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# Characterization of Hydrology and Water Quality of Piceance Creek in the Alkali Flat Area, Rio Blanco County, Colorado, March 2012

Scientific Investigations Report 2015–5147

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

**Front Cover.** Hydrologist measuring streamflow in Piceance Creek, Alkali Flat area, Rio Blanco County, Colorado. Photograph by Judith Thomas, U.S. Geological Survey, March 14, 2012.

**Back Cover.** *Left*, Spring, Alkali Flat area, Rio Blanco County, Colorado. Photograph by Jennifer Moore, U.S. Geological Survey, February 24, 2012. *Right*, Research hydrologist sampling springs, Alkali Flat area, Rio Blanco County, Colorado. Photograph by Judith Thomas, U.S. Geological Survey March 27, 2012.

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By Judith C. Thomas

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**U.S. Geological Survey**

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

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

U.S. Geological Survey, Reston, Virginia: 2015

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## Tables



# Conversion Factors

Inch/Pound to SI

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| mile, nautical (nmi) | 1.852 | kilometer (km) |
| yard (yd) | 0.9144 | meter (m) |
| | Area | |
| square foot ($ft^2$) | 929.0 | square centimeter ($cm^2$) |
| square foot ($ft^2$) | 0.09290 | square meter ($m^2$) |
| square mile ($mi^2$) | 259.0 | hectare (ha) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Volume | |
| cubic foot ($ft^3$) | 0.02832 | cubic meter ($m^3$) |
| acre-foot (acre-ft) | 0.001233 | cubic hectometer ($hm^3$) |
| | Flow rate | |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| | Load | |
| pounds per day | 0.4536 | kilograms per day |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

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).

Specific conductance was given in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

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

# Characterization of Hydrology and Water Quality of Piceance Creek in the Alkali Flat Area, Rio Blanco County, Colorado, March 2012

By Judith C. Thomas

## Abstract

Previous studies by the U.S. Geological Survey identified Alkali Flat as an area of groundwater upwelling, with increases in concentrations of total dissolved solids, and streamflow loss, but additional study was needed to better characterize these observations. The U.S. Geological Survey, in cooperation with the Bureau of Land Management, White River Field Office, conducted a study to characterize the hydrology and water quality of Piceance Creek in the Alkali Flat area of Rio Blanco County, Colorado.

Water-quality samples were collected at five springs on March 27, 2012, to determine field properties, major ions, trace elements, and stable isotopes of water. Major-ion and trace-element chemistry indicated that the springs sampled as part of this study were likely recharged by the bedrock aquifer. Isotopic values for the springs plotted close to that of groundwater from the Parachute Creek Member of the Green River Formation, and the isotopic values from both of these sources are similar to the values for Grand Mesa snow. Based on fluoride, lithium, and strontium concentrations, one spring appeared to have different source water than the other four springs. The spring also had higher concentrations of calcium, magnesium, and sulfate relative to the other four springs. Trace-element and major-ion data indicate that this spring was sourced from the Uinta Formation. It was likely the other four springs were primarily sourced from the lower part of the Parachute Creek Member of the Green River Formation as indicated by low sulfate concentrations and high fluoride, lithium, and boron concentrations.

Water-quality samples were collected at 16 surface-water-quality sites on March 14, 2012, to determine field properties, major ions, and trace elements. Sodium was the dominant cation and concentrations increased steadily from upstream to downstream along the study reach. Calcium, magnesium, and potassium concentrations remained relatively stable along the study reach. Strontium concentrations were relatively stable along the study reach, whereas boron and lithium concentrations increased appreciably at site PC22031 and remained elevated to the end of the study reach.

Loading profiles were used to further refine areas of spring and groundwater input and streamflow gains and losses. Although there was a minor gain in streamflow from sites PC21543 to PC21816 (58 to 59 cubic feet per second ($ft^3/s$) during March 2014), the observed increase in dissolved solids load indicated groundwater contribution to Piceance Creek between these two sites. From sites PC22737 to PC22980, dissolved solids load decreased, which was not observed in concentration profiles and indicated that streamflow loss occurred between these two sites. Barium, boron, lithium, and strontium loads showed similar patterns to that of the major ions along the study reach and indicated similar areas of groundwater gain and loss. Boron and lithium load were not observed to decrease in a similar pattern to that of barium and strontium load which would suggest the contribution to the stream from sources with similar chemistry to that of spring sites PCSP2 through PCSP5. Sodium, chloride, and bicarbonate loads increased and decreased along the study reach in a pattern similar to that of dissolved solids load. A chemical mass balance was used to estimate the amount of groundwater and (or) spring water that contributed to the observed changes in water quality along Piceance Creek. This analysis indicated only 5 percent spring water would need to reach Piceance Creek to result in the observed changes in water quality.

Instantaneous streamflow was measured from sites PC20133 to PC23721 during field reconnaissance (February 2012) and during synoptic sampling (March 2012). During both February and March, the study reach from sites PC20133 to PC23721 was a losing reach with net losses that ranged from 0.5 $ft^3/s$ (February) to 3 $ft^3/s$ (March). Observed changes in streamflow along the study reach helped to depict interactions between groundwater and surface water in the Alkali Flat area.

Water-quality samples were collected at five surface-water sites in December 2010 that were sampled as part of a previous USGS study in 2000. Water-quality data collected during December 2010 showed no appreciable difference from water-quality data collected during December 2000 at the five sites.

# Introduction

Alkali Flat is an area of approximately 0.3 square miles ($mi^2$) along the northern end of Piceance Creek, and is situated approximately 4 miles upstream from the confluence of Piceance Creek and the White River (fig. 1). Springs and seeps occur along Piceance Creek in the Alkali Flat area. Results of previous studies (Ortiz, 2002; Taylor, 1987) identified Alkali Flat as an area of both groundwater upwelling and streamflow loss, and showed that concentrations of dissolved solids in Piceance Creek increased in a downstream direction; however, additional study would be needed to better understand these observations. The U.S. Geological Survey (USGS), in cooperation with the Bureau of Land Management (BLM), White River Field Office, conducted a study to further characterize the hydrology and water quality of Piceance Creek in the Alkali Flat area.

## Purpose and Scope

The purpose of this report is to characterize the hydrology of Piceance Creek in the Alkali Flat area and to identify areas of streamflow gain and loss. Water quality of both springs and Piceance Creek are examined to improve understanding of springs' contribution to the water quality of Piceance Creek. Water-quality samples were collected at five sites in December 2010 that were sampled as part of a previous USGS study (Ortiz, 2002) to understand and identify potential changes that may have occurred since 2000. In addition, 16 stream sites and 5 springs were sampled to characterize water quantity and quality in Piceance Creek in the Alkali Flat area in March 2012.

## Description of Study Area

The study area extends between Piceance Creek at Ryan Gulch streamflow-gaging station 09306200 and Piceance Creek at White River streamflow-gaging station 09306222 (fig. 1), but focuses on the Alkali Flat area. Piceance Creek is a meandering stream channel incised into Quaternary alluvial deposits with steep banks prone to sloughing. In the Alkali Flat area, these alluvial deposits are underlain by the Tertiary Uinta Formation (Tweto, 1979). The Uinta Formation is a gray and yellow-brown marlstone, siltstone, sandstone, and tuff which intertongues with the underlying Parachute Creek Member of the Tertiary Green River Formation (Taylor, 1987). The Parachute Creek Member is composed of dolomitic marlstone and shale layers where water bearing layers are separated by the Mahogany zone into an upper and lower aquifer (Coffin and others, 1971). A northwest-southeast-trending fault zone runs through the Alkali Flat area (Taylor, 1987; Verbeek and Grout, 1983) and likely accounts for the numerous springs and seeps in the Alkali Flat area.

# Methods of Data Collection

In order to understand streamflow quantity and quality, the investigation was conducted under base-flow conditions (March) to minimize the influence of irrigation practices on streamflow. Under base-flow conditions, streamflow increased along the study reach whereas during the irrigation season this pattern was less evident (fig. 2). Using a similar approach to the previous study by Ortiz, sites were identified by a downstream distance from Piceance Creek at Ryan Gulch streamflow-gaging station 09306200 (field site PC0) (Ortiz, 2002). Synoptic samples and streamflow measurements were collected between the area just above Alkali Flat, which was 12.5 miles downstream from site PC0 to just below Alkali Flat, which was 14.7 miles downstream from site PC0. In the Alkali Flat area, from sites PC20408 to PC23721, there were no perennial streams discharging to Piceance Creek (fig. 3).

Water-quality samples were collected at five sites in December 2010 that were sampled as part of a previous USGS study (Ortiz, 2002) to understand and identify potential changes that may have occurred since 2000. Of the five sites, three sites were upstream from the Alkali Flat area (sites PC5280, PC14789, PC16210), one was within the Alkali Flat area (site PC20708), and one was downstream from the Alkali Flat area (site PC24787) (fig. 1 and table 1). At these sites, water-quality samples were collected for major ions, trace elements (boron, barium, arsenic, and strontium), and streamflow measurements and field properties (pH, specific conductance, temperature, and alkalinity) were collected (table 1).

Surface-water quality data at select sites on Piceance Creek, comparing water-quality data from December 2000 to December 2010, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado. Sixteen stream sites and five springs were sampled to characterize water quantity and quality in Piceance Creek in the Alkali Flat area. The study reach and sites were identified during field reconnaissance conducted February 2012 (fig. 3). For all sites, photographs and location data were collected. Streamflow measurements and field properties were collected during reconnaissance. Field properties were collected at springs. During reconnaissance, 14 new surface-water sites and 2 existing surface-water sites were investigated. Existing sites were defined as those sites that have historical data collected at them and new sites were defined as having no data collected at them prior to this study. The two existing surface-water sites were USGS station number 400206108154700 (site PC20708) and USGS station number 400306108150000 (site PC23721). Spring sites were also identified during reconnaissance, including one existing spring site (USGS station number 400216108154000), and four new spring sites (table 2).

