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Characterization of and Relations Among Precipitation, Streamflow, Suspended-Sediment, and Water-Quality Data at the U.S. Army Garrison Fort Carson and Piñon Canyon Maneuver Site, Colorado, Water Years 2016–18

Scientific Investigations Report 2022–5018

U.S. Department of the Interior
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Cover. Purgatoire River Valley near the Piñon Canyon site. [Photograph by William A. Battaglin November 2021]

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By William A. Battaglin and Zachary D. Kisfalusi

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Contents

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Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
	Area	
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)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton, short (2,000 lb)	0.9072	metric ton (t)

International System of Units to U.S. Customary Units

Multiply	By	To obtain
	Volume	
milliliter (mL)	0.03381402	ounce, fluid (fl. oz)
milliliter (mL)	0.00211338	pint (pt)

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

$$°F = (1.8 \times °C) + 32.$$

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).

Elevation, 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 (µS/cm at 25 °C).

Concentrations of chemical parameters in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Suspended-sediment discharge is given in tons per day (t/d). Suspended-sediment yield is given in tons per year per square mile (t/y/mi^2) or tons per season per square mile (t/s/mi^2).

A water year (WY) is the period from October 1 through September 30 of the following year and is designated by the year in which it ends; for example, WY 2018 began October 1, 2017, and ended September 30, 2018.

Abbreviations

>	greater than
<	less than
AGFC	U.S. Army Garrison Fort Carson
APD	absolute percent difference
$CaCO_3$	calcium carbonate
CDPHE	Colorado Department of Public Health and Environment
CV	coefficient of variation
DO	dissolved oxygen
LRL	laboratory reporting level
PCMS	Piñon Canyon Maneuver Site
RPD	relative percent difference
SC	specific conductance
TDS	dissolved solids
USGS	U.S. Geological Survey
WY	water year

Characterization of and Relations Among Precipitation, Streamflow, Suspended-Sediment, and Water-Quality Data at the U.S. Army Garrison Fort Carson and Piñon Canyon Maneuver Site, Colorado, Water Years 2016–18

By William A. Battaglin and Zachary D. Kisfalusi

Abstract

Frequent and prolonged military training maneuvers are an intensive type of land use that may disturb land cover, compact soils, and have lasting effects on adjacent stream hydrology and ecosystems. To better understand the potential effect of military training on hydrologic and environmental processes, the U.S. Geological Survey in cooperation with the U.S. Army established hydrologic and water-quality data-collection networks at the U.S. Army Garrison Fort Carson (AGFC) in 1978 and at the Piñon Canyon Maneuver Site (PCMS) in 1982. The purpose of this report is to present precipitation, streamflow, suspended-sediment, and water-quality data collected by the U.S. Geological Survey at the AGFC and PCMS for water years (WYs) 2016–18 and to evaluate those data in relation to long-term data from the AGFC and PCMS. In WYs 2016–18, the U.S. Geological Survey monitored 26 sites on the AGFC and 17 sites on the PCMS for precipitation amount, streamflow, suspended sediment, and (or) water quality.

On the AGFC, total annual precipitation in WYs 2016–18 was larger than the long-term mean for all 3 years at Rod and Gun Meteorologic Station at Fort Carson, CO (Rod and Gun). There were statistically significant upward trends in annual precipitation at Rod and Gun and Young Hollow Meteorologic Station at Fort Carson, CO (Young Hollow) with slopes of 1.25 and 0.66 inches per year (in/yr), respectively. The precipitation totals for WY 2017 were either the largest on record or in the top three for both sites and at Sullivan Park Meteorologic Station at Fort Carson, CO. On the PCMS, total annual precipitation was larger than the long-term mean in WYs 2016–18 at Brown Sheep Camp Meteorologic Station near Tyrone, CO; CIG Pipeline South Meteorologic Station near Simpson, CO; Bear Springs Hills Meteorologic Station near Houghton, CO (Bear Springs); and Upper Red Rock Canyon Meteorologic Station near Houghton, CO (Upper Red Rock). There were statistically significant upward trends in precipitation at Bear Springs and Upper Red Rock with slopes of 0.16 and 0.19 in/yr, respectively. The precipitation totals for WY 2017 were the largest on record for all sites except for Upper Bent Canyon Meteorological Station near Delhi, CO.

Streamflow was calculated at 18 sites on the AGFC and 7 sites on the PCMS in at least 1 of WYs 2016–18. At AGFC, mean annual (or seasonal) streamflow in WYs 2016–18 was less than the long-term mean at 7 sites and greater than the long-term mean at 3 sites. There were statistically significant downward trends in mean annual or seasonal streamflow at Womack Ditch from Little Fountain Creek near Fort Carson, CO, and Ripley Ditch from Little Fountain Creek at Fort Carson, CO, with slopes of −0.036 and −0.028 cubic feet per second per year ($ft^3/s/y$), respectively; and a significant upward trend in streamflow at Turkey Creek West Seepage below Teller Reservoir near Stone City, CO, with a slope of less than 0.001 $ft^3/s/y$. Unlike for precipitation, the mean annual or seasonal streamflow for WY 2017 was not in the top 3 for any of the 12 sites with measured flow.

At the PCMS, mean annual (or seasonal) streamflow was less than the long-term mean streamflow in WYs 2016–18 at the Taylor Arroyo below Rock Crossing near Thatcher, CO, and Bent Canyon Creek at Mouth near Timpas, CO, sites; and in WYs 2016 and 2018 at the Purgatoire River near Thatcher, CO (Purgatoire Thatcher), and Purgatoire River at Rock Crossing near Timpas, CO (Purgatoire Rock Crossing). There were no statistically significant trends in mean annual (or seasonal) streamflow at sites on the PCMS, and unlike for precipitation, the mean streamflow for WY 2017 was not in the top three for any sites except Purgatoire Rock Crossing. In WYs 2016–18, streamflow from sites on the AGFC and PCMS represented only a small fraction of streamflow in Fountain Creek or the Purgatoire River, and changes in streamflow that resulted from military maneuvers on the AGFC and PCMS were not likely to be detected in the downstream receiving waters.

Suspended-sediment concentrations, loads, and yields for WYs 2016–18, were analyzed at two sites on the AGFC and five sites on the PCMS. On the AGFC, mean seasonal suspended-sediment concentrations ranged from 3.10 to 155 milligrams per liter (mg/L), mean seasonal suspended-sediment loads ranged from 0.04 to 27.1 tons per day (t/d),

and seasonal suspended-sediment yields ranged from 0.28 to 216 tons per season per square mile (t/s/mi^2). Suspended-sediment yields at the two AGFC sites in WYs 2016–18 were all less than the long-term means. On the PCMS, mean seasonal suspended-sediment concentrations (at sites with some streamflow during a WY) ranged from 1.12 to 41.8 mg/L, mean suspended-sediment loads ranged from 0.01 to 13.1 t/d, and seasonal suspended-sediment yields ranged from 0.06 to 57.4 t/s/mi^2. Suspended-sediment yields at the five PCMS sites in WYs 2016–18 were all less than the long-term means. In WYs 2016–18, mean daily suspended-sediment loads at Little Fountain were 1.3, 2.5, and 7.6 percent, respectively, of the mean daily suspended-sediment load at Fountain Creek at Security, Colorado. Likewise, the total of mean daily suspended-sediment loads from the five tributary sites to the Purgatoire River in WYs 2016–18 were about 0.25, 0.17, and 3.2 percent, respectively, of the historical mean daily suspended-sediment load at Purgatoire Thatcher.

Spearman's rank correlation coefficient was used to evaluate the strength and form of the relations between daily total precipitation and daily mean streamflow and between daily mean streamflow and suspended-sediment concentration and load for WYs 2016–18. For the sites on the AGFC and PCMS, there were weak or statistically insignificant positive correlations between precipitation and streamflow at nearby streamgages, but strong statistically significant positive correlations between streamflow and suspended-sediment concentration and load. The ephemeral nature of the streams, quantity and timing of precipitation, air temperature, seasonal soil-moisture deficits, and effective runoff detention in erosion-control ponds could all contribute to inconsistent conversion of precipitation to streamflow.

Water-quality data were analyzed for as many as 43 parameters from 9 samples collected from 3 sites on the AGFC and from 37 samples collected from 4 sites on PCMS during WYs 2016–18. The concentrations of selected water-quality parameters were compared to regulatory standards for aquatic life from the Colorado Department of Public Health and Environment (CDPHE) or aquatic-life criteria from the U.S. Environmental Protection Agency (EPA). There is at least 1 CDPHE standard or EPA criterion for 30 of the 43 water-quality parameters.

For all samples from both the AGFC and the PCMS in WYs 2016–18, the concentrations of most water-quality parameters were compliant with the associated standards or criteria. However, there were some exceedances of standards or criteria: 11 samples exceeded the CDPHE recreational class standard for *Escherichia coli* concentration, 9 samples exceeded the CDPHE chronic unfiltered phosphorus aquatic-life standard, 36 samples exceeded the CDPHE chronic sulfate aquatic-life standard, 5 samples exceeded the EPA criterion for selenium, 7 samples exceeded the EPA criterion for aluminum, 2 samples exceeded the CDPHE chronic standard for iron, and 15 samples exceeded the CDPHE chronic standard for manganese.

Identifying potential effects of military training on water quality in adjacent streams on the AGFC and PCMS is difficult due to the ephemeral nature of streamflow, limited number of sampling locations and samples, and limited access to the study areas. At the PCMS, pairs of water-quality samples were collected in March and May 2017 before and after an April–May 2017 military training event. At the Purgatoire Rock Crossing site, streamflow at the time of the May sample was approximately 35 times larger than streamflow for the March sample. The absolute percent differences of concentrations for 27 parameters ranged from −71.7 to 183 percent, and 7 parameters had increases in concentration whereas 22 parameters had no change or decreases in concentrations. The absolute percent differences of loads for 24 parameters ranged from 141 to 198 percent. The generally lower concentrations and higher loads were expected given the higher streamflows at the time of collection of the May compared to the March samples.

Introduction

The U.S. Department of Defense owns or manages about 39 thousand square miles (mi^2) of land in the United States dedicated to military training and mission readiness (Crim and others, 2011). Military training can be an intensive type of land use, particularly the use of tracked vehicles (Lathrop, 1983; Shaw and Diersing, 1989, 1990; Dale and others, 2005). Frequent and prolonged military training may disturb land cover and soil and such disturbances may have lasting effects on adjacent stream hydrology and ecosystems (Fuchs and others, 2003; Maloney and others, 2005; Crim and others, 2011). Tracked-vehicle training activities include road building and construction of specialized facilities that can cause soil compaction (Prose, 1985) and removal of vegetative cover (Milchunas and others, 2000), both of which can lead to increased sediment loading to streams (Perkins and others, 2007). Roads and trails on military lands are mostly unpaved, and the effects of their use on soil and vegetation are determined by the exact paths of the vehicles (Dale and others, 2005). Military lands may contain rare species and sensitive habitats that can be adversely affected by these training activities (Leslie and others, 1996).

The Integrated Training Area Management Program, which is part of the U.S. Army Sustainable Range Program, combines military training with the monitoring and evaluation of land condition (U.S. Department of the Army, 2005). This integrative approach is intended to limit disturbance of land cover while providing areas that are appropriate for sustainable military training. One approach is to rotate military maneuvers between training areas, which provides periods of nonuse for each area during which any damage to vegetation and soils may be mitigated by natural processes or artificial methods.

The Army manages approximately 584 mi^2 of military training land in southeastern Colorado at the U.S. Army Garrison Fort Carson (AGFC) and the Piñon Canyon Maneuver

Site (PCMS). The Army has site-specific sustainability goals for these two training areas, which include land and natural resource conservation projects and cultural resource assessments (U.S. Department of the Army, 2020a).

In support of military and regulatory programs, the U.S. Geological Survey (USGS), in cooperation with the Army, established a network to collect hydrologic and water-quality data at the AGFC in June 1978 (Leonard, 1984) and another at the PCMS in October 1982 (von Guerard and others, 1987, 1993). The networks were designed to assess the quantity and quality of water resources and to monitor the effects of military training activities on stream discharge (herein referred to as “streamflow”) and water quality. At the PCMS, two preexisting USGS streamgages were incorporated into the data-collection network at the time it was established, providing periods of record that begin as early as 1966 (von Guerard and others, 1987). The original networks consisted of 17 streamgages on the AGFC and 11 streamgages and 4 precipitation sites on the PCMS. Since the establishment of the original networks, data-collection sites have been added or removed to meet changing data needs.

Spatial and temporal variations in precipitation amount, streamflow, suspended-sediment discharge (herein referred to as “load”), and water quality at the AGFC were previously assessed for the periods 1978–2015 (Arnold, 2017), 2008–12 (Brown, 2014), and 2013–14 (Holmberg and others, 2016). Spatial and temporal variations in precipitation amount, streamflow, suspended-sediment loads, and water quality at the PCMS were previously assessed for 1966–2015 (Arnold, 2017), 1983–87 (von Guerard and others, 1993), 1983–2007 (Stevens and others, 2008), and 2008–12 (Brown, 2014). Through water year (WY) 2018, the networks consisted of 26 sites at the AGFC and 17 sites at the PCMS. A WY is the 12-month period beginning October 1 and is designated by the calendar year in which it ends.

Purpose and Scope

The purpose of this report is to describe precipitation, streamflow, suspended-sediment, and water-quality data collected by the USGS at the AGFC and PCMS for WYs 2016–18. This report also evaluates the WYs 2016–18 data in relation to long-term data for the period of record for the AGFC (1978–2018) and the PCMS (1982–2018). Where possible, data were analyzed to determine the possible effects of mechanized military training at AGFC and PCMS on hydrology and water-quality conditions downstream from those training areas.

This report analyzes hydrologic characteristics including the spatial and temporal distribution of precipitation, streamflow, suspended-sediment, and water-quality data, and their relations to historical data. In addition, water-quality data for 43 parameters of concern, including *Escherichia coli* (*E. coli*), arsenic, lead, manganese, mercury, selenium, and uranium, are compared to regulatory numeric aquatic-life standards for surface water.

Description of Study Areas

The following sections briefly describe the landscape, geology, and hydrology of the AGFC and the PCMS.

U.S. Army Garrison Fort Carson

Located along the transition zone between the Great Plains and the Rocky Mountains in Colorado, the AGFC covers 214 mi^2 south of and adjacent to the city of Colorado Springs, Colorado (CO) (fig. 1; Brown, 2014). The AGFC lies at the base of the Rocky Mountains with land-surface elevations ranging from about 5,400 to 6,900 feet (ft) above North American Vertical Datum of 1988 (NAVD 88) with higher elevations in the west and lower elevations in the south and east (Leonard, 1984). The land is characterized by dissected plains and terraces in the northern and eastern parts with local relief ranging from 10 to 50 ft (Arnold, 2017), and deep canyons, hills, and hogbacks of sedimentary rocks with local relief of 50–600 ft (Leonard, 1984) to the west. The northern and western areas are underlain by Jurassic and Cretaceous sedimentary rocks (Tweto, 1979), whereas the rest of AGFC is underlain by Upper Cretaceous Pierre Shale and younger unconsolidated alluvium (fig. 2*A* in Holmberg and others, 2016).

Climate at the AGFC is semiarid with most precipitation occurring as convective rainfall in July through October. More rainfall occurs closer to the mountains to the northwest and less rainfall occurs to the east and south (Brown, 2014; Holmberg and others, 2016). Total annual precipitation varies substantially across the study area, ranging from less than (<) 5 to greater than (>) 33 inches per year (in/yr) (Brown, 2014; Holmberg and others, 2016).

The AGFC is in the Arkansas River Basin, where streams generally flow from northwest to southeast (fig. 1; Diersing and Severinghaus, 1984). The northern and eastern parts of the AGFC are drained by tributaries to Fountain Creek, including Little Fountain, Sand, and Rock Creeks (Leonard, 1984), the southern part is drained by Turkey and Little Turkey Creeks, tributaries of the Arkansas River, and the southwestern part is drained by Red Creek, a tributary of Beaver Creek that eventually flows into the Arkansas River.

Multiple training areas have been designated at the AGFC and PCMS for various types of maneuvers including mechanized and nonmechanized training. However, sensitive areas have been determined to be off limits to training (U.S. Army Corps of Engineers, 2007; U.S. Department of the Army, 2020a). At AGFC in WYs 2016–18, the Army indicated training occurred most frequently in the drainage basins of Red Creek, Turkey Creek, and Little Fountain Creek; however, the potential for effects from maneuvers are widespread, except for the most northern portion of the study area (U.S. Department of the Army, 2020b).

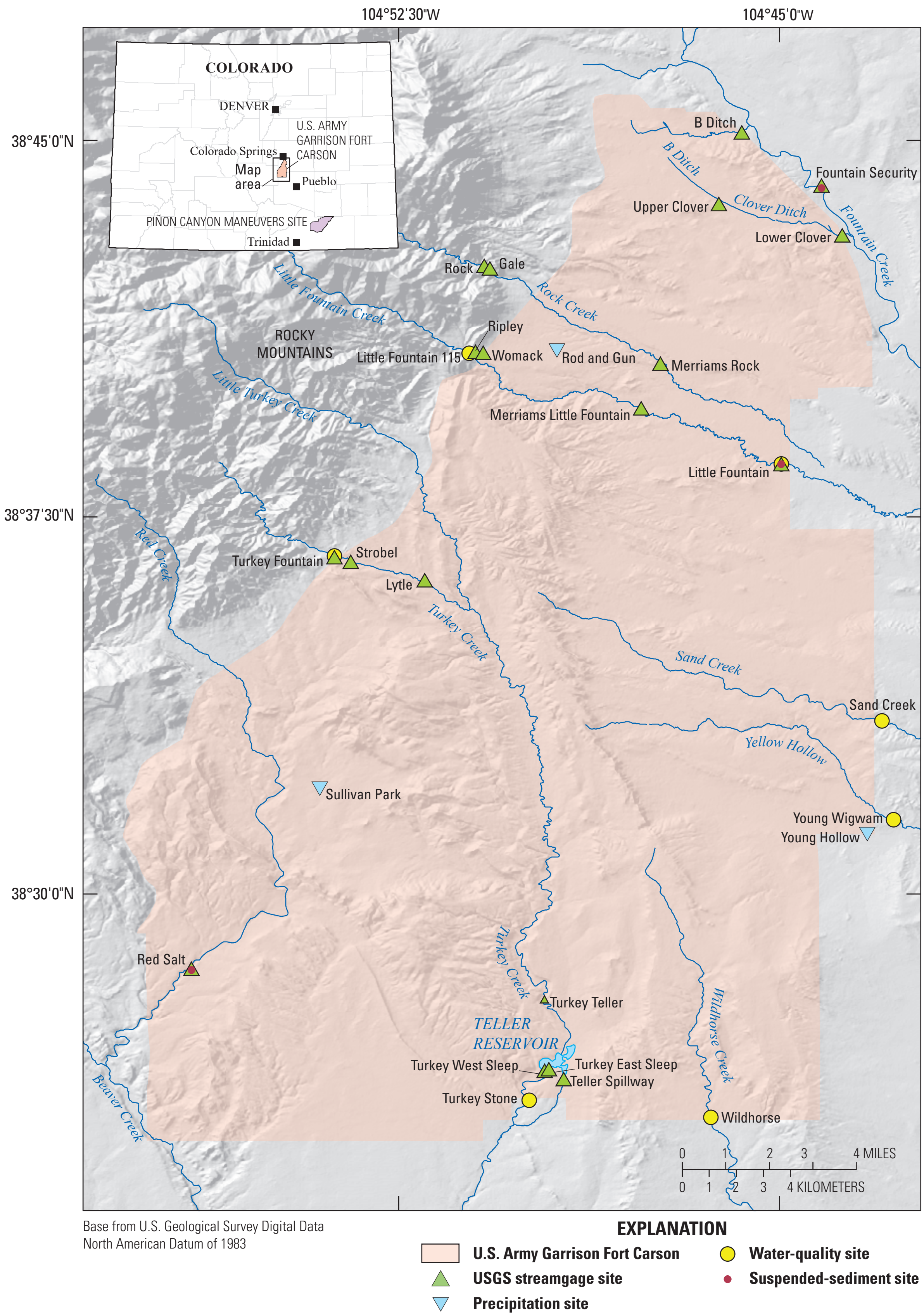


Figure 1. Location of the U.S. Army Garrison Fort Carson data-collection sites. Table 1 provides the short names for the sites that are used on the map (USGS, U.S. Geological Survey).

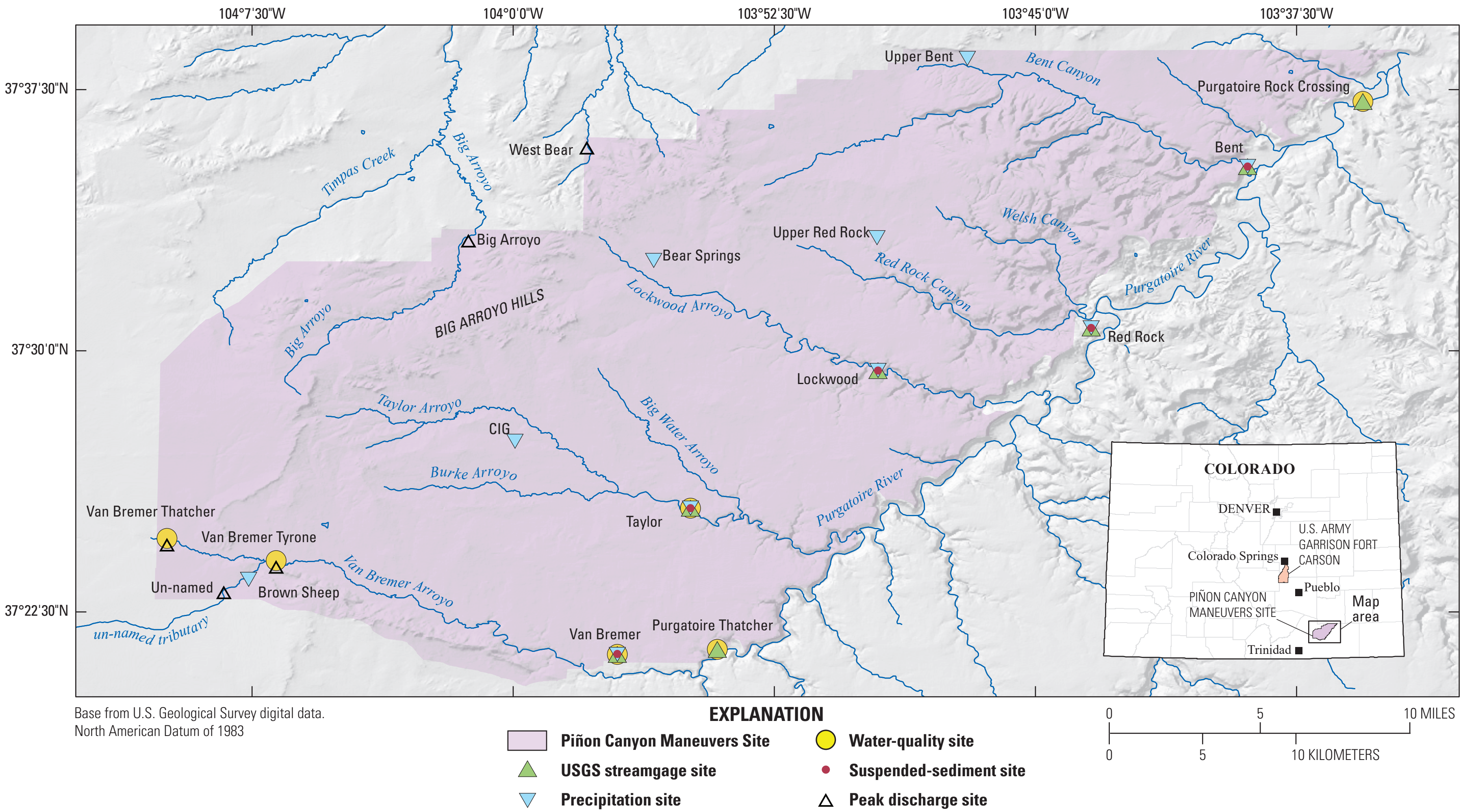


Figure 2. Location of the Piñon Canyon Maneuver Site data-collection sites. Table 2 provides the short names for the sites that are used on the map. (USGS, U.S. Geological Survey)

Piñon Canyon Maneuver Site

Located about 150 miles southeast of the AGFC and about 25 miles northeast of Trinidad, CO, the PCMS covers 369 mi^2 and consists of rangeland and canyons (Holmberg and others, 2016). The study area (fig. 2) is bounded by the Big Arroyo Hills to the west and north, and the 400–500 ft deep canyon of the Purgatoire River on the east (Stevens and others, 2008). Land-surface elevations at the PCMS range from about 4,305 ft above NAVD 88 where the Purgatoire River flows out of the study area to about 5,905 ft above NAVD 88 in the Big Arroyo Hills (von Guerard and others, 1987; Holmberg and others, 2016). The PCMS is underlain primarily by Cretaceous shales with some outcropping of Cretaceous limestone and sandstone in the canyon areas along the eastern border of the study area (von Guerard and others, 1987; Holmberg and others, 2016, fig. 2*B*).

Climate at the PCMS is semiarid with mean seasonal precipitation for April through October of between 10 and 11 inches (in.). Most precipitation occurs as convective rainfall in July through October (Stevens and others, 2008; Holmberg and others, 2016). Total seasonal precipitation can vary substantially across the study area, ranging from <6 in. to >12 in. per season (Stevens and others, 2008, fig. 2; Holmberg and others, 2016, fig. 3*B*).

The PCMS is in the Arkansas River Basin. About 96 percent of the land drains eastward to the Purgatoire River and the remaining 4 percent drains northeast into Timpas Creek (von Guerard and others, 1987; Stevens and others, 2008) through Big Arroyo (fig. 2). Timpas Creek and the Purgatoire River are both tributaries to the Arkansas River. Primary drainages to the Purgatoire River within the PCMS include Bent Canyon, Welsh Canyon, Red Rock Canyon, Lockwood Arroyo, Big Water Arroyo, Taylor Arroyo, Burke Arroyo, and Van Bremer Arroyo (fig. 2). Streams on the PCMS are predominantly intermittent or ephemeral and occupy shallow valleys that form side canyons of the Purgatoire River (von Guerard and others, 1993). Ponds that existed before the Army acquired the PCMS were used either for stock watering or erosion control, or both. The Army has built additional erosion-control ponds since 1983 at the PCMS (Stevens and others, 2008). The erosion-control ponds intercept an unknown amount of runoff and sediment, complicating characterization of the amount of streamflow and suspended-sediment transport that occurs at the PCMS.

At the PCMS, the Army performed three large-scale training exercises that could have potentially affected hydrologic or water-quality conditions downstream from the study area during WYs 2016–18. Those training exercises took place in May–June 2015, April–May 2017, and August–September 2018. Large-scale training at PCMS can encompass most of the study area, except for the arroyo canyons, and during the study period was generally most intensive in the Van Bremer, Taylor, and Lockwood drainage basins.

Methods

The USGS monitored 26 sites on the AGFC and 17 sites on the PCMS for precipitation amount, streamflow, suspended sediment, or water quality in WYs 2016–18. Tables 1 and 2 list the data types collected at each site. All data described in this report are available in a USGS data release (Kisfalusi and Battaglin, 2022) and can be accessed at the USGS National Water Information System database (USGS, 2020). The sites' short names given in tables 1 and 2 are hereinafter used to identify sites in this report. Where applicable, the short name is the same as used by Stevens and others (2008), Brown (2014), and Arnold (2017). More detailed information on site locations, elevations, and associated drainage areas can be found in Holmberg and others (2016).

Data Collection

All data were collected and processed according to standard USGS methods and quality-control measures applicable at the time of collection (USGS, variously dated). Historical data-collection activities at the AGFC and PCMS sites are described by von Guerard and others (1993), Stevens and others (2008), Brown (2014), Holmberg and others (2016), and Arnold (2017).

Precipitation Amount

Precipitation data were collected in accordance with procedures described in USGS (2010) and Holmberg and others (2016). All sites where precipitation data were collected (see tables 1 and 2 and figs. 1 and 2) were equipped with tipping-bucket rain gages having 8-, 10-, or 12-in. openings. Winter precipitation data were considered less accurate because of the difficulty of accurately measuring snowfall in tipping-bucket rain gages (Holmberg and others, 2016). Total daily precipitation amount was recorded at 3 AGFC sites and 10 PCMS sites. Precipitation sites were operated year round at the 3 AGFC sites and at 5 sites on the PCMS, and seasonally at the other 5 PCMS sites (tables 1 and 2).

Streamflow

Daily mean streamflow in cubic feet per second was computed in accordance with standard USGS procedures (Rantz and others, 1982a, 1982b; Kennedy, 1983; Turnipseed and Sauer, 2010). Streamflow was collected at 18 streamgages on the AGFC and 7 on the PCMS (tables 1 and 2). Streamflow was collected year round at 13 streamgages on the AGFC and 1 on the PCMS, and seasonally from April through October at 5 streamgages on the AGFC and 6 on the PCMS (tables 1 and 2).

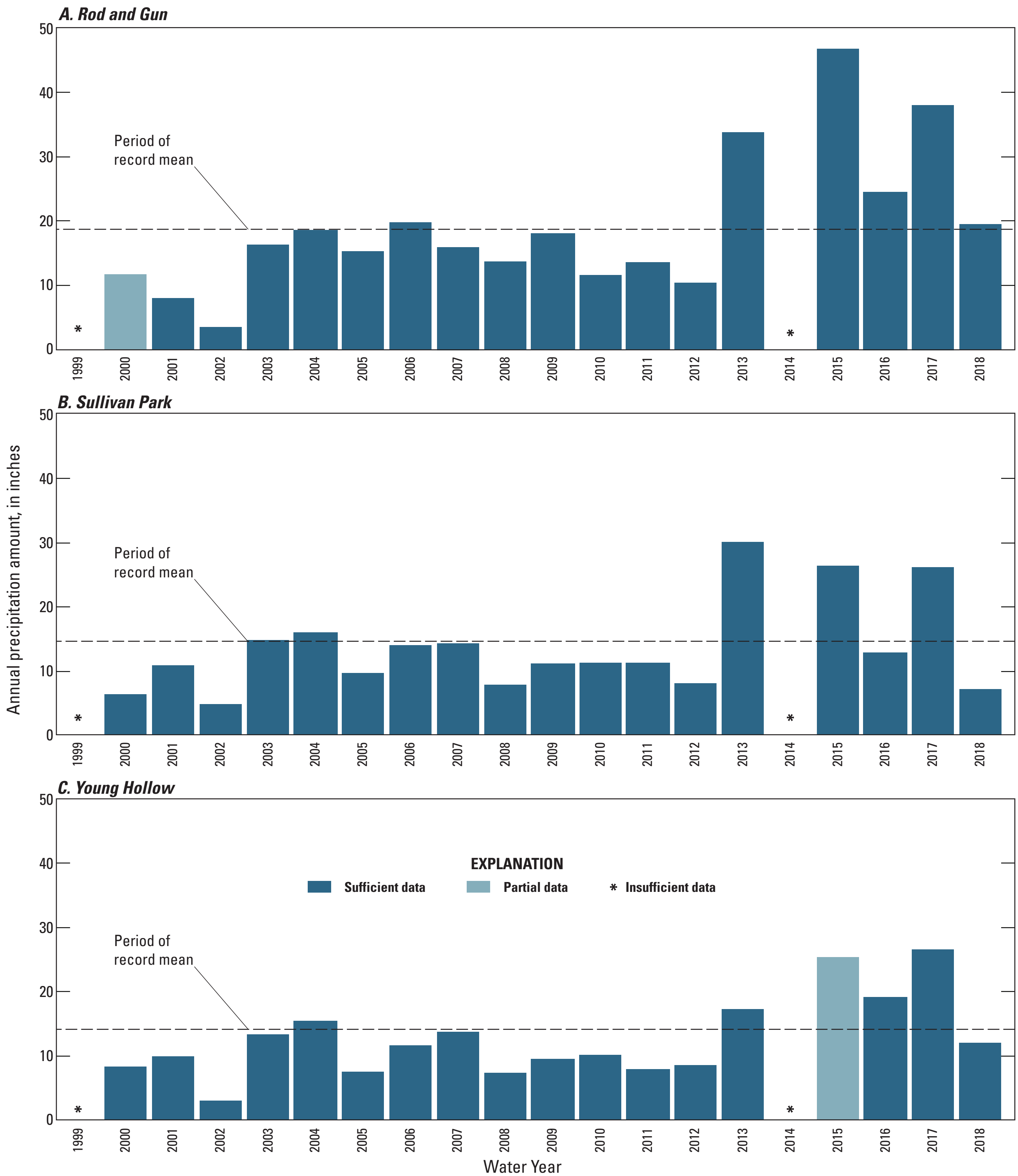


Figure 3. Annual (October 1 through September 30) precipitation at sites in or near U.S. Army Garrison Fort Carson, Colorado: *A*, Rod and Gun; *B*, Sullivan Park; and *C*, Young Hollow. (Site short names from table 1. Year-round sites were classified as "insufficient" if less than 180 days of data were collected, "partial" if between 180 and 300 days of data were collected, and "sufficient" if more than 300 days of data were collected for a water year.)

Table 1. Description of data-collection sites at the U.S. Army Garrison Fort Carson, Colorado, for water years 2016–18, including U.S. Geological Survey (USGS) site number, site name, short name, type of data collected, type of operation, and Colorado Department of Public Health and Environment (CDPHE) aquatic life classification and stream segment identifier.

[CO, Colorado; UAB, Upper Arkansas Basin; FCB, Fountain Creek Basin; MAB, Middle Arkansas Basin; NA, not applicable]

USGS site number	Site name	Short name	Data type(s)	Operation	CDPHE Arkansas River Basin, aquatic-life classification[1]	CDPHE Arkansas River Basin, stream segment designator[2]
07099085	Red Creek above Salt Canyon at Fort Carson, CO	Red Salt	Streamflow Suspended sediment	Seasonal Seasonal	Cold-1	UAB, 24
07099215	Turkey Creek near Fountain, CO	Turkey Fountain	Streamflow Water quality	Seasonal Periodic	Cold-2	UAB, 14f
07099230	Turkey Creek above Teller Reservoir near Stone City, CO	Turkey Teller	Streamflow	Seasonal	Warm-1	UAB, 14d
07099238	Teller Reservoir Spillway near Stone City, CO	Teller Spillway	Streamflow	Seasonal	Warm-1	UAB, 14d
07105780	B Ditch Drain near Security, CO	B Ditch	Streamflow Water temperature	Year round Seasonal	Warm-2	FCB, 4d
07105815	Clover Ditch Drain at Quinn St near Widefield, CO	Upper Clover	Streamflow Water temperature	Year round Seasonal	Warm-2	FCB, 4d
07105820	Clover Ditch Drain near Widefield, CO	Lower Clover	Streamflow Water temperature	Year round Seasonal	Warm-2	FCB, 4d
07105940	Little Fountain Creek near Fountain, CO	Little Fountain	Streamflow Suspended sediment Water quality	Seasonal Seasonal Periodic	Warm-2	FCB, 4e
07105945	Rock Creek above Fort Carson, CO	Rock	Streamflow	Year round	Warm-1	MAB, 4b
07099235	Turkey Creek near Stone City, CO	Turkey Stone	Water quality	Periodic	Warm-2	FCB, 4d
384048104510401	Little Fountain Creek above Highway 115 at Fort Carson, CO	Little Fountain 115	Water quality	Periodic	Cold-1	FCB, 3a
383130104424201	Young Hollow below Fort Carson near Wigwam, CO	Young Wigwam	Water quality	Periodic	Warm-2	FCB, 4d
383325104424801	Sand Creek below Fort Carson near Wigwam, CO	Sand Creek	Water quality	Periodic	Warm-2	FCB, 4d
382532104461801	Wildhorse Creek near Stone City at Fort Carson, CO	Wildhorse	Water quality	Periodic	Warm-2	MAB, 4a

Table 1. Description of data-collection sites at the U.S. Army Garrison Fort Carson, Colorado, for water years 2016–18, including U.S. Geological Survey (USGS) site number, site name, short name, type of data collected, type of operation, and Colorado Department of Public Health and Environment (CDPHE) aquatic life classification and stream segment identifier.—Continued

[CO, Colorado; UAB, Upper Arkansas Basin; FCB, Fountain Creek Basin; MAB, Middle Arkansas Basin; NA, not applicable]

USGS site number	Site name	Short name	Data type(s)	Operation	CDPHE Arkansas River Basin, aquatic-life classification[1]	CDPHE Arkansas River Basin, stream segment designator[2]
382628104493700	Turkey Creek West Seepage below Teller Reservoir near Stone City, CO	Turkey West Seep	Streamflow	Year round	Warm-1	UAB, 14d
382629104493000	Turkey Creek East Seepage below Teller Reservoir near Stone City, CO	Turkey East Seep	Streamflow	Year round	Warm-1	UAB, 14d
383619104520401	Lytle Ditch at Fort Carson, CO	Lytle[3]	Streamflow	Year round	NA	NA
383637104531301	Strobel Ditch from Turkey Creek at Fort Carson, CO	Strobel[3]	Streamflow	Year round	NA	NA
383944104474201	Merriams Little Fountain Ditch at Fort Carson, CO	Merriams Little Fountain[3]	Streamflow	Year round	NA	NA
384037104472001	Merriams Rock Creek Ditch at Fort Carson, CO	Merriams Rock[3]	Streamflow	Year round	NA	NA
384047104510301	Ripley Ditch from Little Fountain Creek at Fort Carson, CO	Ripley[3]	Streamflow	Year round	NA	NA
384048104504901	Womack Ditch from Little Fountain Creek near Fort Carson, CO	Womack[3]	Streamflow	Year round	NA	NA
384220104503701	Gale Ditch from Rock Creek near Fort Carson, CO	Gale[3]	Streamflow	Year round	NA	NA
383109104431301	Young Hollow Meteorologic Station at Fort Carson, CO	Young Hollow	Precipitation	Year round	NA	NA
383159104540701	Sullivan Park Meteorologic Station at Fort Carson, CO	Sullivan Park	Precipitation	Year round	NA	NA
384053104492001	Rod and Gun Meteorologic Station at Fort Carson, CO	Rod and Gun	Precipitation	Year round	NA	NA

[1]Cold-1 and Warm-1 are water classifications that indicate where water bodies are capable of sustaining a wide variety of cold/warm water biota and where the physical habitat, water flows or levels, and water-quality conditions result in no substantial impairment of species. Cold-2 and Warm-2 are water classifications that indicate where water bodies are not capable of sustaining a wide variety of cold or warm water biota because of physical habitat, water flows or levels, or uncorrectable water-quality conditions (CDPHE 2017, 2018).

[2]CDPHE basin and stream segment designator information from CDPHE (2017, 2018).

[3]Site is part of the ditch system for U.S. Army Garrison Fort Carson water rights.

Table 2. Description of data-collection sites at the Piñon Canyon Maneuver Site, Colorado, for water years 2016–18, including U.S. Geological Survey (USGS) site number, site name, short name, type of data collected, type of operation, and Colorado Department of Public Health and Environment (CDPHE) aquatic life classification and stream segment identifier.

[CO, Colorado; LAB, Lower Arkansas Basin; NA, not applicable]

USGS site number	Site name	Short name	Data type(s)	Operation	CDPHE Arkansas River Basin, aquatic-life classification[1]	CDPHE Arkansas River Basin, stream segment designator[2]
07126200	Van Bremer Arroyo near Model, CO	Van Bremer	Precipitation	Seasonal	Warm-1	LAB, 9a
			Streamflow	Seasonal		
			Suspended sediment	Seasonal		
			Water quality	Quarterly		
07126300	Purgatoire River near Thatcher, CO	Purgatoire Thatcher	Streamflow	Year round	Warm-1	LAB, 7
			Water quality	Quarterly		
07126325	Taylor Arroyo below Rock Crossing near Thatcher, CO	Taylor	Precipitation	Seasonal	Warm-2	LAB, 2a
			Streamflow	Seasonal		
			Suspended sediment	Seasonal		
			Water quality	Periodic		
07126390	Lockwood Canyon Creek near Thatcher, CO	Lockwood	Precipitation	Seasonal	Warm-2	LAB, 2a
			Streamflow	Seasonal		
			Suspended sediment	Seasonal		
07126415	Red Rock Canyon Creek at Mouth near Thatcher, CO	Red Rock	Precipitation	Seasonal	Warm-2	LAB, 2a
			Streamflow	Seasonal		
			Suspended sediment	Seasonal		
07126480	Bent Canyon Creek at Mouth near Timpas, CO	Bent	Precipitation	Seasonal	Warm-2	LAB, 2a
			Streamflow	Seasonal		
			Suspended sediment	Seasonal		
07126485	Purgatoire River at Rock Crossing near Timpas, CO	Purgatoire Rock Crossing	Streamflow	Seasonal	Warm-1	LAB, 7
			Water quality	Quarterly		
07120620	Big Arroyo near Thatcher, CO	Big Arroyo	Peak streamflow	Periodic	Warm-2	LAB, 2a
07126130	Van Bremer Arroyo near Thatcher, CO	Van Bremer Thatcher	Peak streamflow	Periodic	Warm-1	LAB, 9a
			Water quality	Quarterly		
07126140	Van Bremer Arroyo near Tyrone, CO	Van Bremer Tyrone	Peak streamflow	Periodic	Warm-1	LAB, 9a
			Water quality	Quarterly		

Table 2. Description of data-collection sites at the Piñon Canyon Maneuver Site, Colorado, for water years 2016–18, including U.S. Geological Survey (USGS) site number, site name, short name, type of data collected, type of operation, and Colorado Department of Public Health and Environment (CDPHE) aquatic life classification and stream segment identifier.—Continued

[CO, Colorado; LAB, Lower Arkansas Basin; NA, not applicable]

USGS site number	Site name	Short name	Data type(s)	Operation	CDPHE Arkansas River Basin, aquatic-life classification[1]	CDPHE Arkansas River Basin, stream segment designator[2]
372308104081801	Un-named Tributary above Van Bremer Arroyo at PCMS, CO	Un-named	Peak streamflow	Periodic	Warm-2	LAB, 2a
373556103575201	West Bear Springs Arroyo at Boundary at PCMS, CO	West Bear	Peak streamflow	Periodic	Warm-2	LAB, 2a
372319104073301	Brown Sheep Camp Meteorologic Station near Tyrone, CO	Brown Sheep	Precipitation	Year round	NA	NA
372721103595601	CIG Pipeline South Meteorologic Station near Simpson, CO	CIG[3]	Precipitation	Year round	NA	NA
373232103555201	Bear Springs Hills Meteorologic Station near Houghton, CO	Bear Springs[4]	Precipitation	Year round	NA	NA
373315103493101	Upper Red Rock Canyon Meteorologic Station near Houghton, CO	Upper Red Rock[5]	Precipitation	Year round	NA	NA
373823103465601	Upper Bent Canyon Meteorologic Station near Delhi, CO	Upper Bent[6]	Precipitation	Year round	NA	NA

[1]Warm-1 is a water classification that indicates where water bodies are capable of sustaining a wide variety of warm water biota and where the physical habitat, water flows or levels, and water-quality conditions result in no substantial impairment of species. Warm-2 is a classification that indicates where water bodies are not capable of sustaining a wide variety of warm water biota because of physical habitat, water flows or levels, or uncorrectable water-quality conditions (CDPHE 2017, 2018).

[2]CDPHE basin and stream segment information from CDPHE (2017, 2018).

[3]Site known as "Taylor precipitation gage" in von Guerard and others (1993).

[4]Site known as "Lockwood precipitation gage" in von Guerard and others (1993).

[5]Site known as "Red Rock precipitation gage" in von Guerard and others (1993).

[6]Site known as "Bent Canyon precipitation gage" in von Guerard and others (1993).

Crest-stage gages are peak-stage recorders often consisting of a vented steel pipe (Rantz and others, 1982a; Sauer and Turnipseed, 2010) that are used to get indirect discharge measurements at sites with ephemeral streamflow (Benson and Dalrymple, 1967). Peak streamflow data were collected at five sites on the PCMS (table 2).

Suspended Sediment

Suspended-sediment samples were collected as described by Edwards and Glysson (1988), Rasmussen and others (2009), and Holmberg and others (2016), and analyzed at the USGS Iowa Water Science Center Sediment Laboratory using methods described by Guy (1969). Suspended-sediment concentrations obtained from samples collected at a single point within the cross section were adjusted based on relations developed from depth-integrated samples collected periodically using the equal-width-increment method (Koltun and others, 1994). Daily suspended-sediment load and concentration were calculated using streamflow as a proxy using the Graphical Constituent Loading Analysis System (Koltun and others, 2006). Suspended-sediment samples were collected seasonally from April through October during WYs 2016–18 at two sites on AGFC and five sites on PCMS (tables 1 and 2).

The total seasonal suspended-sediment load is defined as the sum of the daily suspended-sediment loads computed at a suspended-sediment monitoring site from April through October. The seasonal suspended-sediment yield was calculated by dividing the total seasonal suspended-sediment load by the drainage basin area for each site.

Water Quality

Water-quality samples were collected using standard equipment with width- and depth-integrating techniques when flow conditions allowed (USGS, variously dated). In some cases, because of low-flow conditions, single or multiple vertical dip samples were collected. At the time of sampling, field measurements were made for dissolved oxygen (DO), pH, specific conductance (SC), and water temperature. All samples were collected, processed, and preserved in the field according to standard methods described in USGS (variously dated). The proposed frequency of water-quality sample collection was 2 per year at the 7 sites on or near the AGFC, and 4 per year at the 6 sites on or near the PCMS, depending on streamflow conditions and site access (tables 1 and 2).

Samples were analyzed for 6 physical properties, 27 inorganic metals and nonmetals (Fishman, 1993; Hoffman and others 1996; Garbarino and others, 2005), 7 nutrients (Patton and Kryskalla, 2003), 1 radiochemical—uranium (Garbarino and others, 2005), and 2 biological parameters—*E. coli* and total coliforms (app. 1). All samples were analyzed by the USGS National Water Quality Laboratory in Lakewood, CO, except for the biological analyses. *E. coli* and total coliform samples were collected in the field and then processed, incubated, and counted using the Colilert method at the USGS Colorado Water Science Center, Southeastern Colorado office laboratory as described by Myers and others (2014).

Data Analysis

Data presented in this report were retrieved from the National Water Information System database (USGS, 2020) using the dataRetrieval package in R (De Cicco and others, 2018), and graphs and plots were prepared using the smwrGraphs package (Lorenz and Diekoff, 2017) in R (The R Foundation, 2021). Summary statistics were computed for all data using R version 4.0.3. A mixture of parametric and nonparametric analyses was applied because of the non-normal distribution of some of the data and the low detection frequency for some parameters. Nonparametric statistics are generally preferred with hydrologic data because they are rank based and more resistant to extreme values or outliers (Helsel and others, 2020). For correlation analyses, Spearman's rank correlation coefficient (Spearman's ρ) was used to evaluate the strength and form of the associations with p-values indicating the statistical significance of the tests (Savicky, 2014). Ordinary least-squares regression was used to evaluate the strength and form of trends (Helsel and others, 2020). A p-value of <0.05 (95-percent confidence that the statistical test is valid) was used to reject the null hypothesis of no association or trend for all tests.

When parameter concentrations were reported as less than the laboratory reporting level (LRL; not detected), those concentrations were set to zero for the purposes of calculating detection frequencies, total concentrations, and most other statistics. In some samples, a concentration value was reported as "estimated" (E) or was reported when it was less than the LRL but greater than the instrument limit of detection (Foreman and others, 2021). These concentrations were used as reported.

For some parameters (for example, aluminum), the LRL may be different for each analytical run based on the results of standards that are run along with the samples. Also, instrument sensitivity requires that some samples are diluted with pure water. Those dilution factors can vary from one sample set to another, and so the LRL will also vary.

For the calculation of relative percent difference (RPD) between two concentration values, the reported value was substituted for any values qualified with an "E" code. The RPD was calculated as the absolute value of the difference between the two concentrations (range) divided by the mean of the two concentrations, then that quantity was multiplied by 100. A RPD was not calculated when one or both values were non-detections or greater than values. For the calculation of absolute percent difference (APD) between two concentration values, the reported value was substituted for any values qualified with an "E" code. The APD was calculated as the value of the difference between the downstream site concentration and the upstream site concentration divided by the mean of the two concentrations, then that quantity was multiplied by 100. An APD was not calculated when one or both values were non-detections or greater than values.

Water-quality data were compared to the Colorado Department of Public Health and Environment (CDPHE) regulatory numeric aquatic-life standards for surface water in the Arkansas River Basin (Regulation 32; CDPHE, 2018) and the State of Colorado aquatic-life basic standards for surface water (Regulation 31; CDPHE, 2017). If CDPHE has not established an aquatic-life standard, water-quality data were compared to U.S. Environmental Protection Agency (EPA) aquatic-life criteria (EPA, 2020).

Quality Assurance

Quality-control samples were collected and analyzed to quantify the variability of analytical results and to measure the potential for contamination in the collection and processing of water-quality data. Twelve field blanks were prepared with inorganic-grade blank water from the National Water Quality Laboratory that is quality assured for suitability in the testing of equipment and sampling. The field blank samples were analyzed for 33 inorganic parameters and dissolved solids (Kisfalusi and Battaglin, 2022); blank samples were not analyzed for mercury. There were no detections in the blank samples for 31 parameters and dissolved solids.

Filtered ammonia (sometimes referred to as “dissolved ammonia”) was detected in 2 of the 12 blank samples at concentrations of 0.010 and 0.013 milligrams per liter (mg/L). These concentrations were at or near the LRL for filtered ammonia of 0.01 mg/L. Filtered ammonia was detected in 27 of the 46 water-quality samples with a median concentration of 0.024 mg/L and a maximum concentration of 0.08 mg/L (Kisfalusi and Battaglin, 2022). Four of the ammonia detections were at a concentration equal to or less than the highest concentration in a blank sample.

The LRL for filtered chloride is 0.02 mg/L. Filtered chloride was detected in 4 of the 12 blank samples at concentrations between 0.020 and 0.146 mg/L and was detected in all 46 water-quality samples with a median concentration of 35.7 mg/L and a maximum concentration of 58.8 mg/L. Concentrations of filtered chloride in field blanks were several orders of magnitude lower than concentrations in water-quality samples and thus would not be expected to affect interpretation of the environmental data.

Fifteen equipment blanks were collected during processing of bacteria (*E. coli* and total coliforms). All the bacteria concentrations in equipment blanks were non-detects, indicating that the equipment did not introduce any contamination to the bacteria samples. These results indicate that the potential for contamination in the associated environmental samples is low, and caution may be needed when interpreting the lowest reported concentration of filtered ammonia (Mueller and others, 2015).

