

# Salinization of the Upper Colorado River— Fingerprinting Geologic Salt Sources



Scientific Investigations Report 2009–5072

**COVER:** Uncompahgre River near Ridgway, Colorado.  
Photograph by John G. Elliott, U.S. Geological Survey, July 20, 2005.

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By Michele L. Tuttle and Richard I. Grauch

Scientific Investigations Report 2009–5072

**U.S. Department of the Interior**  
**U.S. Geological Survey**

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# Salinization of the Upper Colorado River—Fingerprinting Geologic Salt Sources

By Michele L. Tuttle and Richard I. Grauch

## Abstract

Salt in the upper Colorado River is of concern for a number of political and socioeconomic reasons. Salinity limits in the 1974 U.S. agreement with Mexico require the United States to deliver Colorado River water of a particular quality to the border. Irrigation of crops, protection of wildlife habitat, and treatment for municipal water along the course of the river also place restrictions on the river's salt content.

Most of the salt in the upper Colorado River at Cisco, Utah, comes from interactions of water with rock formations, their derived soil, and alluvium. Half of the salt comes from the Mancos Shale and the Eagle Valley Evaporite. Anthropogenic activities in the river basin (for example, mining, farming, petroleum exploration, and urban development) can greatly accelerate the release of constituents from these geologic materials, thus increasing the salt load of nearby streams and rivers. Evaporative concentration further concentrates these salts in several watersheds where agricultural land is extensively irrigated.

Sulfur and oxygen isotopes of sulfate show the greatest promise for fingerprinting the geologic sources of salts to the upper Colorado River and its major tributaries and estimating the relative contribution from each geologic formation. Knowing the salt source, its contribution, and whether the salt is released during natural weathering or during anthropogenic activities, such as irrigation and urban development, will facilitate efforts to lower the salt content of the upper Colorado River.

## Introduction

Nearly 33 million people and 4 million acres of farmland in the United States and 3 million people and 500,000 farmland acres in Mexico depend on the Colorado River (U.S. Department of Interior, 2005). The Colorado River is considered one of the most stressed rivers in the world because of increasing salinization (Serageldin, 2000), transporting 9 million tons of dissolved salt each year. Roughly half of

this salinity is from irrigation of agricultural fields, reservoirs, industry, and urbanization, and half from natural weathering. Salinity damages are estimated at \$306 million in the United States alone (U.S. Department of Interior, 2005) and \$1 billion per year overall (U.S. Water News Online, 1995). In accordance with requirements of the Clean Water Act, one million tons of salt per year have been controlled as of 2004, with a target control of 1.8 million tons per year by 2025, set by the Salinity Control Forum in 2002 (cited in U.S. Department of Interior, 2005). Achieving this target control standard requires identification of natural nonpoint sources (soils, geologic formations, and stream channels and banks) and an understanding of processes by which salinization occurs during irrigation and natural weathering. Evaluating the impact of these nonpoint sources is difficult; however, recent application of diagnostic geochemical tracers yielded successful results in other river systems (Vengosh, 2004).

In 2005, an estimated 5.8 million tons of salt was acquired by the Colorado River in the upper Colorado River basin (<http://www.usbr.gov/uc/progact/salinity/index.html>), a large portion of which is the focus of this study. The upper Colorado River and its tributary watersheds are located in mostly sparsely populated areas in mountainous terrain or in valleys that support agriculture; therefore, most solutes come primarily from geologic sources (such as rocks, soils, alluvium, and pediments). River reaches that travel through larger communities (Grand Junction being the largest with a population of around 126,000 at the time of this report) undoubtedly acquire some solutes from point sources such as municipal waste or industrial effluent; however, these contributions are small relative to those from geologic sources (Spahr and others, 2000).

Solutes in ground and surface water are released from geologic sources through natural weathering, or anthropogenic activities such as land development, mining, and irrigation. The major elements that make up the largest proportion of solutes in ground and surface water are calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chloride (Cl), sulfate (SO<sub>4</sub>), and bicarbonate (HCO<sub>3</sub>). These solutes are generally conservative in water, although precipitation of calcite can

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occur and Ca and Mg can be adsorbed during cation exchange reactions (Plummer and others, 2003). Dissolution of carbonate rocks (calcite— $\text{CaCO}_3$  and dolomite— $\text{CaMg}(\text{CO}_3)_2$ ) release Ca, Mg, and  $\text{HCO}_3^-$ ; gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) and anhydrite ( $\text{CaSO}_4$ ) release Ca and  $\text{SO}_4^{2-}$ ; halite ( $\text{NaCl}$ ) releases Na and Cl; and silicate minerals release Na, Ca, Mg, K, and  $\text{HCO}_3^-$ . During oxidation, sulfide minerals release  $\text{SO}_4^{2-}$  and various metals. Reactions on the surfaces or in the interlayers of clay minerals preferentially release sodium and potassium relative to other cations.

The scientific objective of this study was two-fold: (1) develop diagnostic geochemical tracers for the major geologic sources of salt to the upper Colorado River and (2) demonstrate the use of these tracers to understanding contributions of nonpoint geologic sources of salt to the upper Colorado River. Our strategy was to collect water samples from major Colorado River tributaries and along reaches of the upper Colorado River during snowmelt runoff (high-water flow), maximum diversion and irrigation-return (irrigation flow), and base stream flow (base flow). Calculated loading of chemical constituents along with geochemical tracers (element suites, element ratios, and stable isotopes) are applied to distinguish salinity sources, the quantity of salt generated from the source, and its composition. The data represent three snapshots in time and are not meant to represent an overall average of water quality. Our results show that, although element ratios help support the identification of various geologic contributions to the upper Colorado River salt load, the isotopes of sulfate are the most useful for identifying and quantifying specific sources. Trace elements help identify contributions from weathering of mineral deposits or mining waste, water isotopes are used to evaluate the effect of evaporation on increasing loads, and “available” concentrations assess elements dissolved plus those associated with geologic materials in suspension that dissolve when acidified. The latter results have important implications for health of organisms as several environments where acidification can occur are in animal lungs and stomach, plant root zones, and amended soil.

## Methods

### Sample Collection

Stations (fig. 1) were chosen to balance coverage of the upper Colorado River system above Cisco, Utah, with available analytical funds and maximum watershed information. Samples were collected in 2005. At each station, flow, conductivity, and pH were measured in the field. The last two parameters were also measured in the laboratory; laboratory results compared favorably with field values (only laboratory measurements are reported to decrease variability inherent when using different field meters). Six water samples

were collected at each station—two unfiltered and unacidified for alkalinity and water isotopes, two filtered ( $0.45 \mu\text{m}$ ) and unacidified for sulfur isotopes and major anions, one unfiltered and acidified for available cations,<sup>1</sup> and one filtered ( $0.45 \mu\text{m}$ ) and acidified for dissolved cations. “High-water” samples were collected in May during the period when snowmelt results in high stream flow.<sup>2</sup> “Irrigation” samples were collected in mid-July to mid-August when some tributaries of the upper Colorado River are affected by diversion and/or return of irrigation water. “Base flow” samples were collected in mid-October to late November during the period when runoff from irrigation and storms is approaching its minimum. Samples were filtered and acidified in the field, packed in ice, and shipped to the laboratory. Upon receipt, samples were refrigerated until analyzed.

Point-source waters (Glenwood Springs hot springs and Rifle Uranium Mill monitoring wells) were collected identically to stream samples. Composites of geologic samples were collected, transported to the laboratory, and split for various analyses.

## Analytical Procedures

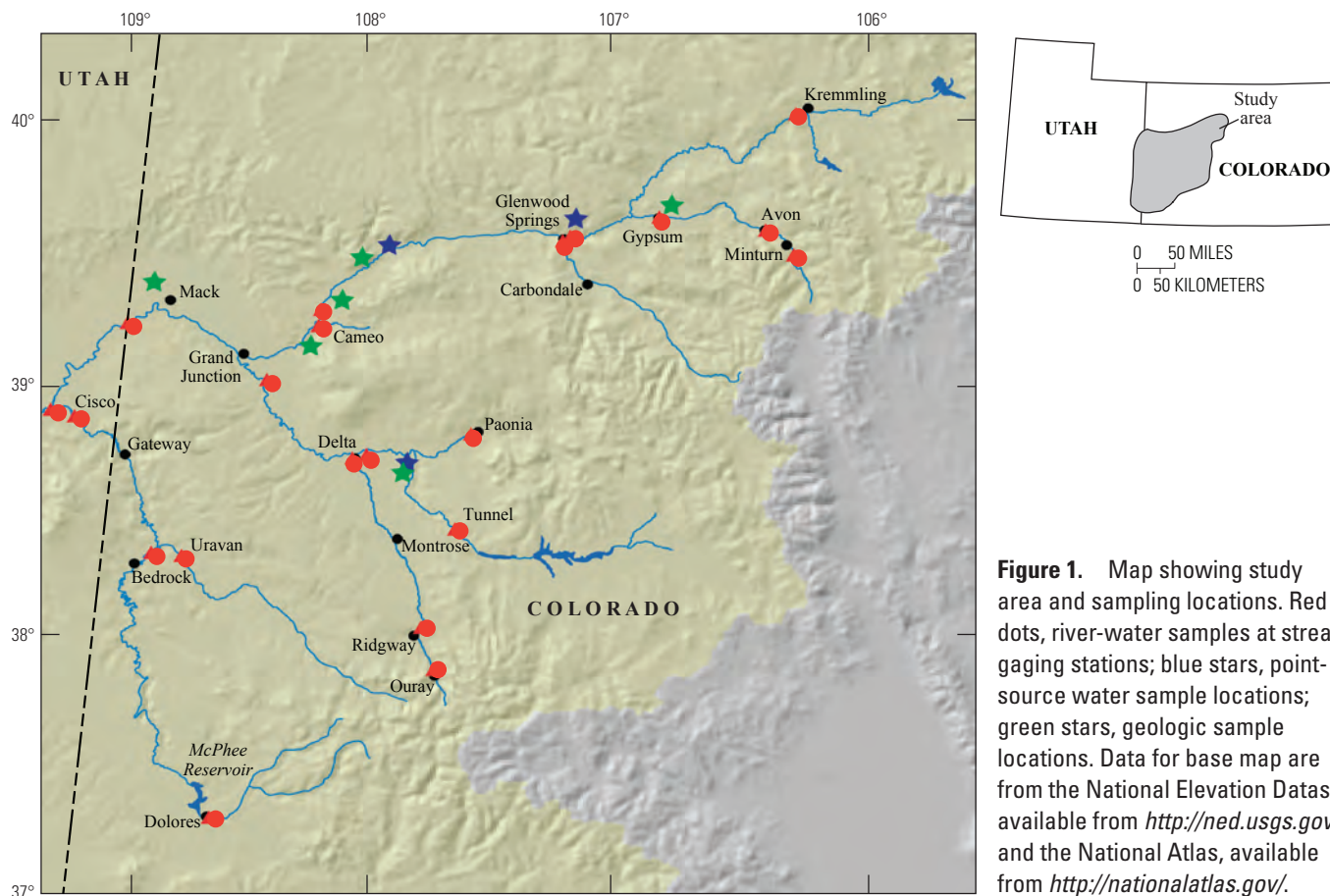
Water samples were analyzed for alkalinity (titration), anions (ion chromatography and gravimetrically), cations (inductive coupled plasma–atomic emission spectrometry and inductive coupled plasma–mass spectrometry), and stable isotopes of water and dissolved sulfate (mass spectrometry) (table 1). Charge balances were all less than 10 percent (average 3 percent), excepting three samples that were between 17 and 25 percent (Colorado River at Kremmling high water, Eagle River at Avon base flow, and Gunnison River below tunnel base flow). These three waters are dilute, and uncertainty in the bicarbonate analysis is suspected.

Geologic samples were completely digested using a lithium metaborate fusion or four-acid digestion (hydrochloric, nitric, perchloric, and hydrofluoric acids) and analyzed for major elements by ICP–AES and for minor and trace elements by ICP–MS (Taggart, 2002). A split was also analyzed for mineral identification and morphology under the SEM–EDX. Sulfur and oxygen isotopic composition was determined on individual sulfur species (oxygen only measured on the sulfate) and reported in standard delta notation<sup>3</sup> (Tuttle and others, 1986;

<sup>1</sup>In this study, available cations include dissolved cations plus those dissolved or desorbed upon acidification. For this analysis, water samples are collected, acidified, and then filtered ( $0.45 \mu\text{m}$ ) just prior to analysis by ICP–MS and ICP–AES.

<sup>2</sup>Sampling periods were chosen to coincide with synoptic sampling for other studies and may not always represent the ideal sampling period.

<sup>3</sup> $\delta(\text{‰}) = (R_{\text{sample}} - R_{\text{standard}}) \times 1,000$ , where  $R$  is the ratio of  $^{34}\text{S}:^{32}\text{S}$ ,  $^2\text{H}:^1\text{H}$ , or  $^{18}\text{O}:^{16}\text{O}$ , and the standards are V-CDT (Vienna Cañon Diablo Troilite) and V-SMOW (Vienna Standard Mean Ocean Water).



**Figure 1.** Map showing study area and sampling locations. Red dots, river-water samples at stream gaging stations; blue stars, point-source water sample locations; green stars, geologic sample locations. Data for base map are from the National Elevation Dataset, available from <http://ned.usgs.gov/>; and the National Atlas, available from <http://nationalatlas.gov/>.

**Table 1.** Methods of chemical analyses, their abbreviation used in the appendixes, and publication references to the procedures.

[References: 1, Taggert (2002); 2, Tuttle and others (1986); 3, Giesemann and others (1995)]

Methods	Abbreviation	Reference
Carbon/hydrogen/nitrogen commercial analyzer	CHN	
Cold vapor atomic adsorption spectrometry	CVAA	1
Combustion: SGS Laboratories (formerly XRAL), Toronto, Canada	COMB1	1
Combustion: USGS	COMB2	1
Coulometric titration	CT	1
Energy dispersive X-ray fluorescence	EDX	1
Graphite furnace	GF	1
Gravimetric	GRAV	2
Hydride generation atomic adsorption spectrometry	HYD	1
Ion chromatography	IC	1
Inductive coupled plasma–atomic emission spectrometry	ICP–AES	1
Inductive coupled plasma–mass spectrometry	ICP–MS	1
Ion selective electrode	ISE	1
Mass spectrometry	MS	3
Scanning electron microscopy–energy dispersive X-ray fluorescence	SEM–EDX	
Sulfur speciation	S <sub>spec</sub>	2

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Giesemann and others, 1995). Hydrogen and oxygen isotopes of water were commercially analyzed and reported in standard delta notation<sup>3</sup> relative to V-SMOW.

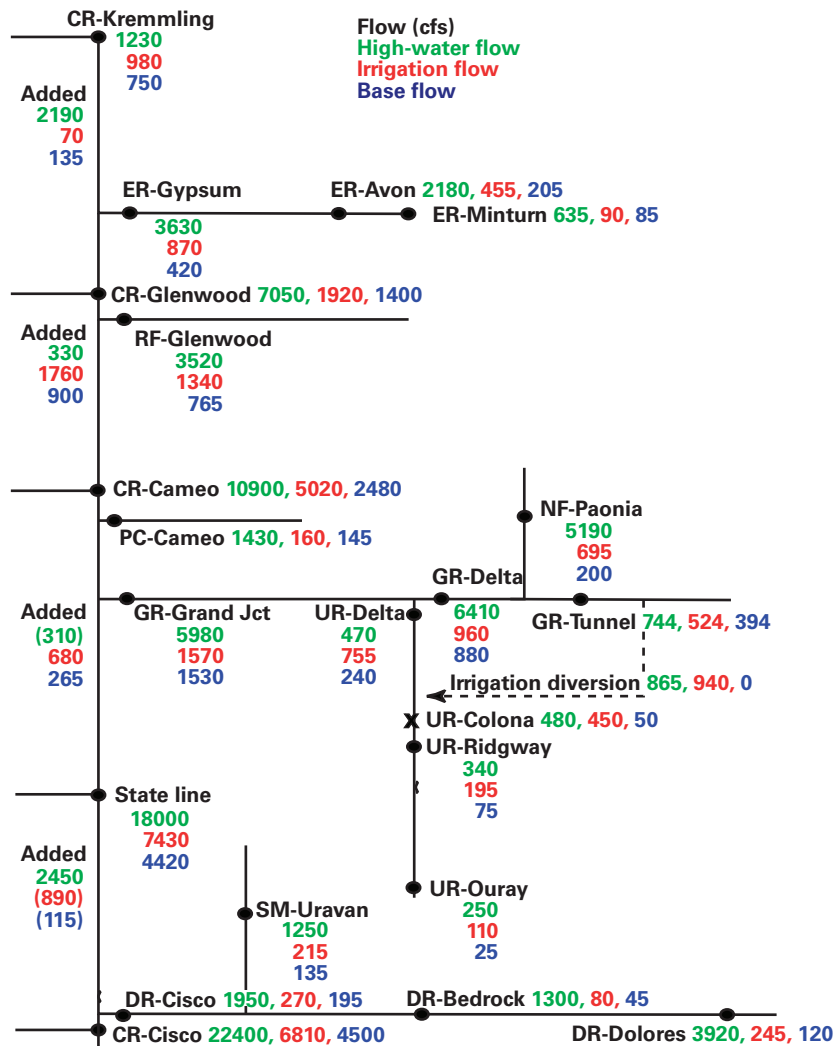
unfiltered sample). In this report, “available” data are only discussed with respect to transport of metals adsorbed to oxides and clays.

## Results

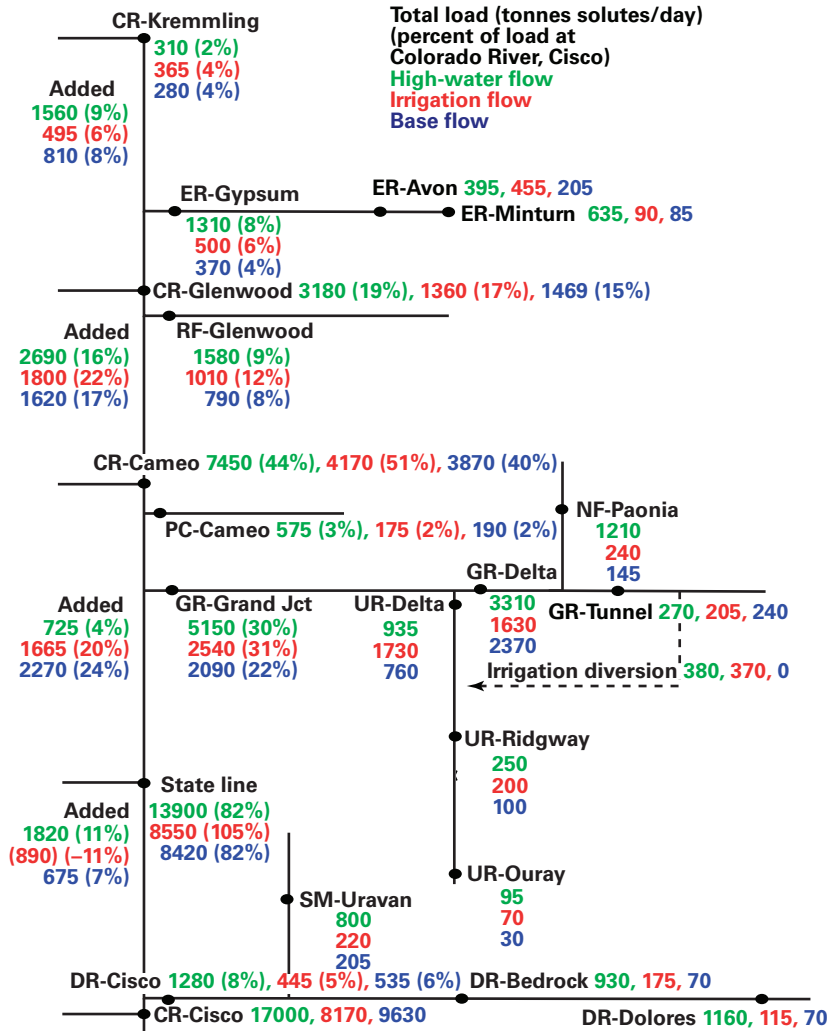
Individual chemical and isotopic results are presented in Appendixes I and III. In this study, we report two concentrations for each cation—aqueous (aq), which is operationally defined as dissolved (the filtered sample), and available (avail), which is defined as the dissolved concentration at the time of sampling plus those elements that dissolve or exchange upon acidification of the sample (the

## Flow and Solute Loads

Solute (chemical) loads in 10<sup>3</sup> kg/d (tonnes solute/day) (Appendix II) have been calculated for all major chemical constituents (aqueous and available) as the product between chemical concentration and flow at the time of sampling. Segment schematics for flow and total loads are shown in figures 2 and 3. When a constituent concentration remains constant, loads increase or decrease with flow rates. In



**Figure 2.** Schematic of flow in cubic feet per second (cfs) during high-water, irrigation, and base flows (not to scale). Also included are flows from irrigation diversion through the Gunnison Tunnel into the Uncompahgre watershed (dashed line; Paul Davidson, Bureau of Reclamation, written commun., 2007) and flows from the Ridgway State Dam at Colona (X symbol; USGS stream gaging data at <http://waterdata.usgs.gov/nwis/uv?09147500>). “Added” values are the increase in flow (calculated as the difference between stations along the Colorado River and represents added flow not directly measured in this study). CR, Colorado River; ER, Eagle River; RF, Roaring Fork River; PC, Plateau Creek; GR, Gunnison River; NF, North Fork of the Gunnison River; UR, Uncompahgre River; SM, San Miguel River; DR, Dolores River.



**Figure 3.** Schematic of total solute loads (tonnes solutes/day) during high-water, irrigation, and base flows (not to scale). Also included are loads from irrigation diversion through the Gunnison Tunnel into the Uncompahgre watershed (dashed line) and percent of the Colorado River load for lowermost tributary stations. “Added” values are loads acquired between stations along the Colorado River not attributable to measured loads in tributaries sampled. CR, Colorado River; ER, Eagle River; RF, Roaring Fork River; PC, Plateau Creek; GR, Gunnison River; NF, North Fork of the Gunnison River; UR, Uncompahgre River; SM, San Miguel River; DR, Dolores River.

some cases, however, loads vary in a more complex manner because concentrations in the water actually change as stream flow conditions change (for example, concentrations related to snow-melt runoff during high-water flow versus those related to ground-water discharge during base flow).

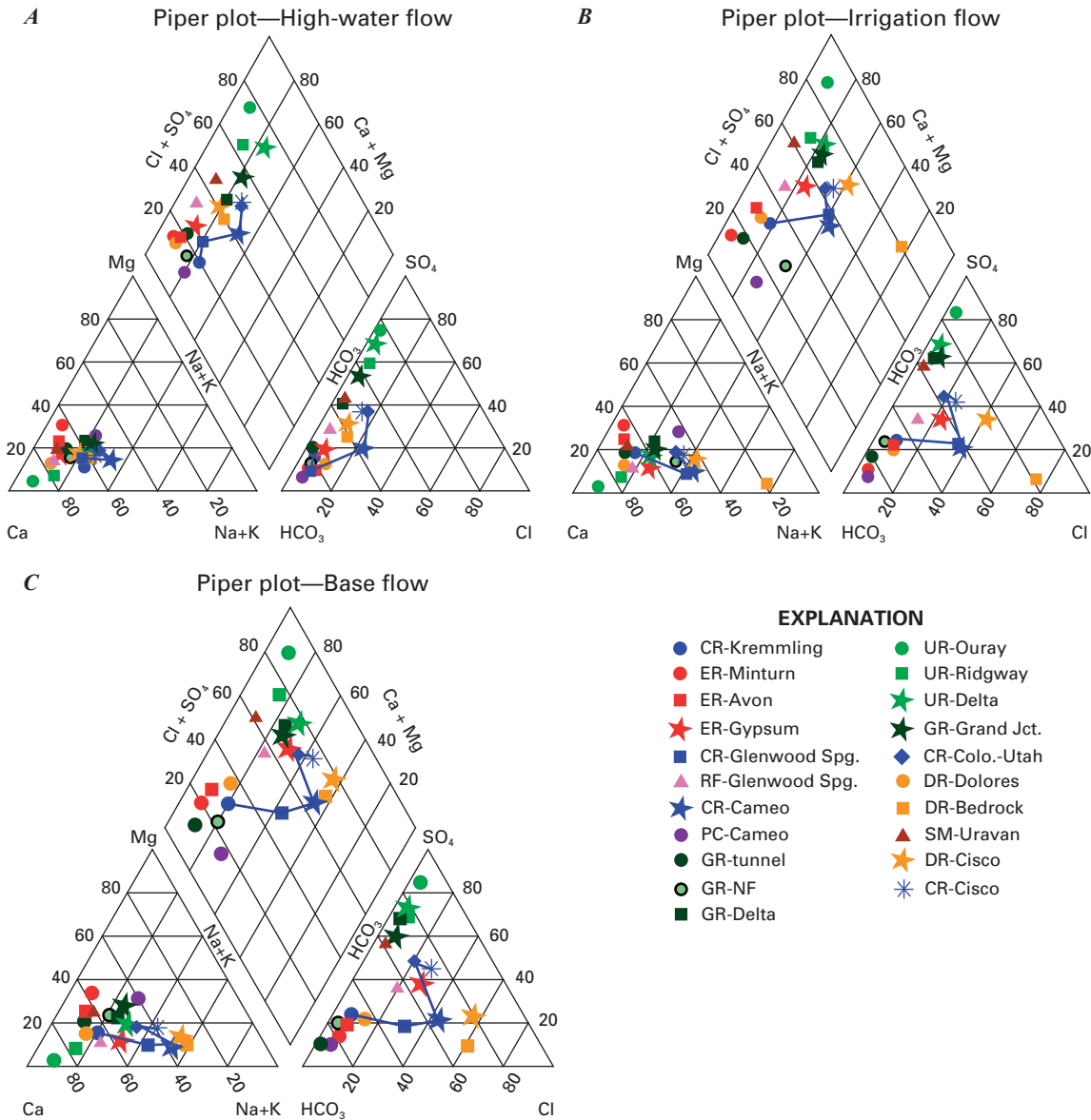
### Piper Diagrams

Piper diagrams, which are used to define water type in a standard format, are shown in figure 4. The blue line on these plots tracks the evolution of the upper Colorado River from

<sup>4</sup>Specific water types are defined as having at least 50 percent of the cation and anion on a milliequivalent (meq) basis. Mixed water types are those with no cation and/or anion that are >50 percent on a meq basis.

its headwater station at Kremmling to the farthest downstream station sampled at Cisco. The major cation (>50 percent on meq basis) in water during high-water flow conditions is Ca (fig. 4A); the major anion is HCO<sub>3</sub> in all but four samples where SO<sub>4</sub> is the dominant anion. Therefore, most of these samples during high water are calcium-bicarbonate water except for the four calcium sulfate waters in the Uncompahgre River and the lowermost Gunnison.<sup>4</sup> The two lowermost Colorado River samples plot just outside the calcium bicarbonate water field and are technically a mixed-water type.

During irrigation-flow conditions, all headwater samples are calcium bicarbonate water, except for the headwater of the Uncompahgre River (fig. 4B). All water in the Uncompahgre River, water in the Gunnison River below its headwater stations, and water at the San Miguel River station



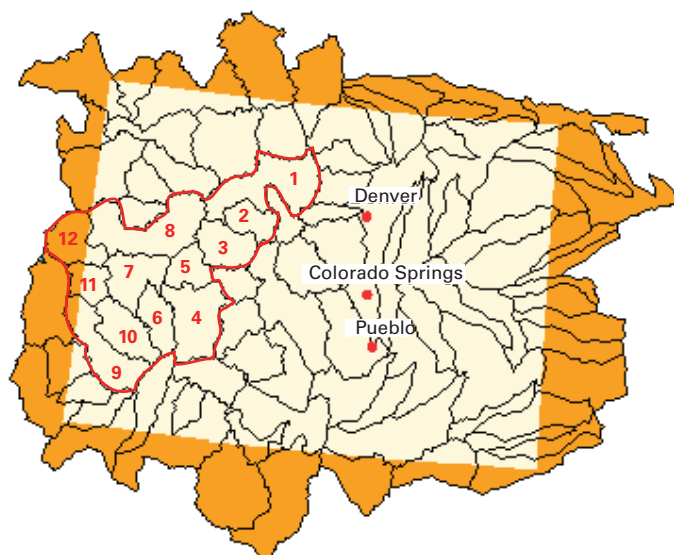
**Figure 4.** Piper plots for water at all stations sampled in this study during (A) high-water flow, (B) irrigation flow, and (C) base flow. Data are plotted on a milliequivalent basis. CR, Colorado River; ER, Eagle River; RF, Roaring Fork River; PC, Plateau Creek; GR, Gunnison River; UR, Uncompahgre River; SM, San Miguel River; DR, Dolores River.

are of a calcium sulfate type. The Dolores River water at Bedrock is a sodium chloride type, whereas all other waters are of a mixed type. All Colorado River water below its headwater station is a mixed type; however, at the Colorado-Utah State line and at Cisco, the water approaches the  $\text{SO}_4$  field.

During base-flow conditions, headwater samples remain calcium bicarbonate water, except at the Uncompahgre River headwater station (fig. 4C). All of the Uncompahgre River and the San Miguel River stations remain calcium sulfate water. The Dolores River at Bedrock and Cisco is sodium chloride water. Water at all other stations is of a mixed type. The largest change in water type in the Colorado River is at Glenwood Springs, where the water type moves toward the Cl field and is very similar to Colorado River water at Cameo.

### Geochemistry at Stations Along Tributary Watersheds to the Upper Colorado River Above Cisco, Utah

The following discussion of individual tributary results has been organized by watershed. Watersheds for each tributary, as well as those for the upper Colorado River within the study area, are indexed with a number in the map in figure 5. Geologic descriptions of these watersheds were taken from Warner and others (1985), Hintz and others (2000), and Day and others (1999). Estimates for the distance of each confluence considered in our study from the uppermost Colorado River sample at Kremmling are in table 2. The data presented herein characterize nearly 350 km of the upper Colorado River.



- |                                    |                                    |
|------------------------------------|------------------------------------|
| 1 Colorado River headwaters        | 7 Lower Gunnison River             |
| 2 Eagle River                      | 8 Colorado River headwater-plateau |
| 3 Roaring Fork River               | 9 Upper Dolores River              |
| 4 Upper Gunnison River             | 10 San Miguel River                |
| 5 North Fork of the Gunnison River | 11 Lower Dolores River             |
| 6 Uncompahgre River                | 12 Westwater Canyon                |

**Figure 5.** Index map for watersheds considered in this study (numbered 1 to 12). This map and those for watersheds listed were downloaded from <http://www.epa.gov/surf/>.

**Table 2.** Approximate distances of major tributary confluences on the Colorado River considered in this study downstream from the Kremmling station.

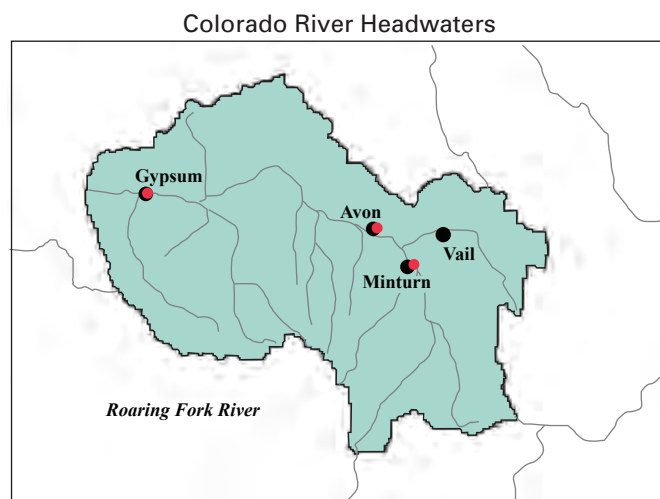
Confluence	Distance (km)
Eagle River	80
Roaring Fork River	112
Plateau Creek	215
Gunnison River	250
Dolores River	345

## Eagle River

Three stations were sampled within the Eagle River watershed (fig. 6)—near or at Minturn, Avon, and Gypsum. The flow of the Eagle River is not controlled by any major reservoirs. The rocks upstream from Minturn are metamorphic and carbonate rocks, some mineralized. Between Minturn and Avon, rocks are predominately sedimentary and include carbonates, sandstones, and shales. Below Avon, the Eagle River crosses large expanses of Pennsylvanian Eagle Valley Evaporite composed of thick salt beds (mostly gypsum at the surface with halite at depth) and some sandstone and shale. Starting along the tributary at Vail and continuing downstream past Avon, the river valley is heavily developed with recreational communities. Some historic mining of base and precious metal ore occurred in the upper reaches of this watershed, and gypsum (Eagle Valley Evaporite) and volcanic cinder are mined in the lower portion of the river valley.

## Eagle River Near Minturn, Colorado

The conductivity at this station is low (less than 140  $\mu\text{S}/\text{cm}$ ), and the water is a calcium bicarbonate type (fig. 4; table 3). Waters at this station contain relatively high concentrations of dissolved and available Fe, Mn, and Zn (table AI-3). These metal concentrations, which are related to historic mining in the headwater area (for example, Eagle mine), decrease downstream. The  $\text{Ca}:\text{SO}_4$  ratio (table 3) at this station during high-water flow is consistent with most Ca being derived from the dissolution of minerals other than gypsum and the  $\text{Na}:\text{Cl}$  ratio with halite dissolution. Exposure of the Eagle Valley Evaporite does not occur in the watershed at or upstream from this station. Although speculative, the application of deicer mixtures that contain halite could explain the ratio during high-water flow, as much of the upstream watershed is in areas where winter high-way maintenance includes deicing roads along the stream. Deicer contamination was also suggested by a concentration in shallow aquifers in the urban corridor on the east side of the continental divide (Flynn, 2003). During irrigation and base-flow conditions (periods when deicer is not being applied to the roads), the  $\text{Na}:\text{Cl}$  ratio increases slightly suggesting another source of sodium, and the  $\text{Ca}:\text{SO}_4$  ratio decreases suggesting an additional source of sulfate. Isotopes for the dissolved sulfate (fig. 7) are relatively constant during irrigation and base flow (the sulfate concentration at high-water flow was too low for isotope measurement). Isotope values are consistent with sulfate derived from oxidation of sulfide ores (fig. 7) predominately with atmospheric oxygen (Taylor and Wheeler, 1994).



**Figure 6.** Map of the Eagle River watershed (no. 2 on fig. 5), showing adjacent sampled watersheds, Minturn (the uppermost stream station), Avon (6 km from Minturn), and Gypsum (50 km from Minturn); the latter is the lowermost station in the watershed. Red dots, stations sampled. This and all subsequent watershed maps modified from those at <http://www.epa.gov/surf/>.

