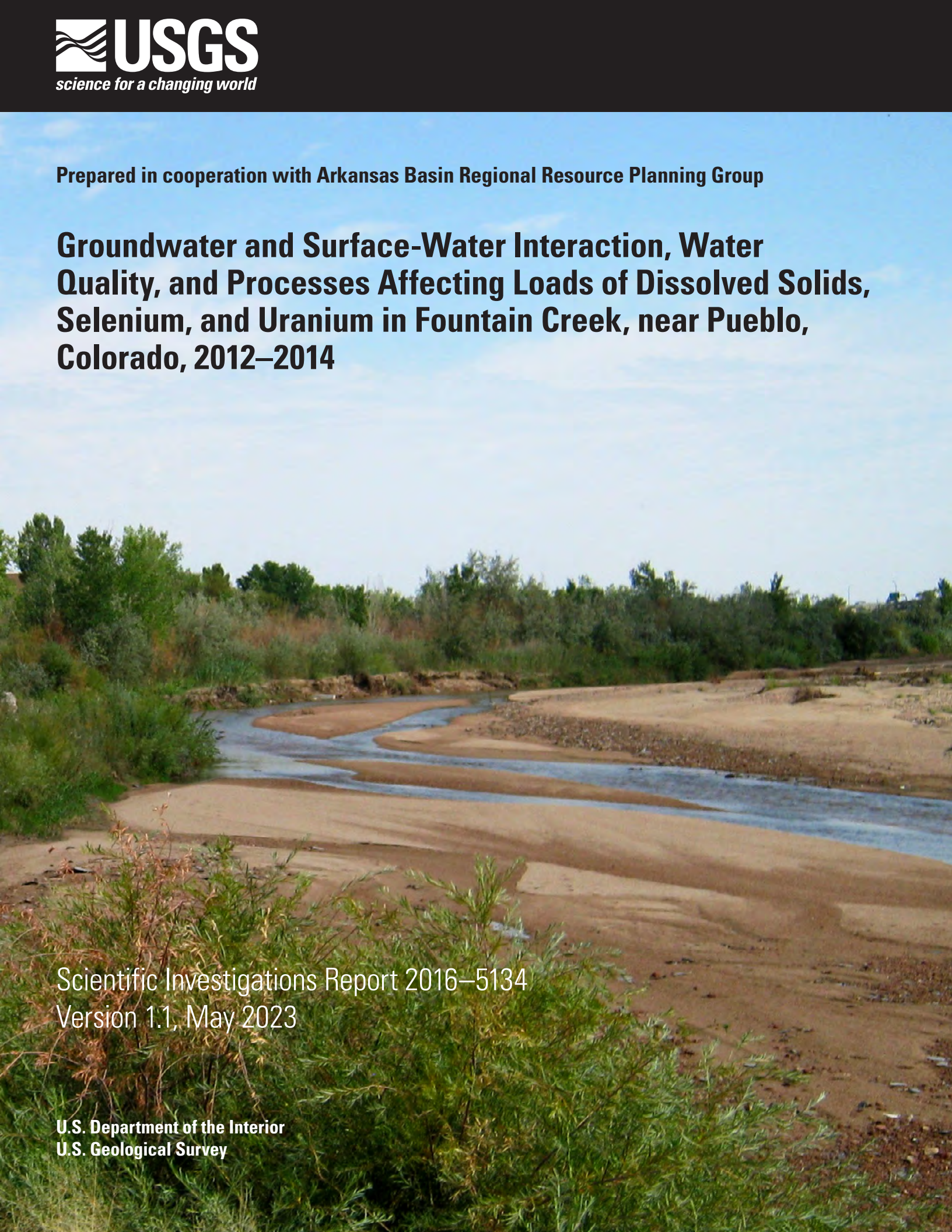


Prepared in cooperation with Arkansas Basin Regional Resource Planning Group

Groundwater and Surface-Water Interaction, Water Quality, and Processes Affecting Loads of Dissolved Solids, Selenium, and Uranium in Fountain Creek, near Pueblo, Colorado, 2012–2014

Scientific Investigations Report 2016–5134
Version 1.1, May 2023

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





Cover. View of Fountain Creek channel about 0.7 mile north of U.S. Geological Survey streamgage 07106500.

Groundwater and Surface-Water Interaction, Water Quality, and Processes Affecting Loads of Dissolved Solids, Selenium, and Uranium in Fountain Creek near Pueblo, Colorado, 2012–2014

By L. Rick Arnold, Roderick F. Ortiz, Christopher R. Brown, and Kenneth R. Watts

Prepared in cooperation with Arkansas Basin Regional Resource Planning Group

Scientific Investigations Report 2016–5134
Version 1.1, May 2023

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

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016
Revised: May 2023 (ver. 1.1)

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit <http://www.usgs.gov> or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit <http://store.usgs.gov/>.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Suggested citation:

Arnold, L.R., Ortiz, R.F., Brown, C.R., and Watts, K.R., 2016, Groundwater and surface-water interaction, water quality, and processes affecting loads of dissolved solids, selenium, and uranium in Fountain Creek, near Pueblo, Colorado, 2012–2014 (ver. 1.1, May 2023): U.S. Geological Survey Scientific Investigation Report 2016–5134, 78 p., <https://doi.org/10.3133/sir20165134>.

ISSN 2328-0328 (online)

Acknowledgments

The valuable participation by the City of Pueblo in granting access to monitoring-well sites along Fountain Creek is gratefully acknowledged. Thanks also are extended to field personnel from the Pueblo Field Office of the U.S. Geological Survey Colorado Water Science Center for assisting with data collection.

Contents

Acknowledgments.....	iii
Abstract.....	1
Introduction.....	2
Purpose and Scope	2
Description of the Study Area	4
Physiography and Climate.....	4
Hydrologic Setting	4
Previous Investigations.....	5
Methods of Investigation.....	6
Groundwater Methods.....	6
Well Installation	6
Hydrogeologic Mapping	6
Hydrogeologic Cross Sections	6
Water Table.....	10
Slug Tests.....	10
Groundwater Levels	10
Groundwater Temperature.....	10
Hyporheic Zone	10
Surface Water Methods.....	11
Streamflow and Stage	11
Stream Temperature.....	11
Water-Quality Methods.....	12
Sample Collection and Processing.....	12
Quality Control.....	15
Groundwater and Surface-Water Interaction	15
Data Analysis.....	15
Hydrogeologic Mapping	15
Hydrologic Analysis.....	16
Slug Tests	16
Quantification of Groundwater Flow	20
Temperature Profiles.....	20
Hyporheic Zone	27
Hydraulic Heads.....	27

Hydrogen- and Oxygen-Isotope Ratios	29
Streamflow Mass Balance	32
Summary of Groundwater and Surface-Water Interaction	32
Water Quality	33
Analytical Results	33
Dissolved Solids	47
Selenium	47
Uranium	49
Nitrate, Alkalinity, and Dissolved Oxygen	50
Oxidation-Reduction Conditions	51
Processes Affecting Loads of Dissolved Solids, Selenium, and Uranium	55
Fountain Creek Loads	55
Loads from Groundwater	55
In-Stream Loads	55
Processes Affecting Loads to Fountain Creek	58
Geologic Source	60
Geochemistry of Dissolved Solids, Selenium, and Uranium	60
Dissolved Solids	60
Selenium	60
Uranium	61
Assessment of Dissolved-Solids, Selenium, and Uranium Concentrations	61
Summary	64
References Cited	66
Appendix 1. Lithologic Logs	71
Appendix 2. Water-quality control data	74

Figures

1. Map showing Fountain Creek Basin, land cover, and study area near Pueblo, Colo	3
2. Photograph showing view of Fountain Creek channel about 0.7 mile north of U.S. Geological Survey streamgage 07106500	4
3. Graph showing mean-monthly streamflow of Fountain Creek at Pueblo (07106500), January 1922–December 2013	5
4. Map showing surficial geology, water-table altitude, monitoring-well locations, and hydrogeologic-section lines through the north, middle, and south transects, Fountain Creek near Pueblo, Colo	7
5. Hydrogeologic sections through the <i>A</i> , north; <i>B</i> , middle; and <i>C</i> , south transects, Fountain Creek near Pueblo, Colo	9
6. Photograph showing typical setup of hydraulic potentiomanometer for measuring differences in hydraulic head between the stream and underlying streambed of Fountain Creek, middle transect, 2013	11
7. Graphs and tables showing relation of stream stage (<i>H</i>) to streamflow discharge (<i>Q</i>) at the (<i>A</i>) north, (<i>B</i>) middle, and (<i>C</i>) south transect, Fountain Creek near Pueblo, Colo	12
8. Graphs and tables showing relation of streamflow discharge in Fountain Creek at the (<i>A</i>) north, (<i>B</i>) middle, and (<i>C</i>) south transect (Q_2) to streamflow discharge at U.S. Geological Survey streamgage 07106500 (Q_1 , Fountain Creek at Pueblo, Colo.)	13

9–20.	Graphs showing:	
9.	Streamflow and dates of stream water-quality samples collected at the <i>A</i> , north; <i>B</i> , middle; and <i>C</i> , south transects, Fountain Creek near Pueblo, Colo., 2012–2013	14
10.	Groundwater levels, stream-surface level, streamflow, and precipitation for <i>A</i> , west side; and <i>B</i> , east side of the north transect, Fountain Creek near Pueblo, Colo., 2012–2014	17
11.	Groundwater levels, stream-surface level, streamflow, and precipitation for the east side of the middle transect, Fountain Creek near Pueblo, Colo., 2012–2014	18
12.	Groundwater levels, stream-surface level, streamflow, and precipitation for <i>A</i> , west side; and <i>B</i> , east side of the south transect, Fountain Creek near Pueblo, Colo., 2012–2014	19
13.	Groundwater and stream temperature, streamflow, and precipitation for <i>A</i> , west side; and <i>B</i> , east side of the north transect, Fountain Creek near Pueblo, Colo., 2012–2014	26
14.	Groundwater and stream temperature, streamflow, and precipitation for the east side of the middle transect, Fountain Creek near Pueblo, Colo., 2012–2014	27
15.	Groundwater and stream temperature, streamflow, and precipitation for <i>A</i> , west side; and <i>B</i> , east side of the south transect, Fountain Creek near Pueblo, Colo., 2012–2014	28
16.	Delta ^2H ($\delta^2\text{H}$) relative to delta ^{18}O ($\delta^{18}\text{O}$) for groundwater, surface water, and hyporheic-zone samples at the <i>A</i> , north; <i>B</i> , middle; and <i>C</i> , south transects, Fountain Creek near Pueblo, Colo., 2012–2013	31
17.	Concentration of <i>A</i> , dissolved solids; <i>B</i> , selenium; and <i>C</i> , uranium in groundwater, surface water, and the hyporheic zone at the north transect, Fountain Creek near Pueblo, Colo., 2012–2013	44
18.	Concentration of <i>A</i> , dissolved solids; <i>B</i> , selenium; and <i>C</i> , uranium in groundwater, surface water, and the hyporheic zone at the middle transect, Fountain Creek near Pueblo, Colo., 2012–2013	45
19.	Concentration of <i>A</i> , dissolved solids; <i>B</i> , selenium; and <i>C</i> , uranium in groundwater, surface water, and the hyporheic zone at the south transect, Fountain Creek near Pueblo, Colo., 2012–2013	46
20.	Concentration of <i>A</i> , dissolved solids; <i>B</i> , selenium; and <i>C</i> , uranium in surface water from Fountain Creek at north, middle, and south transects, 2012–2013	48
21.	Trilinear diagram showing major cationic and anionic composition of samples from groundwater, surface water, and the hyporheic zone, Fountain Creek near Pueblo, Colo., 2012–2013	49
22–27.	Graphs showing:	
22.	Comparison of dissolved solids, selenium, and uranium concentrations in groundwater from the east side of the north transect, groundwater from other locations, surface water, and the hyporheic zone	50
23.	Comparison of nitrate, alkalinity, and dissolved oxygen concentrations in groundwater from the east side of the north transect, groundwater from other locations, surface water, and the hyporheic zone	51
24.	Comparison of dissolved solids, selenium, and uranium concentrations to oxidation-reduction condition for groundwater samples, Fountain Creek near Pueblo, Colo., 2012–2013	54
25.	Streamflow and in-stream loads of <i>A</i> , dissolved solids; <i>B</i> , selenium; and <i>C</i> , uranium, Fountain Creek near Pueblo, Colo., 2012–2013	59

26. Comparison of physical characteristics for groundwater samples collected from wells on the east side of the north transect to groundwater samples from other wells, Fountain Creek near Pueblo, Colo., 2012–2013.....	62
27. Comparison of physical characteristics for groundwater samples with oxic or mixed (oxic-anoxic) conditions to groundwater samples with anoxic, mixed (anoxic), or suboxic conditions, Fountain Creek near Pueblo, Colo., 2012–2013	63

Tables

1. Summary of location, construction, and hydrogeologic information for groundwater monitoring-wells installed at the north, middle, and south transects, Fountain Creek near Pueblo, Colo., 2012.....	8
2. Summary of dimensions and methods used for slug-test analyses and estimated hydraulic conductivity of aquifer materials in the screen interval of monitoring wells installed at the north, middle, and south transects, Fountain Creek near Pueblo, Colo., 2013.	21
3. Data for computing groundwater flow by using the Dupuit equation, Fountain Creek near Pueblo, Colo., 2012–2014.....	24
4. Summary of potentiomanometer measurements of stream and streambed in the hyporheic zone at north, middle, and south transects, Fountain Creek near Pueblo, Colo., 2013	30
5. Summary of synoptic streamflow measurements along Fountain Creek near Pueblo, Colo., and groundwater gains and losses, March 21, April 18, July 1, July 16, July 29, August 16, and September 26, 2013.....	33
6. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for groundwater samples, Fountain Creek near Pueblo, Colo., 2012–2013	34
7. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for surface-water samples from Fountain Creek near Pueblo, Colo., 2012–2013	40
8. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for hyporheic-zone samples, Fountain Creek near Pueblo, Colo., 2012–2013	42
9. Classification of redox categories and processes assigned on the basis of water-quality data (modified from table 2 of Jurgens and others [2009])	52
10. Dissolved oxygen, nitrate, manganese, iron, and sulfate concentrations and classification of oxidation-reduction condition of groundwater samples according to the framework of McMahon and Chapelle (2008), Fountain Creek near Pueblo, Colo., 2012–2013	52
11. Streamflow gain from groundwater and concentrations and loads of dissolved solids, selenium, and uranium, Fountain Creek near Pueblo, Colo., 2012–2013	56
12. Streamflow and concentrations and loads of dissolved solids, selenium, and uranium, Fountain Creek near Pueblo, Colo., 2012–2013.....	57

Appendix Table

2–1. Summary of blank and replicate water-quality samples	74
---	----

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square foot (ft ²)	0.09290	square meter (m ²)
square mile (mi ²)	2.590	square kilometer (km ²)
Flow rate		
foot squared per day (ft ² /d)	0.09290	meter squared per day (m ² /d)
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)
Mass		
pound per day (lb/d)	0.4536	kilogram per day (kg/d)
ton per day (ton/d)	0.9072	megagram per day (Mg/d)
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
 $^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter ($\mu\text{g}/\text{L}$).

Results for measurements of stable isotopes of an element (with symbol E) in water, solids, and dissolved constituents commonly are expressed as the relative difference in the ratio of the number of the less abundant isotope (ⁱE) to the number of the more abundant isotope of a sample with respect to a measurement standard.

Abbreviations

ADV	acoustic Doppler velocimeter
CLMWL	Colorado local meteoric water line
EPA	U.S. Environmental Protection Agency
GMWL	global meteoric water line
ID	inside diameter
LEW	left edge of water (referenced to facing downstream)
LMWL	local meteoric water line
MCL	maximum contaminant levels
N	normal
NED	National Elevation Data Set
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
PVC	polyvinyl chloride
REW	right edge of water (referenced to facing downstream)
RRPG	Arkansas River Basin Regional Resource Planning Group
RSIL	Reston Stable Isotope Laboratory
RSS	Root sum square (computed as the square root of the sum of squared measurement errors)
RTK	Real-time kinematic
USGS	U.S. Geological Survey
VSMOW	Vienna Standard Mean Ocean Water

Groundwater and Surface-Water Interaction, Water Quality, and Processes Affecting Loads of Dissolved Solids, Selenium, and Uranium in Fountain Creek, near Pueblo, Colorado, 2012–2014

By L. Rick Arnold, Roderick F. Ortiz, Christopher R. Brown, and Kenneth R. Watts

Abstract

In 2012, the U.S. Geological Survey, in cooperation with the Arkansas River Basin Regional Resource Planning Group, initiated a study of groundwater and surface-water interaction, water quality, and loading of dissolved solids, selenium, and uranium to Fountain Creek near Pueblo, Colorado, to improve understanding of sources and processes affecting loading of these constituents to streams in the Arkansas River Basin. Fourteen monitoring wells were installed in a series of three transects across Fountain Creek near Pueblo, and temporary streamgages were established at each transect to facilitate data collection for the study. Groundwater and surface-water interaction was characterized by using hydrogeologic mapping, groundwater and stream-surface levels, groundwater and stream temperatures, vertical hydraulic-head gradients and ratios of oxygen and hydrogen isotopes in the hyporheic zone, and streamflow mass-balance measurements. Water quality was characterized by collecting periodic samples from groundwater, surface water, and the hyporheic zone for analysis of dissolved solids, selenium, uranium, and other selected constituents and by evaluating the oxidation-reduction condition for each groundwater sample under different hydrologic conditions throughout the study period. Groundwater loads to Fountain Creek and in-stream loads were computed for the study area, and processes affecting loads of dissolved solids, selenium, and uranium were evaluated on the basis of geology, geochemical conditions, land and water use, and evapoconcentration.

During the study period, the groundwater-flow system generally contributed flow to Fountain Creek and its hyporheic zone (as a single system) except for the reach between the north and middle transects. However, the direction of flow between the stream, the hyporheic zone, and the near-stream aquifer was variable in response to streamflow and stage. During periods of low streamflow, Fountain Creek generally gained flow from groundwater. However, during periods of high streamflow, the hydraulic gradient between groundwater and the stream temporarily reversed, causing the stream to lose flow to groundwater.

Concentrations of dissolved solids, selenium, and uranium in groundwater generally had greater spatial variability than surface water or hyporheic-zone samples, and constituent concentrations in groundwater generally were greater than in surface water. Constituent concentrations in the hyporheic zone typically were similar to or intermediate between concentrations in groundwater and surface water. Concentrations of dissolved solids, selenium, uranium, and other constituents in groundwater samples collected from wells located on the east side of the north monitoring well transect were substantially greater than for other groundwater, surface-water, and hyporheic-zone samples. With one exception, groundwater samples collected from wells on the east side of the north transect exhibited oxic to mixed (oxic-anoxic) conditions, whereas most other groundwater samples exhibited anoxic to suboxic conditions. Concentrations of dissolved solids, selenium, and uranium in surface water generally increased in a downstream direction along Fountain Creek from the north transect to the south transect and exhibited an inverse relation to streamflow with highest concentrations occurring during periods of low streamflow and lowest concentrations occurring during periods of high streamflow.

Groundwater loads of dissolved solids, selenium, and uranium to Fountain Creek were small because of the small amount of groundwater flowing to the stream under typical low-streamflow conditions. In-stream loads of dissolved solids, selenium, and uranium in Fountain Creek varied by date, primarily in relation to streamflow at each transect and were much larger than computed constituent loads from groundwater. In-stream loads generally decreased with decreases in streamflow and increased as streamflow increased. In-stream loads of dissolved solids and selenium increased between the north and middle transects but generally decreased between the middle and south transects. By contrast, uranium loads generally decreased between the north and middle transects but increased between the middle and south transects. In-stream load differences between transects appear primarily to be related to differences in streamflow. However, because groundwater typically flows to Fountain

Creek under low-flow conditions, and groundwater has greater concentrations of dissolved solids, selenium, and uranium than surface water in Fountain Creek, increases in loads between transects likely are affected by inflow of groundwater to the stream, which can account for a substantial proportion of the in-stream load difference between transects. When loads decreased between transects, the primary cause likely was decreased streamflow as a result of losses to groundwater and flow through the hyporheic zone. However, localized groundwater inflow likely attenuated the magnitude by which the in-stream loads decreased.

The combination of localized soluble geologic sources and oxic conditions likely is the primary reason for the occurrence of high concentrations of dissolved solids, selenium, and uranium in groundwater on the east side of the north monitoring well transect. To evaluate conditions potentially responsible for differences in water quality and redox conditions, physical characteristics such as depth to water, saturated thickness, screen depth below the water table, screen height above bedrock, and aquifer hydraulic conductivity were compared by using Wilcoxon rank-sum tests. Results indicated no significant difference between depth to water, screen height above bedrock, and hydraulic conductivity for groundwater samples collected from wells on the east side of the north transect and groundwater samples from all other wells. However, saturated thickness and screen depth below the water table both were significantly smaller for groundwater samples collected from wells on the east side of the north transect than for groundwater samples from other wells, indicating that these characteristics might be related to the elevated constituent concentrations found at that location. Similarly, saturated thickness and screen depth below the water table were significantly smaller for groundwater samples under oxic or mixed (oxic-anoxic) conditions than for those under anoxic to suboxic conditions.

The greater constituent concentrations at wells on the east side of the north transect also could, in part, be related to groundwater discharge from an unnamed alluvial drainage located directly upgradient from that location. Although the quantity and quality of water discharging from the drainage is not known, the drainage appears to collect water from a residential area located upgradient to the east of the wells, and groundwater could become concentrated in nitrate and other dissolved constituents before flowing through the drainage. High levels of nitrate, whether from anthropogenic or natural geologic sources, could promote more soluble forms of selenium and other constituents by affecting the redox condition of groundwater. Whether oxic conditions at wells on the east side of the north transect are the result of physical characteristics or of groundwater inflow from the alluvial drainage, the oxic conditions appear to cause increased dissolution of minerals from the shallow shale bedrock at that location. Because ratios of hydrogen and oxygen isotopes indicate evaporation likely has not had a substantial effect on groundwater, constituent concentrations at that location likely are not the result of evapoconcentration.

Introduction

The U.S. Geological Survey (USGS), in cooperation with the Arkansas River Basin Regional Resource Planning Group (RRPG), has developed a comprehensive, basinwide strategy to address multiple water-quality concerns in the Arkansas River Basin in Colorado, including the occurrence of elevated concentrations of dissolved solids, selenium, and uranium in groundwater and surface water in selected parts of the basin. As part of the first phase of the strategy, available groundwater and surface-water-quality data were compiled to characterize the occurrence and distribution of dissolved-solids, selenium, and uranium concentrations throughout the Arkansas River Basin (Miller and others, 2010). Results of the study indicated that dissolved-solids and uranium concentrations generally increased in a downstream direction in the Arkansas River, and Fountain Creek contributed about 36 percent of the mean annual dissolved-solids load and 31 percent of the selenium load to the Arkansas River near Avondale (USGS streamgage 07109500). Results of the study also indicated that median concentrations and instantaneous loads of dissolved solids, selenium, and uranium also generally increased in a downstream direction along Fountain Creek between Colorado Springs and the confluence of Fountain Creek with the Arkansas River. Subsequent studies further characterized streamflow, water quality, and loads of dissolved solids, selenium, and uranium (Ivahnenko and others, 2013) and estimated gains and losses from unmeasured sources and sinks for streamflow and dissolved-solids loads (Ortiz, 2013) in selected reaches of the Arkansas River. However, further investigation was needed to better understand sources and processes affecting loading of dissolved solids, selenium, and uranium to the Arkansas River and other streams in the Arkansas River Basin.

In 2012, the USGS, in cooperation with the RRPG, initiated a study to improve understanding of sources and processes affecting loads of dissolved solids, selenium, and uranium in streams in the Arkansas River Basin. Fountain Creek near Pueblo, Colorado, (fig. 1) was selected for a detailed study of groundwater and surface-water interaction, water quality, and loads of dissolved solids, selenium, and uranium because (1) Fountain Creek was identified as a substantial contributor of loads to the Arkansas River, (2) concentrations and loads of dissolved solids, selenium, and uranium generally increase in a downstream direction along Fountain Creek, and (3) hydrogeologic conditions potentially related to elevated constituent concentrations and loads are represented in the Fountain Creek Basin.

Purpose and Scope

This report presents the methods of investigation and study results to characterize groundwater and surface-water interaction, water quality, and processes affecting loads of dissolved solids, selenium, and uranium to Fountain Creek near Pueblo, Colorado, for the period from August 2012 to January 2014. Groundwater and surface-water interaction was

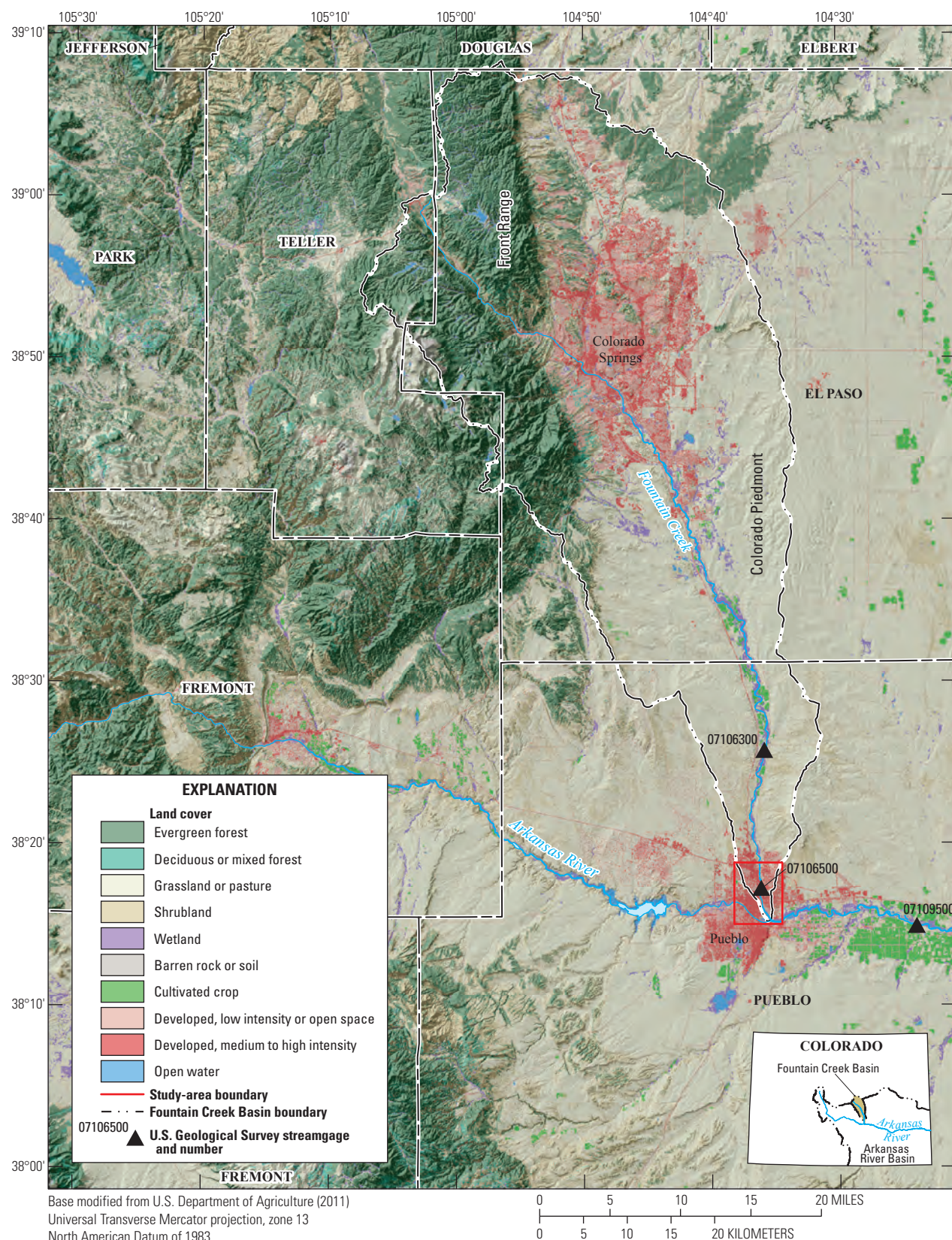


Figure 1. Fountain Creek Basin, land cover, and study area near Pueblo, Colo.

characterized by using (1) hydrogeologic mapping, (2) groundwater and stream-surface levels, (3) groundwater and stream temperatures, (4) vertical hydraulic-head gradients and ratios of oxygen and hydrogen isotopes in the hyporheic zone, and (5) streamflow mass-balance measurements. Water quality was characterized by collecting periodic samples from groundwater, surface water, and the hyporheic zone for analysis of dissolved solids, selenium, uranium, and other selected constituents and by evaluating the oxidation-reduction condition for each groundwater sample under different hydrologic conditions throughout the study period. Groundwater loads to Fountain Creek and in-stream loads were computed for the study area, and processes affecting loads of dissolved solids, selenium, and uranium were evaluated on the basis of geology, geochemical conditions, land and water use, and evapoconcentration.

Description of the Study Area

Physiography and Climate

Fountain Creek is a tributary of the Arkansas River with a basin that encompasses about 930 square miles (mi²), primarily in parts of El Paso and Pueblo Counties in southern Colorado (fig. 1). The upper one-third of the basin lies within the mountains of the Front Range, and the lower two-thirds of the basin is in the Colorado Piedmont section of the Great Plains (Hansen and Crosby, 1982). Topography of the upper basin generally is characterized by steep slopes and relief of hundreds of feet (U.S. Geological Survey, 2013), whereas topography along Fountain Creek in the lower basin generally is characterized by a level flood plain flanked by dissected terraces with local relief of 50–200 feet (ft) (Jenkins, 1964; Kuhn, 1988).

The regional climate of the Fountain Creek Basin is semiarid with annual precipitation ranging from about 32 to 34 inches (in.) in the upper basin to about 12 to 14 in. in the lower basin (Kohn and others, 2014). Potential evaporation in the lower basin was estimated as about 33 in., and actual evapotranspiration was estimated as about 22 in. (Edelmann and Cain, 1986). Land cover in the Fountain Creek Basin consists primarily of evergreen forests in its upper part and herbaceous grassland, shrubland, and developed urban areas in its lower part (U.S. Department of Agriculture, 2011; fig. 1). Wetland areas (woody and emergent herbaceous) and cultivated cropland commonly are present along the Fountain Creek valley south of Colorado Springs. The Colorado Springs metropolitan area, including nearby smaller communities in El Paso County and the City of Pueblo, comprise the primary urban areas in the basin.

Hydrologic Setting

Fountain Creek consists of a complex hydrologic system in which there is continual interaction between water in the stream and water in the alluvial aquifer. The interaction is affected by substantially variable flow (both in timing and

quantity), streamflow diversions, return flows, groundwater withdrawals, and evapotranspiration (Kuhn, 1988). Fountain Creek is used to convey transmountain return flows from Colorado Springs to the Arkansas River (Ortiz, 2004), and the creek receives inflows from wastewater treatment plants (Mau and others, 2007) and storm drains from adjacent urbanized areas (Kenneth Watts, U.S. Geological Survey, oral commun., 2015). Fountain Creek has a sandy, braided channel (fig. 2) that changes morphology in response to day-to-day erosion and large streamflow events (Stogner, 2000). Streamflow in Fountain Creek exhibits considerable seasonal and daily variability (fig. 3). For the period from January 1922 to December 2013, greatest mean-monthly discharge in Fountain Creek at Pueblo (USGS streamgage 07106500) occurred in May as a result of snowmelt runoff from the upper basin. Mean-monthly streamflow also peaked during June and August as a result of summer rainstorms. Low streamflow and base-flow conditions generally occurred from September through March with the lowest mean-monthly discharge occurring in October. Groundwater discharge from alluvium along Fountain Creek and return flows from municipal, agricultural, and industrial water use generally contribute to streamflow throughout the year (Kuhn, 1988). Eighty percent of daily mean flows recorded from January 1922 to December 2013 for Fountain Creek at Pueblo ranged



Figure 2. View of Fountain Creek channel about 0.7 mile north of U.S. Geological Survey streamgage 07106500.

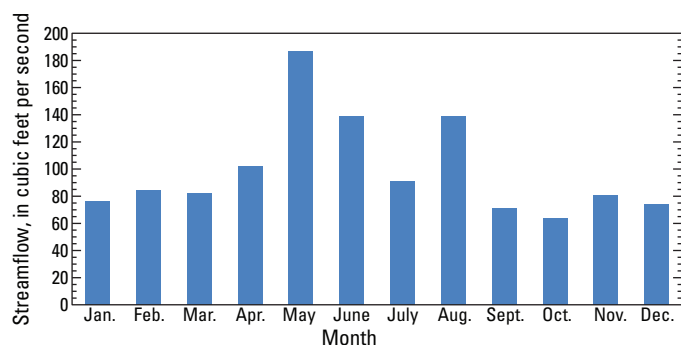


Figure 3. Mean-monthly streamflow of Fountain Creek at Pueblo (07106500), January 1922–December 2013.

from about 1 to 240 cubic feet per second (ft^3/s). However, daily mean flows up to 11,400 ft^3/s have occurred in response to storm events, and days of no flow have been recorded during dry periods. Stream discharge data for Fountain Creek at Pueblo (07106500) are available online through the National Water Information System (NWIS) at URL <http://dx.doi.org/10.5066/F7P55KJN>.

The Fountain Creek alluvial aquifer consists mainly of valley-fill Quaternary sand and gravel deposits with thin layers of silt and clay that become thicker near the edges of the aquifer (Chafin, 1996; Miller and others, 2010). The aquifer is thin and discontinuous in the upper basin but is 0.75–1.5 mile (mi) wide and up to about 80 ft thick in the reach between Colorado Springs and Pueblo (Chafin, 1996). The alluvial aquifer has been developed extensively as a municipal water supply for Colorado Springs and nearby communities and as a source of irrigation water for agricultural areas in the southern part of the basin (Cain and Edelmam, 1986). In addition to the Fountain Creek alluvial aquifer, saturated sediments can occur in alluvial terrace deposits on upland areas and in eolian sands that commonly overlay the alluvial aquifer and terrace deposits (Miller and others, 2010). The saturated thickness of the Fountain Creek alluvial aquifer ranges from 0 to 50 ft with an average thickness of about 20 ft (Cain and Edelmam, 1986). Depth to groundwater ranges from a few feet in the flood plain of Fountain Creek to about 40 ft on the terraces (Edelmam and Cain, 1986).

Underlying the mountainous upper basin of Fountain Creek are granitic rocks of Precambrian age (Tweto, 1979). In the lower basin, Fountain Creek alluvium primarily is underlain by Cretaceous marine bedrock of the Pierre Shale. Pierre Shale also commonly crops out on hillslopes along the margins of the alluvium and in places is exposed along the channel of Fountain Creek (Radell and others, 1994). Where the creek flows directly on Pierre Shale bedrock, alluvium is absent, and the creek does not have direct hydraulic connection with the alluvial aquifer. Near its confluence with the Arkansas River, Fountain Creek alluvium is underlain by the Smoky Hill member of the Cretaceous Niobrara Formation (Scott, 1969).

Previous Investigations

Water quality in the Fountain Creek Basin has been the subject of several previous investigations. Edelmam (1990) conducted a study to describe the general water-quality characteristics of Fountain and Monument Creeks and evaluate the water quality of each stream segment relative to established water-quality standards. Concentrations of dissolved solids, as represented by specific conductance, were found by the study to increase in a downstream direction in Fountain Creek, probably because of discharge from wastewater-treatment plants, irrigation-return flows, and tributary inflow. Edelmam and others (2002) and Mau and others (2007) characterized water quality and suspended-sediment conditions in streams within the Fountain and Monument Creek Basins for different flow regimes. Most stormflow concentrations of dissolved trace elements were found by both studies to be smaller than or similar to concentrations from base-flow or normal-flow samples. However, median concentrations of some trace elements were much larger during periods of stormflow than during base flow or normal flow. Miller and others (2010) investigated the occurrence and distribution of dissolved solids, selenium, and uranium in the Arkansas River Basin (including Fountain Creek), based on retrospective data. Results of Miller and others (2010) indicated that median concentrations and instantaneous loads of dissolved solids, selenium, and uranium generally increased in a downstream direction along Fountain Creek, particularly downstream from USGS streamgage 07106300 (Fountain Creek near Piñon, Colorado; fig. 1) and increases in dissolved solids, as represented by specific conductance, likely were caused by a variety of sources including tributary inflow, wastewater-treatment facilities inflow, irrigation return flow, and groundwater and surface-water interactions. Dissolved-selenium concentrations were found by Miller and others (2010) generally to be lower in samples collected during high streamflows and higher in samples collected during low streamflows along Fountain Creek.

Cain and Edelmam (1986) conducted a groundwater-quality appraisal of the alluvial aquifer along Fountain Creek to provide information about groundwater chemistry and evaluate the relation between water quality, local hydrology, and human activities. Downgradient increases in specific conductance and concentrations of major ions, uranium, and other constituents in groundwater were reported by Cain and Edelmam (1986) to be caused by evapoconcentration from water use and reuse and dissolution of minerals in the aquifer and underlying bedrock. Seleniferous beds in shale bedrock in the southern part of the Fountain Creek valley were attributed as the likely cause of a downgradient increase in selenium concentrations. Similarly, Lewis (1995) attributed large quantities of minerals in groundwater to evapoconcentration by phreatophytes along Fountain Creek and hypothesized that higher dissolved-solids concentrations in some groundwater samples were the result of less permeable alluvium and less saturated thickness, which allowed for more contact time between the groundwater and the Pierre Shale, more dissolution of shale

minerals, and less dilution of minerals in groundwater. Chafin (1996) sampled groundwater in the Fountain Creek Basin to assess water quality in relation to land use, season, depth to water, and streamflow infiltration. Differences in water quality were attributed largely to differences in source water, water treatment, fertilizer application at the land surface, and the effects of evapoconcentration and plant uptake.

Methods of Investigation

Several methods of investigation were used to characterize groundwater, surface water, and water quality for this study. Groundwater methods included installing monitoring wells, mapping hydrogeology, conducting slug tests, measuring groundwater levels and temperature, and measuring vertical hydraulic-head gradients in the hyporheic zone. Surface-water methods included measuring stream stage, flow, and temperature. Samples were collected from groundwater, surface water, and the hyporheic zone to characterize water quality.

Groundwater Methods

Well Installation

Monitoring-well locations were selected on the basis of a reconnaissance survey to identify stream reaches with likely groundwater inflow between USGS streamgage 07106300 (Fountain Creek near Piñon, Colorado; fig. 1) and the confluence of Fountain Creek with the Arkansas River. Areas of likely groundwater inflow were identified by measuring stream discharge, specific conductance, and water temperature at multiple locations along the creek. A surface electromagnetic (geophysical) survey was conducted along Fountain Creek subsequently to the reconnaissance survey to further refine stream reaches with groundwater inflow and to select locations for installation of monitoring-well transects. The geophysical survey was conducted by using a portable multifrequency electromagnetic sensor (GEM-2; Won and others, 1996) to determine differences in the bulk apparent electrical conductivity and (or) magnetic susceptibility of underlying groundwater and aquifer materials. Similar methods used to delineate near-lake groundwater flow in Nebraska are described by Ong and others (2010).

On the basis of survey results, 14 monitoring wells were installed in a series of three transects (north, middle, and south; fig. 4) across Fountain Creek to enable observation of groundwater gradients in the vicinity of the creek and to evaluate the spatial variability of water quality in the alluvial aquifer. Because of difficulties accessing the west side of Fountain Creek at the middle transect, wells were installed only on the east side of the stream at this location. Three sites at the south transect, where saturated sediments were sufficiently thick, were drilled as nested well pairs (shallow and deep) to enable observation of vertical differences in hydraulic head and water quality within the aquifer.

Drilling and monitoring-well installation were performed July 16–August 15, 2012. An initial well (S-EB-W Shallow) was drilled by using portable hand-operated drilling equipment with a nominal solid-stem auger diameter of 4 in. All other wells were drilled by using a track-mounted drilling rig with nominal 8-in. outside diameter hollow-stem augers. Lithologic descriptions (Appendix 1) for each borehole were provided by the driller on the basis of visual inspection of auger cuttings. Alluvial materials at each site ranged from about 12 to 30 ft thick.

Well-completion details are summarized in table 1. Completed well depths range from 9.6 to 29.5 ft below land surface. All wells are constructed of 2-in. nominal diameter, threaded and flush-jointed polyvinyl chloride (PVC) well casing with 2.5-foot-long screens. The annular space adjacent to the screened interval was backfilled with a commercial silica-sand filter pack, and the annular space above the sand pack was sealed with bentonite and (or) cement-bentonite grout to near land surface. Stabilized groundwater levels measured in the wells ranged from 2.9 to 9.2 ft below land surface about 2 weeks after drilling (August 29–31, 2012). All wells were completed at the land surface with a flush-mount protective metal cover. Well construction was in accordance with USGS specifications for water-quality wells (Lapham and others, 1997) and water-well construction rules for the State of Colorado (available at <http://www.water.state.co.us/groundwater/BOE/Pages/BOERules.aspx>). Where possible, land-surface altitude at each well was determined by using a real-time kinematic (RTK) global positioning system. In cases where accurate RTK measurements were not obtained (wells N-WB-E and M-EB-E), land-surface altitude was estimated on the basis of the USGS National Elevation Data Set (NED) with 10-meter resolution (U.S. Geological Survey, 2013), cross sections developed by URS, Inc., (2006), and nearby surveyed well elevations.

Wells were developed after drilling to remove mud and any foreign material from the well and to establish a hydraulic connection between the well and aquifer. Well development was completed by pumping each well until the produced water was clear.

Hydrogeologic Mapping

Hydrogeologic Cross Sections

Hydrogeologic cross sections (figs. 5A–C) were developed for each transect on the basis of lithologic logs for each monitoring-well borehole and lithologic logs for other wells approximately aligned with the installed transect wells. Because of its close proximity to wells N-WB-W and N-WB-E and its offset from the line of cross section, well N-WB-M is not shown on the cross section for the north transect. Additional, pre-existing wells were used to extend cross sections fully across the Fountain Creek Basin and provide a more complete understanding of aquifer geometry at the transect locations. Lithology at the additional well sites was determined by reviewing well construction and test reports on file with the Colorado Division of Water Resources at <http://dwrweblink.state.co.us/dwrweblink/search.aspx?dbid=0>.

