028	0.028	0.005	0.036	0.037	0.015	0.027
Cu	0.31	0.015	0.021	0.024	0.033	0.027	0.33	0.026	0.036	0.028	0.297	0.017	0.022	0.024	0.033
Fe	0.11	1.2	0.12	0.074	<0.007	0.81	0.22	0.078	0.052	ND	ND	1.175	0.222	0.075	0.0489
K	3.3	--	2.5	1.6	1.8	3.2	3.9	1.8	1.9	ND	ND	5.41	2.5	1.6	1.52
Li	0.44	0.19	0.026	0.06	0.013	--	0.47	0.064	0.011	0.627	0.397	0.132	0.018	0.053	0.009
Mg	--	--	--	8.9	5.7	--	--	9.2	5.9	ND	ND	27.6	10.4	8.72	5.6
Mn	0.23	0.47	0.005	0.07	0.015	0.61	0.23	0.078	0.023	ND	ND	0.455	0.018	0.075	0.022
Na	49	--	37	29	--	27	51	31	--	ND	ND	140	34	28.7	100
Ni	<0.02	<0.02	0.076	0.034	0.024	0.004	0.017	0.036	0.024	0.096	0.018	0.017	0.071	0.032	0.022
Pb	0.02	0.011	0.089	0.05	0.017	<0.006	0.023	0.051	0.019	0.005	0.023	0.013	0.083	0.046	0.017
SiO_2	7.8	11	--	5.8	12	3.6	7.9	6.2	12	ND	ND	9.9	23.4	5.79	11.5
Se	<0.02	<0.02	<0.02	<0.02	<0.02	<0.04	<0.04	<0.04	<0.04	0.012	ND	0.010	0.023	0.006	0.012
Sr	--	--	0.32	0.32	0.2	0.39	--	0.33	0.19	0.375	0.612	0.67	0.31	0.31	0.19
V	<0.001	0.014	0.027	0.016	0.012	<0.001	<0.001	0.017	0.013	ND	ND	0.018	0.030	0.019	0.014
Zn	0.013	0.4	0.014	0.067	0.014	0.016	0.03	0.087	0.024	0.017	0.028	0.381	0.020	0.073	0.019

Table 4.2. Results of standard reference water samples used in the IC analyses of Boulder Creek water samples

[mg/L, milligram per liter; --, not analyzed; MPV, most probable value]

	HIGH-FLOW		LOW-FLOW			MPV		
	M140 (mg/L)	M150 (mg/L)	M136 (mg/L)	M140 (mg/L)	M150 (mg/L)	M136 (mg/L)	M140 (mg/L)	M150 (mg/L)
Cl	26	18	94	27	20	92	25.8	17
F	--	1.0	1.07	--	1.00	1.04	0.53	1
SO_4	149	5.23	157	153	5.2	150	150	5.5

respectively, but the relative proportion of these constituents changed. The order of descending concentrations (in millimoles per liter) during high and low flow was bicarbonate, sodium, sulfate, magnesium, calcium, chloride, and silica.

The downstream profiles and seasonal variations for Middle Boulder-Creek-Boulder Creek and the sampled inflows for specific conductance, boron, calcium, chloride, magnesium, silica, sodium, sulfate, and zinc are displayed in figures 4.3 to 4.5 Most dissolved constituents, with the exception of silica, display similar downstream variation with relatively low concentrations in the upper 30-kilometer section, above the mouth of Boulder Canyon (BC-CAN), an increase in concentration in the reach between BC-CAN and the Boulder 75th Street Wastewater Treatment Plant (BC-aWWTP), and a greater increase in solute concentrations in the lower reach (BC-75 to BC-aSV). Most dissolved constituents had higher concentrations during low flow than during high flow. The chemistry of the inflows was quite variable during both high- and low-flow sampling.

The rare earth elements (REEs) are a suite of fourteen trace metals from atomic number 57 (La) to 71 (Lu) that have similar chemical and physical properties because they generally form stable 3^+ ions of similar size. The REEs have been utilized as geochemical tracers to constrain geologic and hydrologic processes. Rare earth element patterns, the plot of the concentration of each REE normalized to a standard reference, provide a graphical means to evaluate changes across the REEs for a given sample or suite of samples. The REE pattern for BLD-EFF has a distinctive enrichment in gadolinium compared to its neighboring REEs europium and terbium (fig. 4.6) None of the upstream Boulder Creek samples have this gadolinium anomaly, but the REE pattern of the first Boulder Creek sampling site downstream of the effluent discharge channel (BC-75) does display a peak at gadolinium. In contrast, the REE pattern of the NED-EFF does not have a peak at gadolinium (fig. 4.6). Similar patterns were observed at high and low flow.

DISCUSSION

Two of the objectives of this study are to determine the natural and anthropogenic sources of dissolved constituents and to identify processes that control the downstream variations of dissolved constituents in Boulder Creek. This chapter focuses on the inorganic chemistry of Boulder Creek, and the following discussion describes the downstream evolution of Boulder Creek's inorganic chemistry. Low-flow data is discussed because similar trends were observed in both sampling events, but the high-flow data have lower concentrations as a result of dilution by snowmelt.

Boulder Creek Upstream of the Range Front

In the headwater portion of the Boulder Creek Watershed, surface and ground waters have short residence times and originate as precipitation from rain or snowmelt. The headwater sites (MBC-ELD, COMO, NBC-LW, and SLP) are fed by precipitation-derived water that has few potential anthropogenic sources including atmospheric deposition, historical hardrock mining, and waste from mountain cabins. The University of Colorado Mountain Research Station monitors the chemistry of precipitation, and numerous research studies have investigated the sources of solutes in precipitation and nearby down-gradient surface waters (Williams and others, 2003). Monthly precipitation samples are collected and analyzed for a suite of constituents through the National Atmospheric Deposition Program. In addition, Mast and others (M.A, Mast, written commun., 2002) have analyzed snowpack samples for a suite of inorganic constituents, including trace metals. Research at University of Colorado's Mountain Research Station on Niwot Ridge has documented that, although the precipitation is quite dilute (specific conductance ~ 5 μS/cm), some anthropogenic input is observed. Williams and others (2003) document that anthropogenic nitrogen, derived primarily from the combustion of fossil fuels and agricultural practices, is present in Niwot Ridge precipitation.

Most major-constituent concentrations in headwater sites were enriched by factors of 10 to 20 compared to Niwot Ridge precipitation. To evaluate possible weathering reactions between meteoric water and bedrock geology, mass balances were constructed using the geochemical modeling program NETPATH (Plummer and others, 1994). In these simulations, meteoric water was reacted with known minerals in bedrock in the upper portion of the watershed to determine whether measured water chemistry was consistent with weathering of the local bedrock. The chemistry of meteoric water was estimated using annual, volume-weighted mean concentrations measured at the precipitation monitoring station at Niwot Ridge. Bedrock geology in the headwater parts of the Boulder Creek Watershed consists mostly of Precambrian-age igneous and metamorphic rocks including the Boulder Creek granodiorite, the Silver Plume monzonite, and an assortment of orthogneisses. The mineralogy is presented in Kile and Eberl (2003).

The measured water chemistry at the uppermost site (MBC-ELD) is consistent with minor weathering of the local bedrock. The modeling results are presented in table 4.7. The minor amount of weathering required to produce the measured chemistry is consistent with relatively short residence time of ground water in the upper part of the watershed and, in general, is similar to results of previous studies in the region (Patterson, 1980; Reddy and Caine, 1989; Clow and others, 1997). To account for the dissolved sulfate, minor dissolution of pyrite is called for, but since metal concentrations are quite low, historical hardrock mining does not appear to affect the metal chemistry at MBC-ELD.

Downstream from MBC-ELD, potential anthropogenic influences include homes in the town of Eldora, Eldora Mountain Ski Area, and the town of Nederland. Within Nederland most wastewater goes to the Nederland WWTP, but some of the surrounding homes have individual septic systems. Comparing the chemistry of MBC-ELD and MBC-W, little change is observed, and the overall water chemistry is consistent with weathering of local bedrock. Nitrate, generally associated with septic systems, had slightly lower concentration at MBC-W compared to MBC-ELD. The effluent from the Nederland WWTP (NED-EFF) enters Middle Boulder Creek just below MBC-W, immediately upstream of Barker Reservoir. Because of the low nitrate concentration at the time of sampling, private septic systems do not appear to affect Boulder Creek upstream of MBC-W. Under different hydrologic conditions, this may change.

For many constituents, NED-EFF has the highest concentrations of all the samples in this study. The next downstream site (MBC-aNBC) has slightly higher concentrations of many elements compared to MBC-W, but the overall water chemistry is still relatively dilute (specific conductance of 84 μS/cm). At the time of sampling, NED-EFF did not appear to have a major effect on the downstream sites because of dilution by water in Barker Reservoir and Middle Boulder Creek. For example, the boron

Table 4.3. Results of standard reference water samples used in the ICP-MS analyses of Boulder Creek water samples

[µg/L, micrograms per liter; --, element not analyzed; MPV, most probable value; ND, not determined in standard]

	HIGH-FLOW							LOW-FLOW			
	NIST1643b (µg/L)	NIST1643d[1] (µg/L)	T135 (µg/L)	T147 (µg/L)	T149 (µg/L)	T157 (µg/L)	PPREE1[2] (µg/L)	NIST1643b (µg/L)	NIST1643d[1] (µg/L)	T135 (µg/L)	T147 (µg/L)
Al	--	12.7	8.87	12.6	35.3	54.9	--		12.8	9.09	12.5
As	--	5.33	10.4	2.31	0.81	25.3	--	56.7	5.59	10.0	2.36
B	--	17	12	50	124	71	--	118	17.9	9.10	50.2
Ba	42.2	51.6	65.9	74.8	42.5	118	--	42.2	51.6	65.9	74.8
Be	--	1.31	63.4	16.1	--	13.2	--	20.2	1.31	58.7	15.6
Cd	17.8	0.63	50.2	15.1	2.09	5.43	--	20.1	0.63	50.4	15.9
Co	26.7	2.48	40.1	--	--	3.92	--	28.6	2.57	39.8	--
Cr	19.0	1.96	81.9	12.4	48.9	32.4	--	19.9	1.84	79.4	12.1
Cu	21.1	2.10	62.4	10.4	5.50	24.1	--	22.4	2.21	61.9	11.8
Li	--	1.72	75.6	17.2	41.4	32.3	--	--	1.79	74.0	17.3
Mn	32.7	4.22	426	18.5	12.3	128	--	33.2	4.06	198	17.4
Mo	93.8	11.1	63.1	11.7	1.07	11.2	--	101	11.8	63.2	12.5
Ni	47.0	5.88	65.7	13.6	31.0	29.7	--	49.3	5.90	64.3	13.3
Pb	23.2	1.86	103	13.6	8.77	6.39	--	23.9	1.91	103	14.4
Sb	--	5.29	76.4	10.0	19.9	10.2	--	--	5.52	76.4	10.3
Se	6.8	1.0	10.0	9.9	1.7	4.0	--	9.89	1.09	9.98	10.6
Sr	227	30.30	49.1	318	332	59.7	--	233	30.6	46.6	318
Th	--	--	--	--	--	--	0.002	--	--	--	--
Tl	7.50	0.74	--	19.3	31.4	8.59	--	7.40	0.72	--	19.6
U	--	--	--	3.24	2.62	3.23	0.005	--	0.009	--	3.23
V	44.0	3.52	54.6	14.8	29.9	15.9	--	46.6	3.69	52.5	14.7
Zn	55.2	6.80	48.2	11.3	2.12	21.9	--	69.6	7.54	48.3	13.9
La	--	--	--	--	--	--	0.81	--	--	--	--
Ce	--	--	--	--	--	--	1.63	--	--	--	--
Pr	--	--	--	--	--	--	0.211	--	--	--	--
Nd	--	--	--	--	--	--	0.94	--	--	--	--
Sm	--	--	--	--	--	--	0.204	--	--	--	--
Eu	--	--	--	--	--	--	0.060	--	--	--	--
Gd	--	--	--	--	--	--	0.239	--	--	--	--
Tb	--	--	--	--	--	--	0.037	--	--	--	--
Dy	--	--	--	--	--	--	0.223	--	--	--	--
Ho	--	--	--	--	--	--	0.045	--	--	--	--
Er	--	--	--	--	--	--	0.120	--	--	--	--
Tm	--	--	--	--	--	--	0.015	--	--	--	--
Yb	--	--	--	--	--	--	0.081	--	--	--	--
Lu	--	--	--	--	--	--	0.011	--	--	--	--

[1] analyzed at 1:10 dilution
[2] analyzed at 1:100 dilution

Table 4.3. Results of standard reference water samples used in the ICP-MS analyses of Boulder Creek water samples--continued

	LOW-FLOW				MPV							
	T149 (μg/L)	T157 (μg/L)	PPREE1[2] (μg/L)	SCREE1[2] (μg/L)	NIST1643b (μg/L)	NIST1643d[1] (μg/L)	T135 (μg/L)	T147 (μg/L)	T149 (μg/L)	T157 (μg/L)	PPREE1[2] (μg/L)	SCREE1[2] (μg/L)
Al	35.5	55.1	--	--	ND	12.8	10.50	14.0	35.5	55.5	--	--
As	0.83	25.3	--	--	ND	5.60	10.0	2.39	0.98	25.4	--	--
B	130	72.2	--	--	ND	14.5	13.10	50.0	128	70.4	--	--
Ba	42.5	118	--	--	44	50.7	67.8	73.0	42.5	118	--	--
Be	--	12.9	--	--	ND	1.25	59.0	16.0	ND	13.0	--	--
Cd	2.17	5.76	--	--	18.6	0.65	50.5	41.0	2.18	5.80	--	--
Co	--	4.08	--	--	26	2.50	40.0	ND	ND	4.03	--	--
Cr	48.7	32.1	--	--	19.9	1.84	79.0	12.8	48.8	31.3	--	--
Cu	7.90	25.4	--	--	21.9	2.05	62.0	11.4	8.00	24.8	--	--
Li	43.4	33.2	--	--	ND	1.65	73.7	18.0	44.2	32.4	--	--
Mn	11.8	57.3	--	--	28	3.77	423	17.2	11.8	143.0	--	--
Mo	1.08	8.99	--	--	85	1.1	63.0	11.8	1.25	13.00	--	--
Ni	31.1	32.6	--	--	49	5.81	65.6	13.6	31.2	30.0	--	--
Pb	9.10	5.94	--	--	23.7	1.82	103	13.8	8.84	6.90	--	--
Sb	20.4	10.5	--	--	ND	5.41	76.3	10.5	21.1	10.8	--	--
Se	1.48	4.12	--	--	9.7	1.14	10.0	10.1	2.10	4.60	--	--
Sr	331	60.2	--	--	227	29.5	46.0	313	331	59.6	--	--
Th	--	--	0.001	0.001	ND	ND	ND	ND	ND	ND	0.001	--
Tl	31.3	8.65	--	--	8.0	0.728	ND	20.0	31.4	8.75	--	--
U	2.57	3.21	0.005	0.006	ND	ND	ND	3.21	2.71	3.19	0.001	0.003
V	29.8	15.6	--	--	45.2	3.51	52.8	15.2	31.0	15.7	--	--
Zn	4.80	23.4	--	--	66.00	7.25	48.2	14.0	5.80	23.5	--	--
La	--	--	0.80	0.099	ND	ND	ND	ND	ND	ND	0.80	0.099
Ce	--	--	1.63	0.246	ND	ND	ND	ND	ND	ND	1.61	0.246
Pr	--	--	0.214	0.044	ND	ND	ND	ND	ND	ND	0.212	0.043
Nd	--	--	0.93	0.228	ND	ND	ND	ND	ND	ND	0.92	0.221
Sm	--	--	0.207	0.069	ND	ND	ND	ND	ND	ND	0.203	0.067
Eu	--	--	0.059	0.015	ND	ND	ND	ND	ND	ND	0.060	0.015
Gd	--	--	0.237	0.085	ND	ND	ND	ND	ND	ND	0.238	0.082
Tb	--	--	0.037	0.014	ND	ND	ND	ND	ND	ND	0.037	0.013
Dy	--	--	0.221	0.084	ND	ND	ND	ND	ND	ND	0.220	0.081
Ho	--	--	0.044	0.016	ND	ND	ND	ND	ND	ND	0.044	0.016
Er	--	--	0.121	0.044	ND	ND	ND	ND	ND	ND	0.119	0.044
Tm	--	--	0.014	0.006	ND	ND	ND	ND	ND	ND	0.015	0.006
Yb	--	--	0.083	0.034	ND	ND	ND	ND	ND	ND	0.082	0.034
Lu	--	--	0.011	0.005	ND	ND	ND	ND	ND	ND	0.011	0.005

