Water Quality of the Boulder Creek Watershed, Colorado

Located within the Rocky Mountain Front Range of Colorado, the 1,160-km^2 Boulder Creek Watershed encompasses a variety of climate zones and geologic units (figs. 1 and 2). Water quality of Boulder Creek is affected by discharge variations from snowmelt, agricultural diversions, and wastewater treatment plant (WWTP) effluent, by point and non-point solute sources, and by in-stream processes. As with many watersheds in the American West, dependable water quality and sufficient water supply are issues facing local water managers and users.

This fact sheet summarizes the results of a cooperative study by the U.S. Geological Survey (USGS) and the city of Boulder to characterize the water quality of the Boulder Creek Watershed. Complete results of the study are published in USGS Water-Resources Investigations Report 03-4045 (Murphy and others, 2003). This study was initiated by discussions at the Boulder Creek Watershed Forum, a monthly gathering of watershed residents, USGS scientists, city of Boulder personnel, and University of Colorado researchers. The primary goals of this study were to 1) characterize Boulder Creek water quality in the year 2000, 2) identify sources and sinks of chemical constituents, and 3) identify the processes controlling water chemistry.

Results from this study provide community members with a better understanding of their watershed and a foundation for protecting and conserving water resources.

Photo 1. Boulder Creek. Lower basin in foreground and foothills and Continental Divide in background.

STUDY AREA

Boulder Creek originates as headwater streams at the Continental Divide and flows through historical mining districts and mountain communities to the mouth of Boulder Canyon. Upon exiting Boulder Canyon, Boulder Creek flows through the city of Boulder and eastward through the plains to the confluence with Saint Vrain Creek, 75 km downstream from the headwaters. Similar to many Front Range areas, the Boulder Creek Watershed area experienced rapid population growth from 1990 to 2000. As a consequence of this growth, acres of farmland in Boulder County decreased by 19 percent between 1992 and 1997 (U.S. Department of Agriculture, 1997).

APPROACH

Because of the large seasonal variation in flow (fig. 3), sampling was done during high-flow (mid-June) and low-flow (mid-October) conditions. Water-quality samples were collected from 18 sites along Boulder Creek and from 11 other sites (tributaries, WWTP effluent, pipelines, canals, and Saint Vrain Creek). Temperature, pH, dissolved oxygen, and specific conductance were measured on site. All samples were analyzed for 54 inorganic constituents, carbon, nitrogen, phosphorous, and fecal coliform bacteria. At ten sites, samples were analyzed for 84 pesticides and 68 wastewater compounds (Table 1).

RESULTS

Discharge

Low-flow conditions occur in Boulder Creek from October through March, and high-flow conditions occur from April to July, as snow melts, feeding the headwater streams. In addition to natural variations in discharge, water management, including impoundments, wastewater effluent, and agricultural diversions, causes temporal and spatial variations in discharge (fig. 3). The removal of water by diversions leaves less for dilution of constituents, such that WWTP

Photo 2. On-site processing, Boulder Creek.

effluent dominates the chemistry of the lower portion of Boulder Creek during low-flow periods.

Inorganic Geochemistry

Specific conductance, an indicator of total dissolved ions, was relatively low above the mouth of Boulder Canyon, increased slightly in the reach between the mouth of Boulder Canyon and upstream of the Boulder 75th Street WWTP (BC-aWWTP), and increased in a step-wise fashion below the WWTP (fig. 4a). Most dissolved inorganic constituents showed a similar downstream trend. Calcium, chloride, magnesium, silica, sodium, bicarbonate, and sulfate accounted for over 90 percent of the dissolved inorganic mass. Concentrations were lower during high flow because of dilution, primarily from snowmelt.

Bedrock geology is an important control of water chemistry in the watershed. When dissolved major ion concentrations in headwater sampling sites are compared to those in precipitation collected along the Continental Divide at Niwot Ridge, most constituents increased by factors of 10 to 20, which is consistent with minor weathering of the local bedrock. A greater amount of mineral dissolution occurs, due to longer ground-water flow paths and greater residence time, at the most downstream site in crystalline bedrock, BC-CAN. Although Boulder Creek passes through historical metal-mining districts, most dissolved metal concentrations, including arsenic, cadmium, chromium, copper, lead, nickel, and zinc, were extremely low, generally less than 1 microgram per liter.

As Boulder Creek flows from the foothills to the plains, not only does bedrock composition change, but potential anthropogenic sources increase. In the reach between Boulder Canyon and the Boulder WWTP, concentrations of most dissolved inorganic constituents increased. Differentiation between natural and anthropogenic sources of solutes is difficult because both likely contribute to the chemistry in this reach. However, the increase in bicarbonate, calcium, magnesium, sodium, and sulfate is consistent with weathering of the underlying sedimentary bedrock. In the reach through the city of Boulder, dissolved metal concentrations remained low.