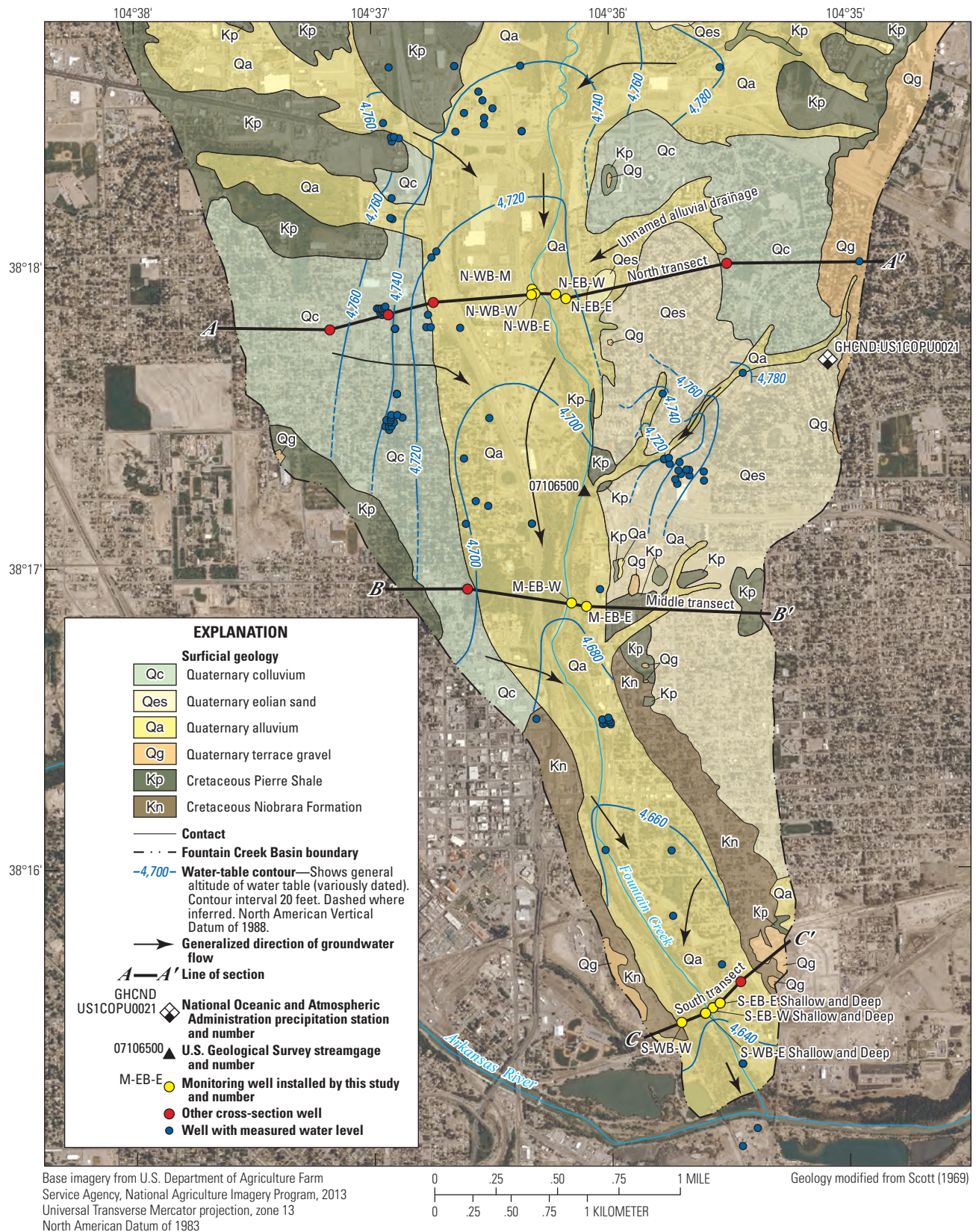


Figure 4. Surficial geology, water-table altitude, monitoring-well locations, and hydrogeologic-section lines through the north, middle, and south transects, Fountain Creek near Pueblo, Colo.

Table 1. Summary of location, construction, and hydrogeologic information for groundwater monitoring-wells installed at the north, middle, and south transects, Fountain Creek near Pueblo, Colo., 2012.

[USGS, U.S. Geological Survey; DDMMSS.S, degrees, minutes, decimal seconds; land-surface altitude in feet; all depths in feet below land surface; --, no data]

Local well name	USGS site number	Date drilled	Latitude ¹ (DDMMSS.S)	Longitude ¹ (DDMMSS.S)	Land-surface altitude ²	Hole depth	Depth to bedrock ³	Depth to water ⁴	Well depth	Depth to top of screen	Depth to bottom of screen	Depth to top of sand pack	Depth to bottom of sand pack
N-WB-W	381754104362001	08/13/2012	381754.3	1043619.7	4,718.2	13.8	13.8	7.3	13.8	11.0	13.5	10.5	13.8
N-WB-M	381755104362001	08/13/2012	381755.4	1043619.5	4,719.6	13.9	--	8.7	13.9	11.1	13.6	10.6	13.9
N-WB-E	381754104361901	08/13/2012	381754.5	1043618.8	4,720	17.0	16.0	9.2	16.7	13.9	16.4	13.4	16.7
N-EB-W	381754104361401	08/13/2012	381754.4	1043613.6	4,719.1	12.0	12.0	7.0	12.0	9.2	11.7	8.7	12.0
N-EB-E	381754104361101	08/13/2012	381753.5	1043611.0	4,718.5	10.0	--	6.4	9.6	6.8	9.3	6.3	9.6
M-EB-W	381653104361001	08/15/2012	381652.9	1043609.9	4,687.3	14.6	14.6	5.0	14.6	11.8	14.3	11.3	14.6
M-EB-E	381652104360601	08/15/2012	381652.2	1043606.1	4,686.6	14.5	14.5	4.0	14.5	11.7	14.2	11.2	14.5
S-WB-W	381529104354201	08/14/2012	381529.3	1043542.5	4,646.7	12.7	12.7	2.9	12.7	9.9	12.4	9.4	12.7
S-WB-E Shallow	381531104353602	08/14/2012	381531.1	1043536.5	4,647.6	13.0	24.7	4.6	13.0	10.2	12.7	9.7	13.0
S-WB-E Deep	381531104353601	08/14/2012	381531.1	1043536.5	4,647.4	24.7	24.7	4.6	24.7	21.9	24.4	21.4	24.7
S-EB-W Shallow	381532104353502	07/16/2012	381532.2	1043534.6	4,646.4	13.0	26.7	3.0	13.0	10.2	12.7	9.7	13.0
S-EB-W Deep	381532104353501	08/14/2012	381532.2	1043534.6	4,647.0	26.7	26.7	3.4	26.7	23.9	26.4	23.4	26.7
S-EB-E Shallow	381533104353302	08/13/2012	381533.1	1043532.8	4,651.8	19.1	29.5	7.1	19.1	16.3	18.8	15.8	19.1
S-EB-E Deep	381533104353301	08/13/2012	381533.2	1043532.8	4,651.5	29.5	29.5	7.8	29.5	26.7	29.2	26.2	29.5

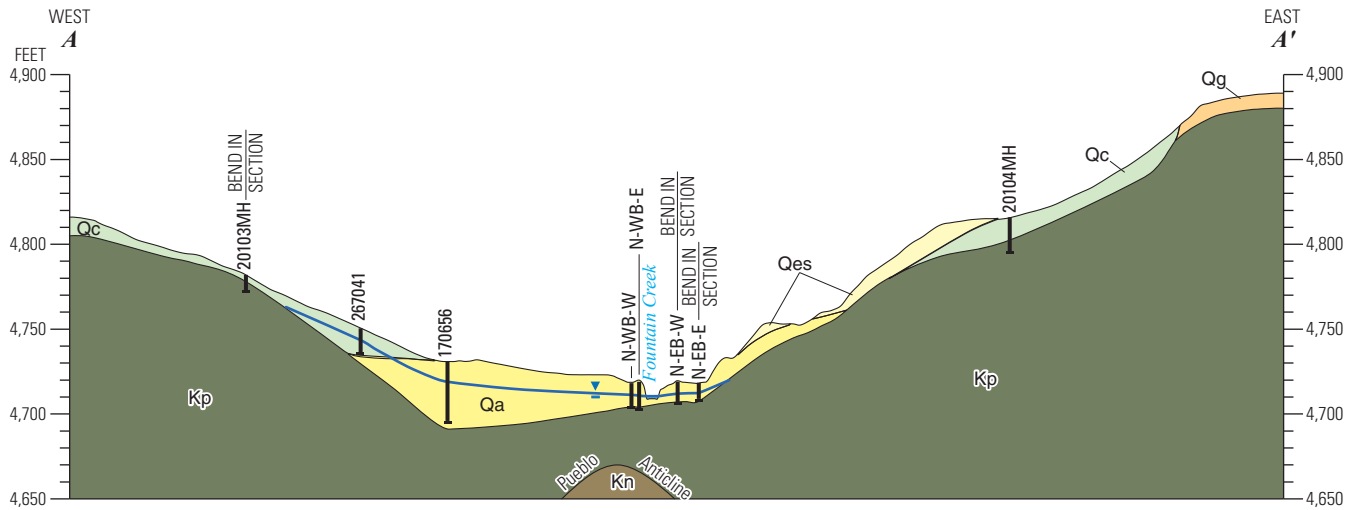
¹Latitude and longitude determined by global positioning system. North American Datum of 1983.

²Land-surface altitude determined by real-time kinematic global positioning system, U.S. Geological Survey (2013), and URS Inc. (2006). North American Vertical Datum of 1988.

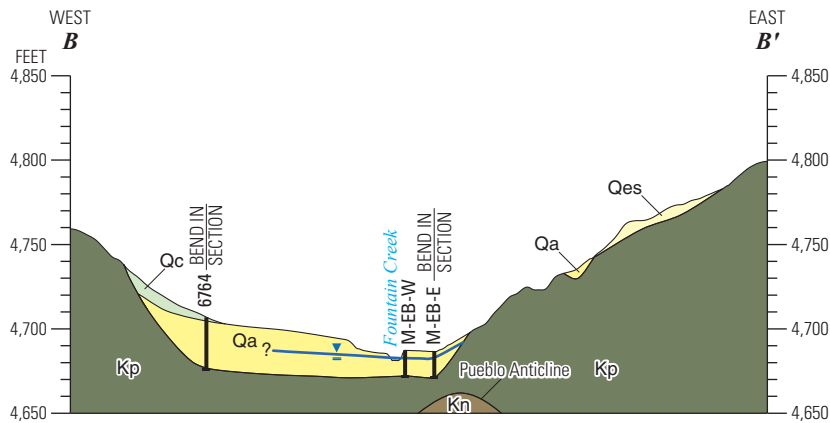
³All wells completed in alluvium overlying shale bedrock.

⁴Measured 08/28/2012 through 08/31/2012, about 2 weeks after drilling.

A. North transect



B. Middle transect



C. South transect

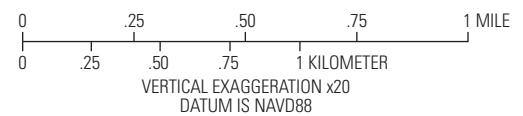
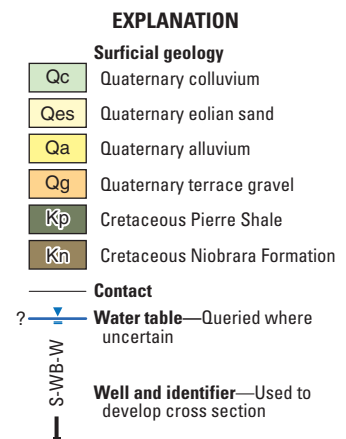
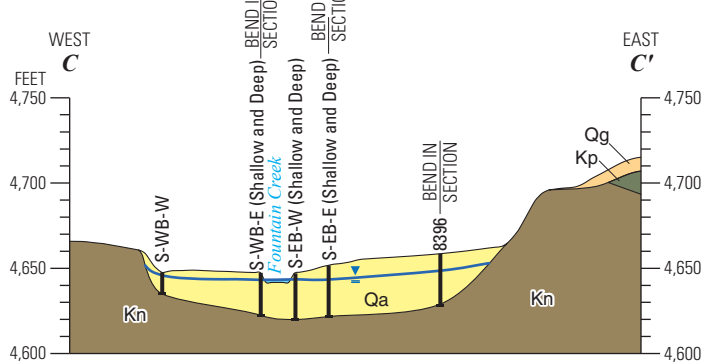


Figure 5. Hydrogeologic sections through the A, north; B, middle; and C, south transects, Fountain Creek near Pueblo, Colo.

Water Table

To better assess general water-level conditions and directions of groundwater flow in the Fountain Creek alluvial aquifer, a map of the water table (fig. 4) was created for the study area on the basis of water levels measured in each installed monitoring well at the time of drilling, water levels reported by McGovern and others (1964), and water-level data in the Colorado Division of Water Resources (CDWR) well-applications database (Colorado Division of Water Resources, 2012). Because the water-level data represent various measurement dates and hydrologic conditions, the resulting water-table map should be considered representative of general water-level conditions in the aquifer rather than precise water-level conditions for a specific location or time. Water levels at any given location could be higher or lower than indicated on the map because of temporal variations in precipitation recharge, streamflow, or pumping.

Water-level altitudes at each well were determined by using a Geographic Information System (ArcGIS 10.0, Environmental Systems Research Institute Inc., 1999–2010) to interpolate land-surface altitude values derived from the NED with 10-meter resolution (U.S. Geological Survey, 2013) to each well location and subtract measured depth to water to obtain a water-level altitude for each well location. Water-level altitude contours were then manually digitized to better interpret the varied and sometimes inconsistent or widely-spaced data values with consideration of dry wells, geology, topography, and surface-water features. Water-table contours generally were drawn using the preponderance of data in a local area and do not necessarily agree with each individual data value. Water levels generally were not contoured for upland areas covered by eolian deposits because of limited data in those areas (fig. 4).

Slug Tests

A slug test is a method of estimating the hydraulic conductivity of aquifer and confining-bed materials near a well by monitoring water-level recovery in response to an induced, near-instantaneous change in hydraulic head in the well. Slug tests were performed August 13–15, 2013, on all 14 monitoring wells. Mechanical slugs were used to perform both falling- and rising-head tests using standard USGS procedures described by Cunningham and Schalk (2011). Mechanical slugs were constructed of 1-in. (nominal) diameter PVC pipe of various lengths, filled with sand, and sealed on both ends. To verify results, each well typically was tested at least four times using two different initial displacements. Prior to initiating slug tests, the static water level was measured with an electric water-level tape, and a submersible pressure transducer was placed in the well at a depth below the level at which the slug would be submerged and below the lowest expected water level for each test. For each falling-head test, the slug was rapidly submerged in the water column, causing a near-instantaneous

water-level rise in the well. For each rising-head test, the slug was rapidly withdrawn from the water column to cause a near-instantaneous water-level decline in the well. Water levels during the tests were measured and recorded every 0.1 second by the submersible pressure transducer until the water level returned to near its static position. Hydraulic-conductivity values were estimated on the basis of slug-test data by using the methods of Bouwer and Rice (1976), Springer and Gelhar (1991), and Butler (1998) as described under in the Groundwater and Surface-Water Interaction section of this report.

Groundwater Levels

Groundwater levels were measured periodically in all 14 wells completed in the Fountain Creek alluvial aquifer from August 28, 2012, to January 15, 2014, by using standard USGS technical procedures described by Cunningham and Schalk (2011). Groundwater-level data for each well are available through the USGS National Water Information System (NWIS) at URL <http://dx.doi.org/10.5066/F7P55KJN>. Submersible, nonvented, pressure transducers also were installed in the wells to continuously monitor groundwater levels at 15-minute intervals throughout the study period. Barometric pressure was measured with a separate pressure sensor to permit correction of absolute pressure measured by the nonvented transducers.

Groundwater Temperature

Groundwater temperature was monitored continuously in the monitoring wells for the duration of the study. Temperature data were collected at 15-minute intervals by using thermistors contained within the transducer sondes.

Hyporheic Zone

The direction of groundwater and surface-water interaction in the hyporheic zone at each transect was measured three times between May 13 and October 23, 2013, by using a hydraulic potentiomanometer (fig. 6), a device that provides a comparison between the hydraulic head (stage) of a surface-water body and the hydraulic head in sediments beneath the surface-water body (Rosenberry and others, 2008). Measurements were made at both the right-edge-of-water (REW) and left-edge-of-water (LEW) at the north and south transects to evaluate the direction of flow between groundwater and surface water on each side of Fountain Creek. Measurements were made only at the LEW at the middle transect, adjacent to where wells are located on the east side of the creek. The terms REW and LEW are given with reference to facing in a downstream direction. Multiple readings were made at each measurement time and location to verify results and determine representative gradients.



Figure 6. Typical setup of hydraulic potentiomanometer for measuring differences in hydraulic head between the stream and underlying streambed of Fountain Creek, middle transect, 2013.

Surface Water Methods

Surface-water sites were established in Fountain Creek at each transect to measure streamflow, stage, and temperature and to provide a consistent reference point for collecting surface-water-quality samples. Surface-water sites were located near the west bank of the north transect and near the east banks of the middle and south transects.

Streamflow and Stage

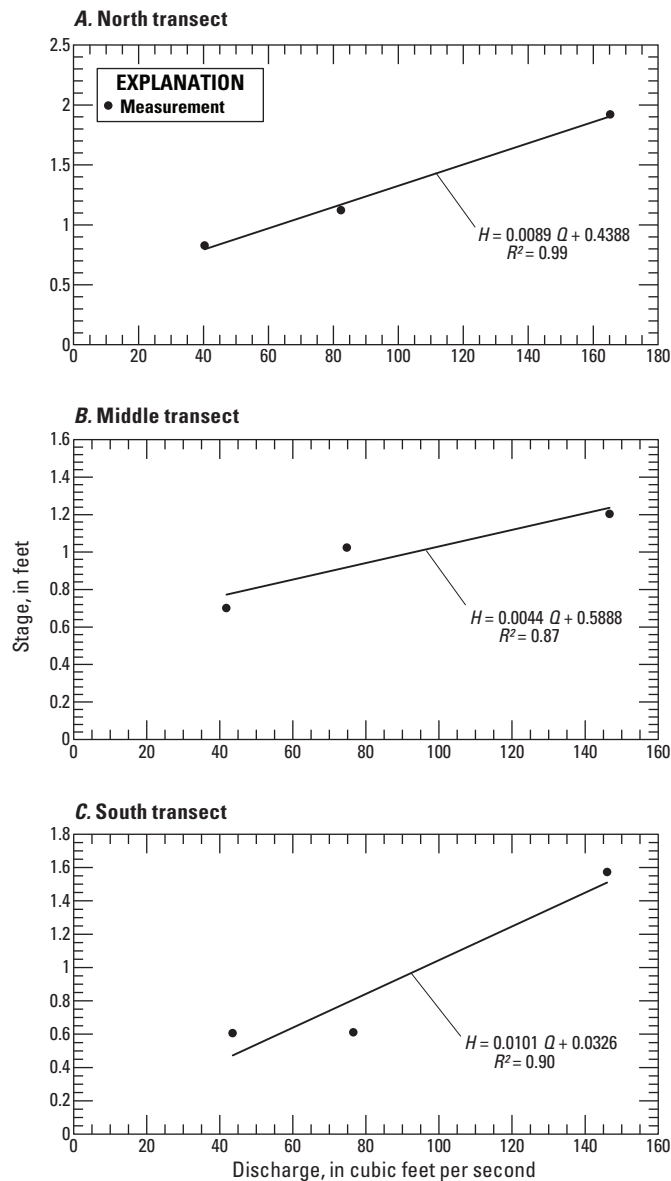
Streamflow was measured in Fountain Creek periodically at each transect from March 21 to September 26, 2013, for use in analyzing groundwater and surface-water interactions, water quality, and for computing instantaneous loads. With

one exception, streamflow measurements were made sequentially in a downstream direction from the north transect to the south transect in order to provide for synoptic comparison of streamflow at each transect. All measurements were made with a SonTek FlowTracker® handheld acoustic Doppler velocimeter (ADV) in accordance with standard USGS methods (Turnipseed and Sauer, 2010). Overall uncertainty of individual measurements at each transect ranged from 2.1 to 3.7 percent with a mean of 2.6 percent.

Direct measurements of stream stage (H) were made in addition to streamflow discharge (Q) on three dates (March 21, April 18, and July 16, 2013) representing a range of flow conditions from about 40 to 165 ft³/s to develop stage-discharge relations for computation of continuous streamflow at each transect (fig. 7). Temporary stream gages with submersible pressure transducers also were installed in Fountain Creek at each transect to record continuous measurements of stream stage. Transducers were placed inside a section of protective PVC pipe attached to a stake that was anchored in the streambed. However, because of instrument failure, changing channel conditions, and sensor movement in the stream, few reliable data were recorded by the transducers. Therefore, continuous streamflow at each transect was computed for the full range of conditions on the basis of a regression comparing streamflow (Q_1) at USGS streamgage 07106500 (Fountain Creek at Pueblo, CO; fig. 4), located between the north and middle transects, to direct measurements of streamflow (Q_2) at each transect (fig. 8). Continuous stage at each transect was then determined on the basis of computed streamflow, the stage-discharge relation for each transect, and available stage and elevation data for the pressure transducers. Because considerable variability in the stage-discharge relation can occur for different flow rates, the stage-discharge relation was considered valid for computing continuous stage values only when streamflow was less than 1.5 times the maximum measured streamflow value used to develop the relation in figure 7. Therefore, continuous stage values were computed from the stage-discharge relation only for streamflow up to 248 ft³/s for the north transect, 220 ft³/s for the middle transect, and 219 ft³/s for the south transect. Stream stage was not computed for periods of high streamflow following storm events because streamflow at these times was much greater than the estimated valid range of the stage-discharge relation.

Stream Temperature

Stream temperature was monitored continuously at each transect by using a thermistor contained in the pressure-transducer sonde. However, because of instrument failure and long periods where the sensor was out of water, few reliable data were recorded by the sensor. Therefore, as with streamflow data, continuous stream temperature recorded at USGS streamgage 07106500 was used to represent stream temperature at each transect. Stream temperatures recorded at streamgage 07106500 generally agreed well with the limited available stream-temperature data at each transect.



Measurement date	Measurement time ¹ (hh:mm:ss)	Streamflow discharge ² (ft ³ /s)	Stream stage ³ (ft)
North transect			
3/21/2013	14:08:01	82	1.12
4/18/2013	7:12:21	40	0.83
7/16/2013	9:39:57	165	1.92
Middle transect			
3/21/2013	15:24:17	75	1.02
4/18/2013	8:23:00	42	0.70
7/16/2013	11:27:37	147	1.20
South transect			
3/21/2013	10:11:27	77	0.61
4/18/2013	9:25:38	44	0.61
7/16/2013	12:46:24	146	1.57

¹hh, hours; mm, minutes; ss, seconds.

²ft³/s, cubic feet per second.

³ft, feet.

Figure 7. Relation of stream stage (H) to streamflow discharge (Q) at the (A) north, (B) middle, and (C) south transect, Fountain Creek near Pueblo, Colo. (R^2 , coefficient of determination).

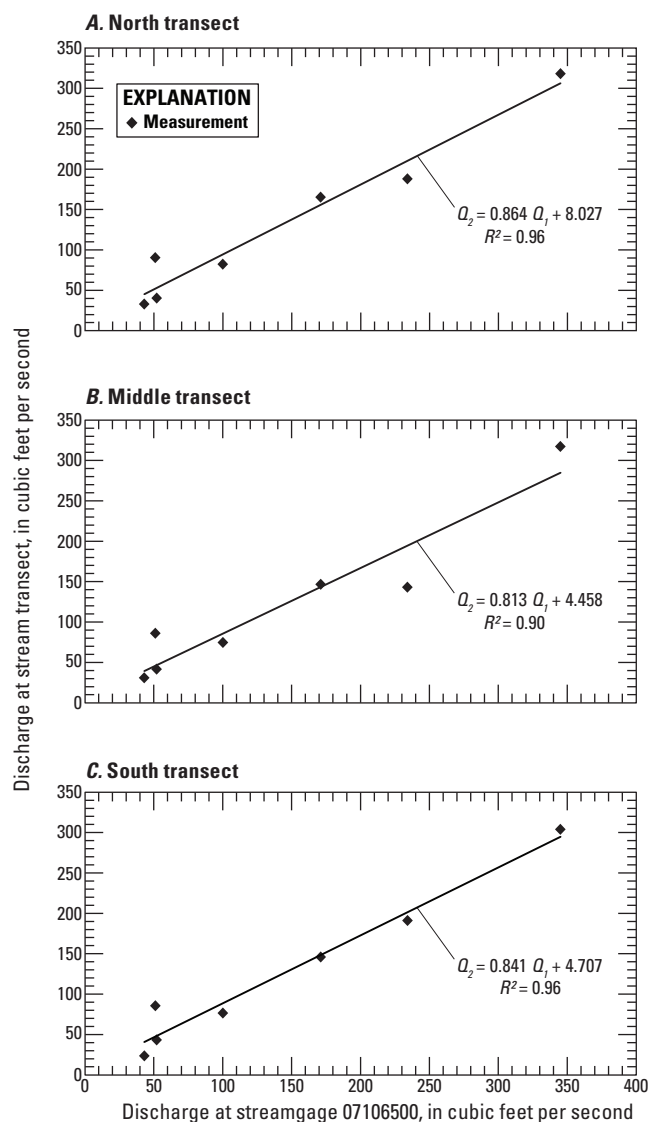
Water-Quality Methods

Sample Collection and Processing

Water samples were collected from Fountain Creek and all monitoring wells during five sampling events from September 12, 2012, to September 26, 2013. Samples were collected from Fountain Creek on the same day (April 18, 2013; July 1, 2013; and September 26, 2013) during three of the events for synoptic comparison of water quality and in-stream loads among the transects. Streamflow conditions on each of the sample dates for surface water from Fountain Creek are shown in figure 9. Water samples also were collected from the hyporheic zone during three sampling events from April 23 to October 23, 2013, at times other than synoptic events. Samples were collected at different times of

the year and under different hydrologic conditions to provide better understanding of in-stream water-quality processes related to loading of dissolved solids, selenium, and uranium. Samples were analyzed for concentrations of dissolved solids, major inorganic constituents (calcium, magnesium, potassium, sodium, chloride, fluoride, and sulfate), nutrients (ammonia, nitrate, nitrite, organic nitrogen, total nitrogen, orthophosphate, and phosphorus), and selected trace elements (barium, iron, manganese, selenium, and uranium). Samples also were analyzed for ratios of hydrogen and oxygen isotopes ($\delta^2\text{H}$ and $\delta^{18}\text{O}$). Water temperature, pH, specific conductance, and dissolved oxygen were measured in the field at the time of each sample collection by using portable field meters.

Sample collection and processing followed procedures described by the “USGS National Field Manual for the Collection of Water-Quality Data” (U.S. Geological Survey,



Measurement date	Measurement time ¹ (hh:mm:ss)	Streamflow discharge ² (ft ³ /s)	Corresponding time at USGS streamgage 07106500 ^{1,3} (hh:mm)	Streamflow at USGS streamgage 07106500 ^{2,3} (ft ³ /s)
North transect				
3/21/2013	14:08:01	82	14:15	100
4/18/2013	7:12:21	40	7:15	52
7/1/2013	11:11:02	33	11:15	43
7/16/2013	9:39:57	165	9:45	171
7/29/2013	11:25:52	90	11:30	51
8/16/2013	8:32:28	188	8:30	234
9/26/2013	9:43:30	318	9:45	345
Middle transect				
3/21/2013	15:24:17	75	14:15	100
4/18/2013	8:23:00	42	7:15	52
7/1/2013	13:54:03	31	11:15	43
7/16/2013	11:27:37	147	9:45	171
7/29/2013	12:42:20	86	11:30	51
8/16/2013	9:40:12	143	8:30	234
9/26/2013	11:14:28	317	9:45	345
South transect				
3/21/2013	10:11:27	77	14:15	100
4/18/2013	9:25:38	44	7:15	52
7/1/2013	15:22:33	24	11:15	43
7/16/2013	12:46:24	146	9:45	171
7/29/2013	13:47:26	86	11:30	51
8/16/2013	10:39:09	191	8:30	234
9/26/2013	12:25:32	304	9:45	345

¹hh, hours; mm, minutes; ss, seconds.

²ft³/s, cubic feet per second.

³USGS, U.S. Geological Survey.

Figure 8. Relation of streamflow discharge in Fountain Creek at the (A) north, (B) middle, and (C) south transect (Q_2) to streamflow discharge at U.S. Geological Survey streamgage 07106500 (Q_1 , Fountain Creek at Pueblo, Colo.; R^2 , coefficient of determination).

variously dated) to obtain representative water samples and to minimize the potential for contamination. Groundwater samples were collected from wells by using a stainless steel submersible pump and Teflon tubing. Prior to sampling groundwater, a minimum of three casing volumes of water was removed from the well (or the well was fully dewatered and allowed to recover), and field readings of water temperature, pH, specific conductance, and dissolved oxygen were continuously monitored during pumping and allowed to stabilize to ensure representative samples were collected. Surface-water samples were collected from Fountain Creek by submersing a 1-liter Teflon DH-81 sampler with a 5/8-in. nozzle at specified intervals across the creek. Surface-water samples from each interval then were composited into a Teflon churn splitter and mixed prior to placing them into sample bottles. Hyporheic-zone samples were collected by

using a peristaltic pump and tubing to withdraw water from temporary piezometers inserted into the streambed. Alkalinity was measured in the field by incremental titration using 0.16 or 1.6 normal (N) sulfuric acid. Water samples collected for the analysis of dissolved solids, major inorganic constituents, nutrients, trace elements, and alkalinity were filtered in the field by using a 0.45-micron capsule filter preconditioned with deionized water. Cation and trace element samples were acidified in the field with 7.5 N nitric acid. Water samples for analysis of hydrogen- and oxygen-isotope ratios were collected in glass bottles with a polyseal cap to prevent evaporation and were untreated.

With the exception of samples for hydrogen- and oxygen-isotope ratios, all samples were analyzed by the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colo., using standard measurement methods for

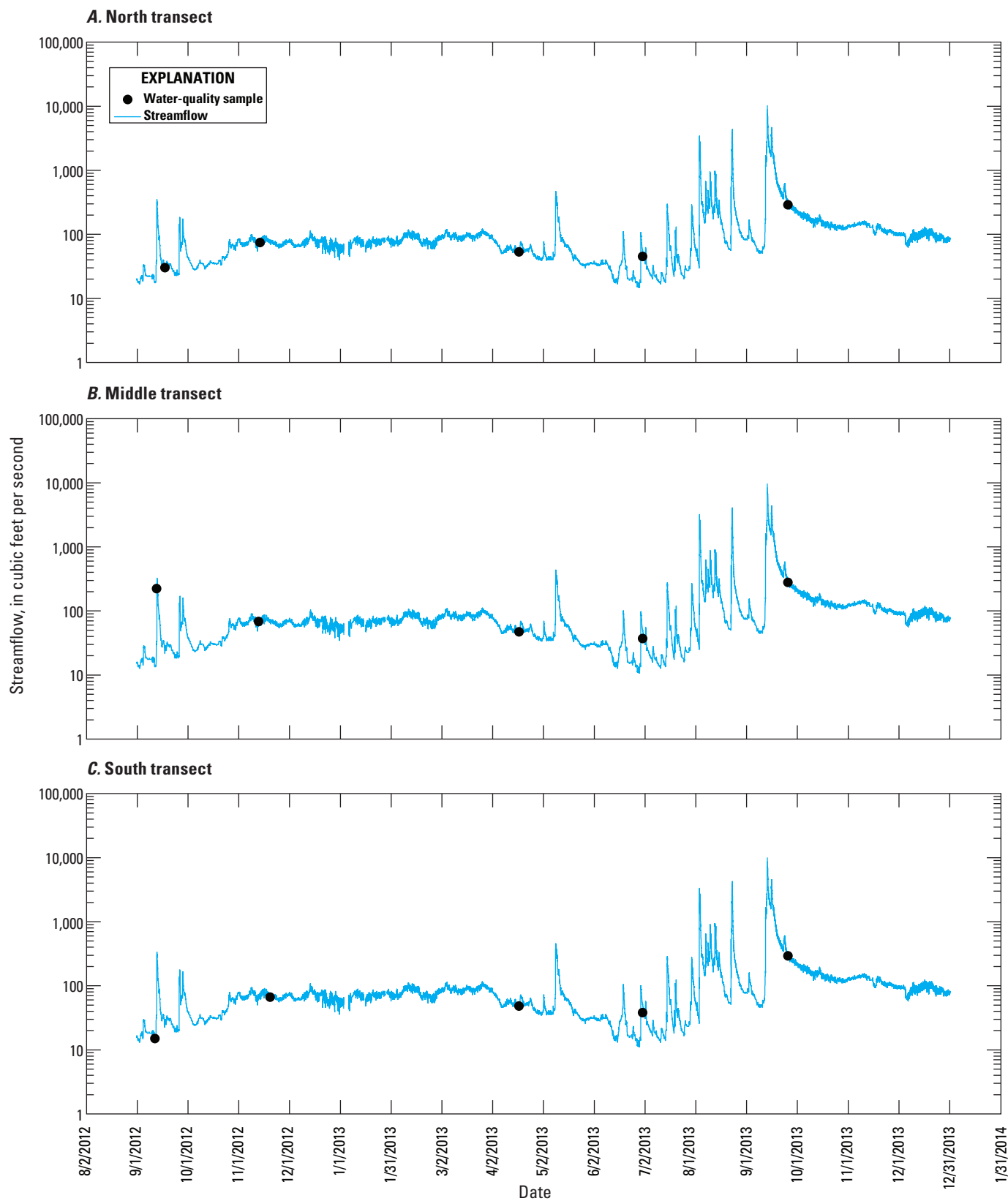


Figure 9. Streamflow and dates of stream water-quality samples collected at the A, north; B, middle; and C, south transects, Fountain Creek near Pueblo, Colo., 2012–2013.

major ions and trace elements (Fishman, 1993; Fishman and Friedman, 1989; Garbarino, 1999; Garbarino and others, 2006) and nutrients (Fishman, 1993; Patton and Kryskalla, 2003; Patton and Kryskalla, 2011). Samples for hydrogen- and oxygen-isotope ratios were analyzed by the USGS Reston Stable Isotope Laboratory (RSIL) in Reston, Va., using methods described by Révész and Coplen (2008a, 2008b).

Quality Control

Quality-control samples were collected to evaluate potential contamination, as well as bias and variability of the data that may have resulted from sample collection, processing, storage, transportation, and laboratory analysis. Six blank samples were prepared using inorganic-free water supplied by the USGS NWQL to verify that ambient conditions and sampling equipment did not introduce contamination to samples. Six replicate samples also were collected to assess sample variability as well as variability resulting from sample collection and processing. Individual sites and dates associated with blank and replicate samples are shown in Appendix Table 2–1.

Blank samples generally exhibited constituent concentrations that were below laboratory reporting levels or were less than about 1 percent of constituent concentrations in environmental samples collected in association with the blanks. However, two blank samples had one or more constituent concentrations that exceeded 1 percent of constituent concentrations in associated environmental samples, indicating that analytical results for the associated environmental samples could be somewhat biased for these constituents. The blank sample for well S-WB-W on April 8, 2013, exhibited concentrations of 0.17 mg/L for fluoride, 0.067 mg/L for nitrate, and 7.5 µg/L for iron, which represents about 6, 3, and 35 percent, respectively, of these constituent concentrations in the associated environmental sample collected from the well on April 22, 2013. Also, the blank sample for well N-WB-W on November 14, 2012, exhibited a nitrite concentration of 0.002 mg/L, which represents about 6 percent of the nitrite concentration for the environmental sample collected at the well on the same date.

Replicate samples were compared to environmental samples by calculating the relative percent difference (RPD) between constituent concentrations in each sample as (U.S. Environmental Protection Agency, 1987):

$$RPD = (E_s - R_s) / ((E_s + R_s) / 2) * 100 \quad (1)$$

where

- E_s is the constituent concentration of the environmental sample, and
- R_s is the constituent concentration of the replicate sample.

Relative percent differences between environmental samples and replicate samples ranged from 0 to about 9 percent for most constituents (Appendix Table 2–1). However, *RPDs* between environmental and replicate samples collected at well N-EB-W on April 16, 2013, were about 53 percent for iron and 27 percent for manganese, and the *RPD* for iron at well N-EB-E on July 9, 2013, was about 100 percent. Relative percent differences in this range indicate that some sample variability or variability resulting from sample collection and processing (perhaps related to the stainless steel sample pump) may exist for these constituents. Overall, quality-control data indicate water-quality results are acceptable for characterizing processes that affect loads of dissolved solids, selenium, and uranium in Fountain Creek.

Groundwater and Surface-Water Interaction

The direction and rate of flow between groundwater and surface water along a stream reach can vary spatially and temporally as a result of differences in lithology and the altitude of the stream level relative to groundwater levels (LaBaugh and Rosenberry, 2008; Winter and others, 1999). If the altitude of the water table in the vicinity of the stream is higher than the altitude of the stream surface, then groundwater will discharge to the stream (the stream reach is gaining). Conversely, if the altitude of the water table in the vicinity of the stream is lower than the altitude of the stream surface, then surface water can potentially recharge groundwater (the stream reach is losing).

Data Analysis

Several methods were used to characterize the interaction of groundwater and surface water along Fountain Creek in the study area. Groundwater and surface-water interaction was characterized by using (1) hydrogeologic mapping; (2) hydrologic analysis of groundwater levels in monitoring wells relative to stream-surface levels, streamflow, and precipitation; (3) temperature profiles of groundwater in relation to stream temperature, streamflow, and precipitation; (4) vertical hydraulic-head gradients and ratios of hydrogen and oxygen isotopes in the hyporheic zone, and (5) streamflow mass-balance calculations.

Hydrogeologic Mapping

The cross sections shown in fig. 5A–C indicate that saturated alluvial sediments in the Fountain Creek valley range from about 0.7 mi wide at the middle transect to about 1 mi wide at the north transect and that groundwater in alluvial sediments extends into colluvium along the west side of the valley (fig. 5A). At the north and middle transects,

Fountain Creek is located near the east side of the alluvial aquifer, and the thickest part of the aquifer is to the west of Fountain Creek. At the south transect, the alluvial aquifer is wider and thicker on the east side of the creek than on its west side. Saturated thickness at the transects ranges from near zero at the margins of the aquifer to about 30 ft at the northern transect, 15 ft at the middle transect, and 25 ft at the southern transect. The cross sections also indicate that groundwater levels near the margins of the aquifer are higher than at Fountain Creek and that large-scale groundwater flow generally is toward the stream. However, groundwater gradients near the creek are small.

The water table shown in figure 4 generally reflects the topography of the land surface with highest altitudes along the margins of the alluvial valley. Groundwater generally flows toward Fountain Creek from both sides of the valley and downstream along the valley. However, the water table between the north and middle transects, where Fountain Creek is near the edge of the aquifer, indicates that the direction of groundwater flow is away from Fountain Creek and westward toward the center of the aquifer (fig. 4). The limited data available for areas of eolian deposits above the flood plain indicate that saturated thickness in the deposits may be thin (generally less than 5 ft) and discontinuous. Although groundwater may be present in eolian deposits upgradient from groundwater in the alluvial valley, the extent of hydraulic connection between the two aquifers is unknown but likely is limited by intervening low-permeability shale bedrock (figs. 5A–C).

Hydrologic Analysis

Discrete and continuous measurements of groundwater-level and stream-surface altitudes at each transect are presented in figs. 10–12 along with streamflow and precipitation. Precipitation data were compiled from the National Oceanic and Atmospheric Administration (2016) for precipitation station GHCND:US1COPU0021 (fig. 4). Groundwater levels in monitoring wells generally were higher than the corresponding stream-surface level of Fountain Creek, and groundwater flowed toward Fountain Creek except during periods of rapid water-level rise in the stream, particularly during a flood event that occurred on September 13, 2013. Although stream-surface levels are not presented for periods during which streamflow exceeded the valid range of the stage-discharge relation, the projected stream-surface elevation above groundwater elevations in nearby wells is evident. Depth to water in the monitoring wells generally ranged from about 3 to 10 ft below land surface during most of the study period, but groundwater levels rose about 2–5 ft in response to high streamflows in late July through September 2013, before beginning to decline again (figs. 10–12). During the flood event on September 13, 2013, groundwater levels in monitoring wells at the middle and south transects commonly rose to near land surface. In response to the flood event, the geometry and position of the

Fountain Creek channel changed substantially, resulting in a systematic shift in groundwater gradients toward the stream at the north and middle transects. Because of the substantial change in channel morphology after the flood, the stage-discharge relation developed before the flood was no longer applicable, and stream-surface levels were not estimated by using the relation for dates after the flood. Groundwater levels in all 14 monitoring wells typically were relatively stable except in response to increases in stream stage and flow. Some rises in groundwater levels may be in response to direct recharge from precipitation or lateral inflow from upgradient groundwater. Groundwater levels in wells nearest the stream commonly had larger and more immediate fluctuations in response to stream stage and flow than did wells farther from the stream. The one exception occurred on the east side of the north transect, where well N-EB-E (farther from the stream) generally had larger groundwater-level fluctuations than well N-EB-W (closer to the stream), perhaps reflecting greater effect from infiltrating precipitation (fig. 10B).

For paired wells at the south transect, the vertical groundwater gradient was variable. The groundwater gradient was slightly downward for wells nearest to the stream (S-WB-E Shallow and Deep and S-EB-W Shallow and Deep) where permeable sand and gravel is present (Appendix 1). By contrast, the groundwater gradient at the well pair farther from the stream (S-EB-E Shallow and Deep) was upward, likely as a result of predominantly clay sediments creating semiconfined conditions and greater hydraulic head in the deeper well at that location.

Slug Tests

Three different solutions, as implemented by the computer program AQTESOLV (HydroSOLV, Inc., 2013), were used to analyze slug-test response data on the basis of hydrogeologic conditions at each well. The Bouwer and Rice solution (Bouwer and Rice, 1976) was used to analyze response data collected during slug tests at 11 of the 14 monitoring wells installed at the north, middle, and south transects across Fountain Creek by using the head range recommended by Butler (1998). The method of Springer and Gelhar (1991) (for unconfined conditions) or the method of Butler (1998) (for confined conditions) was used to analyze slug-test data from the other three wells (N-WB-W, M-EB-W, and S-WB-E Shallow) to better interpret the oscillatory water-level response resulting from the high hydraulic conductivity of aquifer materials at these locations. The Bouwer and Rice solution is a semianalytical solution for analysis of an overdamped slug test in a fully or partially penetrating well in an unconfined or confined aquifer (HydroSOLV, Inc., 2013). The method of Springer and Gelhar (1991) extends the Bouwer and Rice (1976) solution for an unconfined aquifer to account for inertial effects resulting in an oscillatory water-level response sometimes observed in aquifers of high hydraulic conductivity. The Butler (1998) solution accounts for oscillatory water-level responses in a fully or partially penetrating well in a confined aquifer (HydroSOLV, Inc., 2013).