**Table 3.** Summary of geochemical parameters for the Eagle River at Minturn.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Eagle River at Minturn	HW	IRR	BF
Charge balance (percent)	-9	2	1
Conductivity ( $\mu\text{S}/\text{cm}$ )	105	140	110
Water type	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>
Load (tonnes solutes/day)	115	25	18
Percent CR load at Cisco	1	<1	<1
Ca:SO <sub>4</sub> (molar basis)	5.7	4.1	3.1
Na:Cl (molar basis)	1.1	1.4	1.2
Evaporation	no	no	no
SO <sub>4</sub> source	mineralization	mineralization	mineralization

### Eagle River at Avon, Colorado

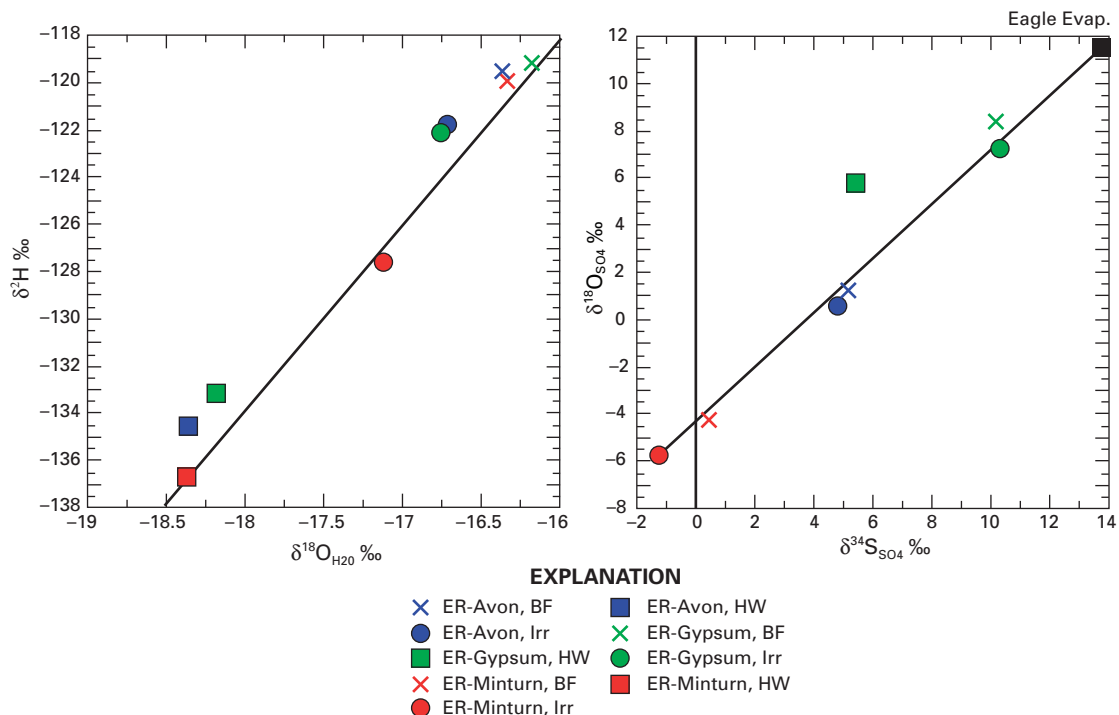
During high-water flow, the water at this station has a composition very similar to that at Minturn (fig. 4); however, the load at Avon increases by 3.5 times that at Minturn because the flow increases by a similar amount (table 4). During irrigation conditions, the Ca:SO<sub>4</sub> ratio decreases (table 4) as the SO<sub>4</sub> concentration more than doubles (although still a small concentration), whereas concentrations of the other major elements change only slightly. The source of the additional sulfate is isotopically heavier than that at Minturn (fig. 7), suggesting that some dissolution of Pennsylvanian evaporites ( $\delta^{34}\text{S}_{\text{SO}_4} = 14\text{‰}$  and  $\delta^{18}\text{O}_{\text{SO}_4} = 11\text{‰}$ ; table AIII-2) is contributing to the salt load. The Na:Cl ratios during all flow conditions are near one, consistent with dissolution of halite in the Eagle Valley Evaporite.

### Eagle River at Gypsum, Colorado

The conductivity of water at this station is between 2 and 2.5 times that at Avon under all flow conditions (table 5). During high-water flow, the river water is a calcium bicarbonate type. During irrigation and base flow, a higher proportion of sulfate changes the water to a mixed anion type with Ca continuing to be the predominant cation (fig. 4). The Ca:SO<sub>4</sub> ratios (table 5) are lower than at Avon and are highest during high-water flow. The dissolution of gypsum in the Eagle Valley Evaporite contributes a greater proportion of sulfate during irrigation and base-flow conditions as evident from the dramatic rise in the  $\delta^{34}\text{S}_{\text{SO}_4}$  and  $\delta^{18}\text{O}_{\text{SO}_4}$  values (fig. 7).

### Geochemical Evolution Along the Eagle River

The composition of the Eagle River between Minturn and Avon changes little (fig. 4); however, there is an increase in sulfate proportion at Gypsum, especially during irrigation and base flow. The increased flow during high water increases the load of the river by over three times that during irrigation or base flow. Between Avon and Gypsum, HCO<sub>3(aq)</sub> and SO<sub>4(aq)</sub> concentrations increase as well as concentrations of many of the “available” elements (table AI-3). “Available” element concentrations significantly influence loads during high flow as soil and fine rock particles are carried in the more turbulent runoff. These particles consist of detrital components rich in resistate minerals containing Ba, rare earths, Sc, Si, Ti, and in oxides and oxide coatings rich in Al, Fe, Mn, and adsorbed metals such as Cd, Co, Cr,



**Figure 7.** Cross plots showing relations between isotopic composition of  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  of water and the GMWL (left) and  $\delta^{18}\text{O}$  and  $\delta^{34}\text{S}$  of dissolved sulfate in the Eagle River (ER) at three sampling stations during three flow seasons (right). HW, high-water flow; Irr, irrigation flow; BF, base flow. Hydrogen and oxygen isotopes measured relative to V-SMOW and sulfur isotopes relative to V-CDT.



**Table 4.** Summary of geochemical parameters for the Eagle River at Avon.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Eagle River at Avon	HW	IRR	BF
Charge balance (percent)	3	2	17
Conductivity ( $\mu\text{S}/\text{cm}$ )	100	130	190
Water type	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>
Load (tonnes solutes/day)	395	105	100
Percent CR load at Cisco	2	1	1
Ca:SO <sub>4</sub> (molar basis)	4.8	2.4	1.9
Na:Cl (molar basis)	0.86	0.98	0.96
Evaporation	no	no	no
SO <sub>4</sub> source	mineralization + evaporites	mineralization + evaporites	mineralization + evaporites

**Table 5.** Summary of geochemical parameters for the Eagle River at Gypsum.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Eagle River at Gypsum	HW	IRR	BF
Charge balance (percent)	9	-2	-3
Conductivity ( $\mu\text{S}/\text{cm}$ )	190	360	555
Water type	Ca-HCO <sub>3</sub>	mixed	mixed
Load (tonnes solutes/day)	1,310	500	370
Percent CR load at Cisco	8	6	4
Ca:SO <sub>4</sub> (molar basis)	2.6	1.6	1.4
Na:Cl (molar basis)	1.3	1.2	1.1
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	evaporites	evaporites	evaporites

Cu, Ni, V, and Zn. During base-flow conditions, significant concentrations of evaporite-related elements such as those from halite (Na and Cl) and from gypsum (Ca, Sr, and SO<sub>4</sub>) influence the load primarily through discharge of ground water that has flowed through Eagle Valley Evaporite.

The  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  values of the Eagle River water for all flow conditions fall on or very close to the global meteoric water line (GMWL; represented by  $\delta^2\text{H} \text{‰} = 8\delta^{18}\text{O} \text{‰} + 10 \text{‰}$  relative to SMOW; Craig, 1961) (fig. 7). Little evaporation of the water takes place along the river, and the variation in position along the water line among flow conditions reflects changing proportions of water derived from snowmelt during high flow (isotopically lighter values<sup>5</sup>) to ground-water discharge during base flow (isotopically heavier values).

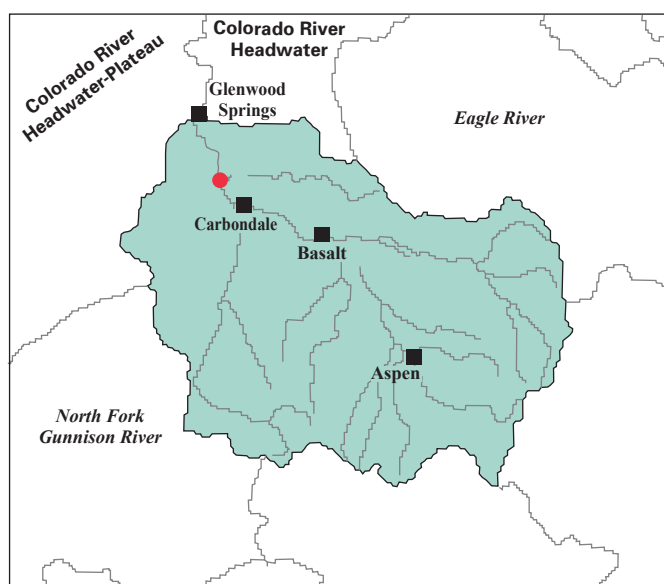
Spatial and temporal variation in the sulfate isotopic composition among the three stations along the Eagle River results in a line, except for the Eagle River at Gypsum during high-water flow (fig. 7). The evolution of the sulfate derived principally from sulfide oxidation is distinct from that derived from Eagle Valley Evaporite, and mixing of these two sources is evident from this linear relation. It is possible that during high-water flow, an additional source contributes to the sulfate, causing the isotopic

<sup>5</sup>In this report, isotopically lighter refers to a depletion in the heavier isotope (<sup>2</sup>H, <sup>18</sup>O, or <sup>34</sup>S), resulting in a smaller  $\delta$  value relative to the appropriate standard, and conversely, isotopically heavier refers to an enrichment in the heavier isotope, resulting in a larger  $\delta$  value.

composition to deviate from the linear trend. Unfortunately, sulfate concentrations were too low in the samples collected from the Eagle River at Minturn and Avon during high water to analyze for isotopes to confirm this additional source. Isotope mass-balance calculations indicate that the source of the dissolved sulfate at Avon during irrigation and base flow is 60 percent from the upstream source (presumably sulfide oxidation that would be consistent with the lighter isotope compositions) and 40 percent from evaporites. At Gypsum, 75 percent of the sulfate is from evaporites and 25 percent from an upstream source.

## Roaring Fork River at Glenwood Springs, Colorado

Flow in the Roaring Fork River (fig. 8) is regulated by Reudi Reservoir east of the town of Basalt. The geology in this watershed is mostly igneous rocks in the headwaters, Pennsylvanian and Permian rocks, including evaporites, and Cretaceous Mancos Shale in the lower portions of the watershed. The water type at this station is calcium bicarbonate during high-water and irrigation flow and a mixed type with increasing sulfate and chloride contributions during base flow (fig. 4, table 6). During irrigation and base flow, the Ca:SO<sub>4</sub> and Na:Cl ratios (table 6) look very similar to those in the Colorado River above Glenwood Springs. During high water, both ratios are higher, likely due to an increased contribution from igneous rocks in the headwaters during runoff (HCO<sub>3</sub> contribution is larger as well). The sulfate isotope data (see fig. 16 in Geochemical Evolution of the Colorado River Above Cisco) fall on a mixing trend of sulfate derived from Eagle Valley Evaporite and likely crystalline rocks upstream. Isotope measurements show that Mancos Shale contributes little sulfate to this river.



**Figure 8.** Map of Roaring Fork River watershed (no. 3 on fig. 5) showing adjacent sampled watersheds. Red dot, station sampled. Map modified from <http://www.epa.gov/surf/>.

**Table 6.** Summary of geochemical parameters for Roaring Fork River at Glenwood Springs.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Roaring Fork River at Glenwood Springs	HW	IRR	BF
Charge balance (percent)	0.4	-0.6	-3
Conductivity ( $\mu\text{S}/\text{cm}$ )	250	440	600
Water type	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>	mixed
Load (tonnes solutes/day)	1,580	1,010	790
Percent CR load at Cisco	9	12	8
Ca:SO <sub>4</sub> (molar basis)	2.2	1.7	1.6
Na:Cl (molar basis)	1.7	1.3	1.2
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	evaporites	evaporites	evaporites

## Gunnison River

The Gunnison River and its tributaries flow through six watersheds. Seven stations within four of these watersheds were sampled (fig. 9). The flow in the Gunnison River is controlled by dams on Taylor River, the mainstream Gunnison River, Muddy Creek, and Uncompahgre River.

## Uncompahgre River

### Uncompahgre River Near Ouray, Colorado

The flow of the water at this station (fig. 9) is not controlled by reservoirs upstream. The geology within the watershed upstream is volcanic rock that is mineralized in places. The conductivities at this station are higher than any others in the headwater group and waters are of a different type (calcium sulfate instead of calcium bicarbonate; fig. 4, table 7). This difference likely reflects the intense mining in this area related to Tertiary mineralization in the watershed. The volcanic rocks along the Uncompahgre River upstream from this station are highly altered with large mining reclamation sites in and along the drainage. Oxidation of sulfide ores and dissolution of primary and secondary gypsum in ores related to these deposits and alteration zones are likely the source of sulfate (see isotope discussion below). Water at this station also contains relatively high concentrations of dissolved Cd, Co, Cu, Ni, and Zn (only Cd and Zn exceed the chronic freshwater maximum contaminant level of 0.25  $\mu\text{g}/\text{L}$  and 120  $\mu\text{g}/\text{L}$ , respectively; EPA, 2006), as well as high concentrations of available base-metal concentrations ( $\text{Cu}_{(\text{avail})}$ ,  $\text{Fe}_{(\text{avail})}$ ,  $\text{Mn}_{(\text{avail})}$ ,  $\text{Pb}_{(\text{avail})}$ , and  $\text{Zn}_{(\text{avail})}$ ). The metal concentrations decrease with distance downstream and are not anomalous in the Gunnison River downstream from its confluence with the Uncompahgre. The Na:Cl ratios (table 7) are greater than one indicating that sodium is probably being derived from the volcanic rocks. The Ca:SO<sub>4</sub> ratios of near one are consistent with sulfate being derived predominately from primary gypsum and/or secondary gypsum that formed following oxidation of sulfides. Pyrite in mineralized areas across the divide from the Uncompahgre headwaters has an average  $\delta^{34}\text{S}_{\text{py}}$  of

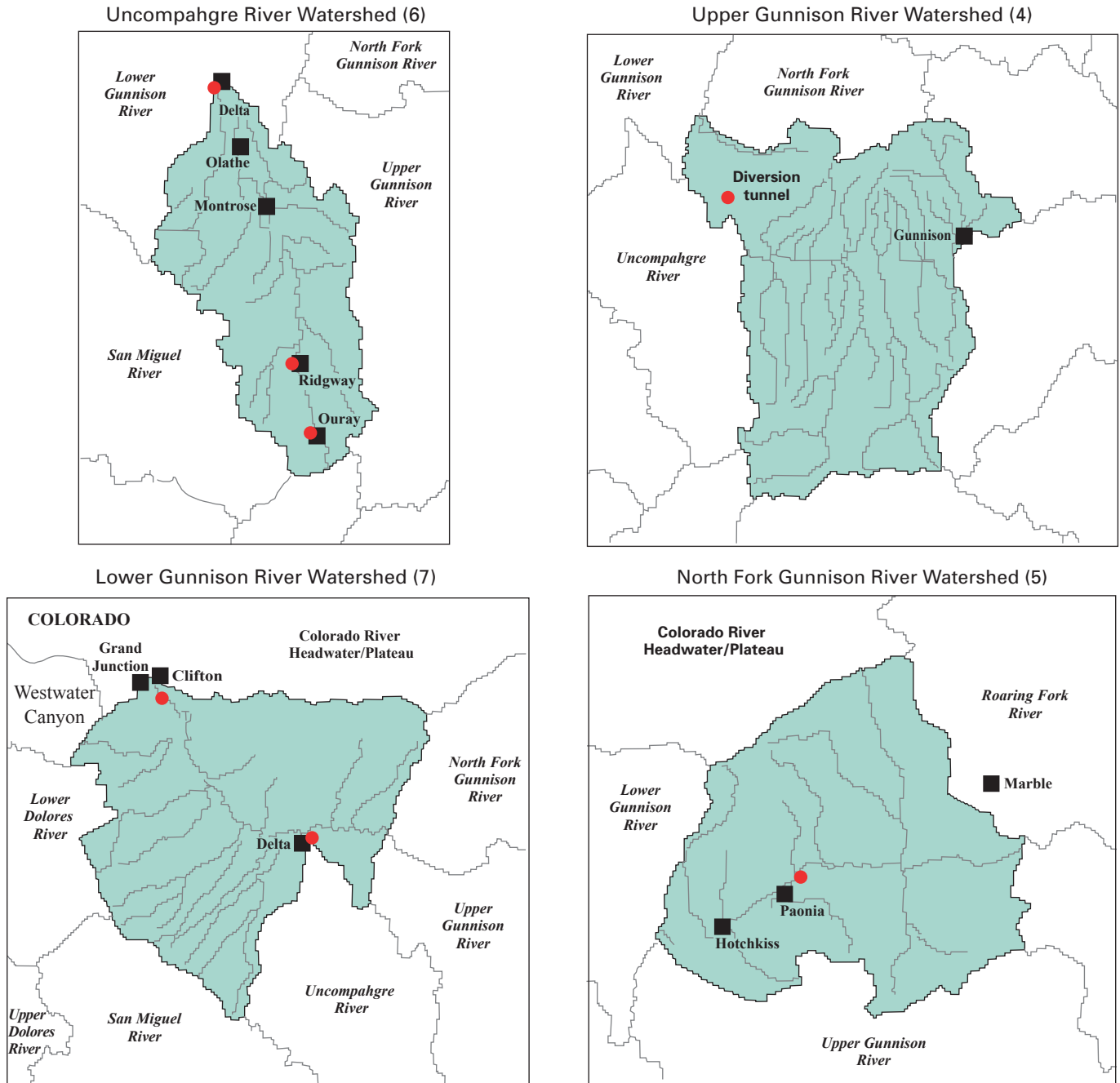
-3 per mil, and cogenetic gypsum has an average of 16 per mil (Nordstrom and others, 2007) compared to the 2.9 per mil in sulfate at our station during high water (fig. 10). From high water to irrigation flow to base flow, there is a small, but systematic shift to isotopically heavier sulfate ( $\delta^{34}\text{S}_{\text{SO}_4} = 2.9$  to 4.1 to 6.8 ‰, respectively), accompanied by a similar small increase in  $\delta^{18}\text{O}_{\text{SO}_4}$  (-4.3 to -3.3 to -1.6 ‰). These data suggest that the sulfate in the Uncompahgre River at Ouray could be derived from both sulfide oxidation and primary gypsum dissolution upstream, with gypsum dissolution becoming more important during low stream flow. The isotope values at the station may also reflect the input of sulfate in Canyon Creek, an upstream tributary, which has a  $\delta^{34}\text{S}_{\text{SO}_4}$  of 7.3 ‰ and a  $\delta^{18}\text{O}_{\text{SO}_4}$  value of -1.6 ‰ (Tuttle, unpub. data). A change in the proportion of this tributary contribution could explain the shift in isotope values among flow conditions. Unfortunately, we do not have adequate data to test these two hypotheses.

### Uncompahgre River Near Ridgway, Colorado

The flow of the Uncompahgre River at this station is not controlled by reservoirs. The geology along this reach of the Uncompahgre River consists predominantly of Tertiary volcanics and Permian, Triassic, and Jurassic sedimentary rocks. The marine, Cretaceous age Mancos Shale crops out at the downstream end of this stretch of the river. The Ca:SO<sub>4</sub> ratio is near one (table 8), suggesting that the source of these solutes is gypsum, and the Na:Cl ratios are three or greater, indicating that the sodium likely is sourced from the volcanic rocks upstream. Ratios are similar under different flow conditions, suggesting that similar sources of solutes are likely. The isotope values for dissolved sulfate (fig. 10) are essentially the same from high-water flow to irrigation flow and are somewhat lighter than those at Ouray, suggesting a new source of sulfate, although the dominant source is still the same as at Ouray. This new source of sulfate is the Mancos Shale, which contains sulfate with negative  $\delta^{34}\text{S}_{\text{SO}_4}$  values (average of -21 ‰; Tuttle, unpub. data). During base flow, the isotopes in the sulfate evolve to heavier values as seen in the Ouray isotopes, reflecting either the change from sulfide to primary gypsum as the dominant source in the headwaters or a change in the proportion of tributary flow upstream.

### Uncompahgre River at Delta, Colorado

The flow of the Uncompahgre River at Delta is controlled by a reservoir upstream (below the station near Ridgway and just above the town of Colona), and, during high-water flow and irrigation conditions, by contributions of water diverted for irrigation from the Gunnison River just above the tunnel station (see discussion below). The geology in this lower portion of the watershed is dominated by the Cretaceous Dakota Sandstone and Mancos Shale. Selenium concentrations exceed the Colorado State freshwater chronic standard of 4.6  $\mu\text{g}/\text{L}$  (CDPHE, 2003) during all flow regimes. The Ca:SO<sub>4</sub> ratios



**Figure 9.** Maps of upper Gunnison River (no. 4), North Fork of the Gunnison River (no. 5), Uncompahgre River (no. 6), and lower Gunnison River (no. 7) watersheds (numbers refer to locations shown on fig. 5) showing adjacent sampled watersheds. The farthest upstream sample on the Gunnison River (Tunnel station) is 80 miles above confluence with the Colorado River (CR). The Paonia station is in the North Fork of the Gunnison watershed and three stations (Ouray, Ridgeway, and Delta stations) are in the Uncompahgre watershed. Red dots, stations sampled. Maps modified from <http://www.epa.gov/surf/>.

are all less than one, and at base flow, fall to 0.7 (table 9). The Na:Cl ratios are high and, together with the low Ca:SO<sub>4</sub> ratios, suggest that dissolution of sodium sulfate efflorescent salts contributes to these solutes. These highly soluble salts are common on and in Mancos soils and form during weathering when CaSO<sub>4</sub> dissolves and Ca exchanges for Na on the marine clays (this process in the Mancos Shale is described in Tuttle

and others, 2005). Although Na-salt dissolution plays a role in solute loading at this station, it does not alter the water from a predominantly calcium sulfate type. Isotopes of sulfate (−18 to −15 ‰; fig. 10) substantiate that the dominant source of sulfate is oxidation products from sulfides in the Mancos Shale during weathering. Evaporation of irrigation water is reflected in the water isotopes (fig. 10).

**Table 7.** Summary of geochemical parameters for the Uncompahgre River near Ouray.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

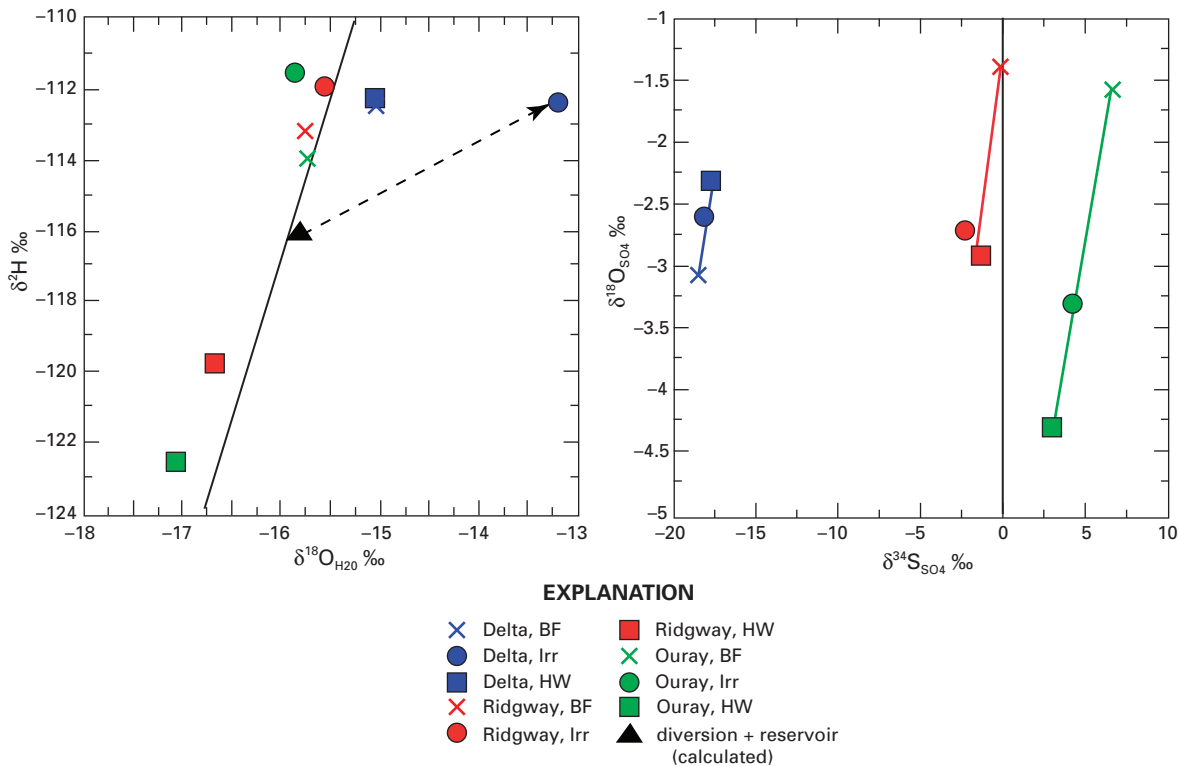
Uncompahgre River near Ouray	HW	IRR	BF
Charge balance (percent)	21	18	4
Conductivity (μS/cm)	235	395	625
Water type	Ca-SO <sub>4</sub>	Ca-SO <sub>4</sub>	Ca-SO <sub>4</sub>
Load (tonnes solutes/day)	96	72	31
Percent CR load at Cisco	1	1	<1
Ca:SO <sub>4</sub> (molar basis)	1.0	0.94	0.89
Na:Cl (molar basis)	2.4	2.4	2.5
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	mineralization	mineralization	mineralization

### Geochemical Evolution Along the Uncompahgre River

The water in the Uncompahgre River is calcium sulfate water throughout the entire year (fig. 4). During high water, concentrations of dissolved major anions and cations increase from the headwaters (Ouray) to the confluence with the Gunnison River whereas most trace metals decrease. Available Fe, SiO<sub>2</sub>, and Ti increase downstream (table AI-3), but few available metal concentrations mirror this trend, suggesting that the metals are not adsorbed to iron, silica, or titanium oxides being carried in the river. Between Ridgway and Delta, available trace metals (Co, Pb, rare earths, Se, and V) increase

as well as does available Al and Mn. This relation suggests that the metals are associated with Al<sub>2</sub>O<sub>3</sub> and MnO<sub>2</sub>. A similar suite of elements increases or (decreases) from Ouray to Delta during irrigation season with a few exceptions, notably SO<sub>4</sub>, which only increases from Ridgway to Delta. During base flow, most metals, with the exception of Se and available Fe, decrease as the water flows to Delta. The increase of SO<sub>4</sub> between Ridgway and Delta is still evident during this flow period.

Water isotopes (fig. 10) indicate that little evaporation takes place along this reach of the river except between Ridgway and Delta during irrigation flow. The starting isotopic composition of the irrigation water (diversion + reservoir in fig. 10) was estimated with mass-balance calculations using the composition of diversion water (see section on Gunnison River below Gunnison Tunnel) and Uncompahgre River water at Ridgway. The large isotope shift in water in the Uncompahgre River at Delta during the irrigation period is due to return of water that has undergone evaporation during the irrigation process. Positioning along the GMWL for the other data reflects snowmelt runoff versus rain and groundwater discharge. A stream-flow budget (table 10) shows that, during high-water and irrigation flow, only 35 to 55 percent of the water delivered by diversion and stream flow returns to the Uncompahgre River. Although some of the diverted water is lost to consumptive use and some is lost as irrigation-return to the Gunnison River, much of the water is lost through



**Figure 10.** Isotope data for the Uncompahgre River including water isotopes for the diversion + reservoir water (calculated using isotope mass-balance equations). HW, high-water flow; Irr, irrigation flow; BF, base flow. Hydrogen and oxygen isotopes measured relative to V-SMOW and sulfur isotopes relative to V-CDT.

**Table 8.** Summary of geochemical parameters for the Uncompahgre River near Ridgeway.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Uncompahgre River near Ridgeway	HW	IRR	BF
Charge balance (percent)	-0.1	-2.5	4.9
Conductivity ( $\mu\text{S}/\text{cm}$ )	420	565	680
Water type	Ca-SO <sub>4</sub>	Ca-SO <sub>4</sub>	Ca-SO <sub>4</sub>
Load (tonnes solutes/day)	250	200	100
Percent CR load at Cisco	1	2	1
Ca:SO <sub>4</sub> (molar basis)	1.2	1.2	0.94
Na:Cl (molar basis)	3.0	3.4	3.7
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	mineralization	mineralization	mineralization

**Table 9.** Summary of geochemical parameters for the Uncompahgre River at Delta.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Uncompahgre River at Delta	HW	IRR	BF
Charge balance (percent)	-3	-3	0.9
Conductivity ( $\mu\text{S}/\text{cm}$ )	1,070	1,150	1,530
Water type	Ca-SO <sub>4</sub>	Ca-SO <sub>4</sub>	Ca-SO <sub>4</sub>
Load (tonnes solutes/day)	935	1,730	760
Percent CR load at Cisco	6	21	8
Ca:SO <sub>4</sub> (molar basis)	0.85	0.87	0.68
Na:Cl (molar basis)	8.3	5.7	8.1
Evaporation	no	yes	no
Dominant SO <sub>4</sub> source	Mancos Shale	Mancos Shale	Mancos Shale

evapotranspiration processes as indicated by its isotopic signature. Some of this loss returns as irrigation water that slowly enters the Uncompahgre River as groundwater discharge during base flow, accounting for the nearly four-fold increase of flow at Delta compared to that discharged from the Ridgeway reservoir upstream (no diversion occurred during base flow).

The influence of the Mancos Shale on the evolution of the isotopic composition of sulfate in the Uncompahgre River can be seen by the smaller decrease in the  $\delta^{34}\text{S}_{\text{SO}_4}$  at the Ridgeway station compared to the Ouray station and the marked decrease at the Delta station (fig. 10). The isotope values at the Delta station do not change dramatically from one flow condition to the next indicating that the Mancos Shale influenced all sampling. Calculations, using isotopic data, estimate that between 87 and 90 percent of the sulfate load in the Uncompahgre River at Delta is released from the Mancos Shale. During irrigation-flow conditions, this accounts for 31 percent of the Colorado River sulfate load at Cisco; whereas flow during the same time only accounts for 10 percent of that at Cisco. The evolution of the sulfate data among different flow conditions at the other two upstream stations is likely due to a change of source (see discussions above).

<sup>6</sup>The flow of this diversion is considered in the discussion on the Uncompahgre River.

## Gunnison River Below Gunnison Tunnel, Colorado

The discharge of the Gunnison River below the Gunnison Tunnel is entirely controlled by Crystal Dam on Morrow Point Reservoir. During irrigation season, water is diverted to the Uncompahgre watershed through the Gunnison Tunnel above this station.<sup>6</sup> The geology in the watershed above the dam is mostly crystalline rocks (metamorphic and volcanic). The Ca:SO<sub>4</sub> and Na:Cl ratios (table 11) are three times greater than expected for dissolution of gypsum and halite, respectively. Contributions of Ca and Na from weathering of crystalline rocks upstream explain these elevated ratios. The isotopic composition of dissolved sulfate at this station (fig. 11) changes very little as flow conditions change due to homogenization in the two large reservoirs immediately upstream (Morrow Point and Blue Mesa). These values likely reflect in part mineralization upstream. In the Lake City area drained by a tributary to the Gunnison River, water heavily affected by mineralization averages  $\delta^{34}\text{S}_{\text{SO}_4} = -4\text{‰}$  (Michele Tuttle, unpub. data).

## North Fork of the Gunnison River Below Paonia, Colorado

The flow of water at this station is, in part, controlled by the upstream reservoir on Muddy Creek. Most rocks in this watershed are sedimentary in origin and low-sulfur, Tertiary age coal is actively mined. Cretaceous Mancos Shale crops out in the lowermost portion of the watershed. The moderate Ca:SO<sub>4</sub> and relatively high Na:Cl ratios (table 12) suggest that dissolution of sodium sulfates such as thenardite (Na<sub>2</sub>SO<sub>4</sub>) associated with the Mancos Shale may contribute solutes to the river, decreasing the Ca:SO<sub>4</sub> ratio and increasing the Na:Cl ratio. The isotopic composition of the sulfate in the river during base flow ( $\delta^{34}\text{S}_{\text{SO}_4} = -11\text{‰}$ ; fig. 11) is consistent with a portion of the sulfate derived from oxidation of sulfides in marine shale. No sulfate isotope data are available for other times of the year, because recovered sulfate was too low for analyses.

## Lower Gunnison River

### Gunnison River at Delta, Colorado

This station is just above the confluence of the Gunnison River with the Uncompahgre River in Delta. The geology below the Gunnison Tunnel consists of metamorphic rocks about halfway to Delta and then Jurassic and Cretaceous sedimentary rocks, including the Mancos Shale. Selenium concentrations exceed Colorado's freshwater chronic standard of 4.6  $\mu\text{g}/\text{L}$  during base flow. During irrigation and base-flow conditions, the Ca:SO<sub>4</sub> and Na:Cl ratios (table 13) are similar to those of the Uncompahgre at Delta, indicating that the Mancos Shale contributes significantly to the salt load under these flow conditions (also confirmed by sulfate isotopes). Ratios during

**Table 10.** Stream flow, total salt load, and SO<sub>4</sub> load for irrigation water diverted from the Gunnison River (Diversion), the Uncompahgre River below reservoir (Reservoir), and for the Uncompahgre River (UR) at Delta. Diversion flows provided by Paul Davidson, Bureau of Reclamation (written commun., 2007); reservoir release estimated with data for the USGS Uncompahgre River flow-gaging station at Colona below the reservoir (data available at <http://waterdata.usgs.gov/nwis/uv?09147500>). Gain/(loss) was calculated by subtracting the actual flow measured at Delta (UR, Delta) from the sum of Diversion and Reservoir (predicted flow). Gain/loss is then reported as the percentage of predicted flow (diversion plus reservoir).

Flow	Diversion cfs	Reservoir cfs	UR, Delta cfs	Gain/(loss) cfs, Delta	Percent predicted flow
High water	865	480	470	(875)	-65
Irrigation	940	450	765	(625)	-45
Base flow	0	50	240	190	+380
Total salt load	Diversion tonnes/day <sup>1</sup>	Reservoir tonnes/day <sup>2</sup>	UR, Delta tonnes/day	Diversion + reservoir tonnes/day	Gain tonnes/day
High water	330	435	935	765	170
Irrigation	370	405	1,730	775	955
Base flow	0	45	760	45	715
Sulfate load	Diversion tonnes/day <sup>1</sup>	Reservoir tonnes/day <sup>2</sup>	UR, Delta tonnes/day	Diversion + reservoir tonnes/day	Gain tonnes/day
High water	38	190	430	230	200
Irrigation	44	175	790	220	570
Base flow	0	20	380	20	360

<sup>1</sup>Chemistry for diversion water is discussed in the section below on the Gunnison River below the Gunnison Tunnel.