The largest increase in dissolved constituents occurs downstream of the Boulder WWTP at site BC-75, with the greatest increases being chloride, nitrogen, sulfate, and sodium. The WWTP discharge accounted for about 75 percent of the discharge during the low-flow sampling and about 35 percent during high flow. The WWTP effluent had a positive gadolinium spike (Fig. 5) that can

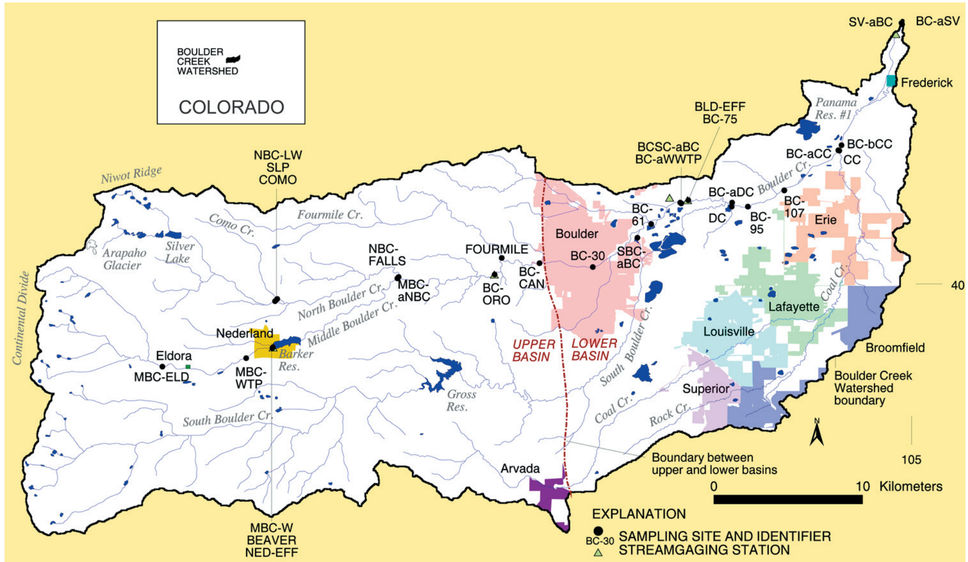
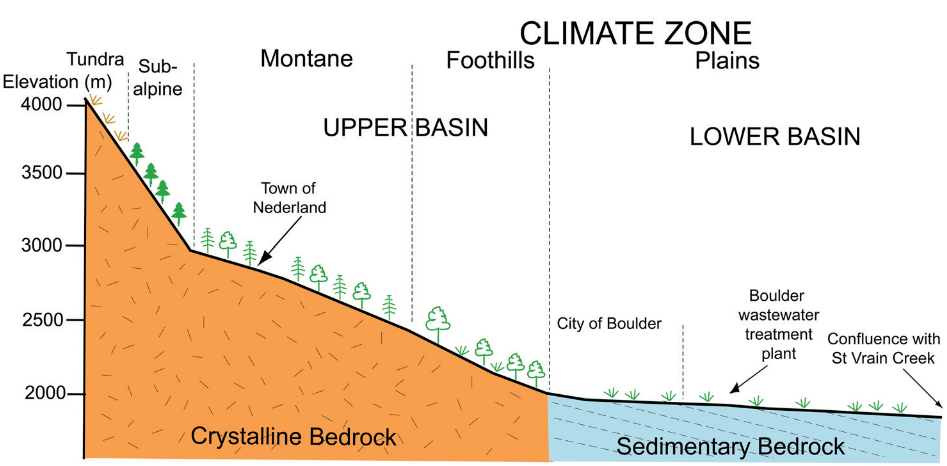


Figure 1. Boulder Creek Watershed: sampling sites and streamgaging stations.

Table 1. Groups of constituents analyzed in this investigation. Number in parentheses is the number of constituents determined in each group.[C, carbon; N, nitrogen; P, phosphorus]

Basic water-quality measurements (9)	**Organic constituents**
	Pesticides (84)
Inorganic constituents	Herbicides
Major anions (4)	Insecticides
Major cations (5)	**Wastewater compounds (68)**
Trace elements (45)	Surfactants
	Hormones
Nutrients (C, N, and P)	Steroids
Bacteria	Prescription drugs
Fecal coliform	Nonprescription drugs

Figure 2. Generalized elevation profile with climate zones and bedrock type.



be used as a geochemical signature of the effluent. Gadolinium (Gd), a rare earth element (REE), is not naturally enriched relative to other REEs, but it has industrial sources, primarily as gadopentetic acid, which is used as a contrasting agent in magnetic resonance imaging (MRI) that is then discharged to the urban wastewater system (Bau and Dulski, 1996). In contrast, the REE pattern of Nederland WWTP effluent does not have a Gd spike, which is consistent with the absence of MRI facilities in Nederland.