Thirteen replicate samples were collected to assess the potential variability among sample results that occurred as a result of field processing and laboratory procedures (Mueller and others, 2015). An RPD of 20 percent or less between replicate-pair concentrations was considered acceptable for this study (Mueller and others, 2015). For the replicate analyses, of 441 possible comparisons, non-detections were observed in 1 or both samples in 156 comparisons. In the 285 comparisons with a detection in both samples, the RPDs ranged from zero to 59 percent, with a median RPD of 2.07 percent (Kisfalusi and Battaglin, 2022). The RPD was within the acceptable limits (<20 percent) for 269 replicate-analyte pairs or 94 percent of the pairs. The replicate-analyte pairs that indicate higher variability in analytical results that may affect data interpretation are listed in table 3.

A total of 18 (4 at AGFC and 14 at PCMS) bacteria-only split replicate samples were collected during the study period. For the replicate analyses, of 34 possible comparisons, non-detections were observed in 1 or both samples in one comparison and a greater than remark code was associated with both samples in 10 comparisons (all for total coliforms). The RPDs for *E. coli* ranged from 3.92 to 128 percent with a median of 34.0 percent. The RPDs for total coliforms ranged from zero to 164 percent with a median of 8.90 percent (Kisfalusi and Battaglin, 2022).

Precipitation, Streamflow, Suspended-Sediment, and Water-Quality Data for Water Years 2016–18

The following sections summarize the hydrologic data (precipitation amount, streamflow, and suspended sediment) and water-quality data from study sites on the AGFC and PCMS (figs. 1 and 2) for WYs 2016–18.

Precipitation Amount

Precipitation is an important driver of hydrologic processes at the AGFC and PCMS study areas. The timing, spatial distribution, and quantity of precipitation at the AGFC and PCMS sites affect storm runoff and soil erosion and may determine the effectiveness of certain conservation practices implemented to mitigate the effects of military maneuvers. Storm runoff, suspended-sediment transport, and contaminant transport are dependent upon precipitation because groundwater contributions to surface streamflow are limited at the AGFC and absent at the tributaries flowing from PCMS, except at Van Bremer and Lockwood where groundwater contribution has been minor (von Guerard and others, 1993; Stevens and others, 2008).

The total daily precipitation amounts at AGFC are summarized for three sites: Young Hollow Meteorologic Station at Fort Carson, CO (Young Hollow), Sullivan Park Meteorologic Station at Fort Carson, CO (Sullivan Park), and Rod and Gun Meteorologic Station at Fort Carson, CO (Rod and Gun) (fig. 1). An historical isohyetal map from WY 2013 indicates

Table 3. Results of sample-replicate analyses for water years 2016–18 at the Piñon Canyon Maneuver Site, Colorado.

[Only samples with a relative percent difference greater than 20 percent are included. µg/L, micrograms per liter; mg/L, milligrams per liter]

Short name (from table 2)	Sample date	Water-quality parameter	Environmental result	Replicate result	Relative percent difference
Purgatoire Rock Crossing	11/23/2015	Nickel, filtered (µg/L)	3.28	2.63	22
Van Bremer	5/25/2016	Antimony, filtered (µg/L)	0.13	0.07	58
Van Bremer	5/25/2016	Iron, filtered (µg/L)	58.4	39.2	39
Purgatoire Rock Crossing	8/15/2016	Iron, filtered (µg/L)	44.1	35.1	23
Purgatoire Rock Crossing	3/23/2017	Ammonia, unfiltered (mg/L)	0.03	0.024	22
Purgatoire Rock Crossing	3/23/2017	Iron, filtered (µg/L)	11.4	16.0	34
Taylor	5/11/2017	Aluminum, filtered (µg/L)	208	128	48
Taylor	5/11/2017	Antimony, filtered (µg/L)	0.25	0.20	38
Taylor	5/11/2017	Cobalt, filtered (µg/L)	1.00	0.54	59
Taylor	5/11/2017	Iron, filtered (µg/L)	152	118	25
Taylor	5/11/2017	Manganese, filtered (µg/L)	4.66	2.95	45
Van Bremer	5/30/2017	Arsenic, filtered (µg/L)	0.67	0.82	20
Van Bremer	5/30/2017	Cobalt, filtered (µg/L)	0.51	0.42	20
Purgatoire Rock Crossing	11/17/2017	Nickel, filtered (µg/L)	1.84	2.30	22
Purgatoire Thatcher	4/18/2018	Ammonia, filtered (mg/L)	0.064	0.046	34
Van Bremer	8/1/2018	Ammonia, unfiltered (mg/L)	0.028	0.038	30

a general pattern of decreasing total annual precipitation from northeast to southwest at the AGFC that is similar to the elevation gradient (Holmberg and others, 2016). The data collected during WYs 2016–18 were somewhat different from those reported by Holmberg and others (2016). The largest annual total precipitation amount for each year was recorded at the Rod and Gun site in WY 2013 as well as WYs 2016, 2017, and 2018. However, the smallest annual total precipitation amount occurred at Young Hollow in WY 2013 but at Sullivan Park in WYs 2016, 2017, and 2018 (table 4; fig. 3).

Total annual precipitation in WYs 2016–18 was larger than the long-term mean for all 3 years at Rod and Gun, in 2016 and 2017 at Young Hollow, and in 2017 only at Sullivan Park (fig. 3). At all three sites on the AGFC, there is an upward trend in annual precipitation totals over the period of record. Those upward trends were statistically significant for Rod and Gun and Young Hollow with slopes of 1.25 and 0.66 in/yr, respectively. The precipitation totals for WY 2017 are either the largest on record (Young Hollow) or in the top three at Rod and Gun and Sullivan Park (fig. 3).

The total daily precipitation amounts at PCMS are summarized for 10 sites (fig. 2). An historical (WY 2013) isohyetal map (Holmberg and others, 2016) indicated a general pattern of decreasing total seasonal precipitation from southwest to northeast at the AGFC, similar to the elevation gradient, with a clumped distribution pattern that may, in part, be explained by the localized nature of summertime storms in the region (Doesken and others, 1984).

The data collected during WYs 2016–18 at PCMS were somewhat different from those reported by Holmberg and others (2016). For the five sites with year-round operation (table 2), the largest annual total precipitation amount occurred at CIG Pipeline South Meteorologic Station near Simpson, CO (CIG) in 2016 and 2017, and at Bear Springs Hills Meteorologic Station near Houghton, CO (Bear Springs) in 2018 (table 4). Both sites are east of the site where the maximum seasonal precipitation occurred in 2013 (Burson Well Meteorologic Station near Thatcher, CO; Holmberg and others, 2016). The largest single day precipitation (maximum daily) occurred at Bear Springs in WYs 2016 and 2018 and at CIG in WY 2017 (table 4; Kisfalusi and Battaglin, 2022). Total annual precipitation was larger than the long-term mean in WYs 2016–18 at Brown Sheep Camp Meteorologic Station near Tyrone, CO (Brown Sheep), CIG, Bear Springs, and Upper Red Rock Canyon Meteorologic Station near Houghton, CO (Upper Red Rock) (fig. 4), and in WYs 2016 and 2017 at Upper Bent Canyon Meteorologic Station near Delhi, CO (Upper Bent).

For the five sites on the PCMS with seasonal operation (table 2), the largest seasonal total precipitation amount in 2016 occurred at Van Bremer Arroyo near Model, CO (Van Bremer), in 2017 at Bent Canyon Creek at mouth near Timpas, CO (Bent), and in 2018 at Lockwood Canyon Creek near Thatcher, CO (Lockwood), and the smallest seasonal total precipitation amount occurred in 2016 at Lockwood, and in 2017 and 2018 at Taylor Arroyo below Rock Crossing near Thatcher, CO (Taylor) (table 4). Total seasonal precipitation

Table 4. Summary statistics of daily and annual precipitation amount collected at sites on or near the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site, Colorado, for water years (WYs) 2016–18.

[in., inch]

Site short name (from tables 1 and 2)	WY 2016				WY 2017				WY 2018			
	Number of collection days	Maximum daily (in.)	Mean daily (in.)	Annual total (in.)	Number of collection days	Maximum daily (in.)	Mean daily (in.)	Annual total (in.)	Number of collection days	Maximum daily (in.)	Mean daily (in.)	Annual total (in.)
U.S Army Garrison Fort Carson												
Young Hollow	366	1.62	0.052	19.16	362	2.73	0.073	26.56	362	1.91	0.033	11.91
Sullivan Park	366	1.00	0.035	12.78	365	2.61	0.072	26.17	361	0.61	0.020	7.14
Rod and Gun	366	2.78	0.067	24.58	365	2.39	0.104	38.01	365	2.15	0.053	19.47
Piñon Canyon Maneuver Site												
Van Bremer[1]	214	1.17	0.053	11.44	214	1.37	0.093	19.80	214	1.40	0.038	8.09
Taylor[1]	214	2.34	0.053	11.28	214	1.52	0.073	15.52	214	1.23	0.030	6.45
Lockwood[1]	214	1.96	0.041	8.67	214	1.99	0.081	17.29	214	2.46	0.041	8.84
Red Rock[1]	214	0.91	0.043	9.17	214	1.69	0.092	19.70	214	2.02	0.037	7.86
Bent[1]	214	0.92	0.042	8.93	214	3.30	0.100	21.48	214	0.75	0.030	6.52
Brown Sheep	366	1.84	0.039	14.16	[2]187	2.27	0.114	21.27	365	1.34	0.035	12.91
CIG	366	1.87	0.058	21.24	364	2.78	0.085	30.84	356	3.03	0.039	14.00
Bear Springs	366	4.10	0.047	17.21	365	2.69	0.068	24.82	365	5.65	0.060	21.83
Upper Red Rock	366	1.50	0.048	17.44	364	1.93	0.063	22.75	365	2.54	0.048	17.49
Upper Bent	366	1.63	0.056	20.34	[2]188	2.71	0.091	17.09	365	2.47	0.033	12.06

[1]Data were collected at this site from April to October.

[2]Data were not collected from mid-November to mid-May.

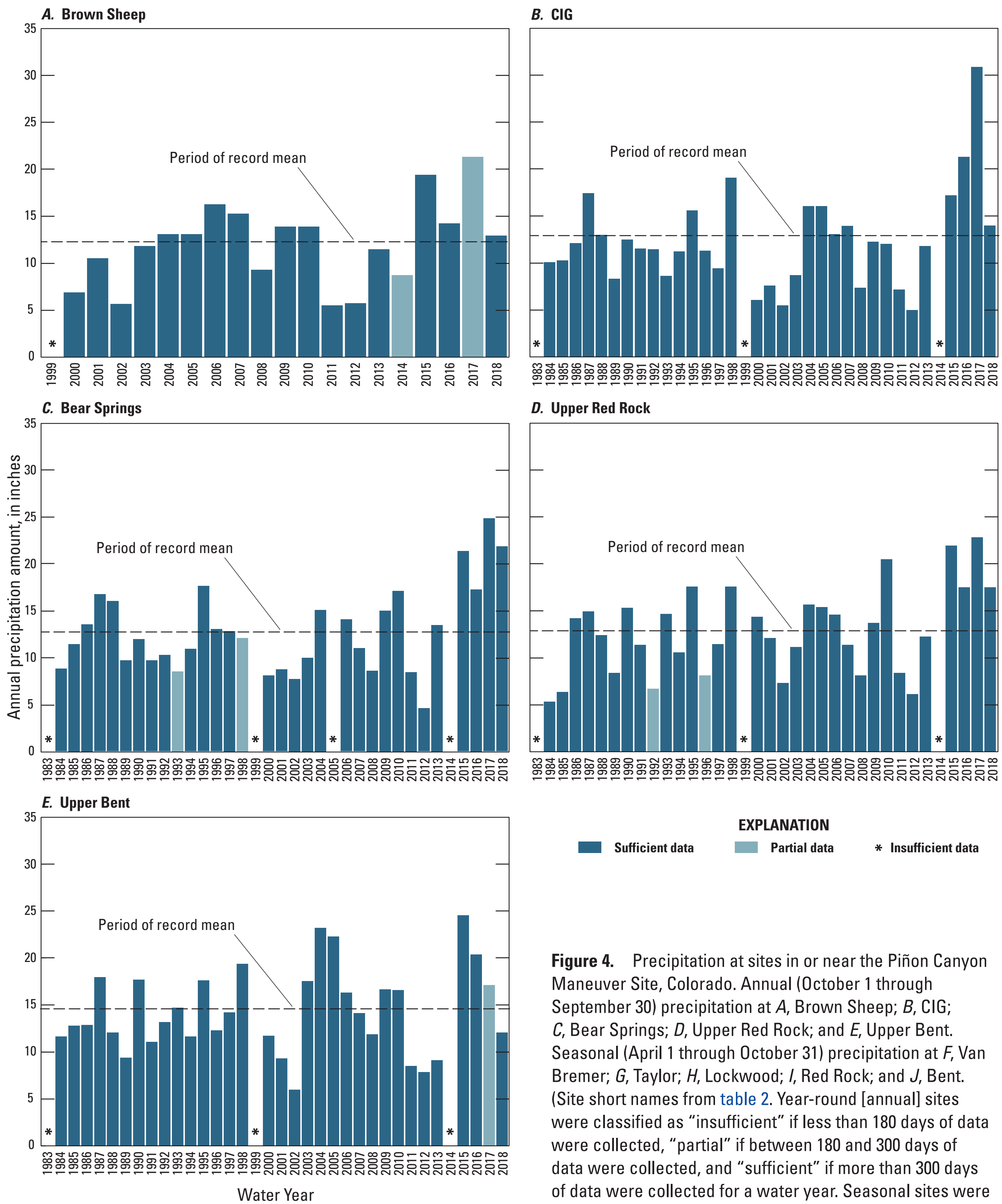


Figure 4. Precipitation at sites in or near the Piñon Canyon Maneuver Site, Colorado. Annual (October 1 through September 30) precipitation at *A*, Brown Sheep; *B*, CIG; *C*, Bear Springs; *D*, Upper Red Rock; and *E*, Upper Bent. Seasonal (April 1 through October 31) precipitation at *F*, Van Bremer; *G*, Taylor; *H*, Lockwood; *I*, Red Rock; and *J*, Bent. (Site short names from table 2. Year-round [annual] sites were classified as "insufficient" if less than 180 days of data were collected, "partial" if between 180 and 300 days of data were collected, and "sufficient" if more than 300 days of data were collected for a water year. Seasonal sites were classified as "insufficient" if less than 90 days of data were collected, "partial" if between 90 and 180 days of data were collected, and "sufficient" if more than 180 days of data were collected for a water year.)

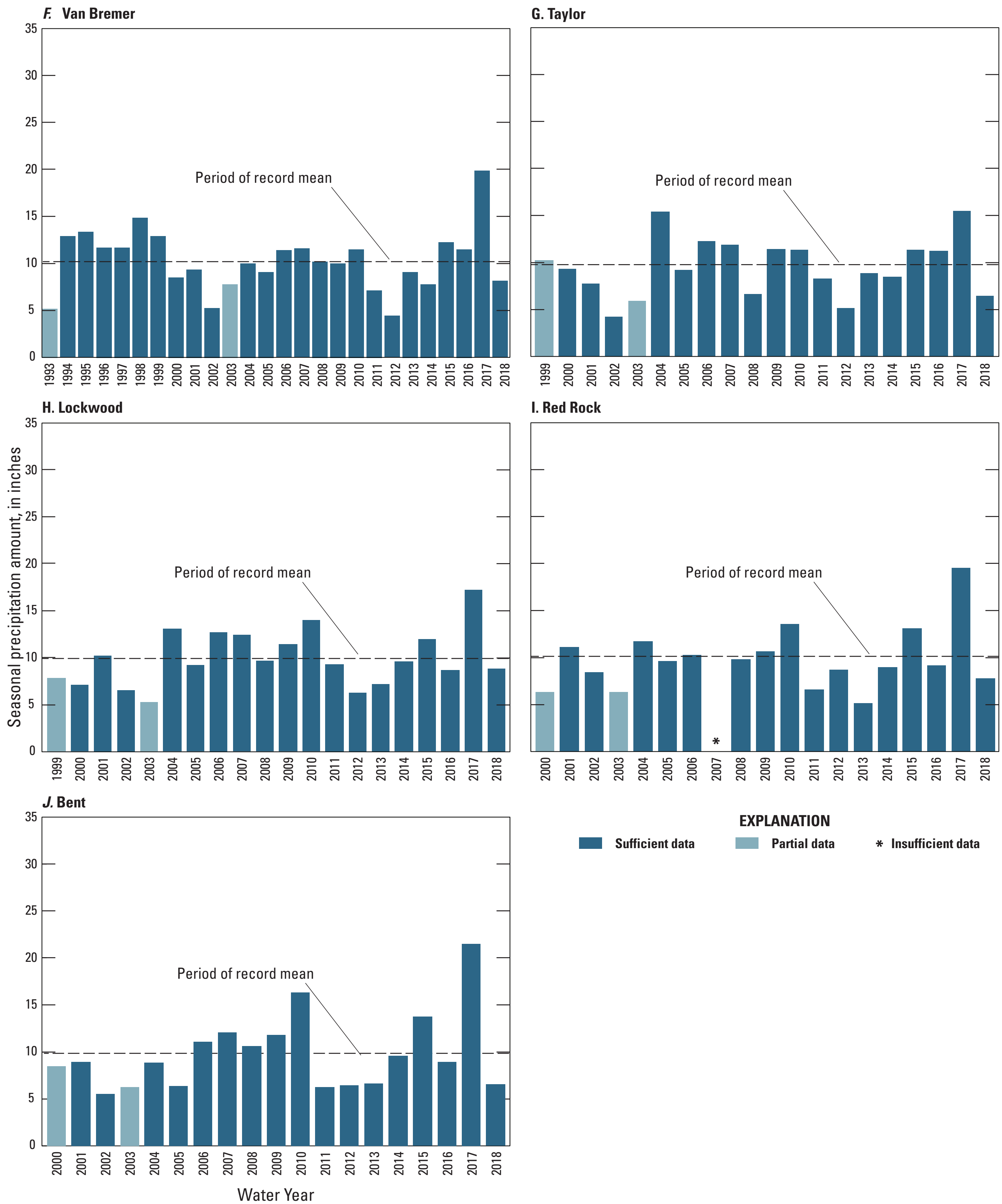


Figure 4.—Continued

was larger than the long-term mean in WYs 2016–17 at Van Bremer and Taylor, and in WY 2017 at Lockwood, Red Rock Canyon Creek at mouth near Thatcher, CO (Red Rock), and Bent (fig. 4).

At all five year-round sites, there was a general upward trend in annual precipitation totals over the period of record (fig. 4*A*–*E*). Those upward trends were statistically significant for Bear Springs and Upper Red Rock with slopes of 0.16 and 0.19 in/yr, respectively. Likewise, for the five seasonally operated sites, there was a general upward trend in seasonal precipitation totals over the period of record (fig. 4*F*–*J*); however, none of those trends were statistically significant. The precipitation total for WY 2017 is the largest on record for 9 of the 10 sites with the exception being Upper Bent which had some missing data during that WY.

These results indicate that there was not always a strong relation between elevation and total annual or seasonal precipitation at PCMS as had been suggested by Holmberg and others (2016). Analysis of spatial distribution of precipitation amount at the AGFC, and to a lesser extent at the PCMS, was constrained by the sparse distribution of precipitation sites within and just outside of the study areas (figs. 1 and 2).

Temporal variations in total daily precipitation amount at the AGFC and PCMS for WYs 2016–18 demonstrated that both study areas are generally semiarid. At the AGFC, the total daily precipitation amount at the three year-round sites was less than or equal to 0.1 in. between 308 and 346 days per year (table 5). At the PCMS, the total daily precipitation amount at the five seasonally operated precipitation sites was less than or equal to 0.1 in. between 175 and 201 days per season, and the total daily precipitation amount at the five year-round operated precipitation sites was less than or equal to 0.1 in. between 312 and 344 days per season (table 5, excluding sites with missing data).

Streamflow

Most of the monitored streams at the AGFC and PCMS are ephemeral or intermittent with periods of no flow followed by periods of flow in response to precipitation (von Guerard and others, 1993; Arnold, 2017). There is little contribution from groundwater, particularly at PCMS (von Guerard and others, 1993). Thus, streamflow is dependent upon precipitation falling in the basins upstream from the streamgages and subsequent runoff. Changes in land use/land cover at the AGFC and PCMS that result from active military training, such as the removal of large areas of vegetation and increased soil compaction, may affect the volume of runoff and streamflow in tributaries draining the two study areas. Increases in streamflow may result in changes in the concentrations of dissolved solids, suspended sediment, and other water-quality conditions in downstream rivers like the Purgatoire River and Fountain Creek.

At the AGFC during WYs 2016–18, three sites, Teller Reservoir spillway near Stone City, CO (Teller Spillway), Strobel Ditch from Turkey Creek at Fort Carson, CO (Strobel), and Gale Ditch from Rock Creek near Fort Carson, CO (Gale), had no recorded streamflow on the days the streamgages were operated (tables 6–8; Kisfalusi and Battaglin, 2022). More than 88 percent of days with data had no recorded streamflow at Red Creek above Salt Canyon at Fort Carson, CO (Red Salt) and Merriams Little Fountain Ditch at Fort Carson, CO (Merriams Little Fountain) (tables 6–8). Nine sites (Turkey Creek near Fountain, CO [Turkey Fountain], Little Fountain Creek near Fountain, CO [Little Fountain], Rock Creek above Fort Carson, CO [Rock], Turkey Creek east seepage below Teller Reservoir near Stone City, CO [Turkey East Seep], Lytle Ditch at Fort Carson, CO [Lytle], Merriams Rock Creek Ditch at Fort Carson, CO [Merriams Rock], B Ditch Drain near Security, CO [B Ditch], Clover Ditch Drain at Quinn St near Widefield, CO [Upper Clover], and Clover Ditch Drain near Widefield, CO [Lower Clover]) had year-round (or seasonal) streamflow on more than 75 percent of the days those sites were operated. At the other streamgages on the AGFC during WYs 2016–18, the percentage of days with zero streamflow ranged from 0 to 69 percent (tables 6–8).

At the AGFC during WYs 2016–18, three sites (Teller Spillway, Strobel, and Gale) had no measured streamflow, and three sites (B Ditch, Upper Clover, and Lower Clover) only have 2 years of data. The median of daily mean streamflow at the 12 AGFC streamgages with some measured flow in WYs 2016–18 ranged from zero (several sites and WYs) to 3.99 ft^3/s at Lower Clover in WY 2017 (tables 6–8). At 8 of the 12 streamgages on the AGFC, there were general downward trends in mean annual or mean seasonal streamflow; however, those trends were only statistically significant for Womack Ditch from Little Fountain Creek near Fort Carson, CO (Womack) and Ripley Ditch from Little Fountain Creek at Fort Carson, CO (Ripley) with slopes of −0.036 and −0.028 cubic feet per second per year ($ft^3/s/y$), respectively (fig. 5). The other four sites (Turkey Fountain, Lytle, Turkey Creek West Seepage below Teller Reservoir near Stone City, CO [Turkey West Seep], and Turkey East Seep show general upward trends in streamflow; however, those trends were only statistically significant for Turkey West Seep with a slope of <0.001 $ft^3/s/y$ (fig. 5). Unlike for precipitation, the mean annual or seasonal streamflow for WY 2017 was not in the top 3 highest values for any of the 12 sites.

The coefficient of variation (CV) for streamflow was calculated by dividing the standard deviation of streamflow by the mean streamflow for each site. The CV is a dimensionless metric that expresses the variability of a sample relative to the mean (Zar, 1974), and allows for magnitude-independent comparison of variations among daily mean streamflow (Holmberg and others, 2016). The CV is of interest because it accounts for changes in streamflow variability caused by changes in the annual mean; for example, dry periods can have lower variability (Pagano and Garen, 2005). At the 15 streamgages on the AGFC that had measured streamflow in at least 1 year during WYs 2016–18, the CV for streamflow ranged from 0.2 at Lytle in WY 2016 and Upper Clover in WY 2017 to 7.7 at Red Salt in WY 2018. The CV for streamflow exceeded 3 at Red Salt in all 3 WYs, at Merriams Little Fountain in WY 2016, and at B Ditch and Little Fountain in WY 2018 (tables 6–8).

Table 5. Frequency of total daily precipitation amounts of less than or equal to 0.1 inch and greater than 0.1 inch for each site at the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site, Colorado, for water years (WYs) 2016–18.

[>, greater than; ≤, less than or equal to]

Site short name (from tables 1 and 2)	Total daily precipitation amount (inches)	WY 2016		WY 2017		WY 2018	
		Number of days during the WY	Percentage of days	Number of days during the WY	Percentage of days	Number of days during the WY	Percentage of days
U.S. Army Garrison Fort Carson							
Young Hollow	>0.1	39	11	39	11	32	9
	≤0.1	327	89	323	89	330	91
Sullivan Park	>0.1	30	8	44	12	19	5
	≤0.1	336	92	321	88	346	95
Rod and Gun	>0.1	43	12	57	16	35	10
	≤0.1	323	88	308	84	330	90
Piñon Canyon Maneuver Site							
Van Bremer[1]	>0.1	26	12	35	16	17	8
	≤0.1	188	88	179	84	197	92
Taylor[1]	>0.1	19	9	33	15	16	7
	≤0.1	195	91	181	85	198	93
Lockwood[1]	>0.1	18	8	34	16	13	6
	≤0.1	196	92	180	84	201	94
Red Rock[1]	>0.1	23	11	37	17	15	7
	≤0.1	191	89	177	83	199	93
Bent[1]	>0.1	21	10	39	18	19	9
	≤0.1	193	90	175	82	195	91
Brown Sheep	>0.1	26	7	[2]29	16	34	9
	≤0.1	340	93	158	84	331	91
CIG	>0.1	37	10	53	15	27	8
	≤0.1	329	90	312	85	329	92
Bear Springs	>0.1	30	8	39	11	23	6
	≤0.1	336	92	326	89	342	94
Upper Red Rock	>0.1	34	9	39	11	22	6
	≤0.1	332	91	325	89	343	94
Upper Bent	>0.1	39	11	[2]28	15	21	6
	≤0.1	327	89	160	85	344	94

[1]Data were collected at this site from April to October.

[2]Data were not collected from mid-November to mid-May.

Table 6. Descriptive statistics for daily mean streamflow, in cubic feet per second, from U.S. Geological Survey streamgages on or near the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site, Colorado, for water year 2016.

[—, undefined, <, less than]

Site short name (from tables 1 and 2)	Minimum	25th percentile	Median	75th percentile	Maximum	Mean	Standard deviation	Coefficient of variation	Number of days with data	Percent of days with flow greater than or equal to the mean	Percent of days with flow less than the mean	Percent of days with zero flow
U.S. Army Garrison Fort Carson												
Red Salt[1]	0.0	0.0	0.0	0.0	6.28	0.17	0.57	4.9	214	10	2	88
Turkey Fountain[2,3]	0.0	0.11	0.41	1.09	3.72	0.71	0.89	1.3	183	35	49	16
Turkey Teller[1]	0.57	0.93	1.48	3.30	13.8	2.62	2.71	1.0	182	29	71	0
Teller Spillway[1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	183	0	0	100
Little Fountain[1]	0.62	1.56	1.92	3.84	18.3	3.21	2.96	0.9	214	28	72	0
Rock	0.23	0.55	0.78	1.29	25.9	1.37	1.99	1.5	366	24	76	0
Turkey West Seep	0.0	0.0	0.01	0.01	0.030	0.01	0.0	0.9	366	54	0	46
Turkey East Seep	0.0	0.03	0.04	0.08	0.300	0.07	0.06	0.9	366	36	62	2
Lytle	0.64	0.87	1.01	1.21	1.43	1.03	0.21	0.2	366	46	54	0
Strobel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	366	0	0	100
Merriams Little Fountain[3]	0.0	0.0	0.0	0.0	0.020	<0.01	0.01	3.4	366	9	0	91
Merriams Rock	0.06	0.51	0.99	1.56	3.59	1.19	0.85	0.7	366	39	61	0
Ripley	0.0	0.01	0.04	0.29	2.32	0.39	0.70	1.8	366	19	60	21
Womack	0.0	0.0	0.04	0.28	1.21	0.16	0.25	1.6	366	34	29	37
Gale[4]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	366	0	0	100
Piñon Canyon Maneuver Site												
Van Bremer[1]	0.04	0.08	0.13	0.20	16.3	0.25	1.12	4.5	214	14	86	0
Purgatoire Thatcher	0.69	17.9	22.2	29.5	433	29.2	33.4	1.1	366	26	74	0
Taylor[1]	0.0	0.0	0.0	0.0	11.7	0.07	0.81	11.5	214	4	1	95
Lockwood[1]	0.0	0.0	0.0	0.0	29.3	0.23	2.35	10.4	214	1	0	99
Red Rock[1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	214	0	0	100
Bent[1]	0.0	0.0	0.0	0.0	3.75	0.02	0.26	14.6	214	1	0	99
Purgatoire Rock Crossing[1]	1.84	14.5	21.0	32.0	288	31.3	35.0	1.1	214	26	74	0

[1]This site operated seasonally from April 1 through October 31.

[2]This site operated seasonally from April 1 through September 31.

[3]Operation at this site was discontinued on September 30, 2017.

[4]Operation at this site was discontinued on September 30, 2016.

Table 7. Descriptive statistics for daily mean streamflow, in cubic feet per second, from U.S. Geological Survey streamgages on or near the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site, Colorado, for water year 2017.

[—, undefined; <, less than]

Site short name (from tables 1 and 2)	Minimum	25th percentile	Median	75th percentile	Maximum	Mean	Standard deviation	Coefficient of variation	Number of days with data	Percent of days with flow greater than or equal to the mean	Percent of days with flow less than the mean	Percent of days with zero flow
U.S. Army Garrison Fort Carson												
Red Salt[1]	0.0	0.0	0.0	0.0	4.43	0.14	0.61	4.2	214	8	3	89
Turkey Fountain[2,3]	0.0	0.13	0.67	1.37	6.85	1.24	1.53	1.2	183	29	62	9
Turkey Teller[1]	0.0	0.30	0.85	1.15	17.5	1.04	1.67	1.6	183	33	63	4
Teller Spillway[1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	214	0	0	100
B Ditch[4]	0.02	0.22	0.27	6.17	73.9	12.4	23.3	1.9	17	24	76	0
Upper Clover[4]	1.63	1.66	1.68	1.87	2.91	1.86	0.38	0.2	19	26	74	0
Lower Clover[4]	3.72	3.83	3.99	11.9	38.0	9.13	9.53	1.0	18	28	72	0
Little Fountain[1]	0.33	0.85	1.14	4.43	11.9	2.72	2.96	1.1	214	30	70	0
Rock	0.15	0.27	0.46	1.97	17.0	1.42	1.93	1.4	365	29	71	0
Turkey West Seep	0.0	0.00	0.0	0.01	0.02	<0.01	0.0	1.5	365	31	0	69
Turkey East Seep	0.0	0.03	0.04	0.05	0.13	0.04	0.02	0.6	365	54	43	3
Lytle	0.55	0.64	0.84	1.16	1.31	0.89	0.26	0.3	365	46	54	0
Strobel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	365	0	0	100
Merriams Little Fountain[3]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	365	0	0	100
Merriams Rock	0.15	0.36	0.48	0.61	3.01	0.76	0.76	1.0	365	18	82	0
Ripley	0.0	0.15	0.19	0.25	0.36	0.19	0.09	0.5	365	58	35	7
Womack	0.0	0.21	0.55	0.73	1.22	0.49	0.33	0.7	365	52	44	4
Piñon Canyon Maneuver Site												
th	0.07	0.13	0.23	0.35	73.0	0.97	5.62	5.8	214	9	91	0
Purgatoire Thatcher	4.60	18.2	22.9	77.3	3,060	115	316	2.7	365	20	80	0
Taylor[1]	0.0	0.0	0.0	0.0	1.80	0.04	.17	4.6	214	10	1	89
Lockwood[1]	0.0	0.0	0.0	0.0	6.28	0.05	00.47	10.5	214	1	0	99
Red Rock[1]	0.0	0.0	0.0	0.0	31.4	0.23	2.25	10.0	214	2	0	98
Bent[1]	0.0	0.0	0.0	0.0	12.2	0.06	0.84	13.8	214	1	0	99
Purgatoire Rock Crossing[1]	3.44	19.6	51.3	196	2,850	190	395	2.1	214	26	74	0

[1]This site operated seasonally from April 1 through October 31.

[2]This site operated seasonally from April 1 through September 31.

[3]Operation at this site was discontinued on September 30, 2017.

[4]Operation at this site began in September 2017.

Table 8. Descriptive statistics for daily mean streamflow, in cubic feet per second, from U.S. Geological Survey streamgages on or near the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site, Colorado, for water year 2018.

[—, undefined; <, less than]

Site short name (from tables 1 and 2)	Minimum	25th percentile	Median	75th percentile	Maximum	Mean	Standard deviation	Coefficient of variation	Number of days with data	Percent of days with flow greater than or equal to the mean	Percent of days with flow less than the mean	Percent of days with zero flow
U.S. Army Garrison Fort Carson												
Red Salt[1]	0.0	0.0	0.0	0.0	3.30	0.04	0.29	7.7	214	3	1	96
Turkey Teller[1]	0.0	0.0	0.0	0.24	0.55	0.10	0.14	1.4	183	35	9	56
Teller Spillway[1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	183	0	0	100
B Ditch[2]	0.02	0.14	0.23	0.33	30.4	0.49	2.14	4.4	365	9	91	0
Upper Clover[2]	0.92	1.39	1.52	1.62	17.2	1.63	1.14	0.7	365	25	75	0
Lower Clover[2]	0.62	1.93	3.46	4.01	26.9	3.30	2.26	0.7	365	53	47	0
Little Fountain[1]	0.0	0.01	0.27	0.54	78.8	0.91	5.43	6.0	214	20	56	24
Rock	0.0	0.33	0.56	0.94	25.9	1.07	1.69	1.6	365	4	92	4
Turkey West Seep	0.0	0.00	0.0	0.01	0.01	<0.01	0.0	1.5	365	32	0.0	68
Turkey East Seep	0.01	0.03	0.04	0.05	0.19	0.05	0.02	0.5	365	33	67	0
Lytle	0.04	0.38	0.49	0.58	1.66	0.58	0.41	0.7	365	25	75	0
Strobel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	365	0	0	100
Merriams Rock	0.0	0.02	0.43	0.69	0.97	0.41	0.31	0.8	365	53	24	23
Ripley	0.0	0.0	0.05	0.13	0.31	0.07	0.08	1.1	365	33	31	36
Womack	0.02	0.49	0.55	0.61	1.03	0.53	0.19	0.4	365	59	41	0
Piñon Canyon Maneuver Site												
Van Bremer[1]	0.09	0.17	0.31	0.51	98.9	1.76	9.72	5.5	214	6	94	0
Purgatoire Thatcher	0.0	9.84	27.9	44.0	1,030	41.2	79.0	1.9	365	30	68	2
Taylor[1]	0.0	0.0	0.0	0.0	5.13	0.05	0.41	8.1	214	3	1	96
Lockwood[1]	0.0	0.0	0.0	0.0	168	0.79	11.5	14.5	214	1	0	99
Red Rock[1]	0.0	0.0	0.0	0.0	177	0.97	12.2	12.5	214	2	0	98
Bent[1]	0.0	0.0	0.0	0.0	24.7	0.17	1.89	10.9	214	1	0	99
Purgatoire Rock Crossing[1]	0.53	3.42	12.3	35.5	1,120	50.9	121	2.4	214	17	83	0

[1]This site operated seasonally from April 1 through October 31.

[2]Operation at this site began in September 2017.

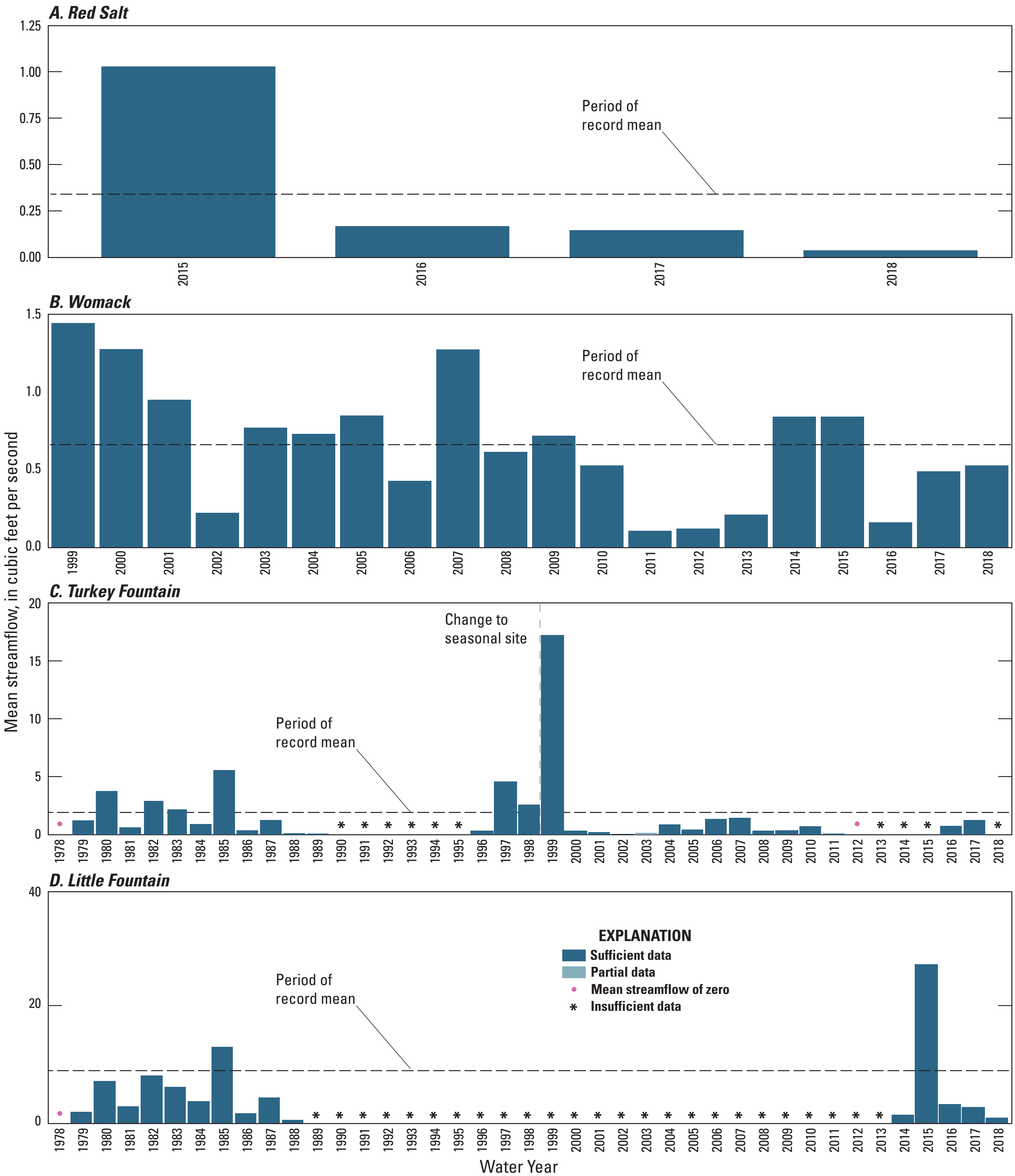


Figure 5. Mean seasonal (streamgage operated April 1 through October 31 of each year) or mean annual (streamgage operated year round) streamflow by water year (October 1 through September 30) at streamgages in or near the U.S. Army Garrison Fort Carson, Colorado: *A*, Red Salt; *B*, Womack; *C*, Turkey Fountain; *D*, Little Fountain; *E*, Turkey Teller; *F*, Rock; *G*, Merriams Rock; *H*, Merriams Little Fountain; *I*, Lytle; *J*, Ripley; *K*, Turkey West Seep; and *L*, Turkey East Seep. (Site short names from table 1. Year-round sites were classified as “insufficient” if less than 180 days of data were collected, “partial” if between 180 and 300 days of data were collected, and “sufficient” if more than 300 days of data were collected for a water year.)

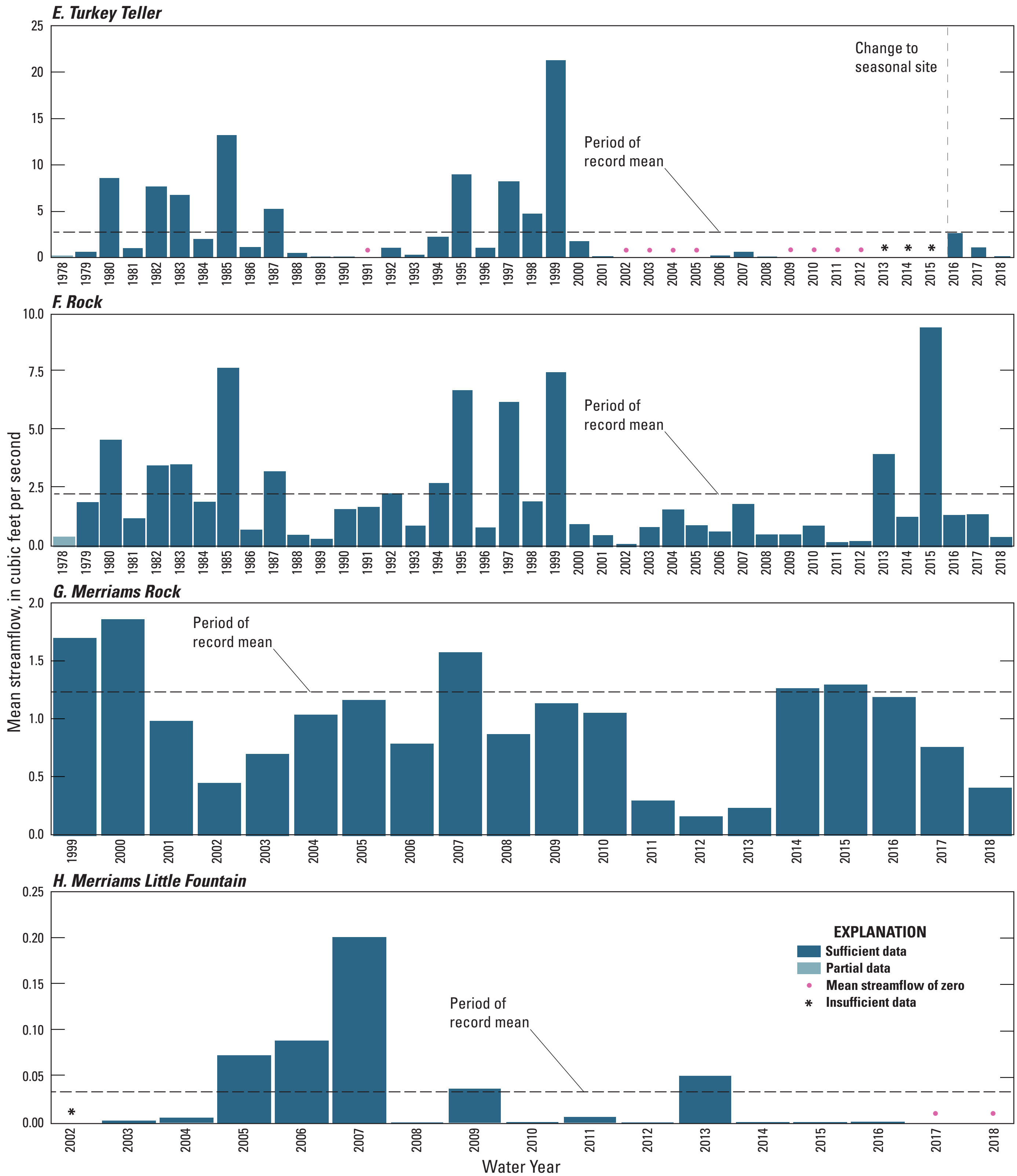


Figure 5.—Continued

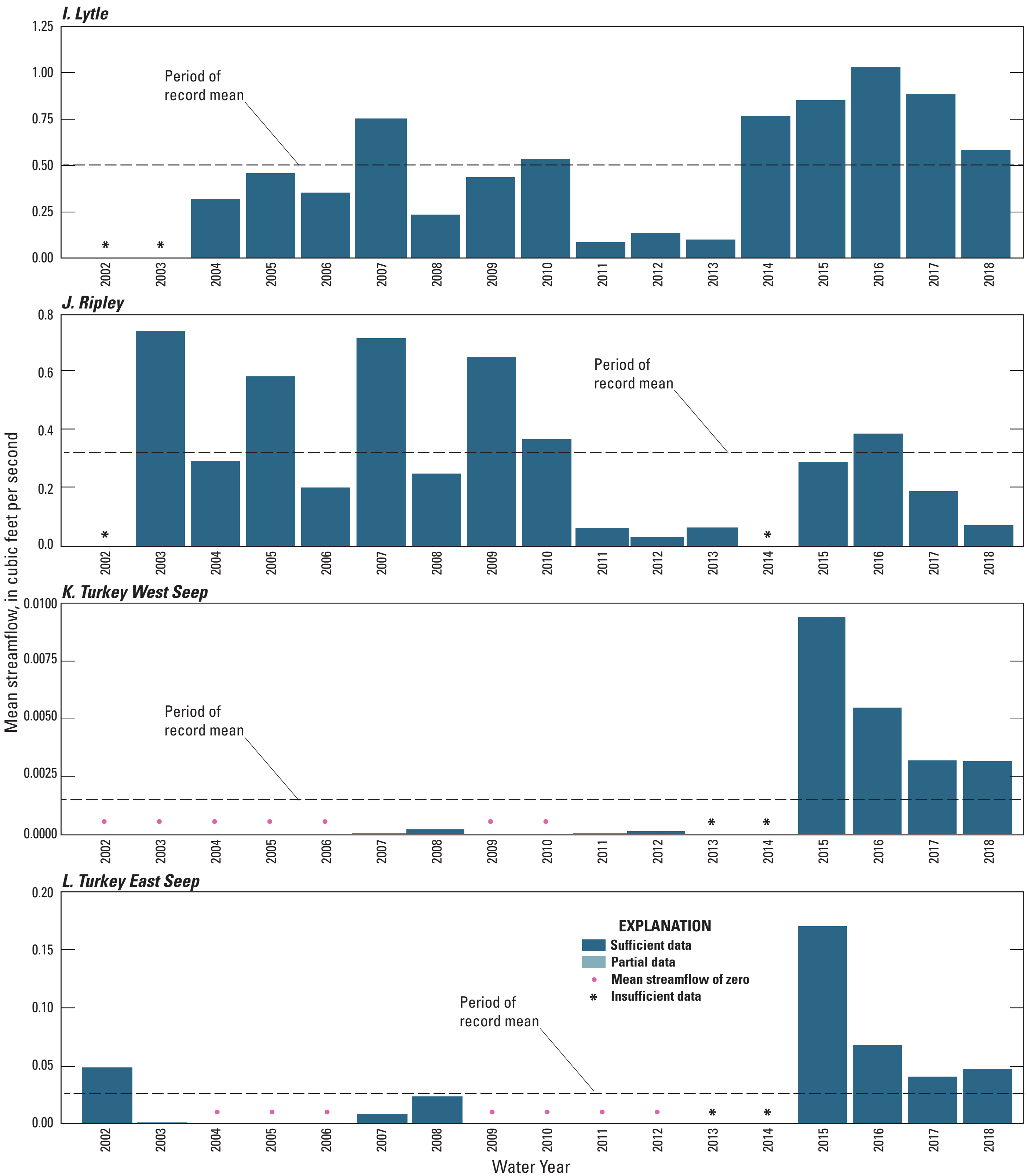


Figure 5.—Continued

Mean annual or seasonal streamflow in WYs 2016–18 was compared to the period of record mean for sites on the AGFC. At Red Salt, Womack, Turkey Fountain, Little Fountain, Turkey Creek above Teller Reservoir near Stone City, CO (Turkey Teller), Rock, Merriams Rock, and Merriams Little Fountain, streamflow was less than the long-term mean for all 3 years due in part to the very large mean streamflow in WY 2015 at some of these sites (fig. 5). At Lytle, Turkey West Seep, and Turkey East Seep, streamflow was greater than the long-term mean for all 3 years, and at Ripley, streamflow in WY 2016 was larger than the long-term mean, but streamflows in WYs 2017 and 2018 were less than the long-term mean (fig. 5).

At the PCMS during WYs 2016–18, four sites (Taylor, Lockwood, Red Rock, and Bent) had no recorded streamflow on more than 88 percent of the days with data. Whereas, at the other three sites (Van Bremer, Purgatoire River near Thatcher, CO [Purgatoire Thatcher], and Purgatoire River at Rock Crossing near Timpas, CO [Purgatoire Rock Crossing]), streamflow was recorded on between 98 and 100 percent of the days those sites were operated (tables 6–8). The median of daily mean streamflow for WYs 2016–18 at the seven PCMS streamgages ranged from zero (Taylor, Lockwood, Red Rock, and Bent in all three WYs) to 51.3 ft^3/s at Purgatoire Rock Crossing in WY 2017 (tables 6–8). Maximum daily streamflow at the seven PCMS sites in WYs 2016–18 (excluding sites with no recorded flow during the WY) ranged from 1.80 ft^3/s at Taylor in WY 2017 to 3,060 ft^3/s at Purgatoire Thatcher in WY 2017 (tables 6–8). At four of the seven sites on the PCMS with streamflow data, there is a general downward trend in mean annual (or seasonal) streamflow, and at the other three sites (Taylor, Red Rock, and Bent), there is a general upward trend, however none of the trends are statistically significant (fig. 6). Unlike for precipitation, the mean annual or seasonal streamflow for WY 2017 was not in the top three highest values for any of the sites except Purgatoire Rock Crossing.