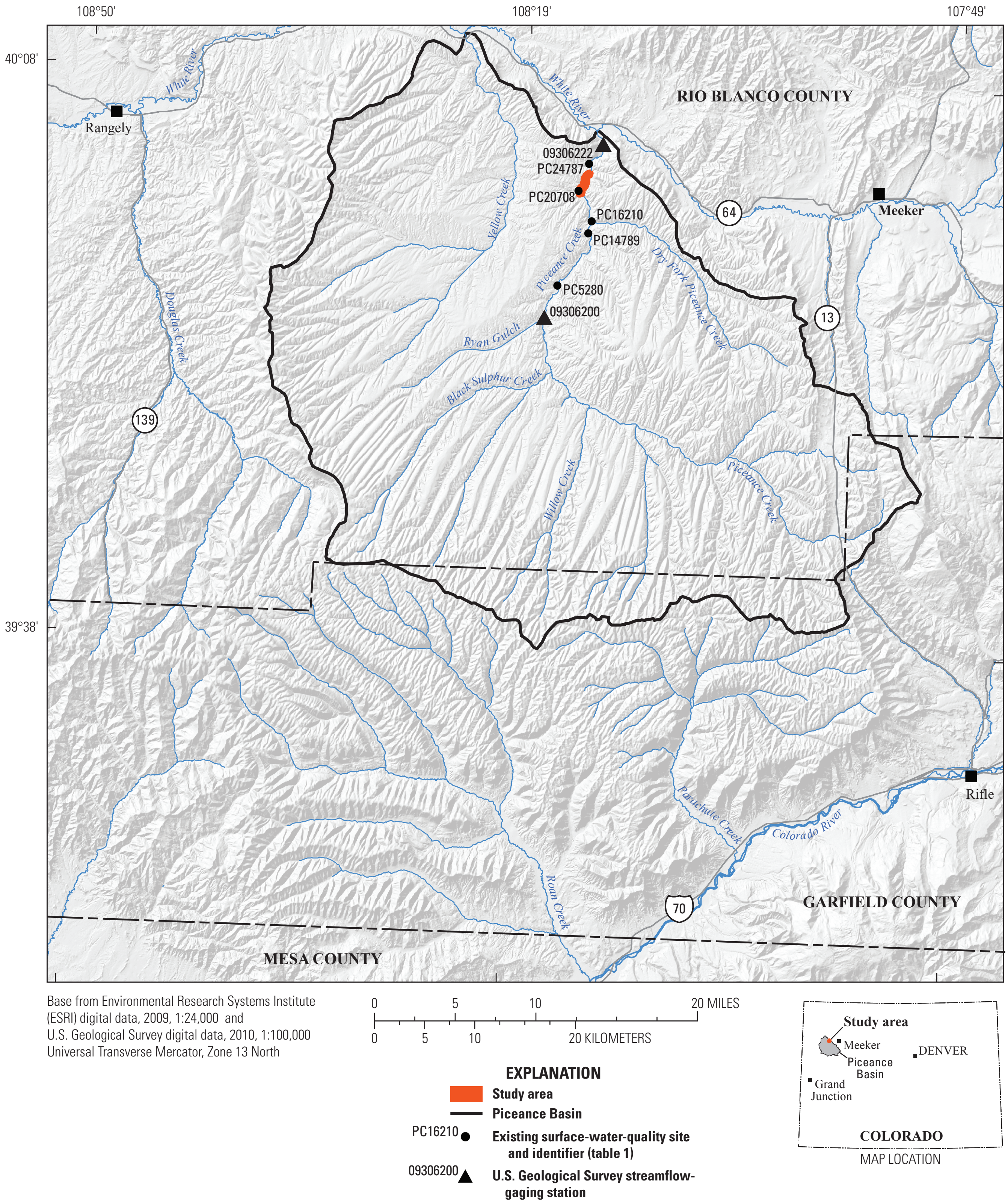



**Figure 1.** Location of study area, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado.

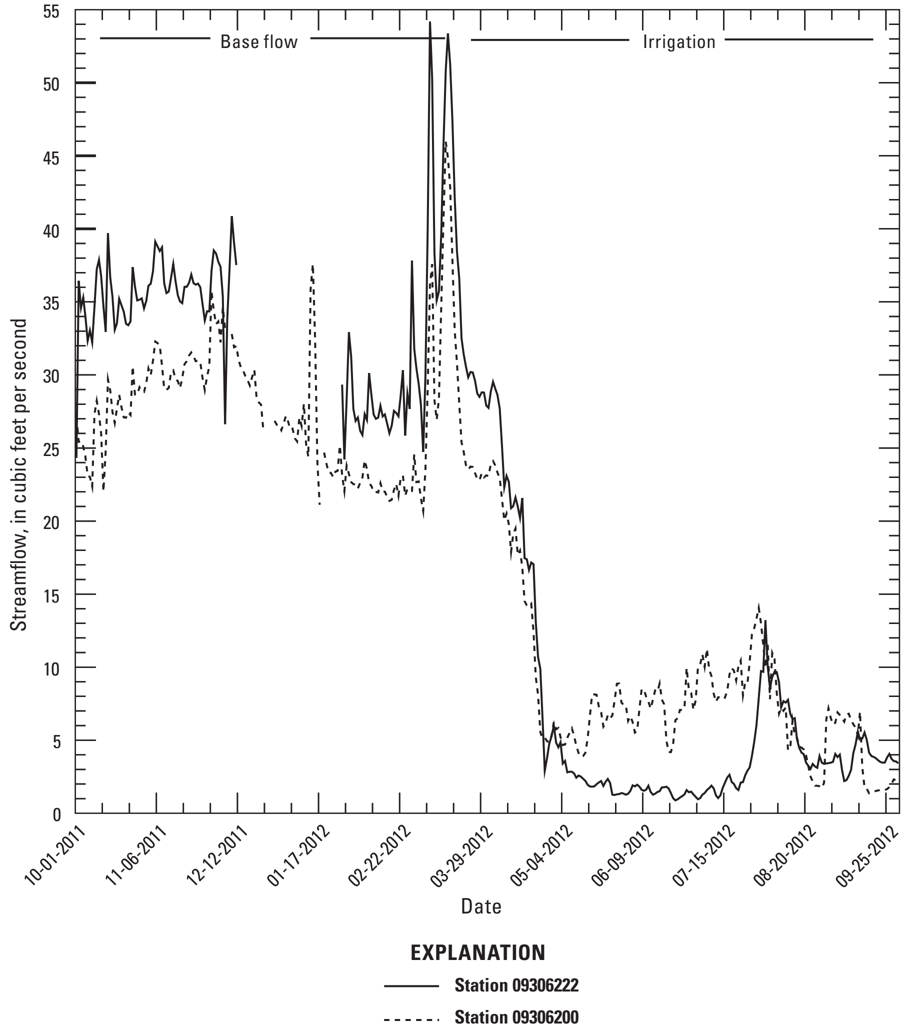



**Figure 2.** Annual hydrograph at U.S. Geological Survey streamflow-gaging stations 09306200 and 09306222 for water year 2012 (a water year is the 12-month period October 1 through September 30 designated by the calendar year in which it ends), Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado.

Synoptic sampling was conducted during March 2012, when water-quality samples and streamflow measurements were collected at all 16 stream sites. Streamflow measurements were collected at surface-water sites during reconnaissance and during the synoptic sampling (February and March 2012, respectively). Streamflow measurements were made using standard techniques (Rantz and others, 1982; Turnipseed and Sauer, 2010). Measurements were rated by the individual making the measurement based on the hydrologic and hydraulic conditions in which the measurements were made (Turnipseed and Sauer, 2010). These ratings are a means of associating a numeric estimate of the percentage of error associated with a measurement, for this study error associated with streamflow measurements ranged from 5 to 8 percent where 5 percent is considered good and 8 percent is considered fair. These data were used to further investigate areas of suspected streamflow loss in the study reach and to determine if streamflow conditions remained constant during synoptic sampling.

Synoptic sampling was conducted to provide a spatially detailed description of the water quality in Piceance Creek by sampling 16 sites in a short period of time. Four staff members were located along Piceance Creek and collected one water-quality sample and one streamflow measurement at each sampling location from upstream to downstream. Samples were collected in clean 4-liter plastic containers from the centroid of flow. Once samples were collected, Bureau of Land Management staff transported samples back to the processing vehicle where samples were processed. During synoptic sampling in March 2012, field properties (temperature, specific conductance, pH, dissolved oxygen, and alkalinity) were measured and samples were collected for

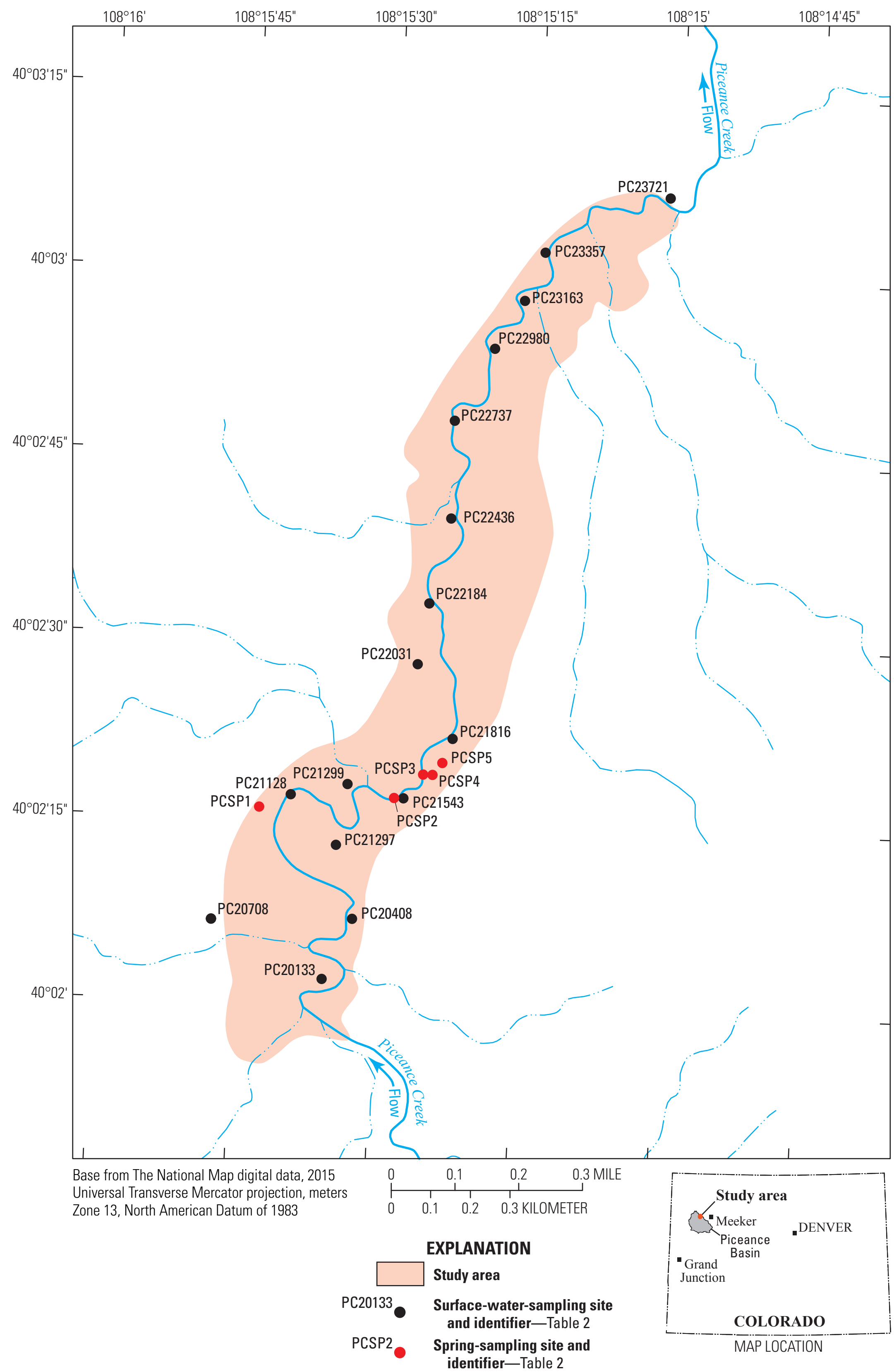



**Figure 3.** Location of surface-water and spring-sampling sites sampled during March 2012, Piceance Creek in the Alkali Flat area (see fig. 1), Rio Blanco County, Colorado.

**Table 1.** Surface-water quality data at select sites on Piceance Creek, comparing water-quality data from December 2000 to December 2010, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado.

[ID, identifier; --, no data; DD, decimal degrees; ft³/s, cubic feet per second; mg/L, milligram per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; µg/L, micrograms per liter; E, estimated; <, less than]

| Station number | Field site ID (see fig. 3 for location) | Date | Sample start time (24-hour) | Latitude (DD) | Longitude (DD) | Stream-flow (ft³/s) | pH (standard units) | Specific conductance (µS/cm at 25 °C) | Temperature (°C) |
|---|---|---|---|---|---|---|---|---|---|
| 395658108170100 | PC5280 | 12/07/2000 | 0700 | 39.949 | –108.284 | -- | 8.1 | 1,590 | -- |
| 395658108170100 | PC5280 | 12/15/2010 | 1405 | 39.949 | –108.284 | 19 | 8.5 | 1,520 | 4.4 |
| 395951108145900 | PC14789 | 12/06/2000 | 1005 | 39.998 | –108.250 | -- | 8 | 1,780 | -- |
| 395951108145900 | PC14789 | 12/15/2010 | 1305 | 39.998 | –108.250 | 21 | 8.5 | 1,610 | 3.9 |
| 400030108144700 | PC16210 | 12/06/2000 | 0910 | 40.008 | –108.246 | -- | 8 | 1,770 | -- |
| 400030108144700 | PC16210 | 12/15/2010 | 1150 | 40.008 | –108.246 | 21 | 8.5 | 1,620 | 3.8 |
| 400206108154700 | PC20708 | 12/06/2000 | 1030 | 40.035 | –108.263 | -- | 8 | 1,730 | -- |
| 400206108154700 | PC20708 | 12/15/2010 | 1045 | 40.035 | –108.263 | 26 | 8.5 | 1,650 | 3.9 |
| 400334108150600 | PC24787 | 12/06/2000 | 0900 | 40.060 | –108.252 | -- | 7.9 | 1,950 | -- |
| 400334108150600 | PC24787 | 12/15/2010 | 0930 | 40.060 | –108.252 | 25 | 8.5 | 1,880 | 3.6 |

| Station number | Calcium, dissolved (mg/L) | Magnesium, dissolved (mg/L) | Potassium, dissolved (mg/L) | Sodium, dissolved (mg/L) | Alkalinity (mg/L as $CaCO_3$) | Bromide, dissolved (mg/L) | Chloride, dissolved (mg/L) | Fluoride, dissolved (mg/L) | Silica, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| 395658108170100 | 88.8 | 79.4 | 2.39 | 175 | 482 | -- | 16.8 | 0.59 | 16.5 |
| 395658108170100 | 89.4 | 84.2 | 2.62 | 182 | 463 | 0.065 | 18.2 | 0.73 | 17.1 |
| 395951108145900 | 79.2 | 84.9 | 2.54 | 203 | 481 | 0.1 | 19.2 | 0.64 | 17 |
| 395951108145900 | 85.5 | 86.5 | 2.76 | 205 | 497 | 0.072 | 21.1 | 0.71 | 17.3 |
| 400030108144700 | 84.2 | 87.8 | 2.53 | 204 | 524 | 0.09 | 19.1 | 0.67 | 16.8 |
| 400030108144700 | 85.9 | 87.4 | 2.85 | 214 | 512 | 0.081 | 20.5 | 0.75 | 17.3 |
| 400206108154700 | 81.4 | 83.1 | 2.48 | 200 | 492 | 0.09 | 20.1 | 0.67 | 16.8 |
| 400206108154700 | 81.6 | 83.6 | 2.7 | 218 | 540 | 0.085 | 22.5 | 0.78 | 17.3 |
| 400334108150600 | 83.3 | 84.9 | 2.54 | 269 | 592 | 0.13 | 33.6 | 0.86 | 16.4 |
| 400334108150600 | 82.4 | 85.3 | 2.96 | 297 | 643 | 0.076 | 51.3 | 0.92 | 17.3 |

| Station number | Sulfate, dissolved (mg/L) | Aluminum, dissolved (µg/L) | Barium, dissolved (µg/L) | Iron, dissolved (µg/L) | Strontium, dissolved (µg/L) | Zinc, dissolved (µg/L) | Antimony, dissolved (µg/L) | Arsenic, dissolved (µg/L) | Boron, dissolved (µg/L) |
|---|---|---|---|---|---|---|---|---|---|
| 395658108170100 | 419 | -- | 75.6 | E6.3 | 3,140 | 2 | 0.117 | E2 | 170 |
| 395658108170100 | 407 | -- | 71.5 | -- | 3,030 | -- | -- | 1.9 | 178 |
| 395951108145900 | 435 | 1.2 | 78.6 | <10.0 | 2,980 | 1.7 | 0.183 | 1.9 | 186 |
| 395951108145900 | 413 | -- | 74.2 | -- | 3,040 | -- | -- | 2 | 188 |
| 400030108144700 | 425 | 1.5 | 79.2 | <10.0 | 3,000 | 2.4 | <0.048 | 2.4 | 192 |
| 400030108144700 | 416 | -- | 78.7 | -- | 3,130 | -- | -- | 2.1 | 190 |
| 400206108154700 | 411 | 1.3 | 82 | <10.0 | 2,810 | 2 | <0.048 | 2.2 | 192 |
| 400206108154700 | 400 | -- | 86.4 | -- | 2,910 | -- | -- | 2.2 | 208 |
| 400334108150600 | 407 | 1.2 | 102 | <30.0 | 2,840 | 1.9 | <0.048 | 2.6 | 229 |
| 400334108150600 | 399 | -- | 111 | -- | 2,900 | -- | -- | 2.2 | 226 |

**Table 2.** Water-quality data and loads at surface-water and spring-sampling sites in the Alkali Flat area, Rio Blanco County, Colorado, March 2012.

