

Chapter 3 - Basic Water Quality in the Boulder Creek Watershed, Colorado, During High-Flow and Low-Flow Conditions, 2000

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Abstract

The city of Boulder collaborated with the U.S. Geological Survey to provide a detailed examination of the water quality of Boulder Creek, Colorado, during high-flow and low-flow conditions in the year 2000. The city measured alkalinity, ammonia, dissolved oxygen, fecal coliform, hardness, nitrate, nitrite, organic nitrogen, orthophosphate, pH, specific conductance, temperature, total dissolved solids, total phosphorus, total suspended solids, and turbidity. Dissolved constituents were typically higher during low-flow conditions, when less water was available for dilution. Total suspended solids and turbidity were higher during high-flow conditions, when spring runoff occurs. Most constituent concentrations were higher in the lower watershed (urban, wastewater-dominated, and agricultural regions, with sedimentary bedrock) than in the upper watershed (headwater and mountain regions, with crystalline bedrock). Concentrations of several constituents in Boulder Creek increased after the creek received wastewater effluent.

INTRODUCTION

Two programs within the city of Boulder's Water Quality and Environmental Services group collect samples from Boulder Creek, reservoirs, and inflows throughout the year. The Sourcewater program conducts monthly sampling and water-quality characterization of city of Boulder drinking water sources, including North Boulder Creek, Middle Boulder Creek, Barker Reservoir, Boulder Reservoir, and their inflows (fig. 3.1). This characterization includes assessing seasonal trends and impacts to water treatment, analyzing

for possible contaminants, and identifying the source of contaminants. The Stormwater program monitors the impacts of point and non-point source pollutants as Boulder Creek flows through the urban corridor. The program collects monthly water-quality samples of Boulder Creek and its inflows from the confluence of North Boulder Creek and Middle Boulder Creek to the confluence of Boulder Creek and Coal Creek (fig. 3.1). Historical data for Sourcewater and Stormwater programs are available on the Boulder Area Sustainability Information Network (BASIN) website, www.basin.org (Murphy and Waterman, 2003; U.S. Environmental Protection Agency [USEPA], 2001).

For this collaborative study with the U.S. Geological Survey (USGS), the two city of Boulder programs performed monthly sampling at their regular sites, and also analyzed samples collected from additional sites during the USGS sampling. City personnel attempted to sample at or near the same time as the USGS sampling. However, due to time constraints, sampling times and days occasionally differ from those of the USGS (Verplanck and others, 2003).

METHODS

The Sourcewater and Stormwater programs have different goals and collect different types of samples, so their analytical methods and detection limits differ for some constituents. The Stormwater program samples waters that contain higher levels of dissolved and suspended constituents, so it uses methods developed for higher concentrations, and these methods usually have higher detection limits. Typically, Sourcewater samples are analyzed at the city of Boulder's Drinking Water Laboratory, and

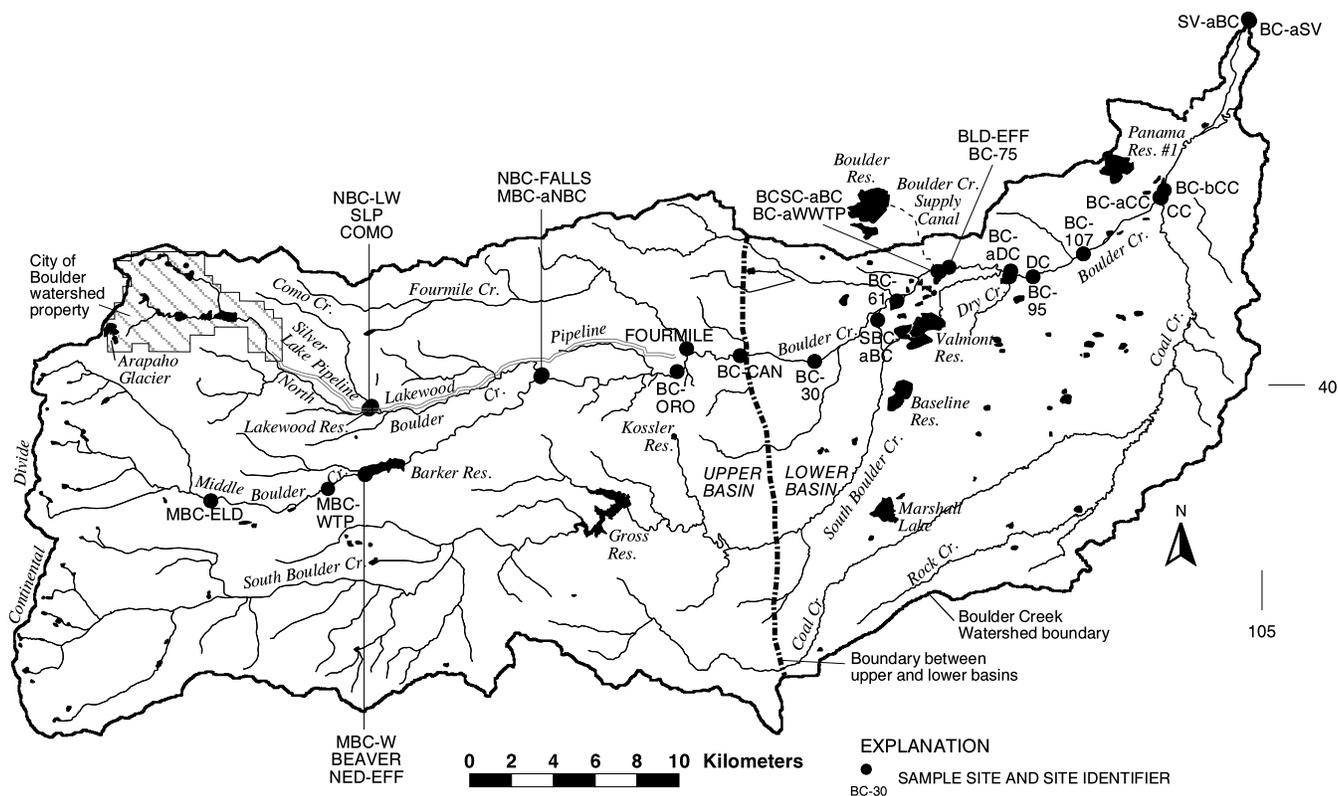


Figure 3.1. Map of Boulder Creek Watershed and sampling sites.

Stormwater samples are analyzed at the city’s Wastewater and Environmental Laboratory. For this study, extensive cooperation between the two laboratories was required to include the analysis of all constituents. The laboratory at which each sample was analyzed is given in tables 3.1 and 3.2.

Sampling

The Sourcewater program collected water-quality samples from North Boulder Creek upstream of Lakewood Reservoir (NBC-LW); Middle Boulder Creek at the Nederland Water Treatment Plant Intake (MBC-WTP) and at the weir upstream of Barker Reservoir (MBC-W); Como Creek upstream of the confluence with North Boulder Creek (COMO); North Beaver Creek upstream of the confluence with Middle Boulder Creek (BEAVER); the Silver Lake

Pipeline (SLP); and Nederland Wastewater Treatment Plant (WWTP) effluent (NED-EFF; fig. 3.1, tables 3.1 and 3.2). Stream samples were vertically- and horizontally-composited using hydrochloric acid washed sample churns. Grab samples were collected for SLP and NED-EFF. All sample bottles were filled from the same aliquot of water. One replicate sample was collected for each sampling event. Field blanks were collected using deionized water. Samples were packed in plastic bags, stored on ice, transported to the Drinking Water Laboratory, and refrigerated until analysis.

The Stormwater program collected water-quality samples from North Boulder Creek upstream of the confluence with Middle Boulder Creek (NBC-FALLS); Middle Boulder Creek upstream of the confluence with North Boulder Creek (MBC-aNBC); Boulder Creek at the Orodell streamgaging station (BC-ORO), at the

mouth of Boulder Canyon (BC-CAN), at 30th Street (BC-30), at 61st Street (BC-61), upstream of the Boulder 75th Street WWTP (BC-aWWTP), at 75th Street (BC-75), upstream of the confluence with Dry Creek (BC-aDC), at 95th Street (BC-95), at 107th Street (BC-107), and upstream and downstream of the confluence with Coal Creek (BC-aCC and BC-bCC); from Coal Creek upstream of the Boulder Creek confluence (CC); and from the Boulder 75th Street WWTP effluent (BLD-EFF; fig. 3.1, tables 3.1 and 3.2). Grab samples were taken from mid-channel or the area in the channel which best represented the discharge. Sample bottles were submerged to approximately 60 percent of the water depth, filled, capped, and shaken. One to two inches of air space was left in the bottle (unless sample analysis required that no air space be left). Replicate samples were collected for each sampling event. Field blanks were collected using deionized water. Samples were stored on ice and transported to the Wastewater and Environmental Laboratory.

Samples at additional sites (Middle Boulder Creek upstream of the town of Eldora, MBC-ELD; Fourmile Creek, FOURMILE; South Boulder Creek, SBC-aBC; Boulder Creek Supply Canal, BCSC-aBC; Dry Creek, DC; Boulder Creek upstream of the confluence with Saint Vrain Creek, BC-aSV; and Saint Vrain Creek upstream of the confluence with Boulder Creek, SV-aBC) were collected during the USGS sampling in June and October for analysis of some parameters (ammonia, fecal coliform, hardness, orthophosphate, total dissolved solids, total phosphorus, total suspended solids, and turbidity) at the Drinking Water Laboratory or the Wastewater and Environmental Laboratory (tables 3.1 and 3.2).

The Sourcewater program also samples water in Barker Reservoir on a monthly basis. In June and October 2000, these samples were collected one week after the cooperative USGS/city of Boulder sampling event. Water samples were collected from the top and bottom of the reservoir, at a distance of 91 m from the middle

of Barker Dam. Composite samples were collected from the photic zone; grab samples were collected from 0.5 m above the bottom of the reservoir using a Van Dorn Water Sampler (J.J. Shelley, unpub. data, 2000).

Field Parameters

The Sourcewater program used a YSI 600XL multi-probe to analyze water temperature, dissolved oxygen (DO), specific conductance (SC), and pH. Calibrations of DO were conducted in the field at the sample site with a moist-air saturated bottle. Specific conductance was calibrated in the laboratory the day of sampling using a potassium chloride (KCl) solution of 1412 microSiemens/centimeter ($\mu\text{S}/\text{cm}$) at 25°C. Calibration of pH was performed in the laboratory the day of sampling with pH 7.00 and 10.01 buffers.

The Stormwater program used an Orion Model 1230 ion-selective probe to measure pH and DO. Calibration of pH was performed in the laboratory the day of sampling using pH 7.00 and 10.01 buffers. An Orion Model 130 conductivity meter was used to measure SC and water temperature. The probe was calibrated in the laboratory the day of sampling with a KCl solution of 1412 $\mu\text{S}/\text{cm}$ at 25°C. A thermometer was used to measure air temperature. Meter failure prevented the measurement of DO for several sites in June 2000 and measurement of SC for several sites in October 2000.

Laboratory Analyses

The Wastewater and Environmental Laboratory measured total dissolved solids (TDS) using Standard Method 2540B of the American Public Health Association (APHA) and others (1998). A 50-mL aliquot of sample was passed through a 1.5- μm filter, and the filtrate was evaporated in a tared dish at 103 to 105°C to a constant weight. Laboratory blanks and field replicates were analyzed for each sampling event (tables 3.1 and 3.2). The detection limit was

Table 3.1. Results of water analyses for Boulder Creek, inflows, and other flows, June 2000

[Units are milligrams per liter unless otherwise indicated; alkalinity and hardness reported as CaCO₃; distance, distance from Boulder Creek/Saint Vrain degrees Celsius; DO, dissolved oxygen; %, percent; SC, specific conductance; μS/cm, microsiemens per centimeter; TDS, total dissolved solids; TSS, total nitrite as N; NH₃-N, ammonia as N; Org-N, organic nitrogen as N; P, phosphorus as P; ortho PO₄-P, orthophosphate as phosphorus; --, not measured; <, less