<sup>2</sup>No chemistry was available for water released from the dam so compositional averages of the water during the three flow conditions (weighted with respect to flow) at the Ridgway station (major contributor to the reservoir) were used for the released water (averages: 160 mg/L SO<sub>4</sub> and 370 mg/L total dissolved solids). Use of these averages is based on the hypothesis that the reservoir tends to homogenize heterogeneity related to seasonal flow.

high water suggest a mixture of solutes from the North Fork and solutes picked up from the Mancos Shale (the North Fork accounts for 80 percent of the water in the Gunnison River at Delta during this period).

## Gunnison River Near Grand Junction, Colorado

There are no reservoirs on the Gunnison River between Delta and its confluence with the Colorado River. The geology in the area consists predominantly of Cretaceous Mancos Shale and Dakota Sandstone and some Jurassic and Triassic sedimentary rocks. During high-water flow, conductivities increase relative to those at Delta indicating an addition of salts. During base flow, conductivities are lower (table 14) than at the upstream station at Delta 715 compared to 1,080 µS/cm indicating that more dilute water is entering the river from tributaries downstream from Delta. The Ca:SO<sub>4</sub> and Na:Cl ratios (table 14) at all times are

**Table 11.** Summary of geochemical parameters for the Gunnison River below Gunnison Tunnel.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

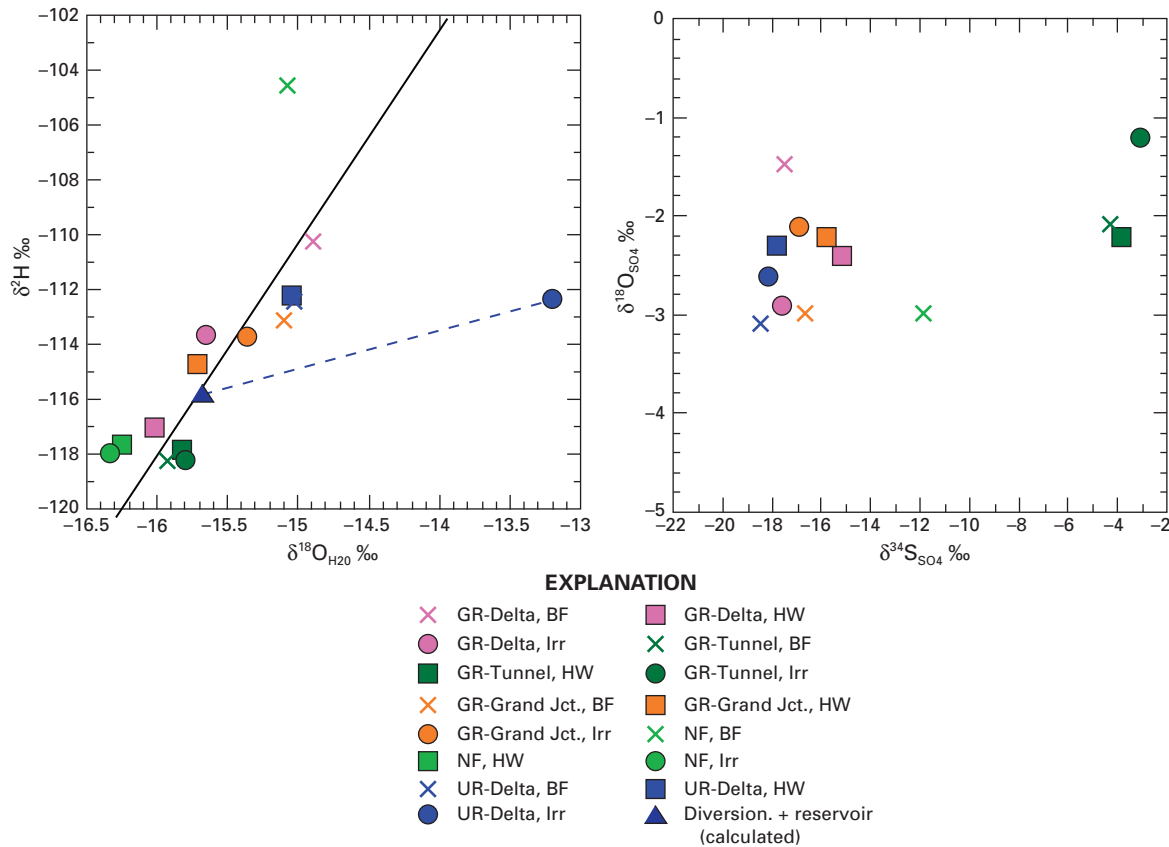
Gunnison River below tunnel	HW	IRR	BF
Charge balance (percent)	-7	-0.4	25
Conductivity (µS/cm)	195	205	200
Water type	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>
Load (tonnes solutes/day)	275	205	240
Percent CR load at Cisco	2	3	3
Ca:SO <sub>4</sub> (molar basis)	3.3	3.3	2.8
Na:Cl (molar basis)	3.8	3.6	3.2
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	mineralization	mineralization	mineralization

similar to those in the Gunnison River at Delta; however, during high water, there is likely a greater contribution of Na and SO<sub>4</sub> from the Mancos than recorded in the ratios at Delta. The δ<sup>34</sup>S<sub>SO4</sub> values are around -17 ‰ and point to the Mancos Shale as the dominant source of sulfate (fig. 11).

## Geochemical Evolution Along the Gunnison River

During all three flow regimes, the North Fork of the Gunnison and the Gunnison River below the tunnel are calcium bicarbonate water types; however, the North Fork water trends more toward Mg and Na than the tunnel water (fig. 4). At the Delta station and downstream, the Gunnison River becomes a calcium sulfate water type as it picks up sulfate from the Mancos Shale. During high-water flow, the total solute load in the Gunnison River doubles from the North Fork station to the Delta station and nearly doubles again to the Grand Junction station (table AII-1). These increases are much larger than can be explained from the sum of solutes from upstream stations, indicating that additional solutes are acquired through groundwater and other tributary input. The same pattern is observed during irrigation and base flow in the Gunnison River at Delta. At the station near Grand Junction, the solute load is less than the sum of solutes in the Gunnison River at Delta and in the Uncompahgre River at Delta, indicating that some of the load has been removed by diversion or alluvium recharge prior to the inflow of the more dilute water discussed above.

During high-water flow, available metal concentrations (table AI-3) are much higher in the North Fork than in the Gunnison River at the tunnel because the water at the tunnel is being directly released from Crystal Dam and does not



**Figure 11.** Isotope data for the Gunnison River, North Fork, lowermost station on the Uncompahgre River, and calculated  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  values for irrigation water in the Uncompahgre watershed. HW, high-water flow; Irr, irrigation flow; BF, base flow; GR, Gunnison River; NF, North Fork of the Gunnison River; UR, Uncompahgre River. Hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotopes relative to V-CDT.

transport sediment with oxide coatings. The sediment transported in the North Fork consists of detrital components rich in resistate minerals containing Ba, rare earths, Sc, Si, and Ti and in oxides and oxide coatings rich in Al, Fe, Mn, and adsorbed metals such as Cd, Co, Cr, Cu, Ni, V, and Zn. Although  $\text{Al}_{(\text{avail})}$  and  $\text{Fe}_{(\text{avail})}$  concentrations decrease some between Delta and Grand Junction, most trace-metal available concentrations remain similar to concentrations upstream. Except for the Uncompahgre River at Delta during irrigation flow, metal concentrations drop dramatically after high flow, indicating that these metals preferentially are transported in the Gunnison River in the spring runoff adsorbed onto aluminum and iron oxides.

Although most of the water isotopes cluster around the meteoric water line, evaporation is evident in the Uncompahgre River at Delta during irrigation flow (fig. 11). The water isotopes on the North Fork of the Gunnison during base flow is above the GMWL. This relative increase in  $\delta^2\text{H}$  relative to  $\delta^{18}\text{O}_{\text{H}_2\text{O}}$  often accompanies methanogenesis. Methanogenesis feasibly could occur in this watershed because of the occurrence of coal, however, this explanation is highly speculative.

The sulfate oxygen isotope data occur in a very narrow range ( $-3$  to  $-1$  ‰) (fig. 11). Conversely, the sulfur isotopes span a fairly broad range ( $-19$  to  $-3$  ‰). The  $\delta^{34}\text{S}_{\text{SO}_4}$  values in water at the Gunnison Tunnel are a result of the

geology upstream including mineralization in the Lake City area ( $\delta^{34}\text{S}_{\text{SO}_4}$  of  $-4$  ‰). Sulfate in the Gunnison River downstream from the tunnel is derived mostly from sulfate salts in the Mancos Shale ( $\delta^{34}\text{S}_{\text{SO}_4}$  average of  $-21$  ‰). Sulfate in the North Fork was insufficient for isotopic analyses during high-water and irrigation-flow conditions. The isotopic composition during base flow indicates a mixture of sulfate from the Mancos Shale and another source, possible Tertiary coal upstream of the station (no sulfur isotopic composition of sulfur in such coal was available).

**Table 12.** Summary of geochemical parameters for the North Fork of the Gunnison River below Paonia.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

North Fork of the Gunnison below Paonia	HW	IRR	BF
Charge balance (percent)	-0.8	-11	9
Conductivity ( $\mu\text{S}/\text{cm}$ )	115	170	310
Water type	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>
Load (tonnes solutes/day)	1,210	240	145
Percent CR load at Cisco	7	3	2
Ca:SO <sub>4</sub> (molar basis)	4.9	2.1	2.0
Na:Cl (molar basis)	2.9	9.3	4.5
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	no data	no data	Mancos Shale + ?

**Table 13.** Summary of geochemical parameters for the Gunnison River at Delta.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Gunnison River at Delta	HW	IRR	BF
Charge balance (percent)	-3	-4	0.6
Conductivity ( $\mu\text{S}/\text{cm}$ )	280	900	1,080
Water type	Ca-HCO <sub>3</sub>	Ca-SO <sub>4</sub>	Ca-SO <sub>4</sub>
Load (tonnes solutes/day)	3,310	1,630	1,910
Percent CR load at Cisco	19	20	20
Ca:SO <sub>4</sub> (molar basis)	1.3	0.84	0.72
Na:Cl (molar basis)	4.4	7.2	7.2
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	Mancos Shale	Mancos Shale	Mancos Shale

**Table 14.** Summary of geochemical parameters for the Gunnison River near Grand Junction.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Gunnison River near Grand Junction	HW	IRR	BF
Charge balance (percent)	4	4	4
Conductivity ( $\mu\text{S}/\text{cm}$ )	455	855	715
Water type	Ca-SO <sub>4</sub>	Ca-SO <sub>4</sub>	mixed
Load (tonnes solutes/day)	5,150	2,540	2,090
Percent CR load at Cisco	30	31	22
Ca:SO <sub>4</sub> (molar basis)	1.1	0.88	0.81
Na:Cl (molar basis)	7.4	6.5	5.2
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	Mancos Shale	Mancos Shale	Mancos Shale

## Dolores and San Miguel Rivers

Maps of the watersheds of the Dolores River are in figure 12. The San Miguel River is the only major tributary to the Dolores River. The flow of the Dolores River is largely controlled by the McPhee Reservoir upstream from the Dolores-San Miguel confluence.

### San Miguel River at Uravan, Colorado

The flow of water at this station (fig. 12) is partially affected by small reservoirs upstream (for example, Taylor Lake, a damned natural lake near the headwaters). The watershed (fig. 12) is underlain by volcanic rocks near the headwaters and Pennsylvanian to Jurassic and Cretaceous rocks in the lower portion. Mancos Shale crops out in some tributaries along the entire stretch of the river. The Ca:SO<sub>4</sub> and Na:Cl ratios (table 15) look similar to those in the Uncompahgre near the Ridgway station. Tributaries to the Uncompahgre from the west drain similar rocks as the San Miguel in the upper portion of its watershed. The Ca:SO<sub>4</sub> ratios drop to one or below after high-water flow suggesting that gypsum dissolution alone controls these solutes. Under all three flow conditions, the sulfate isotopes (fig. 13) are slightly lighter than those for sulfate in the Dolores River headwaters, suggesting that there may be a small component of sulfate derived from the Mancos Shale. However, most of the sulfate is derived

from weathering of mineralized rocks in the upper portion of the watershed, similar to those that supply sulfate in the headwaters of the Uncompahgre and Dolores Rivers.

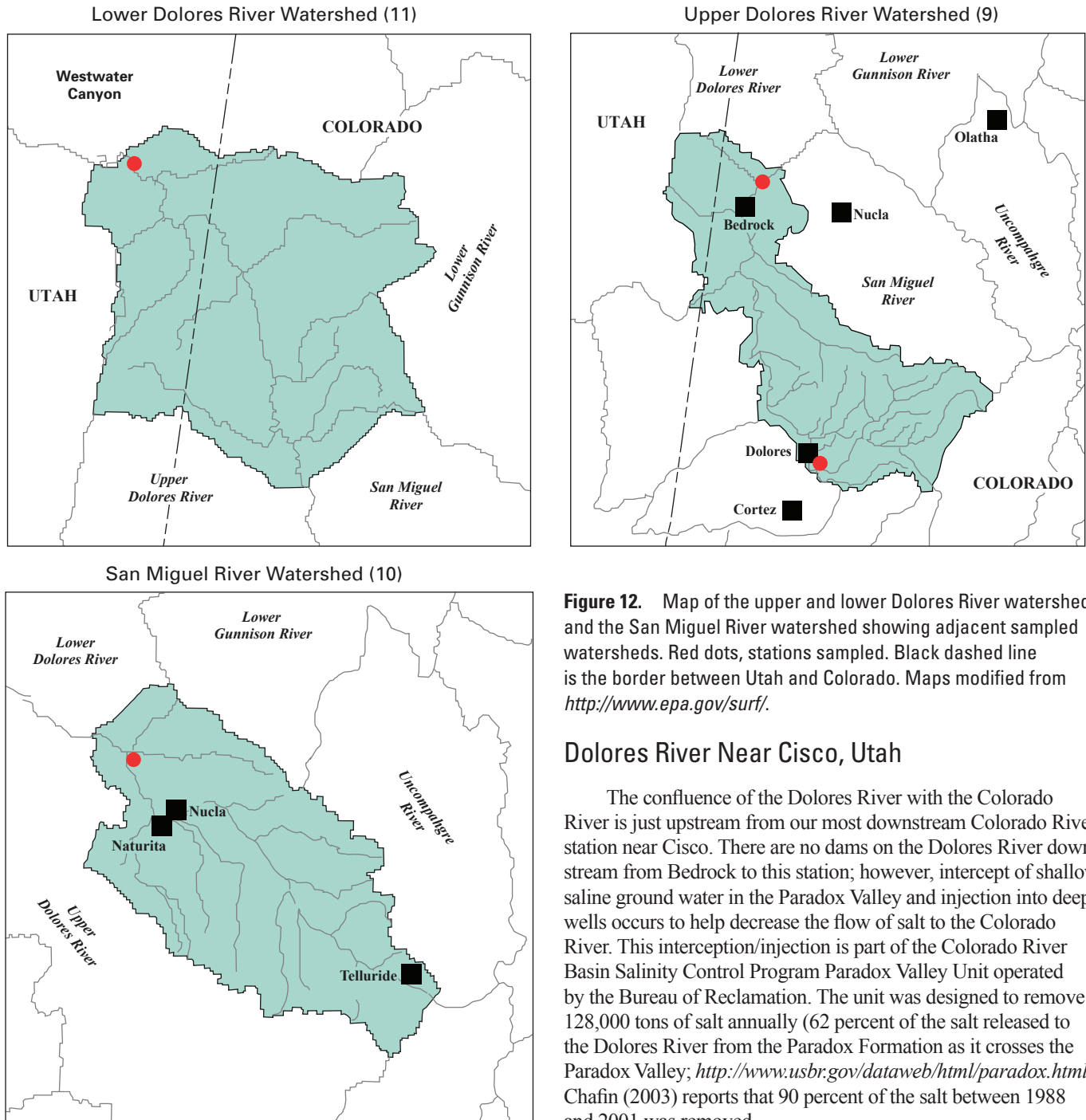
### Dolores River at Dolores, Colorado

The flow of water at this station is not regulated by any significant reservoirs upstream. The geology in the watershed upstream is varied with predominantly Pennsylvanian and Permian sedimentary rocks. During high-water flow, the water is a calcium bicarbonate type (fig. 4) with a high Ca:SO<sub>4</sub> ratio (table 16) that decreases during irrigation and base flow. Similar  $\delta^{34}\text{S}_{\text{SO}_4}$  values during all flow conditions suggest a common source of sulfate (fig. 13). These isotope values are similar to those in the Animas watershed (average  $\delta^{34}\text{S}_{\text{pyrite}}$  of -3 ‰; Nordstrom and others, 2007), a parallel drainage to the east that is extensively mineralized.

### Dolores River at Bedrock, Colorado

The flow of this stretch of the river is controlled by McPhee Reservoir. The dominant geologic unit at the Bedrock station is the Paradox Formation of the Hermosa Group, which contains beds of anhydrite, halite, and some potash. Similar rocks are exposed in the Gypsum Valley upstream. The Mancos Shale is aerially extensive in the Disappointment Creek catchment, which drains into the Dolores River upstream from Bedrock in the spring and intermittently during monsoon season in the late summer (G. Breit, oral commun., 2007). The Dolores River water at Bedrock transitions from a Ca-HCO<sub>3</sub> type during high water to a Na-Cl water during irrigation and base-flow conditions (fig. 4). This transition is likely due to a large release of water from the McPhee Reservoir during high spring runoff (2,000 to more than 4,000 cfs; May through June, 2004) compared to very low release during the rest of the year (<100 cfs) (<http://www.usbr.gov/uc/wcao/water/rsvrs/ds/mcphee.html>). No chemistry is available between McPhee Reservoir and Bedrock, so an average of chemistry for all three flow conditions, weighted with respect to flow at the Dolores station, was used as the composition of reservoir outflow. The Ca:SO<sub>4</sub> ratio (table 17) is greater than one indicating that Ca has an additional source other than dissolution of gypsum in the Mancos Shale or anhydrite in the Paradox Formation. The Na:Cl ratio during high water is greater than one, indicating that halite dissolution is not the sole Na source; dissolution of sodium sulfates in the Mancos Formation in Disappointment Valley may contribute to the increase. During irrigation and base flow, as the water type changes to a Na-Cl water (fig. 4), the Na:Cl ratio is essentially one (table 17), indicating that the primary source of solutes under these flow conditions is dissolution of halite in the Paradox Formation. The sulfur isotopic composition varies systematically among high-water, irrigation, and base-flow conditions (fig. 13). During high-water flow,  $\delta^{34}\text{S}_{\text{SO}_4}$  is isotopically light (-13 ‰). Mixing of the sulfate in the Dolores River at Dolores ( $\delta^{34}\text{S}_{\text{SO}_4} = -3.4$  ‰) with the increased load acquired along the flow to Bedrock, supports





**Figure 12.** Map of the upper and lower Dolores River watersheds and the San Miguel River watershed showing adjacent sampled watersheds. Red dots, stations sampled. Black dashed line is the border between Utah and Colorado. Maps modified from <http://www.epa.gov/surf/>.

### Dolores River Near Cisco, Utah

The confluence of the Dolores River with the Colorado River is just upstream from our most downstream Colorado River station near Cisco. There are no dams on the Dolores River downstream from Bedrock to this station; however, intercept of shallow saline ground water in the Paradox Valley and injection into deep wells occurs to help decrease the flow of salt to the Colorado River. This interception/injection is part of the Colorado River Basin Salinity Control Program Paradox Valley Unit operated by the Bureau of Reclamation. The unit was designed to remove 128,000 tons of salt annually (62 percent of the salt released to the Dolores River from the Paradox Formation as it crosses the Paradox Valley; <http://www.usbr.gov/dataweb/html/paradox.html>). Chafin (2003) reports that 90 percent of the salt between 1988 and 2001 was removed.

The water at the Cisco station is a calcium bicarbonate type during high-water flow, a mixed type during irrigation flow, and a sodium chloride type during base flow (fig. 4). During high-water flow, the Ca:SO<sub>4</sub> and Na:Cl ratios (table 18) look similar to those in the river at Bedrock. During irrigation and base-flow conditions, both Ca:SO<sub>4</sub> and Na:Cl ratios approach one, suggesting that the primary sources of solutes are gypsum/anhydrite dissolution and halite dissolution. The halite is derived from the Paradox Formation. The isotopes of sulfate (fig. 13) indicate that the source of the sulfate is a mixture from the Mancos Shale (dominant source), anhydrite from the Paradox Formation, and mineralization upstream.

the hypothesis that the sulfate during high-water flow in the Dolores River at Bedrock is a mixture of that from upstream (45 percent) and from the Mancos Shale (55 percent). During irrigation, the  $\delta^{34}\text{S}_{\text{SO}_4}$  value increases significantly to 2.3 ‰, suggesting that dissolution of anhydrite in the Paradox Formation ( $\delta^{34}\text{S}_{\text{SO}_4}$  of 13 ‰; Claypool and others, 1980; Tuttle and others, 1996) contributes to the sulfate mix. This result is consistent with dissolution of halite in related evaporite beds during this time of year. The base flow  $\delta^{34}\text{S}_{\text{SO}_4}$  value decreases to -1.2 ‰, indicating that anhydrite contributes a smaller proportion of sulfate during this time of the year.

**Table 15.** Summary of geochemical parameters for the San Miguel River at Uravan.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

San Miguel River at Uravan	HW	IRR	BF
Charge balance (percent)	-0.9	-1	0.8
Conductivity ( $\mu\text{S}/\text{cm}$ )	350	565	750
Water type	Ca-HCO <sub>3</sub>	Ca-SO <sub>4</sub>	Ca-SO <sub>4</sub>
Load (tonnes solutes/day)	800	220	205
Percent CR load at Cisco	5	3	2
Ca:SO <sub>4</sub> (molar basis)	1.5	1.0	0.92
Na:Cl (molar basis)	2.8	3.1	3.0
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	mineralization	mineralization	mineralization

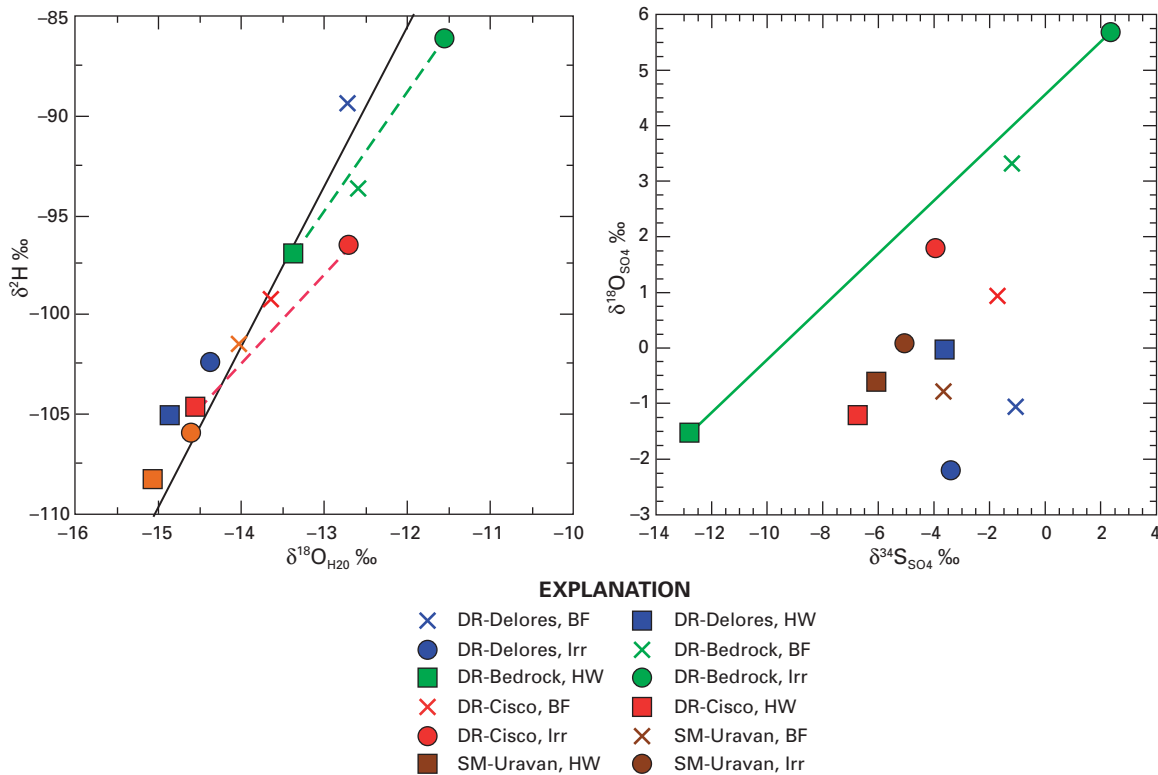
### Geochemical Evolution Along the Dolores River

Below the Dolores station, the water type of the Dolores River changes during the year from a calcium bicarbonate type during high water to a mixed or sodium chloride type during irrigation and base flow (fig. 4). This change reflects the input of solutes from salts derived from the Mancos Shale and Paradox Formation. During high water, transported sediment consists of components rich in resistate minerals containing Ba, rare earths, Si, and Ti, and in oxides and oxide

coatings rich in Al, Fe, and Mn, and adsorbed metals such as Cd, Co, Cr, Cu, Ni, V, and Zn (table AI-3). During the irrigation season, the Dolores River below McPhee Reservoir is also high in many of these available metals even though the flow has decreased dramatically. This is especially evident at the Bedrock station. The cause for the transport of sediment in the Dolores during such low-flow conditions is not readily apparent.

Figure 13 shows that most of the water in the Dolores River falls on the GMWL with respect to its isotopic composition. The small deviation of water at Bedrock and Cisco during irrigation flow suggests that the water has undergone some evaporation.

The isotopes of sulfate in the San Miguel River at Uravan and the Dolores River at Dolores are similar and largely controlled by mineralization in the upper portion of these watersheds (fig. 13); however, in the San Miguel watershed, dissolution of salts in the Mancos Shale soil contribute a small proportion of the sulfate. The influence of the Mancos Shale in the vicinity of Disappointment Valley during high-water flow and the Paradox Formation evaporites in the Paradox Valley during irrigation flow is evident in the Dolores River at Bedrock. The composition of sulfate in the Dolores River near Cisco is a mixture of the sulfate in the river at Bedrock and the sulfate in the San Miguel River.



**Figure 13.** Isotope data for the Dolores and San Miguel Rivers. HW, high-water flow; Irr, irrigation flow; BF, base flow; SM, San Miguel River; DR, Dolores River. Hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotopes relative to V-CDT.

**Table 16.** Summary of geochemical parameters for the Dolores River at Dolores.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Dolores River at Dolores	HW	IRR	BF
Charge balance (percent)	4	-1	-6
Conductivity ( $\mu\text{S}/\text{cm}$ )	155	265	330
Water type	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>
Load (tonnes solutes/day)	1,160	115	71
Percent CR load at Cisco	7	1	<1
Ca:SO <sub>4</sub> (molar basis)	6.3	3.2	3.0
Na:Cl (molar basis)	1.2	1.3	1.3
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	mineralization	mineralization	mineralization

**Table 17.** Summary of geochemical parameters for the Dolores River at Bedrock.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Dolores River at Bedrock	HW	IRR	BF
Charge balance (percent)	0.9	2	-4
Conductivity ( $\mu\text{S}/\text{cm}$ )	400	1,510	1,010
Water type	Ca-HCO <sub>3</sub>	Na-Cl	Na-Cl
Load (tonnes solutes/day)	930	175	69
Percent CR load at Cisco	5	2	<1
Ca:SO <sub>4</sub> (molar basis)	2.1	1.8	2.5
Na:Cl (molar basis)	1.6	.95	1.0
Evaporation	no	yes	yes
Dominant SO <sub>4</sub> source	Mancos Shale	Paradox Formation	Paradox Formation + Mancos Shale

## Geochemistry in Main Stem Colorado River Above Cisco, Utah

Maps of the main stem Colorado River watersheds sampled in this study are shown in figure 14. Also included in this discussion section is Plateau Creek, a tributary to the Colorado River within the Colorado River headwater-plateau watershed.

### Colorado River Near Kremmling, Colorado

The Colorado River near Kremmling station is located in the upper portions of the Colorado River headwater watershed (fig. 14). The composition of the water sampled at this station is considered the Colorado River headwaters natural baseline for this study as the station is the farthest upstream site sampled and is the least impacted by anthropogenic activities, although there are five major reservoirs located upstream. The similarity in conductivities during irrigation and base flow indicates minimal influence from irrigation in this watershed.

The dominant geology in this and tributary watersheds is igneous and metamorphic rocks; however, there are some exposures of Permian, Jurassic, Cretaceous, and Tertiary

sedimentary rocks. This station has calcium bicarbonate water (fig. 4) with Ca:SO<sub>4</sub> and Na:Cl ratios varying little throughout the year (table 19). Ratios of Ca:SO<sub>4</sub> and Na:Cl are two or greater and consistent with crystalline rock sources that release bicarbonate as well as these cations. The  $\delta^{34}\text{S}_{\text{SO}_4}$  values of dissolved sulfate (see fig. 16 in Geochemical Evolution of the Colorado River Above Cisco) at this station vary little with changing flow conditions and are intermediate at about -5 ‰; however, the  $\delta^{18}\text{O}_{\text{SO}_4}$  is larger during high flow. The  $\delta^{34}\text{S}_{\text{SO}_4}$  and  $\delta^{18}\text{O}_{\text{SO}_4}$  values during base flow (see fig. 16 in Geochemical Evolution of the Colorado River Above Cisco) are assumed to be the starting composition of sulfate in the Colorado River.

### Colorado River Above Glenwood Springs, Colorado

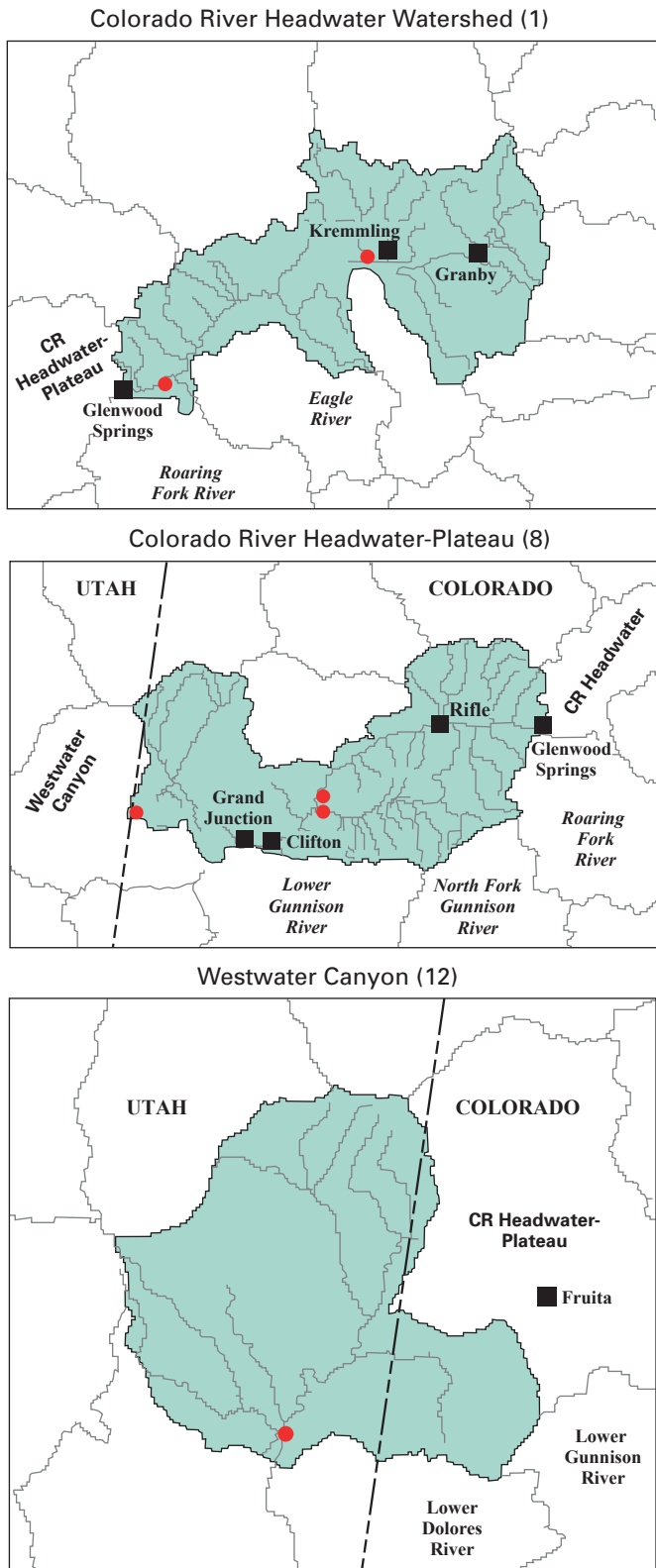
The Colorado River above Glenwood Springs station is downstream from the confluence of the Colorado River with the Eagle River (fig. 14). There are no dams on the Colorado River between Kremmling and this station. Hot springs occur and discharge water along a portion of the Colorado River upstream from this station. As was the case at the Kremmling station, there is no influence due to irrigation as observed in the similar conductivities during irrigation and base flow.

The geology along the stretch of the Colorado from Kremmling halfway to this station consists mostly of igneous and metamorphic rocks. From that point downstream to the sampling station, sedimentary rocks of Cambrian through Permian age dominate; they include the Eagle Valley Evaporite and mudstones/sandstones of the Maroon Formation. Some Cretaceous Mancos Shale and Dakota Sandstone also crop out. The water is a calcium bicarbonate type during high-water flow and a mixed type during other flow conditions, moving more toward a sodium chloride type water during base flow (fig. 4). This change reflects the high content of Na and Cl in the hot spring water, which is overwhelmingly a sodium chloride water

**Table 18.** Summary of geochemical parameters for the Dolores River near Cisco.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Dolores River, Cisco	HW	IRR	BF
Charge balance (percent)	-0.2	7	-4
Conductivity ( $\mu\text{S}/\text{cm}$ )	375	1,070	1,750
Water type	Ca-HCO <sub>3</sub>	mixed	Na-Cl
Load (tonnes solutes/day)	1,280	445	535
Percent CR load at Cisco	8	5	6
Ca:SO <sub>4</sub> (molar basis)	1.8	0.96	1.3
Na:Cl (molar basis)	1.7	0.89	1.1
Evaporation	no	yes	no
Dominant SO <sub>4</sub> source	Mancos Shale	Paradox Formation	Paradox Formation + Mancos Shale



**Figure 14.** Maps of Colorado River (CR) headwater (no. 1 on fig. 5), Colorado River headwater-plateau and Westwater Canyon watersheds (nos. 8 and 12, respectively on fig. 5) showing adjacent sampled watersheds. Black dashed line is the border between Utah and Colorado. Red dots, stations sampled. Maps modified from <http://www.epa.gov/surf/>.

type (Glenwood Springs (GW) hot spring data in table AI-3 and in Eisenhauer, 1983). The trends in the  $\text{Ca}:\text{SO}_4$  and  $\text{Na}:\text{Cl}$  ratios (table 20) throughout the year mimic those in the Eagle River at Gypsum, suggesting that the source of the additional salts to the Colorado River (fig. 3) are similar to those to the downstream portion of the Eagle River. Sulfur isotopic compositions (see fig. 16 in *Geochemical Evolution of the Colorado River Above Cisco*) suggest a mixture of two sources of sulfate during irrigation and base flow—that inherited from the Kremmling station and a major contribution from the Eagle Valley Evaporite.