Table 4.4. Results of standard reference water samples and blanks used in mercury analysis of Boulder Creek water samples

[ng/L, nanograms per liter; stddev, standard deviation; --, element not analyzed; MPV, most probable value; DL, detection limit]

		Hg7[1] (ng/L)	stddev (ng/L)	Hg22[1] (ng/L)	stddev (ng/L)	Hg14[1] (ng/L)	stddev (ng/L)	Hg15[1] (ng/L)	stddev (ng/L)	blank (ng/L)	stddev (ng/L)	DL (ng/L)
Hg-SRWS	High flow	3.1	0.2	11.5	0.3	8.3	0.3	4.1	0.2	0.0	0.2	0.5
Hg-SRWS	Low flow	2.3	0.5	10.7	0.3	7.0	0.3	3.4	0.2	0.0	0.2	0.4
Hg-SRWS	MPV	2.2	0.8	12.4	1.3	7.0	2.9	4.1	2.0	--	--	--

[1]all mercury concentrations for Hg-standards reported at 1/100 dilution, error terms are also at 1/100 assuming no change in relative standard deviation

concentration in NED-EFF is 320   g/L, but at MBC-aNBC, boron is below the detection limit of 3   g/L.

Overall, the major-element chemistry of MBC-aNBC, BC-ORO and BC-CAN is consistent with weathering of the surrounding bedrock. Mass-balance results for BC-CAN are tabulated in table 4.7. In general, mineral proportions are similar to results from MBC-ELD, but a greater amount of mineral dissolution is required and expected because of longer ground-water flow paths and greater residence time in the lower portion of the crystalline part of the watershed.

Overall, the chemistry of Boulder Creek above BC-CAN is consistent with progressive weathering of the crystalline rocks. Historical mining does not seem to have contributed to the metal loading because the metals concentrations (arsenic, cadmium, chromium, copper, lead, nickel, silver, and zinc) are all below 1   g/L. Minor amounts of pyrite dissolution is needed to account for the dissolved sulfate concentrations. Gypsum is another potential source of sulfate but has not been reported as a mineral phase within the upper part of the watershed, although calcic gneisses crop out in the area. Slightly greater concentrations of silica, sulfate, and zinc in Fourmile Creek (FOURMILE) may be a result of historical mining. During high- and low-flow sampling the discharge in Fourmile Creek (0.11 and 0.02 cubic meters per second, m^3/s, respectively; Murphy and others, 2003) were much less than the discharge in the main stem of Boulder Creek (7.1 and 1.1 m^3/s at site BC-ORO), thus these elevated concentrations do not appear elevated in Boulder Creek. These results are similar to the conclusions of Patterson (1980).

Boulder Creek from the Range Front to Boulder 75th Street Wastewater Treatment Plant

As Boulder Creek crosses the range front, at site BC-CAN, the composition of the bedrock and the potential anthropogenic sources of solutes change. Murphy and others (2003) describe these changes. In summary, the bedrock geology changes from crystalline bedrock consisting of felsic igneous and metamorphic rocks, to sedimentary rocks consisting of shales, limestones, and sandstones. These sedimentary rocks are more easily eroded, thus producing the dramatic change in topography. Potential anthropogenic sources are numerous, including transportation, industrial, and urban sources. Figures 4.3 to 4.5 show the general trend of increasing major dissolved solutes from BC-CAN to BC-61 (calcium, chloride, magnesium, sodium, and sulfate). Specific conductance increases from 61   S/cm (BC-CAN) to 232   S/cm (BC-61). In contrast, the dissolved silica concentration decreases from 4.5 to 2.4 mg/L in this reach.

Differentiation between natural and anthropogenic sources of some solutes is difficult because both sources likely contribute to the stream chemistry and a unique, geochemical signature of one source is not always apparent. An example of this is sodium chloride. Anthropogenic sources include the application of sodium chloride to roads and residential uses of sodium and chloride (laundry detergents, for example). The Pierre Shale, one of the primary geologic units in this reach, formed in a marine environment, and not only contains a sodium chloride mineral (halite) but also contains sodium-rich minerals and possibly trapped ocean water.

A water balance study by Bruce and O'Riley (1997) documented the input of ground water in this reach. Simulations with NETPATH, using known minerals from the Pierre Shale (illite, montmorillonite [smectite], chlorite, quartz, potassium feldspar, plagioclase, calcite, dolomite, and halite), were undertaken to evaluate if input of ground water that has reacted with sedimentary bedrock is consistent with the measured chemistry of Boulder Creek. The results are tabulated in table 4.7. Although weathering of known minerals within the shale can account for the measured chemistry of Boulder Creek at site BC-61, these results should not be interpreted as a unique solution. For example, dolomite is present in the Pierre Shale and is included in the model to account for the increase in magnesium, although magnesium also is likely to be on clay sites, and ion exchange with clay minerals could account for the magnesium.

The relative proportion of halite dissolution is high and is needed to account for the chloride in the water. These results are consistent with a previous study of ground-water modeling of the Pierre Shale (Von Damm, 1989), but another potential natural source of chloride in the shale could be trapped fluids, rather than chloride solely residing in a mineral phase. Conversely, a portion of the chloride in Boulder Creek could be derived from anthropogenic sources. Bruce and O'Riley (1997) compared ground-water chemistry of 30 domestic wells in Boulder County that were sampled in 1976 and 1996. The median chloride concentration increased from 10.3 to 15.5 mg/L. Three of the eight wells that had an increase in chloride by a factor of two or more had a similar increase in sodium, which is consistent with salt entering the ground-water system.

Although there are numerous potential anthropogenic sources, the trace metal concentrations of Boulder Creek remained low through the urban reach. This observation is consistent with a storm-water study by Paulson (1994), which documented that during non-storm-event sampling, baseline metal (copper, lead, and zinc) concentrations were low, but increased by an order of magnitude or greater during storm-generated runoff.

Boulder Creek Downstream of the Boulder 75th Street Wastewater Treatment Plant

Compared to Boulder Creek, effluent from the Boulder 75th Street WWTP (BLD-EFF) has elevated concentrations of most constituents. At low flow, mass-balance calculations document that the effluent accounted for 77 percent of the discharge of Boulder Creek at the 75th Street streamgaging station (and 37 percent during the high-flow sampling). The relative proportion of flow was calculated using eight parameters (alkalinity, boron, calcium, chloride, magnesium, silica, sodium, and sulfate) that had different concentrations, and were at least three times greater than the detection limit in BLD-EFF and sample BC-aWWTP. Knowing the dissolved concentrations in the effluent and in Boulder Creek above and below the input of the effluent, the load equation was solved for the relative proportion of flow. A step increase in concentration at BC-75 is displayed in figures 4.3 to 4.5. Although most major constituents in the WWTP effluent have natural and anthropogenic sources, many elevated concentrations of trace elements in BLD-EFF result from domestic and industrial practices.

The positive gadolinium anomaly in the REE pattern of BLD-EFF is a good example of a geochemical signature of the effluent (fig. 4.6). Gadolinium is not naturally enriched relative to other REEs, but has industrial uses. The positive gadolinium anomaly in REE patterns of rivers was first documented in large urban areas of

Table 4.5. Results of water analyses for Boulder Creek, inflows, and other flows, June 2000

[Distance, distance upstream from Boulder Creek/Saint Vrain Creek confluence; SC, specific conductance; µS/cm, microsiemens per centimeter; per liter; ng/L, nanograms per liter; --, sample not analyzed for this constituent; <, less than; meq/L, milliequivalents per liter; %, percent;

Site	Distance (meters)	Date collected	Time	pH	SC (µS/cm)	DO (mg/L)	T_{H2O} (°C)	T_{air} (°C)
Middle Boulder Creek/Boulder Creek								
MBC-ELD	69590	06/12/2000	820	7.47	25.0	9.5	4.0	15
MBC-WTP	62970	06/12/2000	1210	7.57	25.0	--	8.2	--
MBC-W	60920	06/12/2000	1250	7.43	27.5	8.8	9.5	29
BC-aNBC	49440	06/13/2000	845	7.67	36.4	9.1	11.2	18
BC-ORO	41520	06/13/2000	1000	7.54	36.3	8.6	11.6	22
BC-CAN	36710	06/13/2000	1315	7.46	38.7	8.4	13.8	30
BC-30	32990	06/12/2000	1430	7.47	46.3	8.6	14.6	23
BC-61	27320	06/14/2000	900	7.67	96.6	8.4	12.9	17
BC-aWWTP	24440	06/13/2000	1910	8.20	104	7.7	17.8	22
BC-75	23850	06/13/2000	2000	7.19	326	7.2	18.0	18
BC-aDC	20180	06/14/2000	1040	8.48	264	10.7	16.7	26
BC-95	18790	06/14/2000	1300	8.87	310	11.2	19.3	29
BC-107	16320	06/14/2000	1415	8.56	383	10.8	21.9	30
BC-aCC	10970	06/13/2000	1645	9.80	292	12.3	23.2	28
BC-bCC	10540	06/13/2000	1745	9.03	501	11.0	23.1	28
BC-aSV	110	06/12/2000	1700	9.53	651	12.0	32.5	33
Inflows/other flows								
COMO	59340	06/12/2000	1000	7.56	35.8	8.0	9.8	28
NBC-LW	59370	06/12/2000	1100	7.56	25.1	8.7	10.5	30
SLP	59340	06/12/2000	1100	7.57	20.0	--	10.9	--
BEAVER	60910	06/12/2000	1210	8.13	104	8.5	10.3	28
NED-EFF	60880	06/12/2000	1330	7.10	578	--	15.2	--
NBC-FALLS	49420	06/13/2000	800	7.29	29.3	9.5	9.8	18
FOURMILE	40120	06/13/2000	1115	7.79	93.4	8.1	13.1	28
SBC-aBC	29070	06/14/2000	800	8.25	362	6.3	22.1	17
BCSC-aBC	24680	06/14/2000	1515	8.40	182	7.2	21.6	32
BLD-EFF	24380	06/13/2000	2000	7.07	595	--	19.9	--
DC	20040	06/14/2000	1120	8.51	383	11.0	16.1	28
CC	10970	06/13/2000	1615	8.30	810	9.3	24.3	30
SV-aBC	90	06/12/2000	1745	8.73	811	9.3	23.7	33
Field blank		06/13/2000	1600	--	--	--	--	--

DO, dissolved oxygen; T_{H20}, water temperature; $T_{air,}$ air temperature; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms
Dissolved, filtered aliquot; Total, unfiltered aliquot; T, total; II, ferrous]