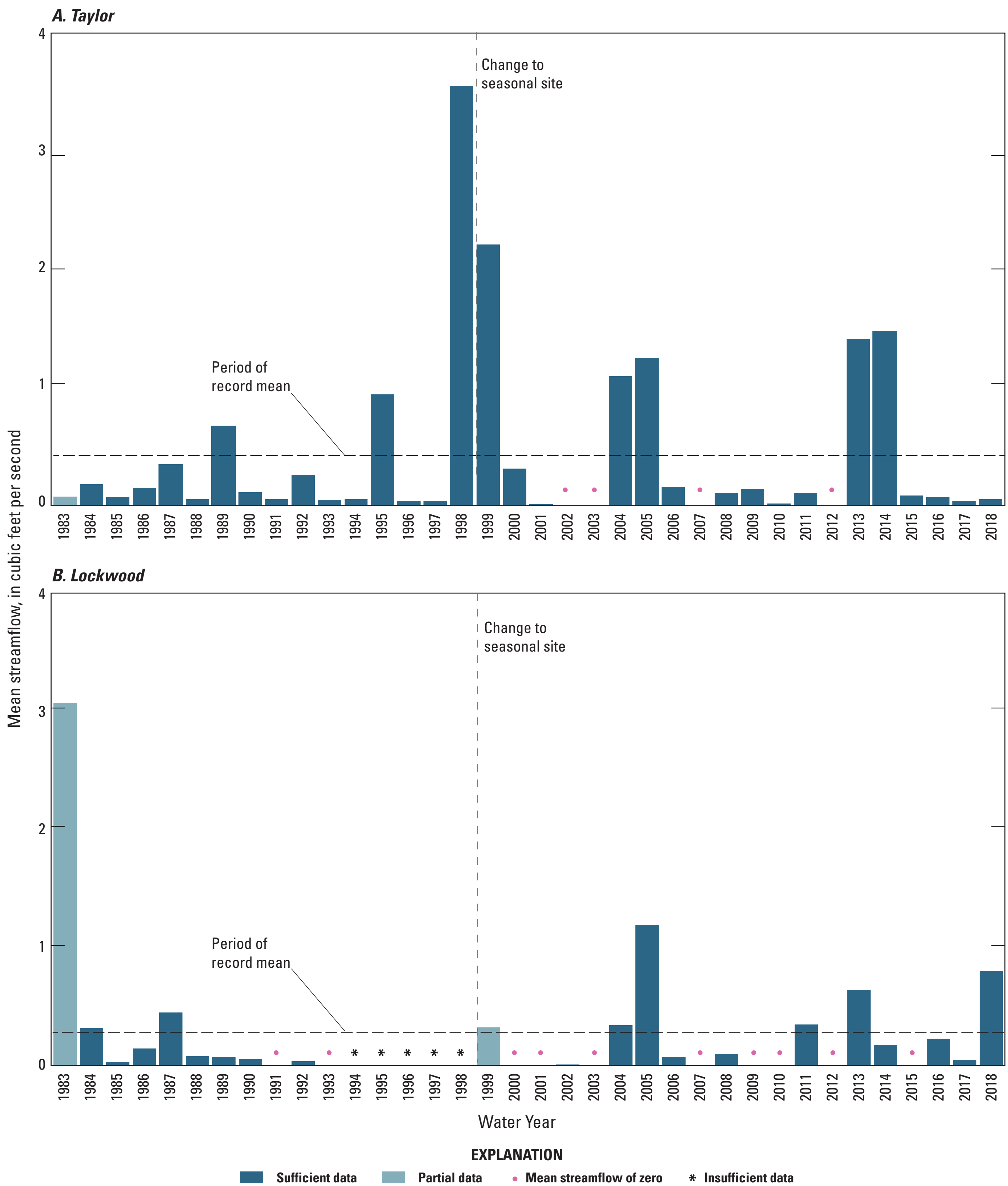
At the seven streamgages on the PCMS that had measured streamflow in at least 1 year during WYs 2016–18, the CV for streamflow ranged from 1.1 at Purgatoire Thatcher and Purgatoire Rock Crossing in WY 2016 to 14.6 at Bent in WY 2016. The CV for streamflow exceeded 3 at Van Bremer, Taylor, Lockwood, and Bent in all 3 WYs, and at Red Rock in WYs 2017 and 2018 (tables 6–8).

Five sites at the PCMS were monitored only for peak stage in at least one of WYs 2016–18 (table 2; fig. 2). In WY 2016, only one site, West Bear Springs Arroyo at boundary at PCMS, CO (West Bear), recorded a peak stage of 8.88 ft on May 31, representing an estimated streamflow of 861 ft^3/s. In WY 2017, Big Arroyo near Thatcher, CO (Big Arroyo) recorded a peak stage of 3.92 ft on June 7, representing an estimated streamflow of 203 ft^3/s; and West Bear recorded a peak stage of 7.85 ft on August 15, representing an estimated streamflow of 475 ft^3/s. In WY 2018, West Bear recorded a peak stage of 8.19 ft on August 7, representing an estimated streamflow of 583 ft^3/s. No flow was recorded at Big Arroyo in WY 2018 (USGS, 2020).

At the AGFC and PCMS study areas, one effect of military maneuvers may be an increase in streamflow due to increased runoff from denuded or compacted lands (von Guerard and others, 1993). A comparison between streamflow in Fountain Creek (Fountain Creek at Security, CO, USGS-07105800, short name Fountain Security [fig. 1]) and the streamflow from the Fountain Creek tributaries that drain the AGFC may indicate the potential effect these tributaries have on streamflow or other hydrologic or water-quality conditions in Fountain Creek. Likewise, a comparison between streamflow in the Purgatoire River between Purgatoire Thatcher and Purgatoire Rock Crossing and streamflow from the Purgatoire River tributaries that drain the PCMS may indicate the potential effects these tributaries have on streamflow or other hydrologic or water-quality conditions in the Purgatoire River.

Streamflow from the monitored sites on the AGFC that drain to Fountain Creek (fig. 1) represent only a small fraction of the streamflow in Fountain Creek. The Fountain Creek tributaries that drain the AGFC had a combined mean annual streamflow of approximately 1.65, 14.2, and 3.62 percent of the mean annual streamflow at Fountain Security, which was 194.7, 170.2, and 131.1 ft^3/s during the WYs 2016, 2017, and 2018, respectively (USGS, 2020; Kisfalusi and Battaglin, 2022). Hence, any changes in streamflow in the Fountain Creek tributaries that result from military maneuvers in those tributary basins are not likely to be detected in Fountain Creek. Likewise, streamflow from the monitored sites on the PCMS that drain to the Purgatoire River represent only a small fraction of the streamflow in the Purgatoire River. The Purgatoire River tributaries that drain the PCMS (fig. 2) had a combined mean seasonal streamflow of approximately 1.8, 0.7, and 7.4 percent of the mean seasonal streamflow at the Purgatoire Rock Crossing site in WYs 2016, 2017, and 2018, respectively (USGS, 2020; Kisfalusi and Battaglin, 2022). The tributary contributions of streamflow relative to streamflow in

Figure 6.—Following pages Streamflow at streamgages in or near the Piñon Canyon Maneuver Site, Colorado. Mean seasonal (streamgage operated April 1 through October 31 of each year) or mean annual (streamgage operated year round) streamflow by water year (October 1 through September 30) at *A*, Taylor; *B*, Lockwood; *C*, Red Rock; and *D*, Bent. Total seasonal (streamgage operated April 1 through October 31 of each year) or total annual (streamgage operated year round) streamflow by water year (October 1 through September 30) at *E*, Purgatoire Thatcher; *F*, Purgatoire Rock Crossing; and *G*, Van Bremer. (Site short names from table 2. Seasonal sites were classified as “insufficient” if less than 90 days of data were collected, “partial” if between 90 and 180 days of data were collected, and “sufficient” if more than 180 days of data were collected for a water year. Year-round sites were classified as “insufficient” if less than 180 days of data were collected, “partial” if between 180 and 300 days of data were collected, and “sufficient” if more than 300 days of data were collected for a water year.)


A. Taylor
Change to seasonal site
Period of record mean
B. Lockwood
Change to seasonal site
Period of record mean
Mean streamflow, in cubic feet per second
Water Year
EXPLANATION
Sufficient data
Partial data
Mean streamflow of zero
Insufficient data

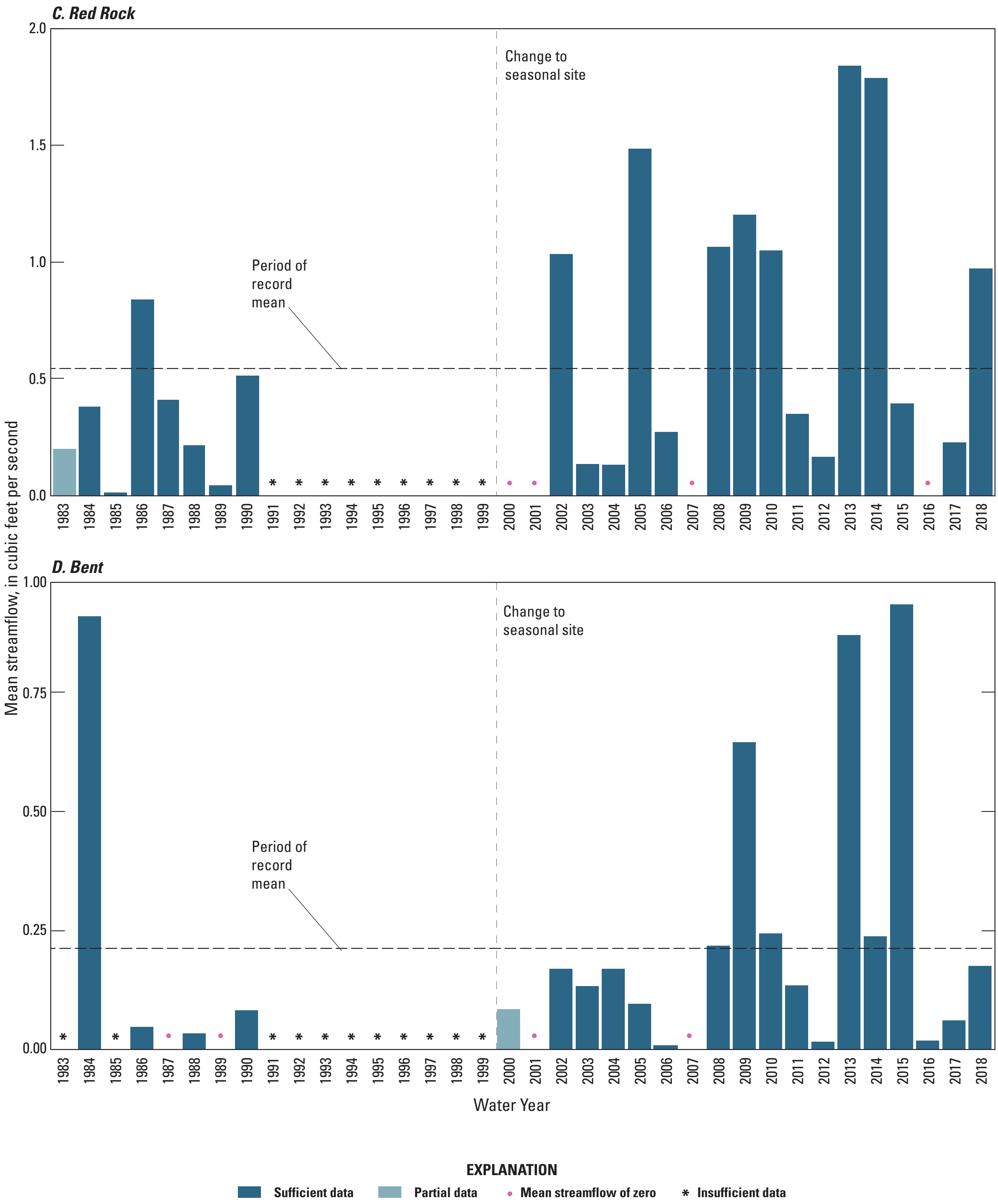


Figure 6.—Continued

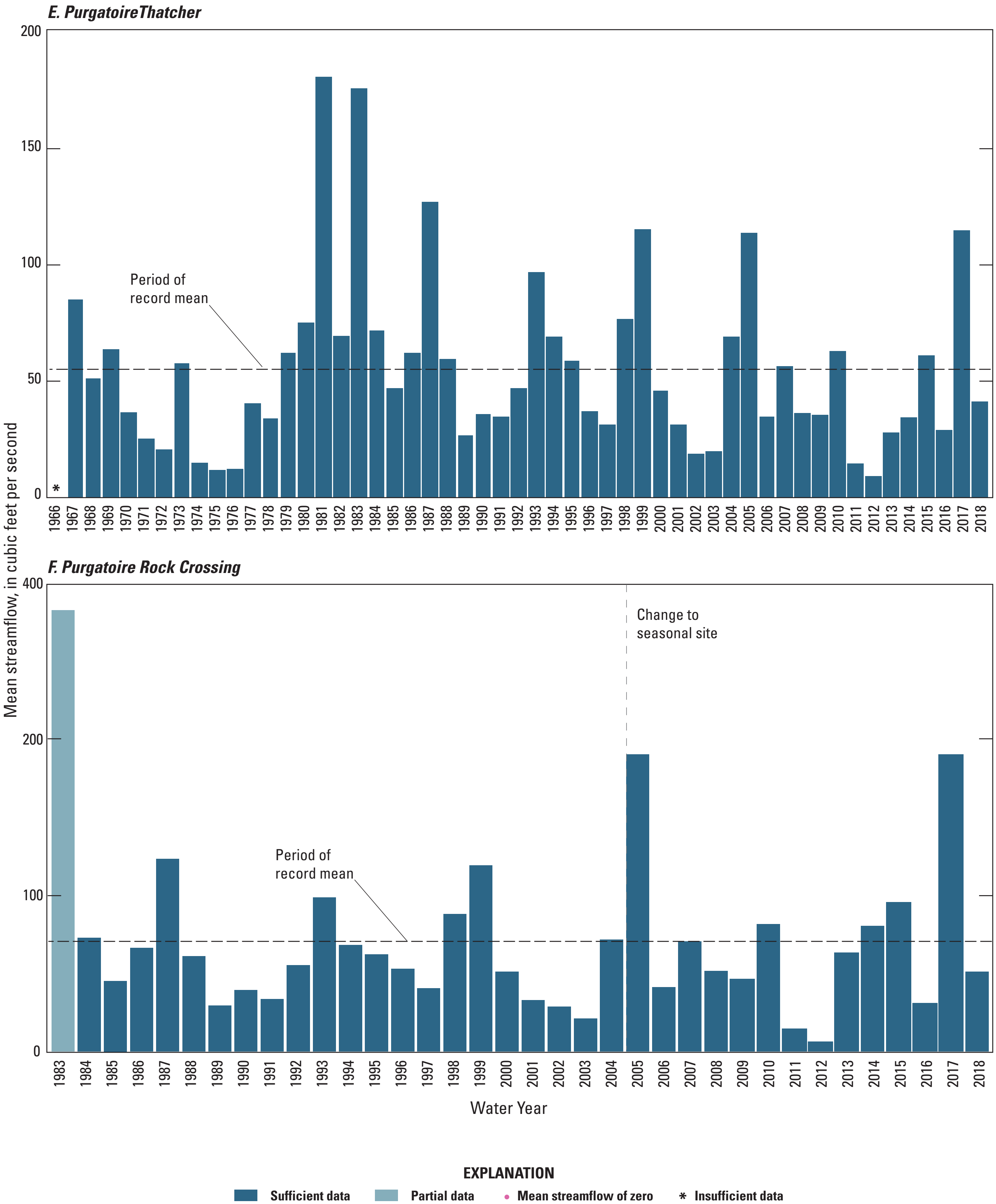


Figure 6.—Continued

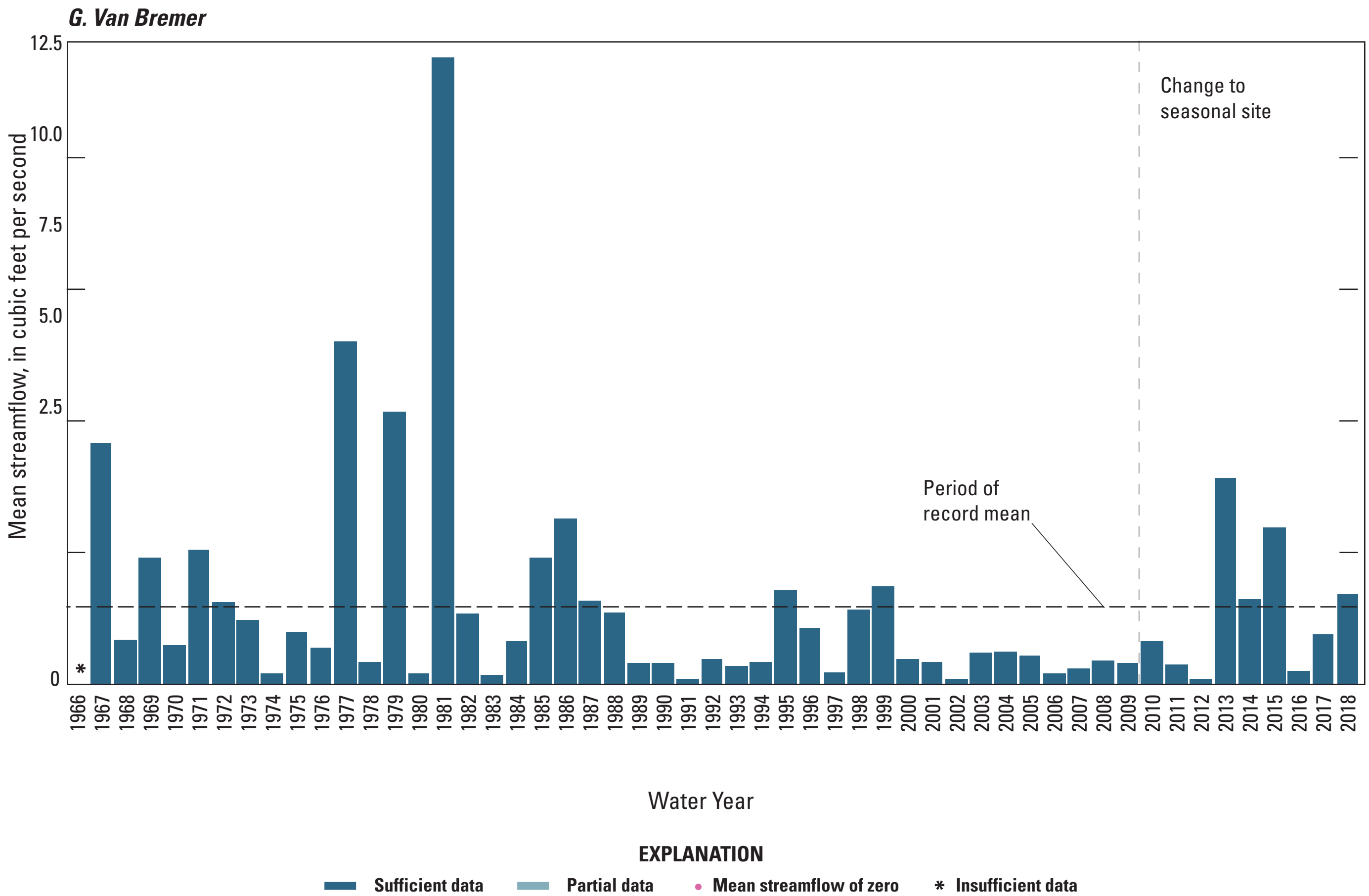


Figure 6.—Continued

the Purgatoire River are similar to those observed historically (Brown, 2014) and confirms the observation by von Guerard and others (1993) that, because streamflow from the PCMS is only a small fraction of streamflow in the Purgatoire River, changes in streamflow in the Purgatoire River that result from military maneuvers on the PCMS are not likely to be detected.

Suspended Sediment

Suspended-sediment concentrations, loads, and yields are summarized for two sites on the AGFC and five sites on the PCMS (tables 9–11).

Suspended Sediment at the U.S. Army Garrison Fort Carson

In WYs 2016–18, mean seasonal suspended-sediment concentrations at Red Salt on the AGFC ranged from 3.10 to 12.4 mg/L, and maximum suspended-sediment concentrations ranged from 300 to 418 mg/L. The mean seasonal suspended-sediment load ranged from 0.04 to 0.29 tons per day (t/d), and the resulting suspended-sediment yields ranged from 0.28 to 1.82 tons per season per square mile (t/s/mi^2; tables 9–11).

In WYs 2016–18, mean seasonal suspended-sediment concentrations at Little Fountain on the AGFC were higher than at Red Salt, and ranged from 128 to 155 mg/L, and maximum suspended-sediment concentrations ranged from 2,070 to 6,000 mg/L. The mean seasonal suspended-sediment load ranged from 4.55 to 27.1 t/d, and the resulting suspended-sediment yields ranged from 36.2 to 216 t/s/mi^2 (tables 9–11), which were much larger than at Red Salt.

Suspended Sediment at the Piñon Canyon Maneuver Site

In WYs 2016–18, mean seasonal suspended-sediment concentration at Van Bremer on the PCMS ranged from 21.0 to 41.8 mg/L, which were the highest values from the five sites in each WY. Maximum suspended-sediment concentrations ranged from 200 to 1,000 mg/L. The mean seasonal suspended-sediment load ranged from 0.24 to 9.86 t/d, and the resulting suspended-sediment yields ranged from 0.32 to 12.9 t/s/mi^2 (tables 9–11).

In WYs 2016–18, mean seasonal suspended-sediment concentration at Taylor on the PCMS ranged from 1.34 to 4.6 mg/L, and maximum suspended-sediment concentrations ranged

Table 9. Descriptive statistics for daily mean suspended-sediment concentration, daily mean suspended-sediment load, and seasonal suspended-sediment load and yield at U.S. Geological Survey suspended-sediment sites at the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site, Colorado, for water year 2016.

[Zeros (0.0) for mean suspended-sediment concentration, seasonal load, and seasonal yield are a result of zero measured streamflow at that site for the water year. mg/L, milligrams per liter; t/d, tons per day; t/s, tons per season; t/s/mi², tons per season per square mile]

Site short name (from tables 1 and 2)	Number of days with data	Suspended-sediment concentration (mg/L)			Suspended-sediment load				Seasonal suspended-sediment yield (t/s/mi²)
		Median	Maximum	Mean	Median (t/d)	Maximum (t/d)	Mean (t/d)	Seasonal total load (t/s)	
U.S. Army Garrison Fort Carson									
Little Fountain	214	43.0	2,070	128	0.18	377	4.55	974	36.2
Red Salt	214	0.0	418	12.4	0.0	7.80	0.19	40.2	1.18
Piñon Canyon Maneuver Site									
Van Bremer	214	13.0	202	21.0	0.0	44.0	0.24	52.1	0.32
Taylor	214	0.0	509	4.6	0.0	26.0	0.14	29.7	0.61
Lockwood	214	0.0	1,780	12.4	0.0	292	2.39	512	10.5
Red Rock	213	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bent	214	0.0	725	3.4	0.0	20.0	0.09	20.0	0.36

Table 10. Descriptive statistics for daily mean suspended-sediment concentration, daily mean suspended-sediment load, and seasonal suspended-sediment load and yield at U.S. Geological Survey suspended-sediment sites at the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site, Colorado, for water year 2017.

[Zeros (0.0) for mean suspended-sediment concentration, seasonal load, and seasonal yield are a result of zero measured streamflow at that site for the water year. mg/L, milligrams per liter; t/d, tons per day; t/s, tons per season; t/s/mi², tons per season per square mile]

Site short name (from tables 1 and 2)	Number of days with data	Suspended-sediment concentration (mg/L)			Suspended-sediment load				Seasonal suspended-sediment yield (t/s/mi²)
		Median	Maximum	Mean	Median (t/d)	Maximum (t/d)	Mean (t/d)	Seasonal total (t/s)	
U.S. Army Garrison Fort Carson									
Little Fountain	214	20	3,000	155	0.07	280	6.63	1,419	52.7
Red Salt	214	0.0	300	10.4	0.0	17.0	0.29	62.0	1.82
Piñon Canyon Maneuver Site									
Van Bremer	214	20	200	28.2	0.01	210	1.28	273	1.67
Taylor	214	0.0	200	3.41	0.0	1.60	0.01	2.7	0.06
Lockwood	214	0.0	300	2.06	0.0	15.0	0.11	22.9	0.47
Red Rock	214	0.0	70	0.70	0.0	44.0	0.26	55.7	1.12
Bent	214	0.0	200	1.12	0.0	54.0	0.25	54.1	0.96

Table 11. Descriptive statistics for daily mean suspended-sediment concentration, daily mean suspended-sediment load, and seasonal suspended-sediment load and yield at U.S. Geological Survey suspended-sediment sites at the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site, Colorado, for water year 2018.

[Zeros (0.0) for mean suspended-sediment concentration, seasonal load, and seasonal yield are a result of zero measured streamflow at that site for the water year. mg/L, milligrams per liter; t/d, tons per day; t/s, tons per season; t/s/mi², tons per season per square mile]

Site short name (from tables 1 and 2)	Number of days with data	Suspended-sediment concentration (mg/L)			Suspended-sediment load				Seasonal suspended-sediment yield (t/s/mi²)
		Median	Maximum	Mean	Median (t/d)	Maximum (t/d)	Mean (t/d)	Seasonal total (t/s)	
U.S. Army Garrison Fort Carson									
Little Fountain	214	15	6,000	140	0.01	5000	27.1	5,807	216
Red Salt	214	0.00	300	3.10	0.00	5.00	0.04	9.4	0.28
Piñon Canyon Maneuver Site									
Van Bremer	214	30	1,000	41.8	0.02	1,300	9.86	2,109	12.9
Taylor	214	0.0	100	1.34	0.00	2.00	0.01	2.7	0.06
Lockwood	214	0.00	2,000	10.3	0.00	2,800	13.1	2,802	57.4
Red Rock	214	0.00	1,000	8.64	0.00	1,300	6.69	1,432	28.7
Bent	214	0.00	1,000	6.54	0.00	300	6.54	1,400	24.9

from 100 to 509 mg/L. The mean seasonal suspended-sediment load ranged from 0.01 to 0.14 t/d, and the resulting suspended-sediment yields ranged from 0.06 to 0.61 t/s/mi² (tables 9–11).

In WYs 2016–18, mean seasonal suspended-sediment concentration at Lockwood on the PCMS ranged from 2.06 to 12.4 mg/L, and maximum suspended-sediment concentrations ranged from 300 to 2,000 mg/L, which were the highest values from the five sites in each WY. The mean seasonal suspended-sediment load ranged from 0.11 to 13.1 t/d, and the resulting suspended-sediment yields ranged from 0.47 to 57.4 t/s/mi² (tables 9–11), which were the largest values from the five sites in WYs 2016 and 2018.

In WYs 2016–18, mean seasonal suspended-sediment concentration at Red Rock on the PCMS ranged from zero (no streamflow during the WY) to 8.64 mg/L, and maximum suspended-sediment concentrations ranged from zero to 1,000 mg/L. The mean seasonal suspended-sediment load ranged from zero to 6.69 t/d, and the resulting suspended-sediment yields ranged from zero to 28.7 t/s/mi² (tables 9–11).

In WYs 2016–18, mean annual suspended-sediment concentration at Bent on the PCMS ranged from 1.12 to 6.54 mg/L, and maximum suspended-sediment concentrations ranged from 200 to 1,000 mg/L. The mean seasonal suspended-sediment load ranged from 0.09 to 6.54 t/d, and the resulting suspended-sediment yields ranged from 0.36 to 24.9 t/s/mi² (tables 9–11).

Suspended Sediment Results

Suspended-sediment yields at the two sites on the AGFC and the five sites on the PCMS in WYs 2016–18 were generally less than the long-term means at those sites. Suspended-sediment yields at Red Salt in WYs 2016–18 were all less than the long-term mean of 45.5 t/s/mi²; however, there is only 1 WY of additional data (WY 2015; USGS, 2020). Suspended-sediment yields at Little Fountain in WYs 2016–18 were all less than the long-term mean of 4,620 t/s/mi² during WYs 2013–18. Suspended-sediment yields at Van Bremer in WYs 2016–18 were all less than the long-term mean of 102 t/s/mi² during WYs 1999–2018. Suspended-sediment yields at Taylor in WYs 2016–18 were all less than the long-term mean of 639 t/s/mi² during WYs 1987–2018. Suspended-sediment yields at Lockwood in WYs 2016–18 were all less than the long-term mean of 230 t/s/mi² during WYs 1999–2018. Suspended-sediment yields at Red Rock in WYs 2016–18 were all less than the long-term mean of 1,100 t/s/mi² during WYs 2002–18. Suspended-sediment yields at Bent in WYs 2016–18 were all less than the long-term mean of 379 t/s/mi² during WYs 2000–18.

At the AGFC and PCMS study areas, one effect of military maneuvers may be an increase in suspended-sediment concentrations and loads due to increased sediment loss from denuded, compacted, or otherwise disturbed lands (von Guerard and others, 1993). A comparison between the suspended-sediment concentrations and loads for Fountain Security and the suspended-sediment concentrations and loads from the Fountain Creek tributaries that drain the AGFC and a comparison between the suspended-sediment concentration and load in the Purgatoire River between Purgatoire Thatcher and Purgatoire Rock Crossing and the inputs from the Purgatoire River tributaries that drain the PCMS indicate the potential effect of these tributaries on suspended-sediment concentration and load, and water-quality conditions in Fountain Creek and the Purgatoire River.

Only one Fountain Creek tributary (Little Fountain, operated seasonally) that drains the AGFC was monitored for suspended sediment in WYs 2016–18 (table 1; fig. 1). The mean daily suspended-sediment concentrations at this site were about 57, 58, and 52 percent, respectively, of the mean daily suspended-sediment concentration at Fountain Security (224, 266, and 267 mg/L during WYs 2016, 2017, and 2018, respectively). The mean daily suspended-sediment loads at Little Fountain were 1.3, 2.5, and 7.6 percent, respectively, of the mean daily suspended-sediment load at Fountain Security, which was 361, 435, and 356 t/d during WYs 2016, 2017, and 2018, respectively (tables 9–11; USGS, 2020). Hence, changes in suspended-sediment concentration and loads in Little Fountain Creek that result from military maneuvers in that tributary basin are not likely to be detected in Fountain Creek.

The same analysis of the relative magnitude of suspended-sediment concentrations and loads cannot be made for the PCMS due to a lack of current suspended-sediment data at either Purgatoire Thatcher or Purgatoire Rock Crossing or any other nearby sites on the Purgatoire River. Suspended-sediment concentrations were measured at Purgatoire Thatcher during WYs 1986–1992. During this time period, mean daily suspended-sediment concentrations ranged from 665 to 2,501 mg/L, with a mean of 1,719 mg/L, and mean daily suspended-sediment load ranged from 229 to 2,064 t/d with a mean of 1,137 t/d (USGS, 2020). Current suspended-sediment concentrations and loads from the tributary sites were compared to historical data from the Purgatoire Thatcher site.

In WYs 2016–18, at the five tributary sites to the Purgatoire River, the means of the mean daily suspended-sediment concentrations were about 0.48, 0.41, and 0.80 percent of the historical mean daily suspended-sediment concentration at Purgatoire Thatcher in WYs 2016, 2017, and 2018, respectively. The totals of mean daily suspended-sediment loads were about 0.25, 0.17, and 3.2 percent of the historical mean daily suspended-sediment load at Purgatoire Thatcher in WYs 2016, 2017, and 2018, respectively (tables 9–11; USGS, 2020). Hence, mean daily suspended-sediment concentrations and combined mean daily suspended-sediment loads from the five tributary sites in WYs 2016–18, were much less than the historical mean values at Purgatoire Thatcher.

Relation Between Precipitation and Streamflow

At some locations on the PCMS, precipitation sites are collocated with streamgages. At other locations on the AGFC and PCMS, precipitation sites fall within the drainage basin of streamgages (figs. 1 and 2). Daily total (sum) precipitation and daily mean streamflow for WYs 2016–18 (app. 2) were visually compared to examine how the streams responded to precipitation measured at the nearby precipitation sites. Correlation analysis (Spearman's ρ) was used to quantitatively evaluate the strength and form of the relations between daily total precipitation and daily mean streamflow for WYs 2016–18.

At both the AGFC and the PCMS, relations can be observed visually; the data show an increase in streamflow during (or shortly following) precipitation. Although most statistical tests indicated a significant positive relation between daily precipitation and streamflow ($\rho < 0.05$), the strength of the relations were generally low based on the maximum ρ values (table 12). For example, on the AGFC, the Rod and Gun precipitation site falls within the drainage basin for the Little Fountain streamgage, and the Sullivan Park precipitation site falls within the drainage basin for the Red Salt and Turkey Teller streamgages (fig. 1). For many of the larger precipitation occurrences at Rod and Gun, a corresponding rise in streamflow was observed at Little Fountain. However, precipitation (like in early WY 2018) had no corresponding increase in streamflow (app. 2). With a Spearman's $\rho = 0.186$, there was a weak positive correlation between daily total precipitation at Rod and Gun and daily mean streamflow at Little Fountain (table 12). There was less similarity between precipitation at Sullivan Park and streamflow at Red Salt (app. 2) because many precipitation occurrences had no corresponding increase in streamflow. However, because each WY had many more days with no streamflow than days with measured streamflow, there was a moderately strong positive correlation (Spearman's $\rho = 0.256$) between daily total precipitation and daily mean streamflow (table 12).

On the PCMS, the Brown Sheep precipitation site falls within the drainage basin for the Van Bremer streamgage, which also has a collocated precipitation site. Likewise, the Upper Bent precipitation site falls within the drainage basin for the Bent streamgage and its collocated precipitation site (fig. 2). For many of the larger precipitation occurrences at Van Bremer and Brown Sheep, a corresponding rise in streamflow was observed at the streamgage (app. 2). There was a moderately strong (statistically significant) positive correlation between daily total precipitation and daily mean streamflow at Van Bremer (Spearman's $\rho = 0.263$) and nearly equal correlations (Spearman's $\rho = 0.255$) between Brown Sheep and Van Bremer (table 12). In contrast, for almost all the larger precipitation occurrences at the Bent and Upper Bent precipitation sites, there was not a corresponding rise in streamflow at the Bent streamgage (app. 2). There were positive correlations (not statistically significant) between daily total precipitation and daily mean streamflow at Bent (Spearman's $\rho = 0.105$) and even weaker correlations (Spearman's $\rho = 0.026$) between Upper Bent precipitation and Bent streamflow (table 12). The Bent precipitation site is the closest site to the Purgatoire Rock Crossing streamgage (fig. 2). For some of the larger precipitation occurrences at the Bent precipitation site, there was a corresponding rise in streamflow at Purgatoire Rock Crossing (app. 2), and a weak positive correlation (Spearman's $\rho = 0.097$) between daily total precipitation at Bent and daily mean streamflow at Purgatoire Rock Crossing (table 12).

Hence at the PCMS, and to a lesser extent at the AGFC, many of the larger precipitation occurrences at either the collocated precipitation sites or at precipitation sites within an associated drainage basin, showed no corresponding spike in

Table 12. Results from Spearman's rank correlation coefficient (Spearman's ρ) correlation analysis for sites on the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site in Colorado, with paired daily mean streamflow and daily total precipitation data for water years 2016–18.

[<, less than; /2, divided by two]

Streamgage site short name (from tables 1 and 2)	Precipitation site short name (from tables 1 and 2)	Spearman's ρ	p-value
U.S. Army Garrison Fort Carson			
Little Fountain	Rod and Gun	0.186	<0.001
Rock	Rod and Gun	0.184	<0.001
Merriams Rock	Rod and Gun	0.025	0.418
Red Salt	Sullivan Park	0.256	<0.001
Turkey Teller	Sullivan Park	0.064	0.224
Piñon Canyon Maneuver Site			
Van Bremer	Van Bremer	0.263	<0.001
Van Bremer	Brown Sheep	0.255	<0.001
Van Bremer	(Van Bremer + Brown Sheep) /2	0.253	<0.001
Taylor	Taylor	0.217	<0.001
Taylor	CIG	0.271	<0.001
Taylor	(Taylor + CIG) / 2	0.258	<0.001
Lockwood	Lockwood	0.130	0.001
Lockwood	Bear Springs	0.134	<0.001
Lockwood	(Lockwood + Bear Springs) / 2	0.135	<0.001
Red Rock	Red Rock	0.186	<0.001
Red Rock	Upper Red Rock	0.114	0.004
Red Rock	(Red Rock + Upper Red Rock) / 2	0.153	<0.001
Bent	Bent	0.105	0.008
Bent	Upper Bent	0.026	0.531
Bent	(Bent + Upper Bent) / 2	0.022	0.584
Purgatoire Thatcher	Van Bremer	0.118	0.004
Purgatoire Thatcher	Brown Sheep	0.142	0.001
Purgatoire Thatcher	(Van Bremer + Brown Sheep) / 2	0.135	0.001
Purgatoire Rock Crossing	Bent	0.097	0.018
Purgatoire Rock Crossing	Upper Bent	0.104	0.011
Purgatoire Rock Crossing	(Bent + Upper Bent) / 2	0.092	0.025

streamflow. This might be because of a combination of factors including the quantity, distribution, and timing of precipitation; air temperature; time since last precipitation occurrences; seasonal soil-moisture deficits; or effective runoff detention in erosion ponds within the basins (Holmberg and others, 2016).

The Little Fountain and Van Bremer sites showed a more responsive rainfall-runoff pattern than the other sites (app. 2). More consistent base flow at these sites may have mitigated potential losses to channel alluvium in these streams compared to the other streams on the AGFC and PCMS. The ephemeral nature of many of these streams, variable precipitation distribution across the larger drainage area, the efficacy of runoff detention ponds, and the resulting inconsistent conversion of precipitation to streamflow likely contributed to the low Spearman's ρ values for these analyses (Holmberg and others, 2016).

Relation Between Streamflow and Suspended Sediment

Daily mean streamflow, suspended-sediment concentration, and suspended-sediment load hydrographs for WYs 2016–18 (app. 2) were visually compared to determine relations among the three parameters. Spearman's ρ was used to quantitatively evaluate the strength and form of the relations between daily mean streamflow and daily mean suspended-sediment concentration and load for WYs 2016–18.

On the AGFC, a rise in suspended-sediment concentration was observed during many of the larger streamflows at Little Fountain. However, suspended-sediment concentrations and loads appear to decline more rapidly than streamflow after a high streamflow at this site (app. 2). For example, on August 17, 2018, a large precipitation occurrence at Rod and Gun (2.15 in.) produced the largest streamflow (78.8 ft^3/s) and resulted in the largest suspended-sediment concentration (6,000 mg/L) and load (5,000 t/d) at Little Fountain during WYs 2016–18 (app. 2). A rise in suspended-sediment concentration also was observed during many of the larger streamflows at Red Salt, and suspended-sediment concentrations and loads appear to decline at about the same rate as streamflow after a streamflow occurence (app. 2). On July 30, 2017, heavy precipitation at Sullivan Park (1.98 in.) produced high streamflow (4.43 ft^3/s) that resulted in a large (for this site) suspended-sediment concentration (200 mg/L) and the largest suspended-sediment load (17 t/d) during WYs 2016–18 (app. 2; Kisfalusi and Battaglin, 2022). Strong statistically significant positive relations between streamflow and suspended-sediment concentration and load were present at both paired sites (table 13).

Similarly, on the PCMS, a rise in suspended-sediment concentration was observed during many of the higher streamflows at Van Bremer. However, suspended-sediment concentrations and loads appear to decline more rapidly than streamflow after high streamflow at this site (app. 2). On July 23, 2018, moderately heavy precipitation at Brown Sheep (1.34 in.) produced relatively high streamflow at Van Bremer (84.7 ft^3/s) and resulted in an elevated suspended-sediment concentration (600 mg/L), and the largest suspended-sediment load (1,300 t/d) for this site during WYs 2016–18 (app. 2). A rise in suspended-sediment concentration was observed for all the high streamflow occurrences at Lockwood. Suspended-sediment concentrations and loads appear to decline at about the same rate as streamflow after high streamflow occurrences at this site (app. 2). On August 6, 2018, the highest streamflow occurrence during WYs 2016–18 at Lockwood and Bear Springs (2.46 in. and 5.65 in., respectively) produced the highest streamflow occurrence at Lockwood (168 ft^3/s) and resulted in the largest suspended-sediment concentration (2,000 mg/L) and the largest suspended-sediment load (2,800 t/d) during WYs 2016–18 (app. 2; Kisfalusi and Battaglin, 2022). All five site pairs on PCMS have very strong statistically significant positive relations between streamflow and suspended-sediment concentration and load (table 13).

Water Quality

Water-quality samples were analyzed for a total of 43 physical, biological, nutrient, inorganic nonmetal, inorganic metal, and radiochemical parameters collected from sites on or near the AGFC and the PCMS during WYs 2016–18, and samples were collected during both routine flow conditions and storm occurrences (Kisfalusi and Battaglin, 2022). Nine water-quality samples were collected from three sites on AGFC, two samples each at Turkey Fountain and Little Fountain Creek above Highway 115 at Fort Carson, CO (Little Fountain 115), and five samples at Little Fountain (Kisfalusi and Battaglin, 2022). Additional samples were not collected at these three sites due to a lack of high streamflow occurrences or limited access to the sites during times of intermittent streamflow. Turkey Creek near Stone City, CO (Turkey Stone), Wildhorse Creek near Stone City at Fort Carson, CO

Table 13. Results from Spearman's rank correlation coefficient (Spearman's ρ) correlation analysis for sites on the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site in Colorado, with paired daily mean streamflow and daily mean suspended-sediment concentration and load values for water years 2016–18.

[<, less than]

Streamgage site short name (from tables 1 and 2)	Precipitation site short name (from tables 1 and 2)	Suspended-sediment concentration		Suspended-sediment load	
		Spearman's ρ	p-value	Spearman's ρ	p-value
U.S. Army Garrison Fort Carson					
Little Fountain	Rod and Gun	0.812	<0.001	0.929	<0.001
Red Salt	Sullivan Park	1.00	<0.001	0.949	<0.001
Piñon Canyon Maneuver Site					
Van Bremer	Van Bremer	0.854	<0.001	0.940	<0.001
Taylor	Taylor	0.989	<0.001	0.866	<0.001
Lockwood	Lockwood	1.000	<0.001	1.00	<0.001
Red Rock	Red Rock	1.000	0.001	1.00	<0.001
Bent	Bent	1.000	<0.001	1.99	<0.001

(Wildhorse), Young Hollow below Fort Carson near Wigwam, CO (Young Wigwam), and Sand Creek below Fort Carson near Wigwam, CO (Sand Creek) are all on ephemeral streams, and no samples were collected at these sites during WYs 2016 and 2017 due to a lack of streamflow at times when the sites could be accessed. Sampling at Wildhorse, Young Wigwam, and Sand Creek was discontinued in WY 2018, and Turkey Stone was not sampled in WYs 2016–18 because of a lack of streamflow.

During WYs 2016–18, 37 water-quality samples were collected from 4 sites at PCMS: 12 samples each at Van Bremer, Purgatoire Thatcher, and Purgatoire Rock Crossing, and 1 sample from Taylor (Kisfalusi and Battaglin, 2022). No samples were collected at Van Bremer Arroyo near Tyrone, CO (Van Bremer Tyrone), and Van Bremer Arroyo near Thatcher, CO (Van Bremer Thatcher) due to a lack of streamflow during USGS visits in WYs 2016–18.

Water-quality data were compared to established water-quality standards and were used to identify the potential effects of mechanized military training on the water quality of streams leaving the AGFC and the PCMS. The CDPHE established stream classifications and water-quality standards for the surface waters of Arkansas River Basin (Regulation 32) and the State of Colorado (Regulation 31; CDPHE 2017, 2018). The standards are based on stream segment and classification of aquatic-life biota (tables 1 and 2). Within this scheme, streams classified as cold- and warm-water are considered separately (Holmberg and others, 2016). If there are no CDPHE aquatic-life standards, water-quality data were compared to EPA aquatic-life criteria (EPA, 2020) for parameters of concern or interest (app. 3).

Results of the laboratory analysis for the 43 water-quality parameters for the 9 samples from the AGFC and the 37 samples from the PCMS are provided in Kisfalusi and Battaglin (2022) and are summarized here. Scatter plots were used to compare the distribution of concentration values measured in samples collected during WYs 2016–18 for selected parameters by study area (fig. 7). Summary statistics of sample concentrations for the full period of record (1978–2018) for the AFGC are presented in appendix 4. Similarly, summary statistics for samples collected during the full period of record (1966–2018) for the PCMS are presented in appendix 5.

Physical Parameters

The six physical parameters that were examined include DO, pH, SC, dissolved solids (TDS), water hardness, and water temperature. At the three AGFC sites, the DO concentrations during WYs 2016–18 ranged from 6.1 mg/L (Little Fountain) to 9.0 mg/L (Turkey Fountain), and the mean DO concentration was larger at Turkey Fountain than at Little Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). The DO concentrations at the three AGFC sites were all higher than the cold-water standard of 6 mg/L and the warm-water standard of 5 mg/L. The DO standard is a lower limit (app. 3). Period of record DO concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from 5.7 to 10.2 mg/L (app. 4).

At the four PCMS sites, the DO concentrations during WYs 2016–18 ranged from 5.3 mg/L (Van Bremer) to 11.4 mg/L (Purgatoire Thatcher), and the mean DO concentration was larger at Purgatoire Thatcher than at Purgatoire Rock Crossing and Van Bremer (Kisfalusi and Battaglin, 2022). The DO concentrations at the four PCMS sites were all higher than the warm-water standard. One sample from Van Bremer had a DO concentration that was less than the cold-water standard, but that site is classified as warm-1 (table 2). Period of record DO concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from 4.9 to 13.7 mg/L (app. 5).

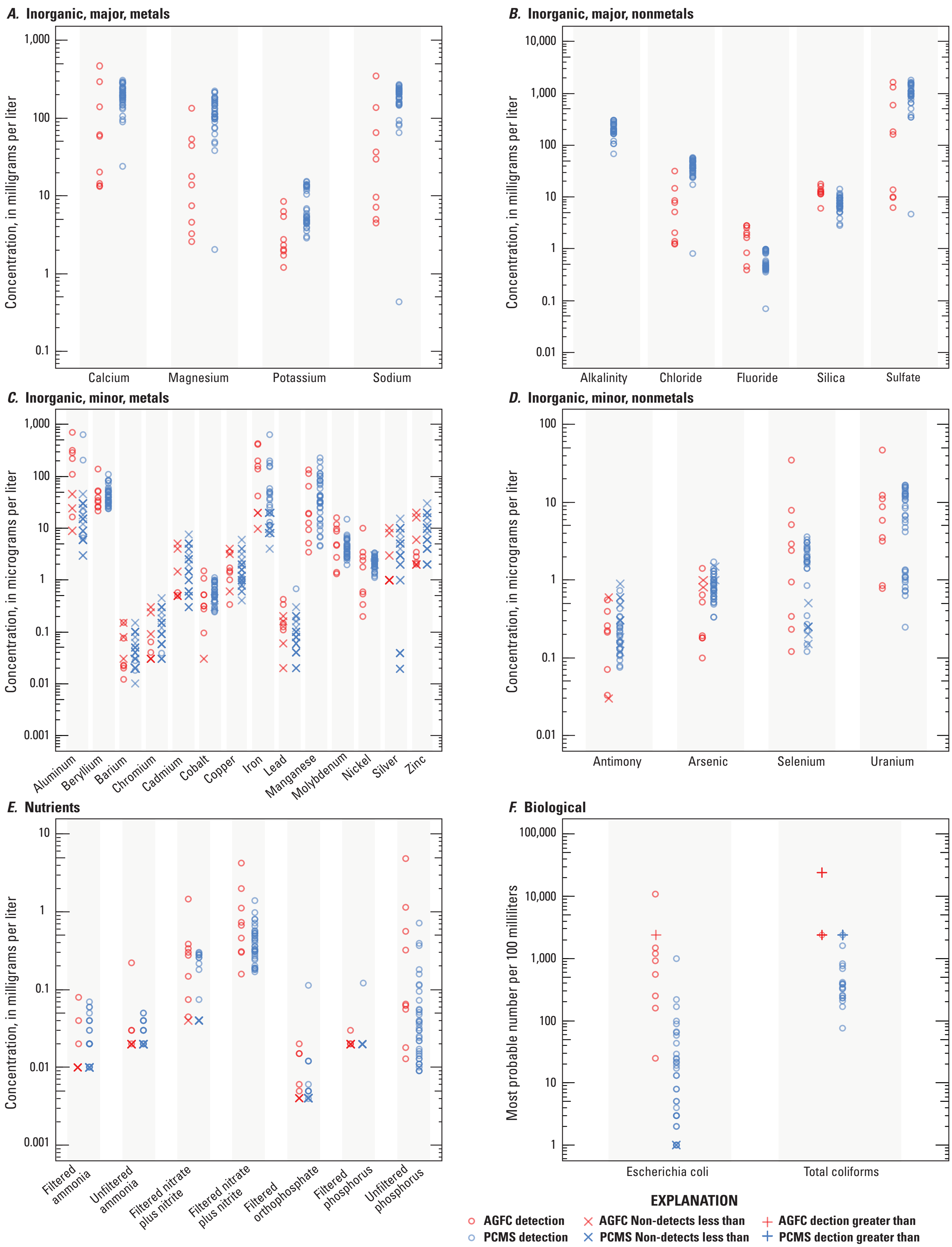
At the three AGFC sites, the pH values during WYs 2016–18 ranged from 7.4 to 8.4 (both at Little Fountain 115), and the median pH was larger at Little Fountain than at Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). The pH values at the three AGFC sites were all between the lower (6.5) and upper (9.0) limits for both cold water and warm water streams (app. 3). Period of record pH values at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from 7.0 to 8.4 (app. 4).

At the four PCMS sites, the pH values during WYs 2016–18 ranged from 7.4 (Van Bremer) to 8.8 (Purgatoire Thatcher), and the median pH was larger at Purgatoire Thatcher and Purgatoire Rock Crossing than at Taylor and Van Bremer (Kisfalusi and Battaglin, 2022). The pH values at the four PCMS sites were all between the lower and upper pH limits for warm water streams. Period of record pH concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from 7.2 to 9.1 (app. 5).

The SC of water at the three AGFC sites during WYs 2016–18 ranged from 112 microsiemens per centimeter (µS/cm) at Little Fountain 115 to 3,140 µS/cm at Little Fountain, and the mean SC was larger at Little Fountain than at Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). There is no CDPHE aquatic-life standard or EPA criterion for SC. Period of record SC values at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from 71 to 3,750 µS/cm (app. 4).

The SC of water at the four PCMS sites during WYs 2016–18 ranged from 144 µS/cm (Taylor) to 3,240 µS/cm (Purgatoire Rock Crossing), and the mean SC was larger at Purgatoire Thatcher than at Purgatoire Rock Crossing and Van Bremer (Kisfalusi and Battaglin, 2022). Period of

Figure 7.—Following page Concentrations for selected water-quality parameters measured in samples collected on the U.S. Army Garrison Fort Carson (AGFC; red symbols) and the Piñon Canyon Maneuver Site (PCMS; blue symbols) in Colorado for water years 2016–18: *A*, inorganic, major metals; *B*, inorganic, major nonmetals; *C*, inorganic minor metals; *D*, inorganic, minor, nonmetals and uranium; *E*, nutrients; and *F*, biological parameters.



