Executive Summary

The Boulder Creek Watershed, Colorado, is 1160 square kilometers in area and ranges in elevation from 1480 to 4120 meters above sea level. Streamflow originates primarily as snowmelt near the Continental Divide, and thus discharge varies seasonally and annually (Chapter 1). Most of the water in Boulder Creek is diverted for domestic, agricultural, and industrial use. Some diverted water is returned to the creek as wastewater effluent and by ditch returns, and additional water enters as groundwater and by transbasin diversions. These diversions and returns lead to complex temporal and spatial variations in discharge. The variations in discharge, along with natural factors such as geology and climate, and anthropogenic factors such as wastewater treatment, agriculture, mining, and urbanization, can affect water chemistry. As with many watersheds in the American West, dependable water quality and sufficient water supply are issues facing local water managers and users.

Detailed water-quality and sediment sampling allows the identification of sources and sinks of chemical constituents and an understanding of the processes at work in a river system. This study, the most comprehensive water-quality analysis performed for Boulder Creek to date, was a cooperative effort of the U.S. Geological Survey (USGS) and the city of Boulder. Geographic information systems and modeling programs were used to delineate watershed boundaries, land cover, and geology (Chapter 2). During high-flow (June 2000) and low-flow (October 2000) conditions, researchers evaluated 226 water-quality variables, including basic water-quality indicators (Chapter 3), major ions and trace elements (Chapter 4), wastewater-derived organic compounds (Chapter 5), and pesticides (Chapter 6). Discharge (Chapter 1) and bed-sediment particle size and mineralogy (Chapter 7) were also evaluated. This cooperative study was facilitated by the Boulder Area Sustainability Information Network (BASIN), which provides public access to environmental information about the Boulder Creek Watershed on a website, www.basin.org. In addition to the USGS and city of Boulder data, researchers at the Institute of Arctic and Alpine Research at the University of Colorado provided water chemistry data for the headwaters of North Boulder Creek, upstream of the reach of the USGS/city of Boulder sampling sites (Chapter 8).

Snowmelt produces high flows in Boulder Creek in late spring to early summer (Chapter 1). Because precipitation falling in the headwaters is very dilute (specific conductance about 5 microsiemens per centimeter), most chemical constituents are present in lower concentrations during high flows (Chapters 3, 4, 5, 6, and 8). However, concentrations of some constituents, such as total suspended solids (Chapter 3) and organic carbon (Chapter 5), increase during the spring snowmelt flush.

The upper basin, which consists of alpine, subalpine, montane, and foothills regions west of the mouth of Boulder Canyon, is underlain by Precambrian igneous and metamorphic rocks (Chapter 1). Major dissolved inorganic constituents in headwater sites were found to be enriched by factors of 10 to 20 relative to precipitation; this is consistent with minor weathering of the local crystalline bedrock (Chapter 4). Some anthropogenic input is observed in the headwaters; precipitation introduces nitrogen derived from fossil fuel combustion and agricultural activities (Chapter 8).

The lower basin, which consists of the plains region east of the mouth of Boulder Canyon, is underlain by Mesozoic sedimentary rock and Quaternary alluvium, and has substantially more anthropogenic sources. Concentrations of most dissolved inorganic constituents increased in the lower basin. Differentiation between natural and anthropogenic sources of some dissolved constituents is difficult because both sources contribute to the water composition in this region. The increase of most major constituents

List of chemical and physical variables analyzed in this study

Field parameters and basic water quality variables	Major elements and anions	Trace elements	Wastewater-derived organic compounds
temperature- water	aluminum	antimony	ethylenediaminetetraacetic acid
temperature- air	calcium	arsenic	nitrilotriacetic acid
pH	iron (total)	barium	4-nonylphenolmonoethoxycarboxylate
specific conductance	iron (II)	beryllium	4-nonylphenoldiethoxycarboxylate
dissolved oxygen	magnesium	bismuth	4-nonylphenoltriethoxycarboxylate
alkalinity	manganese	boron	4-nonylphenoltetraethoxycarboxylate
hardness	potassium	cadmium	bisphenol A
turbidity	silica	cerium	4-*tert*-butylphenol
fecal coliform	sodium	cesium	2[3]-*tert*-butyl-4-methoxyphenol
total dissolved solids		chromium	2,6-di-*tert*-butyl-1,4-benzoquinone
total suspended solids	sulfate	cobalt	2,6-di-*tert*-butyl-4-methylphenol
nitrogen- nitrate	chloride	copper	2,6-di-*tert*-butylphenol
nitrogen- nitrite	bromide	dysprosium	1,2-dichlorobenzene
nitrogen- ammonia	fluoride	erbium	1,3-dichlorobenzene
nitrogen- organic		europium	1,4-dichlorobenzene
orthophosphate		gadolinium	4-ethylphenol
phosphorus- total		holmium	4-methylphenol
carbon- organic		lanthanum	4-nonylphenol
ultraviolet light absorption		lead	4-nonylphenolmonoethoxylate
		lithium	4-nonylphenoldiethoxylate
		lutetium	4-nonylphenoltriethoxylate
		mercury	4-nonylphenoltetraethoxylate
		molybdenum	4-*normal*-octylphenol
		neodymium	4-*tert*-octylphenol
		nickel	4-*tert*-octylphenolmonoethoxylate
		praseodymium	4-*tert*-octylphenoldiethoxylate
		rhenium	4-*tert*-octylphenoltriethoxylate
		rubidium	4-*tert*-octylphenoltetraethoxylate
		samarium	4-*tert*-octylphenolpentaethoxylate
		selenium	4-*tert*-pentylphenol
		strontium	4-propylphenol
		tellurium	triclosan
		terbium	*cis*-androsterone
		thallium	cholesterol
		thorium	coprostanol
		thulium	equilenin
		uranium	equilin
		vanadium	17-α-estradiol
		ytterbium	17-β-estradiol
		yttrium	estriol
		zirconium	estrone
		zinc	17-α-ethynylestradiol
			mestranol
			19-norethisterone
			progesterone
			testosterone