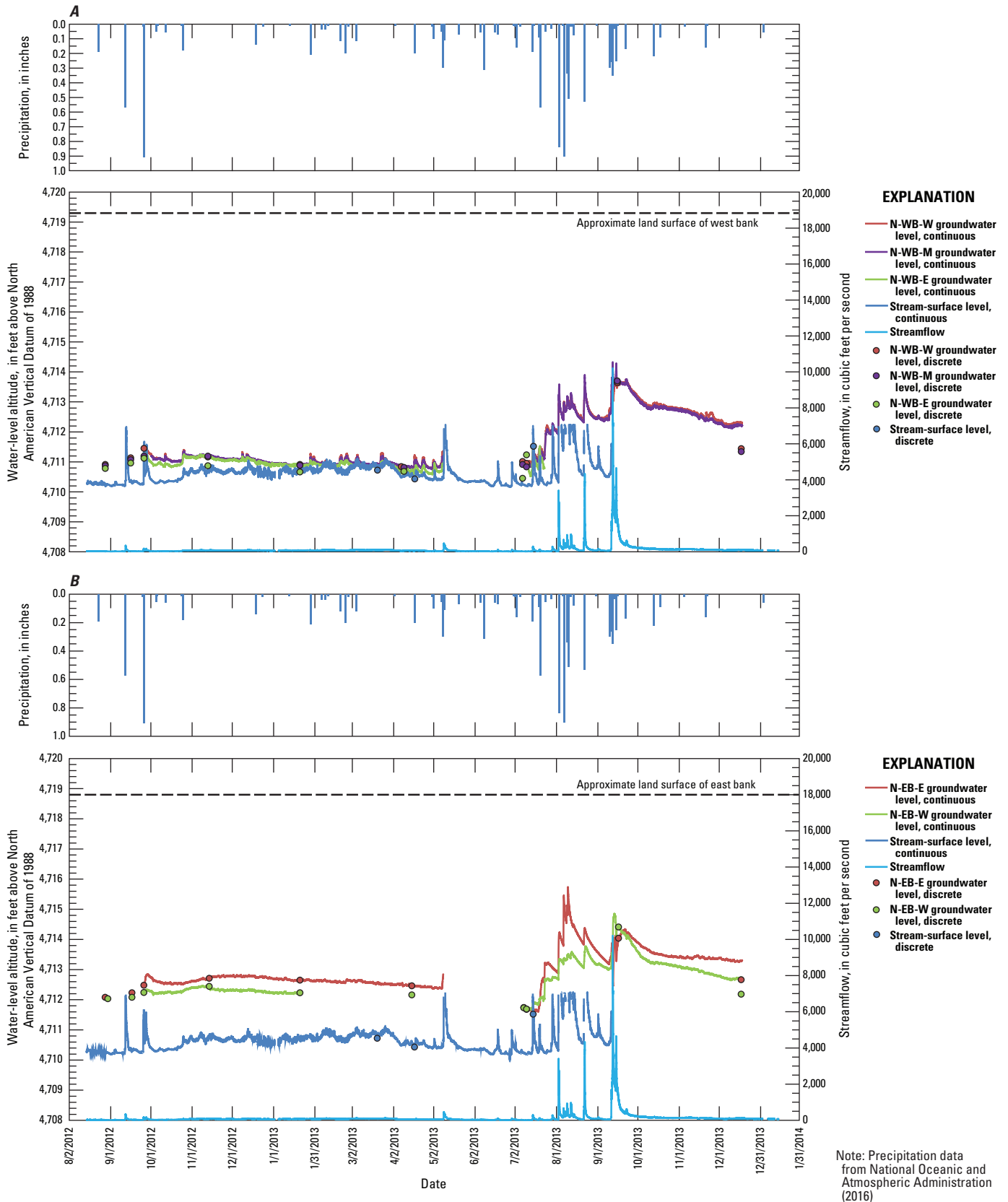


Figure 10. Groundwater levels, stream-surface level, streamflow, and precipitation for *A*, west side; and *B*, east side of the north transect, Fountain Creek near Pueblo, Colo., 2012–2014.

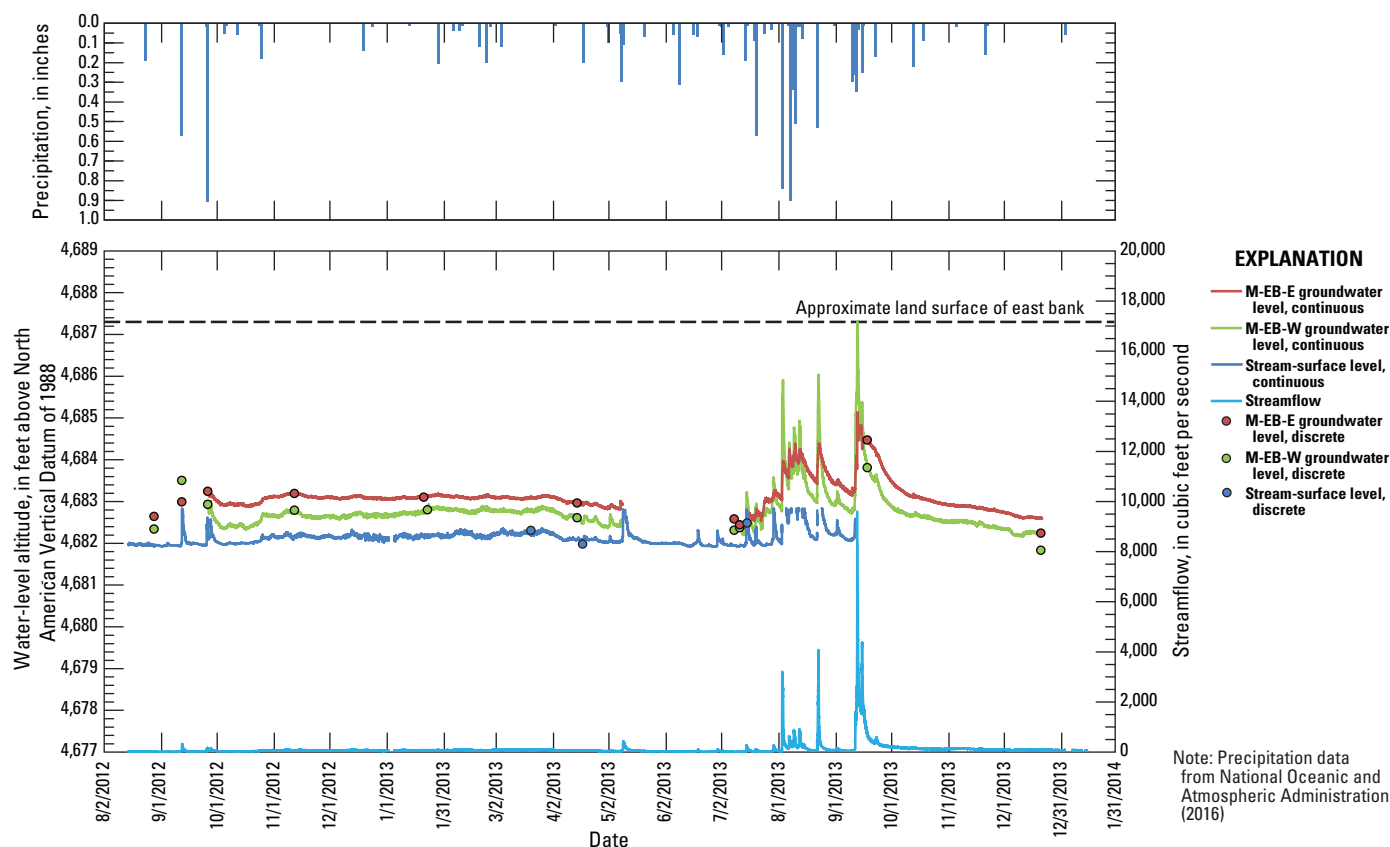


Figure 11. Groundwater levels, stream-surface level, streamflow, and precipitation for the east side of the middle transect, Fountain Creek near Pueblo, Colo., 2012–2014.

The length of the screened interval for all wells tested was 2.5 ft. However, because well N-WB-E is partially screened across shale bedrock at the bottom of the well (table 1), an effective screen length of 2.1 ft was used for slug-test computations at this location. At wells where the actual depth to bedrock is unknown (N-WB-M and N-EB-E), the aquifer base was assumed on the basis of nearby wells to be 1 foot below the bottom of well. For all wells except S-EB-E Shallow and Deep, the well-casing radius was used to represent the radius of the screened interval because aquifer materials at those locations generally consisted of sand and gravel (Appendix 1) considered to have hydrologic properties similar to those of the sand material used to fill the well-bore annulus adjacent to the screened intervals. For wells S-EB-E Shallow and Deep, which were completed in clay, the radius of the borehole was used to represent the radius of the screened interval to better reflect the sharp contrast between the annular sand and the surrounding aquifer materials. A summary of dimensions and methods used for slug-test analyses and estimated hydraulic conductivities of aquifer materials are provided in table 2.

Slug-test results (table 2) indicate substantial variability in aquifer hydraulic conductivity among the well locations

with mean test values at each well ranging from 1 foot per day (ft/d) at well S-EB-E Shallow to 800 ft/d at well M-EB-W. Hydraulic conductivity on the west side of the north transect (fig. 5A) generally is greater than on the east side of the transect. In addition, hydraulic conductivity at wells near the stream is less than at wells farther from the stream. Estimated hydraulic conductivity on the west side of the north transect (fig. 5A) decreases from 350 ft/d at well N-WB-W farthest from the stream to 64 ft/d at well N-WB-E nearest the stream. Similarly, estimated hydraulic conductivity on the east side of the north transect decreases from 46 ft/d at well N-EB-E farthest from the stream to 8 ft/d at well N-EB-W nearer the stream. Estimated hydraulic conductivity on the east side of the middle transect (fig. 5B) varies over a wide range from 11 ft/d at well M-EB-E farther from the stream to 800 ft/d at well M-EB-W nearer the stream. Estimated hydraulic conductivity on the west side of the south transect (fig. 5C) ranges from 25 ft/d at well S-WB-E Deep farthest from the stream to 440 ft/d at well S-WB-E Shallow nearest the stream. Estimated hydraulic conductivity on the east side of the south transect decreases from 130 to 230 ft/d at paired wells S-EB-W Shallow and Deep nearest the stream to 1–8 ft/d at paired wells S-EB-E Shallow and Deep farthest from the stream.

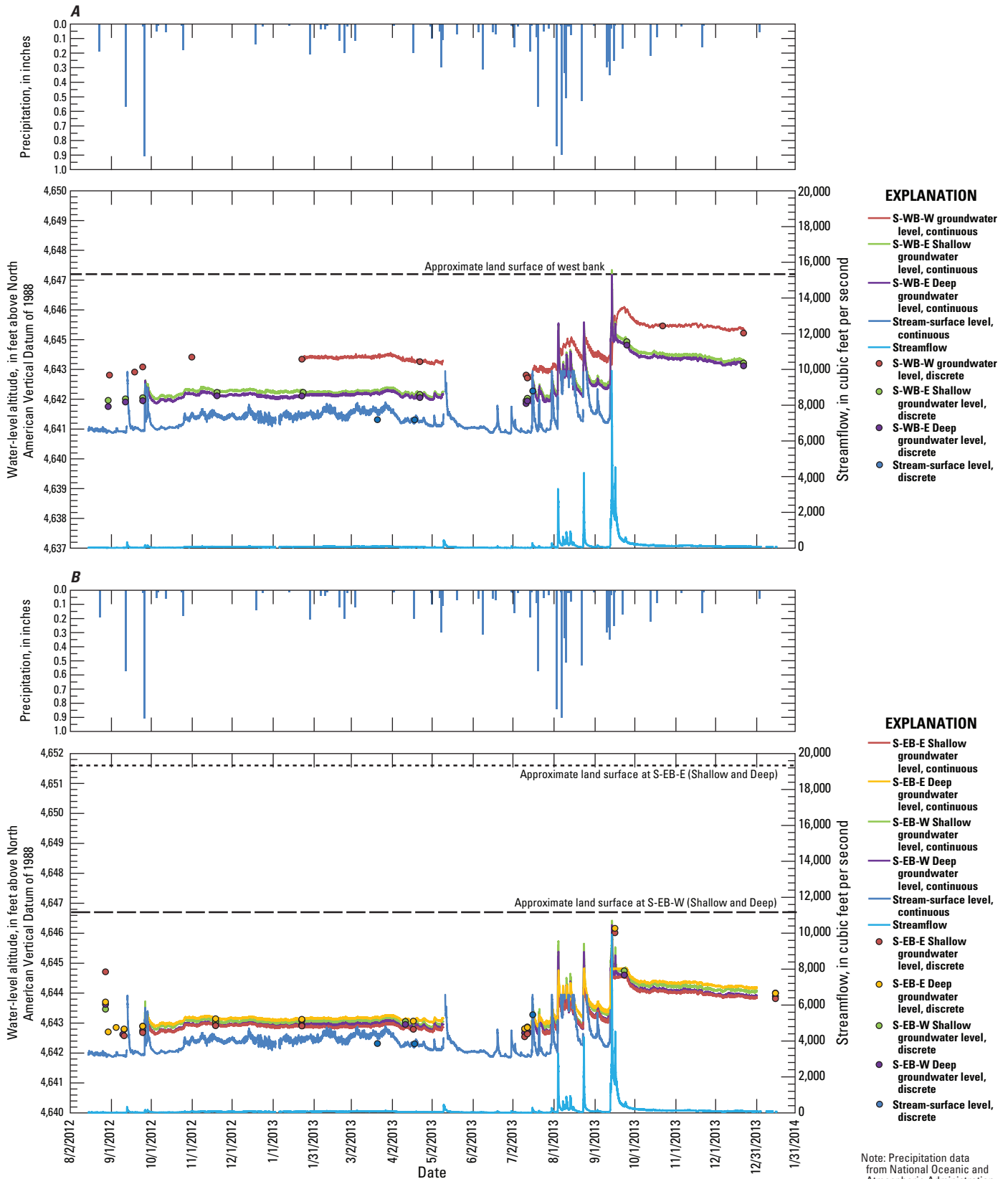


Figure 12. Groundwater levels, stream-surface level, streamflow, and precipitation for *A*, west side; and *B*, east side of the south transect, Fountain Creek near Pueblo, Colo., 2012–2014.

Quantification of Groundwater Flow

Groundwater flow to Fountain Creek at each transect was quantified by using the Dupuit equation (Fetter, 1994):

$$q = K (h_1^2 - h_2^2) / 2L,$$

where

- q is flow per unit aquifer width, in feet squared per day;
- K is aquifer hydraulic conductivity, in feet per day;
- h_1 is groundwater hydraulic head at the well, in feet;
- h_2 is groundwater hydraulic head at the edge of the stream, in feet; and
- L is the flow path distance between the well and stream, in feet.

The Dupuit equation is useful for computing flows in unconfined aquifers because it allows for changes in aquifer thickness related to a sloping water table (Rosenberry and others, 2008). Assumptions underlying the Dupuit equation are (1) the aquifer is homogeneous and isotropic; (2) the hydraulic gradient is equal to the slope of the water table; and (3) for small water-table gradients, flow lines are horizontal.

Flows were computed for each date on which discrete measurements of groundwater levels were made (table 3). Computations represent steady-state flows to Fountain Creek under typical streamflow and groundwater-level conditions when the stream is gaining flow from groundwater. Surface-water losses to groundwater during periods of temporary high streamflow conditions were not estimated by this method because accurate stream-surface altitude data were not available for these periods, and the losses represent transient, rather than steady-state, conditions. Stream-surface altitude at the date and time of each discrete groundwater-level measurement was estimated on the basis of the stage-discharge relation developed for Fountain Creek at each transect (fig. 7) and was used to define groundwater hydraulic head at the edge of the stream (h_2). The farthest monitoring well on each side of Fountain Creek at each transect was used to define the flow-path distance between the well and stream (L), and groundwater hydraulic head (h_1) at the upgradient end of the flow path for each computation. Hydraulic head at the well and stream edge were computed relative to the estimated bedrock altitude at the stream edge on the respective side of each transect. The arithmetic mean of hydraulic-conductivity values determined from slug tests performed at all wells on the respective side of each transect was used to represent aquifer hydraulic conductivity (K) between the farthest well and the stream. The mean flow per unit aquifer width (q) computed for each transect by using the Dupuit equation was multiplied by the distance between each transect and divided by a conversion factor of 86,400 to estimate gains to each reach of Fountain Creek in cubic feet per second.

Groundwater flow to Fountain Creek per unit aquifer width (table 3) varied by date and by transect. Groundwater

flow per unit aquifer width at the north transect ranged from 0.7 to 8.8 ft²/d with a mean value of 5.9 ft²/d for the west side of the transect and 0.9 ft²/d for the east side of the transect, indicating little of the groundwater on the east side of the transect, where the aquifer extent is smaller (fig. 5A), contributed flow to Fountain Creek during the study period. Combined mean flow from both sides of the stream was 6.8 ft²/d, which is 0.42 ft³/s per mile of stream. Groundwater flow to Fountain Creek from the east side of the middle transect ranged from a loss of 0.2 ft²/d to a gain of 13.5 ft²/d with a mean value of 8.3 ft²/d, which is 0.51 ft³/s per mile. Groundwater flow from the west side of the middle transect is unknown because no wells were installed at that location. However, groundwater flow to Fountain Creek from the west side of the middle transect likely is greater than from the east side as indicated by the large-scale groundwater gradients and flow patterns near that location (fig. 4) and larger aquifer extent (fig. 5B). Groundwater flow to Fountain Creek was largest for the south transect, ranging from 15.2 to 22.3 ft²/d for the west side of the transect and 4.4 to 31.7 ft²/d for the east side of the transect. Mean groundwater flow was 17.4 ft²/d for the west side of the transect and 10.3 ft²/d for the east side, resulting in a combined flow of 27.7 ft²/d, or 1.69 ft³/s per mile. Mean streamflow gains to Fountain Creek from groundwater by stream reach were 0.6 ft³/s between the north and middle transects (1.23 mi stream length) and 1.9 ft³/s between the middle and south transects (1.69 mi stream length), indicating the reach between the middle and south transects gained more groundwater than the reach between the north and middle transects during the study period.

Temperature Profiles

Naturally occurring changes in temperature in the near-stream environment are often substantial and can provide a clear thermal signal that is easy to identify and that can be used as a tracer of groundwater movement (Constantz and others, 2008). Whenever there is a difference in temperature between two points along a flow path, heat will move between them by transport in the flowing water (advective heat flow) (Stonestrom and Constantz, 2003). Heat movement, and thus water flow, can be traced by continuous monitoring of temperature patterns in the stream, streambed, and alluvial aquifer.

Groundwater temperatures in wells at the north, middle, and south transects generally reflect broad, seasonal temperature cycles throughout the monitoring period (figs. 13–15) with deeper water levels responding to seasonal temperature changes more slowly than shallower water levels. In contrast to groundwater temperatures, stream temperatures have large diurnal variations superimposed over seasonal cycles, which have greater amplitude than the groundwater cycles. Groundwater-temperature cycles also are delayed relative to stream-temperature cycles, reflecting the insulating effect of the unsaturated zone between the water table and the atmosphere. Groundwater temperatures generally changed

Groundwater and Surface-Water Interaction 21

21

Local well name	Test date	Saturated thickness (ft)	Height of static water above screen (ft)	Screen length ¹ (ft)	Casing radius (ft)	Radius of screen interval (ft)	Test number	Test type ²	Approximate slug volume (ft³)	Analysis method	Estimated hydraulic conductivity (ft/d)
N-WB-W	08/14/2013	8.5	5.7	2.5	0.083	0.083	1	Falling head	0.033	Butler (1998)	390
							2	Rising head	0.033	Butler (1998)	350
							3	Falling head	0.017	Butler (1998)	300
							4	Rising head	0.017	Butler (1998)	410
							Arithmetic mean				
Standard deviation										50	
N-WB-M	08/14/2013	8.3	4.5	2.5	0.083	0.083	1	Falling head	0.017	Bouwer and Rice (1976)	79
							2	Rising head	0.017	Bouwer and Rice (1976)	140
							3	Rising head	0.033	Bouwer and Rice (1976)	120
							4	Falling head	0.033	Bouwer and Rice (1976)	76
							Arithmetic mean				
Standard deviation										30	
N-WB-E	08/14/2013	9.0	6.9	2.1	0.083	0.083	1	Falling head	0.017	Bouwer and Rice (1976)	63
							2	Rising head	0.017	Bouwer and Rice (1976)	70
							3	Falling head	0.033	Bouwer and Rice (1976)	55
							4	Rising head	0.033	Bouwer and Rice (1976)	67
							Arithmetic mean				
Standard deviation										7	
N-EB-W	08/14/2013	6.5	3.7	2.5	0.083	0.083	1	Falling head	0.009	Bouwer and Rice (1976)	8
							2	Rising head	0.009	Bouwer and Rice (1976)	8
							3	Rising head	0.017	Bouwer and Rice (1976)	7
							4	--	--	--	--
							Arithmetic mean				
Standard deviation										1	
N-EB-E	08/14/2013	6.6	2.8	2.5	0.083	0.083	1	Rising head	0.017	Bouwer and Rice (1976)	37
							2	Falling head	0.017	Bouwer and Rice (1976)	38
							3	Rising head	0.009	Bouwer and Rice (1976)	48
							4	Falling head	0.009	Bouwer and Rice (1976)	62
							Arithmetic mean				
Standard deviation										12	
M-EB-W	08/14/2013	11.2	8.4	2.5	0.083	0.083	1	Falling head	0.017	Springer and Gelhar (1991)	800
							2	Rising head	0.017	Springer and Gelhar (1991)	830
							3	Rising head	0.033	Springer and Gelhar (1991)	870
							4	Falling head	0.033	Springer and Gelhar (1991)	680
							Arithmetic mean				
Standard deviation										80	

[ft, feet; ft³, cubic feet; ft/d, feet per day; --, no data]

Local well name	Test date	Saturated thickness (ft)	Height of static water above screen (ft)	Screen length¹ (ft)	Casing radius (ft)	Radius of screen interval (ft)	Test number	Test type²	Approximate slug volume (ft³)	Analysis method	Estimated hydraulic conductivity (ft/d)
M-EB-E	08/14/2013	12.3	9.5	2.5	0.083	0.083	1	Falling head	0.033	Bouwer and Rice (1976)	11
							2	Rising head	0.033	Bouwer and Rice (1976)	12
							3	Rising head	0.033	Bouwer and Rice (1976)	10
							4	Falling head	0.033	Bouwer and Rice (1976)	12
							Arithmetic mean Standard deviation				
S-WB-W	08/15/2013	10.9	8.1	2.5	0.083	0.083	1	Falling head	0.017	Bouwer and Rice (1976)	200
							2	Rising head	0.017	Bouwer and Rice (1976)	190
							3	Rising head	0.033	Bouwer and Rice (1976)	150
							4	Falling head	0.033	Bouwer and Rice (1976)	160
							Arithmetic mean Standard deviation				
S-WB-E Shallow	08/15/2013	20.9	6.4	2.5	0.083	0.083	1	Rising head	0.017	Springer and Gelhar (1991)	410
							2	Falling head	0.017	Springer and Gelhar (1991)	410
							3	Falling head	0.033	Springer and Gelhar (1991)	430
							4	Rising head	0.033	Springer and Gelhar (1991)	490
							Arithmetic mean Standard deviation				
S-WB-E Deep	08/15/2013	21.0	18.2	2.5	0.083	0.083	1	Falling head	0.033	Bouwer and Rice (1976)	30
							2	Rising head	0.033	Bouwer and Rice (1976)	23
							3	Falling head	0.033	Bouwer and Rice (1976)	24
							4	Rising head	0.033	Bouwer and Rice (1976)	22
							Arithmetic mean Standard deviation				
S-EB-W Shallow	08/13/2013	24.5	8.0	2.5	0.083	0.083	1	Falling head	0.017	Bouwer and Rice (1976)	240
							2	Rising head	0.017	Bouwer and Rice (1976)	240
							3	Rising head	0.033	Bouwer and Rice (1976)	220
							4	--	--	--	--
							Arithmetic mean Standard deviation				
S-EB-W Deep	08/13/2013	23.8	21.0	2.5	0.083	0.083	1	Falling head	0.033	Bouwer and Rice (1976)	110
							2	Rising head	0.033	Bouwer and Rice (1976)	120
							3	Falling head	0.017	Bouwer and Rice (1976)	120
							4	Rising head	0.017	Bouwer and Rice (1976)	150
							Arithmetic mean Standard deviation				

Table 2. Summary of dimensions and methods used for slug-test analyses and estimated hydraulic conductivity of aquifer materials in the screen interval of monitoring wells installed at the north, middle, and south transects, Fountain Creek near Pueblo, Colo., 2013.—Continued

[ft, feet; ft³, cubic feet; ft/d, feet per day; --, no data]

Local well name	Test date	Saturated thickness (ft)	Height of static water above screen (ft)	Screen length ¹ (ft)	Casing radius (ft)	Radius of screen interval (ft)	Test number	Test type ²	Approximate slug volume (ft³)	Analysis method	Estimated hydraulic conductivity (ft/d)
S-EB-E Shallow	08/13/2013	21.7	8.5	2.5	0.083	0.333	1	Falling head	0.017	Bouwer and Rice (1976)	1
							2	Rising head	0.017	Bouwer and Rice (1976)	1
							3	Falling head	0.033	Bouwer and Rice (1976)	1
							4	Rising head	0.033	Bouwer and Rice (1976)	1
							Arithmetic mean				
Standard deviation										0	
S-EB-E Deep	08/13/2013	22.3	19.5	2.5	0.083	0.333	1	Falling head	0.033	Bouwer and Rice (1976)	6
							2	Rising head	0.033	Bouwer and Rice (1976)	6
							3	Falling head	0.017	Bouwer and Rice (1976)	7
							4	Rising head	0.017	Bouwer and Rice (1976)	12
							Arithmetic mean				
Standard deviation										3	

¹Effective screen length calculated as actual screen length minus any screen penetration into shale at the aquifer base.

²All slug tests performed by using a mechanical slug.

Table 3. Data for computing groundwater flow by using the Dupuit equation, Fountain Creek near Pueblo, Colo., 2012–2014.[ft, feet; ft/d, feet per day; ft²/d, feet squared per day; ft³/s, cubic feet per second; HF, high streamflow conditions; mi, mile]

Local well name	Date	Distance from well to stream (L) (ft)	Hydraulic conductivity ¹ (K) (ft/d)	Water level in well ² (ft)	Stream-surface altitude ^{2,3} (ft)	Bedrock altitude ^{2,4} (ft)	Hydraulic head at well ⁵ (h_1) (ft)	Hydraulic head at stream ⁶ (h_2) (ft)	Flow per unit aquifer width (q) (ft ² /d)	Streamflow gain from groundwater per mile (ft ³ /s)
North transect										
N-WB-W	8/29/2012	115	170	4,710.9	4,710.2	4,704	6.9	6.2	6.9	0.42
N-WB-W	9/17/2012	115	170	4,711.1	4,710.4	4,704	7.1	6.4	7.3	0.45
N-WB-W	9/27/2012	115	170	4,711.5	4,710.6	4,704	7.4	6.6	8.8	0.54
N-WB-W	11/14/2012	115	170	4,711.2	4,710.7	4,704	7.2	6.7	4.7	0.29
N-WB-W	1/22/2013	115	170	4,710.9	4,710.7	4,704	6.9	6.7	2.1	0.13
N-WB-W	4/8/2013	115	170	4,710.8	4,710.5	4,704	6.8	6.5	3.4	0.20
N-WB-W	7/8/2013	115	170	4,711.0	4,710.2	4,704	7.0	6.2	7.9	0.48
N-WB-W	7/11/2013	115	170	4,711.0	4,710.2	4,704	6.9	6.2	7.3	0.45
N-WB-W	9/17/2013	115	170	4,713.6	HF	4,704	9.6	HF	HF	HF
N-WB-W	12/19/2013	115	170	4,711.4	4,711.0	4,704	7.4	7.0	4.7	0.29
West side mean									5.9	0.36
N-EB-E	8/29/2012	330	27	4,712.1	4,710.2	4,705	7.1	5.2	0.9	0.06
N-EB-E	9/18/2012	330	27	4,712.2	4,710.3	4,705	7.2	5.3	1.0	0.06
N-EB-E	9/27/2012	330	27	4,712.5	4,710.6	4,705	7.5	5.6	1.0	0.06
N-EB-E	11/15/2012	330	27	4,712.7	4,710.8	4,705	7.7	5.8	1.1	0.06
N-EB-E	1/22/2013	330	27	4,712.7	4,710.7	4,705	7.6	5.7	1.1	0.07
N-EB-E	4/16/2013	330	27	4,712.5	4,710.5	4,705	7.5	5.5	1.0	0.06
N-EB-E	7/9/2013	330	27	4,711.7	4,710.2	4,705	6.7	5.2	0.8	0.05
N-EB-E	7/11/2013	330	27	4,711.7	4,710.2	4,705	6.7	5.2	0.7	0.04
N-EB-E	9/18/2013	330	27	4,714.0	HF	4,705	9.0	HF	HF	HF
N-EB-E	12/19/2013	330	27	4,712.7	4,711.0	4,705	7.7	6.0	0.9	0.06
East side mean									0.9	0.06
Combined mean from both sides									6.8	0.42
Middle transect										
M-EB-E	8/29/2012	335	410	4,682.6	4,681.9	4,673	9.6	8.9	8.4	0.51
M-EB-E	9/13/2012	335	410	4,683.0	HF	4,673	10.0	HF	HF	HF
M-EB-E	9/27/2012	335	410	4,683.2	4,682.1	4,673	10.2	9.1	13.5	0.82
M-EB-E	11/13/2012	335	410	4,683.2	4,682.2	4,673	10.2	9.2	11.7	0.72
M-EB-E	1/22/2013	335	410	4,683.1	4,682.2	4,673	10.1	9.2	10.6	0.65
M-EB-E	4/15/2013	335	410	4,683.0	4,682.1	4,673	10.0	9.1	10.0	0.61
M-EB-E	7/9/2013	335	410	4,682.6	4,681.9	4,673	9.6	8.9	7.7	0.47
M-EB-E	7/12/2013	335	410	4,682.4	4,682.0	4,673	9.4	9.0	5.0	0.30
M-EB-E	9/19/2013	335	410	4,684.5	HF	4,673	11.5	HF	HF	HF
M-EB-E	12/22/2013	335	410	4,682.2	4,682.3	4,673	9.2	9.3	−0.2	−0.01
East side mean									8.3	0.51
South transect										
S-WB-W	8/31/2012	520	220	4,643.8	4,641.9	4,623	20.8	18.9	16.0	0.98
S-WB-W	9/19/2012	520	220	4,643.9	4,642.1	4,623	20.9	19.1	15.3	0.94
S-WB-W	9/25/2012	520	220	4,644.1	4,642.0	4,623	21.1	19.0	17.6	1.08
S-WB-W	11/20/2012	520	220	4,644.4	4,642.4	4,623	21.4	19.4	17.4	1.06
S-WB-W	1/23/2013	520	220	4,644.3	4,642.5	4,623	21.3	19.5	15.9	0.97
S-WB-W	4/22/2013	520	220	4,644.3	4,642.3	4,623	21.3	19.3	16.8	1.03
S-WB-W	7/11/2013	520	220	4,643.8	4,641.9	4,623	20.8	18.9	16.0	0.98
S-WB-W	7/12/2013	520	220	4,643.7	4,641.9	4,623	20.7	18.9	15.2	0.93
S-WB-W	10/22/2013	520	220	4,645.5	4,643.1	4,623	22.5	20.1	21.2	1.30
S-WB-W	12/22/2013	520	220	4,645.2	4,642.7	4,623	22.2	19.7	22.3	1.37
West side mean									17.4	1.06

Table 3. Data for computing groundwater flow by using the Dupuit equation, Fountain Creek near Pueblo, Colo., 2012–2014.—Continued[ft, feet; ft/d, feet per day; ft²/d, feet squared per day; ft³/s, cubic feet per second; HF, high streamflow conditions; mi, mile]

Local well name	Date	Distance from well to stream (L) (ft)	Hydraulic conductivity ¹ (K) (ft/d)	Water level in well ² (ft)	Stream-surface altitude ^{2,3} (ft)	Bedrock altitude ^{2,4} (ft)	Hydraulic head at well ⁵ (h_1) (ft)	Hydraulic head at stream ⁶ (h_2) (ft)	Flow per unit aquifer width (q) (ft ² /d)	Streamflow gain from groundwater per mile (ft ³ /s)
S-EB-E Shallow	8/28/2012	190	92	4,644.7	4,641.9	4,620	24.7	21.9	31.7	1.94
S-EB-E Shallow	9/11/2012	190	92	4,642.6	4,641.9	4,620	22.6	21.9	7.2	0.44
S-EB-E Shallow	9/25/2012	190	92	4,642.7	4,642.0	4,620	22.7	22.0	7.4	0.45
S-EB-E Shallow	11/19/2012	190	92	4,642.9	4,642.5	4,620	22.9	22.5	4.5	0.28
S-EB-E Shallow	1/23/2013	190	92	4,642.9	4,642.5	4,620	22.9	22.5	4.4	0.27
S-EB-E Shallow	4/17/2013	190	92	4,642.8	4,642.2	4,620	22.8	22.2	6.4	0.39
S-EB-E Shallow	7/10/2013	190	92	4,642.5	4,641.9	4,620	22.5	21.9	6.9	0.42
S-EB-E Shallow	7/12/2013	190	92	4,642.6	4,641.9	4,620	22.6	21.9	7.9	0.48
S-EB-E Shallow	9/16/2013	190	92	4,646.0	HF	4,620	26.0	HF	HF	HF
S-EB-E Shallow	1/15/2014	190	92	4,643.8	4,642.4	4,620	23.8	22.4	16.0	0.98
East side mean									10.3	0.63
Combined mean from both sides									27.7	1.69

Mean streamflow gain to Fountain Creek by stream reach

Distance along stream between north and middle transects: 1.23 mi

Distance along stream between middle and south transects: 1.69 mi

Mean gain to Fountain Creek from groundwater between north and middle transects: 0.6 ft³/sMean gain to Fountain Creek from groundwater between middle and south transects: 1.9 ft³/s¹Hydraulic conductivity represents the arithmetic mean of values determined from slug tests (table 2) performed at all wells on the respective side of Fountain Creek at each transect.²North American Vertical Datum of 1988.³Stream-surface altitude estimated on the basis of the stage-discharge relation developed for Fountain Creek at each transect (fig. 7).⁴Bedrock altitude represents the estimated altitude at the stream edge on the respective side of each transect.⁵Hydraulic head at well computed as water level in well minus bedrock altitude.⁶Hydraulic head at stream computed as stream-surface altitude minus bedrock altitude.

gradually throughout the monitoring period except during periods of high streamflow, suggesting that groundwater typically flows toward the stream except during periods of high streamflow when a gradient reversal can occur.

At the north transect, groundwater temperatures for wells N-WB-M (fig. 13A) and N-EB-W (fig. 13B) display small downward deflections in temperature lasting several hours during periods when streamflow in Fountain Creek peaked in August and September 2013. However, because the stream temperature on these dates is higher than the groundwater temperature, the deflections likely are caused by downward infiltration of cooler precipitation, which was substantial on the same dates. Although the thermographs for wells N-WB-W (fig. 13A) and N-EB-E (fig. 13B) are somewhat erratic, comparable deflections in groundwater temperature are not observed at those locations. However, the slope of the thermographs deviate upward from its expected seasonal trend during August and September 2013, indicating that the effect of warmer stream water, although attenuated by distance and mixing with groundwater, may be present. Temperature data

for well N-WB-E are missing for the comparable period, so the response of groundwater temperatures to streamflow or precipitation is not known for the well closest to the stream.

Unlike wells at the north transect, groundwater temperatures in well M-EB-W (near the stream) at the middle transect display pronounced upward deflections in response to high streamflow events during July–September 2013 (fig. 14). The seasonal temperature cycle of groundwater in the well also more closely resembles that of the stream, indicating that greater interaction of groundwater and surface water may be occurring during low-flow conditions than at other wells. By comparison, groundwater temperatures in well M-EB-E, which is farther from the creek, deviate only slightly from their seasonal trend in response to high streamflow events except for the flood event on September 13, 2013. Because well M-EB-E is located far from the stream, the spike in groundwater temperature lasting about 9 hours during the flood event possibly is the result of rapid downward infiltration of surface runoff to the shallow water table (about 2 ft below land surface at the start of the event), rather than lateral inflow from the stream.

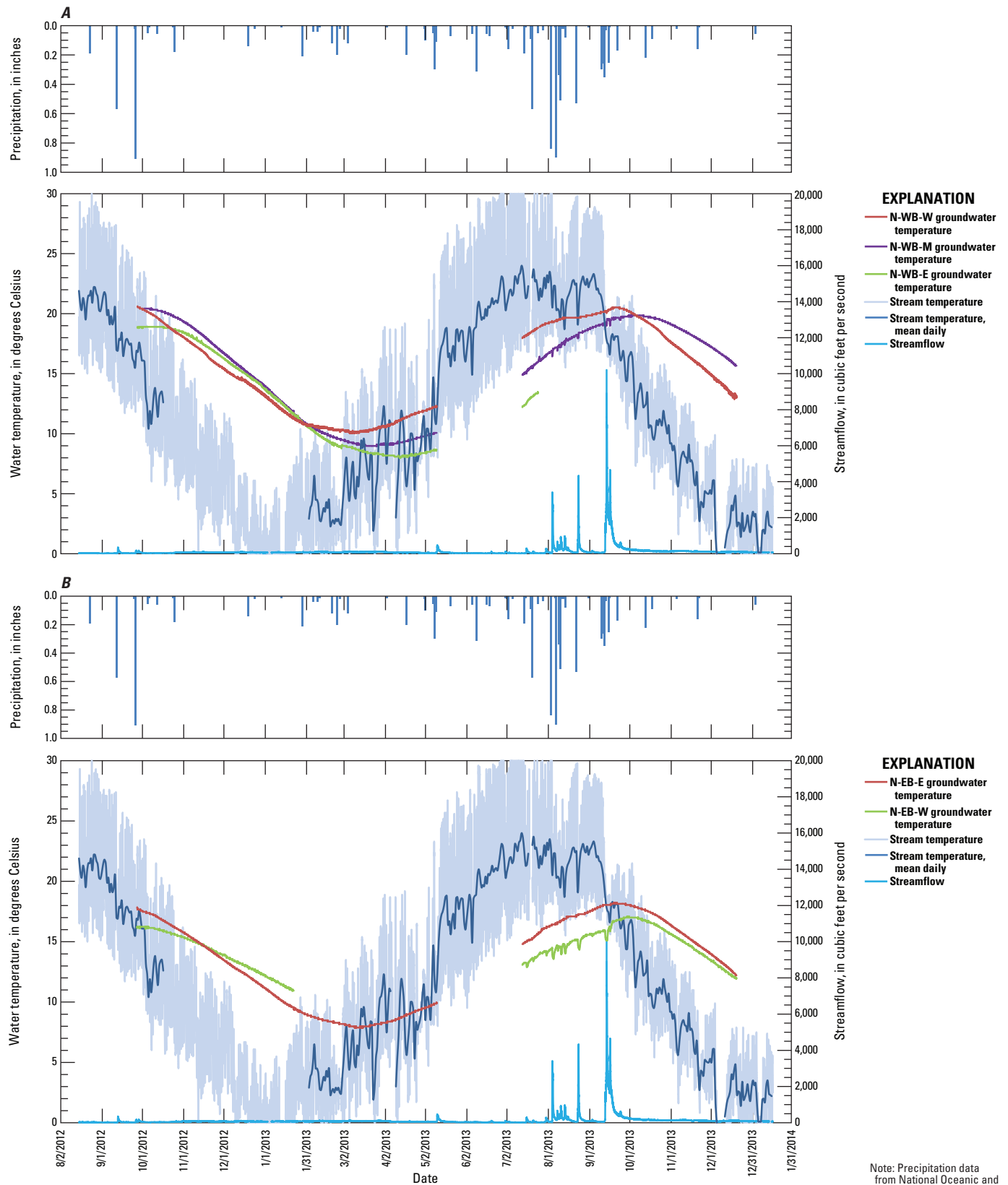


Figure 13. Groundwater and stream temperature, streamflow, and precipitation for A, west side; and B, east side of the north transect, Fountain Creek near Pueblo, Colo., 2012–2014.

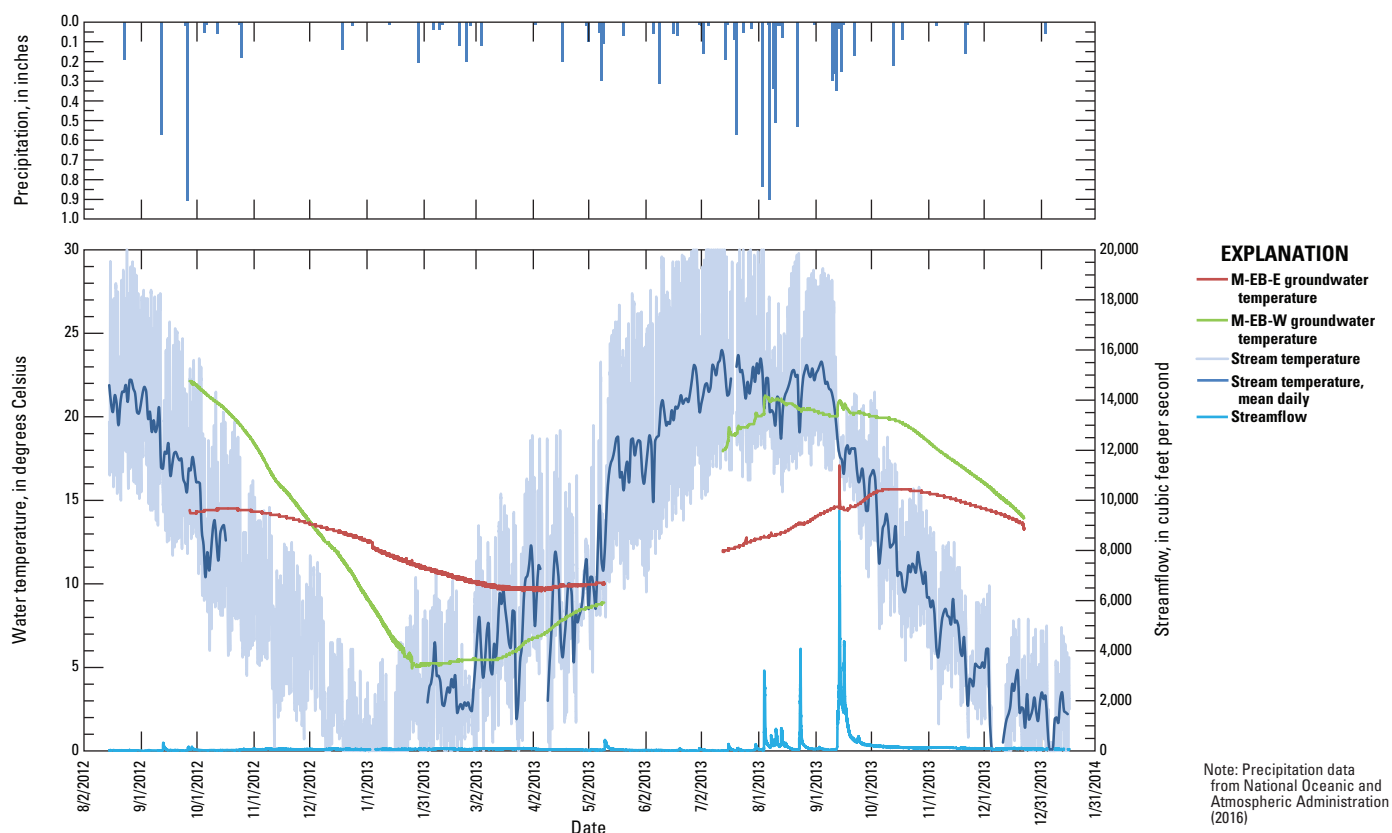


Figure 14. Groundwater and stream temperature, streamflow, and precipitation for the east side of the middle transect, Fountain Creek near Pueblo, Colo., 2012–2014.

