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Water-Quality Characteristics and Trend Analyses for the Tongue, Powder, Cheyenne, and Belle Fourche River Drainage Basins, Wyoming and Montana, for Selected Periods, Water Years 1991 through 2010

Scientific Investigations Report 2012–5117

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

Cover. Clear Creek, Wyoming. Photograph by Melanie L. Clark.

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KEN SALAZAR, Secretary

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Marcia K. McNutt, Director

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Contents

Figures

Tables

Conversion Factors and Datums

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton per day (ton/d)	0.9072	metric ton per day
ton per day (ton/d)	0.9072	megagram per day (Mg/d)

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

°F=(1.8×°C)+32

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

°C=(°F-32)/1.8

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

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

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

Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. For example, the water year ending September 30, 2001 is called water year 2001.

Concentrations of chemical constituents in water in this report are given in milligrams per liter (mg/L).

Abbreviated Water-Quality Units

mg/L	milligrams per liter
µS/cm at 25°C	microsiemens per centimeter at 25 degrees Celsius

Abbreviations

<	less than
CBNG	coalbed natural gas
ESTREND	EStimate TREND
NWIS	National Water Information System
p	p-value
RPD	relative percent difference
SAR	sodium adsorption ratio
USGS	U.S. Geological Survey
WDEQ	Wyoming Department of Environmental Quality

Water-Quality Characteristics and Trend Analyses for the Tongue, Powder, Cheyenne, and Belle Fourche River Drainage Basins, Wyoming and Montana, for Selected Periods, Water Years 1991 through 2010

By Melanie L. Clark

Abstract

The Powder River structural basin in northeastern Wyoming and southeastern Montana is an area of ongoing coalbed natural gas (CBNG) development. Waters produced during CBNG development are managed with a variety of techniques, including surface impoundments and discharges into stream drainages. The interaction of CBNG-produced waters with the atmosphere and the semiarid soils of the Powder River structural basin can affect water chemistry in several ways. Specific conductance and sodium adsorption ratios (SAR) of CBNG-produced waters that are discharged to streams have been of particular concern because they have the potential to affect the use of the water for irrigation. Water-quality monitoring has been conducted since 2001 at main-stem and tributary sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins in response to concerns about CBNG effects. A study was conducted to summarize characteristics of stream-water quality for water years 2001–10 (October 1, 2000, to September 30, 2010) and examine trends in specific conductance, SAR, and primary constituents that contribute to specific conductance and SAR for changes through time (water years 1991–2010) that may have occurred as a result of CBNG development. Specific conductance and SAR are the focus characteristics of this report. Dissolved calcium, magnesium, and sodium, which are primary contributors to specific conductance and SAR, as well as dissolved alkalinity, chloride, and sulfate, which are other primary contributors to specific conductance, also are described.

Stream-water quality in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins was variable during water years 2001–10, in part because of variations in streamflow. In general, annual runoff was less than average during water years 2001–06 and near or above average during water years 2007–10. Stream water of the Tongue River had the smallest specific conductance values, sodium adsorption ratios, and major ion concentrations of the main-stem streams. Sites in the Tongue River drainage basin typically had the smallest range of specific conductance and SAR values. The water chemistry of sites in the Powder River drainage basin generally was the most variable as a result of diverse characteristics of that basin. Plains tributaries in the Powder River drainage basin had the largest range of specific conductance and SAR values, in part due to the many tributaries that receive CBNG-produced waters.

Trends were analyzed using the seasonal Kendall test with flow-adjusted concentrations to determine changes to water quality through time at sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins. Trends were evaluated for water years 2001–10 for 17 sites, which generally were on the main-stem streams and primary tributaries. Trends were evaluated for water years 2005–10 for 26 sites to increase the spatial coverage of sites. Trends were evaluated for water years 1991–2010 for eight sites to include water-quality data collected prior to widespread CBNG development and expand the temporal context of trends.

Consistent patterns were not observed in trend results for water years 2001–10 for flow-adjusted specific conductance and SAR values in the Tongue, Powder, and Belle Fourche River drainage basins. Significant (p-values less than 0.05) upward trends in flow-adjusted specific conductance values were determined for 3 sites, a downward trend was determined for 1 site, and no significant (p-value greater than 0.05) trends were determined for 13 sites. One of the sites with a significant upward trend was the Tongue River at the Wyoming-Montana State line. No trend in flow-adjusted specific conductance values was determined for the Powder River at Moorhead, Mont. Significant upward trends in flow-adjusted SAR values were determined for 2 sites and no significant trends were determined for 15 sites. No trends in flow-adjusted SAR values were determined for the Tongue River at the Wyoming-Montana State line or for the Powder River at Moorhead, Mont. One of the sites with a significant upward trend in flow-adjusted SAR values was the Powder River at Arvada, Wyo.

For water years 2005–10, significant upward trends in flow-adjusted specific conductance values were determined

for 9 sites, downward trends were determined for 4 sites, and no significant trends were determined for 13 sites. A significant upward trend was determined for flow-adjusted specific conductance values for the Tongue River at the Wyoming-Montana State line. No trend in flow-adjusted specific conductance values was determined for the Powder River at Moorhead, Mont. Significant upward trends in flow-adjusted SAR values were determined for 4 sites, downward trends were determined for 5 sites, and no significant trend was determined for 17 sites. No trends in flow-adjusted SAR values were determined for the Tongue River at the Wyoming-Montana State line or for the Powder River at Moorhead, Mont.

Results of the seasonal Kendall test applied to flow-adjusted specific conductance values for water years 1991–2010 indicated no significant trend for eight sites in the Tongue, Powder, and Belle Fourche River drainage basins. No significant trend in flow-adjusted specific conductance was determined for the Tongue River at the Wyoming-Montana State line or the Powder River at Moorhead, Mont. Results of the seasonal Kendall test applied to flow-adjusted SAR values for water years 1991–2010 indicated an upward trend for one site and no significant trend for four sites in the Powder and Belle Fourche River drainage basins. The significant upward trend in flow-adjusted SAR values was determined for the Powder River at Arvada, Wyo., for water years 1991–2010.

Results indicate that CBNG development in the Powder River structural basin may have contributed to some trends, such as the upward trend in flow-adjusted SAR for the Powder River at Arvada, Wyo., for water years 1991–2010. An upward trend in flow-adjusted alkalinity concentrations for water years 2001–10 also was determined for the Powder River at Arvada, Wyo. Trend results are consistent with changes that can occur from the addition of sodium and bicarbonate associated with CBNG-produced waters to the Powder River. Upward trends in constituents at other sites, including the Belle Fourche River, may be the result of declining CBNG development, indicating that CBNG-produced waters may have had a dilution effect on some streams. The factors affecting other trends could not be determined because multiple factors could have been affecting the stream-water quality or because trends were observed at sites upstream from CBNG development that may have affected water-quality trends at sites downstream.

Introduction

Coalbed natural gas (CBNG) has become an increasingly important resource for the United States. Energy production data for 2009 from the U.S. Energy Information Administration (2011) indicate that CBNG represents about 8 percent of the total United States natural gas production. Many of the States with CBNG development are in the western United States. During 2009, Wyoming had the largest CBNG production in the United States with an estimated production of about 535 billion cubic feet (ft^3), which accounted for 28 percent of the total CBNG production (U.S. Energy Information Administration, 2011). Production in other western States included 498 billion ft^3 in Colorado, 432 billion ft^3 in New Mexico, and 12 billion ft^3 in Montana (U.S. Energy Information Administration, 2011).

The Powder River structural basin in northeastern Wyoming and southeastern Montana (fig. 1) is an area of ongoing CBNG development. The structural basin contains large deposits of Tertiary-age coalbeds. Methane, a major component of the natural gas, can form during coalification as a result of biogenic or thermogenic processes (DeBruin, 2010). During early stages of coalification, biogenic methane forms from anaerobic bacteria that produce methane through the consumption of carbon dioxide during anaerobic respiration. As coalification proceeds, temperatures tend to increase as a result of deep burial or increased geothermal gradients and eventually begin to exceed temperatures in which bacteria can survive. When temperatures reach about 120 degrees Celsius (°C), a thermogenic process favors the production of methane over carbon dioxide. Coalbeds of the Powder River structural basin, including those in the Tertiary-age Wasatch and Fort Union Formations, generally are subbituminous in rank and have not undergone substantial thermal alteration (DeBruin, 2010). Deposits generally are thick, laterally continuous, relatively shallow, and contain a large resource of biogenic CBNG. The Powder River structural basin was estimated to contain nearly 14.3 trillion ft^3 (mean estimate) of undiscovered CBNG when it was assessed by the U.S. Geological Survey (USGS) in 2001 (U.S. Geological Survey, 2002).

During CBNG development, water is pumped from wells drilled into coalbeds, thus lowering the hydrostatic pressure in the coalbeds. This allows the natural gas that was confined and stored within the internal surfaces and voids of the coal to flow and be captured for use. The volume of water produced during CBNG development is largest during the early stages of development and decreases as production time proceeds (DeBruin and others, 2004). Although CBNG development in the Powder River structural basin began during the 1980s, it was not widespread until the late 1990s. Information from the Wyoming Oil and Gas Conservation Commission (2011), which has compiled gas and water-production data by drainage, indicates produced waters were being generated in the four major surface drainage basins of the Powder River structural basin by 1999 (fig. 2). The Wyoming Oil and Gas Conservation Commission (2011) database is the most comprehensive public source of information available for CBNG development in Wyoming and was used as a source of information about produced waters for this study. Water-production data by drainage were summed by year and converted to acre-feet (acre-ft), but otherwise were accepted as presented in the Wyoming Oil and Gas Conservation Commission database. The cumulative volume of produced water from 1991 to 2010 for the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins in Wyoming was about 844,000 acre-ft (based on compilation of data retrieved from the Wyoming Oil and Gas Conservation Commission, 2011). In contrast,

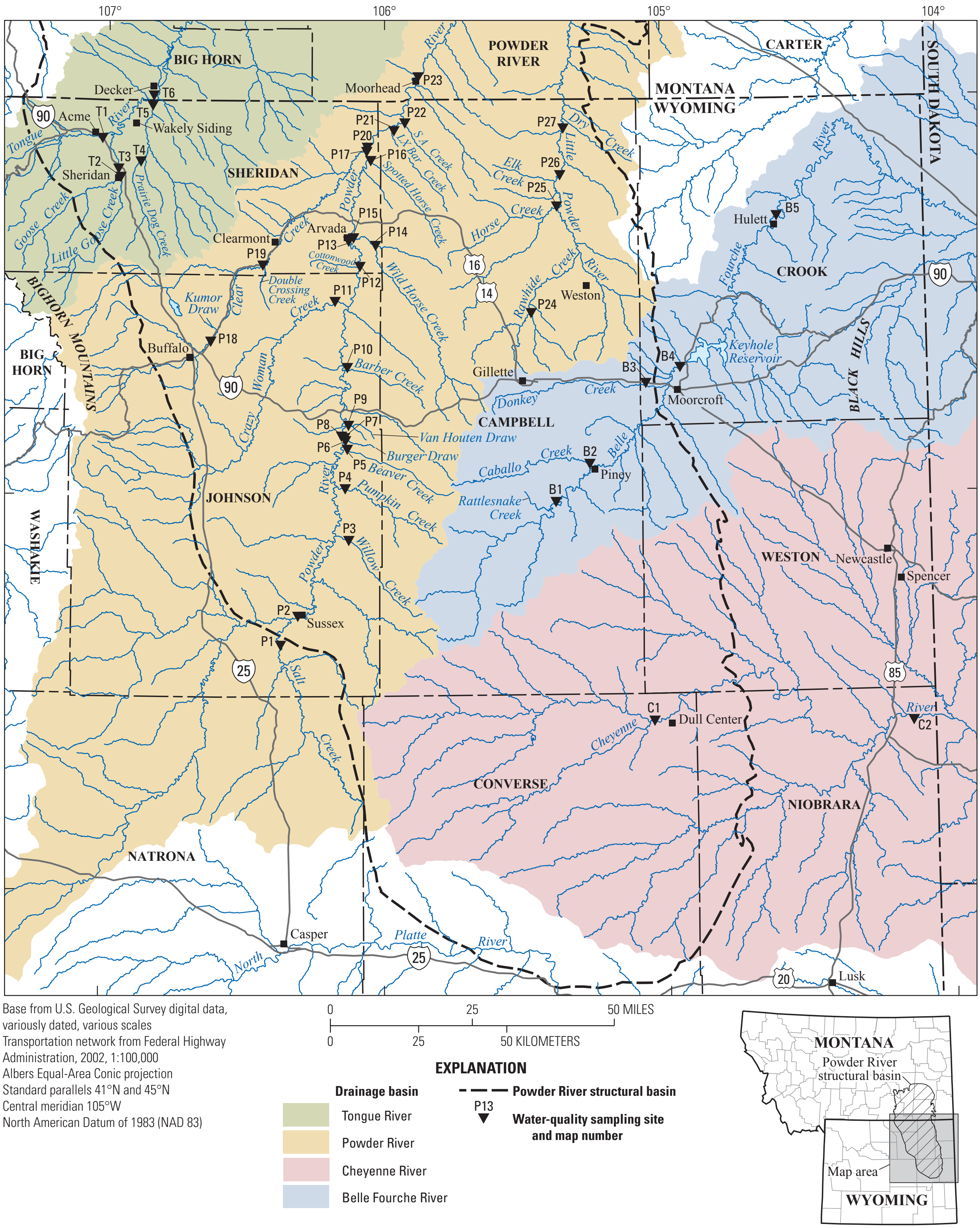

Figure 1. Location of sampling sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

the cumulative volume of produced water in Montana, which is limited to a few operations in the Tongue River drainage basin, was about 19,200 acre-ft through 2008 (Peterson and others, 2010). During the 1990s and through 2001, the largest volumes of waters were produced in the Belle Fourche River drainage basin. As CBNG development continued, the largest volumes of produced waters were in the Powder River drainage basin.