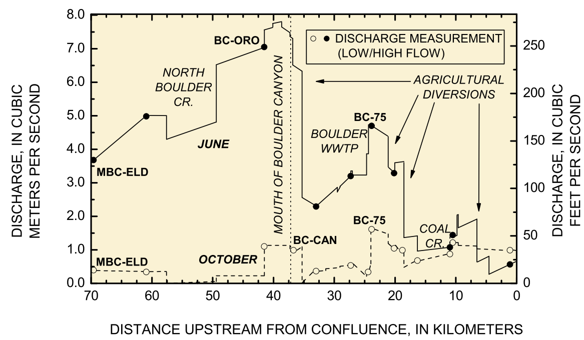


Figure 3. Graph showing estimated discharge along Boulder Creek, June 13 and October 10, 2000.

Another increase in inorganic dissolved constituents occurs from the inflow of Coal Creek, which receives WWTP effluent from Erie, Lafayette, Louisville, and Superior. The decrease in specific conductance during low flow in the reach between Coal Creek and the confluence with Saint Vrain Creek is likely due to dilution by ground-water inflow.

Nutrients

Concentrations of nitrogen (N) species and phosphorous (P) were near or below detection limits for main-stem sites upstream from the Boulder WWTP during both high- and low-flow sampling (Fig 4b). The concentrations of N and P were highest immediately downstream of the Boulder WWTP (BC-75), and then decreased with distance as these nutrients are utilized by plants and microorganisms or attached to particulates in the water column.

In the upper watershed, total organic carbon (TOC) concentrations (fig. 4c) were greater during high flow than low flow due to flushing of natural organic matter from soils by spring runoff. The greatest increase in TOC occurred below the Boulder WWTP, and concentrations decreased downstream due to biodegradation, sorption, and photolysis.

Fecal coliform

Throughout most of Boulder Creek, fecal coliform concentrations were well below the Colorado Department of Public Health and Environment recreation class 1a standard of 200 colonies per 100 milliliters (Colorado Department of Health and the Environment, 2002). However, four low-flow, main-stem Boulder Creek samples (BC-30, BC-75, BC-aDC, and BC-aCC) exceeded this standard.

Wastewater compounds

During high flow, 40 wastewater compounds were detected in the main stem of Boulder Creek at concentrations ranging from less than 1 to 100,000 nanograms per liter (ng/L). During low flow, 41 of these compounds were detected at concentrations up to 270,000 ng/L.

The most abundant wastewater compounds detected were ethylenediaminetetraacetic acid (EDTA), a widely used metal complexing agent, and nonylphenol ethoxycarboxlyates (NPEC), nonionic surfactant degradation products. Maximum concentrations of both EDTA and NPEC occurred downstream from the Boulder WWTP during low-flow conditions. The next most abundant compounds detected were the steroids (cholesterol and coprostanol). Steroid concentrations were an order of magnitude less than those of EDTA and NPEC, except in the upper basin, where natural sources produce steroids and there are limited sources of EDTA and NPEC. Other wastewater compounds detected in at least one Boulder Creek sample include: 1) the nonprescription drugs cotinine (a nicotine metabolite), acetaminophen, ibuprofen, and caffeine; 2) the prescription drugs cimetidine, diltiazem, diphenhydramine, sulfamethoxazole, and trimethoprim; 3) the hormones cis-androsterone, 17-alpha-estradiol, and equilinen; and 4) other organic wastewater compounds used as antioxidants, disinfectants, deodorizers, plasticizers, and surfactants. The concentrations of these compounds were much lower than the steroids, and they contributed only a small fraction of the total organic load. The results for the wastewater compounds measured in this study are consistent with results from a national reconnaissance for