Pharmaceutical compounds	Pesticides	Pesticides (continued)
acetominophen	acetochlor	methiocarb
albuterol	acifluoren	methomyl
caffeine	alachlor	metolachlor
cimetidine	aldicarb	metribuzin
codeine	aldicarb sulfone	molinate
cotinine	aldicarb sulfoxide	napropamide
dehydronifedipine	atrazine	neburon
digoxigenin	azinphos-methyl	norflurazon
digoxin	benfluralin	oryzalin
diltiazem	bentazon	oxamyl
1,7-dimethylxanthine	bromacil	p,p'-dichlorodiphenyldichloroethylene (p,p'-DDE)
diphenhydramine	bromoxynil	parathion
enalaprilat	butylate	methyl parathion
fluoxetine	carbaryl	pebulate
gemfibrozil	carbofuran	pendimethalin
ibuprofen	chloramben, methyl ester	*cis*-permethrin
metformin	chlorothalonil	phorate
paroxetine metabolite	chlorpyrifos	picloram
ranitidine	clopyralid	prometon
sulfamethoxazole	cyanazine	propachlor
trimethoprim	dacthal (DCPA)	propanil
warfarin	dacthal monoacid	propargite
	desethylatrazine	propham
	diazinon	propoxur
	dicamba	propyzamide
	dichlobenil	simazine
	dichloroprop	tebuthiuron
	dieldrin	terbacil
	dinoseb	terbufos
	disulfoton	thiobencarb
	diuron	tri-allate
	s-ethyl dipropylthiocarbamate (EPTC)	triclopyr
	ethalfluralin	trifluralin
	ethoprophos	2,4-dichlorophenoxyacetic acid (2,4-D)
	fenuron	4-(2,4-dichlorophenoxy)butyric acid (2,4-DB)
	fluometuron	2,4,5-trichlorophenoxyacetic acid (2,4,5-T)
	fonofos	2-(2,4,5-trichlorophenoxy) propionic acid (2,4,5-TP)
	glyphosate	2,6-diethylaniline
	alpha-hexachlorocyclohexane (alpha-HCH)	2-methyl-4-chlorophenoxyacetic acid (MCPA)
	gamma-hexachlorocyclohexane (lindane)	4-(2-methyl-4-chlorophenoxy) butyric acid (MCPB)
	linuron	3-hydroxycarbofuran
	malathion	4,6-dinitro-2-methylphenol

(bicarbonate, calcium, chloride, magnesium, sodium, and sulfate) is consistent with weathering of the underlying sedimentary bedrock (Chapter 4). It is likely that anthropogenic loading of constituents in this reach occurs during storm events. Fecal coliform concentrations were variable and in some cases exceeded state standards, primarily during low-flow conditions (Chapter 3).

Effluent from Boulder's 75th Street Wastewater Treatment Plant (WWTP) has a substantial impact on the water chemistry of lower Boulder Creek. The WWTP increases the concentrations of nutrients such as nitrogen and phosphorus (Chapter 3), major ions and trace metals (Chapter 4), and organic carbon (Chapter 5) in Boulder Creek. The effluent contained a spike in gadolinium, a rare earth element that is ingested for magnetic resonance imaging as a contrasting agent and then excreted to the urban wastewater system. The effluent also contained trace organic compounds such as surfactants, pharmaceuticals, hormones (Chapter 5), and pesticides (Chapter 6), which also were detected at downstream Boulder Creek sites. Water chemistry of Boulder Creek downstream of the WWTP is largely controlled by the degree of dilution of the wastewater effluent, which varies depending on the baseflow of Boulder Creek, the volume of wastewater effluent, and depletion by agricultural diversions. Coal Creek, a tributary of Boulder Creek, contains wastewater effluent from four additional WWTPs, and increases the load of many constituents in Boulder Creek. In addition to the impact from wastewater effluent, lower Boulder Creek is affected by agricultural land use. Eleven of 84 analyzed pesticides were detected in Boulder Creek or its inflows, primarily in the eastern section of the watershed (Chapter 6).

This collaborative study provides an in-depth evaluation of the hydrology, water chemistry, and sediment mineralogy of North Boulder Creek, Middle Boulder Creek, Boulder Creek, and major inflows. The detailed sampling and analysis in this report provide a baseline for future reference, as well as information on the effect of land use and geology on water chemistry.

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