A. Inorganic, major, metals
Concentration, in milligrams per liter
1,000
100
10
1
0.1
Calcium
Magnesium
Potassium
Sodium
B. Inorganic, major, nonmetals
Concentration, in milligrams per liter
10,000
1,000
100
10
1
0.1
0.01
Alkalinity
Chloride
Fluoride
Silica
Sulfate
C. Inorganic, minor, metals
Concentration, in micrograms per liter
1,000
100
10
1
0.1
0.01
0.001
Aluminum
Beryllium
Barium
Chromium
Cadmium
Cobalt
Copper
Iron
Lead
Manganese
Molybdenum
Nickel
Silver
Zinc
D. Inorganic, minor, nonmetals
Concentration, in micrograms per liter
100
10
1
0.1
0.01
Antimony
Arsenic
Selenium
Uranium
E. Nutrients
Concentration, in milligrams per liter
10
1
0.1
0.01
0.001
Filtered ammonia
Unfiltered ammonia
Filtered nitrate plus nitrite
Filtered nitrate plus nitrite
Filtered orthophosphate
Filtered phosphorus
Unfiltered phosphorus
F. Biological
Most probable number per 100 milliliters
100,000
10,000
1,000
100
10
1
Escherichia coli
Total coliforms
EXPLANATION
AGFC detection
PCMS detection
AGFC Non-detects less than
PCMS Non-detects less than
AGFC dection greater than
PCMS dection greater than

record SC concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from 19 to 8,000 µS/cm (app. 5).

The TDS concentrations at the three AGFC sites during WYs 2016–18 ranged from 78 mg/L (Little Fountain 115) to 2,780 mg/L (Little Fountain), and the mean TDS was larger at Little Fountain than at Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). There is no CDPHE aquatic-life standard or EPA criterion for TDS. Period of record TDS values at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from 63 to 2,780 mg/L (app. 4).

The TDS of water at the four PCMS sites during WYs 2016–18 ranged from 100 mg/L (Taylor) to 2,900 mg/L (Purgatoire Thatcher), and the mean TDS was slightly larger at Purgatoire Thatcher than at Purgatoire Rock Crossing and Van Bremer (Kisfalusi and Battaglin, 2022). Period of record TDS concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from 92 to 3,850 mg/L (app. 5).

The hardness of water at the three AGFC sites during WYs 2016–18 ranged from 43.4 mg/L as calcium carbonate ($CaCO_3$) at Little Fountain 115 to 1,370 mg/L as $CaCO_3$ at Little Fountain, and the mean water hardness was larger at Little Fountain site than at Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). There is no CDPHE aquatic-life standard or EPA criterion for hardness. Period of record hardness values at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from 28.3 to 1,370 mg/L as $CaCO_3$ (app. 4).

The hardness of water at the four PCMS sites during WYs 2016–18 ranged from 67.8 mg/L as $CaCO_3$ (Taylor) to 1,630 mg/L as $CaCO_3$ (Purgatoire Rock Crossing), and the mean hardness was larger at Purgatoire Thatcher than at Purgatoire Rock Crossing and Van Bremer. Period of record hardness concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from 56 mg/L to 1,900 mg/L as $CaCO_3$ (app. 5).

The water temperatures at the three AGFC sites during WYs 2016–18 ranged from 10.2 degrees Celsius (°C) at Turkey Fountain to 27.5 °C at Little Fountain. The CDPHE has established separate aquatic-life standards for cold and warm water stream temperatures, and the standards are upper limits (CDPHE, 2017). For cold water streams (Turkey Fountain and Little Fountain 115), the April–October standards (the time frame during which all samples were collected in WYs 2016–18) are 18.3 °C and 24.3 °C for chronic and acute exposure, respectively. For warm water streams (Little Fountain), the March–November standards for chronic and acute exposure are 27.5 °C and 28.6 °C, respectively (app. 3). Only one sample (from Little Fountain) equaled an aquatic-life standard. The mean water temperature was higher at Little Fountain than at Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). Period of record water temperatures at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from 0 to 28 °C (app. 4).

The water temperature at the four PCMS sites during WYs 2016–18 ranged from 2.5 °C (Purgatoire Thatcher) to 25.4 °C (Purgatoire Rock Crossing), and the water temperature was higher at Purgatoire Rock Crossing than at Van Bremer and Purgatoire Thatcher (Kisfalusi and Battaglin, 2022). No water temperatures exceeded the warm-water standards at any site. Period of record water temperatures at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from 0 to 31.5 °C (app. 5).

Biological Parameters

Two biological parameters were examined, *E. coli* and total coliforms (app. 1), and the data collected for each of these biological parameters are presented in Kisfalusi and Battaglin, (2022) and were used to prepare figure 7.

The *E. coli* concentrations observed at the three AGFC sites during WYs 2016–18 ranged from 25 most probable number of colonies per 100 milliliters (MPN/100 mL) at Turkey Fountain to 11,000 MPN/100 mL at Little Fountain (fig. 7), and the mean *E. coli* concentration was larger at Little Fountain than at Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). *E. coli* concentrations are all greater than the CDPHE recreational class E and U standard of 126 MPN/100 mL (CDPHE, 2017; app. 3) except for one sample from Turkey Fountain (Kisfalusi and Battaglin, 2022). Period of record *E. coli* concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from <1 (not detected) to 11,000 MPN/100 mL (app. 4).

The *E. coli* concentrations observed at the four PCMS sites during WYs 2016–18 ranged from <1 MPN/100 mL at Van Bremer and Purgatoire Thatcher to 1,000 MPN/100 mL at Taylor (fig. 7), and the mean *E. coli* concentration was larger at Purgatoire Rock Crossing than at the Purgatoire Thatcher and Van Bremer (Kisfalusi and Battaglin, 2022). Except for two samples from Purgatoire Rock Crossing and the one sample from Taylor, *E. coli* concentrations were all less than the CDPHE recreational class E and U standard of 126 MPN/100 mL (Kisfalusi and Battaglin, 2022). Period of record *E. coli* concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from <1 to 3,900 MPN/100 mL (app. 5).

The total coliform concentrations observed at the three AGFC sites during WYs 2016–18 ranged from 2,400 MPN/100 mL at Turkey Fountain to >24,000 MPN/100 mL at Little Fountain and Little Fountain 115 (fig. 7), and all observations, except one from Turkey Fountain, were qualified with a greater than (>) remark code (Kisfalusi and Battaglin, 2022). All total coliform concentrations were >2,000 MPN/100 mL, which was used as the recreation class 2 standard for fecal coliforms prior to the widespread adoption of *E. coli*-based standards (app. 3; CDPHE, 2017). Period of record total coliform concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from 88 to >24,000 MPN/100 mL (app. 4).

The total coliform concentrations observed at the four PCMS sites during WYs 2016–18 ranged from 75 MPN/100 mL at Purgatoire Rock Crossing to >2,400 MPN/100 mL at all four sites (fig. 7), and the mean total coliform concentration was larger at Purgatoire Thatcher than at Purgatoire Rock Crossing and Van Bremer (Kisfalusi and Battaglin, 2022). The 2,000 MPN/100 mL standard was exceeded in 4 of the 12 samples from Van Bremer, 8 of 12 samples from Purgatoire Thatcher, 6 of 12 samples from Purgatoire Rock Crossing, and 1 of 1 sample from Taylor (Kisfalusi and Battaglin, 2022). Period of record total coliform concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from 50 to >24,000 MPN/100 mL (app. 5).

Nutrients

Seven nutrient parameters were examined: filtered and unfiltered ammonia, filtered and unfiltered phosphorus, filtered orthophosphate, filtered nitrite plus nitrate, and unfiltered nitrogen. The data collected for each of these nutrient parameters are presented in figure 7 (Kisfalusi and Battaglin, 2022). Selected parameters of interest are described below. The only CDPHE aquatic-life standards or EPA criteria for nutrients that was exceeded was for unfiltered phosphorus and that standard was exceeded in nine samples (fig. 7; Kisfalusi and Battaglin, 2022).

The unfiltered phosphorus concentrations observed at the three AGFC sites during WYs 2016–18 ranged from 0.013 mg/L at Little Fountain 115 to 4.9 mg/L at Little Fountain (fig. 7), and the mean unfiltered phosphorus concentration was larger at Little Fountain than at Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). The CDPHE aquatic-life standards for unfiltered phosphorus vary by stream segment (CDPHE, 2018) and are set at 0.17 mg/L for Little Fountain and 0.11 mg/L for Turkey Fountain and Little Fountain 115. The unfiltered phosphorus concentrations exceeded the aquatic-life standards in one of two samples collected from Turkey Fountain, and three of five samples collected from Little Fountain (Kisfalusi and Battaglin, 2022). Period of record unfiltered phosphorus concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from 0.009 to 11.9 mg/L (app. 4).

The unfiltered phosphorus concentrations observed at the four PCMS sites during WYs 2016–18 ranged from 0.009 mg/L at Van Bremer to 0.717 mg/L at Purgatoire Rock Crossing (fig. 7), and the mean unfiltered phosphorus concentration was larger at Purgatoire Rock Crossing than at Purgatoire Thatcher and Van Bremer (Kisfalusi and Battaglin, 2022). For all four of the PCMS sites, the aquatic-life standard for unfiltered phosphorus is 0.17 mg/L (CDPHE, 2017, 2018). The unfiltered phosphorus concentrations exceeded the aquatic-life standards in 3 of 12 samples from Purgatoire Thatcher, 1 of 12 samples from Purgatoire Rock Crossing, and the 1 sample from Taylor (Kisfalusi and Battaglin, 2022). Period of record unfiltered phosphorus concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from not detected to 11.7 mg/L (app. 5).

The filtered nitrite plus nitrate concentrations observed at the three AGFC sites during WYs 2016–18 ranged from not detected at Little Fountain to 1.47 mg/L at Little Fountain (fig. 7), and the mean filtered nitrite plus nitrate concentration was larger at Little Fountain than at Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). The CDPHE aquatic-life standards for filtered nitrite plus nitrate vary by stream segment (CDPHE, 2018) and are set at 100 mg/L for Little Fountain and 10 mg/L for Turkey Fountain and Little Fountain 115. The aquatic-life standards for filtered nitrite plus nitrate were not exceeded in the nine samples collected at the AGFC during WYs 2016–18 (Kisfalusi and Battaglin, 2022). Period of record filtered nitrite plus nitrate concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from not detected to 3.06 mg/L (app. 4).

The filtered nitrite plus nitrate concentrations observed at the four PCMS sites during WYs 2016–18 ranged from not detected (at least 1 sample at all sites except Taylor) to 0.301 mg/L at Purgatoire Thatcher (fig. 7), and the mean filtered nitrite plus nitrate concentration was larger at Purgatoire Thatcher than at Purgatoire Rock Crossing and Van Bremer (Kisfalusi and Battaglin, 2022). For all four of the PCMS sites, the aquatic-life standard for filtered nitrite plus nitrate is 10 mg/L (CDPHE, 2017, 2018; app. 3). The aquatic-life standards for filtered nitrite plus nitrate were not exceeded in the 37 samples collected at the PCMS during WYs 2016–18 (Kisfalusi and Battaglin, 2022). Period of record filtered nitrite plus nitrate concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from not detected to 2.80 mg/L (app. 5).

Inorganic Nonmetals

Five major inorganic nonmetals and three minor inorganic nonmetals were examined: filtered alkalinity, filtered chloride, filtered fluoride, filtered silica, filtered sulfate, filtered antimony, filtered arsenic, and filtered selenium (fig. 7; app. 1). The data collected for each of these inorganic nonmetal parameters are presented in Kisfalusi and Battaglin (2022). Selected parameters of interest are described below. The CDPHE aquatic-life standards or EPA criteria for inorganic nonmetals were exceeded in 42 samples (36 for sulfate and 6 for selenium), and no samples exceeded the standards or criteria (when available) for filtered alkalinity, arsenic, chloride, fluoride, silica, and antimony.

The filtered sulfate concentrations observed at the three AGFC sites during WYs 2016–18 ranged from 6.15 mg/L at Little Fountain 115 to 1,650 mg/L at Little Fountain (fig. 7), and the mean filtered sulfate concentration was larger at Little Fountain than at Little Fountain 115 and Turkey Fountain (Kisfalusi and Battaglin, 2022). The CDPHE aquatic-life standards for filtered sulfate vary by stream segment (app. 3; CDPHE, 2018), and the chronic standard is set equal to the water supply standard of 250 mg/L for Little Fountain 115, with no standard listed for Turkey Fountain and Little Fountain. The aquatic-life standards for filtered sulfate were not exceeded in the two samples collected from Little Fountain 115 during WYs 2016–18 (Kisfalusi and Battaglin, 2022). Period of record filtered sulfate concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from not detected to 1,650 mg/L (app. 4).

The filtered sulfate concentrations observed at the four PCMS sites during WYs 2016–18 ranged from 4.71 mg/L at Taylor to 1,790 mg/L at Purgatoire Rock Crossing (fig. 7), and the mean filtered sulfate concentration was larger at Purgatoire Rock Crossing than at Purgatoire Thatcher and Van Bremer (Kisfalusi and Battaglin, 2022). For all four of the PCMS sites, the aquatic-life standard for filtered sulfate is set equal to the water supply standard of 250 mg/L (app. 5; CDPHE, 2017, 2018). The filtered sulfate concentrations exceeded the aquatic-life standards in 36 of the 37 samples collected from the PCMS during WYs 2016–18, with the exception being the 1 sample collected at Taylor (Kisfalusi and Battaglin, 2022). Period of record filtered sulfate concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from 4.71 to 2,400 mg/L (app. 5).

The filtered arsenic concentrations observed at the three AGFC sites during WYs 2016–18 ranged from not detected at Little Fountain to 1.4 micrograms per liter (µg/L) at Little Fountain (fig. 7), and the mean filtered arsenic concentration was larger at Little Fountain than at Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). The CDPHE aquatic-life standards for filtered arsenic vary by stream segment (app. 3; CDPHE, 2018). For filtered arsenic, there is no standard for Turkey Fountain, and the standard for acute exposure is 240 µg/L for Little Fountain and Little Fountain 115. The aquatic-life standard for acute exposure for filtered arsenic was not exceeded in the nine samples collected from the PCMS during WYs 2016–18. Period of record filtered arsenic concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from not detected to 1.4 µg/L (app. 4).

The filtered arsenic concentrations observed at the four PCMS sites during WYs 2016–18 ranged from not detected at Purgatoire Thatcher to 1.7 µg/L at Van Bremer (fig. 7), and the mean filtered arsenic concentration was larger at Van Bremer than at Purgatoire Rock Crossing and Purgatoire Thatcher (Kisfalusi and Battaglin, 2022). For all four of the PCMS sites, the chronic aquatic-life standard for filtered arsenic is 340 µg/L (CDPHE, 2018). The chronic aquatic-life standards for filtered arsenic were not exceeded in the 37 samples collected from the PCMS during WYs 2016–18. Period of record filtered arsenic concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from not detected to 1.8 µg/L (app. 5).

The filtered selenium concentrations observed at the three AGFC sites during WYs 2016–18 ranged from 0.12 µg/L at Little Fountain 115 to 34.5 µg/L at Little Fountain (fig. 7), and the mean filtered selenium concentration was larger at Little Fountain than at Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). The CDPHE aquatic-life standards for filtered selenium vary by stream segment (CDPHE, 2018) and are set at 20 µg/L (chronic) for Turkey Creek, and 18.4 µg/L (acute exposure) and 4.6 µg/L (chronic exposure) for Little Fountain and Little Fountain 115 (app. 3). The EPA chronic criterion is slightly less at 3.1 µg/L. The filtered selenium concentrations exceeded the CDPHE chronic aquatic-life standard and the EPA criterion in three of the five samples and the acute aquatic-life standard in one sample collected from Little Fountain during WYs 2016–18 (Kisfalusi and Battaglin, 2022). Period of record filtered selenium concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from 0.12 to 38.6 µg/L (app. 4).

The filtered selenium concentrations observed at the four PCMS sites during WYs 2016–18 ranged from not detected at Van Bremer to 3.6 µg/L at Purgatoire Rock Crossing (fig. 7), and the mean filtered selenium concentration was larger at Purgatoire Rock Crossing than at Purgatoire Thatcher and Van Bremer (Kisfalusi and Battaglin, 2022). For all four of the PCMS sites, the aquatic-life standards for filtered selenium are 18.4 µg/L for acute exposure and 4.6 µg/L for chronic exposure (app. 3; CDPHE, 2018). The aquatic-life standards for filtered selenium were not exceeded in the 37 samples collected from the PCMS during WYs 2016–18 (Kisfalusi and Battaglin, 2022). However, 2 of the 12 samples from Purgatoire River Rock Crossing exceeded the EPA aquatic-life criterion of 3.1 µg/L (chronic). Period of record filtered selenium concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from not detected to 4.4 µg/L (app. 5).

Inorganic Metals

Four major inorganic metals (calcium, magnesium, potassium, and sodium) and 14 minor inorganic metals (aluminum, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, silver, and zinc) were examined (fig. 7; app. 1). The data collected for each of these inorganic metal parameters plus mercury are presented in Kisfalusi and Battaglin (2022). Selected parameters of interest are described below. The CDPHE aquatic-life standards or EPA criteria for inorganic metals was exceeded in 25 samples (8 for aluminum, 2 for iron, and 15 for manganese), and no samples exceeded standards or criteria (when available) for the other 15 inorganic metals or mercury (Kisfalusi and Battaglin, 2022).

The filtered aluminum concentrations observed at the three AGFC sites during WYs 2016–18 ranged from not detected at Little Fountain to 695 µg/L at Little Fountain 115 (fig. 7), and the mean filtered aluminum concentration was larger at Little Fountain 115 than at Turkey Fountain and Little Fountain (Kisfalusi and Battaglin, 2022). The CDPHE aquatic-life standards for filtered aluminum are calculated as a function of pH and water hardness (CDPHE, 2017), and for the samples from AGFC with filtered aluminum detections, those calculated standards ranged from 1,317 to 10,071 µg/L for acute exposure and 156 to 1,438 µg/L for chronic exposure (app. 3). The EPA aquatic-life criteria for filtered aluminum are more stringent (750 µg/L for acute exposure and 87 µg/L for chronic exposure). The filtered aluminum concentrations exceeded the calculated CDPHE chronic standard in two of the nine samples collected from sites on the AGFC during WYs 2016–18, one each from Turkey Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). The filtered aluminum concentrations exceeded the EPA chronic criterion in one of two samples from Turkey Fountain, two of five samples from Little Fountain, and one of two samples from Little Fountain 115. Period of record filtered aluminum concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from not detected to 695 µg/L (app. 4).

The filtered aluminum concentrations observed at the four PCMS sites during WYs 2016–18 ranged from not detected at Van Bremer and Purgatoire Thatcher to 628 µg/L at Purgatoire Rock Crossing (fig. 7), and filtered aluminum was only detected at Purgatoire Rock Crossing and Taylor (Kisfalusi and Battaglin, 2022). For the samples from PCMS with filtered aluminum detections, the calculated filtered aluminum standards were 10,071 µg/L for acute exposure and 1,438 µg/L for chronic exposure (app. 3). The aquatic-life standards for filtered aluminum were not exceeded in the 37 samples collected from sites on the PCMS during WYs 2016–18. Filtered aluminum concentrations exceeded the EPA chronic criterion in one sample from Purgatoire Rock Crossing and one sample from Taylor. Period of record filtered aluminum concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from not detected to 628 µg/L (app. 5).

The filtered iron concentrations observed at the three AGFC sites during WYs 2016–18 ranged from not detected at Little Fountain to 428 µg/L at Little Fountain 115 (fig. 7), and the mean filtered iron concentration was larger at Little Fountain 115 than at Turkey Fountain or Little Fountain (Kisfalusi and Battaglin, 2022). The CDPHE aquatic-life standards for filtered iron vary by stream segment and are set at 1,000 µg/L (chronic) for Little Fountain, 300 µg/L (chronic) for Little Fountain 115, and no standards for Turkey Fountain (app. 3; CDPHE, 2018). The EPA aquatic-life criterion for filtered iron is similarly stringent (1,000 µg/L chronic). One of the two samples from Little Fountain 115 exceeded the CDPHE chronic iron standard for the associated stream segment (Kisfalusi and Battaglin, 2022). Period of record filtered iron concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from not detected to 570 µg/L (app. 4).

The filtered iron concentrations observed at the four PCMS sites during WYs 2016–18 ranged from not detected at several sites to 644 µg/L at Purgatoire Rock Crossing (fig. 7), and the mean filtered iron concentration was larger at Van Bremer than at the Purgatoire Rock Crossing and Purgatoire Thatcher (Kisfalusi and Battaglin, 2022). The CDPHE chronic aquatic-life standard for iron for all stream segments sampled on the PCMS is 300 µg/L (app. 3). The filtered iron concentrations exceeded the CDPHE iron standard in 1 of the 12 samples collected from Purgatoire Rock Crossing. Period of record filtered iron concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from not detected to 644 µg/L (app. 5).

The filtered manganese concentrations observed at the three AGFC sites during WYs 2016–18 ranged from 3.46 µg/L at Turkey Fountain to 135 µg/L at Little Fountain (fig. 7), and the mean filtered manganese concentration was larger at Little Fountain than at Turkey Fountain or Little Fountain 115 (Kisfalusi and Battaglin, 2022). The CDPHE aquatic-life standards for filtered manganese are calculated as a function water hardness and can also vary by stream segment (CDPHE, 2018). There are no standards for manganese for Turkey Fountain. For the two samples from Little Fountain 155 with manganese detections, the acute standard ranged from 2,390 to 2,764 µg/L, and the chronic standard was 50 µg/L, a water supply standard, which is more stringent than the calculated values (app. 3). For Little Fountain, the standards for manganese vary by sample and ranged from 25.8 to 281 µg/L (acute), and 2,088 to 2,585 µg/L (chronic). There is no EPA aquatic-life criterion for filtered manganese. The filtered manganese concentrations exceeded the CDPHE chronic standards in two of five samples collected from Little Fountain. Period of record filtered manganese concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from not detected to 777 µg/L (app. 4).

The filtered manganese concentrations observed at the four PCMS sites during WYs 2016–18 ranged from 4.46 µg/L at Taylor to 224 µg/L at Van Bremer, and the mean filtered manganese concentration was larger at Van Bremer than at Purgatoire Thatcher and Purgatoire Rock Crossing (Kisfalusi and Battaglin, 2022). For the samples from PCMS with a filtered manganese detection, the calculated filtered manganese standards were 4,679 µg/L for acute and 50 µg/L for chronic (app. 3; CDPHE, 2018). The filtered manganese concentrations did not exceed the calculated acute CDPHE standards, but 1 of 12 samples from Purgatoire Thatcher and all 12 samples from Van Bremer exceeded the chronic standard (Kisfalusi and Battaglin, 2022). Period of record filtered manganese concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from not detected to 267 µg/L (app. 5).

Radiochemical

The data for one radiochemical parameter, filtered uranium, were examined (fig. 7*D;* app. 1) and are presented in Kisfalusi and Battaglin (2022). The filtered uranium concentrations observed at the three AGFC sites during WYs 2016–18 ranged from 0.774 µg/L at Little Fountain 115 to 47.3 mg/L at Turkey Fountain (fig. 7*D*), and the mean filtered uranium concentration was larger at Turkey Fountain than at Little Fountain and Little Fountain 115 (Kisfalusi and Battaglin, 2022). The CDPHE aquatic-life standards for filtered uranium are calculated as a function of water hardness (CDPHE, 2017), and for the samples from AGFC with filtered uranium detections, those calculated standards ranged from

957 to 11,070 µg/L for acute exposure and 598 to 6,915 µg/L for chronic exposure (app. 3). There is no EPA aquatic-life criterion for filtered uranium. In all cases, the calculated aquatic-life standard values are much larger than the domestic water supply standard for uranium in Colorado of 16.8 to 30 µg/L (CDPHE, 2017). The aquatic-life standards for filtered uranium were not exceeded in the nine samples collected from sites on the AGFC during WYs 2016–18, but one sample from Turkey Fountain exceeded the domestic water supply standard (Kisfalusi and Battaglin, 2022). Period of record filtered uranium concentrations at Turkey Fountain, Little Fountain, and Little Fountain 115 ranged from 0.609 to 47.3 µg/L (app. 4).

The filtered uranium concentrations observed at the four PCMS sites during WYs 2016–18 ranged from 0.25 µg/L at Taylor to 16.7 µg/L at Purgatoire Thatcher (fig. 7*D*), and the mean filtered uranium concentration was larger at Purgatoire Thatcher than at Purgatoire Rock Crossing and Van Bremer (Kisfalusi and Battaglin, 2022). For the samples from PCMS with filtered uranium detections, the calculated filtered uranium standards were 11,070 µg/L for acute exposure and 6,915 µg/L for chronic exposure. The aquatic-life standards (or the domestic water supply standard) for filtered uranium were not exceeded in the 37 samples collected from sites on the PCMS during WYs 2016–18. Period of record filtered uranium concentrations at Purgatoire Thatcher, Purgatoire Rock Crossing, Van Bremer, and Taylor ranged from 0.248 to 19.0 µg/L (app. 5).

Upstream Compared to Downstream Water-Quality Assessment

There are several ways to assess the changes in water-quality conditions as streams traverse or pass by the AGFC and PCMS. For sites and parameters with sufficient long-term data, median or mean concentrations can be used to determine which parameters are changing and how they are changing in a general sense. It also can be useful to compare concentrations or loads in paired samples using the Lagrangian sampling method. In this approach, the upstream sample is collected first, and the downstream sample is collected at a later time and date that approximates the travel time of water between the two sites (Meade and Stevens, 1990; Moody, 1993).

There are limited long-term water-quality data at both Little Fountain 115 and Little Fountain (app. 4) so use of medians and means to determine which parameters are changing as water crosses the AGFC may be of limited value. The APD for the mean and median concentrations for the 42 measured parameters are in table 14. Between Little Fountain 115 and Little Fountain, the APD between the mean concentrations for 39 parameters ranged from −166 to 198 percent. There were no data for alkalinity, and two parameters had a non-detection in one or both samples. Of the evaluated parameters, 28 had increases in mean concentration with 19 (*E. coli*, chloride, sulfate, calcium, magnesium, sodium, filtered ammonia, nitrite plus nitrate, unfiltered phosphorus, cobalt, molybdenum, nickel, antimony, arsenic, selenium, uranium, hardness, TDS, and SC) showing increases of more than 100 percent. Between Little Fountain 115 and Little Fountain, 11 parameters showed no change or decreases in mean concentration with 2 (beryllium and iron) showing decreases of more than 100 percent (table 14).

Two pairs of samples collected from Little Fountain and Little Fountain 115 during WYs 2016–18 can be considered Lagrangian paired samples. Little Fountain 115 is located approximately 8 miles upstream from Little Fountain (fig. 1), and stream velocities indicate that the approximate water travel times between the two sites could range between 5.6 and 78 hours with a median of 10 hours. In the samples collected on August 8–9, 2016, streamflow increased from 11 to 15 ft^3/s, and the APDs of concentrations for 32 parameters ranged from −153 to 177 percent (table 15). There were no data for alkalinity and a non-detection or greater than (>) value for one or both samples for nine parameters. Of the evaluated parameters, 21 had increases in concentration with 13 showing increases of more than 100 percent, and 11 had no change or decreases in concentrations (table 15). The APDs of loads for 26 parameters ranged from −138 to 183 percent, 22 parameters had increases in load with 13 showing increases of more than 100 percent, 4 parameters had decreases in loads, and 2 (aluminum and beryllium) had decreases in loads of more than 100 percent (table 15).

In the samples collected from Little Fountain 115 and Little Fountain on August 9–10, 2017, streamflow increased from 4.3 to 17 ft^3/s, and the APDs of concentrations for 28 parameters ranged from −107 to 195 percent. There were no data for alkalinity, and a non-detection or greater than (>) value for 1 or both samples for 13 parameters. Of the evaluated parameters, 24 had increases in concentration with 20 showing increases of more than 100 percent, and 4 had no change or decreases in concentrations with 1 (beryllium) showing a decrease in concentration of more than 100 percent (table 15). The APDs of loads for 23 parameters ranged from 17.9 to 199 percent. No parameters had decreases in loads between Little Fountain 115 and Little Fountain.

There is substantial long-term water-quality data for numerous parameters at both Purgatoire Thatcher and Purgatoire Rock Crossing (app. 4), so use of medians and means to determine which parameters are changing as water in the Purgatoire River passes by the PCMS has some merit. The APD for the mean and median concentrations for the 42 measured parameters are in table 14. At Purgatoire Thatcher and Purgatoire Rock Crossing, the APD between the mean concentrations for 39 parameters ranged from about −114 to 183 percent, and 3 parameters had a non-detection in 1 or both samples. Of the evaluated parameters, 22 had increases in mean concentration with 3 showing increases of more than 50 percent, and 17 showed no change or decreases in mean concentration between Purgatoire Thatcher and Purgatoire Rock Crossing with 1 (copper) showing a decrease of more than 50 percent (table 14).

Table 14. Absolute percent differences (APDs) in mean and median concentrations for water-quality parameters between Little Fountain and Little Fountain 115 on the U.S. Army Garrison Fort Carson, Colorado, and for Purgatoire Rock Crossing and Purgatoire Thatcher on the Piñon Canyon Maneuver Site, Colorado, for the period of record.

[ND, no data; NC, not calculated; $CaCO_3$, calcium carbonate]

Water-quality parameter	Little Fountain—Little Fountain 115		Purgatoire Rock Crossing—Purgatoire Thatcher	
	APD of means	APD of medians	APD of means	APD of medians
Escherichia coli	117	−7.8	41.8	76.9
Total coliforms	53.8	79.2	45.9	−71.6
Alkalinity, filtered	ND	ND	−10.6	−7.9
Chloride, filtered	143	142	−4.3	101.5
Fluoride, filtered	−12.7	−24.9	−5.0	−7.2
Silica, filtered	−12.3	−6.7	−4.6	−9.8
Sulfate, filtered	194	192	0.9	6.9
Calcium, filtered	166	159	3.0	5.3
Magnesium, filtered	176	173	−2.3	−10.8
Potassium, filtered	77.7	65.2	4.3	3.9
Sodium, filtered	181	171	−0.6	0.0
Ammonia, filtered	126	NC	36.4	66.7
Ammonia, unfiltered	56.4	NC	53.1	100.0
Nitrite + nitrate, filtered	118	97.6	−8.1	−55.7
Total nitrogen, unfiltered	72.8	57.7	9.4	0.0
Orthophosphate, filtered	−22.2	NC	0.0	0.0
Phosphorus, filtered	−13.3	NC	−5.7	0.0
Phosphorus, unfiltered	155	144	26.7	54.5
Aluminum, filtered	−96.8	−191	183.1	66.7
Barium, filtered	71.0	42.9	30.1	6.4
Beryllium, filtered	−166	NC	−22.2	0.0
Cadmium, filtered	NC	NC	−11.8	0.0
Chromium, filtered	−15.2	NC	23.9	−50.0
Cobalt, filtered	131	116	3.5	−3.0
Copper, filtered	42.8	106	−113.7	22.2
Iron, filtered	−110	NC	3.5	−8.7
Lead, filtered	−43.0	NC	172.4	0.0
Manganese, filtered	43.5	110	32.2	40.0
Molybdenum, filtered	151	147	46.0	40.6
Nickel, filtered	162	150	9.7	11.3
Silver, filtered	NC	NC	190.2	0.0
Zinc, filtered	−72.7	NC	64.0	0.0
Antimony, filtered	198	121	33.7	31.2
Arsenic, filtered	107	114	24.2	27.0
Selenium, filtered	194	189	10.8	8.0
Uranium, filtered	151	155	−0.9	2.7
Hardness as $CaCO_3$	170	163	−0.2	−9.7
Oxygen, dissolved	−3.3	4.4	−8.6	−10.3
pH, field	NC	3.1	NC	0.0
Solids, dissolved	177	174	−1.6	−3.0
Specific conductance	175	180	−12.7	−18.4
Water temperature	16.8	−3.3	19.0	20.2

Table 15. Absolute percent differences (APDs) in concentrations and loads for select water-quality parameters for Lagrangian paired samples at Little Fountain and Little Fountain 115 on the U.S. Army Garrison Fort Carson, Colorado.

[NC, not calculated; $CaCO_3$, calcium carbonate]

Water-quality parameter	Little Fountain—Little Fountain 115 in August 2016		Little Fountain—Little Fountain 115 in August 2017	
	APD of concentration	APD of load	APD of concentration	APD of load
Escherichia coli	−22.2	NC	NC	NC
Total coliforms	NC	NC	NC	NC
Chloride, filtered	116	135	149	186
Fluoride, filtered	10.3	40.7	−45.7	85.1
Silica, filtered	−7.52	23.4	4.08	122
Sulfate, filtered	177	182	187	197
Calcium, filtered	124	141	127	179
Magnesium, filtered	123	140	149	186
Potassium, filtered	17.3	47.5	114	174
Sodium, filtered	142	156	156	188
Ammonia, filtered	NC	NC	NC	NC
Ammonia, unfiltered	NC	NC	NC	NC
Nitrite + nitrate, filtered	−10.0	20.9	144	184
Total nitrogen, unfiltered	41.7	70.2	10	192
Orthophosphate, filtered	NC	NC	NC	NC
Phosphorus, filtered	NC	NC	NC	NC
Phosphorus, unfiltered	164	172	195	199
Aluminum, filtered	−145	−129	180	195
Barium, filtered	−27.2	3.62	69.0	156
Beryllium, filtered	−153	−138	−107	17.9
Cadmium, filtered	NC	NC	NC	NC
Chromium, filtered	NC	NC	NC	NC
Cobalt, filtered	−13.3	17.6	NC	NC
Copper, filtered	−19.4	11.6	164	190
Iron, filtered	−103	−78.5	164	190
Lead, filtered	−102	−77.6	NC	NC
Manganese, filtered	67.8	93.7	118	175
Molybdenum, filtered	106	127	116	175
Nickel, filtered	100	121	157	188
Silver, filtered	NC	NC	NC	NC
Zinc, filtered	NC	NC	NC	NC
Antimony, filtered	115	134	NC	NC
Arsenic, filtered	93.0	11	173	193
Selenium, filtered	171	178	191	198
Uranium, filtered	122	132	121	111
Hardness as $CaCO_3$	123	NC	134	NC
Oxygen, dissolved	−1.29	NC	2.53	NC
pH, field	7.79	NC	−4.88	NC
Solids, dissolved	126	143	136	181
Specific conductance	126	NC	136	NC
Water temperature	16.9	NC	−15.0	NC

Five pairs of samples collected from Purgatoire Rock Crossing and Purgatoire Thatcher during WYs 2016–18 can be considered Lagrangian paired samples. On the PCMS, Purgatoire Thatcher is located approximately 30 miles upstream from Purgatoire Rock Crossing (fig. 2). Stream velocities measured at Purgatoire Rock Crossing indicate that the approximate water travel time between the two sites could range between 8 and 176 hours with a median of 40 hours.

In the samples collected on May 25–26, 2016, streamflow decreased from 29 to 20 ft^3/s, and the APDs of concentrations for 27 parameters ranged from −93.1 to 56.7 percent (table 16). There was a non-detection or greater than (>) value for 1 or both samples for 15 parameters, 10 parameters had increases in concentration with 2 (*E. coli* and unfiltered total nitrogen) showing increases of more than 50 percent, and 17 parameters had no change or decreases in concentrations between Purgatoire Thatcher and Purgatoire Rock Crossing with 1 (manganese) showing a decrease of more than 50 percent (table 16). The APDs of loads for 21 parameters ranged from −120 to 19.4 percent. Only unfiltered total nitrogen had an increase in load, and 20 parameters had no change or decreases in load between Purgatoire Thatcher and Purgatoire Rock Crossing with 10 showing decreases of more than 50 percent (table 16).

In the samples collected from Purgatoire Thatcher and Purgatoire Rock Crossing on November 14–15, 2016, streamflow was equal at both sites (19 ft^3/s), and the APDs of concentrations for 27 parameters ranged from −73.7 to 86.6 percent (table 16). There was a non-detection or greater than (>) value for 1 or both samples for 15 parameters, 14 parameters had increases in concentration with 1 (manganese) showing an increase of more than 50 percent, and 13 parameters had no change or decreases in concentrations between Purgatoire Thatcher and Purgatoire Rock Crossing with 1 (unfiltered total nitrogen) showing a decrease in concentration of more than 50 percent (table 16). The APDs of loads for 21 parameters ranged from −73.7 to 86.6 percent, 12 parameters had increases in load with 1 (manganese) showing increases of more than 50 percent, and 9 parameters had no change or decreases in loads between Purgatoire Thatcher and Purgatoire Rock Crossing with 1 (unfiltered total nitrogen) showing decreases of more than 50 percent (table 16).

In the samples collected from Purgatoire Thatcher and Purgatoire Rock Crossing on March 22–23, 2017, streamflow decreased from 15 to 14 ft^3/s, and the APDs of concentrations for 29 parameters ranged from about −117 to 112 percent (table 16). There was a non-detection or greater than (>) value for 1 or both samples for 13 parameters, 11 parameters had increases in concentration with 3 (antimony, molybdenum, and unfiltered phosphorus) showing increases of more than 50 percent, and 18 parameters had no change or decreases in concentrations between Purgatoire Thatcher and Purgatoire Rock Crossing with 3 (*E. coli*, filtered ammonia, and iron) showing decreases of more than 50 percent (table 16). The APDs of loads for 23 parameters ranged from about −105 to 107 percent, 7 parameters had increases in load with 1 (unfiltered phosphorus) showing an increase of more than 50 percent, and 16 parameters had no change or decreases in loads between Purgatoire Thatcher and Purgatoire Rock Crossing with 2 (filtered ammonia and iron) showing decreases of more than 50 percent (table 16).

In the samples collected from Purgatoire Thatcher and Purgatoire Rock Crossing on May 23–24, 2017, streamflow increased from 296 to 487 ft^3/s, and the APDs of concentrations for 32 parameters ranged from −30 to 107 percent (table 16). There was a non-detection or greater than (>) value for 1 or both samples for 10 parameters, 25 parameters had increases in concentration with 2 (*E. coli* and unfiltered phosphorus) showing increases of more than 50 percent, and 7 parameters had no change or decreases in concentrations between Purgatoire Thatcher and Purgatoire Rock Crossing with 1 (manganese) showing a decrease of more than 50 percent (table 16). The APDs of loads for the 26 parameters ranged from about −97 to 105 percent, 25 parameters had increases in load, with 19 showing increases of more than 50 percent, and only 1 parameter (manganese) had a decrease in load between Purgatoire Thatcher and Purgatoire Rock Crossing (table 16).

In the samples collected from Purgatoire Thatcher and Purgatoire Rock Crossing on August 1–2, 2018, streamflow increased from 1.6 to 2.9 ft^3/s, and the APDs of concentrations for 26 parameters ranged from −61.1 to 100 percent (table 16). There was a non-detection or greater than (>) value for 1 or both samples for 16 parameters, 9 parameters had increases in concentration with 3 (*E. coli*, manganese, and molybdenum) showing increases of more than 50 percent, and 17 parameters had no change or decreases in concentrations between Purgatoire Thatcher and Purgatoire Rock Crossing with 2 (magnesium and barium) showing decreases of 50 percent or more (table 16). The APDs of loads for 20 parameters ranged from −3.69 to 138 percent, 19 parameters had increases in load with 8 (alkalinity, fluoride, potassium, unfiltered phosphorus, manganese, molybdenum, arsenic, and selenium) showing increases of more than 50 percent, and only magnesium had a decrease in loads between Purgatoire Thatcher and Purgatoire Rock Crossing.

Potential Effect of Geology on Changes in Water Quality

As water moves through geologic materials, the materials slowly dissolve and thus alter the water quality (Vandas and others, 2002). Surficial geology affects the water quality of runoff from precipitation, shallow groundwater, streams, and other surface-water bodies.

At the AGFC, surface water at Little Fountain 115 and Turkey Fountain is affected by the igneous and metamorphic rocks to the west of the study area, whereas water at the downstream Little Fountain site is effected by the shales that underlie the study area (Holmberg and others, 2016). Samples from the two upstream sites generally had lower SC, TDS,

Table 16. Absolute percent differences (APDs) in concentrations and loads for select water-quality parameters for Lagrangian paired samples at Purgatoire Thatcher and Purgatoire Rock Crossing on the Piñon Canyon Maneuver Site, Colorado.

[NC, not calculated; $CaCO_3$, calcium carbonate]

Water-quality parameter	May 2016	November 2016	March 2017	May 2017	August 2018
	APDs of concentration, load	APDs of concentration, load	APDs of concentration, load	APDs of concentration, load	APDs of concentration, load
Escherichia coli	56.7, NC	0.0, NC	−117, NC	107, NC	100, NC
Total coliforms	NC, NC	NC, NC	NC, NC	NC, NC	NC, NC
Alkalinity, filtered	−7.29, −43.7	−18.3, −18.3	−10.9, −17.7	0.519, 49.3	10.5, 67.3
Chloride, filtered	−21.3, −56.9	−4.53, −4.53	−20.4, −27.2	3.29, 51.9	−47.2, 11.3
Fluoride, filtered	0.0, −36.7	0.0, 0.0	2.11, −4.79	2.53, 51.2	12.4, 68.9
Silica, filtered	10.1, −26.9	1.32, 1.32	6.56, −0.33	0.53, 49.3	−24.3, 34.7
Sulfate, filtered	−38.1, −72.3	2.67, 2.67	−24.2, −31.0	8.04, 56.3	−48.1, 10.4
Calcium, filtered	−36.7, −71.1	−1.07, −1.07	−19.4, −26.2	5.51, 53.9	−31.5, 27.5
Magnesium, filtered	−43.7, −77.3	−2.27, −2.27	−31.5, −38.2	6.20, 54.5	−61.1, −3.69
Potassium, filtered	−9.95, −46.3	5.10, 5.10	−1.89, −8.78	6.14, 54.5	11.8, 68.4
Sodium, filtered	−21.2, −56.8	6.24, 6.24	−14.9, −21.7	4.88, 53.4	−36.0, 23.0
Ammonia, filtered	NC, NC	−40.0, −40.0	−100, −105	0.0, 48.8	NC, NC
Ammonia, unfiltered	NC, NC	NC, NC	NC, NC	NC, NC	NC, NC
Nitrite + nitrate, filtered	NC, NC	NC, NC	NC, NC	4.30, 52.8	NC, NC
Total nitrogen, unfiltered	55.1, 19.4	−73.7, −73.7	22.2, 15.4	20.2, 67.4	−13.3, 45.3
Orthophosphate, filtered	NC, NC	NC, NC	NC, NC	0.0, 48.8	NC, NC
Phosphorus, filtered	NC, NC	NC, NC	NC, NC	NC, NC	NC, NC
Phosphorus, unfiltered	27.2, −9.76	5.71, 5.71	112, 107	64.3, 105	−2.60, 55.4
Aluminum, filtered	NC, NC	NC, NC	NC, NC	NC, NC	NC, NC
Barium, filtered	−33.1, −67.8	26.5, 26.5	13.2, 6.36	1.35, 50.1	−50.0, 8.38
Beryllium, filtered	NC, NC	NC, NC	NC, NC	NC, NC	NC, NC
Cadmium, filtered	NC, NC	NC, NC	NC, NC	NC, NC	NC, NC
Chromium, filtered	NC, NC	NC, NC	NC, NC	NC, NC	NC, NC
Cobalt, filtered	−26.7, −61.9	9.10, 9.10	10.9, 3.99	−14.4, 35.0	−17.2, 41.6
Copper, filtered	NC, NC	NC, NC	NC, NC	9.52, 57.6	NC, NC
Iron, filtered	NC, NC	NC, NC	−52.3, −58.7	−15.7, 33.8	NC, NC
Lead, filtered	NC, NC	NC, NC	NC, NC	NC, NC	NC, NC
Manganese, filtered	−93.1, −120	86.6, 86.6	1.47, −5.42	−130, −96.6	99.7, 138
Molybdenum, filtered	24.6, −12.5	43.3, 43.3	53.3, 46.8	20.4, 67.5	81.8, 125
Nickel, filtered	−12.8, −48.9	25.5, 25.5	−34.8, −41.4	15.4, 63.0	−34.8, 24.2
Silver, filtered	NC, NC	NC, NC	NC, NC	NC, NC	NC, NC
Zinc, filtered	NC, NC	NC, NC	NC, NC	NC, NC	NC, NC
Antimony, filtered	3.56, −33.3	NC, NC	53.5, 47.0	11.5, 59.4	NC, NC
Arsenic, filtered	12.0, −25.0	47.1, 47.1	23.4, 16.6	29.9, 75.9	8.00, 65.0
Selenium, filtered	22.2, −14.8	3.77, 3.77	−5.71, −12.6	13.3, 61.1	19.4, 75.0
Uranium, filtered	−37.0, −71.3	−2.56, −2.56	−28.8, −35.5	27.5, 73.8	−33.6, 25.4
Hardness as $CaCO_3$	−40.6, NC	−1.41, NC	−26.1, NC	5.81, NC	−47.7, NC
Oxygen, dissolved	0.0, NC	−0.98, NC	−8.09, NC	−1.20, NC	−8.81, NC
pH, field	2.41, NC	2.41, NC	0.0, NC	−1.20, NC	−2.47, NC
Solids, dissolved	−35.0, −69.5	−0.38, −0.38	−23.5, −30.3	9.50, 57.6	−45.6, 13.0
Specific conductance	−28.4, NC	0.0, NC	−18.6, NC	5.66, NC	−35.3, NC
Water temperature	4.36, NC	36.7, NC	18.1, NC	5.20, NC	0.79, NC

and hardness; and lower concentrations of inorganic metals and nonmetals than did samples from Little Fountain (app. 4; Kisfalusi and Battaglin, 2022). The exceptions were concentrations of aluminum, beryllium, iron, and zinc that were generally higher at Little Fountain 115 and Turkey Fountain than at the Little Fountain site. Many of the parameters with elevated concentrations at Little Fountain, including sulfate, selenium, and uranium, are found in sedimentary rocks (and in particular Cretaceous shales), and may be present from the land surface to the water table as salts, making them easily mobilized by water (Bern and Stogner, 2017; Bern and others, 2020). Other parameters including arsenic, boron, chromium, copper, molybdenum, phosphorus, and zinc have been associated with Cretaceous shales like those exposed on the AGFC, as well as the soils derived from such shales (Tourtelot, 1964; Morrison and others, 2012).

Water in the Purgatoire River is in contact with limestones and sandstones that crop out in the canyon areas along the eastern edge of the PCMS, but the tributaries mainly drain Cretaceous shales (von Guerard and others, 1993; Holmberg and others, 2016). Compared to samples from Purgatoire Thatcher and Purgatoire Rock Crossing, samples from the two tributary sites (Van Bremer and Taylor) generally had lower DO, SC, TDS, and hardness values, and lower concentrations of sulfate, selenium, calcium, magnesium, chromium, molybdenum, and uranium (app. 5; Kisfalusi and Battaglin, 2022). The exception was cobalt, which generally had higher concentrations at Van Bremer and Taylor. Although the results of this study indicate that the geology of the PCMS likely affects the water quality of tributaries to the Purgatoire River (tables 13 and 15), the lack of substantial runoff and sediment transport from those tributaries to the Purgatoire River limits the effect of geology on water quality in the Purgatoire River.

Potential Effect of Training Activities on Sediment Transport and Water Quality

Determining the potential effects of military training on water quality in streams that are adjacent to the training grounds on the AGFC and PCMS is difficult to assess because of the ephemeral nature of the streamflow; the limited number of sampling locations and samples; limited access to the study areas; and the nature of short, intensive tracked vehicle trainings. On the AGFC, the limited number of sites and samples, the more-or-less continuous training activities, and the lack of a control basin (one without training) combine to make any assessment of the effects of military training on water quality limited to the analyses of the Lagrangian paired samples.

On the PCMS, pairs of water-quality samples were collected before and after the April–May 2017 training event at Van Bremer, Purgatoire Thatcher, and Purgatoire Rock Crossing (Kisfalusi and Battaglin, 2022). A comparison of these pairs of samples may provide an indication of the potential effects of military training on the concentrations and loads of the measured water-quality parameters. These comparisons would ideally be made with the before and after samples collected during similar streamflow conditions.

Samples were collected before and after the April–May training exercise at Van Bremer on March 22 and May 25, 2017. Streamflow at the time of the May sample was 0.69 ft^3/s and was approximately 4 times larger than the 0.17 ft^3/s streamflow at the time of the March sample (Kisfalusi and Battaglin, 2022). The APDs of concentrations for 27 parameters ranged from −71.7 to 183 percent (table 17). There was a non-detection or greater than (>) value for one or both samples for 15 parameters, 7 parameters had increases in concentration with 2 (*E. coli* and total coliforms) showing increases of more than 50 percent, and 20 parameters had no change or decreases in concentrations between the March and May samples with 2 (cobalt and manganese) showing a decrease of more than 50 percent (table 17). The APDs of loads for 20 parameters ranged from 62.9 to 135 percent, hence all 20 parameters had increases in load of more than 62 percent (table 17).

Samples were collected before and after the April–May training exercise at Purgatoire Thatcher on March 22 and May 23, 2017. Streamflow at the time of the May sample was 296 ft^3/s and was approximately 20 times larger than the 15 ft^3/s streamflow at the time of the March sample (Kisfalusi and Battaglin, 2022). The APDs of concentrations for 29 parameters ranged from −130 to 168 percent (table 17). There was a non-detection or greater than (>) value for 1 or both samples for 13 parameters, 10 parameters had increases in concentration with 5 (barium, silica, unfiltered total nitrogen, unfiltered phosphorus, and *E. coli*) showing increases of more than 50 percent, and 19 parameters had no change or decreases in concentrations between the March and May samples with 12 showing a decrease of more than 50 percent (table 17). The APDs of loads for 23 parameters ranged from 123 to 198 percent; hence, all 23 parameters had increases in load of more than 123 percent (table 17).

Samples were collected before and after the April–May training exercise at Purgatoire Rock Crossing on March 23 and May 24, 2017. Streamflow at the time of the May sample was 487 ft^3/s and was approximately 35 times larger than the 14 ft^3/s streamflow at the time of the March sample (Kisfalusi and Battaglin, 2022). The APDs of concentrations for 30 parameters ranged from −143 to 191 percent (table 17). There was a non-detection or greater than (>) value for 1 or both samples for 12 parameters, 7 parameters had increases in concentration with 4 (silica, unfiltered total nitrogen, unfiltered phosphorus, and *E. coli*) showing increases of more than 50 percent, and 23 parameters had no change or decreases in concentrations between the March and May samples with 11 showing a decrease of more than 50 percent (table 17). The APDs of loads for 24 parameters ranged from 141 to 198 percent; hence, all 24 parameters had increases in load of more than 140 percent (table 17).