Site		Alkalinity, HCO_3^- (mg/L)	Br (mg/L)	Ca (mg/L)	Cl (mg/L)	F (mg/L)	Fe(T) (mg/L)	Fe(II) (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	NO_3 (mg/L)	SiO_2 (mg/L)	SO_4 (mg/L)
MBC-ELD	Dissolved	5.0	<0.05	3.0	0.8	<0.1	<0.007	--	0.26	0.70	0.61	0.63	3.8	1.8
	Total	--	--	3.0	--	--	0.013	--	0.22	0.66	0.60	--	3.7	--
MBC-WTP	Dissolved	9.5	<0.05	3.1	0.2	<0.1	0.022	--	0.27	0.71	0.72	0.64	4.1	1.9
	Total	--	--	3.2	--	--	0.047	--	0.26	0.71	0.71	--	4.0	--
MBC-W	Dissolved	10.1	<0.05	3.2	0.3	<0.1	<0.007	--	0.29	0.72	0.76	0.59	4.1	2.0
	Total	--	--	3.2	--	--	0.06	--	0.30	0.71	0.72	--	4.1	--
BC-aNBC	Dissolved	12.1	<0.05	4.0	1.4	0.1	<0.007	--	0.37	0.99	1.2	<0.3	2.7	2.5
	Total	--	--	4.1	--	--	0.072	--	0.40	0.99	1.2	--	2.7	--
BC-ORO	Dissolved	11.8	<0.05	3.9	1.1	<0.1	<0.007	--	0.39	0.90	1.5	<0.3	3.7	2.6
	Total	--	--	4.0	--	--	0.17	--	0.44	0.92	1.5	--	3.9	--
BC-CAN	Dissolved	11.0	<0.05	4.0	2.2	<0.1	<0.007	--	0.43	0.98	1.6	<0.3	4.0	2.8
	Total	--	--	4.2	--	--	0.17	--	0.50	1.0	1.5	--	4.2	--
BC-30	Dissolved	15.5	<0.05	4.7	1.9	<0.1	<0.007	--	0.47	1.2	1.7	<0.3	4.2	3.2
	Total	--	--	4.9	--	--	0.18	--	0.46	1.2	2.0	--	4.3	--
BC-61	Dissolved	35.2	<0.05	9.3	5.6	0.1	0.066	0.053	0.65	3.0	4.6	0.6	4.7	6.0
	Total	--	--	9.5	--	--	0.24	--	0.70	3.1	4.0	--	5.0	--
BC-aWWTP	Dissolved	34.9	<0.05	11	3.8	0.1	0.032	0.029	0.66	3.3	4.3	0.31	4.5	11
	Total	--	--	11	--	--	0.33	--	0.81	3.4	4.7	--	5.4	--
BC-75	Dissolved	64.0	<0.05	21	22	0.5	0.020	0.007	3.8	7.2	23	20	5.9	35
	Total	--	--	21	--	--	0.29	--	4.2	7.5	23	--	6.7	--
BC-aDC	Dissolved	60.9	<0.05	19	14	0.3	0.219	0.065	2.8	7.2	16	15	6.8	32
	Total	--	--	20	--	--	0.35	--	2.8	7.1	16	--	6.9	--
BC-95	Dissolved	77.9	<0.05	24	13	0.4	0.017	--	3.3	10	19	16	6.3	41
	Total	--	--	25	--	--	0.34	--	3.4	10	19	--	7.2	--
BC-107	Dissolved	110	0.35	28	16	0.4	0.044	0.027	2.8	12	21	8.0	5.9	44
	Total	--	--	28	--	--	0.17	--	2.4	13	21	--	6.3	--
BC-aCC	Dissolved	88.0	<0.05	22	11	0.5	<0.007	--	2.3	12	18	6.1	5.4	44
	Total	--	--	22	--	--	0.27	--	2.2	12	18	--	6.0	--
BC-bCC	Dissolved	145	<0.05	29	18	0.6	0.187	0.075	3.1	15	39	7.3	7.4	69
	Total	--	--	29	--	--	0.25	--	3.2	16	41	--	7.2	--
BC-aSV	Dissolved	187	0.69	41	21	0.8	0.074	0.066	2.6	34	51	3.7	6.2	170
	Total	--	--	40	--	--	0.099	--	2.5	35	52	--	6.2	--
COMO	Dissolved	15.6	<0.05	3.5	0.5	<0.1	<0.007	--	0.40	1.1	2.0	<0.3	11	1.7
	Total	--	--	3.7	--	--	0.40	--	0.36	1.1	2.0	--	10	--
NBC-LW	Dissolved	8.4	<0.05	2.8	0.1	<0.1	0.04	--	0.32	0.47	0.97	<0.3	5.4	2.1
	Total	--	--	2.9	--	--	0.16	--	0.31	0.47	0.97	--	5.1	--
SLP	Dissolved	5.3	<0.05	2.9	0.3	<0.1	0.011	--	0.31	0.33	0.65	<0.3	3.1	2.5
	Total	--	--	3.0	--	--	0.1	--	0.29	0.34	0.66	--	3.1	--
BEAVER	Dissolved	49.5	<0.05	12	1.2	<0.1	0.02	--	0.69	4.1	2.4	<0.3	13	7.4
	Total	--	--	12	--	--	0.21	--	0.75	4.2	2.3	--	13	--
NED-EFF	Dissolved	200	0.21	19	63	<0.1	0.08	--	12.1	7.5	42	<0.3	11	20
	Total	--	--	19	--	--	0.42	--	12.0	7.9	42	--	11	--
NBC-FALLS	Dissolved	10.6	<0.05	3.3	0.3	<0.1	0.13	--	0.34	0.65	1.1	<0.3	5.5	2.4
	Total	--	--	3.4	--	--	0.25	--	0.36	0.66	1.1	--	5.4	--
FOURMILE	Dissolved	34.2	<0.05	8.5	1.9	<0.1	<0.007	--	0.88	3.5	2.9	<0.3	11	9.9
	Total	--	--	8.6	--	--	0.05	--	0.86	3.6	2.8	--	10	--
SBC-aBC	Dissolved	136	<0.05	32	21	0.6	<0.007	--	2.8	11	23	<0.3	2.9	35
	Total	--	--	33	--	--	0.11	--	2.8	12	24	--	3.0	--
BCSC-aBC	Dissolved	58.7	<0.05	21	1.6	0.1	0.031	0.22	0.86	5.9	5.9	<0.3	4.6	34
	Total	--	--	21	--	--	0.43	--	0.92	6.1	5.8	--	5.4	--
BLD-EFF	Dissolved	118	0.37	37	57	1.1	0.12	--	9.3	13	52	49	8.5	69
	Total	--	--	38	--	--	0.2	--	10.3	14	53	--	8.7	--
DC	Dissolved	136	<0.05	33	6.5	0.4	0.016	--	1.8	18	18	0.5	8.1	67
	Total	--	--	34	--	--	0.24	--	1.7	19	18	--	8.9	--
CC	Dissolved	298	0.41	49	41	0.9	<0.007	--	5.8	26	110	12	10	150
	Total	--	--	50	--	--	0.64	--	6.0	29	110	--	12	--
SV-aBC	Dissolved	165	<0.05	58	19	0.7	0.13	--	3.4	38	56	11	7.3	260
	Total	--	--	61	--	--	0.51	--	3.2	40	58	--	8.0	--
Field blank	Dissolved	<1	<0.05	0.068	0.1	<0.1	<0.007	--	0.01	0.057	0.043	<0.3	<0.01	<0.1
	Total	--	--	<0.05	--	--	0.073	--	0.01	0.009	0.007	--	0.017	--

Table 4.5. Results of water analyses for Boulder Creek, inflows, and other flows, June 2000--continued

Site	Al (µg/L)	As (µg/L)	B (µg/L)	Ba (µg/L)	Be (µg/L)	Bi (µg/L)	Cd (µg/L)	Ce (µg/L)	Co (µg/L)	Cr (µg/L)	Cs (µg/L)	Cu (µg/L)	Dy (µg/L)
Middle Boulder Creek/Boulder Creek													
MBC-ELD	26	0.12	< 2	10.0	< 0.004	0.0091	0.004	0.13	0.012	< 0.2	< 0.02	0.34	0.027
	<80	<20	4	11	<0.1	--	<1	--	<1	<1	--	4	--
MBC-WTP	32	0.07	< 2	9.9	0.004	0.0014	0.022	0.16	0.021	< 0.2	< 0.02	0.52	0.025
	<80	<20	<3	11	<0.1	--	<1	--	<1	<1	--	3	--
MBC-W	20	0.14	< 2	10	< 0.004	0.0019	0.007	0.091	0.019	< 0.2	< 0.02	0.54	0.019
	<80	<20	5	11	<0.1	--	<1	--	<1	<1	--	5	--
BC-aNBC	21	0.09	5	12	0.005	0.0008	0.007	0.12	0.018	< 0.2	< 0.02	0.70	0.021
	<80	<20	4	14	<0.1	--	<1	--	<1	<1	--	6	--
BC-ORO	13	0.11	3	10.0	< 0.004	0.0009	0.002	0.078	0.018	< 0.2	0.26	0.63	0.014
	84	<20	5	13	<0.1	--	<1	--	<1	<1	--	2	--
BC-CAN	12	0.11	5	10.0	0.005	0.0008	0.011	0.073	0.013	< 0.2	< 0.02	0.67	0.012
	<80	<20	5	13	<0.1	--	<1	--	<1	<1	--	<1	--
BC-30	10	0.14	7	12	0.004	0.0005	0.007	0.074	0.015	< 0.2	0.02	0.65	0.012
	<80	<20	7	14	<0.1	--	<1	--	<1	<1	--	5	--
BC-61	29	0.32	13	19	0.006	0.0026	0.007	0.15	0.031	< 0.2	< 0.02	0.75	0.015
	110	<20	25	24	<0.1	--	<1	--	<1	<1	--	<1	--
BC-aWWTP	29	0.33	13	19	< 0.004	0.0014	0.004	0.085	0.021	< 0.2	< 0.02	0.76	0.0088
	220	<20	24	25	<0.1	--	<1	--	<1	<1	--	4	--
BC-75	11	0.39	79	19	< 0.004	0.012	0.021	0.031	0.089	< 0.2	0.05	1.7	0.0054
	270	<20	86	23	<0.1	--	<1	--	<1	<1	--	<1	--
BC-aDC	380	0.62	59	27	0.018	0.028	0.044	0.53	0.18	0.6	0.13	2.1	0.037
	390	<20	63	29	0.2	--	<1	--	<1	<1	--	<1	--
BC-95	15	0.63	72	26	< 0.004	0.0029	0.020	0.029	0.098	< 0.2	3.1	1.00	0.0034
	320	<20	76	33	<0.1	--	<1	--	<1	<1	--	<1	--
BC-107	23	0.82	76	36	< 0.004	0.0053	0.013	0.058	0.17	< 0.2	< 0.02	0.61	0.0087
	100	<20	77	39	<0.1	--	<1	--	<1	<1	--	<1	--
BC-aCC	7.1	0.91	68	22	< 0.004	0.0017	0.015	0.0091	0.13	< 0.2	< 0.02	0.55	0.0023
	280	<20	74	26	<0.1	--	<1	--	<1	<1	--	<1	--
BC-bCC	340	1.1	136	30	0.018	0.023	0.035	0.75	0.48	0.5	0.05	0.70	0.052
	260	<20	140	32	<0.1	--	<1	--	<1	<1	--	<1	--
BC-aSV	133	1.4	172	41	0.006	0.0074	0.023	0.25	0.35	< 0.2	< 0.02	< 0.04	0.017
	<80	<20	180	44	<0.1	--	<1	--	<1	<1	--	4	--
Inflows/other flows													
COMO	18	0.17	< 2	5.4	0.004	0.0011	0.067	0.12	0.054	< 0.2	< 0.02	0.48	0.014
	<80	<20	<3	7	<0.1	--	<1	--	<1	<1	--	4	--
NBC-LW	22	0.19	< 2	4.8	0.006	0.0022	0.065	0.11	0.026	< 0.2	< 0.02	0.73	0.011
	<80	<20	4	6	<0.1	--	<1	--	<1	<1	--	7	--
SLP	9.1	0.08	3	4.3	0.004	0.0018	0.028	0.040	0.008	< 0.2	< 0.02	0.81	0.0068
	<80	<20	3	6	0.2	--	<1	--	<1	<1	--	<1	--
BEAVER	10	0.13	2	30	< 0.004	0.0030	0.026	0.036	0.029	< 0.2	0.03	0.79	0.0042
	<80	<20	5	33	<0.1	--	<1	--	<1	<1	--	5	--
NED-EFF	8.3	0.24	294	7.0	< 0.004	0.040	0.012	0.0076	0.37	< 0.2	0.08	2.1	0.0010
	170	<20	300	24	<0.1	--	<1	--	<1	<1	--	16	--
NBC-FALLS	64	0.11	3	7.0	0.008	0.0022	0.018	0.24	0.056	< 0.2	< 0.02	0.92	0.016
	<80	<20	<3	8	<0.1	--	<1	--	<1	<1	--	<1	--
FOURMILE	3.3	0.84	9	19	< 0.004	0.0013	0.013	0.013	0.007	< 0.2	< 0.02	0.67	0.0025
	<80	<20	10	22	<0.1	--	<1	--	<1	<1	--	3	--
SBC-aBC	3.2	1.0	465	99	0.005	0.0019	0.002	0.0074	< 0.001	< 0.2	< 0.02	0.81	0.0010
	89	<20	470	100	<0.1	--	<1	--	<1	<1	--	<1	--
BCSC-aBC	105	0.46	13	30	0.010	0.0022	0.008	0.081	< 0.001	< 0.2	< 0.02	1.0	0.0076
	380	<20	12	41	<0.1	--	<1	--	<1	<1	--	<1	--
BLD-EFF	18	0.46	197	14	< 0.004	0.080	0.058	0.0094	0.22	0.3	0.12	8.5	0.0027
	110	<20	210	18	<0.1	--	<1	--	<1	<1	--	4	--
DC	5.2	0.49	38	34	< 0.004	0.0033	0.003	0.041	< 0.001	< 0.2	< 0.02	< 0.04	0.0055
	240	<20	41	38	0.2	--	<1	--	<1	<1	--	<1	--
CC	4.7	1.5	340	43	< 0.004	0.0092	0.071	0.034	1.0	< 0.2	< 0.02	0.37	0.014
	470	<20	360	--	57	--	<1	--	<1	<1	--	2	--
SV-aBC	250	1.2	163	36	0.014	0.024	0.036	0.43	0.15	0.6	0.07	< 0.04	0.028
	450	<20	170	--	43	--	<1	--	<1	<1	--	3	--
Field blank	0.6	< 0.01	< 2	0.031	< 0.004	< 0.0005	0.011	0.0019	0.006	< 0.2	0.05	0.12	< 0.0002
	<80	<20	4	--	<0.5	--	<1	--	<1	<1	--	<1	--

Site	Er (µg/L)	Eu (µg/L)	Gd (µg/L)	Ho (µg/L)	La (µg/L)	Li (µg/L)	Lu (µg/L)	Mn (µg/L)	Mo (µg/L)	Nd (µg/L)	Ni (µg/L)	Pb (µg/L)	Pr (µg/L)	Rb (µg/L)
MBC-ELD	0.013	0.0084	0.040	0.0047	0.24	0.14	0.0016	1.9	0.35	0.31	0.08	0.086	0.076	0.36
	--	--	--	--	--	<8	--	<1	--	--	<20	<1	--	--
MBC-WTP	0.012	0.0086	0.040	0.0048	0.24	0.14	0.0015	3.5	0.35	0.30	0.19	0.042	0.074	0.42
	--	--	--	--	--	<8	--	<1	--	--	<20	<1	--	--
MBC-W	0.0087	0.0053	0.028	0.0036	0.16	0.17	0.0010	3.1	0.49	0.20	0.22	0.027	0.048	0.41
	--	--	--	--	--	<8	--	<1	--	--	<20	<1	--	--
BC-aNBC	0.012	0.0084	0.030	0.0041	0.18	0.43	0.0013	1.7	0.52	0.22	0.24	0.083	0.052	0.52
	--	--	--	--	--	<8	--	<1	--	--	<20	<1	--	--
BC-ORO	0.0078	0.0046	0.020	0.0027	0.097	0.36	0.0011	2.2	0.54	0.13	0.19	0.058	0.029	0.50
	--	--	--	--	--	<8	--	5	--	--	<20	<1	--	--
BC-CAN	0.0057	0.0041	0.015	0.0026	0.085	0.43	0.0010	2.4	0.50	0.12	0.20	0.034	0.025	0.54
	--	--	--	--	--	<8	--	6	--	--	<20	<1	--	--
BC-30	0.0062	0.0040	0.016	0.0023	0.084	0.54	0.0009	3.3	0.52	0.11	0.22	0.027	0.025	0.56
	--	--	--	--	--	<8	--	7	--	--	<20	<1	--	--
BC-61	0.0080	0.0042	0.016	0.0033	0.12	1.9	0.0013	9.9	0.68	0.14	0.38	0.18	0.035	0.70
	--	--	--	--	--	<8	--	19	--	--	<20	<1	--	--
BC-aWWTP	0.0052	0.0036	0.011	0.0017	0.055	2.0	0.0007	7.7	0.67	0.069	0.44	0.079	0.016	0.61
	--	--	--	--	--	9	--	15	--	--	<20	<1	--	--
BC-75	0.0035	0.0020	0.021	0.0013	0.023	11	0.0009	18	6.3	0.031	1.3	0.22	0.0070	3.0
	--	--	--	--	--	13	--	27	--	--	<20	<1	--	--
BC-aDC	0.021	0.012	0.060	0.0074	0.30	6.9	0.0025	22	2.9	0.30	1.4	0.72	0.074	2.8
	--	--	--	--	--	<8	--	23	--	--	<20	<1	--	--
BC-95	0.0027	< 0.0001	0.014	0.0009	0.018	8.4	0.0006	9.7	3.2	0.021	1.1	0.16	0.0048	2.4
	--	--	--	--	--	9	--	25	--	--	<20	4	--	--
BC-107	0.0077	0.0017	0.016	0.0022	0.034	12	0.0017	39	3.6	0.043	1.2	0.19	0.0092	1.5
	--	--	--	--	--	13	--	42	--	--	<20	<1	--	--
BC-aCC	0.0021	0.0009	0.0049	0.0007	0.0055	8.8	0.0005	2.9	3.3	0.0089	1.1	0.072	0.0017	1.1
	--	--	--	--	--	10	--	18	--	--	<20	7	--	--
BC-bCC	0.026	0.014	0.073	0.0091	0.37	15	0.0035	26	3.3	0.40	2.0	0.71	0.093	2.3
	--	--	--	--	--	18	--	25	--	--	<20	<1	--	--
BC-aSV	0.014	0.0040	0.027	0.0042	0.13	23	0.0027	29	3.6	0.13	2.0	0.31	0.031	1.5
	--	--	--	--	--	34	--	28	--	--	<20	<1	--	--
COMO	0.0081	0.0047	0.017	0.0033	0.078	0.33	0.0016	7.7	0.67	0.087	0.26	0.044	0.021	0.23
	--	--	--	--	--	<8	--	8	--	--	<20	<1	--	--
NBC-LW	0.0061	0.0037	0.013	0.0023	0.076	0.14	0.0009	4.1	0.69	0.096	0.15	0.13	0.024	0.41
	--	--	--	--	--	<8	--	2	--	--	<20	<1	--	--
SLP	0.0038	0.0020	0.0076	0.0015	0.035	0.14	0.0007	1.5	0.51	0.052	0.20	0.030	0.012	0.42
	--	--	--	--	--	<8	--	7	--	--	<20	<1	--	--
BEAVER	0.0027	0.0009	0.0050	0.0009	0.022	0.52	0.0006	14	4.6	0.023	0.41	0.36	0.0052	0.52
	--	--	--	--	--	<8	--	10	--	--	<20	<1	--	--
NED-EFF	0.0010	0.0005	0.0018	0.0004	0.0042	53	0.0004	38	1.0	0.0066	1.8	0.19	0.0013	9.3
	--	--	--	--	--	65	--	38	--	--	<20	<1	--	--
NBC-FALLS	0.0099	0.0064	0.023	0.0033	0.15	0.23	0.0012	7.4	0.47	0.17	0.27	0.30	0.044	0.54
	--	--	--	--	--	<8	--	7	--	--	<20	<1	--	--
FOURMILE	0.0016	0.0010	0.0020	0.0005	0.0087	1.2	0.0003	4.2	0.40	0.011	0.57	0.017	0.0024	0.75
	--	--	--	--	--	<8	--	3	--	--	<20	<1	--	--
SBC-aBC	0.0018	< 0.0001	0.0019	0.0004	0.0052	12	0.0006	5.7	6.7	0.0062	0.81	0.026	0.0010	1.3
	--	--	--	--	--	14	--	16	--	--	<20	<1	--	--
BCSC-aBC	0.0047	0.0019	0.0088	0.0016	0.045	4.1	0.0006	2.5	0.67	0.045	0.64	0.069	0.011	0.51
	--	--	--	--	--	<8	--	21	--	--	<20	<1	--	--
BLD-EFF	0.0030	0.0011	0.040	0.0008	0.0056	23	0.0009	35	17	0.0065	3.3	0.81	0.0013	7.2
	--	--	--	--	--	31	--	38	--	--	<20	2	--	--
DC	0.0033	0.0012	0.0072	0.0014	0.027	6.9	0.0006	20	1.8	0.034	0.73	0.027	0.0076	0.72
	--	--	--	--	--	<8	--	31	--	--	<20	3	--	--
CC	0.013	0.0019	0.021	0.0042	0.016	32	0.0031	43	4.0	0.028	3.2	0.44	0.0051	2.9
	--	--	--	--	--	45	--	90	--	--	<20	3	--	--
SV-aBC	0.014	0.0065	0.040	0.0053	0.20	24	0.0016	14	3.4	0.22	0.71	0.39	0.052	2.0
	--	--	--	--	--	30	--	29	--	--	<20	<1	--	--
Field blank	0.0002	< 0.0001	< 0.0003	< 0.0001	0.0010	0.03	0.0001	0.20	0.06	0.0010	0.03	0.024	< 0.0001	0.021
	--	--	--	--	--	<8	--	<1	--	--	<20	4	--	--