### Colorado River Near Cameo, Colorado

The Colorado River below the station above Glenwood Springs is not controlled by any large reservoirs; however, in Glenwood Canyon, the water is diverted and returned to the river to generate hydroelectric power. The Roaring Fork River and numerous hot springs enter the Colorado River upstream from this station. The geology along this stretch of the river changes from Mississippian limestone and metamorphic rocks in Glenwood Canyon to Tertiary rocks of the Wasatch and Green River Formations, which are variegated nonmarine mudstone and lacustrine oil shale, respectively, to the Cretaceous coal-bearing Mesaverde Formation in De Beque Canyon just above Cameo. The water at this station is a calcium bicarbonate type during high-water flow and a mixed type during the rest of the year as it picks up greater proportions of sodium and chloride from Eagle Valley Evaporite (fig. 4). The  $\text{Ca}:\text{SO}_4$  and  $\text{Na}:\text{Cl}$  ratios (table 21) are very similar to those in the Colorado River at the station above Glenwood Springs.

Sulfur isotopes (see fig. 16 in *Geochemical Evolution of the Colorado River Above Cisco*) are similar to those in the Roaring Fork during high-water flow and to those at the station above Glenwood Springs during irrigation and base-flow conditions. The isotopic data combined with the sulfate load data have been used to estimate the sulfate isotopic composition of all sulfate unaccounted for in table 22. Sulfate from this unknown source(s) has an isotopic signature of 7.1, 3.4, and 6.5 ‰ during high-water, irrigation, and base-flow conditions, respectively (table 22). Possibilities that may contribute in varying proportions to this unknown sulfate load are sulfate in mudstones of the Wasatch Formation (–13 to –40 ‰; Tuttle, unpub. data) and oxidized sulfides in the Green River Formation (average 15 to 35 ‰; Tuttle and Goldhaber, 1993), both of which crop out along the river and in tributary watersheds through this stretch; sulfur in the Mesaverde Formation that crops out in De Beque Canyon and associated tributaries (1.5 to 3.5 ‰; table AIII-3); sulfate in ground water associated with the abandoned Rifle Uranium Mill sites (–6.5 to 2.4 ‰; table AI-3); and, possibly, produced water related to gas drilling (unknown isotopic composition). Additional detailed sampling along this stretch would be needed to quantify relative contributions from these possible sources.

**Table 19.** Summary of geochemical parameters for the Colorado River near Kremmling.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Colorado River, Kremmling	HW	IRR	BF
Charge balance (percent)	24	-2	3
Conductivity (µS/cm)	140	210	200
Water type	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>
Load (tonnes solutes/day)	310	365	280
Percent CR load at Cisco	2	4	3
Ca:SO <sub>4</sub> (molar basis)	2.2	2.6	2.2
Na:Cl (molar basis)	2.6	2.0	2.4
Evaporation	no	no	no
Dominant SO <sub>4</sub> source	various sources	various sources	various sources

**Table 20.** Summary of geochemical parameters for the Colorado River above Glenwood Springs.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Colorado River, Glenwood Springs	HW	IRR	BF
Charge balance (percent)	7	-4	7
Conductivity (µS/cm)	250	515	565
Water type	Ca-HCO <sub>3</sub>	mixed	mixed
Load (tonnes solutes/day)	3,180	1,570	1,460
Percent CR load at Cisco	19	19	15
Ca:SO <sub>4</sub> (molar basis)	3.0	2.0	1.7
Na:Cl (molar basis)	1.4	1.2	1.2
Evaporation	no	no	no
Predominant SO <sub>4</sub> source	evaporites	evaporites	evaporites

### Plateau Creek Near Cameo, Colorado

The flow of Plateau Creek is controlled, in part, by several small reservoirs. The geology upstream is predominantly mudstones of the Tertiary Wasatch Formation and basalt. The water is calcium bicarbonate type during high-water flow and a mixed type during other times of the year (fig. 4) with a greater proportion of magnesium, but the dominant anion remains HCO<sub>3</sub><sup>-</sup>, consistent with weathering of basaltic material. The Ca:SO<sub>4</sub> and Na:Cl ratios (table 23) are high, also consistent with weathering of basalt. Isotopes of sulfate (see fig. 16 in Geochemical Evolution of the Colorado River Above Cisco) do not vary and are similar to those in the Colorado River near Kremmling during high water and in the Dolores River at Dolores during irrigation and base flow; the dominant geology upstream from these two stations is also crystalline rocks, the likely source of this signature.

### Colorado River Near Colorado-Utah State Line

The flow of the river downstream from Cameo is not dramatically affected by reservoirs; however, during irrigation-flow conditions, water diversion and return occurs. The Gunnison River is a major tributary entering along this stretch. The river below Cameo enters the Grand Valley where intense

agricultural irrigation occurs. The Mancos Shale is the predominant rock in the valley with overlying Tertiary terrestrially deposited rocks high in the tributary drainages. The water type is mixed (fig. 4); however, during high-water flow, the river is closer to a calcium bicarbonate type, and during irrigation and base flow, sodium and sulfate occur in greater proportions. Selenium concentrations are at the State of Colorado's freshwater chronic standard of 4.6 µg/L during the three flow regimes (table AI-3). The Ca:SO<sub>4</sub> ratio (table 24) decreases to one during irrigation and base flow, suggesting that dissolution of gypsum occurs during these flow conditions. The Ca:SO<sub>4</sub> ratio is slightly higher than one during high-water flow and is likely due to a mixture of higher ratios in upstream Colorado River water and ratios of about one in Gunnison River water. The Na:Cl ratios are near two (table 24), reflecting the high ratios in the Gunnison River and Plateau Creek. Isotopes of sulfate (see fig. 16 in Geochemical Evolution of the Colorado River Above Cisco) support a mixture of sulfate derived from dissolution of salts in the Mancos Shale and sulfate derived upstream from the Grand Valley (Colorado River near Cameo).

### Colorado River Near Cisco, Utah

The Dolores River enters the Colorado River upstream from our most downstream sampling station on the Colorado River (near Cisco). There are no reservoirs along this stretch of the Colorado River. In this area, the geology is dominated by Jurassic and Triassic sedimentary rocks. The Mancos Shale does crop out in some of the smaller tributary drainages to the north of the river. The water is a mixed type throughout the year (fig. 4). Additional loading of solutes from the State-line station to this station is due to input from the Dolores River and is most evident during high-water flow and is relatively insignificant during other times of the year. During high water, the Ca:SO<sub>4</sub> ratio (table 25) at this station is lower than in the Dolores River (table 18) and at the State-line station (table 24). The sulfate isotopes during high-water flow (see fig. 16 in Geochemical Evolution of the Colorado River Above Cisco) are within the range expected for mixing of the Dolores River and upstream Colorado River waters, so the additional sulfate would have to be from a

**Table 21.** Summary of geochemical parameters for the Colorado River near Cameo.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Colorado River, Cameo	HW	IRR	BF
Charge balance (percent)	-2	-2	-0.4
Conductivity (µS/cm)	395	525	920
Water type	Ca-HCO <sub>3</sub>	mixed	mixed
Load (tonnes solutes/day)	7,450	4,170	3,870
Percent CR load at Cisco	44	51	40
Ca:SO <sub>4</sub> (molar basis)	2.3	1.8	1.4
Na:Cl (molar basis)	1.4	1.3	1.3
Evaporation	no	no	no
Predominant SO <sub>4</sub> source	? (see text)	evaporites	evaporites

**Table 22.** Sulfate loads and isotopic composition of contributions between the stations above Glenwood Springs and near Cameo on the upper Colorado River.

[HW, high-water flow; Irr, irrigation flow; BF, base flow; CR, Colorado River; V-CDT, Vienna Cañon Diablo Troilite]

Station	SO <sub>4</sub> load (tonnes/day)			δ <sup>34</sup> S <sub>SO<sub>4</sub></sub> ‰ (V-CDT)		
	HW	Irr	BF	HW	Irr	BF
Colorado River above Glenwood Springs <sup>1</sup>	360	295	245	2.3	6.0	6.7
Hot springs, Glenwood Springs	35 <sup>2</sup>	352	352	15.3	15.3	15.3
Roaring Fork, Glenwood Springs	335	255	215	7.2	8.9	9.5
Colorado River near Cameo	1,160	775	700	5.9	6.7	7.9
Unknown source	430	190	205	7.1	3.4	6.5

<sup>1</sup>Includes sulfate load from hot springs near Dotsero.<sup>2</sup>Calculated from data in Eisenhaur (1983) and from this study. Flow and composition of spring water are assumed to be constant during the year.**Table 23.** Summary of geochemical parameters for Plateau Creek near Cameo.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Plateau Creek, Cameo	HW	IRR	BF
Charge balance (percent)	1	3	2
Conductivity (μS/cm)	195	520	590
Water type	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>	Ca-HCO <sub>3</sub>
Load (tonnes solutes/day)	575	175	190
Percent CR load at Cisco	3	2	2
Ca:SO <sub>4</sub> (molar basis)	5.5	3.8	2.8
Na:Cl (molar basis)	5.8	7.5	7.7
Evaporation	no	no	no
Predominant SO <sub>4</sub> source	Basalt	Basalt	Basalt

similar source as that in the Dolores and upstream Colorado Rivers. The Na:Cl ratios (tables 18, 24, and 25) indicate that dissolution of sodium sulfates similar to those found upstream may be added along this river stretch explaining the anomalously low Ca:SO<sub>4</sub> ratio.

## Geochemical Evolution of the Colorado River Above Cisco

In the headwaters of the upper Colorado River, the water is a Ca-HCO<sub>3</sub> type (fig. 4). The water type does not change dramatically during high-flow conditions. During irrigation and base flow, however, the water evolves toward a calcium chloride type as it flows through the Eagle Valley Evaporite and toward a calcium sulfate type as it flows through the Mancos Shale. From its headwaters to the station near Cisco, Utah, the conductivity of the Colorado River throughout our sampling transect increases between 3.4 and 6 times, while the load increases between 22 and 50 times (fig. 15). The load during high-water flow is much greater than during other times of the year because the flow is so much greater; loads during irrigation and base flow are nearly identical. The Gunnison River during high-water flow adds the greatest load to the Colorado River. In the upper portion of the study area (0 to 250 km), loads increase more or less linearly with

distance. Starting at Cameo, loads added per kilometer of river increase at a greater rate as the river and its tributaries flow through the Mancos Shale and as the amount of irrigated land increases.

During high water, the Colorado River carries sediment rich in Al and Fe oxides, accounting for the greater available trace-metal concentrations (table AI-3). Aqueous Se concentrations exceed the Colorado freshwater chronic standard of 4.6 μg/L at downstream stations during base flow.

The isotopes of water (fig. 16) fall along the GMWL trend indicating that evaporation does not significantly affect the salt load in the upper Colorado River above Cisco (fig. 16). Evolution of the isotopes of sulfate (fig. 16) dissolved in the Colorado River is systematic and depends on the geologic formation through which it is flowing. There appear to be three main sources of sulfate—sulfate derived from crystalline rock formations similar to those in the headwaters (starting composition, fig. 16), the Eagle Valley Evaporite, and the Mancos Shale. Mixing between starting composition and Eagle Valley Evaporite is evident in the Colorado River below Kremmling to Cameo, in the Eagle River, and the Roaring Fork River. The impact of the Mancos Shale on the sulfate load in the Colorado River below Cameo and in the Gunnison River is dramatic as shown by the shift in the sulfate isotopes (fig. 16).

**Table 24.** Summary of geochemical parameters for the Colorado River near the Colorado-Utah State line.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

Colorado River, Colorado-Utah State line	HW	IRR	BF
Charge balance (percent)	-2	-4	-9
Conductivity (μS/cm)	435	685	1,090
Water type	mixed	mixed	mixed
Load (tonnes solutes/day)	13,900	8,550	8,420
Percent CR load at Cisco	82	105	87
Ca:SO <sub>4</sub> (molar basis)	1.4	1.1	1.1
Na:Cl (molar basis)	2.1	1.9	2.1
Evaporation	no	no	no
Predominant SO <sub>4</sub> source	Mancos Shale	Mancos Shale	Mancos Shale

**Table 25.** Summary of geochemical parameters for the Colorado River near Cisco.

[HW, high-water flow; IRR, irrigation flow; BF, base flow; CR, Colorado River]

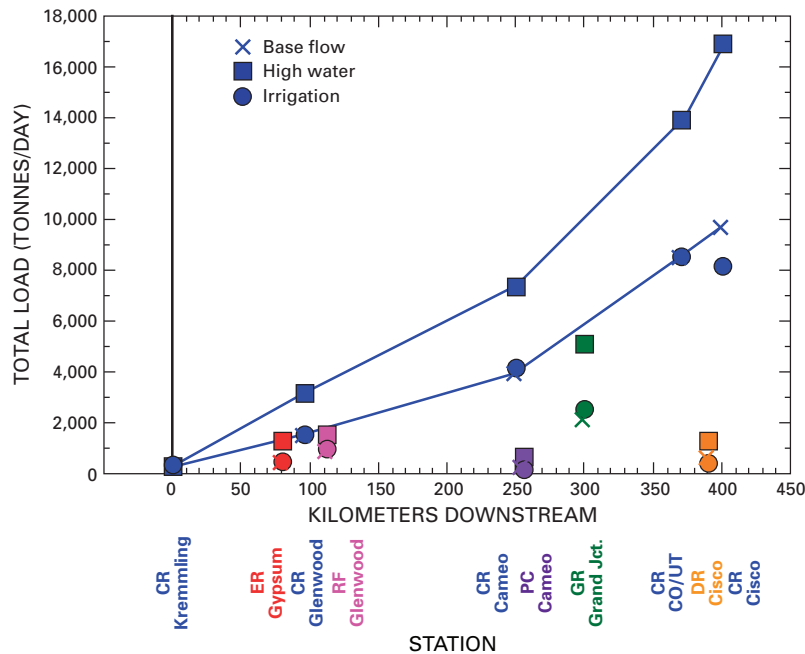
Colorado River, Cisco	HW	IRR	BF
Charge balance (percent)	10	0.8	-10
Conductivity ( $\mu\text{S}/\text{cm}$ )	430	725	1,230
Water type	mixed	mixed	mixed
Load (tonnes solutes/day)	17,000	8,170	9,580
Percent CR load at Cisco	100	100	100
Ca:SO <sub>4</sub> (molar basis)	1.1	0.99	0.98
Na:Cl (molar basis)	1.5	1.5	1.8
Evaporation	no	no	no
Predominant SO <sub>4</sub> source	Mancos Shale	Mancos Shale	Mancos Shale

## Fingerprinting Major Geologic Salt Sources

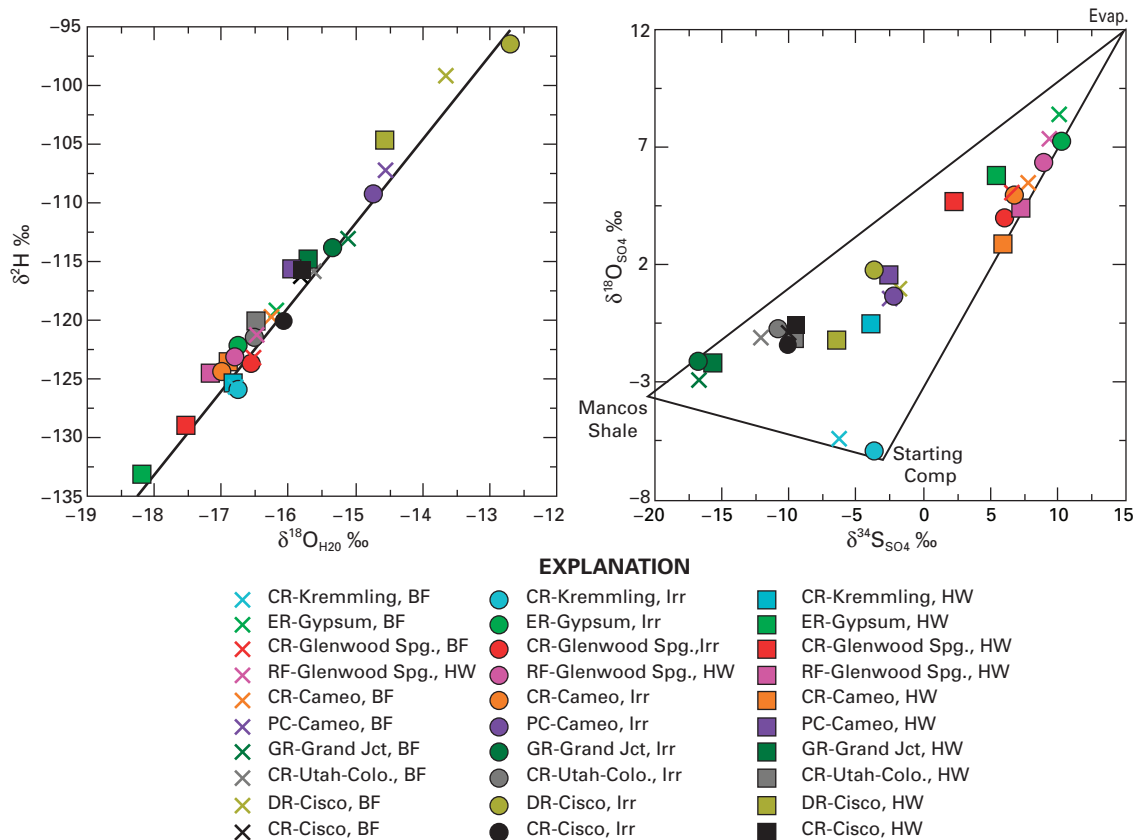
Major geologic influences on the chemistry of the Colorado River are evident in the evolution of the water from a calcium bicarbonate type near its headwaters (weathering of crystalline rocks) toward a sodium chlorite type as it flows through Eagle Valley Evaporite that includes halite, toward a calcium sodium sulfate type as it and tributaries flow through the sulfate-rich Mancos Shale and bedded evaporites (halite and anhydrite) of the Paradox Formation. Sodium, chloride, calcium, and sulfate loads and sulfur isotopic compositions have been used to fingerprint these major salt contributors and to quantitatively determine their relative influence on solutes in the Colorado River.

Chloride is generally a minor contributor to salt loads in the upper Colorado River, accounting for only 6 to 14 percent of the total solute load at the Colorado River station near Cisco. It is less than 5 percent of the load at any one station except for those where the river flows through Eagle Valley Evaporite (Eagle River, Roaring Fork River, Colorado River headwater, and Colorado River headwater-plateau watersheds), or Paradox Formation evaporites (upper and lower Dolores River watersheds). At stations within these watersheds, values increase from 5 percent of the total load during high-water flow in the Dolores River to over 40 percent during irrigation flow. Although 40 percent is a high proportion of the total load, the contribution of chloride at this station to the load in the upper Colorado River near Cisco is still only 2 percent.

Sulfate, on the other hand, is a major contributor, accounting for 25 to 30 percent of the solute load in the Colorado River near Cisco. In watersheds containing significant expanses of Mancos Shale (Gunnison and Uncompahgre Rivers), sulfate makes up nearly half of the total load. Although most sulfate comes from gypsum, some sulfate is derived from the dissolution of anhydrite and thenardite. In most cases, we are not able to constrain how much of the sulfate came from each mineral. Therefore, all mineral weights are reported on a gypsum basis. If *all* sulfate is derived from anhydrite, then using gypsum values results in an overestimation of 20 percent of the amount of mineral dissolved. If all is from thenardite, we overestimated the amount by 17 percent.



**Figure 15.** Total load at stations along the Colorado River and at confluences with tributaries. River kilometers are estimated distance from the Colorado River near Kremmling, Colo., station. CR, Colorado River; ER, Eagle River, RF, Roaring Fork River; PC, Parachute Creek; GR, Gunnison River; and DR, Dolores River.



**Figure 16.** Isotopic composition of water and sulfate along the main stem of the upper Colorado River at and above Cisco and at farthest downstream stations of major tributaries. Solid line connects the starting composition and two major sources of sulfate to the Colorado River—Starting Comp, starting composition at Kremmling station (farthest upstream on Colorado River); evap., evaporites (Eagle Valley Evaporite); and Mancos Shale. CR, Colorado River; ER, Eagle River, RF, Roaring Fork River; PC, Parachute Creek; GR, Gunnison River; DR, Dolores River; HW, high-water flow; Irr, irrigation flow; BF, base flow. In the case of the Dolores River, the evaporite contribution is from the Paradox Formation with a similar isotopic composition to that in the Eagle Valley Evaporite. Hydrogen and oxygen isotopes reported relative V-SMOW and sulfur isotopes relative to V-CDT.

### Evaporites in the Eagle Valley Evaporite

The major input of chloride to the Colorado River is dissolution of halite related to the Eagle Valley Evaporite upstream from Cameo. Based on our limited sampling, we estimate that 1,210 tonnes of halite dissolve per day contributing Cl to the Colorado River during high-water flow, 1,060 tonnes of halite per day during irrigation flow, and 1,340 tonnes of halite per day during base flow.<sup>7</sup> These values are fairly similar, and if we assume their average represents an average daily contribution, then 439,000 tonnes of halite in the Eagle Valley Evaporite are dissolved and added to the Colorado River annually. Using sulfate loads and isotopic compositions, we estimate that at least 345,000 tonnes of gypsum from the Eagle Valley Evaporite are dissolved and added annually as well. The total amount of solutes derived from these evaporites as estimated in this study is 784,000 tonnes solutes/year (18 percent of the estimated annual load of the Colorado River at Cisco). Chafin and Butler (2002) derived an estimate of 817,000 tonnes/year using a very different approach. Considering the number of assumptions in both approaches and that the data are from different years, these estimates are very similar.

### Evaporites in the Paradox Formation

A similar analysis was used to determine the amount of salt derived from the Paradox Formation in the upper Dolores River watershed. Assuming that 58 percent of the chloride in the Dolores River at Bedrock comes from dissolution of halite (load at Bedrock minus load calculated for McPhee Reservoir), 60 tonnes of halite per day are dissolved and added to the river during high flow. During irrigation and base-flow conditions, 100 percent of the Na and Cl is assumed to have been derived from halite as the load from the McPhee Reservoir is negligible. Under these conditions, 115 and 35 tonnes of halite per day, respectively, dissolve and enter the river. Assuming that the average of these three amounts estimates a daily average throughout the year, 25,600 tonnes of Paradox Formation halite dissolve per year upstream from the Bedrock station. Calculations indicate that between

<sup>7</sup>Estimates based on Cl loads in the Colorado River at Cameo, Colo., minus loads for the Colorado River near Kremmling, Colo., and Eagle River near Minturn, Colo.



the Bedrock and Cisco stations, a portion of the load of the Dolores River is lost during high- and irrigation-flow conditions. This loss may be due to recharge of the alluvium aquifer of the Paradox Valley (Chafin, 2003). Under base-flow conditions in the year we sampled, sodium and chloride increase dramatically in a molar ratio of one. This increase suggests that during base flow, additional solutes from the dissolution of 215 tonnes of halite per day are added to the river between these two stations (loads adjusted to exclude solutes carried by the San Miguel River). Assuming base-flow conditions for a third of the year, this amount is equal to 26,200 tonnes of halite. The total amount of Paradox halite dissolved and solutes added to the Dolores River from McPhee Reservoir to Cisco is estimated at 51,800 tonnes per year.

The Paradox Formation evaporites also include bedded anhydrite that contributes to the calcium and sulfate load along the Dolores River. Sulfate isotopes were used to determine the relative contribution of Paradox anhydrite ( $\delta^{34}\text{S}$  of 13 ‰ and  $\delta^{18}\text{O}$  of around 16 ‰; Claypool and others, 1980; Tuttle and others, 1996). Dissolution of anhydrite in the Paradox Formation above the Bedrock station is small, consistent with findings reported in Chafin (2003). Sulfate isotopes indicate that negligible dissolution of anhydrite occurs during high-water flow. During irrigation flow and base flow, solutes from the dissolution of 12 and 8 tonnes anhydrite per day, respectively, are added to the Dolores River. An average of these daily rates indicates that about 2,430 tonnes of anhydrite dissolve in a year (3,100 tonnes per year on a gypsum basis).

During high water, the loss of a portion of the Dolores River flow across the Paradox Valley precludes calculation of contributions of specific salts; however, sulfate isotopes at the Cisco station indicate that 90 percent of the sulfate is acquired from the San Miguel River and 10 percent from upstream. During irrigation and base flow, the sulfate load at Cisco is equal to the sum of the load at the Bedrock and the San Miguel stations, indicating that negligible sulfate is acquired as the Dolores River crosses the Paradox Valley. Sulfate loads indicate that 81 (irrigation flow) and 90 (base flow) percent of the sulfate in the Dolores River is from San Miguel River flow.

## Salts Derived From Weathering of the Mancos Shale

Gypsum and highly soluble thenardite ( $\text{Na}_2\text{SO}_4$ ) are common weathering products associated with the Mancos Shale. Both salts are found in soils derived from the shale. Gypsum is also found along fractures and bedding planes in shale in the unsaturated zone. This deeper gypsum is thought to be related to historic weathering of the shale when the water table was higher and/or the climate wetter (Tuttle and others, 2008). The sulfur isotopes of all salt are very similar to that of pyrite in the Mancos Shale (average of  $-21$  ‰), but the  $\delta^{18}\text{O}$  of the deeper gypsum is isotopically lighter ( $-10$  ‰) than the sulfate salts found in the soil ( $-3$  ‰) (Tuttle and others, 2005).

In the Dolores River watershed, we had good control on the source of sodium, and we were able to determine sulfate derived from gypsum and sulfate derived from thenardite. In all the other watersheds, however, we were unable to differentiate between sulfate derived from these two minerals; therefore, all Mancos Shale calculations in these watersheds and totals at our most downstream station were made on a gypsum basis, realizing that some of the sulfate is indeed from dissolution of thenardite.

## Dolores River Watershed

In the Dolores River watershed, a portion of the sulfate is derived from the Mancos Shale. By assuming that the sodium acquired between the McPhee Reservoir and the Bedrock station during high-water flow, and not attributed to halite, is from dissolution of salt in the Mancos, we can calculate the amount of thenardite ( $\text{Na}_2\text{SO}_4$ ) separately from the gypsum. Calculations indicate that dissolution of 64 tonnes of thenardite per day (78 t/d gypsum equivalent) is needed to supply this sodium load. Dissolution of 57 tonnes of gypsum per day accounts for the remainder of the sulfate load acquired between these two points during high-water flow. Isotopic composition of this sulfate indicates that it comes from Mancos soil. During irrigation flow and base flow, thenardite does not contribute salt to the Dolores River, but gypsum along bedding planes deeper in the Mancos Shale does. Isotopes indicate that 40 and 30 percent, respectively, of the sulfate load at the Bedrock station comes from dissolution of 8 tonnes of gypsum per day during irrigation flow and 3 tonnes of gypsum per day during base flow.

It appears that gypsum in the Mancos Shale soil also contributes sulfate to the San Miguel River (estimated 15 percent at our sampling station). This percentage translates to 66, 25, and 24 tonnes of gypsum per day being dissolved and solutes added to the river during high-water, irrigation, and base flows, respectively. It is possible that, during high-water flow, some of the sulfate may come from thenardite as well, although we have no way to quantify the amount. During high-water flow, dissolution of 200 tonnes of gypsum per day is needed to account for the sulfate load in the Dolores River attributed to the Mancos Shale. This amount drops dramatically to 33 and 27 tonnes per day during irrigation and base flow, respectively. Based on an average daily rate, this represents 31,600 tonnes of gypsum per year.

## Gunnison River Watershed

About half of the solutes and most of the sulfate in the Gunnison River are derived from weathering of the Mancos Shale. Using sulfate isotopes, we calculate that during high water, 87 percent of the sulfate in the Uncompahgre River at Delta is derived from Mancos Shale. During irrigation and base flow, the proportions increase slightly to 90 and 89 percent respectively. Using the same method, we calculate

that 88, 90, and 95 percent of the sulfate in the Gunnison River at Delta during high-water, irrigation, and base flows, respectively, is from Mancos Shale. The amount of gypsum dissolution required to supply this sulfate at the Uncompahgre and Gunnison Rivers confluence a short distance downstream from these two stations is 2,190 (high-water flow), 2,410 (irrigation flow), and 2,120 (base flow) tonnes of gypsum per day. Again, assuming that the average of the amounts during different flow conditions approximates the daily average throughout the year, dissolution of 817,600 tonnes of gypsum is required to supply the sulfate.

During high-water flow, additional sulfate is picked up by the Gunnison River between the confluence with the Uncompahgre River and the Gunnison River near Grand Junction station. Isotopic composition of the sulfate indicates that most of it is from Mancos soil and represents an additional dissolution of 830 tonnes of gypsum per day. During irrigation and base-flow conditions, 22 and 29 percent of the sulfate load is lost over this reach due to alluvium recharge or diversion with no return. Summing the amount of sulfate in the Gunnison River at Delta and in the Uncompahgre River, adding in the sulfate acquired below their confluence during high-water flow, and subtracting that lost during irrigation and base flow, we calculate an average of 1,190 tonnes of sulfate per day from Mancos Shale was supplied to the Colorado River by the Gunnison River. This represents the dissolution of an estimated 777,500 tonnes of Mancos Shale gypsum per year (from base-flow data for Gunnison and Uncompahgre Rivers at Delta), 224,500 tonnes of which was lost to assumed alluvial recharge in the lower Gunnison River stretch. Warner and others (1985) used data from 1977–78 to calculate that the Gunnison River base flow contributed 736,000 tonnes of solutes per year. Using just our base-flow data, we calculate 773,400 tonnes of solutes per year, a value that agrees well with Warner and others (1985).

## Colorado River Headwater-Plateau Watershed

As the Colorado River enters the Grand Valley (reach below Cameo station), it flows through a landscape dominated by Mancos Shale. The Colorado River provides irrigation water that supports extensive agriculture on Mancos Shale in the valley. We estimate from sulfate isotopes that 62 (high-water flow), 67 (irrigation flow), and 65 (base flow) percent of the sulfate load at the Colorado-Utah State line station is derived from Mancos Shale soil. Using these percentages and the sulfate loads at this station, minus the sulfate loads of the Gunnison River at Grand Junction attributed to the Mancos Shale, we calculate a minimum of 1,190, 1,520, and 2,150 tonnes of gypsum per day dissolved in the Grand Valley and contributed sulfate to the Colorado River during high-water, irrigation, and base flows, respectively. These values are minimums as some of the sulfate load may have been removed

during recharge of alluvium. Assuming the average of these amounts reasonably estimates the daily average throughout the year, then 591,700 tonnes of gypsum in the Grand Valley dissolved and the solutes were added to the Colorado River in 2005.

## Summary

In 2005, the amount of salt (halite and gypsum) dissolved from the Eagle Valley Evaporite, Paradox Formation, Mancos Shale, and their associated soils is shown in table 26. Collectively, dissolution of these salts account for just over half of the solutes in the Colorado River at the station near Cisco. The Mancos Shale generates about 33 percent of the solutes, the Eagle Valley Evaporite generates 18 percent of the solutes, and the Paradox Formation generates only 1 percent.

**Table 26.** The 2005 estimated dissolution rates for halite and gypsum in the Eagle Valley, Paradox, and Mancos Formations estimated in this study and a comparison of the derived solutes to the estimated annual Colorado River (CR) load at Cisco.

Formation	Halite (tonnes/a)	Gypsum (tonnes/a)	Percent of CR annual load (Cisco)
Eagle Valley Evaporite	439,000	343,000	18
Paradox Formation	51,800	3,100	1
Mancos Shale, total		1,400,800	33
Dolores River		31,600	1
Gunnison River		777,500 <sup>1</sup>	18
Colorado River headwater/plateau		591,700	14

<sup>1</sup>An estimated 40,200 tonnes per year of additional gypsum dissolved and the sulfate removed from the Gunnison River between Delta and Grand Junction stations during irrigation and base-flow conditions due to alluvium recharge or water diversion.

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# Appendixes

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## Appendix I. Chemical and Isotopic Data for All Water Samples Collected in This Study

**Table A1–1.** Metadata (analytical method, detection limit, the number of samples with censored data, the percent of samples with replaced values, and the replacement value) for reported concentrations. Replacement (red) values ( $0.5 \times$  detection limit) are used when censored values were reported for  $\leq 20$  percent of the samples (14 samples or less). For elements with the number censored = “many,” less than concentrations are reported.