For all three of the sample pairs from the PCMS sites, most parameters had decreases in concentration but increases in loads, which would be expected given the higher

Table 17. Absolute percent differences (APDs) in concentrations and loads for select water-quality parameters for before- and after-military training Lagrangian paired samples at three sites on the Piñon Canyon Maneuver Site, Colorado.

[NC, not calculated; $CaCO_3$, calcium carbonate]

Water-quality parameter	Van Bremer on March 22 and May 25, 2017		Purgatoire Thatcher on March 22 and May 23, 2017		Purgatoire Rock Crossing on March 23 and May 24, 2017	
	APD of concentration	APD of load	APD of concentration	APD of load	APD of concentration	APD of load
Escherichia coli	183	NC	112	NC	191	NC
Total coliforms	70.0	NC	NC	NC	NC	NC
Alkalinity, filtered	−17.7	109	−1.04	181	10.4	190
Chloride, filtered	−1.71	120	−84.4	156	−63.9	179
Fluoride, filtered	−1.02	120	−18.6	177	−18.2	187
Silica, filtered	−29.8	100	109	194	104	196
Sulfate, filtered	2.51	123	−130	123	−109	165
Calcium, filtered	−20.3	107	−105	144	−85.7	173
Magnesium, filtered	−10.9	114	−128	125	−103	167
Potassium, filtered	−2.88	119	−51.7	168	−44.1	183
Sodium, filtered	−14.1	112	−99.5	148	−83.8	174
Ammonia, filtered	NC	NC	−100	147	0	189
Ammonia, unfiltered	NC	NC	NC	NC	−40.0	183
Nitrite + nitrate, filtered	NC	NC	NC	NC	NC	NC
Total nitrogen, unfiltered	22.2	134	85.7	192	84.1	195
Orthophosphate, filtered	NC	NC	NC	NC	NC	NC
Phosphorus, filtered	NC	NC	NC	NC	NC	NC
Phosphorus, unfiltered	0	121	168	198	146	198
Aluminum, filtered	NC	NC	NC	NC	NC	NC
Barium, filtered	4.97	124	60.9	189	49.9	193
Beryllium, filtered	NC	NC	NC	NC	NC	NC
Cadmium, filtered	NC	NC	NC	NC	NC	NC
Chromium, filtered	NC	NC	NC	NC	NC	NC
Cobalt, filtered	−56.2	78.0	10.3	183	−15.0	187
Copper, filtered	NC	NC	NC	NC	NC	NC
Iron, filtered	−11.7	113	−38.3	172	−0.89	189
Lead, filtered	NC	NC	NC	NC	NC	NC
Manganese, filtered	−71.7	62.9	−23.5	176	−143	141
Molybdenum, filtered	−31.2	99.1	−35.7	173	−67.4	178
Nickel, filtered	23.1	135	−76.9	159	−30.3	185
Silver, filtered	NC	NC	NC	NC	NC	NC
Zinc, filtered	NC	NC	NC	NC	NC	NC
Antimony, filtered	NC	NC	29.5	185	−13.6	187
Arsenic, filtered	−8.57	115	15.1	183	21.6	191
Selenium, filtered	NC	NC	−25.0	176	−6.06	188
Uranium, filtered	−27.4	102	−120	133	−77.2	176
Hardness as $CaCO_3$	−16.0	NC	−117	NC	−94.1	NC
Oxygen, dissolved	−2.63	NC	−6.90	NC	0	NC
pH, field	0	NC	1.20	NC	0	NC
Solids, dissolved	−2.99	119	−119	133	−96.0	170
Specific conductance	−3.87	NC	−99.3	NC	−79.9	NC
Water temperature	12.9	NC	9.79	NC	−3.12	NC

streamflow at the time of collection of the May compared to the March samples. The limited number of samples and the large difference in streamflow between the three sets of before and after training samples limit this study's ability to assess the effects of military training on water quality with the data collected in WYs 2016–18.

Future Needs

The spatial variability of precipitation and the ephemeral nature of streamflow on the AGFC and PCMS makes identification of changes in streamflow, suspended-sediment transport, and water quality that may result from military training activities difficult to observe or quantify. There are several areas where refinements in data collection or an expanded study area would help land managers better understand the potential effects of military training activities on waters downstream from the AGFC and PCMS.

Collection or evaluation of Lagrangian paired (upstream from training and downstream from training) water-quality and suspended-sediment samples could help to evaluate the effects of erosion-control ponds on the PCMS. These samples could be collected at an upstream site and the currently monitored downstream sites in Van Bremer, Taylor, Lockwood, Red Rock, or Bent drainage basins (fig. 2). Observed changes in water quality or suspended-sediment transport could then be correlated with the number, size, capacity, and spatial distribution of the erosion-control ponds within these drainage basins. Targeted pre- and post-maneuver sediment and water-quality sampling and increased collection of Lagrangian paired samples could help define the effects of military training on environmental processes and support land-management decisions. Having more robust datasets at fewer key sites would improve the ability to detect spatial and temporal changes in suspended-sediment transport or water quality caused by training activities. This could be done by reducing the precipitation network, eliminating some water-quality sampling at sites that are frequently dry, and establishing continuous streamflow, suspended-sediment, and water-quality monitors at selected sites near the boundaries of the AGFC and PCMS.

Summary

Frequent and prolonged military training maneuvers are an intensive type of land use that may disturb land cover, compact soils, and have lasting effects on the hydrology and ecosystems of adjacent streams. In support of military and regulatory programs, and to better understand the potential effect of military training activities on hydrologic and environmental processes, the U.S. Geological Survey (USGS) in cooperation with the Army established a hydrologic and water-quality data-collection network on the U.S. Army Garrison Fort Carson (AGFC) in 1978 and on the Piñon Canyon Maneuver Site (PCMS) in 1982. The networks were designed to assess the quantity and quality of water resources and monitor the potential effects of military training activities on streamflow, sediment transport, and water quality. The purpose of this report is to present precipitation amount, streamflow, suspended-sediment, and water-quality data collected by the USGS at the AGFC and PCMS for water years (WYs) 2016–18 and to evaluate those data in relation to long-term data from the AGFC and PCMS. The USGS monitored as many as 26 sites on the AGFC and 17 sites on the PCMS for precipitation amount, streamflow, suspended sediment, and (or) water quality in WYs 2016–18.

On the AGFC, total annual precipitation in WYs 2016–18 was higher than the long-term mean for all 3 years at the Rod and Gun Meteorologic Station at Fort Carson, Colorado (CO; Rod and Gun). The precipitation totals for WY 2017 were either the largest on record or in the top three for Rod and Gun, Young Hollow Meteorologic Station at Fort Carson, CO (Young Hollow), and Sullivan Park Meteorologic Station at Fort Carson, CO. There were statistically significant upward trends in annual precipitation at Rod and Gun and Young Hollow.

On the PCMS, total annual precipitation in WYs 2016–18 was larger than the long-term mean for all 3 years at Brown Sheep Camp Meteorologic Station near Tyrone, CO; CIG Pipeline South Meteorologic Station near Simpson, CO; Bear Springs Hills Meteorologic Station near Houghton, CO (Bear Springs); and Upper Red Rock Canyon Meteorologic Station near Houghton, CO (Upper Red Rock). The precipitation totals for WY 2017 were the largest on record for all precipitation sites on the PCMS except Upper Bent Canyon Meteorologic Station near Delhi, CO (Upper Bent). There were statistically significant upward trends in precipitation at Bear Springs and Upper Red Rock.

Streamflow was calculated for 18 sites on the AGFC and seven sites on the PCMS in at least one of WYs 2016–18. For sites on the AGFC in WYs 2016–18, 3 sites had no measured streamflow, 3 sites had only 2 years of data, the median of daily mean streamflow for the other 12 sites ranged from 0.0 at several sites to 12.4 cubic feet per second (ft^3/s) at B Ditch Drain near Security, CO (B Ditch), and zero streamflow was recorded on more than 50 percent of days in each WY at 5 sites. Mean annual (or seasonal) streamflow in WYs 2016–18 was less than the long-term mean at Red Creek above Salt Canyon at Fort Carson, CO (Red Salt); Turkey Creek near Fountain, CO (Turkey Fountain); Turkey Creek above Teller Reservoir near Stone City, CO; Little Fountain Creek near Fountain, CO (Little Fountain); Rock Creek above Fort Carson, CO; Womack Ditch from Little Fountain Creek near Fort Carson, CO (Womack); and Merriams Little Fountain Ditch at Fort Carson, CO; and greater than the long-term mean at Lytle Ditch at Fort Carson, CO (Lytle); Turkey Creek West Seepage below Teller Reservoir near Stone City, CO (Turkey West Seep); and Turkey Creek East Seepage below Teller Reservoir near Stone City, CO (Turkey East Seep). At 8 of the 12 streamgages on the AGFC with streamflow data, there were general downward trends in mean annual or mean seasonal streamflow; however, those trends were only statistically significant for two sites, Womack and Ripley Ditch from Little Fountain Creek at Fort Carson, CO. The other four sites: Turkey Fountain, Lytle, Turkey West Seep, and Turkey East Seep, show upward trends in streamflow. However, those trends were only statistically significant for one site, Turkey West Seep. Unlike for precipitation, the mean annual or seasonal streamflow on the AGFC for WY 2017 was not in the top 3 for any of the 12 sites.

For sites on the PCMS in WYs 2016–18, the median of daily mean streamflow ranged from 0.0 ft^3/s at Red Rock Canyon Creek at mouth near Thatcher, CO (Red Rock) to 190 ft^3/s at Purgatoire River at Rock Crossing near Timpas, CO (Purgatoire Rock Crossing), and zero streamflow was recorded on more than 85 percent of days in each WY at four of the seven sites. In WYs 2016–18, mean annual (or seasonal) streamflow was less than the long-term mean streamflow in all 3 years at Taylor Arroyo below Rock Crossing near Thatcher, CO (Taylor), and Bent Canyon Creek at mouth near Timpas, CO (Bent). There were no statistically significant trends in mean annual (or seasonal) streamflow at sites on the PCMS and, unlike for precipitation, the mean streamflow for WY 2017 were not in the top three for any of the sites except Purgatoire Rock Crossing.

At the AGFC and PCMS study areas, one effect of military maneuvers may be an increase in streamflow resulting from increased runoff from denuded or compacted lands. A comparison between streamflow in Fountain Creek upstream from the AGFC and streamflow from the Fountain Creek tributaries that drain the AGFC indicate the potential effect these tributaries have on streamflow, suspended-sediment concentration and load, and water-quality conditions in Fountain Creek. In WYs 2016, 2017, and 2018, Fountain Creek tributaries that drain the AGFC had a combined mean annual streamflow of approximately 1.65, 14.2, and 3.62 percent of the mean annual streamflow at Fountain Creek at Security, Colo (Fountain Security), respectively.

Likewise, a comparison between streamflow in the Purgatoire River between Purgatoire River near Thatcher, CO (Purgatoire Thatcher) and Purgatoire Rock Crossing and streamflow from the Purgatoire River tributaries that drain the PCMS indicate the potential effects these tributaries have on streamflow or other conditions in the Purgatoire River. In WYs 2016, 2017, and 2018, Purgatoire River tributaries that drain the PCMS had a combined mean annual streamflow of approximately 1.8, 0.7, and 7.4 percent of the mean annual streamflow at the Purgatoire Rock Crossing site, respectively. Hence, streamflow from the monitored sites on the AGFC and PCMS represented only a small fraction of the streamflow in Fountain Creek and the Purgatoire River, and changes in streamflow that result from military maneuvers in the tributary basins were not likely to be detected in the downstream receiving waters.

Suspended-sediment concentrations, loads, and yields for WYs 2016–18 were analyzed at two sites on the AGFC. In WYs 2016, 2017, and 2018, mean seasonal suspended-sediment concentrations ranged from 3.10 milligrams per liter (mg/L) at Red Salt in WY 2018 to 155 mg/L at Little Fountain in WY 2017. Mean seasonal suspended-sediment loads ranged from 0.04 tons per day (t/d) at Red Salt in WY 2018 to 27.1 t/d at Little Fountain in WY 2018. The resulting suspended-sediment yields ranged from 0.28 tons per season per square mile ($t/s/mi^2$) at Red Salt in WY 2018 to 216 tons per year per square mile ($t/y/mi^2$) at Little Fountain in WY 2017. Suspended-sediment yields at Red Salt and Little Fountain in WYs 2016–18 were all less than the long-term means at those sites.

Suspended-sediment concentrations, loads, and yields for WYs 2016–18, were analyzed at five sites on the PCMS. In WYs 2016–18, mean seasonal suspended-sediment concentrations (at sites with some streamflow during the WY) ranged from 1.12 mg/L to 41.8 mg/L, mean suspended-sediment loads ranged from 0.01 t/d to 13.1 t/d, and the resulting seasonal suspended-sediment yields ranged from 0.06 to 57.4 $t/s/mi^2$. Suspended-sediment yields at Van Bremer Arroyo near Model, CO (Van Bremer), Taylor, Lockwood Canyon Creek near Thatcher, CO (Lockwood), Red Rock, and Bent in WYs 2016–18, were all less than the long-term means.

At the AGFC and PCMS study areas, one effect of military maneuvers may be an increase in suspended-sediment concentrations and loads due to increased sediment loss from denuded, compacted, or otherwise disturbed lands. A comparison between the suspended-sediment concentrations and loads for Fountain Security and the suspended-sediment concentrations and loads from the Fountain Creek tributaries that drain the AGFC indicate the potential effect of these tributaries on suspended-sediment concentration and load, and water-quality conditions in Fountain Creek. In WYs 2016, 2017, and 2018, the Fountain Creek tributaries that drain the AGFC had seasonal suspended-sediment loads of approximately 1.3, 2.5, and 7.6 percent of the seasonal suspended-sediment load at Fountain Security, respectively.

The same analysis of the relative magnitude of suspended-sediment concentrations and loads cannot be made for the PCMS because of a lack of current suspended-sediment data at either Purgatoire Thatcher or Purgatoire Rock Crossing. Current suspended-sediment concentrations and loads from the tributary sites were compared to historical (WYs 1986–92) data from the Purgatoire Thatcher site. In WYs 2016, 2017, and 2018, at the five tributary sites to the Purgatoire River, the sums of seasonal suspended-sediment loads were about 0.25, 0.17, and 3.2 percent of the historical mean of suspended-sediment loads at Purgatoire Thatcher, respectively.

Spearman's rank correlation coefficient was used to evaluate the strength and form of the relations between daily total precipitation and daily mean streamflow and between daily mean streamflow and suspended-sediment concentration and load for WYs 2016–18. For the sites on the AGFC and PCMS, there was weak or statistically insignificant positive correlations between precipitation and streamflow at nearby streamgages, but strong statistically significant positive correlations between streamflow and suspended-sediment concentration and load. The ephemeral nature of the streams, the quantity and timing of precipitation, air temperature, seasonal soil-moisture deficits, and effective runoff detention in erosion–control ponds could all contribute to inconsistent conversion of precipitation to streamflow. Correlation was also used to evaluate the strength and form of the relations between daily mean streamflow and daily mean suspended-sediment concentration and load for WYs 2016–18. All sites on the AGFC and PCMS had very strong statistically significant positive relations between streamflow and suspended-sediment concentration and load.

Water-quality data for as many as 43 parameters, including 6 physical properties, *Escherichia coli* (*E. coli*), and total coliforms (biological), 7 nutrients, 8 inorganic nonmetals, 18 inorganic metals, mercury, and uranium (radiochemical) were analyzed from samples collected from sites on or near the AGFC and the PCMS during WYs 2016–18. At 3 sites on the AGFC, 9 water-quality samples were collected, and 37 samples were collected from four sites on the PCMS. The concentrations of selected water-quality parameters were compared to regulatory standards for aquatic life set forth by Colorado Department of Public Health and Environment (CDPHE) Regulation 31 and Regulation 32 or, if there is no CDPHE standard, to U.S. Environmental Protection Agency (EPA) aquatic-life criteria. There is at least 1 CDPHE standard or EPA criterion for 30 of the 43 water-quality parameters.

For samples from both the AGFC and the PCMS in WYs 2016–18, the concentrations of most water-quality parameters were compliant with the associated standards or criteria. However, there were some exceedances of standards or criteria.

Of the 9 samples from the AGFC, 8 exceeded the recreational class standard for *E. coli* concentration, 4 exceeded the chronic phosphorus aquatic-life standard, 3 exceeded the CDPHE chronic aquatic-life standard and the EPA criterion for selenium, 2 exceeded the CDPHE chronic standard for aluminum, 5 exceeded the EPA chronic criterion for aluminum, 1 exceeded the CDPHE chronic iron standard, and 2 exceeded the CDPHE chronic manganese standard for the associated stream segment.

Of the 37 samples from the PCMS, 3 exceeded the recreational class standard for *E. coli* concentration, 5 exceeded the chronic phosphorus aquatic-life standard, 36 exceeded the chronic sulfate aquatic-life standard, 2 exceeded the EPA aquatic-life criterion for selenium, 2 exceeded the EPA chronic aluminum criterion, 1 exceeded the CDPHE chronic iron standard, and 13 exceeded the CDPHE chronic manganese standard for the associated stream segment.

Changes in water-quality conditions that occur as streams traverse or pass by the AGFC and PCMS were assessed by comparing long-term mean and median concentrations at upstream and downstream sites, and changes in concentrations and loads in upstream and downstream Lagrangian paired samples.

On the AGFC, the absolute percent difference (APD) between the long-term median concentrations for Little Fountain Creek above Highway 115 at Fort Carson, CO (Little Fountain 115) and Little Fountain for 39 parameters ranged from −166 to 198 percent. Of the 39 parameters, 28 had increases in median concentration and 11 had either no change or decreases in median concentration. In a Lagrangian pair of samples collected from Little Fountain and Little Fountain 115 in August 2016, streamflow increased from 11 to 15 ft^3/s, and the APDs of loads for 26 parameters ranged from −138 to 183 percent, and 22 parameters had increases in load and 4 parameters had decreases in loads. In a Lagrangian pair of samples collected from Little Fountain 115 and Little Fountain on August 9–10, 2017, streamflow increased from 4.3 to 17 ft^3/s, the APDs of loads for 23 parameters ranged from 17.9 to 199 percent, and no parameters had decreases in loads.

On the PCMS, the ADP between the long-term median concentrations for Purgatoire Thatcher and Purgatoire Rock Crossing for 39 parameters ranged from −114 to 183 percent, 22 parameters had increases in mean concentration, and 17 parameters had no change or decreases in median concentration. In a Lagrangian pair of samples collected from Purgatoire Rock Crossing and Purgatoire Thatcher in November 2016, streamflow was equal at both sites and the APDs of loads for 21 parameters ranged from −73.7 to 86.6 percent, 12 parameters had increases in load, and 9 parameters had no change or decreases in loads. In a Lagrangian pair of samples collected from Purgatoire Thatcher and Purgatoire Rock Crossing in August 2018, streamflow increased from 1.6 to 2.9 ft^3/s, and the APDs of loads for 20 parameters ranged from −3.69 to 138 percent, 19 parameters had increases in load, and only magnesium had a decrease in load.

The surficial geology affects the water quality of runoff from precipitation, shallow groundwater, and the streams and other surface-water bodies on the AGFC and PCMS. Many of the elements with elevated concentrations at sites on the AGFC and PCMS, including arsenic, phosphorus, molybdenum, selenium, and sulfate, are found in the Cretaceous shales that underlie the majority of both study locations.

Identifying the potential effects of military training on water quality in adjacent streams on the AGFC and PCMS is difficult because of the ephemeral nature of streamflow, the limited number of sampling locations and samples, and limited access to the study areas. At three sites on the PCMS, pairs of water-quality samples were collected before and after an April–May 2017 training event. A comparison of concentrations and loads for these pairs of samples may provide an indication of the potential effects of military training. Streamflow at the time of the May sample was approximately 4 times larger than streamflow at the time of the March sample at Van Bremer, 20 times larger than streamflow for the March sample at Purgatoire Thatcher, and 35 times larger than streamflow for the March sample at Purgatoire Rock Crossing. The APDs of concentrations for 27 parameters ranged from −71.7 to 183 percent, and 7 parameters had increases in concentration, whereas 22 parameters had no change or decreases in concentrations. The APDs of loads for 24 parameters ranged from 141 to 198 percent. Hence, most parameters had decreases in concentration but increases in load, which is what would be expected given the higher streamflow at the time of collection of the May compared to the March samples.

Spatial variability of precipitation and ephemeral streamflow on the AGFC and PCMS makes identification of changes in streamflow, suspended-sediment transport, and water quality that may result from military training activities difficult to observe. Areas where refinements in data collection would help land managers better understand the potential effects of military training activities on surface water on and downstream from the AGFC and PCMS could include collection of additional Lagrangian paired water-quality and suspended-sediment samples, targeted pre- and post-maneuver sediment and water-quality samples, and more robust datasets at fewer key sites; and establishment of continuous streamflow, suspended-sediment, and water-quality monitors at key sites near the boundaries of the AGFC and PCMS.

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Appendixes

Appendix 1. Analysis Methods for Water-Quality Parameters

Appendix 1 presents a table of information related to the analytical methods used for this study.

Table 1.1. U.S. Geological Survey water-quality parameters, parameter groups, parameter codes, result units, analytical methods, and laboratory reporting levels (from U.S. Geological Survey, 2020).

[MPN/100 mL, most probable number of colonies per 100 milliliters; —, not reported; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; ft^3/s, cubic feet per second; °C, degree Celsius]

Water-quality parameter	Parameter group	Parameter code	Result units	Analytical method	Laboratory reporting level
Escherichia coli	Biological	50468	MPN/100 mL	Water, colilert	—
Total coliforms	Biological	50569	MPN/100 mL	Water, colilert	—
Alkalinity, filtered	Inorganics, majors, nonmetals	29801	mg/L as $CaCO_3$	Fixed endpoint (pH 4.5) titration in laboratory	0.1
Chloride, filtered	Inorganics, majors, nonmetals	00940	mg/L	Ion chromatography	0.02–0.06
Fluoride, filtered	Inorganics, majors, nonmetals	00950	mg/L	Ion chromatography	0.01
Silica, filtered	Inorganics, majors, nonmetals	00955	mg/L	Inductively coupled plasma	0.018
Sulfate, filtered	Inorganics, majors, nonmetals	00945	mg/L	Ion chromatography	0.02–0.09
Calcium, filtered	Inorganics, majors, metals	00915	mg/L	Inductively coupled plasma	0.022
Magnesium, filtered	Inorganics, majors, metals	00925	mg/L	Inductively coupled plasma	0.011
Potassium, filtered	Inorganics, majors, metals	00935	mg/L	Inductively coupled plasma	0.03
Sodium, filtered	Inorganics, majors, metals	00930	mg/L	Inductively coupled plasma	0.06
Ammonia, filtered	Nutrients	00608	mg/L	Colorimetry	0.01
Ammonia, unfiltered	Nutrients	00610	mg/L	Colorimetry	0.02
Nitrite plus nitrate, filtered	Nutrients	00631	mg/L	Colorimetry	0.04
Total nitrogen, unfiltered [nitrate + nitrite + ammonia + organic-N]	Nutrients	62855	mg/L	Colorimetry	0.05
Orthophosphate, filtered	Nutrients	00671	mg/L	Colorimetry	0.004
Phosphorus, filtered	Nutrients	00666	mg/L	Colorimetry	0.02
Phosphorus, unfiltered	Nutrients	00665	mg/L	Colorimetry	0.004
Aluminum, filtered	Inorganics, minor, metals	01106	µg/L	Inductively coupled plasma-mass spectrometry	2.2
Barium, filtered	Inorganics, minor, metals	01005	µg/L	Inductively coupled plasma-mass spectrometry	0.1–0.25
Beryllium, filtered	Inorganics, minor, metals	01010	µg/L	Inductively coupled plasma-mass spectrometry	0.006–0.02
Cadmium, filtered	Inorganics, minor, metals	01025	µg/L	Inductively coupled plasma-mass spectrometry	0.016–0.03
Chromium, filtered	Inorganics, minor, metals	01030	µg/L	Inductively coupled plasma-mass spectrometry	0.07–0.3
Cobalt, filtered	Inorganics, minor, metals	01035	µg/L	Inductively coupled plasma-mass spectrometry	0.023–0.05
Copper, filtered	Inorganics, minor, metals	01040	µg/L	Inductively coupled plasma-mass spectrometry	0.8
Iron, filtered	Inorganics, minor, metals	01046	µg/L	Inductively coupled plasma-mass spectrometry	4
Lead, filtered	Inorganics, minor, metals	01049	µg/L	Inductively coupled plasma-mass spectrometry	0.025–0.04
Manganese, filtered	Inorganics, minor, metals	01056	µg/L	Inductively coupled plasma-mass spectrometry	0.15–0.4

Table 1.1. U.S. Geological Survey water-quality parameters, parameter groups, parameter codes, result units, analytical methods, and laboratory reporting levels (from U.S. Geological Survey, 2020).—Continued

[MPN/100 mL, most probable number of colonies per 100 milliliters; —, not reported; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; ft^3/s, cubic feet per second; °C, degree Celsius]

Water-quality parameter	Parameter group	Parameter code	Result units	Analytical method	Laboratory reporting level
Mercury, unfiltered	Inorganics, minor, metals	71900	µg/L	Inductively coupled plasma-mass spectrometry	0.005
Molybdenum, filtered	Inorganics, minor, metals	01060	µg/L	Inductively coupled plasma-mass spectrometry	0.014–0.5
Nickel, filtered	Inorganics, minor, metals	01065	µg/L	Inductively coupled plasma-mass spectrometry	0.09–0.2
Silver, filtered	Inorganics, minor, metals	01075	µg/L	Inductively coupled plasma-mass spectrometry	0.005–0.02
Zinc, filtered	Inorganics, minor, metals	01090	µg/L	Inductively coupled plasma-mass spectrometry	1.4–2.0
Antimony, filtered	Inorganics, minor, nonmetals	01095	µg/L	Inductively coupled plasma-mass spectrometry	0.027
Arsenic, filtered	Inorganics, minor, nonmetals	01000	µg/L	Inductively coupled plasma-mass spectrometry	0.04–0.1
Selenium, filtered	Inorganics, minor, nonmetals	01145	µg/L	Inductively coupled plasma-mass spectrometry	0.03–0.05
Uranium, filtered [natural]	Radiochemical	22703	µg/L	Inductively coupled plasma-mass spectrometry	0.004–0.014
Hardness as $CaCO_3$	Physical	00900	mg/L	Calculated	1
Oxygen, dissolved	Physical	00300	mg/L	Luminescence	0.1
pH, unfiltered, field	Physical	00400	standard pH units	Multiprobe	0.1
Solids, dissolved	Physical	70300	mg/L	Evaporation	20
Specific conductance	Physical	00095	µS/cm	Multiprobe	1
Discharge, instantaneous	Physical	00061	ft^3/s	Stage-discharge rating	0.01
Suspended–sediment concentration	Physical	80154	mg/L	Filtration	1
Suspended–sediment discharge	Physical	80155	tons/day	Filtration	1
Water temperature	Physical	00010	°C	Multiprobe	0.1

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U.S. Geological Survey [USGS], 2020, National Water Information System—USGS water data for the Nation: U.S. Geological Survey website, accessed October 2020 at https://doi.org/10.5066/F7P55KJN.

Appendix 2. Graphs of Daily Total Precipitation, Daily Mean Streamflow, and Daily Mean Suspended–Sediment Concentration and Load for Sites on the U.S. Army Garrison Fort Carson and the Piñon Canyon Maneuver Site, Colorado, for Water Years 2016–18

Appendix 2 presents graphs generated from the U.S. Geological Survey National Water Information System database (https://doi.org/10.5066/F7P55KJN). Some of the values that are shown are reported as estimated (Novak, 1985). For streamflow at the study sites, gage height can be affected by backwater from ice, beaver dam, debris, and so forth, if the site was considered to be in backwater, the stage-discharge model was not valid, and streamflow must be estimated. Abbreviations used in graphs and captions are those used in the National Water Information System database (Ft, Fort; Ft., Fort; CO, Colorado; nr, near; Met, Meterologic; Met., Meterologic; ab, above; Res, Reservoir; bl, below). For an explanation of other terms refer to the U.S. Geological Survey website at https://wdr.water.usgs.gov/current/documentation.html.

U.S. Army Garrison Fort Carson

Figures 2.1–2.11 provide graphs of daily total precipitation, daily mean streamflow, and daily mean suspended–sediment concentration and load for sites on the U.S. Army Garrison Fort Carson, Colorado, for water years 2016–18.

Piñon Canyon Maneuver Site

Figures 2.12–2.37 provide graphs of daily total precipitation, daily mean streamflow, and daily mean suspended–sediment concentration and load for sites on the Piñon Canyon Maneuver Site, Colorado, for water years 2016–18.

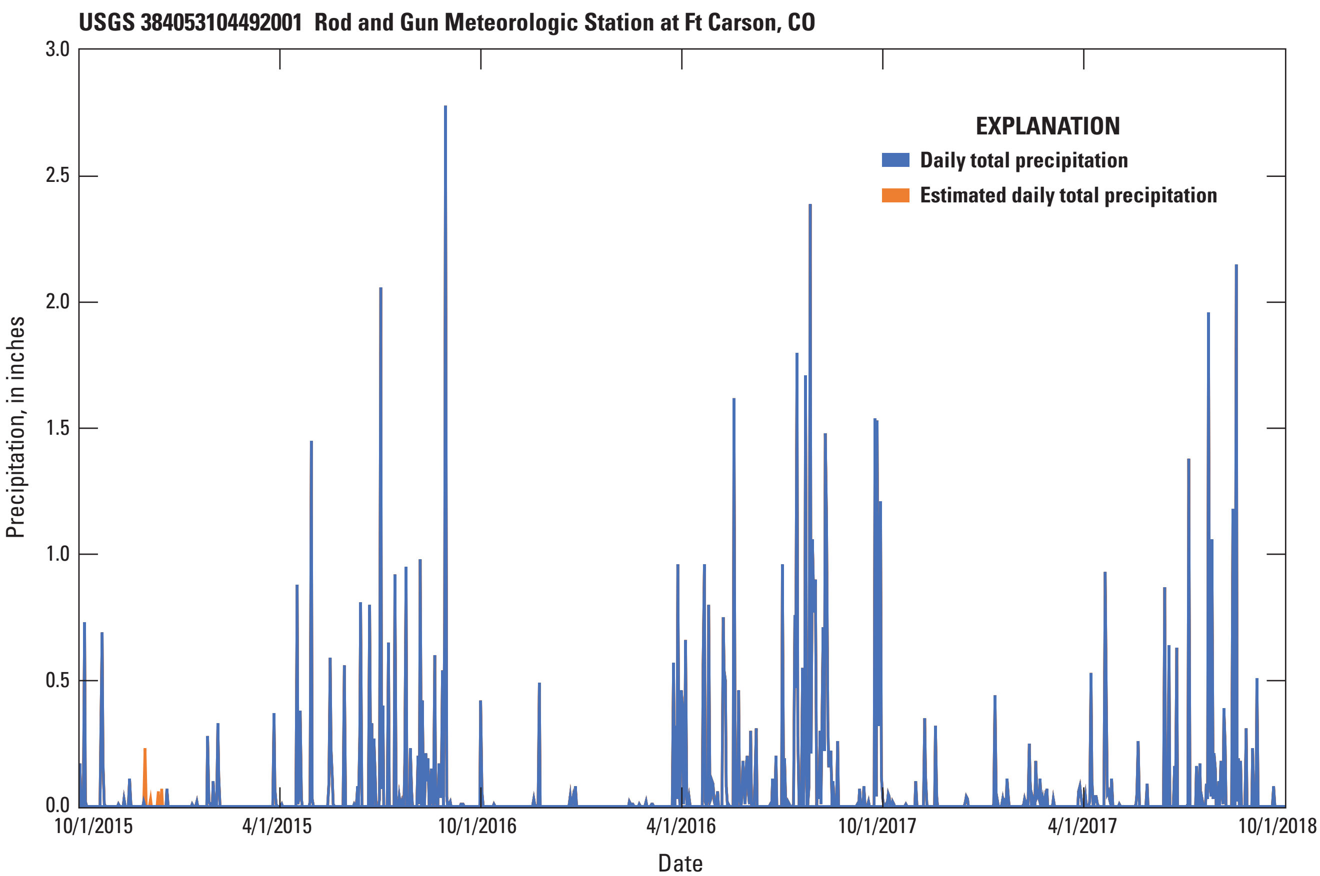

Figure 2.1. Daily total (sum) precipitation at Rod and Gun Meteorologic Station at Ft Carson, CO.

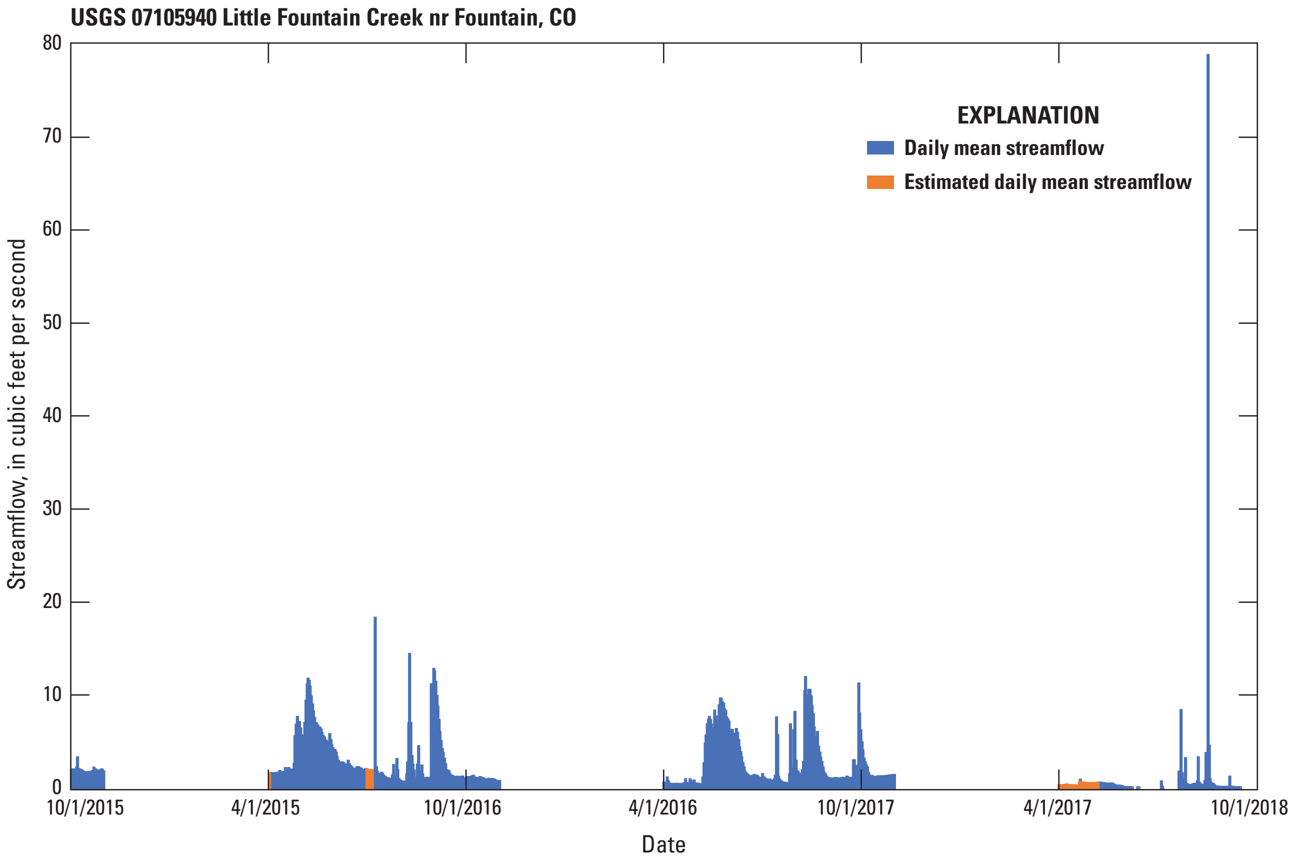

Figure 2.2. Daily mean streamflow (discharge) at Little Fountain Creek nr Fountain, CO.

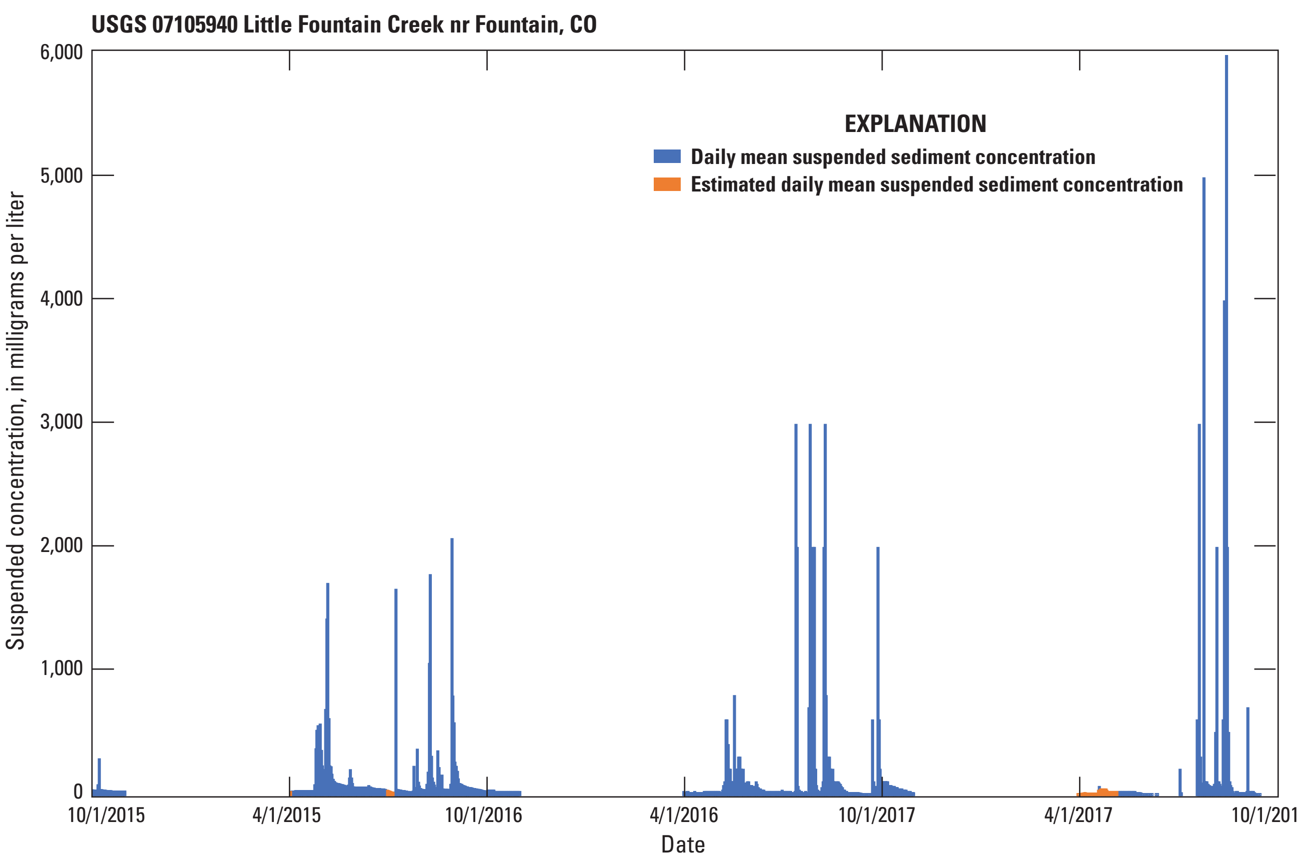

Figure 2.3. Daily mean suspended-sediment concentration at Little Fountain Creek nr Fountain, CO.

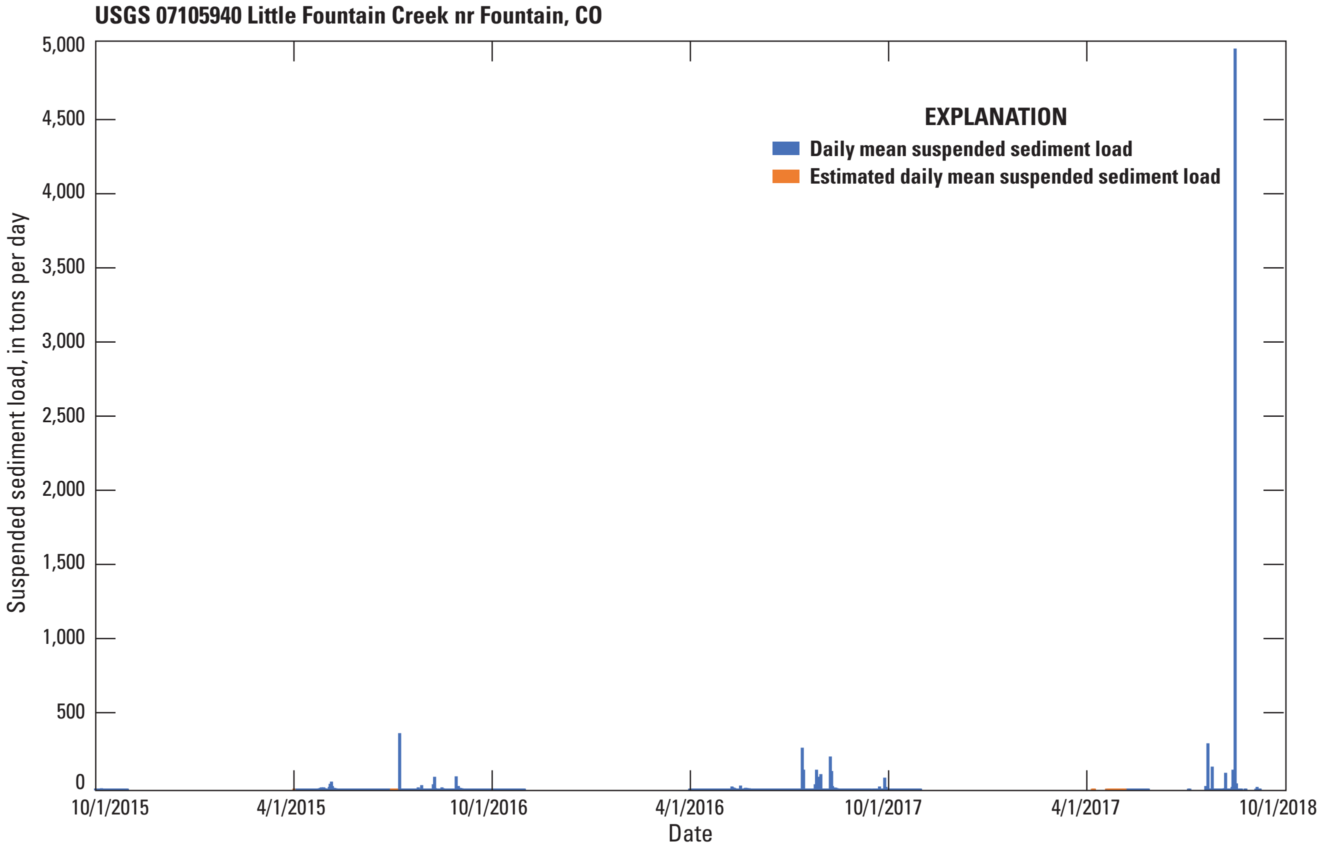

Figure 2.4. Daily mean suspended-sediment discharge (load) at Little Fountain Creek nr Fountain, CO.

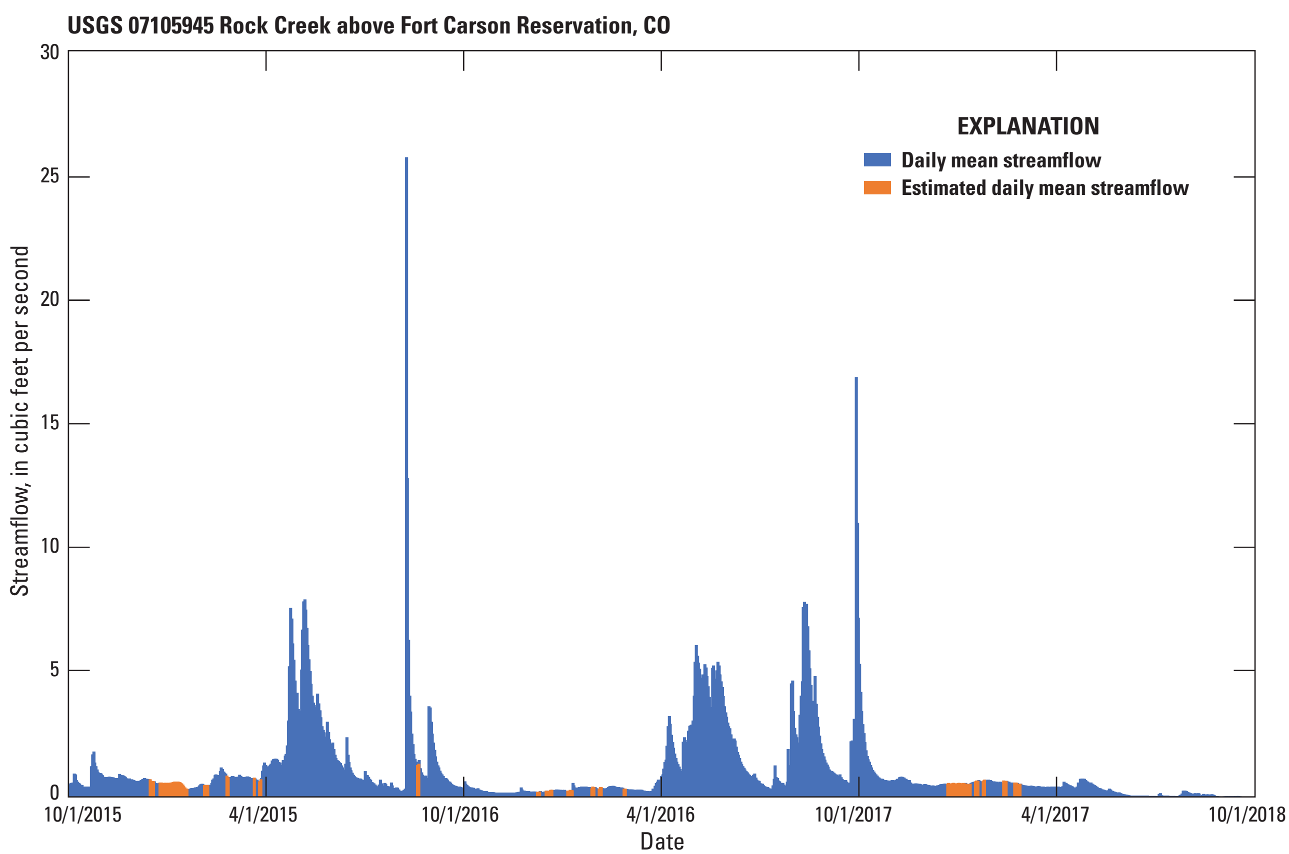

Figure 2.5. Daily mean streamflow (discharge) at Rock Creek above Fort Carson Reservation, CO.

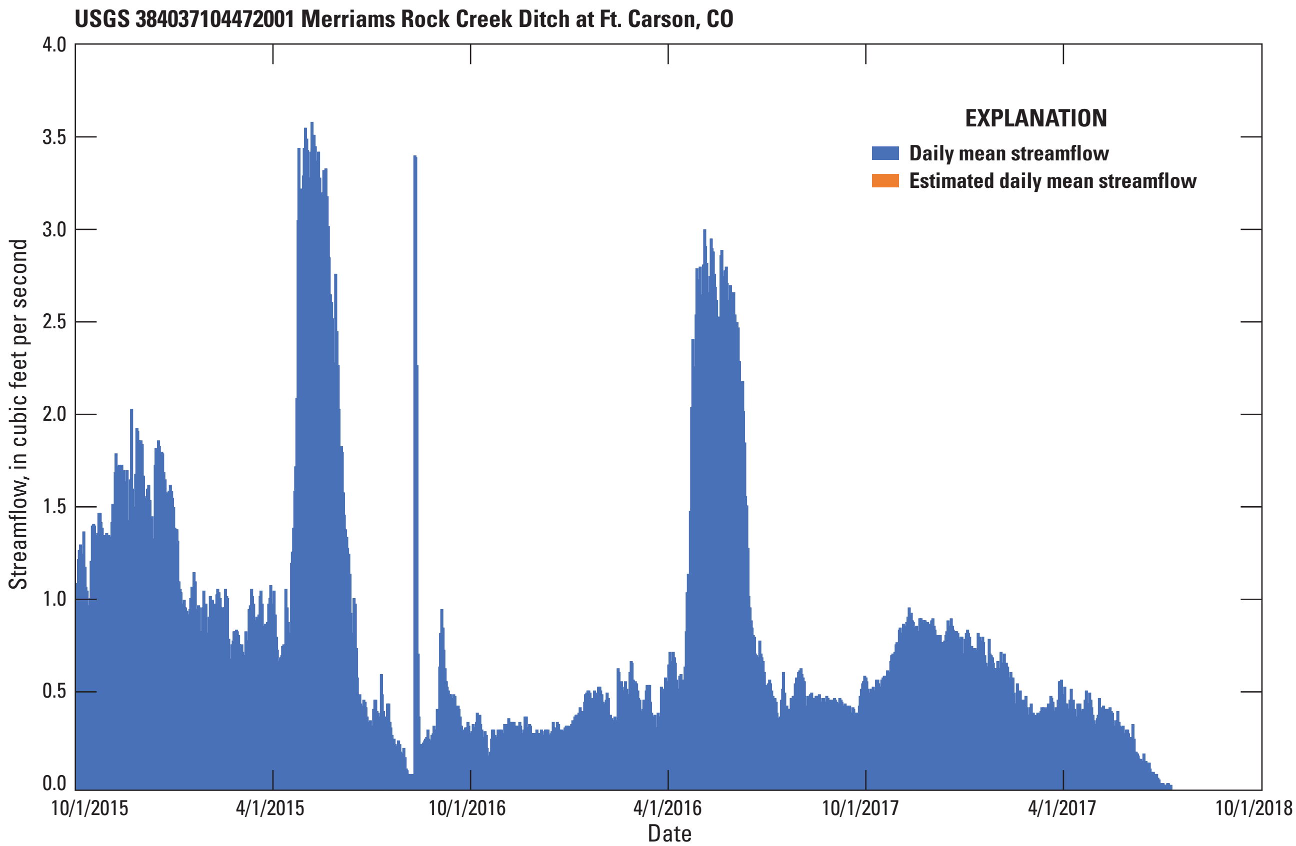

Figure 2.6. Daily mean streamflow (discharge) at Merriams Rock Creek Ditch at Ft. Carson, CO.