Site	Distance (meters)	Discharge (m ³ /s)	Sample date	Sample time	Lab	T _{air} (°C)	T _{water} (°C)	DO	DO saturation ¹ (%)	SC (μS/cm)	pH (units)	TDS
Middle Boulder Creek/Boulder Creek												
MBC-ELD	69590	3.7	--	--	³	--	--	--	--	--	--	--
MBC-WTP	62970	--	6/12/00	1216	DW	--	8.2	8.5	100	25	7.57	15 ⁴
MBC-W	60920	4.9	6/12/00	1309	DW	--	9.4	9.9	120	23	7.55	14 ⁴
MBC-aNBC	49440	--	6/13/00	805	WW	14	11	--	--	27	7.68	14
BC-ORO	41520	6.5	6/13/00	900	WW	15	11	--	--	26	7.62	20
BC-CAN	36710	--	6/13/00	925	WW	20	12	--	--	28	7.49	16
BC-30	32990	2.3	--	--	³	--	--	--	--	--	--	--
BC-61	27320	3.2	6/13/00	1110	WW	22	15	--	--	56	7.57	<1
BC-aWWTP	24440	2.5	6/13/00	1320	WW	27	18	10	130	94	8.36	26
BC-75	23850	5.1	6/13/00	1405	WW	24	19	7.9	100	330	7.36	190
BC-aDC	20180	3.3	6/13/00	1525	WW	27	20	9.3	120	210	8.49	34
BC-95	18790	--	6/13/00	1600	WW	26	21	9.9	140	230	8.92	110
BC-107	16320	--	6/13/00	1615	WW	26	22	9.2	130	250	9.19	120
BC-aCC	10970	1.1	6/13/00	1645	WW	19	23	9.7	140	280	9.79	122
BC-bCC	10540	1.4	6/13/00	1655	WW	19	23	13	180	340	9.63	220
BC-aSV	110	0.45	--	--	³	--	--	--	--	--	--	--
Inflows/other flows												
COMO	59340	0.15	6/12/00	1012	DW	--	9.5	8.1	100	34	7.56	21 ⁴
NBC-LW	59370	1.7	6/12/00	1023	DW	--	9.1	8.1	100	23	7.57	14 ⁴
SLP	59340	--	6/12/00	1050	DW	--	11	8.0	100	20	7.57	12 ⁴
BEAVER	60910	0.09	6/12/00	1249	DW	--	11	9.5	120	95	7.91	58 ⁴
NED-EFF	60880	0.005	6/12/00	1323	DW	--	15	0.89	10	580	7.10	350 ⁴
NBC-FALLS	49420	--	6/13/00	825	WW	14	9.9	--	--	20	7.56	10
FOURMILE	40120	0.11	--	--	³	--	--	--	--	--	--	--
SBC-aBC	29070	--	--	--	³	--	--	--	--	--	--	--
BCSC-aBC	24680	0.63	--	--	³	--	--	--	--	--	--	--
BLD-EFF	24380	0.88	6/13/00	1345	WW	25	20	6.9	90	600	7.07	400
DC	20040	--	--	--	³	--	--	--	--	--	--	--
CC	10970	0.30	6/13/00	1650	WW	19	22	10	140	870	9.22	580
SV-aBC	90	3.28	--	--	³	--	--	--	--	--	--	--
Quality assurance/quality control- Drinking Water Laboratory												
Field blank			6/12/00	1245	DW	--	--	--	--	--	--	--
Laboratory blank			--	--	DW	--	--	--	--	--	--	--
BEAVER field replicate			6/12/00	1255	DW	--	--	--	--	--	--	--
Standard reference percent recovery			--	--	--	--	--	--	--	--	--	--
Quality assurance/quality control- Wastewater Laboratory												
Laboratory blank			--	--	WW	--	--	--	--	--	--	<1
BC-aDC field replicate			6/13/00	1525	WW	--	--	--	--	--	--	10
NBC-FALLS lab duplicate			6/13/00	825	WW	--	--	--	--	--	--	--
Standard reference percent recovery			--	--	--	--	--	--	--	--	--	--

¹ Calculated from dissolved oxygen, temperature, and elevation.

² All turbidity measurements analyzed by DW.

³ Samples for these sites were collected during USGS sampling and analyzed for hardness, total phosphate, and orthophosphate by WW, and for fecal

⁴ Estimated from specific conductance.

Creek confluence; m³/s, cubic meters per second; Lab, city of Boulder laboratory that analyzed sample; T_{air}, air temperature; T_{water}, water temperature; °C, suspended solids; NTU, nephelometric turbidity units; cols/100 mL, number of colonies per 100 milliliters; NO₂+NO₃-N, nitrite plus nitrate as N; NO₂, than; DW, Drinking Water Laboratory; WW, Wastewater and Environmental Laboratory; discharge from Murphy and others, 2003]

Site	Alka- linity	Hard- ness	TSS	Turbidity ² (NTU)	Fecal coliform (cols/100 mL)	NO ₂ + NO ₃ -N	NO ₂ -N	NH ₃ -N	Org-N	P (total)	ortho PO ₄ -P
MBC-ELD	--	40	--	0.56	2	--	--	--	--	0.03	<0.03
MBC-WTP	10	12	2	1.0	<1	0.08	--	--	--	0.01	--
MBC-W	11	11	2	0.83	<1	0.07	--	--	--	0.01	--
MBC-aNBC	13	15	7	2.5	<20	<0.1	<0.001	<0.1	0.2	0.03	<0.03
BC-ORO	13	15	10	2.5	20	<0.1	<0.001	<0.1	0.3	0.05	<0.03
BC-CAN	14	15	9	3.0	20	<0.1	<0.001	0.1	0.3	0.03	<0.03
BC-30	--	90	--	3.1	170	--	--	--	--	<0.02	0.06
BC-61	23	30	13	2.6	170	<0.1	<0.001	<0.1	0.4	<0.02	<0.03
BC-aWWTP	33	60	13	10	140	<0.1	<0.001	<0.1	0.2	0.03	<0.03
BC-75	59	260	8	4.7	170	4.9	0.255	2.1	0.9	0.90	0.85
BC-aDC	45	90	7	8.6	80	3.0	0.203	0.7	0.9	0.43	0.46
BC-95	52	90	10	11	20	2.7	0.218	0.5	0.9	0.44	0.42
BC-107	55	90	7	2.1	130	2.9	0.259	0.4	0.8	0.47	0.46
BC-aCC	71	110	8	5.6	40	1.0	0.035	<0.1	0.6	0.29	0.29
BC-bCC	93	120	19	9.4	110	1.2	0.031	<0.1	0.7	0.33	0.33
BC-aSV	--	20	--	3.9	<10	--	--	--	--	0.22	0.35
COMO	2	14	6	4.6	6	<0.01	--	--	--	0.02	--
NBC-LW	9	9	5	1.6	2	<0.01	--	--	--	0.01	--
SLP	8	9	2	1.3	<1	0.01	--	--	--	0.01	--
BEAVER	41	45	4	2.4	1	<0.01	--	--	--	0.01	--
NED-EFF	160	79	69	55	1300	<0.01	--	24	10.5	5.25	--
NBC-FALLS	11	10	5	1.6	<20	<0.1	<0.001	<0.1	0.1	0.05	<0.03
FOURMILE	--	50	--	1.6	80	--	--	--	--	0.04	<0.03
SBC-aBC	--	140	--	2.3	--	--	--	--	--	--	<0.03
BCSC-aBC	--	80	--	28	--	--	--	--	--	0.02	0.06
BLD-EFF	95	370	5	3.3	<20	10.2	0.540	5.0	1.7	1.95	2.67
DC	--	160	--	5.4	80	--	--	--	--	0.12	0.05
CC	250	240	77	29	230	1.8	0.026	<0.1	1.2	0.66	0.65
SV-aBC	--	230	--	23	210	--	--	--	--	0.55	0.58
	1.3	<1	--	0.05	--	<0.01	--	--	--	0.0009	--
	--	--	--	--	--	--	--	--	--	0.0006	--
	41	45	--	2.5	--	<0.01	--	--	--	0.01	--
	--	--	--	--	--	133%	--	--	--	107-110%	--
	1.1	--	<1	--	<20	--	0.003	<0.1	--	<0.003	<0.003
	54	--	4	--	--	--	0.260	0.4	--	0.43	0.46
	11	--	--	--	--	--	0.202	--	--	--	--
	--	99-102%	--	--	--	97-111%	99-101%	--	--	93-101%	98-101%

coliform and turbidity by DW.

Table 3.2. Results of water analyses for Boulder Creek, inflows, and other flows, October 2000

[Units are milligrams per liter unless otherwise indicated; alkalinity and hardness reported as CaCO₃; distance, distance from Boulder Creek/Saint Vrain degrees Celsius; DO, dissolved oxygen; %, percent; SC, specific conductance; μS/cm, microsiemens per centimeter; TDS, total dissolved solids; TSS, total nitrite as N; NH₃-N, ammonia as N; Org-N, organic nitrogen as N; P, phosphorus as P; ortho PO₄-P, orthophosphate as phosphorus; --, not measured; <, less

Site	Distance (meters)	Discharge (m ³ /s)	Sample date	Sample time	Lab	T _{air} (°C)	T _{water} (°C)	DO	DO Saturation (%)	SC (μS/cm)	pH (units)	TDS
Middle Boulder Creek/Boulder Creek												
MBC-ELD	69590	0.40	--	--	²	--	--	--	--	--	--	8 ³
MBC-WTP	62970	--	10/9/00	1204	DW	--	4.0	9.7	100	48	7.48	29 ⁴
MBC-W	60920	0.33	10/9/00	1257	DW	--	5.6	9.3	100	48	7.54	29 ⁴
MBC-aNBC	49440	--	10/10/00	900	WW	8	4.2	9.8	94	89	7.62	84
BC-ORO	41520	1.3	10/10/00	1000	WW	10	8.0	9.4	96	54	7.59	60
BC-CAN	36710	1.0	10/10/00	1045	WW	11	8.2	9.3	96	62	7.64	56
BC-30	32990	0.38	--	--	²	--	--	--	--	--	--	68 ³
BC-61	27320	0.53	10/10/00	1120	WW	25	10	10	110	188	8.95	168
BC-aWWTP	24440	0.35	10/10/00	1355	WW	18	12	9.1	100	221	8.90	--
BC-75	23850	1.6	10/10/00	1325	WW	17	18	11	140	572	7.80	368
BC-aDC	20180	1.1	10/10/00	1355	WW	18	17	13	160	527	7.82	332
BC-95	18790	1.0	10/10/00	1435	WW	22	18	14	180	543	8.46	374
BC-107	16320	0.69	10/10/00	1510	WW	22	17	13	160	--	8.62	296
BC-aCC	10970	0.87	10/10/00	1545	WW	22	16	13	150	--	9.32	374
BC-bCC	10540	1.2	10/10/00	1610	WW	21	15	12	150	--	8.59	432
BC-aSV	110	0.49	--	--	²	--	--	--	--	--	--	450 ³
Inflows/other flows												
COMO	59340	0.03	10/9/00	1023	DW	--	3.8	9.8	100	67	7.57	41 ⁴
NBC-LW	59370	0.17	10/9/00	1040	DW	--	2.8	10	100	32	7.34	20 ⁴
SLP	59340	0.16	10/9/00	1058	DW	--	5.2	8.5	91	22	7.72	13 ⁴
BEAVER	60910	0.01	10/9/00	1230	DW	--	6.1	9.1	99	180	8.04	110 ⁴
NED-EFF	60880	0.003	10/9/00	1317	DW	--	7.3	3.0	30	579	7.07	350 ⁴
NBC-FALLS	49420	--	10/10/00	920	WW	--	3.3	9.7	92	75	7.47	82
FOURMILE	40120	0.02	--	--	²	--	--	--	--	--	--	184
SBC-aBC	29070	0.01	--	--	²	--	--	--	--	--	--	192 ³
BCSC-aBC	24680	0.05	--	--	²	--	--	--	--	--	--	110 ³
BLD-EFF	24380	0.91	10/10/00	1310	WW	20	20	6.1	83	682	7.37	396
DC	20040	0.03	10/10/00	--	²	--	--	--	--	--	--	712 ³
CC	10970	0.34	10/10/00	1555	WW	22	15	12	120	--	8.50	668
SV-aBC	90	1.9	--	--	²	--	--	--	--	--	--	904 ³
Quality assurance/quality control- Drinking Water Laboratory												
Field blank			10/9/00	1225	DW	--	--	--	--	--	--	--
BEAVER field replicate			10/9/00	1235	DW	--	--	--	--	--	--	--
Standard reference percent recovery			--	--	--	--	--	--	--	--	--	--
Quality assurance/quality control- Wastewater Laboratory												
Laboratory blank			--	--	DW	--	--	--	--	--	--	6
BC-CAN field replicate			10/10/00	1045	WW	--	--	--	--	--	--	48
Standard reference percent recovery			--	--	--	--	--	--	--	--	--	--

¹ All turbidity measurements analyzed by DW.

² Samples for these sites were collected during USGS sampling and analyzed for TDS, TSS, hardness, ammonia, total phosphate, and orthophosphate by

³ Analyzed 22 days after holding time.

⁴ Estimated from specific conductance.