Produced waters associated with CBNG development can be managed with a variety of techniques—including surface impoundments, direct stream discharge, irrigation, and reinjection. In Wyoming, about 84 percent of the water produced during CBNG development in the Powder River structural basin is managed on the land surface, either as discharges into surface impoundments (64 percent), where it is allowed to evaporate or infiltrate into the subsurface, or as discharges into ephemeral or perennial drainages (20 percent), where it may infiltrate or become part of the streamflow (Wyoming Department of Environmental Quality, 2009). Water discharged to streams may be treated (9 percent) or untreated (11 percent) prior to being discharged, depending on the quality of the produced waters and requirements of the discharge permit. The remaining 16 percent of the water produced during CBNG development is used for other beneficial uses such as irrigation (8 percent) and subsurface irrigation (5 percent) or disposed of through deep-well injection (3 percent). In Montana, the primary method of management has been discharges to streams, which accounts for about 61–65 percent of produced water (National Research Council of the National Academies, 2010), and only about 5 percent of the water is disposed of using impoundments. Beneficial uses such as dust control (4–5 percent) and surface or subsurface irrigation (26–30 percent) account for the remainder. Since 2010, the State of Montana has required all discharges of CBNG-produced waters to Montana streams to undergo water treatment (Frost and Mailloux, 2011).

Because most waters produced during CBNG development in the Powder River structural basin are disposed of on the land surface, concerns have been raised regarding the effect CBNG-produced waters may have on water quality in the area. The quantity and quality of the produced waters vary depending on the coalbed source (Rice and others, 2000; Clarey and Stafford, 2008). The major ion composition of coalbed waters varies with depth. Shallow coalbed waters generally are dominated by mixed cations and sulfate compared to deep coalbed waters, which are dominated by sodium and bicarbonate as a result of ion exchange and sulfate reduction (Bartos and Ogle, 2002). Specific conductance, which is a measure of a substance's ability to conduct an electrical current, is a general indicator of overall water quality that directly relates to the amount of dissolved ions (or dissolved-solids concentrations) in solution. Specific conductance values ranged from 665 to 4,180 microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C) for coalbed waters in the eastern Powder River structural basin (Bartos and Ogle, 2002). Sodium adsorption ratio (SAR) values, which indicate the quantity of sodium relative to calcium and magnesium, ranged from 5.0 to 26 for coalbed waters (Bartos and Ogle,

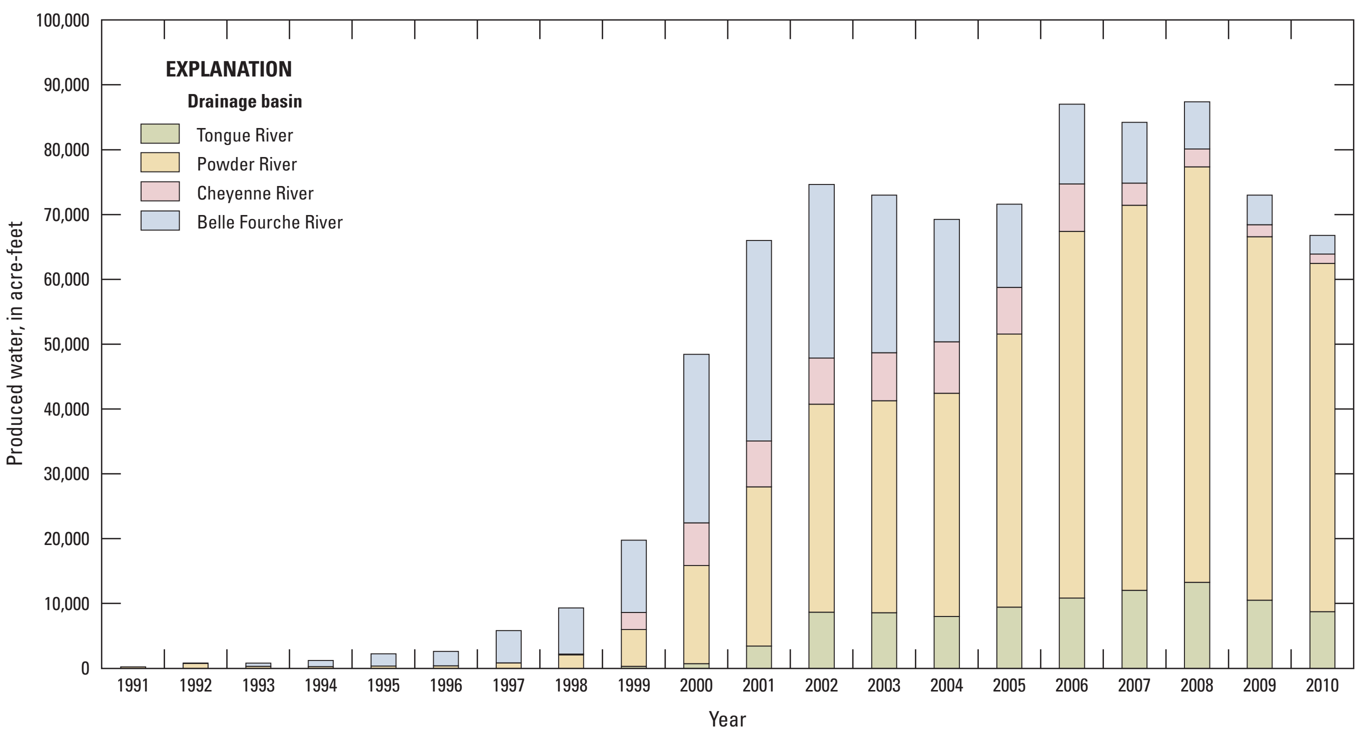

Figure 2. Amount of produced water from coalbed-natural gas wells, Powder River structural basin, Wyoming, calendar years 1991–2010 (Wyoming Oil and Gas Conservation Commission, 2011).

2002). Rice and others (2002) reported SAR values as large as 68.9 in waters produced from coalbeds of the Fort Union Formation. Coalbed waters generally have not been reported to have large trace element concentrations, with the exception of barium, iron, and manganese, which are soluble under reduced conditions (Rice and others, 2002). Elevated ammonia concentrations also were associated with the reduced coalbed waters (Rice and others, 2000). In general, concentrations of dissolved constituents are smallest near coalbed recharge areas and increase as water flows away from recharge areas, because the contact time with aquifer materials increases. Clinker, which is high permeability rock composed of burned coalbeds and baked sediments associated with the coalbeds, enhances groundwater recharge along the eastern margins of the Powder River structural basin (Heffern and Coates, 1999). Groundwater flow in coalbeds in the eastern part of the basin generally is from the southeast to the northwest (Daddow, 1986). As a result of groundwater flow patterns, dissolved-solids concentrations (or specific conductance) and SAR values of coalbed waters in the Powder River structural basin generally increase from east to west and from south to north (Rice and others, 2002; Clarey and Stafford, 2008).

The interaction of CBNG-produced waters with the atmosphere and the semiarid soils of the Powder River structural basin can affect water chemistry in several ways. When produced waters from the coalbeds interact with oxygen in the air and surface environment at outfalls, minerals such as calcite, iron hydroxide, and barite can precipitate, resulting in decreases in concentrations of calcium, iron, and barium from outfalls to surface waters, such as CBNG impoundments (Brinck and others, 2008). Concentrations of other constituents increase from outfalls to CBNG impoundments or stream channels as a result of dissolution and adsorption and desorption processes (Patz and others, 2006; Jackson and Reddy, 2007a; Jackson and Reddy, 2010). For example, arsenic and selenium can be soluble and mobilize in semiarid alkaline environments like the Powder River structural basin; thus, increases in arsenic and selenium concentrations have been observed in stream channels and impoundments. Selenium has been a trace element of concern in surface disposal of CBNG-produced waters because of toxicity issues related to fish and aquatic birds (U.S. Fish and Wildlife Service, 2005). In general, concentrations of arsenic are small in streams and did not exceed any State of Wyoming aquatic-life criteria in the CBNG development area (Clark and Mason, 2007). Concentrations of selenium have exceeded chronic aquatic-life criteria in some samples (Clark and Mason, 2007). The potential increase of bicarbonate concentrations in stream waters from CBNG-produced waters also has been a concern for aquatic life. Elevated concentrations of sodium bicarbonate have been shown to be toxic to some species of larval fish and aquatic invertebrates (Skaar and others, 2006; Farag and others, 2010). Smith and others (2009) found that ammonia in discharged coalbed waters increases the dissolved inorganic nitrogen load to surface waters during certain times of the year.

When produced waters infiltrate into the subsurface beneath CBNG impoundments, salts dissolve in the subsurface, resulting in increased concentrations of dissolved constituents in groundwater (Brinck and others, 2008; Healy and others, 2008). A study of groundwater quality in the Powder River drainage basin determined that CBNG-produced waters were not the primary source of solutes in the groundwater beneath a CBNG impoundment; rather, naturally occurring salts and minerals in the unsaturated zone that were mobilized by infiltrating CBNG-produced waters accounted for most of the solute mass (Healy and others, 2011). Tracking of solutes and water from subsurface drip irrigation that used CBNG-produced waters determined that the evaporation and dissolution of native salts in the vadose zone, not the CBNG-produced waters themselves, were the primary source of the solutes (Engle and others, 2011).

Specific conductance and SAR characteristics of CBNG-produced waters that are discharged to streams have been of particular concern because they have the potential to affect the use of the water for irrigation (Bureau of Land Management, 2003, 2012). Irrigating with waters that have large specific conductance values can cause soil flocculation and aeration of the soil; however, irrigating with waters that have excessive dissolved salts can have a negative effect on plant health. Surface applications of waters that have large SAR values can result in the exchange of sodium ions for calcium and magnesium ions in clay particles of soils, which can induce swelling of clay particles (Hanson and others, 2006). The swelling of clay particles can cause soil dispersion, thereby reducing infiltration rates and increasing erosion. McBeth and others (2003) found that adding CBNG-produced waters to the soils of drainages in the eastern part of the Powder River structural basin caused precipitation of calcium carbonate in soils, which also may decrease infiltration rates. In general, for a given SAR, the potential for reductions to infiltration rates increases as specific conductance values decrease (Hanson and others, 2006). Because the Tongue River is characterized by small specific conductance values, even small increases in SAR have potential to cause reductions in infiltration. A study conducted by Kinsey and Nimick (2011) determined that the Tongue River is particularly vulnerable to SAR increases from CBNG discharges during low-flow conditions.

In response to concerns about effects of CBNG-produced waters on streams, the USGS, in cooperation with the Wyoming Department of Environmental Quality (WDEQ) and the Bureau of Land Management, began monitoring water quality during 2001 in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins (table 1). Characteristics of field constituents, major ions, and trace elements collected during water years 2001–05 were summarized in Clark and Mason (2007). Data requirements for trend analysis, a statistical technique to examine whether data are changing through time, were met at a few of the sampling sites at the time of that report. Trend analysis for the period 1991–2005 indicated no significant trend for specific conductance values at eight sites when values were adjusted for streamflow variability

(Clark and Mason, 2007); trends that were not significant for the Clark and Mason (2007) study were indicated by p-values greater than (>) 0.10. Significant upward trends in SAR values (adjusted for streamflow variability) were determined for two sites on the Powder River; however, one of the sites with the upward trend was upstream from CBNG development; trends that were significant for the Clark and Mason (2007) study were indicated by p-values less than (<) 0.10. Wang and others (2007) analyzed trends for four sites on the Powder River for pre- and post-CBNG development time periods. Those results also indicated that specific conductance values generally were unchanged and that SAR values showed upward trends on the Powder River during the post-CBNG development time period of 1991–2002. An upward trend was not determined for the Powder River upstream from CBNG development in the Wang and others (2007) study; however, the trend analysis periods differed between the two studies. Rank sum tests were conducted for pre- and post-CBNG development time periods by Dawson (2007) in the upper Tongue River drainage basin for water years 1967–2005. Results of those tests generally indicated that CBNG development did not substantially affect specific conductance and SAR in the upper Tongue River drainage basin; however, some increase in SAR values was observed in samples from the Tongue River at the Wyoming-Montana State line. The cause of the SAR increase was not determined, and additional monitoring and analysis through time was recommended. CBNG development and water-quality monitoring has continued in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins since these studies were completed.