Groundwater temperature data collected at the south transect generally are noisy from about November 2012 through April 2013 and from November 2013 through December 2013 but still display broad seasonal trends punctuated by infrequent upward and downward deflections during periods of high streamflow and little noise (fig. 15). Upward temperature deflections can be attributed to the mixing of warmer stream water with groundwater, but because the stream temperature is higher than the groundwater temperature, downward temperature deflections more likely are the result of precipitation infiltration. Groundwater temperatures in wells S-WB-W, S-EB-E Shallow, and S-EB-E Deep, which are located far from the stream, were relatively stable compared to groundwater temperatures in other wells, and generally did not respond to high streamflow events. Because well S-WB-W is located about 550 ft from the stream, the rise in groundwater temperature observed there during the flood event on September 13, 2013, likely is in response to downward infiltration of surface runoff or from groundwater flow upgradient from the well rather than in response to lateral inflow from the stream.

Hyporheic Zone

The subsurface zone where stream water flows through short segments of its adjacent bed and banks is referred to as the “hyporheic zone” (Winter and others, 1999). Hyporheic exchanges typically are composed of localized flow processes embedded within larger hillslope groundwater systems, and the timing and magnitude of exchanges are temporally variable (Malard and Hervant, 1999). To evaluate the interaction of groundwater and surface water in the hyporheic zone of Fountain Creek in the study area, a hydraulic potentiometer was used to measure hydraulic-head differences between the stream and underlying groundwater in the streambed to determine vertical hydraulic gradients, and the ratios of hydrogen and oxygen isotopes in water sampled from the hyporheic zone were analyzed.

Hydraulic Heads

Differences in hydraulic head between the stream and underlying streambed indicate the direction of flow between groundwater in the hyporheic zone and water in the stream.

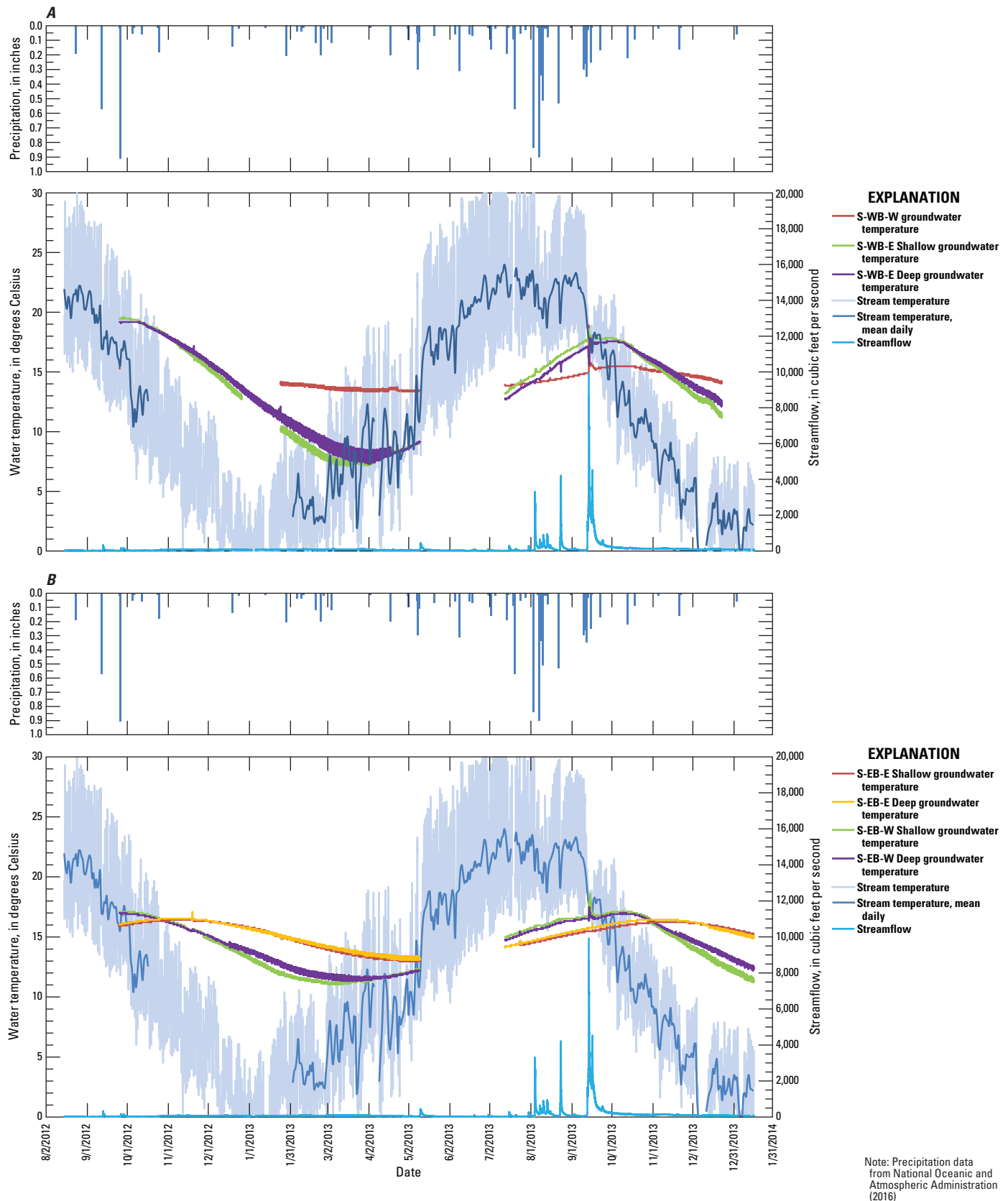


Figure 15. Groundwater and stream temperature, streamflow, and precipitation for A, west side; and B, east side of the south transect, Fountain Creek near Pueblo, Colo., 2012–2014.

When the hydraulic head in the streambed is higher than in the stream, the stream is gaining groundwater. Conversely, when hydraulic head in the streambed is lower than in the stream, the stream is losing water to the hyporheic zone. The actual quantity of flow between groundwater and the stream depends on the hydraulic gradient between the streambed and stream and the hydraulic conductivity of the sediments.

Hydraulic head (as represented by the mean of individual potentiometer readings at each time and location) in the streambed of Fountain Creek typically was higher than in the stream, indicating an upward gradient from the streambed to the stream and that Fountain Creek generally gained flow from groundwater at the times and locations measured (table 4). No measurements indicated downward gradients or losing conditions for the stream, and only one measurement (south transect, REW on October 23, 2013) indicated neutral hydraulic-head conditions between the streambed and the stream. Vertical hydraulic-head gradients between the streambed and stream on the west side of Fountain Creek at the north transect (REW) ranged from 0.002 to 0.025, and gradients on the east side of the creek (LEW) were 0.009–0.010. For the east side of the middle transect (LEW), hydraulic-head gradients from the streambed to the stream were 0.016–0.040. Because monitoring wells were not installed at the middle transect on the west side of Fountain Creek, hydraulic-head measurements in the streambed and stream were not made on the west side (REW) of the creek. Hydraulic-head gradients between the streambed and stream at the south transect were 0.000–0.019 on the west side of Fountain Creek (REW) and 0.022–0.038 on the east side of the creek (LEW).

Hydrogen- and Oxygen-Isotope Ratios

The ratios of naturally occurring stable isotopes of hydrogen ($^2\text{H}/^1\text{H}$) and oxygen ($^{18}\text{O}/^{16}\text{O}$) were measured to help identify the source of water in the hyporheic zone and the direction of flow between groundwater and surface water along Fountain Creek. Stable-isotope ratios are affected by temperature, altitude, distance inland, latitude, humidity, evaporation, and other environmental conditions (Kendall and Coplen, 2001; Coplen, 1993). Waters recharged at different times, in different locations, or that followed different flow paths are often isotopically distinct (Kendall and McDonnell, 1998), and evaporation preferentially enriches surface water in $\delta^{18}\text{O}$ relative to $\delta^2\text{H}$ (Hunt and others, 2005). Stable-isotope compositions of hydrogen and oxygen normally are reported as delta (δ) values, where δ has units of parts per thousand (denoted as ‰ or per mil) relative to a standard of known composition (Kendall and McDonnell, 1998). The reference standard for hydrogen ($\delta^2\text{H}$) and oxygen ($\delta^{18}\text{O}$) isotopes is Vienna Standard Mean Ocean Water (VSMOW), which is assigned $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values of 0 per mil. A positive δ value indicates the isotopic ratio of the sample is greater than that of the standard, whereas a negative δ value indicates the isotopic ratio of the sample is less than that of the standard (Kendall and McDonnell, 1998). When $\delta^2\text{H}$ is plotted relative to $\delta^{18}\text{O}$ for precipitation samples collected from locations around

the world, the data form a linear band that can be described by the Global Meteoric Water Line (GMWL; Craig, 1961, fig. 16). Differences in $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values compared to the GMWL reflect the effect of local fractionation processes. To more accurately characterize local variability of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values, Local Meteoric Water Lines (LMWL) were developed by Kendall and Coplen (2001) for river waters across the United States, including those in Colorado (fig. 16).

For the Fountain Creek study area near Pueblo, Colo., groundwater samples had $\delta^2\text{H}$ values ranging from –96.22 to –71.30 per mil and $\delta^{18}\text{O}$ values ranging from –12.30 to –9.60 per mil (fig. 16). Surface-water samples collected from Fountain Creek had a smaller range of $\delta^2\text{H}$ (–94.43 to –80.43 per mil) and $\delta^{18}\text{O}$ (–12.11 to –10.47 per mil) than groundwater samples. With the exception of the middle transect, groundwater samples generally plot above the Colorado Local Meteoric Water Line (CLMWL), and surface-water samples collected during low-flow conditions (less than or equal to 200 ft³/s) plot near the CLMWL. Surface-water samples collected during high-flow conditions (greater than 200 ft³/s) were enriched (less negative) with respect to $\delta^2\text{H}$ relative to surface water under low-flow conditions and also plot above the CLMWL. Like groundwater samples, hyporheic-zone samples generally plot above the CLMWL and generally display a larger range of $\delta^2\text{H}$ (–94.43 to –80.42 per mil) and $\delta^{18}\text{O}$ (–12.11 to –10.47 per mil) values than surface water. Nearly all samples plot below the GMWL. Because only a few groundwater samples plot below the CLMWL with $\delta^{18}\text{O}$ enriched relative to $\delta^2\text{H}$ (most commonly at the middle transect) and the linear trends of groundwater samples have steeper slopes than the CLMWL, evaporation effects on groundwater likely are negligible.

At the north transect, groundwater samples collected from the east side of Fountain Creek had a greater range of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values than samples collected at any other location, suggesting that some water on the east side of the north transect might have a different source or have been affected by different environmental conditions than samples collected at other locations. Samples collected from the hyporheic zone at the north transect had $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values and a linear trend similar to those of groundwater on the west side of Fountain Creek, indicating that hyporheic-zone samples likely are composed largely of groundwater from the west side of the north transect. However, because the isotopic composition of groundwater from both sides of Fountain Creek and surface water overlap, the source of hyporheic-zone water cannot clearly be determined, and some mixing of the three sources might be occurring.

Groundwater from the east side of the middle transect has $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values that plot near the CLMWL and substantially overlap with the isotopic composition of surface water, suggesting that some groundwater samples might be affected by mixing with surface water or are more strongly affected by infiltration of precipitation than other groundwater samples. Hyporheic-zone samples collected from the middle transect had a greater range of hydrogen- and oxygen-isotope

Table 4. Summary of potentiomanometer measurements of stream and streambed in the hyporheic zone at north, middle, and south transects, Fountain Creek near Pueblo, Colo., 2013.

[ft, feet; REW, right edge of water; LEW, left edge of water; --, no data; in., inches]

Local transect name	Date	Time	Bank	Approximate distance from bank (ft)	Depth of surface-water column (ft)	Depth of screen interval below stream (ft)	Potentiomanometer measurements (in.)			Hydraulic-head gradient (dimensionless)
							Stream	Streambed	Difference	
North transect	5/14/2013	--	REW	1.5	0.42	2.00	30.71	30.71	0.00	0.000
							35.35	35.43	0.08	0.003
							20.79	20.87	0.08	0.003
							20.55	20.63	0.08	0.003
Mean								0.06	0.002	
North transect	7/15/2013	11:30	REW	1.5	1.05	1.48	30.31	30.55	0.24	0.013
							21.34	21.73	0.39	0.022
							23.62	24.33	0.71	0.040
							Mean			
North transect	7/15/2013	12:30	LEW	2.5	0.15	1.90	22.28	22.60	0.31	0.014
							35.75	35.98	0.24	0.010
							27.32	27.48	0.16	0.007
							Mean			
North transect	10/23/2013	8:30	REW	1.5	1.27	2.17	29.21	29.29	0.08	0.003
							23.15	23.31	0.16	0.006
							36.93	37.09	0.16	0.006
							Mean			
North transect	10/23/2013	9:20	LEW	2	0.56	1.26	33.23	33.31	0.08	0.005
							33.07	33.31	0.24	0.016
							27.80	27.87	0.08	0.005
							Mean			
Middle transect	5/13/2013	--	LEW	2.5	0.70	1.65	29.29	30.08	0.79	0.040
							27.17	27.87	0.71	0.036
							33.94	34.65	0.71	0.036
							14.96	15.91	0.94	0.048
Mean								0.79	0.040	
Middle transect	7/17/2013	8:20	LEW	2	0.50	1.40	24.49	24.65	0.16	0.009
							36.54	36.93	0.39	0.023
							33.39	33.62	0.24	0.014
							Mean			
South transect	4/30/2013	--	REW	1.5	0.26	3.25	22.68	22.91	0.24	0.006
							24.41	24.65	0.24	0.006
							28.35	28.74	0.39	0.010
							Mean			
South transect	4/30/2013	--	LEW	1.5	0.80	0.63	27.24	27.48	0.24	0.031
							19.76	20.08	0.31	0.042
							34.49	34.80	0.31	0.042
							Mean			
South transect	7/18/2013	10:30	REW	1.5	0.26	1.63	27.32	27.72	0.39	0.020
							22.68	22.99	0.31	0.016
							35.75	36.14	0.39	0.020
							Mean			
South transect	7/18/2013	9:30	LEW	1.5	0.27	1.02	30.87	31.34	0.47	0.039
							30.79	31.34	0.55	0.045
							22.05	22.28	0.24	0.019
							Mean			
South transect	10/23/2013	13:00	REW	1.5	0.25	2.34	34.41	34.41	0.00	0.000
							25.04	25.04	0.00	0.000
							28.43	28.43	0.00	0.000
							Mean			
South transect	10/23/2013	12:45	LEW	1.5	0.75	1.35	32.91	33.46	0.55	0.034
							32.76	32.99	0.24	0.015
							26.69	27.01	0.31	0.019
							27.64	27.95	0.31	0.019
Mean								0.35	0.022	

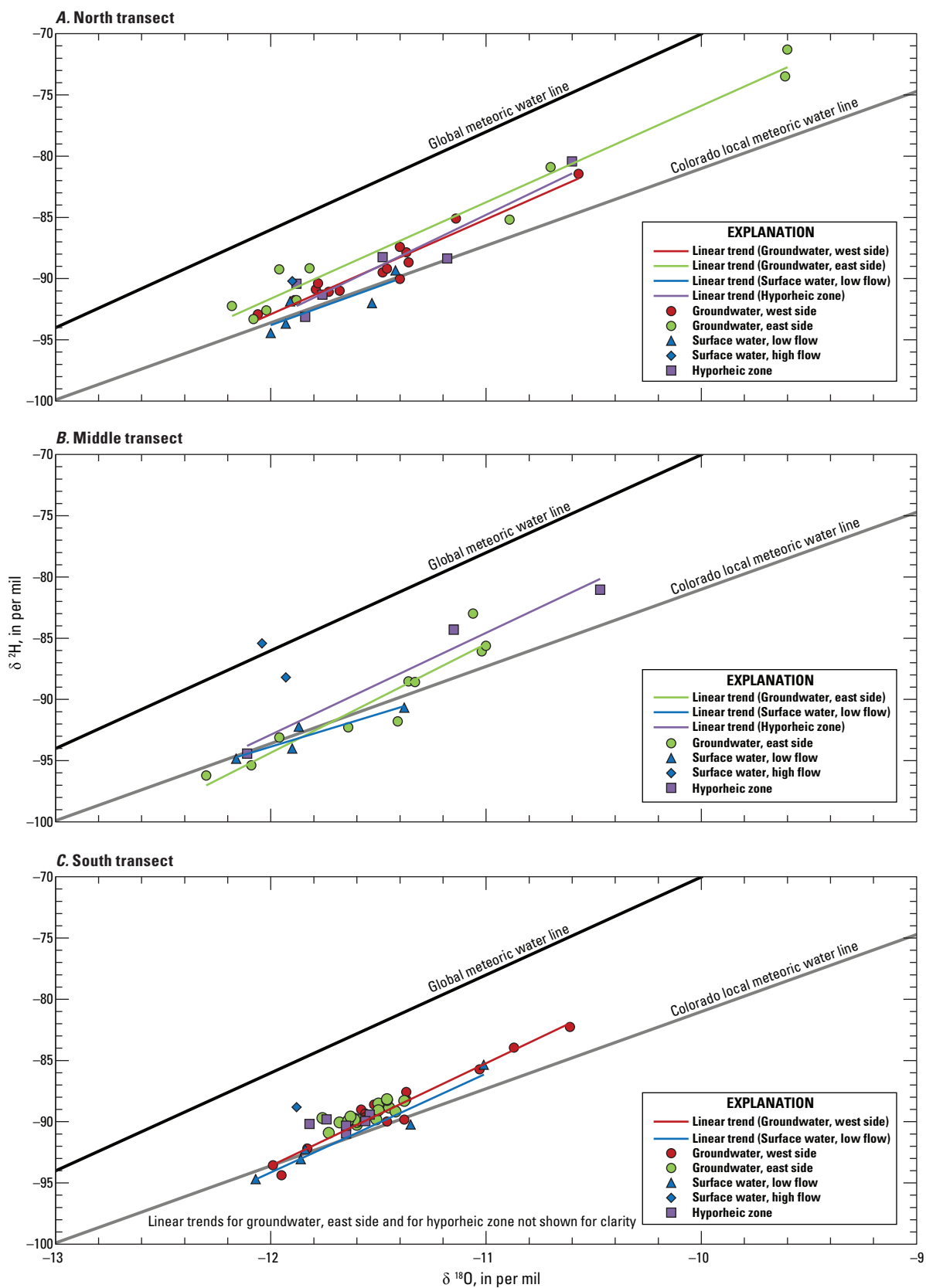


Figure 16. Delta ^2H ($\delta^2\text{H}$) relative to delta ^{18}O ($\delta^{18}\text{O}$) for groundwater, surface water, and hyporheic-zone samples at the A, north; B, middle; and C, south transects, Fountain Creek near Pueblo, Colo., 2012–2013.

ratios than either groundwater or surface-water samples. However, similar to the north transect, $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values of hyporheic-zone water at the middle transect generally plot above the CLMWL and have a linear trend that is nearly parallel to that of the groundwater samples, indicating that water in the hyporheic zone likely is composed primarily of groundwater near the east bank (LEW) of Fountain Creek, where samples were collected. Because wells were not installed and samples were not collected from the west side of Fountain Creek at the middle transect, the isotopic composition of groundwater and hyporheic-zone water on the west side of the creek at the middle transect is unknown.

Groundwater from the west side of the south transect had a range of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values similar to that of groundwater from the west side of the north transect and the east side of the middle transect. However, groundwater from the east side of the south transect had a smaller range of $\delta^2\text{H}$ (−11.76 to −1.38 per mil) and $\delta^{18}\text{O}$ (−90.93 to −88.17 per mil) values than other groundwater samples, suggesting greater isotopic uniformity of source water or environmental conditions, perhaps related to flow-path length or recharge rates, at that location. Hyporheic-zone samples collected from the south transect also had a small range of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values similar to that of groundwater from the east side of the south transect, indicating that hyporheic-zone water at the south transect likely is composed largely of groundwater from the east side of the transect. However, because of the substantial overlap among groundwater samples from both sides of the transect and from surface water, some mixing of groundwater and surface water in the hyporheic zone is likely.

Streamflow Mass Balance

The streamflow mass-balance method estimates the interaction of groundwater and surface water along a stream reach by comparing stream discharge at the upstream and downstream ends of a reach and accounting for surface-water inflows and diversions along the reach. If net discharge at the downstream measurement site is greater than discharge at the upstream measurement site, the additional flow may be attributed to groundwater or unmeasured surface-water inflow to the stream (streamflow gain) between the two sites. If net stream discharge has decreased between the two sites, the decreased flow may be attributed to surface-water loss to groundwater, unmeasured diversions, or evapotranspiration (streamflow loss).

A limitation of the gain-loss estimation method is that the combined measurement uncertainty can exceed the magnitude of the estimated gain or loss value. For this study, uncertainty associated with each gain or loss determination was computed as the square root of the sum of squared errors (root sum square, or RSS; Castrup, 2004) for each discharge measurement used for the mass-balance computation. Because measured differences between discharge at upstream and downstream sites on Fountain Creek typically were small, the uncertainty sometimes exceeded or was equal to the estimated gain or loss (table 5).

The reach of Fountain Creek between the north transect and the middle transect appeared generally to lose flow to groundwater during the study period with values ranging from a loss of 18 ft³/s to a gain of 1 ft³/s and a mean loss 6 ft³/s. On the basis of data for which measurements of streamflow gain or loss was greater than measurement uncertainty (March 21, July 1, July 16, July 29, and August 16, 2013), the reach of Fountain Creek between the north transect and the middle transect exhibited losses ranging from 2 to 18 ft³/s. Conversely, the reach of Fountain Creek between the middle transect and the south transect appeared to gain and lose flow on the same number of days with values ranging from a loss of 13 ft³/s to a gain of 13 ft³/s and a mean value of 0 ft³/s. For dates on which measurements of streamflow gain or loss were greater than measurement uncertainty (April 18, July 1, August 16, and September 26, 2013), flows also ranged from a loss of 13 ft³/s to a gain of 13 ft³/s. Because uncertainty in the estimated mean gain or loss between the middle and south transects exceeded the estimated value (table 5), the mean gain or loss along the reach is indeterminate. There are no known tributary inflows to Fountain Creek or diversions of outflow from Fountain Creek in either reach, which indicates that estimated gains and losses likely primarily are the result of groundwater and surface-water interaction.

Summary of Groundwater and Surface-Water Interaction

Hydrogeologic mapping of the Fountain Creek alluvial aquifer indicated that groundwater generally flows toward Fountain Creek and down valley except along the reach between the north and middle transects, where the stream runs along the edge of the aquifer. Along this reach, groundwater gradients appear to be away from Fountain Creek and westward toward the center of the aquifer. Hydraulic-head and temperature data confirm that Fountain Creek generally gains flow from groundwater during low-streamflow conditions, but the hydraulic gradient between groundwater and the stream can temporarily reverse during periods of high streamflow, causing the stream to lose flow to groundwater. Comparison of vertical hydraulic-head gradients between the stream and streambed of Fountain Creek and analysis of hydrogen- and oxygen-isotope ratios of water in the hyporheic zone further indicated that groundwater likely contributes flow to Fountain Creek under low-streamflow conditions. However, mixing of groundwater and surface water in the streambed is likely, particularly at the middle transect, as evidenced by some isotope ratios. Hydrologic analysis using the Dupuit equation indicated that Fountain Creek gained flow from groundwater between all transects under low-streamflow conditions with mean gains ranging from 0.6 ft³/s for the reach between the north and middle transects to 1.9 ft³/s for the reach between the middle and south transects. However, synoptic comparison of streamflow by using the streamflow mass-balance method indicated that the reach between the north and middle transects generally lost streamflow (2–18 ft³/s for values exceeding

Table 5. Summary of synoptic streamflow measurements along Fountain Creek near Pueblo, Colo., and groundwater gains and losses, March 21, April 18, July 1, July 16, July 29, August 16, and September 26, 2013.[Values in bold indicate gain or loss exceeding streamflow measurement uncertainty; ft³/s, cubic feet per second]

Date	Streamflow						Gain or loss ¹			
	North transect (ft ³ /s)	North transect uncertainty (ft ³ /s)	Middle transect (ft ³ /s)	Middle transect uncertainty (ft ³ /s)	South transect (ft ³ /s)	South transect uncertainty (ft ³ /s)	North to middle transect (ft ³ /s)	North to middle transect uncertainty ² (ft ³ /s)	Middle to south transect (ft ³ /s)	Middle to south transect uncertainty ² (ft ³ /s)
3/21/2013	82	2	75	2	77	2	-7	3	2	3
4/18/2013	40	1	41	1	44	1	1	1	3	1
7/1/2013	33	1	31	1	24	1	-2	1	-7	1
7/16/2013	165	4	147	3	146	4	-18	5	-1	5
7/29/2013	90	2	86	2	86	2	-4	3	0	3
8/16/2013	188	5	178	5	191	5	-10	7	13	7
9/26/2013	318	8	317	8	304	8	-1	12	-13	12
Mean	131	3	125	3	125	3	-6	5	0	5

¹Positive values indicate gain to stream; negative values indicate loss from stream.²Uncertainty associated with gains or losses between transects was computed as the root sum square (RSS) of uncertainties for each individual load estimate.

measurement uncertainty) with a mean loss of 6 ft³/s, whereas the reach between the middle and south transects exhibited more variable gain-loss conditions (loss of 13 ft³/s to gain of 13 ft³/s for values exceeding measurement uncertainty). Mean gain or loss between the middle and south transects was indeterminate because measurement uncertainty exceeded the estimated value.

Differences in the estimates of gains or losses to Fountain Creek between the two methods could be attributed to the different spatial and temporal scales related to each method, unmeasured flow through the hyporheic zone, or evapotranspiration. The direction and magnitude of flow between groundwater and the stream at individual transects can differ from that of the entire reach, resulting in differences in computed flow when average conditions at the transects are applied over the full reach. Losses between the north and middle transects computed by the mass-balance method are consistent with the results of hydrogeologic mapping for the reach, which shows large-scale flow through the aquifer. In addition to losses to the groundwater system between the north and middle transects, losses computed by the mass-balance method could be the result of stream water bypassing measurement locations by flowing through the substantial hyporheic zone created by the sandy, braided conditions of the stream channel. To a lesser extent, losses also could be attributed to evapotranspiration by trees and other plant life along the stream channel, which would remove water from the stream and the hyporheic zone between transects. Consideration of all method results suggests that the larger groundwater-flow system generally contributes flow to Fountain Creek and its hyporheic zone (as a single system) except for the reach between the north and middle transects. However, the direction of flow between the stream, the hyporheic zone, and the near-stream aquifer is variable in response to streamflow and stage.

Water Quality

Water quality in streams can be affected by natural geologic, hydrologic, and biologic conditions and by anthropogenic factors associated with land- and water-use practices. Water quality can vary seasonally or in relation to streamflow or groundwater flow. Water samples collected from groundwater, surface water, and the hyporheic zone along Fountain Creek were analyzed for selected constituents to characterize the water quality in the basin and compute loads for dissolved solids, selenium, and uranium in the stream.

Analytical Results

Results of field measurements and laboratory analyses of groundwater, surface-water, and hyporheic-zone samples are presented in tables 6–8. Water-quality data for each sample also are available through NWIS at URL <http://dx.doi.org/10.5066/F7P55KJN>. Constituent concentrations in groundwater, surface water, and the hyporheic zone varied by date and location. Figures 17–19 illustrate the cross-sectional distribution of dissolved-solids, selenium, and uranium concentrations across the north, middle, and south transects for each date sampled. Concentrations of dissolved solids, selenium, and uranium in groundwater generally had greater spatial variability than surface water or hyporheic-zone samples, and constituent concentrations in groundwater generally were greater than in surface water. Constituent concentrations in the hyporheic zone typically were similar to or intermediate between concentrations in groundwater and surface water except at the middle transect, where hyporheic-zone samples had concentrations less than both groundwater and surface water (fig. 18). The lower concentrations of dissolved solids, selenium, and uranium in hyporheic-zone samples collected from the middle transect could indicate that geochemical

Table 6. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for groundwater samples, Fountain Creek near Pueblo, Colo., 2012–2013.

[USGS, U.S. Geological Survey; °C, degrees Celsius; $\mu\text{S}/\text{cm}$ at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than; --, no data; M, value is below the reporting level but at or above the detection level; E, estimated; $\delta^{18}\text{O}$, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); $\delta^2\text{H}$, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil]

Local well name	USGS site number	Date	Field measurements					Residue on evaporation at 180 °C (dissolved solids) (mg/L)	Calcium, filtered (mg/L)	Magnesium, filtered (mg/L)	Potassium, filtered (mg/L)
			Water temperature (°C)	pH, standard units	Specific conductance ($\mu\text{S}/\text{cm}$ at 25 °C)	Dissolved oxygen (mg/L)	Alkalinity (mg/L as CaCO_3)				
N-WB-W	381754104362001	09/17/2012	19.9	7.2	1,730	0.1	274	1,230	111	89.9	6.03
N-WB-W	381754104362001	11/14/2012	17.5	7.3	1,640	0.1	259	1,230	107	87.9	5.75
N-WB-W	381754104362001	04/08/2013	12.4	7.2	1,560	--	250	1,110	95.4	81.2	5.31
N-WB-W	381754104362001	07/08/2013	17.2	7.1	1,500	M	269	1,020	85.2	69.9	5.41
N-WB-W	381754104362001	09/17/2013	19.8	7.2	1,830	0.1	243	1,310	116	90.4	6.16
N-WB-M	381755104362001	09/17/2012	20.7	7.4	1,770	0.1	292	1,270	102	90.7	7.11
N-WB-M	381755104362001	11/14/2012	18.7	7.5	1,500	M	242	1,130	91.8	79.4	6.08
N-WB-M	381755104362001	04/10/2013	9.9	7.4	1,630	0.1	262	1,190	102	86.6	5.58
N-WB-M	381755104362001	07/08/2013	15.8	7.2	1,580	M	290	1,090	93.4	75.4	5.83
N-WB-M	381755104362001	09/17/2013	20.2	7.4	1,420	M	197	998	83.8	62.5	6.43
N-WB-E	381754104361901	09/17/2012	19.8	7.5	1,620	0.1	224	1,160	125	57.6	8.58
N-WB-E	381754104361901	11/14/2012	18.0	7.7	1,320	1.6	199	955	98.6	48.7	6.63
N-WB-E	381754104361901	04/10/2013	8.5	7.6	1,620	0.5	228	1,210	128	69.5	7.06
N-WB-E	381754104361901	07/08/2013	13.9	7.4	1,580	0.2	215	1,110	106	59.8	7.99
N-EB-W	381754104361401	09/18/2012	19.8	7.3	8,100	1.0	483	8,050	304	748	16.2
N-EB-W	381754104361401	11/15/2012	17.1	7.2	8,760	0.7	556	9,510	386	958	17.4
N-EB-W	381754104361401	04/16/2013	10.4	7.5	10,500	E1.5	558	11,700	444	1,190	16.5
N-EB-W	381754104361401	07/09/2013	15.3	7.2	11,000	<0.9	562	11,600	449	1,160	17.1
N-EB-W	381754104361401	09/18/2013	19.8	7.2	6,460	0.7	368	6,290	228	549	13.3
N-EB-E	381754104361101	09/18/2012	19.1	6.9	8,170	1.0	514	8,770	476	755	13.4
N-EB-E	381754104361101	11/15/2012	15.4	6.8	8,520	1.2	560	8,910	524	818	12.0
N-EB-E	381754104361101	04/16/2013	9.9	7.0	8,020	3.6	512	8,420	433	774	12.4
N-EB-E	381754104361101	07/09/2013	17.6	6.8	7,080	2.2	469	7,210	388	609	10.9
N-EB-E	381754104361101	09/18/2013	19.5	6.7	6,330	0.1	449	6,160	364	524	10.6
M-EB-W	381653104361001	09/13/2012	22.3	7.5	1,540	0.3	198	1,160	124	51.9	9.12
M-EB-W	381653104361001	11/13/2012	16.7	7.5	1,440	1.0	205	1,030	115	50.3	7.07
M-EB-W	381653104361001	04/15/2013	8.9	7.6	1,220	3.9	184	825	88.1	40.3	5.18
M-EB-W	381653104361001	07/09/2013	18.4	7.4	1,580	M	200	1,090	117	47.6	8.00
M-EB-W	381653104361001	09/19/2013	21.0	7.5	1,200	0.1	184	789	92.5	36.5	7.25
M-EB-E	381652104360601	09/13/2012	15.0	7.4	1,410	0.1	195	1,030	113	45.4	7.72
M-EB-E	381652104360601	11/13/2012	15.1	7.3	1,540	0.3	196	1,110	127	50.5	7.65
M-EB-E	381652104360601	04/15/2013	10.6	7.4	1,290	0.1	198	901	99.2	39.8	5.83
M-EB-E	381652104360601	07/09/2013	13.2	7.2	1,320	0.1	201	862	94.4	37.7	6.15
M-EB-E	381652104360601	09/19/2013	15.7	7.3	1,560	0.1	204	1,090	130	49.3	7.86

Table 6. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for groundwater samples, Fountain Creek near Pueblo, Colo., 2012–2013.—Continued

[USGS, U.S. Geological Survey; °C, degrees Celsius; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; <, less than; --, no data; M, value is below the reporting level but at or above the detection level; E, estimated; δ¹⁸O, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); δ²H, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil]

Local well name	USGS site number	Date	Field measurements					Residue on evaporation at 180 °C (dissolved solids) (mg/L)	Calcium, filtered (mg/L)	Magnesium, filtered (mg/L)	Potassium, filtered (mg/L)
			Water temperature (°C)	pH, standard units	Specific conductance (µS/cm at 25 °C)	Dissolved oxygen (mg/L)	Alkalinity (mg/L as CaCO ₃)				
S-WB-W	381529104354201	09/19/2012	15.7	7.1	3,800	0.1	325	3,380	247	215	13.8
S-WB-W	381529104354201	11/20/2012	16.5	7.1	3,130	0.1	304	2,720	184	193	12.7
S-WB-W	381529104354201	04/22/2013	14.8	7.2	2,630	0.1	259	2,130	162	168	10.6
S-WB-W	381529104354201	07/11/2013	14.9	7.1	2,880	M	293	2,360	166	178	10.6
S-WB-W	381529104354201	10/22/2013	16.3	7.0	2,500	0.1	262	2,020	143	147	10.4
S-WB-E Shallow	381531104353602	09/12/2012	20.1	7.4	1,570	0.1	181	1,140	118	57.5	8.39
S-WB-E Shallow	381531104353602	11/20/2012	17.8	7.4	1,550	0.4	194	1,140	123	54.8	7.76
S-WB-E Shallow	381531104353602	04/22/2013	9.8	7.4	1,670	1.4	198	1,270	142	67.2	6.62
S-WB-E Shallow	381531104353602	07/11/2013	15.1	7.4	2,130	0.1	239	1,760	189	88.5	8.05
S-WB-E Shallow	381531104353602	09/25/2013	18.9	7.2	2,080	0.1	214	1,680	192	82.5	9.39
S-WB-E Deep	381531104353601	09/12/2012	17.3	7.4	1,580	0.1	190	1,100	118	58.4	7.72
S-WB-E Deep	381531104353601	11/20/2012	18.3	7.2	1,650	M	203	1,240	130	62.7	8.07
S-WB-E Deep	381531104353601	04/22/2013	11.0	7.3	1,970	0.1	212	1,550	176	83.7	7.06
S-WB-E Deep	381531104353601	07/11/2013	12.8	7.2	2,580	M	254	2,150	249	110	8.42
S-WB-E Deep	381531104353601	09/25/2013	16.4	7.0	2,870	0.1	259	2,470	278	123	10.9
S-EB-W Shallow	381532104353502	09/11/2012	18.6	7.1	2,870	0.1	301	2,470	225	171	8.41
S-EB-W Shallow	381532104353502	11/19/2012	16.7	7.0	2,770	M	307	2,340	227	165	8.19
S-EB-W Shallow	381532104353502	04/11/2013	12.4	7.1	2,680	0.1	296	2,270	218	164	7.63
S-EB-W Shallow	381532104353502	07/10/2013	15.9	7.0	2,960	0.1	321	2,620	230	173	7.86
S-EB-W Shallow	381532104353502	09/23/2013	17.7	6.9	3,840	0.1	326	3,430	305	237	9.89
S-EB-W Deep	381532104353501	09/10/2012	16.1	7.0	2,850	E0.2	300	2,490	219	175	8.07
S-EB-W Deep	381532104353501	11/19/2012	16.1	7.0	2,760	0.1	298	2,290	213	167	7.69
S-EB-W Deep	381532104353501	04/11/2013	14.2	7.0	2,590	0.1	281	2,190	202	161	7.95
S-EB-W Deep	381532104353501	07/10/2013	15.0	7.0	2,870	M	307	2,510	216	170	7.38
S-EB-W Deep	381532104353501	09/23/2013	16.3	6.9	3,360	0.1	307	2,807	270	208	8.95
S-EB-E Shallow	381533104353302	09/11/2012	18.6	7.2	2,490	0.2	292	2,090	231	136	9.04
S-EB-E Shallow	381533104353302	11/19/2012	18.7	7.1	2,400	0.1	296	2,000	215	131	8.76
S-EB-E Shallow	381533104353302	04/17/2013	15.3	7.2	2,270	E0.1	279	1,870	196	121	7.57
S-EB-E Shallow	381533104353302	07/10/2013	16.3	7.1	2,290	0.2	301	1,880	194	119	7.07
S-EB-E Shallow	381533104353302	09/16/2013	20.0	7.1	2,340	0.2	286	1,880	199	124	7.48
S-EB-E Deep	381533104353301	09/11/2012	19.1	7.1	2,150	0.1	266	1,760	189	110	7.8
S-EB-E Deep	381533104353301	11/19/2012	16.6	7.1	2,060	0.2	256	1,660	192	88.2	5.87
S-EB-E Deep	381533104353301	04/17/2013	15.4	7.1	2,060	0.1	249	1,650	186	102	6.99
S-EB-E Deep	381533104353301	07/10/2013	17.2	7.0	2,100	0.1	261	1,700	181	99.8	6.63
S-EB-E Deep	381533104353301	09/16/2013	16.4	7.0	2,440	0.1	269	2,000	222	128	7.58

Table 6. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for groundwater samples, Fountain Creek near Pueblo, Colo., 2012–2013.—Continued

[USGS, U.S. Geological Survey; °C, degrees Celsius; $\mu\text{S}/\text{cm}$ at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than; --, no data; M, value is below the reporting level but at or above the detection level; E, estimated; $\delta^{18}\text{O}$, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); $\delta^2\text{H}$, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil]

Local well name	Date	Sodium, filtered (mg/L)	Chloride, filtered (mg/L)	Fluoride, filtered (mg/L)	Sulfate, filtered (mg/L)	Ammonia, as N filtered (mg/L)	Nitrate, as N filtered (mg/L)	Nitrite, as N filtered (mg/L)	Organic nitrogen, unfiltered (mg/L)	Total nitrogen, unfiltered (mg/L)	Orthophosphate, as P filtered (mg/L)
N-WB-W	09/17/2012	176	91.8	1.77	538	0.02	0.752	0.049	0.07	0.88	0.014
N-WB-W	11/14/2012	162	89.6	1.89	553	<0.01	1.06	0.032	<0.12	1.2	0.014
N-WB-W	04/08/2013	152	88.0	1.90	504	<0.01	0.171	0.002	<0.09	0.26	0.012
N-WB-W	07/08/2013	150	83.4	2.08	446	<0.01	0.094	0.001	<0.09	0.19	0.014
N-WB-W	09/17/2013	159	91.8	1.97	634	<0.01	0.090	0.002	<0.13	0.22	0.015
N-WB-M	09/17/2012	169	93.4	1.94	552	0.03	0.063	0.003	0.07	0.17	0.046
N-WB-M	11/14/2012	157	87.4	1.95	484	0.02	0.535	0.011	0.15	0.72	0.045
N-WB-M	04/10/2013	160	109	1.50	661	<0.01	0.021	<0.001	<0.08	0.11	0.041
N-WB-M	07/08/2013	152	84.4	1.96	472	0.03	<0.010	<0.001	0.09	0.13	0.049
N-WB-M	09/17/2013	128	66.5	2.03	431	<0.01	0.657	0.020	<0.19	0.87	0.051
N-WB-E	09/17/2012	160	82.7	1.79	527	0.02	0.557	0.006	0.09	0.67	0.105
N-WB-E	11/14/2012	136	76.7	1.99	396	<0.01	1.77	0.004	<0.18	2.0	0.085
N-WB-E	04/10/2013	164	82.4	1.70	541	<0.01	1.23	0.001	<0.14	1.4	0.093
N-WB-E	07/08/2013	154	84.9	2.12	530	<0.01	0.794	0.004	<0.18	0.97	0.115
N-EB-W	09/18/2012	892	83.6	1.54	4,990	0.19	38.9	0.147	1.4	41	0.121
N-EB-W	11/15/2012	1,060	95.2	1.48	5,990	0.19	46.2	0.059	1.7	48	0.142
N-EB-W	04/16/2013	1,280	120	1.30	7,980	0.22	64.4	0.023	1.4	66	0.149
N-EB-W	07/09/2013	1,280	116	2.40	6,950	0.23	65.5	0.034	2.0	68	0.174
N-EB-W	09/18/2013	807	95.6	2.47	3,510	0.15	30.8	0.039	1.3	32	0.121
N-EB-E	09/18/2012	973	111	1.36	5,250	0.17	83.9	0.021	0.83	85	0.029
N-EB-E	11/15/2012	994	117	1.18	5,590	0.18	81.2	0.005	1.9	83	0.029
N-EB-E	04/16/2013	990	163	1.10	7,430	0.16	77.2	0.002	1.3	79	0.026
N-EB-E	07/09/2013	713	96.7	2.06	3,760	0.15	56.8	0.004	1.3	58	0.026
N-EB-E	09/18/2013	675	70.0	1.71	3,410	0.15	49.2	0.032	1.3	51	0.027
M-EB-W	09/13/2012	161	82.2	1.89	528	<0.01	0.762	<0.001	<0.14	0.90	0.215
M-EB-W	11/13/2012	152	79.7	1.83	448	<0.01	1.32	<0.001	<0.14	1.5	0.209
M-EB-W	04/15/2013	120	86.7	1.80	328	<0.01	2.82	<0.001	<0.16	3.0	0.194
M-EB-W	07/09/2013	159	88.2	2.18	489	<0.01	1.50	0.004	<0.13	1.6	0.215
M-EB-W	09/19/2013	110	62.1	2.08	345	<0.01	0.929	0.066	<0.21	1.2	0.212
M-EB-E	09/13/2012	145	78.5	1.78	443	<0.01	0.921	0.039	<0.2	1.2	0.016
M-EB-E	11/13/2012	163	80.8	2.00	513	<0.01	0.362	0.031	<0.15	0.54	0.019
M-EB-E	04/15/2013	130	77.9	1.90	361	0.01	2.23	0.025	0.32	2.6	0.018
M-EB-E	07/09/2013	121	82.8	2.06	333	<0.01	2.33	0.027	<0.18	2.5	0.020
M-EB-E	09/19/2013	145	98.0	2.05	505	<0.01	1.18	0.051	<0.41	1.6	0.020