Creek confluence; m³/s, cubic meters per second; Lab, city of Boulder laboratory that analyzed sample; T_{air}, air temperature; T_{water}, water temperature; °C, suspended solids; NTU, nephelometric turbidity units; cols/100 mL, number of colonies per 100 milliliters; NO₂+NO₃-N, nitrite plus nitrate as N; NO₂, than; DW, Drinking Water Laboratory; WW, Wastewater and Environmental Laboratory; discharge measurements from Murphy and others, 2003]

Site	Alka- linity	Hard- ness	TSS	Turbidity ¹ (NTU)	Fecal coliform (cols/100 mL)	NO ₂ + NO ₃ -N	NO ₂ -N	NH ₃ -N	Org-N	P (total)	ortho PO ₄ -P
MBC-ELD	--	40	2 ³	0.22	1	--	--	<0.1	<0.1	<0.02	<0.03
MBC-WTP	17	19	4	0.66	<1	0.09	--	--	--	0.01	--
MBC-W	17	20	2	0.51	<1	--	--	--	--	0.01	--
MBC-aNBC	22	50	1	0.38	50	<0.1	<0.001	<0.1	<0.1	0.07	<0.03
BC-ORO	17	--	3	3.0	20	<0.1	<0.001	0.1	0.2	0.06	<0.03
BC-CAN	18	50	1	1.7	20	<0.1	<0.001	<0.1	0.1	0.04	<0.03
BC-30	--	190	6 ³	2.8	690	--	--	<0.1	--	<0.02	0.09
BC-61	58	260	1	2.3	130	<0.1	<0.001	<0.1	1.7	0.04	<0.03
BC-aWWTP	68	120	4	5.3	80	<0.1	<0.001	<0.1	0.1	0.11	<0.03
BC-75	112	210	4	3.8	330	6.7	0.408	7.8	1.4	1.73	1.49
BC-aDC	111	200	5	4.1	230	6.2	0.152	6.8	1.5	1.44	1.26
BC-95	123	200	3	3.0	80	5.9	0.104	6.2	1.4	1.34	1.18
BC-107	109	190	4	2.1	80	2.9	0.026	3.6	0.9	0.99	0.87
BC-aCC	139	260	3	2.2	220	3.2	0.007	1.6	0.1	0.82	0.75
BC-bCC	164	300	14	9.2	130	3.1	0.025	1.2	1.1	0.78	0.64
BC-aSV	--	330	10 ³	3.1	2	--	--	<0.1	--	0.48	0.50
COMO	31	27	4	2.4	85	<0.01	--	--	--	0.02	--
NBC-LW	14	13	2	0.95	<1	<0.01	--	--	--	0.01	--
SLP	10	9	1	1.3	<1	<0.01	--	--	--	0.01	--
BEAVER	69	82	2	2.3	1	--	--	--	--	0.01	--
NED-EFF	123	88	50	43	30	--	--	--	--	5.45	--
NBC-FALLS	27	80	1	1.3	<20	<0.1	<0.001	<0.1	0.7	0.04	<0.03
FOURMILE	--	180	<1	0.38	17	--	--	--	--	0.02	0.14
SBC-aBC	--	290	18 ³	6.6	5	--	--	--	--	<0.02	0.06
BCSC-aBC	--	80	6 ³	32	6	--	--	--	--	<0.02	0.02
BLD-EFF	125	350	6	2.4	790	7.7	0.490	9.9	0.2	2.29	3.64
DC	--	510	6 ³	1.1	1560	--	--	--	--	0.02	0.01
CC	255	320	39	--	330	2.7	0.093	<0.1	0.9	0.51	0.45
SV-aBC	--	560	6 ³	4.7	240	--	--	--	--	0.71	0.75
	1.2	<1	--	0.038	--	<0.01	--	--	--	0.0006	--
	69	82	--	2.35	--	--	--	--	--	0.0140	--
	--	--	--	--	--	125%	--	--	--	104-145%	--
	--	<1	<1	--	--	<0.1	<0.001	--	--	0.07	<0.03
	19	50	2	--	--	<0.1	0.003	<0.1	--	--	--
	--	100%	--	--	--	96-112%	99-102%	--	--	99-108%	96-106%

WW, and for fecal coliform and turbidity by DW.

1 mg/L. The Drinking Water Laboratory estimated TDS from SC by multiplying SC by 0.61, based on the laboratory's previous studies of the correlation between TDS and SC for samples from the same sites.

Alkalinity was measured at both laboratories using Standard Method 2320 (APHA and others, 1998). A 200-mL aliquot of unfiltered sample was stirred and titrated to a pH of 4.5 with 0.02N sulfuric acid. This method assumes that alkalinity consists of bicarbonate, carbonate, and/or hydroxide. The Drinking Water Laboratory analyzed field blanks and field replicates for each sampling event. The Wastewater and Environmental Laboratory analyzed laboratory blanks and field replicates for each sampling event (tables 3.1 and 3.2). The detection limit was 1 mg/L as calcium carbonate (CaCO_3).

Hardness was measured at both laboratories using Standard Method 2340 (APHA and others, 1998). A buffered indicator solution was added to a 100-mL aliquot of unfiltered sample to bring the pH to 10. The sample turned red if calcium and magnesium were present. The sample was then titrated with ethylenediaminetetraacetic acid (EDTA) until it turned blue, indicating that all calcium and magnesium had complexed with EDTA. The amount of EDTA added represented the hardness (from calcium and magnesium) of the sample. The Drinking Water Laboratory analyzed field blanks and field replicates for each sampling event. The Wastewater and Environmental Laboratory analyzed laboratory blanks and field replicates for each sampling event (tables 3.1 and 3.2), and also analyzed standard reference samples (percent recoveries ranged from 99 to 102 percent). The detection limit was 1 mg/L as CaCO_3 .

Both laboratories measured Total Suspended Solids (TSS) using Standard Method 2540D (APHA and others, 1998). A 100-mL aliquot of sample was passed through a 1.5- μm filter, and the filter with residue was dried at 103 to 105°C to a constant weight. The Drinking Water Laboratory analyzed laboratory blanks and field

replicates for each sampling event (tables 3.1 and 3.2). The detection limit was 1 mg/L.

Turbidity values of all samples were measured with a nephelometer at the Drinking Water Laboratory using Standard Method 2130B (APHA and others, 1998). Field blanks and field replicates for each sampling event were analyzed. The detection limit for this method was 0.03 nephelometric turbidity units (NTU).

The Drinking Water Laboratory measured fecal coliform using Standard Method 9222D (membrane filter method; APHA and others, 1998). The water sample was filtered through a sterile membrane filter. The filter was transferred to a sterile petri dish and placed on a nutrient pad saturated with a fecal coliform-specific broth. The plates were inverted, placed in watertight plastic bags, and incubated in a water bath at 44.5°C for 24 hours. Colonies produced by fecal coliform bacteria were counted using a microscope or magnifying lens. The fecal coliform density was recorded as the number of colonies per 100 mL (cols/100 mL) of sample; the detection limit was 1 cols/100 mL. The Wastewater and Environmental Laboratory measured fecal coliform using a modified version of Standard Method 9221E (most probable number method; APHA and others, 1998). A "presumptive test" was first performed, in which a series of fermentation tubes containing lauryl tryptose broth were inoculated with varying dilutions of water samples and incubated for 24 hours at 35.6°C. The fermentation tubes contained an inverted tube to trap gases produced by the coliform bacteria. The fermentation tubes were examined for gas production after 24 and 48 hours. If gas production was observed by the end of 48 hours, the presumptive test was positive and coliform bacteria were present in the sample. A "confirmed test" was then performed to determine if fecal coliform bacteria were present. A portion of the content of the fermentation tube was transferred with a sterile loop to a fermentation tube containing a fecal coliform-specific broth. The sample was incubated in a water bath at 44.5°C for 24 hours. Gas production

in the fermentation tube after 24 hours indicated fecal coliform. Based on which dilutions showed positive for coliform and/or fecal coliform, a table of most probable numbers was used to estimate the coliform content of the sample. The results were reported as most probable number of coliform per 100 mL. The detection limit for this method was 20 cols/100 mL.

Both laboratories measured and reported nitrite and nitrate together (designated nitrite+nitrate, NO_2+NO_3). The Drinking Water Laboratory used Hach Method 8192 (low-range cadmium reduction) on a filtered sample, while the Wastewater and Environmental Laboratory used Hach Method 8039 (high-range cadmium reduction; Hach Company, 2001) on an unfiltered sample. Both methods involved the reduction of nitrate to nitrite with cadmium, followed by the addition of sulfanilic acid to form an intermediate diazonium salt. In Method 8192, the diazonium salt coupled with chromotropic acid, and the pink-colored product was analyzed with a spectrophotometer at a wavelength of 507 nanometers (nm). In Method 8039, the diazonium salt coupled with gentisic acid, and the amber-colored product was analyzed at 500 nm. The Drinking Water Laboratory corrected NO_2+NO_3 sample concentrations by subtracting a reagent blank. The Drinking Water Laboratory analyzed field blanks and standard reference samples (133 percent recovery in June and 125 percent recovery in October) for each sampling event (tables 3.1 and 3.2). The Wastewater and Environmental Laboratory analyzed standard reference samples (between 96 and 112 percent recovery). A correction factor was then obtained by averaging the two analyses, subtracting the reagent blank from the average, and then dividing the actual standard concentration by this number. The correction factor was then subtracted from each analytic result. Field replicates were also analyzed (tables 3.1 and 3.2). The detection limits for Methods 8192 and 8039 were approximately 0.01 mg/L as N and 0.1 mg/L as N, respectively. The Wastewater and Environmental Laboratory also measured nitrite separately using Hach

Method 8507 (low range) and a Hach DR4000 spectrophotometer. This method is similar to Method 8192, described above, without the cadmium reduction. Nitrite (NO_2) concentrations were corrected in the same manner as NO_2+NO_3 . Field replicates were also analyzed (tables 3.1 and 3.2). The detection limit for NO_2 was approximately 0.001 mg/L as N.

All ammonia (NH_3) and organic nitrogen (organic N) analyses were performed at the Wastewater and Environmental Laboratory, using Standard Methods 4500-NH₃ B and 4500-NH₃ C (APHA and others, 1998) on an unfiltered sample. Both the ammonium ion (NH_4^+) and unionized ammonia (NH_3) were included in the ammonia measurement. Sodium borate buffer was added to the sample, and the pH of the sample was adjusted to 9.5 with sodium hydroxide. Ammonia was separated from organic N by distilling the sample into a flask containing a boric acid/color indicator solution. Sample concentrations were corrected by subtracting the concentration in a reagent blank. The detection limit for both NH_3 and organic N was 0.1 mg/L as N.

For determination of total phosphorus (total P), both laboratories first prepared an unfiltered sample with a persulfate digestion; the Drinking Water Laboratory used Standard Method 4500-P B.5 (APHA and others, 1998) while the Wastewater and Environmental Laboratory used Hach Method 8190 (Hach Company, 2001), which is based on Standard Method 4500-P B.5. In the persulfate digestion, condensed and organic phosphorus were converted to orthophosphate by adding sulfuric acid, ammonium persulfate, and phenolphthalein indicator and boiling the sample. After boiling, the sample was cooled and additional phenolphthalein indicator was added. The sample was then neutralized to a faint pink color with sodium hydroxide. The sample was then analyzed for orthophosphate. The Drinking Water Laboratory analyzed the converted orthophosphate using Standard Method 4500-P E (ascorbic acid method), in which phenolphthalein indicator, sulfuric acid, potassium antimonyl

tartrate, ammonium molybdate, and ascorbic acid were added to the sample. Potassium antimonyl tartrate and ammonium molybdate formed phosphomolybdic acid, which was then reduced by ascorbic acid. The blue-colored product was analyzed with a spectrophotometer at a wavelength of 430 nm. The Drinking Water Laboratory analyzed field blanks, laboratory blanks, and field replicates for each sampling event, and also analyzed standard reference samples (percent recoveries ranged from 107 to 145 percent). The detection limit for this method was approximately 0.002 mg/L as P. The Wastewater and Environmental Laboratory analyzed the converted orthophosphate using Hach Method 8114 (Hach Company, 2001), which is based on Standard Method 4500-P C (vanadomolybdophosphoric acid method; APHA and others, 1998). In this method, molybdovanadate reagent was added to the sample, forming vanadomolybdophosphoric acid. The yellow-colored product was analyzed with a spectrophotometer at a wavelength of 430 nm. The Wastewater and Environmental Laboratory analyzed laboratory blanks and field replicates for each sampling event (tables 3.1 and 3.2), and also analyzed standard reference samples (percent recoveries ranged from 96 to 106 percent). The detection limit for this method was 0.05 mg/L as phosphate (PO_4); values were converted to mg/L as P by dividing by 3.07.

Orthophosphate was measured only by the Wastewater and Environmental Laboratory using an unfiltered sample and Hach Method 8114 as discussed above, without persulfate digestion. The Wastewater and Environmental Laboratory analyzed laboratory blanks and field replicates for each sampling event (tables 3.1 and 3.2), and also analyzed standard reference samples (percent recoveries ranged from 93 to 108 percent). The detection limit was approximately 0.05 mg/L as PO_4 ; values provided in tables 3.1 and 3.2 were converted to mg/L as P by dividing by 3.07.

RESULTS

Analytical results for the June and October sampling events are provided in tables 3.1 and 3.2. 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 flow into Boulder Creek. Sampling sites are shown in figure 3.1 and described in Murphy and others (2003).

Lateral profiles for the physical and chemical measurements of Middle Boulder Creek/Boulder Creek and sampled inflows are shown in figures 3.2 through 3.7. Data collected from Barker Reservoir one week after the sampling event (J.J. Shelley, unpub. data, 2000) are included in these figures. Seasonal and longitudinal trends in water quality are presented in this section; the trends will be discussed in more depth in the Discussion section. Most water-quality variables had higher concentrations during low-flow conditions (October) than during high-flow conditions (June), and were typically higher in the lower watershed (downstream of site BC-CAN) than in the upper watershed.

