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Scientific Investigations Report 2022–5086

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

Front cover. Photograph showing weir structure at the Rapid Creek below Pactola Dam streamgage (06411500).

Inset photograph showing hydrologic technician measuring streamflow at Rapid Creek above the water reclamation facility near Rapid City, South Dakota (06418800).

Back cover. Photograph showing streamgage location of Rapid Creek at Rapid City, South Dakota (06414000).

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By Wyatt S. Tatge, Galen K. Hoogestraat, and Rochelle A. Nustad

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U.S. Geological Survey, Reston, Virginia: 2022

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Suggested citation:
Tatge, W.S., Hoogestraat, G.K., and Nustad, R.A., 2022, Water-quality data and trends in the Rapid Creek Basin, South Dakota, 1970–2020: U.S. Geological Survey Scientific Investigations Report 2022–5086, 67 p., https://doi.org/10.3133/sir20225086.

Associated data for this publication:
Tatge, W.S., Nustad, R.A., and Hoogestraat, G.K., 2022, Model scripts and water-quality data for trends in the Rapid Creek Basin, South Dakota, 1970–2020: U.S. Geological Survey data release, https://doi.org/10.5066/P9D8BSXR.

U.S. Geological Survey, 2022, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, https://doi.org/10.5066/F7P55KJN.

ISSN 2328-0328 (online)

Acknowledgments

The authors would like to thank the South Dakota Department of Agriculture and Natural Resources and the City of Rapid City Public Works Department for providing data and technical guidance for this study.

The authors also would like to acknowledge the staff from the U.S. Geological Survey Dakota Water Science Center who supported the project by assisting with data collection, administration, and technical reviews.

Contents

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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 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 constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Bacteria are given in either colony forming units per 100 milliliters (cfu/100 mL) or most probable number per 100 milliliters (mpn/100 mL).

A water year is the period from October 1 to September 30 and is designated by the year in which it ends; for example, water year 2020 was from October 1, 2019, to September 30, 2020.

Abbreviations

E. coli	*Escherichia coli*
EPA	U.S. Environmental Protection Agency
GMC	geometric mean concentration
NWIS	National Water Information System
p	probability
SC	specific conductance
SD DANR	South Dakota Department of Agriculture and Natural Resources
SSC	suspended sediment concentration
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TSS	total suspended solids
USGS	U.S. Geological Survey
WQP	Water Quality Portal
WRF	water reclamation facility

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Abstract

Surface-water-quality data in the Rapid Creek Basin in South Dakota were compiled to assess basic trends in the water quality of Rapid Creek. Spatial and temporal patterns in water quality were described for major ions, sediment, total suspended solids, nutrients, field measurements, bacteria, and select metals for the period of 1970–2020, and a water-quality trend analysis was completed for sites with enough data for selected constituents.

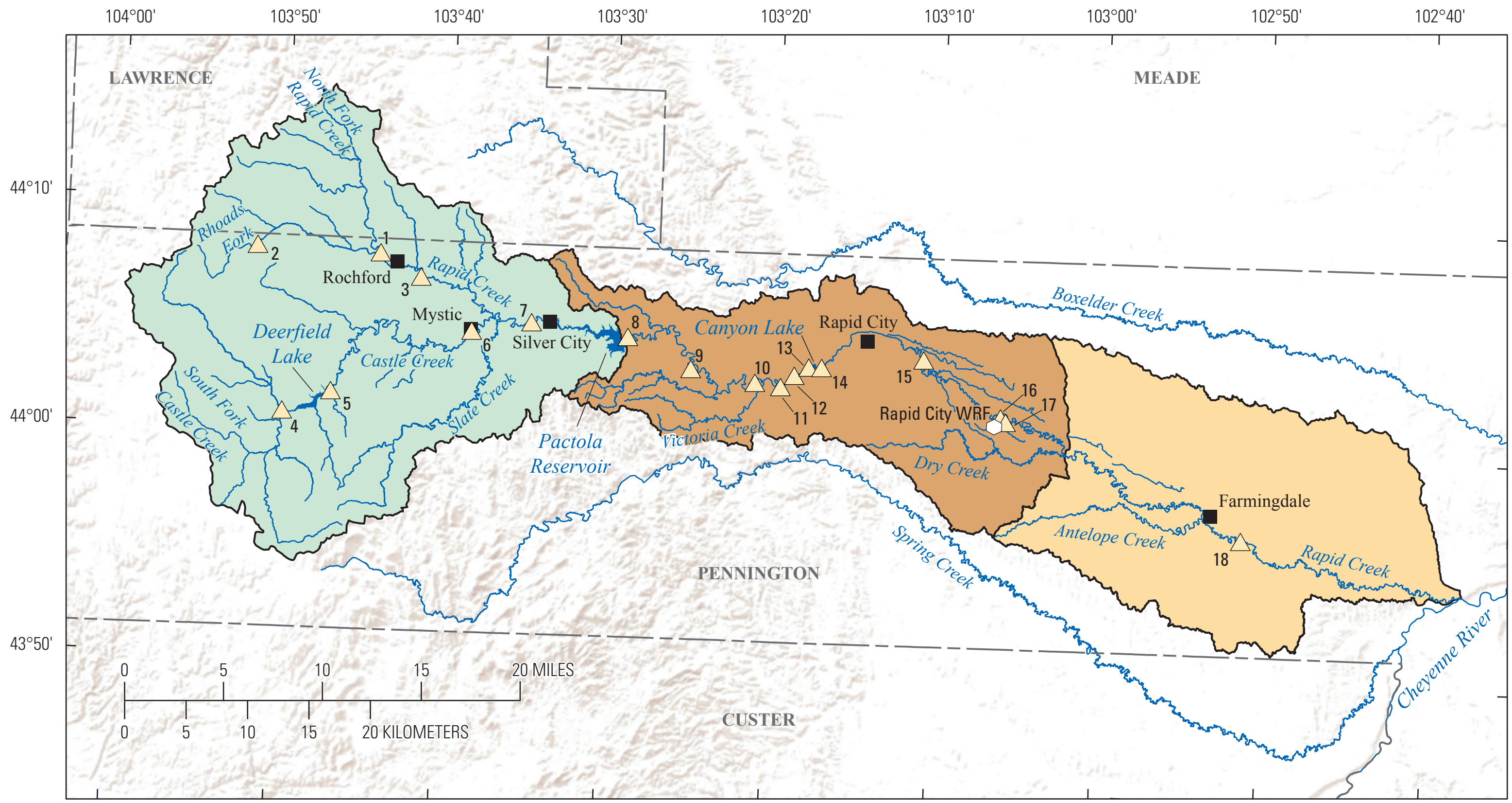
Major ions and total suspended solids had higher median concentrations in the lower basin (downstream from the city of Rapid City) relative to the upper and middle basins. Nutrient concentrations were generally low, and increased concentrations were only detected at the sites downstream from the City of Rapid City Water Reclamation Facility. Fecal indicator bacteria (*Escherichia coli* and fecal coliform) concentrations were highest downstream from the main urbanized area of Rapid City.

Water-quality trends were analyzed for total dissolved solids, specific conductance, calcium, magnesium, total suspended solids, total phosphorus, dissolved phosphorus, and total Kjeldahl nitrogen for the period of 1979–2019. Concentrations for major ions and total dissolved solids typically changed by less than 15 percent. Total dissolved solids concentrations upstream from Rapid City were generally decreasing, whereas concentrations downstream were generally increasing. The flow-averaged geometric mean concentration of total dissolved solids at three sites upstream from Rapid City decreased overall by 3–5 percent, and concentrations at two sites downstream from Rapid City increased by at least 7 percent between 1979 and 2019. Trends in specific conductance in the Rapid Creek Basin were mixed with alternating increasing and decreasing trends at many of the sites between 1979 and 2014. Total suspended solids concentrations were observed to be decreasing at two sites analyzed for trends. Concentrations in total phosphorus were observed to be decreasing at every site analyzed for trends between 1989 and 2014. Significant downward trends in total Kjeldahl nitrogen were observed at two sites in the lower Rapid Creek Basin for the trend period of 1999–2019. The decreases in total suspended solids and nutrient concentrations in the Rapid Creek Basin could be related to several processes such as the implementation of a stormwater management plan in Rapid City, improvements to the water reclamation facility downstream from Rapid City, and residual climatic effects.

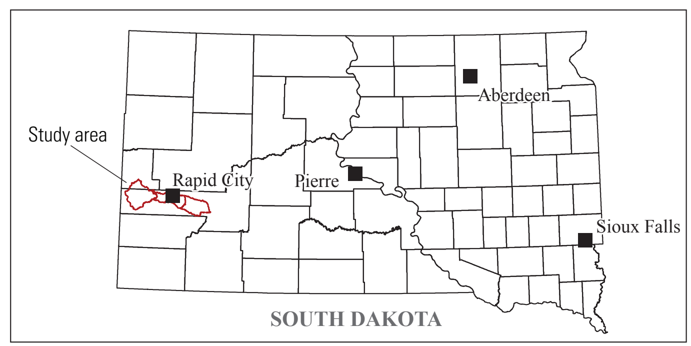
Introduction

Rapid Creek in the Black Hills of South Dakota is a valuable spawning area for a self-sustaining trout fishery, actively used for recreation; a municipal water supply for the city of Rapid City and other entities; and a water supply for agricultural irrigation. It is important to monitor and assess changes in water-quality conditions in Rapid Creek for management and sustainability of these uses. The South Dakota Department of Agriculture and Natural Resources (SD DANR) assigns streams and rivers in the State with 1 or more of 11 beneficial uses: (1) domestic water-supply waters; (2) cold water permanent fish life propagation waters; (3) cold water marginal fish life propagation waters; (4) warm water permanent fish life propagation waters; (5) warm water semipermanent fish life propagation waters; (6) warm water marginal fish life propagation waters; (7) immersion recreation waters; (8) limited contact recreation waters; (9) fish and wildlife propagation, recreation, and stock watering waters; (10) irrigation waters; and (11) commerce and industry waters (South Dakota Department of Agriculture and Natural Resources, 2021). Rapid Creek within and upstream from the city of Rapid City has beneficial uses of groups 1, 2, and 7–10, representing uses for water supply, fisheries, recreation, and irrigation. Rapid Creek downstream from the Rapid City Water Reclamation Facility (WRF; fig. 1) has beneficial uses of groups 4 and 7–10.

Numerous governmental and academic entities have collected water-quality data in the Rapid Creek Basin since the 1970s with varying record durations and spatial locations. Data collected as part of the SD DANR's ambient water-quality monitoring program (South Dakota Department of Agriculture and Natural Resources, 2022) form the longest and most complete record of long-term water quality in Rapid Creek, and data from 1970 through 2020 were collected at numerous sites. Several other synoptic studies have been completed in the Rapid Creek Basin, typically lasting 3–5 years. In these shorter term studies, water-quality constituents associated with the SD DANR beneficial-use criteria were often the



Base modified from U.S. Geological Survey and other digital data



EXPLANATION

Rapid Creek study area

- Upper
- Middle
- Lower

1 **Water-quality site with map identification number (table 1)**

WRF—Water reclamation facility

Figure 1. Location of Rapid Creek and study sites.

only constituents monitored, and the most common were total suspended solids (TSS), fecal indicator bacteria (*Escherichia coli* [*E. coli*] and fecal coliform; referred to as “bacteria”), nutrient constituents, and field measurements (pH, specific conductance [SC], dissolved oxygen, and water temperature). Data from these studies are not always stored in a uniform manner, and some data are not archived in publicly available online databases, which represents a challenge to Rapid Creek water management agencies when comparing water-quality information from the last 5 to 10 years to previous data collected over the past 50 years.

Purpose and Scope

The purpose of this report is to compile and describe the available surface-water-quality data in the Rapid Creek Basin spatially and temporally using statistical summaries and trend analysis, where sufficient data exist. This effort is intended to meet a critical need to understand water quality in the basin by describing spatial and temporal patterns in water quality, identifying gaps in the data, and providing a framework for future monitoring efforts. Water-quality data were compiled for 1970–2020 from the National Water Quality Monitoring Council Water Quality Portal (WQP; National Water Quality Monitoring Council, 2022), and streamflow data for selected sites were obtained from the U.S. Geological Survey (USGS) National Water Information System (NWIS) database (U.S. Geological Survey, 2022).

Description of Study Area

Rapid Creek originates from springs on what is commonly referred to as the “Limestone Plateau” in the western Black Hills and flows east through Rapid City to its mouth at the Cheyenne River, draining an area of about 715 square miles (mi^2; fig. 1). The mean annual streamflow for Rapid Creek above Pactola Reservoir at Silver City (site 7; fig. 1, table 1) was 56 cubic feet per second (ft^3/s) during water years 1970–2020 with a drainage area of 293 mi^2. The mean annual streamflow for Rapid Creek at Rapid City (USGS streamgage 06414000, not shown) during water years 1970–2020 was 78 ft^3/s with a drainage area of 413 mi^2. The mean annual streamflow during water years 1970–2020 for Rapid Creek near Farmingdale (site 18) was 89 ft^3/s with a drainage area of 603 mi^2. All streamflow data are from the USGS NWIS database (U.S. Geological Survey, 2022).

Land use in the Rapid Creek Basin is largely rural; 48 percent is forested, 35 percent is grasslands, and only 5 percent is developed (fig. 2; Dewitz and U.S. Geological Survey, 2021). Agricultural land use in the basin consists of only about 5 percent of the basin, 3 percent is hay and pasture and 2 percent is cultivated crops, and generally is in the lower basin (fig. 2; Dewitz and U.S. Geological Survey, 2021). Forest land use is mainly in the upper basin and is defined as evergreen forest, deciduous forest, and mixed forest land-use types (Homer and others, 2015; Dewitz and U.S. Geological Survey, 2021). Developed land use in the Rapid Creek Basin increased from about 34 mi^2 in 2001 to 39 mi^2 in 2019, or about 1 percent (Homer and others, 2004; Dewitz and U.S. Geological Survey, 2021). Cotillon (2013) investigated land-use changes in the Black Hills from 1950 to 2010 and determined that in the Black Hills National Forest, 53 percent of the sampled area’s land use had changed; however, most of that change was from dense forest to medium forest, open forest, or grassland. That study also indicated that some of the changes included converting forest land to pasture or developed land (Cotillon, 2013).

Most of the higher elevations in the basin are heavily forested with *Pinus ponderosa* Douglas ex P. Lawson & C. Lawson (ponderosa pine), which is the primary product of an active timber industry. *Picea engelmannii* Parry ex Engelm. (white spruce), *Populus tremuloides* Michx. (quaking aspen), *Betula papyrifera* Marshall (paper birch), and other native trees and shrubs are in cooler, wetter areas (Orr, 1959). The lower elevation areas surrounding the Black Hills primarily are urban, suburban, and agricultural. Rangeland, hay land, and winter wheat farming are the principal agricultural uses for dryland areas. Alfalfa, corn, and vegetables are produced in bottom lands and in irrigated areas. Various other crops, primarily for cattle fodder, are produced in dryland areas and in bottom lands.

Beginning in the 1870s, the Black Hills have been mined for many commodities including gold, silver, tin, tungsten, mica, feldspar, bentonite, beryl, lead, zinc, uranium, lithium, sand, gravel, and oil (U.S. Department of Interior, 1967). Mines within the study area have used placer mining, small surface pits, underground mines, and open-pit mines. Much of the mining activities in the Rapid Creek Basin were active in the upper basin near Rochford, South Dakota, but those mines have not been operational since the late 1930s (Bayley, 1972).

Previous Work

Water-quality conditions in the Black Hills through 1998 are summarized in Williamson and Carter (2001) and include primarily USGS data sources. Surface-water quality depends largely on the geology of the area. Williamson and Carter (2001) described water quality for headwater springs, crystalline core sites, artesian springs, and exterior sites of the Black Hills. Headwater springs originate from the Paleozoic units, such as the Madison Limestone, on the western side of the Black Hills, and the springs tend to have mostly unchanging water-quality characteristics because of the groundwater source. Other streams originate in the Precambrian rocks of the crystalline core and tend to have more variability than the headwater springs. Artesian springs develop downgradient from loss zones and contribute much of the base flow to exterior streams beyond the Black Hills (Williamson and Carter, 2001). The Rapid Creek Basin is within all four of

Table 1. Sites in the Rapid Creek Basin included in the data compilation and analyses.

[USGS, U.S. Geological Survey; SD DANR, South Dakota Department of Agriculture and Natural Resources; --, not applicable; SS, statistical summary; T, trend analysis; WRF, water reclamation facility]

Map identification number (fig. 1)	USGS site identification number(s)[1]	SD DANR site identification number(s)	Site name	Collecting agency	Latitude, in decimal degrees	Longitude, in decimal degrees	Flow data	Analysis type[1]
1	--	UPRAPIDT04, 460178	North Fork Rapid Creek, S. Dak.	SD DANR	44.13143	−103.73629	--	SS
2	06408700	460179	Rhoads Fork near Rochford, S. Dak.	USGS, SD DANR	44.13387149	−103.86159	USGS, 06408700	SS, T
3	--	460647	Rapid Creek near Rochford, S. Dak.	SD DANR	44.11485	−103.69431	Estimated	SS, T
4	06409000	--	Castle Creek above Deerfield Reservoir near Hill City, S. Dak.	USGS	44.01359238	−103.83048	USGS, 06409000	SS, T
5	06410000	RAPSPECCCD03, CASTLETSS03,	Castle Creek below Deerfield Dam, S. Dak.	USGS, SD DANR	44.02914848	−103.78187	USGS, 06410000	SS, T
6	--	RAPSPECCCD01, 460646	Castle Creek near Mystic, S. Dak.	SD DANR	44.076833	−103.64096	Estimated	SS, T
7	06410500	RAPSPECRC0A	Rapid Creek above Pactola Reservoir at Silver City, S. Dak.	USGS, SD DANR	44.08470785	−103.58047	USGS, 06410500	SS, T
8	06411500, 440436103285402	CANYONZCL01, RAPSPECRC0, RAPSPECRC1, 460920	Rapid Creek below Pactola Dam, S. Dak.	USGS, SD DANR	44.07665378	−103.48213	USGS, 06411500	SS, T
9	06412000	CANYONZCL02, CANYONZCL03	Rapid Creek at Big Bend near Rapid City, S. Dak.	USGS	44.05498747	−103.41713	USGS, 06412000	SS
10	06412200	--	Rapid Creek above Victoria Creek near Rapid City, S. Dak.	USGS	44.0465988	−103.35157	USGS, 06412200	SS
11	440239103193001	RAPSPECRC4, 460669	Rapid Creek below Tittle Springs, S. Dak.	USGS, SD DANR	44.04415446	−103.32546	Estimated	SS, T
12	06412500, 06412510	LRCABOVECANYON	Rapid Creek above Canyon Lake near Rapid City, S. Dak.	USGS, SD DANR	44.05276555	−103.31185	USGS, 06412510	SS, T
13	06412900	--	Rapid Creek below Cleghorn Springs at Rapid City, S. Dak.	USGS	44.0591544	−103.29741	USGS, 06412900	SS
14	06413200, 440333103170001	CANYONZCL07, LRCPARKDRIVE	Rapid Creek below Park Drive at Rapid City, S. Dak.	USGS, SD DANR	44.05915448	−103.28435	USGS, 06413200	SS

Table 1. Sites in the Rapid Creek Basin included in the data compilation and analyses.—Continued

[USGS, U.S. Geological Survey; SD DANR, South Dakota Department of Agriculture and Natural Resources; --, not applicable; SS, statistical summary; T, trend analysis; WRF, water reclamation facility]

Map identification number (fig. 1)	USGS site identification number(s)[1]	SD DANR site identification number(s)	Site name	Collecting agency	Latitude, in decimal degrees	Longitude, in decimal degrees	Flow data	Analysis type[1]
15	06416000	LRCHAWTHORNE, 460173	Rapid Creek below Hawthorn Ditch at Rapid City, S. Dak.	USGS, SD DANR	44.06726568	−103.18093	USGS, 06416000	SS
16	06418800, 440126103054701	LRCABOVEWWTP, 460110	Rapid Creek above WRF near Rapid City, S. Dak.	USGS, SD DANR	44.02680556	−103.10111	USGS, 06418800	SS, T
17	06418900, 440123103053300	LRCBELOWWWTP, LOWCHEYRPC03, 46092	Rapid Creek below sewage treatment plant near Rapid Creek, S. Dak.	USGS, SD DANR	44.0236549	−103.09584	USGS, 06418900	SS, T
18	06421500, 435630102511502	LOWCHEYRPC04, LRCFARMINGDALE, 460910	Rapid Creek near Farmingdale, S. Dak.	USGS, SD DANR	43.94210239	−102.85392	USGS, 06421500	SS, T

[1]U.S. Geological Survey (2022).

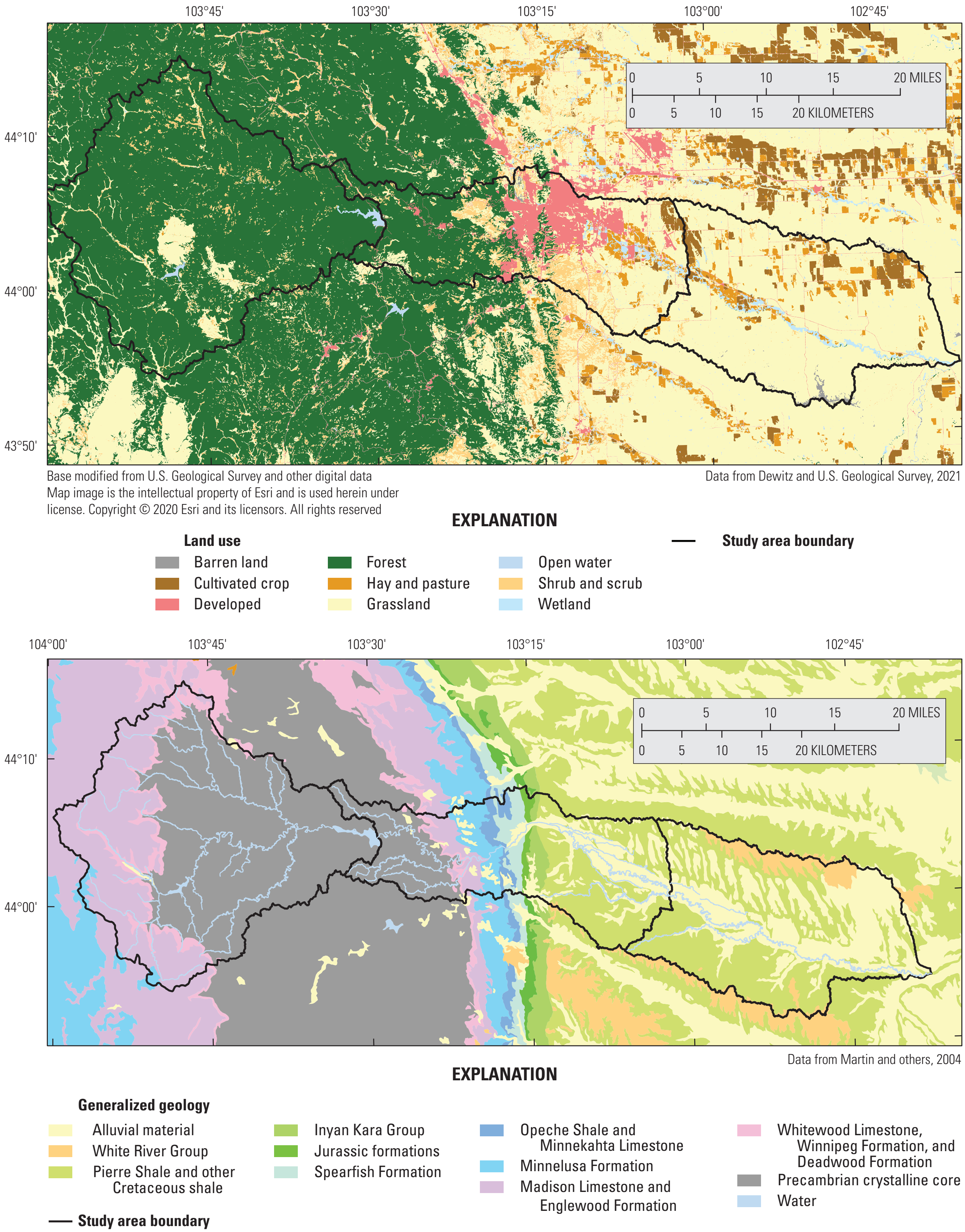


Figure 2. Land use (modified from Dewitz and U.S. Geological Survey, 2021) and generalized geology (modified from Martin and others, 2004) in the Rapid Creek Basin.

these geologic areas, originating in the western headwater springs and flowing east across the crystalline core and onto the exterior plains (fig. 2).

Several short-term (3 to 5 years) monitoring efforts have examined Rapid Creek water quality on the western edge of Rapid City upstream from and within Canyon Lake. Stewart and others (1989) sampled nine sites between 1987 and 1988 to examine the effects of the Cleghorn Springs State Fish Hatchery on downstream water quality. Delzer (1993) describes a similar extension of this monitoring effort during 1991 and 1992. These studies focused on nutrient loading coming from the Cleghorn Springs State Fish Hatchery discharge entering Rapid Creek just upstream from Canyon Lake. The Cleghorn Springs State Fish Hatchery was renovated in 2006 in part to improve the water quality of discharged water to Rapid Creek (Woodard, 2006). More recent USGS sampling efforts have collected nutrient and bacteria data around Canyon Lake during 2017–21; these data are available in the USGS NWIS database (U.S. Geological Survey, 2022). Another sampling study focused on sources of bacteria in Rapid Creek in the reach from Canyon Lake downstream to the WRF during 2016–17 (H2E, Inc., 2018).

For the urban area inside the Rapid City boundary, multiple studies have examined the quantity and quality of the runoff associated with storm events. Hoogestraat (2015, 2020) provided the most recent compilation of stormwater information in the Rapid City area, wherein stormwater quality was assessed in urban drainages during 2008–18. In those studies, event-mean concentrations of TSS and bacteria typically exceeded relevant beneficial-use criteria for Rapid Creek by 1–2 orders of magnitude. Baker (2010) presented an early subset of the water-quality data for the Arrowhead drainage basin (not shown). Fisher (2011) evaluated the effectiveness of several structures for the management of stormwater quantity and quality on the Rapid Creek drainage basin. Krantz (2002) implemented a 2-year water-quality sampling program on Rapid Creek to investigate potential effects of stormwater runoff on the *Salmo trutta* (Linnaeus, 1758) (brown trout) population. Results of the study by Krantz (2002) indicated that TSS and turbidity increase in Rapid Creek through the city of Rapid City to levels that could potentially pose a threat to trout health. Pirner and Harms (1978) completed a study to determine the potential of urban runoff as a source of pollution in Rapid Creek. The Nationwide Urban Runoff Program chose Rapid City as one of its locations for study during the early 1980s and tested for numerous water-quality constituents (U.S. Environmental Protection Agency, 1983). In a report to the South Dakota Department of Environment and Natural Resources and the City of Rapid City, Kenner and Craft (1997) described a study on different parts of the Rapid Creek drainage to assess the effects on the quality of the overall creek system. Schiferl (2011) evaluated the potential contribution of bottom sediments as a source of fecal coliform bacteria in stormwater runoff in two drainage basins in Rapid City. Prann (2013) evaluated the effect of impervious surfaces on surface-water quality using calibrated hydrologic models. All these studies indicate that the TSS concentrations and fecal coliform concentrations in the stormwater runoff in urban drainage basins have the potential to adversely affect the quality of the waters in the Rapid Creek Basin. Groundwater quality in the Rapid Creek Basin was not a focus of this study but is described in Williamson and Carter (2001), Driscoll and others (2002), and Putnam and others (2008).