Limited analysis has been conducted on stream monitoring data collected since 2005. Water year 2010 marked the completion of 10 years of monitoring at many stream sites. A study was conducted by the USGS, in cooperation with the WDEQ, to summarize stream-water quality for water years 2001–10 and examine trends in specific conductance, SAR, and primary constituents that contribute to specific conductance and SAR for changes through time that may have occurred as a result of CBNG development. An additional study by the USGS, in cooperation with the Montana Department of Environmental Quality, currently (2012) is being conducted to examine long-term changes in water quality of the Tongue River and Powder River (Steven Sando, U.S. Geological Survey, written commun., 2011). The Montana study includes fewer sites in the upper basins in Wyoming and focuses more on water-quality trends in the lower Tongue and Powder River drainage basins of Montana compared to the WDEQ study.

Purpose and Scope

The purpose of this report is to summarize water quality of streams in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins through water year 2010. Specifically, this report presents (1) summaries of selected water-quality characteristics during water years 2001–10 and (2) summaries of trend analyses for selected sites and water-quality characteristics through water year 2010. Trend analyses were initially conducted for the 10-year period of water years 2001–10. Additional trend analyses were conducted for water years 2005–10, to expand the spatial coverage of sites, and for water years 1991–2010, to include water-quality data collected prior to widespread CBNG development and expand the temporal context of trends. Specific conductance and SAR are the focus characteristics of this report. Dissolved calcium, magnesium, and sodium, which are primary contributors to specific conductance and SAR, as well as dissolved alkalinity, chloride, and sulfate, which are other primary contributors to specific conductance, also are described.

The site numbers given in table 1 and on figure 1 are used throughout the report for site identification; the formal USGS site-identification numbers and site names are given in table 1. The site numbers are composed of a letter followed by a number. The letter denotes the major drainage basin in which the site is located: T, Tongue River; P, Powder River; C, Cheyenne River; and B, Belle Fourche River. The number denotes the downstream order of the site or the downstream order in which streamflow from a tributary enters the main stem of the drainage. For example, site P1 is the farthest upstream site in the Powder River drainage basin, site P2 is the second farthest upstream site, and so on. For the sake of brevity, sites are referred to in the text by their abbreviated site names (table 1).

Study Area Description

The study area for this report includes those parts of the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins within or near the southern two-thirds of the Powder River structural basin (fig. 1). Sampling sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins are in Wyoming, with the exception of two sites in Montana that are near the Wyoming-Montana State line (Tongue River at State line, site T6, and Powder River at Moorhead, site P23).

The study area includes parts of the Middle Rocky Mountains and Northwestern Great Plains ecoregions (Omernik, 1987; Zelt and others, 1999). Altitudes in the study area range from about 3,350 feet (ft) above the National Geodetic Vertical Datum of 1929 (NGVD 29) at the streamgage at Moorhead (site P23) to more than 13,100 ft above NGVD 29 in the Bighorn Mountains. The dominant land cover in the mountainous areas, which includes the Bighorn Mountains and Black Hills, is evergreen forest and mixed forest (Homer and others, 2004). The dominant land cover in the plains is shrubland and herbaceous grassland. Agricultural land cover is sparse in the study area. The main areas with pasture/hay or cultivated crops are along the Tongue River and in the Goose Creek, Prairie Dog Creek, and Clear Creek drainage basins. Large coal mines are in the Little Powder River, Cheyenne River, and Belle Fourche River drainage basins near Gillette, Wyo. The largest city in

Table 1. Selected characteristics for sampling sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana.

[Shading indicates main-stem sites. USGS, U.S. Geological Survey; —, not determined. Vertical datum: National Geodetic Vertical Datum of 1929]

Site number (fig. 1)	USGS site identification number	USGS site name	Abbreviated site name	Site group	Drainage area, in square miles	Altitude, in feet above vertical datum
T1	06299980	Tongue River at Monarch, Wyo.	Tongue River at Monarch	Tongue River	478	3,620
T2	06304500	Little Goose Creek at Sheridan, Wyo.	Little Goose Creek	Tongue River	159	3,740
T3	06305500	Goose Creek below Sheridan, Wyo.	Goose Creek	Tongue River	392	3,701
T4	06306200	Prairie Dog Creek at Wakeley Siding, near Sheridan, Wyo.	Prairie Dog Creek near Sheridan	Tongue River	88	3,695
T5	06306250	Prairie Dog Creek near Acme, Wyo.	Prairie Dog Creek near Acme	Tongue River	358	3,450
T6	06306300	Tongue River at State line, near Decker, Mont.	Tongue River at State line	Tongue River	1,453	3,429
P1	06313400	Salt Creek near Sussex, Wyo.	Salt Creek	Powder River plains tributary	769	4,480
P2	06313500	Powder River at Sussex, Wyo.	Powder River at Sussex	Powder River main stem	3,090	4,362
P3	06313540	Willow Creek near mouth, near Sussex, Wyo.	Willow Creek	Powder River plains tributary	—	4,295
P4	06313560	Pumpkin Creek near mouth, near Sussex, Wyo.	Pumpkin Creek	Powder River plains tributary	—	4,180
P5	06313585	Beaver Creek at mouth, near Sussex, Wyo.	Beaver Creek	Powder River plains tributary	—	4,020
P6	06313590	Powder River above Burger Draw, near Buffalo, Wyo.	Powder River above Burger Draw	Powder River main stem	4,290	4,000
P7	06313604	Burger Draw at mouth, near Buffalo, Wyo.	Burger Draw	Powder River plains tributary	—	3,990
P8	06313605	Powder River below Burger Draw, near Buffalo, Wyo.	Powder River below Burger Draw	Powder River main stem	—	3,990
P9	06313633	Van Houten Draw at mouth, near Buffalo, Wyo.	Van Houten Draw	Powder River plains tributary	—	3,970
P10	06313750	Barber Creek at mouth, near Buffalo, Wyo.	Barber Creek	Powder River plains tributary	—	3,875
P11	06316400	Crazy Woman Creek at Upper Station, near Arvada, Wyo.	Crazy Woman Creek	Powder River mountain tributary	937	3,780
P12	06316900	Cottonwood Creek at mouth, near Arvada, Wyo.	Cottonwood Creek	Powder River plains tributary	—	3,700
P13	06317000	Powder River at Arvada, Wyo.	Powder River at Arvada	Powder River main stem	6,050	3,620
P14	06317020	Wild Horse Creek near Arvada, Wyo.	Wild Horse Creek near Arvada	Powder River plains tributary	250	3,730
P15	06317030	Wild Horse Creek at mouth, at Arvada, Wyo.	Wild Horse Creek at mouth	Powder River plains tributary	—	3,630
P16	06317095	Spotted Horse Creek at mouth, near Arvada, Wyo.	Spotted Horse Creek	Powder River plains tributary	—	3,530

Table 1. Selected characteristics for sampling sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana.—Continued

[Shading indicates main-stem sites. USGS, U.S. Geological Survey; —, not determined. Vertical datum: National Geodetic Vertical Datum of 1929]

Site number (fig. 1)	USGS site identification number	USGS site name	Abbreviated site name	Site group	Drainage area, in square miles	Altitude, in feet above vertical datum
P17	06317100	Powder River above Clear Creek, near Arvada, Wyo.	Powder River above Clear Creek	Powder River main stem	—	3,495
P18	06320210	Clear Creek above Kumor Draw, near Buffalo, Wyo.	Clear Creek near Buffalo	Powder River mountain tributary	—	4,410
P19	06323550	Clear Creek above Double Crossing Creek, near Clearmont, Wyo.	Clear Creek near Clearmont	Powder River mountain tributary	—	3,970
P20	06324000	Clear Creek near Arvada, Wyo.	Clear Creek near Arvada	Powder River mountain tributary	1,110	3,507
P21	06324200	LX Bar Creek at mouth, near Moorhead, Mont.	LX Bar Creek	Powder River plains tributary	—	3,480
P22	06324300	SA Creek at mouth, near Moorhead, Mont.	SA Creek	Powder River plains tributary	—	3,440
P23	06324500	Powder River at Moorhead, Mont.	Powder River at Moorhead	Powder River main stem	8,086	3,351
P24	06324870	Rawhide Creek at mouth, near Gillette, Wyo.	Rawhide Creek	Little Powder River	—	4,030
P25	06324940	Horse Creek at mouth, near Weston, Wyo.	Horse Creek	Little Powder River	—	3,595
P26	06324950	Little Powder River below Elk Creek, near Weston, Wyo.	Little Powder River below Elk Creek	Little Powder River	—	3,500
P27	06324970	Little Powder River above Dry Creek, near Weston, Wyo.	Little Powder River above Dry Creek	Little Powder River	1,237	3,410
C1	06365900	Cheyenne River near Dull Center, Wyo.	Cheyenne River near Dull Center	Cheyenne River	1,527	4,310
C2	06386500	Cheyenne River near Spencer, Wyo.	Cheyenne River near Spencer	Cheyenne River	5,350	3,626
B1	06425720	Belle Fourche River below Rattlesnake Creek, near Piney, Wyo.	Belle Fourche River near Piney	Belle Fourche River	495	4,535
B2	06425900	Caballo Creek at mouth, near Piney, Wyo.	Caballo Creek	Belle Fourche River	260	—
B3	06426400	Donkey Creek near Moorcroft, Wyo.	Donkey Creek	Belle Fourche River	246	—
B4	06426500	Belle Fourche River below Moorcroft, Wyo.	Belle Fourche River below Moorcroft	Belle Fourche River	1,690	4,110
B5	06428050	Belle Fourche River below Hulett, Wyo.	Belle Fourche River below Hulett	Belle Fourche River	—	—

the study area is Gillette, Wyo., with a population of about 29,100; followed by Sheridan, Wyo., with a population of about 17,400 (U.S. Census Bureau, 2011). Rural populations are dispersed throughout the study area.

The Powder River structural basin is an asymmetric syncline with a northwest-to-southeast trending axis along the western margin (Rice and others, 2002). The structural basin is flanked by uplifts, including the Bighorn Mountains to the west and the Black Hills on the east. The CBNG development is associated with coalbeds in both the Wasatch and the Fort Union Formations. In Wyoming, the central part of the structural basin is dominated by terrestrial sedimentary rocks of the Wasatch Formation from the Eocene epoch. The Wasatch Formation contains alluvial sediments consisting primarily of mudstone and sandstone, with minor amounts of conglomerate, carbonaceous shale, and coal. Terrestrial sedimentary rocks of the Fort Union Formation from the Paleocene epoch crop out along the margins of the sedimentary basin in Wyoming. In Montana, the Wasatch Formation largely has been eroded, and the Fort Union Formation is the near-surface bedrock throughout the lower part of the basin. Sandy soils are associated with the Wasatch Formation in Wyoming in contrast to clayey soils that are associated with the Fort Union Formation in Montana. This difference in geology has increased concerns about the effects of CBNG-produced waters in Montana, because the high clay content of soils makes them susceptible to problems associated with sodium ion exchange in clay particles (Wheaton and Donato, 2004).

The geologic characteristics of the four major drainage basins are diverse. Detailed geology for the State of Wyoming is presented by Love and Christiansen (1985). Generalized maps for the Tongue and Powder River drainage basins (Zelt and others, 1999) and the Powder River structural basin (Rice and others, 2002) describe the geology for the Montana part of the study area. The bedrock of the western edge of the Tongue and Powder River drainage basins includes metamorphic gneiss and plutonic igneous rocks from the Precambrian era, and sedimentary rocks of marine origin from the Paleozoic and Mesozoic eras compose the Bighorn Mountains (Love and Christiansen, 1985). The bedrock of the eastern part of the Tongue River drainage basin and a large part of the central Powder River drainage basin is underlain by the Wasatch Formation. The Fort Union Formation is prevalent in the lower drainage basins of the Tongue River, Clear Creek, the Powder River, and the Little Powder River. The upper parts of the Cheyenne and Belle Fourche River drainage basins are underlain by the Wasatch Formation, with Fort Union Formation in the lower reaches of those drainage basins that are still within the structural basin. Farther downstream and outside the boundary of the structural basin (fig. 1), bedrock geology includes sedimentary rocks of terrestrial and marine origin from the Cretaceous period. The lower part of the Belle Fourche River drainage basin (southeast of site B5) is underlain by rocks from the Paleozoic and Mesozoic era that compose part of the Black Hills.

The Tongue, Powder, Cheyenne, and Belle Fourche Rivers are part of the Missouri River drainage basin. The Tongue and Powder Rivers generally flow northward toward the Missouri River, whereas the Cheyenne and Belle Fourche Rivers generally flow eastward toward the Missouri River. The Tongue River drainage basin is the smallest of the four drainage basins, with a drainage area of 1,453 square miles (mi^2) at the Tongue River at State line (site T6). The Powder River drainage basin is the largest of the four drainage basins, with a drainage area of 8,086 mi^2 for the Powder River at Moorhead (site P23). The hydrologic characteristics vary among the drainage basins. Mean annual precipitation, which accounts for much of the difference, ranges from about 10 to 15 inches (in.) in the plains to nearly 40 in. at high altitudes in the Bighorn Mountains (PRISM Climate Group, 2006). The hydrograph for the Tongue River typically is dominated by a single peak of moderate duration from snowmelt in the Bighorn Mountains during late spring through early summer and generally has relatively low variability in streamflow throughout the remainder of the year (Clark and Mason, 2007). In contrast, streamflows of the Powder, Cheyenne, and Belle Fourche Rivers are more variable. The Powder River generally has an early spring peak in response to lowland snowmelt, followed by a higher peak from snowmelt in the Bighorn Mountains. Short duration peaks occur in response to rainfall, and periods of low flow or no flow are common in late summer. The Cheyenne and Belle Fourche Rivers generally have an increase in streamflow during spring in response to lowland snowmelt, intermittent peaks in response to rainstorms, and extended periods of low flow. For the Cheyenne River, extended periods of no flow are common.