Temperature

Water temperatures at Boulder Creek sampling sites were higher in June than in October (tables 3.1 and 3.2, fig. 3.2a). During both sampling events, water temperatures increased down the Middle Boulder Creek/Boulder Creek profile from MBC-WTP (8.2°C in June and 4.0°C in October) to the site upstream of the Boulder 75th Street WWTP (BC-aWWTP; 18°C and 12°C). The WWTP effluent (BLD-EFF), which was about 20°C during both sampling events, caused temperatures in Boulder Creek to increase; at the site downstream of the WWTP (BC-75), temperatures were 19°C in June and 18°C in October. In June, water temperatures continued to increase downstream of BC-75, reaching 23°C at the site downstream of Coal

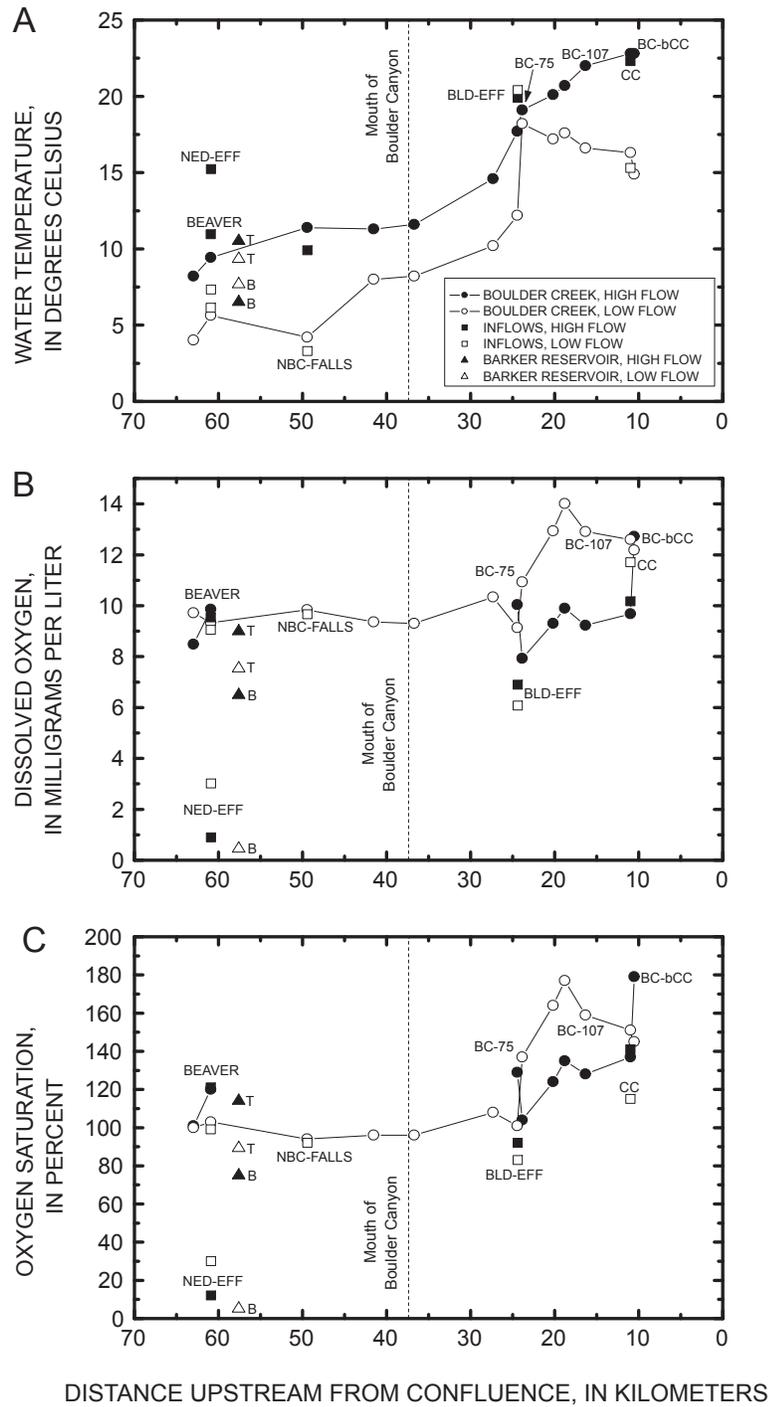


Figure 3.2. Graphs showing downstream variation in (A) water temperatures, (B) dissolved oxygen concentrations, and (C) oxygen saturation values for Middle Boulder Creek/Boulder Creek and major inflows, June and October 2000. (Distance from Boulder Creek and Saint Vrain Creek confluence; B, sample collected at bottom of Barker Reservoir; T, sample collected from top of Barker Reservoir)

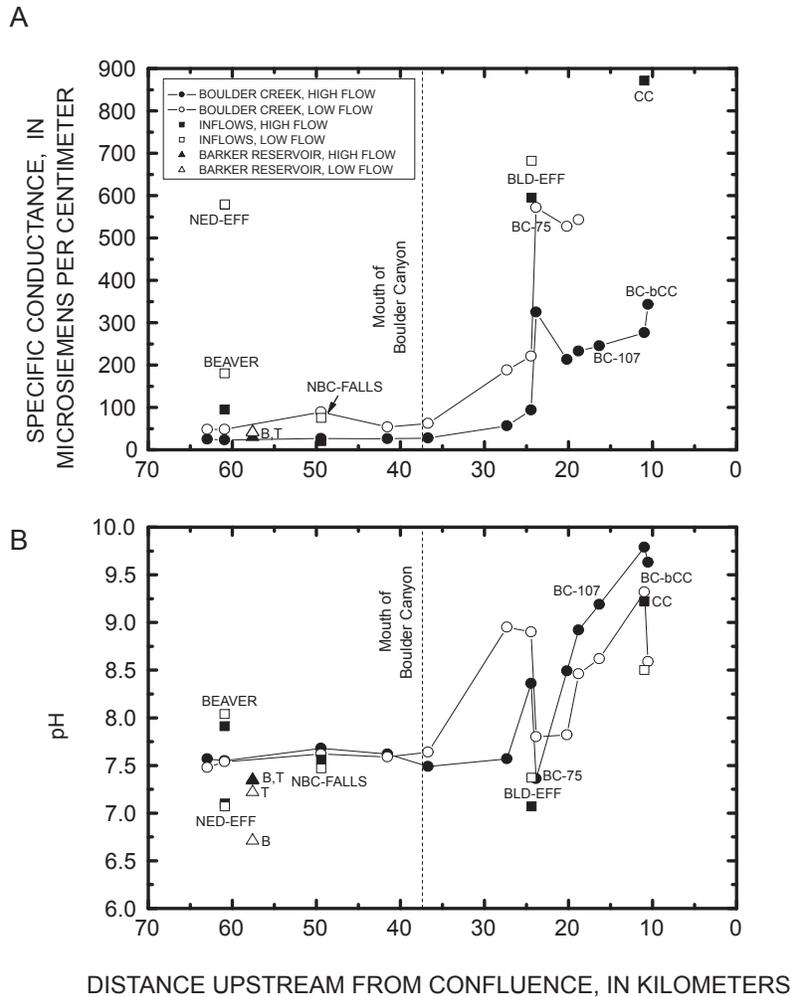


Figure 3.3. Graphs showing downstream variation in (A) specific conductance and (B) pH values for Middle Boulder Creek/Boulder Creek and major inflows, June and October 2000. (Distance from Boulder Creek and Saint Vrain Creek confluence; B, sample collected at bottom of Barker Reservoir; T, sample collected from top of Barker Reservoir)

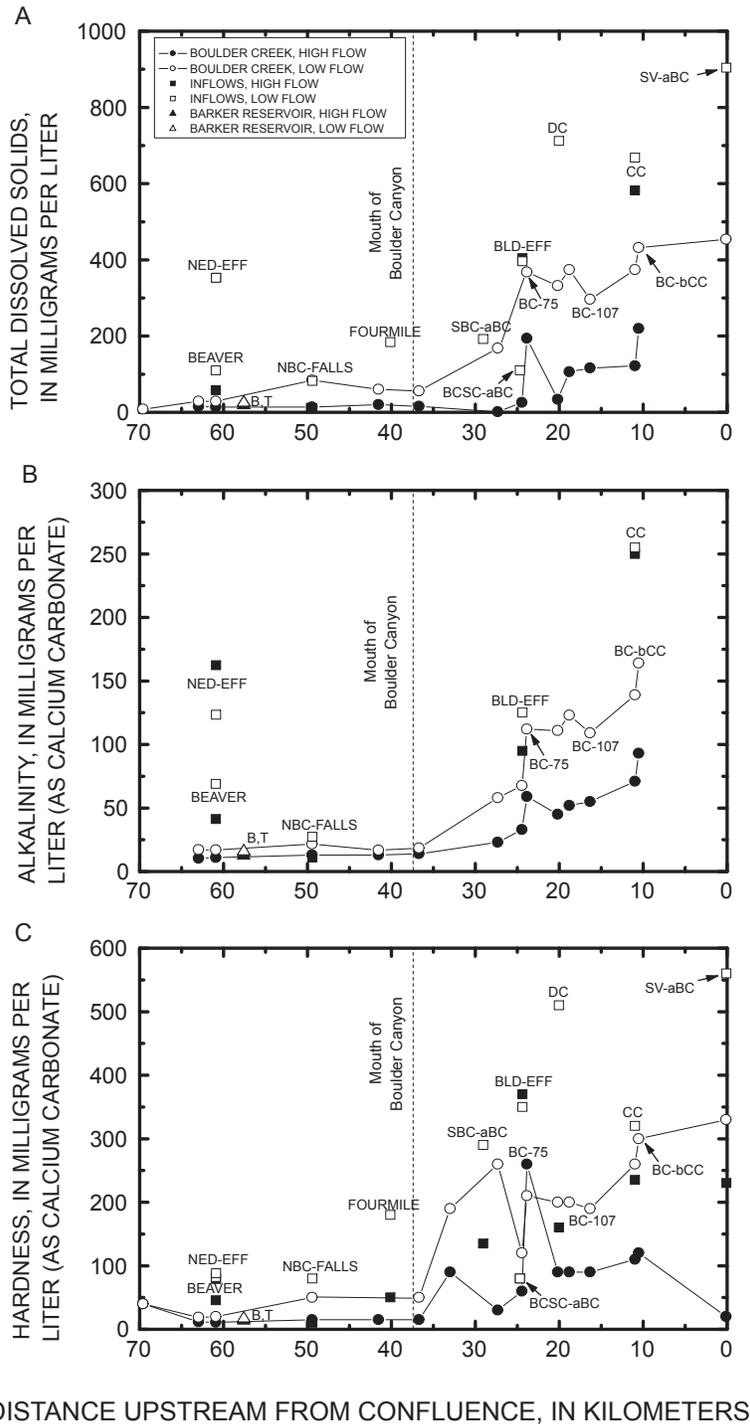


Figure 3.4. Graphs showing downstream variation in (A) total dissolved solids, (B) hardness, and (C) alkalinity values for Middle Boulder Creek/Boulder Creek and major inflows, June and October 2000. (Distance from Boulder Creek and Saint Vrain Creek confluence; B, sample collected at bottom of Barker Reservoir; T, sample collected from top of Barker Reservoir)

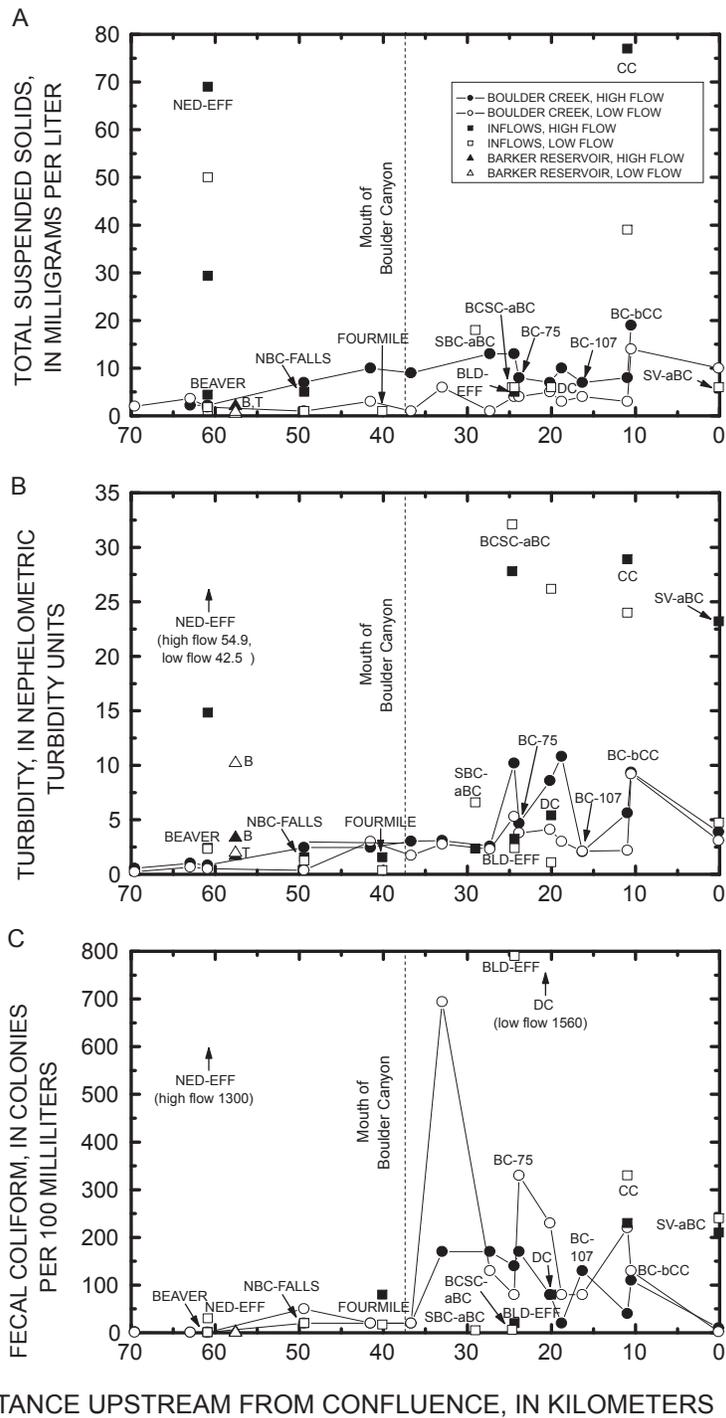


Figure 3.5. Graphs showing downstream variation in (A) total suspended solids, (B) turbidity, and (C) fecal coliform for Middle Boulder Creek/Boulder Creek and major inflows, June and October 2000. (Distance from Boulder Creek and Saint Vrain Creek confluence; B, sample collected at bottom of Barker Reservoir; T, sample collected from top of Barker Reservoir)