Methods of Analysis

Water-quality data for selected sites and constituents in the Rapid Creek Basin were obtained from the WQP (National Water Quality Monitoring Council, 2022), and available streamflow data for selected sites were obtained from the USGS NWIS database (U.S. Geological Survey, 2022). Data were selected for the period of 1970–2020. The water-quality data compiled and described in this report also are available in a USGS data release (Tatge and others, 2022b). Analyses applied to this study include descriptive statistics, such as percentiles of constituent concentrations, and trend analysis to evaluate long-term changes in the Rapid Creek Basin.

Site and Constituent Selection

Water-quality data for all sites with major ions, total dissolved solids (TDS), suspended sediment and solids, nutrients, field measurements, bacteria, and trace metals in the Rapid Creek Basin were retrieved from the WQP (National Water Quality Monitoring Council, 2022). Trace metal data before 1992 were not used in this study because of changes in analyses at the USGS National Water Quality Laboratory and changes in data collection methods (Hoffman and others, 1996). The WQP retrieval included data collected by various Federal and State agencies, including the USGS and SD DANR.

Within the Rapid Creek Basin, 18 sites were selected for water-quality analyses (table 1; fig. 1). The initial retrieval of water-quality data from the WQP produced 382 sites. Sites associated with an urban study and lake, spring, and precipitation sites were removed. Additionally, USGS sites with one value or only 1 year of sampling were removed, and colocated USGS sites that had different USGS station numbers were combined. Lastly, USGS and SD DANR sites that were in proximity were combined to finalize the 18 stream sites with enough data available for analysis.

Constituents collected at the selected sites in the basin also were evaluated for data availability, and constituents with less than 20 samples were eliminated. Some constituents, such as color and volatile solids, were eliminated because they provided minimal value in understanding water quality in the basin. The remaining constituents were mostly major ions, sediment or suspended solids, nutrients, field measurements, bacteria, and some trace metals (table 2). Each constituent also had multiple descriptors in the dataset such as total,

Table 2. Summary of constituents evaluated in the Rapid Creek Basin.

[WQP, National Water Quality Monitoring Council Water Quality Portal; SD DANR, South Dakota Department of Agriculture and Natural Resources; mg/L, milligram per liter; --, not applicable; SO_4, sulfate; µg/L, microgram per liter; N, nitrogen; P, phosphorus; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µohm/cm, microohm per centimeter; >, greater than; mpn, most probable number; mL, milliliter; cfu, colony forming units; no., number]

Constituent name	Used unit	WQP descriptions	Censoring levels in raw data	Used recensored level	SD DANR standard[a]	SD DANR beneficial-use criteria[a]
		Major ions				
Bicarbonate	mg/L	Bicarbonate, total, mg/L	--	--	--	--
Calcium	mg/L	Calcium, dissolved, mg/L	0.2, 1, −1	1	--	--
		Calcium, total, mg/L				
Chloride	mg/L	Chloride, dissolved, mg/L	1, 3[b], 5[b], −1[b]	1	100	2
		Chloride, total, mg/L				
Potassium	mg/L	Potassium, dissolved, mg/L	0.2, 1	1	--	--
		Potassium, total, mg/L				
Sodium	mg/L	Sodium, dissolved, mg/L	1, −1	1	--	--
		Sodium, total, mg/L				
Sulfate	mg/L	Sulfate, dissolved, mg/L	0.01, 1, 5[b], 10[b]	1	--	--
		Sulfate, total, mg/L				
		Sulfate as SO_4, dissolved, mg/L				
Magnesium, dissolved	mg/L	Magnesium, dissolved, mg/L	--	--	--	--
Magnesium, total	µg/L	Magnesium, total recoverable, µg/L	0.2[b], 1[b], −1[b]	--	--	--
		Magnesium, total, µg/L				
Total dissolved solids	mg/L	Total dissolved solids, dissolved, mg/L	5	5	1,000	1
		Total dissolved solids, total, mg/L				
		Trace metals				
Iron, dissolved	µg/L	Iron, dissolved, µg/L	3, 8, 6	--	--	--
		Iron, dissolved, mg/L	0.02, 0.03			
Iron, total	µg/L	Iron, total, µg/L	10, 3	--	--	--
Manganese, dissolved	µg/L	Manganese, dissolved, µg/L	1	--	--	--
		Manganese, dissolved, mg/L	0.01, 0.2, 0.4			
Manganese, total	µg/L	Manganese, total, µg/L	--	--	--	--
		Manganese, total, mg/L	0.01			
		Nutrients				
Ammonia, total	mg/L as N	Ammonia and ammonium, total, mg/L as N	0.002, 0.01, 0.02, 0.05, 0.06, 0.1	0.1	2.4[c]	2
		Ammonia nitrogen, total, mg/L				
Ammonia, dissolved	mg/L as N	Ammonia and ammonium, dissolved, mg/L as N	--	--	--	--
		Ammonia nitrogen, dissolved, mg/L				

Table 2. Summary of constituents evaluated in the Rapid Creek Basin.—Continued

[WQP, National Water Quality Monitoring Council Water Quality Portal; SD DANR, South Dakota Department of Agriculture and Natural Resources; mg/L, milligram per liter; --, not applicable; SO_4, sulfate; µg/L, microgram per liter; N, nitrogen; P, phosphorus; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µohm/cm, microohm per centimeter; >, greater than; mpn, most probable number; mL, milliliter; cfu, colony forming units; no., number]

Constituent name	Used unit	WQP descriptions	Censoring levels in raw data	Used recensored level	SD DANR standard[a]	SD DANR beneficial-use criteria[a]
		Nutrients—Continued				
Nitrate plus nitrite	mg/L as N	Inorganic nitrogen (nitrate and nitrite), dissolved, mg/L Inorganic nitrogen (nitrate and nitrite), dissolved, mg/L as N Inorganic nitrogen (nitrate and nitrite) as N, dissolved, mg/L Inorganic nitrogen (nitrate and nitrite), total, mg/L Inorganic nitrogen (nitrate and nitrite), total, mg/L as N Inorganic nitrogen (nitrate and nitrite) as N, total, mg/L Nitrate, dissolved, mg/L Nitrate, dissolved, mg/L as N Nitrate, total, mg/L as N Nitrate, total, mg/L	0.005, 0.01, 0.016, 0.021, 0.03, 0.038, 0.039, 0.05, 0.1, 0.3[b], 0.8[b], 1[b], −1[b]	0.1	10	1
Ammonia plus organic nitrogen, total	mg/L as N	Kjeldahl nitrogen, total, mg/L Kjeldahl nitrogen, total, mg/L as N	0.02, 0.05, 0.1, 0.2, 0.5, −1	0.5	--	--
Phosphorus, dissolved	mg/L as P	Phosphorus, dissolved, mg/L as P Phosphorus, dissolved, mg/L Phosphate phosphorus, dissolved, mg/L	0.001, 0.002, 0.006, 0.01, 0.03[b], 0.05[b], −1[b]	0.03	--	--
Phosphorus, total	mg/L as P	Phosphorus, total, mg/L as P Phosphate phosphorus as P, total, mg/L Phosphate phosphorus, total, mg/L	0.002, 0.003, 0.008, 0.01, 0.02[b], 0.012[b], 0.02[b], 0.031[b], 0.07[b], 0.1[b], 0.5[b], −1[b]	0.01	--	--
		Physical measurements and calculated constituents				
Specific conductance	µS/cm at 25°C	Specific conductance, µS/cm Specific conductance, µohm/cm Specific conductance, µS/cm Specific conductance Conductivity, µS/cm Conductivity, µohm/cm	--	--	2,500	10
pH	Standard units	pH	--	--	6.5–9.0	1, 2, 9

Table 2. Summary of constituents evaluated in the Rapid Creek Basin.—Continued

[WQP, National Water Quality Monitoring Council Water Quality Portal; SD DANR, South Dakota Department of Agriculture and Natural Resources; mg/L, milligram per liter; --, not applicable; SO_4, sulfate; µg/L, microgram per liter; N, nitrogen; P, phosphorus; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µohm/cm, microohm per centimeter; >, greater than; mpn, most probable number; mL, milliliter; cfu, colony forming units; no., number]

Constituent name	Used unit	WQP descriptions	Censoring levels in raw data	Used recensored level	SD DANR standard[a]	SD DANR beneficial-use criteria[a]
Dissolved oxygen	mg/L	Dissolved oxygen, mg/L Oxygen, dissolved, mg/L	--	--	>5.0	7, 8
		Sediment and suspended solids				
Suspended sediment concentration	mg/L	Suspended sediment concentration, suspended, mg/L	--	--	--	--
Total suspended solids	mg/L	Total suspended solids, mg/L Total suspended solids, total, mg/L Total suspended solids, nonfilterable, mg/L	0.002, 0.02, 1, 2, 3, 4, 5, 10, −1	10	30	2
		Biological indicators				
Escherichia coli	mpn/100 mL	*Escherichia coli*, no./100 mL *Escherichia coli* *Escherichia coli*, cfu/100 mL	0.1, 1	1	126	7
Fecal coliform	cfu/100 mL	Fecal coliform, total, no./100 mL Fecal coliform, total Fecal coliform, no./100 mL Fecal coliform, nonfilterable, no./100 mL Fecal coliform, total, cfu/100 mL Fecal coliform, nonfilterable Fecal coliform Fecal coliform, cfu/100 mL	1, 2, 3, 4, 5, 10, 20, 100[b], 600[b], −1[b]	10	--	--

[a]From South Dakota Department of Agriculture and Natural Resources (2022). If multiple beneficial uses are listed, the most stringent value for a constituent is used.

[b]Censoring value with 5 or fewer data points.

[c]From equation 3 in appendix A of South Dakota Department of Agriculture and Natural Resources (2022), using a typical pH of 8.0 and temperature of 15 degrees Celsius.

dissolved, and total recoverable, and some constituents also had multiple descriptors in the WQP. The data were examined statistically and graphically. Laboratory methods were reviewed to determine if constituents with different descriptors were comparable—if the different descriptors were comparable, these data were combined, if not, these data were kept separate. For example, the nitrogen species often referred to by USGS as “nitrate plus nitrite as nitrogen” also was identified in the WQP data results as inorganic nitrogen, dissolved nitrate, and total nitrate among other collection agencies. These constituents spanned 10 combinations of names and descriptors. For the analysis discussed in this report, these 10 constituents were combined into 1 constituent, referred to as “nitrate plus nitrite” (table 2); however, variations of “total” phosphorus were combined separately from variations of “dissolved” phosphorus (table 2). The final list of constituents selected for analysis in this report, including the various combinations of constituent names, descriptors, and units, is provided in table 2. Relevant beneficial-use criteria information for water-quality constituents listed by the SD DANR (South Dakota Department of Agriculture and Natural Resources, 2022) also is included in table 2.

Many of the selected constituents had censored values, which are values that represent concentrations too low to be accurately quantified (Foreman and others, 2021). The censoring level can change through time and among laboratories because of changes in analytical methods, sensitivity of laboratory equipment, or dilutions during laboratory analysis. Censored values are an important consideration in statistical analysis, especially for trend and load analyses (Helsel and others, 2020). For comparability of data and consistent statistical analysis, constituents with multiple censoring levels were recensored to a common value, and the newly censored dataset was used for all analyses. When choosing a common censoring level, the highest consistent censoring level or most recently observed was thought to be most likely to represent an actual measured concentration and was selected. On occasion, a higher censoring level was reported, and these censoring levels were generally isolated or outliers because of a dilution issue with a laboratory; these higher values were not used if fewer than 5 values were with the censoring level. When these values were censored at a value greater than the common censoring level, they were left unchanged because the program used to determine trends, R–QWTREND, can handle multiple censoring levels (Vecchia and Nustad, 2020). The remaining censored values were recoded to the common censoring level, and uncensored values less than the common censoring level were recoded as censored values at the common censoring level. For most constituents, a higher censoring level was chosen because the lower censor levels were reported in the earlier period of data collection and likely did not represent an actual measured concentration. For example, TSS data had censoring levels ranging from 1 to 10 milligrams per liter (mg/L), and 10 mg/L was the highest consistent censoring level and was selected as the common censoring level (table 2). A censoring level of −1 was listed for some data points in the Rapid Creek Basin and was determined to be a placeholder for unknown censoring levels, which was generally used for what SD DANR considers “historical” data (Aaron Leingang, SD DANR, written commun., 2021). Data points with censoring levels of −1 were eliminated from the analysis. Eight of the selected constituents (TSS, ammonia, nitrate plus nitrite, dissolved phosphorus, total phosphorus, total Kjeldahl nitrogen [TKN], *E. coli*, and fecal coliform) had multiple censoring levels that were recoded to a common censoring level for data analyses (table 2).

Streamflow

Streamflow data from the USGS NWIS database also were compiled for the 18 selected sites (U.S. Geological Survey, 2022; table 1). Four of the selected sites (North Fork Rapid Creek [site 1], Rapid Creek near Rochford [site 3], Castle Creek near Mystic [site 6], and Rapid Creek below Tittle Springs [site 11]) did not have available streamflow data for the trend analysis; therefore, it was estimated, which is described later in this section. Four other sites (Castle Creek below Deerfield Dam [site 5], Rapid Creek above WRF near Rapid City [site 16], Rapid Creek below WRF near Rapid City [site 17], and Rapid Creek near Farmingdale [site 18]) had a seasonal or incomplete daily record of streamflow that was estimated for periods of missing record. Streamflow estimation techniques at selected sites may have introduced bias into the results but were necessary because of the lack of streamflow data at some of the sites in the basin.

Seven sites, three of which were in the upper basin, were identified with water-quality data suitable for trend analysis but had incomplete streamflow records. A complete daily streamflow record is a requirement to compute trends using the R–QWTREND program (Vecchia and Nustad, 2020). Site 5 has a USGS streamgage (06410000) that was operated as a year-round streamgage until 1983 when it was transitioned to a seasonal streamgage operating from March through September. To fill in the missing winter streamflow values at this site, releases from Deerfield Reservoir by the Bureau of Reclamation were used to estimate flow during the winter months (Bureau of Reclamation, 2021). Site 3 had a USGS streamgage (06408860) that was operated from October 1, 1989, to September 30, 1994, but a complete streamflow record was needed from 1975 to 2020. To estimate flow for the remaining period at site 3, the recorded and estimated data from site 5 were subtracted from streamflow at Rapid Creek above Pactola Reservoir at Silver City, S. Dak. (site 7; Joel Petersen, USGS, written commun., 2021). Underlying geology in this section of the Rapid Creek Basin is the impervious crystalline core (Redden and DeWitt, 2008), and minimal water loss to groundwater or water use was assumed through this reach. Site 6 did not have any streamflow data, and the streamflow record from site 5 was used at site 6 because it was assumed that geology and land use gains and losses in this reach were minimal (Joel Petersen, USGS, written commun., 2021).

The remaining four sites were in the middle and lower basins. Site 11 did not have a streamflow record and is in a section of Rapid Creek with various streamflow gains and losses (Hortness and Driscoll, 1998; Anderson and others, 1999; Driscoll and others, 2002). Streamflow losses between the confluence with Victoria Creek and Rapid Creek above Canyon Lake near Rapid City (site 12; USGS streamgage 06412510) were estimated to be 8.5 ft^3/s (Anderson and others, 1999). The distance between site 11 and site 12 was determined to be 1.25 miles (mi), and the distance between Victoria Creek and site 12 was 3.5 mi. This ratio (1.25/3.5 mi) of 0.36 multiplied by the 8.5-ft^3/s loss in this section was determined to be 3 ft^3/s, and 3 ft^3/s was added to streamflow from site 12 to estimate the streamflow at site 11. At site 16, a USGS streamgage (06418800) was established in 2016 and collects daily streamflow data. This streamgage was previously at site 17, USGS streamgage (06418900), which was downstream from the WRF, from 1981 to 2016 and collected daily streamflow data (Joel Petersen, USGS, written commun., 2021). Releases from the WRF were known from 2016 to 2020 (Leah Hall, City of Rapid City, written commun., 2021) and were estimated based on the population of Rapid City, Rapid Valley (not shown), and Blackhawk (not shown) from 1970 to 2016 (U.S. Census Bureau, 2021). Streamflow data at site 17 were estimated for 2016–20 by adding discharges from the WRF to streamflow data from site 16. To estimate streamflow before 2016 at site 16, estimates for WRF discharge were subtracted from site 17 to estimate the record of streamflow at site 16. Site 18 had a USGS streamgage (06421500) recording daily streamflow data for the study period of 1970–2020, except for 1991. In 1991, the USGS operated a streamgage on Rapid Creek at Creston, S. Dak. (USGS streamgage 06422000; not shown; U.S. Geological Survey, 2022), and these data were used for the missing year of data at site 18 (Joel Petersen, USGS, written commun., 2021).

Descriptive Statistics

Descriptive statistics were computed for selected constituents at the 18 sites in the Rapid Creek Basin with at least 10 samples collected between 1970 and 2020 to describe the spatial variability of concentrations in the basin. The total number of values or observations for constituents varied by site because samples were collected by multiple agencies or groups for different purposes. Constituents were recensored to the highest common censoring level, as previously described (table 2). Statistics included the minimum; maximum; and 10th, 25th, 50th (median), 75th, and 90th percentiles of values for individual constituents at each site. Median concentrations for selected constituents were plotted on maps of the Rapid Creek Basin to show spatial patterns in concentration across the basin.

Trend Analysis

Water-quality trends were evaluated using R–QWTREND, which is a statistical model for estimating constituent concentrations from water-quality samples and streamflow data (Vecchia, 2000, 2003, 2005; Vecchia and Nustad, 2020). R–QWTREND can run the time-series model, determine model fit, verify trend models, and produce an output for interpreting and evaluating the results (Vecchia and Nustad, 2020). One of the model's variables, *FRVAR,* was designed to capture as much natural flow-related variability in logarithmically transformed concentrations as possible. *FRVAR* is a function of variables called flow anomalies that depend on concurrent and antecedent streamflow (Vecchia and Nustad, 2020). Flow anomalies address the relation between a constituent concentration and concurrent and lagged streamflow at annual, seasonal, and daily time scales. In addition, the periodic functions of sine and cosine are included to model seasonal variation that is not captured by flow anomalies (Vecchia and Nustad, 2020). Because of the variable hydroclimate in the basin, characterizing flow-related variability in concentrations at multiple time scales is important because concentrations of water-quality constituents interact with the streamflow in complex ways that cannot be captured using a simple regression between concentration and concurrent streamflow. By accounting for the natural flow-related variability, the ability to detect trends in concentration that are independent of streamflow and climate variability is greatly increased (Vecchia, 2003). In R–QWTREND, step trends based on sample attributes can be used to model potential bias; that is, a systemic tendency for sample concentrations to over or underestimate actual concentration based on a particular laboratory-analytical method or collection method (Vecchia and Nustad, 2020). Step trends were used in this study to account for laboratory differences, reporting differences, and known changes at the Rapid City WRF.

Trends detected by R–QWTREND indicate long-term (generally 10 or more years) changes in the annual "flow-averaged" geometric mean concentration (GMC) that are unrelated to year-to-year changes in streamflow (Vecchia and Nustad, 2020). R–QWTREND requires at least 60 water-quality samples distributed between seasons, a complete daily streamflow record, and preferably no more than 25 percent of the dataset containing censored values (Vecchia and Nustad, 2020). To determine the significance of the trend results, the generalized likelihood ratio test statistic was used and is described in Vecchia and Nustad (2020). Three levels of significance were used for this study: a probability (p) value of less than or equal to 0.01 was considered significant, a p-value between 0.01 and 0.05 was considered mildly significant, and a p-value greater than 0.05 was considered nonsignificant. A small *p*-value indicates that a real trend was detected by R–QWTREND; for example, a trend with a *p*-value of less than 0.05 indicates a less than 5-percent chance that the results of the analysis are random, which indicates that the null (no trend) model should be rejected. A nonsignificant trend indicates that a trend was inconclusive given the available data and does not necessarily mean the data have no trend (Helsel and others, 2020). It is possible that these data have a trend that is too small to be detected in relation to the natural variability of the data.

Censored values, or values less than the method detection level for which an exact value is not known (Foreman and others, 2021), need to be considered during trend analysis (Helsel and others, 2020). R–QWTREND handles censored values and estimates a value, but it is recommended the dataset be no more than 25-percent censored (Vecchia and Nustad, 2020). To include as many sites and constituents as possible in the analysis, sites with constituents having as much as 55-percent censored data were analyzed for trends for this report. Results at sites 3, 6, and 16 for total phosphorus and site 17 for TSS had more censored data than recommended and should be interpreted with caution. Too few data were available to evaluate trends for ammonia in the Rapid Creek Basin, because nearly all the data were censored. Nitrate plus nitrite, total phosphorus, dissolved phosphorus, TKN, and TSS had multiple censoring levels and were recensored to a common censoring level (table 2). After recensoring, some sites had more than 55-percent censored data and were not analyzed for trends.

After the data cleanup, trend analyses were completed for 8 constituents among 12 of the 18 sites. The 8 constituents were divided into 4 categories: major ions (TDS, calcium, and magnesium), field measurements (specific conductance [SC]), TSS, and nutrients (total phosphorus, dissolved phosphorus, and TKN). Major ion trends were identified among 5 sites, SC trends were identified at 13 sites, TSS trends were identified at 5 sites, and nutrient trends were identified among 5 sites.

Water-Quality Data in the Rapid Creek Basin

Water-quality data from the 18 selected sites in the basin were summarized using descriptive statistics. Summaries were provided for select constituents with 10 or more values and included number of values, number of censored values, percentage of data censored, and the period of record at each site (tables 3–7). Within the basin, 9 of the 18 sites (sites 3, 4, 6, 8, 11, Rapid Creek below Hawthorn Ditch at Rapid City, S. Dak. [site 15], and 16–18) had the bulk of the data collected (tables 3–7). Summary statistics are presented using five constituent groups: major ions and dissolved solids, total suspended solids and suspended sediment, nutrients, field measurements, and bacteria. Summary statistics were not computed for trace metals because too few data were available across the basin.

Table 3. Summary of available data and descriptive statistics for major ions and total dissolved solids for selected sites in the Rapid Creek Basin.

[<, less than; --, not applicable]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration: Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Total dissolved solids, in milligrams per liter													
1	74	1	1	2001	2020	19	<5	240	138	160	187	200	213
2	29	0	0	1991	2020	29	203	261	211	224	235	250	256
3	501	0	0	1970	2020	50	118	340	182	210	230	249	266
4	385	4	1	1970	1996	26	148	476	227	242	257	266	274
5	--	--	--	--	--	--	--	--	--	--	--	--	--
6	505	0	0	1970	2020	50	100	440	197	218	238	255	276
7	12	0	0	1999	2020	21	193	262	216	223	232	248	256
8	221	0	0	1970	2009	39	124	304	201	205	214	224	235
9	66	0	0	1987	2007	20	164	306	186	201	218	234	255
10	26	0	0	1989	1993	4	204	253	210	214	224	238	247
11	495	1	<1	1975	2020	45	<5	783	173	196	214	230	249
12	34	1	3	1980	2000	20	<5	228	184	193	197	212	218
13	19	0	0	1991	2000	9	184	228	202	207	210	218	223
14	90	4	4	1987	2007	20	<5	292	180	193	204	216	236
15	162	3	2	1980	2020	40	<5	534	271	302	345	386	417
16	359	1	<1	1987	2020	33	<5	966	321	371	439	520	590
17	476	2	<1	1979	2020	41	<5	3,800	406	486	560	637	748
18	942	3	<1	1970	2020	50	<5	1,700	446	532	628	702	803
Sulfate, in milligrams per liter													
1	15	1	7	2001	2002	1	<1	83	29	35	48	68	79
2	2	0	0	1991	1995	4	--	--	--	--	--	--	--
3	499	0	0	1970	2020	50	4	3,640	25	28	31	35	40
4	203	9	4	1970	1996	26	<1	29	5	6	7	9	11
5	1	0	0	2009	2009	0	--	--	--	--	--	--	--
6	44	0	0	1974	2009	35	25	85	31	37	48	73	81
7	9	0	0	2005	2020	15	--	--	--	--	--	--	--
8	172	1	<1	1970	2009	39	10	65	39	42	44	48	51
9	66	0	0	1987	2007	20	20	70	34	37	40	44	51
10	13	0	0	1989	1993	4	38	47	39	41	44	46	46
11	508	1	<1	1975	2020	45	<1	3,470	33	35	40	44	48
12	11	0	0	1980	1994	14	38	46	39	39	39	42	44
13	--	--	--	--	--	--	--	--	--	--	--	--	--
14	45	0	0	1987	2007	20	24	47	30	31	35	37	40
15	129	0	0	1980	2020	40	55	166	76	87	102	117	131
16	152	0	0	1993	2020	27	71	350	104	124	146	171	198

Table 3. Summary of available data and descriptive statistics for major ions and total dissolved solids for selected sites in the Rapid Creek Basin.—Continued

[<, less than; --, not applicable]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Sulfate, in milligrams per liter—Continued													
17	8	0	0	1991	2007	16	--	--	--	--	--	--	--
18	224	2	<1	1970	2009	39	<1	406	170	200	239	278	310
Chloride, in milligrams per liter													
1	9	0	0	2002	2002	0	--	--	--	--	--	--	--
2	2	1	50	1991	1995	4	--	--	--	--	--	--	--
3	497	129	26	1970	2020	50	<1	22	<1	<1	1.9	3.0	4.0
4	202	73	36	1970	1996	26	<1	10	<1	<1	1.2	1.6	2.6
5	1	0	0	2009	2009	0	--	--	--	--	--	--	--
6	44	12	27	1974	2009	35	<1	5.6	<1	<1	2.0	2.8	4.4
7	9	1	11	2005	2020	15	--	--	--	--	--	--	--
8	172	22	13	1970	2009	39	<1	11	<1	1	2	2	3
9	3	0	0	2007	2007	0	--	--	--	--	--	--	--
10	13	0	0	1989	1993	4	1.7	6.5	2.0	2.5	3.2	5.7	6.1
11	510	44	9	1975	2020	45	<1	27	1.6	3.0	4.0	5.4	7.0
12	47	1	2	1980	1994	14	<1	4.5	1.4	2.2	3.0	3.5	3.8
13	--	--	--	--	--	--	--	--	--	--	--	--	--
14	2	0	0	1988	2007	19	--	--	--	--	--	--	--
15	180	0	0	1980	2020	40	2.6	100	7.1	13	20	28	44
16	151	0	0	1993	2020	27	4.0	310	15.0	22	29	35	50
17	8	0	0	1991	2007	16	--	--	--	--	--	--	--
18	224	2	<1	1970	2009	39	<1	140	14	25	34	50	63
Potassium, in milligrams per liter													
1	9	0	0	2002	2002	0	--	--	--	--	--	--	--
2	2	2	100	1991	1995	4	--	--	--	--	--	--	--
3	38	0	0	1974	1977	3	1.3	2.4	1.5	1.6	1.8	1.9	2.1
4	205	31	15	1970	1996	26	<1	6.8	<1	1.1	1.2	1.4	1.7
5	1	0	0	2009	2009	0	--	--	--	--	--	--	--
6	43	0	0	1974	2009	35	2.4	4.6	2.7	2.9	3.1	3.4	3.6
7	5	0	0	2005	2005	0	--	--	--	--	--	--	--
8	177	1	<1	1970	2009	39	<1	7.0	2.5	2.6	2.7	2.9	3.4
9	3	0	0	2007	2007	0	--	--	--	--	--	--	--
10	13	0	0	1989	1993	4	2.5	3.1	2.5	2.6	2.7	2.7	2.9
11	44	0	0	1975	2009	34	2.0	3.0	2.2	2.4	2.5	2.6	2.8
12	11	0	0	1980	1994	14	2.2	3.1	2.4	2.5	2.5	2.6	2.8

Table 3. Summary of available data and descriptive statistics for major ions and total dissolved solids for selected sites in the Rapid Creek Basin.—Continued