The general stream-water chemistry of the Tongue, Powder, Cheyenne, and Belle Fourche Rivers varies because of differences in geologic and hydrologic characteristics. For the Tongue River at the State line (site T6), which integrates the upper basin, water type is magnesium-calcium bicarbonate. The Tongue River has the smallest specific conductance values, sodium adsorption ratios, and major ion concentrations, because it has the largest percentage of area underlain by older and more resistant rocks of the Bighorn Mountains (Clark and Mason, 2007) of the streams included in the study. In general, high annual precipitation and steep gradients for much of the Tongue River drainage basin produce relatively fast stream velocities, which result in a short contact time between stream waters and basin materials. The Powder River drainage basin has mixed characteristics. Water type is a sodium-sulfate, and dissolved constituents are concentrated in stream water in the upper and eastern part of the drainage basin that originates in the plains, including the Little Powder River, which drains into the Powder River downstream from Moorhead, Mont. Drainage basins in the plains have low precipitation, soluble geologic materials, and relatively low gradients that produce slow stream velocities and long contact times. Western tributaries of Crazy Woman Creek and Clear Creek that drain from the Bighorn Mountains have a dilution effect on dissolved constituents of the Powder River, and the water type of the Powder River in the lower basin changes to a mixed sodium-magnesium-calcium-sulfate type (Clark and Mason, 2007). Water type of the Cheyenne River, which lies entirely in the plains, is a sodium-sulfate type, and dissolved constituents are concentrated. The Belle Fourche River is characterized as a sodium-sulfate type, and dissolved constituents are concentrated in the upper basin. Cations are mixed, and dilution occurs in the lower Belle Fourche River drainage basin as a result of changes in geology and precipitation associated with the Black Hills.

Data Collection and Analysis

Water-quality data for 40 sampling sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins were compiled for this report (table 2). Sampling sites and water-quality characteristics monitored have varied slightly through the monitoring period. When monitoring for effects of CBNG development began in water year 2001, sites generally were established on the main-stem streams and their primary tributaries. Additional sites were established in the Powder River drainage basin during summer 2004, commonly on small tributaries that receive discharges of CBNG-produced waters. Water-quality sampling did not begin at some of these sites until after water year 2004 because some streams were not flowing during early visits. Sampling frequency generally was on a monthly basis; however, sampling frequency was substantially less at sites that did not have perennial flow. Sampling frequency was increased at a few sites, including the Tongue River at State line (site T6) and the Powder River at Moorhead (site P23). A few samples that were collected as part of other sampling programs, such as the USGS National Water-Quality Assessment Program and the Tongue River monitoring network (Nimick, 2004) were included in this report to supplement data at a few sites. Data collection methods and chemical analysis methods for those programs were similar to those used for this study. Sampling was discontinued at a few sites where monitoring needs changed or where monitoring could be more efficiently conducted at a different site. For example, monitoring in the Cheyenne River drainage basin initially was conducted at sampling sites on some small tributaries. A site was eventually established on the Cheyenne River near Dull Center (site C1) to integrate water quality in the upper part of the drainage basin. Data summaries for discontinued sites were not compiled for this report, but may be found in Clark and Mason (2007).

Water-quality characteristics analyzed for this report varied by site because of differences in analytical services requests. For all sites, field measurements of streamflow, pH, and specific conductance are reported. The major ion concentrations and properties of calcium, magnesium, sodium, SAR, alkalinity, chloride, sulfate, and dissolved solids are summarized for sites where major ion analyses were requested (table 2). For other sites, major cations (calcium, magnesium, and sodium), SAR, and dissolved solids are summarized where abbreviated analytical services were requested. Additional constituents, such as potassium, fluoride, nutrients, or trace elements, were analyzed in some samples, but results are not included in this report because these constituents do not contribute substantially to specific conductance compared to other major ions. A description of all water-quality characteristics is beyond the scope of this report; however, all water-quality data are electronically stored in the USGS's National Water Information System (NWIS) and are available to the public from NWISWeb (U.S. Geological Survey, 2011a) at *http://waterdata.usgs.gov/nwis/*.

Field and Analytical Methods

Field measurements were made and samples were collected in accordance with methods established by the USGS (U.S. Geological Survey, variously dated). Instantaneous streamflow typically was measured using a current meter. For sampling sites where streamgages are operated, some instantaneous streamflow measurements were obtained by recording gage heights and determining the streamflow using the most current streamflow rating curve. Specific conductance and pH generally were measured in-stream using a multiparameter water-quality probe. For large streams during normal streamflow conditions, samples to be analyzed for major ion concentrations generally were collected using depth-integrated samplers and applying the equal-width-increment method described by Ward and Harr (1990). When samples were collected from large streams during extreme conditions, such as hazardous ice conditions and very low flows of shallow depth, traditional depth- and width-integrating techniques may not have been possible and multiple vertical or grab-sampling techniques were used. For small streams, streamflow conditions generally did not meet depth-integrated sampler requirements; therefore, grab-sampling techniques were used.

Samples were processed onsite using standard methods and equipment described by the U.S. Geological Survey (variously dated). Subsamples analyzed for major ion concentrations were filtered in the field using a disposable filter with a pore size of 0.45 micrometer, and concentrations are reported as dissolved. Subsamples analyzed for major cation concentrations were acidified in the field with nitric acid. Samples were sent to the USGS National Water Quality Laboratory in Lakewood, Colo., for analysis using standard USGS methods (Fishman and Friedman, 1989; Fishman, 1993). Alkalinity values were determined in the laboratory using a fixed-end titration method and are reported as the equivalent amount of calcium carbonate. Alkalinity values represent the combined bicarbonate and carbonate concentrations, with bicarbonate being the primary contributor. Dissolved-solids concentrations were determined analytically for an aliquot of filtered water using a method for residue on evaporation at 180°C. The SAR values were calculated on the basis of laboratory results for

Table 2. Periods for which water-quality data were analyzed for sampling sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana.

[Shading indicates main-stem sites. USGS, U.S. Geological Survey; F, field measurements of streamflow, pH, and specific conductance; M, analyses of major ions, sodium-adsorption ratio, and dissolved solids; C, analyses of cations, sodium adsoprtion ratio, and dissolved solids]

Site number (fig. 1)	USGS site identification number	Water-quality characteristics data summary period (water years)	Water-quality characteristics included in this report	Water year 2001–10 trends	Water year 2005–10 trends	Water year 1991–2010 trends
T1	06299980	2004–10	F, M	No	Yes	No
T2	06304500	2001–10	F, M[1]	Yes	No	No
T3	06305500	2001–10	F, M[1]	Yes	No	Yes
T4	06306200	2004–10	F, M	No	Yes	No
T5	06306250	2001–10	F, M	Yes	Yes	No
T6	06306300	2001–10	F, M	Yes	Yes	Yes
P1	06313400	2001–10	F, M	Yes	Yes	Yes
P2	06313500	2001–10	F, M	Yes	Yes	Yes
P3	06313540	2008–10	F, C[2]	No	No	No
P4	06313560	2005–10	F, C[2]	No	Yes	No
P5	06313585	2004–10	F, C[2]	No	Yes	No
P6	06313590	2003–10	F, M	No	Yes	No
P7	06313604	2004–10	F, C[2]	No	Yes	No
P8	06313605	2001–10	F, M	Yes	Yes	No
P9	06313633	2004–10	F, C[2]	No	No	No
P10	06313750	2005–10	F, C[2]	No	No	No
P11	06316400	2001–10	F, M	Yes	Yes	No
P12	06316900	2004–10	F, C[2]	No	No	No
P13	06317000	2001–10	F, M	Yes	Yes	Yes
P14	06317020	2001–10	F, M	No	No	No
P15	06317030	2004–10	F, C[2]	No	Yes	No
P16	06317095	2004–10	F, C[2]	No	No	No
P17	06317100	2004–10	F, C	No	Yes	No
P18	06320210	2001–10	F, M[1]	Yes	Yes	No
P19	06323550	2004–10	F, C[2]	No	Yes	No
P20	06324000	2001–10	F, M	Yes	Yes	No
P21	06324200	2005–10	F, C[2]	No	No	No
P22	06324300	2004–10	F, C[2]	No	Yes	No
P23	06324500	2001–10	F, M	Yes	Yes	Yes
P24	06324870	2007–10	F, C	No	No	No
P25	06324940	2005–10	F, C	No	No	No
P26	06324950	2004–10	F, C	No	Yes	No
P27	06324970	2001–10	F, M	Yes	Yes	Yes
C1	06365900	2004–10	F, M	No	No	No
C2	06386500	2005–10	F, M	No	Yes	No
B1	06425720	2001–10	F, M	Yes	Yes	No
B2	06425900	2001–10	F, M	No	No	No
B3	06426400	2001–10	F, M	Yes	Yes	No
B4	06426500	2001–10	F, M	Yes	Yes	Yes
B5	06428050	2001–10	F, M[1]	Yes	No	No

[1]Major ions added in water year 2002.

[2]Anions included in water year 2010.

discrete samples. The SAR values were calculated using the analytical results for dissolved calcium, dissolved magnesium, and dissolved sodium obtained for a discrete sample using the following equation:

$$SAR = \frac{(Na^{+})}{\sqrt{1/2\left[\left(Ca^{2+}\right)+\left(Mg^{2+}\right)\right]}} \qquad (1)$$

where Na^{+}, Ca^{2+}, and Mg^{2+} represent concentrations expressed in milliequivalents per liter for sodium, calcium, and magnesium, respectively.

Data Analysis Methods

Data for this report were analyzed using several statistical techniques. Descriptive summary statistics (minimum value, 25th percentile, median (50th percentile), 75th percentile, and maximum value) were compiled by site for selected water-quality characteristics of streamflow, pH, specific conductance, dissolved solids, instantaneous dissolved-solids loads, dissolved calcium, dissolved magnesium, SAR, dissolved sodium, alkalinity, dissolved chloride, and dissolved sulfate. Boxplots are used to graphically summarize specific conductance and SAR data by site group. Sites were grouped together for boxplots because of the large number of monitoring sites. Sites in the Tongue, Cheyenne, and Belle Fourche River drainage basins were grouped together by their major drainage basin because water-quality characteristics generally were similar in their range of values. Because of the wide range of water-quality characteristics and large number of sites in the Powder River drainage basin, sites were grouped as Powder River plains tributaries, Powder River mountain tributaries, Powder River main stem, and Little Powder River (table 1). For the boxplots, the lower and upper edges of the box indicate the 25th and 75th percentiles, respectively, and the median is a line within the box. The whiskers extend to the smallest value within 1.5 times the interquartile range below the 25th percentile and the largest value within 1.5 times the interquartile range above the 75th percentile. Values outside this range are shown as individual points. Scatter plots of specific conductance and SAR for selected main-stem sites are shown with a locally weighted, scatterplot smoothing curve, which is a nonparametric technique used to reduce apparent scatter in the overall pattern of data (TIBCO Software, Inc., 2008). The curve does not necessarily correspond with a significant statistical trend through time when seasonal variation is taken into account.

Trend analysis techniques, which are used to determine if data have statistically changed through time, have been developed by the USGS and account for the inherent variability of water-quality data. Trend analysis techniques vary in their statistical strength and data requirements. For example, the water-quality model, QWTREND, is a robust parametric technique that evaluates data for nonmonotonic trends (trends that have one or more changes in slope during the period being evaluated); however, it requires a daily mean streamflow record and a water-quality record of at least 15 years (Vecchia, 2005). The EStimate TREND (ESTREND) statistical trend procedure uses the seasonal Kendall test, which is a nonparametric test to determine monotonic (single direction through the entire specified trend period) trends in water-quality data (Schertz and others, 1991). Data requirements for the ESTREND procedure are less restrictive than for the QWTREND model in that only instantaneous measurements of streamflow are required to be associated with water-quality data and recommended minimum data requirements include a 5-year period of water-quality record and at least 50 observations. The ESTREND procedure is less statistically robust than QWTREND; however, less rigid data requirements allows ESTREND to be applied to more sites. The ESTREND procedure was selected as the statistical procedure for this study because of the relatively short sampling period since 2001 when the monitoring for CBNG development began and because daily mean streamflow records do not exist for many sites.

The ESTREND procedure is contained as a program within the USGS library for S-PLUS for Windows, Release 2.1 (Slack and others, 2003). The program divides the selected time period into a beginning-ending period that is about 40 percent of the analysis period and a middle period that is about 60 percent of the analysis period. Seasonal definitions can range from 2 seasons per year to as many as 12 seasons per year. Minimum criteria were established for the percentage of possible comparisons within a season adequate to define a trend (50 percent) and the percentage of seasons that meet the criterion for seasonal definition (80 percent). The program computes a separate Mann-Kendall test for each of the defined seasons. By restricting the possible comparisons to water-quality values that are collected during the same season, the effect of seasonal variation is reduced (Hirsch and others, 1982; Helsel and Hirsch, 1992). The null hypothesis for the Mann-Kendall test is that the probability distribution of the variable has not changed over time (Schertz and others, 1991). The test makes all possible pair-wise comparisons of time-ordered water-quality values within the season and assigns a large value that is later in time a “plus” and a small value that is later in time a “minus.” The test statistic is computed as the difference between the total number of pluses and the total number of minuses; therefore, the more the test statistic deviates from zero, the more likely a trend exists. The ESTREND program computes the seasonal Kendall test by combining results of the Mann-Kendall tests. The p-value (p) is obtained from a standard normal distribution of the overall test statistic.