[ID, identifier; --, no data; DD, decimal degrees; ft³/sec, cubic feet per second; mg/L, milligram per liter; µS/cm, microsiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; µg/L, micrograms per liter; <, less than]

| Field site ID (see fig. 3 for location) | Station number | Site type | Distance downstream from station 09306200, in miles | Date | Sample start time | Latitude (DD) | Longitude (DD) | Stream-flow (ft³/s) | Dissolved oxygen (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| PC20133 | 400202108153501 | Surface water | 12.5 | 03/14/2012 | 0900 | 40.034 | –108.260 | 56 | -- |
| PC20408 | 400207108153201 | Surface water | 12.7 | 03/14/2012 | 1030 | 40.035 | –108.259 | 56 | -- |
| PC20708 | 400206108154700 | Surface water | 12.9 | 03/14/2012 | 1250 | 40.035 | –108.263 | 57 | -- |
| PC21128 | 400217108153901 | Surface water | 13.1 | 03/14/2012 | 1600 | 40.038 | –108.261 | 60 | 9.2 |
| PC21297 | 400213108153401 | Surface water | 13.2 | 03/14/2012 | 1500 | 40.037 | –108.259 | 59 | 9.3 |
| PC21299 | 400218108153301 | Surface water | 13.2 | 03/14/2012 | 1400 | 40.038 | –108.259 | 56 | 9.6 |
| PC21543 | 400217108152701 | Surface water | 13.4 | 03/14/2012 | 1245 | 40.038 | –108.258 | 58 | 9.9 |
| PC21816 | 400222108152201 | Surface water | 13.6 | 03/14/2012 | 1130 | 40.039 | –108.256 | 59 | 10.1 |
| PC22031 | 400228108152601 | Surface water | 13.7 | 03/14/2012 | 1015 | 40.041 | –108.257 | 58 | 10 |
| PC22184 | 400233108152501 | Surface water | 13.8 | 03/14/2012 | 0845 | 40.043 | –108.257 | 58 | 10.1 |
| PC22436 | 400240108152301 | Surface water | 13.9 | 03/14/2012 | 0905 | 40.044 | –108.256 | 60 | 10.5 |
| PC22737 | 400248108152301 | Surface water | 14.1 | 03/14/2012 | 1010 | 40.047 | –108.256 | 59 | 10.8 |
| PC22980 | 400254108151901 | Surface water | 14.3 | 03/14/2012 | 1105 | 40.048 | –108.255 | 51 | 9.6 |
| PC23163 | 400258108151601 | Surface water | 14.4 | 03/14/2012 | 1335 | 40.049 | –108.254 | 49 | 10.8 |
| PC23357 | 400302108151401 | Surface water | 14.5 | 03/14/2012 | 1235 | 40.051 | –108.254 | 53 | 10.6 |
| PC23721 | 400306108150000 | Surface water | 14.7 | 03/14/2012 | 1450 | 40.052 | –108.250 | 53 | -- |
| PCSP1 | 400216108154000 | Spring | -- | 03/27/2012 | 1630 | 40.038 | –108.262 | -- | <0.5 |
| PCSP2 | 400217108152801 | Spring | -- | 03/27/2012 | 1445 | 40.038 | –108.258 | -- | <0.5 |
| PCSP3 | 400219108152501 | Spring | -- | 03/27/2012 | 1045 | 40.039 | –108.257 | -- | <0.5 |
| PCSP4 | 400219108152401 | Spring | -- | 03/27/2012 | 1230 | 40.039 | –108.257 | -- | <0.5 |
| PCSP5 | 400220108152301 | Spring | -- | 03/27/2012 | 1330 | 40.039 | –108.256 | -- | <0.5 |

| Field site ID (see fig. 3 for location) | pH (standard units) | Specific conductance (µS/cm at 25 °C) | Temperature (°C) | Calcium, dissolved (mg/L) | Calcium load (pounds/day) | Magnesium, dissolved (mg/L) | Potassium, dissolved (mg/L) | Sodium, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|
| PC20133 | -- | 1,030 | 3.9 | 58.4 | 17,663 | 48.2 | 3.77 | 106 |
| PC20408 | -- | 1,040 | 4.4 | 59.1 | 17,836 | 48.9 | 3.77 | 107 |
| PC20708 | -- | 1,030 | 6.2 | 58.8 | 17,933 | 48.4 | 3.86 | 112 |
| PC21128 | 8.4 | 1,030 | 8.9 | 58.8 | 19,132 | 48.2 | 3.92 | 116 |
| PC21297 | 8.5 | 1,030 | 8.2 | 58.3 | 18,691 | 48 | 3.83 | 117 |
| PC21299 | 8.4 | 1,040 | 7.4 | 58.6 | 17,690 | 48.5 | 3.85 | 121 |
| PC21543 | 8.4 | 1,060 | 6.2 | 58.8 | 18,409 | 48.5 | 3.87 | 124 |
| PC21816 | 8.4 | 1,080 | 5.1 | 59.2 | 18,822 | 49 | 3.84 | 129 |
| PC22031 | 8.4 | 1,100 | 4.2 | 58.2 | 18,253 | 48.3 | 3.8 | 130 |
| PC22184 | 8 | 1,080 | 3.4 | 57.2 | 18,030 | 46.8 | 3.72 | 130 |
| PC22436 | 8.7 | 1,090 | 3.3 | 56.6 | 18,199 | 46.9 | 3.78 | 133 |
| PC22737 | 8.8 | 1,110 | 4 | 58.5 | 18,646 | 48 | 3.85 | 136 |
| PC22980 | 8.7 | 1,140 | 5.2 | 59.3 | 16,319 | 49 | 3.82 | 141 |
| PC23163 | 8.8 | 1,140 | 7.8 | 58.8 | 15,579 | 48.3 | 3.81 | 142 |
| PC23357 | 8.8 | 1,140 | 6.9 | 60.2 | 17,135 | 49.1 | 3.9 | 140 |
| PC23721 | 8.9 | 1,130 | 8.8 | 58.3 | 16,648 | 48 | 3.84 | 143 |
| PCSP1 | 7.6 | 12,700 | 14.5 | 18 | -- | 52.4 | 8.62 | 3,420 |
| PCSP2 | 7.8 | 34,000 | 15.6 | 8.66 | -- | 10.5 | 32.9 | 11,300 |
| PCSP3 | 7.5 | 36,900 | 14.7 | 4.56 | -- | 8.36 | 32.2 | 12,100 |
| PCSP4 | 7.6 | 40,800 | 18.4 | 4.32 | -- | 4.64 | 39 | 14,800 |
| PCSP5 | 7.5 | 37,400 | 14.5 | 6.43 | -- | 9.03 | 34.8 | 12,100 |

**Table 2.** Water-quality data and loads at surface-water and spring-sampling sites in the Alkali Flat area, Rio Blanco County, Colorado, March 2012.—Continued

[ID, identifier; --, no data; DD, decimal degrees; ft$^3$/sec, cubic feet per second; mg/L, milligram per liter; µS/cm, microsiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; µg/L, micrograms per liter; <, less than]

| Field site ID (see fig. 3 for location) | Sodium load (pounds/day) | Alkalinity (mg/L as $CaCO_3$) | Bicarbonate (mg/L) | Bicarbonate load (pounds/day) | Chloride, dissolved (mg/L) | Chloride load (pounds/day) | Fluoride, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|
| PC20133 | 32,059 | 322 | 393 | 118,861 | 15.2 | 4,597 | 0.467 |
| PC20408 | 32,292 | 333 | 406 | 122,530 | 15.4 | 4,648 | 0.49 |
| PC20708 | 34,158 | 340 | 414 | 126,263 | 15.9 | 4,849 | 0.5 |
| PC21128 | 37,743 | 346 | 403 | 131,125 | 16.9 | 5,499 | 0.53 |
| PC21297 | 37,511 | 356 | 434 | 139,142 | 17.3 | 5,546 | 0.53 |
| PC21299 | 36,528 | 355 | 433 | 130,716 | 17.7 | 5,343 | 0.53 |
| PC21543 | 38,822 | 358 | 436 | 136,502 | 18.7 | 5,855 | 0.54 |
| PC21816 | 41,013 | 366 | 446 | 141,798 | 19.9 | 6,327 | 0.55 |
| PC22031 | 40,771 | 376 | 458 | 143,638 | 20.8 | 6,523 | 0.55 |
| PC22184 | 40,978 | 398 | 486 | 153,194 | 20.5 | 6,462 | 0.55 |
| PC22436 | 42,764 | 375 | 457 | 146,940 | 20.7 | 6,656 | 0.56 |
| PC22737 | 43,349 | 379 | 462 | 147,259 | 21.1 | 6,725 | 0.57 |
| PC22980 | 38,803 | 394 | 481 | 132,369 | 21.8 | 5,999 | 0.58 |
| PC23163 | 37,622 | 407 | 497 | 131,677 | 22.3 | 5,908 | 0.59 |
| PC23357 | 39,849 | 401 | 489 | 139,188 | 21.9 | 6,234 | 0.59 |
| PC23721 | 40,835 | 402 | 491 | 140208 | 22.3 | 6,368 | 0.61 |
| PCSP1 | -- | 7,480 | 9,120 | -- | 961 | -- | 11.8 |
| PCSP2 | -- | 24,900 | 30,400 | -- | 2,420 | -- | 38 |
| PCSP3 | -- | 26,800 | 32,700 | -- | 2,610 | -- | 41.3 |
| PCSP4 | -- | 30,400 | 37,000 | -- | 2,930 | -- | 54.2 |
| PCSP5 | -- | 27,900 | 34,000 | -- | 2,600 | -- | 54.9 |

| Field site ID (see fig. 3 for location) | Silica, dissolved (mg/L) | Sulfate, dissolved (mg/L) | Sulfate load (pounds/day) | Dissolved solids (mg/L) | Dissolved-solids load (pounds/day) | Aluminum, dissolved (µg/L) | Aluminum load (pounds/day) |
|---|---|---|---|---|---|---|---|
| PC20133 | 12.7 | 233 | 70,470 | 673 | 203,546 | 17.9 | 5.41 |
| PC20408 | 12.9 | 237 | 71,526 | 686 | 207,034 | 15.9 | 4.80 |
| PC20708 | 12.9 | 232 | 70,756 | 691 | 210,743 | 18.6 | 5.67 |
| PC21128 | 13.1 | 232 | 75,487 | 698 | 227,111 | 16.3 | 5.30 |
| PC21297 | 13 | 230 | 73,739 | 703 | 225,384 | 12.5 | 4.01 |
| PC21299 | 12.9 | 230 | 69,433 | 708 | 213,734 | 19.4 | 5.86 |
| PC21543 | 13 | 234 | 73,260 | 718 | 224,790 | 17.8 | 5.57 |
| PC21816 | 12.9 | 236 | 75,032 | 733 | 233,044 | 37.2 | 11.83 |
| PC22031 | 12.7 | 234 | 73,387 | 736 | 230,825 | 21.3 | 6.68 |
| PC22184 | 12.6 | 226 | 71,238 | 739 | 232,943 | 24.6 | 7.75 |
| PC22436 | 12.6 | 226 | 72,666 | 727 | 233,753 | 20.4 | 6.56 |
| PC22737 | 12.6 | 231 | 73,629 | 742 | 236,506 | 20.7 | 6.60 |
| PC22980 | 12.7 | 235 | 64,671 | 763 | 209,975 | 18.6 | 5.12 |
| PC23163 | 12.8 | 233 | 61,732 | 768 | 203,477 | 16.6 | 4.40 |
| PC23357 | 12.8 | 236 | 67,175 | 767 | 218,318 | 19 | 5.41 |
| PC23721 | 12.9 | 231 | 65,964 | 763 | 217,879 | 17.7 | 5.05 |
| PCSP1 | 25.5 | 27.8 | -- | 9,010 | -- | 28.3 | -- |
| PCSP2 | 17.8 | <9.00 | -- | <28,800 | -- | 124 | -- |
| PCSP3 | 16.8 | 13.9 | -- | 30,900 | -- | 80.3 | -- |
| PCSP4 | 15.2 | <9.00 | -- | <36,100 | -- | 171 | -- |
| PCSP5 | 19.2 | 17.4 | -- | 31,500 | -- | 73.5 | -- |

**Table 2.** Water-quality data and loads at surface-water and spring-sampling sites in the Alkali Flat area, Rio Blanco County, Colorado, March 2012.—Continued

[ID, identifier; --, no data; DD, decimal degrees; ft³/sec, cubic feet per second; mg/L, milligram per liter; µS/cm, microsiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; µg/L, micrograms per liter; <, less than]

| Field site ID (see fig. 3 for location) | Barium, dissolved (µg/L) | Barium load (pounds/day) | Beryllium, dissolved (µg/L) | Cadmium, dissolved (µg/L) | Chromium, dissolved (µg/L) | Cobalt, dissolved (µg/L) | Copper, dissolved (µg/L) | Iron, dissolved (µg/L) |
|---|---|---|---|---|---|---|---|---|
| PC20133 | 73.3 | 22.17 | <0.006 | 0.024 | 0.19 | 1.6 | <0.80 | 45.2 |
| PC20408 | 75.4 | 22.76 | <0.006 | 0.02 | 0.19 | 1.78 | <0.80 | 41.2 |
| PC20708 | 75.8 | 23.12 | <0.006 | 0.024 | 0.21 | 0.475 | <0.80 | 39.9 |
| PC21128 | 80.6 | 26.23 | <0.006 | 0.03 | 0.18 | 0.841 | <0.80 | 39.7 |
| PC21297 | 79.7 | 25.55 | <0.006 | 0.023 | 0.19 | 0.775 | <0.80 | 36.5 |
| PC21299 | 81.2 | 24.51 | <0.006 | 0.027 | 0.2 | 1.01 | <0.80 | 45.3 |
| PC21543 | 81.6 | 25.55 | <0.006 | 0.026 | 0.26 | 0.991 | <0.80 | 40 |
| PC21816 | 83.4 | 26.52 | <0.006 | 0.03 | 0.23 | 1.51 | <0.80 | 71.5 |
| PC22031 | 80.1 | 25.12 | 0.007 | 0.026 | 0.17 | 1.01 | 0.81 | 41.8 |
| PC22184 | 80.7 | 25.44 | <0.006 | 0.031 | 0.18 | 0.869 | <0.80 | 53.9 |
| PC22436 | 82.1 | 26.40 | <0.006 | 0.027 | 0.16 | 0.921 | <0.80 | 46.5 |
| PC22737 | 80.2 | 25.56 | <0.006 | 0.028 | 0.15 | 0.901 | <0.80 | 44.3 |
| PC22980 | 81.9 | 22.54 | <0.006 | 0.026 | 0.17 | 1.44 | <0.80 | 46.5 |
| PC23163 | 83.2 | 22.04 | 0.007 | 0.027 | 0.18 | 0.973 | <0.80 | 40.2 |
| PC23357 | 84.2 | 23.97 | <0.006 | 0.028 | 0.18 | 0.969 | <0.80 | 43.3 |
| PC23721 | 84.7 | 24.19 | <0.006 | 0.023 | 0.17 | 0.961 | <0.80 | 39.8 |
| PCSP1 | 5,210 | -- | 0.185 | 0.458 | <0.56 | 0.247 | <6.4 | <32.0 |
| PCSP2 | 3,790 | -- | 0.708 | 0.968 | <1.4 | <0.420 | <16.0 | <64.0 |
| PCSP3 | 3,630 | -- | 1.09 | 0.668 | <1.4 | <0.420 | <16.0 | <64.0 |
| PCSP4 | 4,410 | -- | 1.22 | 0.925 | <3.5 | <1.05 | <40.0 | 138 |
| PCSP5 | 3,560 | -- | 1.03 | 0.714 | <1.4 | <0.420 | <16.0 | <64.0 |