Table 4.5. Results of water analyses for Boulder Creek, inflows, and other flows, June 2000--continued

Site	Re (μg/L)	Sb (μg/L)	Se (μg/L)	Sm (μg/L)	Sr (μg/L)	Tb (μg/L)	Te (μg/L)	Th (μg/L)	Tl (μg/L)	Tm (μg/L)	U (μg/L)	V (μg/L)	Y (μg/L)
Middle Boulder Creek/Boulder Creek													
MBC-ELD	0.0008	0.020	< 0.1	0.054	22	0.0049	< 0.005	0.025	0.003	0.0016	0.14	0.06	0.14
	--	--	<20	--	21	--	--	--	--	--	--	<1	--
MBC-WTP	0.0011	0.019	< 0.1	0.053	23	0.0051	< 0.005	0.022	0.003	0.0016	0.15	0.09	0.13
	--	--	<20	--	24	--	--	--	--	--	--	<1	--
MBC-W	0.0012	0.036	< 0.1	0.035	24	0.0037	< 0.005	0.020	0.003	0.0012	0.11	0.11	0.10
	--	--	<20	--	24	--	--	--	--	--	--	<1	--
BC-aNBC	0.0014	0.045	< 0.1	0.039	31	0.0040	< 0.005	0.019	0.003	0.0012	0.14	0.11	0.12
	--	--	<20	--	32	--	--	--	--	--	--	<1	--
BC-ORO	0.0014	0.046	< 0.1	0.024	32	0.0024	< 0.005	0.017	0.004	0.0010	0.099	0.12	0.081
	--	--	<20	--	34	--	--	--	--	--	--	<1	--
BC-CAN	0.0014	0.043	< 0.1	0.022	34	0.0023	< 0.005	0.013	0.004	0.0010	0.098	0.14	0.072
	--	--	<20	--	36	--	--	--	--	--	--	<1	--
BC-30	0.0015	0.050	< 0.1	0.019	40	0.0021	< 0.005	0.015	0.003	0.0009	0.11	0.14	0.070
	--	--	<20	--	41	--	--	--	--	--	--	<1	--
BC-61	0.0033	0.083	< 0.1	0.026	89	0.0027	0.006	0.013	0.006	0.0010	0.26	0.26	0.079
	--	--	<20	--	91	--	--	--	--	--	--	<1	--
BC-aWWTP	0.0042	0.071	< 0.1	0.014	92	0.0017	< 0.005	0.0097	0.004	0.0006	0.34	0.35	0.051
	--	--	<20	--	98	--	--	--	--	--	--	<1	--
BC-75	0.016	0.16	0.3	0.0075	176	0.0010	< 0.005	0.015	0.006	0.0006	0.37	0.42	0.032
	--	--	<20	--	180	--	--	--	--	--	--	<1	--
BC-aDC	0.014	0.14	0.3	0.058	182	0.0070	0.009	0.079	0.013	0.0031	0.95	1.6	0.19
	--	--	<20	--	180	--	--	--	--	--	--	<1	--
BC-95	0.017	0.23	0.4	0.0038	229	0.0005	0.009	0.0060	0.004	0.0004	1.4	0.66	0.022
	--	--	<20	--	240	--	--	--	--	--	--	<1	--
BC-107	0.018	0.15	< 0.1	0.011	317	0.0015	0.007	0.0096	0.006	0.0013	2.6	0.97	0.051
	--	--	<20	--	320	--	--	--	--	--	--	<1	--
BC-aCC	0.016	0.50	0.4	0.0022	305	0.0003	0.009	0.0048	0.004	0.0003	2.8	1.3	0.016
	--	--	<20	--	320	--	--	--	--	--	--	2	--
BC-bCC	0.026	0.19	0.8	0.076	385	0.0086	0.013	0.055	0.011	0.0034	5.1	2.7	0.25
	--	--	<20	--	420	--	--	--	--	--	--	2	--
BC-aSV	0.049	0.17	0.8	0.024	686	0.0029	0.030	0.050	0.008	0.0020	8.0	2.6	0.11
	--	--	<20	--	720	--	--	--	--	--	--	2	--
Inflows/other flows													
COMO	0.0016	0.087	< 0.1	0.019	34	0.0023	< 0.005	0.017	0.003	0.0011	0.020	0.27	0.080
	--	--	<20	--	35	--	--	--	--	--	--	<1	--
NBC-LW	0.0013	0.054	< 0.1	0.016	26	0.0020	< 0.005	0.012	0.006	0.0008	0.034	0.16	0.064
	--	--	<20	--	25	--	--	--	--	--	--	<1	--
SLP	0.0015	0.031	< 0.1	0.011	26	0.0011	< 0.005	0.014	0.003	0.0005	0.048	< 0.06	0.038
	--	--	<20	--	27	--	--	--	--	--	--	<1	--
BEAVER	0.0081	0.18	< 0.1	0.0050	95	0.0007	< 0.005	0.0064	0.003	0.0005	0.54	0.24	0.026
	--	--	<20	--	100	--	--	--	--	--	--	<1	--
NED-EFF	0.0071	0.46	< 0.1	0.0013	99	0.0002	0.009	0.0045	0.005	0.0002	0.011	0.41	0.0074
	--	--	<20	--	110	--	--	--	--	--	--	<1	--
NBC-FALLS	0.0017	0.036	< 0.1	0.029	30	0.0032	< 0.005	0.013	0.004	0.0013	0.051	0.31	0.092
	--	--	<20	--	31	--	--	--	--	--	--	<1	--
FOURMILE	0.0023	0.12	< 0.1	0.0030	106	0.0003	0.006	0.0034	0.005	0.0003	0.16	0.17	0.013
	--	--	<20	--	110	--	--	--	--	--	--	<1	--
SBC-aBC	0.019	0.39	1.0	0.0020	374	0.0002	< 0.005	0.0033	0.004	0.0003	2.3	1.0	0.012
	--	--	<20	--	410	--	--	--	--	--	--	<1	--
BCSC-aBC	0.0097	0.090	0.3	0.0090	162	0.0014	< 0.005	0.016	0.005	0.0006	0.72	0.75	0.046
	--	--	<20	--	170	--	--	--	--	--	--	<1	--
BLD-EFF	0.031	0.78	0.3	0.0082	300	0.0004	0.009	0.0056	0.008	0.0005	0.67	0.55	0.022
	--	--	<20	--	320	--	--	--	--	--	--	<1	--
DC	0.014	0.084	0.4	0.0078	366	0.0010	0.011	0.010	0.009	0.0005	3.1	0.74	0.041
	--	--	<20	--	380	--	--	--	--	--	--	<1	--
CC	0.052	0.34	1.8	0.0069	632	0.0021	0.023	0.024	0.008	0.0018	11	3.1	0.10
	--	--	<20	--	670	--	--	--	--	--	--	3	--
SV-aBC	0.058	0.42	1.9	0.042	976	0.0061	0.036	0.054	0.009	0.0020	9.7	2.7	0.16
	--	--	<20	--	100	--	--	--	--	--	--	3	--
Field blank	0.0002	0.009	< 0.1	0.0005	0.07	0.0001	< 0.005	< 0.0007	0.002	< 0.0001	< 0.002	< 0.06	0.0008
	--	--	<20	--	<1	--	--	--	--	--	--	<1	--

Site	Yb (μg/L)	Zn (μg/L)	Zr (μg/L)	Hg (ng/L)	Sum Cations (meq/L)	Sum Anions (meq/L)	Charge Imbalance (%)
MBC-ELD	0.0097	1.5	0.023	0.9	0.24	0.15	46
	--	<1	--	--			
MBC-WTP	0.010	0.92	0.018	--	0.25	0.21	17
	--	<1	--	--			
MBC-W	0.0089	1.0	0.021	1.4	0.26	0.22	15
	--	<1	--	--			
BC-aNBC	0.0094	0.83	0.024	3.0	0.34	0.29	15
	--	<1	--	--			
BC-ORO	0.0059	0.93	0.019	3.5	0.34	0.28	21
	--	<1	--	--			
BC-CAN	0.0057	0.49	0.017	1.7	0.36	0.3	19
	--	<1	--	--			
BC-30	0.0057	1.0	0.021	2.7	0.41	0.37	11
	--	<1	--	--			
BC-61	0.0066	0.84	0.020	--	0.92	0.87	6.0
	--	4	--	--			
BC-aWWTP	0.0047	0.26	0.021	1.6	1.0	0.9	11
	--	<1	--	--			
BC-75	0.0046	8.2	0.035	2.5	2.7	2.7	0.1
	--	13	--	--			
BC-aDC	0.016	7.0	0.39	--	2.2	2.2	0.1
	--	10	--	--			
BC-95	0.0032	5.5	0.032	--	2.8	2.6	5.7
	--	10	--	--			
BC-107	0.0096	2.4	0.038	--	3.2	3.1	2.0
	--	5	--	--			
BC-aCC	0.0027	0.98	0.021	1.7	2.5	2.4	2.8
	--	5	--	--			
BC-bCC	0.023	5.2	0.28	--	4.1	4.1	0.1
	--	9	--	--			
BC-aSV	0.014	0.17	0.14	5.1	5.7	5.9	-3.8
	--	<1	--	--			
COMO	0.0088	14	0.045	2.3	0.36	0.3	17
	--	<1	--	--			
NBC-LW	0.0056	3.0	0.017	<0.5	0.22	0.18	22
	--	<1	--	--			
SLP	0.0041	3.0	0.017	--	0.21	0.15	33
	--	3	--	--			
BEAVER	0.0032	7.8	0.014	3.0	1.0	0.99	6.0
	--	9	--	--			
NED-EFF	0.0015	9.9	0.093	2.0	5.2	5.4	-3.8
	--	24	--	--			
NBC-FALLS	0.0082	2.2	0.020	0.6	0.28	0.23	19
	--	<1	--	--			
FOURMILE	0.0020	3.1	0.0079	2.0	0.85	0.81	5.1
	--	<1	--	--			
SBC-aBC	0.0025	0.82	0.019	--	3.4	3.4	-0.7
	--	2	--	--			
BCSC-aBC	0.0044	0.06	0.070	--	1.7	1.6	4.2
	--	3	--	--			
BLD-EFF	0.0042	23	0.20	6.4	5.6	5.6	-1.2
	--	30	--	--			
DC	0.0036	< 0.05	0.043	--	3.6	3.6	1.3
	--	3	--	--			
CC	0.014	13	0.12	1.1	8.6	8.7	-1.3
	--	26	--	--			
SV-aBC	0.015	0.61	0.18	1.1	7.3	7.7	-4.5
	--	8	--	--			
Field blank	< 0.0003	0.66	< 0.0006	<0.5	--	--	--
	--	<1	--	--			

Table 4.6. Results of water analyses for Boulder Creek, inflows, and other flows, October 2000

[Distance, distance upstream from Boulder Creek/Saint Vrain Creek confluence; SC, specific conductance; µS/cm, microsiemens per centimeter; per liter; ng/L, nanograms per liter; --, sample not analyzed for this constituent; <, less than; meq/L, milliequivalents per liter; %, percent;