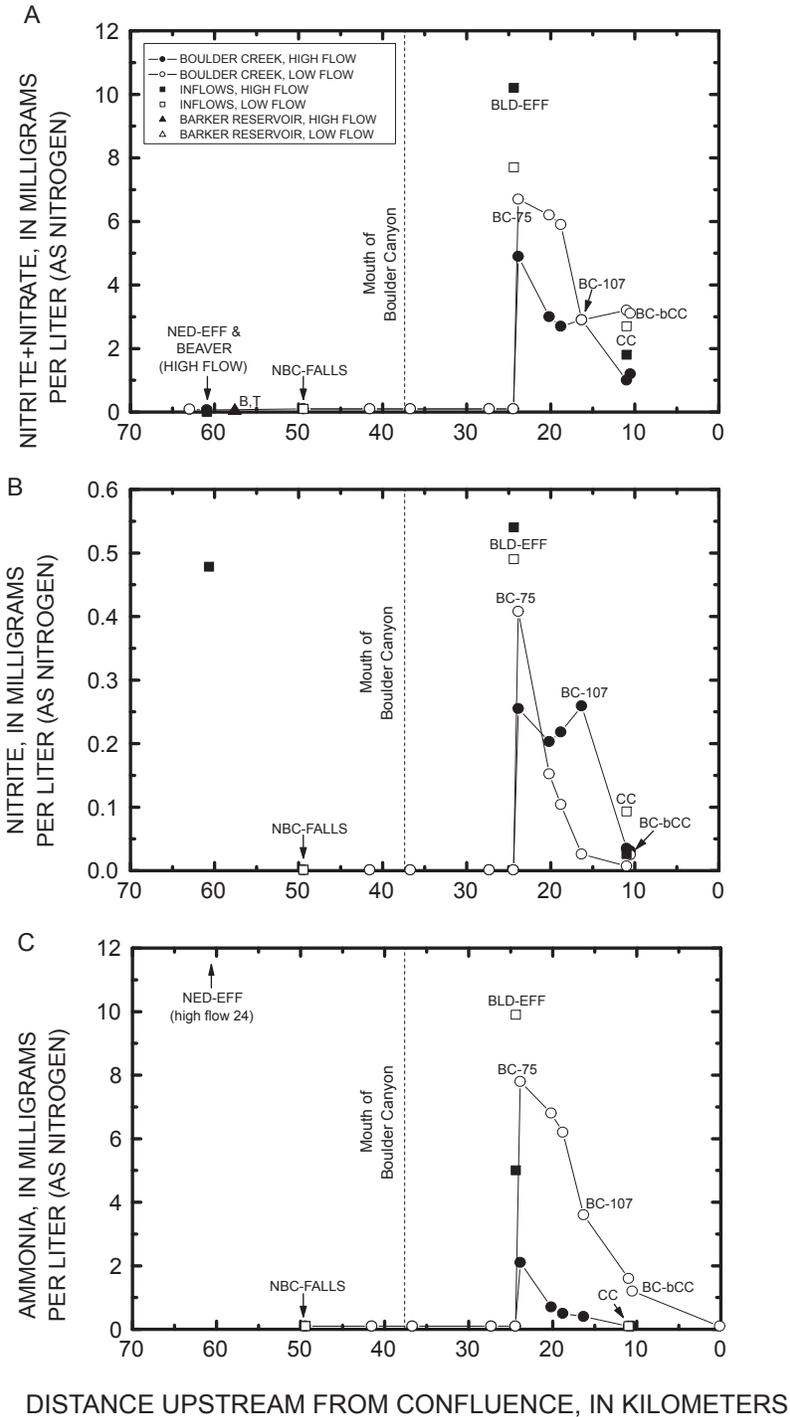


Figure 3.6. Graphs showing downstream variation in (A) nitrite+nitrate, (B) nitrite, and (C) ammonia concentrations or Middle Boulder Creek/Boulder Creek and major inflows, June and October 2000. (Distance from Boulder Creek and Saint Vrain Creek confluence; B, sample collected at bottom of Barker Reservoir; T, sample collected from top of Barker Reservoir)

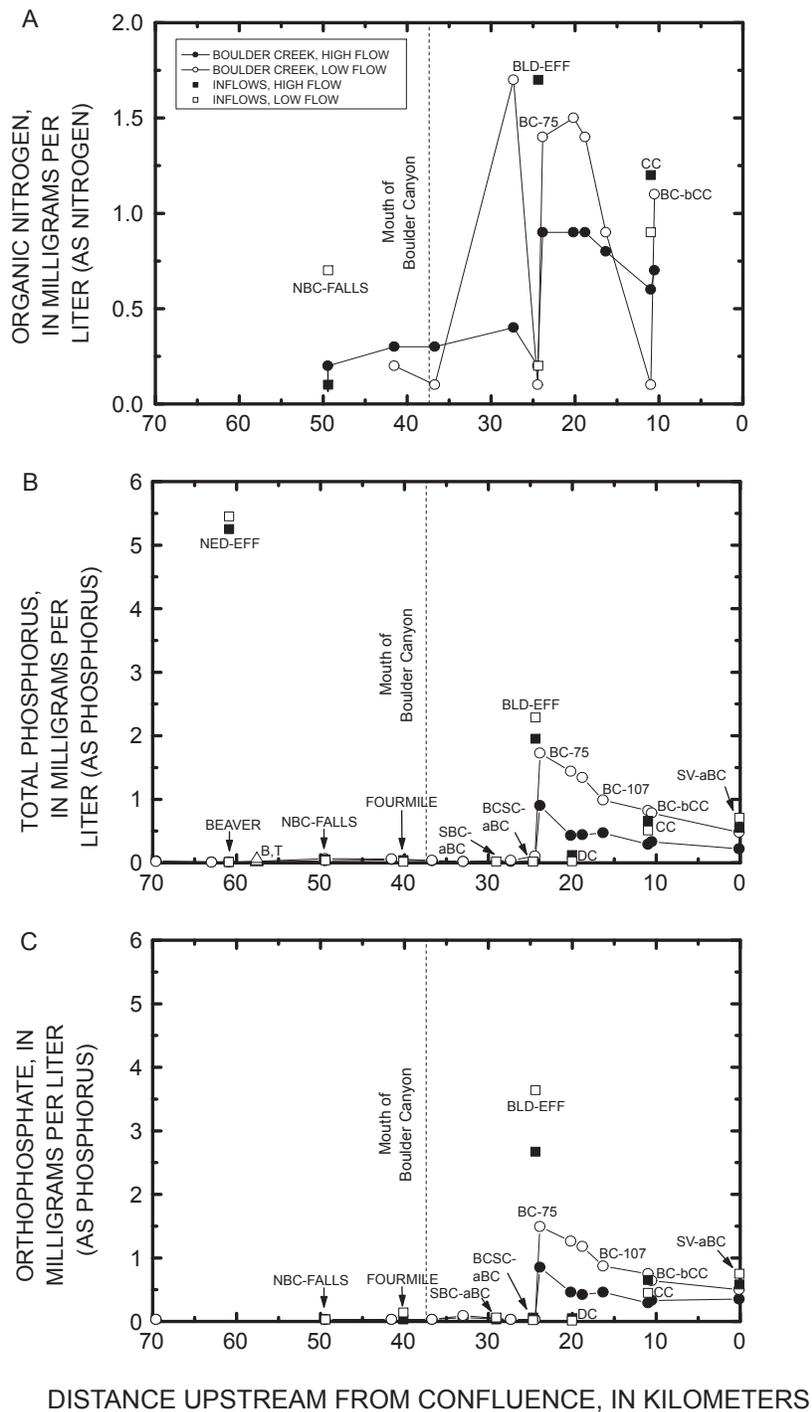


Figure 3.7. Graphs showing downstream variation in (A) organic nitrogen, (B) total phosphorus, and (C) orthophosphate concentrations for Middle Boulder Creek/Boulder Creek and major inflows, June and October 2000. (Distance from Boulder Creek and Saint Vrain Creek confluence; B, sample collected at bottom of Barker Reservoir; T, sample collected from top of Barker Reservoir)

Creek (BC-bCC). In October, water temperatures decreased downstream to 15°C at BC-bCC.

Dissolved Oxygen

It is difficult to compare DO concentrations among the sampling sites because of the variations in temperature and atmospheric pressure in the watershed. Therefore, it is best to compare the percent oxygen saturation. While DO was measured both as concentration and percent saturation in October, only concentration was measured in June (tables 3.1 and 3.2, fig. 3.2b). However, percent oxygen saturation can be estimated from measured oxygen concentration, temperature, atmospheric pressure, and SC (APHA and others, 1998). Comparisons of calculated percent oxygen saturation to measured percent oxygen saturation for October samples showed good agreement; therefore, percent oxygen saturation values were calculated for June samples.

Sample sites along the Middle Boulder Creek/Boulder Creek profile were at or near 100 percent oxygen saturation from site MBC-WTP through site BC-aWWTP (tables 3.1 and 3.2, fig. 3.2c; due to meter malfunction, DO values were not available for several sites in June). The BLD-EFF sample was 92 and 83 percent saturated with oxygen in June and October, respectively. Downstream of the WWTP, all sample sites were saturated or supersaturated with oxygen. In June, oxygen saturation increased downstream to 180 percent at BC-bCC. In October, oxygen saturation increased to a maximum of 180 percent at BC-95, then decreased to 150 percent at BC-bCC. Most sites downstream of the WWTP had higher oxygen saturation values in October than in June.

Oxygen saturation values of samples from the surface of Barker Reservoir were 114 and 89 percent in June and October, respectively. Samples from the bottom of the reservoir had oxygen saturation values of 75 and 5 percent in June and October, respectively.

Specific Conductance

Specific conductance values were higher in October than in June, and were much higher in the lower watershed (below the mouth of Boulder Canyon) than in the upper watershed (tables 3.1 and 3.2, fig. 3.3a). Specific conductance values in the upper watershed were below 30 $\mu\text{S}/\text{cm}$ in June and below 90 $\mu\text{S}/\text{cm}$ in October at all sites except BEAVER and NED-EFF, with no obvious downstream trend. In the lower watershed, SC values of Boulder Creek increased from 28 $\mu\text{S}/\text{cm}$ at the mouth of Boulder Canyon (BC-CAN) to 94 $\mu\text{S}/\text{cm}$ at BC-aWWTP in June, and from 62 $\mu\text{S}/\text{cm}$ to 220 $\mu\text{S}/\text{cm}$ at the same sites in October. Site BLD-EFF had SC values of 595 and 682 $\mu\text{S}/\text{cm}$ in June and October, respectively, leading to increases in SC at BC-75 (325 $\mu\text{S}/\text{cm}$ in June and 572 $\mu\text{S}/\text{cm}$ in October). In both June and October, SC values decreased at the next site, but then increased downstream. In June, SC was 343 $\mu\text{S}/\text{cm}$ at BC-bCC. Due to a meter malfunction, SC values were not obtained at most downstream sites in October; SC at site BC-95 was 543 $\mu\text{S}/\text{cm}$.

pH

Most sites in the upper watershed had pH values between 7 and 8, with little seasonal or spatial variation (tables 3.1 and 3.2, fig. 3.3b). In the lower watershed, however, pH values varied seasonally and spatially. Upstream of the Boulder 75th Street WWTP, pH values were higher during low-flow sampling; pH at BC-aWWTP was 8.36 in June and 8.90 in October. After input of BLD-EFF, pH values decreased to 7.36 in June and 7.80 in October at BC-75. Downstream of BC-75, pH values of Boulder Creek were higher during high-flow sampling, and increased downstream to 9.79 in June and 9.32 in October at the site upstream of Coal Creek (BC-aCC). Downstream of Coal Creek, pH decreased in both June and October.

Total Dissolved Solids

Concentrations of TDS were higher in October than in June, and were higher in the lower watershed than in the upper watershed (tables 3.1 and 3.2, fig. 3.4a). In the upper watershed, TDS values were generally low and fairly constant from MBC-ELD to BC-CAN, with values between 14 and 20 mg/L in June and between 8 and 84 mg/L in October. In the lower watershed, TDS remained low at the sites from BC-CAN to BC-aWWTP in June, but increased to 168 mg/L at BC-61 in October. BLD-EFF had TDS concentrations of about 400 mg/L in both June and October, leading to an increase in TDS at BC-75 to values of 190 mg/L in June and 368 mg/L in October. Downstream of BC-75, TDS values decreased at the next site, then increased downstream to 220 mg/L in June and 432 mg/L in October at BC-bCC; TDS concentration at BC-aSV in October was 454 mg/L. Coal Creek and Dry Creek contributed a large amount of dissolved constituents to Boulder Creek; these tributaries had TDS concentrations between 580 and 712 mg/L.

Hardness

Hardness values were higher in October than in June, and were higher in the lower watershed than in the upper watershed (tables 3.1 and 3.2, fig. 3.4b). Hardness was fairly constant from MBC-ELD to BC-CAN, with values between 11 and 40 mg/L as CaCO₃ in June and between 19 and 50 mg/L in October. Downstream of BC-CAN, hardness values were erratic but showed an overall increase downstream, with hardness values of 60 mg/L in June and 120 mg/L in October measured at BC-aWWTP. After input of BLD-EFF, which had hardness values of 370 mg/L in June and 350 mg/L in October, hardness increased to 260 mg/L in June and 210 mg/L in October at BC-75. Hardness decreased at the next site, but showed an overall increase downstream, reaching 120 mg/L in June and 300 mg/L in October at BC-bCC.