| Field site ID (see fig. 3 for location) | Iron load (pounds/day) | Lead, dissolved (µg/L) | Lithium, dissolved (µg/L) | Lithium load (pounds/day) | Manganese, dissolved (µg/L) | Molybdenum, dissolved (µg/L) | Nickel, dissolved (µg/L) |
|---|---|---|---|---|---|---|---|
| PC20133 | 13.67 | 0.081 | 9.38 | 2.84 | 16.4 | 5.52 | 1.1 |
| PC20408 | 12.43 | 0.078 | 8.72 | 2.63 | 18.4 | 5.69 | 1.0 |
| PC20708 | 12.17 | 0.076 | 9.91 | 3.02 | 19.0 | 5.65 | 1.0 |
| PC21128 | 12.92 | 0.075 | 10.4 | 3.38 | 20.4 | 5.89 | 1.1 |
| PC21297 | 11.70 | 0.067 | 10.3 | 3.30 | 20.2 | 5.90 | 1.1 |
| PC21299 | 13.68 | 0.08 | 10.2 | 3.08 | 19.9 | 5.67 | 1.1 |
| PC21543 | 12.52 | 0.081 | 10.7 | 3.35 | 20.2 | 5.74 | 1.1 |
| PC21816 | 22.73 | 0.104 | 10.8 | 3.43 | 20.7 | 5.71 | 1.1 |
| PC22031 | 13.11 | 0.086 | 15.4 | 4.83 | 18.2 | 5.69 | 1.2 |
| PC22184 | 16.99 | 0.092 | 12.6 | 3.97 | 16.4 | 5.55 | 1.1 |
| PC22436 | 14.95 | 0.085 | 11.1 | 3.57 | 15.4 | 5.46 | 1.1 |
| PC22737 | 14.12 | 0.084 | 15.2 | 4.84 | 17.2 | 5.60 | 1.2 |
| PC22980 | 12.80 | 0.099 | 15 | 4.13 | 18.7 | 5.67 | 1.2 |
| PC23163 | 10.65 | 0.075 | 15.2 | 4.03 | 20.3 | 5.65 | 1.2 |
| PC23357 | 12.32 | 0.076 | 15.5 | 4.41 | 19.3 | 5.81 | 1.2 |
| PC23721 | 11.37 | 0.074 | 15.5 | 4.43 | 20.5 | 5.71 | 1.2 |
| PCSP1 | -- | <0.200 | 717 | -- | 3.1 | <0.112 | <0.72 |
| PCSP2 | -- | <0.500 | 2,110 | -- | 16.3 | 0.306 | <1.8 |
| PCSP3 | -- | <0.500 | 1,920 | -- | 9.48 | <0.280 | <1.8 |
| PCSP4 | -- | <1.25 | 2,130 | -- | 14 | <0.700 | <4.5 |
| PCSP5 | -- | <0.500 | 1,960 | -- | 12.6 | <0.280 | <1.8 |

**Table 2.** Water-quality data and loads at surface-water and spring-sampling sites in the Alkali Flat area, Rio Blanco County, Colorado, March 2012.—Continued

[ID, identifier; --, no data; DD, decimal degrees; ft$^3$/sec, cubic feet per second; mg/L, milligram per liter; µS/cm, microsiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; µg/L, micrograms per liter; <, less than]

| Field site ID (see fig. 3 for location) | Silver, dissolved (µg/L) | Strontium, dissolved (µg/L) | Strontium load (pounds/day) | Vanadium, dissolved (µg/L) | Zinc, dissolved (µg/L) | Antimony, dissolved (µg/L) | Arsenic, dissolved (µg/L) |
|---|---|---|---|---|---|---|---|
| PC20133 | <0.005 | 1,820 | 550 | 5.96 | <1.4 | 0.233 | 2.1 |
| PC20408 | <0.005 | 1,950 | 589 | 5.8 | <1.4 | 0.248 | 2.0 |
| PC20708 | <0.005 | 1,880 | 573 | 6.1 | <1.4 | 0.185 | 2.0 |
| PC21128 | <0.005 | 1,890 | 615 | 6.3 | <1.4 | 0.223 | 2.0 |
| PC21297 | <0.005 | 1,880 | 603 | 6.4 | <1.4 | 0.216 | 2.0 |
| PC21299 | <0.005 | 1,920 | 580 | 6.2 | <1.4 | 0.226 | 2.0 |
| PC21543 | <0.005 | 1,920 | 601 | 6.1 | <1.4 | 0.225 | 2.0 |
| PC21816 | <0.005 | 1,990 | 633 | 6.2 | <1.4 | 0.228 | 2.0 |
| PC22031 | 0.007 | 1,750 | 549 | 7.1 | <1.4 | 0.214 | 2.0 |
| PC22184 | <0.005 | 1,820 | 574 | 6 | <1.4 | 0.209 | 2.1 |
| PC22436 | <0.005 | 1,860 | 598 | 5.9 | <1.4 | 0.215 | 2.1 |
| PC22737 | 0.006 | 1,780 | 567 | 6.6 | <1.4 | 0.18 | 2.1 |
| PC22980 | 0.007 | 1,810 | 498 | 6.7 | 1.7 | 0.208 | 2.2 |
| PC23163 | 0.006 | 1,820 | 482 | 7.1 | <1.4 | 0.21 | 2.1 |
| PC23357 | 0.007 | 1,830 | 521 | 6.9 | <1.4 | 0.219 | 2.2 |
| PC23721 | 0.007 | 1,830 | 523 | 7.1 | <1.4 | 0.223 | 2.1 |
| PCSP1 | 0.991 | 4,730 | -- | 2.4 | 78.5 | 0.256 | <0.24 |
| PCSP2 | 1.54 | 1,050 | -- | 10.1 | 77.6 | <0.540 | <0.60 |
| PCSP3 | 1.45 | 956 | -- | 8.2 | 70.8 | <0.540 | <0.60 |
| PCSP4 | 2.06 | 840 | -- | 6 | 226 | <1.35 | <1.5 |
| PCSP5 | 1.47 | 1,010 | -- | 8.2 | 58 | <.540 | <0.60 |

| Field site ID (see fig. 3 for location) | Boron, dissolved (µg/L) | Boron load (pounds/day) | Selenium, dissolved (µg/L) | Uranium (natural), dissolved (µg/L) | delta oxygen-18 (per mil) | Deuterium/protium ratio (per mil) |
|---|---|---|---|---|---|---|
| PC20133 | 99.9 | 30 | 1.03 | 2.61 | -- | -- |
| PC20408 | 92.0 | 28 | 1.10 | 2.7 | -- | -- |
| PC20708 | 106 | 32 | 1.20 | 2.7 | -- | -- |
| PC21128 | 105 | 34 | 1.20 | 2.76 | -- | -- |
| PC21297 | 105 | 34 | 1.20 | 2.72 | -- | -- |
| PC21299 | 101 | 30 | 1.20 | 2.69 | -- | -- |
| PC21543 | 102 | 32 | 1.10 | 2.71 | -- | -- |
| PC21816 | 98.0 | 31 | 1.10 | 2.69 | -- | -- |
| PC22031 | 122 | 38 | 1.00 | 2.61 | -- | -- |
| PC22184 | 106 | 33 | 1.10 | 2.6 | -- | -- |
| PC22436 | 93.0 | 30 | 1.10 | 2.6 | -- | -- |
| PC22737 | 121 | 39 | 1.00 | 2.61 | -- | -- |
| PC22980 | 120 | 33 | 0.990 | 2.66 | -- | -- |
| PC23163 | 124 | 33 | 1.00 | 2.66 | -- | -- |
| PC23357 | 125 | 36 | 1.10 | 2.68 | -- | -- |
| PC23721 | 124 | 35 | 1.00 | 2.67 | -- | -- |
| PCSP1 | 1,150 | -- | <0.24 | <0.032 | –18.04 | –143 |
| PCSP2 | 5,540 | -- | <0.60 | <0.080 | –17.51 | –141 |
| PCSP3 | 5,730 | -- | <0.60 | <0.080 | –17.49 | –142 |
| PCSP4 | 6,430 | -- | <1.5 | <0.200 | –17.6 | –144 |
| PCSP5 | 5,370 | -- | <0.60 | <0.080 | –17.4 | –143 |

analysis of trace elements and major ions at all 16 stream sites. Temperature, specific conductance, pH, and dissolved oxygen were measured in-situ using a multiparameter sonde in the stream. Sondes were calibrated according to standard procedures outlined in the National Field Manual (U.S. Geological Survey, 2012). Sample processing involved filtering the sample (0.45-micrometer capsule filter) in the field and storing the sample in precleaned plastic bottles. Alkalinity was determined by incremental titration from an aliquot of filtered sample in the processing vehicle. Filtered samples for analysis of trace elements and major cations were acidified in the field to pH less than 2 using nitric acid. Additional filtered, unacidified samples were collected for analysis of major anions. Samples for trace elements and major ions were submitted to the USGS National Water Quality Laboratory (NWQL) for analysis. Trace elements analyzed included aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, uranium (natural), vanadium, and zinc (Garbarino, 1999). When values are estimated by the NWQL, an “E” remark code proceeds the numeric value (Childress and others, 1999). Major ions included bromide (only analyzed in the December 2010 samples), calcium, chloride, fluoride, magnesium, potassium, silica, sodium, and sulfate (Fishman and Friedman, 1989). All data collected as part of this study are available via the National Water Information System (NWISWeb at http://nwis.waterdata.usgs.gov/co/nwis/). Data were compared to previous studies (Ortiz, 2002), groundwater-quality data (Thomas and McMahon, 2013), and field-reconnaissance data.

During late March 2012, the five springs were sampled. Spring samples were collected by inserting a drive point into the spring (figs. 4*A* and *B*). The drive point was made using electrical conduit (galvanized metal) approximately 5 feet long and 0.5 inch in diameter. The end of this conduit was hammered closed and holes were drilled to allow water to enter the drive point near the closed end (fig. 4*A*). Samples were pumped from the drive point using a peristaltic pump (fig. 4*B*). Field properties, trace elements, and major ions were collected at all five spring sites, as described previously for surface-water sites. In addition, unfiltered, unacidified samples were collected for stable isotopes of water (delta oxygen-18 ($\delta^{18}O[H_2O]$), and deuterium/protium,($\delta^{2}H[H_2O]$)) for all five spring sites. The unfiltered sample was collected in a 2-ounce glass bottle with polyseal cap provided by USGS Reston Stable Isotope Laboratory (RSIL). Samples were stored at ambient temperature and shipped to RSIL for analysis. Stable isotopes were analyzed by hydrogen and carbon dioxide gas equilibration and mass spectrometry (U.S. Geological Survey, 2013).

Approximately 10 percent of the samples collected were quality-control samples, which included equipment blanks, replicates, and field blanks. The equipment blank of the spring-sampling apparatus resulted in detections of calcium, sodium, barium, cobalt at low concentrations close to the reporting level; however, iron and zinc were found at higher concentrations in the equipment blank (28 micrograms per liter and 7.6 micrograms per liter respectively). The spring-sampling apparatus is constructed from galvanized electrical conduit; it is likely that this material is the source of these detections in the equipment blank. These detections do not affect the analysis as they are at concentrations well below those detected in the springs. No detections were found in field blank samples. All major-ion concentrations in replicate pairs were within 5 percent of each other based on the relative percent difference (RPD), which is the difference between the replicate values divided by the mean of the replicate values times 100. The majority of trace-element concentrations in replicate pairs were within 10 percent (RPD) of each other with the exception of boron (14 percent), chromium (54 percent), vanadium (12 percent), aluminum (12 percent), lithium (19 percent), and selenium (12 percent). Charge balances derived from summation of major cations and anions were less than 10 percent.

Loading profiles were used to aid in understanding the hydrology along Piceance Creek. The profiles were constructed with instantaneous loads that were calculated by multiplying concentration (milligrams per liter or micrograms per liter) times streamflow (cubic feet per second) and a unit conversion factor.

# Characterization of Surface-Water Hydrology

In a previous USGS investigation of Piceance Creek (Ortiz, 2002), a decrease in streamflow (approximately 5 cubic feet per second [$ft^3/s$]) was observed between 12.9 miles and 14.7 miles downstream from Piceance Creek at Ryan Gulch station number 09306200). Instantaneous streamflow was measured from sites PC20133 to PC23721 during field reconnaissance (February 2012) and during synoptic sampling (March 2012). Distances between sites ranged from around 7 to 1,400 feet, with a median distance of around 800 feet. Continuous streamflow at Piceance Creek at Ryan Gulch and Piceance Creek at White River were used to understand overall flow conditions during both February 2012 reconnaissance and March 2012 synoptic sampling (figs. 5 and 6). Conditions were represented in the study reach by shifting continuous streamflow in Piceance Creek at Ryan Gulch 7 hours forward in time based on an average stream velocity of 2.5 feet per second (ft/s) and a distance of 66,000 feet from sites PC0 to PC20133. Continuous streamflow in Piceance Creek at White River was shifted 1.7 hours backward in time based on an average stream velocity of 2.5 ft/s and a distance of 15,000 feet from sites PC23721 to PC28348. Site reconnaissance during February 2012 was conducted during 3 days (February 22, 23, and 29, 2012) (fig. 5) and streamflow at the

*A*

*B*

**Figure 4.** Photograph of drive point end showing perforation and hammered end. *B*, Photograph of deployed drive point in spring (site PCSP3) with tubing and peristaltic pump.