The ESTREND program was used to compute a seasonal Kendall test on unadjusted concentrations and flow-adjusted concentrations. Trend results for unadjusted concentrations may be useful to water managers because unadjusted concentrations commonly are used for making water-quality assessments, such as comparisons to water-quality criteria. Otherwise, the usefulness of trend results for unadjusted concentrations is limited because concentrations of water-quality constituents commonly are correlated with streamflow, which may change in response to seasonal and annual climatic variability. An apparent trend in unadjusted concentrations may simply be an artifact of streamflow conditions at the time of sampling. Flow-adjusting techniques increase the likelihood that a resulting trend is real and not an artifact of streamflow variability. Parametric models that use linear regression and nonparametric models that use locally weighted least-squares regression exist within the ESTREND program for filtering out streamflow-related variability before analyzing for constituent trends.

The strength of relations between streamflow and water-quality data characteristics was variable among sites, particularly in some of the small tributary drainages. As a result, a nonparametric local regression model with base-10 logarithm transformation of streamflow was selected in the ESTREND program for flow adjustment. The residuals (estimated values minus measured values), which are called flow-adjusted concentrations, are then tested using the seasonal Kendall trend test (Schertz and others, 1991). Results from the seasonal Kendall test include tau, a rank-based correlation coefficient, which measures the strength of the monotonic relation between a water-quality variable and time, with values ranging from -1 to +1. Tau values greater than zero indicate the variable has a tendency to increase over time, and negative tau values indicate a tendency to decrease. As deviations of tau from zero increase, the strength of the correlation increases. The upward or downward direction of the trend is presented if the trend was significant, which was determined using a 95-percent confidence level ($p<0.05$). Slopes of trends also were calculated. For unadjusted trend tests, the slopes of trends reflect changes per year in original measurement units; for flow-adjusted trend tests, the slopes reflect relative changes in units after adjustment for streamflow variability.

Sample size for the trend test is determined by both the length of the trend period and the seasonal period. Efforts were made to maximize the number of sites meeting the requirement of 50 observations by adjusting trend periods and seasonal definitions. Trend analysis initially was scoped for the 10-year period of water years 2001–10 to coincide with the data collection period for CBNG monitoring. Bimonthly seasonal periods were defined for the seasonal Kendall test as October through November, December through January, February through March, April through May, June through July, and August through September. Data from 17 of the 40 sites (table 2) met the trend test requirements for the period of water years 2001–10. In order to increase the spatial coverage of sites, trends were analyzed for the 6-year period of water years 2005–10 to include those sites added to the monitoring program during 2004. Data from 26 of the 40 sites (table 2) met the trend test requirements for the period of water years 2005–10. Seasonal periods were defined for the seasonal Kendall test to correspond with the monthly sampling frequency. Data were not sufficient to meet trend test requirements for either the 2001–10 or 2005–10 trend periods at 11 sites that commonly were dry (table 2). To place the trends in a longer time frame and include data collected prior to widespread CBNG development, a 20-year trend period of water years 1991–2010 was analyzed for eight sites that had historical data (table 2). Seasonal periods were defined as October through December, January through March, April through June, and July through September, to coincide with historical quarterly sampling frequencies.

Quality Assurance

Quality assurance can be assessed using data-quality checks and quality-control samples. Data-quality checks routinely are conducted on laboratory results. Field and laboratory values are checked for compatibility; ion balances are calculated and percent differences are checked; and data ratios (such as dissolved solids to specific conductance) are checked against typical data ranges. For a few samples, constituent values were rejected during this review period and were not included in this report. Where a field specific conductance value was missing or rejected, a laboratory specific conductance value was used to complete the time-series record for this report. The median ion balance difference was 1.4 percent for 2,878 samples where an ion balance could be calculated. Less than 2 percent of samples had ion balance differences greater than the quality-check range of plus or minus 5.5 percent. Samples with ion balances outside this range were further evaluated. Ratios of dissolved-solids concentration to specific conductance typically are from 0.55 to 0.75 for natural waters, with the full range expected from 0.54 to 0.96 (Hem, 1985). About 98 percent of samples were within this range. A few samples that had differences or ratios outside these ranges were samples with large dissolved-solids concentrations. Samples with large dissolved-solids concentrations typically had large sulfate concentrations that can cause large ratios of dissolved-solids concentration to specific conductance (Hem, 1985). Also, samples with large dissolved-solids concentrations may require laboratory dilution, which can result in some additional analytical variability.

Quality-control samples, including equipment blank samples and replicate samples, are collected to help estimate the bias and variability resulting from sample collection, processing, and chemical analysis. Equipment blank samples typically are collected and processed using inorganic-grade deionized water to demonstrate that field methods and laboratory analysis have not introduced contamination to the sample, thus providing a measure of bias (Mueller and others, 1997). Replicate samples are prepared by splitting the routine environmental sample into duplicate subsamples, which are considered to be identical in composition. Laboratory analyses of replicate samples provide a measure of variability (or reproducibility). Measurement variability for replicate samples was determined for constituents by calculating a relative percent difference (RPD) between concentrations in the paired replicate samples using the following equation:

$$RPD = 100 \times \frac{|\,routine\ environment\ sample\ concentration - replicate\ sample\ concentration\,|}{\left[\left(routine\ environment\ sample\ concentration + replicate\ sample\ concentration\right)/2\right]} \quad (2)$$

Analysis of quality-control samples for water years 2001–05 (Clark and Mason, 2007) indicated contamination was not causing widespread bias and that laboratory reproducibility was good; therefore, an abbreviated summary of quality-control data collected during water years 2001–10 is provided in this report. The maximum concentration for major cation constituents of dissolved calcium, magnesium, and sodium was 0.2 mg/L or less in 165 equipment blank samples (table 3). The maximum concentration for major anion constituents of dissolved chloride and sulfate was 0.4 mg/L or less in 117 equipment blank samples. Alkalinity (as calcium carbonate) concentrations were less than the laboratory reporting level of 8 mg/L for 108 equipment blank samples. The median RPD was 1.6 percent or less for 173 samples for replicate measurements of dissolved calcium, magnesium, and sodium. The median RPD was 0.53 percent or less for 123 samples for replicate measurements of alkalinity, dissolved chloride, and dissolved sulfate. Results for data-quality checks and quality-control samples for water years 2001–10 continue to support findings that field and laboratory procedures are not introducing bias and variability that affect the interpretation of environmental samples.

Table 3. Quality-control summary for equipment blank samples and replicate samples collected at sampling sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

[<, less than]

Constituent	Number of equipment blank samples	Maximum concentration in equipment blank sample, in milligrams per liter	Number of replicate sample pairs	Median relative percent difference
Calcium, dissolved	165	0.08	173	1.6
Magnesium, dissolved	165	0.04	173	1.4
Sodium, dissolved	165	0.2	173	1.6
Alkalinity, as calcium carbonate	108	<8.0	123	0.29
Chloride, dissolved	117	0.4	123	0.53
Sulfate, dissolved	117	0.4	123	0.28

Water-Quality Characteristics

Water-quality characteristics at 40 sampling sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins were summarized for water years 2001–10 (appendix 1). Statistical summaries include properties of streamflow, pH, specific conductance, and SAR and concentrations of selected constituents including dissolved solids, major ions, and alkalinity (appendix 1). The statistical summaries represent the range of conditions for a given site for the period of data collection (table 2). General patterns in the data for streamflow, specific conductance, and SAR are described in this section.

Streamflow

Hydrologic conditions are an important factor in water-quality variability and are described to provide perspective on differences in water quality that can occur annually. Annual runoff for selected main-stem sites on the Tongue, Powder, Cheyenne, and Belle Fourche Rivers varied substantially during water years 2001–10 (fig. 3). For comparison, average annual runoff for period of record (U.S. Geological Survey, 2011b) is 316,500 acre-ft (water years 1961–2010) for the Tongue River at State line (site T6); 319,100 acre-ft (water years 1930–2010, excluding 1973 and 1974) for the Powder River at Moorhead (site P23); 35,080 acre-ft (water years 1949–2010, excluding 1975–2003) for the Cheyenne River near Spencer (site C2); and 16,380 acre-ft (water years 1944–2010, excluding 1971–75, 1984–85, and 1988–90) for the Belle Fourche River below Moorcroft (site B4). In general, annual runoff was less than average as a result of less than average precipitation during water years 2001–06 on the Tongue, Powder, and Belle Fourche Rivers (Natural Resources Conservation Service, 2011). Annual runoff was near or above average for sites on those rivers during water years 2007–10. Annual runoff for the Cheyenne River was less than average during water years 2004–10.

Variability in streamflows primarily results from variability in the distribution of precipitation in these drainage basins. The magnitude of streamflow during a sampling event can affect stream-water quality in several ways. Large magnitude streamflows tend to have small concentrations of dissolved constituents as a result of dilution but commonly have large concentrations of suspended constituents. Streamflow at a site can vary by orders of magnitude; thus, it is important to collect water-quality samples throughout the year to adequately characterize extremes, seasonal differences, and average conditions.

Streamflow measured during sampling events for the Tongue River at State line (site T6) ranged from 10 cubic feet per second (ft^3/s) to 5,430 ft^3/s during water years 2001–10 (appendix 1) and generally covered the hydrograph for continuous streamflow data collected at the USGS streamgage at this site (fig. 4). Streamflow measured during sampling events for the Powder River at Moorhead (site P23) ranged from 0.57 to 5,220 ft^3/s and generally covered the hydrograph for the USGS streamgage at this site (fig. 4). Because streamflow peaks on the Tongue and Powder Rivers generally are associated with snowmelt runoff and are sustained for a period of time, sampling events are able to capture nearly all of the full range of conditions. Streamflow measured during sampling events ranged from 0.01 to 121 ft^3/s for the Cheyenne River near Spencer (site C2) during water years 2005–10 and from 0.02 to 599 ft^3/s for the Belle Fourche River below Moorcroft (site B4) during water years 2001–10. Peak streamflow events on the Cheyenne and Belle Fourche Rivers are difficult to capture during sampling events because they occur rapidly in response to rainfall.

Streamflow varied substantially for tributaries in the drainage basins during water years 2001–10 (appendix 1). In the Tongue River drainage basin, Goose Creek has a large part of its drainage area in the Bighorn Mountains and contributes substantial flow to the Tongue River, particularly during snowmelt runoff. Instantaneous streamflow during sampling events for Goose Creek (site T3) ranged from 3.8 to 1,790 ft^3/s. In contrast, streamflow for Prairie Dog Creek near Acme (site T5), which has most of its drainage area in the plains, ranged from 0.21 to 127 ft^3/s. Streamflows in Prairie Dog Creek are augmented by transbasin diversions for irrigation in the summer and are larger than would naturally occur (Sheridan County Conservation District, 2011). In the Powder River drainage basin, the range of instantaneous streamflow measured for plains tributaries in the eastern part of the basin generally is small; for example, streamflow ranged from 0.06 to 1.6 ft^3/s for Willow Creek (site P3); from 0.04 to 2.8 ft^3/s for Burger Draw (site P7); and from 0.03 to 3.6 ft^3/s for Van Houten Draw (site P9). Streamflow in these small drainages responds very quickly to precipitation events, and runoff events, if they occur at all during the year, rarely coincided with sampling events. Discharges of CBNG-produced waters can sustain flows in some of these small drainages for extended periods; however, tributaries were completely dry during some site visits. In contrast to the eastern tributaries, instantaneous streamflow for sampling events ranged from 0.01 to 422 ft^3/s on Crazy Woman Creek (site P11) and from 0.24 to 2,230 ft^3/s on Clear Creek near Arvada (site P20) because snowmelt from the Bighorn Mountains contributes to streamflows in the spring. In the Belle Fourche River drainage basin, instantaneous streamflow values measured on Donkey Creek (site B3) ranged from 0.05 to 46 ft^3/s and were larger than streamflows measured on Caballo Creek (site B2), which ranged from 0.02 to 7.4 ft^3/s. Flows on Donkey Creek generally are sustained from discharges of CBNG-produced water, discharges from coal mines, and discharges from the City of Gillette (Wyoming Department of Environmental Quality, 2010).