Site	Distance (meters)	Date collected	Time	pH	SC (µS/cm)	DO (mg/L)	DO (%)	T_{H2O} (°C)	T_{air} (°C)
Middle Boulder Creek/Boulder Creek									
MBC-ELD	69590	10/09/2000	830	7.72	38	10.2	96.5	0.3	0.5
MBC-WTP	62970	10/09/2000	1204	7.52	48	--	--	--	--
MBC-W	60920	10/09/2000	1300	7.74	48	9.40	101	5.8	19
MBC-aNBC	49440	10/10/2000	815	7.93	84	9.70	95.3	4.1	2.5
BC-ORO	41520	10/10/2000	1000	7.85	54	9.46	99.3	7.9	9.5
BC-CAN	36710	10/10/2000	1230	7.82	61	9.37	100	9.3	9.7
BC-30	32990	10/10/2000	1345	7.61	118	10.1	109	9.6	14.5
BC-61	27320	10/11/2000	1415	9.25	232	12.5	145	13.8	26
BC-aWWTP	24440	10/11/2000	815	7.97	240	8.78	91.5	8.7	7
BC-75	23850	10/11/2000	900	7.28	569	7.20	92.0	17.6	9.8
BC-aDC	20180	10/11/2000	1015	7.60	449	7.26	85.0	13.7	14.4
BC-95	18790	10/11/2000	1215	8.02	472	9.05	109	15.2	18
BC-107	16320	10/11/2000	1315	8.34	510	10.3	124	15.5	24
BC-aCC	10970	10/10/2000	1640	9.17	510	10.8	133	16.6	20.5
BC-bCC	10540	10/10/2000	1745	8.62	771	9.31	111	14.9	16.5
BC-aSV	110	10/09/2000	1545	9.58	695	17.1	199	14.5	17.5
Inflows/other flows									
COMO	59340	10/09/2000	1015	7.59	70	10.0	101	3.4	18
NBC-LW	59370	10/09/2000	1050	7.68	33	9.58	96.1	3.0	20
SLP	59340	10/09/2000	1058	7.04	25	--	--	--	--
BEAVER	60910	10/09/2000	1210	8.33	183	8.95	95.1	5.3	19.5
NED-EFF	60880	10/09/2000	1317	7.24	601	--	--	--	--
NBC-FALLS	49420	10/10/2000	900	7.92	72	10.0	96.0	3.0	12
FOURMILE	40120	10/10/2000	1050	8.02	286	9.73	97.0	5.8	10.5
SBC-aBC	29070	10/10/2000	1445	8.08	325	7.47	90.3	14.9	20.2
BCSC-aBC	24680	10/09/2000	1745	8.80	131	8.61	102	15.0	17
BLD-EFF	24380	10/11/2000	830	7.28	624	--	--	--	--
DC	20040	10/11/2000	1100	8.51	1023	10.4	111	9.9	22
CC	10970	10/10/2000	1600	8.35	923	8.6	103	14.8	19
SV-aBC	90	10/09/2000	1630	9.09	1238	14.9	174	14.4	18
Field blank		10/11/2000	830	--	--	--	--	--	--

DO, dissolved oxygen; T_{H20}, water temperature; $T_{air,}$ air temperature; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms
Dissolved, filtered aliquot; Total, unfiltered aliquot; T, total; II, ferrous]

Site		Alkanlinity, HCO_3 (mg/L)	Br (mg/L)	Ca (mg/L)	Cl (mg/L)	F (mg/L)	Fe(T) (mg/L)	Fe(II) (mg/L)	K (mg/L)	Mg (mg/L)
MBC-ELD	Dissolved	10.3	<0.1	4.4	3.3	0.04	0.025	0.020	0.25	1.0
	Total	--	--	4.4	--	--	<0.008	--	0.27	1.0
MBC-WTP	Dissolved	19.2	<0.1	5.7	0.8	0.04	0.095	0.072	0.38	1.3
	Total	--	--	5.7	--	--	0.21	--	0.39	1.3
MBC-W	Dissolved	19.7	<0.1	5.9	1.2	0.04	0.081	0.061	0.40	1.4
	Total	--	--	6.0	--	--	0.19	--	0.41	1.4
MBC-aNBC	Dissolved	27.7	<0.1	8.6	7.2	0.06	0.026	0.023	0.68	2.2
	Total	--	--	8.8	--	--	0.050	--	0.72	2.2
BC-ORO	Dissolved	20.2	<0.1	5.7	2.4	0.04	0.102	0.099	0.47	1.4
	Total	--	--	5.8	--	--	0.29	--	0.47	1.5
BC-CAN	Dissolved	21.7	<0.1	6.3	3.1	0.04	0.089	0.089	0.52	1.7
	Total	--	--	6.2	--	--	0.27	--	0.53	1.7
BC-30	Dissolved	39.5	<0.1	12	7.9	0.07	0.083	0.074	0.77	3.2
	Total	--	--	12	--	--	0.30	--	0.79	3.4
BC-61	Dissolved	87.7	<0.1	25	18	0.2	0.020	0.020	1.5	8.2
	Total	--	--	24	--	--	0.25	--	1.4	8.6
BC-aWWTP	Dissolved	89.4	<0.1	24	14	0.2	0.041	0.039	1.2	8.5
	Total	--	--	24	--	--	0.35	--	1.3	8.5
BC-75	Dissolved	116	<0.1	35	35	0.9	0.044	0.014	8.0	12
	Total	--	--	35	--	--	0.22	--	8.1	12
BC-aDC	Dissolved	108	<0.1	34	31	0.7	0.039	0.020	5.1	13
	Total	--	--	32	--	--	0.35	--	5.0	14
BC-95	Dissolved	105	<0.1	33	29	0.7	0.048	0.031	5.2	14
	Total	--	--	33	--	--	0.27	--	5.5	14
BC-107	Dissolved	126	<0.1	37	28	0.8	0.043	0.029	5.5	17
	Total	--	--	37	--	--	0.19	--	5.5	18
BC-aCC	Dissolved	158	<0.1	35	32	0.9	0.011	0.008	5.2	19
	Total	--	--	37	--	--	0.14	--	5.2	19
BC-bCC	Dissolved	205	<0.1	41	36	0.9	0.015	0.009	5.2	21
	Total	--	--	41	--	--	0.37	--	5.2	22
BC-aSV	Dissolved	215	<0.1	43	33	1.1	0.010	0.007	4.4	30
	Total	--	--	47	--	--	0.11	--	4.5	32
COMO	Dissolved	37.9	<0.1	6.8	0.8	0.05	0.161	0.160	0.64	2.1
	Total	--	--	7.2	--	--	0.67	--	0.68	2.2
NBC-LW	Dissolved	15.8	<0.1	3.9	0.3	<0.03	0.135	0.130	0.30	0.76
	Total	--	--	4.0	--	--	0.28	--	0.33	0.76
SLP	Dissolved	8.6	<0.1	3.3	0.7	<0.03	0.012	0.011	0.21	0.35
	Total	--	--	3.2	--	--	0.22	--	0.22	0.34
BEAVER	Dissolved	84.9	<0.1	21	3.2	0.04	0.189	0.157	1.3	7.6
	Total	--	--	20	--	--	0.47	--	1.3	7.6
NED-EFF	Dissolved	154	<0.1	19	73	0.1	0.102	0.099	11	10
NBC-FALLS	Dissolved	32.3	<0.1	7.7	1.6	0.04	0.045	0.045	0.68	2.1
	Total	--	--	7.7	--	--	0.19	--	0.70	2.1
FOURMILE	Dissolved	92.3	<0.1	28	9.0	0.09	0.037	0.037	2.1	12
	Total	--	--	31	--	--	0.063	--	2.3	12
SBC-aBC	Dissolved	118	<0.1	29	22	0.5	0.071	0.070	2.6	11
	Total	--	--	29	--	--	0.11	--	2.7	10
BCSC-aBC	Dissolved	48.0	<0.1	16	1.5	0.1	0.013	0.009	0.63	4.4
	Total	--	--	16	--	--	1.0	--	0.85	4.5
BLD-EFF	Dissolved	119	<0.1	39	41	1.0	0.092	0.028	11	14
DC	Dissolved	373	<0.1	83	17	1.1	0.017	0.016	2.5	70
	Total	--	--	84	--		0.083	--	2.5	70
CC	Dissolved	313	<0.1	53	45	1.0	0.022	0.008	5	28
	Total	--	--	53	--	--	0.63	--	5.6	32
SV-aBC	Dissolved	260	<0.1	90	48	1.0	0.042	0.032	3.3	63
	Total	--	--	89	--	--	0.12	--	3.7	63
Field blank	Dissolved	<1	<0.1	<0.05	0.3	<0.03	0.004	---	0.039	<0.0001

Table 4.6. Results of water analyses for Boulder Creek, inflows, and other flows, October 2000--continued

Site	Na (mg/L)	NH_4 (mg/L)	NO_3 (mg/L)	NO_2 (mg/L)	SiO_2 (mg/L)	SO_4 (mg/L)	Al (µg/L)	As (µg/L)	B (µg/L)	Ba (µg/L)	Be (µg/L)	Bi (µg/L)
Middle Boulder Creek/Boulder Creek												
MBC-ELD	0.72	<0.01	0.79	<0.1	3.9	3.7	6.4	0.08	< 3	12	0.010	< 0.001
	0.73	--	--	--	3.8	--	< 80	< 30	< 3	12	<0.1	--
MBC-WTP	1.2	<0.01	0.58	<0.1	5.4	4.2	3.5	0.07	< 3	15	< 0.008	0.002
	1.2	--	--	--	5.4	--	120	< 30	< 3	16	0.6	--
MBC-W	1.3	<0.01	0.57	<0.1	5.7	4.3	4.6	0.07	< 3	14	<0.01	0.0032
	1.3	--	--	--	5.7	--	< 80	< 30	< 3	17	<0.1	--
MBC-aNBC	4.1	<0.01	0.29	<0.1	4.3	5.6	4.4	0.07	< 3	24	< 0.008	< 0.001
	4.1	--	--	--	4.2	--	< 80	< 30	< 3	27	0.9	--
BC-ORO	2.1	<0.01	0.53	<0.1	4.4	4.1	5.5	0.12	4	17	< 0.008	0.006
	2.1	--	--	--	4.6	--	140	< 30	5	19	0.5	--
BC-CAN	2.4	<0.01	0.43	<0.1	4.5	5.0	5.4	0.16	5	17	< 0.008	0.003
	2.5	--	--	--	4.7	--	130	< 30	4	19	0.4	--
BC-30	5.5	<0.01	1.4	<0.1	5.1	10.3	5.3	0.20	22	27	< 0.008	0.002
	5.6	--	--	--	5.4	--	150	< 30	24	31	0.6	--
BC-61	14	<0.01	<0.1	<0.1	2.4	18	3.1	0.31	53	40	< 0.008	< 0.001
	13	--	--	--	2.4	--	120	< 30	50	43	0.2	--
BC-aWWTP	12	<0.01	<0.1	<0.1	2.6	24	26	0.30	46	46	< 0.008	0.002
	12	--	--	--	3.8	--	260	< 30	47	53	0.2	--
BC-75	42	7.2	53	14	8.3	62	8.4	0.39	200	17	< 0.008	0.027
	42	--	--	--	8.5	--	100	< 30	200	20	0.2	--
BC-aDC	34	2.5	29	1.7	5.8	51	4.1	0.44	150	25	< 0.008	0.008
	31	--	--	--	6.1	--	110	< 30	140	30	<0.1	--
BC-95	32	2.1	46	<0.1	5.5	59	21	0.47	140	26	< 0.008	0.012
	32	--	--	--	6.0	--	130	< 30	140	30	0.5	--
BC-107	37	2.0	29	<0.1	4.9	64	4.8	0.57	150	27	< 0.008	0.005
	38	--	--	--	5.3	--	120	< 30	140	29	0.4	--
BC-aCC	41	1.5	17	<0.1	4.9	69	6.7	0.61	160	29	< 0.008	0.005
	41	--	--	--	5.5	--	<80	< 30	180	31	0.2	--
BC-bCC	62	1.0	18	<0.1	6.8	98	6.8	0.59	240	32	< 0.008	0.009
	63	--	--	--	8.3	--	290	< 30	240	38	<0.1	--
BC-aSV	64	<0.01	24.	<0.1	5.3	128	8.1	0.85	240	35	< 0.008	0.005
	70	--	--	--	6.6	--	110	< 30	280	38	0.2	--
Inflows/other flows												
COMO	3.4	<0.01	<0.1	<0.1	18	2.9	7.7	0.11	< 3	8.2	< 0.008	0.006
	3.7	--	--	--	19	--	< 80	< 30	< 3	9.0	<0.1	--
NBC-LW	1.2	<0.01	<0.1	<0.1	6.6	2.3	9.2	0.08	< 3	5.2	< 0.008	0.002
	1.2	--	--	--	6.7	--	< 80	< 30	< 3	7.0	<0.1	--
SLP	0.64	<0.01	<0.1	<0.1	2.9	2.1	2.6	0.08	< 3	3.9	< 0.008	< 0.001
	0.60	--	--	--	3.0	--	< 80	< 30	< 3	5.0	<0.1	--
BEAVER	4.8	<0.01	<0.1	<0.1	14	19.3	2.7	0.13	< 3	51	< 0.008	0.002
	4.7	--	--	--	12	--	< 80	< 30	< 3	53	<0.1	--
NED-EFF	46	16.9	14	<0.1	8.8	26.0	10	0.40	360	4.1	< 0.008	0.067
NBC-FALLS	3.4	<0.01	<0.1	<0.1	10	6.0	3.2	0.11	< 3	15	< 0.008	< 0.001
	3.4	--	--	--	10	--	< 80	< 30	< 3	15	0.6	--
FOURMILE	11	<0.01	<0.1	<0.1	12	50	1.3	1.5	21	54	< 0.008	< 0.001
	12	--	--	--	13	--	< 80	< 30	23	58	0.4	--
SBC-aBC	22	<0.01	<0.1	<0.1	2.9	33	29	0.68	280	67	< 0.008	0.002
	22	--	--	--	3.0	--	< 80	< 30	290	74	<0.1	--
BCSC-aBC	4.8	<0.01	<0.1	<0.1	5.3	21	8.9	0.52	8	27	< 0.008	0.003
	4.5	--	--	--	10	--	1200	< 30	9	42	0.9	--
BLD-EFF	51	7.8	62	2.0	11	70	8.5	0.50	260	9.9	-0.01	0.056
DC	57	<0.01	1.5	<0.1	6	263	3.6	0.32	140	60	0.027	0.017
	56	--	--	--	6.2	--	< 80	< 30	140	63	<0.1	--
CC	110	<0.01	19	<0.1	11	160	27	0.66	390	41	0.013	0.020
	120	--	--	--	14	--	570	< 30	400	50	<0.1	--
SV-aBC	110	<0.01	23.	<0.1	7.6	398	19	0.61	310	31	< 0.008	0.008
	110	--	--	--	7.9	--	< 80	< 30	320	33	<0.1	--
Field blank	0.021	<0.01	<0.1	<0.1	<0.01	<0.3	0.8	< 0.02	< 3	0.03	0.018	< 0.001