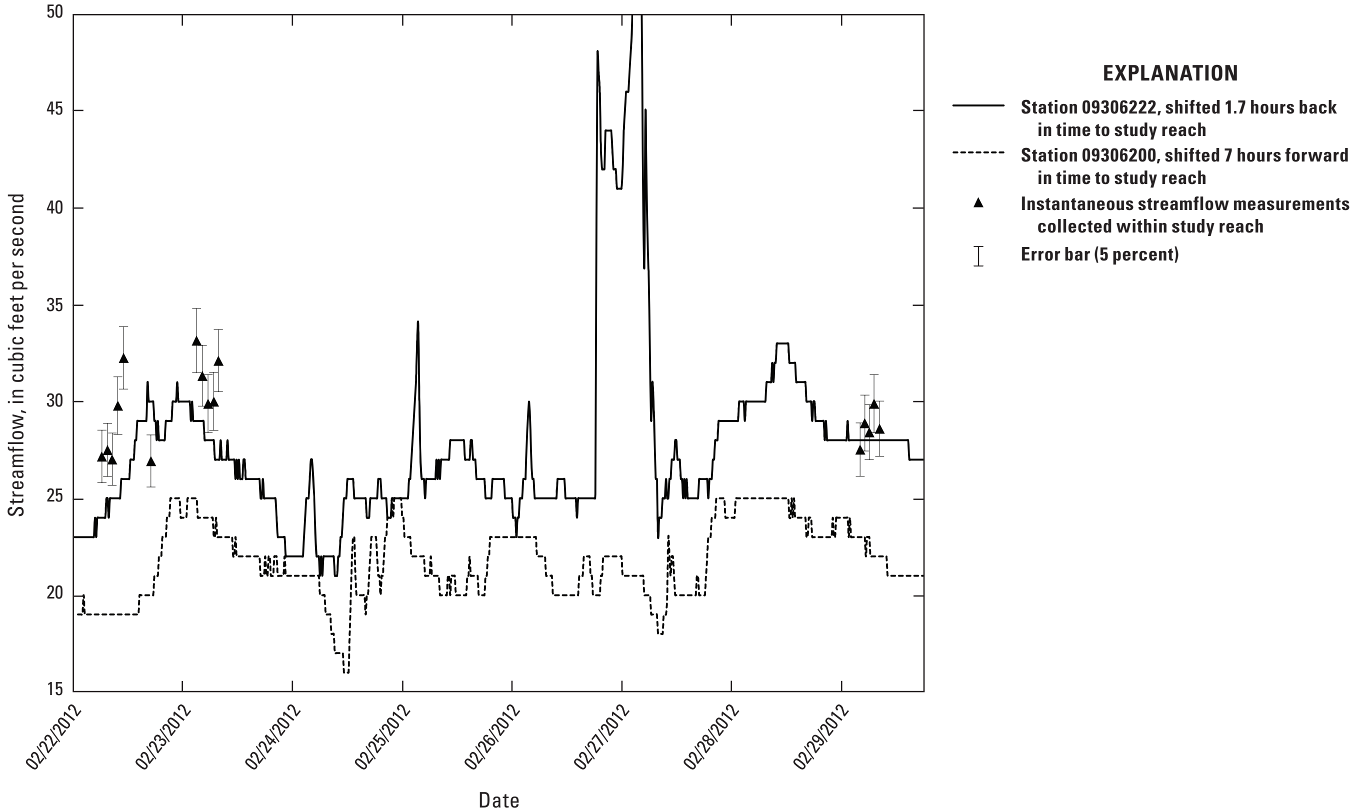



**Figure 5.** Instantaneous streamflow measurements and continuous streamflow from U.S. Geological Survey gaging station within the study reach, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado, February 22–29, 2012.

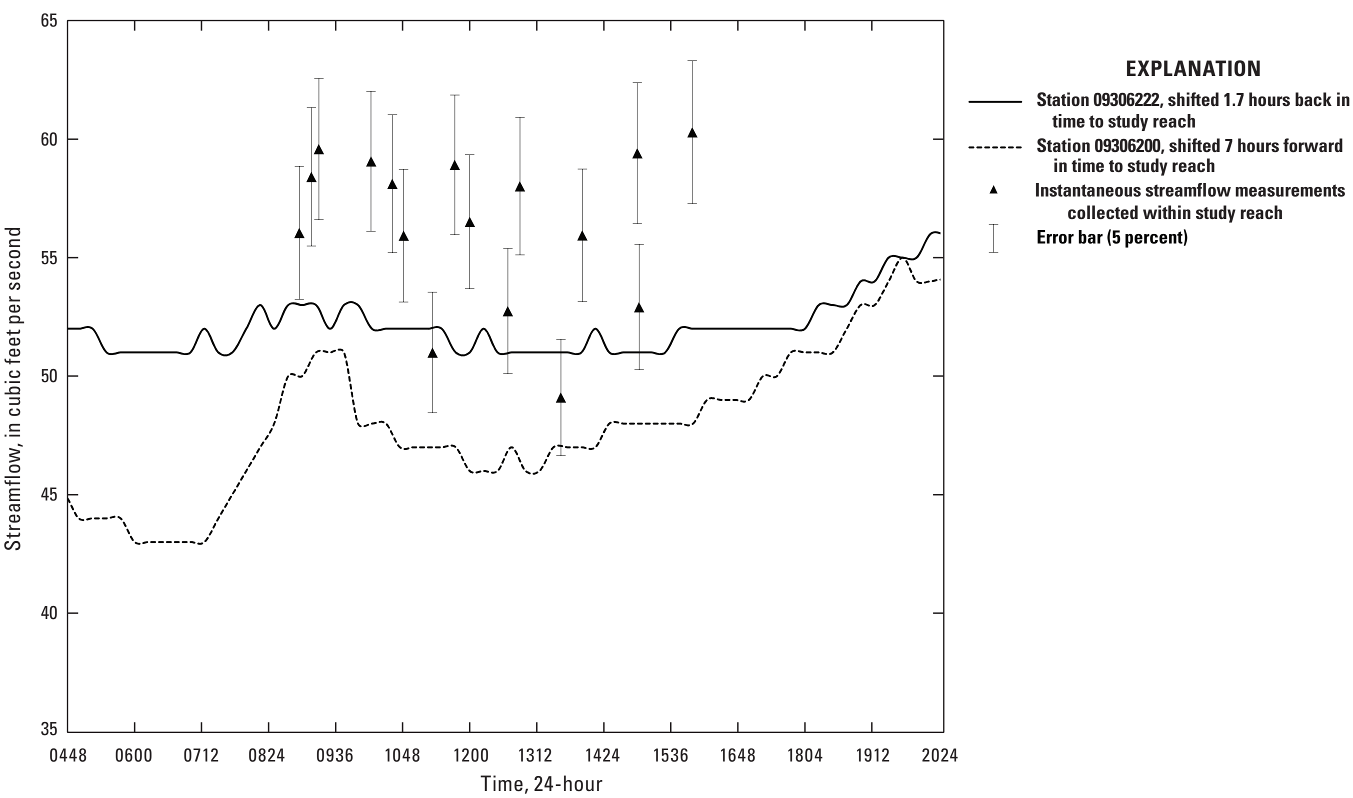



**Figure 6.** Instantaneous streamflow measurements and continuous streamflow from U.S. Geological Survey gaging stations within the study reach, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado, March 14, 2012.

gages was relatively stable during this period. Synoptic sampling was conducted in a single day (March 14, 2012) when streamflow at the gages was relatively stable (fig. 6).

Instantaneous streamflow measurements collected during February and March allow for examination of streamflow gains and losses along the study reach (fig. 7). During February and March, changes in streamflow were observed along the study reach (fig. 7). During February, streamflow increased 6 $ft^3/s$ from 27 $ft^3/s$ at site PC20133 to 33 $ft^3/s$ at site PC21816 (downstream distances of 12.5 and 13.6 miles, respectively). Just downstream, streamflow decreased 5.5 $ft^3/s$ from 33 $ft^3/s$ at site PC21816 to 27.5 $ft^3/s$ at site PC23721 (downstream distance 14.7 miles). During February, the study reach from sites PC20133 to PC23721 was a losing reach with net losses of 0.5 $ft^3/s$. During March, streamflow increased 4 $ft^3/s$ from 56 $ft^3/s$ at site PC20133 to 60 $ft^3/s$ at site PC21128 (downstream distance 13.1 miles). Downstream, streamflow decreased 7 $ft^3/sec$ from 60 $ft^3/s$ at site PC21128 to 53 $ft^3/s$ at site PC23721. During March, the study reach from sites PC20133 to PC23721 was a losing reach with net losses of 3 $ft^3/s$. Observed changes in streamflow along the study reach helped to depict interactions between groundwater and surface water in the Alkali Flat area.

## Characterization of Surface-Water Quality

Water-quality samples were collected at five sites in December 2010 that were sampled as part of a previous USGS study (Ortiz, 2002) to understand and identify potential changes that may have occurred since 2000 (table 1 and fig. 1). Sites were located upstream (PC5280, PC14789, and PC16210), within (PC20708), and downstream (PC24787) from the Alkali Flat area (table 1 and fig. 1). Water-quality data collected during December 2010 showed no appreciable difference from water-quality data collected during December 2000 at the five sites (table 1).

Water-quality samples were collected at 16 surface-water-quality sites on March 14, 2012, to determine field properties, and major-ion and trace-element concentrations (table 2). Sampling was conducted to collect samples as close in time to one another to minimize streamflow variability between sites and to provide a snapshot of water-quality conditions within the study reach. Field properties of dissolved oxygen, pH, specific conductance, and temperature were measured in the stream at sites during sampling. Values of dissolved oxygen,

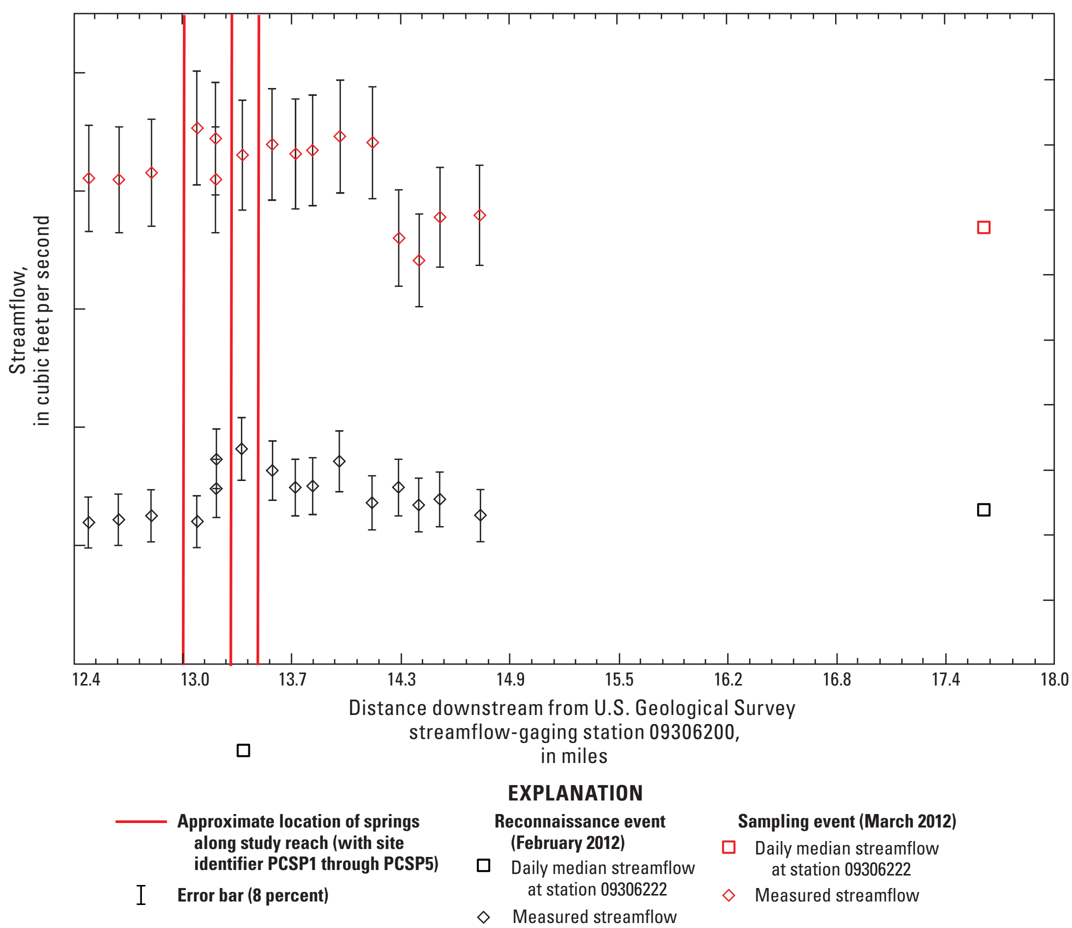



**Figure 7.** Instantaneous streamflow measurements along the study reach, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado, February and March 2012.

pH, and temperature remained relatively stable along the study reach with median values of 10.05 milligrams per liter (mg/L) for dissolved oxygen, 8.5 standard units for pH, and 5.7 degrees Celsius for temperature (table 2). Specific conductance increased along the study reach with values that ranged from 1,030 microsiemens per centimeter at 25 degrees Celsius (µS/cm) to 1,140 µS/cm with a median of 1,080 µS/cm.

Sodium was the dominant cation in the study reach in 2012 with concentrations that ranged from 106 to 143 mg/L with a median concentration of 129 mg/L (table 2). Concentrations increased steadily along the study reach with a total increase of 35 percent from upstream to downstream (fig. 8). Calcium, magnesium, and potassium concentrations remained relatively stable along the study reach with median concentrations of 58.7 mg/L, 48.3 mg/L, and 3.8 mg/L, respectively (table 2 and fig. 8). Bicarbonate and chloride concentrations were observed to increase along the study reach. Titration indicates bicarbonate was the dominant ion in alkalinity with carbonate being less than 5 mg/L. Bicarbonate concentrations increased by 25 percent from upstream to downstream (fig. 9). Bicarbonate concentrations ranged from 393 mg/L to 497 mg/L with a median concentration of 451 mg/L (table 2). Chloride concentrations ranged from 15.2 to 22.3 mg/L, an increase of 47 percent from upstream to downstream and the median concentration was 20.2 mg/L (table 2). Dissolved solids concentrations ranged from 673 to 768 mg/L, an increase of 14 percent from upstream to downstream and the median concentration was 730 mg/L (table 2). Sodium, bicarbonate, and chloride concentrations increased appreciably from PC20708 to PC22031 (12.9 and 13.7 miles downstream, respectively) indicating an area of input of springs and (or) groundwater to Piceance Creek (fig. 9). Sulfate, silica, and fluoride concentrations remain relatively stable along the study reach with median concentrations of 232 mg/L, 12.8 mg/L, and 0.55 mg/L, respectively (table 2 and fig. 9).

Strontium concentrations along the study reach ranged from 1,750 micrograms per liter (µg/L) to 1,990 µg/L with a median strontium concentration of 1,850 µg/L (table 2). Strontium concentrations remained relatively stable along the study reach, similar to what was observed in previous studies (Ortiz, 2002) (table 2 and fig. 10). Barium concentrations increased slightly along the study reach, ranging from 73.3 to 84.7 with a median concentration of 81 µg/L. Boron and lithium concentrations increased appreciably at site PC22031 (13.7 miles downstream) and remained elevated to the end of the study reach (fig. 10), which indicated an area of focused input from springs and (or) groundwater to Piceance Creek. Boron concentrations ranged from 92 to 125 µg/L with a median of 105 µg/L (table 2). Lithium concentrations ranged from 8.72 to 15.5 µg/L, an increase of 78 percent from upstream to downstream, and the median concentration was 10.9 µg/L (table 2).