[IC, ion chromatography; ICP–MS, inductive coupled plasma–mass spectrometry; ICP–AES, inductive coupled plasma–atomic emission spectrometry; na, not analyzed]

Element	Method	Detection limit	No. censored	Percent replaced	Replacement
NO <sub>3</sub>	IC	0.08 mg/L	14	20	0.04 mg/L
Al	ICP–MS	2 µg/L	13	19	1 µg/L
Al	ICP–AES	10 µg/L	many	na	
B	ICP–AES	5 µg/L	many	na	
Cd	ICP–MS	0.02 µg/L	many	na	
Cd (raw)	ICP–MS		6	10	0.01 µg/L
Ce	ICP–MS	0.01 µg/L	8	13	0.005 µg/L
Ce (raw)	ICP–MS	0.01 µg/L	1	2	0.005 µg/L
Co	ICP–MS	0.02 µg/L	3	5	0.01 µg/L
Co (raw)	ICP–MS	0.02 µg/L	1	2	0.01 µg/L
Cr	ICP–MS	0.1 µg/L	many	na	
Cr (raw)	ICP–MS	0.1 µg/L	many	na	
Cs	ICP–MS	0.02 µg/L	many	na	
Cs (raw)	ICP–MS	0.02 µg/L	9	14	0.01 µg/L
Dy	ICP–MS	0.005 µg/L	many	na	
Dy (raw)	ICP–MS	0.005 µg/L	1	2	0.003 µg/L
Er	ICP–MS	0.005 µg/L	many	na	
Er (raw)	ICP–MS	0.005 µg/L	2	3	0.003 µg/L
Eu	ICP–MS	0.005 µg/L	3	4	0.003 µg/L
Eu (raw)	ICP–MS	0.005 µg/L	2	3	0.003 µg/L
Fe	ICP–MS	50 µg/L	many	na	
Fe (raw)	ICP–MS	50 µg/L	8	13	25 µg/L
Gd	ICP–MS	0.005 µg/L	many	na	
Gd (raw)	ICP–MS	0.005 µg/L	1	2	0.003 µg/L
Ho	ICP–MS	0.005 µg/L	many	na	
Ho (raw)	ICP–MS	0.005 µg/L	11	17	0.003 µg/L
La	ICP–MS	0.01 µg/L	many	na	
La (raw)	ICP–MS	0.01 µg/L	1	2	0.005 µg/L
Li	ICP–AES	1 µg/L	2	3	0.5 µg/L
Mo	ICP–MS	2 µg/L	many	na	
Mo (raw)	ICP–MS	2 µg/L	many	na	
Mn	ICP–AES	10 µg/L	many	na	
Nd	ICP–MS	0.01 µg/L	9	14	0.005 µg/L
P	ICP–MS	0.01 mg/L	many	na	
P (raw)	ICP–MS	0.01 mg/L	many	na	
Pb	ICP–MS	0.05 µg/L	many	na	
Pr	ICP–MS	0.01 µg/L	many	na	
Pr (raw)	ICP–MS	0.01 µg/L	2	3	0.005 µg/L
Se	ICP–MS	1 µg/L	many	na	
Se (raw)	ICP–MS	1 µg/L	many	na	
Sm	ICP–MS	0.01 µg/L	many	na	
Sm (raw)	ICP–MS	0.01 µg/L	2	3	0.005 µg/L
Tb	ICP–MS	0.005 µg/L	many	na	
Tb (raw)	ICP–MS	0.005 µg/L	12	19	0.003 µg/L
Ti	ICP–MS	0.5 µg/L	8	13	0.3 µg/L
Y	ICP–MS	0.5 µg/L	many	na	
Y (raw)	ICP–MS	0.5 µg/L	10	16	0.3 µg/L
Yb	ICP–MS	0.005 µg/L	many	na	
Yb (raw)	ICP–MS	0.005 µg/L	3	5	0.003 µg/L
Zn	ICP–AES	10 µg/L	many	na	

**Table AI-2.** Elements not reported in Appendix 1, because all reported values were less than detection limit, or the few values reported were very near the detection limit. In some instances where the available concentrations did not meet this criteria, concentrations for the few samples were reported.

[ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry]

Element	Method	Detection limit
Ag, Ag (raw)	ICP-MS	3 µg/L
Ag	ICP-AES	1 µg/L
As, As (raw)	ICP-MS	1 µg/L
As	ICP-AES	100 µg/L
Be, Be (raw)	ICP-MS	0.05 µg/L
Be	ICP-AES	10 µg/L
Bi, Bi (raw)	ICP-MS	0.2 µg/L
Cd	ICP-AES	5 µg/L
Co	ICP-AES	10 µg/L
Cr	ICP-AES	10 µg/L
Cu	ICP-AES	11 µg/L
Fe	ICP-AES	20 µg/L
Ga, Ga (raw)	ICP-MS	0.05 µg/L
Ge, Ge (raw)	ICP-MS	0.05 µg/L
Lu, Lu (raw)	ICP-MS	0.1 µg/L
Mo	ICP-AES	20 µg/L
Nb, Nb (raw)	ICP-MS	0.2 µg/L
Ni	ICP-AES	10 µg/L
P	ICP-AES	0.1 mg/L
Pb	ICP-AES	50 µg/L
Sb	ICP-AES	50 µg/L
Sb, Sb (raw)	ICP-MS	0.3 µg/L
Ta, Ta (raw)	ICP-MS	0.02 µg/L
Th, Th (raw)	ICP-MS	0.2 µg/L
Ti	ICP-AES	50 µg/L
Tl, Tl (raw)	ICP-MS	0.1 µg/L
Tm, Tm (raw)	ICP-MS	0.005 µg/L
V	ICP-AES	10 µg/L
W, W (raw)	ICP-MS	0.5 µg/L
Zr, Zr (raw)	ICP-MS	0.2 µg/L

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Station ID	Station name	Site name	WS #	Flow condition	N. lat °	W. long °	Date
09058000	Colorado River near Kremmling, Colo.	CR-Kremmling	1	High water	40.0367	-106.4394	5/24/05
09058000	Colorado River near Kremmling, Colo.	CR-Kremmling	1	Irrigation	40.0367	-106.4394	8/30/05
09058000	Colorado River near Kremmling, Colo.	CR-Kremmling	1	Base flow	40.0367	-106.4394	10/12/05
09064600	Eagle River near Minturn, Colo.	ER-Minturn	2	High water	39.5539	-106.4019	5/26/05
09064600	Eagle River near Minturn, Colo.	ER-Minturn	2	Irrigation	39.5539	-106.4019	7/29/05
09064600	Eagle River near Minturn, Colo.	ER-Minturn	2	Base flow	39.5539	-106.4019	10/20/05
09067005	Eagle River at Avon, Colo.	ER-Avon	2	High water	39.6317	-106.5219	5/26/05
09067005	Eagle River at Avon, Colo.	ER-Avon	2	Irrigation	39.6317	-106.5219	7/26/05
09067005	Eagle River at Avon, Colo.	ER-Avon	2	Base flow	39.6317	-106.5219	10/19/05
09069000	Eagle River at Gypsum, Colo.	ER-Gypsum	2	High water	39.6500	-106.9517	5/24/05
09069000	Eagle River at Gypsum, Colo.	ER-Gypsum	2	Irrigation	39.6500	-106.9517	7/26/05
09069000	Eagle River at Gypsum, Colo.	ER-Gypsum	2	Base flow	39.6500	-106.9517	10/20/05
09071750	Colorado River above Glenwood Springs, Colo.	CR-Glenwood	1	High water	39.5606	-107.2997	5/23/05
09071750	Colorado River above Glenwood Springs, Colo.	CR-Glenwood	1	Irrigation	39.5606	-107.2997	7/28/05
09071750	Colorado River above Glenwood Springs, Colo.	CR-Glenwood	1	Base flow	39.5606	-107.2997	10/21/05
09085000	Roaring Fork at Glenwood Springs, Colo.	RF-Glenwood	3	High water	39.5436	-107.3289	6/3/05
09085000	Roaring Fork at Glenwood Springs, Colo.	RF-Glenwood	3	Irrigation	39.5436	-107.3289	7/29/05
09085000	Roaring Fork at Glenwood Springs, Colo.	RF-Glenwood	3	Base flow	39.5436	-107.3289	10/27/05
09105000	Plateau Creek near Cameo, Colo.	PC-Cameo	8	High water	39.1833	-108.2672	6/3/05
09105000	Plateau Creek near Cameo, Colo.	PC-Cameo	8	Irrigation	39.1833	-108.2672	7/14/05
09105000	Plateau Creek near Cameo, Colo.	PC-Cameo	8	Base flow	39.1833	-108.2672	10/27/05
09095500	Colorado River near Cameo, Colo.	CR-Cameo	8	High water	39.2392	-108.2656	6/3/05
09095500	Colorado River near Cameo, Colo.	CR-Cameo	8	Irrigation	39.2392	-108.2656	7/13/05
09095500	Colorado River near Cameo, CO Colo.	CR-Cameo	8	Base flow	39.2392	-108.2656	10/27/05
09134100	North Fork Gunnison River below Paonia, Colo.	GR-NF	5	High water	38.8575	-107.6219	5/24/05
09134100	North Fork Gunnison River below Paonia, Colo.	GR-NF	5	Irrigation	38.8575	-107.6219	7/5/05
09134100	North Fork Gunnison River below Paonia, Colo.	GR-NF	5	Base flow	38.8575	-107.6219	11/30/05
09128000	Gunnison River below Gunnison Tunnel, Colo.	GR-Tunnel	4	High water	38.5292	-107.6483	6/24/05
09128000	Gunnison River below Gunnison Tunnel, Colo.	GR-Tunnel	4	Irrigation	38.5292	-107.6483	7/20/05
09128000	Gunnison River below Gunnison Tunnel, Colo.	GR-Tunnel	4	Base flow	38.5292	-107.6483	10/17/05
09144250	Gunnison River at Delta, Colo.	GR-Delta	7	High water	38.7531	-108.0778	5/27/05
09144250	Gunnison River at Delta, Colo.	GR-Delta	7	Irrigation	38.7531	-108.0778	8/11/05
09144250	Gunnison River at Delta, Colo.	GR-Delta	7	Base flow	38.7531	-108.0778	11/30/05
09146020	Uncompahgre River near Ouray, Colo.	UR-Ouray	6	High water	38.0433	-107.6825	6/14/05
09146020	Uncompahgre River near Ouray, Colo.	UR-Ouray	6	Irrigation	38.0433	-107.6825	8/10/05
09146020	Uncompahgre River near Ouray, Colo.	UR-Ouray	6	Base flow	38.0433	-107.6825	11/18/05
09146200	Uncompahgre River near Ridgway, Colo.	UR-Ridgway	6	High water	38.1839	-107.7453	6/14/05
09146200	Uncompahgre River near Ridgway, Colo.	UR-Ridgway	6	Irrigation	38.1839	-107.7453	8/10/05
09146200	Uncompahgre River near Ridgway, Colo.	UR-Ridgway	6	Base flow	38.1839	-107.7453	11/18/05
09149500	Uncompahgre River at Delta, Colo.	UR-Delta	6	High water	38.7419	-108.0803	5/27/05
09149500	Uncompahgre River at Delta, Colo.	UR-Delta	6	Irrigation	38.7419	-108.0803	8/11/05
09149500	Uncompahgre River at Delta, Colo.	UR-Delta	6	Base flow	38.7419	-108.0803	11/29/05
09152500	Gunnison River near Grand Junction, Colo.	GR-Grand Jct.	7	High water	38.9833	-108.4500	6/2/05
09152500	Gunnison River near Grand Junction, Colo.	GR-Grand Jct.	7	Irrigation	38.9833	-108.4500	7/12/05
09152500	Gunnison River near Grand Junction, Colo.	GR-Grand Jct.	7	Base flow	38.9833	-108.4500	10/31/05
09163500	Colorado River near Colorado-Utah State Line	CR-State line	8	High water	39.1328	-109.0264	6/1/05
09163500	Colorado River near Colorado-Utah State Line	CR-State line	8	Irrigation	39.1328	-109.0264	7/11/05
09163500	Colorado River near Colorado-Utah State Line	CR-State line	8	Base flow	39.1328	-109.0264	10/26/05
09166500	Dolores River at Dolores, Colo.	DR-Dolores	9	High water	37.4725	-108.4969	5/25/05
09166500	Dolores River at Dolores, Colo.	DR-Dolores	9	Irrigation	37.4725	-108.4969	7/19/05
09166500	Dolores River at Dolores, Colo.	DR-Dolores	9	Base flow	37.4725	-108.4969	10/3/05



**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Station ID	Station name	Site name	WS #	Flow condition	N. lat °	W. long °	Date
09171100	Dolores River near Bedrock, Colo.	DR-Bedrock	9	High water	38.3569	-108.8328	5/31/05
09171100	Dolores River near Bedrock, Colo.	DR-Bedrock	9	Irrigation	38.3569	-108.8328	7/28/05
09171100	Dolores River near Bedrock, Colo.	DR-Bedrock	9	Base flow	38.3569	-108.8328	11/15/05
09177000	San Miguel at Uravan, Colo.	SM-Uravan	10	High water	38.3572	-108.7122	6/1/05
09177000	San Miguel at Uravan, Colo.	SM-Uravan	10	Irrigation	38.3572	-108.7122	7/29/05
09177000	San Miguel at Uravan, Colo.	SM-Uravan	10	Base flow	38.3572	-108.7122	11/15/05
09180000	Dolores River near Cisco, Utah	DR-Cisco	11	High water	38.7972	-109.1944	6/23/05
09180000	Dolores River near Cisco, UTUtah	DR-Cisco	11	Irrigation	38.7972	-109.1944	8/5/05
09180000	Dolores River near Cisco, UTUtah	DR-Cisco	11	Base flow	38.7972	-109.1944	11/8/05
09180500	Colorado River near Cisco, UTUtah	CR-Cisco	12	High water	38.8106	-109.2928	5/21/05
09180500	Colorado River near Cisco, UTUtah	CR-Cisco	12	Irrigation	38.8106	-109.2928	7/12/05
09180500	Colorado River near Cisco, UTUtah	CR-Cisco	12	Base flow	38.8106	-109.2928	11/21/05
	Glenwood Springs hot spring	GW hot spring			39.55088	-107.32206	8/16/05
	Rifle Uranium Mill monitoring well 305	RUM 305					4/25/06
	Rifle Uranium Mill monitoring well 310	RUM 310					4/26/06
	Rifle Uranium Mill monitoring well 590	RUM 590					4/26/06
	Rifle Uranium Mill monitoring well 855	RUM 855					4/26/06

Site name	AA meter discharge CFS	Electrode conductivity $\mu\text{S}/\text{cm}$	Electrode pH	Mass spec. $\delta^{18}\text{O}(\text{H}_2\text{O})$ ‰	Mass spec. $\delta^2\text{H}$ ‰	Titration $\text{HCO}_3$ mg/L	IC Cl mg/L
CR-Kremmling	1,230	140	7.13	-16.8	-125	62	2.3
CR-Kremmling	980	211	8.20	-16.8	-126	72	5.0
CR-Kremmling	750	200	8.20	-16.8	-126	78	4.5
ER-Minturn	634	103	7.42	-18.4	-137	45	1.7
ER-Minturn	91	140	7.61	-17.1	-128	70	1.7
ER-Minturn	86	110	7.60	-16.3	-120	52	2.3
ER-Avon	2,180	100	7.37	-18.4	-135	47	2.5
ER-Avon	457	131	7.53	-16.7	-122	50	3.0
ER-Avon	206	190	8.00	-16.4	-120	120	6.1
ER-Gypsum	3,630	191	7.57	-18.2	-133	86	4.5
ER-Gypsum	871	360	7.54	-16.8	-122	82	22
ER-Gypsum	418	555	8.70	-16.2	-119	99	47
CR-Glenwood	7,050	248	7.50	-17.5	-129	105	10
CR-Glenwood	1,920	515	7.75	-16.6	-124	110	55
CR-Glenwood	1,404	565	8.10	-16.5	-123	175	64
RF-Glenwood	3,520	251	7.62	-17.2	-125	88	5.0
RF-Glenwood	1,340	440	7.89	-16.8	-123	120	19
RF-Glenwood	764	600	8.40	-16.4	-121	140	42
PC-Cameo	1,430	195	7.70	-16.0	-115	26	2.0
PC-Cameo	158	520	8.21	-14.8	-109	22	6.4
PC-Cameo	145	590	8.30	-14.5	-107	35	8
CR-Cameo	10,900	397	7.64	-16.9	-124	83	28
CR-Cameo	5,020	527	7.91	-17.0	-124	105	55
CR-Cameo	2,480	920	8.20	-16.2	-120	115	135
GR-NF	5,190	117	7.42	-16.3	-118	175	2.0
GR-NF	696	171	7.59	-16.3	-118	200	2.0
GR-NF	199	310	7.90	-15.1	-105	250	5.2
GR-Tunnel	744	194	7.74	-15.8	-118	55	2.0
GR-Tunnel	524	204	7.54	-15.8	-118	67	2.0
GR-Tunnel	394	200	7.80	-15.9	-118	175	2.4

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	AA meter discharge CFS	Electrode conductivity $\mu\text{S}/\text{cm}$	Electrode pH	Mass spec. $\delta^{18}\text{O}(\text{H}_2\text{O})$ ‰	Mass spec. $\delta^2\text{H}$ ‰	Titration $\text{HCO}_3$ mg/L	IC Cl mg/L
GR-Delta	6,410	279	7.59	-16.0	-117	76	3.9
GR-Delta	960	900	8.15	-15.7	-114	90	11
GR-Delta	878	1,080	8.00	-14.9	-110	175	15
UR-Ouray	252	234	7.24	-17.1	-123	82	2.0
UR-Ouray	110	395	6.99	-15.9	-112	175	3.9
UR-Ouray	27	625	7.40	-15.7	-114	205	7.3
UR-Ridgway	342	420	7.66	-16.7	-120	110	5.0
UR-Ridgway	193	566	7.80	-15.6	-112	160	6.5
UR-Ridgway	76	680	7.90	-15.7	-113	145	8.4
UR-Delta	470	1,067	7.78	-15.1	-112	100	11
UR-Delta	767	1,150	7.92	-13.2	-112	280	18
UR-Delta	242	1,530	8.00	-15.0	-112	330	22
GR-Grand Jct.	5,980	455	7.69	-15.7	-115	120	4.6
GR-Grand Jct.	1,570	853	7.74	-15.4	-114	120	11
GR-Grand Jct.	1,530	715	8.20	-15.1	-113	190	13
CR-State line	18,000	433	7.77	-16.5	-120	120	18
CR-State line	7,430	684	7.93	-16.5	-121	135	40
CR-State line	4,420	1,087	8.10	-15.6	-116	175	70
DR-Dolores	3,920	157	7.43	-14.9	-105	78	2.2
DR-Dolores	247	263	8.04	-14.4	-102	105	6.5
DR-Dolores	122	330	8.10	-12.7	-89	115	11
DR-Bedrock	1,300	400	7.62	-13.4	-97	135	18
DR-Bedrock	82	1,508	7.54	-11.6	-86	155	365
DR-Bedrock	46	1,010	8.10	-12.6	-94	155	190
SM-Uravan	1,250	351	7.52	-15.1	-108	105	4.3
SM-Uravan	217	567	7.83	-14.6	-106	120	6.4
SM-Uravan	134	750	8.10	-14.0	-102	185	13
DR-Cisco	1,950	376	7.54	-14.6	-105	115	14
DR-Cisco	270	1,071	7.63	-12.7	-96	155	150
DR-Cisco	193	1,745	8.00	-13.6	-99	205	330
CR-Cisco	22,400	431	7.41	-15.8	-116	135	21
CR-Cisco	6,810	724	7.48	-16.1	-120	140	55
CR-Cisco	3,500	1,230	8.10	-15.8	-116	175	120
GW hot spring	na	34,200	6.66	-18.0	-134	585	10,500
RUM 305	na	1,420	7.44	na	na	145	95
RUM 310	na	1,860	7.23	na	na	205	185
RUM 590	na	4,770	6.79	na	na	135	190
RUM 855	na	2,480	6.81	na	na	105	175

Site name	IC F mg/L	IC $\text{NO}_3$ mg/L	IC $\text{SO}_4$ mg/L	ICP-MS $\text{SO}_4$ mg/L	ICP-MS $\text{SO}_4$ (avail.) mg/L	Gravimetric $\text{SO}_4$ mg/L	Mass spec. $\delta^{34}\text{S}(\text{SO}_4)$ ‰	Mass spec. $\delta^{18}\text{O}(\text{SO}_4)$ ‰
CR-Kremmling	0.6	0.3	11	6	9.0	12	-4.0	-0.5
CR-Kremmling	2	0.3	24	26	22	29	-3.7	-5.9
CR-Kremmling	0.08	0.4	24	23	22	28	-6.1	-5.5
ER-Minturn	0.1	1	5.5	3	4.0	2.9	ins	ins
ER-Minturn	0.1	0.6	9.3	8	6.0	9.3	-1.3	-5.7
ER-Minturn	0.3	0.2	9.2	7.0	5.0	9	0.5	-4.3
ER-Avon	0.1	0.7	6	4	5.0	2.6	ins	ins
ER-Avon	0.1	0.3	15	13	12	16	4.8	0.6
ER-Avon	0.2	0.7	31	31	27	33	5.2	1.2
ER-Gypsum	0.1	0.8	20	18	18	21	5.4	5.8
ER-Gypsum	0.2	1	58	56	49	63	10.3	7.3
ER-Gypsum	0.8	1.9	99	105	105	105	10.2	8.3
CR-Glenwood	0.1	0.9	20	18	17	21	2.3	4.7

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	IC F mg/L	IC NO <sub>3</sub> mg/L	IC SO <sub>4</sub> mg/L	ICP-MS SO <sub>4</sub> mg/L	ICP-MS SO <sub>4</sub> (avail.) mg/L	Gravimetric SO <sub>4</sub> mg/L	Mass spec. δ <sup>34</sup> S(SO <sub>4</sub> ) ‰	Mass spec. δ <sup>18</sup> O(SO <sub>4</sub> ) ‰
CR-Glenwood	0.4	0.8	56	55	55	63	6.0	4.0
CR-Glenwood	0.8	0.8	64	71	67	72	6.7	5.0
RF-Glenwood	0.2	1	36	33	31	39	7.2	4.4
RF-Glenwood	0.3	0.7	76	67	66	78	8.9	6.4
RF-Glenwood	0.8	0.04	110	115	110	115	9.5	7.3
PC-Cameo	0.6	0.4	8.7	8	7.0	9.4	-2.6	1.6
PC-Cameo	2	0.04	31	30	31	36	-2.3	0.7
PC-Cameo	0.5	0.04	45	46	39	48	-2.4	0.5
CR-Cameo	0.2	2	39	38	36	44	5.9	2.9
CR-Cameo	0.3	0.04	56	55	55	63	6.7	5.0
CR-Cameo	1.4	0.04	110	120	115	115	7.9	5.4
GR-NF	0.1	2	7.4	5	6.0	6.0	ins	ins
GR-NF	0.1	0.2	21	29	19	25	ins	-3.0
GR-NF	0.5	0.6	41	40	34	42	-11.8	-3.0
GR-Tunnel	0.6	1	18	18	16	21	-3.9	-2.2
GR-Tunnel	0.6	0.04	19	18	18	21	-3.1	-1.2
GR-Tunnel	0.1	0.04	22	22	16	24	-4.2	-2.1
GR-Delta	0.2	1	54	55	51	62	-15.2	-2.4
GR-Delta	0.6	2	300	325	285	300	-17.6	-2.9
GR-Delta	1.2	5.9	435	415	385	625	-17.4	-1.5
UR-Ouray	0.2	0.9	79	78	61	80	2.9	-4.3
UR-Ouray	0.5	0.8	160	165	140	160	4.1	-3.3
UR-Ouray	0.4	1.2	295	260	170	295	6.8	-1.6
UR-Ridgway	0.4	1	120	125	110	125	-1.4	-2.9
UR-Ridgway	0.6	1	180	190	165	185	-2.3	-2.7
UR-Ridgway	0.6	1.2	280	246	245	275	0.0	-1.4
UR-Delta	0.7	8.3	395	415	345	375	-17.8	-2.3
UR-Delta	1	8.9	440	470	370	420	-18.2	-2.6
UR-Delta	2.7	14.7	665	245	615	645	-18.4	-3.1
GR-Grand Jct.	0.3	2	120	140	120	130	-15.8	-2.2
GR-Grand Jct.	0.6	3	285	315	270	300	-16.9	-2.1
GR-Grand Jct.	1.3	2.0	225	235	215	235	-16.6	-3.0
CR-State line	0.3	2	78	87	65	86	-9.7	-1.1
CR-State line	0.5	2	145	165	150	155	-10.9	-0.7
CR-State line	2.6	3.6	235	290	280	290	-12	-1.2
DR-Dolores	1	1	8.4	7	7.0	7.7	-3.4	0.0
DR-Dolores	0.2	0.04	28	25	27	30	-3.1	-2.2
DR-Dolores	0.5	0.04	37	38	32	39	-1.0	-1.1
DR-Bedrock	2.0	5	51	51	46	59	-12.8	-1.5
DR-Bedrock	0.7	2	63	50	50	57	2.3	5.7
DR-Bedrock	1.4	0.04	57	67	50	57	-1.2	3.3
SM-Uravan	0.3	1	74	84	62	80	-5.8	-0.6
SM-Uravan	0.4	0.04	170	175	155	175	-4.8	0.1
SM-Uravan	1.3	0.04	260	270	255	265	-3.6	-0.8
DR-Cisco	0.3	0.9	57	56	49	65	-6.5	-1.2
DR-Cisco	1	0.04	190	155	155	175	-3.7	1.8
DR-Cisco	3.0	2.1	200	230	205	210	-1.7	0.9
CR-Cisco	0.3	2	90	61	54	72	-9.6	-0.6
CR-Cisco	0.6	2	155	150	145	150	-10.2	-1.4
CR-Cisco	2.7	4.0	270	295	265	275	-9.9	-1.0
GW hot spring	125	55	1,300	1,270	1,270	na	15.3	134
RUM 305	3.6	3.4	425	410	405	na	-6.8	1.2
RUM 310	41	.04	685	645	590	na	-6.5	1.5
RUM 590	41	93	1,000	2,440	2,180	na	2.8	6.6
RUM 855	7.3	295	2,570	1,120	1,020	na	2.4	6.8

Table AI-3. Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-AES Al µg/L	ICP-MS Al µg/L	ICP-MS Al (avail.) µg/L	ICP-AES B µg/L	ICP-AES Ba µg/L	ICP-MS Ba µg/L	ICP-MS Ba (avail.) µg/L	ICP-AES Ca mg/L	ICP-MS Ca mg/L
CR-Kremmling	<10	12	1,450	<5	18	18	69	11	10
CR-Kremmling	<10	1.0	53	<5	36	23	40	26	26
CR-Kremmling	<10	2	2	6.7	34	18	22	25	22
ER-Minturn	33	47	240	<5	37	34	39	13	13
ER-Minturn	<10	19	37	<5	43	42	40	16	16
ER-Minturn	12	16	57	<5	33	32	34	13	12
ER-Avon	47	51	685	<5	38	35	50	13	12
ER-Avon	15	28	79	<5	31	31	31	15	15
ER-Avon	<10	7.3	160	5.4	46	47	49	26	24
ER-Gypsum	22	32	4,640	<5	34	32	105	22	22
ER-Gypsum	<10	9.8	145	<5	37	35	42	40	39
ER-Gypsum	22	3.0	130	14	41	41	44	61	58
CR-Glenwood	14	17	5,040	<5	35	32	110	26	25
CR-Glenwood	<10	8.3	870	<5	48	48	58	44	46
CR-Glenwood	<10	2.2	195	16	43	42	45	52	45
RF-Glenwood	<10	20	585	<5	41	37	52	34	33
RF-Glenwood	<10	8.1	130	<5	47	45	47	55	55
RF-Glenwood	<10	1.0	21	15	56	53	51	82	73
PC-Cameo	<10	25	4,110	<5	44	42	92	19	20
PC-Cameo	<10	3.0	450	<5	110	110	130	48	49
PC-Cameo	<10	1.0	430	53	122	115	120	60	52
CR-Cameo	<10	23	2,640	<5	44	41	84	38	37
CR-Cameo	<10	4.9	420	<5	43	43	54	42	42
CR-Cameo	<10	1.0	130	31	51	49	50	71	65
GR-NF	11	24	9,160	<5	33	30	145	15	15
GR-NF	13	28	125	<5	30	29	34	18	18
GR-NF	<10	1.0	555	37	83	77	85	42	34
GR-Tunnel	<10	33	165	<5	38	35	40	25	25
GR-Tunnel	<10	4.1	63	<5	35	35	38	25	26
GR-Tunnel	<10	2.8	22	9.4	40	37	36	30	26
GR-Delta	<10	18	6,780	<5	40	37	110	29	30
GR-Delta	<10	1.0	495	<5	44	44	57	94	105
GR-Delta	<10	1.0	1,500	110	53	53	58	130	130
UR-Ouray	40	46	1,350	<5	36	33	37	34	34
UR-Ouray	25	35	2,430	<5	47	46	51	62	63
UR-Ouray	23	25	3,790	17	46	45	46	120	110
UR-Ridgway	52	63	1,200	<5	38	35	47	61	61
UR-Ridgway	39	53	1,340	<5	48	47	61	83	90
UR-Ridgway	40	26	1,690	41	39	40	40	115	110
UR-Delta	<10	11	8,660	24	58	53	215	130	140
UR-Delta	<10	2.7	4,750	44	54	53	78	145	160
UR-Delta	<10	1.0	125	175	37	35	36	210	190
GR-Grand Jct.	<10	18	5,530	<5	52	50	110	53	53
GR-Grand Jct.	<10	1.0	220	<5	46	45	53	96	105
GR-Grand Jct.	<10	5.8	88	71	49	49	48	78	76
CR-State line	<10	14	5,070	<5	50	47	110	43	44
CR-State line	<10	6.7	695	<5	50	49	72	64	65
CR-State line	26	1.0	390	82	56	52	55	110	105
DR-Dolores	24	32	6,110	<5	66	61	225	21	22
DR-Dolores	<10	9.9	47	<5	94	90	105	37	37
DR-Dolores	17	18	39	29	104	105	105	50	46
DR-Bedrock	<10	11	2,460	<5	86	81	170	43	44
DR-Bedrock	26	26	7,930	<5	218	205	510	49	47

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-AES Al µg/L	ICP-MS Al µg/L	ICP-MS Al (avail.) µg/L	ICP-AES B µg/L	ICP-AES Ba µg/L	ICP-MS Ba µg/L	ICP-MS Ba (avail.) µg/L	ICP-AES Ca mg/L	ICP-MS Ca mg/L
DR-Bedrock	13	1.0	710	40	161	165	170	59	60
SM-Uravan	<10	24	2,250	<5	53	51	89	44	45
SM-Uravan	<10	16	515	<5	49	49	64	73	74
SM-Uravan	<10	4.4	83	51	58	56	55	105	100
DR-Cisco	30	52	3,260	<5	67	61	130	41	42
DR-Cisco	<10	13	7,110	<5	130	135	245	69	76
DR-Cisco	21	3.5	895	68	108	100	105	96	105
CR-Cisco	18	34	6,270	<5	63	61	160	42	42
CR-Cisco	12	7.9	930	<5	53	55	80	59	64
CR-Cisco	<10	2.6	535	86	70	59	61	120	110
GW hot spring	<10	1.0	3.2	1,490	74	78	89	440	690
RUM 305	na	1.0	2.0	na	na	36	37	na	140
RUM 310	na	1.0	2.6	na	na	32	31	na	220
RUM 590	na	6	8.2	na	na	16	15	na	635
RUM 855	na	16	15	na	na	23	20	na	505

Site name	ICP-MS Ca (avail.) mg/L	ICP-MS Cd µg/L	ICP-MS Cd (avail.) µg/L	ICP-MS Ce µg/L	ICP-MS Ce (avail.) µg/L	ICP-MS Co µg/L	ICP-MS Co (avail.) µg/L	ICP-MS Cr µg/L
CR-Kremmling	18	0.03	0.09	0.09	5.6	0.08	1.0	<1
CR-Kremmling	26	0.04	0.04	0.005	0.20	0.04	0.07	4.2
CR-Kremmling	22	0.05	0.04	0.01	0.005	0.02	0.01	3.3
ER-Minturn	13	0.13	0.18	0.15	0.54	0.08	0.15	<1
ER-Minturn	14	0.14	0.16	0.07	0.16	0.15	0.14	<1
ER-Minturn	11	0.16	0.21	0.10	0.25	0.11	0.16	<1
ER-Avon	14	0.04	0.16	0.16	1.3	0.06	0.38	<1
ER-Avon	14	0.03	0.04	0.05	0.21	0.05	0.08	<1
ER-Avon	22	0.05	0.10	0.02	0.37	0.04	0.16	<1
ER-Gypsum	35	<0.02	0.76	0.10	8.6	0.08	2.5	<1
ER-Gypsum	40	<0.02	0.06	0.02	0.41	0.04	0.16	<1
ER-Gypsum	56	<0.02	0.06	0.02	0.34	0.03	0.14	<1
CR-Glenwood	36	<0.02	0.55	0.07	9.9	0.14	2.7	<1
CR-Glenwood	46	0.02	0.06	0.02	2.4	0.16	0.56	<1
CR-Glenwood	42	<0.02	0.05	0.02	0.51	0.06	0.20	<1
RF-Glenwood	35	<0.02	0.11	0.06	1.5	0.04	0.33	1.0
RF-Glenwood	53	0.02	0.06	0.01	0.3	0.05	0.08	<1
RF-Glenwood	67	0.03	0.04	0.01	0.07	0.01	0.02	<1
PC-Cameo	24	<0.02	0.05	0.13	7.6	0.09	1.3	<1
PC-Cameo	48	<0.02	0.02	0.04	1.3	0.11	0.27	<1
PC-Cameo	46	<0.02	0.02	0.02	0.81	0.08	0.32	<1
CR-Cameo	45	<0.02	0.17	0.02	4.9	0.08	1.1	<1
CR-Cameo	41	0.02	0.05	0.02	1.0	0.05	0.21	<1
CR-Cameo	58	0.03	0.04	0.01	0.31	0.05	0.13	<1
GR-NF	17	<0.02	0.15	0.21	20	0.08	2.9	<1
GR-NF	17	<0.02	0.01	0.04	0.42	0.11	0.09	<1
GR-NF	32	<0.02	0.01	0.02	1.5	0.11	0.39	<1
GR-Tunnel	25	<0.02	0.01	0.02	0.34	0.04	0.07	<1
GR-Tunnel	25	<0.02	0.01	0.005	0.18	0.03	0.04	<1
GR-Tunnel	23	<0.02	0.01	0.005	0.06	0.01	0.02	<1
GR-Delta	35	<0.02	0.14	0.15	13	0.12	2.2	<1
GR-Delta	93	<0.02	0.07	0.01	1.9	0.16	0.42	<1
GR-Delta	125	<0.02	0.61	0.005	7.2	0.15	1.4	<1

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma–mass spectrometry; ICP-AES, inductive coupled plasma–atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS Ca (avail.) mg/L	ICP-MS Cd µg/L	ICP-MS Cd (avail.) µg/L	ICP-MS Ce µg/L	ICP-MS Ce (avail.) µg/L	ICP-MS Co µg/L	ICP-MS Co (avail.) µg/L	ICP-MS Cr µg/L
UR-Ouray	32	0.73	0.86	0.02	1.6	2.5	2.6	<1
UR-Ouray	58	1.01	1.2	0.12	2.2	4.5	4.7	<1
UR-Ouray	100	1.1	1.3	0.09	2.4	6.1	6.3	<1
UR-Ridgway	59	0.32	0.48	0.02	1.8	0.81	1.1	<1
UR-Ridgway	82	0.29	0.55	0.02	2.5	1.2	1.9	<1
UR-Ridgway	105	0.45	0.59	0.02	1.2	2.5	2.7	<1
UR-Delta	160	<0.02	0.45	0.03	19	0.26	3.2	1.0
UR-Delta	170	0.02	1.2	0.02	21	0.22	4.7	<1
UR-Delta	175	<0.02	<b>0.01</b>	<0.01	0.33	0.15	0.2	<1
GR-Grand Jct.	60	<0.02	0.14	0.05	9.8	0.16	1.6	<1
GR-Grand Jct.	90	<0.02	0.05	0.02	0.66	0.13	0.19	<1
GR-Grand Jct.	65	<0.02	<b>0.01</b>	0.04	0.49	0.12	0.15	<1
CR-State line	53	<0.02	0.22	0.03	9.7	0.12	1.6	1.0
CR-State line	63	<0.02	0.10	0.01	2.6	0.09	0.52	<1
CR-State line	93	0.02	0.08	<b>0.005</b>	1.0	0.10	0.33	<1
DR-Dolores	27	0.04	0.52	0.21	16	0.08	2.5	<1
DR-Dolores	34	0.03	0.06	0.01	0.17	0.02	0.03	<1
DR-Dolores	40	<0.02	0.04	0.02	0.11	<b>0.01</b>	0.03	<1
DR-Bedrock	70	<0.02	0.42	0.04	7.9	0.16	2.0	<1
DR-Bedrock	76	<0.02	0.38	2.7	20	0.14	3.6	<1
DR-Bedrock	51	<0.02	0.07	0.02	2.1	0.10	0.37	<1
SM-Uravan	46	0.04	0.38	0.04	4.2	0.11	0.89	1.2
SM-Uravan	66	0.02	0.18	<b>0.005</b>	1.6	0.10	0.45	<1
SM-Uravan	88	0.03	0.04	0.01	0.22	0.09	0.11	<1
DR-Cisco	49	<0.02	0.27	0.05	5.9	0.06	1.2	1.0
DR-Cisco	86	<0.02	0.21	0.02	13	0.15	2.4	<1
DR-Cisco	90	<0.02	0.06	0.02	1.7	0.10	0.33	<1
CR-Cisco	56	<0.02	0.32	0.06	13	0.05	2.2	1.4
CR-Cisco	64	<0.02	0.07	<b>0.005</b>	2.1	0.09	0.41	<1
CR-Cisco	98	0.02	0.04	0.02	1.1	0.12	0.29	<1
GW hot spring	550	<0.02	0.02	0.02	0.02	0.26	0.02	<1
RUM 305	150	2.7	2.7	0.04	0.05	2.4	2.5	5.5
RUM 310	205	1.0	1.0	0.08	0.13	2.3	2.4	6.5
RUM 590	565	24	22	1.1	1.1	20	18	6.4
RUM 855	465	4.8	4.4	0.08	0.08	1.6	1.3	4.5