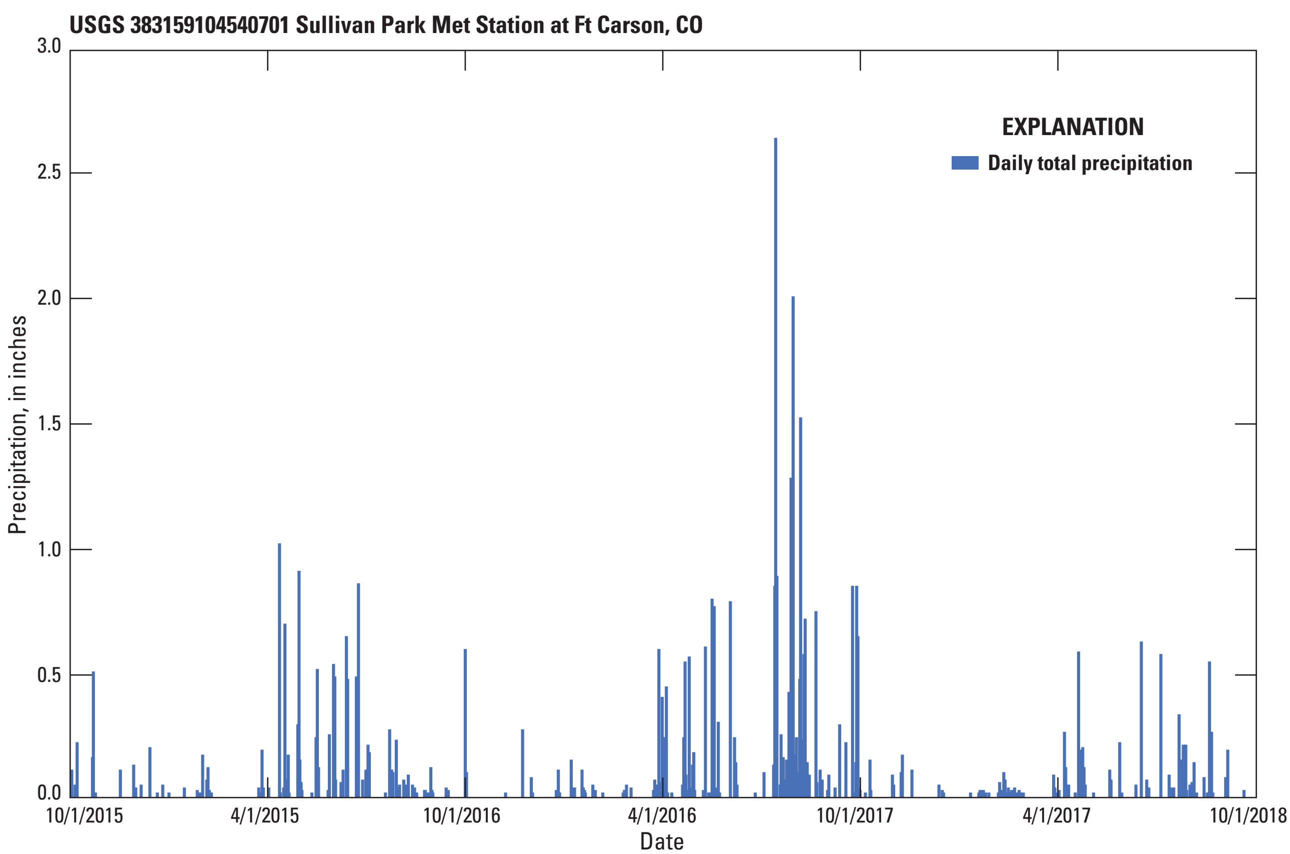

Figure 2.7. Daily total (sum) precipitation at Sullivan Park Met Station at Fort Carson, CO.

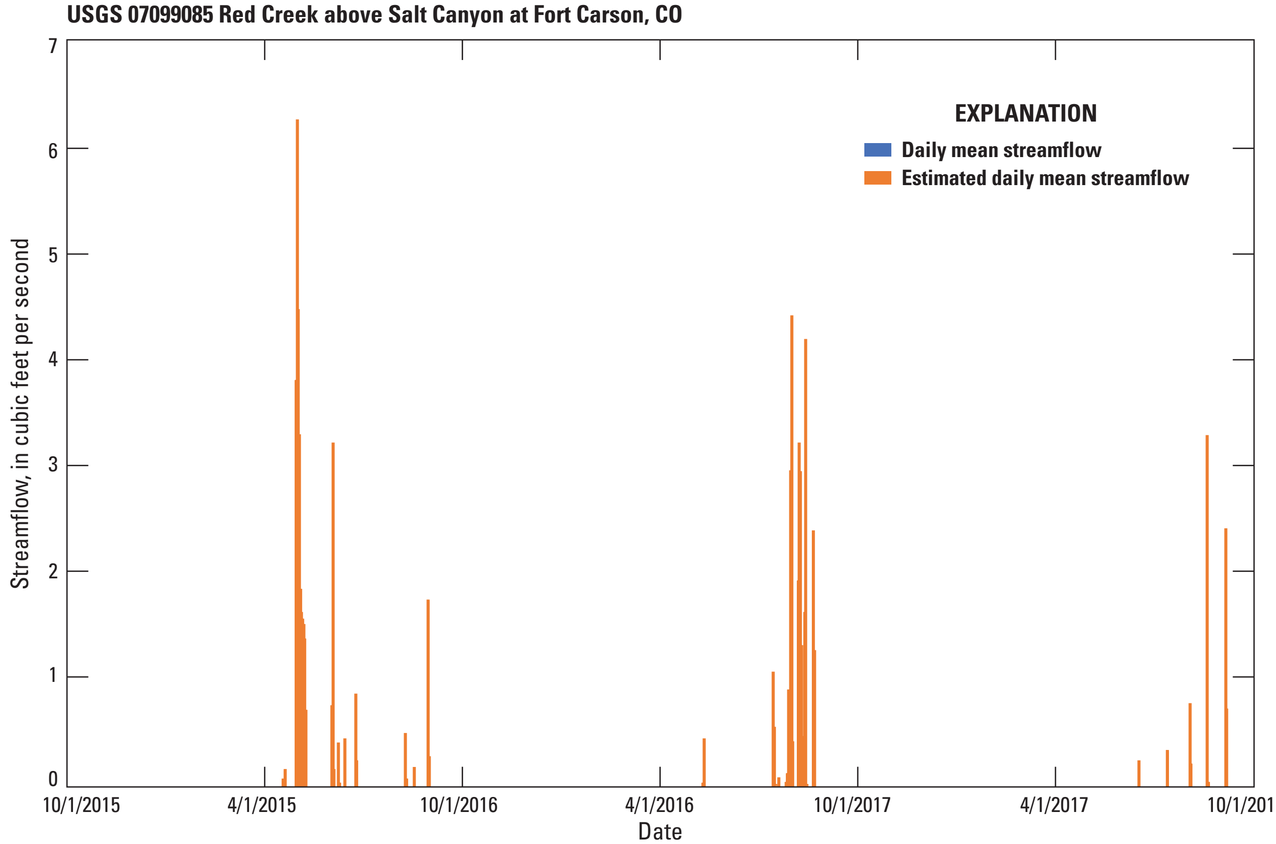

Figure 2.8. Daily mean streamflow (discharge) at Red Creek above Salt Canyon at Fort Carson, CO.

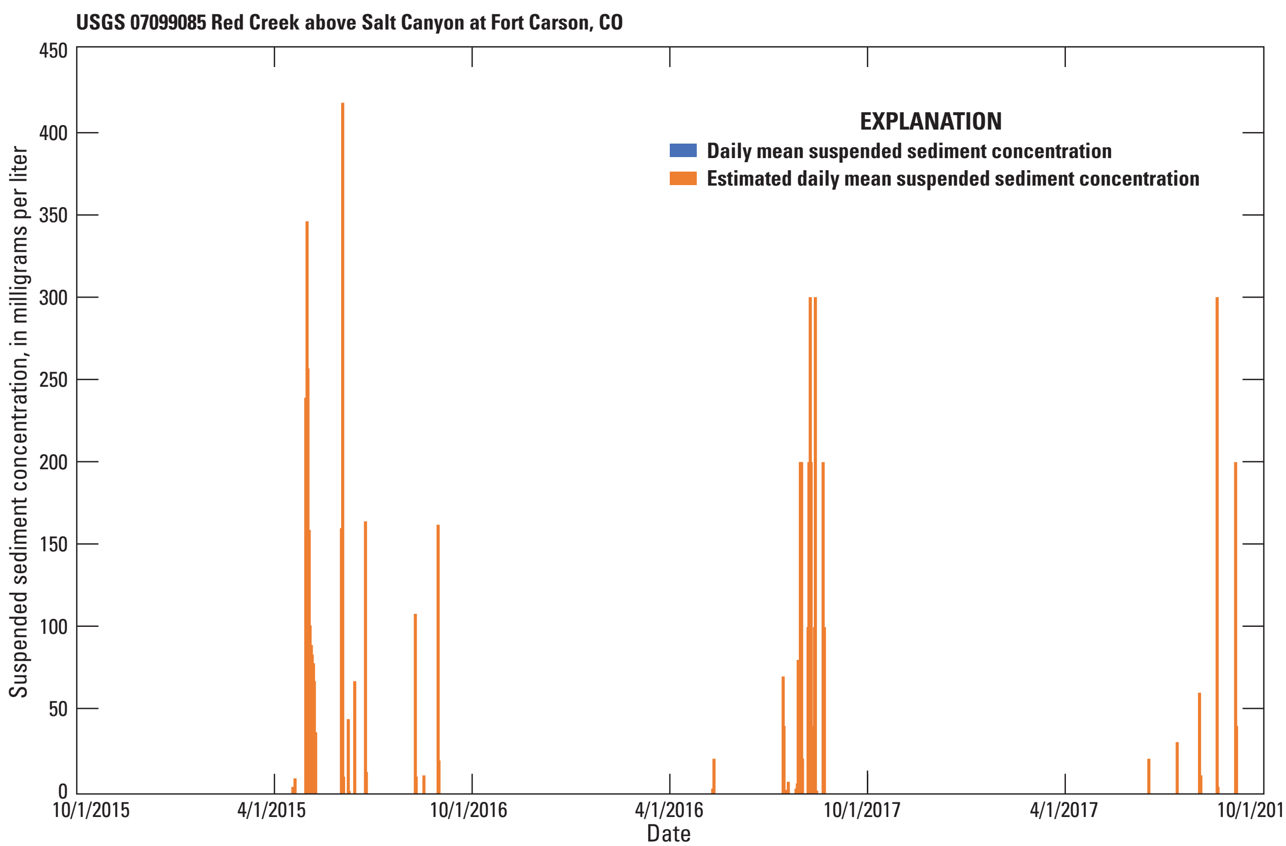

Figure 2.9. Daily mean suspended-sediment concentration at Red Creek above Salt Canyon at Fort Carson, CO.

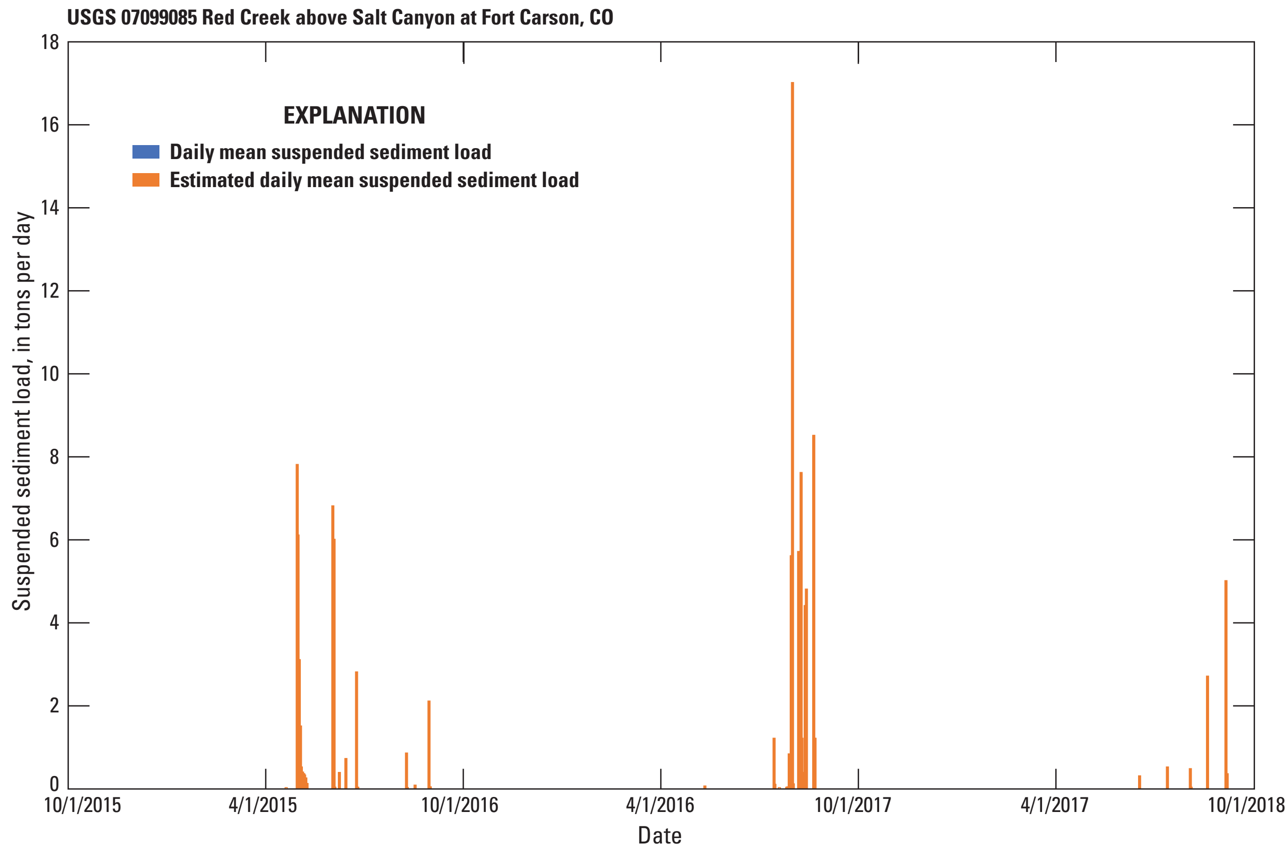

Figure 2.10. Daily mean suspended-sediment discharge (load) at Red Creek above Salt Canyon at Fort Carson, CO.

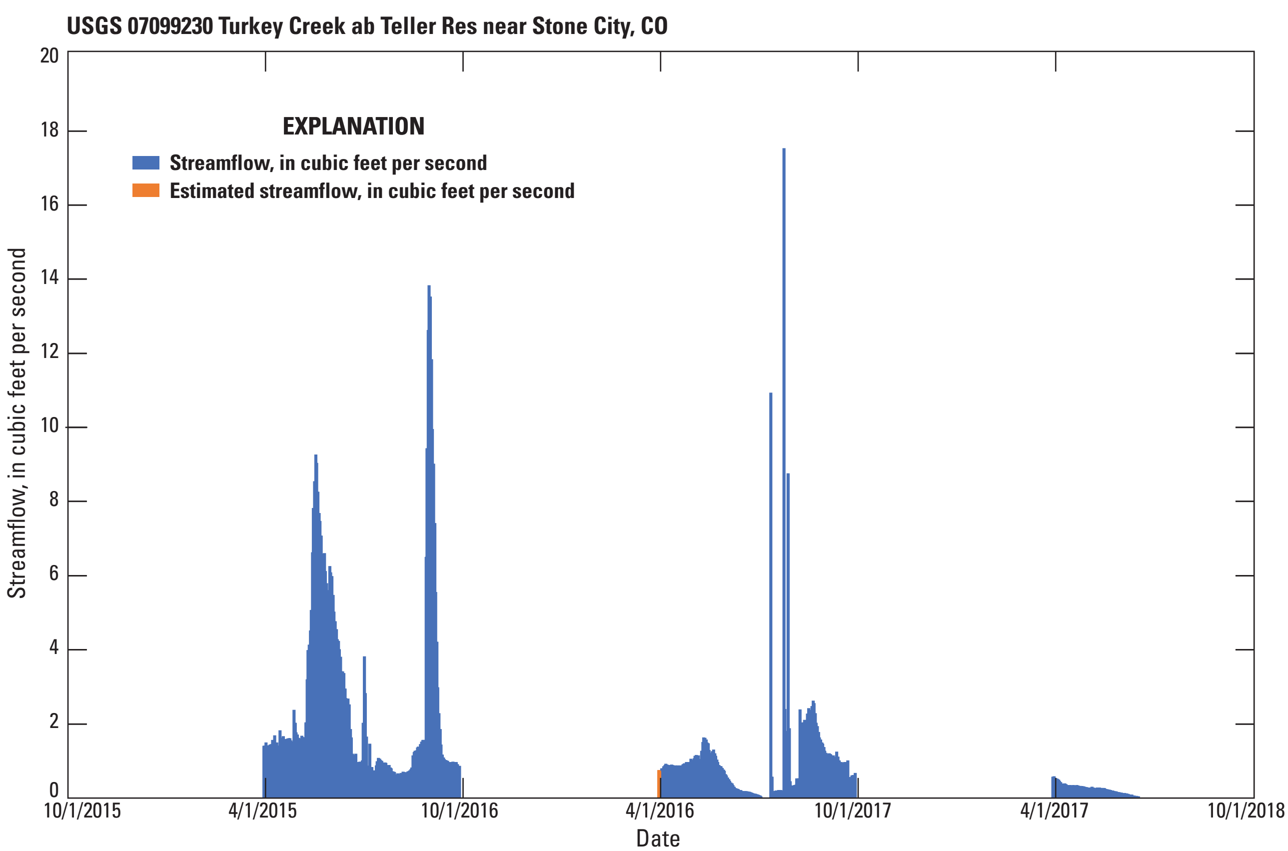

Figure 2.11. Daily mean streamflow (discharge) at Turkey Creek ab Teller Res near Stone City, CO.

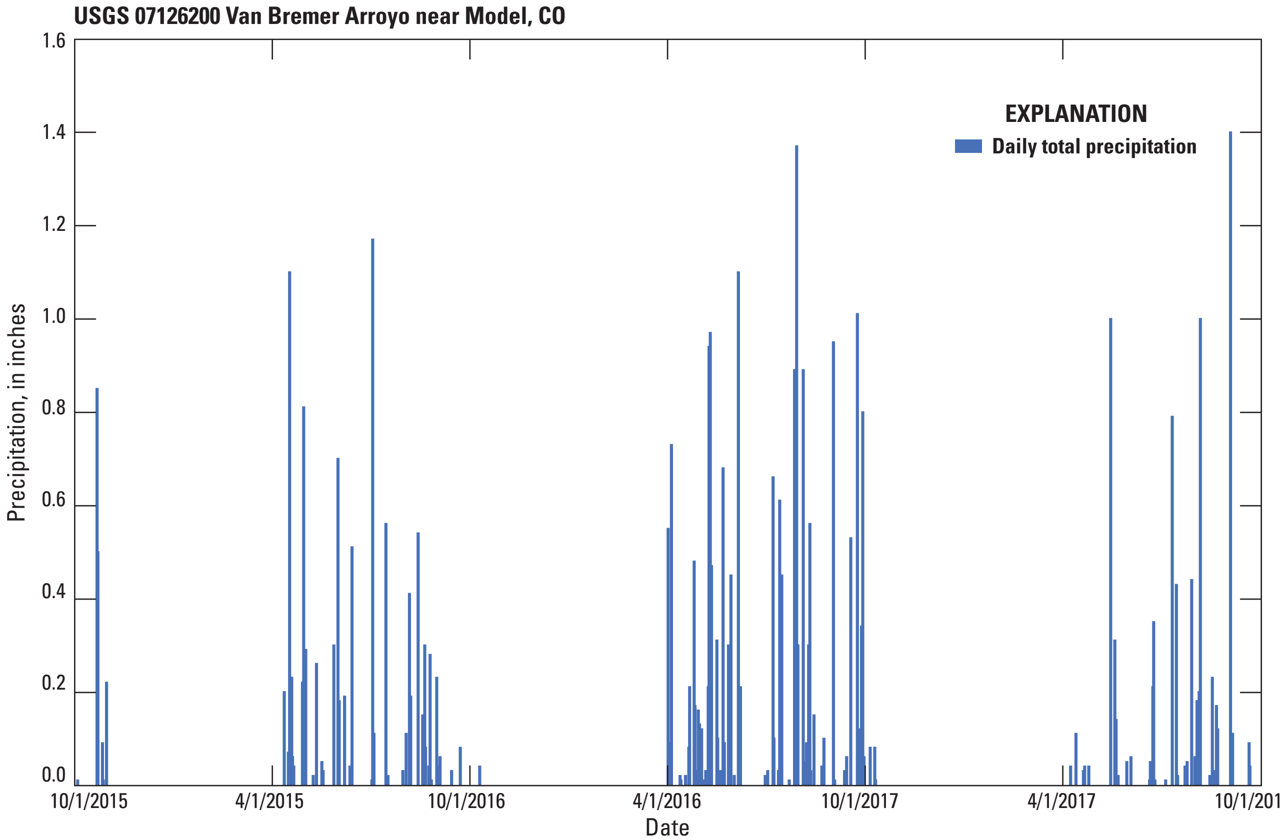

Figure 2.12. Daily total (sum) precipitation at Van Bremer Arroyo near Model, CO.

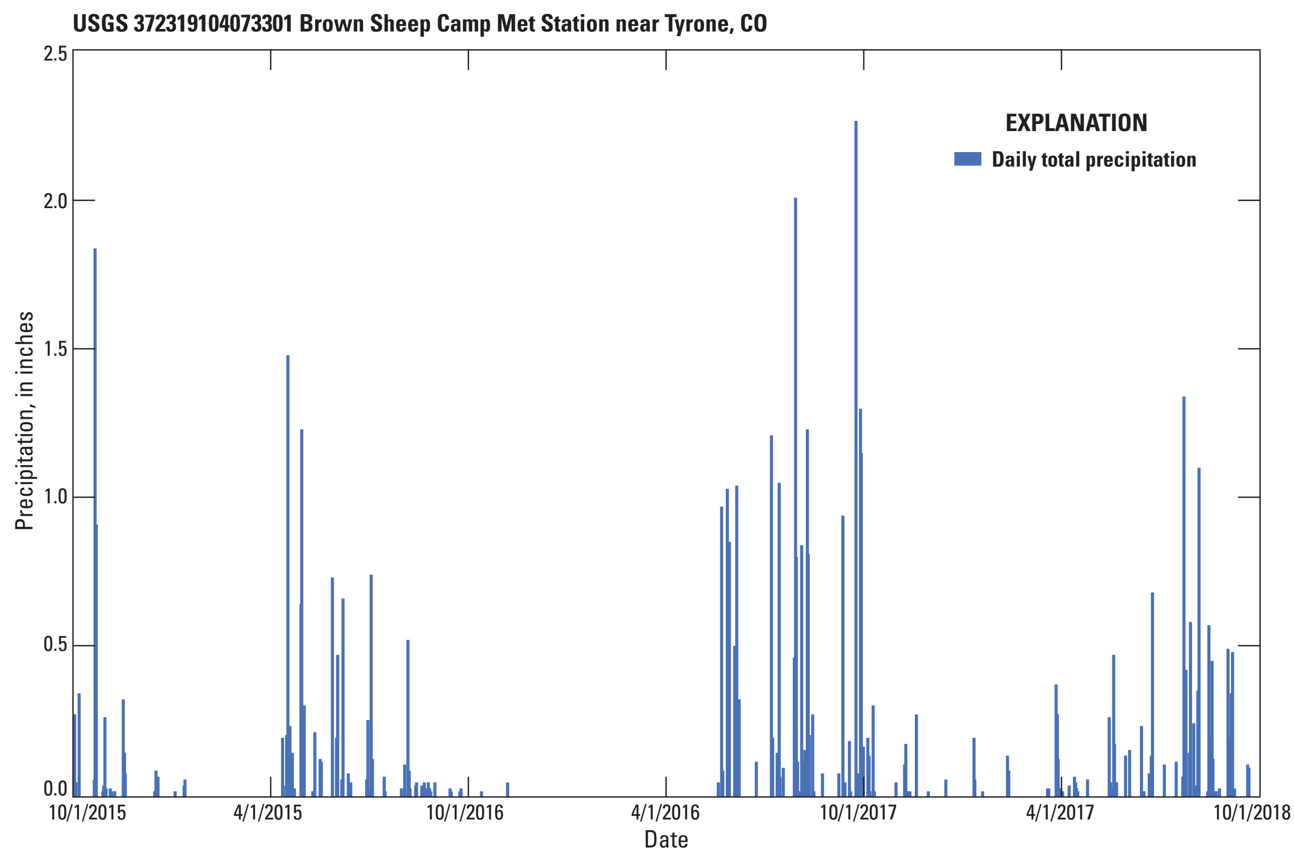

Figure 2.13. Daily total (sum) precipitation at Brown Sheep Camp Met Station near Tyrone, CO.

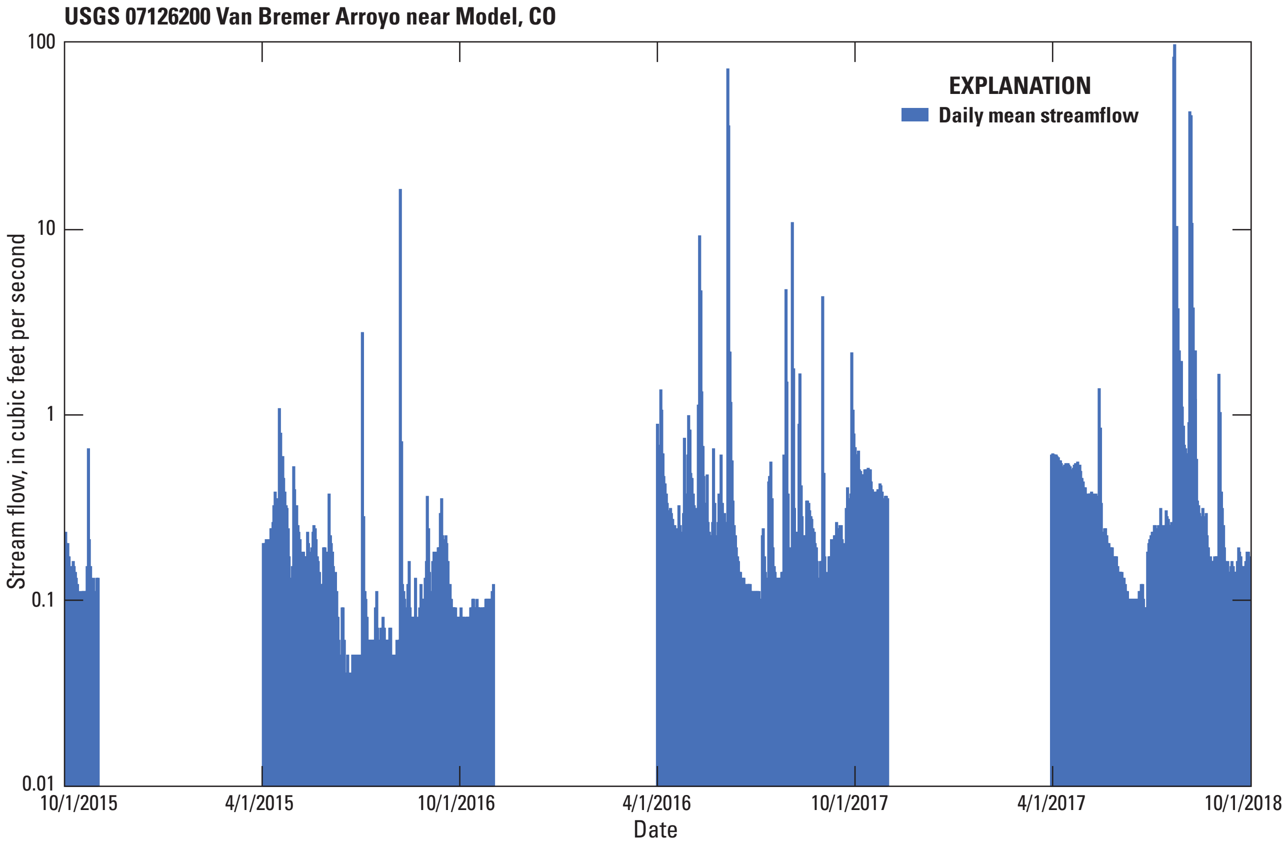

Figure 2.14. Daily mean streamflow (discharge) at Van Bremer Arroyo near Model, CO.

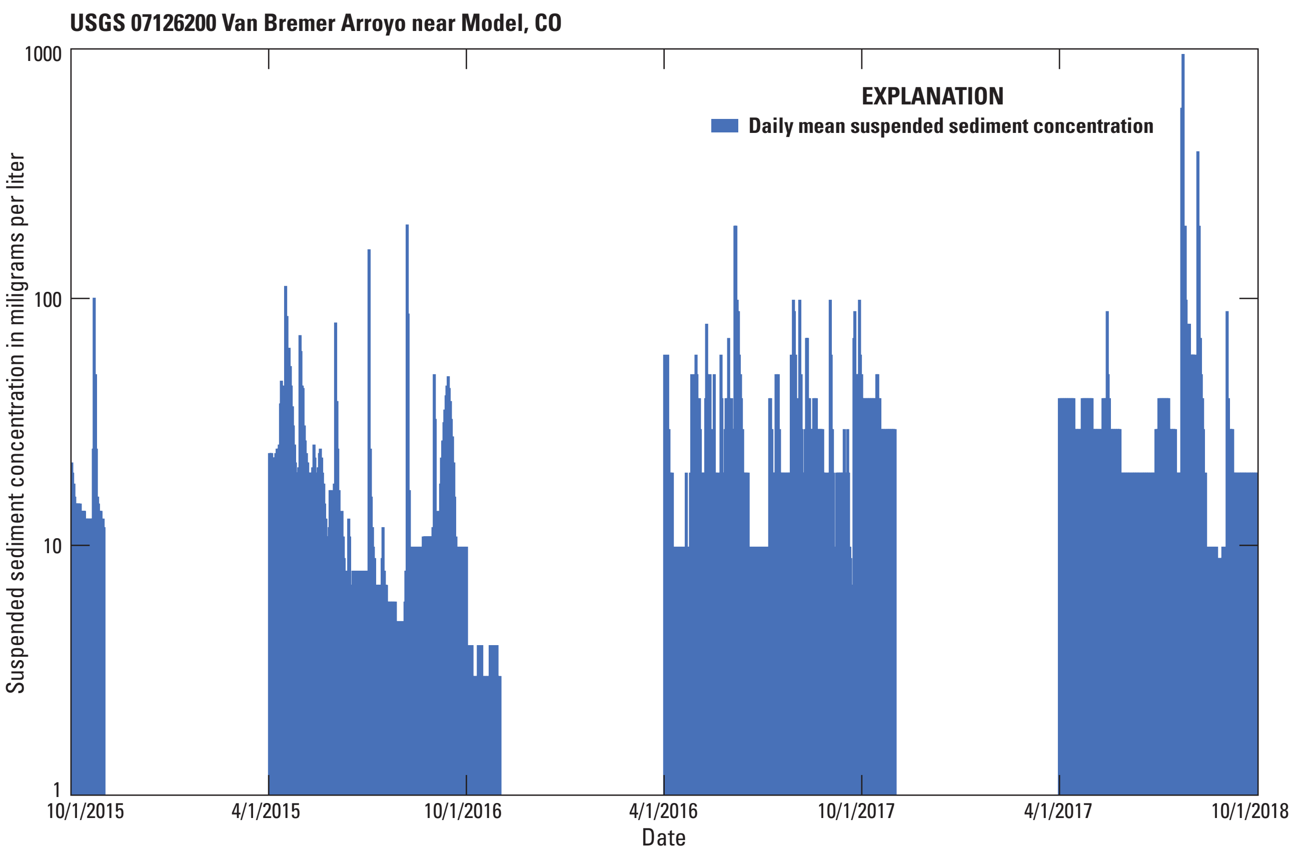

Figure 2.15. Daily mean suspended-sediment concentration at Van Bremer Arroyo near Model, CO.

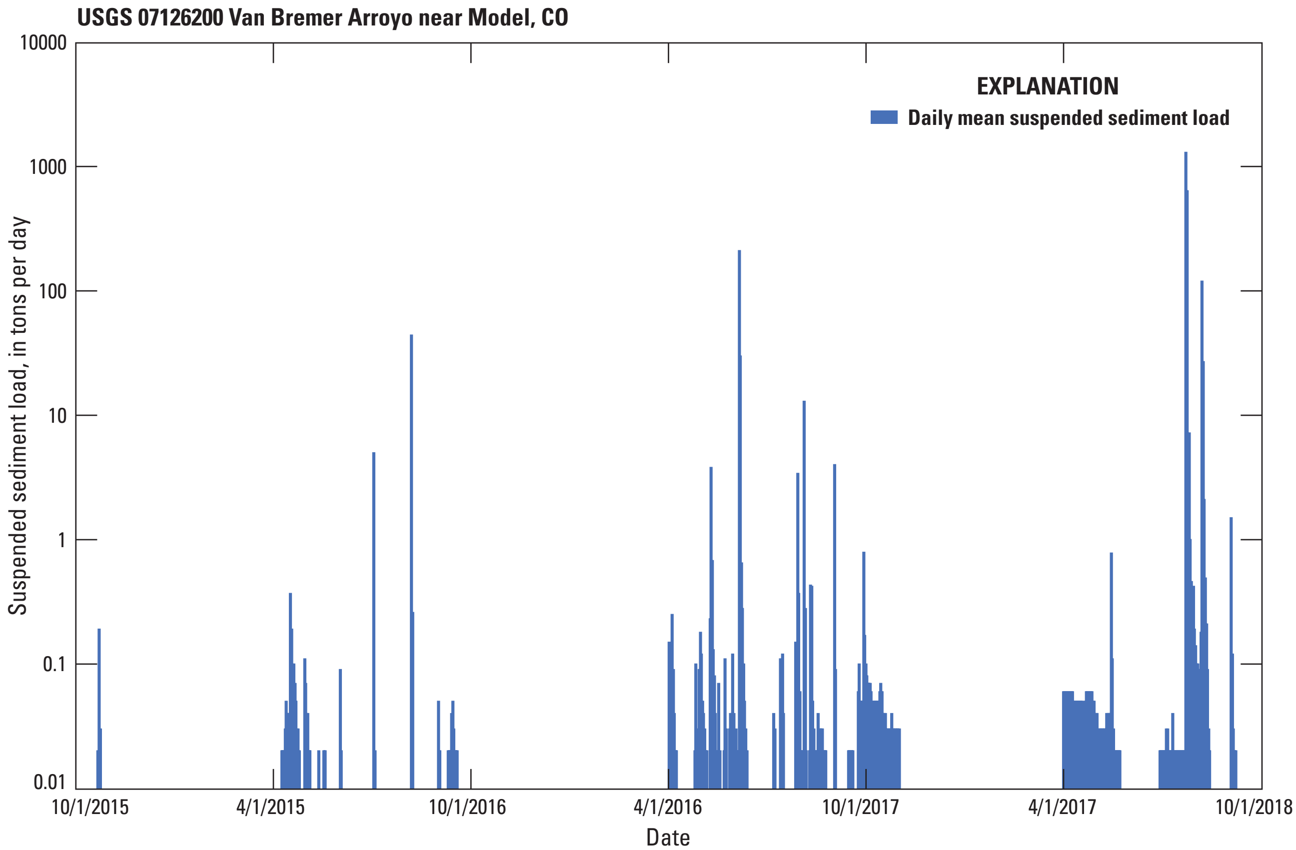

Figure 2.16. Daily mean suspended-sediment discharge (load) at Van Bremer Arroyo near Model, CO.

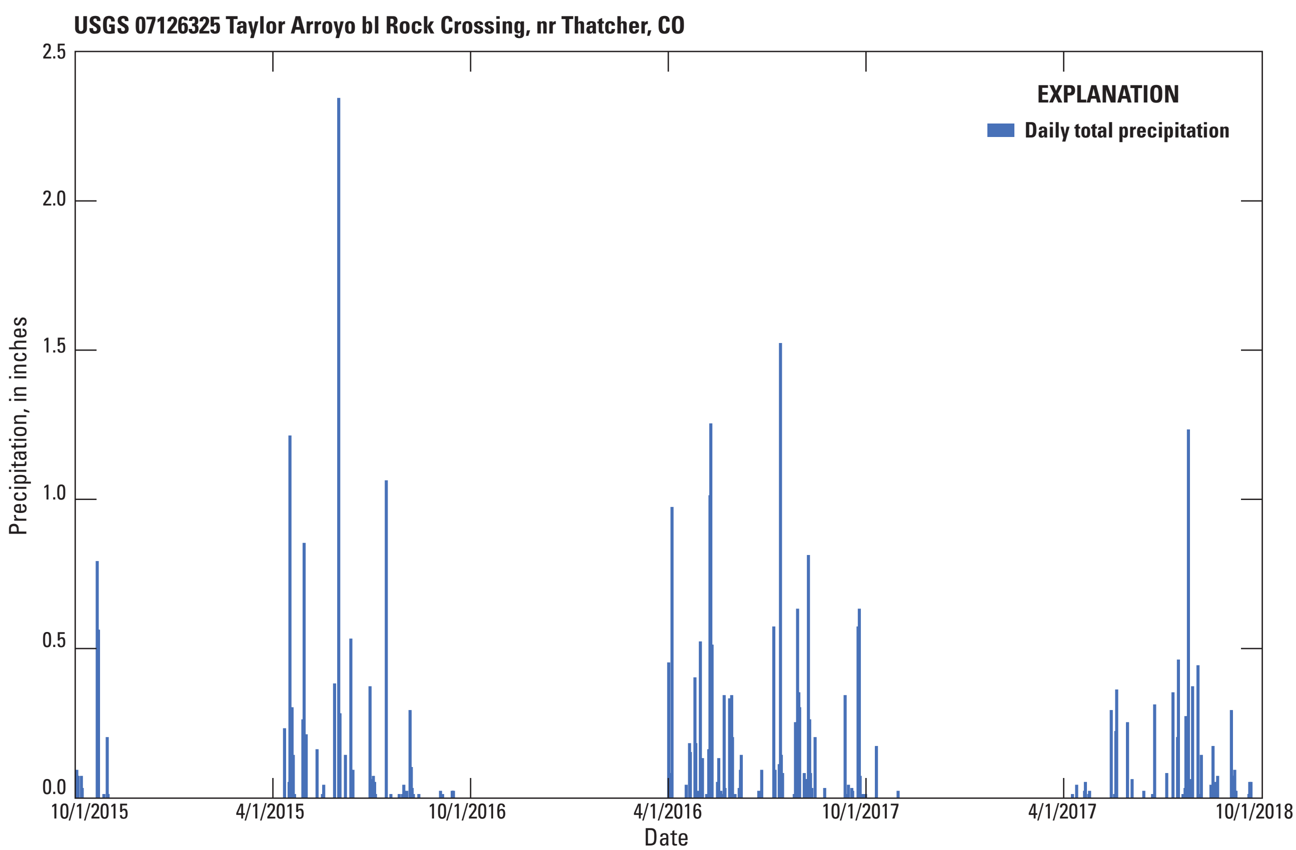

Figure 2.17. Daily total (sum) precipitation at Taylor Arroyo bl Rock Crossing, nr Thatcher, CO.

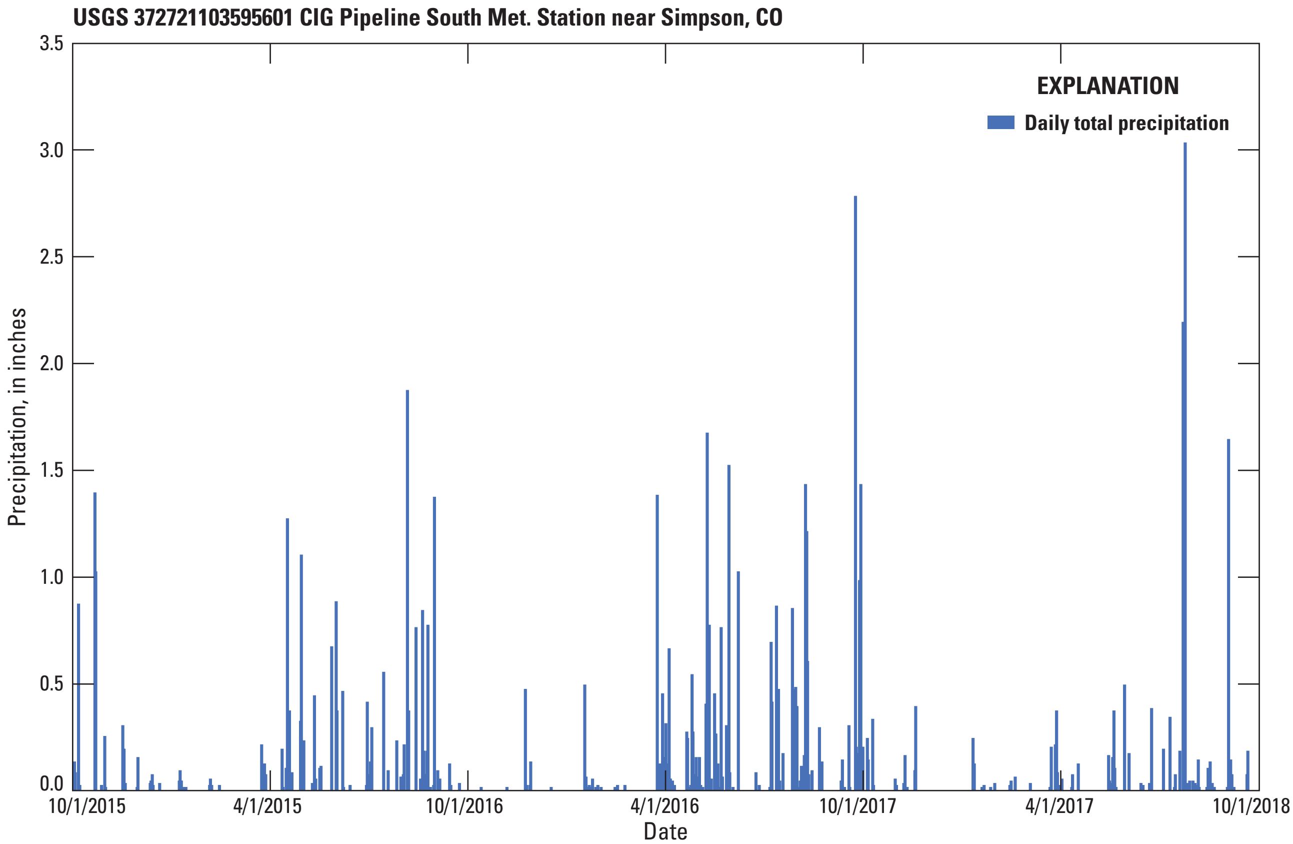

Figure 2.18. Daily total (sum) precipitation at CIG Pipeline South Meteorologic Station near Simpson, CO.

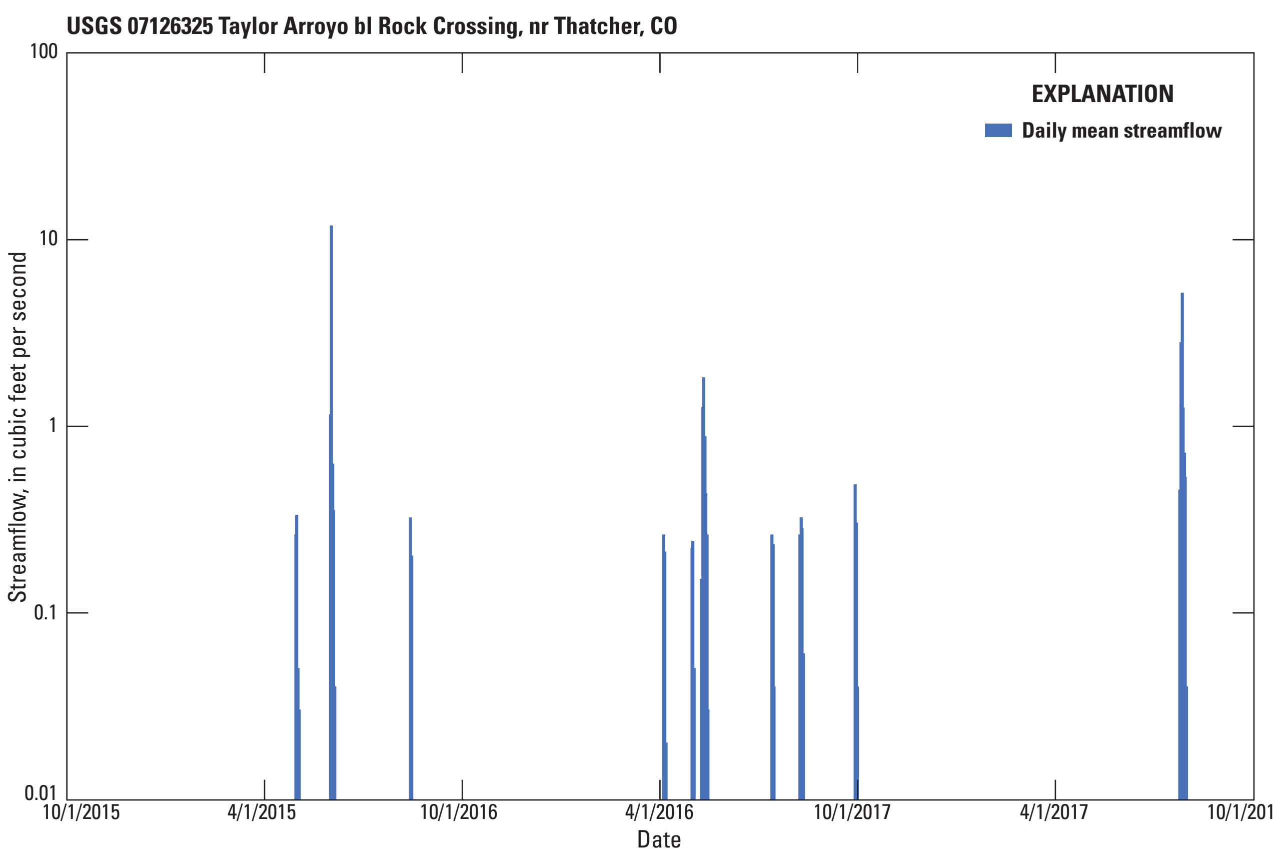

Figure 2.19. Daily mean streamflow (discharge) at Taylor Arroyo bl Rock Crossing, nr Thatcher, CO.

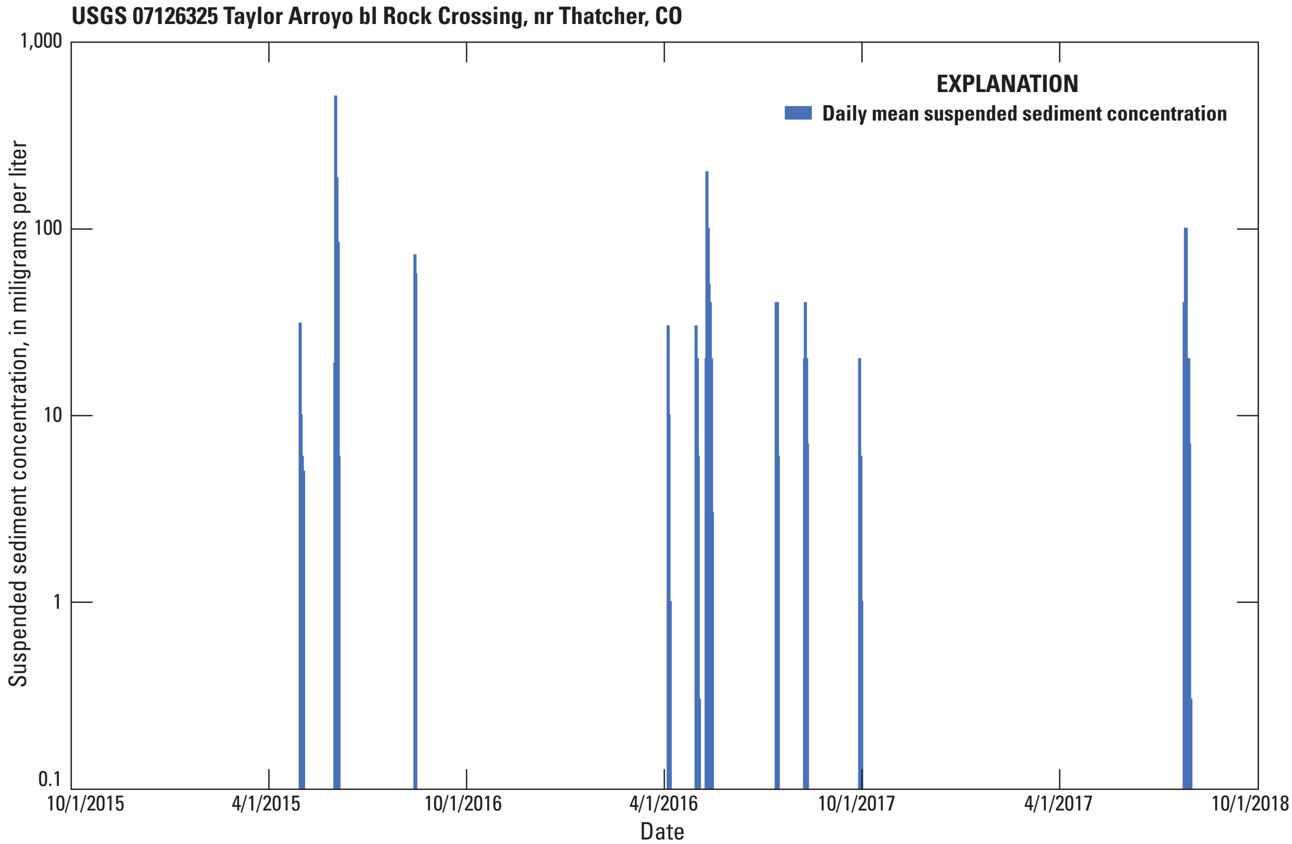

Figure 2.20. Daily mean suspended-sediment concentration at Taylor Arroyo bl Rock Crossing, nr Thatcher, CO.