Alkalinity

Alkalinity values were higher in October than in June, and were higher in the lower watershed than in the upper watershed (tables 3.1 and 3.2, fig. 3.4c). Alkalinity was fairly constant from MBC-WTP to BC-CAN, with values between 10 and 14 mg/L as CaCO₃ in June and between 17 and 22 mg/L in October. Downstream of BC-CAN, alkalinity increased to 33 mg/L in June and 68 mg/L in October at BC-aWWTP. After input of BLD-EFF, which had alkalinity values of 95 mg/L in June and 125 mg/L in October, alkalinity increased to 59 mg/L in June and 112 mg/L in October at BC-75. Alkalinity decreased slightly at the next site but showed an overall increase downstream, reaching 93 mg/L in June and 164 mg/L in October at BC-bCC.

Total Suspended Solids

In contrast to most parameters, TSS concentrations in the watershed were generally higher in June than in October, and were not substantially higher in the lower watershed than in the upper watershed (tables 3.1 and 3.2, fig. 3.5a). In June, TSS concentrations in Middle Boulder Creek/Boulder Creek increased downstream from MBC-WTP (2 mg/L) to BC-aWWTP (13 mg/L), then decreased to 8 mg/L at BC-75 after receiving BLD-EFF (5 mg/L). Between BC-75 and BC-aCC, TSS concentrations in June were between 7 and 10 mg/L. In October, most TSS concentrations in both the upper and lower watersheds were between 0 and 7 mg/L. Coal Creek, which had TSS concentrations of 77 mg/L in June and 39 mg/L in October, caused increases in TSS at BC-bCC to 19 mg/L in June and 14 mg/L in October.

Turbidity

Turbidity values at most Boulder Creek sampling sites, similarly to TSS concentrations, were higher in June than in October (tables 3.1 and 3.2, fig. 3.5b). During both sampling events,

turbidity showed an overall increase from MBC-ELD (0.56 NTU in June and 0.22 NTU in October) to BC-61 (2.6 and 2.3 NTU). The Boulder Creek Supply Canal site (BCSC-aBC), which had turbidity values of about 30 NTU in both June and October, caused turbidity to increase to 10 NTU in June and 5.3 NTU in October at the next Boulder Creek site, BC-aWWTP. Turbidity values then decreased to 4.7 NTU in June and 3.8 NTU in October at BC-75 after receiving BLD-EFF (3.3 and 2.4 NTU). Below BC-75, turbidity values of Boulder Creek were between 2 and 11 NTU in June and October; Coal Creek had high turbidity values (29 NTU in June and 24 NTU in October).

Fecal Coliform

Fecal coliform concentrations in the watershed were variable. Differing detection limits for the methods used by the two city laboratories (1 cols/100 mL for samples analyzed by the Drinking Water Laboratory, 20 cols/100 mL for those analyzed by the Wastewater and Environmental Laboratory) complicated comparisons. The only obvious trend observed was that concentrations were higher in the lower watershed than in the upper watershed (tables 3.1 and 3.2, fig. 3.5c). Most Middle Boulder Creek/Boulder Creek sites in the upper watershed had concentrations of 20 cols/100 mL or less. In the lower watershed, fecal coliform concentrations of Boulder Creek ranged from less than 10 to 170 cols/100 mL in June and from 2 to 700 cols/100 mL in October. Several tributaries had higher fecal coliform concentrations; the highest fecal coliform concentration (1560 cols/100 mL) observed during either sampling event was found in Dry Creek in October.

Nitrogen

Nitrite+nitrate, nitrite, and ammonia concentrations were much higher in the lower watershed than the upper watershed, and were higher in October than in June (tables 3.1 and 3.2,

fig. 3.6). Middle Boulder Creek/Boulder Creek sites upstream of the Boulder 75th Street WWTP had NO₂+NO₃ concentrations at or below 0.1 mg/L as N, NO₂ concentrations below 0.001 mg/L as N, and NH₃ concentrations below 0.1 mg/L as N. Concentrations of NO₂+NO₃, NO₂, and NH₃ increased downstream of the Boulder 75th Street WWTP. BLD-EFF, which had NO₂+NO₃ concentrations of 10.2 mg/L as N in June and 7.7 mg/L in October, caused concentrations in Boulder Creek to increase to 4.9 mg/L in June and 6.7 mg/L in October at BC-75. NO₂+NO₃ concentrations then decreased downstream, with concentrations of 1.2 mg/L in June and 3.1 mg/L in October at BC-bCC. Nitrite and NH₃ behaved similarly; NO₂ concentrations at BC-75 were 0.255 mg/L in June and 0.408 mg/L in October, and declined to 0.031 mg/L in June and 0.025 mg/L in October at BC-bCC; NH₃ concentrations were 2.1 mg/L in June and 7.8 mg/L in October at BC-75, and declined to less than 0.1 mg/L in June and 1.2 mg/L in October at BC-bCC.

Organic nitrogen concentrations were erratic, with values ranging from less than 0.1 mg/L to 1.7 mg/L in stream samples (fig. 3.7a). In the upper watershed, concentrations were higher during high flow; in the lower watershed, concentrations were usually higher during low flow.

Phosphorus

Total P and orthophosphate concentrations were much higher in the lower watershed than the upper watershed, and were higher in October than in June (tables 3.1 and 3.2, figs. 3.7b and c). Middle Boulder Creek/Boulder Creek sites upstream of the Boulder 75th Street WWTP had total P concentrations that ranged from 0.01 mg/L as P in June to 0.11 mg/L in October. Orthophosphate concentrations were similar, indicating that most of the phosphorus is orthophosphate.

Concentrations of total P and orthophosphate species increased substantially downstream of the

Boulder 75th Street WWTP. BLD-EFF, which had total P concentrations of 1.95 mg/L in June and 2.29 mg/L in October, caused total P concentrations to increase to 0.9 mg/L in June and 1.73 mg/L in October at BC-75. Total P concentrations then decreased as Boulder Creek flowed downstream, reaching concentrations of 0.22 mg/L in June and 0.48 mg/L in October at BC-aSV. Orthophosphate concentration profiles were similar. Higher concentrations of orthophosphate than total P are likely due to laboratory error.

DISCUSSION

Streamflow in the Boulder Creek Watershed originates primarily as snowmelt; therefore, discharge varies seasonally (Murphy and others, 2003). The much higher discharge during spring runoff (June) provides dilution for dissolved constituents, producing lower values of SC, TDS, alkalinity, hardness, nitrogen, and phosphorus than during low-flow conditions (October). Total suspended solids and turbidity were generally higher in June, when water with higher discharge can carry more suspended particles.

In addition to seasonal patterns, chemical variations were observed from upstream to downstream. These variations are caused by natural factors, such as climate and geology, and by anthropogenic factors, such as wastewater treatment, agriculture, and urbanization. This section will discuss water chemistry as it moves downstream through the headwater, mountain, urban, wastewater-dominated, and wastewater/agricultural/aggregate-mining regions. A more detailed description of the environmental setting of these regions is provided in Murphy and others (2003).

Headwater and Mountain Regions

Stream sites in the headwater and mountain regions of the watershed are snowmelt-dominated waters that have had little reaction time with the

metamorphic and igneous bedrock of the region. Potential anthropogenic sources of solutes are relatively few, and include atmospheric deposition (Williams and others, 2003), historical hardrock mining (Verplanck and others, 2003), and effects from small communities, recreation, and road runoff. Sampling sites on North, Middle, and mainstem Boulder Creeks in the headwater and mountain regions were found to be relatively dilute in both June and October, with low values of SC, TDS, alkalinity, hardness, turbidity, fecal coliform, nitrogen, and phosphorus (figs. 3.3 to 3.7). Most sites had circumneutral pH values (fig. 3.3), with oxygen at or near saturation (fig. 3.2). Elevated levels of SC, pH, TDS, alkalinity, and hardness were observed in North Beaver Creek (BEAVER); this stream and its tributaries flow through the town of Nederland and historical and operating mining districts. Elevated values of most constituents were observed in the Nederland WWTP effluent (NED-EFF). The Nederland WWTP operates an aerated lagoon treatment process, and discharged about 0.003 to 0.005 m³/s of water into Middle Boulder Creek immediately upstream of Barker Reservoir during the sampling events (Murphy and others, 2003). The volume of water discharged by the Nederland WWTP is less than 1% of the total flow to Barker Reservoir (City of Boulder, 2002) and does not appear to have a substantial effect on water quality of the reservoir or the next site on Middle Boulder Creek (MBC-aNBC) during the sampling event (figs. 3.2 to 3.7). However, oxygen saturation values at the bottom of Barker Reservoir were low, particularly during October (fig. 3.2), when waters in the reservoir are stratified (City of Boulder, 2002). Nutrient loading from NED-EFF may contribute to eutrophication of the reservoir.

Urban Corridor

Between the mouth of Boulder Canyon and the Boulder 75th Street WWTP, increases in temperature, SC, pH, alkalinity, and hardness were observed (table 3.1 and 3.2, figs. 3.2, 3.3,

and 3.4). These increases are likely caused by both natural and anthropogenic factors. As Boulder Creek leaves Boulder Canyon and flows onto the plains, the underlying geology transitions from igneous and metamorphic rocks to more easily eroded sedimentary rocks (Murphy and others, 2003). Potential anthropogenic sources, such as instream recreational activities and road and lawn runoff, increase as the creek flows through the city of Boulder. Much of the water in Boulder Creek is diverted in this reach, leaving less water for dilution. There were no storm events during either sampling period; previous studies have suggested that the loading of many constituents to urban streams occur during storm events (USEPA, 1983, 2000; Paulson, 1994). Nitrogen and phosphorus species remained low or below detection in the urban reach. However, fecal coliform concentrations increased, with one particularly high value measured during low flow in the sample from site BC-30 (table 3.2, fig. 3.5). This site is located downstream of a city park, the main campus of the University of Colorado, and a shopping center.

Wastewater-Dominated Reach

A substantial change in water quality occurs downstream of the Boulder 75th Street WWTP. Increases in SC, TDS, alkalinity, hardness, NO₂+NO₃, NO₂, NH₃, total P, and orthophosphate were observed at site BC-75 (figs. 3.3, 3.4, 3.6, and 3.7), while decreases were observed in DO, pH, TSS, and turbidity (figs. 3.2, 3.3, and 3.5). These changes reflect the composition of the wastewater effluent, which adds to the dissolved load of Boulder Creek but has low TSS and turbidity. Effluent comprised a greater proportion of flow during low flow than during high flow, and therefore had a greater effect on water quality of Boulder Creek during low flow. Mass-balance calculations were used to estimate the contribution of effluent to the discharge at the 75th Street streamgaging station using SC, alkalinity, hardness, NO₂+NO₃, and total P values in the effluent and in samples taken

from above and below the Boulder 75th Street WWTP (BC-aWWTP and BC-75). These calculations suggest that effluent contributed about 49 percent of the discharge of Boulder Creek at the 75th Street streamgaging station in June, and 71 percent during low-flow conditions. Other mass-balance calculations performed for this sampling event by Barber and others (2003) and Verplanck and others (2003) suggest that the effluent contributed about 38 percent during high flow and about 76 to 78 percent during low flow. Discharge calculations indicate that the effluent contributed between 15 and 20 percent during high flow, and between 50 and 65 percent during low flow (range due to varying rates of effluent discharged; Murphy and others, 2003). Mass-balance discrepancies for the high-flow event may be due to different sampling times (and therefore different contributions of effluent) by the USGS and the city of Boulder. Additional discharge and mass-balance calculation discrepancies may be due to the collection of grab samples at BC-75, where baseflow and effluent had not completely mixed; the sample was collected from the same bank where effluent was discharged, so may contain a higher proportion of effluent than would a fully width-integrated sample.

Wastewater/Agricultural/Aggregate-Mining Region

Dissolved oxygen and pH increased substantially downstream of BC-75 (figs. 3.2 and 3.3). Supersaturated levels of oxygen and high pH values are similar to daytime measurements of lower Boulder Creek made by Aquatic and Wetland Consultants (1987). These workers evaluated Boulder Creek over 24-hour periods and observed diurnal fluctuations in DO and pH; maximum diel variations of 2.1 pH units and 12 mg/L DO concentrations were recorded at a site on Boulder Creek immediately upstream of Coal Creek. These fluctuations are driven by aquatic vegetation. Photosynthesis, which occurs during daylight hours, produces oxygen and

consumes carbon dioxide, causing pH to increase. Respiration and decomposition, which occur 24 hours a day, consume oxygen and produce carbon dioxide, causing pH to increase. Therefore, DO and pH levels are elevated during the day and low at night. While this is a naturally-occurring process, several factors exaggerate the fluctuations. Lower Boulder Creek has been channelized, loses much of its water to diversions, and has little riparian vegetation shading the creek. The shallow, slow-moving water receives direct sunlight and reaches very high temperatures (fig. 3.2a), accelerating vegetation growth. Wastewater effluent contributes nutrients to the creek, further increasing growth rates and thus exaggerating DO and pH fluctuations. This study found that oxygen saturation values were typically higher during low flow than during high flow, due to lower water temperatures and the subsequent ability of waters to hold more oxygen.