Table 6. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for groundwater samples, Fountain Creek near Pueblo, Colo., 2012–2013.—Continued

[USGS, U.S. Geological Survey; °C, degrees Celsius; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; <, less than; --, no data; M, value is below the reporting level but at or above the detection level; E, estimated; δ¹⁸O, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); δ²H, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil]

Local well name	Date	Sodium, filtered (mg/L)	Chloride, filtered (mg/L)	Fluoride, filtered (mg/L)	Sulfate, filtered (mg/L)	Ammonia, as N filtered (mg/L)	Nitrate, as N filtered (mg/L)	Nitrite, as N filtered (mg/L)	Organic nitrogen, unfiltered (mg/L)	Total nitrogen, unfiltered (mg/L)	Orthophosphate, as P filtered (mg/L)
S-WB-W	09/19/2012	371	144	1.88	1,870	0.14	3.62	0.071	0.21	4.0	0.008
S-WB-W	11/20/2012	330	119	2.06	1,460	<0.01	3.07	0.080	<0.26	3.4	0.008
S-WB-W	04/22/2013	281	108	2.70	1,170	0.01	2.25	0.071	0.22	2.6	0.008
S-WB-W	07/11/2013	265	111	2.38	1,290	0.04	3.07	0.052	0.23	3.4	0.009
S-WB-W	10/22/2013	248	99.0	2.47	994	0.02	7.43	0.084	0.32	7.8	0.009
S-WB-E Shallow	09/12/2012	158	77.1	1.96	531	<0.01	0.938	0.017	<0.15	1.1	0.097
S-WB-E Shallow	11/20/2012	153	80.1	1.76	531	<0.01	1.42	<0.001	<0.15	1.6	0.103
S-WB-E Shallow	04/22/2013	158	85.1	1.80	616	0.02	1.77	<0.001	0.14	1.9	0.086
S-WB-E Shallow	07/11/2013	179	88.7	1.80	912	<0.01	1.45	<0.001	<0.14	1.6	0.094
S-WB-E Shallow	09/25/2013	181	75.7	1.85	811	<0.01	1.21	0.018	<0.15	1.4	0.103
S-WB-E Deep	09/12/2012	152	77.7	1.80	527	0.03	1.07	0.004	0.14	1.2	0.028
S-WB-E Deep	11/20/2012	167	82.7	1.72	590	<0.01	1.63	0.001	<0.13	1.8	0.030
S-WB-E Deep	04/22/2013	189	86.9	1.60	811	<0.01	1.09	0.003	<0.10	1.2	0.026
S-WB-E Deep	07/11/2013	221	87.8	1.51	1,150	<0.01	1.24	0.005	<0.18	1.4	0.027
S-WB-E Deep	09/25/2013	246	80.1	1.61	1,180	<0.01	1.51	0.004	<0.14	1.6	0.029
S-EB-W Shallow	09/11/2012	264	91.0	2.28	1,350	0.03	0.091	0.051	0.08	0.25	0.016
S-EB-W Shallow	11/19/2012	262	90.4	2.25	1,280	0.02	0.054	0.038	0.08	0.19	0.017
S-EB-W Shallow	04/11/2013	246	101	2.00	1,380	<0.01	0.147	0.040	<0.16	0.34	0.014
S-EB-W Shallow	07/10/2013	240	94.0	2.77	1,420	0.03	0.099	0.041	0.11	0.28	0.019
S-EB-W Shallow	09/23/2013	365	123	2.50	1,770	0.17	0.139	0.054	0.10	0.46	0.020
S-EB-W Deep	09/10/2012	262	90.5	2.23	1,350	0.05	0.267	0.015	0.06	0.39	0.010
S-EB-W Deep	11/19/2012	269	89.2	2.27	1,280	0.01	0.207	0.011	0.10	0.33	0.013
S-EB-W Deep	04/11/2013	233	95.9	2.10	1,280	<0.01	0.507	0.013	<0.15	0.67	0.011
S-EB-W Deep	07/10/2013	239	92.0	2.60	1,350	0.03	0.271	0.011	0.09	0.41	0.013
S-EB-W Deep	09/23/2013	285	95.9	2.19	1,610	0.10	0.405	0.022	0.08	0.61	0.014
S-EB-E Shallow	09/11/2012	207	84.6	2.66	1,130	0.06	0.059	0.013	0.16	0.30	0.008
S-EB-E Shallow	11/19/2012	216	83.3	2.71	1,050	0.05	0.048	0.012	0.17	0.28	0.011
S-EB-E Shallow	04/17/2013	197	85.9	2.70	980	0.04	0.132	0.020	0.13	0.32	0.010
S-EB-E Shallow	07/10/2013	181	84.1	3.21	938	0.06	0.110	0.016	0.09	0.27	0.010
S-EB-E Shallow	09/16/2013	182	84.3	2.84	976	0.05	0.028	0.007	0.24	0.32	0.009
S-EB-E Deep	09/11/2012	186	81.7	2.25	922	0.03	0.234	0.006	0.70	0.97	0.007
S-EB-E Deep	11/19/2012	142	81.0	2.35	851	<0.01	0.315	0.003	<0.09	0.41	0.009
S-EB-E Deep	04/17/2013	170	85.2	2.30	860	<0.01	0.708	0.003	<0.15	0.86	0.008
S-EB-E Deep	07/10/2013	167	83.7	2.64	853	<0.01	0.541	0.003	<0.07	0.61	0.010
S-EB-E Deep	09/16/2013	192	85.1	2.36	1,060	<0.01	0.012	<0.001	<0.12	0.13	0.010

Table 6. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for groundwater samples, Fountain Creek near Pueblo, Colo., 2012–2013.—Continued

[USGS, U.S. Geological Survey; °C, degrees Celsius; $\mu\text{S}/\text{cm}$ at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than; --, no data; M, value is below the reporting level but at or above the detection level; E, estimated; $\delta^{18}\text{O}$, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); $\delta^2\text{H}$, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil]

Local well name	Date	Phosphorus, as P unfiltered (mg/L)	Barium, filtered (μg/L)	Iron, filtered (μg/L)	Manganese, filtered (μg/L)	Selenium, filtered (μg/L)	Uranium, natural filtered (μg/L)	$\delta^{18}\text{O}$ (‰)	$\delta^2\text{H}$ (‰)
N-WB-W	09/17/2012	0.013	23.8	5.6	840	16.0	12.0	-11.78	-90.40
N-WB-W	11/14/2012	0.012	24.0	4.6	829	20.4	11.6	-12.06	-92.90
N-WB-W	04/08/2013	0.018	21.1	9.3	700	11.6	11.9	-11.36	-88.70
N-WB-W	07/08/2013	0.017	20.3	16.7	680	10.6	9.42	-11.40	-87.40
N-WB-W	09/17/2013	0.029	29.4	7.0	989	6.6	10.3	-10.57	-81.50
N-WB-M	09/17/2012	0.051	33.6	10.0	1,400	6.0	8.87	-11.79	-90.90
N-WB-M	11/14/2012	0.057	29.7	4.0	1,050	9.7	8.19	-11.89	-91.80
N-WB-M	04/10/2013	0.058	26.1	6.7	934	1.5	10.3	-11.46	-89.20
N-WB-M	07/08/2013	0.053	26.1	6.6	885	0.33	8.34	-11.37	-87.90
N-WB-M	09/17/2013	0.068	26.3	9.4	676	8.4	4.43	-11.14	-85.10
N-WB-E	09/17/2012	0.112	41.5	19.2	111	11.1	10.1	-11.48	-89.50
N-WB-E	11/14/2012	0.088	33.2	33.8	27.3	14.2	9.60	-11.68	-91.00
N-WB-E	04/10/2013	0.102	36.1	13.7	23.7	18.9	11.9	-11.73	-91.10
N-WB-E	07/08/2013	0.122	36.1	28.9	26.4	17.2	8.79	-11.40	-90.00
N-EB-W	09/18/2012	0.206	22.7	25.5	158	1,250	94.4	-9.61	-73.50
N-EB-W	11/15/2012	0.366	25.2	40.0	54.9	1,330	149	-10.70	-80.90
N-EB-W	04/16/2013	0.807	22.6	39.5	23.5	1,700	171	-11.88	-91.80
N-EB-W	07/09/2013	0.573	20.5	34.9	8.92	1,920	140	-12.02	-92.60
N-EB-W	09/18/2013	0.179	22.7	16.4	11.4	1,190	71.3	-11.96	-89.30
N-EB-E	09/18/2012	0.027	33.5	31.2	46.2	2,280	136	-10.89	-85.20
N-EB-E	11/15/2012	0.033	32.4	<20.0	20.3	1,670	195	-11.82	-89.20
N-EB-E	04/16/2013	0.105	23.0	38.9	5.91	1,920	184	-12.08	-93.30
N-EB-E	07/09/2013	0.033	21.0	93.3	6.80	1,580	127	-12.18	-92.20
N-EB-E	09/18/2013	0.034	28.9	20.7	44.1	1,250	74.3	-9.60	-71.30
M-EB-W	09/13/2012	0.234	59.1	3.2	1.90	19.8	8.33	-11.00	-85.60
M-EB-W	11/13/2012	0.216	53.7	4.4	0.32	25.9	11.1	-11.33	-88.60
M-EB-W	04/15/2013	0.211	37.6	4.0	0.54	13.7	9.68	-12.30	-96.20
M-EB-W	07/09/2013	0.207	55.5	4.0	0.49	23.1	8.60	-11.41	-91.80
M-EB-W	09/19/2013	0.223	40.0	4.2	0.99	9.3	5.55	-11.06	-83.00
M-EB-E	09/13/2012	0.092	54.7	4.1	444	15.8	7.37	-11.36	-88.50
M-EB-E	11/13/2012	0.022	55.3	12.5	383	17.5	9.43	-11.02	-86.10
M-EB-E	04/15/2013	0.119	44.1	71.9	287	38.8	9.44	-11.96	-93.10
M-EB-E	07/09/2013	0.027	36.4	14.8	245	31.0	7.96	-12.09	-95.40
M-EB-E	09/19/2013	0.174	50.6	10.6	317	26.4	9.63	-11.64	-92.30
S-WB-W	09/19/2012	0.011	22.7	11.1	286	58.9	26.8	-11.95	-94.40

Table 6. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for groundwater samples, Fountain Creek near Pueblo, Colo., 2012–2013.—Continued

[USGS, U.S. Geological Survey; °C, degrees Celsius; $\mu\text{S}/\text{cm}$ at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than; --, no data; M, value is below the reporting level but at or above the detection level; E, estimated; $\delta^{18}\text{O}$, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); $\delta^2\text{H}$, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil]

Local well name	Date	Phosphorus, as P unfiltered (mg/L)	Barium, filtered (μg/L)	Iron, filtered (μg/L)	Manganese, filtered (μg/L)	Selenium, filtered (μg/L)	Uranium, natural filtered (μg/L)	$\delta^{18}\text{O}$ (‰)	$\delta^2\text{H}$ (‰)
S-WB-W	11/20/2012	0.011	18.2	11.9	205	45.2	19.9	-11.52	-88.60
S-WB-W	04/22/2013	0.023	14.7	21.3	151	44.2	15.9	-11.38	-89.80
S-WB-W	07/11/2013	0.012	24.8	14.5	254	96.4	27.1	-11.99	-93.60
S-WB-W	10/22/2013	0.045	19.8	12.4	202	49.5	15.9	-11.83	-92.20
S-WB-E Shallow	09/12/2012	0.103	32.2	5.5	2.63	19.3	8.22	-10.61	-82.30
S-WB-E Shallow	11/20/2012	0.123	35.2	6.5	2.94	27.7	12.3	-11.37	-87.60
S-WB-E Shallow	04/22/2013	0.130	30.0	15.7	4.62	23.3	17.8	-11.61	-90.17
S-WB-E Shallow	07/11/2013	0.116	44.8	19.6	1.19	30.8	19.9	-11.56	-89.86
S-WB-E Shallow	09/25/2013	0.145	44.8	8.0	1.88	26.9	13.2	-11.03	-85.74
S-WB-E Deep	09/12/2012	0.038	36.3	8.7	183	23.1	11.3	-10.87	-84.00
S-WB-E Deep	11/20/2012	0.028	35.5	6.7	92.5	28.2	13.9	-11.58	-89.00
S-WB-E Deep	04/22/2013	0.031	33.3	10.4	54.0	30.4	20.8	-11.37	-88.20
S-WB-E Deep	07/11/2013	0.027	43.7	16.5	68.3	43.4	25.6	-11.46	-90.00
S-WB-E Deep	09/25/2013	0.046	50.9	8.0	79.4	48.2	25.1	-11.56	-89.40
S-EB-W Shallow	09/11/2012	0.015	29.6	15.7	1,290	18.2	17.7	-11.46	-88.20
S-EB-W Shallow	11/19/2012	0.017	27.4	18.2	1,150	12.2	18.7	-11.46	-88.20
S-EB-W Shallow	04/11/2013	0.013	23.8	13.5	1,220	13.7	17.0	-11.64	-89.90
S-EB-W Shallow	07/10/2013	0.016	30.6	22.2	1,400	21.1	18.9	-11.63	-89.60
S-EB-W Shallow	09/23/2013	0.030	34.7	16.0	1,600	28.4	24.6	-11.50	-89.10
S-EB-W Deep	09/10/2012	0.009	28.8	14.9	1,500	23.6	18.5	-11.51	-89.80
S-EB-W Deep	11/19/2012	0.011	27.3	15.8	1,360	19.1	18.1	-11.38	-88.30
S-EB-W Deep	04/11/2013	0.012	24.7	9.6	1,370	26.7	14.7	-11.65	-90.20
S-EB-W Deep	07/10/2013	0.011	26.6	8.0	1,390	24.4	17.0	-11.68	-90.10
S-EB-W Deep	09/23/2013	0.012	28.7	8.0	1,602	42.1	21.7	-11.61	-89.80
S-EB-E Shallow	09/11/2012	0.053	22.6	28.1	2,560	5.5	21.4	-11.60	-90.00
S-EB-E Shallow	11/19/2012	0.065	22.7	42.9	2,330	5.0	18.4	-11.50	-88.50
S-EB-E Shallow	04/17/2013	0.011	23.4	24.6	2,250	5.5	17.1	-11.56	-89.60
S-EB-E Shallow	07/10/2013	0.014	19.7	22.0	2,270	5.6	17.8	-11.61	-89.80
S-EB-E Shallow	09/16/2013	0.064	27.5	34.8	1.54	0.76	0.916	-11.59	-89.90
S-EB-E Deep	09/11/2012	0.883	37.6	30.7	2,510	12.9	11.9	-11.60	-90.30
S-EB-E Deep	11/19/2012	0.035	27.3	8.8	1,410	14.0	11.9	-11.45	-88.90
S-EB-E Deep	04/17/2013	0.055	27.0	8.0	1,300	13.7	10.9	-11.73	-90.90
S-EB-E Deep	07/10/2013	0.031	23.1	8.0	1,120	15.8	11.2	-11.79	-89.70
S-EB-E Deep	09/16/2013	0.029	25.9	22.1	1.01	0.64	0.836	-11.42	-89.20

Table 7. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for surface-water samples from Fountain Creek near Pueblo, Colo., 2012–2013.

[USGS, U.S. Geological Survey; °C, degrees Celsius; $\mu\text{S}/\text{cm}$ at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than; --, no data; E, estimated; $\delta^{18}\text{O}$, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); $\delta^2\text{H}$, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil]

Local site name	USGS site number	Date	Field measurements					Residue on evaporation at 180 °C (dissolved solids) (mg/L)	Calcium, filtered (mg/L)	Magnesium, filtered (mg/L)	Potassium, filtered (mg/L)
			Water temperature (°C)	pH, standard units	Specific conductance ($\mu\text{S}/\text{cm}$ at 25 °C)	Dissolved oxygen (mg/L)	Alkalinity (mg/L as CaCO_3)				
North transect	381754104361902	09/18/2012	24.0	8.2	1,450	E7.4	209	1,030	112	49.5	7.40
North transect	381754104361902	11/14/2012	7.8	8.4	1,160	9.6	189	788	95.6	33.3	7.10
North transect	381754104361902	04/18/2013	1.8	8.2	1,320	12.3	191	882	98.4	39.2	6.08
North transect	381754104361902	07/01/2013	22.8	8.3	1,310	6.8	194	887	98.8	39.4	6.85
North transect	381754104361902	09/26/2013	13.9	8.1	894	10.1	142	601	77.9	23.7	6.66
Middle transect	381653104361002	09/13/2012	16.1	8.5	556	E8.2	92	376	46.3	15.0	6.33
Middle transect	381653104361002	11/13/2012	7.1	8.2	1,180	10.4	185	804	97.2	34.0	7.09
Middle transect	381653104361002	04/18/2013	3.8	8.3	1,340	12.3	191	936	102	41.7	6.20
Middle transect	381653104361002	07/01/2013	28.1	8.3	1,400	6.9	196	968	103	42.8	6.82
Middle transect	381653104361002	09/26/2013	16.0	8.1	915	8.5	142	609	78.1	24.1	6.63
South transect	381532104353503	09/12/2012	17.1	8.0	1,790	--	222	1,330	129	75.3	7.40
South transect	381532104353503	11/20/2012	3.5	8.2	1,280	11.5	196	892	99	39.9	7.55
South transect	381532104353503	04/18/2013	6.5	8.4	1,380	11.2	194	989	102	46.0	6.43
South transect	381532104353503	07/01/2013	29.5	8.3	1,510	6.0	203	1,060	104	49.2	7.17
South transect	381532104353503	09/26/2013	17.2	8.2	927	8.1	142	624	79.6	25.2	6.70

Local site name	Date	Sodium, filtered (mg/L)	Chloride, filtered (mg/L)	Fluoride, filtered (mg/L)	Sulfate, filtered (mg/L)	Ammonia, as N filtered (mg/L)	Nitrate, as N filtered (mg/L)	Nitrite, as N filtered (mg/L)	Organic nitrogen, unfiltered (mg/L)	Total nitrogen, unfiltered (mg/L)	Orthophosphate, as P filtered (mg/L)
North transect	09/18/2012	150	80.1	1.79	450	0.02	1.20	0.009	0.16	1.4	0.162
North transect	11/14/2012	122	72.5	1.86	301	0.02	2.50	0.005	0.46	3.0	0.398
North transect	04/18/2013	136	87.9	1.90	394	<0.01	2.39	0.003	<0.34	2.7	0.179
North transect	07/01/2013	120	80.5	2.13	379	0.02	1.60	0.02	0.55	2.2	0.181
North transect	09/26/2013	80	51.4	2.12	220	<0.01	1.91	0.004	<0.72	2.6	0.128
Middle transect	09/13/2012	52.1	29.4	0.98	138	<0.01	1.68	0.003	<14	15	0.203
Middle transect	11/13/2012	123	72.6	1.88	304	0.03	2.72	0.005	0.92	3.7	0.391
Middle transect	04/18/2013	136	86.2	1.90	399	<0.01	2.56	0.003	<0.35	2.9	0.180
Middle transect	07/01/2013	122	78.9	2.09	392	0.02	1.73	0.023	0.65	2.4	0.184
Middle transect	09/26/2013	80.7	54.0	2.08	237	<0.01	1.91	0.004	<0.69	2.6	0.131
South transect	09/12/2012	172	84.9	1.94	638	<0.01	0.930	0.008	<0.24	1.2	0.076
South transect	11/20/2012	131	74.9	1.61	359	<0.01	2.42	0.003	<0.45	2.9	0.309
South transect	04/18/2013	147	94.3	1.90	466	<0.01	2.51	0.004	<0.32	2.8	0.191
South transect	07/01/2013	128	79.8	2.12	437	0.02	1.61	0.024	0.66	2.3	0.181
South transect	09/26/2013	80.7	47.0	1.86	206	<0.01	1.90	0.004	<0.68	2.6	0.128

Table 7. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for surface-water samples from Fountain Creek near Pueblo, Colo., 2012–2013.—Continued

[USGS, U.S. Geological Survey; °C, degrees Celsius; $\mu\text{S}/\text{cm}$ at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than; --, no data; E, estimated; $\delta^{18}\text{O}$, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); $\delta^2\text{H}$, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil]

Local site name	Date	Phosphorus, as P unfiltered (mg/L)	Barium, filtered ($\mu\text{g}/\text{L}$)	Iron, filtered ($\mu\text{g}/\text{L}$)	Manganese, filtered ($\mu\text{g}/\text{L}$)	Selenium, filtered ($\mu\text{g}/\text{L}$)	Uranium, natural filtered ($\mu\text{g}/\text{L}$)	$\delta^{18}\text{O}$ (‰)	$\delta^2\text{H}$ (‰)
North transect	09/18/2012	0.140	61.8	3.2	32.9	13.1	9.33	–11.42	–89.30
North transect	11/14/2012	0.628	45.0	11.6	6.56	7.7	7.26	–11.93	–93.70
North transect	04/18/2013	0.251	39.2	4.0	5.97	10.4	8.33	–12.00	–94.50
North transect	07/01/2013	0.363	48.2	9.2	17.5	10.2	7.85	–11.53	–92.00
North transect	09/26/2013	0.659	39.6	15.5	15.1	4.4	5.28	–11.90	–90.20
Middle transect	09/13/2012	5.03	33.4	52.7	4.00	6.5	3.47	–12.04	–85.40
Middle transect	11/13/2012	0.814	44.7	11.0	4.13	9.9	7.30	–11.90	–94.00
Middle transect	04/18/2013	0.267	41.5	4.0	3.94	14.9	8.73	–12.16	–94.90
Middle transect	07/01/2013	0.326	48.0	8.5	14.8	15.3	7.90	–11.38	–90.70
Middle transect	09/26/2013	0.641	39.4	6.9	11.3	5.5	5.17	–11.93	–88.20
South transect	09/12/2012	0.094	55.4	4.1	16.9	27.4	11.1	–11.01	–85.40
South transect	11/20/2012	0.504	46.3	6.3	8.24	12.8	8.16	–11.86	–93.10
South transect	04/18/2013	0.248	41.3	4.0	6.30	15.5	9.16	–12.07	–94.70
South transect	07/01/2013	0.352	53.9	35.8	23.5	16.3	9.00	–11.35	–90.20
South transect	09/26/2013	0.606	40.0	5.3	9.90	5.5	5.46	–11.88	–88.80

Table 8. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for hyporheic-zone samples, Fountain Creek near Pueblo, Colo., 2012–2013.

[LEW, left edge of water; REW, right edge of water; USGS, U.S. Geological Survey; °C, degrees Celsius; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; <, less than; E, estimated; δ¹⁸O, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); δ²H, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil]

Local site name	USGS site number	Date	Field measurements					Residue on evaporation at 180 °C (dissolved solids) (mg/L)	Calcium, filtered (mg/L)	Magnesium, filtered (mg/L)	Potassium, filtered (mg/L)
			Water temperature (°C)	pH, standard units	Specific conductance (µS/cm at 25 °C)	Dissolved oxygen (mg/L)	Alkalinity (mg/L as CaCO ₃)				
North transect-REW	381754104361902	04/25/2013	9.4	7.5	1,340	1.0	202	927	87.0	48.7	6.56
North transect-REW	381754104361902	07/15/2013	20.9	7.8	1,350	1.8	166	971	103	48.3	6.94
North transect-REW	381754104361902	10/23/2013	15.4	7.1	2,930	0.8	274	2,500	188	198	8.62
North transect-LEW	381754104361902	04/25/2013	11.8	7.6	1,460	E4.3	303	1,080	95.1	62.8	6.93
North transect-LEW	381754104361902	07/15/2013	21.5	7.4	1,550	0.3	210	1,100	110	58.4	7.77
North transect-LEW	381754104361902	10/23/2013	10.6	8.0	1,140	8.8	171	769	91.7	31.4	6.83
Middle transect-LEW	381653104361002	04/25/2013	9.8	7.8	1,280	E4.8	188	860	95.8	36.5	6.52
Middle transect-LEW	381653104361002	07/17/2013	21.3	7.7	929	0.4	161	620	70.3	28.9	7.28
Middle transect-LEW	381653104361002	10/23/2013	13.8	7.6	1,100	E3.6	175	767	91.4	34.0	6.67
South transect-REW	381532104353503	04/23/2013	11.0	7.4	2,930	E4.5	303	2,590	230	179	7.92
South transect-REW	381532104353503	07/18/2013	19.0	7.0	3,210	0.3	304	2,810	259	197	9.33
South transect-REW	381532104353503	10/23/2013	12.1	7.4	1,180	0.3	213	779	97.3	34.6	7.00
South transect-LEW	381532104353503	04/23/2013	9.1	7.2	2,840	E1.4	260	2,460	222	171	7.39
South transect-LEW	381532104353503	07/18/2013	17.9	7.1	3,090	0.4	310	2,650	250	185	8.86
South transect-LEW	381532104353503	10/23/2013	14.7	7.0	3,980	0.3	353	3,570	295	243	10.4

Local site name	Date	Sodium, filtered (mg/L)	Chloride, filtered (mg/L)	Fluoride, filtered (mg/L)	Sulfate, filtered (mg/L)	Ammonia, as N filtered (mg/L)	Nitrate, as N filtered (mg/L)	Nitrite, as N filtered (mg/L)	Organic nitrogen, unfiltered (mg/L)	Total nitrogen, unfiltered (mg/L)	Orthophosphate, as P filtered (mg/L)
North transect-REW	04/25/2013	132	87.8	2.03	391	0.01	2.35	0.009	0.39	2.8	0.183
North transect-REW	07/15/2013	122	66.0	2.00	462	0.02	1.37	0.054	0.52	2.0	0.186
North transect-REW	10/23/2013	281	103	1.81	1,280	0.06	0.554	0.034	0.56	1.2	0.046
North transect-LEW	04/25/2013	154	82.3	2.01	436	14.3	0.634	0.023	8.3	23	0.065
North transect-LEW	07/18/2013	146	84.3	1.88	513	<0.01	0.283	0.016	<0.14	0.44	0.127
North transect-LEW	10/23/2013	110	67.2	1.81	296	<0.01	2.62	<0.001	<0.61	3.2	0.149
Middle transect-LEW	04/25/2013	128	88.7	1.97	359	<0.01	3.16	<0.001	<0.60	3.8	0.262
Middle transect-LEW	07/17/2013	86.6	58.2	1.43	245	0.12	0.252	0.008	0.32	0.71	0.234
Middle transect-LEW	10/23/2013	111	65.3	1.92	321	<0.01	1.02	0.005	<0.22	1.2	0.135
South transect-REW	04/23/2013	264	109	2.87	1,430	0.05	0.378	0.003	0.18	0.61	0.025
South transect-REW	07/18/2013	276	92.3	2.28	1,500	0.04	0.448	0.005	0.04	0.53	0.067
South transect-REW	10/23/2013	113	63.5	1.67	277	0.03	0.281	0.017	0.24	0.56	0.081
South transect-LEW	04/23/2013	251	95.8	2.51	1,360	0.02	0.276	0.042	0.28	0.62	0.018
South transect-LEW	07/18/2013	263	97.8	2.49	1,390	0.06	0.120	0.014	0.13	0.32	0.029
South transect-LEW	10/23/2013	416	128	2.20	1,830	0.19	0.080	0.034	0.08	0.38	0.013

Table 8. Field measurements and dissolved-solids, major-ion, nutrient, trace-element, and isotope data for hyporheic-zone samples, Fountain Creek near Pueblo, Colo., 2012–2013.—Continued

[LEW, left edge of water; REW, right edge of water; USGS, U.S. Geological Survey; °C, degrees Celsius; $\mu\text{S}/\text{cm}$ at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than; E, estimated; $\delta^{18}\text{O}$, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); $\delta^2\text{H}$, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil]

Local site name	Date	Phosphorus, as P unfiltered (mg/L)	Barium, filtered ($\mu\text{g}/\text{L}$)	Iron, filtered ($\mu\text{g}/\text{L}$)	Manganese, filtered ($\mu\text{g}/\text{L}$)	Selenium, filtered ($\mu\text{g}/\text{L}$)	Uranium, natural filtered ($\mu\text{g}/\text{L}$)	$\delta^{18}\text{O}$ (‰)	$\delta^2\text{H}$ (‰)
North transect-REW	04/25/2013	0.308	45.7	5.0	35.0	12.1	8.25	−11.84	−93.10
North transect-REW	07/15/2013	0.267	48.0	4.0	7.87	11.4	6.44	−10.60	−80.40
North transect-REW	10/23/2013	0.325	86.0	11.0	813	28.7	13.3	−11.48	−88.30
North transect-LEW	04/25/2013	2.31	236.0	954.0	263	6.4	5.45	−11.76	−91.30
North transect-LEW	07/18/2013	0.129	42.8	4.0	4.88	12.3	9.45	−11.18	−88.40
North transect-LEW	10/23/2013	0.308	36.6	4.0	0.40	6.3	6.61	−11.88	−90.40
Middle transect-LEW	04/25/2013	0.411	44.6	9.4	0.84	13.0	7.81	−12.11	−94.40
Middle transect-LEW	07/17/2013	0.260	43.6	6.5	396	2.6	5.63	−10.47	−81.00
Middle transect-LEW	10/23/2013	0.162	36.8	4.0	1.21	7.2	6.73	−11.15	−84.30
South transect-REW	04/23/2013	0.028	27.0	8.0	1,600	23.5	18.7	−11.65	−90.30
South transect-REW	07/18/2013	0.067	47.6	8.0	2.60	38.5	15.1	−11.56	−90.00
South transect-REW	10/23/2013	0.119	66.1	4.0	296	2.7	5.39	−11.82	−90.20
South transect-LEW	04/23/2013	0.076	27.4	13.7	1,380	20.5	17.3	−11.65	−91.00
South transect-LEW	07/18/2013	0.078	31.0	13.2	1,540	19.0	20.6	−11.54	−89.40
South transect-LEW	10/23/2013	0.054	41.0	704.0	1,740	24.7	29.3	−11.74	−89.80

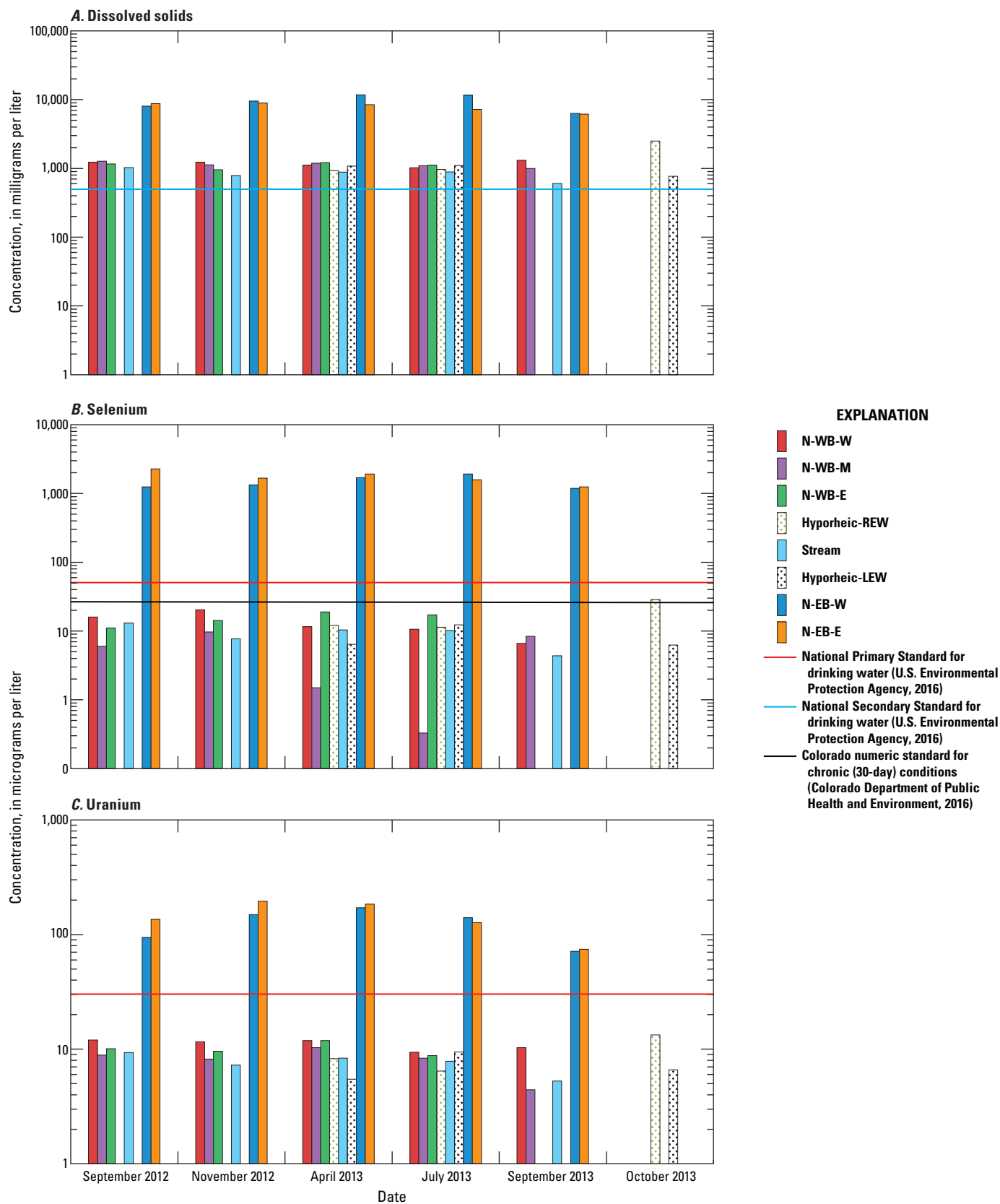


Figure 17. Concentration of *A*, dissolved solids; *B*, selenium; and *C*, uranium in groundwater, surface water, and the hyporheic zone at the north transect, Fountain Creek near Pueblo, Colo., 2012–2013.

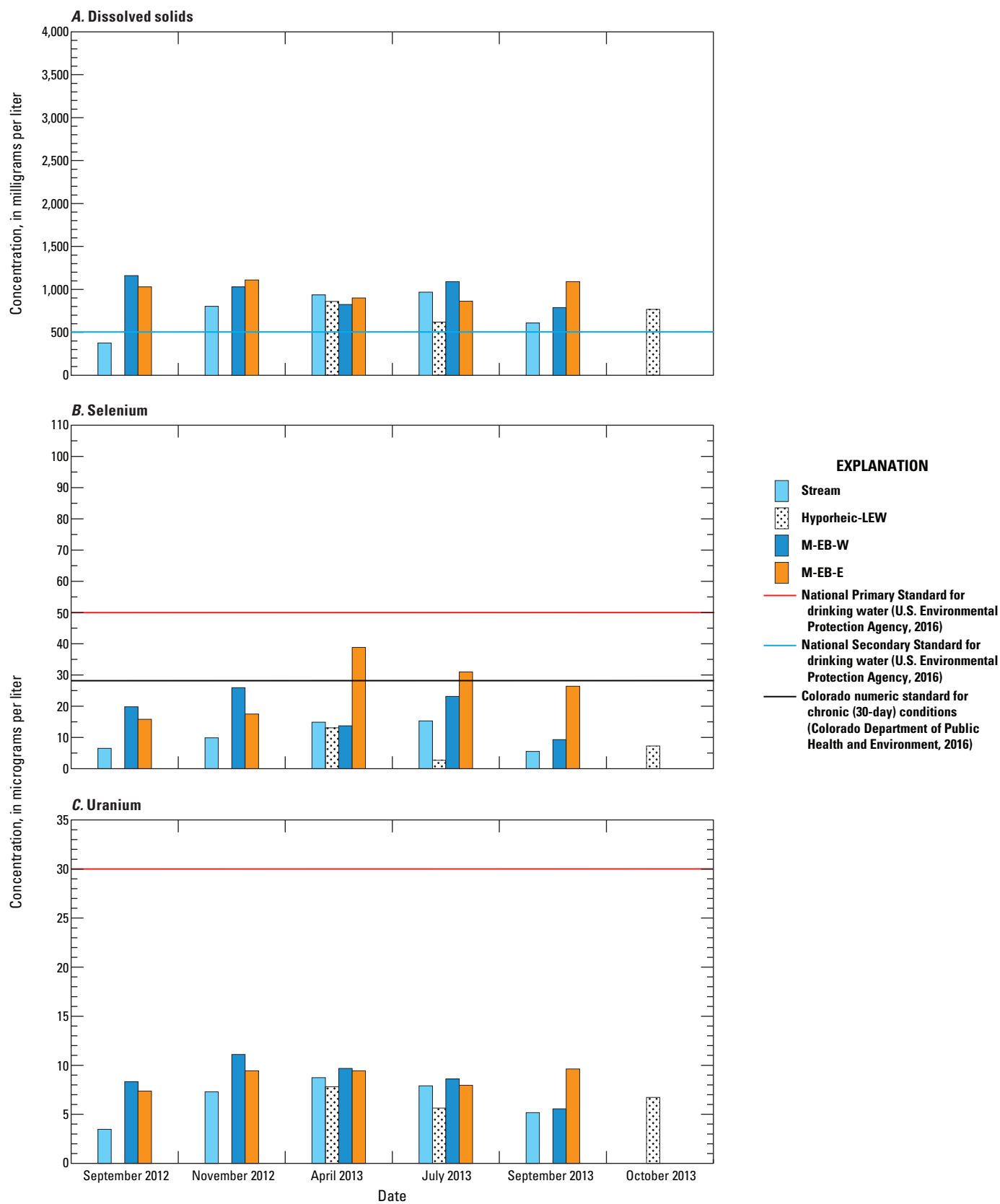


Figure 18. Concentration of *A*, dissolved solids; *B*, selenium; and *C*, uranium in groundwater, surface water, and the hyporheic zone at the middle transect, Fountain Creek near Pueblo, Colo., 2012–2013.

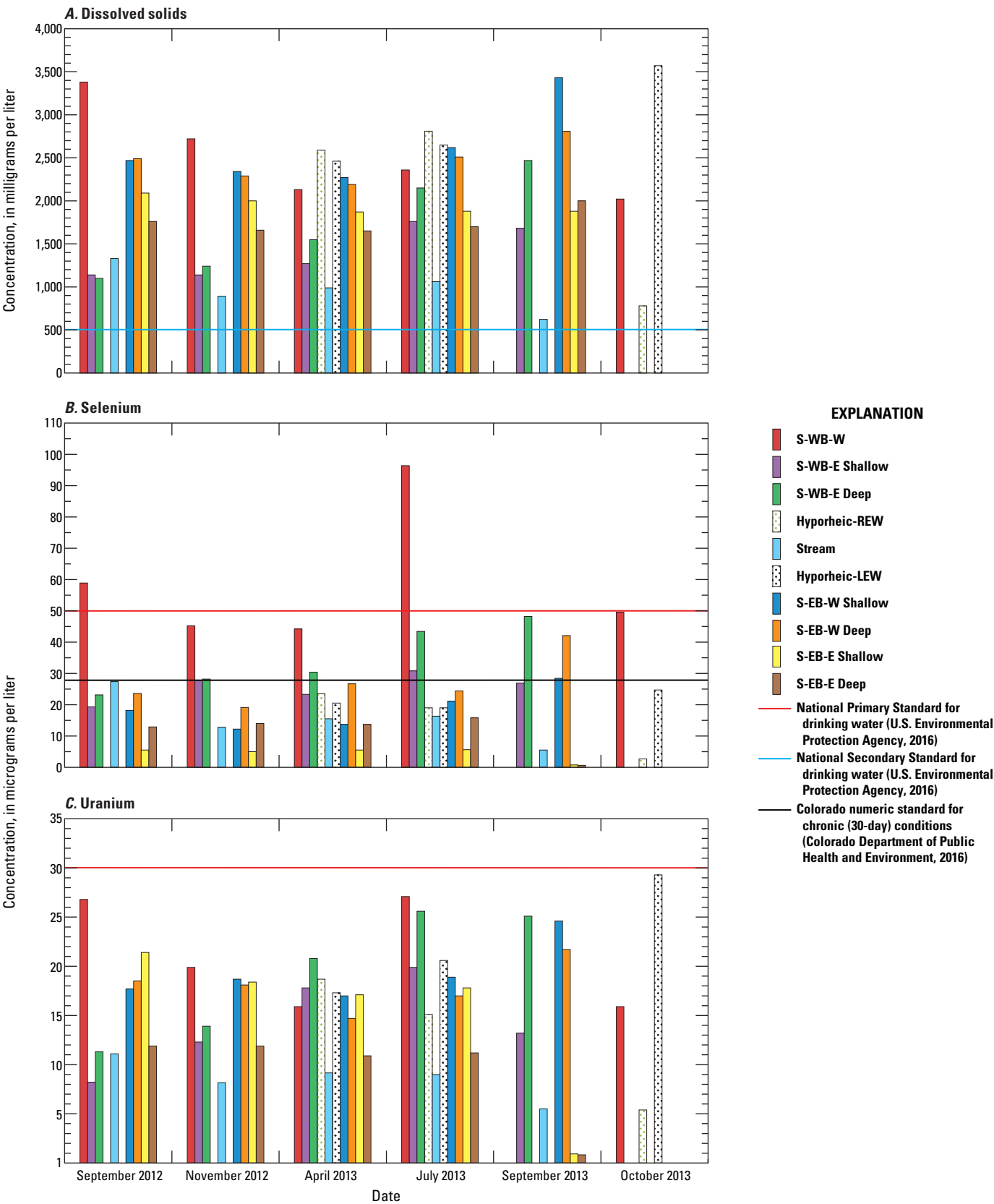


Figure 19. Concentration of *A*, dissolved solids; *B*, selenium; and *C*, uranium in groundwater, surface water, and the hyporheic zone at the south transect, Fountain Creek near Pueblo, Colo., 2012–2013.

or biological processes are affecting concentrations in these samples. Constituent concentrations in groundwater samples collected from wells located on the east side of the north transect (wells N-EB-W and N-EB-E) were substantially greater than in other groundwater, surface-water, and hyporheic-zone samples (fig. 17). For paired wells at the south transect, selenium concentrations were consistently greater in the deeper installation, but the relation of concentration to depth for dissolved solids and uranium varied (fig. 19). On the west side of Fountain Creek, groundwater samples collected from well S-WB-E Deep generally had greater dissolved-solids and uranium concentrations than samples collected from well S-WB-E Shallow, whereas groundwater samples collected from both well pairs on the east side of Fountain Creek (S-EB-W Shallow and Deep, S-EB-E Shallow and Deep) generally exhibit greater dissolved-solids and uranium concentrations in the shallower installation.