Site name	ICP-MS Cr (avail.) µg/L	ICP-MS Cs µg/L	ICP-MS Cs (avail.) µg/L	ICP-MS Cu µg/L	ICP-MS Cu (avail.) µg/L	ICP-MS Dy µg/L	ICP-MS Dy (avail.) µg/L	ICP-MS Er µg/L	ICP-MS Er (avail.) µg/L
CR-Kremmling	1.4	<0.02	0.33	0.84	6.2	0.009	0.33	0.006	0.16
CR-Kremmling	<1	<0.02	<b>0.01</b>	0.67	1.1	<0.005	0.02	<0.005	0.01
CR-Kremmling	3.4	<0.02	<b>0.01</b>	1.8	0.55	<0.005	<b>0.003</b>	<0.005	<b>0.003</b>
ER-Minturn	<1	<0.02	0.04	2.6	3.7	0.03	0.06	0.02	0.03
ER-Minturn	<1	<0.02	<b>0.01</b>	1.6	2.0	0.01	0.02	0.005	0.01
ER-Minturn	<1	<0.02	<b>0.01</b>	1.7	2.6	0.01	0.02	0.008	0.01
ER-Avon	1.4	<0.02	0.09	2.1	4.1	0.03	0.12	0.02	0.06
ER-Avon	<1	<0.02	<b>0.01</b>	1.8	2.2	0.008	0.02	<0.005	0.01
ER-Avon	<1	<0.02	0.05	1.5	2.5	0.005	0.03	<0.005	0.02
ER-Gypsum	5.4	<0.02	0.58	1.5	11	0.02	0.78	0.01	0.34
ER-Gypsum	<1	<0.02	0.02	1.1	5.0	<0.005	0.04	<0.005	0.02
ER-Gypsum	<1	<0.02	0.02	1.4	1.8	<0.005	0.05	<0.005	0.03
CR-Glenwood	5.6	<0.02	0.70	0.93	10	0.01	0.78	0.008	0.34
CR-Glenwood	1.1	<0.02	0.18	0.95	2.0	0.005	0.15	<0.005	0.06
CR-Glenwood	<1	<0.02	0.06	0.88	2.2	<0.005	0.06	<0.005	0.02

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS Cr (avail.) µg/L	ICP-MS Cs µg/L	ICP-MS Cs (avail.) µg/L	ICP-MS Cu µg/L	ICP-MS Cu (avail.) µg/L	ICP-MS Dy µg/L	ICP-MS Dy (avail.) µg/L	ICP-MS Er µg/L	ICP-MS Er (avail.) µg/L
RF-Glenwood	<1	<0.02	0.10	0.88	1.8	0.02	0.15	0.009	0.07
RF-Glenwood	<1	<0.02	0.06	0.66	0.95	<0.005	0.03	<0.005	0.01
RF-Glenwood	<1	0.02	0.03	0.78	0.83	<0.005	0.01	<0.005	0.005
PC-Cameo	3.1	<0.02	0.23	1.0	4.2	0.03	0.47	0.02	0.23
PC-Cameo	<1	<0.02	0.04	1.4	1.9	0.007	0.07	<0.005	0.04
PC-Cameo	<1	<0.02	0.02	1.0	1.6	<0.005	0	<0.005	0.051
CR-Cameo	2.4	<0.02	0.33	0.86	3.9	0.008	0.39	0.005	0.17
CR-Cameo	<1	0.04	0.16	1.3	1.4	<0.005	0.08	<0.005	0.03
CR-Cameo	<1	0.10	0.15	0.94	1.1	<0.005	0.04	<0.005	0.02
GR-NF	5.3	<0.02	0.66	1.1	8.8	0.04	1.2	0.02	0.58
GR-NF	<1	<0.02	<b>0.01</b>	0.93	0.76	0.01	0.04	0.009	0.03
GR-NF	<1	<0.02	0.07	0.69	1.4	0.005	0.13	<0.005	0.05
GR-Tunnel	<1	<0.02	0.02	0.84	1.2	0.005	0.03	<0.005	0.01
GR-Tunnel	<1	<0.02	<b>0.01</b>	1.2	1.8	<0.005	0.02	<0.005	0.01
GR-Tunnel	<1	<0.02	<b>0.01</b>	0.92	1.1	<0.005	0.006	<0.005	<b>0.003</b>
GR-Delta	4.0	<0.02	0.41	1.2	6.4	0.03	0.89	0.02	0.40
GR-Delta	<1	<0.02	0.12	1.5	2.7	<0.005	0.18	<0.005	0.08
GR-Delta	1.9	<0.02	0.08	2.4	4.6	<0.005	0.83	<0.005	0.35
UR-Ouray	<1	0.40	0.50	5.2	66	<0.005	0.15	<0.005	0.06
UR-Ouray	<1	0.78	0.96	6.4	105	0.006	0.22	<0.005	0.10
UR-Ouray	<1	2.7	2.7	9.0	135	0.005	0.25	<0.005	0.11
UR-Ridgway	<1	0.18	0.40	6.0	27	<0.005	0.13	<0.005	0.05
UR-Ridgway	<1	0.18	0.46	4.6	42	<0.005	0.23	<0.005	0.10
UR-Ridgway	<1	0.99	1.05	5.4	58	<0.005	0.13	<0.005	0.05
UR-Delta	5.9	<0.02	1.1	2.4	15	0.01	1.2	<0.005	0.54
UR-Delta	5.5	<0.02	0.26	2.3	15	0.006	2.1	<0.005	0.90
UR-Delta	<1	<0.02	0.03	2.7	3.1	<0.005	0.03	<0.005	0.01
GR-Grand Jct.	3.8	<0.02	0.52	1.5	6.0	0.01	0.67	0.01	0.30
GR-Grand Jct.	<1	<0.02	0.05	1.9	2.4	0.005	0.06	<0.005	0.02
GR-Grand Jct.	<1	<0.02	0.04	1.2	1.4	0.009	0.05	0.005	0.02
CR-State line	3.9	<0.02	0.55	2.2	6.2	0.009	0.65	0.006	0.29
CR-State line	<1	<0.02	0.14	1.3	2.6	<0.005	0.22	<0.005	0.10
CR-State line	<1	<0.02	0.05	1.7	2.5	<0.005	0.12	<0.005	0.05
DR-Dolores	3.9	<0.02	0.94	1.8	10	0.051	1.1	0.03	0.51
DR-Dolores	<1	0.17	0.23	0.69	0.8	<0.005	0.02	<0.005	0.01
DR-Dolores	<1	0.27	0.31	0.94	1.3	<0.005	0.02	<0.005	0.01
DR-Bedrock	2.7	<0.02	0.16	1.1	6	0.005	0.84	<0.005	0.38
DR-Bedrock	4.0	<0.02	0.13	2.7	16	0.15	2.0	0.04	0.83
DR-Bedrock	<1	<0.02	0.07	1.1	2.1	<0.005	0.15	<0.005	0.07
SM-Uravan	1.7	<0.02	0.39	2.4	9.3	0.01	0.29	0.007	0.13
SM-Uravan	<1	<0.02	0.08	1.6	3.3	<0.005	0.11	<0.005	0.06
SM-Uravan	<1	<0.02	<b>0.01</b>	1.8	2.0	<0.005	0.02	<0.005	0.01
DR-Cisco	2.3	<0.02	0.36	2.3	7.5	0.008	0.45	<0.005	0.20
DR-Cisco	4.8	<0.02	0.84	1.9	8.6	0.006	0.81	<0.005	0.37
DR-Cisco	1.1	<0.02	0.13	1.5	2.4	<0.005	0.12	<0.005	0.05
CR-Cisco	5.2	<0.02	0.66	4.3	14	0.005	0.89	<0.005	0.39
CR-Cisco	1.3	<0.02	0.19	1.4	3.0	<0.005	0.14	<0.005	0.06
CR-Cisco	<1	<0.02	0.09	1.7	3.0	0.005	0.08	<0.005	0.03
GW hot spring	1.0	59	73	4.1	7.6	0.006	0.005	<0.005	0.006
RUM 305	4.2	0.28	0.29	7.0	8.0	0.01	0.009	0.006	0.007
RUM 310	5.9	0.70	0.68	3.2	3.4	0.02	0.02	0.02	0.02
RUM 590	5.8	10	9.5	18	17	0.20	0.21	0.13	0.13
RUM 855	4.9	0.17	0.16	7.0	7.1	0.03	0.02	0.02	0.02

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Table AI-3. Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS Eu µg/L	ICP-MS Eu (avail.) µg/L	ICP-MS Fe µg/L	ICP-MS Fe (avail.) µg/L	ICP-MS Gd µg/L	ICP-MS Gd (avail.) µg/L	ICP-MS Ho µg/L	ICP-MS Ho (avail.) µg/L	ICP-AES K mg/L	ICP-MS K mg/L
CR-Kremmling	0.006	0.11	51	2,700	0.009	0.46	<0.005	0.05	1.0	0.90
CR-Kremmling	<b>0.003</b>	0.01	<50	140	<0.005	0.02	<0.005	<b>0.003</b>	1.6	1.6
CR-Kremmling	<b>0.003</b>	<b>0.003</b>	<50	<b>25</b>	<0.005	<b>0.003</b>	<0.005	<b>0.003</b>	1.7	1.6
ER-Minturn	0.01	0.02	<50	345	0.04	0.08	0.005	0.01	0.72	0.64
ER-Minturn	0.01	0.01	310	485	0.02	0.02	<0.005	<b>0.003</b>	0.59	0.6
ER-Minturn	0.006	0.01	222	555	0.01	0.03	<0.005	0.005	0.80	0.73
ER-Avon	0.02	0.05	63	785	0.054	0.18	0.006	0.02	0.58	0.49
ER-Avon	0.007	0.01	101	190	0.01	0.03	<0.005	<b>0.003</b>	0.55	0.52
ER-Avon	0.006	0.02	<50	325	0.007	0.05	<0.005	0.006	0.96	0.88
ER-Gypsum	0.01	0.27	<50	6,170	0.03	1.2	0.005	0.12	0.88	0.79
ER-Gypsum	0.006	0.02	<50	230	<0.005	0.06	<0.005	0.007	1.3	1.2
ER-Gypsum	0.007	0.02	<50	245	0.005	0.08	<0.005	0.008	2.0	1.9
CR-Glenwood	0.01	0.27	<50	6,600	0.02	1.2	<0.005	0.13	1.1	1.1
CR-Glenwood	0.008	0.06	<50	1,020	<0.005	0.23	<0.005	0.02	2.2	2.0
CR-Glenwood	0.007	0.02	<50	265	<0.005	0.09	<0.005	0.01	2.3	2.1
RF-Glenwood	0.01	0.05	<50	730	0.02	0.23	<0.005	0.02	0.81	0.77
RF-Glenwood	0.007	0.01	<50	180	<0.005	0.04	<0.005	0.005	1.2	1.2
RF-Glenwood	0.007	0.01	<50	<b>25</b>	<0.005	0.01	<0.005	<b>0.003</b>	1.7	1.5
PC-Cameo	0.02	0.16	<50	2,900	0.04	0.71	0.005	0.08	1.4	1.3
PC-Cameo	0.02	0.04	<50	390	0.01	0.12	<0.005	0.02	3.7	3.8
PC-Cameo	0.02	0.05	<50	315	0.005	0.15	<0.005	0.02	4.1	3.7
CR-Cameo	0.009	0.14	<50	2,280	0.008	0.6	<0.005	0.06	1.3	1.4
CR-Cameo	0.006	0.03	<50	410	0.005	0.13	<0.005	0.01	1.7	1.7
CR-Cameo	0.008	0.02	<50	125	0.005	0.06	<0.005	0.007	3.1	2.9
GR-NF	0.02	0.44	<50	8,290	0.04	1.9	0.007	0.20	0.9	0.91
GR-NF	0.008	0.02	<50	105	0.01	0.06	<0.005	0.008	4.6	4.7
GR-NF	0.01	0.05	<50	660	<0.005	0.20	<0.005	0.02	1.1	0.99
GR-Tunnel	0.006	0.01	<50	110	0.008	0.04	<0.005	<b>0.003</b>	1.6	1.6
GR-Tunnel	0.005	0.01	<50	<b>25</b>	<0.005	0.02	<0.005	<b>0.003</b>	1.4	1.4
GR-Tunnel	0.005	0.006	<50	<b>25</b>	<0.005	0.009	<0.005	<b>0.003</b>	1.5	1.4
GR-Delta	0.01	0.31	<50	5,770	0.03	1.3	0.005	0.14	1.5	1.5
GR-Delta	0.007	0.06	<50	757	0.006	0.27	<0.005	0.03	3.9	4.0
GR-Delta	0.007	0.26	<50	1,870	<0.005	1.2	<0.005	0.14	4.1	4.0
UR-Ouray	0.006	0.05	<50	1,370	<0.005	0.23	<0.005	0.02	0.59	0.57
UR-Ouray	0.009	0.07	<50	2,420	0.007	0.32	<0.005	0.04	0.84	0.86
UR-Ouray	0.007	0.08	<50	1,280	0.006	0.38	<0.005	0.04	1.4	1.3
UR-Ridgway	0.006	0.05	<50	925	<0.005	0.20	<0.005	0.02	1.3	1.3
UR-Ridgway	0.007	0.08	<50	1,690	0.005	0.34	<0.005	0.04	1.6	1.7
UR-Ridgway	0.005	0.04	<50	1,250	<0.005	0.18	<0.005	0.02	2.0	1.8
UR-Delta	0.01	0.44	<50	7,780	0.007	1.9	<0.005	0.20	3.2	3.4
UR-Delta	0.009	0.59	<50	7,450	<0.005	2.89	<0.005	0.35	4.5	4.8
UR-Delta	0.005	0.01	<50	145	<0.005	0.04	<0.005	0.006	4.0	3.5
GR-Grand Jct.	0.01	0.23	<50	4,410	0.02	1.1	<0.005	0.11	2.0	2.1
GR-Grand Jct.	0.007	0.02	<50	175	0.006	0.07	<0.005	0.01	2.8	3.1
GR-Grand Jct.	0.009	0.02	<50	125	0.02	0.10	<0.005	0.007	3.3	3.3
CR-State line	0.009	0.22	<50	4,370	0.01	0.99	<0.005	0.1	1.6	1.7
CR-State line	0.007	0.07	<50	870	0.005	0.32	<0.005	0.04	2.2	2.3
CR-State line	0.007	0.04	<50	405	<0.005	0.17	<0.005	0.02	3.8	3.4
DR-Dolores	0.02	0.39	<50	5,140	0.066	1.7	0.008	0.18	0.94	0.92
DR-Dolores	0.01	0.02	<50	<b>25</b>	<0.005	0.03	<0.005	<b>0.003</b>	1.4	1.3
DR-Dolores	0.02	0.02	<50	<b>25</b>	<0.005	0.02	<0.005	<b>0.003</b>	1.9	1.9



**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS Eu µg/L	ICP-MS Eu (avail.) µg/L	ICP-MS Fe µg/L	ICP-MS Fe (avail.) µg/L	ICP-MS Gd µg/L	ICP-MS Gd (avail.) µg/L	ICP-MS Ho µg/L	ICP-MS Ho (avail.) µg/L	ICP-AES K mg/L	ICP-MS K mg/L
DR-Bedrock	0.01	0.27	<50	3,750	0.01	1.2	<0.005	0.14	2.2	2.3
DR-Bedrock	0.1	0.65	<50	4,260	0.36	3.0	0.02	0.33	13	13
DR-Bedrock	0.03	0.08	<50	660	<0.005	0.26	<0.005	0.02	5.1	5.0
SM-Uravan	0.01	0.11	<50	1,580	0.01	0.47	<0.005	0.04	1.2	1.2
SM-Uravan	0.008	0.04	<50	415	<0.005	0.17	<0.005	0.02	1.6	1.6
SM-Uravan	0.009	0.01	<50	53	<0.005	0.03	<0.005	<b>0.003</b>	2.1	1.9
DR-Cisco	0.01	0.15	<50	2,660	0.006	0.68	<0.005	0.07	1.7	1.7
DR-Cisco	0.02	0.34	83	4,110	0.005	1.4	<0.005	0.15	5.5	5.9
DR-Cisco	0.02	0.06	<50	715	<0.005	0.20	<0.005	0.02	11	12
CR-Cisco	0.01	0.29	<50	5,560	0.009	1.3	<0.005	0.14	1.7	1.7
CR-Cisco	0.009	0.06	<50	885	<0.005	0.22	<0.005	0.02	2.4	2.7
CR-Cisco	0.01	0.04	<50	470	0.005	0.13	<0.005	0.01	5.2	4.5
GW hot spring	0.01	0.01	<50	<50	0.005	0.006	<0.005	<0.005	160	160
RUM 305	<b>0.003</b>	0.006	<50	<b>25</b>	<0.005	0.006	<0.005	<0.005	5.9	na
RUM 310	0.007	0.008	710	820	0.01	0.02	0.005	0.005	7.7	na
RUM 590	0.04	0.05	<50	<b>25</b>	0.34	0.33	0.05	0.05	19	na
RUM 855	0.005	<b>0.003</b>	280	300	0.03	0.03	0.008	0.007	9.5	na

Site name	ICP-MS K (avail.) mg/L	ICP-MS La µg/L	ICP-MS La (avail.) µg/L	ICP-AES Li µg/L	ICP-MS Li µg/L	ICP-MS Li (avail.) µg/L	ICP-AES Mg mg/L	ICP-MS Mg mg/L	ICP-MS Mg (avail.) mg/L	ICP-AES Mn µg/L
CR-Kremmling	1.9	0.05	2.7	2.6	3.1	6.8	1.8	1.7	3.0	51
CR-Kremmling	1.6	<0.01	0.11	6.2	5.6	6.3	4.7	4.6	4.3	<10
CR-Kremmling	1.7	0.01	<b>0.005</b>	6.7	5.6	7.3	4.4	4.3	4.3	<10
ER-Minturn	0.66	0.10	0.27	1.0	1.3	1.4	4.7	4.5	3.9	28
ER-Minturn	0.55	0.04	0.09	1.2	1.0	1.8	5.6	5.7	4.8	99
ER-Minturn	0.76	0.05	0.13	<b>0.5</b>	1.0	1.5	4.9	4.8	4.5	90
ER-Avon	0.71	0.16	0.73	2.0	1.4	2.2	3.2	2.9	3.2	10
ER-Avon	0.52	0.04	0.14	2.0	1.4	2.3	3.8	3.9	3.4	12
ER-Avon	0.89	0.01	0.20	5.2	3.9	5.2	7.3	7.3	6.8	44
ER-Gypsum	1.9	0.08	3.9	1.4	2.2	7.6	4.4	4.2	6.3	13
ER-Gypsum	1.2	0.02	0.20	3.6	3.2	4.2	7.3	7.2	7.0	10
ER-Gypsum	1.9	<0.01	0.15	3.8	2.6	5.4	12	11	11	<10
CR-Glenwood	2.4	0.04	4.5	3.4	3.7	9.3	5.4	5.3	7.3	43
CR-Glenwood	2.2	0.01	0.98	6.8	7.2	9.4	8.2	8.7	8.7	13
CR-Glenwood	2.1	0.01	0.22	8.2	5.6	8.6	10	9.6	9.3	13
RF-Glenwood	0.87	0.05	0.7	3.1	3.7	4.2	5.3	5.2	4.8	<10
RF-Glenwood	1.2	<0.01	0.15	5.8	5.5	5.4	8.6	8.7	8.2	<10
RF-Glenwood	1.5	0.01	0.04	8.1	5.6	8.4	14	12	12	<10
PC-Cameo	2.1	0.08	3.2	3.0	3.8	6.9	6.3	6.6	7.7	<10
PC-Cameo	3.8	0.02	0.52	13	12	17	23	24	23	<10
PC-Cameo	3.7	0.01	0.33	16	15	18	32	30	27	<10
CR-Cameo	2.1	0.02	2.1	6.8	6.4	9.7	8.8	9.0	11	<10
CR-Cameo	1.7	0.01	0.46	7.6	8.9	12	8.6	9.1	8.8	<10
CR-Cameo	2.8	<0.01	0.13	17	17	20	17	15	14	<10
GR-NF	2.7	0.13	8.7	<b>0.5</b>	1.5	7.2	2.7	2.7	4.3	12
GR-NF	0.61	0.03	0	12	12	3.4	5.0	5.0	4.6	11
GR-NF	1.1	0.01	0.61	5.8	4.1	6.3	11	11	10	39
GR-Tunnel	1.6	0.02	0.15	4.3	4.8	4.9	5.5	5.5	4.9	<10
GR-Tunnel	1.4	<0.01	0.09	3.7	4.7	6.0	5.2	5.3	5.1	<10
GR-Tunnel	1.3	<0.01	0.03	5.5	5.1	6.2	6.3	6.0	5.1	<10
GR-Delta	2.7	0.08	5.7	9.0	9.6	15	8.5	8.7	11	18
GR-Delta	3.8	<0.01	0.76	41	42	49	31	33	29	26
GR-Delta	3.8	<0.01	2.8	60	56	67	42	39	36	10

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-AES
	K (avail.) mg/L	La µg/L	La (avail.) µg/L	Li µg/L	Li µg/L	Li (avail.) µg/L	Mg mg/L	Mg mg/L	Mg (avail.) mg/L	Mn µg/L
UR-Ouray	0.56	0.02	0.79	12	13	12	2.2	2.2	1.8	213
UR-Ouray	0.81	0.12	1.0	28	30	29	3.2	3.2	2.9	307
UR-Ouray	1.3	0.1	1.1	68	54	68	5.0	4.2	4.1	360
UR-Ridgway	1.3	0.01	0.88	28	29	29	6.3	6.2	5.2	94
UR-Ridgway	1.6	0.02	1.1	42	43	44	9.2	9.6	8.3	130
UR-Ridgway	1.8	0.02	0.56	67	59	71	11	10	9.9	185
UR-Delta	6.0	0.02	8.2	61	59	70	32	33	28	30
UR-Delta	5.1	<0.01	8.5	65	63	74	35	37	31	23
UR-Delta	3.4	<0.01	0.14	120	92	110	63	48	48	50
GR-Grand Jct.	3.3	0.03	4.1	20	21	26	14	15	17	16
GR-Grand Jct.	2.9	<0.01	0.29	42	43	51	27	29	25	<10
GR-Grand Jct.	3.1	0.02	0.17	31	31	35	30	29	26	38
CR-State line	2.9	0.02	4.2	11	13	17	11	12	14	<10
CR-State line	2.3	<0.01	1.1	19	22	27	17	18	17	<10
CR-State line	3.3	<0.01	0.40	42	39	44	34	31	27	<10
DR-Dolores	2.4	0.16	7.3	3.3	4.2	8.2	3.1	3.1	4.9	14
DR-Dolores	1.2	0.01	0.1	13	14	18	5.3	5.3	5.0	10
DR-Dolores	1.8	0.01	0.06	22	24	27	7.4	7.7	6.9	<10
DR-Bedrock	3.0	0.02	3.1	14	16	20	9.0	9.4	13	<10
DR-Bedrock	14	1.47	9.2	17	17	33	13	13	18	11
DR-Bedrock	4.9	0.01	0.92	30	32	35	16	17	15	10
SM-Uravan	1.7	0.03	1.9	9.8	11	12	9.6	10	10	21
SM-Uravan	1.5	<0.01	0.72	21	23	27	18	18	16	11
SM-Uravan	1.8	<0.01	0.1	34	33	37	33	31	28	24
DR-Cisco	2.7	0.02	2.6	11	12	14	8.6	8.7	10	<10
DR-Cisco	8.8	0.01	5.9	22	23	39	19	20	23	<10
DR-Cisco	11	0.01	0.72	30	27	31	31	34	29	<10
CR-Cisco	3.4	0.04	5.5	10	11	17	10	10	13	<10
CR-Cisco	2.8	<0.01	0.91	18	21	27	16	17	17	<10
CR-Cisco	4.4	<0.01	0.45	46	38	41	39	36	32	11
GW hot spring	170	0.01	0.01	850	630	795	83	87	105	47
RUM 305	5.9	0.03	0.03	na	35	36	na	61	62	na
RUM 310	7.1	0.07	0.10	na	53	50	na	110	105	na
RUM 590	17	0.82	0.79	na	95	86	na	62	55	na
RUM 855	8.4	0.08	0.07	na	35	31	na	28	25	na

Site name	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
	Mn µg/L	Mn (avail.) µg/L	Mo µg/L	Mo (avail.) µg/L	Na mg/L	Na mg/L	Na (avail.) mg/L	Nd µg/L	Nd (avail.) µg/L	Ni µg/L
CR-Kremmling	45	320	<2	<2	3.9	3.8	5.8	0.05	2.7	0.8
CR-Kremmling	1.8	31	20	17	6.8	6.6	6.1	0.005	0.13	0.9
CR-Kremmling	11	11	20	14	7.3	7.1	7.4	0.01	0.01	0.9
ER-Minturn	25	40	<2	<2	1.2	1.2	1.1	0.16	0.36	0.7
ER-Minturn	97	89	<2	<2	1.4	1.5	1.3	0.06	0.11	1.0
ER-Minturn	87	105	<2	<2	1.7	1.8	1.8	0.08	0.17	0.8
ER-Avon	9.3	73	<2	<2	1.5	1.4	1.5	0.23	0.95	0.7
ER-Avon	12	19	<2	<2	1.8	1.9	1.7	0.05	0.13	1.0
ER-Avon	43	71	<2	<2	3.8	3.8	3.7	0.02	0.23	0.9
ER-Gypsum	12	275	<2	<2	3.8	3.8	3.8	0.13	5.5	1.2
ER-Gypsum	9.6	26	<2	<2	17	17	16	0.02	0.25	1.0
ER-Gypsum	8.6	28	<2	<2	34	34	34	0.02	0.26	1.6
CR-Glenwood	38	295	<2	<2	9.2	8.9	8.3	0.06	5.9	1.6
CR-Glenwood	13	60	9.5	9.6	41	42	40	0.02	1.3	2.1

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS Mn µg/L	ICP-MS Mn (avail.) µg/L	ICP-MS Mo µg/L	ICP-MS Mo (avail.) µg/L	ICP-AES Na mg/L	ICP-MS Na mg/L	ICP-MS Na (avail.) mg/L	ICP-MS Nd µg/L	ICP-MS Nd (avail.) µg/L	ICP-MS Ni µg/L
CR-Glenwood	13	30	6.0	4.5	50	50	54	0.02	0.34	1.8
RF-Glenwood	4.4	30	<2	<2	5.5	5.4	4.8	0.07	0.93	1.1
RF-Glenwood	5.2	12	<2	<2	16	16	15	0.01	0.19	1.6
RF-Glenwood	3.2	6	<2	<2	37	33	33	0.01	0.05	1.6
PC-Cameo	6.2	83	<2	<2	7.2	7.5	7.7	0.13	3.9	1.4
PC-Cameo	4.3	33	2.9	3.2	30	31	29	0.03	0.62	1.9
PC-Cameo	5.9	40	2.7	<2	43	40	38	0.02	0.54	1.9
CR-Cameo	4.9	72	<2	<2	26	26	27	0.02	2.9	1.5
CR-Cameo	3.4	24	4.0	4.2	44	45	42	0.02	0.57	1.2
CR-Cameo	3.7	14	4.6	3.8	110	110	99	0.005	0.23	1.8
GR-NF	12	195	<2	<2	3.7	3.7	4.2	0.19	10	0.8
GR-NF	10	17	<2	<2	12	12	6.7	0.05	0.27	1.0
GR-NF	35	62	<2	<2	17	15	14	0.02	0.88	1.2
GR-Tunnel	3.3	18	<2	<2	5	4.9	4.4	0.02	0.16	0.9
GR-Tunnel	1.6	13	<2	<2	4.5	4.6	4.4	0.01	0.10	0.9
GR-Tunnel	0.80	5.8	<2	<2	5.4	5.0	4.6	0.005	0.03	0.8
GR-Delta	17	150	<2	<2	12	11	12	0.12	6.9	1.5
GR-Delta	24	61	2.3	1.9	49	51	43	0.02	1.1	3.0
GR-Delta	12	120	2.4	<2	70	70	67	0.005	5.3	4.2
UR-Ouray	205	205	<2	<2	3	3.1	2.6	0.02	0.96	3.0
UR-Ouray	305	315	<2	<2	6.0	6.1	5.3	0.05	1.2	4.9
UR-Ouray	375	390	<2	<2	14	12	13	0.03	1.4	7.3
UR-Ridgway	91	120	<2	<2	9.9	9.8	8.1	0.005	1.0	2.5
UR-Ridgway	130	170	<2	<2	15	15	12	0.01	1.5	2.6
UR-Ridgway	185	195	<2	<2	22	20	21	0.01	0.74	4.6
UR-Delta	28	260	3.6	4.0	58	59	46	0.03	9.8	4.7
UR-Delta	23	415	3.7	<2	65	66	48	0.02	13	3.7
UR-Delta	49	56	3.5	3.4	115	115	115	0.005	0.18	5.7
GR-Grand Jct.	16	125	<2	<2	21	22	22	0.06	5.3	2.2
GR-Grand Jct.	9	23	2.4	2.4	44	46	40	0.01	0.39	2.6
GR-Grand Jct.	37	44	<2	<2	45	44	40	0.05	0.39	2.4
CR-State line	5.2	125	<2	2.1	24	25	24	0.03	5.2	2.0
CR-State line	2.2	47	3.8	2.7	46	48	43	0.005	1.5	1.7
CR-State line	4.4	30	3.9	2.4	94	94	92	0.005	0.71	3.6
DR-Dolores	13	385	<2	<2	1.6	1.7	2.5	0.22	8.5	1.0
DR-Dolores	9.7	22	<2	<2	5.2	5.3	4.8	0.01	0.11	0.9
DR-Dolores	0.40	20	<2	<2	9.0	9.3	8.7	0.02	0.08	1.5
DR-Bedrock	4.9	120	2	<2	19	19	20	0.03	5.2	2.6
DR-Bedrock	11	375	2.1	<2	225	225	225	1.52	13	1.9
DR-Bedrock	11	30	<2	<2	125	125	120	0.01	1.3	2.2
SM-Uravan	20	130	<2	<2	7.7	7.9	7.7	0.04	2.2	1.6
SM-Uravan	11	77	2.1	<2	13	13	11	0.01	0.87	1.9
SM-Uravan	24	29	<2	<2	26	25	23	0.005	0.14	3.1
DR-Cisco	1.7	120	<2	<2	15	15	15	0.03	3.3	1.8
DR-Cisco	2.4	240	3.1	3.0	87	87	87	0.01	7.5	3.1
DR-Cisco	10	27	2.4	2.4	230	230	205	0.01	0.97	4.1
CR-Cisco	0.20	170	2.2	1.9	20	20	20	0.04	6.8	2.0
CR-Cisco	0.3	36	4.2	4.5	48	54	52	0.01	1.1	2.2
CR-Cisco	11	24	4.5	4.5	140	140	105	0.01	0.59	4.2
GW hot spring	54	50	<2	<2	150	120	165	0.01	0.01	8.2
RUM 305	265	265	39	17	na	120	125	0.03	0.03	2.7
RUM 310	1,380	1,330	43	37	na	nr	nr	0.05	0.08	2.6
RUM 590	9,980	9,110	2,130	1,950	na	nr	nr	0.76	0.70	12
RUM 855	1,410	1,240	1,600	1,470	na	180	164	0.06	0.06	7.4