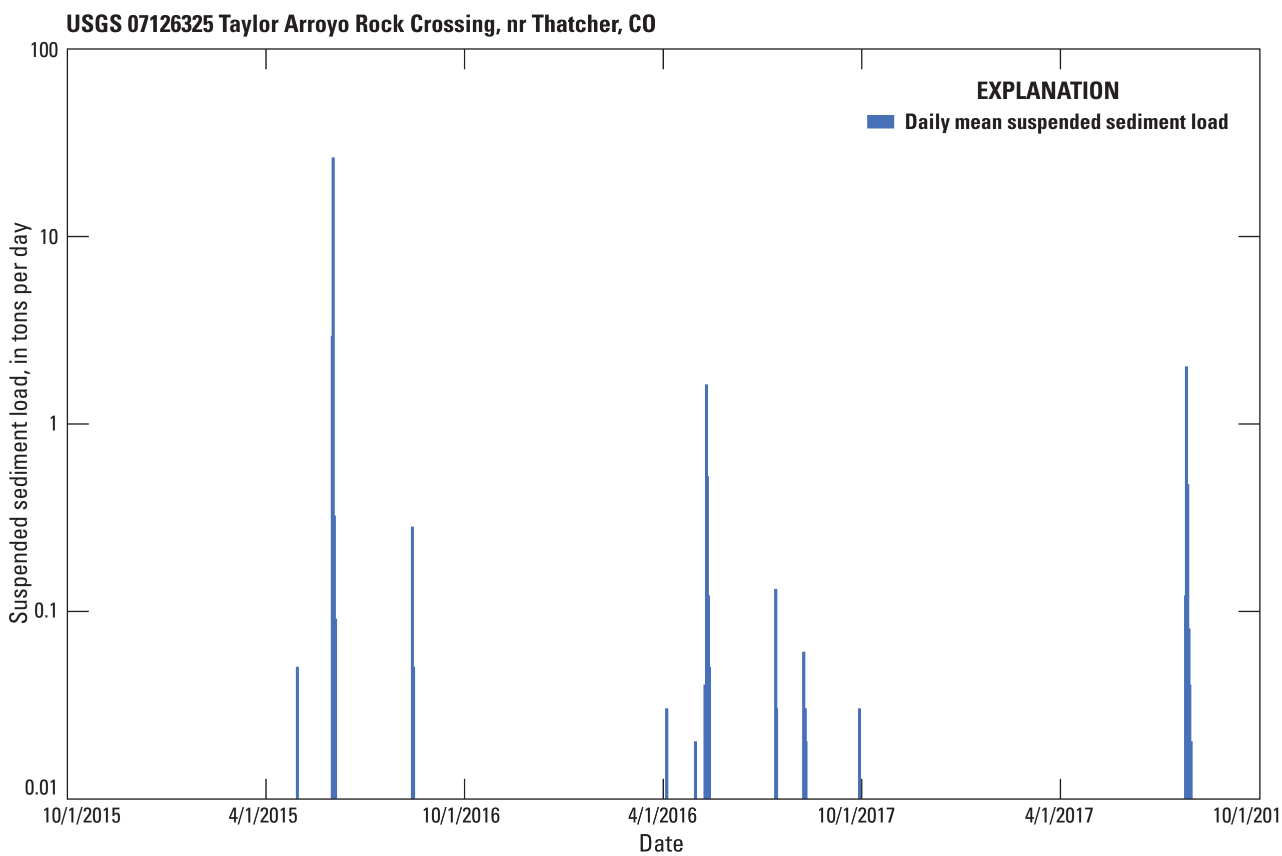

Figure 2.21. Daily mean suspended-sediment discharge (load) at Taylor Arroyo bl Rock Crossing, nr Thatcher, CO.

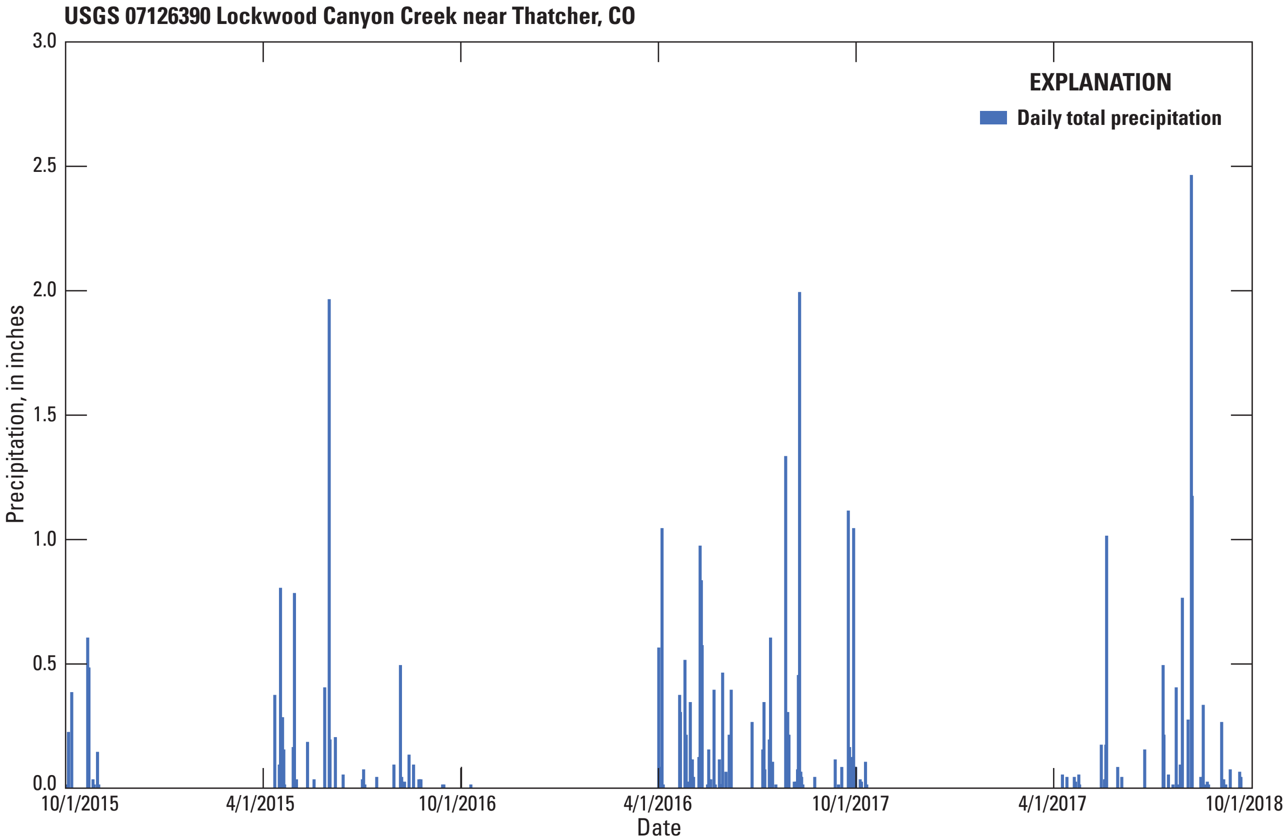

Figure 2.22. Daily total (sum) precipitation at Lockwood Canyon Creek near Thatcher, CO.

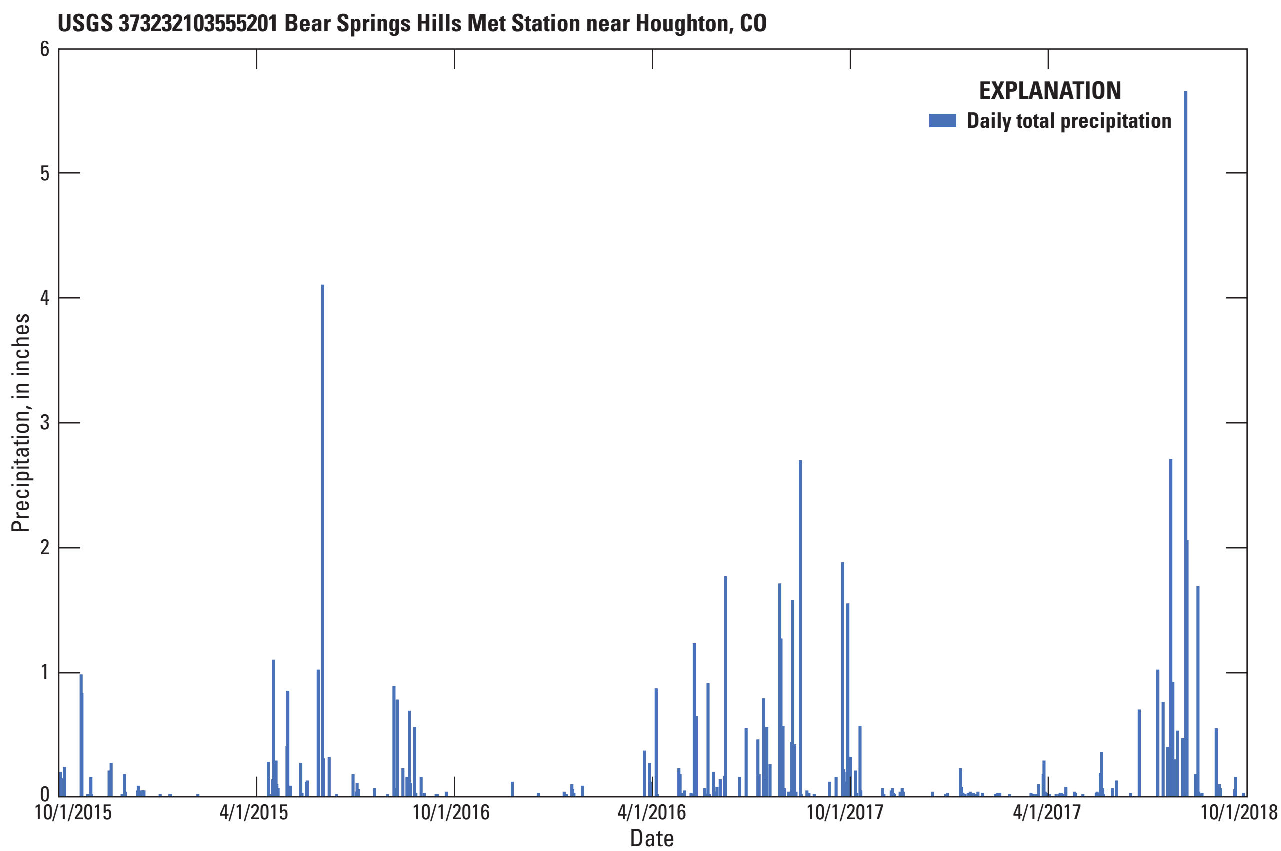

Figure 2.23. Daily total (sum) precipitation at Bear Springs Hills Met Station near Houghton, CO.

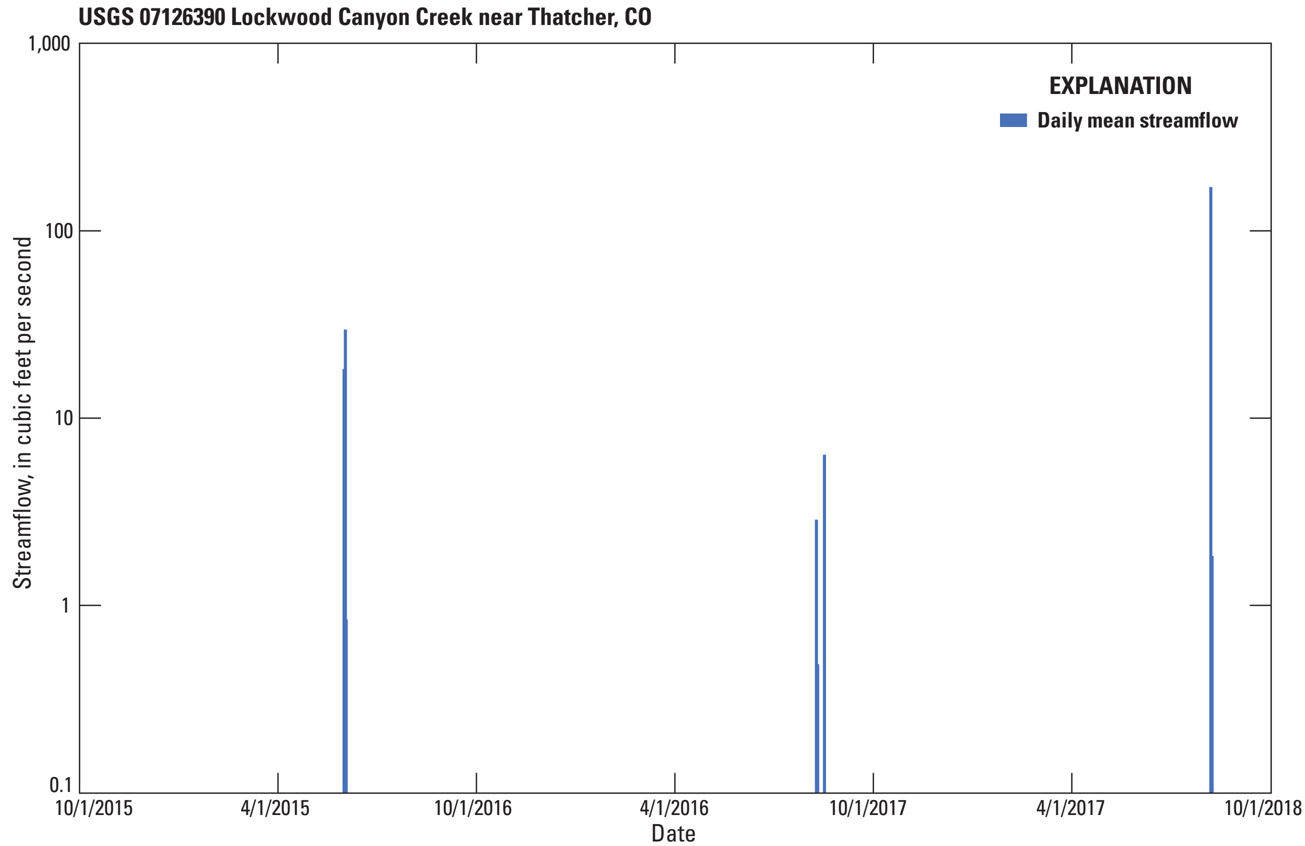

Figure 2.24. Daily mean streamflow (discharge) at Lockwood Canyon near Thatcher, CO.

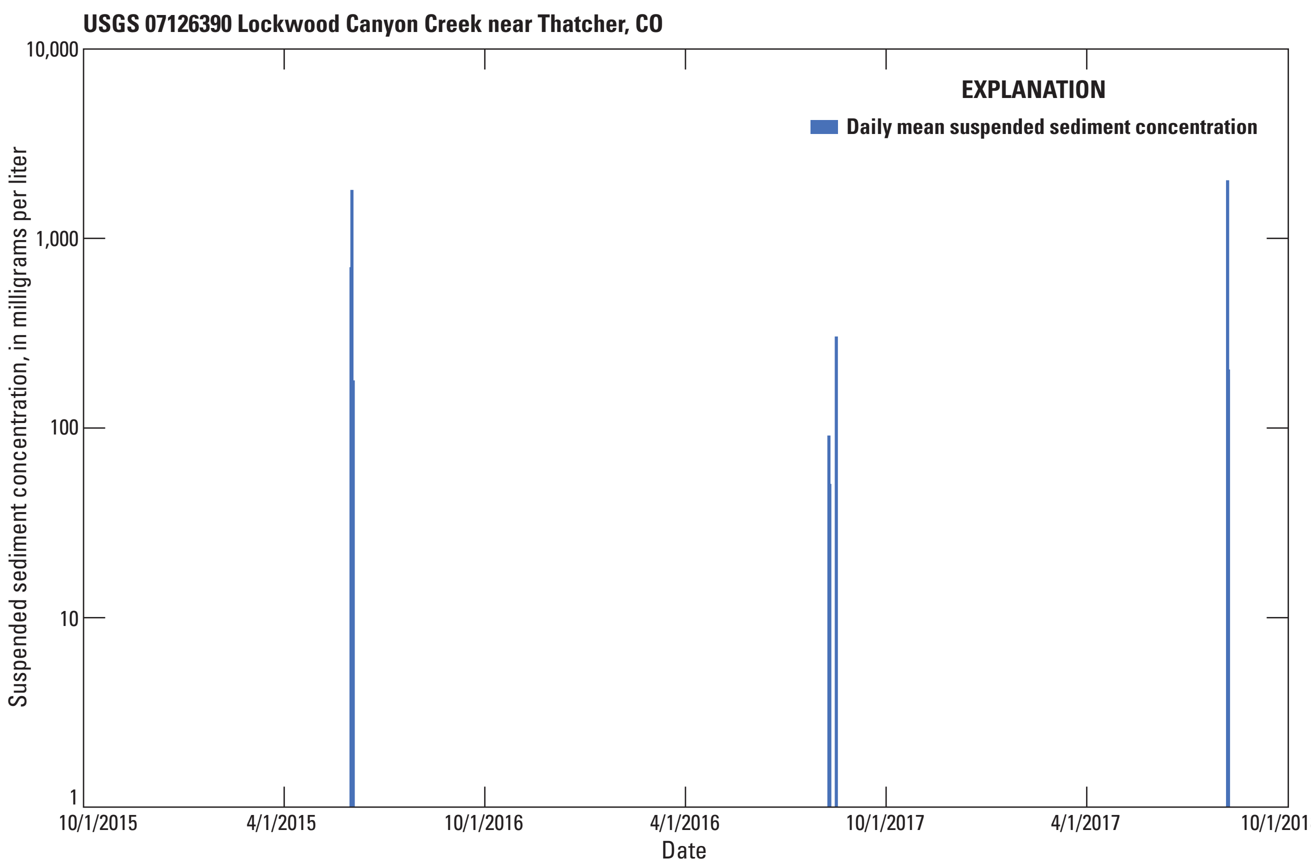

Figure 2.25. Daily mean suspended-sediment concentration at Lockwood Canyon near Thatcher, CO.

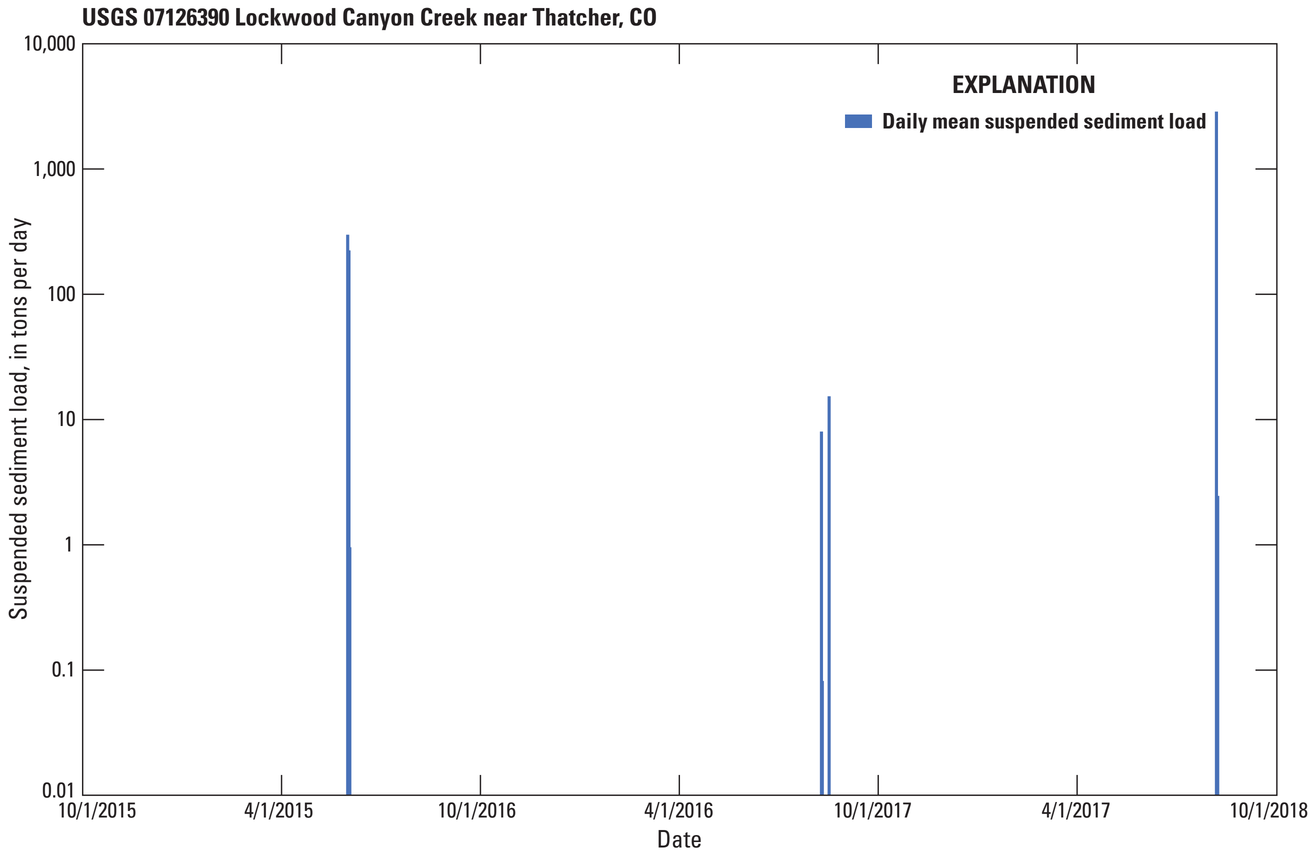

Figure 2.26. Daily mean suspended-sediment discharge (load) at Lockwood Canyon near Thatcher, CO.

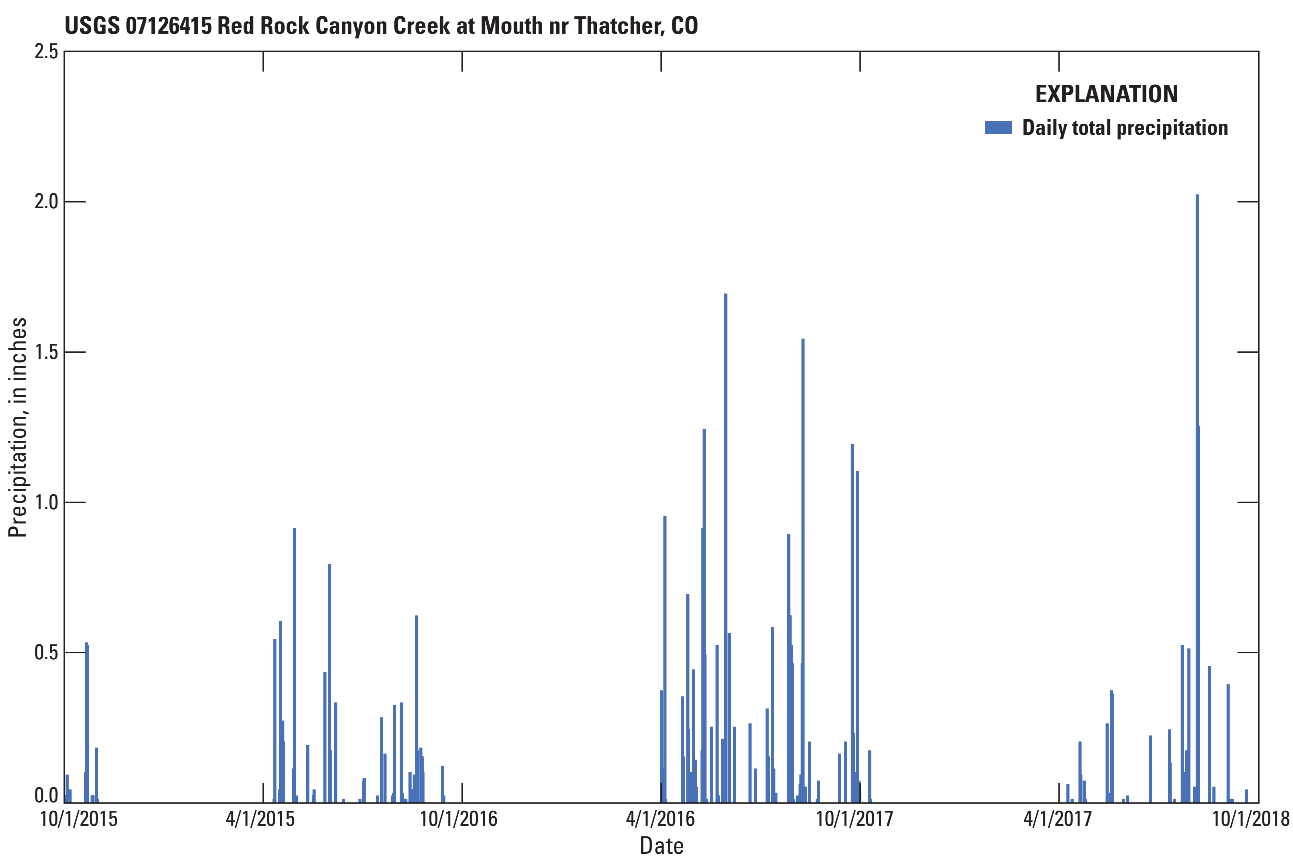

Figure 2.27. Daily total (sum) precipitation at Red Rock Canyon at Mouth nr Thatcher, CO.

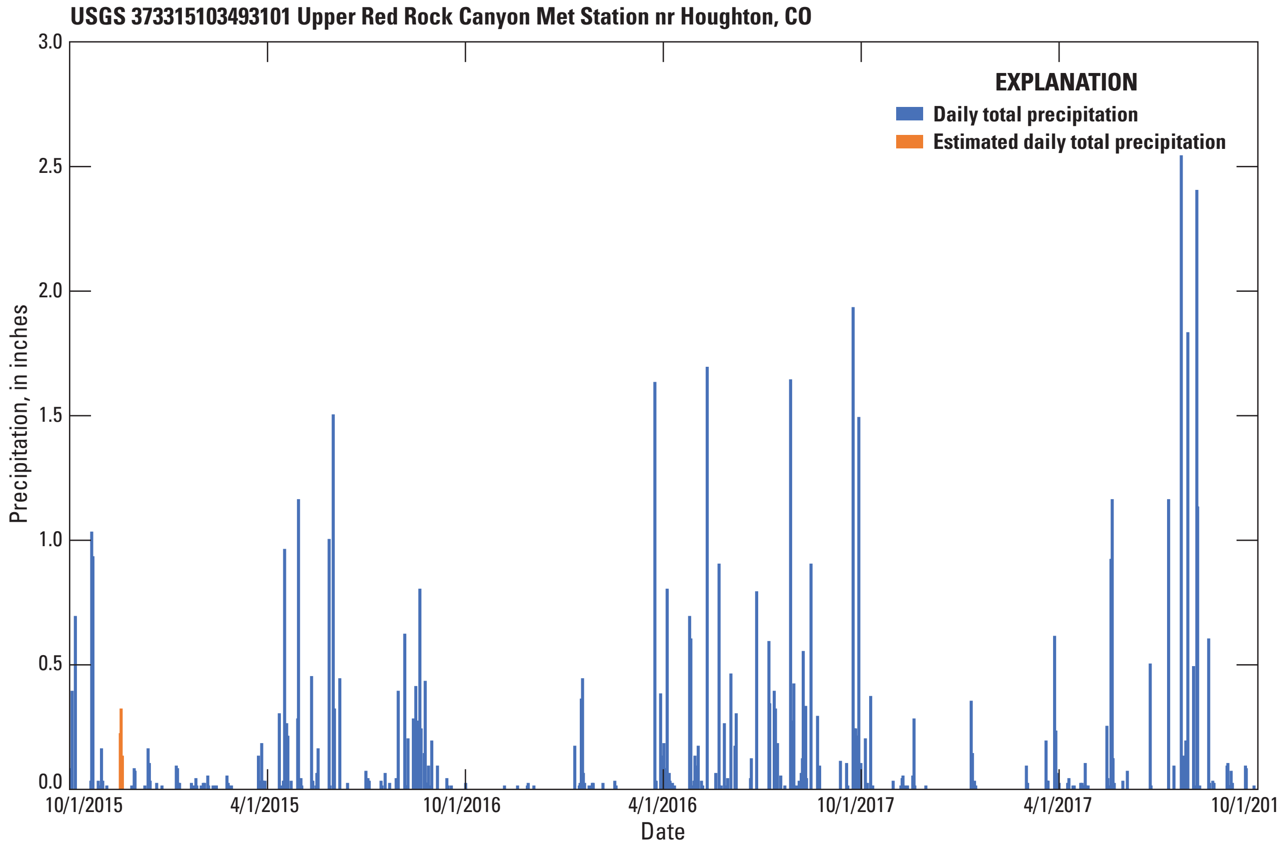

Figure 2.28. Daily total (sum) precipitation at Upper Red Rock Canyon Met Station nr Houghton, CO.

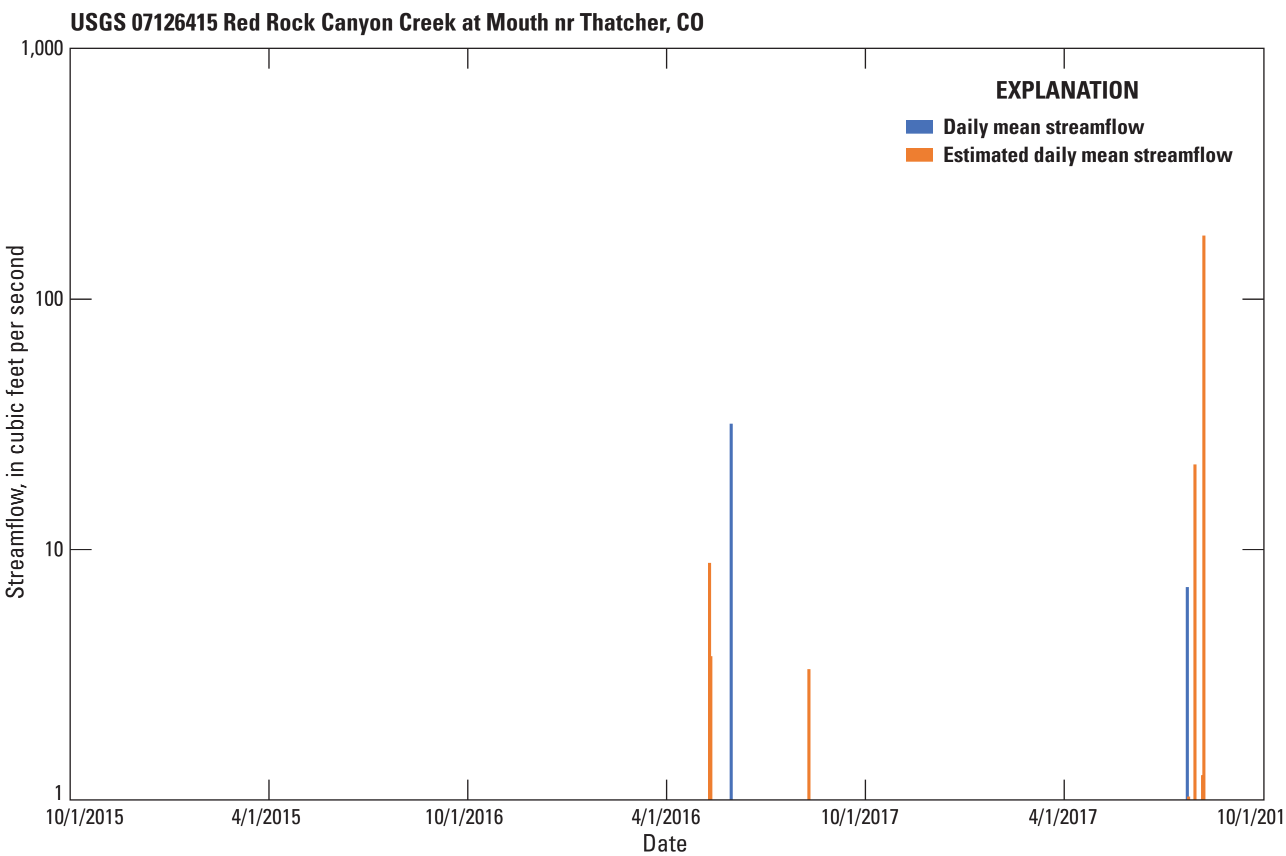

Figure 2.29. Daily mean streamflow (discharge) at Red Rock Canyon Creek at Mouth nr Thatcher, CO.

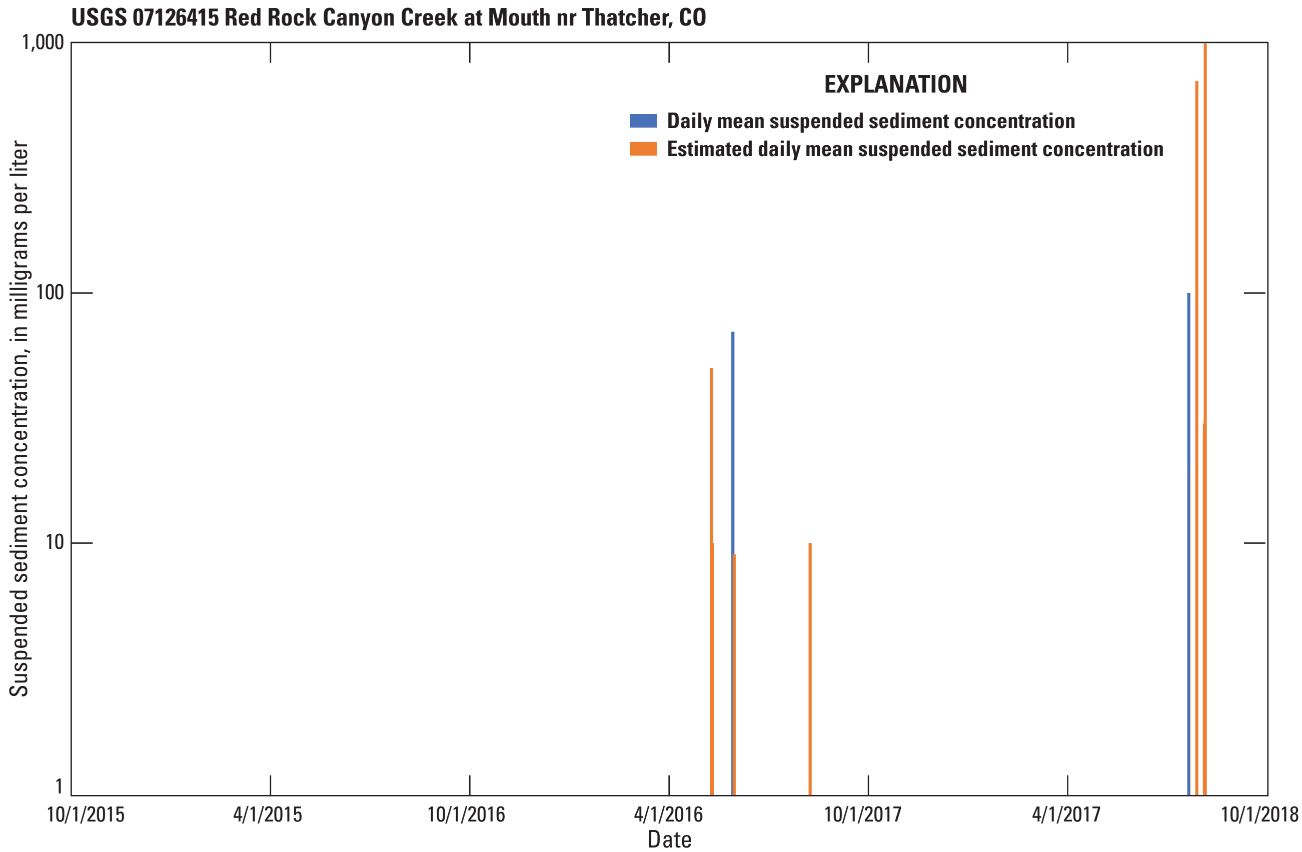

Figure 2.30. Daily mean suspended-sediment concentration at Red Rock Canyon Creek at Mouth nr Thatcher, CO.

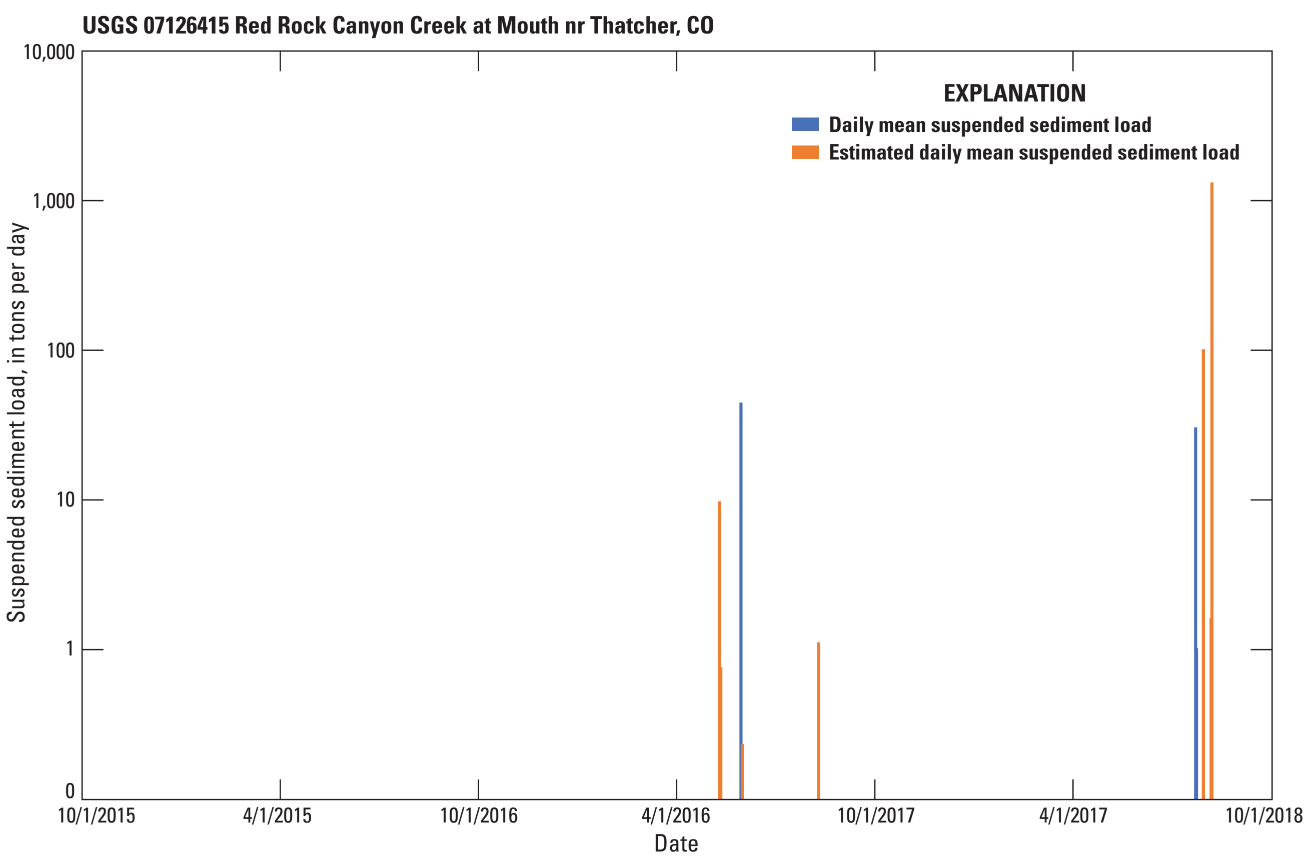

Figure 2.31. Daily mean suspended-sediment discharge (load) at Red Rock Canyon Creek at Mouth nr Thatcher, CO.

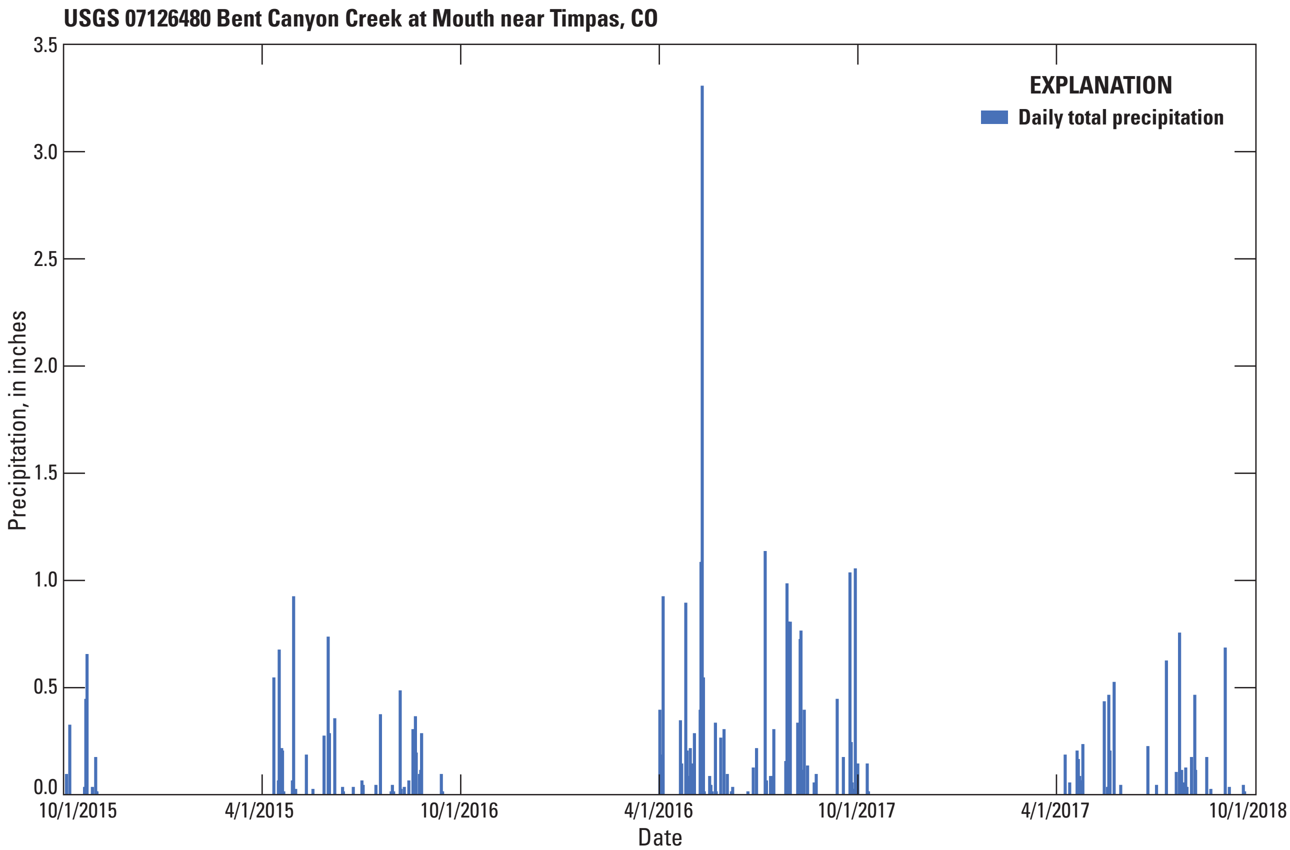

Figure 2.32. Daily total (sum) precipitation at Bent Canyon Creek at Mouth near Timpas, CO.

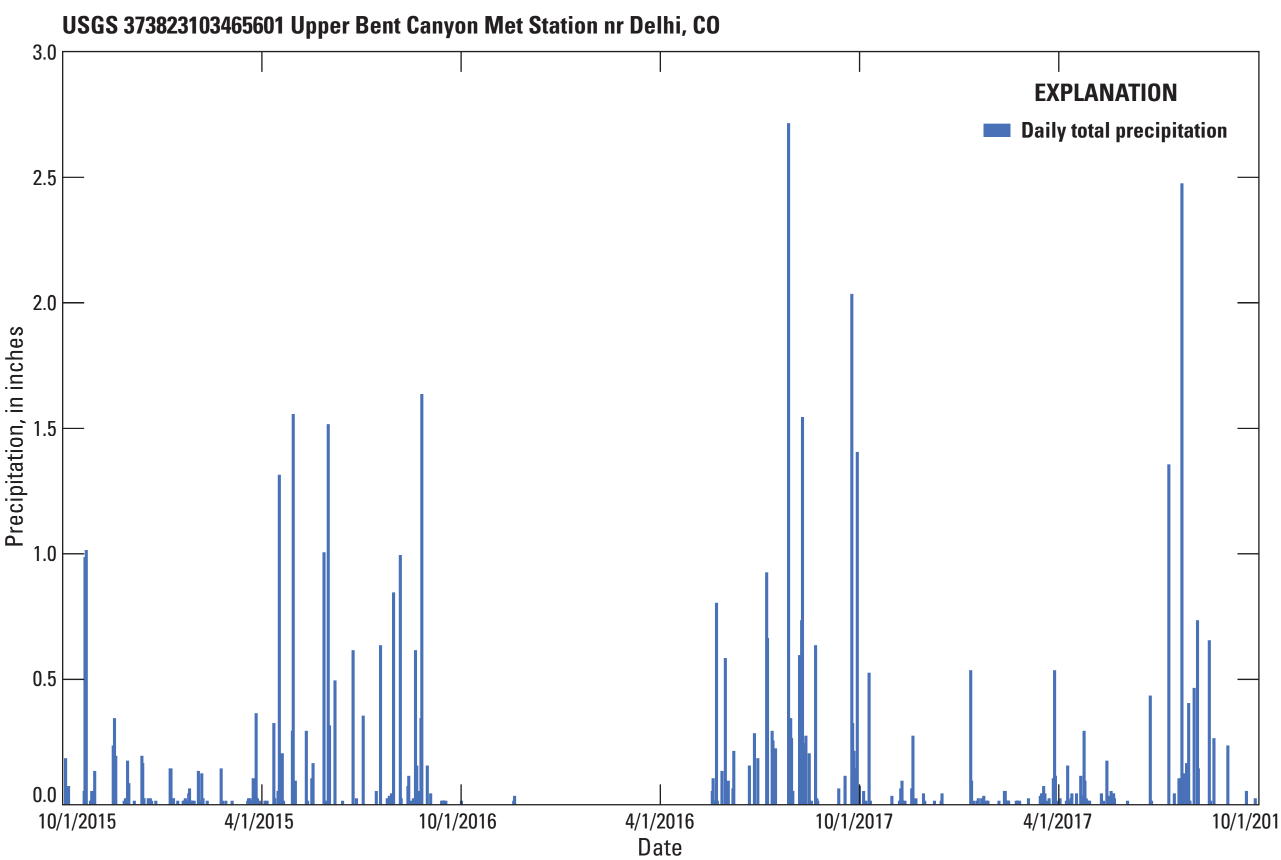

Figure 2.33. Daily total (sum) precipitation at Upper Bent Canyon Met Station nr Delhi, CO.

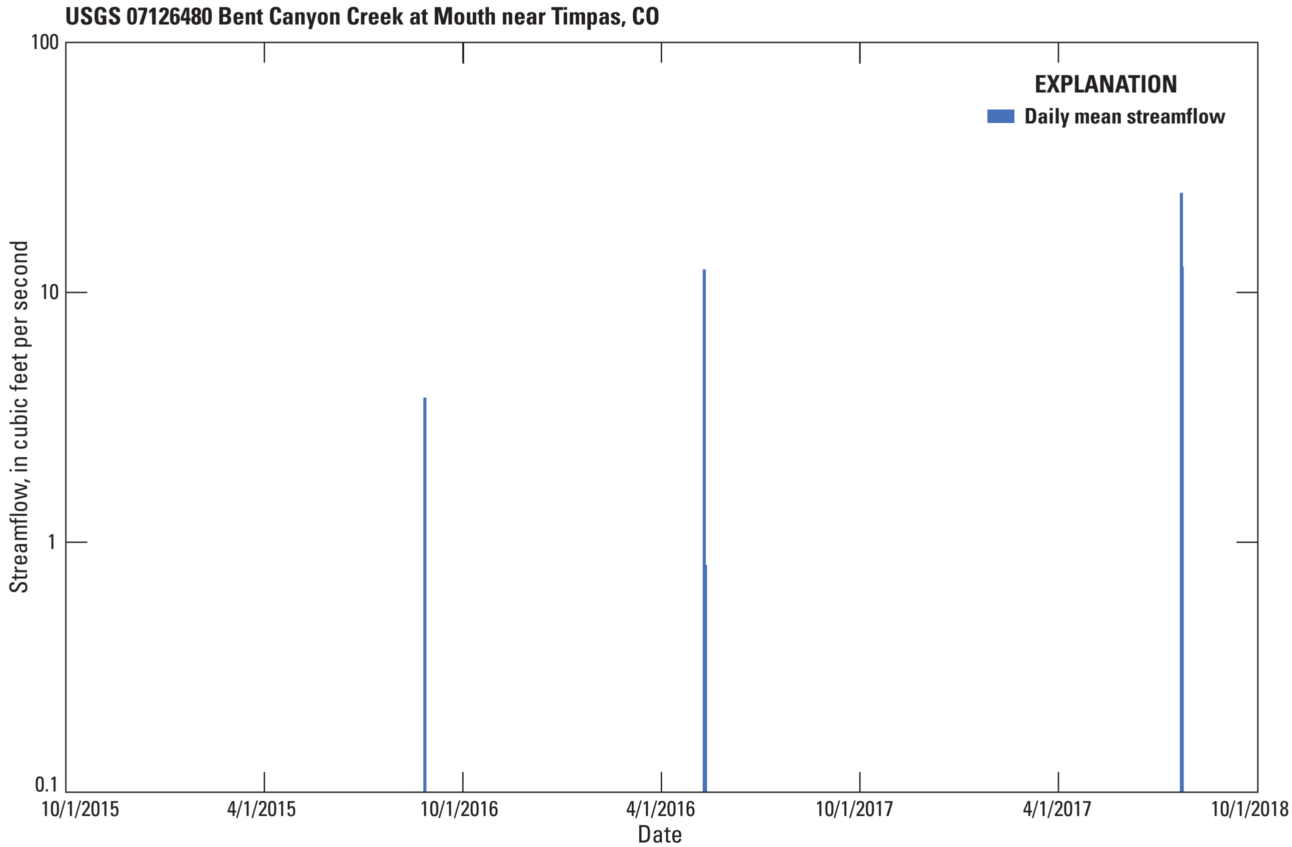

Figure 2.34. Daily mean streamflow (discharge) at Bent Canyon Creek at Mouth near Timpas, CO.