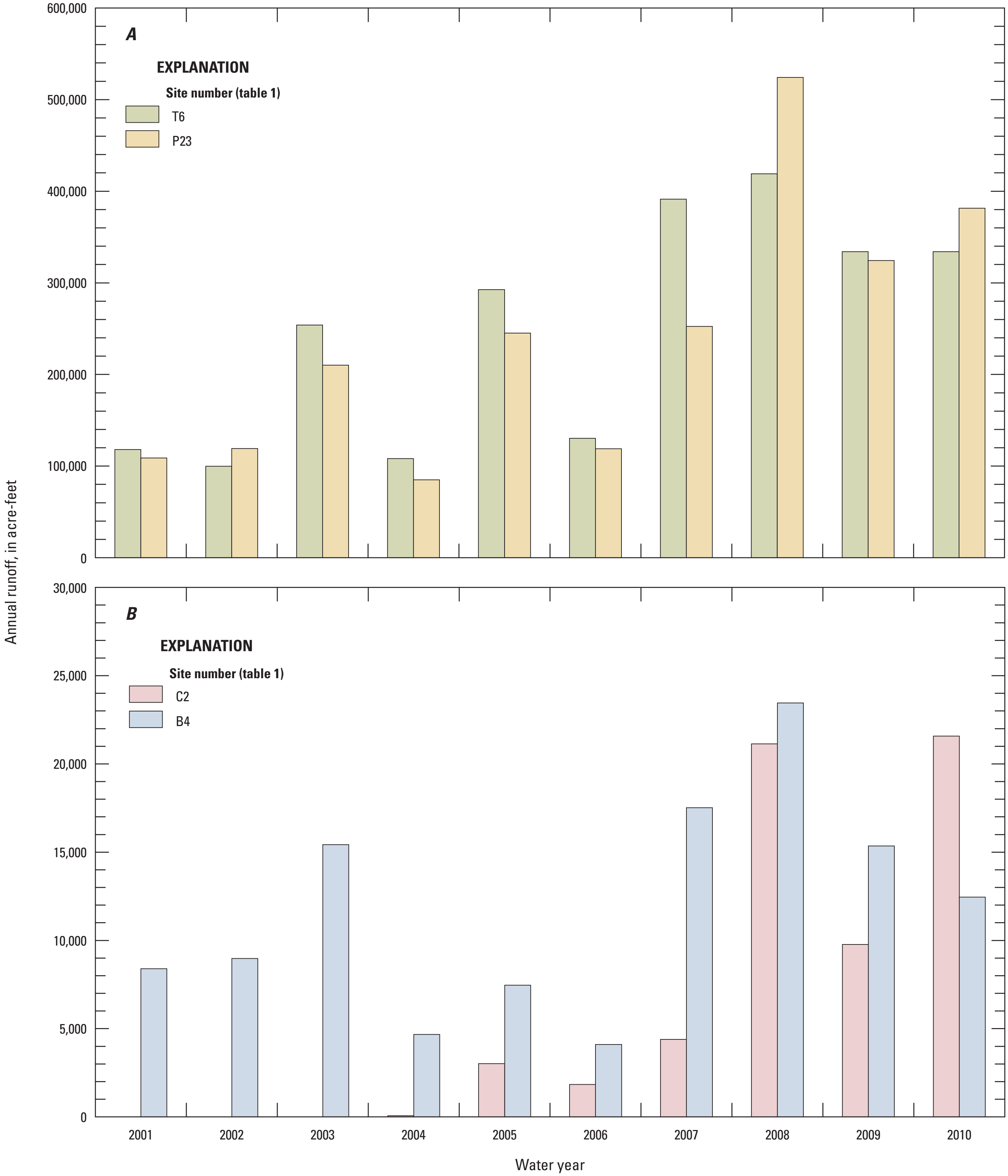

Figure 3. Annual runoff for selected main-stem sampling sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

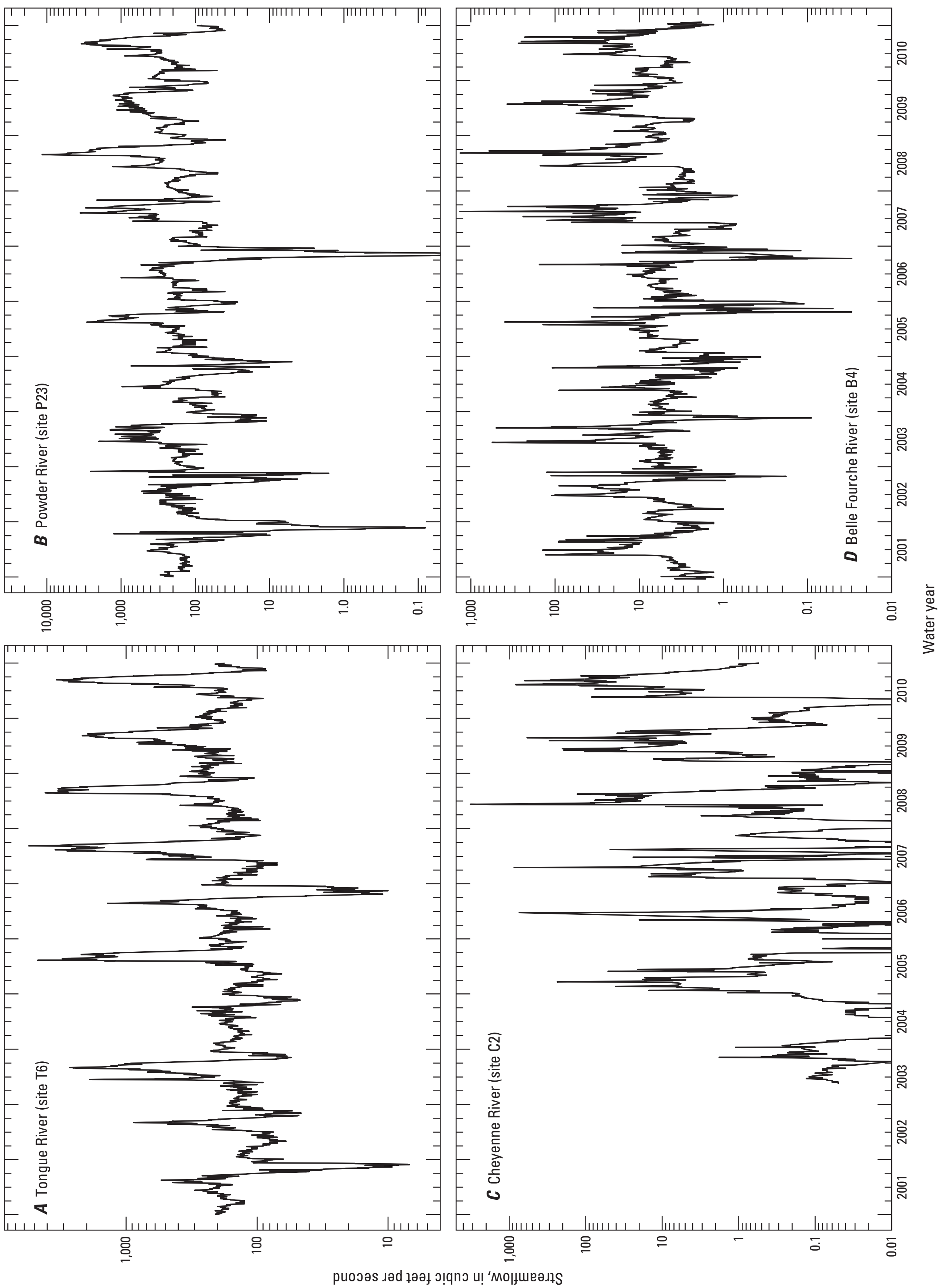

Figure 4. Streamflow at sites in the *A*, Tongue; *B*, Powder; *C*, Cheyenne; and *D*, Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

Specific Conductance

Field measurements of specific conductance in streams varied among site groups for the four major drainage basins. Stream water in the Tongue River drainage basin had the smallest median specific conductance values of the four drainage basins, indicating that concentrations are diluted by large runoff in this drainage basin. Water concentrations are largest, as indicated by the largest median specific conductance, in the Cheyenne River drainage basin. Specific conductance values were most variable for plains tributaries to the Powder River (fig. 5).

For selected Tongue, Powder, Cheyenne, and Belle Fourche River main-stem sites, specific conductance values were examined through time (fig. 6). The range of specific conductance values measured on the main stem of the Tongue River (site T6) is substantially smaller and the least variable through time compared to specific conductance values measured on the Powder River (site P23), Cheyenne River (site C2), and Belle Fourche River (site B4). Specific conductance values measured on the Cheyenne River (site C2) were highly variable through time. The curve (fig. 6) smoothes the overall pattern of data with time; however, it may not necessarily correspond with a significant trend through time when seasonal variation is taken into account.

Median specific conductance values at sites in the Tongue River drainage basin ranged from 411 μS/cm at 25°C for the Tongue River at Monarch (site T1) to 1,460 μS/cm at 25°C for Prairie Dog Creek near Acme (site T5) during water years 2001–10 (appendix 1). Median specific conductance is substantially smaller (936 μS/cm at 25°C) upstream on Prairie Dog Creek near Sheridan (site T4) compared to near Acme (site T5), which is downstream from much of the CBNG development (based on compilation of data retrieved from Wyoming Oil and Gas Conservation Commission, 2011). Irrigated areas occur throughout the Prairie Creek drainage basin (Sheridan County Conservation District, 2011). Overall, specific conductance values are smaller for Prairie Dog Creek compared to other plains tributaries because transbasin diversions, which are contributed from tributaries that originate in the Bighorn Mountains and receive snowmelt runoff, likely have a dilution effect on specific conductance. Although the Prairie Dog Creek drainage basin has the most CBNG production in the Tongue River drainage basin (based on compilation of data retrieved from Wyoming Oil and Gas Conservation Commission, 2011), CBNG-produced waters generally are

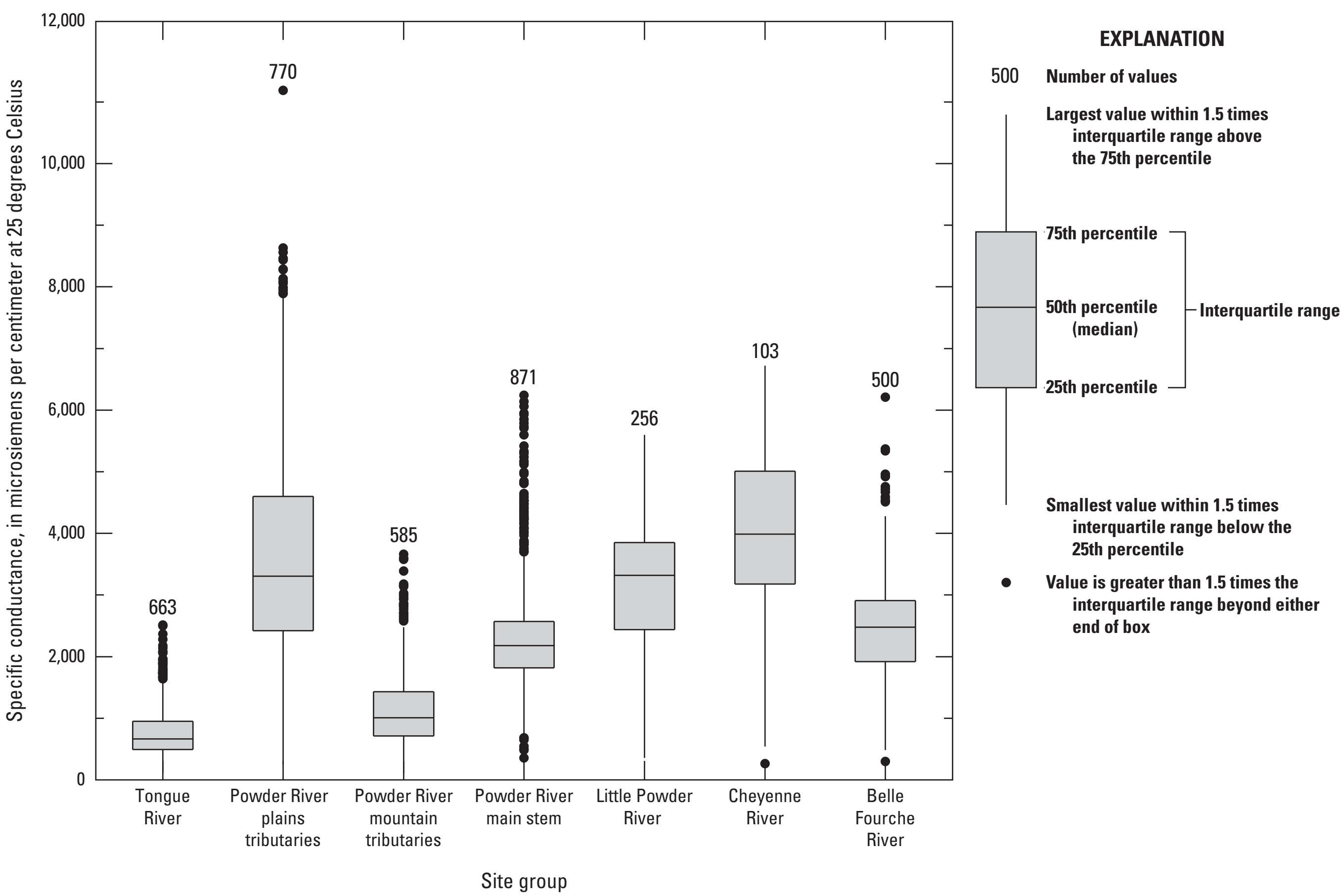

Figure 5. Statistical summary of specific conductance for site groups in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

not discharged directly into Prairie Dog Creek. Most produced waters are discharged into on- and off-channel impoundments in unnamed draws or small streams that drain into Prairie Dog Creek (Sheridan County Conservation District, 2011). Quillinan and others (2012) identified a small tributary that originates in the plains and flows into Prairie Dog Creek between sites T4 and T5 as a major contributor to the specific conductance of lower Prairie Dog Creek. Specific conductance increased on the main stem of the Tongue River from the upstream site at Monarch (site T1) to downstream at State line (site T6), where the median value was 636 µS/cm at 25°C, in part because of inflows from Prairie Dog Creek.