Table AI-3. Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS Ni (avail.) µg/L	ICP-MS P mg/L	ICP-MS P (avail.) mg/L	ICP-MS Pb µg/L	ICP-MS Pb (avail.) µg/L	ICP-MS Pr µg/L	ICP-MS Pr (avail.) µg/L	ICP-MS Rb µg/L	ICP-MS Rb (avail.) µg/L
CR-Kremmling	2.0	0.03	0.1	<0.05	2.7	0.01	0.65	0.61	4.8
CR-Kremmling	0.5	<0.01	<0.01	<0.05	0.20	<0.01	0.03	1.1	1.3
CR-Kremmling	0.6	<0.01	<0.01	0.08	0.05	<0.01	0.005	1.1	1.3
ER-Minturn	0.6	<0.01	<0.01	0.3	1.9	0.03	0.08	0.39	0.76
ER-Minturn	0.5	0.02	<0.01	0.2	0.58	0.01	0.02	0.52	0.55
ER-Minturn	0.7	<0.01	<0.01	0.2	0.94	0.02	0.04	0.68	0.79
ER-Avon	1.0	<0.01	0.02	0.2	11	0.05	0.21	0.34	1.6
ER-Avon	0.6	0.02	0.02	0.2	0.40	0.01	0.03	0.54	0.63
ER-Avon	1.4	<0.01	<0.01	<0.05	0.86	<0.01	0.05	0.69	1.0
ER-Gypsum	8.3	0.01	0.2	0.09	16	0.02	1.2	0.38	7.8
ER-Gypsum	0.7	<0.01	0.02	0.06	0.68	<0.01	0.06	0.61	0.90
ER-Gypsum	1.8	0.03	0.03	0.06	0.72	<0.01	0.05	0.88	1.1
CR-Glenwood	8.7	0.01	0.2	0.06	12	0.01	1.31	0.65	8.9
CR-Glenwood	2.2	0.02	0.05	0.06	1.1	<0.01	0.31	1.1	3.1
CR-Glenwood	1.9	<0.01	<0.01	0.05	0.54	<0.01	0.08	1.5	1.8
RF-Glenwood	1.0	<0.01	0.02	0.1	3.9	0.02	0.21	0.62	1.6
RF-Glenwood	0.9	<0.01	0.01	0.1	1.3	<0.01	0.04	1.0	1.3
RF-Glenwood	1.6	<0.01	<0.01	0.2	0.61	<0.01	0.01	1.4	1.4
PC-Cameo	4.0	0.03	0.1	<0.05	1.7	0.03	0.90	0.46	4.8
PC-Cameo	1.3	0.03	0.06	0.08	0.40	<0.01	0.16	1.7	2.5
PC-Cameo	2.0	<0.01	<0.01	<0.05	0.40	<0.01	0.11	1.7	2.2
CR-Cameo	3.6	<0.01	0.1	<0.05	3.7	<0.01	0.61	1.2	4.9
CR-Cameo	0.8	<0.01	0.02	0.2	1.2	<0.01	0.14	2.2	3.1
CR-Cameo	1.5	<0.01	<0.01	0.06	0.40	<0.01	0.04	4.4	4.8
GR-NF	6.8	<0.01	0.2	0.06	6.5	0.04	2.4	0.36	11
GR-NF	0.4	0.06	<0.01	0.06	0.2	<0.01	0.06	0.84	0.44
GR-NF	1.4	<0.01	0.01	<0.05	0.89	<0.01	0.19	0.27	1.0
GR-Tunnel	0.4	<0.01	0.01	<0.05	0.20	<0.01	0.04	1.4	1.8
GR-Tunnel	0.4	<0.01	<0.01	0.06	0.2	<0.01	0.02	1.3	1.6
GR-Tunnel	0.5	<0.01	<0.01	<0.05	0.05	<0.01	0.005	1.2	1.4
GR-Delta	6.0	0.01	0.2	<0.05	4.7	0.02	1.6	0.64	7.2
GR-Delta	2.1	<0.01	0.04	<0.05	1.3	<0.01	0.26	2.4	3.7
GR-Delta	7.9	<0.01	0.2	<0.05	3.3	<0.01	1.1	2.0	4.2
UR-Ouray	2.3	<0.01	<0.01	<0.05	6.2	<0.01	0.21	1.5	1.7
UR-Ouray	4.0	<0.01	<0.01	<0.05	8.2	0.01	0.29	3.1	3.5
UR-Ouray	7.3	<0.01	<0.01	<0.05	4.7	<0.01	0.31	7.5	7.8
UR-Ridgway	1.6	<0.01	0.02	<0.05	4.8	<0.01	0.23	1.8	2.6
UR-Ridgway	2.4	<0.01	0.05	<0.05	7.6	<0.01	0.33	2.7	3.6
UR-Ridgway	5.0	<0.01	<0.01	<0.05	3.1	<0.01	0.16	4.8	5.0
UR-Delta	10	0.06	0.4	<0.05	13	<0.01	2.3	1.3	16
UR-Delta	15	0.03	0.5	<0.05	18	<0.01	2.8	1.8	9.9
UR-Delta	5.5	<0.01	0.01	<0.05	0.40	<0.01	0.05	1.8	2.0
GR-Grand Jct.	5.5	<0.01	0.2	0.07	4.6	<0.01	1.2	1.0	7.3
GR-Grand Jct.	1.4	<0.01	<0.01	<0.05	0.66	<0.01	0.09	1.6	2.1
GR-Grand Jct.	1.6	<0.01	<0.01	<0.05	0.20	<0.01	0.08	2.1	2.3
CR-State line	5.0	0.01	0.2	0.09	7.1	<0.01	1.2	0.95	7.3
CR-State line	1.9	<0.01	0.05	0.06	1.9	<0.01	0.35	1.8	3.2
CR-State line	3.0	<0.01	<0.01	<0.05	0.83	<0.01	0.14	2.7	3.4
DR-Dolores	5.7	<0.01	0.2	0.2	19	0.05	2.0	0.78	9.0
DR-Dolores	0.4	<0.01	<0.01	<0.05	0.20	<0.01	0.03	3.8	4.2
DR-Dolores	1.0	<0.01	<0.01	<0.05	0.2	<0.01	0.02	5.9	6.3

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS Ni (avail.) µg/L	ICP-MS P mg/L	ICP-MS P (avail.) mg/L	ICP-MS Pb µg/L	ICP-MS Pb (avail.) µg/L	ICP-MS Pr µg/L	ICP-MS Pr (avail.) µg/L	ICP-MS Rb µg/L	ICP-MS Rb (avail.) µg/L
DR-Bedrock	7.8	<0.01	0.2	<0.05	4.7	<0.01	1.1	0.82	4.4
DR-Bedrock	7.9	<0.01	0.3	0.07	15	0.34	2.9	3.8	13
DR-Bedrock	2.6	<0.01	0.02	<0.05	0.85	<0.01	0.28	1.4	2.3
SM-Uravan	1.9	<0.01	0.08	0.1	14	<0.01	0.51	0.55	3.3
SM-Uravan	1.0	<0.01	0.01	0.3	4.2	<0.01	0.20	0.84	1.7
SM-Uravan	2.0	<0.01	<0.01	0.06	0.40	<0.01	0.03	0.92	1.1
DR-Cisco	3.7	<0.01	0.1	0.1	11	<0.01	0.75	0.68	4.8
DR-Cisco	6.1	0.03	0.2	0.07	6.8	<0.01	1.8	1.4	12
DR-Cisco	3.6	0.03	0.03	<0.05	0.87	<0.01	0.22	2.8	4.0
CR-Cisco	7.4	0.01	0.2	0.09	11	<0.01	1.5	0.83	9.1
CR-Cisco	1.8	<0.01	0.05	0.07	1.5	<0.01	0.26	1.8	3.4
CR-Cisco	3.6	0.01	0.03	<0.05	0.60	<0.01	0.14	3.2	3.9
GW hot spring	0.4	<0.01	<0.01	<0.05	0.08	<0.01	<0.01	680	610
RUM 305	3.1	0.02	0.03	<0.05	0.05	<0.01	<0.01	7.4	7.7
RUM 310	2.7	<0.01	<0.01	<0.05	<0.05	0.01	0.02	7.5	7.5
RUM 590	12	0.02	0.02	<0.05	<0.05	0.14	0.15	150	145
RUM 855	7.1	0.6	0.6	<0.05	<0.05	0.01	0.02	11	11

Site name	ICP-MS Sc ug/L	ICP-MS Sc (avail.) ug/L	ICP-MS Se µg/L	ICP-MS Se (avail.) µg/L	ICP-AES SiO <sub>2</sub> mg/L	ICP-MS SiO <sub>2</sub> mg/L	ICP-MS SiO <sub>2</sub> (avail.) mg/L	ICP-MS Sm µg/L	ICP-MS Sm (avail.) µg/L
CR-Kremmling	1.4	3.2	<1	<1	9.8	11	20	0.02	0.51
CR-Kremmling	0.9	0.9	<1	<1	7.0	7.8	6.6	<0.01	0.03
CR-Kremmling	1.1	1.2	<1	<1	9.0	8.4	10	<0.01	<b>0.005</b>
ER-Minturn	0.8	0.9	<1	<1	6.2	6.1	5.8	0.03	0.08
ER-Minturn	0.8	0.7	<1	<1	5.2	5.8	4.6	0.01	0.02
ER-Minturn	0.6	0.7	<1	<1	5.8	4.6	5.3	0.02	0.03
ER-Avon	0.7	1.2	<1	<1	5.3	5.4	7.4	0.05	0.18
ER-Avon	0.6	0.6	<1	<1	3.9	4.4	4.0	0.01	0.03
ER-Avon	0.6	0.7	<1	<1	4.9	3.9	4.7	<0.01	0.05
ER-Gypsum	0.8	4.7	<1	<1	5.8	6.2	23	0.03	1.2
ER-Gypsum	0.6	0.7	<1	<1	5.1	4.9	5.2	<0.01	0.07
ER-Gypsum	0.8	0.8	<1	<1	6.3	4.9	6.0	<0.01	0.06
CR-Glenwood	1.0	5.3	<1	<1	7.8	8.4	27	0.02	1.3
CR-Glenwood	1.1	1.6	<1	<1	7.8	8.6	13	<0.01	0.24
CR-Glenwood	1.0	1.0	<1	<1	8.3	6.3	8.0	<0.01	0.08
RF-Glenwood	0.8	1.2	<1	<1	6.5	7.0	7.6	0.02	0.21
RF-Glenwood	0.9	0.8	<1	<1	6.9	7.4	8.0	<0.01	0.04
RF-Glenwood	1.0	1.0	<1	<1	9.0	6.8	7.6	<0.01	0.02
PC-Cameo	1.8	4.9	<1	<1	14	15	31	0.04	0.77
PC-Cameo	3.2	2.9	<1	<1	26	26	31	<0.01	0.13
PC-Cameo	3.3	3.1	<1	<1	30	23	27	<0.01	0.12
CR-Cameo	1.0	2.9	<1	<1	7.6	8.4	19	<0.01	0.6
CR-Cameo	0.7	0.8	<1	<1	5.3	5.5	8.4	<0.01	0.12
CR-Cameo	0.8	0.8	<1	<1	7.1	5.3	6.3	<0.01	0.05
GR-NF	1.2	8.0	<1	<1	9.4	10	42	0.05	2.0
GR-NF	1.1	0.7	<1	<1	8.8	8.6	8.7	0.01	0.05
GR-NF	1.2	1.3	<1	<1	11	8.6	11	<0.01	0.18
GR-Tunnel	1.5	1.6	<1	<1	12	13	11	<0.01	0.04
GR-Tunnel	1.3	1.0	<1	<1	9.5	10	11	<0.01	0.02
GR-Tunnel	1.0	0.9	<1	<1	9.5	7.4	7.8	<0.01	<b>0.005</b>
GR-Delta	1.4	6.3	1.2	1.3	11	12	38	0.03	1.4
GR-Delta	1.8	1.6	4.4	4.6	13	15	17	<0.01	0.25
GR-Delta	1.8	2.3	9.2	9.5	14	12	17	<0.01	1.2

Table AI-3. Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS Sc ug/L	ICP-MS Sc (avail.) ug/L	ICP-MS Se µg/L	ICP-MS Se (avail.) µg/L	ICP-AES SiO <sub>2</sub> mg/L	ICP-MS SiO <sub>2</sub> mg/L	ICP-MS SiO <sub>2</sub> (avail.) mg/L	ICP-MS Sm µg/L	ICP-MS Sm (avail.) µg/L
UR-Ouray	0.9	1.1	<1	<1	6.5	7.2	6.7	<0.01	0.21
UR-Ouray	1.1	1.1	<1	<1	8.1	8.7	9.4	<0.01	0.25
UR-Ouray	1.3	1.6	<1	<1	11	8.9	11	<0.01	0.30
UR-Ridgway	1.1	1.8	<1	<1	8.5	9.3	11	<0.01	0.19
UR-Ridgway	1.3	1.5	<1	1.0	10	11	13	<0.01	0.32
UR-Ridgway	1.2	1.5	1	1.1	11	8.6	11	<0.01	0.14
UR-Delta	1.8	9.7	8.6	11	14	16	53	0.01	2.0
UR-Delta	2.0	5.1	9.0	9.1	15	17	38	<0.01	2.8
UR-Delta	2.0	2.1	18	19	17	12	15	<0.01	0.05
GR-Grand Jct.	1.6	6.1	2.3	2.2	13	15	36	0.02	1.1
GR-Grand Jct.	1.2	1.0	4.4	5.0	8.7	9.4	10	<0.01	0.09
GR-Grand Jct.	1.6	1.3	3.9	4.0	14	11	13	0.01	0.10
CR-State line	1.3	5.1	1.8	1.9	9.8	11	31	0.01	1.1
CR-State line	1.0	1.2	2.8	2.8	7.6	8.0	12	<0.01	0.33
CR-State line	1.3	1.3	5.0	5.0	12	8.6	11	<0.01	0.15
DR-Dolores	0.7	4.7	<1	<1	5.3	5.8	27	0.06	1.8
DR-Dolores	0.6	0.6	<1	<1	4.7	4.6	5.2	<0.01	0.03
DR-Dolores	0.8	0.7	<1	<1	6.5	5.4	5.8	<0.01	0.02
DR-Bedrock	0.8	2.8	1.2	1.1	6.0	6.8	15	0.01	1.1
DR-Bedrock	0.7	5.4	2.2	1.8	5.4	5.5	51	0.41	2.9
DR-Bedrock	0.6	1.0	2.1	1.9	5.2	4.2	7.2	<0.01	0.27
SM-Uravan	1.0	2.7	1.0	<1	7.9	9.1	17	0.01	0.47
SM-Uravan	0.8	0.8	<1	<1	6.5	6.6	9.3	<0.01	0.18
SM-Uravan	0.9	0.8	1.0	1.1	7.8	6.0	6.9	<0.01	0.03
DR-Cisco	0.8	3.3	1.1	1.0	6.4	7.1	20	<0.01	0.72
DR-Cisco	1.0	5.3	1.6	1.3	6.4	7.4	45	<0.01	1.5
DR-Cisco	1.0	1.4	2.4	2.1	6.6	6.4	9.8	<0.01	0.21
CR-Cisco	1.1	5.9	1.6	1.8	8.0	8.5	34	<0.01	1.3
CR-Cisco	1.0	1.4	2.7	2.4	6.7	7.6	14	<0.01	0.23
CR-Cisco	1.6	1.7	4.3	3.9	13	9.9	13	<0.01	0.12
GW hot spring	5.9	6.3	<1	<1	31	31	39	<0.01	<0.01
RUM 305	1.5	1.6	62	60	na	19	19	<0.01	<0.01
RUM 310	2.2	2.1	6.1	7.9	na	27	25	<0.01	<0.01
RUM 590	0.9	0.9	89	84	na	10	9.0	0.13	0.13
RUM 855	2.7	2.5	1,560	1,450	na	32	30	0.01	0.01

Site name	ICP-AES Sr µg/L	ICP-MS Sr µg/L	ICP-MS Sr (avail.) µg/L	ICP-MS Tb µg/L	ICP-MS Tb (avail.) µg/L	ICP-MS Ti ug/L	ICP-MS Ti (avail.) ug/L	ICP-MS U µg/L	ICP-MS U (avail.) µg/L	ICP-MS V µg/L
CR-Kremmling	93	86	180	<0.005	0.06	<b>0.3</b>	8.7	0.34	1.0	0.6
CR-Kremmling	150	140	155	<0.005	<b>0.003</b>	0.8	1.3	0.3	0.89	1.4
CR-Kremmling	145	135	160	<0.005	<b>0.003</b>	0.6	0.6	0.28	0.31	1.2
ER-Minturn	49	43	46	0.005	0.01	0.7	5.5	0.49	0.48	0.3
ER-Minturn	63	58	55	<0.005	<b>0.003</b>	<b>0.3</b>	0.9	0.69	0.54	<0.5
ER-Minturn	55	52	56	<0.005	0.005	<b>0.3</b>	1.2	0.43	0.47	<0.5
ER-Avon	48	41	50	0.007	0.02	0.7	20	0.48	0.60	<0.5
ER-Avon	74	71	68	<0.005	<b>0.003</b>	<b>0.3</b>	2.2	0.54	0.46	<0.5
ER-Avon	130	130	135	<0.005	0.005	<b>0.3</b>	5.3	0.55	0.7	<0.5
ER-Gypsum	150	135	200	<0.005	0.15	0.6	66	0.62	1.1	0.5
ER-Gypsum	375	350	405	<0.005	0.008	0.8	2.7	0.56	0.75	<0.5
ER-Gypsum	585	585	605	<0.005	0.009	1.5	2.6	0.92	1.1	<0.5
CR-Glenwood	170	150	210	<0.005	0.15	0.6	63	0.72	1.1	0.8
CR-Glenwood	385	380	395	<0.005	0.03	1.1	20	1.4	1.4	0.8

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-AES Sr µg/L	ICP-MS Sr µg/L	ICP-MS Sr (avail.) µg/L	ICP-MS Tb µg/L	ICP-MS Tb (avail.) µg/L	ICP-MS Ti ug/L	ICP-MS Ti (avail.) ug/L	ICP-MS U µg/L	ICP-MS U (avail.) µg/L	ICP-MS V µg/L
CR-Glenwood	435	405	415	<0.005	0.01	1.1	2.3	1.1	1.2	<0.5
RF-Glenwood	220	200	230	<0.005	0.03	0.8	5.4	0.77	0.74	<0.5
RF-Glenwood	390	370	380	<0.005	0.003	1.1	2.8	1.5	1.4	<0.5
RF-Glenwood	605	555	555	<0.005	0.003	1.8	2.1	2.0	2.0	<0.5
PC-Cameo	170	165	195	0.005	0.09	0.6	51	0.94	1.0	1.4
PC-Cameo	535	515	540	<0.005	0.02	0.7	3.7	3.6	4.0	3.2
PC-Cameo	685	605	630	<0.005	0.02	0.7	0.9	3.4	4.4	3.0
CR-Cameo	260	245	300	<0.005	0.07	0.8	14	1.1	1.2	0.9
CR-Cameo	335	325	335	<0.005	0.02	0.9	7.7	1.4	1.4	0.6
CR-Cameo	635	565	580	<0.005	0.008	1.8	2.2	1.7	2.1	0.7
GR-NF	125	120	165	0.007	0.23	0.6	73	0.25	0.61	0.6
GR-NF	140	135	150	<0.005	0.01	0.6	0.6	0.36	0.4	0.6
GR-NF	360	305	320	<0.005	0.02	0.6	5.4	1.1	1.2	<0.5
GR-Tunnel	140	135	150	<0.005	0.01	0.6	3.1	1.0	0.96	0.9
GR-Tunnel	140	140	145	<0.005	0.003	0.3	1.1	1.1	1.2	0.6
GR-Tunnel	170	140	150	<0.005	0.003	0.3	0.6	0.88	1.0	0.5
GR-Delta	260	240	290	0.005	0.16	1.3	39	1.3	1.5	0.9
GR-Delta	945	945	1,010	<0.005	0.04	4.6	6.3	5.4	5.7	1.2
GR-Delta	1,330	1,280	1,390	<0.005	0.16	6.8	5.6	6.0	8.2	1.2
UR-Ouray	485	440	465	<0.005	0.03	1.2	3.1	<0.1	0.14	<0.5
UR-Ouray	895	850	910	<0.005	0.04	2.1	4.6	<0.1	0.29	<0.5
UR-Ouray	1,670	1,600	1,650	<0.005	0.05	4.0	4.5	0.10	0.44	<0.5
UR-Ridgway	780	715	780	<0.005	0.02	1.9	19	0.52	0.52	<0.5
UR-Ridgway	1,060	1,030	1,110	<0.005	0.04	2.5	4.8	0.69	0.92	<0.5
UR-Ridgway	1,450	1,480	1,510	<0.005	0.02	3.7	5.1	0.79	0.98	<0.5
UR-Delta	1,460	1,410	1,720	<0.005	0.23	6.0	77	8.2	7.6	1.9
UR-Delta	1,510	1,470	1,640	<0.005	0.39	6	7.1	7.6	8.2	2.1
UR-Delta	2,330	2,200	2,230	<0.005	0.006	9.4	11	13	13	0.7
GR-Grand Jct.	520	495	540	<0.005	0.12	2.2	53	2.8	2.6	1.2
GR-Grand Jct.	1,000	990	1,050	<0.005	0.01	4.3	5.1	5.5	5.5	1.5
GR-Grand Jct.	740	685	715	<0.005	0.01	3.6	4.0	5.2	5.3	0.9
CR-State line	375	360	415	<0.005	0.12	1.3	48	1.9	2.0	1.2
CR-State line	620	610	655	<0.005	0.04	2.2	4.3	3.1	3.1	1.2
CR-State line	1,140	1,040	1,080	<0.005	0.02	4.8	4.7	4.4	5.5	1.0
DR-Dolores	190	175	225	0.008	0.21	0.5	39	0.22	0.42	<0.5
DR-Dolores	345	325	330	<0.005	0.003	0.3	0.9	0.32	0.33	<0.5
DR-Dolores	460	435	450	<0.005	0.003	0.7	0.8	0.50	0.46	<0.5
DR-Bedrock	410	395	515	<0.005	0.15	0.9	4.4	1.3	1.6	1
DR-Bedrock	620	585	745	0.04	0.40	1.2	1.6	2.4	7.6	4.4
DR-Bedrock	770	720	740	<0.005	0.03	1.0	3.6	3.4	3.8	1.0
SM-Uravan	460	445	5.0	<0.005	0.06	1.4	28	0.98	0.92	0.6
SM-Uravan	965	945	970	<0.005	0.02	2.5	4.0	1.2	1.3	<0.5
SM-Uravan	1,410	1,270	1,300	<0.005	0.003	4.4	4.4	1.7	2.3	<0.5
DR-Cisco	430	405	455	<0.005	0.08	1.2	30	1.2	1.3	1
DR-Cisco	915	945	1,030	<0.005	0.18	2.8	56	2.7	3.0	2.7
DR-Cisco	1,240	1,130	1,140	<0.005	0.02	4.3	10	3.8	3.8	0.7
CR-Cisco	365	350	425	<0.005	0.16	1.3	46	1.9	2.1	1.6
CR-Cisco	580	620	660	<0.005	0.03	2.3	13	3.3	3.1	1.2
CR-Cisco	1,300	1,040	1,050	<0.005	0.02	5.2	9.7	6.0	6.0	1.0
GW hot spring	6,420	9,050	7,950	<0.005	<0.005	23	16	0.3	0.17	<0.5
RUM 305	na	2,130	2,180	<0.005	<0.005	4.0	4.2	55	55	470
RUM 310	na	2,610	2,540	<0.005	<0.005	6.6	6.1	245	225	12
RUM 590	na	2,020	1,870	0.04	0.04	23	21	54	50	470
RUM 855	na	1,070	995	<0.005	<0.005	12	11	87	83	13,800

**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS V (avail.) µg/L	ICP-MS Y µg/L	ICP-MS Y (avail.) µg/L	ICP-MS Yb µg/L	ICP-MS Yb (avail.) µg/L	ICP-MS Zn µg/L	ICP-MS Zn µg/L	ICP-MS Zn (avail.) µg/L
CR-Kremmling	4.0	0.05	1.6	0.006	0.13	<10	2.1	17
CR-Kremmling	<b>0.3</b>	0.01	0.08	<0.005	0.01	<10	1.2	3.5
CR-Kremmling	1	0.02	0.01	<0.005	<b>0.003</b>	10	2.6	5.0
ER-Minturn	0.5	0.13	0.28	0.01	0.02	56	54	52
ER-Minturn	<b>0.3</b>	0.05	0.08	<0.005	0.01	70	65	76
ER-Minturn	<b>0.3</b>	0.06	0.12	0.006	0.01	82	83	105
ER-Avon	1.0	0.16	0.55	0.01	0.04	15	12	49
ER-Avon	<b>0.3</b>	0.04	0.10	<0.005	0.01	12	8.2	16
ER-Avon	<b>0.3</b>	0.02	0.16	<0.005	0.01	27	26	53
ER-Gypsum	8.8	0.13	3.5	0.01	0.26	<10	4.3	135
ER-Gypsum	0.7	0.03	0.23	<0.005	0.01	12	6.4	14
ER-Gypsum	0.7	0.03	0.24	<0.005	0.02	12	4.3	17
CR-Glenwood	9.8	0.07	3.6	0.007	0.27	10	1.8	99
CR-Glenwood	2.2	0.03	0.60	<0.005	0.05	24	3.1	7.7
CR-Glenwood	0.9	0.03	0.27	<0.005	0.02	<10	1.5	6.6
RF-Glenwood	1.1	0.09	0.73	0.01	0.06	12	6.4	13
RF-Glenwood	0.5	0.03	0.13	<0.005	0.01	<10	3.6	5.0
RF-Glenwood	<b>0.3</b>	0.04	0.07	<0.005	<b>0.003</b>	14	5.3	3.4
PC-Cameo	5.1	0.16	2.0	0.02	0.18	<10	0.7	15
PC-Cameo	3.8	0.07	0.36	<0.005	0.03	<10	1.4	27
PC-Cameo	3.4	0.04	0.50	<0.005	0.04	<10	0.7	3
CR-Cameo	4.4	0.05	1.7	<0.005	0.12	<10	3.0	43
CR-Cameo	1.2	0.03	0.34	<0.005	0.02	<10	3.6	6.2
CR-Cameo	0.9	0.03	0.18	<0.005	0.01	<10	1.3	2.8
GR-NF	10	0.22	5.3	0.02	0.42	18	13	32
GR-NF	0.5	0.08	0.22	0.006	0.02	505	545	1.5
GR-NF	1.2	0.04	0.55	0.006	0.04	<10	1.8	4.3
GR-Tunnel	1.0	0.04	0.16	0.005	0.02	<10	0.7	2.0
GR-Tunnel	0.7	0.03	0.09	<0.005	0.01	<10	1.1	5.0
GR-Tunnel	0.5	0.02	0.04	<0.005	<b>0.003</b>	<10	0.8	1.4
GR-Delta	8.4	0.16	3.8	0.01	0.30	<10	1.6	23
GR-Delta	2.8	0.05	0.76	<0.005	0.05	10	2.5	6.8
GR-Delta	7.3	0.03	3.9	<0.005	0.24	13	2.1	19
UR-Ouray	0.5	0.03	0.74	<0.005	0.04	135	125	200



**Table AI-3.** Chemical and isotopic data for all water samples collected in this study.—Continued

[Site name is an abbreviation for station name; WS#, watershed number (see fig. 5 for location); red values are replacement values; na, not analyzed; nr, not reported; CFS, cubic feet per second; IC, ion chromatography; ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; (avail.), available loads (operationally defined as total dissolved after acidification of unfiltered sample); ins, insufficient sample; hydrogen and oxygen isotopes reported relative to V-SMOW and sulfur isotope values relative to V-CDT]

Site name	ICP-MS V (avail.) µg/L	ICP-MS Y µg/L	ICP-MS Y (avail.) µg/L	ICP-MS Yb µg/L	ICP-MS Yb (avail.) µg/L	ICP-MS Zn µg/L	ICP-MS Zn µg/L	ICP-MS Zn (avail.) µg/L
UR-Ouray	0.8	0.04	0.99	<0.005	0.07	180	195	290
UR-Ouray	<b>0.3</b>	0.05	1.3	<0.005	0.08	205	215	335
UR-Ridgway	1.0	0.03	0.6	<0.005	0.04	49	38	99
UR-Ridgway	1.5	0.03	1.0	<0.005	0.07	29	24	105
UR-Ridgway	<b>0.3</b>	0.03	0.63	<0.005	0.04	54	49	145
UR-Delta	19	0.07	5.9	0.006	0.38	16	5.3	57
UR-Delta	20	0.06	9.1	<0.005	0.65	12	2.3	67
UR-Delta	1.1	0.04	0.17	<0.005	0.01	16	5.8	5.3
GR-Grand Jct.	8.5	0.09	2.9	0.008	0.22	13	4.6	26
GR-Grand Jct.	2.0	0.04	0.25	<0.005	0.02	<10	1.5	3.7
GR-Grand Jct.	1.0	0.06	0.21	0.005	0.01	<10	2.3	2.7
CR-State line	7.7	0.06	2.7	0.005	0.21	15	6.8	25
CR-State line	2.7	0.04	0.94	<0.005	0.07	<10	1.1	8.9
CR-State line	1.9	0.04	0.54	<0.005	0.04	12	1.6	5.1
DR-Dolores	7.9	0.26	5.1	0.02	0.35	12	5.5	89
DR-Dolores	<b>0.3</b>	0.04	0.09	<0.005	0.01	<10	3.5	6.2
DR-Dolores	<b>0.3</b>	0.03	0.08	<0.005	0.01	<10	2.6	5.5
DR-Bedrock	8.2	0.05	3.9	<0.005	0.26	16	10	28
DR-Bedrock	42	0.56	7.8	0.01	0.56	<10	1.2	34
DR-Bedrock	3.0	0.03	0.63	<0.005	0.04	<10	1.1	4.4
SM-Uravan	3.1	0.07	1.3	0.005	0.09	16	12	73
SM-Uravan	1.2	0.03	0.52	<0.005	0.03	12	5.0	29
SM-Uravan	<b>0.3</b>	0.03	0.10	<0.005	0.01	15	10	12
DR-Cisco	6.5	0.04	1.9	<0.005	0.14	10	4.8	49
DR-Cisco	13	0.04	3.3	<0.005	0.23	13	4.6	29
DR-Cisco	2.6	0.04	0.53	<0.005	0.04	12	3.5	7.7
CR-Cisco	11	0.04	3.8	<0.005	0.26	82	75	42
CR-Cisco	2.9	0.03	0.60	<0.005	0.05	12	5.5	9.3
CR-Cisco	1.7	0.04	0.34	<0.005	0.02	14	3.1	6.8
GW hot spring	<0.5	0.09	0.07	<0.005	0.01	23	3.6	4.4
RUM 305	480	0.10	0.12	0.008	0.01	na	13	12
RUM 310	12	0.46	0.47	0.01	0.01	na	81	78
RUM 590	425	3.6	3.46	0.06	0.07	na	430	400
RUM 855	12,500	0.31	0.3	0.02	0.02	na	14	13

## Appendix II. Chemical Loads for Major Chemical Elements and Total Solutes

**Table AII-1.** Conductivity and chemical load (tonnes/day) for major chemical elements.

[(aq), dissolved loads; (avail); available loads (operationally defined as total dissolved after acidification); Al (aq), Mn (aq) <1 tonne/day. Full station name in Table AI-3]

Station ID	Site name	Flow	EC µS/cm	HCO <sub>3</sub> (aq)	Cl (aq)	SO <sub>4</sub> (aq)	Al (avail)	Ca (aq)	Ca (avail)	Fe (avail)	K (aq)	K (avail)	Mg (aq)	Mg (avail)
09058000	CR-Kremmling	High water	140	185	7	35	4	31	55	8	3	6	5	9
09058000	CR-Kremmling	Irrigation	210	170	12	69	<1	62	61	<1	4	4	11	10
09058000	CR-Kremmling	Base flow	200	145	8	51	<1	40	40	<1	3	3	8	8
09064600	ER-Minturn	High water	105	70	3	4	<1	20	19	1	1	1	7	6
09064600	ER-Minturn	Irrigation	140	16	<1	2	<1	4	3	<1	<1	<1	1	1
09064600	ER-Minturn	Base flow	110	11	<1	2	<1	2	2	<1	<1	<1	1	1
09067005	ER-Avon	High water	100	250	13	14	4	66	75	4	3	4	16	17
09067005	ER-Avon	Irrigation	130	56	3	18	<1	17	16	<1	1	1	4	4
09067005	ER-Avon	Base flow	190	61	3	17	<1	12	11	<1	<1	<1	4	3
09069000	ER-Gypsum	High water	190	760	40	185	41	190	305	55	7	17	37	56
09069000	ER-Gypsum	Irrigation	360	175	47	135	<1	82	86	<1	3	3	15	15
09069000	ER-Gypsum	Base flow	555	100	48	105	<1	59	57	<1	2	2	12	11
09071750	CR-Glenwood	High water	250	1,800	180	360	87	435	625	115	19	41	91	125
09071750	CR-Glenwood	Irrigation	515	520	260	295	4	215	215	5	9	11	41	41
09071750	CR-Glenwood	Base flow	565	610	220	245	1	155	145	1	7	7	33	32
09085000	RF-Glenwood	High water	250	760	43	335	5	285	300	6	7	7	45	41
09085000	RF-Glenwood	Irrigation	440	400	62	255	<1	180	170	1	4	4	29	27
09085000	RF-Glenwood	Base flow	600	260	79	215	<1	135	125	<1	3	3	23	22
09105000	PC-Cameo	High water	195	360	7	33	14	71	84	10	5	7	23	27
09105000	PC-Cameo	Irrigation	520	110	2	14	<1	19	19	<1	2	1	9	9
09105000	PC-Cameo	Base flow	590	115	3	17	<1	18	16	<1	1	1	11	10
09095500	CR-Cameo	High water	395	3,250	745	1,160	70	995	1,210	61	37	56	240	290
09095500	CR-Cameo	Irrigation	525	1,460	675	775	5	520	505	5	21	21	110	110
09095500	CR-Cameo	Base flow	920	1,150	820	700	<1	395	355	1	18	17	94	84
09134100	GR-Northfork	High water	115	695	25	77	115	190	210	105	12	34	35	54
09134100	GR-Northfork	Irrigation	170	115	3	42	<1	30	29	<1	8	1.0	8	8
09134100	GR-Northfork	Base flow	310	86	3	20	<1	17	15	<1	1	1	5	5
09128000	GR-tunnel	High water	195	140	4	38	<1	46	46	<1	3	3	10	9
09128000	GR-tunnel	Irrigation	205	115	3	27	<1	34	32	<1	2	2	7	6
09128000	GR-tunnel	Base flow	200	170	2	21	<1	29	22	<1	1	1	6	5
09144250	GR-Delta	High water	280	1,280	61	965	105	470	550	91	23	43	135	170
09144250	GR-Delta	Irrigation	900	415	26	705	1	245	220	2	9	9	77	67
09144250	GR-Delta	Base flow	1,080	445	32	890	3	280	270	4	9	8	83	77
09146020	UR-Ouray	High water	235	16	1	49	1	21	19	1	<1	<1	1	1
09146020	UR-Ouray	Irrigation	395	6	1	43	<1	17	16	1	<1	<1	1	1
09146020	UR-Ouray	Base flow	625	2	<1	19	<1	7	7	<1	<1	<1	<1	<1
09146200	UR-Ridgway	High water	420	70	4	105	1	51	49	1	1	1	5	4
09146200	UR-Ridgway	Irrigation	565	50	3	87	1	43	39	1	1	1	5	4
09146200	UR-Ridgway	Base flow	680	22	2	51	<1	20	20	<1	<1	<1	2	2
09149500	UR-Delta	High water	1,070	205	13	430	10	160	185	9	4	7	38	32
09149500	UR-Delta	Irrigation	1,150	380	34	790	9	300	320	14	9	10	69	59
09149500	UR-Delta	Base flow	1,530	150	13	380	<1	115	105	<1	2	2	29	28
09152500	GR-GJ	High water	455	1,620	67	1,900	81	775	875	65	30	48	220	245
09152500	GR-GJ	Irrigation	855	610	42	1,150	1	405	345	1	12	11	110	96
09152500	GR-GJ	Base flow	715	550	49	880	<1	285	245	<1	12	12	110	96
09163500	CR-CO/UT	High water	435	5,230	795	3,790	225	1,940	2,310	190	74	130	530	605

Table AII-1. Conductivity and chemical load (tonnes/day) for major chemical elements.—Continued

(aq), dissolved loads; (avail); available loads (operationally defined as total dissolved after acidification); Al (aq), Mn (aq) <1 tonne/day. Full station name in Table AI-3]