[<, less than; --, not applicable]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Potassium, in milligrams per liter—Continued													
13	5	0	0	1991	1998	7	--	--	--	--	--	--	--
14	9	0	0	1988	2007	19	--	--	--	--	--	--	--
15	3	0	0	1980	1981	1	--	--	--	--	--	--	--
16	10	0	0	1993	1994	1	3.1	5.5	3.2	3.2	3.2	3.3	4.2
17	4	0	0	1993	2007	14	--	--	--	--	--	--	--
18	223	2	<1	1970	2009	39	<1	12.0	4.7	5.4	6.4	7.3	8.3
Sodium, in milligrams per liter													
1	9	0	0	2002	2002	0	--	--	--	--	--	--	--
2	2	2	100	1991	1995	4	--	--	--	--	--	--	--
3	352	12	3	1970	2020	50	<1	45	1.9	2.0	2.0	2.4	3.0
4	203	7	3	1970	1996	26	<1	6.2	1.2	1.4	1.5	1.9	2.5
5	1	0	0	2009	2009	0	--	--	--	--	--	--	--
6	45	0	0	1974	2009	35	2.2	6.0	2.4	2.9	3.3	3.8	4.0
7	5	0	0	2005	2005	0	--	--	--	--	--	--	--
8	176	1	<1	1970	2009	39	<1	83	3.0	3.1	3.4	4.0	4.7
9	3	0	0	2007	2007	0	--	--	--	--	--	--	--
10	13	0	0	1989	1993	4	3.4	4.9	3.6	3.7	4.2	4.5	4.7
11	457	0	0	1975	2020	45	2.0	78	3.2	3.9	4.0	4.8	5.5
12	19	0	0	1980	1994	14	3.6	4.9	3.8	4.0	4.1	4.2	4.4
13	4	0	0	1991	1992	1	--	--	--	--	--	--	--
14	6	0	0	1988	2007	19	--	--	--	--	--	--	--
15	148	0	0	1980	2020	40	7.0	72	9.4	11	13	16	30
17	166	0	0	1979	2020	41	10	140	16	25	37	49	67
18	387	1	<1	1970	2020	50	1.0	240	22	33	46	58	70
Bicarbonate, in milligrams per liter													
1	6	0	0	2002	2002	0	--	--	--	--	--	--	--
2	1	0	0	1995	1995	0	--	--	--	--	--	--	--
3	139	0	0	1974	2015	41	95	290	160	210	230	240	260
4	119	0	0	1970	1990	20	180	350	260	290	310	320	320
5	1	0	0	2009	2009	0	--	--	--	--	--	--	--

Table 3. Summary of available data and descriptive statistics for major ions and total dissolved solids for selected sites in the Rapid Creek Basin.—Continued

[<, less than; --, not applicable]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Bicarbonate, in milligrams per liter—Continued													
6	146	0	0	1974	2015	41	140	260	180	190	210	220	230
7	1	0	0	1999	1999	0	--	--	--	--	--	--	--
8	155	0	0	1970	2009	39	160	210	170	180	180	190	200
9	--	--	--	--	--	--	--	--	--	--	--	--	--
10	--	--	--	--	--	--	--	--	--	--	--	--	--
11	133	0	0	1975	2015	40	270	170	180	180	200	200	200
12	--	--	--	--	--	--	--	--	--	--	--	--	--
13	1	0	0	1997	1997	1	--	--	--	--	--	--	--
14	1	0	0	1997	1997	1	--	--	--	--	--	--	--
15	56	0	0	2010	2015	5	180	380	200	210	210	220	230
16	95	0	0	2007	2015	8	120	1,020	190	210	220	230	240
17	94	0	0	2007	2015	8	140	260	200	210	210	220	230
18	276	0	0	1970	2015	45	120	310	200	220	240	260	270
Calcium, in milligrams per liter													
1	15	1	7	2001	2002	1	<1	57	37	39	40	47	51
2	2	0	0	1991	1995	4	--	--	--	--	--	--	--
3	313	0	0	1974	2020	46	21	74	37	45	49	54	58
4	203	0	0	1970	1996	26	25	67	50	53	56	58	59
5	1	0	0	2009	2009	0	--	--	--	--	--	--	--
6	235	0	0	1974	2015	41	35	62	39	42	43	46	49
7	5	0	0	2005	2005	0	--	--	--	--	--	--	--
8	176	1	<1	1970	2009	39	<1	120	38	39	41	43	44
9	3	0	0	2007	2007	0	--	--	--	--	--	--	--
10	13	0	0	1989	1993	4	40	49	42	43	43	47	47
11	360	0	0	1975	2020	45	18	230	38	40	42	44	47
12	11	0	0	1980	1994	14	38	43	38	39	39	41	42
13	4	0	0	1991	1992	1	--	--	--	--	--	--	--
14	6	0	0	1988	2007	19	--	--	--	--	--	--	--
15	130	0	0	1980	2020	40	48	98	56	61	69	76	82
16	302	0	0	1986	2020	34	9	150	64	72	84	94	110

Table 3. Summary of available data and descriptive statistics for major ions and total dissolved solids for selected sites in the Rapid Creek Basin.—Continued

[<, less than; --, not applicable]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Calcium, in milligrams per liter—Continued													
17	292	1	<1	1979	2020	41	<1	410	68	80	90	100	110
18	512	4	<1	1970	2020	50	<1	170	71	83	95	110	120
Magnesium, in milligrams per liter													
1	15	1	7	2001	2002	1	<1	23	15	17	17	21	23
2	2	0	0	1991	1995	4	--	--	--	--	--	--	--
3	313	0	0	1974	2020	46	8	52	16	20	22	24	25
4	203	0	0	1970	1996	32	20	34	28	29	30	31	31
5	1	0	0	2009	2009	0	--	--	--	--	--	--	--
6	235	0	0	1974	2015	41	18	39	24	25	27	28	30
7	5	0	0	2005	2005	15	--	--	--	--	--	--	--
8	176	1	<1	1970	2009	41	<0.2	43	19	20	20	22	23
9	3	0	0	2007	2007	0	--	--	--	--	--	--	--
10	13	0	0	1989	1993	4	20	26	21	22	24	24	25
11	360	0	0	1975	2020	45	3	32	18	19	21	23	24
12	11	0	0	1980	1994	14	18	22	18	18	18	21	22
13	4	0	0	1991	1992	7	--	--	--	--	--	--	--
14	6	0	0	1988	2007	19	--	--	--	--	--	--	--
15	130	0	0	1980	2020	67	19	33	22	25	26	28	29
16	303	0	0	1986	2020	34	18	97	27	30	33	37	41
17	289	0	0	1979	2020	41	19	210	28	32	36	40	44
18	510	2	<1	1970	2020	67	<1	111	29	34	39	45	50

Table 4. Summary of available data and descriptive statistics for total suspended solids and suspended sediment concentration at selected sites in the Rapid Creek Basin.

[<, less than; --, not applicable]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Total suspended solids, in milligrams per liter													
1	74	49	66	2001	2020	19	<10	45	<10	<10	<10	14	25
2	27	27	100	1991	2020	29	<10	10	<10	<10	<10	<10	<10
3	531	295	56	1970	2020	50	<10	240	<10	<10	<10	17	33
4	11	7	64	1970	1977	7	<10	23	<10	<10	<10	11	20
5	10	10	100	2009	2017	8	<10	10	<10	<10	<10	<10	<10
6	528	277	52	1970	2020	50	<10	410	<10	<10	<10	21.25	42
7	9	8	89	2005	2020	15	<10	59	<10	<10	<10	<10	20
8	52	49	94	1987	2009	22	<10	20	<10	<10	<10	<10	<10
9	63	61	97	1987	1988	1	<10	18	<10	<10	<10	<10	<10
10	14	13	93	1988	1993	5	<10	16	<10	<10	<10	<10	<10
11	488	433	89	1975	2020	45	<10	240	<10	<10	<10	<10	11
12	59	54	92	1980	2000	20	<10	25	<10	<10	<10	<10	<10
13	30	30	100	1991	2019	28	<10	10	<10	<10	<10	<10	<10
14	103	98	95	1987	2019	32	<10	64	<10	<10	<10	<10	<10
15	218	139	64	1980	2020	40	<10	1,800	<10	<10	<10	25	330
16	390	218	56	1987	2020	33	<10	460	<10	<10	<10	20	42
17	519	200	39	1979	2020	41	<10	1,500	<10	<10	15	30	49
18	797	153	19	1970	2020	50	<10	46,000	<10	13	34	90	200
Suspended sediment concentration, in milligrams per liter													
1	--	--	--	--	--	--	--	--	--	--	--	--	--
2	1	0	0	1991	1991	0	--	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--	--	--	--	--	--
4	192	0	0	1967	1996	26	3.0	370	21	31	47	75	98
5	--	--	--	--	--	--	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--	--	--	--	--	--	--
7	--	--	--	--	--	--	--	--	--	--	--	--	--
8	1	0	0	1998	1998	0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
9	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 4. Summary of available data and descriptive statistics for total suspended solids and suspended sediment concentration at selected sites in the Rapid Creek Basin.—Continued

[<, less than; --, not applicable]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Suspended sediment concentration, in milligrams per liter—Continued													
10	7	0	0	1990	1997	7	0.8	34	2.1	4.0	5.0	9.0	20
11	--	--	--	--	--	--	--	--	--	--	--	--	--
12	38	0	0	1980	1982	2	1.0	170	1.0	4.0	10	25	57
13	27	0	0	1996	1998	2	2.0	700	4.8	7.0	13	22	50
14	27	0	0	1996	1998	2	2.0	1,500	3.0	5.0	6.0	11	23
15	52	0	0	1980	1982	2	4	3,600	23	49	190	550	990
16	1	0	0	1994	1994	0	--	--	--	--	--	--	--
17	2	0	0	1994	1994	0	--	--	--	--	--	--	--
18	8	0	0	1991	1997	6	--	--	--	--	--	--	--

Table 5. Summary of available data and descriptive statistics for nutrients for selected sites in the Rapid Creek Basin.

[--, not applicable; <, less than]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Dissolved phosphorus, in milligrams per liter as phosphorus													
1	--	--	--	--	--	--	--	--	--	--	--	--	--
2	1	1	100	1991	1991	0	--	--	--	--	--	--	--
3	184	180	98	1999	2015	16	<0.03	0.11	<0.03	<0.03	<0.03	<0.03	<0.03
4	107	87	81	1970	1996	28	<0.03	0.10	<0.03	<0.03	<0.03	<0.03	0.04
5	1	1	100	2009	2009	0	--	--	--	--	--	--	--
6	189	186	98	1999	2015	16	<0.03	0.07	<0.03	<0.03	<0.03	<0.03	<0.03
7	8	8	100	1999	2005	6	--	--	--	--	--	--	--
8	143	130	91	1970	2009	39	<0.03	2.00	<0.03	<0.03	<0.03	<0.03	<0.03
9	3	3	100	2007	2007	0	--	--	--	--	--	--	--
10	21	21	100	1988	1997	9	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
11	191	189	99	1989	2015	26	<0.03	0.07	<0.03	<0.03	<0.03	<0.03	<0.03
12	27	27	100	1980	1982	2	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
13	6	6	100	1997	2000	3	--	--	--	--	--	--	--
14	12	12	100	1988	2007	19	<0.03	0.05	<0.03	<0.03	<0.03	<0.03	<0.03
15	92	81	88	1980	2015	35	<0.03	0.09	<0.03	<0.03	<0.03	<0.03	0.04
16	177	170	96	1988	2015	27	<0.03	0.08	<0.03	<0.03	<0.03	<0.03	<0.03
17	202	2	1	1999	2015	16	<0.03	2.20	0.21	0.35	0.52	0.71	1.00
18	356	18	5	1970	2015	45	<0.03	2.00	0.09	0.18	0.31	0.62	0.97
Total phosphorus, in milligrams per liter as phosphorus													
1	37	10	27	2001	2017	16	<0.01	0.06	<0.01	<0.01	0.02	0.02	0.034
2	11	3	27	2016	2017	1	<0.01	0.01	<0.01	0.01	0.01	0.01	0.012
3	386	172	45	1978	2017	39	<0.01	1.30	<0.01	<0.01	0.02	0.03	0.057
4	187	48	26	1970	1996	26	<0.01	0.64	<0.01	<0.01	0.02	0.04	0.06
5	1	0	0	2009	2009	0	--	--	--	--	--	--	--
6	393	151	38	1978	2017	39	<0.01	0.34	<0.01	<0.01	0.02	0.03	0.05
7	12	8	67	1999	2020	21	<0.01	0.09	<0.01	<0.01	<0.01	0.01	0.03
8	179	83	46	1970	2009	39	<0.01	0.18	<0.01	<0.01	0.01	0.03	0.05
9	64	33	52	1987	2007	20	<0.01	0.28	<0.01	<0.01	<0.01	0.02	0.02

Table 5. Summary of available data and descriptive statistics for nutrients for selected sites in the Rapid Creek Basin.—Continued

[--, not applicable; <, less than]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration: Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Total phosphorus, in milligrams per liter as phosphorus—Continued													
10	4	3	75	1988	1989	1	--	--	--	--	--	--	--
11	382	237	62	1978	2017	39	<0.01	0.51	<0.01	<0.01	<0.01	0.02	0.04
12	51	30	59	1980	2000	20	<0.01	0.05	<0.01	<0.01	<0.01	0.02	0.04
13	33	23	70	1991	2019	28	<0.01	0.05	<0.01	<0.01	0.02	0.03	0.03
14	106	37	35	1987	2019	32	<0.01	0.25	<0.01	0.01	0.02	0.03	0.04
15	159	63	40	1980	2017	37	<0.01	1.6	<0.01	<0.01	0.02	0.07	0.34
16	305	104	34	1987	2017	30	<0.01	0.68	<0.01	<0.01	0.02	0.04	0.06
17	413	2	<1	1981	2017	36	<0.01	5.3	0.27	0.42	0.71	1.1	2.0
18	568	5	1	1970	2017	47	<0.01	9.8	0.25	0.35	0.52	0.83	1.3
Ammonia, in milligrams per liter as nitrogen													
1	37	37	100	2001	2017	16	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2	11	11	100	2016	2017	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3	170	170	100	2004	2017	13	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4	48	42	88	1980	1992	12	<0.1	0.17	<0.1	<0.1	<0.1	<0.1	0.11
5	1	1	100	2009	2009	0	--	--	--	--	--	--	--
6	180	180	100	2004	2017	13	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
7	5	5	100	2005	2005	0	--	--	--	--	--	--	--
8	27	27	100	1988	2009	21	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
9	63	63	100	1987	1988	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
10	4	4	100	1988	1989	1	--	--	--	--	--	--	--
11	184	184	100	1989	2017	28	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
12	25	25	100	1980	2000	20	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13	--	--	--	--	--	--	--	--	--	--	--	--	--
14	72	71	99	1987	2000	13	<0.1	0.14	<0.1	<0.1	<0.1	<0.1	<0.1
15	122	111	91	1980	2017	37	<0.1	0.40	<0.1	<0.1	<0.1	<0.1	<0.1
16	188	187	99	1988	2017	29	<0.1	0.13	<0.1	<0.1	<0.1	<0.1	<0.1
17	182	143	79	1999	2017	18	<0.1	1.8	<0.1	<0.1	<0.1	<0.1	0.25
18	209	188	90	1988	2017	29	<0.1	0.76	<0.1	<0.1	<0.1	<0.1	0.10

Table 5. Summary of available data and descriptive statistics for nutrients for selected sites in the Rapid Creek Basin.—Continued

[--, not applicable; <, less than]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Nitrate plus nitrite, in milligrams per liter as nitrogen													
1	37	29	78	2001	2017	16	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	0.1
2	13	6	46	1987	2017	30	<0.1	0.2	<0.1	<0.1	0.10	0.1	0.1
3	175	107	61	1988	2017	29	<0.1	0.6	<0.1	<0.1	<0.1	0.2	0.3
4	224	91	41	1971	1996	25	<0.1	2	<0.1	<0.1	0.1	0.2	0.2
5	1	1	100	1987	1987	0	--	--	--	--	--	--	--
6	179	122	68	1988	2017	29	<0.1	1	<0.1	<0.1	<0.1	0.1	0.3
7	7	6	86	1999	2020	21	--	--	--	--	--	--	--
8	161	130	81	1970	2000	30	<0.1	1	<0.1	<0.1	<0.1	<0.1	0.1
9	66	46	70	1987	2007	20	<0.1	0.3	<0.1	<0.1	<0.1	0.1	0.2
10	25	22	88	1988	1997	9	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	0.1
11	171	150	88	1988	2017	29	<0.1	0.7	<0.1	<0.1	<0.1	<0.1	0.1
12	52	44	85	1980	2000	20	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	0.1
13	33	17	52	1991	2019	28	<0.1	0.2	<0.1	<0.1	<0.1	0.2	0.2
14	111	63	57	1987	2019	32	<0.1	2	<0.1	<0.1	<0.1	0.2	0.2
15	159	24	15	1980	2017	37	<0.1	2	<0.1	0.19	0.3	0.4	0.5
16	197	60	30	1988	2017	29	<0.1	0.8	<0.1	<0.1	0.2	0.3	0.4
17	187	2	1	1988	2017	29	<0.1	9	1	2	3	5	6
18	359	15	4	1970	2017	47	<0.1	6	0.5	0.9	2	3	4
Total Kjeldahl nitrogen, in milligrams per liter as nitrogen													
1	59	59	100	2016	2020	4	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2	26	26	100	2016	2020	4	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
3	232	208	90	1974	2020	46	<0.5	3	<0.5	<0.5	<0.5	<0.5	0.5
4	75	57	76	1980	1996	16	<0.5	5	<0.5	<0.5	<0.5	<0.5	0.8
5	2	2	100	2009	2009	0	--	--	--	--	--	--	--
6	245	227	93	1974	2020	46	<0.5	2	<0.5	<0.5	<0.5	<0.5	<0.5
7	9	8	89	2005	2020	15	--	--	--	--	--	--	--
8	61	54	89	1987	2009	22	<0.5	1	<0.5	<0.5	<0.5	<0.5	0.6
9	63	58	92	1987	1988	1	<0.5	0.6	<0.5	<0.5	<0.5	<0.5	<0.5

Table 5. Summary of available data and descriptive statistics for nutrients for selected sites in the Rapid Creek Basin.—Continued

[--, not applicable; <, less than]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Total Kjeldahl nitrogen, in milligrams per liter as nitrogen—Continued													
10	4	4	100	1988	1989	1	--	--	--	--	--	--	--
11	241	228	95	1989	2020	31	<0.5	2	<0.5	<0.5	<0.5	<0.5	<0.5
12	47	46	98	1980	2000	20	<0.5	0.6	<0.5	<0.5	<0.5	<0.5	<0.5
13	29	29	100	1991	2019	28	<0.5	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
14	102	94	92	1987	2019	32	<0.5	2	<0.5	<0.5	<0.5	<0.5	<0.5
15	189	156	83	1980	2020	40	<0.5	5	<0.5	<0.5	<0.5	<0.5	1
16	253	210	83	1988	2020	32	<0.5	7	<0.5	<0.5	<0.5	<0.5	0.6
17	289	47	16	1999	2020	21	<0.5	4	<0.5	0.6	0.9	1	1
18	327	54	17	1974	2020	46	<0.5	10	<0.5	0.6	0.9	1	2

Table 6. Summary of available data and descriptive statistics for field parameters at selected sites in the Rapid Creek Basin.

[--, not applicable; <, less than]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
pH, in standard units													
1	67	0	0	2001	2020	19	6.8	8.9	7.8	8.0	8.2	8.4	8.5
2	30	0	0	1991	2020	29	7.9	8.6	8.1	8.2	8.4	8.4	8.5
3	662	0	0	1970	2020	50	6.9	8.8	7.8	8.1	8.2	8.4	8.5
4	281	0	0	1970	1996	26	7.2	9.6	8.0	8.1	8.3	8.4	8.6
5	9	0	0	2016	2017	1	--	--	--	--	--	--	--
6	663	0	0	1970	2020	50	6.9	8.8	7.8	8.1	8.3	8.4	8.5
7	13	0	0	1999	2020	21	7.5	9.0	7.6	7.9	8.2	8.3	8.5
8	212	0	0	1970	2008	38	7.0	8.8	7.7	7.9	8.1	8.2	8.4
9	130	0	0	1987	2007	20	7.2	8.6	7.6	7.8	7.9	8.0	8.3
10	34	0	0	1988	1997	9	8.0	8.9	8.2	8.2	8.4	8.5	8.6
11	654	0	0	1975	2020	45	6.8	8.9	7.8	8.1	8.3	8.4	8.6
12	114	0	0	1980	2000	20	7.4	8.8	7.9	8.0	8.1	8.3	8.4
13	54	0	0	1988	2019	31	7.5	8.5	7.9	8.0	8.2	8.3	8.4
14	160	0	0	1987	2019	32	7.5	8.9	7.9	8.0	8.2	8.3	8.4
15	246	0	0	1980	2020	40	7.3	8.7	7.7	7.9	8.2	8.3	8.4
16	567	0	0	1982	2020	38	6.9	9.1	7.6	7.9	8.1	8.2	8.4
17	614	0	0	1979	2020	41	6.8	8.9	7.5	7.8	8.0	8.2	8.3
18	1,086	1	<1	1970	2020	50	6.0	11	7.7	8.0	8.2	8.4	8.6
Specific conductance, in microsiemens per centimeter													
1	57	0	0	2016	2020	4	175	473	252	325	356	371	381
2	241	0	0	1981	2020	39	296	525	430	442	457	466	474
3	482	0	0	1970	2020	50	200	540	320	370	400	423	447
4	523	0	0	1970	2015	45	53	715	420	450	470	482	502
5	278	0	0	1977	2017	40	266	1,950	375	393	409	430	447
6	485	0	0	1970	2020	50	130	510	362	390	410	430	450
7	350	0	0	1977	2020	43	135	506	301	360	388	410	428
8	514	0	0	1970	2015	45	222	728	333	352	370	388	400
9	193	0	0	1987	2014	27	319	450	360	375	390	400	414

Table 6. Summary of available data and descriptive statistics for field parameters at selected sites in the Rapid Creek Basin.—Continued

[--, not applicable; <, less than]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Specific conductance, in microsiemens per centimeter—Continued													
10	209	0	0	1988	2015	27	211	748	324	352	372	389	406
11	489	0	0	1975	2020	45	250	6,700	340	356	374	390	407
12	483	0	0	1977	2015	38	1.00	740	329	350	368	385	399
13	171	0	0	1987	2019	32	225	450	321	342	370	385	393
14	217	0	0	1987	2019	32	1.00	681	319	345	369	380	390
15	362	0	0	1980	2020	40	1.00	998	373	464	537	630	687
16	381	0	0	1986	2020	34	1.00	1,670	547	603	699	796	900
17	818	0	0	1979	2020	41	2.00	4,340	660	777	895	1,000	1,120
18	1,276	0	0	1970	2020	50	1.00	2,400	690	823	945	1,070	1,200
Dissolved oxygen, in milligrams per liter													
1	67	0	0	2001	2020	19	7.5	14	8.5	9.4	11	12	13
2	24	0	0	2016	2020	4	9.7	12	10	11	11	11	12
3	526	0	0	1970	2020	50	7.5	15	8.9	9.8	11	12	13
4	--	--	--	--	--	--	--	--	--	--	--	--	--
5	9	0	0	2016	2017	1	9.2	11	9.3	9.5	10	10	11
6	527	0	0	1970	2020	50	7.9	18	9.1	10.0	11	12	13
7	3	0	0	2005	2005	0	--	--	--	--	--	--	--
8	32	0	0	1987	2008	21	11	14	11	11	12	12	13
9	62	0	0	1987	1988	1	8.9	14	9.7	11	12	12	13
10	--	--	--	--	--	--	--	--	--	--	--	--	--
11	528	0	0	1975	2020	45	6.0	120	9.3	9.9	11	12	13
12	17	0	0	1999	2000	1	7.5	15	8.6	9.3	10	12	12
13	--	--	--	--	--	--	--	--	--	--	--	--	--
14	56	0	0	1987	2000	13	7.6	14	9.2	9.9	11	12	12
15	139	0	1	1999	2020	21	2.9	15	8.8	9.5	11	13	14
16	466	0	0	1982	2020	38	5.3	16	7.6	8.7	11	12	13
17	506	1	<1	1979	2020	41	4.6	22	7.5	8.7	10	12	12
18	572	0	0	1970	2020	50	1.9	18	7.8	9.0	11	13	14

Table 7. Summary of available data and descriptive statistics for bacteria parameters at selected sites in the Rapid Creek Basin.

[<, less than; --, not applicable]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Escherichia coli, in most probable number per 100 milliliters													
1	25	1	4	2016	2020	4	<1.0	1,050	13.5	29.2	70.8	276	704
2	20	3	15	2016	2020	4	<1.0	18.7	1.0	2.0	4.7	8.9	9.9
3	57	1	2	2009	2020	11	<1.0	345	10.4	19.0	41.0	86.0	166
4	--	--	--	--	--	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	--	--	--	--	--	--	--
6	62	2	3	2009	2020	11	<1.0	115	3.3	12.1	28.1	45.0	61.9
7	--	--	--	--	--	--	--	--	--	--	--	--	--
8	1	0	0	1998	1998	1	--	--	--	--	--	--	--
9	--	--	--	--	--	--	--	--	--	--	--	--	--
10	--	--	--	--	--	--	--	--	--	--	--	--	--
11	62	0	0	2009	2020	11	2.0	186	7.0	8.6	16.0	31.8	57.9
12	--	--	--	--	--	--	--	--	--	--	--	--	--
13	3	0	0	1997	1998	2	--	--	--	--	--	--	--
14	3	0	0	1997	1998	2	--	--	--	--	--	--	--
15	49	0	0	2011	2020	9	8.0	2,420	25.2	44.0	80.0	144	330
16	62	1	2	2009	2020	11	<1.0	1,990	42.3	68.4	127	240	576
17	60	0	0	2009	2020	11	21.8	2,420	76.8	105	173	393	877
18	91	0	0	2000	2020	20	5.0	2,420	18.0	61.2	132	291	727
Fecal coliform, in colony forming units per 100 milliliters													
1	8	5	63	2001	2002	2	--	--	--	--	--	--	--
2	1	1	100	1991	1991	1	--	--	--	--	--	--	--
3	222	91	41	1970	2014	44	<10	1,200	<10	<10	18	38	70
4	136	74	54	1973	1996	23	<10	600	<10	<10	<10	34	70
5	--	--	--	--	--	--	--	--	--	--	--	--	--
6	183	92	50	1970	2014	44	<10	870	<10	<10	<10	23	48
7	--	--	--	--	--	--	--	--	--	--	--	--	--
8	20	19	95	1988	1998	10	<10	13	<10	<10	<10	<10	<10
9	29	12	41	1988	1988	1	<10	130	<10	<10	15	42	76

Table 7. Summary of available data and descriptive statistics for bacteria parameters at selected sites in the Rapid Creek Basin.—Continued

[<, less than; --, not applicable]

Map identification number (fig. 1)	Number of observations	Number of censored values	Percentage of data that are censored	Beginning sample year	Ending sample year	Number of years of sample record	Concentration						
							Minimum	Maximum	10th percentile	25th percentile	Median	75th percentile	90th percentile
Fecal coliform, in colony forming units per 100 milliliters—Continued													
10	9	9	100	1989	1993	4	--	--	--	--	--	--	--
11	203	102	50	1975	2014	39	<10	140	<10	<10	<10	24	50
12	42	7	17	1980	2000	20	<10	700	<10	20	55	185	256
13	13	6	46	1991	1998	7	<10	55	<10	<10	13	28	46
14	48	19	40	1988	2000	12	<10	420	<10	<10	16	38	82
15	67	4	6	1980	2014	34	<10	51,000	18	58	200	2,500	9,000
16	179	15	8	1982	2018	36	<10	490,000	15	49	120	290	1,000
17	302	4	1	1979	2018	39	<10	94,000	100	200	575	9,100	20,000
18	563	64	11	1967	2014	47	<10	33,000	<10	37	110	270	794

Major Ions and Total Dissolved Solids

Median concentrations of all major ions and TDS were generally similar at sites upstream from Rapid City, and median concentrations at sites downstream from Rapid City were generally higher (figs. 3 and 4, table 3); however, two patterns were detected in median concentrations for different constituents in the basin. The first pattern includes TDS, sulfate, chloride, potassium, and sodium, and the second pattern includes bicarbonate, calcium, and magnesium. Patterns in water quality in the Rapid Creek Basin are likely affected by natural geologic sources, groundwater interactions, urban activities, and agricultural activities. Also, some of the sites in this analysis have few (10–20) observations, so the median concentrations may be less representative of the long-term (50-year) concentrations compared to other sites with more years of data.