The Powder River drainage basin has the largest drainage area and most diverse site conditions among the four major drainage basins resulting in the most variable specific conductance values (fig. 5). Median specific conductance values in the basin ranged from 672 µS/cm at 25°C for Clear Creek near Buffalo (site P18) during water years 2001–10 to 7,350 µS/cm at 25°C for SA Creek (site P22) during water years 2004–10 (appendix 1). Salt Creek (site P1) had the second largest median specific conductance of 5,950 µS/cm at 25°C during water years 2001–10. Salt Creek contributes the largest dissolved-solids load to the Powder River of any plains tributary because of its larger streamflows. Salt Creek is upstream from any CBNG development in the Powder River drainage basin; however, it receives discharges of saline groundwaters that are associated with conventional gas and oil production in that basin (RETEC Group, Inc., 2004). In the upper part of the Powder River drainage basin, eastern drainages such as Willow Creek (site P3), Pumpkin Creek (site P4), and Burger Draw (site P7) receive discharges of CBNG-produced waters and generally have larger specific conductance values than the main-stem sites on the Powder River (appendix 1). In the lower part of the Powder River drainage basin downstream from Arvada, Wyo., eastern drainages receiving CBNG-produced waters with large specific conductance values include Wild Horse Creek (site P14 and site P15) and Spotted Horse Creek (site P16). The largest specific conductance measured for any sampling event was 11,200 µS/cm at 25°C on LX Bar Creek (site P21). LX Bar Creek and SA Creek (site P22) are eastern plains drainage basins with CBNG development that drain into the Powder

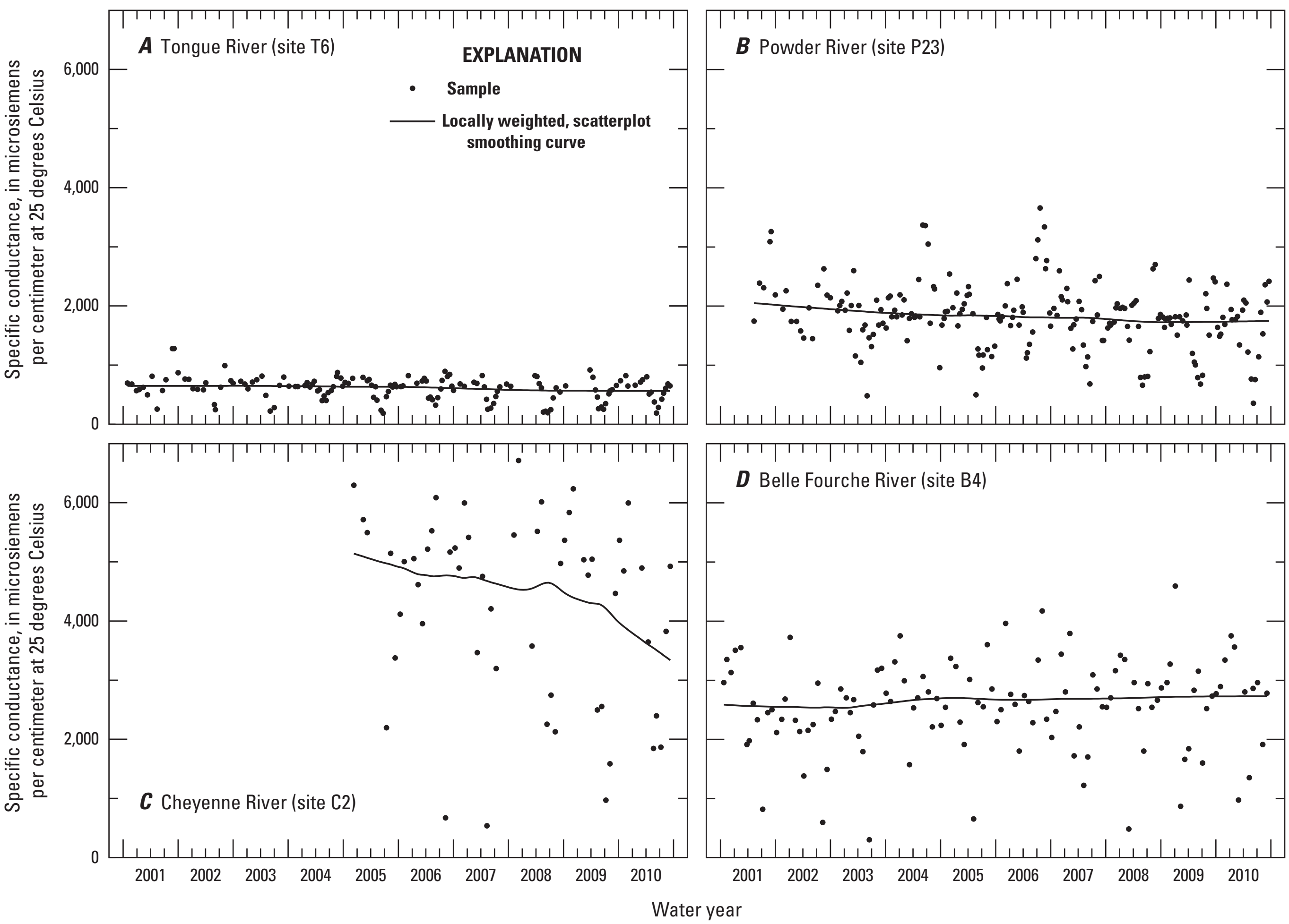

Figure 6. Specific conductance through time at sites in the *A*, Tongue; *B*, Powder; *C*, Cheyenne; and *D*, Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

River downstream from Clear Creek and upstream from the Powder River at Moorhead (site P23). Median specific conductance (1,820 µS/cm at 25°C) at Moorhead (site P23) is smaller than median specific conductance (2,200 µS/cm at 25°C) upstream at the Powder River above Clear Creek (site P17) because of the dilution effects from Clear Creek.

Median specific conductance values for the Cheyenne River were 3,645 µS/cm at 25°C near Dull Center (site C1) during water years 2004–10 and 4,900 µS/cm at 25°C near Spencer (site C2) during water years 2005–10 (appendix 1). The entire Cheyenne River drainage basin is in the plains, where low precipitation and relatively low land-surface gradients produce slow stream velocities and long contact times with soluble geologic materials, resulting in large amounts of dissolved solids. Water quality for the Cheyenne River near Dull Center (site C1) generally is representative of groundwater, because flow at site C1 issues from nearby groundwater seeps. The Cheyenne River channel typically is completely dry upstream from the seeps at site C1. Fogg and others (1991) reported groundwater in the local flow system in the upper Cheyenne River drainage basin may be discharged by springs and flowing wells. The Cheyenne River near Dull Center (site C1) has the smallest median pH (7.8) compared to all other sampling sites, which is consistent with a groundwater source. Springs sampled in the study by Bartos and Ogle (2002) had pH values that were similar to pH values measured at site C1. Specific conductance and major ion concentrations at site C1 during water years 2004–10 generally were larger than historical data collected prior to CBNG development (Peterson, 1988); however, streamflows were much smaller during water years 2004–10 as a result of drought conditions compared to historical values reported by Peterson (1988).

In the Belle Fourche River drainage basin, median specific conductance was largest (2,860 µS/cm at 25°C) for the Belle Fourche River near Piney (site B1). Specific conductance decreases in the downstream direction on the Belle Fourche River and is smallest (median of 1,900 µS/cm at 25°C) below Hulett (site B5). The upper part of the Belle Fourche River drainage basin lies in the plains; however, downstream near Hulett, Wyo., dilution occurs as a result of changes in geology and precipitation associated with the Black Hills. A reservoir between site B4 and site B5 on the Belle Fourche River also may affect the water quality at site B5. Median specific conductance values for tributaries were 1,920 µS/cm at 25°C for Caballo Creek (site B2) and 2,780 µS/cm at 25°C for Donkey Creek (site B3). Specific conductance values reported by Rice and others (2000) for coalbed waters in the eastern part of the Powder River structural basin generally were less than specific conductance values for sites in the Belle Fourche River drainage basin. Median specific conductance values were smaller for the Belle Fourche River near Piney (site B1), Caballo Creek (site B2), and Donkey Creek (site B3) compared to historical data collected prior to CBNG development (Peterson, 1988), indicating that CBNG-produced waters may have a dilution effect on these streams.

Sodium Adsorption Ratios

The SAR values for samples collected from streams varied among site groups for the four major drainage basins (fig. 7). The SAR values were most variable in the Powder River drainage basin. Plains tributaries and Powder River main-stem site groups had large ranges of SAR values. In contrast, the mountain tributaries to the Powder River had a small range of SAR values. The Tongue River had the smallest median value and range of SAR values of the site groups.

For selected main-stem sites, the range of SAR values in samples collected from the Tongue River (site T6) is substantially smaller and less variable through time (fig. 8) compared to SAR values for samples collected from the Powder River (site P23), Cheyenne River (site C2), and Belle Fourche River (site B4). The SAR values were most variable in samples collected from the Cheyenne River. The curve (fig. 8) smoothes the overall pattern of data with time; however, it may not necessarily correspond with a significant trend through time when seasonal variation is taken into account.

Median SAR values in the Tongue River drainage basin ranged from 0.32 for the Tongue River at Monarch (site T1) during water years 2004–10 to 1.3 for Prairie Dog Creek near Acme (site T5) during water years 2001–10 (appendix 1) . The median SAR was 0.73 for the Tongue River at State line (site T6) during water years 2001–10.

Sites in the Powder River drainage basin had the largest range of median SAR values, from 0.87 (sites P18 and P19) on Clear Creek to 32.8 on Cottonwood Creek (site P12) during water years 2001–10 (appendix 1). Large median SAR values generally were for sites on eastern plains tributaries that receive discharges of CBNG-produced waters, such as 19.1 for Pumpkin Creek (site P4), 16.0 for Beaver Creek (site P5), 29.8 for Burger Draw (site P7), 15.8 for Barber Creek (site P10), and 15.3 for LX Bar Creek (site P21). Cottonwood Creek (site P12), which is a plains tributary with CBNG development that drains the western side of the Powder River, had the largest SAR value (46.7) reported for any sample as well as the largest median value. Coalbeds in the Powder River structural basin near Cottonwood Creek are deeper than coalbeds in the eastern part of the basin. The quality of coalbed waters generally decreases, in terms of increasing concentrations of sodium, as the depth to the coal increases (Rice and others, 2002). Salt Creek, which receives discharges from conventional oil and gas development, also had a large median SAR value of 18.0. For the Powder River main-stem sites, samples collected from the Powder River below Burger Draw (site P8) had a median SAR value of 5.6 and ranged from 1.9 to 26.7. Large SAR values in samples from site P8 were observed when flows were small and Burger Draw (site P7) substantially contributed to the streamflow of the Powder River. The SAR values for samples from the Powder River generally were smallest at Moorhead (site P23), which had a median SAR value of 4.1 and ranged from 1.1 to 9.0. The median SAR value for Clear Creek near Arvada (site P20) was 1.2. Similar to specific conductance, median SAR values are affected by dilution by tributary inflow from Clear Creek as observed in the decrease in median SAR values from 5.6 for the Powder River above Clear Creek (site P17) to 4.1 for the Powder River at Moorhead (site P23).

Median SAR values for the Cheyenne River were 4.8 at the upstream site (site C1) during water years 2004–10 and 10.4 at the downstream site (site C2) during water years 2005–10. The SAR values for samples collected at site C1 likely are representative of groundwater because of flow conditions previously described for site C1. The CBNG development occurs in tributary basins upstream from site C1; however, discharges of CBNG-produced waters do not directly contribute to streamflow in the Cheyenne River upstream from site C1 because the site generally is dry just upstream from the sampling location. The CBNG development also occurs in tributary drainages between site C1 and site C2; however, the Cheyenne River may go dry between these sites.

The SAR values for samples from the Belle Fourche River generally are largest at the farthest upstream site near Piney (site B1) and smallest below Hulett (site B5). The median SAR value on the Belle Fourche River decreased from 5.6 near Piney (site B1) to 1.3 below Hulett (site B5) during water years 2001–10 (appendix 1). Substantially larger calcium concentrations and smaller sodium concentrations occur below Hulett (site B5) compared to upstream sites on the Belle Fourche River (sites B1 and site B4), likely as a result of changes in geology. Although Caballo Creek and Donkey Creek (sites B2 and B3) receive discharges of CBNG-produced waters, median SAR values for samples from these tributaries (4.9 and 4.1) are much smaller than tributaries that receive CBNG-produced waters in the Powder River drainage basin. The SAR values reported by Rice and others (2000) for coalbed waters in the southeastern part of the Powder River structural basin near Gillette, Wyo., generally were less than 9.0. Although specific conductance values generally were smaller in the Belle Fourche River drainage basin during water years 2001–10 compared to historical values (Peterson, 1988), some mixed geochemical changes may have occurred in stream waters. For example, SAR values for Caballo Creek (site B2) generally increased compared to historical data collected prior to CBNG development (Peterson, 1988). The change in SAR values coincides with smaller calcium concentrations at site B2 during water years 2001–10. In contrast, SAR values for Donkey Creek (site B3) generally decreased compared to historical values owing to smaller sodium concentrations during water years 2001–10.