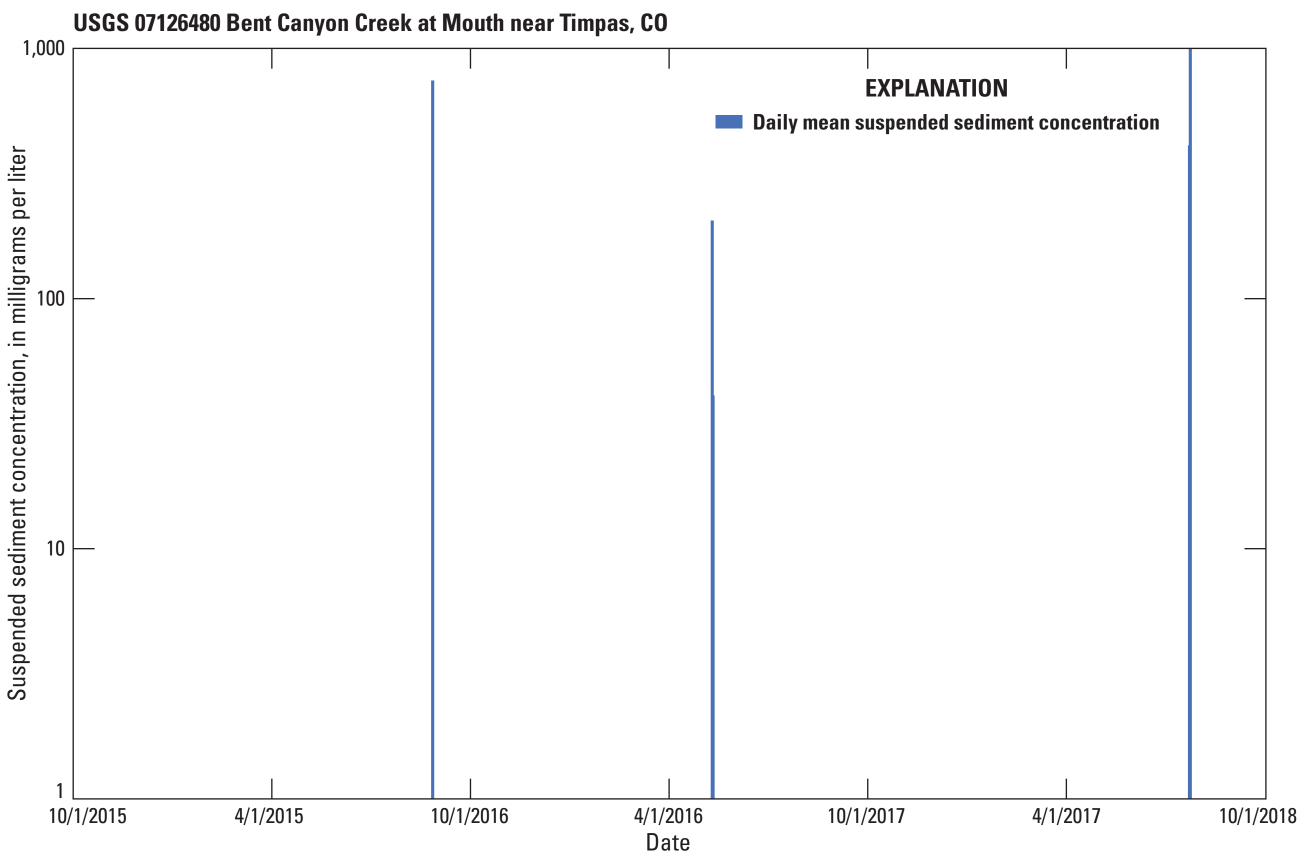

Figure 2.35. Daily mean suspended-sediment concentration at Bent Canyon Creek at Mouth near Timpas, CO.

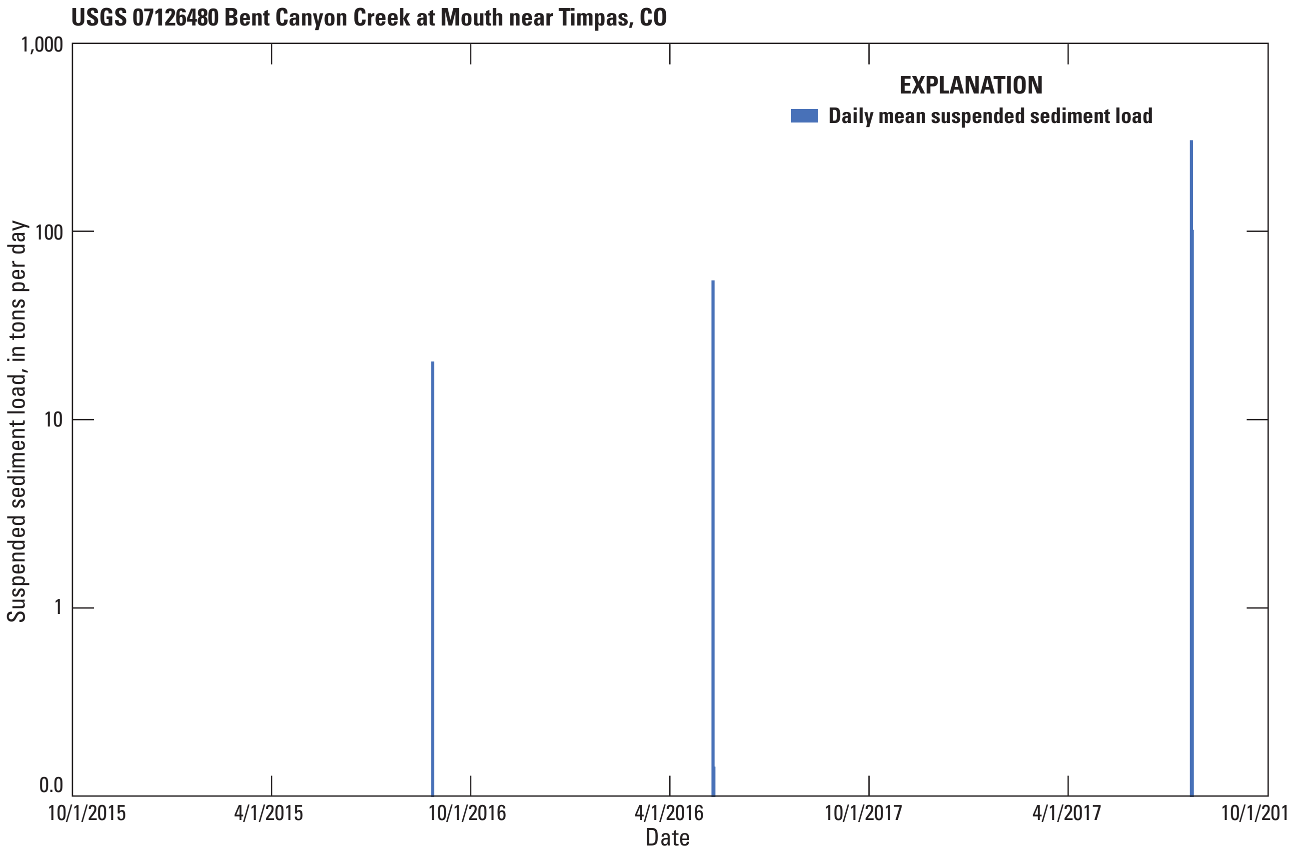

Figure 2.36. Daily mean suspended-sediment discharge (load) at Bent Canyon Creek at Mouth near Timpas, CO.

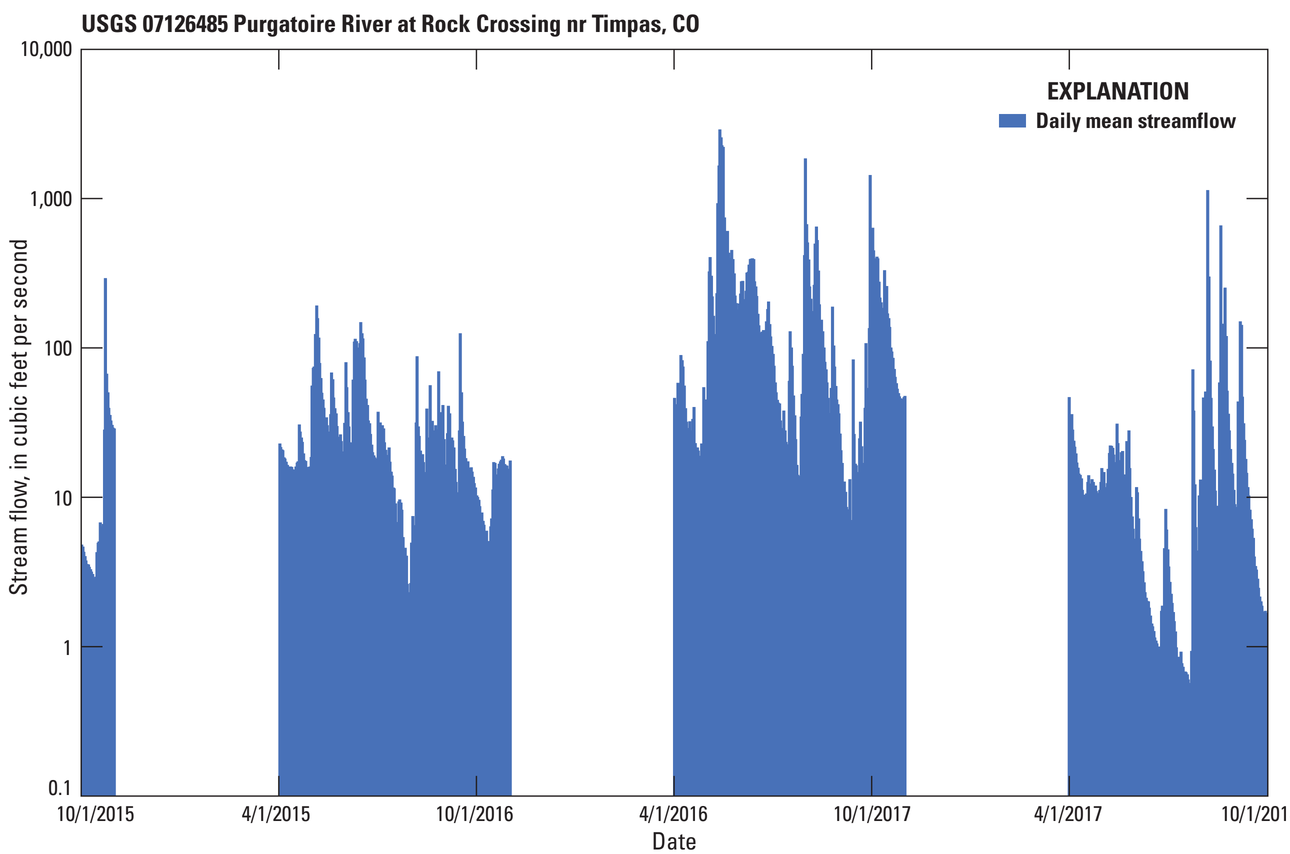

Figure 2.37. Daily mean streamflow (discharge) at Purgatoire River at Rock Crossing nr Timpas, CO.

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Novak, C.E., 1985, WRD data reports preparation guide: U.S. Geological Survey Open-File Report 85–480, 199 p. [Also available at https://pubs.usgs.gov/of/1985/0480/report.pdf.]

Appendix 3. Colorado Department of Public Health and Environment Aquatic-Life Water Standards and U.S. Environmental Protection Agency Aquatic-Life Criteria for Selected Water-Quality Parameters

Appendix 3 presents information related to the aquatic-life standards and criteria used for this study. Table 3.1 provides the Colorado Department of Public Health and Environment aquatic-life water standards and table 3.2 presents the U.S. Environmental Protection Agency aquatic-life criteria for selected water-quality parameters.

Table 3.1. Colorado Department of Public Health and Environment (CDPHE) aquatic-life water standards for selected water-quality parameters. For some parameters, CDPHE standards vary by stream segment or with other water-quality parameters, so a pair or range of standard values are shown.

[MPN/100 mL, most probable number of colonies per 100 milliliters; —, no standard or criteria; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; °C, degree Celsius]

Water-quality parameter	Regulatory numeric aquatic-life standard(s)	Source of aquatic-life standard (CDPHE 2017, 2018)
Escherichia coli	126 MPN/100 mL	CDPHE Regulations 31 and 32
Total coliforms	2,000 MPN/100 mL	CDPHE Regulation 31
Alkalinity, filtered	—	—
Chloride, filtered	— or 250 mg/L[1]	CDPHE Regulation 32
Fluoride, filtered	—	—
Silica, filtered	—	—
Sulfate, filtered	— or 250 mg/L[1]	CDPHE Regulation 32
Calcium, filtered	—	—
Magnesium, filtered	—	—
Potassium, filtered	—	—
Sodium, filtered	—	—
Ammonia, filtered	—	—
Ammonia, unfiltered	2.59–15.3 mg/L[2]	CDPHE Regulation 31
	0.84–4.53 mg/L[1]	CDPHE Regulation 31
Nitrite plus nitrate, filtered	10 mg/L[2]	CDPHE Regulation 32
	100 mg/L[2,3]	CDPHE Regulation 32
Total nitrogen, unfiltered [nitrate + nitrite + ammonia + organic-N]	—	—
Orthophosphate, filtered	—	—
Phosphorus, filtered	—	—
Phosphorus, unfiltered	0.11 mg/L[1]	CDPHE Regulations 31 and 32
	0.17 mg/L[1]	CDPHE Regulations 31 and 32
Aluminum, filtered	1,317–10,071 µg/L[2]	CDPHE Regulation 32
	156–1,438 µg/L[1]	CDPHE Regulation 32
Barium, filtered	—	—
Beryllium, filtered	100 µg/L[3]	CDPHE Regulation 31
Cadmium, filtered	5.48–9.15 µg/L[2]	CDPHE Regulation 31
	0.74–1.20 µg/L[1]	CDPHE Regulation 31
Chromium, filtered	16 µg/L[2]	CDPHE Regulations 31 and 32
	11 µg/L[1]	CDPHE Regulations 31 and 32
	100 µg/L[3]	CDPHE Regulations 31 and 32
Cobalt, filtered	—	—
Copper, filtered	6.12–49.6 µg/L[2]	CDPHE Regulation 32
	4.39–29.3 µg/L[1]	CDPHE Regulation 32
Iron, filtered	300 µg/L[1]	CDPHE Regulation 31
	1,000 µg/L[1]	CDPHE Regulation 31
Lead, filtered	27.0–281 µg/L[2]	CDPHE Regulation 32
	5.59–10.9 µg/L[1]	CDPHE Regulation 32

Table 3.1. Colorado Department of Public Health and Environment (CDPHE) aquatic-life water standards for selected water-quality parameters. For some parameters, CDPHE standards vary by stream segment or with other water-quality parameters, so a pair or range of standard values are shown.—Continued

[MPN/100 mL, most probable number of colonies per 100 milliliters; —, no standard or criteria; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; °C, degree Celsius]

Water-quality parameter	Regulatory numeric aquatic-life standard(s)	Source of aquatic-life standard (CDPHE 2017, 2018)
Manganese, filtered	25.8–4,679 µg/L[2]	CDPHE Regulation 32
	50–2,585 µg/L[1]	CDPHE Regulation 32
Mercury, unfiltered	0.01 µg/L[1]	CDPHE Regulation 32
Molybdenum, filtered	150 µg/L[1]	CDPHE Regulation 32
Nickel, filtered	231–1,513 µg/L[2]	CDPHE Regulation 32
	25.7–200 µg/L[1]	CDPHE Regulation 32
Silver, filtered	0.48–22 µg/L[2]	CDPHE Regulation 32
	0.02–3.47 µg/L[1]	CDPHE Regulation 32
Zinc, filtered	84.9–564 µg/L[2]	CDPHE Regulation 32
	64.3–428 µg/L[1]	CDPHE Regulation 32
Antimony, filtered	5.6 µg/L[4]	CDPHE Regulation 31
Arsenic, filtered	340 µg/L[2]	CDPHE Regulation 32
	7.6 µg/L[1,3]	CDPHE Regulation 32
Selenium, filtered	18.4 µg/L[2]	CDPHE Regulation 32
	4.6 µg/L[1]	CDPHE Regulation 32
	20 µg/L[1,3]	CDPHE Regulation 32
Uranium, filtered [natural]	16.8–30 µg/L	CDPHE Regulation 32
Hardness as $CaCO_3$	—	—
Oxygen, dissolved	6 mg/L[5]	CDPHE Regulation 31
	5 mg/L[6]	CDPHE Regulation 31
pH, unfiltered, field	Between 6.5 and 9.0 pH units[5,6]	CDPHE Regulation 31
Solids, dissolved	—	—
Specific conductance	—	—
Water temperature	18.3 °C[2,5]	CDPHE Regulation 31
	24.3 °C[1,5]	CDPHE Regulation 31
	27.5 °C[2,6]	CDPHE Regulation 31
	28.6 °C[1,6]	CDPHE Regulation 31

[1]Class 1 and 2 cold-water standard.

[2]Class 1 and 2 warm-water standard.

[3]Acute exposure standard.

[4]Chronic exposure standard.

[5]Water and fish standard.

[6]Agricultural use standard.

Table 3.2. U.S. Environmental Protection Agency aquatic-life criteria for selected water-quality parameters (EPA, 2020).

[—, no standard or criteria; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate]

Water-quality parameter	Acute	Chronic
Escherichia coli	—	—
Total coliforms	—	—
Alkalinity, filtered	—	20 mg/L
Chloride, filtered	860 mg/L	230 mg/L
Fluoride, filtered	—	—
Silica, filtered	—	—
Sulfate, filtered	—	—
Calcium, filtered	—	—
Magnesium, filtered	—	—
Potassium, filtered	—	—
Sodium, filtered	—	—
Ammonia, filtered	—	1.9 mg/L
Ammonia, unfiltered	—	1.9 mg/L
Nitrite plus nitrate, filtered	—	—
Total nitrogen, unfiltered [nitrate + nitrite + ammonia + organic-N]	—	—
Orthophosphate, filtered	—	—
Phosphorus, filtered	—	0.76 mg/L
Phosphorus, unfiltered	—	0.76 mg/L
Aluminum, filtered	750 µg/L	87 µg/L
Barium, filtered	—	—
Beryllium, filtered	—	—
Cadmium, filtered	1.8 µg/L	0.72 µg/L
Chromium, filtered	16 µg/L	11 µg/L
Cobalt, filtered	—	—
Copper, filtered	—	—
Iron, filtered	—	1,000 µg/L
Lead, filtered	65 µg/L	2.5 µg/L
Manganese, filtered	—	—
Mercury, unfiltered	1.4 µg/L	0.77 µg/L
Molybdenum, filtered	—	—
Nickel, filtered	470 µg/L	52 µg/L
Silver, filtered	3.2 µg/L	—
Zinc, filtered	120 µg/L	120 µg/L
Antimony, filtered	—	—
Arsenic, filtered	340 µg/L	150 µg/L
Selenium, filtered	—	3.1 µg/L
Uranium, filtered [natural]	—	—
Hardness as $CaCO_3$	—	—
Oxygen, dissolved	—	—

Table 3.2. U.S. Environmental Protection Agency aquatic-life criteria for selected water-quality parameters (EPA, 2020).—Continued

[—, no standard or criteria; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate]

Water-quality parameter	Acute	Chronic
pH, unfiltered, field	—	—
Solids, dissolved	—	—
Specific conductance	—	—
Water temperature	—	—

References Cited

Colorado Department of Public Health and Environment [CDPHE], 2017, Water Quality Control Commission Regulation 31—The basic standards and methodologies for surface water (effective January 31, 2018): Colorado Department of Public Health and Environment, Water Quality Control Commission, 238 p. [Also available at https://www.sos.state.co.us/CCR/GenerateRulePdf.do?ruleVersionId=7455&fileName=5%20CCR%201002-31.]

Colorado Department of Public Health and Environment [CDPHE], 2018, Water Quality Control Commission Regulation 32—Classification of numeric standards for Arkansas River Basin and Regulation 32 tables (effective December 31, 2018): Colorado Department of Public Health and Environment Water Quality Control Commission, 251 p. [Also available at https://www.sos.state.co.us/CCR/GenerateRulePdf.do?ruleVersionId=7876&fileName=5%20CCR%201002-32.]

U.S. Environmental Protection Agency [EPA], 2020, National recommended water quality criteria—Aquatic life criteria table: U.S. Environmental Protection Agency website, accessed July 2020 at https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table.

Appendix 4. Statistical Summary of Selected Water-Quality Data by Parameter for Active Sites on the U.S. Army Garrison Fort Carson, Colorado, for Water Years 1978–2018

Appendix 4 is a table that provides a statistical summary of water-quality data by water-quality parameter for monitoring sites on the U.S. Army Garrison Fort Carson in Colorado.

Table 4.1. Statistical summary of selected water-quality data by parameter for active sites on the U.S. Army Garrison Fort Carson, Colorado, for water years 1978–2018. (Data are from U.S. Geological Survey, 2020).

[%, percent; CO, Colorado; MPN/100 mL, most probable number of colonies per 100 milliliters; >, greater than; mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; NC, not calculated; µS/cm, microsiemens per centimeter; °C, degree Celsius]

Water-quality parameter (reporting units)	Number of samples	Percent detection (%)	Minimum	Median	Maximum	Mean
Turkey Creek near Fountain, CO						
Escherichia coli (MPN/100 mL)	5	100	25	100	3,100	841
Total coliforms (MPN/100 mL)	5	100	2,400	2,600	>24,000	7,440
Chloride, filtered (mg/L)	14	100	1.23	2.4	3.9	2.51
Fluoride, filtered (mg/L)	13	100	0.36	0.5	11	0.511
Silica, filtered (mg/L)	14	100	9.38	16.6	21	16.2
Sulfate, filtered (mg/L)	14	79	<5	13.7	37	16.5
Calcium, filtered (mg/L)	14	100	10	19	28	19.1
Magnesium, filtered (mg/L)	14	100	3.1	6.6	10	6.52
Potassium, filtered (mg/L)	14	100	1.20	1.79	5.52	2.09
Sodium, filtered (mg/L)	14	100	5.23	9.68	15	9.73
Ammonia, filtered (mg/L)	5	60	<0.01	0.01	0.1	0.024
Ammonia, unfiltered (mg/L)	5	60	<0.02	0.02	0.17	0.048
Nitrite plus nitrate, filtered (mg/L)	14	100	0.075	0.31	3.06	0.664
Total nitrogen, unfiltered (mg/L)	5	100	0.3	1.16	5.93	2.18
Orthophosphate, filtered (mg/L)	6	100	0.015	0.043	0.139	0.050
Phosphorus, filtered (mg/L)	14	93	<0.02	0.035	0.15	0.039
Phosphorus, unfiltered (mg/L)	5	100	0.062	0.569	11.9	3.06
Aluminum, filtered (µg/L)	5	100	190	219	283	238
Barium, filtered (µg/L)	5	100	19.2	27.3	52.7	34.4
Beryllium, filtered (µg/L)	5	100	0.012	0.032	0.033	0.026
Cadmium, filtered (µg/L)	5	20	<0.03	<0.03	0.044	0.009
Chromium, filtered (µg/L)	5	40	<0.3	<0.3	0.5	0.118
Cobalt, filtered (µg/L)	5	100	0.094	0.313	0.434	0.301
Copper, filtered (µg/L)	5	100	1	2.4	5.3	2.56
Iron, filtered (µg/L)	14	86	<10	35	570	123
Lead, filtered (µg/L)	5	100	0.124	0.157	0.189	0.161
Manganese, filtered (µg/L)	14	43	<10	<10	40	5.31
Total mercury (µg/L)	4	100	0.005	0.053	0.2	0.078
Molybdenum, filtered (µg/L)	5	100	2.47	3.24	14.8	6.41
Nickel, filtered (µg/L)	5	100	0.2	0.54	0.95	0.554
Silver, filtered (µg/L)	5	0	<0.02	<0.02	<0.02	<0.02
Zinc, filtered (µg/L)	5	80	<1.4	2.1	3.5	1.96
Antimony, filtered (µg/L)	5	100	0.033	0.107	0.211	0.117
Arsenic, filtered (µg/L)	5	100	0.18	0.37	0.76	0.376
Selenium, filtered (µg/L)	5	100	0.34	0.59	1.2	0.732
Uranium, filtered (µg/L)	5	100	2.25	11	47.3	17.3
Hardness as $CaCO_3$ (mg/L)	5	100	37.8	76	110	74.6
Oxygen, dissolved (mg/L)	13	100	5.7	8.5	10	8.15
pH, field	14	100	7.0	7.9	8.4	NC

Table 4.1. Statistical summary of selected water-quality data by parameter for active sites on the U.S. Army Garrison Fort Carson, Colorado, for water years 1978–2018. (Data are from U.S. Geological Survey, 2020).—Continued

[%, percent; CO, Colorado; MPN/100 mL, most probable number of colonies per 100 milliliters; >, greater than; mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; NC, not calculated; µS/cm, microsiemens per centimeter; °C, degree Celsius]

Water-quality parameter (reporting units)	Number of samples	Percent detection (%)	Minimum	Median	Maximum	Mean
Turkey Creek near Fountain, CO—Continued						
Solids, dissolved (mg/L)	5	100	88	106	137	108
Specific conductance (µS/cm)	115	100	94	225	1,400	241
Water temperature (°C)	116	100	0	13	28	13.1
Little Fountain Creek above Highway 115 at Fort Carson, CO						
Escherichia coli (MPN/100 mL)	6	83	<100	335	1,500	509
Total coliforms (MPN/100 mL)	6	100	88	2,400	>24,000	6,430
Chloride, filtered (mg/L)	6	100	1.14	1.45	3.23	1.85
Fluoride, filtered (mg/L)	6	100	1.85	2.71	3.07	2.52
Silica, filtered (mg/L)	6	100	9.36	12.4	13.8	12.1
Sulfate, filtered (mg/L)	6	100	6.1	9.01	10.2	8.53
Calcium, filtered (mg/L)	6	100	8.32	13.8	18.6	13.9
Magnesium, filtered (mg/L)	6	100	1.83	2.74	3.59	2.80
Potassium, filtered (mg/L)	6	100	1.62	1.78	2.32	1.85
Sodium, filtered (mg/L)	6	100	2.83	5.06	8.34	5.23
Ammonia, filtered (mg/L)	6	33	<0.01	<0.01	0.02	0.005
Ammonia, unfiltered (mg/L)	6	33	<0.02	<0.02	0.12	0.028
Nitrite plus nitrate, filtered (mg/L)	6	83	<0.040	0.086	0.336	0.128
Total nitrogen, unfiltered (mg/L)	6	100	0.09	0.475	1.78	0.620
Orthophosphate, filtered (mg/L)	6	50	<0.004	0.003	0.015	0.005
Phosphorus, filtered (mg/L)	6	33	<0.02	<0.02	0.03	0.008
Phosphorus, unfiltered (mg/L)	6	100	0.009	0.051	0.725	0.163
Aluminum, filtered (µg/L)	6	100	15.9	72.9	695	193
Barium, filtered (µg/L)	6	100	15.9	29.7	34.8	27.8
Beryllium, filtered (µg/L)	6	100	0.044	0.107	0.294	0.130
Cadmium, filtered (µg/L)	6	0	<0.03	<0.03	<0.03	<0.03
Chromium, filtered (µg/L)	6	17	<0.3	<0.3	0.51	0.085
Cobalt, filtered (µg/L)	6	83	<0.03	0.16	0.442	0.199
Copper, filtered (µg/L)	6	50	<0.8	0.17	1.7	0.607
Iron, filtered (µg/L)	6	100	41.2	173	428	209
Lead, filtered (µg/L)	6	67	<0.02	0.07	0.34	0.130
Manganese, filtered (µg/L)	6	100	5.07	11.6	334	66.2
Molybdenum, filtered (µg/L)	6	100	0.816	1.51	2.03	1.47
Nickel, filtered (µg/L)	6	100	0.250	0.445	0.990	0.512
Silver, filtered (µg/L)	6	0	<0.02	<0.02	<0.02	<0.02
Zinc, filtered (µg/L)	6	33	<2.0	<2.0	2.5	0.75
Antimony, filtered (µg/L)	6	83	<0.03	0.064	0.117	0.059
Arsenic, filtered (µg/L)	6	100	0.1	0.175	0.340	0.187
Selenium, filtered (µg/L)	6	100	0.120	0.185	0.300	0.190
Uranium, filtered (µg/L)	6	100	0.609	0.925	3.42	1.34

Table 4.1. Statistical summary of selected water-quality data by parameter for active sites on the U.S. Army Garrison Fort Carson, Colorado, for water years 1978–2018. (Data are from U.S. Geological Survey, 2020).—Continued

[%, percent; CO, Colorado; MPN/100 mL, most probable number of colonies per 100 milliliters; >, greater than; mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; NC, not calculated; µS/cm, microsiemens per centimeter; °C, degree Celsius]

Water-quality parameter (reporting units)	Number of samples	Percent detection (%)	Minimum	Median	Maximum	Mean
Turkey Creek near Fountain, CO—Continued—Continued						
Hardness as $CaCO_3$ (mg/L)	6	100	28.3	46.8	61.3	46.3
Oxygen, dissolved (mg/L)	6	100	7.0	7.85	10.2	8.42
pH, field	6	100	7.4	7.85	8.4	NC
Solids, dissolved (mg/L)	6	100	63	78.5	97	80.3
Specific conductance (µS/cm)	6	100	71	116	150	118
Water temperature (°C)	6	100	5.5	15.5	20.1	13.1
Little Fountain Creek near Fountain, CO						
Escherichia coli (MPN/100 mL)	8	100	29	310	11,000	1,947
Total coliforms (MPN/100 mL)	8	100	1400	5,550	>24,000	11,160
Chloride, filtered (mg/L)	15	100	2.30	8.56	31.6	11.2
Fluoride, filtered (mg/L)	15	100	0.83	2.11	3.00	2.22
Silica, filtered (mg/L)	15	100	4.40	11.6	13.0	10.7
Sulfate, filtered (mg/L)	15	100	55.9	460	1,650	593
Calcium, filtered (mg/L)	15	100	30.5	120	474	152
Magnesium, filtered (mg/L)	15	100	5.16	38.0	133	44.8
Potassium, filtered (mg/L)	15	100	1.70	3.50	9.20	4.20
Sodium, filtered (mg/L)	15	100	8.42	64.8	347	102
Ammonia, filtered (mg/L)	10	70	<0.01	0.02	0.08	0.022
Ammonia, unfiltered (mg/L)	10	90	<0.02	0.03	0.22	0.050
Nitrite plus nitrate, filtered (mg/L)	15	93	<0.040	0.250	1.80	0.495
Total nitrogen, unfiltered (mg/L)	8	100	0.31	0.860	4.22	1.33
Orthophosphate, filtered (mg/L)	9	33	<0.004	<0.004	0.020	0.004
Phosphorus, filtered (mg/L)	15	47	<0.02	<0.02	0.020	0.007
Phosphorus, unfiltered (mg/L)	10	100	0.009	0.313	4.90	1.28
Aluminum, filtered (µg/L)	8	50	<9.0	1.75	319	67.1
Barium, filtered (µg/L)	8	100	18.5	45.9	136	58.4
Beryllium, filtered (µg/L)	8	38	<0.03	<0.03	0.051	0.012
Cadmium, filtered (µg/L)	8	63	<0.09	0.051	0.133	0.046
Chromium, filtered (µg/L)	8	13	<0.3	<0.3	0.58	0.073
Cobalt, filtered (µg/L)	8	100	0.280	0.599	2.73	0.960
Copper, filtered (µg/L)	8	50	<0.6	0.55	3.4	0.938
Iron, filtered (µg/L)	15	47	<10	<10	421	60.6
Lead, filtered (µg/L)	8	38	<0.06	<0.06	0.421	0.084
Manganese, filtered (µg/L)	15	87	<10	40	777	103
Total mercury (µg/L)	2	100	0.20	NC	0.30	NC
Molybdenum, filtered (µg/L)	8	100	3.40	9.96	23.8	10.6
Nickel, filtered (µg/L)	8	100	1.3	3.1	12.7	4.81
Silver, filtered (µg/L)	8	0	<0.02	<0.02	<0.02	<0.02
Zinc, filtered (µg/L)	8	13	<2.0	<2.0	2.8	0.35

Table 4.1. Statistical summary of selected water-quality data by parameter for active sites on the U.S. Army Garrison Fort Carson, Colorado, for water years 1978–2018. (Data are from U.S. Geological Survey, 2020).—Continued

[%, percent; CO, Colorado; MPN/100 mL, most probable number of colonies per 100 milliliters; >, greater than; mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; NC, not calculated; µS/cm, microsiemens per centimeter; °C, degree Celsius]

Water-quality parameter (reporting units)	Number of samples	Percent detection (%)	Minimum	Median	Maximum	Mean
Turkey Creek near Fountain, CO—Continued						
Antimony, filtered (µg/L)	8	88	<0.6	0.258	38.6	13.2
Arsenic, filtered (µg/L)	8	75	<0.80	0.635	1.4	0.621
Selenium, filtered (µg/L)	8	100	2.40	6.55	38.6	13.2
Uranium, filtered (µg/L)	8	100	2.40	7.33	32.4	9.66
Hardness as $CaCO_3$ (mg/L)	15	100	97.4	460	1,370	565
Oxygen, dissolved (mg/L)	13	100	6.1	8.2	9.7	8.15
pH, field	14	100	7.5	8.1	8.2	NC
Solids, dissolved (mg/L)	8	100	161	1,150	2,780	1,314
Specific conductance (µS/cm)	78	100	200	2,210	3,750	1,781
Water temperature (°C)	77	100	0.5	15	28	15.5

Reference Cited

U.S. Geological Survey [USGS], 2020, National Water Information System—USGS water data for the Nation: U.S. Geological Survey website, accessed October 2020 at https://doi.org/10.5066/F7P55KJN.

Appendix 5. Statistical Summary of Selected Water-Quality Data by Parameter for Active Sites on the Piñon Canyon Maneuver Site, Colorado, for Water Years 1966–2018

Appendix 5 is a table that provides a statistical summary of water-quality data by water-quality parameter for monitoring sites on the Piñon Canyon Maneuver Site in Colorado.

Table 5.1. Statistical summary of selected water-quality data by parameter for active sites on the Piñon Canyon Maneuver Site, Colorado, for water years 1966–2018. (Data are from U.S. Geological Survey, 2020).

[%, percent; CO, Colorado; MPN/100 mL, most probable number of colonies per 100 milliliters; <, less than; >, greater than; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; NC, not calculated; µS/cm, microsiemens per centimeter; °C, degree Celsius; —, no data]

Water-quality parameter (reporting units)	Number of samples	Percent detection (%)	Minimum	Median	Maximum	Mean
Van Bremer Arroyo near Model, CO						
Escherichia coli (MPN/100 mL)	23	78	<1	3.0	130	15.6
Total coliforms (MPN/100 mL)	23	100	170	490	>24,000	2,051
Alkalinity, filtered (mg/L as $CaCO_3$)	11	100	185	261	308	266
Chloride, filtered (mg/L)	52	100	8.90	34.2	220	42.5
Fluoride, filtered (mg/L)	52	100	0.30	0.86	1.4	0.780
Silica, filtered (mg/L)	52	100	5.0	7.8	14.1	8.43
Sulfate, filtered (mg/L)	52	100	200	835	2,100	818
Calcium, filtered (mg/L)	52	100	44	166	212	157
Magnesium, filtered (mg/L)	52	100	15	83.6	180	82.0
Potassium, filtered (mg/L)	52	100	1.1	12	19	12.0
Sodium, filtered (mg/L)	52	100	24	176	660	188
Ammonia, filtered (mg/L)	24	83	<0.01	0.02	0.06	0.025
Ammonia, unfiltered (mg/L)	24	67	<0.02	0.03	0.07	0.031
Nitrite plus nitrate, filtered (mg/L)	52	21	<0.040	<0.040	0.48	0.163
Total nitrogen, unfiltered (mg/L)	24	96	<0.05	0.19	0.66	0.238
Orthophosphate, filtered (mg/L)	24	25	<0.004	<0.004	0.01	0.002
Phosphorus, filtered (mg/L)	52	37	<0.01	<0.01	0.48	0.020
Phosphorus, unfiltered (mg/L)	24	96	<0.004	0.012	0.116	0.021
Aluminum, filtered (µg/L)	24	8	<3.0	<3.0	18.1	1.01
Barium, filtered (µg/L)	24	100	22.8	34.1	127	42.9
Beryllium, filtered (µg/L)	24	25	<0.05	<0.05	0.035	0.006
Cadmium, filtered (µg/L)	24	8	<0.03	<0.03	0.023	0.002
Chromium, filtered (µg/L)	24	0	<0.3	<0.3	<0.3	<0.3
Cobalt, filtered (µg/L)	24	100	0.507	0.928	1.34	0.929
Copper, filtered (µg/L)	24	4	<0.4	<0.4	0.86	0.036
Iron, filtered (µg/L)	52	98	<8.0	43	280	69.5
Lead, filtered (µg/L)	25	0	<0.02	<0.02	<0.02	<0.02
Manganese, filtered (µg/L)	52	100	5.0	107	267	103
Molybdenum, filtered (µg/L)	24	100	2.61	3.54	5.91	3.62
Nickel, filtered (µg/L)	24	100	1.8	2.6	4.5	2.72
Silver, filtered (µg/L)	24	4	<0.04	<0.04	0.007	<0.001
Zinc, filtered (µg/L)	24	0	<2.0	<2.0	<2.0	<2.0
Antimony, filtered (µg/L)	24	75	<0.12	0.073	0.245	0.075
Arsenic, filtered (µg/L)	24	100	0.57	0.89	1.8	0.978
Selenium, filtered (µg/L)	24	71	<0.15	0.15	3.2	0.275
Uranium, filtered (µg/L)	24	100	0.623	1.02	1.42	1.01
Hardness as $CaCO_3$ (mg/L)	52	100	176	760	1,270	729
Oxygen, dissolved (mg/L)	38	100	4.9	7.55	11.0	7.58
pH, field	42	100	7.4	7.8	8.3	NC
Solids, dissolved (mg/L)	48	100	416	1,580	3,730	1,580

Table 5.1. Statistical summary of selected water-quality data by parameter for active sites on the Piñon Canyon Maneuver Site, Colorado, for water years 1966–2018. (Data are from U.S. Geological Survey, 2020).—Continued

[%, percent; CO, Colorado; MPN/100 mL, most probable number of colonies per 100 milliliters; <, less than; >, greater than; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; NC, not calculated; µS/cm, microsiemens per centimeter; °C, degree Celsius; —, no data]

Water-quality parameter (reporting units)	Number of samples	Percent} detection (%)	Minimum	Median	Maximum	Mean
Van Bremer Arroyo near Model, CO—Continued						
Specific conductance (µS/cm)	235	100	115	1,860	4,460	1,850
Water temperature (°C)	336	100	1.0	17	30.9	15.9
Taylor Arroyo below Rock Crossing near Thatcher, CO						
Escherichia coli (MPN/100 mL)	2	100	440	—	1,000	720
Total coliforms (MPN/100 mL)	2	100	>2,400	—	>2,400	>2,400
Alkalinity, filtered (mg/L as $CaCO_3$)	1	100	68	—	—	—
Chloride, filtered (mg/L)	30	100	0.82	2.7	11	3.40
Fluoride, filtered (mg/L)	30	97	<0.1	0.4	0.7	0.369
Silica, filtered (mg/L)	30	100	2.4	5.7	10	5.63
Sulfate, filtered (mg/L)	30	100	4.71	525	1,500	499
Calcium, filtered (mg/L)	30	100	19	175	370	151
Magnesium, filtered (mg/L)	30	100	2.05	30	96	32.1
Potassium, filtered (mg/L)	30	100	3.0	8.14	18.0	8.17
Sodium, filtered (mg/L)	30	100	0.43	31	110	32.0
Ammonia, filtered (mg/L)	2	0	<0.01	—	<0.01	<0.01
Ammonia, unfiltered (mg/L)	2	0	<0.02	—	<0.02	<0.02
Nitrite plus nitrate, filtered (mg/L)	30	100	0.260	0.765	2.80	0.942
Total nitrogen, unfiltered (mg/L)	2	100	1.41	—	1.49	1.45
Orthophosphate, filtered (mg/L)	2	100	0.087	—	0.114	0.101
Phosphorus, filtered (mg/L)	30	100	0.01	0.02	0.12	0.035
Phosphorus, unfiltered (mg/L)	2	100	0.391	—	0.80	0.596
Aluminum, filtered (µg/L)	2	100	140	—	208	174
Barium, filtered (µg/L)	2	100	38.7	—	53.5	46.1
Beryllium, filtered (µg/L)	2	50	<0.02	—	0.018	0.009
Cadmium, filtered (µg/L)	2	50	<0.03	—	0.039	0.019
Chromium, filtered (µg/L)	2	0	<0.3	—	<0.3	<0.3
Cobalt, filtered (µg/L)	2	100	0.829	—	0.999	0.914
Copper, filtered (µg/L)	2	100	1.7	—	2.1	1.9
Iron, filtered (µg/L)	30	100	7.0	30	152	41.5
Lead, filtered (µg/L)	2	100	0.1	—	0.178	0.139
Manganese, filtered (µg/L)	30	87	<1.0	6.0	50	12.1
Molybdenum, filtered (µg/L)	2	100	1.48	—	1.99	1.74
Nickel, filtered (µg/L)	2	100	1.1	—	1.2	1.15
Silver, filtered (µg/L)	2	0	<0.02	—	<0.02	<0.02
Zinc, filtered (µg/L)	2	0	<2.0	—	<2.0	<2.0
Antimony, filtered (µg/L)	2	100	0.134	—	0.246	0.190
Arsenic, filtered (µg/L)	2	100	0.67	—	1.0	0.835
Selenium, filtered (µg/L)	2	100	0.35	—	0.45	0.40
Uranium, filtered (µg/L)	2	100	0.248	—	0.282	0.265
Hardness as $CaCO_3$ (mg/L)	30	100	56	566	1,320	509

Table 5.1. Statistical summary of selected water-quality data by parameter for active sites on the Piñon Canyon Maneuver Site, Colorado, for water years 1966–2018. (Data are from U.S. Geological Survey, 2020).—Continued

[%, percent; CO, Colorado; MPN/100 mL, most probable number of colonies per 100 milliliters; <, less than; >, greater than; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; NC, not calculated; µS/cm, microsiemens per centimeter; °C, degree Celsius; —, no data]

Water-quality parameter (reporting units)	Number of samples	Percent} detection (%)	Minimum	Median	Maximum	Mean
Van Bremer Arroyo near Model, CO—Continued						
Oxygen, dissolved (mg/L)	5	100	6.2	8.0	8.5	7.50
pH, field	5	100	7.9	8.0	8.2	NC
Solids, dissolved (mg/L)	27	100	92	854	2,300	819
Specific conductance (µS/cm)	16	100	140	735	2,400	919
Water temperature (°C)	30	100	9.0	21.7	28	20.2
Purgatoire River near Thatcher, CO						
Escherichia coli (MPN/100 mL)	23	83	<1	4	2,800	140
Total coliforms (MPN/100 mL)	23	100	54	>2,400	>24,000	2,684
Alkalinity, filtered (mg/L as $CaCO_3$)	11	100	108	197	230	189
Chloride, filtered (mg/L)	80	100	4.8	9.8	81.4	30.7
Fluoride, filtered (mg/L)	80	100	0.20	0.43	0.93	0.434
Silica, filtered (mg/L)	80	100	2.17	8.05	15.0	7.96
Sulfate, filtered (mg/L)	81	100	160	1,120	2,400	1,170
Calcium, filtered (mg/L)	79	100	47	202	350	200
Magnesium, filtered (mg/L)	79	100	17	137	250	132
Potassium, filtered (mg/L)	79	100	2.3	5.0	14.3	5.26
Sodium, filtered (mg/L)	79	100	24	180	380	168
Ammonia, filtered (mg/L)	24	46	<0.01	<0.01	0.1	0.018
Ammonia, unfiltered (mg/L)	24	50	<0.02	0.01	0.08	0.018
Nitrite plus nitrate, filtered (mg/L)	76	62	<0.040	0.195	0.76	0.231
Total nitrogen, unfiltered (mg/L)	24	100	0.29	0.44	6.34	0.759
Orthophosphate, filtered (mg/L)	24	33	<0.004	<0.004	0.025	0.003
Phosphorus, filtered (mg/L)	76	54	<0.02	0.01	0.23	0.018
Phosphorus, unfiltered (mg/L)	24	100	0.011	0.036	9.66	0.490
Aluminum, filtered (µg/L)	24	17	<3	<3	23.9	1.41
Barium, filtered (µg/L)	24	100	24.8	43.6	107	50.0
Beryllium, filtered (µg/L)	24	13	<0.02	<0.02	0.506	0.025
Cadmium, filtered (µg/L)	24	8	<0.03	<0.03	0.173	0.009
Chromium, filtered (µg/L)	54	19	<0.5	<0.5	20	1.40
Cobalt, filtered (µg/L)	24	96	<0.3	0.614	0.96	0.587
Copper, filtered (µg/L)	24	25	<0.8	<0.8	18.1	0.982
Iron, filtered (µg/L)	79	85	<8.0	24	250	39.1
Lead, filtered (µg/L)	24	4	<0.02	<0.02	0.136	0.006
Manganese, filtered (µg/L)	80	93	<1.0	20	154	27.6
Molybdenum, filtered (µg/L)	24	100	2.42	3.98	7.83	4.20
Nickel, filtered (µg/L)	24	96	<2.0	2.5	5.9	2.65
Silver, filtered (µg/L)	24	4	<0.04	<0.04	0.027	0.001
Zinc, filtered (µg/L)	24	4	<2.0	<2.0	24.7	1.03
Antimony, filtered (µg/L)	24	83	<0.3	0.165	0.43	0.180
Arsenic, filtered (µg/L)	24	92	<1.0	0.625	1.50	0.668

Table 5.1. Statistical summary of selected water-quality data by parameter for active sites on the Piñon Canyon Maneuver Site, Colorado, for water years 1966–2018. (Data are from U.S. Geological Survey, 2020).—Continued

[%, percent; CO, Colorado; MPN/100 mL, most probable number of colonies per 100 milliliters; <, less than; >, greater than; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; NC, not calculated; µS/cm, microsiemens per centimeter; °C, degree Celsius; —, no data]

Water-quality parameter (reporting units)	Number of samples	Percent} detection (%)	Minimum	Median	Maximum	Mean
Van Bremer Arroyo near Model, CO—Continued						
Selenium, filtered (µg/L)	24	100	1.4	2.4	3.7	2.37
Uranium, filtered (µg/L)	31	100	1.6	11.0	18.5	10.7
Hardness as $CaCO_3$ (mg/L)	79	100	187	1,130	1,900	1,044
Oxygen, dissolved (mg/L)	58	100	7.0	9.2	13.7	9.46
pH, field	60	100	7.4	8.3	8.8	NC
Solids, dissolved (mg/L)	69	100	352	2,050	3,850	2,001
Specific conductance (µS/cm)	231	100	19	2,790	8,000	2,670
Water temperature (°C)	369	100	0.0	14.7	30	13.8
Purgatoire River at Rock Crossing near Timpas, CO						
Escherichia coli (MPN/100 mL)	22	86	<1	9	3,900	214
Total coliforms (MPN/100 mL)	22	100	50	1,135	>24,000	4,283
Alkalinity, filtered (mg/L as $CaCO_3$)	11	100	108	182	209	170
Chloride, filtered (mg/L)	81	100	4.3	30	68.3	29.4
Fluoride, filtered (mg/L)	81	99	<0.1	0.4	1.2	0.413
Silica, filtered (mg/L)	81	100	1.56	7.3	15	7.60
Sulfate, filtered (mg/L)	81	100	150	1,200	2,200	1,180
Calcium, filtered (mg/L)	80	100	43	213	340	206
Magnesium, filtered (mg/L)	81	100	15	123	240	129
Potassium, filtered (mg/L)	81	100	2.5	5.2	11.7	5.49
Sodium, filtered (mg/L)	81	100	17	180	310	167
Ammonia, filtered (mg/L)	22	77	<0.01	0.02	0.07	0.026
Ammonia, unfiltered (mg/L)	21	67	<0.02	0.03	0.14	0.031
Nitrite plus nitrate, filtered (mg/L)	80	58	<0.040	0.11	0.83	0.213
Total nitrogen, unfiltered (mg/L)	22	100	0.24	0.44	7.66	0.834
Orthophosphate, filtered (mg/L)	22	27	<0.004	<0.004	0.03	0.003
Phosphorus, filtered (mg/L)	80	54	<0.02	0.01	0.25	0.017
Phosphorus, unfiltered (mg/L)	22	100	0.016	0.063	11.7	0.641
Aluminum, filtered (µg/L)	22	36	<6.0	<6.0	628	31.9
Barium, filtered (µg/L)	22	100	24.1	46.5	175	67.7
Beryllium, filtered (µg/L)	22	0	<0.02	<0.02	<0.02	<0.02
Cadmium, filtered (µg/L)	22	17	<0.03	<0.03	0.074	0.008
Chromium, filtered (µg/L)	55	24	<0.3	<0.3	20	1.78
Cobalt, filtered (µg/L)	22	95	<0.3	0.596	1.11	0.608
Copper, filtered (µg/L)	22	23	<1.0	<1.0	1.6	0.270
Iron, filtered (µg/L)	81	86	<8.0	22	644	40.5
Lead, filtered (µg/L)	22	9	<0.02	<0.02	1.09	0.081
Manganese, filtered (µg/L)	81	96	<1.0	30	260	38.2
Molybdenum, filtered (µg/L)	22	100	2.97	6.01	14.9	6.71
Nickel, filtered (µg/L)	22	95	<3.0	2.8	6.2	2.92
Silver, filtered (µg/L)	22	0	<0.04	<0.04	<0.04	<0.04

Table 5.1. Statistical summary of selected water-quality data by parameter for active sites on the Piñon Canyon Maneuver Site, Colorado, for water years 1966–2018. (Data are from U.S. Geological Survey, 2020).—Continued

[%, percent; CO, Colorado; MPN/100 mL, most probable number of colonies per 100 milliliters; <, less than; >, greater than; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; NC, not calculated; µS/cm, microsiemens per centimeter; °C, degree Celsius; —, no data]

Water-quality parameter (reporting units)	Number of samples	Percent} detection (%)	Minimum	Median	Maximum	Mean
Van Bremer Arroyo near Model, CO—Continued						
Zinc, filtered (µg/L)	22	0	<2.0	<2.0	<2.0	<2.0
Antimony, filtered (µg/L)	22	88	<0.15	0.226	0.724	0.253
Arsenic, filtered (µg/L)	22	95	<1.5	0.82	1.5	0.852
Selenium, filtered (µg/L)	22	100	1.4	2.6	4.4	2.64
Uranium, filtered (µg/L)	30	100	2.2	11.3	19.0	10.6
Hardness as $CaCO_3$ (mg/L)	80	100	169	1,025	1,840	1,042
Oxygen, dissolved (mg/L)	56	100	5.6	8.3	13.0	8.68
pH, field	64	100	7.2	8.3	9.1	NC
Solids, dissolved (mg/L)	70	100	341	1,990	3,420	1,969
Specific conductance (µS/cm)	184	100	441	2,320	4,190	2,351
Water temperature (°C)	237	100	0.0	18.0	31.5	16.7

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U.S. Geological Survey [USGS], 2020, National Water Information System—USGS water data for the Nation: U.S. Geological Survey website, accessed October 2020 at https://doi.org/10.5066/F7P55KJN.

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