Median concentrations of TDS, sulfate, chloride, potassium, magnesium, and sodium were lowest at sites in the upper basin and were highest in the lower basin (figs. 3 and 4). For TDS and chloride and all sites in the basin, median concentrations were less than SD DANR standards (tables 2 and 3). The highest median concentrations for TDS, sulfate, chloride, potassium, magnesium, and sodium were observed at site 18 and were 628, 239, 34, 6.4, 39, and 46 mg/L, respectively (table 3). For TDS concentrations, the lowest median value in the basin was 187 mg/L at site 1 in the upper basin (table 3). Site 4 had the lowest concentrations in the basin for sulfate, chloride, potassium, and sodium with median values of 7, 1.2, 1.2, and 1.5 mg/L, respectively (table 3).

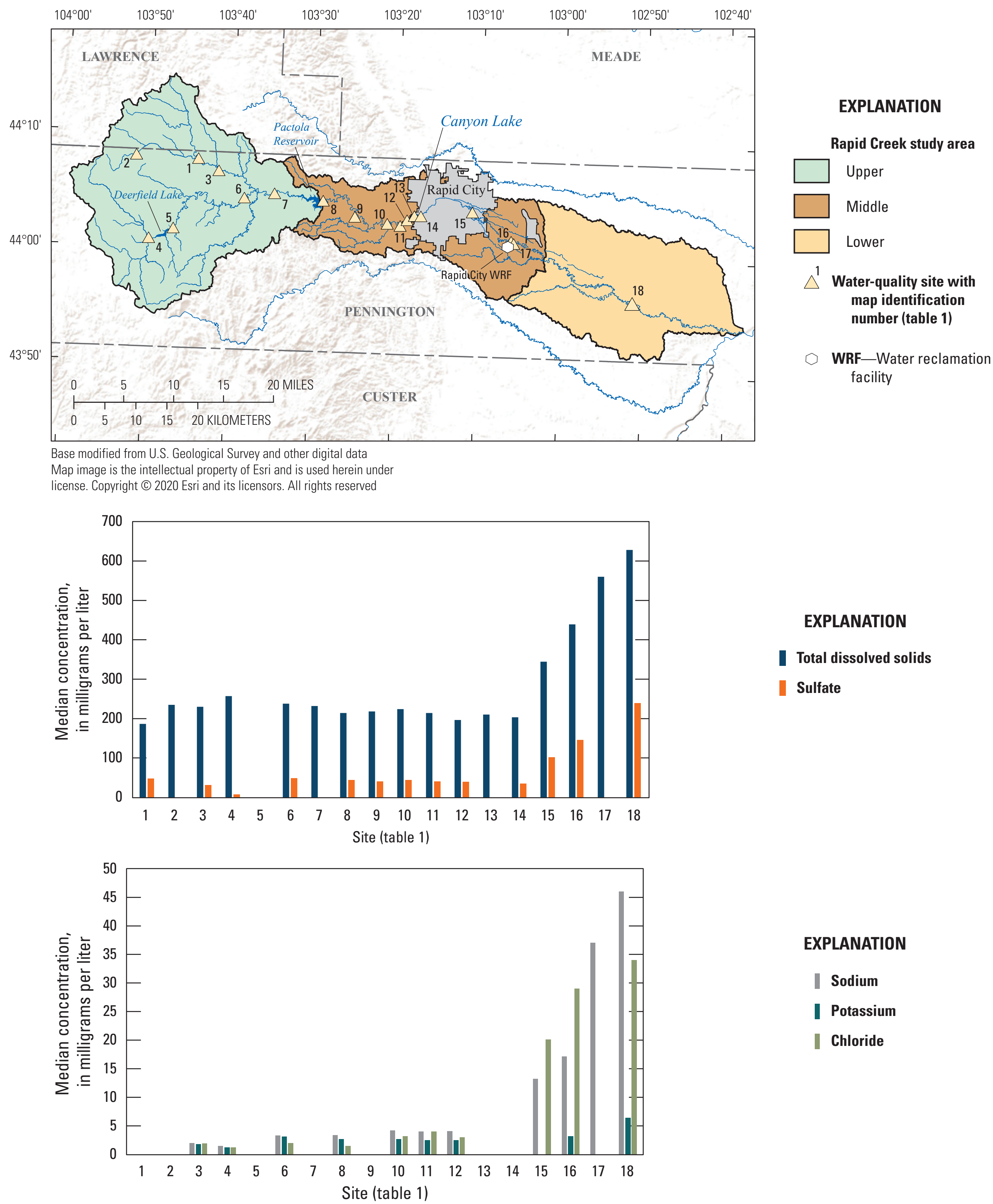
Effects on TDS, sulfate, chloride, potassium, and sodium concentrations in the Rapid Creek Basin are likely from urban activities, natural geologic sources, and agricultural practices. Evidence for the listed sources were observed in the patterns of these constituents where the highest concentrations were downstream from Rapid City on the plains east of the Black Hills (not shown; figs. 3 and 4). TDS in streams is composed of major ions (such as calcium, magnesium, sodium, potassium, sulfate, and chloride) and many other constituents that are present in small quantities. TDS concentrations may be affected by different constituents in different locations; for example, downstream from Rapid City, TDS was affected more by sulfate, chloride, and sodium, whereas upstream, it was affected more by bicarbonate, calcium, and magnesium. Sulfate in streams may be affected by land-use changes that can increase or decrease the exposure of naturally occurring sulfur to surface runoff, such as the irrigation practices and livestock management in the lower basin (Tatge and others, 2022a). Urban effects on sulfate include emissions from burning fossil fuels and wastewater discharge from municipal operations (Hem, 1985). Soils in the northern Great Plains have high contents of salts including sodium-sulfate salts, which can correspond to higher concentrations of sulfate because anions are removed from the soil by water more easily than cations (Carlson and others, 2015). The sodium-sulfate salts detected in soils in the northern Great Plains also dissolve and affect sodium concentrations in Rapid Creek. Additional urban activities that may introduce additional chloride and sodium in the Rapid Creek Basin include roadway and driveway deicing and industrial or municipal wastewater discharge (Hem, 1985; Granato and others, 2015).

Median concentrations of bicarbonate, calcium, and magnesium indicated a different pattern than TDS, sulfate, chloride, potassium, and sodium, where the lowest median concentrations generally were detected between Pactola Reservoir and Rapid City and the highest median concentrations were at sites upstream from Pactola Reservoir and downstream from Rapid City (figs. 3 and 4). Sites 8–14 had the lowest median concentrations of bicarbonate and for calcium sites 1 and 8–14 had the lowest median concentrations (table 3). Site 4 had the highest median concentration for bicarbonate at 306 mg/L. Site 18 had the highest median concentration for calcium and magnesium at 95 and 39 mg/L, respectively (table 3). Site 8 and 12, which are between Pactola Reservoir and Rapid City, had the lowest median bicarbonate and calcium concentrations of 183 mg/L and 39 mg/L, respectively. Sites 1 and 12 had the lowest concentrations of magnesium with median values of 17 and 18 mg/L, respectively. Overall median magnesium concentrations were observed to be lower between Pactola Reservoir and Rapid City than in the upper basin (fig. 4).

Regional geology and groundwater-surface-water interactions most likely have the most control on bicarbonate, calcium, and magnesium concentrations in the Rapid Creek Basin (Williamson and Carter, 2001; Driscoll and others, 2002). Rapid Creek is sourced from springs on the Limestone Plateau in the Madison Limestone unit. The spring water likely has higher concentrations of bicarbonate and calcium and moderate concentrations of magnesium because of the dissolution of calcite and dolomite. Magnesium concentrations in the basin are lower, likely because of dissolution kinetics in which calcite dissolves faster than dolomite (Appelo and Postma, 2005). Between Pactola Reservoir and Rapid City, many gains and losses in streamflow have been studied. The gains and losses mostly are detected where the stream crosses outcrops of the Madison Limestone (Hortness and Driscoll, 1998; Anderson and others, 1999; Driscoll and others, 2002). This interaction between the groundwater and surface water likely contributes to the patterns in bicarbonate, calcium, and magnesium. Increased concentrations in the lower basin and downstream from Rapid City likely have two sources: urban effects from Rapid City and the marine Cretaceous shales, notably the Pierre Shale, that form the bedrock of the plains to the east of the Black Hills (Schultz and others, 1980; Martin and others, 2004).

Total Suspended Solids and Suspended Sediment

Patterns in TSS concentrations were similar to TDS, where concentrations were higher at lower basin sites compared to upper basin sites, and the highest concentrations were



Base modified from U.S. Geological Survey and other digital data

Figure 3. Median concentrations of total dissolved solids, sulfate, sodium, potassium, and chloride in the Rapid Creek Basin. Sites are ordered from upstream to downstream by site number (table 1).

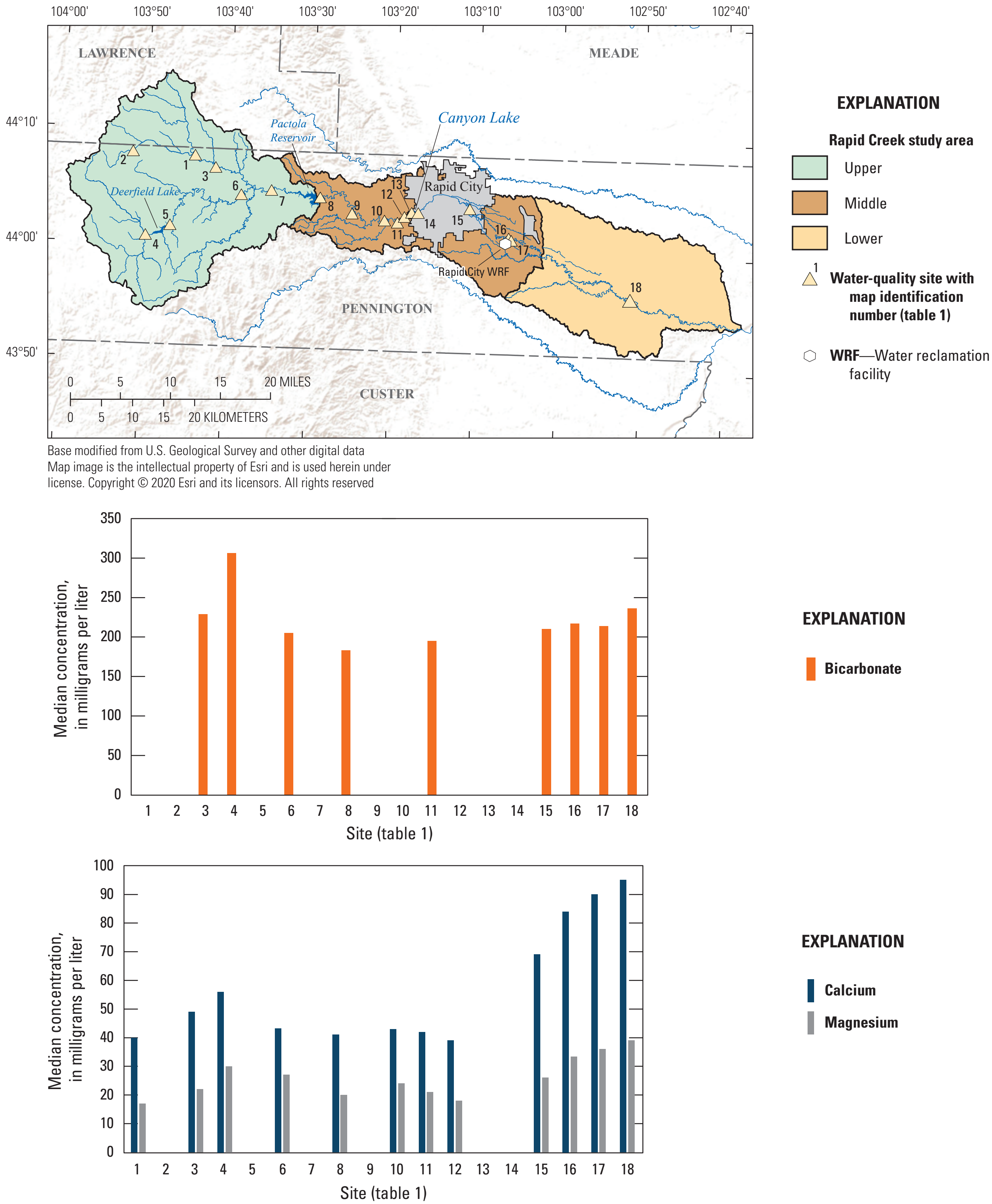


Figure 4. Median concentrations of bicarbonate, calcium, and magnesium in the Rapid Creek Basin. Sites are ordered from upstream to downstream by site number (table 1).

at site 18, the farthest downstream site. Median TSS concentrations at sites upstream from Rapid City and through Rapid City (sites 1–16) were less than 10 mg/L, and only two sites had a median TSS concentration greater than 10 mg/L in the basin. The highest median TSS concentration was 34 mg/L at site 18 (table 4). The SD DANR standard for TSS is 30 mg/L, and only site 18 had a median value that exceeded that standard (table 2; South Dakota Department of Agriculture and Natural Resources, 2022).

Only five sites had data for suspended sediment concentration (SSC), and the spatial pattern seems to indicate the highest concentrations at sites in the middle and lower basin, except for site 4. Median SSC concentrations ranged from 6 mg/L at Rapid Creek below Canyon Lake Park (site 14) to 194 mg/L at site 15 (table 4). Both constituents measure the sediment or solids component of the water sample; however, analytical differences between these constituents do not allow the combination of SSC and TSS data (Gray and others, 2000).

Effects on TSS and SSC are likely from urban activities and surface and bank erosion. TSS concentrations likely increase downstream from Rapid City because of the stormwater runoff discharging into Rapid Creek and the WRF discharging into Rapid Creek. The U.S. Environmental Protection Agency (EPA) requires the City of Rapid City to monitor stormwater for water-quality compliance (U.S. Environmental Protection Agency, 2000). Rapid City invests in improving the stormwater discharges and runoff; however, TSS concentrations are still higher likely due to the large urban area with impervious surfaces, which increase solid particle runoff. Bank and surface erosion downstream from Rapid City also are likely affecting the increase in concentrations in the lower basin. The shale bedrock units provide materials for the creek and runoff to erode (Redden and DeWitt, 2008) and may increase concentrations.

Nutrients

Summary statistics were computed for five nutrient constituents with available data in the Rapid Creek Basin: dissolved phosphorus, total phosphorus, ammonia, nitrate plus nitrite, and TKN. Median nutrient concentrations were mostly low in the basin, and concentrations were higher at sites downstream from the Rapid City WRF (fig. 5). The Rapid Creek Basin is mostly rural with minor urban and agricultural effects. Upstream from Rapid City, much of the basin is forest land cover or minor urban effects; however, downstream from Rapid City, farming or ranching and urban effects from Rapid City dominate.

Median concentrations of dissolved and total phosphorus in the Rapid Creek Basin are generally lower upstream from the Rapid City WRF, and the highest concentrations for both are at sites downstream from the Rapid City WRF (fig. 5). Of the 18 sites in the study, 10 had median concentrations of dissolved phosphorus at the reporting level (less than 0.03 mg/L as phosphorus). The two most downstream sites in the study had concentrations greater than the reporting level, and the highest median concentration of 0.52 mg/L as phosphorus was at site 17, immediately downstream from the WRF (fig. 5, table 5). Median total phosphorus concentrations ranged from less than 0.01 mg/L as phosphorus at five sites to 0.71 mg/L as phosphorus at site 17 (fig. 5, table 5).

Median concentrations of ammonia, nitrate plus nitrite, and TKN were at or less than the reporting level for each constituent at sites in the upper and middle basins of the Rapid Creek Basin (fig. 5). Median concentrations of nitrate plus nitrite and TKN were highest in the lower Rapid Creek Basin sites, and median concentrations of ammonia were at the recensored reporting level of 0.1 mg/L as nitrogen for all sites (table 5). The SD DANR standard for total ammonia is 2.4 mg/L as nitrogen (table 2; South Dakota Department of Agriculture and Natural Resources, 2022), and the highest concentration during the study period was 1.8 mg/L as nitrogen at site 17. Median nitrate plus nitrite concentrations in the basin ranged from less than 0.1 mg/L as nitrogen at 10 sites to 3.3 mg/L as nitrogen at site 17 (table 5). Nitrate plus nitrite concentrations at all sites were less than the SD DANR standard for nitrate plus nitrite of 10 mg/L as nitrogen (table 2; South Dakota Department of Agriculture and Natural Resources, 2022). Median TKN concentrations were at or less than the recensored level of 0.5 mg/L as nitrogen at all sites except two; the highest median concentration was 0.9 mg/L as nitrogen at site 18 (table 5). Concentrations of nitrate plus nitrite and TKN were higher at sites downstream from the Rapid City WRF (fig. 5).

Nutrient dynamics are controlled by activities in the basin and instream processes. WRF discharge and septic system discharge can be major point sources of nitrogen (mainly nitrate), phosphorus, and organic material (Hem, 1985). The upper basin is rural and sparsely populated, and septic systems could be possible point sources that may affect nutrient concentrations. Farther downstream, higher median concentrations of nutrients at sites downstream from the WRF indicate that the WRF likely affects the concentrations of nutrients in Rapid Creek (fig. 5). The lower Rapid Creek Basin also has more agricultural and urban land use, which also can affect nutrient concentrations through livestock production and urban stormwater runoff (Hem, 1985). Several microbiologically mediated processes control the nitrogen cycle, cycling the initial form of nitrogen from organic matter or fertilizers to ammonia and ammonium, then to nitrite and nitrate, and finally either back to organic matter by plant consumption or transformed to nitrogen gas through the denitrification process (Sawyer, 2006). Instream nitrogen cycle processes also are likely working to lower nutrient concentrations between site 17 and site 18 (fig. 5).

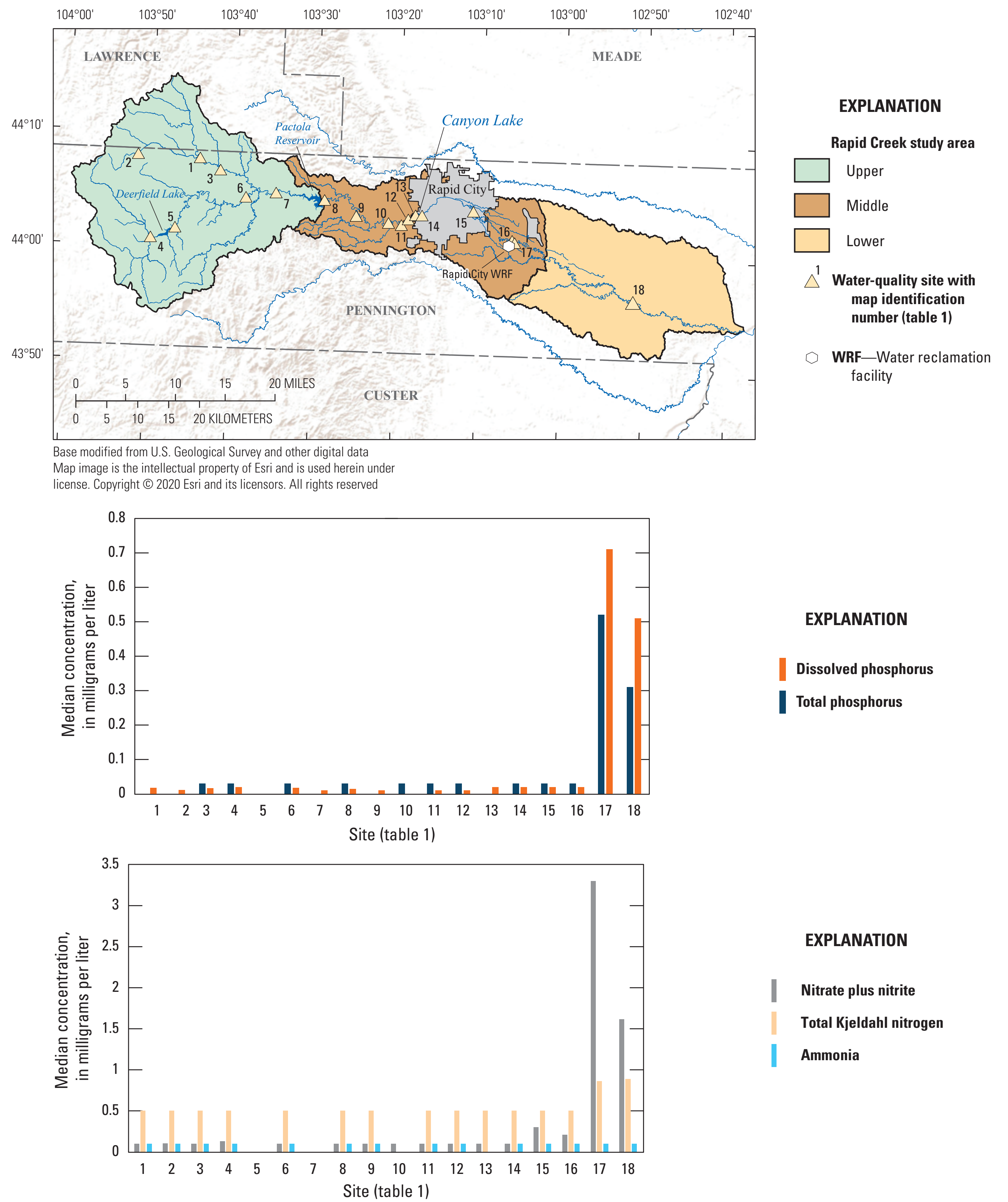


Figure 5. Median concentrations of nitrate plus nitrite, total Kjeldahl nitrogen, ammonia, dissolved phosphorus, and total phosphorus in the Rapid Creek Basin. Sites are ordered from upstream to downstream by site number (table 1).

Field Measurements

Field measurements include water temperature, pH, dissolved oxygen, SC, and turbidity and are typically measured in the stream. Only pH, SC, and dissolved oxygen were included in the statistical summary for the selected sites. Summary statistics for pH and SC were computed at all 18 sites, and summary statistics for dissolved oxygen were computed at only 15 sites because of insufficient data available at 3 sites.

In the Rapid Creek Basin, median pH values were generally highest in the upper basin and lowest downstream from Pactola Reservoir (fig. 6, table 6). The median pH values ranged from 7.9 at Rapid Creek at Big Bend near Rapid City (site 9) to 8.4 at sites 2 and 10. All but site 9 had median pH values between 8 and 8.4, which meets the SD DANR pH standard of 6.5–9.0 (table 2; South Dakota Department of Agriculture and Natural Resources, 2022). Median pH values for Rapid Creek are between 6.5 and 8.5, which is the range of pH in natural streams not affected by pollution (Hem, 1985). The pH is likely controlled by limestone geology in the basin, which can act as a buffer and create a small range of pH values within the basin (Hem, 1985).

Median SC values were generally highest downstream from Rapid City (fig. 6, table 6). Median SC values were generally greater than or equal to 400 microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C) in the upper basin, except for site 1, which had the lowest median value in the basin, and site 7. In contrast, median SC values were less than 400 µS/cm in the middle basin upstream from Rapid City (sites 8–14; table 6). Median SC values were higher at sites downstream from Rapid City, and the highest median value for the basin was at site 18. The SD DANR standard for SC is 2,500 µS/cm, and all sites had median values that were less than the standard (table 2; South Dakota Department of Agriculture and Natural Resources, 2022). SC is often correlated to measures of total dissolved solids and thus closely follows the pattern previously described with TDS. Like effects on TDS, geology, urban activities, and agricultural activities in the Rapid Creek Basin also affect SC concentrations.

Median dissolved oxygen concentrations were generally highest in the upper basin but varied little across the basin (fig. 6; table 6). Dissolved oxygen concentrations vary seasonally and diurnally, which can cause variation depending upon sampling time; however, the median concentrations should give a representative concentration at selected sites in the basin. Median dissolved oxygen concentrations ranged from 10.1 mg/L at sites 5 and 12 to 11.7 mg/L at site 9, and the lowest measured dissolved oxygen concentration in the basin was 1.9 mg/L at site 18 (table 6). The SD DANR standard for dissolved oxygen is a daily minimum greater than 5 mg/L, which was met at all sites for median dissolved oxygen concentrations, but sites in the lower Rapid Creek Basin had minimum dissolved oxygen concentrations that did not meet the criterion (table 2; South Dakota Department of Agriculture and Natural Resources, 2022). Rapid Creek may have higher concentrations in the upper basin because of a steeper slope, more turbulence, and less organic matter, and in the lower basin, the stream has a shallower slope, less turbulence, and more organic matter.

Bacteria

Fecal indicator bacteria (such as fecal coliform, *E. coli*, or enterococci) are not necessarily a health threat themselves when present in water but are used to indicate if other potentially harmful bacteria may be present. Sources of fecal indicator bacteria include wastewater treatment plant effluent; leaking septic systems; stormwater runoff; domestic animal and wildlife waste; and runoff from manure storage areas, pastures, rangelands, and feedlots. Natural, nonfecal sources of fecal indicator bacteria, including plants, sand, soil, and sediments, also contribute to a certain background level in ambient waters and vary based on local environmental and meteorological conditions. In the 1960s, the U.S. Public Health Service recommended using fecal coliform as the fecal indicator bacteria for recreational waters. Later, the EPA published revised criteria in 1986 that recommended *E. coli* as the fecal indicator bacteria for recreational waters (U.S. Environmental Protection Agency, 2022). *E. coli* is part of the fecal coliform group and has been credited to be a more specific indicator of fecal contamination than the more general test for fecal coliform bacteria. The presence of nonfecal coliform bacteria from sources other than the gastrointestinal tracts of humans and other warm-blooded animals reduces the usefulness of fecal coliforms as an indicator of fecal contamination of surface water. In 2012, the EPA recommended using the fecal indicator bacteria enterococci or *E. coli* as indicators of fecal contamination for freshwater and enterococci for marine water (U.S. Environmental Protection Agency, 2022). Bacteria are measured by analyzing bacterial growth in laboratory analyses, either by a membrane filter procedure (with final values listed with units of colony forming units per 100 milliliters [cfu/100 mL]) or by colorimetric test kits (typically listed with units of most probable number per 100 milliliters [mpn/100 mL]).

In the Rapid Creek Basin, fecal coliform and *E. coli* data were available during 1970–2020. The most common fecal indicator bacteria data before 2000 were fecal coliform; fecal coliform and *E. coli* data were available between 2000 and 2014, and *E. coli* was generally the only fecal bacteria indicator used after 2014. Only *E. coli* concentrations are discussed in the following paragraphs because *E. coli* represents the most accurate indicator of contamination for freshwater according to the EPA (U.S. Environmental Protection Agency, 2022).