Concentrations of dissolved solids, selenium, and uranium in surface water generally increased in a downstream direction along Fountain Creek from the north transect to the south transect (fig. 20) and exhibited an inverse relation to streamflow with highest concentrations occurring during periods of low streamflow and lowest concentrations occurring during periods of high streamflow. Although shown for comparison to other dates, samples for September 2012 and November 2012 were not collected synoptically, and their results should not be used to directly infer water-quality relations among transects. The large differences in concentrations of dissolved solids, selenium, and uranium for the sampling event in September 2012 primarily is related to different streamflow conditions on each sample date (fig. 9). A surface-water sample was collected from Fountain Creek at the middle transect on September 13, 2012, under high-flow conditions, whereas samples were collected from the stream at the south transect on September 12, 2012, prior to the high-flow event and at the north transect on September 18, 2012, during the recession curve of the high-flow event. Because of the substantially greater constituent concentrations in groundwater from the east side of the north transect relative to other groundwater samples, subsequent analysis of groundwater quality is divided into two groups. Samples collected from the east side of the north transect are assigned to group 1, whereas all other groundwater samples are assigned to group 2.

Concentrations of major cations (calcium, magnesium, sodium, and potassium) and anions (sulfate, chloride, bicarbonate, nitrate plus nitrite, and fluoride) were plotted on a trilinear diagram (fig. 21) to compare the general chemical composition of samples collected from groundwater, surface water, and the hyporheic zone. Most groundwater (group 2) and surface-water samples exhibited a similar range of cationic compositions with calcium, magnesium, and sodium plus potassium occurring in approximately equal proportions. Most groundwater (group 2) and surface-water samples similarly exhibited a similar composition of anions with sulfate generally predominant relative to bicarbonate and

to chloride plus nitrate, nitrite, and fluoride. Groundwater samples from the east side of the north transect (group 1) had a somewhat different composition than other samples with more magnesium and sulfate than other samples. Hyporheic-zone samples had chemical compositions similar to groundwater (group 2) and surface-water samples but exhibited less variability, perhaps because of biogeochemical activity.

Dissolved Solids

Dissolved-solids concentrations for groundwater samples collected from wells on the east side of the north transect (group 1) ranged from 6,160 to 11,700 mg/L with a median concentration of 8,595 mg/L, whereas dissolved-solids concentrations for all other groundwater samples (group 2) ranged from 789 to 3,430 mg/L with a median concentration of 1,550 mg/L (fig. 22). Dissolved-solids concentrations ranged from 376 to 1,330 mg/L with a median value of 887 mg/L for surface-water samples and from 620 to 3,570 mg/L with a median value of 1,080 mg/L for hyporheic-zone samples. For synoptic measurements, dissolved-solids concentrations of surface-water samples exhibited a mean increase of about 13 percent between the north and south transects (fig. 20; table 7). Dissolved-solids concentrations for surface-water samples from each transect are similar to historical values reported by Miller and others (2010; table 6) for USGS streamgage 07106500 (Fountain Creek at Pueblo, CO), which had values ranging from 332 to 1,020 mg/L with a median value of 792 mg/L. With the exception of one sample collected from surface water in Fountain Creek at the middle transect on September 13, 2012, dissolved-solids concentrations for all samples exceeded the U.S. Environmental Protection Agency (EPA) National secondary drinking water standard of 500 mg/L (U.S. Environmental Protection Agency, 2016).

Selenium

Concentrations of dissolved selenium in groundwater, surface water, and the hyporheic zone (figs. 17–19) along Fountain Creek generally were less than the maximum contaminant level (MCL) of 50 micrograms per liter ($\mu\text{g/L}$) established by the EPA for National primary drinking water standards (U.S. Environmental Protection Agency, 2016). However, groundwater samples collected from wells on the east side of the north transect and from well S-WB-W (on September 19, 2012, and July 11, 2013, only) were greater than the MCL for selenium, and selenium concentrations for most samples exceeded the chronic (30-day) numeric standard of 28.1 $\mu\text{g/L}$ established by the state of Colorado for the reach of Fountain Creek sampled by study (Colorado Department of Public Health and Environment, 2016). Selenium concentrations in groundwater samples collected from wells on the east side of the north transect (group 1) ranged from 1,190 to 2,280 $\mu\text{g/L}$, with a median value of 1,625 $\mu\text{g/L}$ (fig. 22), which is substantially greater than selenium concentrations in other samples. Selenium concentrations in

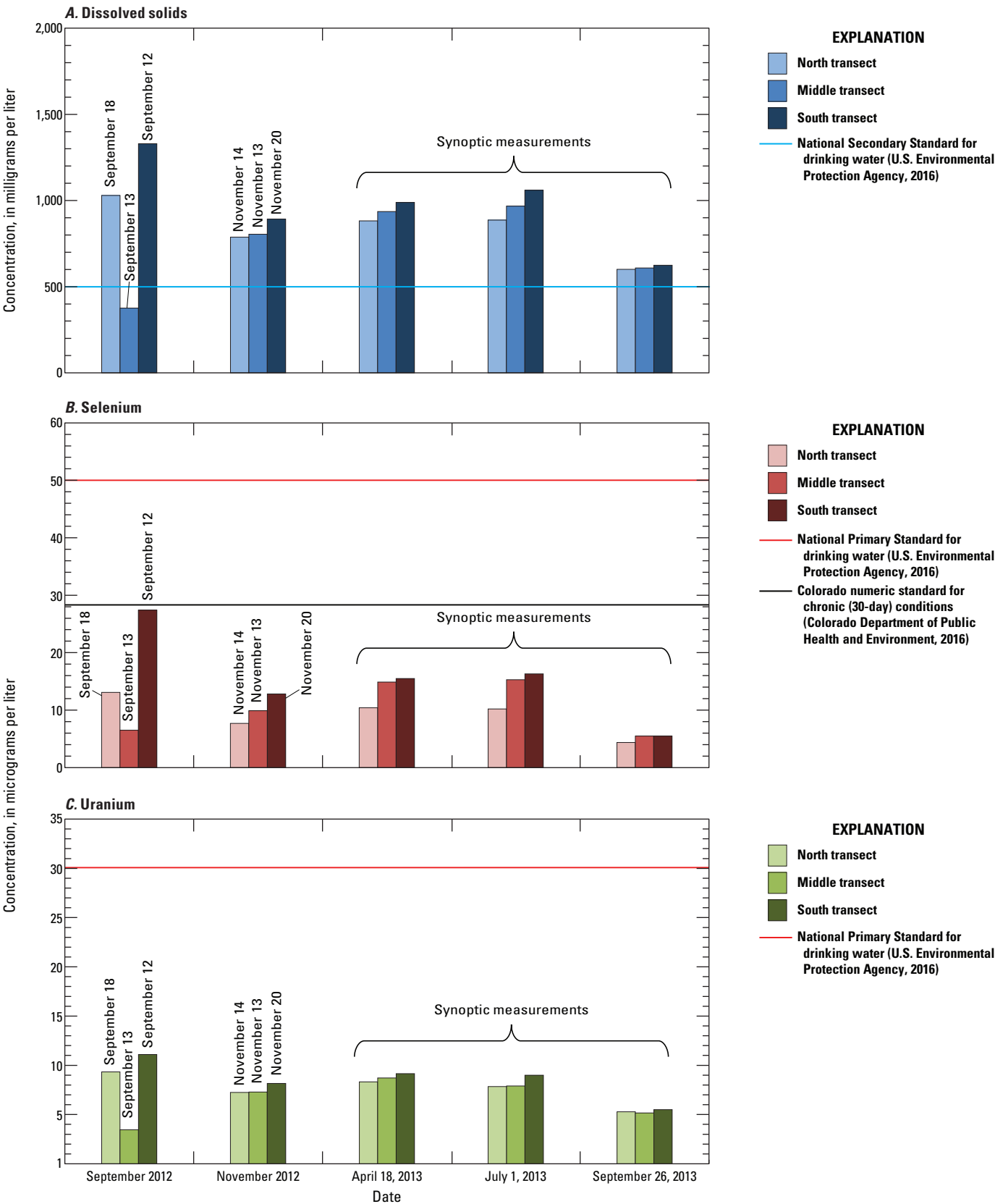


Figure 20. Concentration of *A*, dissolved solids; *B*, selenium; and *C*, uranium in surface water from Fountain Creek at north, middle, and south transects, 2012–2013.

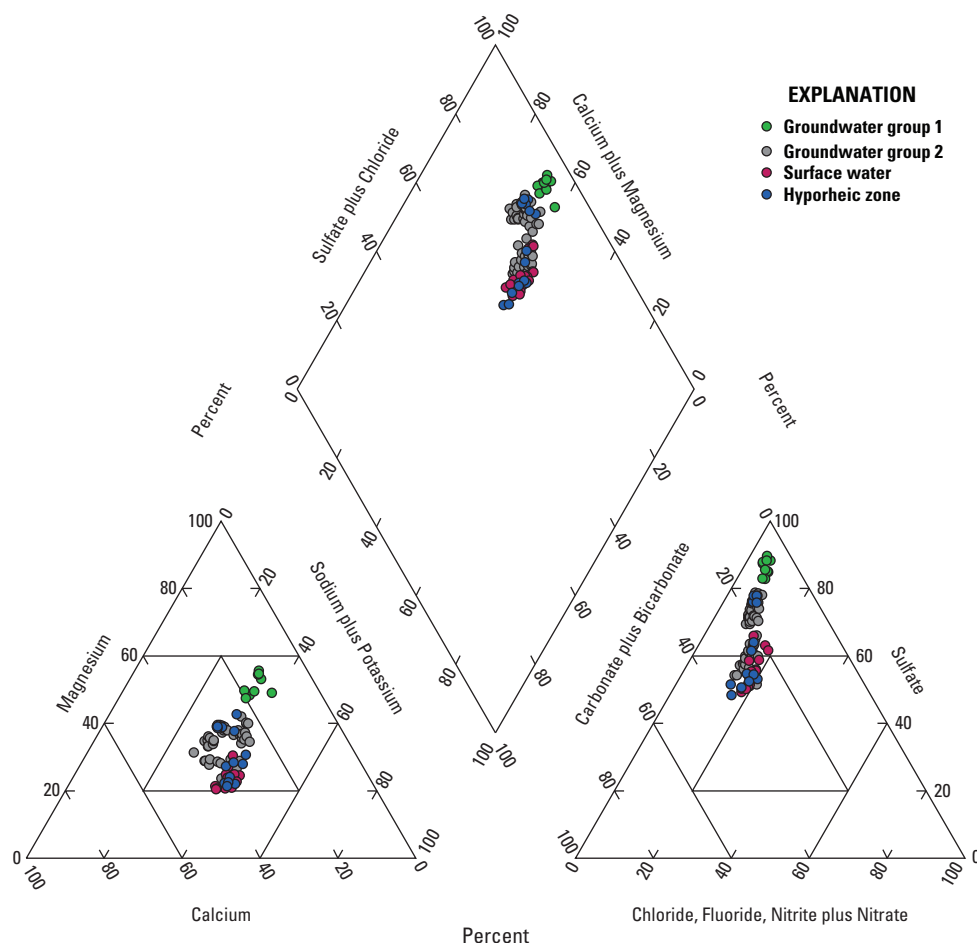


Figure 21. Trilinear diagram showing major cationic and anionic composition of samples from groundwater, surface water, and the hyporheic zone, Fountain Creek near Pueblo, Colo., 2012–2013.

other samples ranged from 0.33 to 96.4 $\mu\text{g/L}$ for groundwater group 2 (median 18.9 $\mu\text{g/L}$), 4.37–27.4 $\mu\text{g/L}$ for surface water (median 10.4 $\mu\text{g/L}$), and 2.6–38.5 $\mu\text{g/L}$ for the hyporheic zone (median 12.3 $\mu\text{g/L}$) (fig. 22). Selenium concentrations of synoptic surface-water samples collected from Fountain Creek exhibited a mean increase of about 49 percent between the north and south transects (fig. 20, table 7). Historical surface-water selenium concentrations in Fountain Creek at USGS streamgage 07106500 were reported by Miller and others (2010) to have a larger range (4.5–116.0 $\mu\text{g/L}$) and median value (15.0 $\mu\text{g/L}$) than samples collected at the transect locations.

Uranium

With the exception of groundwater samples collected on the east side of the north transect, all groundwater, surface-water, and hyporheic-zone samples had uranium concentrations below the National primary drinking water

MCL of 30 $\mu\text{g/L}$ (figs. 17–19). Uranium concentrations for groundwater samples collected on the east side of the north transect (group 1) ranged from 71.3 to 195 $\mu\text{g/L}$ with a median value of 138 $\mu\text{g/L}$ (fig. 22). As with dissolved solids and selenium, uranium concentrations in other groundwater samples (group 2), surface-water samples, and hyporheic-zone samples were substantially less than in groundwater samples from the east side of the north transect. Uranium concentrations were 0.83–27.1 $\mu\text{g/L}$ (median 11.9 $\mu\text{g/L}$) for other groundwater samples, 3.47–11.1 $\mu\text{g/L}$ (median 7.9 $\mu\text{g/L}$) for surface-water samples, and 5.39–29.3 $\mu\text{g/L}$ (median 8.3 $\mu\text{g/L}$) for hyporheic-zone samples (fig. 22). For synoptic measurements, surface-water uranium concentrations in Fountain Creek exhibited a mean increase of about 10 percent between the north and south transects (fig. 20; table 7), and uranium concentrations for surface-water samples are somewhat greater than the range of 2.6–8.3 $\mu\text{g/L}$ (median 6.5 $\mu\text{g/L}$) reported by Miller and others (2010) for samples collected at USGS streamgage 07106500.

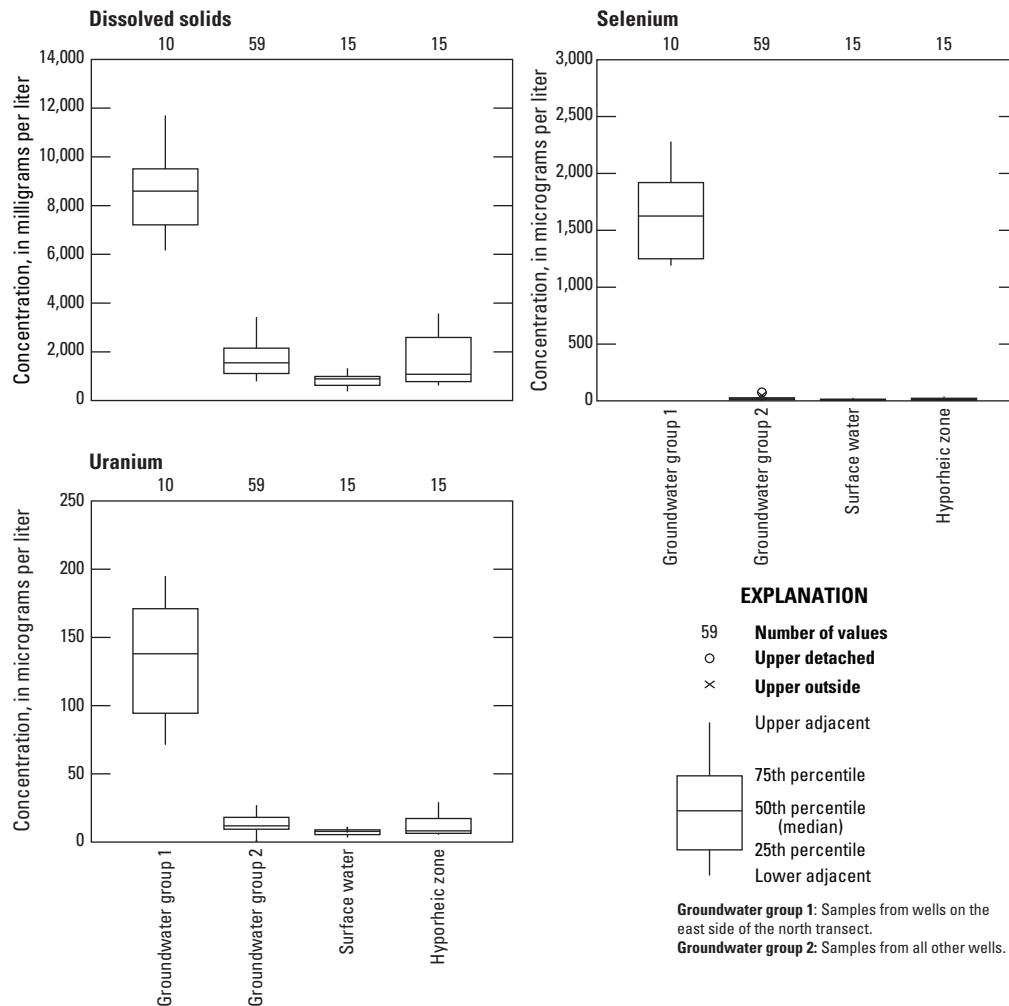


Figure 22. Comparison of dissolved solids, selenium, and uranium concentrations in groundwater from the east side of the north transect, groundwater from other locations, surface water, and the hyporheic zone.

Nitrate, Alkalinity, and Dissolved Oxygen

In addition to elevated concentrations of dissolved solids, selenium, and uranium, groundwater samples collected from the east side of the north transect (group 1) exhibited greater concentrations of most other constituents, including nitrate as nitrogen (herein referred to as “nitrate”), alkalinity as calcium carbonate (herein referred to as “alkalinity”), and dissolved oxygen (fig. 23). Groundwater samples collected from wells on the east side of the north transect had nitrate concentrations of 30.8–83.9 mg/L (median 60.6 mg/L), alkalinities of 368–562 mg/L (median 513 mg/L), and dissolved oxygen concentrations of 0.1–3.6 mg/L (median 1.0 mg/L). By comparison, other groundwater samples had nitrate concentrations of 0.01–7.43 mg/L (median 0.71 mg/L), alkalinities of 181–326 mg/L (median 259 mg/L), and dissolved oxygen concentrations ranging from below

the reporting level (censored data) to 3.9 mg/L (median 0.1 mg/L) (fig. 23). Surface water generally exhibited higher concentrations of nitrate and dissolved oxygen than other groundwater samples but had lower alkalinity. Surface-water samples had nitrate concentrations of 0.93–2.72 mg/L (median 1.91 mg/L), alkalinities of 92–222 mg/L (median 191 mg/L), and dissolved oxygen concentrations of 6.0–12.3 mg/L (median 9.1 mg/L) (fig. 23). Hyporheic-zone samples had nitrate concentrations of 0.08–3.16 mg/L with a median of 0.45 mg/L, which is less than the median for either groundwater or surface-water samples; alkalinities of 161–353 mg/L with a median of 213 mg/L, which is intermediate between median values for groundwater and surface water; and dissolved oxygen concentrations of 0.3–8.8 mg/L with a median of 1.0 mg/L, which is equivalent to the median value for groundwater samples collected from the east side of the north transect.

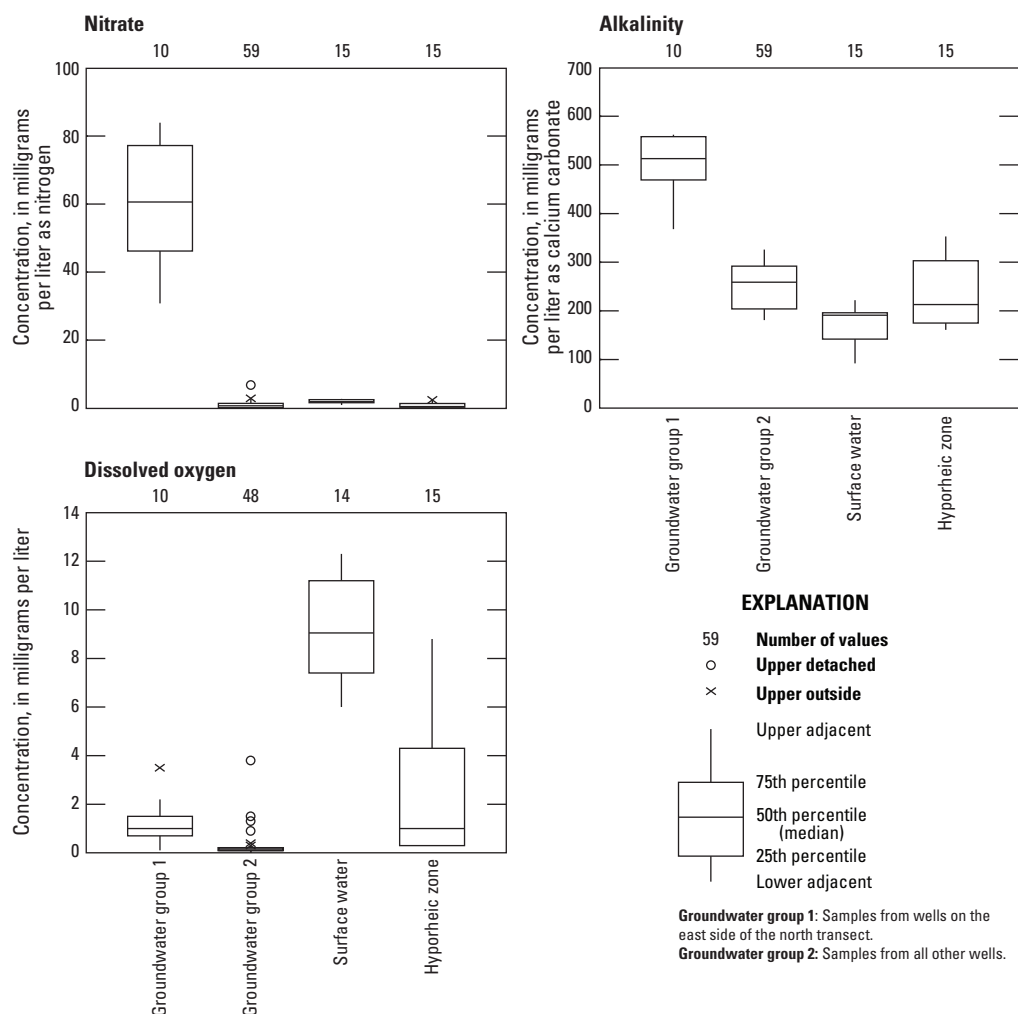


Figure 23. Comparison of nitrate, alkalinity, and dissolved oxygen concentrations in groundwater from the east side of the north transect, groundwater from other locations, surface water, and the hyporheic zone.

Oxidation-Reduction Conditions

Oxidation-reduction (redox) conditions can affect chemical speciation and the solubility and mobility of water-quality constituents, such as selenium and uranium. To assess the redox condition of each groundwater sample collected by the study, concentrations of dissolved oxygen, nitrate (as nitrogen), manganese, iron, and sulfate were evaluated by using the framework of McMahon and Chapelle (2008) (table 9) as implemented by a spreadsheet workbook developed by Jurgens and others (2009). Categories assigned by the workbook, in order of decreasing redox condition, are oxic, mixed (oxic-anoxic), suboxic, mixed (anoxic), and anoxic. A summary of redox conditions determined by using the workbook for samples collected by this study is presented in table 10. To simplify comparison of water-quality data with respect to

redox conditions for samples collected by this study, the oxic and mixed (oxic-anoxic) categories of Jurgens and others (2009) are considered to represent generally oxic conditions, herein referred to as “oxic to mixed (oxic-anoxic).” Similarly, anoxic, mixed (anoxic), and suboxic categories are considered to represent generally anoxic or low redox conditions, herein referred to as “anoxic to suboxic.”

With one exception (well N-EB-E on September 18, 2013), groundwater samples collected from wells on the east side of the north transect (group 1) exhibited oxic to mixed (oxic-anoxic) conditions, whereas most other groundwater samples exhibited anoxic to suboxic conditions. In addition to samples collected from wells on the east side of the north transect, some samples from wells at other locations (N-WB-E on November 14, 2012, and April 10, 2013; M-EB-W on November 13, 2012, and April 15, 2013; and S-WB-E Shallow

Table 9. Classification of redox categories and processes assigned on the basis of water-quality data (modified from table 2 of Jurgens and others [2009]).

[Redox category: $O_2 \geq 0.5$ mg/L, dissolved oxygen greater than or equal to 0.5 mg/L; $O_2 < 0.5$ mg/L, dissolved oxygen less than 0.5 mg/L. Redox process: O_2 , oxygen reduction; NO_3 , nitrate reduction; Mn(IV), manganese reduction; Fe(III), iron reduction; SO_4 , sulfate reduction; CH_4 gen, methanogenesis. Abbreviations: mg/L, milligram per liter; \geq , greater than or equal to; $>$, greater than; Y, yes; N, no; —, criteria do not apply because the species concentration is not affected by the redox process; -, and; x, not applicable]

Redox category	Redox process	Dissolved oxygen >0.5 mg/L	Nitrate, as nitrogen >0.5 mg/L	Manganese >0.05 mg/L	Iron >0.01 mg/L	Sulfate >0.5 mg/L	Iron/sulfide mass ratio >0.3	Iron/sulfide mass ratio >10
Oxic	O_2	Y	—	N	N	—	x	x
Suboxic	Suboxic	N	N	N	N	—	x	x
Anoxic	NO_3	N	Y	N	N	—	x	x
Anoxic	Mn(IV)	N	N	Y	N	—	x	x
Anoxic	Fe(III)/ SO_4	N	N	—	Y	Y	no data	no data
Anoxic	CH_4 gen	N	N	—	Y	N	x	x
Mixed (oxic-anoxic)	O_2 -Mn(IV)	Y	—	Y	N	—	x	x
Mixed (oxic-anoxic)	O_2 -Fe(III)/ SO_4	Y	N	—	Y	Y	no data	no data
Mixed (oxic-anoxic)	O_2 - CH_4 gen	Y	N	—	Y	N	x	x
Mixed (anoxic)	NO_3 -Mn(IV)	N	Y	Y	N	—	x	x
Mixed (anoxic)	NO_3 -Fe(III)/ SO_4	N	Y	—	Y	Y	no data	no data
Mixed (anoxic)	NO_3 - CH_4 gen	N	Y	—	Y	N	x	x
Anoxic	SO_4	N	N	—	Y	Y	N	N
Mixed (anoxic)	Fe(III)- SO_4	N	N	—	Y	Y	Y	N
Anoxic	Fe(III)	N	N	—	Y	Y	Y	Y
Mixed (oxic-anoxic)	O_2 - SO_4	Y	N	—	Y	Y	N	N
Mixed (oxic-anoxic)	O_2 -Fe(III)- SO_4	Y	N	—	Y	Y	Y	N
Mixed (oxic-anoxic)	O_2 -Fe(III)	Y	N	—	Y	Y	Y	Y
Mixed (anoxic)	NO_3 - SO_4	N	Y	—	Y	Y	N	N
Mixed (anoxic)	NO_3 -Fe(III)- SO_4	N	Y	—	Y	Y	Y	N
Mixed (anoxic)	NO_3 -Fe(III)	N	Y	—	Y	Y	Y	Y

Table 10. Dissolved oxygen, nitrate, manganese, iron, and sulfate concentrations and classification of oxidation-reduction condition of groundwater samples according to the framework of McMahon and Chapelle (2008), Fountain Creek near Pueblo, Colo., 2012–2013.

[mg/L, milligrams per liter; N, nitrogen; μ g/L, micrograms per liter; redox, oxidation-reduction; REW, right edge of water; LEW, left edge of water; $<$, less than; M, value is below the reporting level but at or above the detection level; E, estimated]

Location name	Sample collection date	Dissolved oxygen (mg/L)	Nitrate, as N (mg/L)	Manganese (μ g/L)	Iron (μ g/L)	Sulfate (mg/L)	Redox state
N-WB-W	9/17/2012	0.1	0.752	840	5.6	538	Mixed (anoxic)
N-WB-W	11/14/2012	0.1	1.06	829	4.6	553	Mixed (anoxic)
N-WB-W	4/8/2013	M	0.171	700	9.3	504	Anoxic
N-WB-W	7/8/2013	M	0.094	680	16.7	446	Anoxic
N-WB-W	9/17/2013	0.1	0.09	989	7.0	634	Anoxic
N-WB-M	9/17/2012	0.1	0.063	1,400	10	552	Anoxic
N-WB-M	11/14/2012	M	0.535	1,050	<4	484	Mixed (anoxic)
N-WB-M	4/10/2013	0.1	0.021	934	6.7	661	Anoxic
N-WB-M	7/8/2013	M	<0.01	885	6.6	472	Anoxic
N-WB-M	9/17/2013	M	0.657	676	9.4	431	Mixed (anoxic)

Table 10. Dissolved oxygen, nitrate, manganese, iron, and sulfate concentrations and classification of oxidation-reduction condition of groundwater samples according to the framework of McMahon and Chapelle (2008), Fountain Creek near Pueblo, Colo., 2012–2013.—Continued

[mg/L, milligrams per liter; N, nitrogen; µg/L, micrograms per liter; redox, oxidation-reduction; REW, right edge of water; LEW, left edge of water; <, less than; M, value is below the reporting level but at or above the detection level; E, estimated]

Location name	Sample collection date	Dissolved oxygen (mg/L)	Nitrate, as N (mg/L)	Manganese (µg/L)	Iron (µg/L)	Sulfate (mg/L)	Redox state
N-WB-E	9/17/2012	0.1	0.557	111	19.2	527	Mixed (anoxic)
N-WB-E	11/14/2012	1.6	1.77	27.3	33.8	396	Oxic
N-WB-E	4/10/2013	0.5	1.23	23.7	13.7	541	Oxic
N-WB-E	7/8/2013	0.2	0.794	26.4	28.9	530	Anoxic
N-EB-W	9/18/2012	1.0	38.9	158	25.5	4,990	Mixed (oxic-anoxic)
N-EB-W	11/15/2012	0.7	46.2	54.9	<40	5,990	Mixed (oxic-anoxic)
N-EB-W	4/16/2013	E1.5	64.4	23.5	39.5	7,980	Oxic
N-EB-W	7/9/2013	<0.9	65.5	8.92	34.9	6,950	Oxic
N-EB-W	9/18/2013	0.7	30.8	11.4	16.4	3,510	Oxic
N-EB-E	9/18/2012	1.0	83.9	46.2	31.2	5,250	Oxic
N-EB-E	11/15/2012	1.2	81.2	20.3	<20	5,590	Oxic
N-EB-E	4/16/2013	3.6	77.2	5.91	38.9	7,430	Oxic
N-EB-E	7/9/2013	2.2	56.8	6.80	93.3	3,760	Oxic
N-EB-E	9/18/2013	0.1	49.2	44.1	20.7	3,410	Anoxic
M-EB-W	9/13/2012	0.3	0.762	1.90	<3.2	528	Anoxic
M-EB-W	11/13/2012	1.0	1.32	0.32	4.4	448	Oxic
M-EB-W	4/15/2013	3.9	2.82	0.54	<4	328	Oxic
M-EB-W	7/9/2013	M	1.50	0.49	<4	489	Anoxic
M-EB-W	9/19/2013	0.1	0.929	0.99	4.2	345	Anoxic
M-EB-E	9/13/2012	0.1	0.921	444	4.1	443	Mixed (anoxic)
M-EB-E	11/13/2012	0.3	0.362	383	12.5	513	Anoxic
M-EB-E	4/15/2013	0.1	2.23	287	71.9	361	Mixed (anoxic)
M-EB-E	7/9/2013	0.1	2.33	245	14.8	333	Mixed (anoxic)
M-EB-E	9/19/2013	0.1	1.18	317	10.6	505	Mixed (anoxic)
S-WB-W	9/19/2012	0.1	3.62	286	11.1	1,870	Mixed (anoxic)
S-WB-W	11/20/2012	0.1	3.07	205	11.9	1,460	Mixed (anoxic)
S-WB-W	4/22/2013	0.1	2.25	151	21.3	1,170	Mixed (anoxic)
S-WB-W	7/11/2013	M	3.07	254	14.5	1,290	Mixed (anoxic)
S-WB-W	10/22/2013	0.1	7.43	202	12.4	994	Mixed (anoxic)
S-WB-E Shallow	9/12/2012	0.1	0.938	2.63	5.5	531	Anoxic
S-WB-E Shallow	11/20/2012	0.4	1.42	2.94	6.5	531	Anoxic
S-WB-E Shallow	4/22/2013	1.4	1.77	4.62	15.7	616	Oxic
S-WB-E Shallow	7/11/2013	0.1	1.45	1.19	19.6	912	Anoxic
S-WB-E Shallow	9/25/2013	0.1	1.21	1.88	<8	811	Anoxic
S-WB-E Deep	9/12/2012	0.1	1.07	183	8.7	527	Mixed (anoxic)
S-WB-E Deep	11/20/2012	M	1.63	92.5	6.7	590	Mixed (anoxic)
S-WB-E Deep	4/22/2013	0.1	1.09	54.0	10.4	811	Mixed (anoxic)
S-WB-E Deep	7/11/2013	M	1.24	68.3	16.5	1,150	Mixed (anoxic)
S-WB-E Deep	9/25/2013	0.1	1.51	79.4	<8	1,180	Mixed (anoxic)
S-EB-W Shallow	9/11/2012	0.1	0.091	1,290	15.7	1,350	Anoxic
S-EB-W Shallow	11/19/2012	M	0.054	1,150	18.2	1,280	Anoxic
S-EB-W Shallow	4/11/2013	0.1	0.147	1,220	13.5	1,380	Anoxic
S-EB-W Shallow	7/10/2013	0.1	0.099	1,400	22.2	1,420	Anoxic
S-EB-W Shallow	9/23/2013	0.1	0.139	1,600	16.0	1,770	Anoxic
S-EB-W Deep	9/10/2012	E0.2	0.267	1,500	14.9	1,350	Anoxic
S-EB-W Deep	11/19/2012	0.1	0.207	1,360	15.8	1,280	Anoxic
S-EB-W Deep	4/11/2013	0.1	0.507	1,370	9.6	1,280	Mixed (anoxic)
S-EB-W Deep	7/10/2013	M	0.271	1,390	<8	1,350	Anoxic
S-EB-W Deep	9/23/2013	0.1	0.405	1,602	<8	1,610	Anoxic
S-EB-E Shallow	9/11/2012	0.2	0.059	2,560	28.1	1,130	Anoxic
S-EB-E Shallow	11/19/2012	0.1	0.048	2,330	42.9	1,050	Anoxic

Table 10. Dissolved oxygen, nitrate, manganese, iron, and sulfate concentrations and classification of oxidation-reduction condition of groundwater samples according to the framework of McMahon and Chapelle (2008), Fountain Creek near Pueblo, Colo., 2012–2013.—Continued

[mg/L, milligrams per liter; N, nitrogen; µg/L, micrograms per liter; redox, oxidation-reduction; REW, right edge of water; LEW, left edge of water; <, less than; M, value is below the reporting level but at or above the detection level; E, estimated]

Location name	Sample collection date	Dissolved oxygen (mg/L)	Nitrate, as N (mg/L)	Manganese (µg/L)	Iron (µg/L)	Sulfate (mg/L)	Redox state
S-EB-E Shallow	4/17/2013	E0.1	0.132	2,250	24.6	980	Anoxic
S-EB-E Shallow	7/10/2013	0.2	0.110	2,270	22.0	938	Anoxic
S-EB-E Shallow	9/16/2013	0.2	0.028	1.54	34.8	976	Suboxic
S-EB-E Deep	9/11/2012	0.1	0.234	2,510	30.7	922	Anoxic
S-EB-E Deep	11/19/2012	0.2	0.315	1,410	8.8	851	Anoxic
S-EB-E Deep	4/17/2013	0.1	0.708	1,300	<8	860	Mixed (anoxic)
S-EB-E Deep	7/10/2013	0.1	0.541	1,120	<8	853	Mixed (anoxic)
S-EB-E Deep	9/16/2013	0.1	0.012	1.01	22.1	1,060	Suboxic

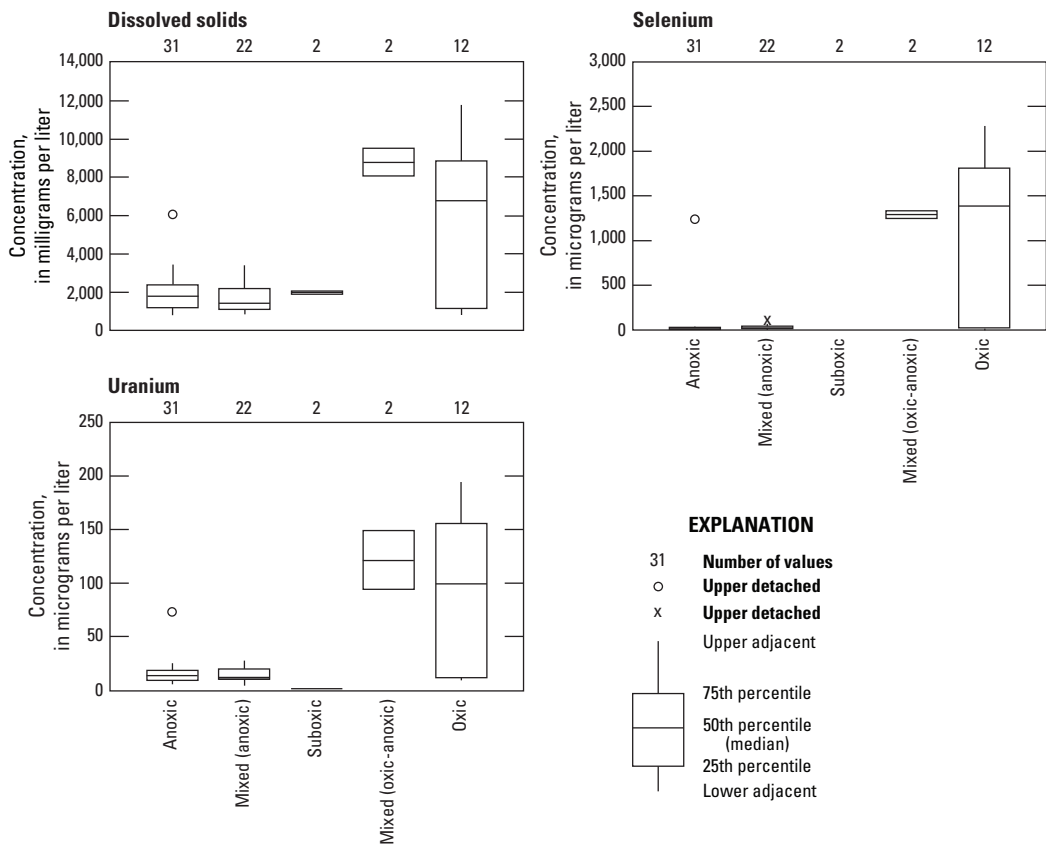


Figure 24. Comparison of dissolved solids, selenium, and uranium concentrations to oxidation-reduction condition for groundwater samples, Fountain Creek near Pueblo, Colo., 2012–2013.

on April 22, 2013) exhibited oxic to mixed (oxic-anoxic) conditions as a result of dissolved oxygen concentrations greater than 0.5 mg/L on those dates. Samples with oxic to mixed (oxic-anoxic) conditions generally exhibited greater concentrations of dissolved solids, selenium, and uranium than samples with anoxic to suboxic conditions (fig. 24). However, not all oxic to mixed (oxic-anoxic) samples (those collected at wells N-WB-E, M-EB-W, and S-WB-E Shallow) exhibited greater constituent concentrations than anoxic to suboxic samples, which resulted in a larger range of concentrations for oxic to mixed (oxic-anoxic) samples than for other samples. The single anoxic sample shown as the upper detached value on figure 24 (collected from well N-EB-E on September 18, 2013), likely reflects a short-term transient decrease in dissolved oxygen, and constituent concentrations in the sample were similar to those of oxic samples collected from the same well.

Dissolved-solids concentrations for all oxic to mixed (oxic-anoxic) samples ranged from 825 to 11,700 mg/L with a median of 6,750 mg/L for oxic samples and 8,780 mg/L for mixed (oxic-anoxic) samples (fig. 24). By comparison, dissolved-solids concentrations were 789–6,160 mg/L for anoxic to suboxic samples with a median value of 1,760 mg/L for anoxic samples, 1,395 mg/L for mixed (anoxic) samples, and 1,940 mg/L for suboxic samples. Selenium and uranium concentrations for oxic and mixed (oxic-anoxic) samples also generally were greater than those for anoxic to suboxic samples. Selenium concentrations ranged from 13.7 to 2,280 µg/L for oxic to mixed (oxic-anoxic) samples with a median value of 1,385 µg/L for oxic samples and 1,290 µg/L for mixed (oxic-anoxic) samples, whereas selenium concentrations were 0.33–1,250 µg/L for anoxic to suboxic samples with a median of 17.2 µg/L for anoxic samples, 27.5 µg/L for mixed (anoxic) samples, and 0.7 µg/L for suboxic samples. Uranium concentrations were 9.6–195 µg/L for oxic to mixed (oxic-anoxic) samples with a median of 99.2 µg/L for oxic samples and 121.7 µg/L for mixed (oxic-anoxic) samples, compared to uranium concentrations of 0.83–74.3 µg/L for anoxic to suboxic samples with median values of 13.2 µg/L for anoxic samples, 11.8 µg/L for mixed (anoxic) samples, and 0.88 µg/L for suboxic samples.

Processes Affecting Loads of Dissolved Solids, Selenium, and Uranium

Fountain Creek Loads

Loads from Groundwater

Groundwater loads of dissolved solids, selenium, and uranium to Fountain Creek (table 11) were estimated for each date on which water-quality samples were collected for groundwater from September 10, 2012, to October 22, 2013. Dissolved-solids loads to Fountain Creek were computed as the product of streamflow gain computed using the Dupuit

equation (table 3), in cubic feet per second per stream mile, and dissolved-solids concentration, in milligrams per liter. The product was then multiplied by a unit conversion factor of 0.0027 to present loads in tons per day (ton/d). Selenium and uranium loads similarly were computed as the product of computed streamflow gain, constituent concentration in micrograms per liter, and a unit conversion factor of 0.0054 to present results in pounds per day (lb/d).