Aluminum and iron concentrations were greater than those observed in the Ortiz study (2002). Aluminum concentrations ranged from 12.5 to 37.2 µg/L with a median concentration of 18.6 µg/L (table 2) compared to previous studies where aluminum concentrations ranged from less than detection (less than 0.1 µg/L) to 2.7 µg/L (Ortiz, 2002). Iron

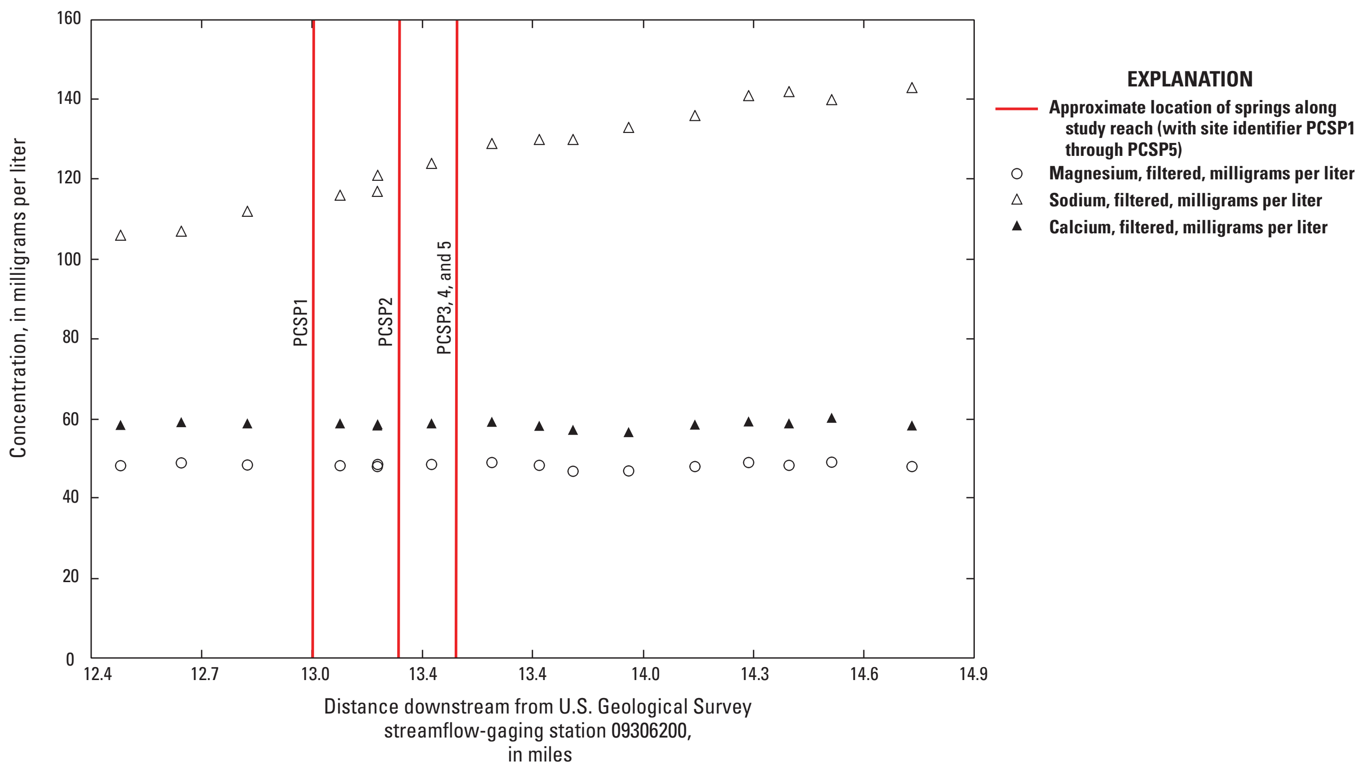



**Figure 8.** Selected dissolved-cation concentrations March 14, 2012, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado.

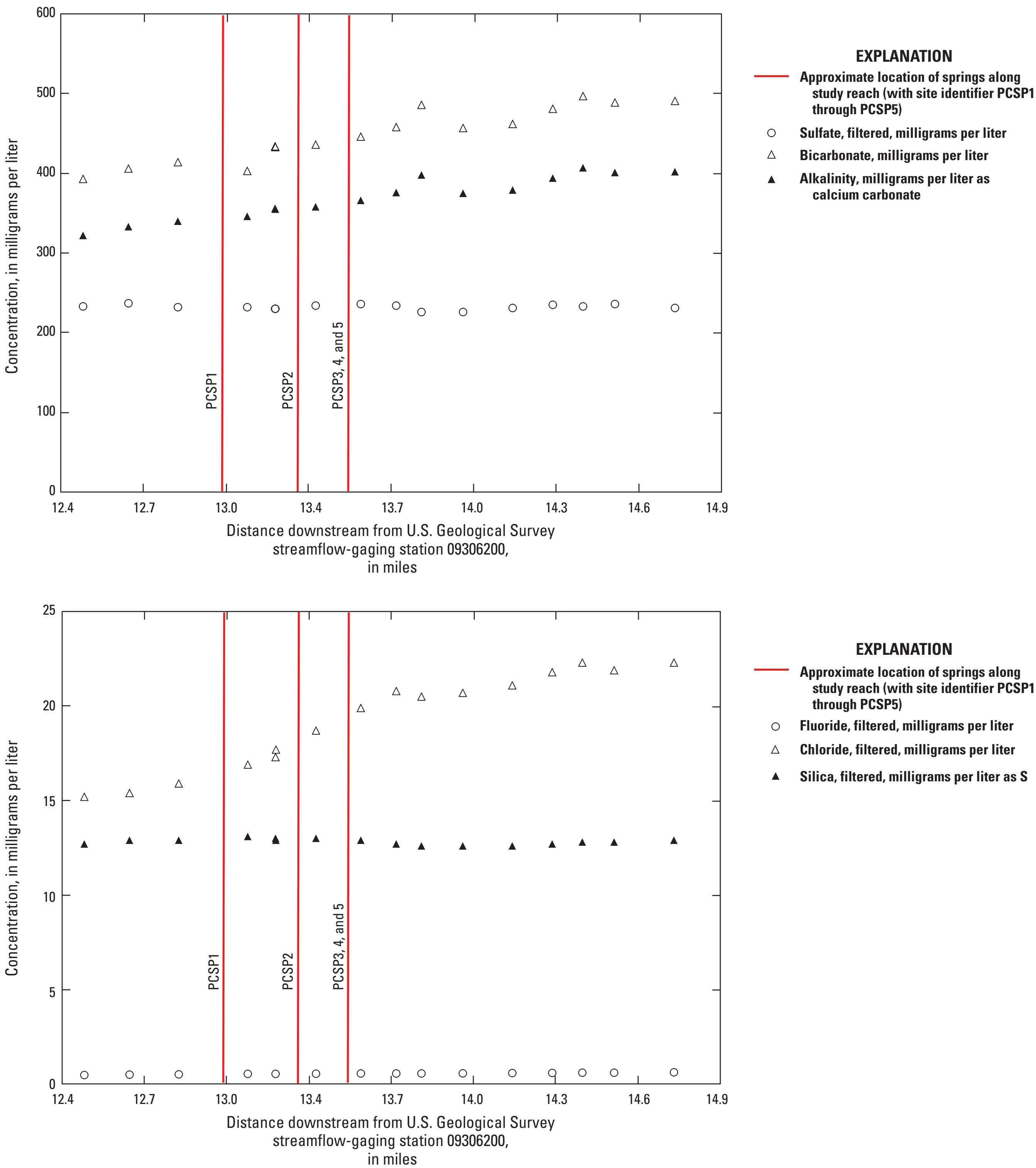



**Figure 9.** Selected dissolved-anion concentrations March 14, 2012, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado.

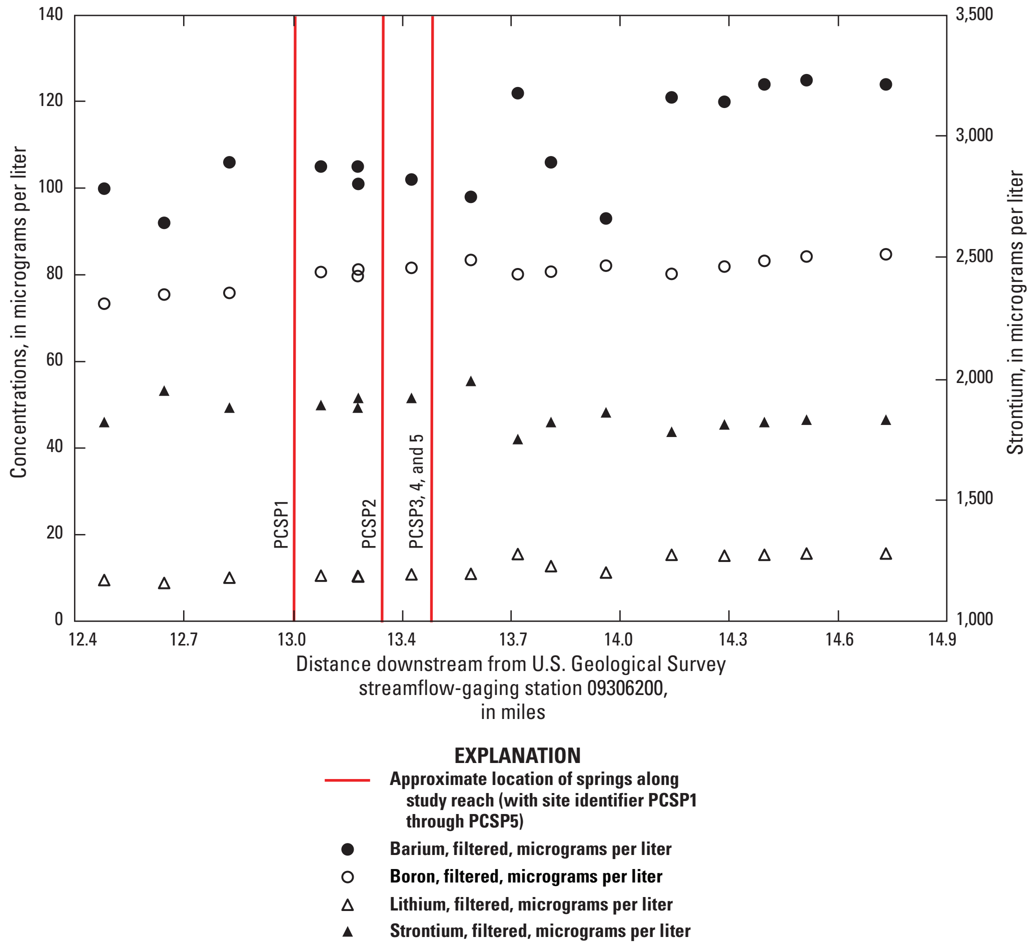



**Figure 10.** Selected dissolved trace-element concentrations March 14, 2012, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado.

concentrations ranged from 36.5 to 71.5 µg/L with a median concentration of 42.5 µg/L (table 2) compared to previous studies where iron concentration were less than detection (less than 10 µg/L to less than 30 µg/L) (Ortiz, 2002). The reason for the observed increase in concentration of both aluminum and iron between previous studies and concentrations observed on March 14, 2012, was unclear and inconsistent with other trace-element concentrations between the two study periods.

# Sources of Recharge to Springs and Spring Contribution to Piceance Creek

Water-quality samples were collected at five springs on March 27, 2012, to determine field properties, major ions, trace elements, and stable isotopes of water (table 2, fig. 3). Field properties of dissolved oxygen, pH, specific conductance, and temperature were measured in the springs during sampling (table 2). Dissolved-oxygen concentrations at all springs were less than 0.5 mg/L indicating suboxic or anoxic conditions, and values of pH ranged from 7.5 to 7.8. Specific conductance ranged from 12,700 µS/cm at site PCSP1 to 40,800 µS/cm at site PCSP4, and temperatures ranged from 14.5 degrees Celsius at sites PCSP1 and PCSP5 to 18.4 degrees Celsius at site PCSP4 (table 2). Site PCSP4 generally had the highest concentrations of sodium, chloride, and bicarbonate, whereas site PCSP1 had the lowest. Site PCSP4 had the highest concentrations of aluminum and iron, 171 µg/L and 138 µg/L, respectively, whereas site PCSP1 had the lowest concentrations of aluminum and iron, 28.3 µg/L and less than 32.0 µg/L, respectively. Sites PCSP2, PCSP3, PCSP4, and PCSP5 were similar to one another in major-ion and trace-element chemistry; however, site PCSP4 had the highest concentrations of sodium, chloride, bicarbonate, lithium, and boron, and the lowest concentrations of calcium, magnesium, and strontium of the four springs. Piceance Creek water was a mixed-cation-bicarbonate-sulfate type water, whereas spring water was a sodium-bicarbonate type water (fig. 11). Trace-element concentrations in the stream samples were substantially lower than those in spring samples (table 2). Major-ion and trace-element chemistry indicate that the springs sampled as part of this study were likely recharged by the bedrock aquifer (McMahon and others, 2013; Tobin, 1987).

The stable isotopic composition of spring water helps determine sources of recharge to the springs. Isotopic values for the springs are similar to those of groundwater from the Parachute Creek Member of the Green River Formation, and the isotopic values from both of these sources are similar to the values for Grand Mesa snow (McMahon and others, 2013) (fig. 12). Recharge to the Parachute Creek Member of the Green River Formation was mostly derived from snowmelt infiltrating into the bedrock aquifers at higher elevations, which then was the likely source of water to the springs in the Alkali Flat area. Because spring samples did not have isotopic compositions that were at all similar to that of produced water from the Mesaverde Group, this source can be ruled out (fig. 12). The positive shift of the isotopic values for groundwater compared to snow indicates water may have undergone some evaporation prior to recharging the aquifers. Spring samples were shifted even further in the positive direction than groundwater samples, which may indicate that spring water has undergone additional evaporation after discharging to the land surface (fig. 12).