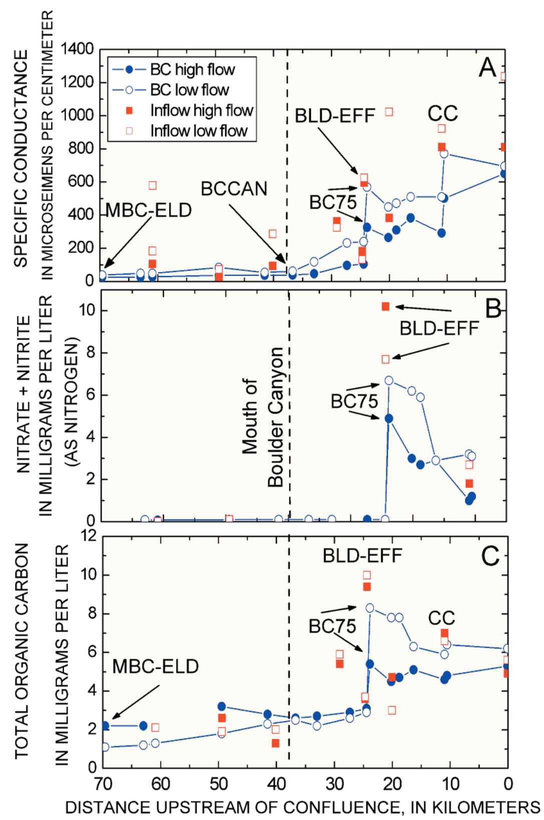


Figure 4. Graphs showing downstream variation of specific conductance (A), nitrogen (B), and carbon (C).

many of the same compounds (Kolpin and others, 2002).

Pesticides

About 7,890 kilograms of pesticides (active ingredient) are applied annually to agricultural land (primarily alfalfa, barley, corn, and wheat) in Boulder County, mostly in the lower basin. The most commonly applied pesticides are the herbicides atrazine, 2,4-D, dicamba, metolachlor, and glyphosate, and the insecticides terbufos, carbofuran, and chlorpyrifos.

Eleven pesticides were found at one or more sites in Boulder Creek or its inflows. This study used improved analytical methods that provided a broader range of pesticides analyzed and lower detection levels than previous studies. Pesticides were detected during both the high- and low-flow sampling, with more pesticides detected during low flow. Pesticides were mainly detected in samples from the lower basin, and the most frequently detected pesticide was diazinon (found at three Boulder Creek sites, Boulder WWTP effluent, and Coal Creek). Dichlobenil was the pesticide found at highest concentration (8 µg/L). Atrazine, metolachlor and parathion-methyl, used mainly in corn production, were found in Boulder Creek, but none of the other pesticides that are most commonly applied to lands in Boulder County were detected.

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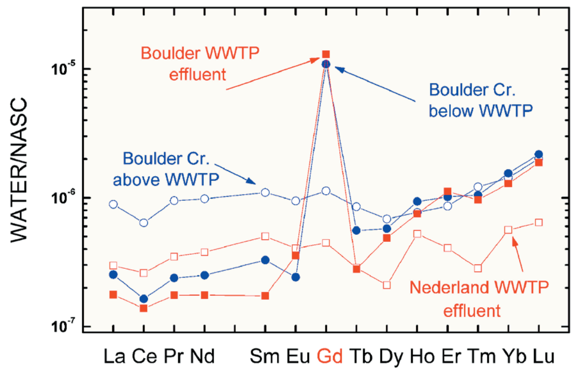

Figure 5. Graph showing the rare earth element patterns of selected low-flow samples. Concentrations normalized to concentrations in North American Shale Composite (NASC).

CONCLUSIONS

Rivers receive water that has interacted with upstream regions, such that water chemistry reflects both natural and human activity in a watershed. The detailed sampling and analysis in this report provide a baseline for future reference, as well as information on the relation between land use, geology, and downstream changes in water chemistry. The chemical analyses presented in this report include traditional water-quality constituents as well as low-level determinations of trace elements, pesticides, and wastewater compounds determined by relatively new analytical techniques.

Results include:

- High-flow concentrations were lower than low-flow concentrations due to greater dilution by snowmelt.
- Water quality of the headwater region reflects minor mineral dissolution of the crystalline bedrock; historical hardrock mining did not have a major effect on stream chemistry during these flow regimes.
- Concentrations of many constituents increased as Boulder Creek flows through the city of Boulder, in part reflecting the more easily weathered sedimentary bedrock.
- Treated effluent from the Boulder WWTP, which meets Colorado state water quality standards, dominates the chemistry of lower Boulder Creek, in part because upstream flow is diverted for municipal and agricultural uses and cannot provide instream dilution.
- Wastewater compounds were identified during both high- and low-flow conditions, indicating they are not removed during secondary treatment.
- Few pesticides were detected and were likely derived from urban and agricultural land uses.
- Boulder Creek contains a complex mixture of inorganic and organic constituents that are useful for determining geochemical and anthropogenic sources.

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Additional information about the Boulder Creek Watershed can be obtained at the Boulder Area Sustainability Information Network (BASIN) website at www.basin.org.