Specific conductance, TDS, alkalinity, and hardness decreased at the site downstream of BC-75, then increased downstream (figs. 3.3, and 3.4). These increases are partly due to inputs from Dry Creek and Coal Creek. Coal Creek receives effluent from Erie, Lafayette, Louisville, and Superior WWTPs, which are permitted to discharge a total of 0.36 m³/s (8.2 million gallons per day) of effluent to Coal Creek or its tributary Rock Creek (USEPA, 2003). Coal Creek may also be affected by agricultural return flows and a greater proportion of sedimentary rock along its channel. Incoming ground water that has interacted with sedimentary bedrock may also contribute solutes to Boulder Creek. Bruce and O'Riley (1997) found that ground water in wells near lower Boulder Creek had SC values between 380 and 1347 mg/L and alkalinity levels of 108 to 466 mg/L as CaCO₃, which are higher than those measured at the lower Boulder Creek sites. In addition, evaporation may concentrate constituents in the creek.

Concentrations of NO₂+NO₃, NO₂, NH₃, total P, and orthophosphate decreased downstream of site BC-75 (figs. 3.6 and 3.7).

These nutrients are used by vegetation and can also sorb to sediment and organic matter. Ammonia in surface waters is typically converted rapidly to NO₂ and then to NO₃ by bacteria. Nutrient concentrations may also be diluted by incoming ground water. An August 1996 study found that wells near lower Boulder Creek had NO₂+NO₃ concentrations between 1 and 5 mg/L as N, NO₂ concentrations ranging from less than 0.01 to 0.05 mg/L as N, NH₃ concentrations ranging from less than 0.01 to 0.06 mg/L as N, and dissolved P concentrations ranging from less than 0.01 to 0.09 mg/L as P (Bruce and O'Riley, 1997). Most NO₂, NH₃, and dissolved P concentrations were lower in ground water than in surface water, while NO₂+NO₃ concentrations were similar to or higher than surface water concentrations. However, studies in the South Platte River Basin found that microorganisms in streambed sediments remove a substantial portion of NO₃ as ground water moves into surface water (McMahon and Böhlke, 1996).

Comparison to Previous Studies

Boulder Creek

The city of Boulder has monitored Boulder Creek water quality since 1983. Water quality data is available for the years 1998 to the present (August 2003) on the BASIN website (www.BASIN.org; Murphy and Waterman, 2003). Water-quality during the June and October 2000 study was similar to 1998-2003 data, with dissolved constituents typically higher during low-flow conditions than during high-flow conditions. Additional studies of Boulder Creek chemistry were performed by Hall and others (1979), Patterson (1980), and Aquatic and Wetland Consultants (1987). Unfortunately, few water-quality measurements were common to all studies. Comparison of water quality is further complicated by the considerable annual, seasonal, and diel variability of discharge in the Boulder Creek Watershed. Historical data collected at similar times of the year as the 2000 study are

provided in table 3.3. Hall and others (1979) evaluated Boulder Creek, Dry Creek, and Fourmile Creek for temperature, SC, TDS, alkalinity, hardness, fecal coliform, NO_2+NO_3 , NO_2 , and orthophosphate during low-flow conditions in 1975 (table 3.3). Values were similar to the October 2000 data with the exception of higher fecal coliform at sampling sites on Middle Boulder Creek in Nederland, Boulder Creek at Orodell, Boulder Creek within the city of Boulder, and Fourmile Creek, but lower concentrations in Dry Creek, in 1975.

Patterson (1980) evaluated Boulder Creek chemistry during high-flow (June) and low-flow (September) conditions in 1977. Most of the 1977 measurements (temperature, pH, TDS, alkalinity, NO_2+NO_3 , and total P) were similar to those measured in 2000, with the exception of higher TDS, alkalinity, and total P, and lower NO_2+NO_3 in 1977 for some samples from lower Boulder Creek. Discharge was similar during low-flow conditions in 1977 and 2000. However, during high flow, discharge in the upper watershed was lower in 1977 than in 2000, but much higher in the lower watershed. The greater discharge in the lower watershed is largely explained by a much greater input from the Boulder Creek Supply Canal in June 1977, when Boulder Creek received an average daily input of $4.1 \text{ m}^3/\text{s}$ of water from the canal (Colorado Water Conservation Board and Colorado Division of Water Resources, 2002). The canal supplied Boulder Creek with only $0.63 \text{ m}^3/\text{s}$ of water during sampling in June 2000 (table 3.1). Because of the drastically different discharge, it is difficult to assess if water quality has changed substantially. Higher NO_2+NO_3 concentrations in 2000 may be due to the installation of a nitrifying trickling filter at the Boulder 75th Street WWTP in 1989, which decreased NH_3 concentrations in the effluent but increased NO_2+NO_3 (Floyd Bebler, city of Boulder, written commun., 2002). Ammonia was not included in the 1977 study, so this hypothesis cannot be verified. A solids contact system and deep secondary clarifiers were also installed in 1989.

Aquatic and Wetland Consultants (1987) measured temperature, DO, pH, SC, TDS, alkalinity, turbidity, and NH_3 in lower Boulder Creek at several times of the year during 1985; the October 1985 data is included in table 3.3. Discharge was similar in October 1985 and October 2000. Most of the water-quality constituents were similar in 1985 and 2000, with some exceptions. Dissolved-oxygen values immediately downstream of the Boulder 75th Street WWTP outfall were lower in 1985, while turbidity values were higher. Improvements in DO and turbidity values are likely due to the 1989 WWTP upgrades mentioned above. Ammonia concentrations were similar in 1985 and 2000; NO_2+NO_3 concentrations were not measured in 1985. Some sites had lower SC and TDS in 1985 than in 2000.

South Platte River

The South Platte River Basin, which includes the Boulder Creek Watershed, has been extensively studied as part of the USGS National Water-Quality Assessment (NAWQA) Program (Leahy and others, 1990; Dennehy, 1991). The NAWQA study evaluated data based on five land use categories: forest, agricultural, urban, mixed urban/agricultural, and rangeland (Litke and Kimbrough, 1998). Data from the present study were similar to data from the South Platte River Basin NAWQA study in the same land-use categories. The NAWQA study found that most surface-water sampling sites located in urban, agricultural, and mixed urban-agricultural land-use areas of the South Platte River Basin had nutrient concentrations that were among the highest 25 percent of all 20 NAWQA Study Units sampled during 1992-95 (that is, 75 percent or more of samples from each site had total nitrogen concentrations greater than 7.3 mg/L as N and total P concentrations greater than 0.87 mg/L as P; Dennehy and others, 1998). Nutrient levels in mountain and rangeland sampling sites in the South Platte River Basin, however, were among the lowest nationally. These findings are similar

Table 3.3. Water quality data from previous Boulder Creek studies

[Units are milligrams per liter unless otherwise indicated; alkalinity and hardness reported as CaCO₃; m³/s, cubic meters per second; T_{water}, water temperature; turbidity units (1 JTU is approximately equal to 1 nephelometric turbidity unit); cols/100 mL, number of colonies per 100 milliliters; NO₂+NO₃-N, nitrite+nitrate-nitrogen; E, estimated]

Site	Similar 2000 site	Date	Time	Discharge (m ³ /s)	T _{water} (°C)	DO	SC (µS/cm)	pH
HIGH FLOW- 1977 (Patterson, 1980)								
Nederland	MBC-W	6/1977	--	4.22	11	--	--	6.9
Castle Rock	MBC-aNBC	6/1977	--	2.61	14.5	--	--	7.2
Orodel	BC-ORO	6/1977	--	3.54	16.5	--	--	7.4
Eben Fine Park	BC-CAN	6/1977	--	1.56	16.5	--	--	7.1
55 th	BC-30 & BC-61	6/1977	--	0.48	23	--	--	8.8
75 th	BC-75	6/1977	--	9.06	20	--	--	7.5
County Line	BC-bCC	6/1977	--	>8	26	--	--	8.9
North Boulder Cr.- Caribou	NBC-LW	6/1977	--	0.85	16	--	--	7.3
Fourmile	FOURMILE	6/1977	--	5.95	19.5	--	--	7.7
LOW FLOW- 1975 (Hall and others, 1979)								
MBC1	MBC-ELD	10/02/1975	1000	--	4	--	<50	--
MBC2	MBC-W	09/30/1975	1800	0.40	6.5	--	60	--
BC1	BC-ORO	09/30/1975	1200	--	11	--	65	--
BC3	BC-30 & BC-61	09/30/1975	1100	--	12.5	--	160	--
BC4	BC-107 & BC-aCC	09/26/1975	1500	--	20.5	--	575	--
NBC1	NBC-LW	09/30/1975	1850	--	--	--	40	--
NBC2	NBC-FALLS	09/30/1975	1450	--	7	--	112	--
FC2	FOURMILE	09/30/1975	1130	--	9	--	391	--
DC1	DC	09/26/1975	1600	--	20	--	858	--
LOW FLOW- 1977 (Patterson, 1980)								
Nederland	MBC-W	9/1977	--	0.34	9	--	--	6.9
Castle Rock	MBC-aNBC	9/1977	--	0.00	8	--	--	7
Orodel	BC-ORO	9/1977	--	0.40	16.5	--	--	6.9
Eben Fine Park	BC-CAN	9/1977	--	0.48	14	--	--	7.3
55 th	BC-30 & BC-61	9/1977	--	0.45	20	--	--	8.7
75 th	BC-75	9/1977	--	1.98	20	--	--	7.4
County Line	BC-bCC	9/1977	--	0.89	20	--	--	8.9
North Boulder Cr.- Caribou	NBC-LW	9/1977	--	0.08	10	--	--	6.8
Fourmile	FOURMILE	9/1977	--	0.14	12	--	--	7.4
Arapahoe Pass	Williams and others (2003)	9/1977	--	0.04	8	--	--	6.7
LOW FLOW- 1985 (Aquatic and Wetland Consultants, 1987)								
BC-1	BC-aWWTP	10/7-14/1985	--	0.52	9.5	10.6	150	8.11
BC-3	BC-75	10/7-14/1985	--	1.33	16.0	5.4	398	2.29 ¹
BC-4b	BC-95	10/7-14/1985	--	1.46	14.0	5.8	285	7.60
BC-5	BC-107	10/7-14/1985	--	1.06	9.5	10.1	285	7.93
BC-6	--	10/7-14/1985	--	0.98	10.5	12.6	330	8.32
BC-7a	BC-aCC	10/7-14/1985	--	0.95	12.5	13.8	360	8.68
BC-7b	BC-bCC	10/7-14/1985	--	1.66	13.5	12.4	430	8.83
BC-8	--	10/7-14/1985	--	1.91	9.5	11.1	305	8.95
BC-9	--	10/7-14/1985	--	2.27	9.5	11.1	335	8.60
BC-10	BC-aSV	10/7-14/1985	--	2.14	12.0	10.2	340	8.60

¹ Alkaline pH values recorded at this site during other sampling events by these workers indicate this is probably an erroneous measurement.

temperature; °C, degrees Celsius; DO, dissolved oxygen; SC, specific conductance; µS/cm, microsiemens per centimeter; TDS, total dissolved solids; JTU, nitrite plus nitrate as N; NO₂, nitrite as N; NH₃-N, ammonia as N; PO₄, phosphate as P; --, not measured; >, greater than; <, less than; Cr., Creek; B, non

Site	TDS	Alka- linity	Hard- ness	Turbidity (JTU)	Fecal coliform (cols/100 mL)	NO ₂ + NO ₃ -N	NO ₂ -N	NH ₃ -N	PO ₄ -P	P, ortho
Nederland	25.2	11.7	--	--	--	0.07	--	--	0.01	--
Castle Rock	29.6	12.3	--	--	--	0.08	--	--	0.00	--
Orodel	34.4	14.9	--	--	--	0.15	--	--	0.01	--
Eben Fine Park	42.4	16.2	--	--	--	0.32	--	--	0.02	--
55 th	102.7	34.9	--	--	--	0.18	--	--	0.03	--
75 th	265.3	97.6	--	--	--	0.32	--	--	0.72	--
County Line	379.7	151.1	--	--	--	0.25	--	--	0.40	--
North Boulder Cr.- Caribou	36.7	16.9	--	--	--	0.08	--	--	0.02	--
Fourmile	112.5	43.8	--	--	--	0.04	--	--	0.02	--
MBC1	19	10	12	--	B1	0.07	0.00	--	--	0.00
MBC2	37	25	25	--	B120	0.03	0.01	--	--	0.00
BC1	39	22	25	--	>1000	0.03	0.00	--	--	0.00
BC3	111	58	73	--	B4700	0.47	0.03	--	--	0.00
BC4	364	194	240	--	B73	2.30	0.47	--	--	0.82
NBC1	31	18	17	--	<1	0.08	0.01	--	--	0.00
NBC2	70	40	47	--	B3	0.04	0.00	--	--	0.00
FC2	232	71	160	--	B250	0.01	0.00	--	--	0.01
DC1	620	235	440	--	B280	0.34	0.01	--	--	0.00
Nederland	45	20	--	--	--	0.13	--	--	0.10	--
Castle Rock	83	39	--	--	--	0.25	--	--	0.00	--
Orodel	47	19	--	--	--	0.16	--	--	0.00	--
Eben Fine Park	49	20	--	--	--	0.13	--	--	0.08	--
55 th	152	64	--	--	--	0.32	--	--	0.09	--
75 th	413	161	--	--	--	2.61	--	--	4.01	--
County Line	736	271	--	--	--	3.07	--	--	1.07	--
North Boulder Cr.- Caribou	77	35	--	--	--	0.13	--	--	0.07	--
Fourmile	257	102	--	--	--	0.30	--	--	0.07	--
Arapahoe Pass	45	19	--	--	--	0.30	--	--	0.00	--
BC-1	120	96	--	6	--	--	--	0	--	--
BC-3	348	132.5	--	16	--	--	--	5.7	--	--
BC-4b	324	1045	--	7.5	--	--	--	3.14	--	--
BC-5	180	95.5	--	10	--	--	--	1.80	--	--
BC-6	230	103.5	--	9	--	--	--	0.78	--	--
BC-7a	96	125.5	--	10.5	--	--	--	1.23	--	--
BC-7b	612	151	--	15	--	--	--	0	--	--
BC-8	388	159	--	16	--	--	--	0	--	--
BC-9	440	164.5	--	14	--	--	--	1.12	--	--
BC-10	452	164	--	16	--	--	--	0.84	--	--

to the 2000 study of Boulder Creek. Notably, however, nitrogen concentrations at sites within the city of Boulder were low (fig. 3.6).