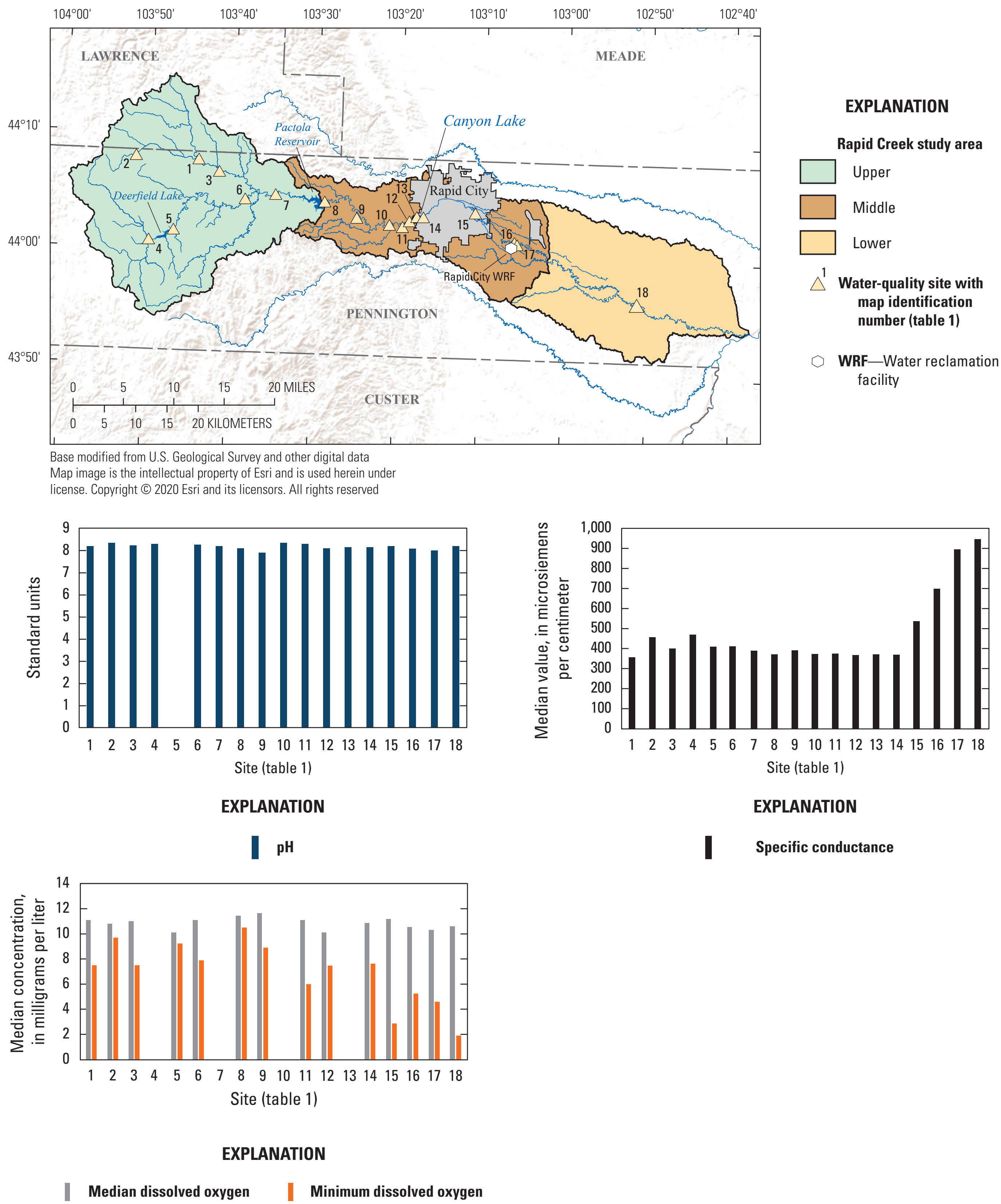


Figure 6. Median concentrations of pH, specific conductance, and dissolved oxygen in the Rapid Creek Basin. Minimum dissolved oxygen concentrations also were plotted with median. Sites are ordered from upstream to downstream by site number (table 1).

In general, *E. coli* concentrations were highest downstream from Rapid City at sites 15–18 (table 7, fig. 7). Median *E. coli* concentrations in the Rapid Creek Basin ranged from 4.7 mpn/100 mL at site 2 (Rhoads Fork near Rochford) to 173 mpn/100 mL at site 17. The median concentrations for sites 17 and 18 exceeded the SD DANR standard for *E. coli* of 126 mpn/100 mL (table 2; South Dakota Department of Agriculture and Natural Resources, 2022). The 126 mpn/100 mL SD DANR standard is a geometric mean based on a minimum of five samples obtained during separate 24-hour periods for any 30-day period. A standard of 235 mpn/100 mL of *E. coli* also should not be exceeded in any one sample. Median fecal coliform concentrations ranged from less than the detection level of 10 cfu/100 mL at four sites upstream from Rapid City (sites 4, 6, 8, and 11) to 575 cfu/100 mL at site 17. Notable increases in median bacteria concentrations were detected between the upper and lower Rapid Creek Basin boundaries and Rapid City. Median *E. coli* densities were generally higher at sites 16–18 than the upper and middle basin sites. Median fecal coliform densities increased from 16 to 200 cfu/100 mL between sites 14 and 15, representing approximately the upper and lower boundaries for the city of Rapid City. Another subsequent increase in median fecal coliform densities was between sites 16 and 17 (120 and 575 cfu/100 mL, respectively), which is likely attributed to the effect of the Rapid City WRF effluent discharge into Rapid Creek.

Bacteria concentrations are typically affected by urban and agricultural effects. In the Rapid Creek Basin, the agricultural effects upstream from Rapid City are minor with most of the basin in a forested land coverage. Urban effects in the Rapid Creek Basin are primarily from stormwater runoff within the city of Rapid City (Hoogestraat, 2015, 2020) and wastewater treatment (Kenner and Smith, 2010). These two urban effects are documented in the bacteria data for site 15 (representing only urban stormwater runoff effects) and farther downstream at site 17 (representing stormwater and wastewater treatment effects). Median *E. coli* concentrations increased from 16.0 mpn/100 mL at site 11 to 80.0 mpn/100 mL at site 15, indicating the urban development effects, and further increased to 173 mpn/100 mL at site 17, indicating the additional wastewater treatment effects. Effluent from wastewater treatment plants can be treated to varying levels of fecal bacteria content during the year because the SD DANR beneficial-use criteria for the immersion recreation only applies during the months of May–September of a calendar year (South Dakota Department of Agriculture and Natural Resources, 2021). Thus, some fecal coliform samples collected outside the recreation season months were exceptionally high compared to those collected during the warmer summer months when different treatment processes were used at the WRF. Agricultural effects on bacteria can include manure application to fields or from pastures with livestock (Kenner and Smith, 2010).

Water-Quality Trends for Selected Sites in the Rapid Creek Basin

Water-quality data from 1970 to 2020 were used to analyze water-quality trends for the trend period of 1979–2019. Trends were analyzed for TDS, SC, calcium, magnesium, TSS, dissolved phosphorus, total phosphorus, and TKN. A two- or three-period trend model was used for TDS, SC, and TSS analysis, and the trend period (1979–2019) was broken into two or three monotonic trends using a combination of the early (1979–89), middle (1989–99), and late (1999–2019) periods. A one-trend model between 1989 and 2019 was used for calcium and magnesium trends, and a one-trend model was used between 1999 and 2019 for dissolved phosphorus, total phosphorus, and TKN. Total phosphorus had available data from 1989 through 2014, and SC had available data from 1979 through 2014; these were the trend periods used for those constituents. As discussed in the “Methods of Analysis” section, a trend is considered significant if the *p*-value is less than 0.01, mildly significant if the *p*-value is between 0.01 and 0.05, and nonsignificant if the *p*-value is greater than 0.05. Concentrations for constituents are reported in the flow-averaged GMC as R–QWTREND removes the effects of streamflow on water-quality concentrations (Vecchia and Nustad, 2020). Results for the trend analysis provide insight into temporal and spatial water-quality changes in the basin. The results are presented using figures showing the change in concentration from the start to the end of the period in annual flow-averaged GMC plotted with the annual GMC, a map showing water-quality trends at each site, and a table that summarizes the results. Annual GMC is an annual mean concentration that is not flow averaged and can indicate the flow-related variability of a given constituent (Nustad and Vecchia, 2020; Vecchia and Nustad, 2020). The greater variation of annual GMC from the fitted trend line indicates that flow-related variability is greater for that constituent.

Major Ions and Total Dissolved Solids

Major ion and dissolved ion constituents analyzed for trends in the Rapid Creek Basin include TDS, calcium, and magnesium. For two sites, a step trend was applied to account for differences in the dataset. A step trend was applied for calcium at site 11 to account for the difference between total and dissolved calcium. Dissolved calcium, in this case, was biased high compared to total calcium by 4 percent at site 11, which would not be physically possible. These differences may be related to a change in the analyzing laboratory. A step trend was applied for SC at site 17 because of differences between SC corrected to 25 degrees Celsius and SC that was not corrected by temperature. In this case, SD DANR data were biased low by about 3.5 percent compared to USGS

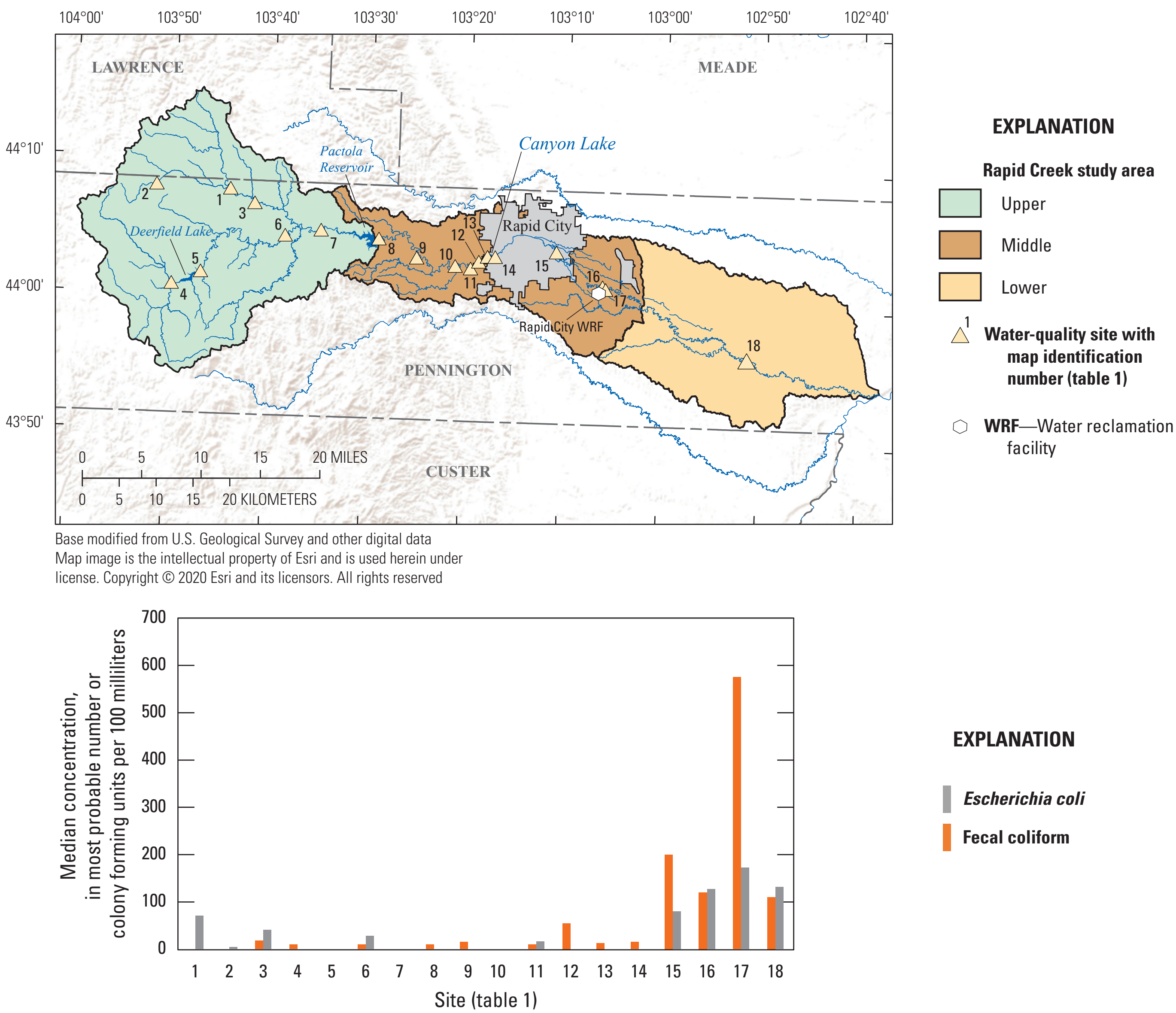


Figure 7. Median concentrations of *Escherichia coli* (in most probable number per 100 milliliters) and fecal coliform concentrations (in colony forming units per 100 milliliters) in the Rapid Creek Basin. Sites are ordered from upstream to downstream by site number (table 1).

data. These changes were accounted for in the model when the changes were known and determined to be statistically significant (p-value less than 0.01) to eliminate artificial trends in the dataset.

Changes in major ions and TDS concentrations in the Rapid Creek Basin were determined to be small (less than 15 percent) or mostly constant. Trends in TDS were evaluated at five sites with small, generally decreasing concentrations at sites upstream from Rapid City (sites 3, 6, and 11) and increasing concentrations at sites downstream from Rapid City (sites 17 and 18; figs. 8 and 9). In the early period (1979–89), four sites could be analyzed, and all sites had significant or mildly significant decreasing concentrations except for site 18, which had mildly significant increasing concentrations (fig. 9). For the middle period (1989–99), five sites were analyzed; upstream from Rapid City, concentrations were significantly increasing, and downstream from Rapid City, concentrations were nonsignificantly or mildly significantly decreasing (fig. 9). Five sites also were analyzed for the late period with significant and mildly significant decreasing concentrations at sites upstream from Rapid City and nonsignificant and mildly significant increasing concentrations at sites downstream from Rapid City (fig. 9). Between 1979 and 2019, sites upstream from Rapid City had a decrease in the flow-averaged GMC of TDS and sites downstream from Rapid City had an increase in the flow-averaged GMC of TDS (table 8).

Less flow-related variability in TDS concentrations was evident at sites in the upper Rapid Creek Basin compared to the middle and lower Rapid Creek Basin. The flow-related variability in concentration is determined by how closely the annual GMC values compare to the fitted trend line (fig. 8). The annual GMC for TDS indicates that TDS concentrations had less flow-related variability at sites 3, 6, and 11 in the upper part of Rapid Creek Basin compared to sites 17 and 18 in the middle and lower Rapid Creek Basin that had higher flow variability (fig. 8). Removing the flow variability from variations in water quality indicates the trends are based on changes from effects other than streamflow.

Although many of the trends in TDS concentration were significant or mildly significant, the percentage change from starting to ending year were small and indicate that changes on the land surface in the basin have largely not affected total dissolved solids concentrations in Rapid Creek. Total dissolved solids concentrations in the basin are likely dominated by calcium, magnesium, and bicarbonate concentrations in the upper and middle basins because of the limestone units. The small trends in TDS concentrations observed across the basin were likely due to the strong effect of groundwater interactions and lack of major land-use changes (Anderson and others, 1999; Cotillon, 2013). Sites 17 and 18 on Rapid Creek east of Rapid City had small increases in TDS concentrations, potentially because of the change in geology in the lower basin compared to the upper and middle basin (Martin and others, 2004).

Small nonsignificant trends were detected at all sites for calcium and magnesium concentrations between 1989 and 2019 (sites 3, 11, 17, and 18; figs. 10–13, table 8). Calcium concentrations nonsignificantly decreased at all sites between 1989 and 2019, except site 3, which had nonsignificant increasing concentrations (figs. 10 and 11, table 8). The change for calcium concentrations ranged from 3 to −5 percent across the basin (table 8). Magnesium concentrations were determined to be nonsignificantly increasing at sites across the basin except site 17 (figs. 12 and 13, table 8). The change in the flow-averaged GMC of magnesium ranged from −1 to 5 percent (table 8).

At sites near Rapid Creek's headwaters, the annual GMC for calcium had lower flow-related variability than sites farther downstream (fig. 10); for example, sites 3 and 11 are near the headwaters and calcium concentrations have less flow-related variability. Sites 17 and 18 in the lower basin had larger flow-related variability. The annual GMC for magnesium follows a similar trend, except flow-related variability is evident at all sites (fig. 12). Differences in flow-related variability between calcium and magnesium are likely due to the differential dissolution rates between calcite and dolomite in limestones. The mostly constant trends in calcium and magnesium also are likely the result of dissolution of calcite and dolomite within the Madison Limestone. Flow rates in springs are generally consistent, but in response to a prolonged wet period and increase in flow rates (Carter and others, 2002), more magnesium may be transported in response to the increase in water table and flow.

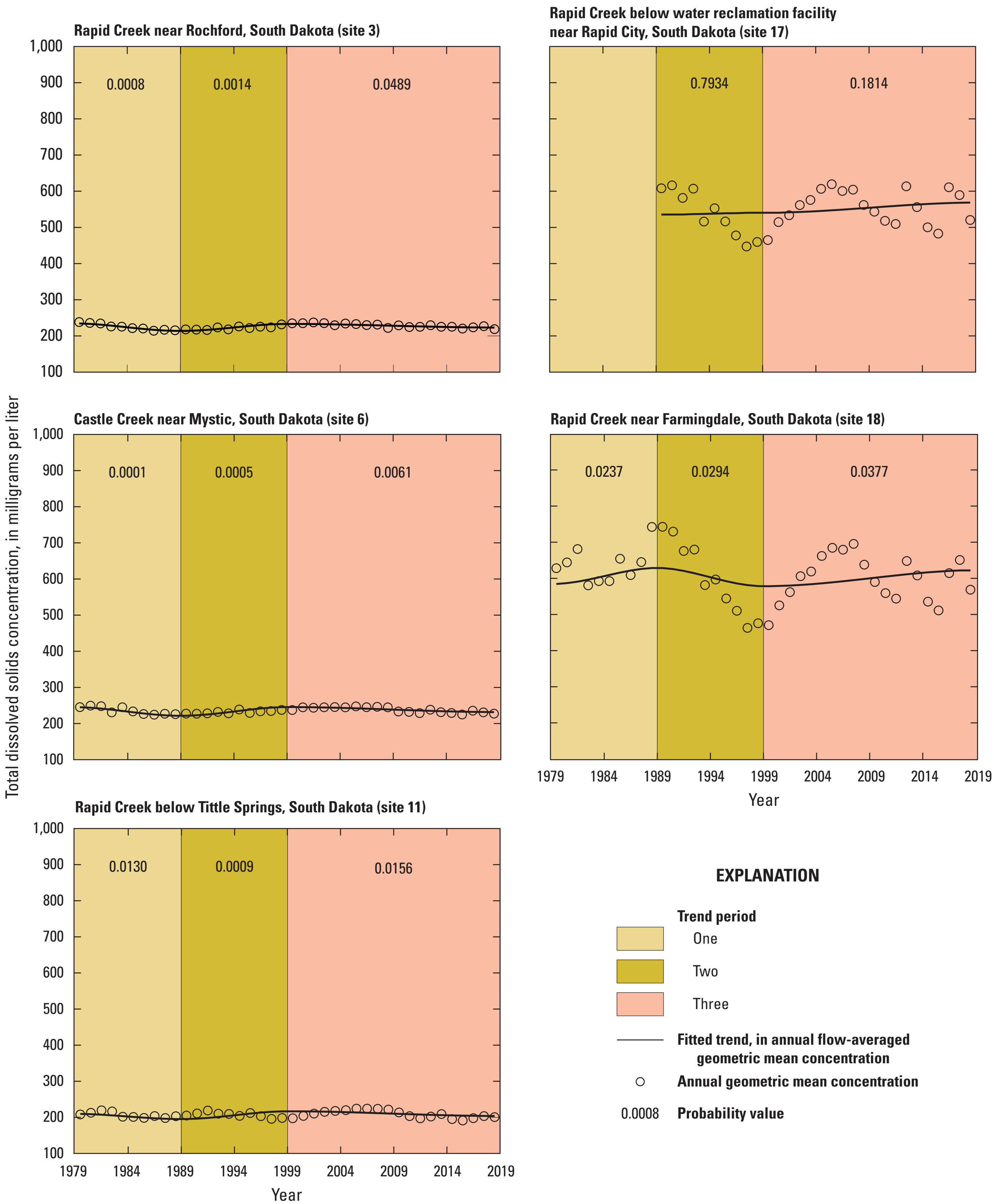


Figure 8. Fitted trends for total dissolved solids in annual flow-averaged geometric mean concentration of total dissolved solids at five sites in the Rapid Creek Basin for the trend period (1979–2019).

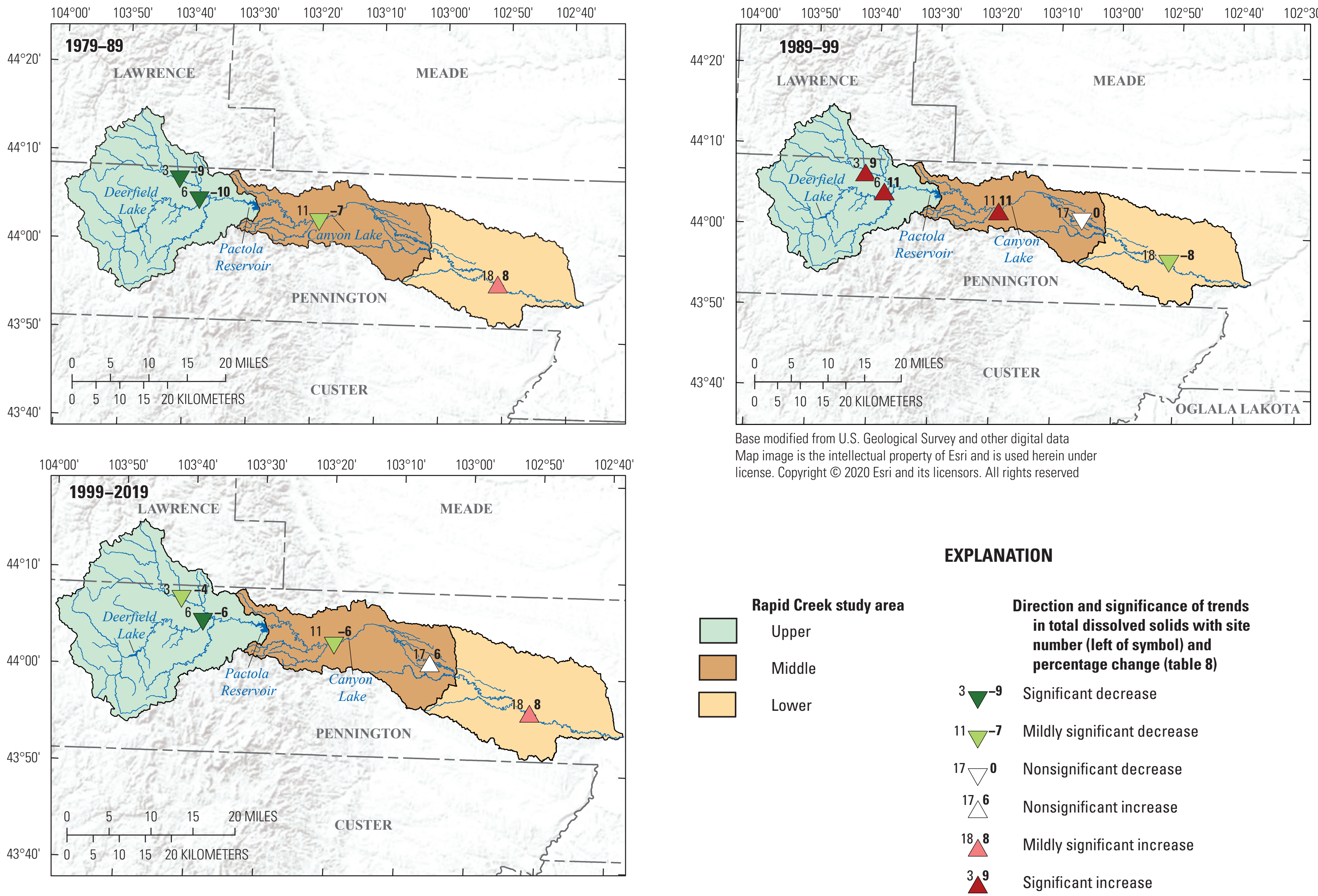


Figure 9. Direction and significance of trends in total dissolved solids at 5 sites for each of the 3 periods analyzed for trends between 1979 and 2019 in the Rapid Creek Basin.

Table 8. Summary of trend results for total dissolved solids, major ions, specific conductance, and total suspended solids at selected sites in the Rapid Creek Basin between 1979 and 2019.