Groundwater loads of dissolved solids, selenium, and uranium to Fountain Creek varied by date but were small because of the small amount of groundwater flowing to the stream under low-streamflow conditions. The combined mean groundwater load per stream mile from both sides of Fountain Creek at the north transect was 3.57 ton/d for dissolved solids, 0.89 lb/d for selenium, and 0.09 lb/d for uranium. Computed groundwater loads to Fountain Creek at the middle and south transects also were small. The mean groundwater load to Fountain Creek from the east side of the middle transect, where wells were installed, was 1.58 ton/d for dissolved solids, 0.08 lb/d for selenium, and 0.03 lb/d for uranium. At the south transect, the combined mean groundwater load per stream mile from both sides of Fountain Creek was 7.12 ton/d for dissolved solids, 0.24 lb/d for selenium, and 0.13 lb/d for uranium. Total groundwater loading to Fountain Creek between the north and middle transects is estimated to be 3.17 ton/d for dissolved solids, 0.60 lb/d for selenium, and 0.08 lb/d for uranium. By comparison, total groundwater loads to Fountain Creek between the middle and south transects was computed as 7.35 ton/d for dissolved solids, 0.27 lb/d for selenium, and 0.14 lb/d for uranium.

In-Stream Loads

Loads of dissolved solids, selenium, and uranium (table 12) in Fountain Creek also were estimated for each date on which water-quality samples were collected for surface water from September 13, 2012, to September 26, 2013. For dates on which streamflow and water-quality data were collected synoptically (April 18, July 1, and September 26, 2013), differences in constituent loads were computed for the reach between each transect. Dissolved-solids loads were computed as the product of measured instantaneous streamflow, in cubic feet per second, dissolved-solids concentration, in milligrams per liter, and a unit conversion factor of 0.0027 to present loads in tons per day (ton/d). Selenium and uranium loads similarly were computed as the product of measured instantaneous streamflow, constituent concentration in micrograms per liter, and a unit conversion factor of 0.0054 to present results in pounds per day (lb/d). Uncertainty for load estimates was computed by multiplying loads by the fractional uncertainty (percent error) estimated for the synoptic streamflow measurements (table 5). For dates on which instantaneous streamflow was not measured (September 18 and November 14, 2012, at the north transect; September 13 and November 13, 2012, at the middle transect; and September 12 and November 20, 2012, at the south transect),

Table 11. Streamflow gain from groundwater and concentrations and loads of dissolved solids, selenium, and uranium, Fountain Creek near Pueblo, Colo., 2012–2013.[ft³/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; ton/d, tons per day; lb/d, pounds per day; HF, high-flow conditions]

Transect side	Date ¹	Streamflow gain from groundwater per mile ² (ft ³ /s)	Dissolved solids concentration ³ (mg/L)	Dissolved solids load (ton/d)	Selenium concentration ³ (µg/L)	Selenium load (lb/d)	Uranium concentration ³ (µg/L)	Uranium load (lb/d)
North transect								
West	9/17/2012	0.45	1,220	1.48	11.0	0.03	10.3	0.03
West	11/14/2012	0.29	1,105	0.87	14.8	0.02	9.8	0.02
West	4/8-4/10/2013	0.20	1,170	0.63	10.7	0.01	11.4	0.01
West	7/8/2013	0.48	1,073	1.39	9.4	0.02	8.9	0.02
West	9/17/2013	HF	1,154	HF	7.5	HF	7.4	HF
	Mean	0.40	1,144	1.24	10.7	0.02	9.5	0.02
East	09/18/2012	0.06	8,410	1.36	1,765	0.57	115	0.03
East	11/15/2012	0.06	9,210	1.49	1,500	0.49	172	0.03
East	04/16/2013	0.06	10,060	1.63	1,810	0.59	178	0.03
East	07/09/2013	0.05	9,405	1.27	1,750	0.47	134	0.02
East	09/18/2013	HF	6,225	HF	1,220	HF	72.8	HF
	Mean	0.10	8,662	2.34	1,609	0.87	134	0.07
Combined mean from both sides		0.50		3.57		0.89		0.09
Middle transect								
East	09/13/2012	HF	1,095	HF	17.8	HF	7.85	HF
East	11/13/2012	0.72	1,070	2.08	21.7	0.08	10.3	0.04
East	04/15/2013	0.61	863	1.42	26.3	0.09	9.56	0.03
East	07/09/2013	0.47	976	1.24	27.1	0.07	8.3	0.02
East	09/19/2013	HF	940	HF	17.9	HF	7.59	HF
	Mean	0.60	989	1.58	22	0.08	9	0.03
South transect								
West	9/12-9/19/2012	0.94	1,873	4.75	33.8	0.17	15.4	0.08
West	11/20/2012	1.06	1,700	4.87	33.7	0.19	15.4	0.09
West	4/22/2013	1.03	1,650	4.59	32.6	0.18	18.2	0.10
West	7/11/2013	0.98	2,090	5.53	56.9	0.30	24.2	0.13
West	9/25-10/22/2013	1.30	2,057	HF	41.5	HF	18.1	HF
	Mean	1.06	1,874	4.93	39.7	0.21	18.2	0.10
East	9/10-9/11/2012	0.44	2,203	2.62	15.1	0.04	17.4	0.04
East	11/19/2012	0.28	2,073	1.57	12.6	0.02	16.8	0.03
East	4/11-4/17/2013	0.39	1,995	2.10	14.9	0.03	14.9	0.03
East	07/10/2013	0.42	2,178	2.47	16.7	0.04	16.2	0.04
East	9/16-9/23/2013	HF	2,529	HF	18.0	HF	12.0	HF
	Mean	0.38	2,195	2.19	15.4	0.03	15.5	0.03
Combined mean from both sides		1.44		7.12		0.24		0.13
Mean groundwater load to Fountain Creek by stream reach								
North to middle transect				3.17		0.60		0.08
Middle to south transect				7.35		0.27		0.14

¹Dates represent range over which water-quality samples were collected for comparison.²Streamflow gain from groundwater per mile taken from table 3.³Constituent concentrations represent the mean of all groundwater samples (table 6) collected from the respective side of Fountain Creek on the date(s) shown.

Table 12. Streamflow and concentrations and loads of dissolved solids, selenium, and uranium, Fountain Creek near Pueblo, Colo., 2012–2013.

[ft³/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; ton/d, tons per day; lb/d, pounds per day; --, no data; bold values indicate computed difference is greater than measurement uncertainty; negative values indicate decrease between transects]

Date	Stream-flow ¹ (ft ³ /s)	Dissolved solids concentration (mg/L)	Dissolved solids load (ton/d)	Dissolved solids load uncertainty ² (ton/d)	Selenium concentration (µg/L)	Selenium load (lb/d)	Selenium load uncertainty ² (lb/d)	Uranium concentration (µg/L)	Uranium load (lb/d)	Uranium load uncertainty ² (lb/d)
North transect										
9/18/2012	30	1,030	83.4	--	13.1	2.1	--	9.33	1.51	--
11/14/2012	74	788	157	--	7.7	3.1	--	7.26	2.90	--
4/18/2013	40	882	96.0	2.5	10.4	2.2	0.1	8.33	1.80	0.05
7/1/2013	33	887	79.0	2.1	10.2	1.8	0.0	7.85	1.40	0.04
9/26/2013	318	601	517	13.4	4.4	7.6	0.2	5.28	9.07	0.24
Synoptic ³ mean	130	790	231	6.0	8.3	3.9	0.1	7.15	4.09	0.11
Overall mean	99	838	186	6.0	9.2	3.4	0.1	7.61	3.34	0.11
Middle transect										
9/13/2012	222	376	225	--	6.5	7.8	--	3.47	4.16	--
11/13/2012	68	804	148	--	9.9	3.6	--	7.30	2.68	--
4/18/2013	41	936	104	2.4	14.9	3.3	0.1	8.73	1.93	0.04
7/1/2013	31	968	80.7	2.0	15.3	2.6	0.1	7.90	1.32	0.03
9/26/2013	317	609	522	13.6	5.5	9.4	0.2	5.17	8.85	0.23
Synoptic ³ mean	130	838	236	6.0	11.9	5.1	0.1	7.27	4.03	0.10
Overall mean	136	739	216	6.0	10.4	5.3	0.1	6.51	3.79	0.10
South transect										
9/12/2012	15	1,330	53.9	--	27.4	2.2	--	11.1	0.90	--
11/20/2012	66	892	159	--	12.8	4.6	--	8.16	2.91	--
4/18/2013	44	989	116	2.4	15.5	3.7	0.1	9.16	2.18	0.05
7/1/2013	24	1,060	68.7	2.5	16.3	2.1	0.1	9.00	1.17	0.04
9/26/2013	304	624	512	13.8	5.5	9.0	0.2	5.46	8.96	0.24
Synoptic ³ mean	124	891	232	6.3	12.4	4.9	0.1	7.87	4.10	0.11
Overall mean	91	979	182	6.3	15.5	4.3	0.1	8.58	3.22	0.11
Difference, north to middle transect ⁴										
4/18/2013	1	54	8.0	3.5	4.5	1.1	0.1	0.40	0.13	0.06
7/1/2013	-2	81	1.7	2.9	5.1	0.8	0.1	0.05	-0.08	0.05
9/26/2013		8	5.0	19.1	1.1	1.8	0.3	-0.11	-0.22	0.33
Synoptic ³ mean	-0.7	47.7	4.9	8.5	3.6	1.2	0.2	0.11	-0.06	0.15
Difference, middle to south transect ⁴										
4/18/2013	3	53	12.0	3.4	0.6	0.4	0.1	0.43	0.25	0.06
7/1/2013	-7	92	-12.0	3.2	1.0	-0.5	0.1	1.10	-0.15	0.05
9/26/2013	-13	15	-10.0	19.4	0.0	-0.4	0.3	0.29	0.11	0.33
Synoptic ³ mean	-5.7	53.3	-3.3	8.7	0.5	-0.2	0.2	0.61	0.07	0.15

¹Streamflow for 2012 dates were estimated from regression relation to streamflow at U.S. Geological Survey streamgage 07106500.

²Load uncertainty for dissolved solids, selenium, and uranium was computed on the basis of uncertainty in flow measurements only (see table 5). Laboratory uncertainty of constituent concentrations was not considered. Uncertainty associated with load differences between transects was computed as the root sum square (RSS) of uncertainties for each individual load estimate.

³Synoptic samples collected April 18, July 1, and September 26, 2013.

⁴Differences were computed only for dates on which synoptic data were collected.

streamflow was estimated by using the regression equation relating streamflow at each transect to streamflow at USGS streamgage 07106500 (Fountain Creek at Pueblo, CO; fig. 8). Loads were computed on the basis of the estimated streamflow on these dates, but uncertainty in the load estimates was not computed. Uncertainty associated with computed load differences between transects was computed as the RSS of uncertainties for each individual load estimate.

Instantaneous loads of dissolved solids, selenium, and uranium in Fountain Creek varied by date, primarily in relation to streamflow at each transect (fig. 25) and were much larger than computed constituent loads from groundwater. In-stream loads generally decreased with decreases in streamflow and increased as streamflow increased. Dissolved-solids loads ranged from 53.9 to 522 ton/d, selenium loads ranged from 1.8 to 9.4 lb/d, and uranium loads ranged from 0.90 to 9.07 lb/d (table 12). For comparison, the mean dissolved-solids load at USGS streamgage 07106500 (Fountain Creek at Pueblo, CO) was reported as 289 ton/d (105,500 tons per year) for the period 1999 to 2007 (Miller and others, 2010). For the reach of Fountain Creek between the north transect and the middle transects, constituent loads exhibited a mean increase of 4.9 ton/d (2 percent) for dissolved solids and 1.2 lb/d (32 percent) for selenium, whereas the mean uranium load decreased by 0.06 lb/d (1 percent). Conversely, for the reach of Fountain Creek between the middle and south transects, constituent loads exhibited a mean decrease of 3.3 ton/d (1 percent) for dissolved solids and 0.2 lb/d (3 percent) for selenium, whereas the mean uranium load increased by 0.07 lb/d (2 percent).

For dates on which synoptic measurements of streamflow and constituent concentrations were made, loads of dissolved solids and selenium increased between the north and middle transects (fig. 25) but generally decreased between the middle and south transects. By contrast, uranium loads generally decreased between the north and middle transects but increased between the middle and south transects. Differences in constituent loading between transects on Fountain Creek were within measurement uncertainty for about three quarters of the computed values (table 12). For the reach of Fountain Creek between the north and middle transects, the estimated difference in dissolved solids was greater than measurement uncertainty only on April 18, 2013, which indicated an 8-percent increase of 8.0 ton/d. Increases in selenium loads over the same reach were greater than measurement uncertainty for all dates and ranged from 0.8 to 1.8 lb/d, representing a 24–50 percent increase. The estimated difference in uranium load between the north and middle transects was greater than measurement uncertainty on April 18, 2013, which indicated a 7-percent increase of 0.13 lb/d, and on July 1, 2013, which indicated a 6-percent decrease of 0.08 lb/d. Based on dates for which estimated load differences between the middle and south transects exceeded measurement uncertainty, constituent loads increased on April 18, 2013, but decreased on July 1, 2013. On April 18, 2013, constituent loads increased by 12.0 ton/d (12 percent) for dissolved solids, 0.4 lb/d (12 percent) for selenium, and 0.25 lb/d (13 percent)

for uranium. By comparison, on July 1, 2013, constituent loads decreased by 12.0 ton/d (15 percent) for dissolved solids, 0.5 lb/d (19 percent) for selenium, and 0.15 lb/d (11 percent) for uranium. The difference in constituent loads between the middle and south transect exceeded measurement uncertainty on September 26, 2013, only for selenium, which indicated a decrease of 0.4 lb/d (4 percent).

In-stream load differences between transects appear primarily to be related to differences in streamflow. However, because groundwater typically flows to Fountain Creek (the stream is gaining) under low-flow conditions, and groundwater has greater concentrations of dissolved solids, selenium, and uranium than surface water in the creek, increases in loads between transects likely are affected by inflow of groundwater to the stream, which can account for a substantial proportion of the in-stream load difference between transects. For the reach of Fountain Creek between the north and middle transects, the mean groundwater contribution was 3.17 ton/d for dissolved solids and 0.60 lb/d for selenium (table 11), which represents 65 percent and 50 percent, respectively, of the mean in-stream load increase of 4.9 ton/d and 1.2 lb/d, respectively, for these constituents (table 12). For the reach of Fountain Creek between the middle and south transects, the mean groundwater contribution for uranium was 0.14 lb/d, which is greater than the estimated mean increase of 0.07 lb/d for the in-stream load. On dates when in-stream loads decrease between transects, the primary cause likely is decreased streamflow as a result of losses to groundwater and flow through the hyporheic zone. However, localized groundwater inflow likely attenuates the magnitude by which the in-stream loads decrease.

Processes Affecting Loads to Fountain Creek

Loads to streams can be affected by a number of natural and anthropogenic environmental conditions, including geology, geochemical conditions, land use, water use, and evapoconcentration. Because land use (developed urban area; fig. 1) in the study area is similar near each monitoring well transect, differences in land use are unlikely to be responsible for the substantial differences observed in water quality between groundwater sampled from wells on the east side of the north transect and all other samples. Because there are no known diversions or direct return flows between the north and south transects, and pumping from the alluvial aquifer is limited to small-capacity wells, water use among all transect locations likely is similar. As discussed previously, ratios of hydrogen and oxygen isotopes in samples (fig. 16) indicate evaporation likely has not had a substantial effect on groundwater, so the high constituent concentrations on the east side of the north transect likely are not the result of evapoconcentration. For these reasons, the focus of the following discussion is on geologic sources and geochemistry of dissolved solids, selenium, and uranium and on physical characteristics that may be related to promoting elevated concentrations of these constituents.

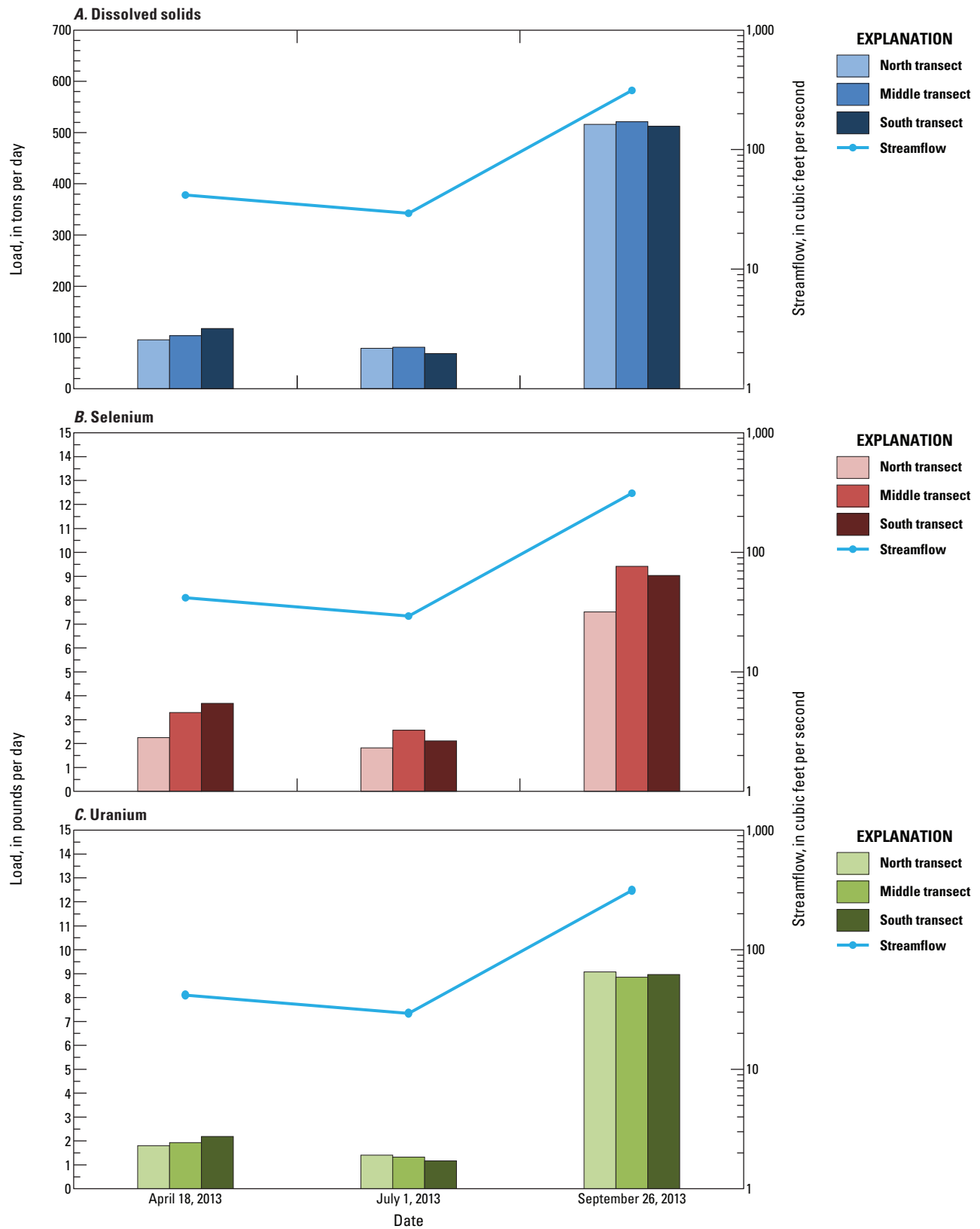


Figure 25. Streamflow and in-stream loads of *A*, dissolved solids; *B*, selenium; and *C*, uranium, Fountain Creek near Pueblo, Colo., 2012–2013.

Geologic Source

Groundwater commonly contains more dissolved solids than surface water because it remains in contact with soils and rocks for longer periods of time (Jenkins, 1964). The principal source of dissolved solids in groundwater and surface water in the Arkansas River Basin (including Fountain Creek) is the Pierre Shale, Niobrara Formation, and other Upper Cretaceous rocks of marine origin (Miller and others, 2010). The Pierre Shale and upper Niobrara Formation also are known sources of selenium and uranium (Landis, 1959; Zielinski and others, 1995; Kulp and Pratt, 2004; Miller and others, 2010). Samples of groundwater collected from upper Cretaceous shale and limestone (such as the Pierre Shale and Niobrara Formation) were found to have substantially greater median concentrations of dissolved solids and selenium than unconsolidated Quaternary deposits (such as alluvium) in the Fountain Creek Basin (Miller and others, 2010). However, median concentrations of dissolved uranium in groundwater were found to be similar in magnitude between Cretaceous and Quaternary deposits. Concentrations of selenium and uranium in the Pierre Shale and Niobrara Formation can have considerable spatial variability. Sequential extractions conducted on soil samples collected from the Pierre Shale and Niobrara Formation in South Dakota by Kulp and Pratt (2004) indicated whole-rock selenium concentrations ranging from 2.58 to 70.70 mg/kg. The proportion of water-soluble selenium to total recoverable selenium in samples varied by lithology, ranging from a mean of 1.3 percent for shale and 3.8 percent for chalk to 26.7 percent for bentonite. Groundwater sampled from the Mancos Shale (a formation that correlates with the lower part of the Pierre Shale and the upper part of the Niobrara Formation; Izett and others, 1971) in western Colorado, New Mexico, and Utah by Morrison and others (2012) had concentrations that commonly exceeded 1,000 $\mu\text{g/L}$ for selenium, 200 $\mu\text{g/L}$ for uranium, and 250 mg/L for nitrate. The greatest concentrations were in groundwater samples associated with shale beds, but they were not correlated with geographic area, stratigraphic position, or source of water. Similarly, selenium concentrations of soil samples collected from the Mancos Shale in the Gunnison Gorge National Conservation area in Colorado were found to be somewhat erratically distributed (Tuttle and others, 2013). Results of laboratory leaching experiments and geochemical modeling conducted by Mast and others (2014) indicated selenium was naturally present in nonirrigated soils derived from the Mancos Shale primarily in the form of highly soluble salts and gypsum that were readily dissolved by water. Conversely, soluble forms of selenium were depleted in irrigated soils because of flushing, and most selenium was associated with organic matter that was stable under near-surface weathering conditions (Mast and others, 2014). High concentrations of extractable nitrate also were found in nonirrigated soils and bedrock that appeared to be partially derived from weathered organic matter from the shale rather

than from fertilizer or other agricultural sources (Mast and others, 2014). Similar work by Paschke and others (2013) found that selenium concentrations in Toll Gate Creek near Denver, Colo., were the result of water-rock interaction among groundwater, surface water, and selenium-bearing bedrock of the Denver Formation.

Geochemistry of Dissolved Solids, Selenium, and Uranium

Concentrations of dissolved solids, selenium, and uranium in water depend on both the availability of soluble source material and geochemical conditions. Selenium and uranium are largely insoluble in anoxic reducing environments but are mobile in oxidized environments (Naftz and Rice, 1989; Murphy and Shock, 1999; Jurgens and others, 2010; Bailey and others, 2012).

Dissolved Solids

Dissolved solids is a measure of the total concentration of all dissolved ions in a water sample, and all water naturally contains dissolved solids as a result of weathering processes in rocks and soils (Anning and Flynn, 2014). Dissolved solids in natural waters typically are derived primarily from geologic sources, but dissolved solids also can be contributed by anthropogenic sources and the atmosphere (Hem, 1989; Gaillardet and others, 1997; Roy and others, 1999). Evapotranspiration by plants or direct evaporation of surface water, groundwater, or soil water in the unsaturated zone can increase constituent concentrations or cause precipitation of salts (Miller and others, 2010; Paschke and others, 2013). These evaporative deposits can then be rapidly dissolved when resaturated during rainfall-runoff events or periods of groundwater-level rise and rapidly increase loads of dissolved solids to streams or groundwater.

Selenium

Selenium occurs in four oxidation states as selenate (SeO_4^{2-} , 6⁺ oxidation state), selenite (SeO_3^{2-} , 4⁺ oxidation state), elemental selenium (Se^0 , neutral), and selenide (Se^{2-} , 2⁻ oxidation state) (McNeal and Balistrieri, 1989). Selenium can readily be oxidized from Se^0 to Se^{4+} or Se^{6+} (Shamburger, 1981). Selenate and selenide generally are soluble in water, whereas elemental selenium and most forms of selenide are insoluble (Bailey and others, 2012). Selenium speciation is largely dependent on pH and redox conditions, but selenate typically has been found to be the most abundant form of soluble selenium in soil and aquatic environments (Masscheleyn and others, 1990; Gates and others, 2009; Bailey and others, 2012; Mast and others, 2014). Selenate is highly mobile, especially under alkaline and oxidizing conditions (Naftz and Rice, 1989), because its salts are highly soluble and it adsorbs weakly to particles (McNeal and Balistrieri, 1989). Selenite is stable in alkaline

to mildly acidic conditions and is more readily immobilized by adsorption onto clay minerals, organic matter, and iron oxyhydroxides (Howard, 1977; Shamburger, 1981; McNeal and Balistrieri, 1989; Balistrieri and Chao, 1990; Boulton and others, 1998). The speciation of selenium in water also is affected by the concentration of nitrate present (Wright, 1999; Gates and others, 2009; Bailey and others, 2012), which inhibits the reduction of selenate to less soluble forms of selenium by autotrophic denitrification. Results of flow-through column tests performed by Bailey and others (2012) suggest that nitrate concentrations greater than about 5 mg/L inhibits the reduction of selenate. The accumulation of selenium in plants depends on plant species, age and phase of plant growth, nature of selenium compounds available, and other environmental factors (Rosenfeld and Beath, 1964). Selenate is the form of selenium most readily taken up by plants and algae, and microbial action can change the speciation of selenium through changes in redox state or the formation of organic selenium compounds (McNeal and Balistrieri, 1989; Kulp and Pratt, 2004).

Uranium

The speciation of uranium in the aquatic environment is controlled primarily by oxidation-reduction potential, pH, and presence of complexing ligands (Murphy and Shock, 1999; Altmaier and Vercoeur, 2012). Speciation of uranium also can be affected by solution ionic strength, temperature, microbial activity, and reaction kinetics. Reactions involving more than one uranium oxidation state are complex, and different oxidation states can be found depending on specific redox conditions. When reducing conditions prevail, uranium occurs predominantly in the tetravalent (4+) state (Murphy and Shock, 1999) and uranium generally has low solubility and mobility (Felmlee, 1979; Jurgens and others, 2010). When oxidizing conditions dominate, the common oxidation state for uranium is hexavalent (6+), uranium becomes soluble, and aqueous concentrations of dissolved uranium generally increase. Hydroxide and carbonate are the dominant ions that form complexes with uranium, but fluoride and phosphate ions and organic molecules also may contribute to aqueous speciation of uranium. At the concentration of dissolved uranium in most natural waters, uranium solubility is most likely limited by sorptive processes rather than by uranium mineral saturation (Langmuir, 1978). Sorption of uranium is inhibited by alkaline conditions and the presence of dissolved carbonate and dissolved inorganic carbon, which complex with uranium and increase its solubility and mobility (Langmuir, 1978; Hsi and Langmuir, 1985; Echevarria and others, 2001; Jurgens and others, 2010). High solubility of uranium is expected in oxygenated alkaline waters if they contain sufficient concentrations of dissolved carbonate to stabilize uranium as uranyl carbonate complexes (Langmuir, 1978).

Assessment of Dissolved-Solids, Selenium, and Uranium Concentrations

The combination of localized soluble geologic sources and oxic conditions likely is the primary reason for the occurrence of elevated concentrations of dissolved solids, selenium, and uranium in groundwater at wells N-EB-W and N-EB-E on the east side of the north monitoring well transect (group 1). However, elevated constituent concentrations at wells on the east side of the north transect also could be related to differences in physical characteristics that increase groundwater exposure to bedrock or promote oxic conditions. To evaluate conditions potentially responsible for water-quality differences among groundwater samples, physical characteristics such as depth to water, saturated thickness, screen depth below the water table, screen height above bedrock, and aquifer hydraulic conductivity were compared (fig. 26). Physical characteristics potentially related to redox conditions, such as saturated thickness, screen depth below the water table, and depth to water, also were compared (fig. 27) to evaluate the potential cause of oxic conditions at wells on the east side of the north transect. Screen depth below the water table and screen height above bedrock were determined on the basis of the screen midpoint.

The Wilcoxon rank-sum test (Helsel and Hirsch, 2002) was used to determine if physical characteristics for groundwater samples collected from wells on the east side of the north transect were significantly different from physical characteristics at other wells. Assuming a significance level of 0.10, test results indicated no significant difference for depth to water ($p = 0.244$), screen height above bedrock ($p = 0.783$), or hydraulic conductivity ($p = 0.273$) between groundwater samples from wells on the east side of the north transect (group 1) and groundwater from all other wells (group 2). However, saturated thickness and screen depth below the water table both were significantly ($p = 0.000$) smaller for group 1 samples than for group 2, indicating that these characteristics might be related to the elevated constituent concentrations found in group 1 wells. Comparison of physical characteristics to redox conditions by using the Wilcoxon rank-sum test similarly indicated that saturated thickness and screen depth below the water table were significantly ($p = 0.000$) smaller for groundwater samples under oxic or mixed (oxic-anoxic) conditions than for those under anoxic to suboxic conditions. Depth to water was not found to be significantly different ($p = 0.292$) between samples with respect to redox conditions.

Redox conditions likely are affected by smaller saturated thickness and screen depth below the water table, because groundwater at shallow depths below the water table has greater exposure to the oxygenated atmosphere than groundwater deeper in the aquifer. In addition to promoting oxic conditions that can increase constituent concentrations, smaller saturated thickness also may contribute to larger constituent

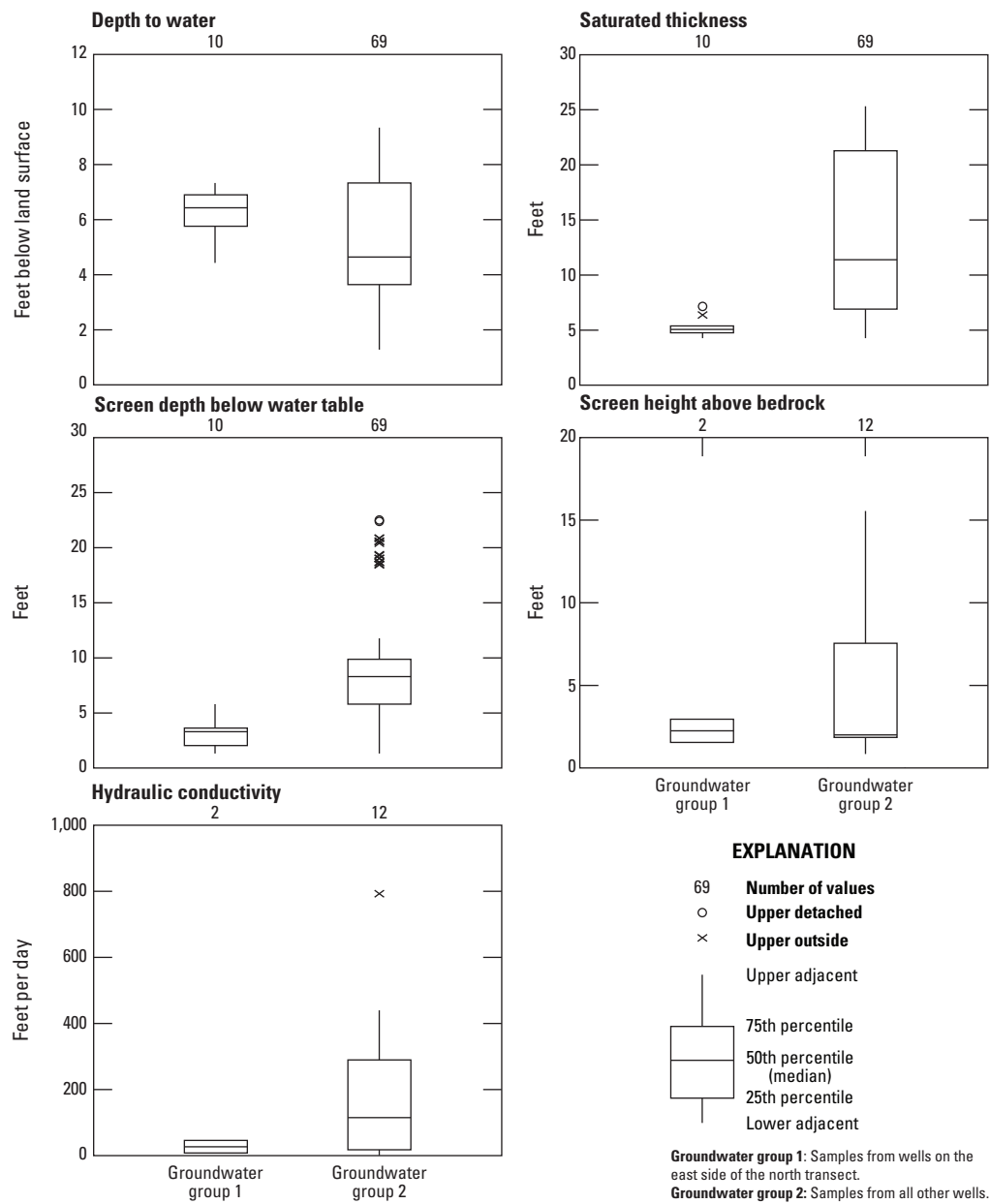


Figure 26. Comparison of physical characteristics for groundwater samples collected from wells on the east side of the north transect to groundwater samples from other wells, Fountain Creek near Pueblo, Colo., 2012–2013.

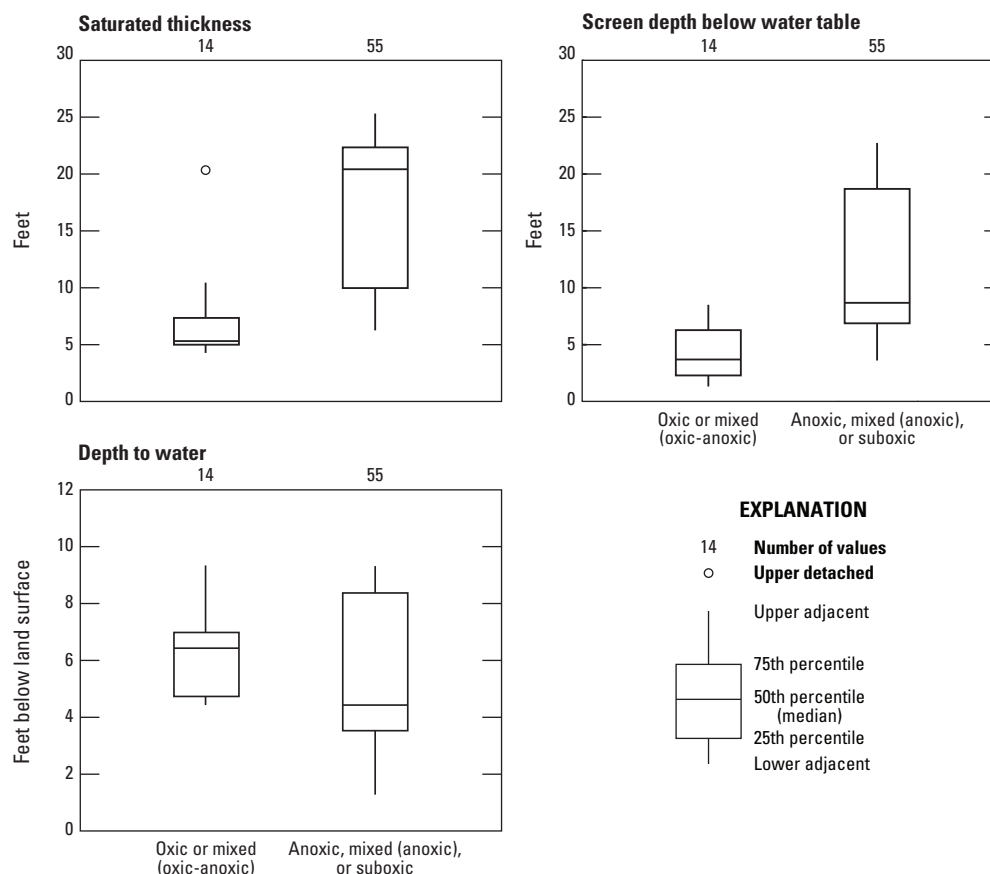


Figure 27. Comparison of physical characteristics for groundwater samples with oxic or mixed (oxic-anoxic) conditions to groundwater samples with anoxic, mixed (anoxic), or suboxic conditions, Fountain Creek near Pueblo, Colo., 2012–2013.

concentrations by increasing groundwater exposure to bedrock (relative to groundwater volume) through shallow mixing and contact with bedrock. Although the effects of biogeochemical activity also could be partly responsible for the different redox conditions observed among groundwater samples, the extent and magnitude of such effects is not known. Because biogeochemical activity generally uses up dissolved oxygen, resulting in generally anoxic conditions (Winter and others, 1999), biogeochemical activity is unlikely to be related to the oxic conditions at wells on the east side of the north transect.

The greater constituent concentrations at wells on the east side of the north transect (group 1) also could, in part, be related to groundwater discharge from an unnamed alluvial drainage (fig. 4) located directly upgradient from wells N-EB-W and N-EB-E. Although the quantity and quality of water discharging from the drainage is not known, the drainage appears to collect water from a residential area located upgradient to the east of the wells. Because the residential area appears to overlie a thin deposit of eolian (wind-blown) sand covering Pierre Shale (figs. 4 and 5A), water that infiltrates into the ground from lawn irrigation,

precipitation, or other sources could form a thin layer of perched groundwater on the bedrock surface and become concentrated in dissolved constituents before flowing through the drainage. Nutrients applied to lawns and gardens at the land surface also could accumulate in the perched water and be subsequently discharged through the drainage, causing the elevated nitrate concentrations observed at wells N-EB-W and N-EB-E. High levels of nitrate, whether from anthropogenic or natural geologic sources, could promote more soluble forms of selenium (Bailey and others, 2012) and other constituents by affecting the redox condition of groundwater at those locations. Whether oxic conditions at wells on the east side of the north transect are the result of physical characteristics, such as saturated thickness or screen height above the water table, or of groundwater inflow from the alluvial drainage, the oxic conditions appear to cause increased dissolution of minerals from the shallow shale bedrock at that location. Because ratios of hydrogen and oxygen isotopes (fig. 16) indicate evaporation likely has not had a substantial effect on groundwater, constituent concentrations at that location likely are not the result of evapoconcentration.

Summary

In 2012 the U.S. Geological Survey, in cooperation with the Arkansas River Basin Regional Resource Planning Group, initiated a study to improve understanding of sources and processes affecting loading of dissolved solids, selenium, and uranium to streams in the Arkansas River Basin. Fountain Creek near Pueblo, Colorado, was selected for a detailed study of groundwater and surface-water interaction, water quality, and loads of dissolved solids, selenium, and uranium because Fountain Creek was identified as a substantial contributor of loads to the Arkansas River, concentrations and loads of dissolved solids, selenium, and uranium generally increase in a downstream direction along Fountain Creek, and hydrogeologic conditions potentially related to elevated constituent concentrations and loads are represented in the Fountain Creek Basin.

Groundwater and surface-water interaction, water quality, and processes affecting loading of dissolved solids, selenium, and uranium were characterized for the period from August 2012 to January 2014. Groundwater and surface-water interaction was characterized by using (1) hydrogeologic mapping, (2) groundwater and surface-water levels, (3) groundwater and surface-water temperatures, (4) vertical hydraulic-head gradients and ratios of oxygen and hydrogen isotopes in the hyporheic zone, and (5) streamflow mass-balance measurements. Water quality was characterized by collecting periodic samples from groundwater, surface water, and the hyporheic zone for analysis of dissolved solids, selenium, uranium, and other selected constituents and by evaluating the oxidation-reduction condition for each groundwater sample under different hydrologic conditions throughout the study period. Groundwater loads to Fountain Creek and in-stream loads were computed for the study area, and processes affecting loads of dissolved solids, selenium, and uranium were evaluated on the basis of geology, geochemical conditions, land and water use, and evapoconcentration.

Fourteen monitoring wells were installed in a series of three transects (north, middle, and south) across Fountain Creek and temporary streamgages were established at each transect to facilitate data collection for the study. Because of difficulties accessing the west side of Fountain Creek at the middle transect, wells were installed only on the east side of the stream at this location. Three sites at the south transect, where saturated sediments were sufficiently thick, were drilled as nested well pairs (shallow and deep) to enable observation of vertical differences in hydraulic head and water quality within the aquifer. Slug tests were performed on all 14 monitoring wells to estimate the hydraulic conductivity of aquifer materials near each well.

Hydrogeologic mapping indicated that groundwater generally flows toward Fountain Creek from both sides of the alluvial valley and downstream along the valley. However, between the north and middle transects, where Fountain Creek is near the edge of the aquifer, the direction of groundwater

flow was away from Fountain Creek and westward toward the center of the aquifer. Hydraulic-head and temperature data indicated Fountain Creek generally gains flow from groundwater during low-streamflow conditions. However, during periods of high streamflow, the hydraulic gradient between groundwater and the stream can temporarily reverse, causing the stream to lose flow to groundwater. Comparison of vertical hydraulic-head gradients and hydrogen- and oxygen-isotope ratios in the hyporheic zone further indicated that groundwater likely contributes flow to Fountain Creek under low-streamflow conditions, but some mixing of groundwater and surface water in the hyporheic zone is likely, particularly at the middle transect. Hydrologic analysis using the Dupuit equation indicated that Fountain Creek gained flow from groundwater between all transects under low-streamflow conditions with mean gains ranging from 0.6 cubic feet per second (ft^3/s) for the reach between the north and middle transects to 1.9 ft^3/s for the reach between the middle and south transects. However, synoptic comparison of streamflow by using the streamflow mass-balance method indicated that the reach between the north and middle transects generally lost streamflow (2–18 ft^3/s for values exceeding measurement uncertainty) with a mean loss of 6 ft^3/s for all measurements, whereas the reach between the middle and south transects exhibited more variable gain-loss conditions (loss of 13 ft^3/s to gain of 13 ft^3/s for values exceeding measurement uncertainty) with a mean value of 0 ft^3/s for all measurements. However, because uncertainty in the estimated mean gain or loss between the middle and south transects exceeded the estimated value, the mean gain or loss along the reach was indeterminate. Differences in the estimates of gains or losses to Fountain Creek between the two methods could be attributed to the different spatial and temporal scales related to each method, unmeasured flow through the hyporheic zone, or evapotranspiration. Consideration of all method results suggests that the larger groundwater-flow system generally contributes flow to Fountain Creek and its hyporheic zone (as a single system) except for the reach between the north and middle transects. However, the direction of flow between the stream, the hyporheic zone, and the near-stream aquifer is variable in response to streamflow and stage.

Concentrations of dissolved solids, selenium, and uranium in groundwater generally had greater spatial variability than surface water or hyporheic-zone samples, and constituent concentrations in groundwater generally were greater than in surface water. Constituent concentrations in the hyporheic zone typically were similar to or intermediate between concentrations in groundwater and surface water except at the middle transect, where hyporheic-zone samples had concentrations less than both groundwater and surface water, possibly reflecting the effect of geochemical or biological processes. Dissolved solids, selenium, and uranium concentrations in groundwater samples collected from wells located on the east side of the north monitoring well transect were substantially greater than for other groundwater, surface-water, and hyporheic-zone samples. Groundwater

samples collected from the east side of the north transect also exhibited greater concentrations of most other constituents, including nitrate as nitrogen, alkalinity as calcium carbonate, and dissolved oxygen. For paired wells at the south transect, selenium concentrations in the deeper installation were consistently greater than in the shallower installation, but no consistent depth relation was observed for dissolved-solids and uranium concentrations. Concentrations of dissolved solids, selenium, and uranium in surface water generally increased in a downstream direction along Fountain Creek from the north transect to the south transect and exhibited an inverse relation to streamflow with highest concentrations occurring during periods of low streamflow and lowest concentrations occurring during periods of high streamflow. For synoptic measurements, constituent concentrations of surface-water samples exhibited a mean increase between the north and south transects of about 13 percent for dissolved solids, 49 percent for selenium, and 10 percent for uranium. With one exception, groundwater samples collected from wells on the east side of the north transect exhibited oxic to mixed (oxic-anoxic) conditions, whereas most other groundwater samples exhibited anoxic to suboxic conditions.