Comparison to Water Quality Standards

The Colorado Department of Public Health and Environment (CDPHE) has established water-quality use classifications for the surface waters of Colorado (CDPHE, 2002a). Stream water-quality standards vary based on the use classification for each stream segment, and include recreational, aquatic-life, domestic water supply, and agricultural standards. The classifications and standards for segments of the Boulder Creek Watershed are provided in table 3.4 (CDPHE, 2002b). Effluent concentrations are not included in this comparison to stream water standards; nor is the Saint Vrain Creek sample, which is outside of the Boulder Creek Watershed.

Temperature

Temperature standards are provided for waters with Aquatic-life class 1 cold and warm classifications (CDPHE, 2002a). Aquatic-life class 1 cold waters should have temperatures less than 20°C; aquatic-life class 1 warm waters should have temperatures less than 30°C. The sampling sites on Middle Boulder Creek, North Boulder Creek, and Boulder Creek upstream of the confluence with South Boulder Creek are classified as suitable for cold-water aquatic-life class 1 (CDPHE, 2002b). All of these sites had temperatures below 20°C (tables 3.1 and 3.2). The remaining mainstem Boulder Creek sites are classified as suitable for warm-water aquatic-life class 1. All of these sites had temperatures below 30°C. Tributary sites DC, BCSC-aBC, and CC are classified as warm-water aquatic-life class 2 (no temperature requirement).

Dissolved Oxygen

Minimum DO stream standards for Boulder Creek and its tributaries range from 5.0 to 7.0 mg/L (table 3.4; CDPHE, 2002a). None of the stream water DO concentrations were below 5.0 mg/L (tables 3.1 and 3.2). However, as discussed earlier, DO in lower Boulder Creek varies diurnally, with lowest DO values occurring at night. This study did not include night-time measurements.

pH

Stream standards for Boulder Creek and its tributaries allow a pH in the range of 6.5 to 9.0 (table 3.4; CDPHE, 2002a). Four sites in June 2000 (BC-107, BC-aCC, BC-bCC, and CC) and one site in October 2000 (BC-aCC) had pH values greater than 9.0 (tables 3.1 and 3.2). These elevated pH values are due to high rates of photosynthetic activity in the lower watershed; because of diurnal variation, nighttime pH values would be substantially lower.

Fecal Coliform

All of the Boulder Creek and tributary sampling sites are classified as suitable for recreation class 1a, which require fecal coliform concentrations to be below 200 cols/100 mL (table 3.4; CDPHE, 2002a). One site (CC) exceeded 200 cols/100 mL in June 2000 (table 3.1), while six sites (BC-30, BC-75, BC-aDC, BC-aCC, DC, and CC) exceeded 200 cols/100 mL in October 2000 (table 3.2).

Nitrogen- Nitrite and Nitrate

All of the Boulder Creek and tributary sampling sites except the Coal Creek site are classified as suitable for domestic water supply, which has a NO₂+NO₃ stream standard of 10 mg/L as N at the point of intake (table 3.4; CDPHE, 2002b). None of the Boulder Creek or tributary sites had NO₂+NO₃ concentrations

Table 3.4. Selected standards for stream segments evaluated in this study

[from Colorado Department of Public Health and Environment (CDPHE), 2002b; mg/L, milligrams per liter; Cr., Creek; Aq., aquatic; DO, dissolved oxygen; NH₃, ammonia; ac, acute; TVS, table value standard (numerical criteria set forth in CDPHE, 2002a); sp, spawning; ch, chronic; NO₂, nitrite; F. Coli, fecal coliform; S., South]

Stream Segment Description	Sample sites		Segment classification *	Numeric standards	
	Mainstem	Tributaries		Physical and biological	Inorganic (mg/L)
Mainstem of Boulder Cr., including all tributaries, lakes, reservoirs, and wetlands, from the boundary of Indian Peaks Wilderness Area to a point immediately above the confluence with S. Boulder Cr. (excluding Middle Boulder Cr. from source to the outlet of Barker Reservoir)	MBC-aNBC	NBC-LW	Aq. life cold 1	DO=6.0 mg/L	NH ₃ (ac)=TVS
	BC-ORO	NBC-FALLS	Recreation 1a	DO(sp)=7.0 mg/L	NH ₃ (ch)=0.02
	BC-CAN	SLP	Water supply	pH=6.5-9.0	NO ₂ =0.05
	BC-30	COMO FOURMILE	Agriculture	F.Coli=200/100 mL	NO ₃ =10
Mainstem of Middle Boulder Cr., Including all tributaries, lakes, reservoirs, and wetlands, from source to the outlet of Barker Reservoir	MBC-ELD	BEAVER	Aq. life cold 1	DO=6.0 mg/L	NH ₃ (ac)=TVS
	MBC-WTP		Recreation 1a	DO(sp)=7.0 mg/L	NH ₃ (ch)=0.02
	MBC-W		Water supply	pH=6.5-9.0	NO ₂ =0.05
			Agriculture	F.Coli=200/100 mL	NO ₃ =10
Mainstem of S. Boulder Cr. from S. Boulder Road to the confluence with Boulder Cr.		SBC-aBC	Aq. life warm 1	DO=5.0 mg/L	NH ₃ (ac)=TVS
			Recreation 1a	pH=6.5-9.0	NH ₃ (ch)=0.06
			Water supply	F.Coli=200/100 mL	NO ₂ =0.5
			Agriculture		NO ₃ =10
Mainstem of Coal Cr. from Highway 36 to the confluence with Boulder Cr.		CC	Aq. life warm 2	DO=5.0 mg/L	NH ₃ (ac)=TVS
			Recreation 1a	pH=6.5-9.0	NH ₃ (ch)=0.06
			Agriculture	F.Coli=200/100 mL	NO ₂ =0.5
Mainstem of Boulder Cr. from a point immediately above the confluence with S. Boulder Cr. to the confluence with Coal Cr.	BC-61		Aq. life warm 1	DO=5.0 mg/L	NH ₃ (ac)=TVS
	BC-aWWTP		Recreation 1a	pH=6.5-9.0	NH ₃ (ch)=0.06
	BC-75		Water supply	F.Coli=200/100 mL	NO ₂ =0.5
	BC-aDC		Agriculture		NO ₃ =10
	BC-95 BC-107 BC-aCC				
Mainstem of Boulder Cr. from the confluence with Coal Cr. to the confluence with St. Vrain Cr.	BC-bCC		Aq. life warm 1	DO=5.0 mg/L	NH ₃ (ac)=TVS
	BC-aSV		Recreation 1a	pH=6.5-9.0	NH ₃ (ch)=0.06
			Water supply	F.Coli=200/100 mL	NO ₂ =0.5
			Agriculture		NO ₃ =10
All tributaries to Boulder Cr. from immediately above the S. Boulder Cr. confluence to Saint Vrain Cr. confluence (excluding S. Boulder Cr. and Coal Cr.)		BCSC-aBC	Aq. life warm 2	DO=5.0 mg/L	NH ₃ (ac)=TVS
		DC	Recreation 1a	pH=6.5-9.0	NH ₃ (ch)=0.10
			Agriculture	F.Coli=200/100 mL	NO ₂ =0.5
					NO ₃ =10

* Segment classifications are defined as follows: Aq. Life cold 1 (aquatic life cold water 1)- surface waters that presently sustain a wide variety of cold water biota, including sensitive species, or could sustain such biota but for correctable water quality conditions; Aq. Life warm 1 (aquatic life warm water 1)- surface waters that presently sustain a wide variety of warm water biota, including sensitive species, or could sustain such biota but for correctable water quality conditions; Aq. Life warm 2 (aquatic life warm water 2- surface waters that are not capable of sustaining a wide variety of warm water biota, including sensitive species, due to physical habitat, water flows or levels, or uncorrectable water quality conditions that result in substantial impairment of the abundance and diversity of species; Recreation 1a (recreation class 1a, existing primary contact)- surface waters in which primary contact uses (recreation in or on the water when the ingestion of small quantities of water is likely to occur) have been documented or are presumed to be present; Water supply-surface waters suitable or intended to become suitable for potable water supplies; Agriculture- surface waters suitable or intended to become suitable for irrigation of crops usually grown in Colorado and which are not hazardous as drinking water for livestock.

greater than 10 mg/L as N (tables 3.1 and 3.2). Maximum NO₂ standards for aquatic-life are determined on a case-by-case basis, according to species present and chloride concentration (CDPHE, 2002b). The sampling sites on Middle Boulder Creek, North Boulder Creek, and Boulder Creek upstream of the confluence with South Boulder Creek have a maximum NO₂ standard of 0.05 mg/L as N (table 3.4). All of these sites had NO₂ concentrations below the detection limit of 0.001 mg/L as N (tables 3.1 and 3.2). The remaining Boulder Creek and tributary sites have a maximum NO₂ standard of 0.5 mg/L as N. None of these sites exceeded 0.5 mg/L as N.

Nitrogen- Ammonia

Acute and chronic stream standards for ammonia in Boulder Creek and its tributaries are provided for un-ionized ammonia (table 3.4; CDPHE, 2002b). Un-ionized ammonia (dissolved ammonia gas) is much more toxic to aquatic life than the ammonium ion (USEPA, 1999). Un-ionized ammonia can be calculated from total ammonia concentrations, pH, and temperature with the equation $f = 1 / (10^{pK_a - pH} + 1)$, where f is the fraction of ammonia in un-ionized form, $pK_a = 0.09018 + 2729.92 / (273.2 + T)$, and T is water temperature in degrees Celsius (Emerson and others, 1975). Un-ionized ammonia concentrations in Boulder Creek in June and October 2000 ranged from below detection to 0.62 mg/L as N. Chronic stream standards for un-ionized ammonia in Boulder Creek are 0.02 mg/L in the upper watershed and 0.06 mg/L in the lower watershed (table 3.4). These standards were exceeded at lower Boulder Creek sites BC-aDC, BC-95, and BC-107 in June and October 2000, and BC-75, BC-aCC, and BC-bCC in October 2000. Acute un-ionized ammonia standards vary based on pH, temperature, and presence of cold-water species (CDPHE, 2002a) and are not discussed here. Elevated concentrations of un-ionized ammonia have been an issue in lower Boulder Creek for years due to high water temperatures and high daytime pH values

(TetraTech, Inc., 1993). The reach of Boulder Creek from South Boulder Creek to Saint Vrain Creek is included in the State of Colorado 303(d) list of impaired waters because of un-ionized ammonia (CDPHE, 2003). The city of Boulder has attempted to improve water quality in lower Boulder Creek by restoring streambank stability, planting willows, and deepening channels (TetraTech, Inc., 1993).

SUMMARY

Water quality of a 70-km reach of Boulder Creek was evaluated by the city of Boulder and the U.S. Geological Survey during high-flow and low-flow conditions of the year 2000. Dissolved constituents generally were present in lower concentrations during high-flow conditions, due to dilution by greater streamflow volumes from snowmelt runoff. Total suspended solids and turbidity were typically higher during high-flow conditions, likely due to greater water velocity. Constituent concentrations were relatively low in the upper Boulder Creek Watershed, due to minimal bedrock contribution and few anthropogenic sources. An increase in some variables was observed as Boulder Creek flowed through the city of Boulder, as geology changes to sedimentary rocks and anthropogenic sources increase. Downstream of the Boulder 75th Street Wastewater Treatment Plant (WWTP), water quality is effluent-dominated, with dissolved constituents showing a large increase immediately downstream of the plant. Total suspended solids and turbidity in Boulder Creek typically decreased after receiving the effluent. Impact of the WWTP was greater during low flow, when WWTP effluent comprises a greater proportion of stream discharge. Downstream of the WWTP, nutrients decreased along the profile due to chemical and biological processes and possibly ground water input, while alkalinity, hardness, SC, and TDS increased after the creek received tributary and ground water input. Dissolved oxygen, pH, and temperature reached

high levels in lower Boulder Creek during daylight hours. Diurnal fluctuations in DO and pH are controlled by the growth of aquatic vegetation; growth rates are accelerated due to shallow waters, direct sunlight, and elevated nutrient concentrations. Comparison of water-quality variables measured in this study to those measured in earlier studies showed that many were similar; however, it is difficult to assess whether substantial changes in water quality have occurred due to differing variables measured and variations in discharge. Samples collected from Boulder Creek and its tributaries met most Colorado water-quality standards; however, fecal coliform concentrations in some lower Boulder Creek samples exceeded state standards, primarily during low-flow conditions. Maximum pH standards were exceeded, again primarily during low-flow conditions, due to high rates of photosynthesis activity. High temperatures and pH values led to un-ionized ammonia concentrations higher than chronic stream standards.

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