[*p*-value, probability value; GMC, geometric mean concentration; WRF, water reclamation facility]

Site location (fig. 1)	Rapid Creek Basin identifier	Site name	Trend model	Trend period	Step trend	*p*-value	Significance level	Annual flow-averaged GMC for first year in trend period	Annual flow-averaged GMC for last year in trend period	Change, in percent, from first to last year[a]
				Total dissolved solids, in milligrams per liter						
3	Upper	Rapid Creek near Rochford, S. Dak.	Three	1979–89	No	0.0008	Significant decrease	234	214	−9
				1989–99		0.0014	Significant increase	214	233	9
				1999–2019		0.0489	Mildly significant decrease	233	223	−4
6	Upper	Castle Creek at Mystic, S. Dak.	Three	1979–89	No	0.0001	Significant decrease	245	222	−10
				1989–99		0.0005	Significant increase	222	246	11
				1999–2019		0.0061	Significant decrease	246	232	−6
11	Middle	Rapid Creek below Tittle Springs, S. Dak.	Three	1979–89	No	0.0130	Mildly significant decrease	215	201	−7
				1989–99		0.0009	Significant increase	201	222	11
				1999–2019		0.0156	Mildly significant decrease	222	209	−6
17	Middle	Rapid Creek below WRF near Rapid City, S. Dak.	Two	1989–99	No	0.7934	Nonsignificant decrease	536	540	0
				1999–2019		0.1814	Nonsignificant increase	540	569	6
18	Lower	Rapid Creek near Farmingdale, S. Dak.	Three	1979–89	No	0.0237	Mildly significant increase	584	628	8
				1989–99		0.0294	Mildly significant decrease	628	578	−8
				1999–2019		0.0377	Mildly significant increase	578	622	8
				Calcium, in milligrams per liter						
3	Upper	Rapid Creek near Rochford, S. Dak.	One	1989–2019	No	0.4302	Nonsignificant increase	48	50	3
11	Middle	Rapid Creek below Tittle Springs, S. Dak.	One	1989–2019	Yes	0.7052	Nonsignificant decrease	42	41	−2

Table 8. Summary of trend results for total dissolved solids, major ions, specific conductance, and total suspended solids at selected sites in the Rapid Creek Basin between 1979 and 2019.—Continued

[*p*-value, probability value; GMC, geometric mean concentration; WRF, water reclamation facility]

Site location (fig. 1)	Rapid Creek Basin identifier	Site name	Trend model	Trend period	Step trend	*p*-value	Significance level	Annual flow-averaged GMC for first year in trend period	Annual flow-averaged GMC for last year in trend period	Change, in percent, from first to last year[a]
Calcium, in milligrams per liter—Continued										
17	Middle	Rapid Creek below WRF near Rapid City, S. Dak.	One	1989–2019	No	0.1568	Nonsignificant decrease	92	88	−5
18	Lower	Rapid Creek near Farmingdale, S. Dak.	One	1989–2019	No	0.6890	Nonsignificant decrease	93	92	−1
Magnesium, in milligrams per liter										
3	Upper	Rapid Creek near Rochford, S. Dak.	One	1989–2019	No	0.3001	Nonsignificant increase	21	22	5
11	Middle	Rapid Creek below Tittle Springs, S. Dak.	One	1989–2019	No	0.3830	Nonsignificant increase	21	22	5
17	Middle	Rapid Creek below WRF near Rapid City, S. Dak.	One	1989–2019	No	0.8465	Nonsignificant de-crease	36	35	−1
18	Lower	Rapid Creek near Farmingdale, S. Dak.	One	1989–2019	No	0.1628	Nonsignificant increase	38	39	5
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius										
2	Upper	Rhoads Fork near Rochford, S. Dak.	Two	1989–99	No	0	Significant increase	444	464	5
				1999–2014		0.5256	Nonsignificant decrease	464	462	−1
3	Upper	Rapid Creek near Rochford, S. Dak.	Three	1979–89	No	0.1334	Nonsignificant increase	382	392	3
				1989–99		0.6675	Nonsignificant decrease	392	389	−1
				1999–2014		0.0322	Mildly significant increase	389	402	3
4	Upper	Castle Creek above Deerfield Reservoir near Hill City, S. Dak.	Three	1979–89	No	0.0014	Significant decrease	475	453	−5
				1989–99		0.0071	Significant increase	453	476	5
				1999–2014		0.2333	Nonsignificant decrease	476	466	−2

Table 8. Summary of trend results for total dissolved solids, major ions, specific conductance, and total suspended solids at selected sites in the Rapid Creek Basin between 1979 and 2019.—Continued

[*p*-value, probability value; GMC, geometric mean concentration; WRF, water reclamation facility]

Site location (fig. 1)	Rapid Creek Basin identifier	Site name	Trend model	Trend period	Step trend	*p*-value	Significance level	Annual flow-averaged GMC for first year in trend period	Annual flow-averaged GMC for last year in trend period	Change, in percent, from first to last year[a]
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius—Continued										
5	Upper	Castle Creek below Deerfield Dam, S. Dak.	Three	1979–89	No	0	Significant decrease	441	399	−10
				1989–99		0.0265	Mildly significant increase	399	412	3
				1999–2014		0.0086	Significant decrease	412	399	−3
6	Upper	Castle Creek near Mystic, S. Dak.	Three	1979–89	No	0.1180	Nonsignificant increase	412	421	2
				1989–99		0.0026	Significant decrease	421	398	−6
				1999–2014		0.0625	Nonsignificant increase	398	409	3
7	Upper	Rapid Creek above Pactola Reservoir at Silver City, S. Dak.	Three	1979–89	No	0.0089	Significant decrease	395	369	−7
				1989–99		0.0051	Significant increase	369	396	7
				1999–2014		0.0032	Significant decrease	396	369	−7
8	Middle	Rapid Creek below Pactola Dam, S. Dak.	Three	1979–89	No	0.6527	Nonsignificant decrease	360	357	−1
				1989–99		0.0367	Mildly significant increase	357	375	5
				1999–2014		0.2192	Nonsignificant decrease	375	365	−3
11	Middle	Rapid Creek below Tittle Springs, S. Dak.	Three	1979–89	No	0.1988	Nonsignificant increase	361	371	3
				1989–99		0.4749	Nonsignificant increase	371	377	1
				1999–2014		0.8221	Nonsignificant increase	377	378	0.4

Table 8. Summary of trend results for total dissolved solids, major ions, specific conductance, and total suspended solids at selected sites in the Rapid Creek Basin between 1979 and 2019.—Continued

[*p*-value, probability value; GMC, geometric mean concentration; WRF, water reclamation facility]

Site location (fig. 1)	Rapid Creek Basin identifier	Site name	Trend model	Trend period	Step trend	*p*-value	Significance level	Annual flow-averaged GMC for first year in trend period	Annual flow-averaged GMC for last year in trend period	Change, in percent, from first to last year[a]
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius—Continued										
12	Middle	Rapid Creek above Canyon Lake near Rapid City, S. Dak.	Three	1979–89	No	0.0331	Mildly significant decrease	374	353	−6
				1989–99		0.0151	Mildly significant increase	353	377	7
				1999–2014		0.7647	Nonsignificant decrease	377	375	−1
16	Middle	Rapid Creek above WRF near Rapid City, S. Dak.	Two	1989–99	No	0.8575	Nonsignificant decrease	662	658	−1
				1999–2014		0.0016	Significant increase	658	732	11
17	Middle	Rapid Creek below WRF near Rapid City, S. Dak.	Two	1989–99	Yes	0.0152	Significant decrease	898	833	−7
				1999–2014		0.0010	Significant increase	833	928	12
18	Lower	Rapid Creek near Farmingdale, S. Dak.	Three	1979–89	No	0.0012	Significant increase	883	963	9
				1989–99		0.0038	Significant decrease	963	885	−8
				1999–2014		0.0003	Significant increase	885	981	11
Total suspended solids, in milligrams per liter										
17	Middle	Rapid Creek below WRF near Rapid City, S. Dak.	Two	1989–99	Yes	0.0025	Significant decrease	24	16	−33
				1999–2019		0.006	Significant decrease	16	11	−31
18	Lower	Rapid Creek near Farmingdale, S. Dak.	Three	1979–89	Yes	0.1481	Nonsignificant decrease	40	34	−14
				1989–99		0.2184	Nonsignificant increase	34	39	14
				1999–2019		0.0020	Significant decrease	39	27	−30

[a]Percentage change values are directly calculated from R–QWTREND. Starting and ending concentrations in the table are rounded and may not produce the exact percentage change.

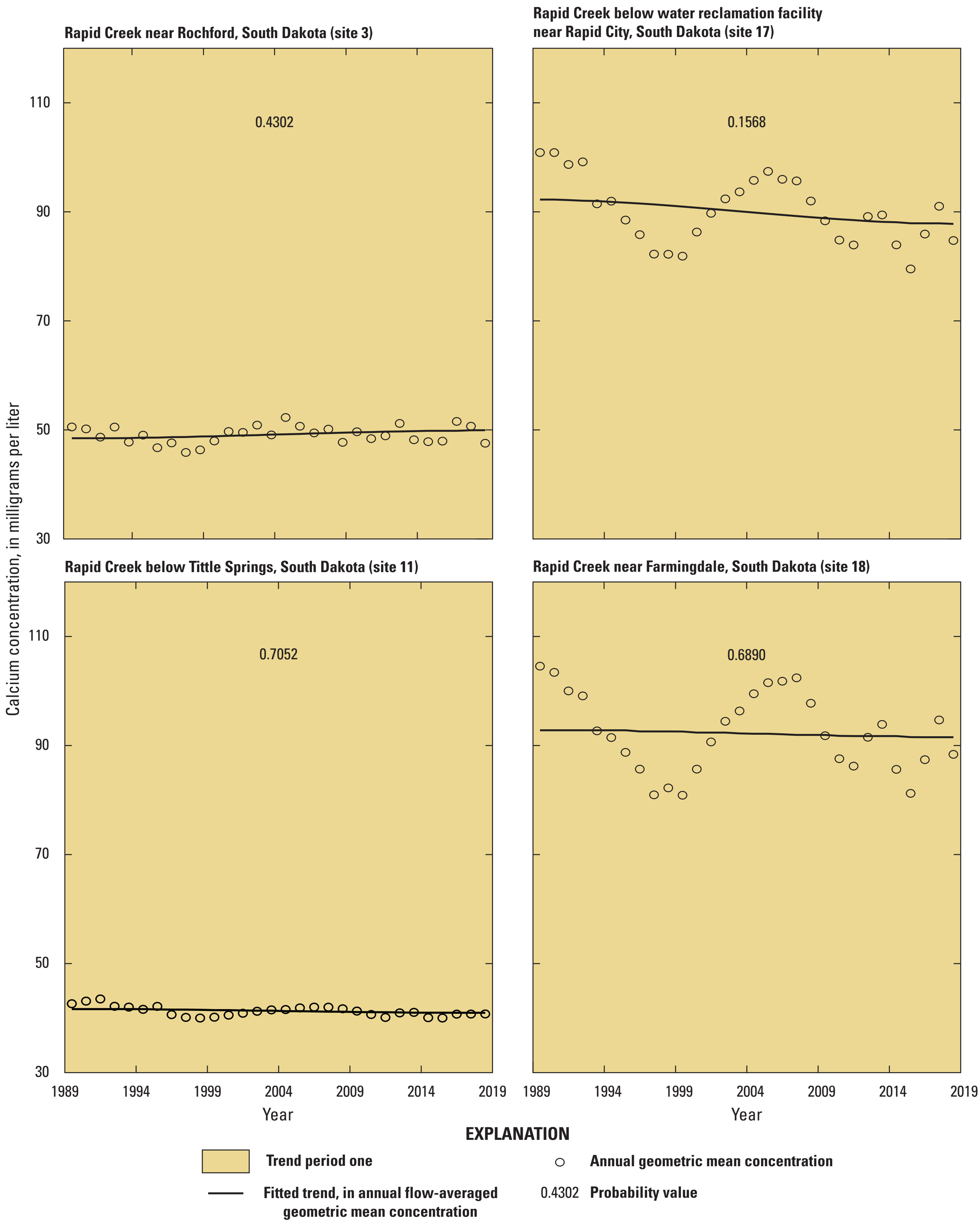
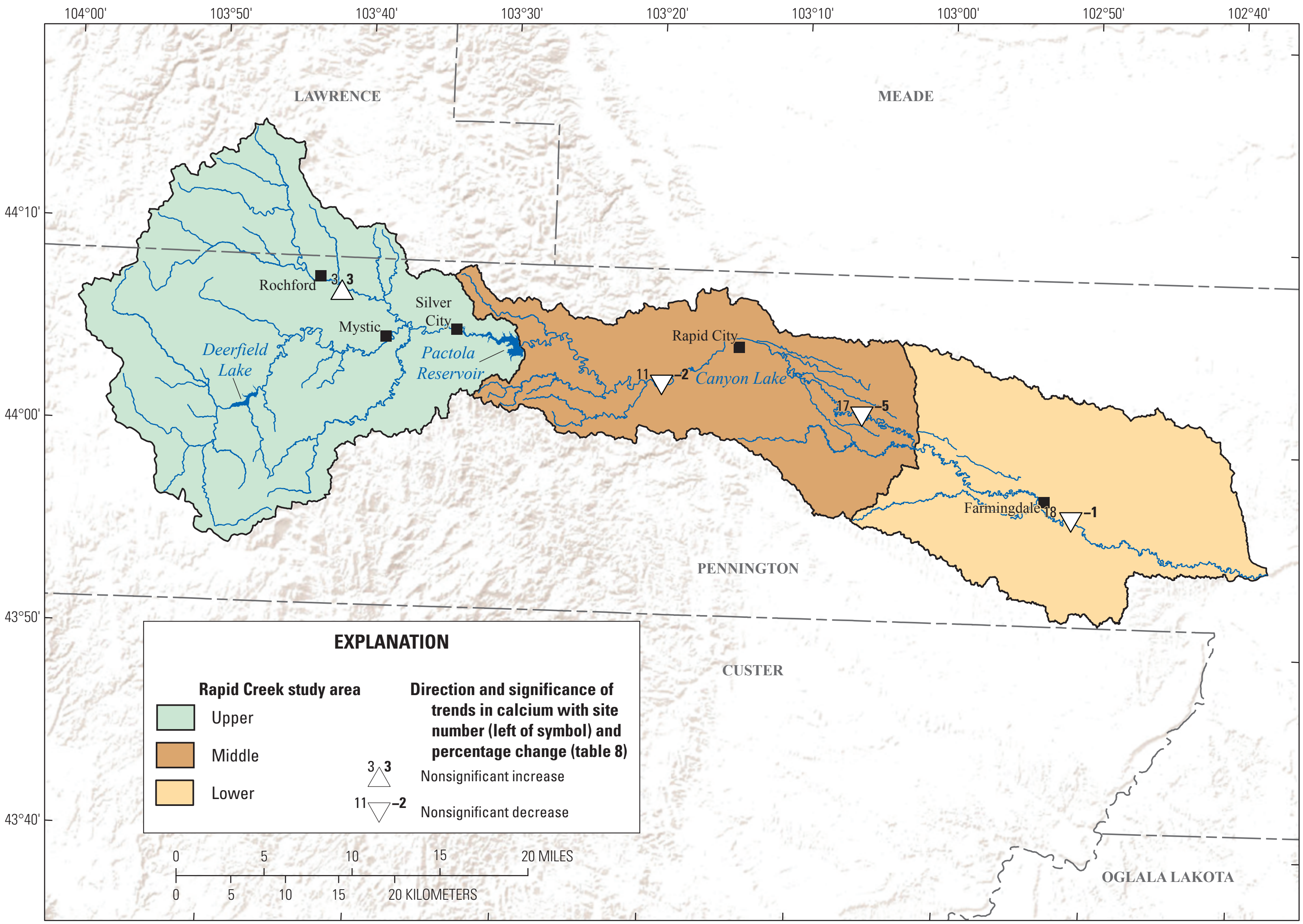


Figure 10. Fitted trends for calcium in annual flow-averaged geometric mean concentration of calcium at four sites in the Rapid Creek Basin for the trend period (1989–2019).



Base modified from U.S. Geological Survey and other digital data

Figure 11. Direction and significance of trends in calcium at four sites for the period analyzed for trends between 1979 and 2019 in the Rapid Creek Basin.

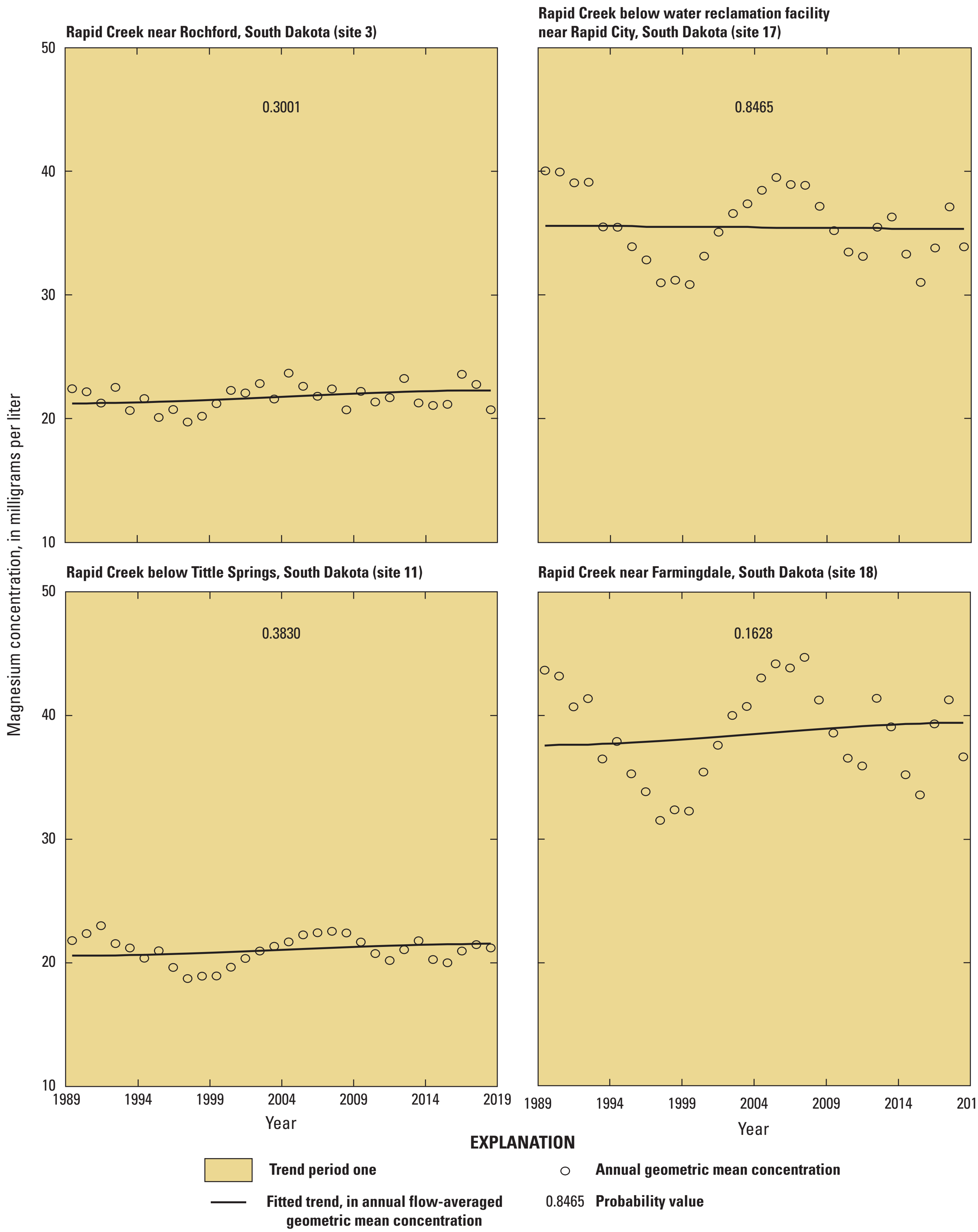
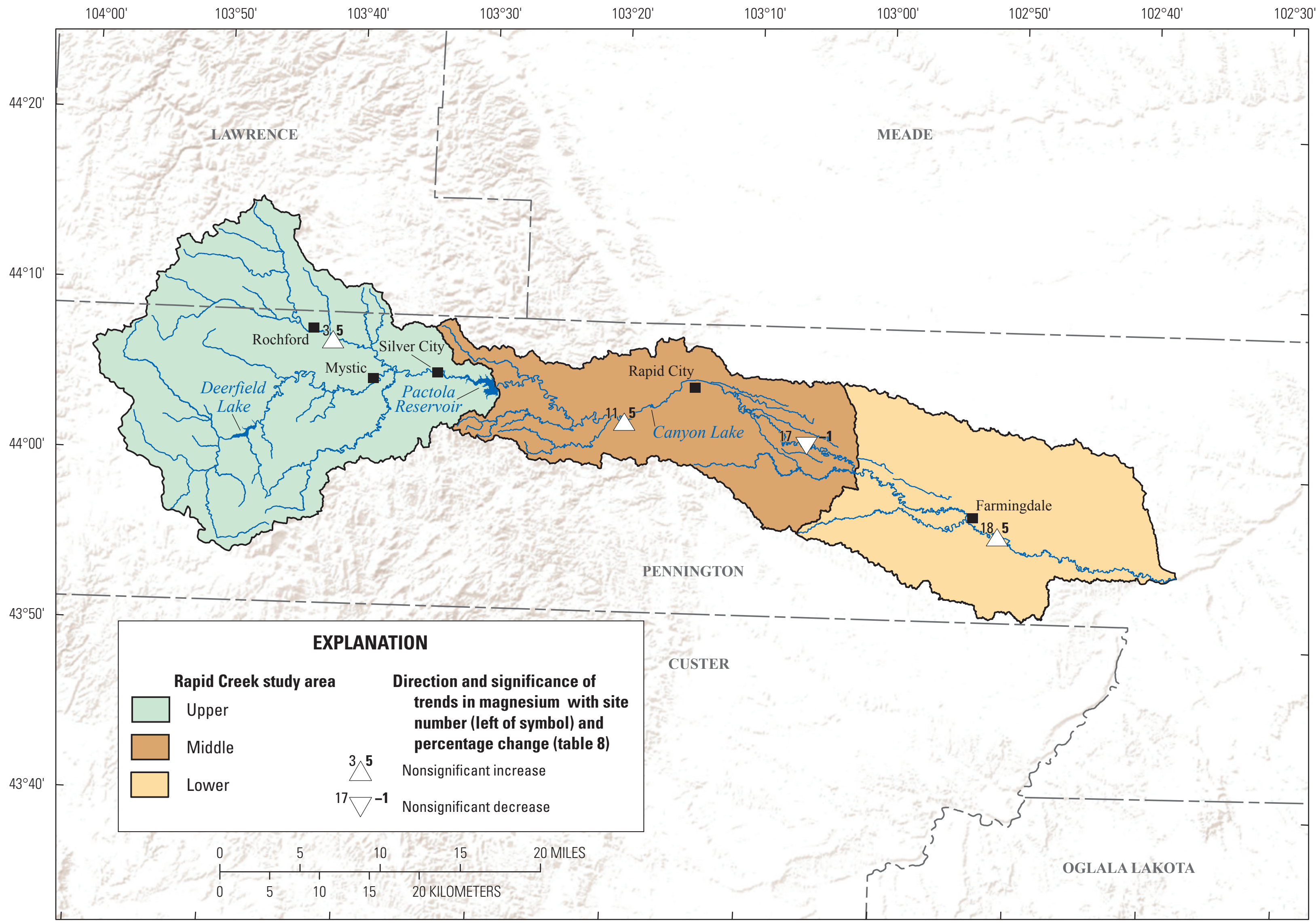


Figure 12. Fitted trends for magnesium in annual flow-averaged geometric mean concentration of magnesium at four sites in the Rapid Creek Basin for the trend period (1989–2019).



Base modified from U.S. Geological Survey and other digital data

Figure 13. Direction and significance of trends in magnesium at four sites for the period analyzed for trends between 1979 and 2019 in the Rapid Creek Basin.

Field Measurements

A total of 12 sites were evaluated for SC trends: 6 sites in the upper Rapid Creek Basin (sites 2–7) and 6 sites in the middle and lower basins (fig. 14*A*, *B*). Trends in SC values in the Rapid Creek Basin were mixed with alternating increasing and decreasing trends at many of the sites between 1979 and 2014 (fig. 15). The annual GMC for SC follows the same general pattern as TDS, as expected, with flow-related variability less pronounced upstream and more evident downstream (fig. 14*A*, *B*).

Upper basin trends in SC had mixed trend directions but had little change between 1979 and 2014 (figs. 14*A* and 15, table 8). Five upper basin sites (sites 3, 4, 5, 6, and 7) were evaluated for SC trends in the early period (1979–89); sites 4, 5, and 7 had decreasing concentrations, and sites 3 and 6 had increasing concentrations. The same five sites in the middle period (1989–99) each changed in the trend direction, where sites 4, 5, and 7 had increasing concentrations and sites 3 and 6 had decreasing concentrations (fig. 14*A*). In addition, site 2 was added during the middle period and had an increase in SC concentrations. During the late period (1999–2014), the six sites reversed trend direction again, so sites 2, 4, 5, and 7 had decreasing concentrations and sites 3 and 6 had increasing concentrations (table 8 and fig. 14*A*).

The six sites in the middle and lower basins evaluated for trends in SC concentrations were generally increasing from 1979 to 2014, and differing trend directions were detected among the three trend periods (figs. 14*B* and 15). During the early period (1979–89), four sites were evaluated for trends (sites 8, 11, 12, and 18). Sites 11 and 18 had increasing concentrations (nonsignificant and significant, respectively) and sites 8 and 12 had decreasing concentrations in SC (nonsignificant and mildly significant, respectively; table 8). Sites 16 and 17 were added during the middle period, and of the six sites evaluated, three had increasing concentrations and three had decreasing concentrations. Sites 8 and 12 had mildly significantly increasing concentrations, and site 11 had nonsignificantly increasing concentrations. Sites 17 and 18 had significantly decreasing concentrations in the middle period, and site 16 had nonsignificantly decreasing concentrations. During the late period, all sites upstream from Rapid City had nonsignificant trends with two decreasing (sites 8 and 12) and one increasing (site 11). The sites downstream from Rapid City in the late period all had significantly increasing concentrations. All the sites among the three periods (early, middle, and late) had the direction of the trend change, except site 11, which had nonsignificantly increasing concentrations over each of the three periods.

Trends in SC can be used as a proxy for sites with too few data for TDS trends to be analyzed. Overall, trends in SC indicated that total dissolved solids concentrations in Rapid Creek have not been largely affected by changes in land surface. The trends in SC across the basin were generally small and indicated little change in total dissolved solids in Rapid Creek. Geologic and hydrologic effects on Rapid Creek are likely the reason for less significant changes in concentration upstream from Rapid City. Because of the crystalline core of the Black Hills, dilution from many of the small tributaries containing low total dissolved solids concentrations likely affects the concentrations in Rapid Creek upstream from Rapid City. Urban, geologic, and agricultural effects are likely affecting the significant changes in concentrations downstream from Rapid City.

Total Suspended Solids

TSS concentrations were observed to be decreasing at the two sites analyzed for trends in the Rapid Creek Basin between 1979 and 2019 (figs. 16 and 17, table 8). Site 18 was analyzed using a three-trend model between 1979 and 2019, and site 17 was analyzed using a two-trend model between 1989 and 2019. Step trends were used to correct for differences in data caused by nonenvironmental factors such as laboratory-analytical methods at the two sites analyzed in the basin (table 8). At site 17, samples analyzed using EPA method 160.1 were determined to be biased high by about 35 percent compared to the standard method 2540D. A step trend was applied to account for these laboratory differences. At site 18, TSS results from SD DANR that were identified as suspended were determined to be biased high by about 25 percent compared to TSS results from USGS and SD DANR identified as not applicable (NA), and a significant step trend was applied. Accounting for these biases provides the reasonable assumption that the trends analyzed for TSS reflect changes from factors other than laboratory differences, such as land-use changes. Each step trend applied was tested to ensure that it was statistically significant (p-value less than or equal 0.1).

Trends in TSS concentrations were generally observed to be decreasing at the two sites between 1979 and 2019 (figs. 16 and 17, table 8). Site 17 had significant decreases in flow-averaged GMC for TSS in the middle and late periods compared to site 18, which only had a significant decrease in the late period and had a nonsignificant increase in the middle period. At site 18, between 1979 and 1999, the concentration did not change because both periods had nonsignificant trends (table 8). Sites upstream from Rapid City had too few data to analyze trends to determine if similar trends were observed. The annual GMC (fig. 16) was observed to have more flow-related variability at site 18 as compared to site 17. Site 17 likely has less flow-related variability because a substantial amount of the flow in this part of Rapid Creek during low flow conditions is most likely discharge from the WRF.

The decreases in TSS concentrations in the Rapid Creek Basin could be related to several factors such as the implementation of a stormwater management plan in Rapid City, improvements to the Rapid City WRF, and residual effects of the overall climatic regime. The EPA began to require urbanized areas to manage stormwater in 1990, beginning with large cities with populations greater than 100,000, and then

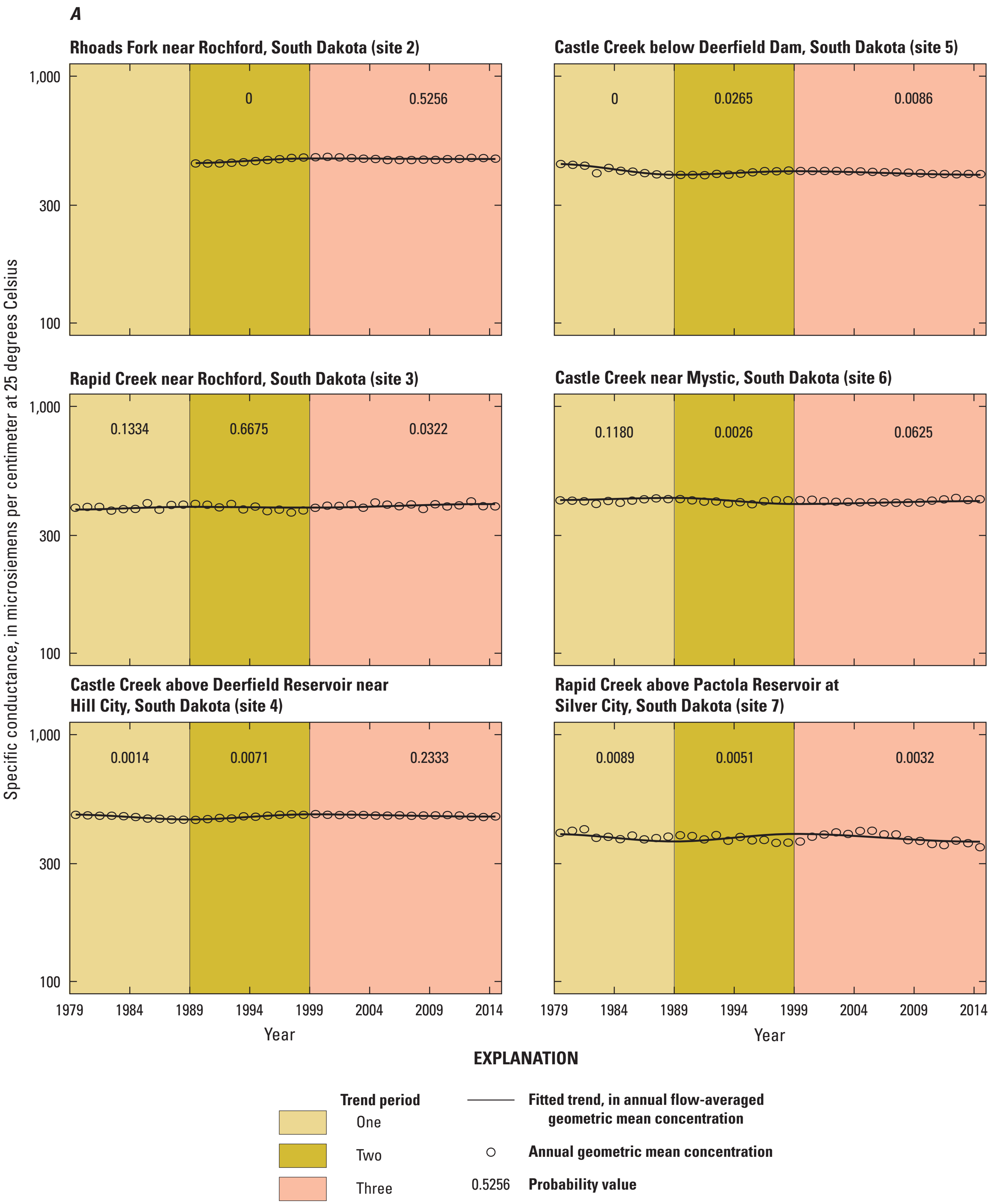


Figure 14. Fitted trends for specific conductance in annual flow-averaged geometric mean concentration of specific conductance at 12 sites with annual geometric mean concentrations for specific conductance in the Rapid Creek Basin for the trend period (1979–2014). *A*, upper basin; *B,* middle and lower basin.