Site	Cd (µg/L)	Ce (µg/L)	Co (µg/L)	Cr (µg/L)	Cs (µg/L)	Cu (µg/L)	Dy (µg/L)	Er (µg/L)	Eu (µg/L)	Gd (µg/L)	Ho (µg/L)
MBC-ELD	0.008	0.065	0.030	0.5	0.02	0.32	0.0088	0.0047	0.0020	0.0098	0.0017
	<1	--	<1	<1	--	<1	--	--	--	--	--
MBC-WTP	0.031	0.080	0.029	< 0.3	< 0.01	0.36	0.0061	0.0042	0.0017	0.0091	0.0014
	<1	--	<1	<1	--	<1	--	--	--	--	--
MBC-W	0.061	0.070	0.019	0.4		1.2	0.0059	0.0030	0.0025	0.0093	0.0012
	<1	--	<1	<1	--	3	--	--	--	--	--
MBC-aNBC	0.006	0.037	< 0.002	0.4	0.02	0.60	0.0063	0.0033	0.0026	0.0084	0.0012
	<1	--	<1	<1	--	<1	--	--	--	--	--
BC-ORO	< 0.002	0.10	0.023	0.5	0.01	0.63	0.0080	0.0052	0.0024	0.013	0.0016
	<1	--	<1	<1	--	<1	--	--	--	--	--
BC-CAN	< 0.002	0.085	0.015	< 0.3	< 0.01	0.65	0.0073	0.0041	0.0025	0.011	0.0015
	<1	--	<1	<1	--	<1	--	--	--	--	--
BC-30	0.004	0.077	0.013	< 0.3	< 0.01	0.80	0.0071	0.0051	0.0021	0.0078	0.0014
	<1	--	<1	2	--	<1	--	--	--	--	--
BC-61	0.052	0.023	< 0.002	< 0.3	< 0.01	0.86	0.0033	0.0031	0.0004	0.0034	0.0008
	<1	--	<1	<1	--	<1	--	--	--	--	--
BC-aWWTP	< 0.002	0.047	< 0.002	0.4	< 0.01	0.87	0.0040	0.0029	0.0012	0.0059	0.0008
	<1	--	<1	<1	--	2	--	--	--	--	--
BC-75	0.009	0.012	1.2	0.5	0.08	3.7	0.0033	0.0035	0.0003	0.057	0.0010
	<1	--	<1	2	--	7	--	--	--	--	--
BC-aDC	0.033	0.016	0.76	0.4	0.04	2.9	0.0037	0.0038	0.0005	0.041	0.0011
	<1	--	<1	<1	--	9	--	--	--	--	--
BC-95	0.010	0.047	0.69	0.4	0.04	3.2	0.0051	0.0043	0.0019	0.041	0.0014
	<1	--	<1	2	--	4	--	--	--	--	--
BC-107	0.014	0.016	0.93	0.4	0.04	2.8	0.0056	0.0057	0.0006	0.026	0.0016
	<1	--	<1	<1	--	3	--	--	--	--	--
BC-aCC	0.010	0.019	0.10	< 0.3	0.06	2.4	0.0052	0.0049	< 0.0003	0.014	0.0014
	<1	--	<1	<1	--	4	--	--	--	--	--
BC-bCC	0.027	0.027	0.36	0.3	0.04	2.3	0.0083	0.0071	0.0009	0.026	0.0022
	<1	--	<1	2	--	3	--	--	--	--	--
BC-aSV	0.014	0.025	0.28	0.7	0.01	1.6	0.0072	0.0077	0.0015	0.039	0.0020
	<1	--	<1	<1	--	3	--	--	--	--	--
COMO	0.011	0.076	0.041	0.3	0.01	0.29	0.0055	0.0035	0.0017	0.0076	0.0012
	<1	--	<1	<1	--	1	--	--	--	--	--
NBC-LW	0.015	0.056	0.024	0.5	0.03	0.50	0.0044	0.0022	0.0010	0.0055	0.0008
	<1	--	<1	<1	--	3	--	--	--	--	--
SLP	0.012	0.013	0.021	< 0.3	< 0.01	0.60	0.0011	0.0014	0.0004	0.0014	0.0003
	<1	--	<1	<1	--	2	--	--	--	--	--
BEAVER	0.004	0.028	< 0.002	< 0.3	0.02	0.60	0.0034	0.0018	0.0006	0.0036	0.0007
	<1	--	<1	<1	--	2	--	--	--	--	--
NED-EFF	0.039	0.019	0.63	< 0.3	0.06	9.0	0.0012	0.0014	0.0005	0.0023	0.0005
NBC-FALLS	0.005	0.032	< 0.002	< 0.3	0.03	0.42	0.0029	0.0016	0.0010	0.0038	0.0006
	<1	--	<1	<1	--	<1	--	--	--	--	--
FOURMILE	0.029	0.017	< 0.002	< 0.3	< 0.01	0.67	0.0031	0.0024	0.0010	0.0025	0.0007
	<1	--	<1	<1	--	3	--	--	--	--	--
SBC-aBC	< 0.002	0.093	< 0.002	< 0.3	< 0.01	0.90	0.0054	0.0037	0.0014	0.0061	0.0011
	<1	--	<1	<1	--	5	--	--	--	--	--
BCSC-aBC	< 0.002	0.0091	< 0.002	0.4	< 0.01	2.0	0.0017	0.0023	< 0.0003	0.0016	0.0006
	<1	--	<1	<1	--	<1	--	--	--	--	--
BLD-EFF	0.073	0.010	1.4	0.5	--	6.0	0.0028	0.0038	0.0004	0.068	0.0008
DC	0.019	0.026	< 0.002	< 0.3	< 0.01	0.30	0.0034	0.0028	0.0003	0.0040	0.0009
	<1	--	<1	2	--	2	--	--	--	--	--
CC	0.061	0.080	0.82	< 0.3	< 0.01	2.1	0.017	0.014	0.0025	0.045	0.0042
	<1	--	<1	2	--	5	--	--	--	--	--
SV-aBC	0.007	0.037	< 0.002	0.4	0.01	2.0	0.0058	0.0044	0.0016	0.0075	0.0016
	<1	--	<1	<1	--	4	--	--	--	--	--
Field blank	0.009	0.0013	0.004	< 0.3	< 0.01	0.05	< 0.0005	< 0.0004	< 0.0003	< 0.0004	0.0001

Table 4.6. Results of water analyses for Boulder Creek, inflows, and other flows, October 2000--continued

Site	La (µg/L)	Li (µg/L)	Lu (µg/L)	Mn (µg/L)	Mo (µg/L)	Nd (µg/L)	Ni (µg/L)	Pb (µg/L)	Pr (µg/L)	Rb (µg/L)	Re (µg/L)
Middle Boulder Creek/Boulder Creek											
MBC-ELD	0.052	0.13	0.0006	9.2	0.46	0.071	0.14	0.24	0.017	0.46	0.0013
	--	<8	--	<1	--	--	<2	<6	--	--	--
MBC-WTP	0.057	0.22	0.0005	10	0.67	0.070	0.13	0.033	0.018	0.59	0.0017
	--	<8	--	14	--	--	<2	<6	--	--	--
MBC-W	0.056	0.20	0.0005	7.6	0.53	0.067	0.14	0.027	0.016	0.57	0.0017
	--	<8	--	11	--	--	<2	<6	--	--	--
MBC-aNBC	0.050	0.91	0.0004	0.60	0.55	0.064	0.16	0.065	0.014	1.1	0.0021
	--	<8	--	1	--	--	<2	<6	--	--	--
BC-ORO	0.086	0.76	0.0008	8.8	0.79	0.098	0.19	0.17	0.024	0.72	0.0020
	--	<8	--	18	--	--	<2	<6	--	--	--
BC-CAN	0.071	0.90	0.0006	5.2	0.74	0.085	0.19	0.16	0.020	0.82	0.0019
	--	<8	--	13	--	--	<2	<6	--	--	--
BC-30	0.059	1.9	0.0010	7.8	0.70	0.065	0.19	0.15	0.016	0.88	0.0033
	--	<8	--	13	--	--	<2	<6	--	--	--
BC-61	0.016	6.2	0.0010	7.5	1.1	0.019	0.27	0.060	0.0042	1.1	0.0069
	--	<8	--	17	--	--	<2	<6	--	--	--
BC-aWWTP	0.029	6.0	0.0010	16	1.1	0.032	0.34	0.077	0.0075	0.91	0.011
	--	<8	--	22	--	--	<2	<6	--	--	--
BC-75	0.0081	19	0.0010	21	3.7	0.0083	3.0	0.58	0.0019	6.4	0.028
	--	21	--	26	--	--	3	<6	--	--	--
BC-aDC	0.0091	14	0.0010	29	3.1	0.014	2.1	0.46	0.0026	4.1	0.029
	--	16	--	39	--	--	<2	<6	--	--	--
BC-95	0.025	15	0.0013	18	3.0	0.027	2.1	0.46	0.0065	4.0	0.028
	--	17	--	28	--	--	3	<6	--	--	--
BC-107	0.0077	17	0.0013	7.3	3.6	0.015	2.4	0.35	0.0027	4.0	0.029
	--	19	--	12	--	--	<2	<6	--	--	--
BC-aCC	0.0095	19	0.0015	2.6	4.0	0.016	1.5	0.20	0.0033	4.5	0.029
	--	23	--	7	--	--	3	<6	--	--	--
BC-bCC	0.013	24	0.0016	6.2	4.2	0.023	1.7	0.26	0.0046	3.9	0.038
	--	28	--	16	--	--	<2	<6	--	--	--
BC-aSV	0.014	25	0.0022	2.3	4.4	0.021	1.6	0.17	0.0045	2.6	0.047
	--	34	--	6	--	--	3	<6	--	--	--
Inflows/other flows											
COMO	0.042	0.53	0.0006	12	0.89	0.043	0.28	0.042	0.010	0.41	0.0026
	--	<8	--	10	--	--	<2	<6	--	--	--
NBC-LW	0.035	0.17	0.0005	5.2	0.56	0.039	0.44	0.15	0.0098	0.39	0.0016
	--	<8	--	8	--	--	<2	<6	--	--	--
SLP	0.0071	0.15	0.0002	8.3	0.89	0.0084	0.14	0.058	0.0017	0.43	0.0010
	--	<8	--	17	--	--	<2	<6	--	--	--
BEAVER	0.021	1.5	0.0005	16	8.7	0.020	0.23	0.27	0.0048	0.96	0.019
	--	<8	--	21	--	--	<2	<6	--	--	--
NED-EFF	0.0095	129	0.0003	30	1.8	0.012	2.2	0.41	0.0028	10	0.0009
NBC-FALLS	0.022	0.73	0.0003	1.2	0.69	0.024	0.13	0.047	0.0055	0.74	0.0024
	--	<8	--	3	--	--	<2	<6	--	--	--
FOURMILE	0.012	4.4	0.0008	8.0	0.55	0.015	0.90	0.023	0.0030	2.0	0.0053
	--	<8	--	10	--	--	4	<6	--	--	--
SBC-aBC	0.050	11	0.0012	42	4.1	0.048	0.53	0.17	0.012	1.5	0.015
	--	11	--	90	--	--	<2	<6	--	--	--
BCSC-aBC	0.0057	2.9	0.0002	0.93	0.66	0.0073	0.27	0.010	0.0015	0.27	0.0077
	--	<8	--	220	--	--	<2	<6	--	--	--
BLD-EFF	0.0057	20	0.0009	20	4.1	0.0058	3.5	0.70	0.0014	7.1	0.029
DC	0.013	29	0.0005	5.0	3.7	0.016	< 0.007	0.095	0.0035	0.68	0.041
	--	27	--	7	--	--	<2	<6	--	--	--
CC	0.038	35	0.0031	17	4.8	0.052	2.1	0.40	0.011	3.1	0.063
	--	44	--	36	--	--	3	<6	--	--	--
SV-aBC	0.018	37	0.0009	6.8	4.0	0.022	0.65	0.14	0.0064	1.6	0.10
	--	50	--	11	--	--	<2	<6	--	--	--
Field blank	0.0004	< 0.04	< 0.0001	0.09	0.05	0.0009	0.091	0.023	0.0002	0.009	< 0.0002

Site	Sb (µg/L)	Se (µg/L)	Sm (µg/L)	Sr (µg/L)	Tb (µg/L)	Te (µg/L)	Th (µg/L)	Tl (µg/L)	Tm (µg/L)	U (µg/L)	V (µg/L)
MBC-ELD	0.022	< 0.1	0.014	34.1	0.0013	< 0.009	0.0086	0.007	0.0006	0.053	0.13
	--	<40	--	--	--	--	--	--	--	--	<1
MBC-WTP	0.022	< 0.1	0.010	43.7	0.0012	< 0.009	0.0075	0.004	0.0004	0.044	0.10
	--	<40	--	--	--	--	--	--	--	--	<1
MBC-W	0.020	-0.09	0.011	40.9	0.0011	<0.009	0.0069	<0.01	0.0006	0.055	-0.2
	--	<40	--	--	--	--	--	--	--	--	<1
MBC-aNBC	0.044	< 0.1	0.012	78.5	0.0013	< 0.009	0.0048	0.007	0.0004	0.097	< 0.06
	--	<40	--	--	--	--	--	--	--	--	<1
BC-ORO	0.041	< 0.1	0.017	48.9	0.0017	< 0.009	0.0096	0.006	0.0006	0.13	0.12
	--	<40	--	--	--	--	--	--	--	--	<1
BC-CAN	0.049	< 0.1	0.015	55.3	0.0012	< 0.009	0.0085	0.004	0.0006	0.15	0.12
	--	<40	--	--	--	--	--	--	--	--	<1
BC-30	0.059	< 0.1	0.012	98	0.0009	< 0.009	0.0067	0.007	0.0006	0.45	0.12
	--	<40	--	--	--	--	--	--	--	--	<1
BC-61	0.12	< 0.1	0.0047	221	0.0005	< 0.009	0.0036	0.006	0.0005	1.3	< 0.06
	--	<40	--	--	--	--	--	--	--	--	<1
BC-aWWTP	0.11	< 0.1	0.0063	230	0.0007	< 0.009	0.0060	0.007	0.0006	1.1	0.07
	--	<40	--	--	--	--	--	--	--	--	<1
BC-75	0.25	< 0.1	0.0019	278	0.0005	< 0.009	0.0065	0.007	0.0005	0.76	0.52
	--	<40	--	--	--	--	--	--	--	--	<1
BC-aDC	0.20	0.20	0.0036	301	0.0006	< 0.009	0.0049	0.006	0.0007	1.2	0.40
	--	<40	--	--	--	--	--	--	--	--	<1
BC-95	0.20	0.15	0.0060	330	0.0010	< 0.009	0.0081	0.007	0.0007	1.6	0.51
	--	<40	--	--	--	--	--	--	--	--	<1
BC-107	0.22	< 0.1	0.0035	341	0.0008	< 0.009	0.0034	0.008	0.0008	2.5	0.59
	--	<40	--	--	--	--	--	--	--	--	<1
BC-aCC	0.20	< 0.1	0.0040	485	0.0007	< 0.009	0.0059	0.009	0.0007	5.1	0.92
	--	<40	--	--	--	--	--	--	--	--	<1
BC-bCC	0.23	0.53	0.0046	516	0.0011	< 0.009	0.0038	0.008	0.0011	7.1	1.0
	--	<40	--	--	--	--	--	--	--	--	3
BC-aSV	0.21	< 0.1	0.0050	675	0.0013	0.014	0.016	0.008	0.0012	8.3	1.6
	--	<40	--	--	--	--	--	--	--	--	2
COMO	0.017	< 0.1	0.0087	61.8	0.0010	< 0.009	0.0081	< 0.003	0.0005	0.024	0.36
	--	<40	--	--	--	--	--	--	--	--	<1
NBC-LW	0.029	< 0.1	0.0064	33.3	0.0007	< 0.009	0.0031	< 0.003	0.0002	0.019	0.13
	--	<40	--	--	--	--	--	--	--	--	<1
SLP	0.038	< 0.1	0.0012	23.9	0.0004	< 0.009	0.0038	0.007	< 0.0001	0.026	0.12
	--	<40	--	--	--	--	--	--	--	--	<1
BEAVER	0.16	< 0.1	0.0050	174	0.0006	< 0.009	0.0039	0.003	0.0003	1.0	0.16
	--	<40	--	--	--	--	--	--	--	--	<1
NED-EFF	0.40	< 0.1	0.0029	74.0	0.0002	< 0.009	0.0035	0.005	0.0001	0.019	0.19
NBC-FALLS	0.046	< 0.1	0.0040	70.7	0.0005	< 0.009	0.0033	0.003	0.0002	0.26	0.12
	--	<40	--	--	--	--	--	--	--	--	<1
FOURMILE	0.22	< 0.1	0.0030	314	0.0005	< 0.009	0.0017	0.007	0.0005	1.6	0.09
	--	<40	--	--	--	--	--	--	--	--	<1
SBC-aBC	0.24	0.16	0.0089	308	0.0009	< 0.009	0.016	0.004	0.0006	2.1	0.44
	--	<40	--	--	--	--	--	--	--	--	<1
BCSC-aBC	0.086	0.25	0.0016	115	0.0003	< 0.009	0.0029	0.003	0.0001	0.42	0.64
	--	<40	--	--	--	--	--	--	--	--	3
BLD-EFF	0.26	0.42	0.0010	300	0.0002	< 0.009	0.0037	-0.010	0.0005	0.62	0.9
DC	0.087	0.46	0.0029	166	0.0007	0.020	0.0093	0.016	0.0004	11	0.33
	--	<40	--	--	--	--	--	--	--	--	<1
CC	0.29	2.0	0.013	664	0.0023	< 0.009	0.011	0.010	0.0018	12	1.4
	--	<40	--	--	--	--	--	--	--	--	2
SV-aBC	0.18	2.3	0.0050	1640	0.0013	0.023	0.013	0.005	0.0005	16	0.84
	--	<40	--	--	--	--	--	--	--	--	<1
Field blank	0.017	< 0.1	< 0.0008	< 0.1	< 0.0002	< 0.009	0.0008	0.004	< 0.0001	< 0.002	0.06