Springs and groundwater contribute to surface-water-quality changes in Piceance Creek along the study reach. Loading profiles were used to further refine areas of spring and groundwater input and streamflow gains and losses. Although there was a minor gain in streamflow from sites PC21543 to PC21816 (58 to 59 $ft^3/s$ during March 2014 at downstream distances of 13.4 and 13.6 miles), the increase in dissolved solids load indicated groundwater contribution to Piceance Creek between these two sites. From sites PC22737 to PC22980 (downstream distances 14.1 and 14.3 miles), dissolved solids load decreases (fig. 13), which was not observed in concentration data (table 2) and provides additional insight to streamflow loss identified earlier in the report to occur between these two sites. Sodium, calcium, bicarbonate, sulfate, and chloride loads increase and decrease along the study reach in a similar pattern to that of dissolved solids load (fig. 13).

Concentrations of most trace elements (barium, lithium, zinc, and boron) in springs were greater than those of surface water, whereas strontium concentrations were similar between four of the springs and surface water (table 2). Previous studies have identified the two major bedrock aquifers in Piceance Creek as having characteristic trace elements where strontium is found in high concentrations in association with the Uinta Formation and barium, boron, and lithium are found in high concentrations in association with the lower portion of the Parachute Creek Member of the Green River Formation

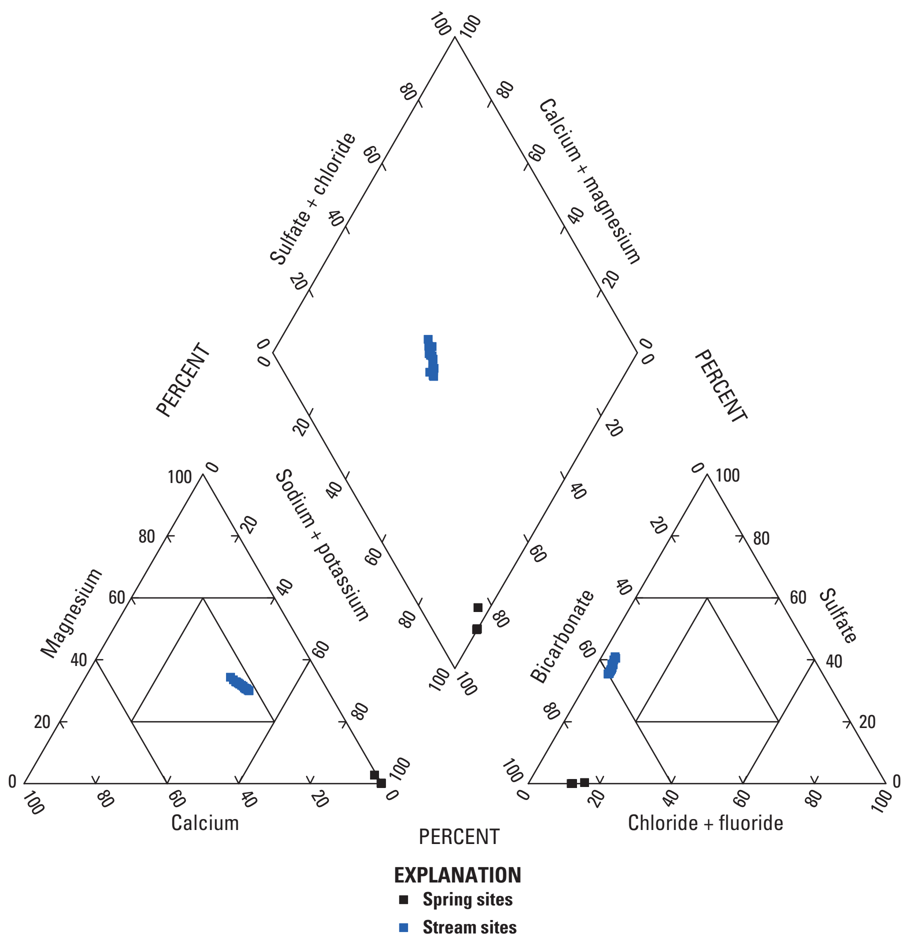



**Figure 11.** Major-ion chemistry of water from Piceance Creek and spring samples, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado.

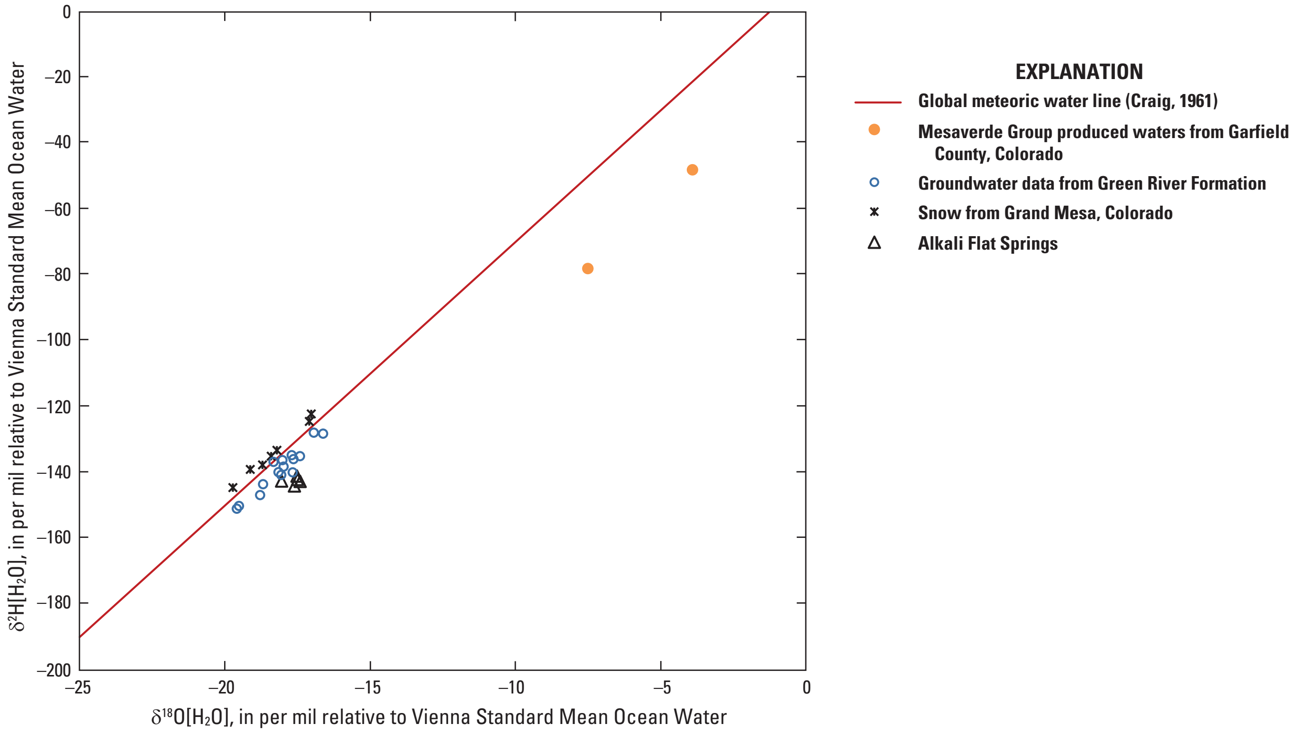



**Figure 12.** Stable isotopic composition of water (delta oxygen-18, $\delta^{18}O[H_2O]$, and deuterium/protium -, $\delta^{2}H[H_2O]$) from springs in the Alkali Flat area compared to groundwater from the Green River Formation, snow from Grand Mesa, Colorado, and produced waters from the Mesaverde Group in Piceance Basin, western Colorado.

(Tobin, 1987). Based on fluoride, lithium, and strontium concentrations, site PCSP1 appeared to have different source water than the other four springs. Site PCSP1 also had higher concentrations of calcium, magnesium, and sulfate relative to the other four springs. Trace-element and major-ion data indicate site PCSP1 was sourced from the Uinta Formation. It was likely the other four springs were primarily sourced from the lower portion of the Parachute Creek Member of the Green River Formation as indicated by low sulfate concentrations and high fluoride, lithium, and boron concentrations.

Barium, boron, lithium, and strontium loads showed similar patterns to that of the major ions along the study reach indicating similar areas of groundwater gain and loss. Boron and lithium loads increased between sites PC22031 and PC22737 (downstream distances 13.1 and 13.7, respectively), a pattern not observed in barium and strontium loads (fig. 14). Barium and strontium loads were generally stable along the study reach until site PC21816 (downstream distance 13.6) after which the loads generally decreased to the end of the study reach indicating streamflow loss (fig. 14). Boron and lithium were not observed to decrease in a similar pattern to that of barium and strontium which would suggest the contribution to the stream from sources with similar chemistry to that of spring sites PCSP2 through PCSP5. Sites PCSP2 through PCSP5 had concentrations of lithium and boron greater than 1,900 µg/L and 5,000 µg/L, respectively. Because lithium and boron loads in Piceance Creek do not increase along the study reach, they also indicate a loss of streamflow and agree with the findings observed with the other constituents.

Although it was clear from this study that groundwater and (or) spring water was contributing to changes in water quality in Piceance Creek, the amount of groundwater and (or) spring water that resulted in these changes was unknown. In order to estimate the amount of groundwater and (or) spring water that was contributing to changes in water quality along Piceance Creek, a chemical mass balance approach was used. Chloride is a conservative constituent and was used to estimate the amount of groundwater and (or) spring water that was being added to Piceance Creek. The amount of groundwater and (or) spring-water flux was determined for the mostly gaining portion of the stream from sites PC20133 to PC22737 by subtracting the streamflow at sites PC20133 from PC22737 (table 2). The chloride load at site PC20133 was subtracted from the load at site PC22737 (table 2) and the result represented the chloride load from groundwater/spring-water contributions. The chloride load (expressed as milligrams per second) divided by the groundwater and (or) spring-water flux (expressed as liters per second) represents the approximate concentration of chloride of the groundwater and (or) spring-water input (expressed as milligrams per liter). Dividing this concentration by the median chloride concentrations of the five springs sampled (2,600 mg/L), it would take only 5 percent of the spring water to reach Piceance Creek to result in the observed changes in water quality in Piceance Creek. It is not understood how variable this contribution is, but it would be important to understand if certain activities such as nahcolite mining, gas development, or oil shale development could increase this contribution and possibly degrade the water quality in Piceance Creek.

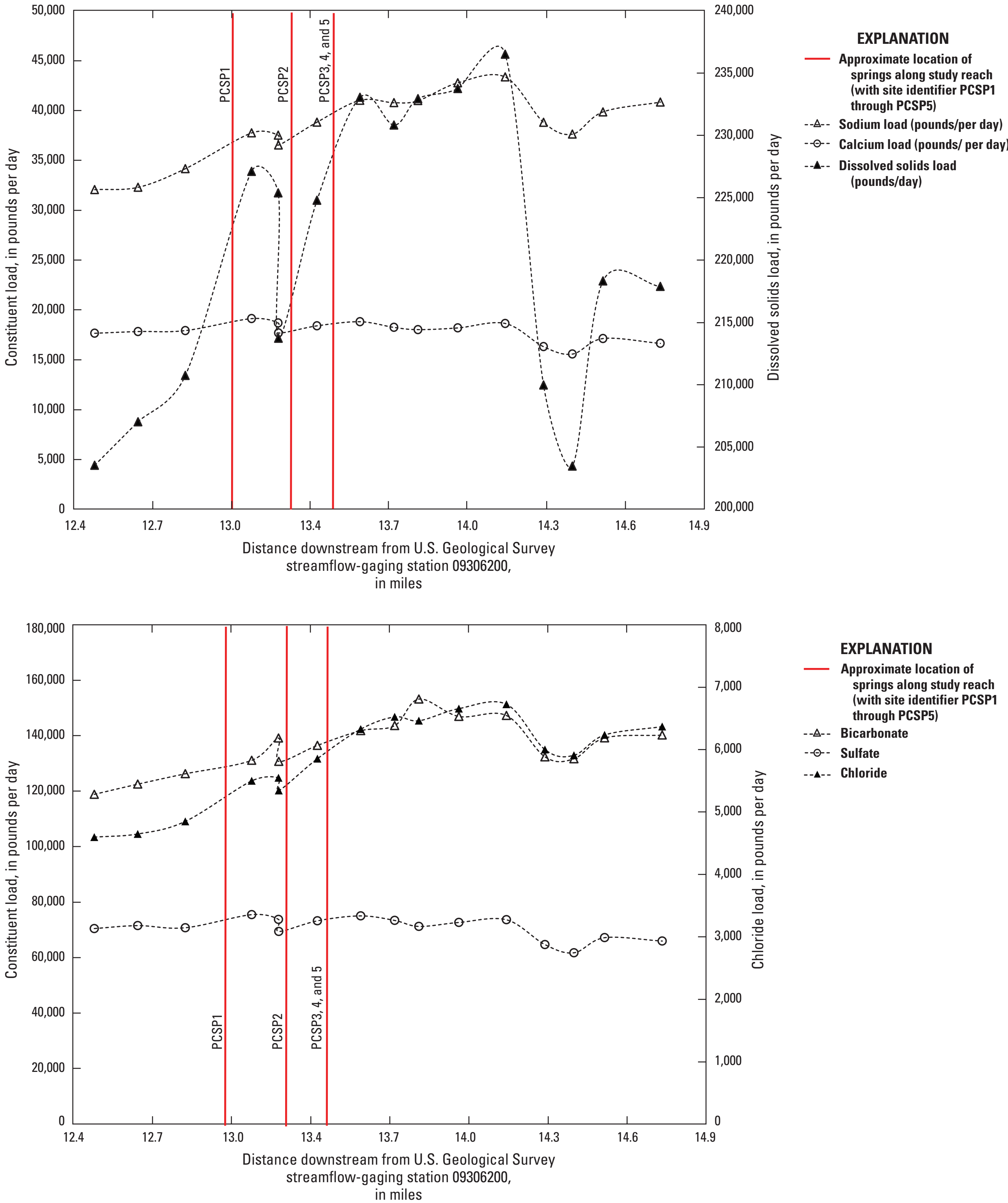
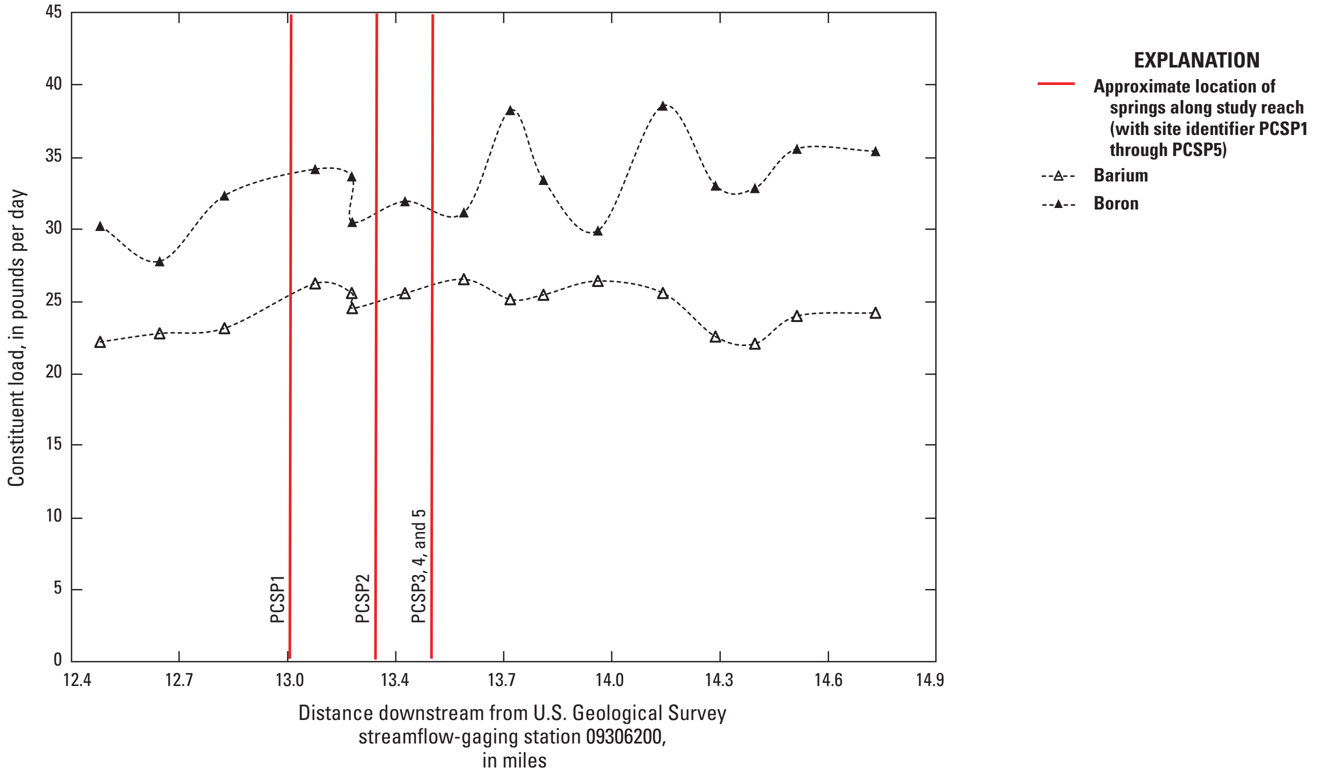