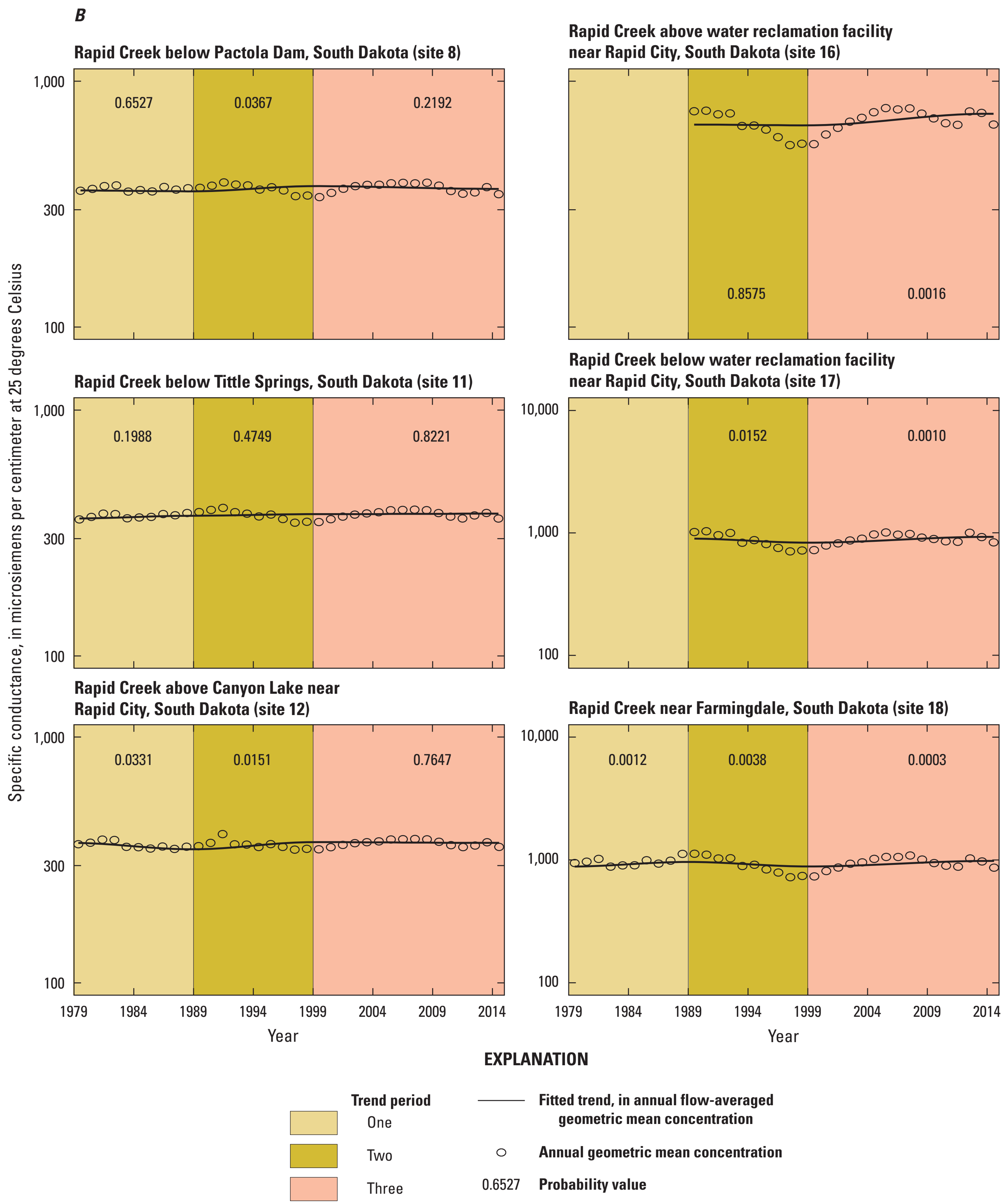


Figure 14. Fitted trends for specific conductance in annual flow-averaged geometric mean concentration of specific conductance at 12 sites with annual geometric mean concentrations for specific conductance in the Rapid Creek Basin for the trend period (1979–2014). *A*, upper basin; *B,* middle and lower basin.—Continued

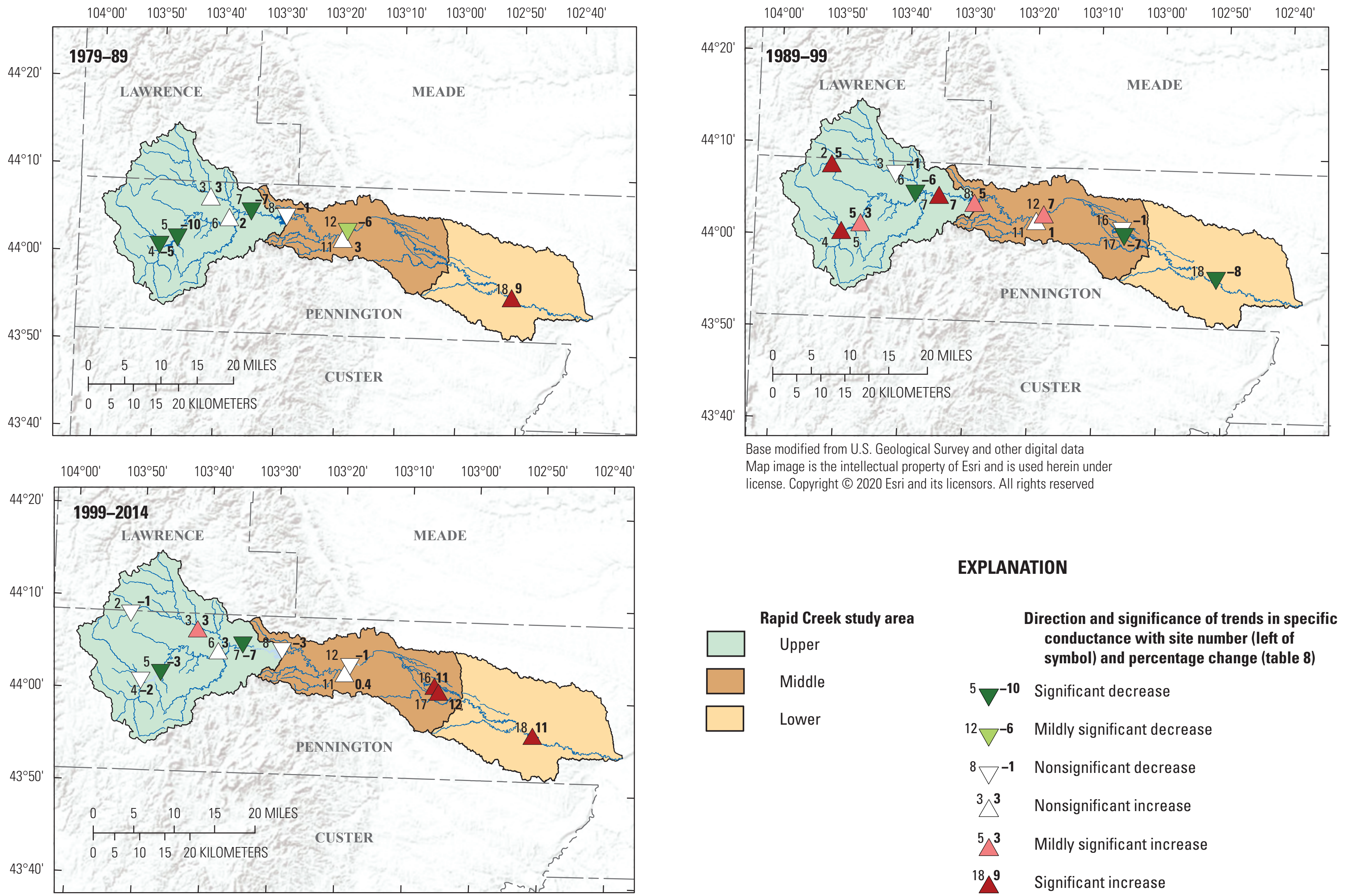


Figure 15. Direction and significance of trends in specific conductance at 12 sites for each of the 3 periods analyzed for trends between 1979 and 2014 in the Rapid Creek Basin.

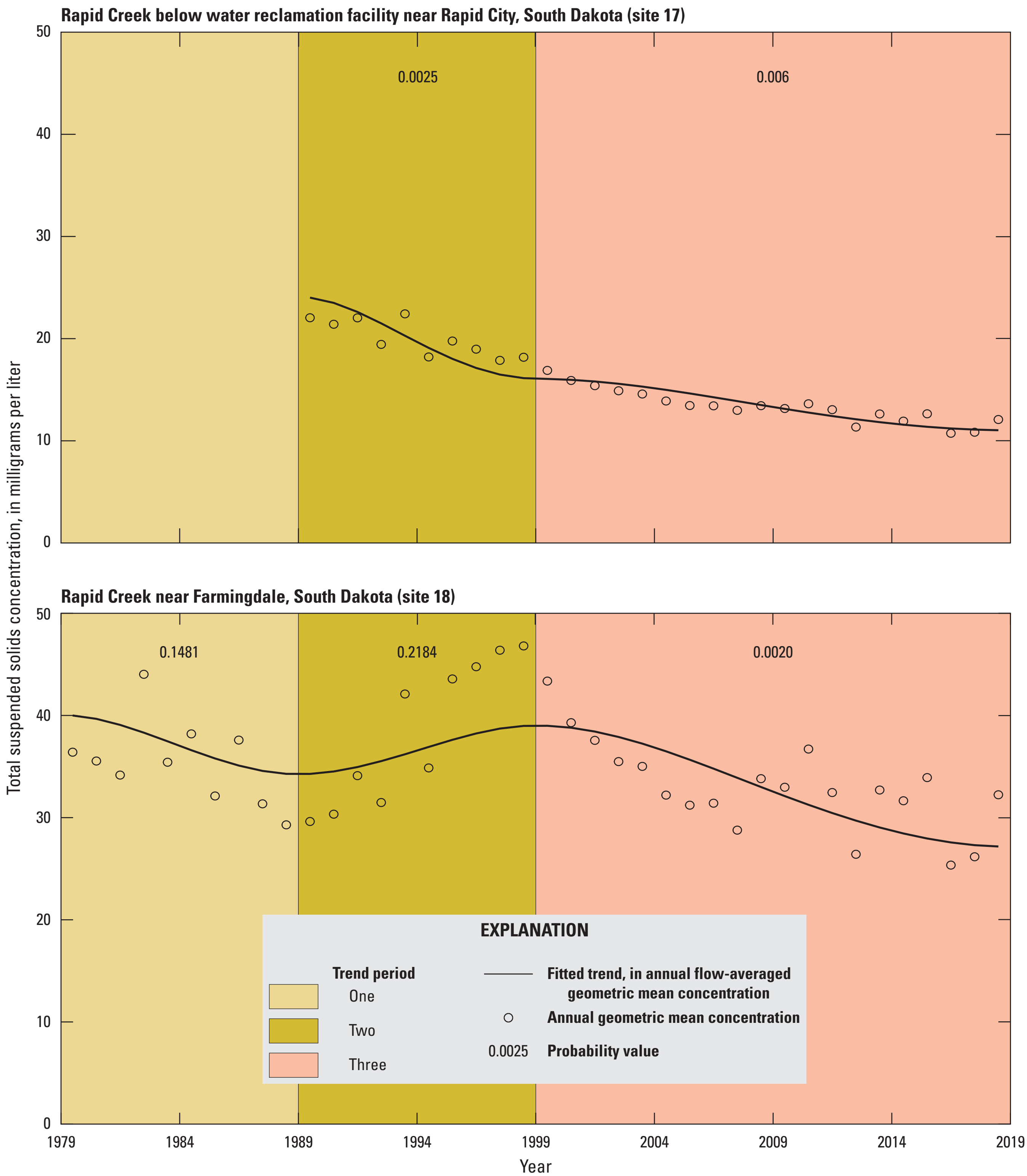


Figure 16. Fitted trends for total suspended solids in annual flow-averaged geometric mean concentration of total suspended solids at two sites with annual geometric mean concentrations in the Rapid Creek Basin for the trend period (1979–2019).

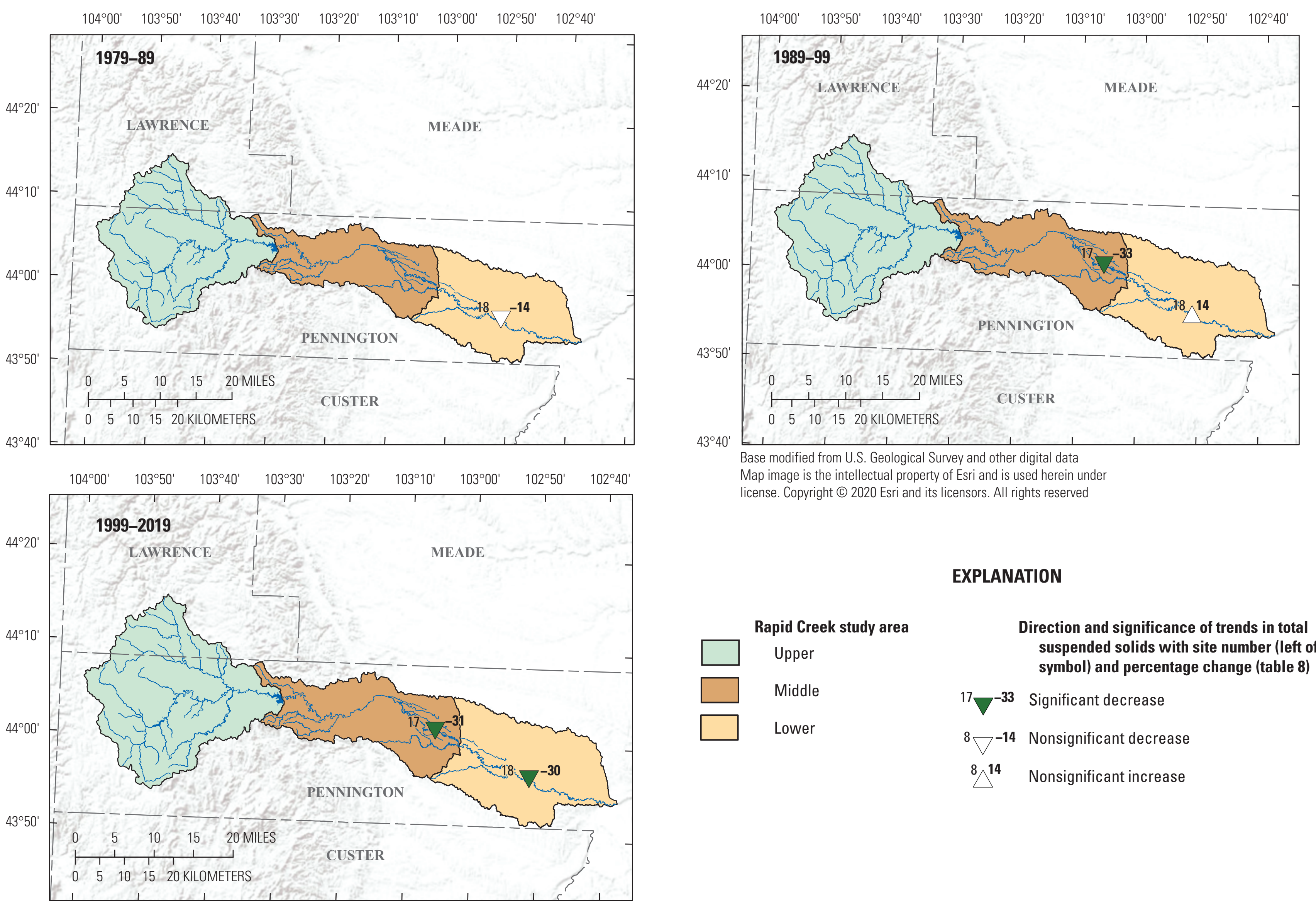


Figure 17. Direction and significance of trends in total suspended solids at 2 sites for each of the 3 periods analyzed between 1979 and 2019 in the Rapid Creek Basin.

in 1999, smaller cities such as Rapid City were subject to the same regulations (U.S. Environmental Protection Agency, 2000). Management of stormwater by Rapid City after 1999 may be contributing to decreasing concentrations at the sites below the WRF (fig. 17). The Rapid City WRF also has had numerous improvements during the trend period, which may have had some effect on the decreases in TSS concentrations (HDR, 2016).

Nutrients

Total phosphorus, dissolved phosphorus, and TKN were analyzed for trends in the Rapid Creek Basin. Five sites were analyzed for total phosphorus concentration trends using a one-period trend model between 1989 and 2014. Data were available to analyze trends for dissolved phosphorus and TKN concentrations at only two sites in the basin between 1999 and 2014 and 1999 and 2019, respectively. An interval-based step trend was applied at sites 17 and 18 for total phosphorus to account for major renovations and improvements to the Rapid City WRF in 1992 and 2003 (HDR, 2016). An interval-based step trend is used to model abrupt changes in the flow-adjusted concentrations from an anthropogenic source, such as the WRF on Rapid Creek (Vecchia and Nustad, 2020).

To account for the improvements to the WRF, two interval-based step trends in 1992 and 2003 (HDR, 2016) were tested at sites 17 and 18. Both step trends indicated a significant decrease in total phosphorus when tested without a monotonic trend; however, when the monotonic trend was added, the step trends were smaller and nonsignificant but still indicated decreasing concentrations. Given that these are known improvements, the interval-based step trends were included in the final models, and although the magnitude of the decrease cannot be reliably determined, the analysis indicates that WRF improvements in 1992 and 2003 resulted in decreased total phosphorus concentrations at downstream sites. By applying the interval-based step trends, the effects from WRF improvements were removed and the changes in concentration detected from the monotonic trends were assumed to be the results of other processes in the basin.

Concentrations in total phosphorus were observed to be significantly decreasing at all sites between 1989 and 2014 (figs. 18 and 19, table 9). Each site had a significant decrease in total phosphorus concentrations that ranged from 43 to 75 percent. Each of the three sites upstream from the Rapid City WRF had relatively low flow-averaged GMCs that decreased from about 0.03 to 0.01 mg/L as phosphorus (table 9). The two sites downstream from the Rapid City WRF had smaller percentage changes but larger flow-averaged GMCs that decreased by 0.35 and 0.30 mg/L as phosphorus at sites 17 and 18, respectively (table 9). As previously mentioned, the trend results in table 9 reflect a decrease in concentrations that is due to processes unrelated to the known WRF improvements. Annual GMCs of total phosphorus show that site 16 had the least flow-related variability and site 17 had the largest flow-related variability (fig. 18).

Trends in dissolved phosphorus concentrations in the Rapid Creek Basin were analyzed at the two farthest downstream sites (17 and 18), and concentrations were unchanging or decreasing between 1999 and 2014 (figs. 20 and 21, table 9). Compared to total phosphorus, dissolved phosphorus concentrations at site 17 did not follow the same pattern. A nonsignificant increase in the dissolved phosphorus flow-averaged GMC indicated that different processes have affected the dissolved phosphorus flow-averaged GMC compared to total phosphorus. Total phosphorus will capture particulate phosphorus that can be transported with sediment, whereas dissolved phosphorus does not capture phosphorus in sediment, which could account for the differences. Site 18 had a significant decrease in the flow-averaged GMC of dissolved phosphorus and was like the trend in total phosphorus at this site (table 9). The annual GMC of dissolved phosphorus at site 17 had more flow-related variability compared to site 18, potentially because of WRF discharge, which could be a considerable part of the streamflow during periods of low flow conditions (fig. 20).

Significant decreases in TKN concentrations were observed at both sites in the Rapid Creek Basin for the trend period of 1999–2019 (figs. 22 and 23, table 9). These trends in flow-averaged GMC of TKN follow a similar pattern observed in total and dissolved phosphorus. Sites 17 and 18 had similar decreases of 0.46 and 0.45 mg/L as nitrogen, respectively. The annual GMC of TKN at sites 17 and 18 indicate flow-related variability during the trend period with more variability in the early part of the trend period before 2009 and less in the later years of the trend period (fig. 22).

Factors affecting nutrient concentrations included biological cycling by plants and microbes, livestock, stormwater runoff, and WRFs. No large-scale land-use changes or increase in livestock grazing land were observed between 1950 and 2010 (Cotillon, 2013), and the implementation of different conservation practices may have been a factor in the decreasing nutrient concentrations. Stormwater runoff from urban areas can negatively affect the nutrient concentrations, and the EPA regulations requiring the City of Rapid City to implement a stormwater management plan likely could have contributed to the decreasing nutrient concentrations (U.S. Environmental Protection Agency, 2000; City of Rapid City, 2009). Finally, continued improvements at the WRF over the 20- or 30-year trend periods have likely contributed to the decreasing trends observed in the nutrient concentrations (HDR, 2016).

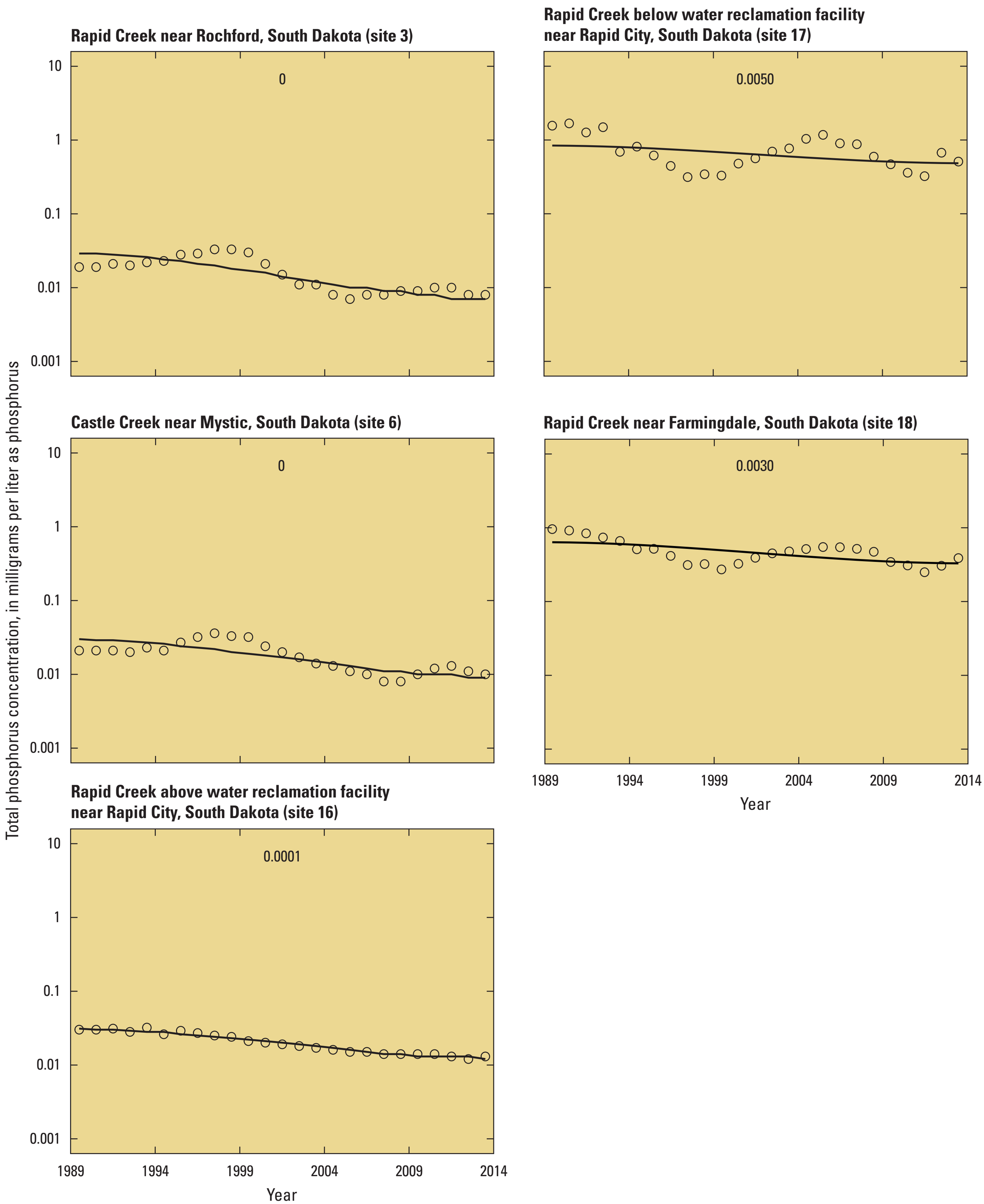
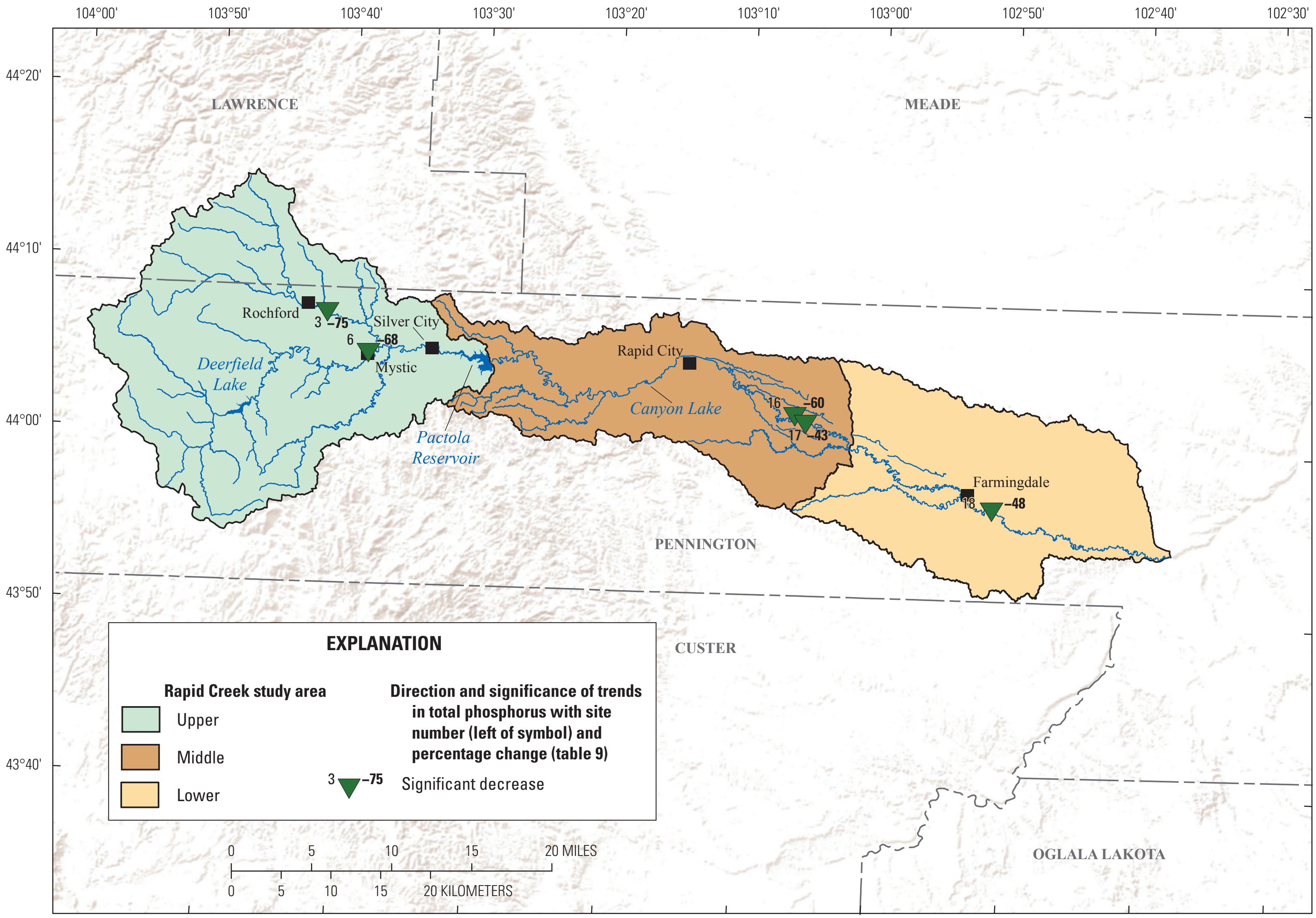


Figure 18. Fitted trends for total phosphorus in annual flow-averaged geometric mean concentration of total phosphorus at five sites with annual geometric mean concentrations in the Rapid Creek Basin for the trend period (1989–2019).