Table 4.6. Results of water analyses for Boulder Creek, inflows, and other flows, October 2000--continued

Site	Y (µg/L)	Yb (µg/L)	Zn (µg/L)	Zr (µg/L)	Hg (ng/L)	Sum Cations (meq/L)	Sum Anions (meq/L)	Charge Imbalance (%)
Middle Boulder Creek/Boulder Creek								
MBC-ELD	0.046	0.0040	2.4	--	0.5	0.34	0.35	-3.4
	--	--	<1	--	--			
MBC-WTP	0.038	0.0032	0.98	--	--	0.46	0.43	4.8
	--	--	3	--	--			
MBC-W	0.036	0.0032	0.82	0.005	1.1	0.48	0.45	5.1
	--	--	2	--	--			
MBC-aNBC	0.037	0.0028	1.3	--	4.6	0.80	0.78	3.4
	--	--	3	--	--			
BC-ORO	0.054	0.0042	1.0	--	0.9	0.51	0.49	2.5
	--	--	3	--	--			
BC-CAN	0.047	0.0041	1.0	--	0.6	0.57	0.55	3.9
	--	--	3	--	--			
BC-30	0.040	0.0049	1.9	--	0.7	1.1	1.1	1.5
	--	--	6	--	--			
BC-61	0.023	0.0040	1.8	--	--	2.4	2.2	10.4
	--	--	5	--	--			
BC-aWWTP	0.029	0.0044	1.9	--	0.5	2.4	2.3	3.5
	--	--	4	--	--			
BC-75	0.020	0.0048	18	--	3.3	5.0	5.2	-4.1
	--	--	25	--	--			
BC-aDC	0.025	0.0066	13	--	--	4.4	4.1	7.1
	--	--	20	--	--			
BC-95	0.032	0.0060	12	--	--	4.3	4.4	-2.4
	--	--	16	--	--			
BC-107	0.030	0.0070	12	--	--	4.9	4.5	8.8
	--	--	15	--	--			
BC-aCC	0.031	0.0072	9.1	--	1.9	4.9	4.8	1.2
	--	--	11	--	--			
BC-bCC	0.055	0.0096	14	--	--	6.3	6.3	-1.3
	--	--	18	--	--			
BC-aSV	0.054	0.011	8.0	--	1.1	6.5	6.5	-0.5
	--	--	12	--	--			
Inflows/Other flows								
COMO	0.036	0.0043	4.7	--	0.4	0.68	0.70	-3.4
	--	--	1	--	--			
NBC-LW	0.025	0.0028	4.4	--	<0.4	0.32	0.31	2.4
	--	--	1	--	--			
SLP	0.0085	0.0011	1.4	--	--	0.23	0.20	11.3
	--	--	4	--	--			
BEAVER	0.023	0.0020	7.4	--	0.6	1.9	1.8	2.3
	--	--	11	--	--			
NED-EFF	0.0097	0.0017	20	--	7.5	5.0	5.3	-6.5
NBC-FALLS	0.019	0.0019	1.1	--	1.0	0.7	0.7	3.3
	--	--	5	--	--			
FOURMILE	0.020	0.0037	5.9	--	0.9	2.8	2.7	4.4
	--	--	9	--	--			
SBC-aBC	0.031	0.0055	1.5	--	--	3.3	3.2	4.0
	--	--	1	--	--			
BCSC-aBC	0.014	0.0016	0.23	--	--	1.3	1.2	9.9
	--	--	13	--	--			
BLD-EFF	0.017	0.0040	21	0.13	2.9	5.9	5.3	6.5
DC	0.037	0.0031	2.8	--	--	11.0	10.6	3.2
	--	--	7	--	--			
CC	0.12	0.017	21	--	<0.4	9.2	9.5	-2.5
	--	--	220	--	--			
SV-aBC	0.042	0.0045	5.5	--	--	12.3	12.1	2.0
	--	--	7	--	2.0			
Field blank	0.0005	0.0003	1.8	--	--			

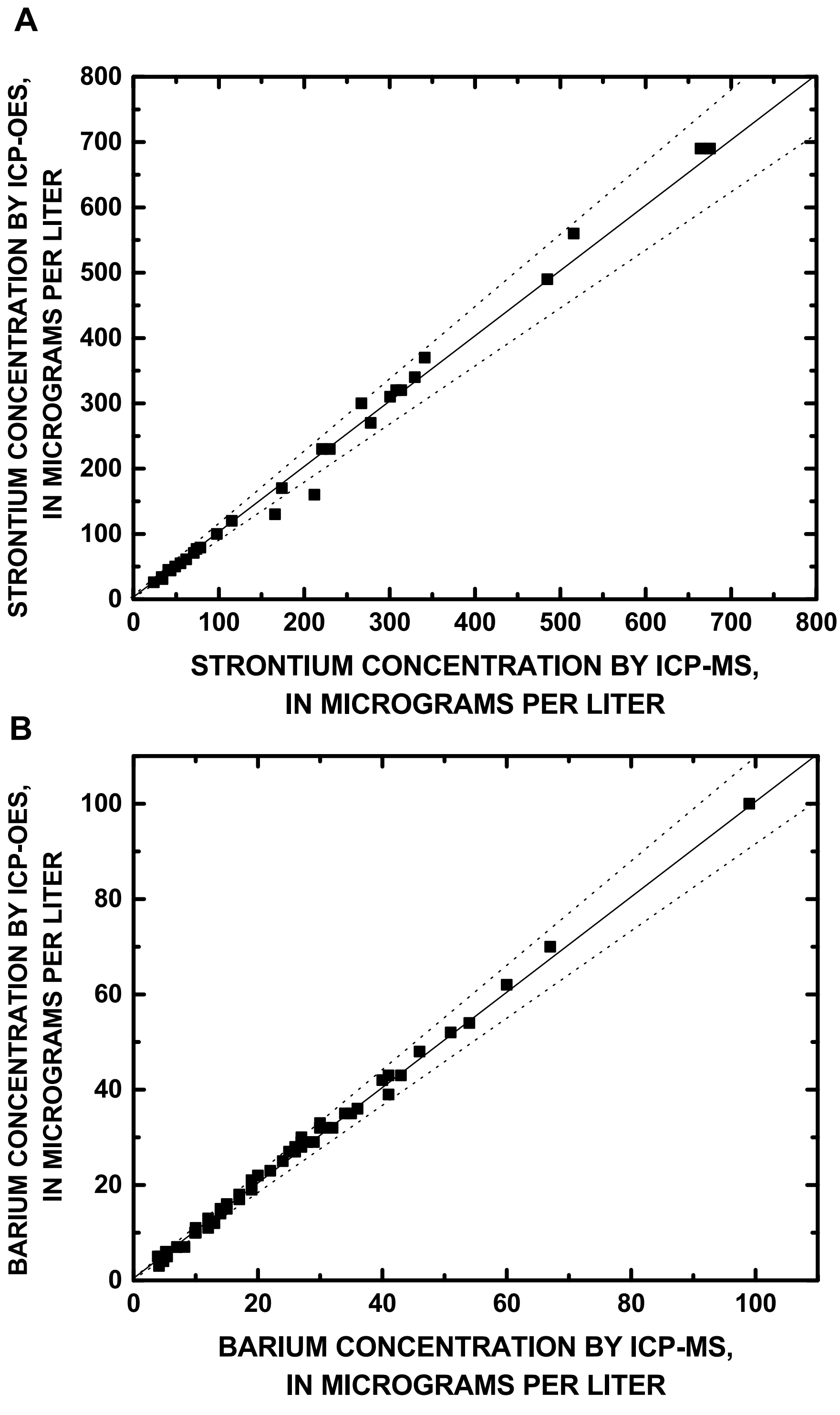

Figure 4.2. Graphs showing (A) dissolved strontium concentrations and (B) dissolved barium concentrations analyzed by ICP-OES and ICP-MS. (Diagonal line is 1:1 correspondence, dashed lines are ±10 percent.)

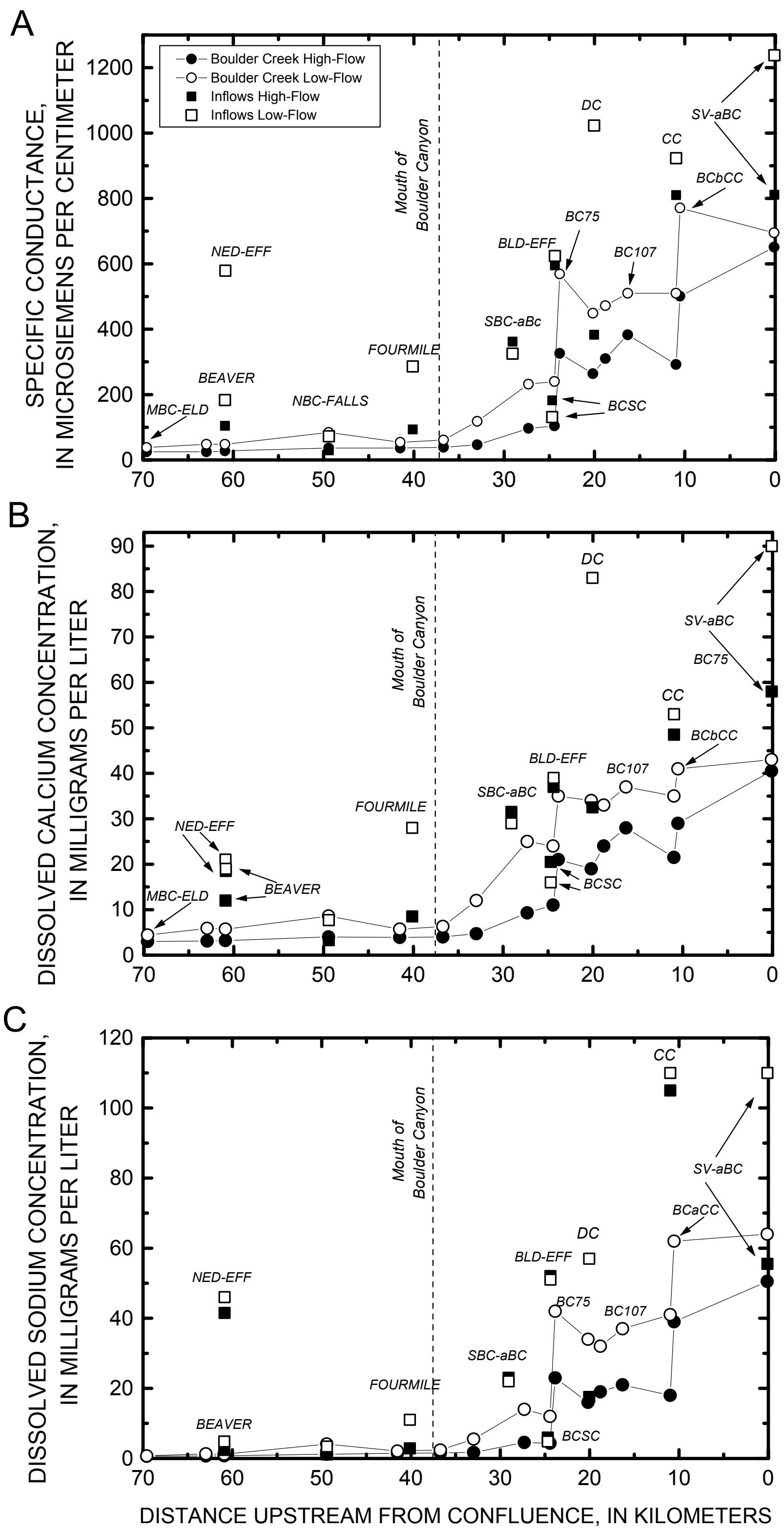

Figure 4.3. Graphs showing downstream variation in (A) specific conductance, (B) dissolved calcium concentrations, and (C) dissolved sodium concentrations for Middle Boulder Creek/Boulder Creek and major inflows, June and October 2000. (Distance from Boulder Creek and Saint Vrain Creek confluence)