**Figure 13.** Selected dissolve-cation and dissolved-anion loads for March 14, 2012, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado.



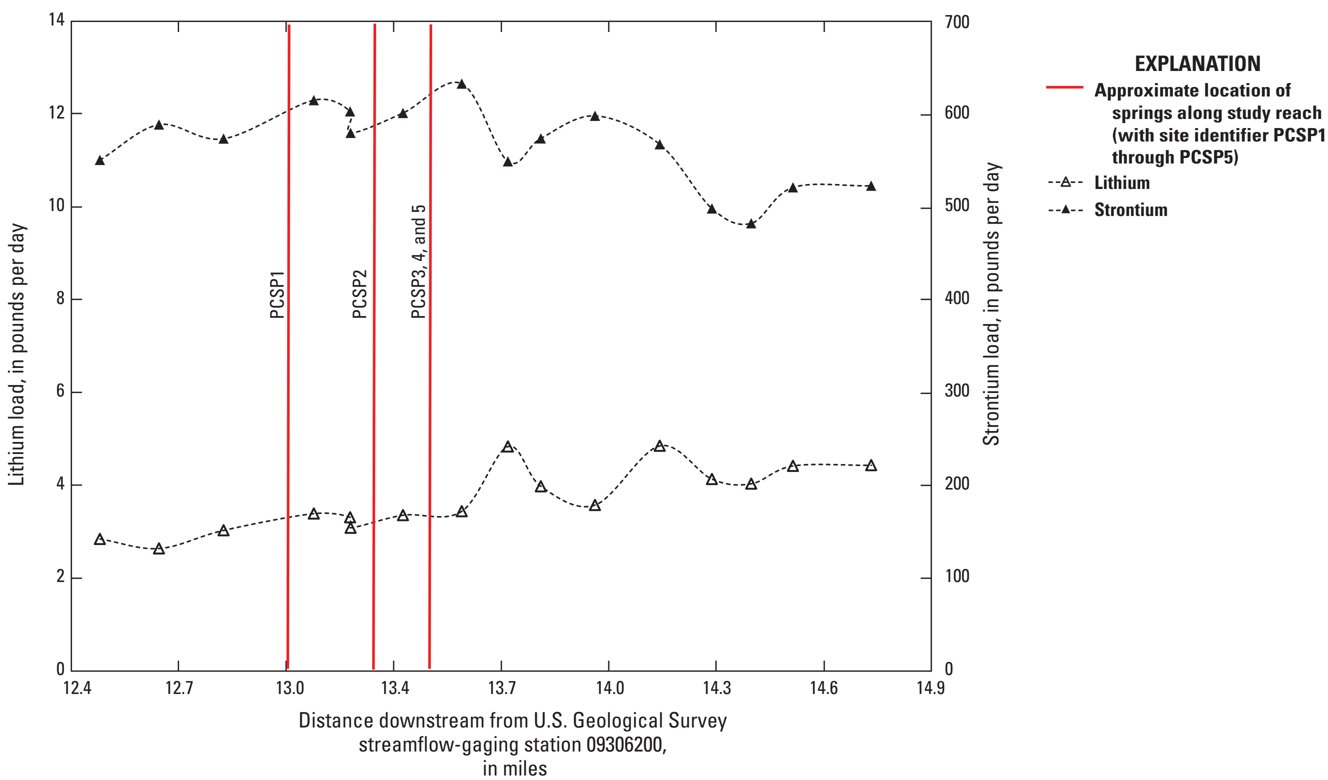




**Figure 14.** Selected dissolved trace-element loads for March 14, 2012, Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado.

# Summary

Previous studies by the U.S. Geological Survey (USGS) identified Alkali Flat as an area of groundwater upwelling, with increases in concentrations of total dissolved solids, and streamflow loss, but additional study would be needed to better characterize these observations. The U.S. Geological Survey, in cooperation with the Bureau of Land Management, White River Field Office, conducted a study to further characterize surface-water hydrology and surface-water quality of Piceance Creek in the Alkali Flat area. The purpose of this report was to characterize the hydrology and water quality of Piceance Creek in the Alkali Flat area to further understand areas of streamflow gain and loss.

Instantaneous streamflow was measured from sites PC20133 to PC23721 during field reconnaissance (February 2012) and during synoptic sampling (March 2012). Continuous streamflow at Piceance Creek at Ryan Gulch and Piceance Creek at White River were used to understand overall flow conditions during both February 2012 reconnaissance and March 2012 synoptic sampling. Instantaneous streamflow measurements collected during February and March allow for examination of streamflow gains and losses along the study reach. During both February and March, the study reach from sites PC20133 to PC23721 was a losing reach with net losses ranging from 0.5 cubic foot per second (February) to 3 cubic foot per second (March). Observed changes in streamflow along the study reach helped to depict interactions between groundwater and surface water in the Alkali Flat area.

Water-quality samples were collected at five sites in December 2010 that were sampled as part of a previous USGS study to understand and identify potential changes that may have occurred since 2000. Water-quality data collected during December 2010 showed no appreciable difference from water-quality collected during December 2000 at the five sites.

Water-quality samples were collected at 16 surface-water quality sites on March 14, 2012, to determine field properties, major ions, and trace elements. Sodium was the dominant cation and concentrations increased steadily along the study reach with a total increase of 35 percent from upstream to downstream. Calcium, magnesium, and potassium concentrations remained relatively stable along the study reach. Bicarbonate and chloride concentrations increased, whereas sulfate, silica, and fluoride concentrations were relatively stable along the study reach. Strontium concentrations were relatively stable along the study reach, similar to what was observed in previous studies. Boron and lithium concentrations increased appreciably at site PC22031 and remained elevated to the end of the study reach indicating an area of focused input from springs and (or) groundwater to Piceance Creek. Aluminum and iron concentrations were greater than those observed in previous studies. The reason for the observed increase in concentration of both aluminum and iron between previous studies and concentrations observed on March 14, 2012, was unclear and inconsistent with other trace-element concentrations between the two study periods.

Water-quality samples were collected at five springs on March 27, 2012, to determine field properties, major ions, trace elements, and stable isotopes of water. Major-ion and trace-element chemistry indicate that the springs sampled as part of this study were likely recharged by the bedrock aquifer. Isotopic values for the springs are similar to those of groundwater from the Parachute Creek Member of the Green River Formation, and the isotopic values from both of these sources are similar to the values for Grand Mesa snow. Springs and groundwater contribute to surface-water quality changes in Piceance Creek along the study reach. Loading profiles were used to further refine areas of spring and groundwater input and streamflow gains and loss. Although there was a minor gain in streamflow from sites PC21543 to PC21816 (58 to 59 cubic feet per second during March 2014), the increase in dissolved solids load indicated groundwater contribution to Piceance Creek between these two sites. From sites PC22737 to PC22980, dissolved solids load decreases, which was not observed in concentration profiles and provides additional insight to streamflow loss identified earlier in the report to occur between these two sites. Sodium, calcium, bicarbonate, sulfate, and chloride loads increase and decrease along the study reach in a similar pattern to that of dissolved solids load. Trace-element concentrations in springs were typically greater than those of surface water, whereas barium, lithium, zinc, and boron concentrations in springs were greater than those observed in surface water. Strontium concentrations were similar between four of the springs and surface water. Previous studies have identified the two major bedrock aquifers in Piceance Creek as having characteristic trace elements where strontium is found in high concentrations in association with the Uinta Formation, and barium, boron, and lithium are found in high concentrations in association with the lower portion of the Parachute Creek Member of the Green River Formation. Based on fluoride, lithium, and strontium concentrations, site PCSP1 appeared to have different source water than the other four springs. It was likely the other four springs were primarily sourced from the lower portion of the Parachute Creek Member of the Green River Formation as indicated by low sulfate concentrations and high fluoride, lithium, and boron concentrations. Barium, boron, lithium, and strontium loads showed similar patterns to that of the major ions along the study reach and indicated similar areas of groundwater gain and loss. Boron and lithium were not observed to decrease in a similar pattern to that of barium and strontium which would suggest the contribution to the stream from sources with similar chemistry to that of spring sites PCSP2 through PCSP5.

Although it was clear from this study that groundwater and (or) spring water was contributing to changes in water quality in Piceance Creek, the amount of groundwater and (or) spring water that resulted in these changes was unknown. In order to estimate the amount of groundwater and (or) spring water that was contributing to these changes in water quality along Piceance Creek, a chemical mass balance approach was used. Based on this analysis, it would take only 5 percent of the spring water to reach Piceance Creek to result in the observed changes in water quality in Piceance Creek. The variability of this contribution is not understood within the study area, but it would be important to understand if activities such as nahcolite mining, gas development, or oil shale development could increase the contribution from the study area and possibly degrade the water quality in Piceance Creek downstream of Alkali Flat.

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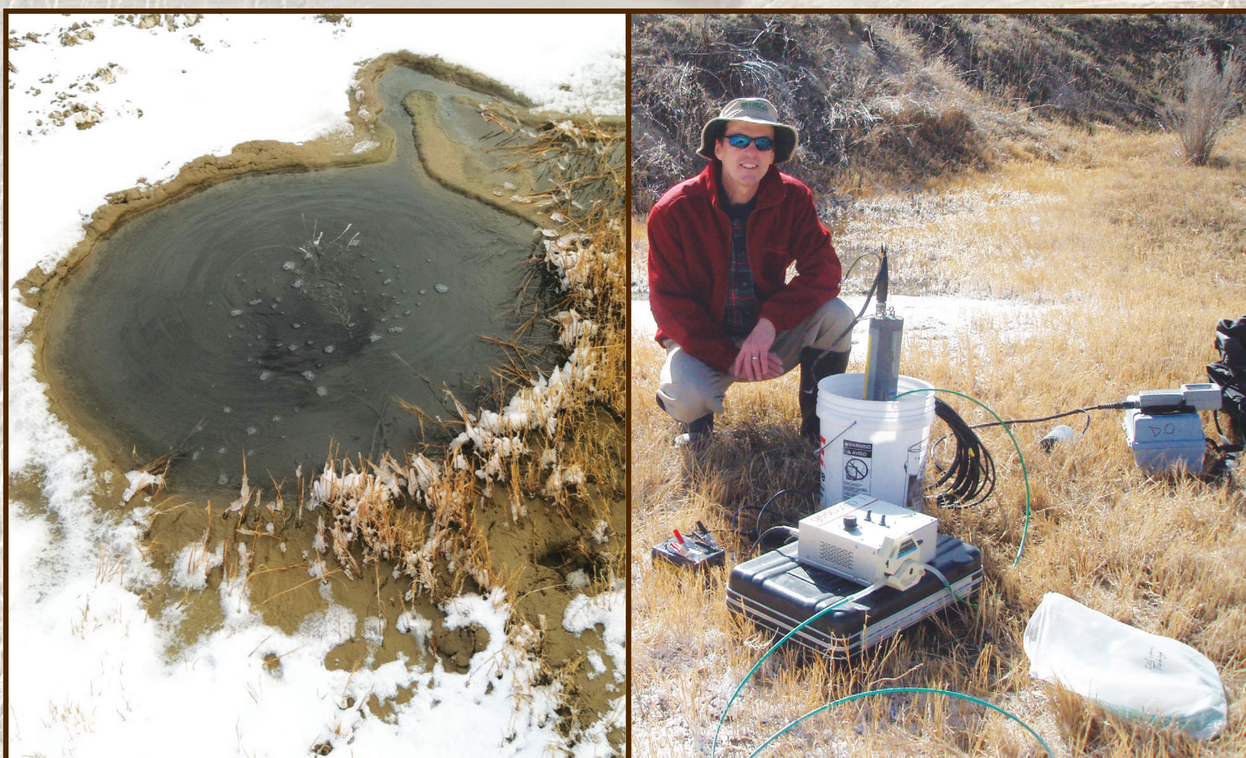

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