Base modified from U.S. Geological Survey and other digital data

Figure 19. Direction and significance of trends in total phosphorus at 5 sites for each of the 3 periods analyzed for trends between 1989 and 2019 in the Rapid Creek Basin.

Table 9. Summary of trend results for nutrients at selected sites in the Rapid Creek Basin between 1979 and 2019.

[*p*-value, probability value; GMC, geometric mean concentration; WRF, water reclamation facility]

Site location (fig. 1)	Rapid Creek Basin identifier	Site name	Trend model	Trend period	Step trend	*p*-value	Significance level	Annual flow-averaged GMC for first year in trend period	Annual flow-averaged GMC for last year in trend period	Change, in percent, from first to last year[a]
Total phosphorus, in milligrams per liter as phosphorus										
3	Upper	Rapid Creek near Rochford, S. Dak.	One	1989–2014	No	0	Significant decrease	0.03	0.01	−75
6	Upper	Castle Creek near Mystic, S. Dak.	One	1989–2014	No	0	Significant decrease	0.03	0.01	−68
16	Middle	Rapid Creek above WRF near Rapid City, S. Dak.	One	1989–2014	No	0.0001	Significant decrease	0.03	0.01	−60
17	Middle	Rapid Creek below WRF near Rapid City, S. Dak.	One	1989–2014	Yes	0.0050	Significant decrease	0.84	0.49	−43
18	Lower	Rapid Creek near Farmingdale, S. Dak.	One	1989–2014	Yes	0.0030	Significant decrease	0.62	0.32	−48
Dissolved phosphorus, in milligrams per liter as phosphorus										
17	Middle	Rapid Creek below WRF near Rapid City, S. Dak.	One	1999–2014	No	0.2926	Nonsignificant increase	0.42	0.46	8
18	Lower	Rapid Creek near Farmingdale, S. Dak.	One	1999–2014	No	0.0006	Significant decrease	0.28	0.17	−40
Total Kjeldahl nitrogen, in milligrams per liter as nitrogen										
17	Middle	Rapid Creek below WRF near Rapid City, S. Dak.	One	1999–2019	No	0.0005	Significant decrease	1.10	0.64	−42
18	Lower	Rapid Creek near Farmingdale, S. Dak.	One	1999–2019	No	0	Significant decrease	1.09	0.64	−41

[a]Percentage change values are directly calculated from R–QWTREND. Starting and ending concentrations in the table are rounded and may not produce the exact percentage change.

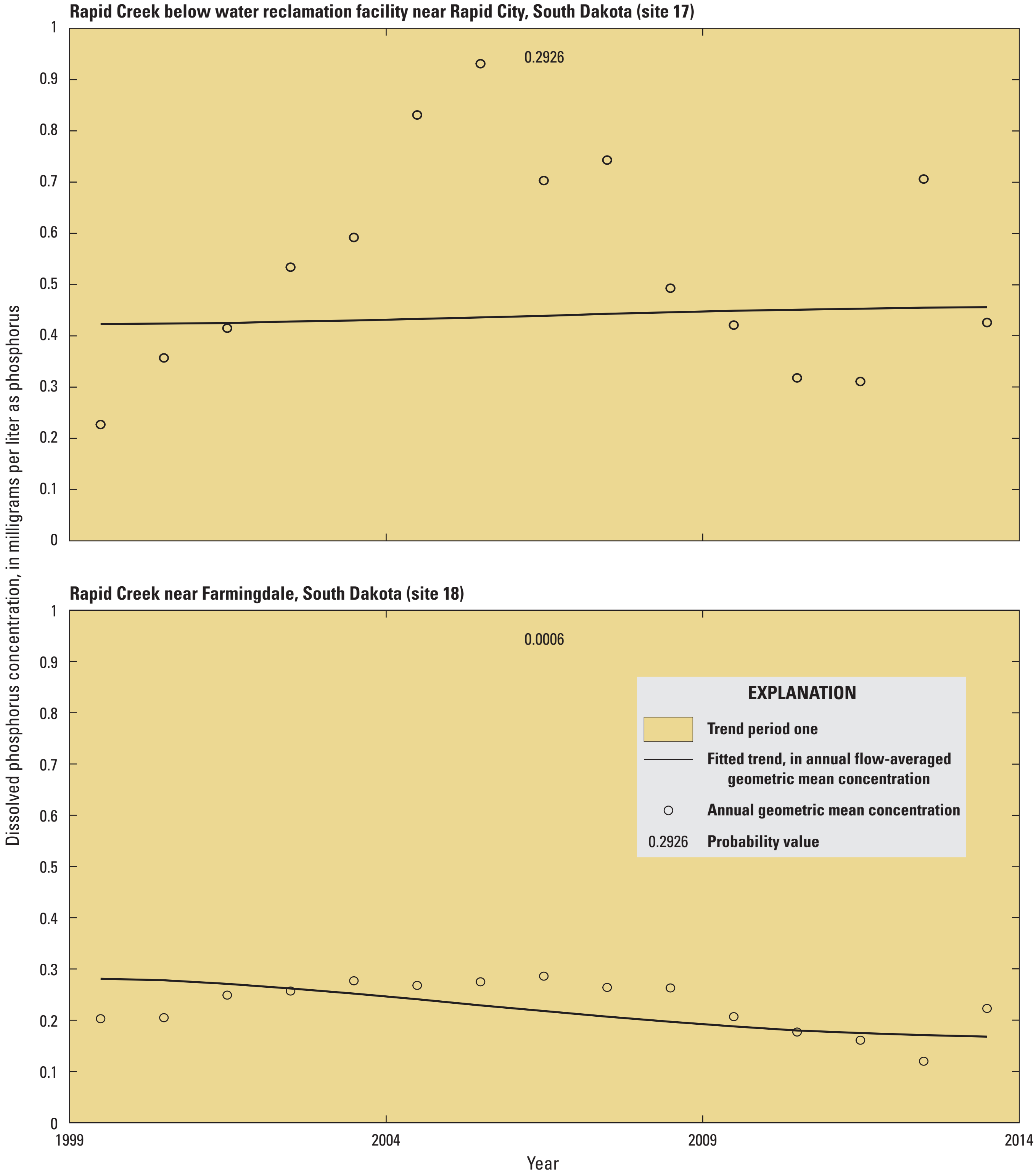
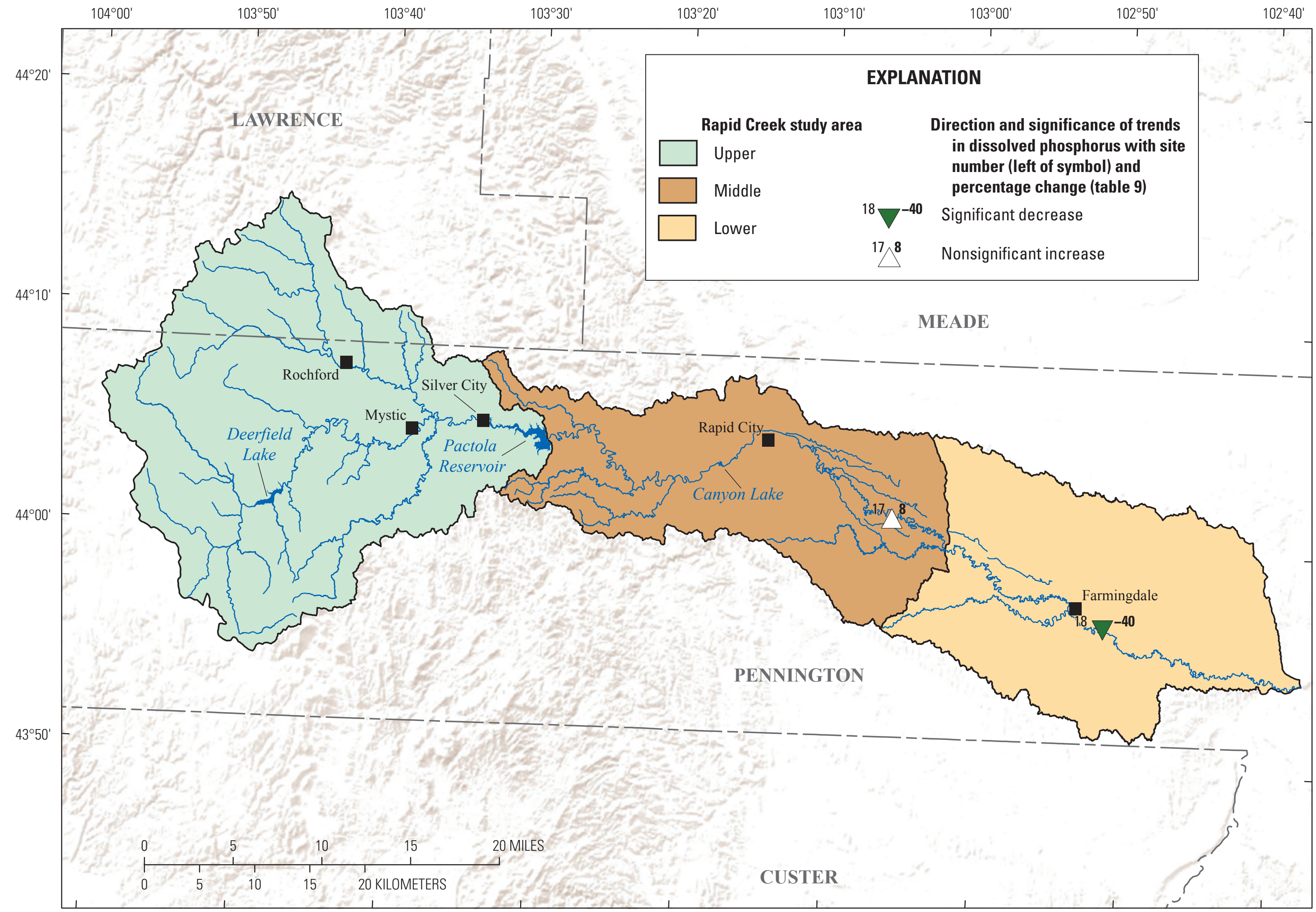


Figure 20. Fitted trends for dissolved phosphorus in annual flow-averaged geometric mean concentration of dissolved phosphorus at two sites with annual geometric mean concentrations in the Rapid Creek Basin for the trend period (1999–2014).



Base modified from U.S. Geological Survey and other digital data

Figure 21. Direction and significance of trends in dissolved phosphorus at two sites for the period analyzed for trends between 1999 and 2014 in the Rapid Creek Basin.

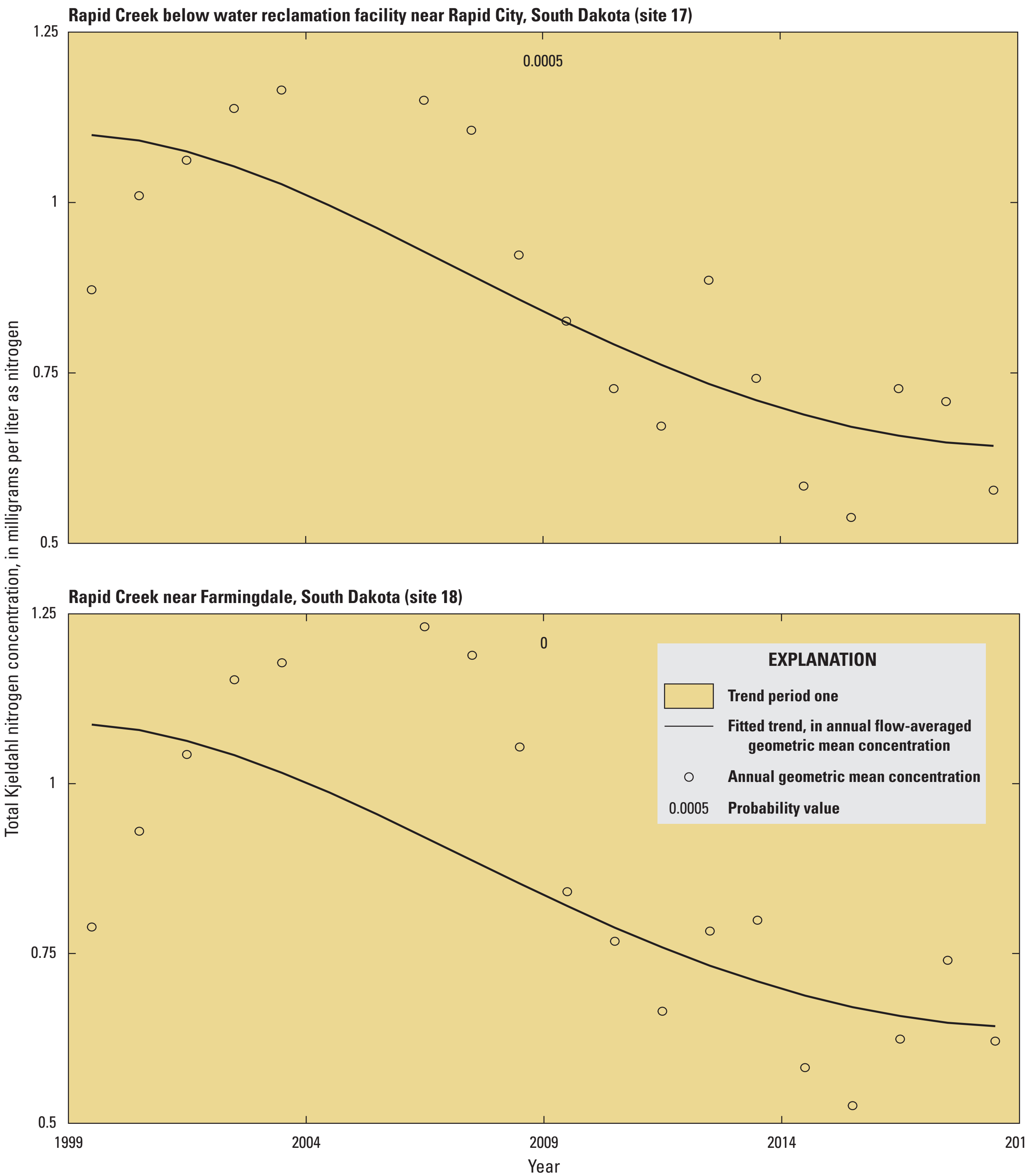
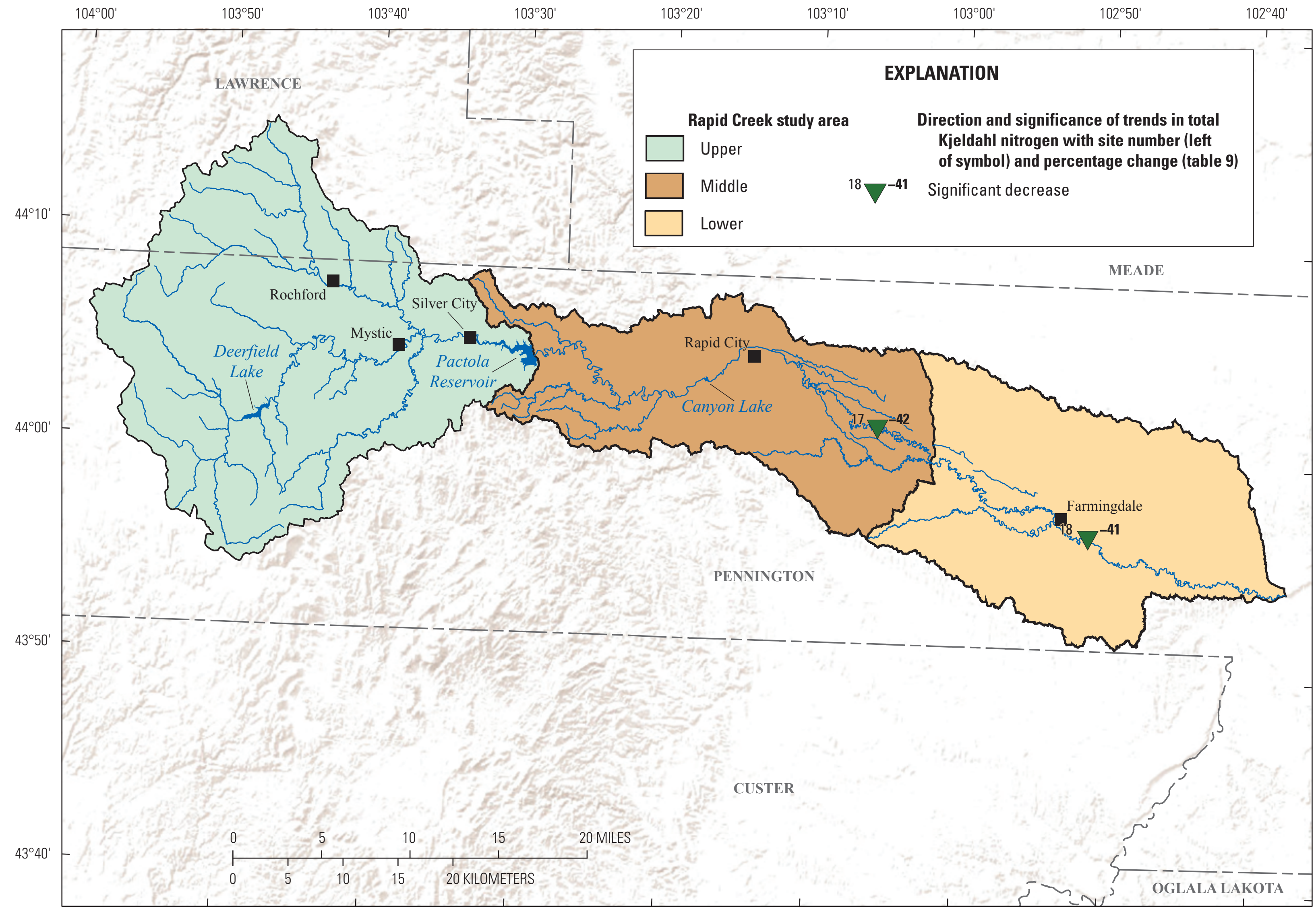


Figure 22. Fitted trends for total Kjeldahl nitrogen in annual flow-averaged geometric mean concentration of total Kjeldahl nitrogen at two sites with annual geometric mean concentrations in the Rapid Creek Basin for the trend period (1999–2019).



Base modified from U.S. Geological Survey and other digital data

Figure 23. Direction and significance of trends in total Kjeldahl nitrogen at two sites for the period analyzed for trends between 1999 and 2019 in the Rapid Creek Basin.

Summary

A compilation of surface-water-quality data in the Rapid Creek Basin in South Dakota was completed to assess basic trends in the water quality of Rapid Creek. Spatial and temporal patterns in water quality were described for major ions, sediment, total suspended solids, nutrients, field measurements, bacteria, and select metals for the period of 1970–2020, and a water-quality trend analysis was completed for sites with enough data for selected constituents. Water-quality data at selected sites in the Rapid Creek Basin were obtained from the National Water Quality Monitoring Council Water Quality Portal for the period of 1970–2020, and available streamflow data for selected sites were obtained from the U.S. Geological Survey (USGS) National Water Information System database. Descriptive statistics were computed for all sites in the Rapid Creek Basin with at least 10 samples collected between 1970 and 2020 to describe the spatial variability of concentrations in the basin.

Generally, major ions had the highest median concentrations at sites in the lower basin (downstream from the city of Rapid City) compared to sites in the upper and middle basins. The highest median concentration of total dissolved solids (TDS) was 628 milligrams per liter (mg/L) at site 18 (Rapid Creek near Farmingdale), and the lowest median concentration was 187 mg/L at site 1 (North Fork Rapid Creek). Patterns in total suspended solids (TSS) are similar to major ions, where concentrations increase downstream and the highest concentrations are the farthest downstream. Median TSS concentrations upstream from Rapid City are less than 10 mg/L, and median concentrations increased to a maximum of 34 mg/L at site 18 downstream from Rapid City. For nutrients, median concentrations for all five constituents were generally low, and increased concentrations were only detected at the site downstream from the Rapid City Water Reclamation Facility (WRF) and farther downstream. For bacteria, *Escherichia coli* and fecal coliform concentrations were highest downstream from Rapid City, starting at site 15 (Rapid Creek below Hawthorn Ditch at Rapid City). Median *Escherichia coli* concentrations in the Rapid Creek Basin ranged from 4.7 most probable number per 100 milliliters (mpn/100 mL) at site 2 (Rhoads Fork near Rochford) to 173 mpn/100 mL at site 17 (Rapid Creek below the WRF near Rapid City). Four metals constituents were compiled; however, the understanding of metals conditions in the Rapid Creek Basin is limited by too few data across the basin.

Water-quality trends were analyzed for the trend period of 1979–2019. Trends were analyzed for TDS, specific conductance (SC), calcium, magnesium, TSS, dissolved phosphorus, total phosphorus, and total Kjeldahl nitrogen (TKN). A two- or three-period trend model was used for TDS, SC, and TSS analysis, and the analyses were broken into two or three monotonic trends using a combination of the early (1979–89), middle (1989–99), and late (1999–2019) periods. Concentrations for constituents are reported in the annual flow-averaged geometric mean concentration (GMC) as R–QWTREND removes the effects of streamflow on water-quality concentrations. Results for the trend analysis provide insight into temporal and spatial water-quality changes in the basin.

Trends in major ions and TDS concentrations in the Rapid Creek Basin were determined to be small (less than 15 percent) or mostly constant. Trends in TDS were evaluated at five sites with generally decreasing trends at sites upstream from Rapid City (sites 3, 6, and 11) and increasing trends at sites downstream from Rapid City (sites 17 and 18). Between 1979 and 2019, sites upstream from Rapid City had a decrease in the flow-averaged GMC of TDS and sites downstream from Rapid City had an increase in the flow-averaged GMC of TDS. The annual GMC for TDS indicates that TDS concentrations had less flow-related variability at sites 3, 6, and 11 in the upper part of the Rapid Creek Basin compared to sites 17 and 18, which had higher flow variability. Nonsignificant trends were detected for calcium and magnesium concentrations at selected sites in the Rapid Creek Basin between 1989 and 2019. Trends in SC values in the Rapid Creek Basin were mixed with alternating increasing and decreasing trends at many of the sites between 1979 and 2014. Upper basin trends in SC were mixed with trend direction alternating back and forth between periods. The six sites in the middle and lower basins evaluated for SC trends had generally increasing concentrations for the overall period and had differing trend directions among the three smaller periods. The annual GMC for SC follows the same general pattern as TDS, as expected, with flow-related variability less pronounced upstream and more evident downstream.

TSS concentrations were observed to be decreasing at the two sites analyzed for trends in the Rapid Creek Basin between 1979 and 2019. Step trends were used to correct for differences in data caused by nonenvironmental factors such as laboratory-analytical methods at the two sites analyzed in the basin. At site 17, samples analyzed using U.S. Environmental Protection Agency method 160.1 were determined to be biased high by about 35 percent, and a step trend was applied to account for the laboratory differences. At site 18, TSS results from South Dakota Department of Agriculture and Natural Resources that were identified as suspended were determined to be biased high by about 25 percent compared to TSS results from USGS and South Dakota Department of Agriculture and Natural Resources identified as not applicable (NA), and a significant step trend was applied. Trends in TSS concentrations were generally observed to be decreasing at the two sites between 1979 and 2019. Site 17 had significant decreases in flow-averaged GMC for TSS in the middle and late periods compared to site 18, which only had a significant decrease in the late period and had a nonsignificant increase in the middle period. The annual GMC seems to have more flow-related variability at site 18 compared to site 17. Site 17 likely has less flow-related variability because of the WRF discharge, which likely accounts for a substantial amount of the flow in this part of Rapid Creek during low flows. The decreases in TSS concentrations in the Rapid Creek Basin could be related to several processes such as the implementation of a stormwater management plan in Rapid City, improvements to the Rapid City WRF, and residual effects of the overall climatic regime.

Total phosphorus, dissolved phosphorus, and TKN were analyzed for trends in the Rapid Creek Basin. Trends in total phosphorus were observed to be significantly decreasing at all sites between 1989 and 2014. To account for the improvements to the WRF, two interval-based step trends in 1992 and 2003 were tested at sites 17 and 18. Both step trends indicated a significant decrease in total phosphorus when tested without a monotonic trend; however, when the monotonic trend was added, the step trends were smaller and nonsignificant but still indicated decreasing concentrations. Given that these are known improvements, the interval-based step trends were included in the final models, and although the magnitude of the decrease cannot be reliably determined, the analysis indicates that WRF improvements in 1992 and 2003 resulted in decreased total phosphorus concentrations at downstream sites. Each site had a significant decrease in total phosphorus concentrations ranging from 43- to 75-percent reductions. The large magnitude of the reductions is mainly due to small changes in the low nutrient concentrations in the Rapid Creek Basin. Each of the three sites upstream from the Rapid City WRF had low flow-averaged GMCs that decreased from about 0.03 to 0.01 mg/L. Trends in dissolved phosphorus concentrations in the Rapid Creek Basin were analyzed at the two farthest downstream sites (17 and 18), and concentrations were unchanging or decreasing between 1999 and 2014. Significant decreasing trends in TKN were observed at two sites in the lower Rapid Creek Basin for the trend period of 1999–2019. Both sites had similar decreases of 0.46 and 0.45 mg/L as nitrogen, respectively. Factors affecting nutrient concentrations included biological cycling by plants and microbes, livestock, stormwater runoff, and WRFs. Continued improvements at the WRF over the 20- or 30-year trend periods have likely contributed to the decreasing trends observed in the nutrient concentrations.

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Publishing support provided by the
Rolla Publishing Service Center

Tatge and others—**Water-Quality Data and Trends in the Rapid Creek Basin, South Dakota, 1970–2020**—SIR 2022–5086

ISSN 2328-0328 (online)
https://doi.org/10.3133/sir20225086