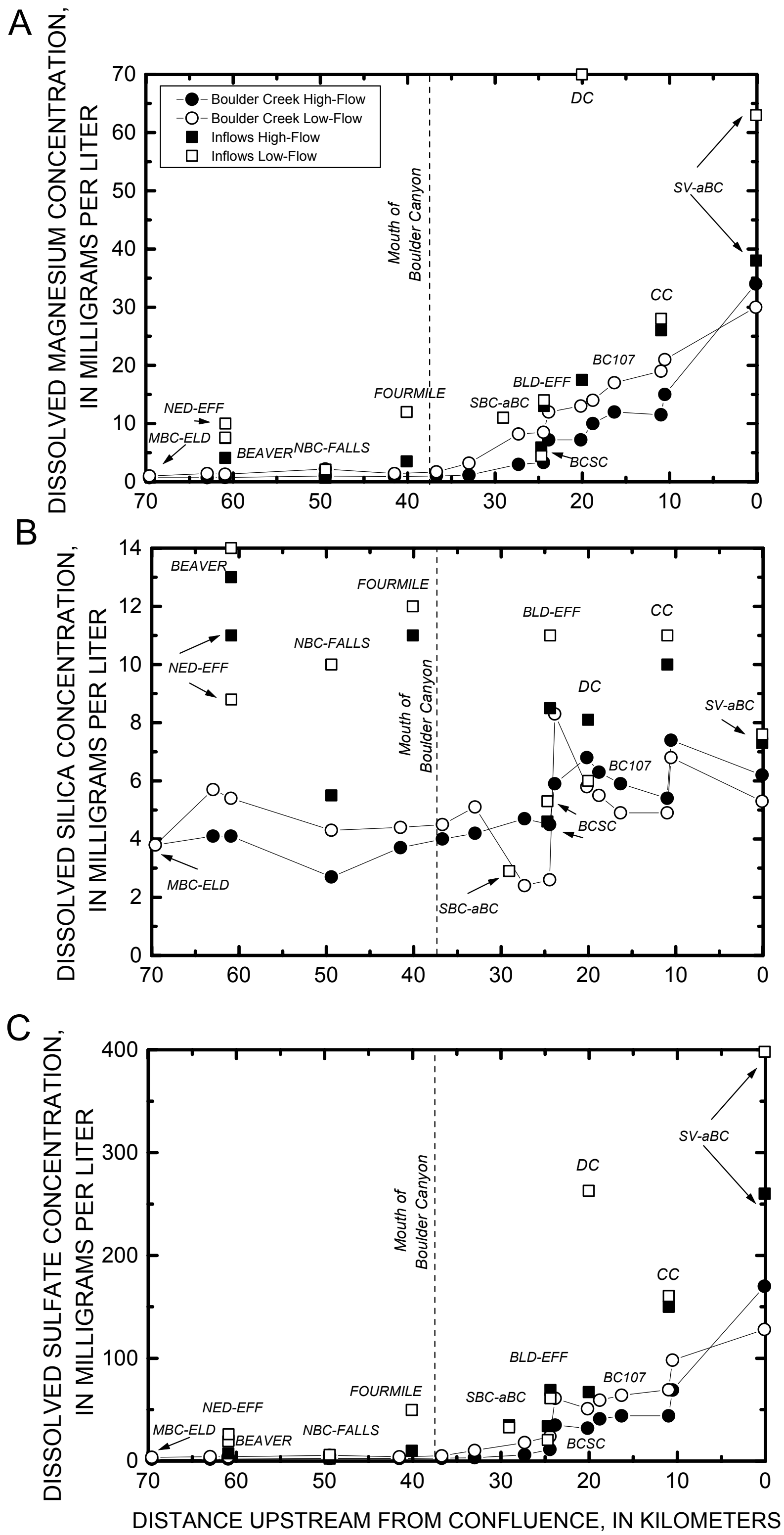

Figure 4.4. Graphs showing downstream variation in (A) dissolved magnesium concentrations, (B) dissolved silica concentrations, and (C) dissolved sulfate concentrations for Middle Boulder Creek/Boulder Creek and major inflows, June and October 2000. (Distance from Boulder Creek and Saint Vrain Creek confluence)

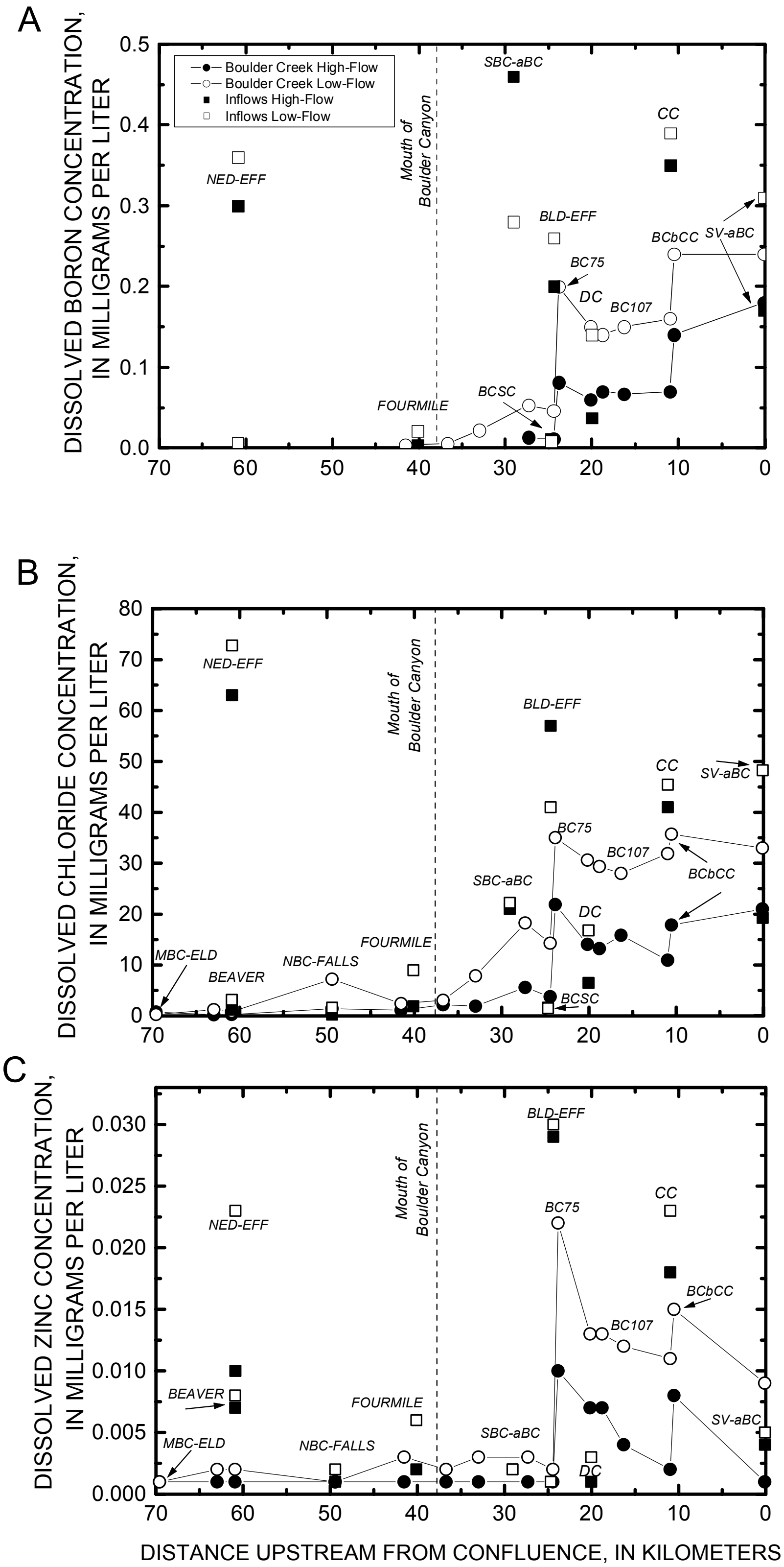

Figure 4.5. Graphs showing downstream variation in (A) dissolved boron concentrations, (B) dissolved chloride concentrations, and (C) dissolved zinc concentrations for Middle Boulder Creek/Boulder Creek and major inflows, June and October 2000. (Distance from Boulder Creek and Saint Vrain Creek confluence)

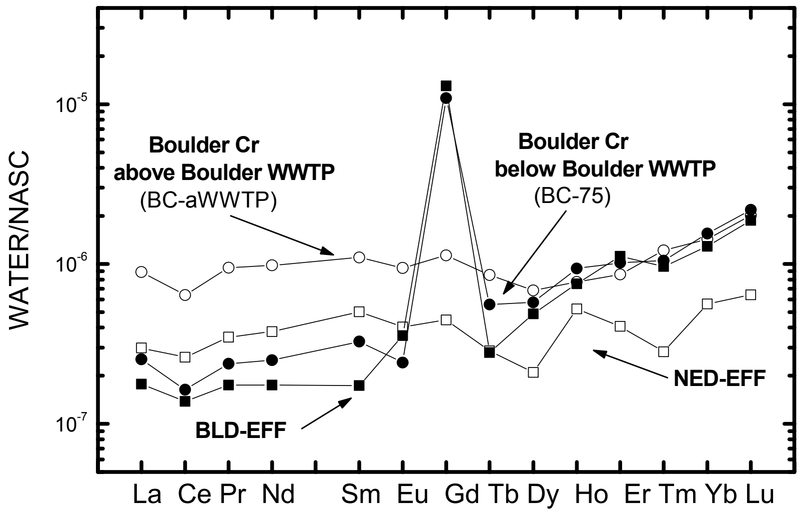

Figure 4.6. Graph showing the rare earth element patterns of select low-flow water samples. (Dissolved rare earth elements concentrations normalized to North American Shale Composite [NASC] with values from Haskin and others, 1968, and Gromet and others, 1984)

Germany and is believed to have originated from the use of gadopentetic acid in magnetic resonance imaging (Bau and Dulski, 1996). This acid is ingested as a contrasting agent and then quickly excreted, entering the urban wastewater system. Boulder has one magnetic resonance imaging facility. In contrast, Nederland does not have any, and the REE pattern of NED-EFF does not have a positive gadolinium anomaly.

Downstream of BC-75, identifying sources of solutes and geochemical processes that may control stream chemistry and quantifying their relative contribution is difficult because multiple sources and processes are likely at work. Sources of solutes include surface- and ground-water inflows, chemical reactions with bed sediments and particulates in the water column, and biological reactions. Processes that potentially control the dissolved concentrations of inorganic constituents in Boulder Creek include evaporation, dilution, sorption, precipitation, photoreduction, gas transfer, and biogeochemical reactions. In addition, the relative proportion of effluent to stream water varies throughout the day, primarily because of variation in effluent discharge (Murphy and others, 2003). The daily effluent maximum moves downstream as a pulse. At low-flow, the wastewater dominated reach was sampled in one day (October 11) by sampling at the Boulder 75th Street WWTP, and then sampling sites downstream in order from BC-aWWTP to BC-107. An accurate estimate of stream water travel time was not available for this flow regime, so it is likely that the same package of water was not sampled at all the downstream sites.

Concentrations of most dissolved constituents decrease in the reach of Boulder Creek downstream of BC-75. Between sites BC-75 and BC-aDC discharge in Boulder Creek decreased from 1.5 to 1.1 m^3/s during low flow, in part due to removal of water by the Leggett Ditch (Murphy and others, 2003). Removal of water does not lower concentration, but if water were replaced by more dilute water, perhaps from ground-water inflows, concentrations would decrease. In-stream chemical and biogeochemical reactions likely also are partially responsible for the change in solute concentrations.

In the reach between BC-aDC and BC-aCC, some constituents continue to decrease (silica and zinc), while others increase (calcium, magnesium, sodium, and sulfate; figs. 4.3 to

Table 4.7. Results of mass-balance modeling of Boulder Creek water. (Positive values indicate mineral dissolution and negative values indicate mineral precipitation in units of millimoles of mineral per liter of water)

PHASE	MBC-ELD	BC-CAN	BC-61
Hornblende	+0.032	+0.050	--
Plagioclase (An_{25})	+0.039	+0.136	--
Calcite	+0.063	+0.067	+0.117
Biotite	+0.006	+0.013	--
Pyrite	+0.016	+0.023	--
SiO_2	-0.171	-0.514	-1.449
Goethite	-0.056	-0.091	--
Dolomite	--	--	+0.320
Gypsum	--	--	+0.182
Illite	--	--	+0.062
Montmorillonite	--	--	+0.346
Halite	--	--	+0.494

4.5) in concentration. No surface-water inflows were observed in this reach, but between BC-107 and BC-aCC discharge increased from 0.68 to 0.88 m^3/s. Input of ground water that has reacted with sedimentary bedrock is consistent with the observed variation in stream chemistry. As discussed above, ground water that has interacted with sedimentary bedrock is enriched in calcium, chloride, magnesium, sodium, and sulfate and has low concentrations of silica and metals.

Concentrations of most dissolved constituents in Coal Creek (CC) are high, and, since the discharge is approximately one third of Boulder Creek, a step increase in figures 4.3 to 4.5 is displayed. Water in Coal Creek has a complex history including receiving WWTP from Erie, Lafayette, Louisville, and Superior, as well as receiving agriculture diversion ditch return flow. Coal Creek was the only other inflow that contained a positive gadolinium anomaly in the REE pattern (fig. 4.7), consistent with the presence of medical facilities in upstream communities.

Land use along the lowest reach of Boulder Creek, BC-bCC to BC-aSV, is dominated by agricultural and aggregate mining. The chemical change in dissolved constituents is quite variable, but, in general, displays similar variations to the reach between BC-aDC and BC-aCC (fig. 4.3 to 4.5). Differentiating between natural and anthropogenic sources and identifying geochemical processes is difficult in this reach. Some of the chemical variation is likely due to the input of ground water that has interacted with sedimentary bedrock.

SUMMARY

During high and low flow of 2000, field parameters and water samples were collected and analyzed for twenty-nine sites along Boulder Creek, Colorado, including sixteen mainstem and twelve tributary/inflow sites from upstream of the town of Eldora to the confluence of Boulder Creek and Saint Vrain Creek. In general, most dissolved constituents in Boulder Creek increased in concentration downstream, with a slight increase between the most upstream site and the mouth of Boulder Canyon, a greater increase between the mouth of Boulder Canyon and the Boulder 75th Street Wastewater Treatment Plant (WWTP), and the greatest increase downstream of the WWTP. These trends were observed in both the high- and low-flow samples, but the low-flow samples tended to have higher concentrations of dissolved constituents. Dilution of Boulder Creek by snowmelt leads to lower

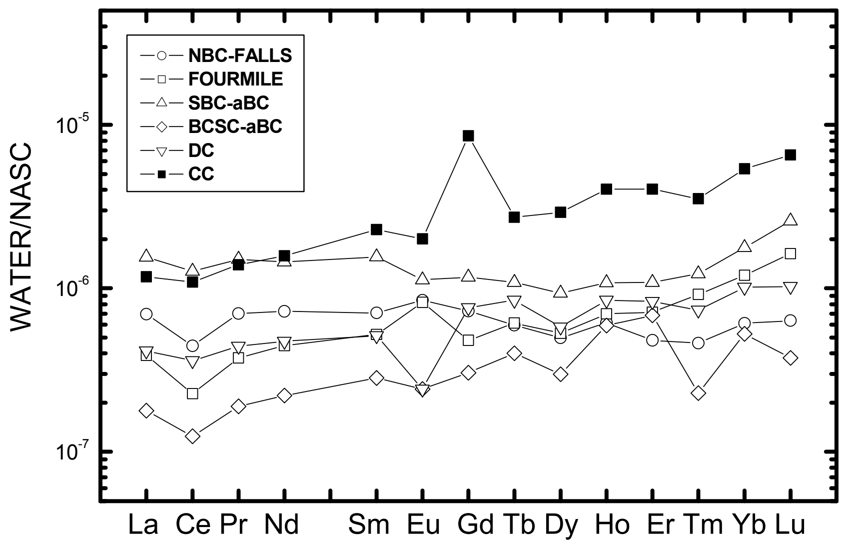

Figure 4.7. Graph showing the rare earth element patterns of select low-flow, inflow water samples. (Dissolved rare earth elements concentrations normalized to North American Shale Composite [NASC] with values from Haskin and others, 1968, and Gromet and others, 1984).

dissolved inorganic concentrations during high-flow conditions.

The inorganic water chemistry of the upper reach, above BC-CAN, is consistent with weathering of the local bedrock, which is composed primarily of Precambrian-age igneous and high-grade metamorphic rocks. The inorganic chemistry of the reach between BC-CAN and the Boulder 75th Street WWTP is more complex because of numerous potential natural and anthropogenic sources of solutes, but in general is consistent with the weathering of the local bedrock, composed of Mesozoic-age sedimentary units. Effluent from the WWTP is the greatest loading inflow to Boulder Creek, and dominates the chemistry of the Creek downstream from BC-75. In the lowest reach, differentiating between sources of solutes and processes that affect the stream chemistry is difficult, but by integrating information from the entire data set (inorganic and organic constituents, pesticides, and bed sediment composition) it may be possible.

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