Field No.	Site	Flow	EC, $\mu\text{S/cm}$	$\text{HCO}_3$ (aq)	Cl (aq)	$\text{SO}_4$ (aq)	Al (avail)	Ca (aq)	Ca (avail)	Fe (avail)	K (aq)	K (avail)	Mg (aq)	Mg (avail)
09163500	CR-CO/UT	Irrigation	685	2,440	725	2,820	13	1,190	1,150	16	42	42	325	310
09163500	CR-CO/UT	Base flow	1,090	1,910	755	3,140	4	1,140	1,000	4	36	35	335	295
09166500	DR-Dolores	High water	155	745	21	74	59	210	255	49	9	23	30	47
09166500	DR-Dolores	Irrigation	265	63	4	18	<1	22	20	<1	1	1	3	3
09166500	DR-Dolores	Base flow	330	35	3	12	<1	14	12	<1	1	1	2	2
09171100	DR-Bedrock	High water	400	425	57	185	8	140	220	12	7	9	30	42
09171100	DR-Bedrock	Irrigation	1,510	31	73	11	2	9	15	1	3	3	3	4
09171100	DR-Bedrock	Base flow	1,010	17	21	6	<1	7	6	<1	1	1	2	2
09177000	SMR-Uravan	High water	350	320	13	245	7	140	140	5	4	5	32	31
09177000	SMR-Uravan	Irrigation	565	63	3	93	<1	39	35	<1	1	1	9	8
09177000	SMR-Uravan	Base flow	750	60	4	87	<1	33	29	<1	1	1	10	9
09180000	DR-Cisco	High water	375	555	67	310	16	200	230	13	8	13	42	48
09180000	DR-Cisco	Irrigation	1,070	100	99	115	5	50	57	3	4	6	13	15
09180000	DR-Cisco	Base flow	1,745	98	155	99	<1	50	42	<1	5	5	16	14
09180500	CR-Cisco	High water	430	7,350	1,150	3,930	345	2,290	3,060	305	92	185	560	720
09180500	CR-Cisco	Irrigation	725	2,340	915	2,500	16	1,060	1,070	15	44	47	290	290
09180500	CR-Cisco	Base flow	1,230	1,950	1,330	3,040	6	1,210	1,090	5	60	59	390	365

Site	Flow	Mn (avail)	Na (aq)	Na (avail)	$\text{SiO}_2$ (aq)	$\text{SiO}_2$ (avail)	Total (aq)	% CR Cisco
CR-Kremmling	High water	1	11	18	32	60	310	2
CR-Kremmling	Irrigation	<1	16	15	19	16	365	4
CR-Kremmling	Base flow	<1	13	14	15	19	280	3
ER-Minturn	High water	<1	2	2	9	9	115	<1
ER-Minturn	Irrigation	<1	<1	<1	1	1	25	<1
ER-Minturn	Base flow	<1	<1	<1	1	1	18	<1
ER-Avon	High water	<1	8	8	29	39	395	2
ER-Avon	Irrigation	<1	2	2	5	4	105	1
ER-Avon	Base flow	<1	2	2	2	2	100	1
ER-Gypsum	High water	2	33	34	55	205	1,310	8
ER-Gypsum	Irrigation	<1	35	34	10	11	500	6
ER-Gypsum	Base flow	<1	34	35	5	6	370	4
CR-Glenwood	High water	5	155	145	145	470	3,180	19
CR-Glenwood	Irrigation	<1	195	185	40	62	1,570	19
CR-Glenwood	Base flow	<1	170	185	22	27	1,460	15
RF-Glenwood	High water	<1	47	41	60	65	1,580	9
RF-Glenwood	Irrigation	<1	51	48	24	26	1,010	12
RF-Glenwood	Base flow	<1	61	61	13	14	790	8
PC-Cameo	High water	<1	26	27	52	110	575	3
PC-Cameo	Irrigation	<1	12	11	10	12	175	2
PC-Cameo	Base flow	<1	14	13	8	10	190	2
CR-Cameo	High water	2	695	720	225	510	7,450	44
CR-Cameo	Irrigation	<1	545	515	68	105	4,170	51
CR-Cameo	Base flow	<1	670	600	32	38	3,870	40
GR-Northfork	High water	2	47	53	130	540	1,210	7
GR-Northfork	Irrigation	<1	20	11	15	15	240	3
GR-Northfork	Base flow	<1	7	7	4	6	145	2
GR-tunnel	High water	<1	9	8	24	21	275	2
GR-tunnel	Irrigation	<1	6	6	13	14	205	3
GR-tunnel	Base flow	<1	5	4	7	8	240	3
GR-Delta	High water	2	180	195	195	600	3,310	19

**Table AII-1.** Conductivity and chemical load (tonnes/day) for major chemical elements.—Continued

[(aq), dissolved loads; (avail); available loads (operationally defined as total dissolved after acidification); Al (aq), Mn (aq) <1 tonne/day. Full station name in Table AI-3]

Site	Flow	Mn (avail)	Na (aq)	Na (avail)	SiO <sub>2</sub> (aq)	SiO <sub>2</sub> (avail)	Total (aq)	% CR Cisco
GR-Delta	Irrigation	<1	120	100	34	40	1,630	20
GR-Delta	Base flow	<1	150	145	25	37	1,910	20
UR-Ouray	High water	<1	2	2	4	4	96	1
UR-Ouray	Irrigation	<1	2	1	2	3	72	1
UR-Ouray	Base flow	<1	1	1	1	1	31	<1
UR-Ridgway	High water	<1	8	7	8	9	250	1
UR-Ridgway	Irrigation	<1	7	6	5	6	200	2
UR-Ridgway	Base flow	<1	4	4	2	2	100	1
UR-Delta	High water	<1	68	53	18	60	935	6
UR-Delta	Irrigation	1	125	91	32	71	1,730	21
UR-Delta	Base flow	<1	68	68	7	9	760	8
GR-GJ	High water	2	320	315	215	535	5,150	30
GR-GJ	Irrigation	<1	175	155	36	40	2,540	31
GR-GJ	Base flow	<1	165	150	42	47	2,090	22
CR-CO/UT	High water	6	1,080	1,070	495	1,380	13,900	82
CR-CO/UT	Irrigation	1	865	775	145	215	8,550	105
CR-CO/UT	Base flow	<1	1,020	995	93	115	8,420	87
DR-Dolores	High water	4	16	24	56	260	1,160	7
DR-Dolores	Irrigation	<1	3	3	3	3	115	1
DR-Dolores	Base flow	<1	3	3	2	2	71	<1
DR-Bedrock	High water	<1	60	63	22	48	930	5
DR-Bedrock	Irrigation	<1	45	45	1	10	175	2
DR-Bedrock	Base flow	<1	14	14	<1	1	69	<1
SMR-Uravan	High water	<1	24	23	28	51	800	5
SMR-Uravan	Irrigation	<1	7	6	4	5	220	3
SMR-Uravan	Base flow	<1	8	8	2	2	205	2
DR-Cisco	High water	1	70	70	34	95	1,280	8
DR-Cisco	Irrigation	<1	57	58	5	30	445	5
DR-Cisco	Base flow	<1	110	97	3	5	535	6
CR-Cisco	High water	9	1,110	1,070	465	1,870	17,000	
CR-Cisco	Irrigation	1	895	860	125	225	8,170	
CR-Cisco	Base flow	<1	1,540	1,170	110	150	9,630	

## Appendix III. Chemical, Isotopic, and Mineralogical Data for All Geologic Samples Collected in This Study

**Table AIII-1.** Metadata (analytical method, detection limit, the number of samples with censored data, the percent of samples with replaced values, and the replacement value) for reported concentrations.

[Replacement (red) values ( $0.5 \times$  detection limit) are used when censored values were reported for  $\geq 20$  percent of the samples (14 samples or less). For elements with the number censored = "many," less than concentrations are reported. For tables AIII-1—4: ICP-MS, inductive coupled plasma-mass spectrometry; ICP-AES, inductive coupled plasma-atomic emission spectrometry; HYD, hydride generation atomic adsorption spectrometry; COMB, combustion; CVAA, cold vapor atomic adsorption spectrometry; GF, graphite furnace; ISE, ion selective electrode; nd, not determined; ins, insufficient sample]

Element	Method	Detection limit	Number censored	Percent censored	Replacement
As	HYD	0.6 mg/kg	1	6	0.3 mg/kg
As	ICP-MS	1 mg/kg	1	6	0.5 mg/kg
Ba	ICP-AES	10 mg/kg	5	28	
Ba	ICP-MS	6 mg/kg	2	11	3 mg/kg
Be	ICP-MS	0.1 mg/kg	1	6	0.05 mg/kg
Bi	ICP-MS	0.04 mg/kg	5	28	
C (CO <sub>3</sub> )	COMB	0.003 mg/kg	8	44	
Cd	ICP-MS	0.01 mg/kg	6	33	
Cl	ICE	50 mg/kg	7	39	
Cr	ICP-AES	10 mg/kg	3	17	5 mg/kg
Cr	ICP-MS	1 mg/kg	4	22	0.5 mg/kg
F	ISE	20 mg/kg	1	6	10 mg/kg
Fe	ICP-AES	0.01 %	1	6	0.01 %
Hg	CVAA	0.02 mg/kg	12	67	
La	ICP-MS	0.5 mg/kg	3	17	0.3 mg/kg
Li	ICP-MS	1 mg/kg	1	6	0.5 mg/kg
Mg	ICP-AES	0.01 %	1	6	0.01 %
Mg	ICP-MS	0.01 %	1	6	0.005 %
Na	ICP-AES	0.01 %	2	11	0.005 %
P	ICP-MS	50 mg/kg	7	39	
Sb	ICP-MS	0.05 mg/kg	2	11	0.03 mg/kg
Se	HYD	0.2 mg/kg	4	22	
Sn	ICP-MS	0.1 mg/kg	1	6	0.05 mg/kg
Th	ICP-MS	0.2 mg/kg	3	17	0.1 mg/kg
Ti	ICP-AES	0.01 %	5	28	
Ti	ICP-MS	0.01 %	5	28	
Tl	GF	0.1 mg/kg	4	22	
U	ICP-MS	0.1 mg/kg	3	17	0.05 mg/kg
V	ICP-MS	1 mg/kg	2	11	0.5 mg/kg
W	ICP-MS	0.1 mg/kg	2	11	0.05 mg/kg
Y	ICP-MS	0.1 mg/kg	1	6	0.05 mg/kg
Zn	ICP-AES	1 mg/kg	1	6	0.5 mg/kg
Zr	ICP-AES	10 mg/kg	3	17	5 mg/kg

### Elements removed from table as values below detection limit

Element	Technique	Detection limit
Ag	ICP-MS	1 mg/kg
P	ICP-AES	0.01 %
In	ICP-MS	0.02 mg/kg
Te	ICP-MS	0.1 mg/kg
Nb	ICP-AES	10 mg/kg
Y	ICP-AES	10 mg/g

**Table AIII-2.** Chemical data for all geologic samples collected in this study.

Sample no.	Site	Location	Sample type	N. Lat °	W. Long °
AGEM-1B	American Gypsum Eagle mine	near surface—hi-grade ore	massive gypsum in Eagle Valley Evap.	39.67597	-106.95027
AGEM-2	American Gypsum Eagle mine	deeper low-grade	massive gypsum in Eagle Valley Evap.	39.67597	-106.95027
BW-2A-S	Badger Wash (Mancos Shale)	near entrance to Basin 2A	efflorescent salt	39.3317	-108.93697
BW-2A-G	Badger Wash (Mancos Shale)	near entrance to Basin 2A	surface gypsum	39.3316	-108.93684
BW-3B-S	Badger Wash (Mancos Shale)	near entrance to Basin 3B	efflorescent salt	39.34320	-108.93324
SC-1	Mesaverde Fm. Snowcap coal	coal on outcrop outside mine	coal	39.1423	-108.31345
SC-2	Mesaverde Fm. Snowcap coal	shale on outcrop outside mine	shale	39.1423	-108.31345
SM 1	GGNCA sulfur mine—Dakota Fm.	middle working (the ridge)	fine white powder	38.79016	-107.84089
SM 2	GGNCA sulfur mine—Dakota Fm.	middle working (the ridge)	yellow popcorn salt	38.79016	-107.84089
SM 3	GGNCA sulfur mine—Dakota Fm.	middle working (the ridge)	gray popcorn salt (cemented)	38.79016	-107.84089
SM 4	GGNCA sulfur mine—Dakota Fm.	middle working (the ridge)	gray-yellow hard layer (ash?)	38.79016	-107.84089
SM 5	GGNCA sulfur mine—Dakota Fm.	middle working (the ridge)	soft gray (ash-feeling) salt	38.79016	-107.84089
SM 6	GGNCA sulfur mine—Dakota Fm.	middle working (the ridge)	massive white salt (lowermost)	38.79016	-107.84089
SM 7	GGNCA sulfur mine—Dakota Fm.	middle working (the ridge)	massive xl mat—white salt	38.79016	-107.84089
SM 12	GGNCA sulfur mine—Dakota Fm.	lower workings "S face"	ss with native S	38.78923	-107.84168
SM 17-S	GGNCA sulfur mine—Dakota Fm.	lower workings pond in main drainage	efflorescent salt from bank	38.78923	-107.84168
I-70-1	Salts on Mesaverde Fm.	I-70 parking (between Cameo and Debeque)	massive efflorescent salt	39.19412	-108.27422
I-70-2	Salts on Mesaverde Fm.	I-70 parking (between Cameo and Debeque)	efflorescent salt scrapping	39.19412	-108.27422

Sample no.	Date sampled	Al % ICP-AES	Al % ICP-MS	As mg/kg HYD	As mg/kg ICP-MS	Ba mg/kg ICP-AES	Ba mg/kg ICP-MS
AGEM-1B	8/17/07	0.02	0.02	1.5	2	<10	3
AGEM-2	8/17/07	0.03	0.03	1.6	4	<10	3
BW-2A-S	8/17/07	3.9	3.5	6.4	4	450	500
BW-2A-G	8/17/07	0.05	0.07	1.6	3	<10	7
BW-3B-S	8/17/07	3.4	3.7	5.4	6	370	405
SC-1	8/18/07	6.2	4.9	1.5	0.5	620	510
SC-2	8/18/07	8.1	8.6	5.3	5	1,690	1,830
SM 1	8/18/07	0.62	0.64	2.8	2	40	40
SM 2	8/18/07	6.5	6.2	12	13	<10	7
SM 3	8/18/07	7.0	6.3	3.1	3	40	36
SM 4	8/18/07	2.6	2.7	88	115	40	32
SM 5	8/18/07	5.0	4.2	6.0	6	20	26
SM 6	8/18/07	1.2	1.2	6.4	6	20	14
SM 7	8/18/07	nd	nd	0.7	nd	nd	nd
SM 12	8/18/07	0.56	0.47	83	68	40	43
SM 17-S	8/18/07	2.9	2.7	120	140	<10	8
I-70-1	8/18/07	2.2	2.1	4.3	3	320	220
I-70-2	8/18/07	1.6	1.6	0.3	2	190	185

Table AIII-2. Chemical data for all geologic samples collected in this study.—Continued

Sample no.	Be mg/kg ICP-MS	Bi mg/kg ICP-MS	Ca % ICP-AES	Ca % ICP-MS	C (tot) % COMB	C (org) % COMB
AGEM-1B	0.05	<0.04	24	27	0.02	0.02
AGEM-2	0.1	<0.04	29	31	0.09	0.01
BW-2A-S	1.4	0.19	4.9	4.2	2.1	0.36
BW-2A-G	0.1	<0.04	23	21	0.06	0.05
BW-3B-S	1.0	0.19	4.4	4.9	2.1	0.35
SC-1	3.7	0.45	0.02	0.02	43	42
SC-2	1.7	0.59	0.05	0.05	4.5	4.5
SM 1	0.2	0.05	1.4	1.3	nd	nd
SM 2	4.0	0.08	0.11	0.12	0.06	0.06
SM 3	3.6	0.81	0.16	0.14	0.56	0.55
SM 4	1.3	1.26	0.14	0.15	0.11	0.11
SM 5	0.5	0.13	0.13	0.11	0.22	0.21
SM 6	0.2	<0.04	0.31	0.33	0.18	0.17
SM 7	nd	nd	nd	nd	nd	nd
SM 12	0.1	0.14	0.11	0.1	0.11	0.1
SM 17-S	2.3	<0.04	0.3	0.27	0.12	0.12
I-70-1	0.6	0.04	1.3	1.3	0.41	0.06
I-70-2	0.5	0.08	3.1	3.1	nd	nd
Sample no.	Cd mg/kg ICP-MS	Ce mg/kg ICP-MS	Cl mg/kg ISE	Co mg/kg ICP-MS	Cr mg/kg ICP-AES	Cr mg/kg ICP-MS
AGEM-1B	<0.1	0.29	<50	0.6	5	0.5
AGEM-2	<0.1	0.38	100	0.4	10	0.5
BW-2A-S	0.4	30	120	4.6	50	32
BW-2A-G	<0.1	0.56	<50	0.9	5	0.5
BW-3B-S	0.4	34	190	4.2	40	27
SC-1	0.2	29	150	5.3	20	7
SC-2	0.2	92	90	5.7	60	42
SM 1	<0.1	9.7	nd	1.3	10	0.5
SM 2	1.2	24	<50	36	20	10
SM 3	1.4	25	<50	27	10	5
SM 4	0.8	13	60	7.8	20	16
SM 5	0.2	21	<50	1.7	20	11
SM 6	<0.1	7.4	810	1.7	10	2
SM 7	ins	nd	nd	nd	nd	nd
SM 12	0.3	19	<50	0.2	5	2
SM 17-S	0.2	4.8	<50	2.5	20	8
I-70-1	<0.1	31	360	1.7	20	8
I-70-2	0.2	17	nd	2.2	20	7

**Table AIII-2.** Chemical data for all geologic samples collected in this study.—Continued

Sample no.	F mg/kg ISE	Fe % ICP-AES	Fe % ICP-MS	Ga mg/kg ICP-MS	Hg mg/kg CVAA	K % ICP-AES	K % ICP-MS	La mg/kg ICP-MS
AGEM-1B	10	0.005	0.01	0.12	<0.02	0.01	0.02	0.3
AGEM-2	60	0.03	0.02	0.17	<0.02	0.01	0.03	0.3
BW-2A-S	540	1.55	1.3	9.8	<0.02	1.5	1.4	15
BW-2A-G	30	0.02	0.02	0.22	<0.02	0.03	0.04	0.3
BW-3B-S	520	1.31	1.5	7.6	0.02	1.3	1.5	18
SC-1	270	0.17	0.15	13	0.14	0.2	0.13	15
SC-2	840	1.51	1.8	20	0.11	2.3	2.4	47
SM 1	nd	0.23	0.25	1.7	<0.02	0.08	0.08	4.8
SM 2	130	3.2	3.3	14	<0.02	0.4	0.37	9.1
SM 3	560	0.41	0.39	3.8	0.77	0.18	0.14	10
SM 4	260	21.4	21	37	0.54	3.8	3.9	5.7
SM 5	110	2.5	2.5	15	<0.02	0.57	0.52	11
SM 6	90	0.91	1	3.0	<0.02	0.42	0.43	3.9
SM 7	nd	nd	nd	nd	<0.02	nd	nd	nd
SM 12	40	0.12	0.08	1.1	1.1	0.02	0.01	13
SM 17-S	60	0.94	0.92	8.9	<0.02	0.44	0.38	2
I-70-1	130	0.49	0.51	4.5	<0.02	1.2	1.2	18
I-70-2	nd	0.35	0.36	3.4	<0.02	0.78	0.77	9.3
Sample no.	Mg % ICP-AES	Mg % ICP-MS	Mn mg/kg ICP-MS	Mo mg/kg ICP-MS	Na % ICP-AES	Na % ICP-MS	Nb mg/kg ICP-MS	
AGEM-1B	0.005	0.005	5	0.18	0.03	0.01	0.4	
AGEM-2	0.1	0.09	6	0.69	0.005	0.02	0.2	
BW-2A-S	1.8	1.5	235	1.3	1.64	1.3	4.6	
BW-2A-G	0.02	0.02	17	0.09	0.02	0.02	0.2	
BW-3B-S	1.6	1.8	185	1.2	2.78	2.5	4.3	
SC-1	0.12	0.11	23	1.1	0.2	0.13	11	
SC-2	0.39	0.45	40	1.2	0.82	0.76	12	
SM 1	11	10	31	0.18	0.005	0.02	1.8	
SM 2	1.1	1.1	740	0.45	1.02	0.81	0.4	
SM 3	1.5	1.5	735	0.82	0.1	0.08	2.4	
SM 4	0.24	0.24	170	16	1.1	0.97	2.3	
SM 5	0.37	0.37	71	0.35	0.68	0.49	2.1	
SM 6	6.3	7.2	24	0.28	9.85	8.3	1.0	
SM 7	nd	nd	nd	nd	nd	nd	nd	
SM 12	0.01	0.01	11	0.32	0.05	0.01	1.9	
SM 17-S	2.0	2.0	99	0.4	12.9	10.7	0.3	
I-70-1	0.54	0.57	110	0.23	13.6	11.9	3.5	
I-70-2	1.3	1.4	65	0.87	18	14.9	2.1	



Table AIII-2. Chemical data for all geologic samples collected in this study.—Continued

Sample no.	Ni mg/kg ICP-MS	P mg/kg ICP-MS	Pb mg/kg ICP-MS	Rb mg/kg ICP-MS	S % ICP-MS	S (tot) % COMB	Sb mg/kg ICP-MS
AGEM-1B	1.5	<50	1.2	0.6	22	17	0.03
AGEM-2	1.2	180	1.0	1.3	23	23	0.08
BW-2A-S	18	710	15	66	1.4	1.11	0.67
BW-2A-G	1.7	<50	0.6	1.4	23	17	0.06
BW-3B-S	18	960	15	59	2.4	1.59	0.68
SC-1	13	<50	13	6	0.49	0.78	1.5
SC-2	16	450	30	160	0.82	0.6	1.3
SM 1	2.6	<50	4.5	4	14	nd	0.1
SM 2	43	<50	8.1	8.8	11	14	0.07
SM 3	27	<50	5.9	8.4	8.8	12	0.26
SM 4	15	100	81	86	14	12	1.2
SM 5	4.7	170	4.9	27	7.05	17	0.12
SM 6	3.9	<50	2.3	12	18	16	0.07
SM 7	nd	nd	nd	nd	nd	nd	nd
SM 12	0.9	160	11	0.7	1.2	18	0.19
SM 17-S	6.8	210	1.3	7.9	18	19	0.03
I-70-1	4.8	310	10	43	8.9	8.2	0.29
I-70-2	5.8	140	6.5	25	13	nd	0.25
Sample no.	Sc mg/kg ICP-MS	Se mg/kg Hydride	Si % ICP-AES	Sn mg/kg ICP-MS	Sr mg/kg ICP-AES	Sr mg/kg ICP-MS	Th mg/kg ICP-MS
AGEM-1B	0.4	<0.2	0.02	0.05	1,230	1,210	0.1
AGEM-2	0.4	<0.2	0.03	0.1	1,440	1,250	0.1
BW-2A-S	6.1	1.2	28	1.2	190	175	6.6
BW-2A-G	0.6	0.5	0.17	0.1	380	350	0.1
BW-3B-S	4.7	1	27	1.0	150	155	6.1
SC-1	5.2	1.8	8.5	1.1	30	18	8.4
SC-2	9.2	1.7	27	2.4	140	135	15
SM 1	0.5	0.7	2.3	0.4	60	53	1.8
SM 2	6.5	0.5	0.82	0.4	30	27	11
SM 3	2.8	1.4	5.3	0.6	40	36	3.9
SM 4	4.6	0.9	4.3	3.5	100	96	11
SM 5	3.9	<0.2	5.5	0.6	160	140	3.4
SM 6	0.7	0.2	3.1	0.3	130	130	1.2
SM 7	nd	<0.2	nd	nd	nd	nd	nd
SM 12	0.8	0.3	33	0.4	30	21	0.9
SM 17-S	3.7	0.6	1.7	0.2	120	105	1.6
I-70-1	1.7	3.6	22	0.5	220	210	4.4
I-70-2	1.4	7.9	12	0.4	450	120	2.5

**Table AIII-2.** Chemical data for all geologic samples collected in this study.—Continued

Sample no.	Ti % ICP-MS	Tl mg/kg GF	Tl mg/kg ICP-MS	U mg/kg ICP-MS	V mg/kg ICP-MS	W mg/kg ICP-MS	Y mg/kg ICP-MS
AGEM-1B	<0.01	0.4	<0.1	<b>0.05</b>	<b>0.5</b>	0.1	<b>0.05</b>
AGEM-2	<0.01	<0.1	<0.1	<b>0.05</b>	<b>0.5</b>	1.3	0.1
BW-2A-S	0.12	0.6	0.5	2.5	72	0.6	13
BW-2A-G	<0.01	<0.1	<0.1	<b>0.05</b>	1.0	<b>0.05</b>	0.2
BW-3B-S	0.11	0.5	0.5	2.3	73	0.6	13
SC-1	0.12	<0.1	0.1	4.6	27	0.3	14
SC-2	0.31	1.1	1.1	5.5	120	1.7	18
SM 1	0.02	<0.1	<0.1	0.6	3	0.3	2.8
SM 2	<0.01	0.6	0.5	0.7	6	<b>0.05</b>	12
SM 3	0.04	1	0.8	0.9	7	1.5	17
SM 4	0.05	6.3	6.5	1.0	41	1.2	7.9
SM 5	0.04	0.4	0.3	0.6	27	0.3	5.5
SM 6	0.02	0.6	0.6	0.9	7	0.2	2.1
SM 7	nd	nd	nd	nd	nd	nd	nd
SM 12	0.04	0.3	0.3	5.9	3	0.6	345
SM 17-S	<0.01	0.2	0.2	1.0	36	0.2	4.4
I-70-1	0.09	0.2	0.2	0.9	24	0.5	6.4
I-70-2	0.05	ins	0.2	0.8	17	0.4	4.2

Sample no.	Zn mg/kg ICP-MS	Zr mg/kg ICP-AES
AGEM-1B	<b>0.5</b>	<b>5</b>
AGEM-2	1	<b>5</b>
BW-2A-S	59	260
BW-2A-G	1	<b>5</b>
BW-3B-S	63	270
SC-1	42	140
SC-2	56	210
SM 1	11	30
SM 2	280	10
SM 3	195	60
SM 4	64	80
SM 5	33	70
SM 6	21	40
SM 7	nd	nd
SM 12	13	100
SM 17-S	59	10
I-70-1	18	140
I-70-2	19	80

**Table AIII-3.** Sulfur isotope data for geologic samples collected in this study.

[S(H<sub>2</sub>O), sulfate that dissolves in water; S(HCl), sulfate that dissolves in acid; S(elem), elemental sulfur; S(av), sulfur in monosulfide minerals; S(DI), sulfur in disulfide minerals such as pyrite; nq, not quantified. Blanks indicate no data; oxygen isotopes reported relative to V-SMOW and sulfur isotopes relative to V-CDT]

Sample no.	Site	Location	Sample type	lat	long	% S(H <sub>2</sub> O)
AGEM-1A	American Gypsum Eagle mine	near surface	gypsum (var. selenite)	39.67597	-106.95027	9.7
AGEM-1B	American Gypsum Eagle mine	near surface–hi-grade ore	massive gypsum	39.67597	-106.95027	9.8
AGEM-2	American Gypsum Eagle mine	deeper low-grade	massive gypsum	39.67597	-106.95027	7.1
BW-3BS	Badger Wash	near entrance to Basin 3B	salts	39.34320	-108.93324	1.6
BW-2AG	Badger Wash	near entrance to Basin 2A	gypsum	39.3316	-108.93684	9.2
BW-2AS	Badger Wash	near entrance to Basin 2A	salt	39.3317	-108.93697	1.0
SM-1	Sulfur mine	middle working (the ridge)	fine white powder	38.79016	-107.84089	13
SM-2	Sulfur mine	middle working (the ridge)	yellow popcorn salt	38.79016	-107.84089	12
SM-3	Sulfur mine	middle working (the ridge)	white-gray popcorn salt	38.79016	-107.84089	12
SM-4	Sulfur mine	middle working (the ridge)	gray-white-yellow hard layer	38.79016	-107.84089	8.0
SM-5	Sulfur mine	middle working (the ridge)	soft gray (ash-feeling) salt	38.79016	-107.84089	15
SM-6	Sulfur mine	middle working (the ridge)	lowermost white salt	38.79016	-107.84089	16
SM-7	Sulfur mine	middle working (the ridge)	massive xl mat–white salt	38.79016	-107.84089	11
SM-8	Sulfur mine	middle working (the ridge)	massive siliceous layer	38.79016	-107.84089	
SM-9	Sulfur mine	middle working (the ridge)	yellow-white massive salt	38.79016	-107.84089	
SM-10	Sulfur mine	middle working (the ridge)–down stream	cherty silicified layer	38.79016	-107.84092	
SM-11	Sulfur mine	middle working (the ridge)–down stream	S(native) on fractures	38.79016	-107.84092	
SM-12	Sulfur mine	lower workings "S face"	sandstone with native S	38.78923	-107.84168	
SM-17	Sulfur mine	lower workings pond in main drainage	salts from bank	38.78923	-107.84168	nq
SC-1	Snowcap coal	coal on outcrop outside mine	coal	39.1423	-108.31345	
SC-2	Snowcap coal	shale on outcrop outside mine	shale	39.1423	-108.31345	
I-70-1	Mesa Verde	I-70 parking (between Cameo/Debeque)	massive salt	39.19412	-108.27422	8.7
I-70-2	Mesa Verde	I-70 parking (between Cameo/Debeque)	salt scraping	39.19412	-108.27422	17

**Table AIII-3.** Sulfur isotope data for geologic samples collected in this study.—Continued

[S(H<sub>2</sub>O), sulfate that dissolves in water; S(HCl), sulfate that dissolves in acid; S(elem), elemental sulfur; S(av), sulfur in monosulfide minerals; S(DI), sulfur in disulfide minerals such as pyrite; nq, not quantified. Blanks indicate no data; oxygen isotopes reported relative to V-SMOW and sulfur isotopes relative to V-CDT]

Sample	$\delta^{34}\text{S}(\text{H}_2\text{O})\text{‰}$	$\delta^{18}\text{O}(\text{H}_2\text{O})$	%S (HCl-1N)	$\delta^{34}\text{S}(\text{HCl})\text{‰}$	%S(elem)	$\delta^{34}\text{S}(\text{ele})\text{‰}$	%S(AV)	$\delta^{34}\text{S}(\text{AV})\text{‰}$	%S(DI)	$\delta^{34}\text{S}(\text{Di})\text{‰}$
AGEM-1A	14.5	12.6	8.2	14.5						
AGEM-1B	14.3	11.5	7.8	14.1						
AGEM-2	13.7	10.2	13	13.6						
BW-3BS	-20.9	-9.0	0.014	nd						
BW-2AG	-22.7	-2.9	7.9	-22.8						
BW-2AS	-17.0	-8.6	0.019	nd						
SM-1	-6	-7.5	0.027	nd						
SM-2	-1.5	-4.0		-2.0	0.004	nd				
SM-3	-3.7	-4.6			0.003	nd				
SM-4	1.7	-5.0	nq	-3.2	0.006	nd				
SM-5	1.3	nd	0.008	nd						
SM-6	-18.9	-3.7	0.014	nd						
SM-7	-1.5	13.6			0.087	nd				
SM-8										
SM-9										
SM-10										
SM-11										
SM-12			nq	-0.4	6.2	4.5	0.67	2.80	6.7	3.9
SM-17	-7.4	2.9			0.025	nd				
SC-1			nq	3.7	0.003	nd	0.0003	nd	0.034	nd
SC-2			nq	-1.5	0.008	nd	0.0010	nd	0.006	nd
I-70-1	3.4	-3.6	0.011	nd						
I-70-2	3.6	-2.9	0.014	nd						

**Table AIII-4.** Mineralogical data for selected geologic samples collected in this study. Data on elements present in the samples are based on examination with a scanning electron microscope (SEM) equipped with an energy dispersive X-ray fluorescence detector. Elements are listed in order of abundance, except O, which is always listed last. Mineral identification is based on morphology and element suites.

[\*, amount of hydroxyl present in each sample was not determined and may have changed between the time of sample collection and SEM examination]

Sample	Site	Location	Sample type	Elements*	Interpreted minerals
AGEM-1A	American Gypsum Eagle mine	near surface	gypsum (var. selenite)	nd	gypsum
AGEM-1B	American Gypsum Eagle mine	near surface–hi-grade ore	massive gypsum	nd	gypsum
AGEM-2	American Gypsum Eagle mine	deeper low-grade	massive gypsum	nd	gypsum
BW-3BS	Badger Wash	near entrance to Basin 3B	salts	NaSO, CaSO	thenardite, gypsum
BW-2AG	Badger Wash	near entrance to Basin 2A	gypsum	CaSO	gypsum
BW-2AS	Badger Wash	near entrance to Basin 2A	salt	NaSO	thenardite
SM-1	Sulfur mine	middle working (the ridge)	fine white powder	NaAlSO, MgAlSO, Fe(NaSiK)SO	
SM-2	Sulfur mine	middle working (the ridge)	yellow popcorn salt	MgSO, CaSO	
SM-3	Sulfur mine	middle working (the ridge)	white-gray popcorn salt	AlMgSO, AlSO, MgAlSO, CaSO, FeSO, NaAlSO, AlSiSO	
SM-4	Sulfur mine	middle working (the ridge)	gray-white-yellow hard layer	AlMgSO, AlSO	
SM-5	Sulfur mine	middle working (the ridge)	soft gray (ash-feeling) salt	AlSO, FeSO, KFeAlMgSO	voltaite(?)
SM-6	Sulfur mine	middle working (the ridge)	lowermost white salt	NaMgSO, S, MgSO, NaAlSO, AlMgSO, KAlSO	native sulfur
SM-7	Sulfur mine	middle working (the ridge)	massive xl mat—white salt	MgAlSO, MgFeAlSO, AlSO	voltaite(?)
SM-8	Sulfur mine	middle working (the ridge)	massive siliceous layer		
SM-9	Sulfur mine	middle working (the ridge)	yellow-white massive salt		
SM-10	Sulfur mine	middle working (the ridge)—down stream	cherty silicified layer		
SM-11	Sulfur mine	middle working (the ridge)—down stream	S (native) on fractures		
SM-12	Sulfur mine	lower workings “S face”	sandstone with native S		
SM-17	Sulfur mine	lower workings pond in main drainage	salts from bank	NaSO, NaFeSO, NaAlSO, NaMgSO	
SC-1	Snowcap coal	coal on outcrop outside mine	coal	nd	nd
SC-2	Snowcap coal	shale on outcrop outside mine	shale	nd	nd
I-70-1	Mesa Verde	I-70 parking (between Cameo/Debeque)	Salt scraping—massive and dendritic	NaSO rounded xls	thenardite
I-70-2	Mesa Verde	I-70 parking (between Cameo/Debeque)	salt scraping—massive white salt, some dendritic xls	NaSO, CaSO, NaCaSO, NaMgSO	thenardite, gypsum

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