Groundwater loads of dissolved solids, selenium, and uranium to Fountain Creek varied by date but were small because of the small amount of groundwater flowing to the stream under typical low-streamflow conditions. Total groundwater loading to Fountain Creek between the north and middle transects was computed as 3.17 tons per day (ton/d) for dissolved solids, 0.60 pound per day (lb/d) for selenium, and 0.08 lb/d for uranium. By comparison, total groundwater loads to Fountain Creek between the middle and south transects was computed as 7.35 ton/d for dissolved solids, 0.27 lb/d for selenium, and 0.14 lb/d for uranium. In-stream loads of dissolved solids, selenium, and uranium in Fountain Creek varied by date, primarily in relation to streamflow at each transect and were much larger than computed constituent loads from groundwater. In-stream loads generally decreased with decreases in streamflow and increased as streamflow increased. Dissolved-solids loads ranged from 53.9 to 522 ton/d, selenium loads ranged from 1.8 to 9.4 lb/d, and uranium loads ranged from 0.90 to 9.07 lb/d. Synoptic measurements of streamflow and constituent concentrations indicated loads of dissolved solids and selenium increased between the north and middle transects but generally decreased between the middle and south transects. By contrast, uranium loads generally decreased between the north and middle transects but increased between the middle and south transects. For the reach of Fountain Creek between the north transect and the middle transect, mean constituent loads increased by 2 percent for dissolved solids and 32 percent for selenium, whereas the mean uranium load decreased by 1 percent. Conversely, for the reach of Fountain Creek between the middle and south transects, mean constituent loads decreased by 1 percent for dissolved solids and 3 percent for selenium, whereas the mean uranium load increased by 2 percent. For dates on which computed differences in constituent loads were greater than measurement

uncertainty, loads to Fountain Creek increased between the north and middle transects by 8.0 ton/d for dissolved solids and 0.8–1.8 lb/d for selenium. Load differences in excess of measurement uncertainty between the north and middle transects were variable for uranium, ranging from a decrease of 0.08 lb/d to an increase of 0.13 lb/d. Between the middle and south transects, loads to Fountain Creek ranged from a decrease of 12 ton/d to an increase of 12 ton/d for dissolved solids, a decrease of 0.5 lb/d to an increase of 0.4 lb/d for selenium, and a decrease of 0.15 lb/d to an increase of 0.25 lb/d for uranium. In-stream load differences between transects appear primarily to be related to differences in streamflow. However, because groundwater typically flows to Fountain Creek (the stream is gaining) under low-flow conditions, and groundwater has greater concentrations of dissolved solids, selenium, and uranium than surface water in the creek, increases in loads between transects likely are affected by inflow of groundwater to the stream, which can account for a substantial proportion of the in-stream load difference between transects. On dates when loads decrease between transects, the primary cause likely is decreased streamflow as a result of losses to groundwater and flow through the hyporheic zone. However, localized groundwater inflow likely attenuates the magnitude by which the in-stream loads decrease.

The combination of localized soluble geologic sources and oxic conditions likely is the primary reason for the occurrence of high concentrations of dissolved solids, selenium, and uranium in groundwater at wells N-EB-W and N-EB-E on the east side of the north monitoring well transect. To evaluate conditions potentially responsible for differences in water quality and redox conditions, physical characteristics such as depth to water, saturated thickness, screen depth below the water table, screen height above bedrock, and aquifer hydraulic conductivity were compared by using Wilcoxon rank-sum tests. Results indicated no significant difference between depth to water, screen height above bedrock, and hydraulic conductivity for groundwater samples collected from wells on the east side of the north transect and groundwater samples from all other wells. However, saturated thickness and screen depth below the water table both were significantly smaller for groundwater samples collected from wells on the east side of the north transect than for groundwater samples from other wells, indicating that these characteristics might be related to the elevated constituent concentrations found at that location. Comparison of physical characteristics to redox conditions similarly indicated that saturated thickness and screen depth below the water table were significantly smaller for groundwater samples under oxic or mixed (oxic-anoxic) conditions than for those under anoxic to suboxic conditions. Water quality and redox conditions for groundwater samples from wells on the east side of the north transect likely are affected by smaller saturated thickness and screen depth below the water table because groundwater at shallow depths has greater exposure to the oxygenated atmosphere than deeper groundwater. Smaller saturated thickness also may contribute to larger constituent

concentrations in groundwater by increasing groundwater exposure to bedrock (relative to groundwater volume).

The greater constituent concentrations at wells on the east side of the north transect also could, in part, be related to groundwater discharge from an unnamed alluvial drainage located directly upgradient from wells N-EB-W and N-EB-E. Although the quantity and quality of water discharging from the drainage is not known, the drainage appears to collect water from a residential area located upgradient to the east of the wells, which could become concentrated in nitrate and other dissolved constituents before flowing through the drainage. High levels of nitrate, whether from anthropogenic or natural geologic sources, could promote more soluble forms of selenium and other constituents by affecting the redox condition of groundwater. Whether oxic conditions at wells on the east side of the north transect are the result of physical characteristics, such as saturated thickness or screen height above the water table, or of groundwater inflow from the alluvial drainage, the oxic conditions appear to cause increased dissolution of minerals from the shallow shale bedrock at that location. Because ratios of hydrogen and oxygen isotope indicate evaporation likely has not had a substantial effect on groundwater, constituent concentrations at that location likely are not the result of evapoconcentration.

References Cited

- Altmaier, M., and Vercouter, T., 2012, Aquatic chemistry of the actinides: aspects relevant to their environmental behavior, chap. 3 of Poinssot, Christophe, and Geckeis, Horst, eds., 2012, Radionuclide behaviour in the natural environment—Science, implications and lessons for the nuclear industry: Sawston, UK, Woodhead Publishing Limited, p. 44–69.
- Anning, D.W., and Flynn, M.E., 2014, Dissolved-solids sources, loads, yields, and concentrations in streams of the conterminous United States: U.S. Geological Survey Scientific Investigations Report 2014–5012, 101 p., accessed April 13, 2015, at <http://dx.doi.org/10.3133/sir20145012>.
- Bailey, R.T., Hunter, W.J., and Gates, T.K., 2012, The influence of nitrate on selenium in irrigated agricultural groundwater systems: *Journal of Environmental Quality*, v. 41, p. 783–792.
- Balistrieri, L.S., and Chao, T.T., 1990, Adsorption of selenium by amorphous iron oxyhydroxide and manganese dioxide: *Geochemica et Cosmochimica Acta*, v. 54, p. 739–751.
- Boult, K.A., Cowper, M.M., Heath, T.G., Sato, H., Shibutani, T., and Yui, M., 1998, Towards an understanding of the sorption of U(VI) and Se(IV) on sodium bentonite: *Journal of Contaminant Hydrology*, v. 35, p. 141–150.
- Butler, J.J., Jr., 1998, The design, performance, and analysis of slug tests: New York, Lewis Publishers, 252 p.
- Bouwer, Herman, and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: *Water Resources Research*, v. 12, no. 3, p. 423–428.
- Cain, Doug, and Edelman, Patrick, 1986, A reconnaissance water-quality appraisal of the Fountain Creek alluvial aquifer between Colorado Springs and Pueblo, Colorado, including trace elements and organic constituents: U.S. Geological Survey Water-Resources Investigations Report 86–4085, 45 p.
- Castrup, Howard, 2004, Estimating and combining uncertainties, in International Test and Evaluation Association Workshop, 8th annual meeting, Lancaster, Calif., May 5, 2004: Lancaster, Calif., International Test and Evaluation Association, 7 p.
- Chafin, Daniel, 1996, Effects of land use on water quality of the Fountain Creek alluvial aquifer, east-central Colorado: U.S. Geological Survey Water-Supply Paper 2381–D, 99 p., 1 pl.
- Colorado Department of Public Health and Environment, 2016, Regulation no. 32, classifications and numeric standards for Arkansas River Basin (5 CCR 1002-32), accessed April 13, 2016, at <https://www.colorado.gov/pacific/sites/default/files/Regulation-32.pdf>.
- Colorado Division of Water Resources, 2012, Well application information: Colorado Division of Water Resources spatial representation of well application data available on the Web, accessed April 18, 2012, at <http://water.state.co.us/Data-Maps/GISandMaps/Pages/GISDownloads.aspx>.
- Constantz, J.E., Niswonger, R.G., and Stewart, A.E., 2008, Analysis of temperature gradients to determine stream exchanges with ground water, chap. 4 of Rosenberry, D.O., and LaBaugh, J.W., eds., 2008, Field techniques for estimating water fluxes between surface water and ground water: U.S. Geological Survey Techniques and Methods 4–D2, p. 117–128.
- Coplen, T.B., 1993, Uses of environmental isotopes, in Alley, W.M., ed., Regional ground-water quality: New York, Van Nostrand Reinhold, 634 p.
- Craig, H., 1961, Isotopic variations in meteoric waters: *Science*, v. 133, p. 1702–1703.
- Cunningham, W.L., and Schalk, C.W., comps., 2011, Groundwater technical procedures of the U.S. Geological Survey: U.S. Geological Survey Techniques and Methods book 1, chap. A1, 151 p., [Also available at <http://pubs.usgs.gov/tm/1a1/>.]
- Echevarria, G., Sheppard, M.I., and Morel, J., 2001, Effect of pH on the sorption of uranium in soils: *Journal of Environmental Radioactivity*, v. 53, p. 257–264.

- Edelmann, Patrick, Ferguson, S.A., Stogner, R.W., Sr., August, M., Payne, W.F., and Bruce, J.F., 2002, Evaluation of water quality, suspended sediment, and stream morphology with an emphasis on effects of stormflow on Fountain and Monument Creek Basins, Colorado Springs and vicinity, Colorado, 1981 through 2001: U.S. Geological Survey Water-Resources Investigations Report 2002-4104, 59 p.
- Edelmann, Patrick, and Cain, Doug, 1986, Sources of water and nitrogen to the Widefield aquifer, southwestern El Paso County, Colorado: U.S. Geological Survey Water-Resources Investigations Report 85-4162, 81 p.
- Environmental Systems Research Institute (Esri) Inc., 1999–2010, ArcGIS, version 10.0: Redlands, Calif. [Available at <http://www.esri.com/>.]
- Felmlee, J.K., and Cadigan, R.A., 1979, Radium and uranium concentrations and associated hydrogeochemistry in ground water in southwestern Pueblo County, Colorado: U.S. Geological Survey Open-File Report 79-974, 54 p.
- Fetter, C.W., 1994, Applied hydrogeology (3d ed.): New York, Prentice-Hall, 691 p.
- Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.
- Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.
- Gaillardet, J., Dupre, B., Allegre, C.J., and Negrel, P., 1997, Chemical and physical denudation in the Amazon River Basin: Chemical Geology, v. 142, p. 141–173.
- Garbarino, J.R., 1999, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of dissolved arsenic, boron, lithium, selenium, strontium, thallium, and vanadium using inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 99-093, 31 p.
- Garbarino, J.R., Kanagy, L.K., and Cree, M.E., 2006, Determination of elements in natural-water, biota, sediment, and soil samples using collision/reaction cell inductively coupled plasma-mass spectrometry: U.S. Geological Survey Techniques and Methods, book 5, sec. B, chap. 1, 88 p.
- Gates, T.K., Cody, B.M., Donnelly, J.P., Herting, A.W., Bailey, R.T., and Price, J.M., 2009, Assessing selenium contamination in the irrigated stream-aquifer system of the Arkansas River, Colorado: Journal of Environmental Quality, v. 38, p. 2344–2356.
- Hansen, W.R., and Crosby, E.J., 1982, Environmental geology of the Front Range urban corridor and vicinity, Colorado, *with a section on* Physical properties and performance characteristics of surficial deposits and rock units in the greater Denver area, by R.R. Shroba: U.S. Geological Survey Professional Paper 1230, 99 p.
- Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 510 p.
- Hem, J.D., 1989, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.
- Howard, J.H., III, 1977, Geochemistry of selenium: formation of ferroselite and selenium behavior in the vicinity of oxidizing sulfide and uranium deposits: *Geochimica et Cosmochimica Acta*, v. 41, p. 1665–1678.
- Hsi, C.K.D., and Langmuir, D., 1985, Adsorption of uranyl onto ferric oxyhydroxides—Application of the surface complexation site-binding model: *Geochimica et Cosmochimica Acta*, v. 49, p. 1931–1941.
- Hunt, R.J., Coplen, T.B., Haas, N.L., Saad, D.A., and Borchardt, M.A., 2005, Investigating surface water-well interaction using stable isotope ratios of water: *Journal of Hydrology*, v. 302, no. 1–4, p. 154–172.
- HydroSOLV, Inc., 2013, AQTESOLV for Windows, version 4.50—Professional: Reston, Va., HydroSOLV, Inc., accessed November 18, 2013, at <http://www.aqtesolv.com/>.
- Ivahnenko, Tamara, Ortiz, R.F., and Stogner, R.W., Sr., 2013, Characterization of streamflow, water quality, and instantaneous dissolved solids, selenium, and uranium loads in selected reaches of the Arkansas River, southeastern Colorado, 2009–2010: U.S. Geological Survey Scientific Investigations Report 2012-5234, 60 p., accessed January 21, 2015, at <http://pubs.usgs.gov/sir/2012/5234/>.
- Izett, G.A., Cobban, W.A., and Gill, J.R., 1971, The Pierre Shale near Kremmling, Colorado, and its correlation to the east and the west: U.S. Geological Survey Professional Paper 648-A, 19 p.
- Jenkins, E.D., 1964, Ground water in Fountain and Jimmy Camp Valleys, El Paso County, Colorado, *with a section on* Computations of drawdowns caused by the pumping of wells in Fountain Valley by R.E. Glover and E.D. Jenkins: U.S. Geological Survey Water-Supply Paper 1583, 66 p.
- Jurgens, B.C., McMahon, P.B., Chapelle, F.H., and Eberts, S.M., 2009, An Excel® workbook for identifying redox processes in ground water: U.S. Geological Survey Open-File Report 2009-1004, 8 p., accessed April 6, 2015, at <http://pubs.usgs.gov/of/2009/1004/>.

- Jurgens, B.C., Fram, M.S., Belitz, Kenneth, Burow, K.R., and Landon, M.K., 2010, Effects of groundwater development on uranium: Central Valley, California, USA: *Groundwater* v. 48, no. 6, p. 913–928.
- Kendall, C., and Coplen, T.B., 2001, Distribution of oxygen-18 and deuterium in river waters across the United States: *Hydrological Processes*, v. 15, p. 1363–1393.
- Kendall, C., and McDonnell, J.J., eds., 1998, Isotope tracers in catchment hydrology: Amsterdam, Elsevier Science B.V., 839 p.
- Kohn, M.S., Fulton, J.W., Williams, C.A., and Stogner, R.W., Sr., 2014, Remediation scenarios for attenuating peak flows and reducing sediment transport in Fountain Creek, Colorado, 2013: U.S. Geological Survey Scientific Investigations Report 2014–5019, 62 p., accessed March 16, 2015, at <http://dx.doi.org/10.3133/sir20145019>.
- Kuhn, Gerhard, 1988, Methods to determine transit losses for return flows of transmountain water in Fountain Creek between Colorado Springs and the Arkansas River, Colorado: U.S. Geological Survey Water-Resources Investigations Report 87–4119, 183 p.
- Kulp, T.R., and Pratt, L.M., 2004, Speciation and weathering of selenium in Upper Cretaceous chalk and shale from South Dakota and Wyoming, USA: *Geochimica et Cosmochimica Acta*, v. 68, p. 3687–3701.
- LaBaugh, J.W., and Rosenberry, D.O., 2008, Introduction and characteristics of flow, chap. 1 of Rosenberry, D.O. and LaBaugh, J.W., eds., 2008, Field techniques for estimating water fluxes between surface water and ground water: U.S. Geological Survey Techniques and Methods 4–D2, p. 43–70.
- Landis, E.R., 1959, Radioactivity and uranium content, Sharon Springs member of the Pierre Shale, Kansas and Colorado: U.S. Geological Survey Bulletin 1046-L, in *Contributions to the geology of uranium*, p. 299–319, 4 pls.
- Langmuir, D., 1978, Uranium solution-mineral equilibria at low temperatures with applications to sedimentary ore deposits: *Geochimica et Cosmochimica Acta*, v. 42, p. 547–569.
- Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1997, Guidelines and standard procedures for studies of ground-water quality—Selection and installation of wells, and supporting documentation: U.S. Geological Survey Water-Resources Investigations Report 96–4233, 110 p.
- Lewis, M.E., 1995, Quality of water in the alluvial aquifer and tributary alluvium of the Fountain Creek Valley, southwestern El Paso County, Colorado, 1991–92: U.S. Geological Survey Water-Resources Investigations Report 94–4118, 39 p.
- Masscheleyn, P.H., Delaune, R.D., and Patrick, W.H., 1990, Transformations of selenium as affected by sediment oxidation-reduction potential and pH: *Environmental Science and Technology*, v. 24, p. 91–96.
- Malard, F., and Hervant, F., 1999, Oxygen supply and the adaptations of animals in groundwater: *Freshwater Biology*, v. 40, p. 1–30.
- Mast, M.A., Mills, T.J., Paschke, S.S., Keith, G., and Linard, J.I., 2014, Mobilization of selenium from the Mancos Shale and associated soils in the lower Uncompahgre River Basin, Colorado: *Applied Geochemistry*, v. 48, p. 16–27.
- Mau, D.P., Stogner, R.W., Sr., and Edelmann, Patrick, 2007, Characterization of stormflows and wastewater treatment-plant effluent discharges on water quality, suspended sediment, and stream morphology for Fountain and Monument Creek Watersheds, Colorado, 1981–2006: U.S. Geological Survey Scientific Investigations Report 2007–5104, 76 p.
- McGovern, H.E., Gregg, D.O., and Brennan, R., 1964, Hydrogeologic data of the alluvial deposits in Pueblo and Fremont Counties, Colorado: Colorado Water Conservation Board Basic-Data Release No. 18, 27 p., 2 pls.
- McMahon, P.B., and Chapelle, F.H., 2008, Redox processes and water quality of selected principal aquifer systems: *Groundwater*, v. 46, no. 2, p. 259–271.
- McNeal, J.M., and Balistrieri, L.S., 1989, Geochemistry and occurrence of selenium, an overview, in Jacobs, L.W., ed., *Selenium in agriculture and the environment*: Madison, Wis., Soil Science Society of America, Inc., special publication no. 23, p. 1–13.
- Miller, L.D., Watts, K.R., Ortiz, R.F., Ivahnenko, T., 2010, Occurrence and distribution of dissolved solids, selenium, and uranium in groundwater and surface water in the Arkansas River Basin from the headwaters to Coolidge, Kansas, 1970–2009: U.S. Geological Survey Scientific Investigations Report 2010–5069, 56 p.
- Morrison, S.J., Goodknight, C.S., Tigar, A.D., Bush, R.P., and Gil, A., 2012, Naturally occurring contamination in the Mancos Shale: *Environmental Science and Technology*, v. 46, p. 1379–1387.
- Murphy, W.M., and Shock, E.L., 1999, Environmental aqueous geochemistry of actinides, chap. 5 of Burns, P.C., and Finch, R., eds., 1999, *Uranium: Mineralogy, geochemistry and the environment*: Mineralogical Society of America Reviews in Mineralogy, v. 38, p. 221–253.
- Naftz, D.L., and Rice, J.A., 1989, Geochemical processes controlling selenium in ground water after mining, Powder River Basin, Wyoming, USA: *Applied Geochemistry*, v. 4, p. 565–575.

- National Oceanic and Atmospheric Administration, National Centers for Environmental Information, 2016, Precipitation data for station GHCND:US1COPU0021 (PUEBLO 1.9 E CO US): National Oceanic and Atmospheric Administration database, accessed February 22, 2016, at <http://www.ncdc.noaa.gov/cdo-web/>.
- Ong, J.B., Lane, J.W., Jr., Zlotnik, V.A., Halihan, Todd, and White, E.A., 2010, Combined use of frequency-domain electromagnetic and electrical resistivity surveys to delineate near-lake groundwater flow in the semi-arid Nebraska Sand Hills, USA: *Hydrogeology Journal*, v. 18, p. 1539–1545.
- Ortiz, R.F., 2004, Methods to identify changes in background water-quality conditions using dissolved-solids concentrations and loads as indicators, Arkansas River and Fountain Creek, in the vicinity of Pueblo, Colorado: U.S. Geological Survey Scientific Investigations Report 2004–5024, 20 p.
- Ortiz, R.F., 2013, Estimates of gains and losses from unmeasured sources and sinks for streamflow and dissolved-solids loads in selected reaches of the Arkansas River, southeastern Colorado, 2009–2010: U.S. Geological Survey Scientific Investigations Report 2012–5252, 53 p., accessed January 21, 2015, at <http://pubs.usgs.gov/sir/2012/5252/>.
- Paschke, S.S., Runkel, R.L., Walton-Day, Katherine, Kimball, B.A., Schaffrath, K.R., 2013, Streamflow and water-quality conditions including geologic sources and processes affecting selenium loading in the Toll Gate Creek watershed, Aurora, Arapahoe County, Colorado, 2007: U.S. Geological Survey Scientific Investigations Report 2012–5280, 108 p.
- Patton, C.J., and Kryskalla, J.R., 2003, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Evaluation of alkaline persulfate digestion as an alternative to Kjeldahl digestion for determination of total and dissolved nitrogen and phosphorus in water: U.S. Geological Survey Water-Resources Investigations Report 2003–4174, 33 p.
- Patton, C.J., and Kryskalla, J.R., 2011, Colorimetric determination of nitrate plus nitrite in water by enzymatic reduction, automated discrete analyzer methods: U.S. Geological Survey Techniques and Methods, book 5, chap. B8, 34 p.
- Radell, M.J., Lewis, M.E., and Watts, K.R., 1994, Hydrogeologic characteristics of the alluvial aquifer and adjacent deposits of the Fountain Creek Valley, El Paso County, Colorado: U.S. Geological Survey Water-Resources Investigations Report 94–4129, 4 sheets.
- Révész, Kinga, and Coplen, T.B., 2008a, Determination of the $\delta(^2\text{H}/^1\text{H})$ of water: RSIL lab code 1574, chap. C1 of Révész, Kinga, and Coplen, T.B., eds., *Methods of the Reston Stable Isotope Laboratory*: U.S. Geological Survey Techniques and Methods 10–C1, 27 p.
- Révész, Kinga, and Coplen, T.B., 2008b, Determination of the $\delta(^{18}\text{O}/^{16}\text{O})$ of water: RSIL lab code 489, chap. C2 of Révész, Kinga, and Coplen, Tyler B., eds., *Methods of the Reston Stable Isotope Laboratory*: U.S. Geological Survey Techniques and Methods, 10–C2, 28 p.
- Rosenberry, D.O., LaBaugh, J.W., and Hunt, R.J., 2008, Use of monitoring wells, portable piezometers, and seepage meters to quantify flow between surface water and ground water, chap. 2 of Rosenberry, D.O., and LaBaugh, J.W., eds., 2008, *Field techniques for estimating water fluxes between surface water and ground water*: U.S. Geological Survey Techniques and Methods 4–D2, p. 43–70.
- Rosenfeld, Irene, and Beath, O.A., 1964, *Selenium, Geobotany, biochemistry, toxicity, and nutrition*: New York, Academic Press, 411 p.
- Roy, S., Gaillardet, J., and Allegre, C.J., 1999, Geochemistry of dissolved and suspended loads of the Seine River, France: Anthropogenic impact, carbonate and silicate weathering: *Geochimica et Cosmochimica Acta*, v. 63, no. 9, p. 1277–1292.
- Scott, G.R., 1969, General and engineering geology of the northern part of Pueblo, Colorado: U.S. Geological Survey Bulletin 1262, 131 p., 1 pl.
- Shamburger, R.J., 1981, Selenium in the environment: *Science of the Total Environment*, v. 17, p. 59–74.
- Springer, R.K., and Gelhar, L.W., 1991, Characterization of large-scale aquifer heterogeneity in glacial outwash by analysis of slug tests with oscillatory response, Cape Cod, Massachusetts, in Mallard, G.E., and Aronson, D.A. (eds.), U.S. Geological Survey Toxic Substances Hydrology Program proceedings of the technical meeting, Monterey, Calif., March 11–15, 1991: U.S. Geological Survey Water-Resources Investigations Report 1991–4034, p. 36–40.
- Stogner, R.W., Sr., 2000, Trends in precipitation and streamflow and changes in stream morphology in the Fountain Creek watershed, Colorado, 1939–99: U.S. Geological Survey Water-Resources Investigations Report 00–4130, 43 p.
- Stonestrom, D.A., and Constantz, Jim, 2003, Heat as a tool for studying the movement of ground water near streams: U.S. Geological Survey Circular 1260, 96 p.
- Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 p. [Also available online at <http://pubs.usgs.gov/tm/tm3-a8/>.]
- Tuttle, M.L.W., Fahy, J.W., Elliot, J.G., Grauch, R.I., and Stillings, L.L., 2013, Contaminants from Cretaceous black shale—I. Natural weathering processes controlling contaminant cycling in Mancos Shale, southwestern United States, with emphasis on salinity and selenium: *Applied Geochemistry*, v. 46, p. 57–71.

- Tweto, Ogden, 1979, Geologic map of Colorado: U.S. Geological Survey, scale 1:500,000.
- URS, Inc., 2006, Fountain Creek watershed study, hydraulics report, final: Prepared for U.S. Army Corps of Engineers, Albuquerque District, Contract number W912PP-04-C-0006, Task order number 005, 115 p.
- U.S. Department of Agriculture, 2011, 2011 National Land Cover Dataset (NLCD): U.S. Department of Agriculture Natural Resources Conservation Service, National Geospatial Center of Excellence raster digital data, accessed January 7, 2015, at <http://viewer.nationalmap.gov/viewer>.
- U.S. Environmental Protection Agency, 1987, Data quality objectives for remedial response activities example scenario: RI/FS activities at a site with contaminated soils and groundwater: Washington, D.C., U.S. Environmental Protection Agency, Report EPA/540/G-87/004.
- U.S. Environmental Protection Agency, 2016, Drinking water contaminants—Standards and regulations: U.S. Environmental Protection Agency, accessed March 21, 2016, at <https://www.epa.gov/dwstandardsregulations>.
- U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A9. [Also available online at <http://pubs.water.usgs.gov/twri9A>.]
- U.S. Geological Survey, 2013, 1/3-Arc second national elevation dataset: U.S. Geological Survey raster digital data, accessed January 26, 2015, at <http://viewer.nationalmap.gov/viewer>.
- Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1999, Ground water and surface water—A single resource (reprinted): U.S. Geological Survey Circular 1139, 79 p.
- Won, I.J., Keiswetter, D.A., Fields, G.R.A., Sutton, L.C., 1996, GEM-2: A new multifrequency electromagnetic sensor: *Journal of Environmental and Engineering Geophysics*, v. 1, no. 2, pp. 129–137.
- Wright, W.G., 1999, Oxidation and mobilization of selenium by nitrate in irrigation drainage: *Journal of Environmental Quality*, v. 28, p. 1182–1187.
- Zielinski, R.A., Asher-Bolinder, S., and Meier, A.L., 1995, Uraniferous waters of the Arkansas River valley, Colorado, U.S.A., A function of geology and land use: *Applied Geochemistry*, v. 10, no. 2, p. 133–144.

Publishing support provided by:
Denver Publishing Service Center

For more information concerning this publication, contact:
Director, USGS Colorado Water Science Center
Box 25046, Mail Stop 415
Denver, CO 80225
(303) 236-4882

Or visit the Colorado Water Science Center Web site at:
<http://co.water.usgs.gov/>

Appendix 1. Lithologic Logs

Well N-WB-W

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–5	No description
5–8	Clay
8–14	Gravel
14	Bedrock shale

Well screen interval: 11.0–13.5 ft
Depth to water: 7.3 ft on 08/29/2012

Well N-WB-M

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–8	No description
8–14	Sand and gravel

Well screen interval: 11.1–13.6 ft
Depth to water: 8.7 ft on 08/29/2012

Well N-WB-E

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–16	Gravel and clay
16–17	Bedrock shale

Well screen interval: 13.9–16.4 ft
Depth to water: 9.2 ft on 08/29/2012

Well N-EB-W

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–3	Fine sand
3–12	Sand and gravel
12	Bedrock?

Well screen interval: 9.2–11.7 ft
Depth to water: 7.0 ft on 08/31/2012

Well N-EB-E

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–4.5	Fine sand
4.5–10	Sandy clay

Well screen interval: 6.8–9.3 ft
Depth to water: 6.4 ft on 08/29/2012

Well M-EB-W

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–2	Clay and silt
2–5	Clay, silt, and sand
5–14	Sand and gravel
14–15	Clay
15	Bedrock

Well screen interval: 11.8–14.3 ft
Depth to water: 5.0 ft on 08/29/2012

Well M-EB-E

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–2	Clay and silt
2–5	Clay, silt, and sand
5–14	Sand and gravel
14–15	Clay
15	Bedrock

Well screen interval: 11.7–14.2 ft
Depth to water: 4.0 ft on 08/29/2012

Well S-WB-W

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–5	Clay, silt, sand
5–10	Silty sand and gravel
10–13	Silty sand
13	Bedrock

Well screen interval: 9.9–12.4 ft
Depth to water: 2.9 ft on 08/31/2012

Well S-WB-E Shallow

NO LOG—See Well S-WB-E Deep

Well screen interval: 10.2–12.7 ft
Depth to water: 4.6 ft on 08/30/2012

Well S-WB-E Deep

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–25	Sand and gravel
25	Bedrock

Well screen interval: 21.9–24.4 ft
Depth to water: 4.6 ft on 08/30/2012

Well S-EB-W Shallow

NO LOG—See Well S-EB-W Deep

Well screen interval: 10.2–12.7 ft
Depth to water: 3.0 ft on 08/28/2012

Well S-EB-W Deep

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–27	Sand and gravel
27	Bedrock

Well screen interval: 23.9–26.4 ft
Depth to water: 3.4 ft on 08/28/2012

Well S-EB-E Shallow

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–7	Sand
7–19	Clay

Well screen interval: 16.3–18.8 ft
Depth to water: 7.1 ft on 08/28/2012

Well S-EB-E Deep

[Depth intervals in feet below land surface; ft, feet]

Depth	Description
0–7	Sand
7–30	Clay
30	Black shale

Well screen interval: 26.7–29.2 ft
Depth to water: 7.8 ft on 08/28/2012

Appendix 2. Water-Quality Control Data

Appendix Table 2–1. Summary of blank and replicate water-quality samples.

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; °C, degrees Celsius; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; <, less than; --, no data; E, estimated value is below the reporting level but at or above the detection level; $\delta^{18}\text{O}$, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); $\delta^2\text{H}$, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil; RPD, relative percent difference between environmental (Es) and replicate (Rs) sample concentrations, computed as absolute value of $(\text{Es} - \text{Rs}) / ((\text{Es} + \text{Rs}) / 2) * 100$]

Blank sample results									
Local site name	USGS site number	Collection date	Residue on evaporation at 180 °C (dissolved solids), filtered (mg/L)	Calcium, filtered (mg/L)	Magnesium, filtered (mg/L)	Potassium, filtered (mg/L)	Sodium, filtered (mg/L)	Chloride, filtered (mg/L)	Fluoride, filtered (mg/L)
N-WB-W	381754104362001	11/14/2012	<20	0.080	0.027	<0.03	0.07	<0.06	<0.04
N-WB-W	381754104362001	7/8/2013	<20	0.025	<0.011	<0.03	<0.06	<0.06	<0.01
M-EB-E	381652104360601	9/16/2013	<20	0.212	0.086	<0.03	0.12	0.07	<0.01
S-WB-W	381529104354201	4/8/2013	<20	0.109	0.024	<0.03	<0.06	<0.06	0.17
S-EB-W Shallow	381532104353502	9/11/2012	<20	0.220	0.082	<0.03	0.13	0.09	<0.04
South transect	381532104353503	9/16/2013	--	--	--	--	--	--	--
Local site name	Collection date	Sulfate, filtered (mg/L)	Ammonia, as N filtered (mg/L)	Nitrate, as N filtered (mg/L)	Nitrite, as N filtered (mg/L)	Organic nitrogen, unfiltered (mg/L)	Orthophosphate, as P filtered (mg/L)	Phosphorus, as P unfiltered (mg/L)	Total nitrogen, unfiltered (mg/L)
N-WB-W	11/14/2012	0.23	<0.01	<0.008	0.002	<0.07	<0.004	<0.004	<0.08
N-WB-W	7/8/2013	<0.09	<0.01	<0.010	<0.001	<0.07	<0.004	<0.004	<0.08
M-EB-E	9/16/2013	0.66	<0.01	<0.010	<0.001	<0.07	<0.004	0.004	<0.08
S-WB-W	4/8/2013	0.20	<0.01	0.067	<0.001	<0.07	<0.004	<0.004	<0.14
S-EB-W Shallow	9/11/2012	1.09	<0.01	<0.010	<0.001	<0.07	<0.004	<0.004	<0.08
South transect	9/16/2013	--	--	--	--	--	--	--	--
Local site name	Collection date	Barium, filtered (µg/L)	Iron, filtered (µg/L)	Manganese, filtered (µg/L)	Selenium, filtered (µg/L)	Uranium, natural filtered (µg/L)	$\delta^{18}\text{O}$ (‰)	$\delta^2\text{H}$ (‰)	
N-WB-W	11/14/2012	<0.10	<4.0	0.22	<0.03	<0.004	–0.75	–5.80	
N-WB-W	7/8/2013	<0.10	<4.0	0.36	<0.03	<0.004	--	--	
M-EB-E	9/16/2013	0.16	<4.0	1.41	<0.03	0.006	--	--	
S-WB-W	4/8/2013	0.17	7.5	0.66	<0.03	<0.004	--	--	
S-EB-W Shallow	9/11/2012	0.19	<3.2	2.55	<0.03	<0.004	--	--	
South transect	9/16/2013	<0.10	--	<0.15	<0.03	<0.004	--	--	

Appendix Table 2–1. Summary of blank and replicate water-quality samples.—Continued

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; °C, degrees Celsius; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; <, less than; --, no data; E, estimated value is below the reporting level but at or above the detection level; δ¹⁸O, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); δ²H, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil; RPD, relative percent difference between environmental (Es) and replicate (Rs) sample concentrations, computed as absolute value of (Es – Rs) / ((Es + Rs) / 2) * 100]

Local well name	USGS site number	Collection date	Sample type	Replicate sample results					
				Residue on evaporation at 180 °C (dissolved solids), filtered (mg/L)	Calcium, filtered (mg/L)	Magnesium, filtered (mg/L)	Potassium, filtered (mg/L)	Sodium, filtered (mg/L)	Chloride, filtered (mg/L)
N-EB-W	381754104361401	11/15/2012	Environmental	9,510	386	958	17.4	1,060	95.2
			Replicate	--	--	--	--	--	--
			RPD	--	--	--	--	--	--
N-EB-W	381754104361401	4/16/2013	Environmental	11,700	444	1,190	16.5	1,280	120
			Replicate	--	--	--	--	--	--
			RPD	--	--	--	--	--	--
N-EB-E	381754104361101	11/15/2012	Environmental	8,910	524	818	12.0	994	117
			Replicate	--	--	--	--	--	--
			RPD	--	--	--	--	--	--
N-EB-E	381754104361101	7/9/2013	Environmental	7,210	388	609	10.9	713	96.7
			Replicate	7,210	385	601	10.8	704	100
			RPD	0.0	0.8	1.3	0.9	1.3	3.4
M-EB-E	381652104360601	9/19/2013	Environmental	1,090	130	49.3	7.86	145	98.0
			Replicate	1,100	131	50.2	7.92	145	97.3
			RPD	0.9	0.8	1.8	0.8	0.0	0.7
S-WB-E Deep	381531104353601	4/22/2013	Environmental	1,550	176	83.7	7.06	189	86.9
			Replicate	1,550	179	83.9	6.97	183	86.8
			RPD	0.0	1.7	0.2	1.3	3.2	0.1

Appendix Table 2–1. Summary of blank and replicate water-quality samples.—Continued

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; °C, degrees Celsius; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; <, less than; --, no data; E, estimated value is below the reporting level but at or above the detection level; $\delta^{18}\text{O}$, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); $\delta^2\text{H}$, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil; RPD, relative percent difference between environmental (Es) and replicate (Rs) sample concentrations, computed as absolute value of $(\text{Es} - \text{Rs}) / ((\text{Es} + \text{Rs}) / 2) * 100$]

Local well name	Collection date	Sample type	Replicate sample results						
			Fluoride, filtered (mg/L)	Sulfate, filtered (mg/L)	Ammonia, as N filtered (mg/L)	Nitrate, as N filtered (mg/L)	Nitrite, as N filtered (mg/L)	Organic nitrogen, unfiltered (mg/L)	Orthophosphate, as P filtered (mg/L)
N-EB-W	11/15/2012	Environmental	1.48	5,990	0.19	46.2	0.059	1.7	0.142
		Replicate	--	--	0.19	45.8	0.064	1.6	0.143
		RPD	--	--	0.0	0.9	8.1	6.1	0.7
N-EB-W	4/16/2013	Environmental	1.30	7,980	0.22	64.4	0.023	1.4	0.149
		Replicate	--	--	0.24	65.5	0.023	1.5	0.148
		RPD	--	--	8.7	1.7	0.0	6.9	0.7
N-EB-E	11/15/2012	Environmental	1.18	5,590	0.18	81.2	0.005	1.9	0.029
		Replicate	--	--	0.17	80.0	0.005	2.0	0.030
		RPD	--	--	5.7	1.5	0.0	5.1	3.4
N-EB-E	7/9/2013	Environmental	2.06	3,760	0.15	56.8	0.004	1.3	0.026
		Replicate	2.11	3,960	0.14	57.1	0.004	1.4	0.026
		RPD	2.4	5.2	6.9	0.5	0.0	7.4	0.0
M-EB-E	9/19/2013	Environmental	2.05	505	<0.01	1.18	0.051	<0.41	0.020
		Replicate	2.07	496	<0.01	1.19	0.051	<0.36	0.020
		RPD	1.0	1.8	--	0.8	0.0	--	0.0
S-WB-E Deep	4/22/2013	Environmental	1.60	811	<0.01	1.09	0.003	<0.10	0.026
		Replicate	1.60	809	<0.01	1.09	0.003	<0.09	0.025
		RPD	0.0	0.2	--	0.0	0.0	--	3.9

Appendix Table 2–1. Summary of blank and replicate water-quality samples.—Continued

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; °C, degrees Celsius; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; <, less than; --, no data; E, estimated value is below the reporting level but at or above the detection level; δ¹⁸O, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); δ²H, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil; RPD, relative percent difference between environmental (Es) and replicate (Rs) sample concentrations, computed as absolute value of (Es – Rs) / ((Es + Rs) / 2) * 100]

Replicate sample results									
Local well name	Collection date	Sample type	Phosphorus, as P unfiltered (mg/L)	Total nitrogen, unfiltered (mg/L)	Barium, filtered (µg/L)	Iron, filtered (µg/L)	Manganese, filtered (µg/L)	Selenium, filtered (µg/L)	Uranium, natural filtered (µg/L)
N-EB-W	11/15/2012	Environmental	0.366	48	25.2	40.0	54.9	1,330	149
		Replicate	0.366	48	26.9	39.7	60.0	1,410	161
		RPD	0.0	0.0	6.5	0.8	8.9	5.8	7.7
N-EB-W	4/16/2013	Environmental	0.807	66	22.6	39.5	23.5	1,700	171
		Replicate	0.772	67	21.0	67.8	17.9	1,660	164
		RPD	4.4	1.5	7.3	52.7	27.1	2.4	4.2
N-EB-E	11/15/2012	Environmental	0.033	83	32.4	20.0	20.3	1,670	195
		Replicate	0.035	82	31.7	<20.0	19.7	1,660	192
		RPD	5.9	1.2	2.2	--	3.0	0.6	1.6
N-EB-E	7/9/2013	Environmental	0.033	58	21.0	93.3	6.80	1,580	127
		Replicate	0.031	59	21.9	31.0	7.47	1,600	135
		RPD	6.3	1.7	4.2	100.2	9.4	1.3	6.1
M-EB-E	9/19/2013	Environmental	0.174	1.6	50.6	10.6	317	26.4	9.63
		Replicate	0.168	1.6	49.9	11.0	315	26.0	9.83
		RPD	3.5	0.0	1.4	3.7	0.6	1.5	2.1
S-WB-E Deep	4/22/2013	Environmental	0.031	1.2	33.3	10.4	54.0	30.4	20.8
		Replicate	0.031	1.2	33.2	10.3	54.6	30.7	20.8
		RPD	0.0	0.0	0.3	1.0	1.1	1.0	0.0

Appendix Table 2–1. Summary of blank and replicate water-quality samples.—Continued

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; °C, degrees Celsius; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; <, less than; --, no data; E, estimated value is below the reporting level but at or above the detection level; δ¹⁸O, isotope ratio of oxygen-18 to oxygen-16 relative to Vienna Standard Mean Ocean Water (VSMOW); δ²H, isotope ratio of hydrogen-2 to hydrogen-1 relative to VSMOW; ‰, per mil; RPD, relative percent difference between environmental (Es) and replicate (Rs) sample concentrations, computed as absolute value of (Es – Rs) / ((Es + Rs) / 2) * 100]

Local well name	Collection date	Replicate sample results		
		Sample type	δ ¹⁸ O (‰)	δ ² H (‰)
N-EB-W	11/15/2012	Environmental	–10.70	–80.90
		Replicate	--	--
		RPD	--	--
N-EB-W	4/16/2013	Environmental	–11.88	–91.80
		Replicate	--	--
		RPD	--	--
N-EB-E	11/15/2012	Environmental	–11.82	–89.20
		Replicate	--	--
		RPD	--	--
N-EB-E	7/9/2013	Environmental	–12.18	–92.20
		Replicate	–12.22	–92.70
		RPD	0.3	0.5
M-EB-E	9/19/2013	Environmental	–11.64	–92.30
		Replicate	–11.64	–90.70
		RPD	0.0	1.7
S-WB-E Deep	4/22/2013	Environmental	–11.37	–88.20
		Replicate	–11.29	–88.00
		RPD	0.7	0.2