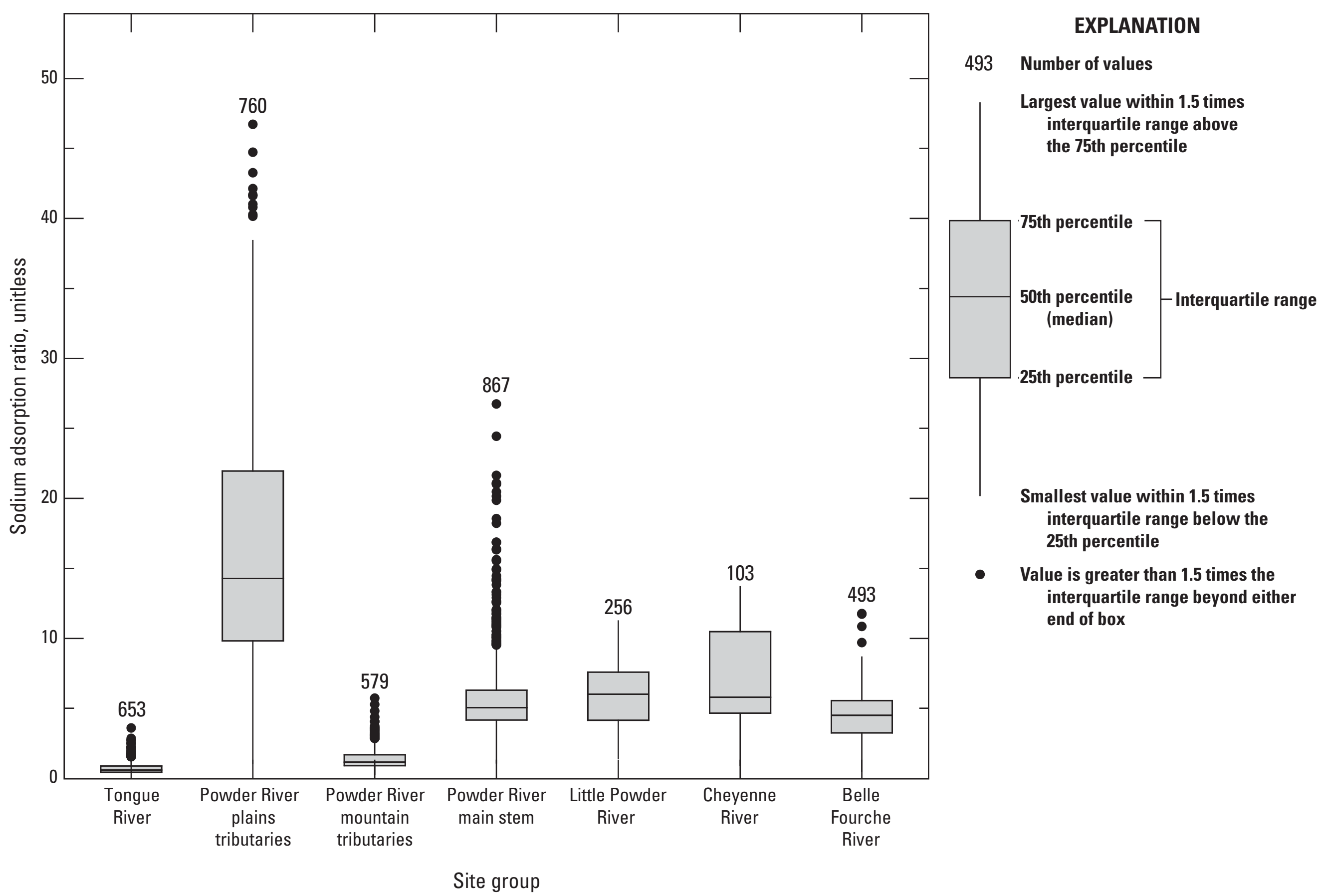

Figure 7. Statistical summary of sodium adsorption ratios for site groups in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

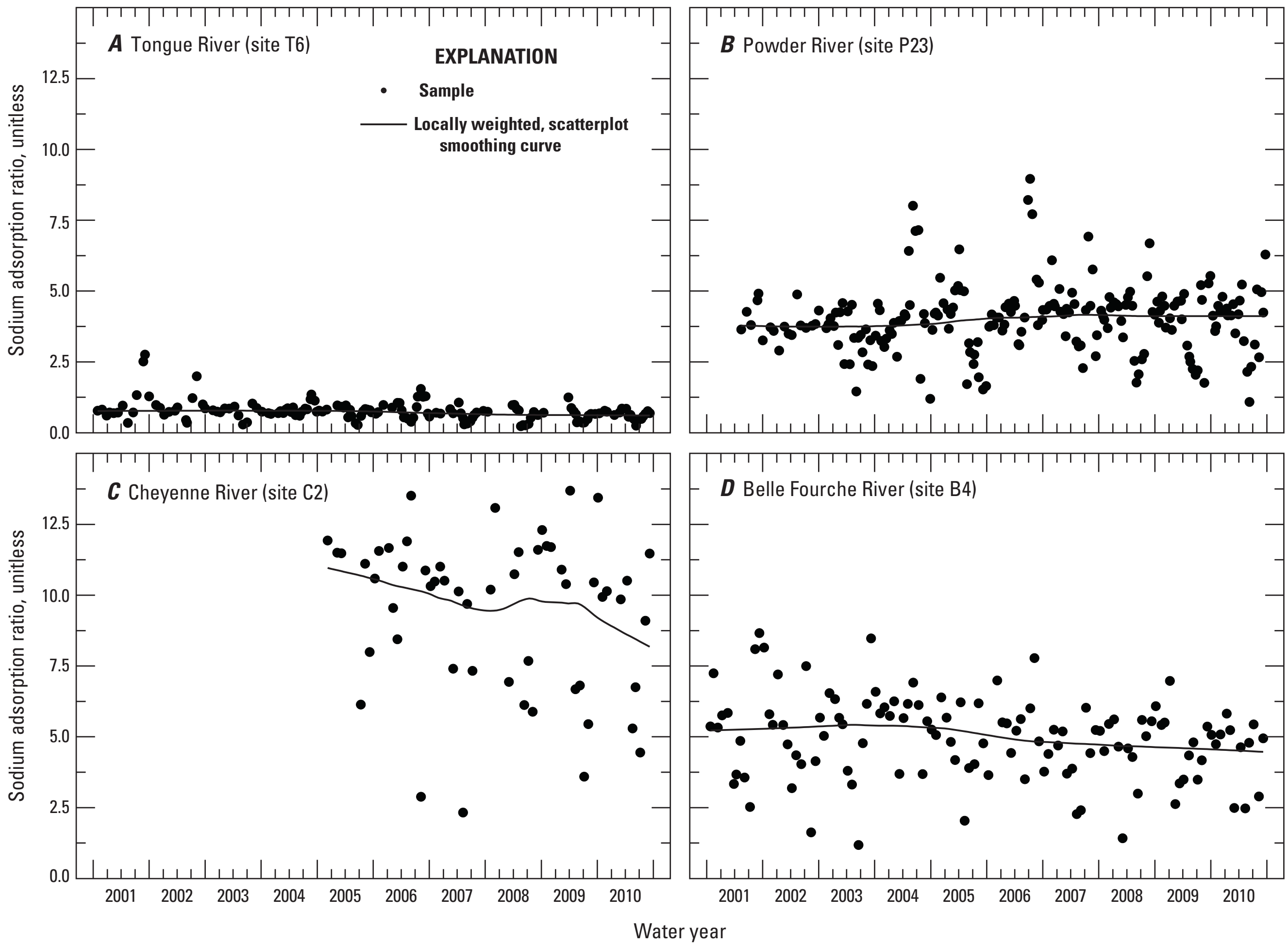

Figure 8. Graphs showing sodium adsorption ratios through time at sites in the *A*, Tongue; *B*, Powder; *C*, Cheyenne; and *D*, Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

Trend Analyses of Selected Water-Quality Characteristics

Trends were analyzed for selected sites to help evaluate whether changes in water-quality characteristics have occurred through time. Increases in specific conductance and SAR as a result of CBNG development could affect water use for irrigation. Trends were evaluated for unadjusted and flow-adjusted specific conductance and SAR values using the seasonal Kendall test. Results for the various trend analyses are presented in appendix 2. Because streamflow typically has a relation with specific conductance and SAR for sites in the study area and was variable during the study period, it is difficult to determine cause and effect relations for unadjusted values. The description of trends in the following sections is limited to results of the seasonal Kendall test applied to flow-adjusted values, because they are more useful for determining potential factors affecting trends.

Trend Analysis for Water Years 2001–10

Trends were evaluated for the 10-year period of water years 2001–10 at sites in the Tongue River drainage basin (4 sites); Powder River drainage basin (9 sites); and the Belle Fourche River drainage basin (4 sites). Most of the sites evaluated for trends for water years 2001–10 are on the main-stem rivers or on primary tributaries in those drainages (table 2). In addition to specific conductance and SAR, trends were evaluated for dissolved concentrations of calcium, magnesium, sodium, alkalinity, chloride, and sulfate to determine which of the primary components may be contributing to a trend in specific conductance or SAR.

Specific Conductance

Consistent basinwide patterns were not observed in trend results for specific conductance for water years 2001–10 in the Tongue, Powder, and Belle Fourche River drainage basins (fig. 9). Significant ($p<0.05$) upward trends in flow-adjusted specific conductance values were determined for 3 sites, a downward trend was determined for 1 site, and no significant ($p>0.05$) trends were determined for 13 sites.

In the Tongue River drainage basin, results of the seasonal Kendall test applied to flow-adjusted specific conductance values for water years 2001–10 indicated significant ($p<0.05$) upward trend on the Tongue River at Stateline (site T6). No significant ($p>0.05$) trends were determined for flow-adjusted specific conductance values on Little Goose Creek (site T2), Goose Creek (site T3), and Prairie Dog Creek near Acme (site T5).

Significant ($p<0.05$) upward trends also were determined for flow-adjusted concentrations of calcium, chloride, and sulfate on the Tongue River at Stateline (site T6), which would contribute to the upward trend in specific conductance. A significant upward trend in flow-adjusted chloride concentrations was determined for Prairie Dog Creek near Acme (site T5), which may have contributed to increasing chloride concentrations of the Tongue River. Determining the source of trends for the Tongue River at State line (site T6) for water years 2001–10 is complicated by several factors. Large concentrations of calcium, chloride, and sulfate are not directly associated with coalbed waters. The subsurface movement of major ions dissolved from soils as a result of infiltrating CBNG-produced waters is one potential source of calcium, chloride, or sulfate to streams; however, other land uses also may have contributed to trends in major ions. Irrigation, which occurs in the Tongue River drainage basin, can increase concentrations of dissolved constituents in the soil profile or in return flows as a result of evaporation and transpiration (Hanson and others, 2006). Rural septic systems in the drainage basin may also contribute to dissolved solids (Canter and Knox, 1984), as well as the city of Sheridan. Drought conditions that persisted in the Tongue River drainage basin during water years 2001–06 may have produced an accumulation of salts at the surface and in the near subsurface through evaporation. When precipitation returned to normal (Natural Resources Conservation Service, 2011), some of these accumulated salts may have been flushed to streams. Quillinan and others (2012) reported that increased dissolved solids observed in the Tongue River during early spring runoff are likely the result of soluble salts being mobilized from the soil profile in the basin interior.

In the Powder River drainage basin, results of the seasonal Kendall test applied to flow-adjusted specific conductance values for water years 2001–10 indicated a significant ($p<0.05$) upward trend on Clear Creek near Buffalo (site P18). A significant downward trend in flow-adjusted specific conductance values was determined for the Powder River below Burger Draw (site P8). No significant ($p>0.05$) trend in flow-adjusted specific conductance values were determined for Salt Creek (site P1), Powder River at Sussex (site P2), Crazy Woman Creek (site P11), the Powder River at Arvada (site P13), Clear Creek near Arvada (site P20), the Powder River at Moorhead (site P23), and the Little Powder River above Dry Creek (site P27).

Results of the seasonal Kendall test applied to major ion concentrations indicated significant ($p<0.05$) upward trends in flow-adjusted concentrations of calcium, magnesium, and alkalinity contributed to the upward trend in specific conductance for Clear Creek near Buffalo (site P18). Calcium, magnesium, and alkalinity commonly are associated with carbonate rocks, which are present in the upper basin. Trends in these constituents may indicate that groundwater composed a relatively larger part of the streamflow as a result of drought conditions, because concentrations of calcium, magnesium, and alkalinity typically are larger under base-flow conditions compared to surface runoff. Sparse CBNG development has occurred in the upper Clear Creek drainage basin upstream from site P18 (based on compilation of data retrieved from Wyoming Oil and Gas Conservation Commission, 2011).

Results of the seasonal Kendall test applied to major ion constituents indicated a significant ($p<0.05$) downward trend for flow-adjusted sulfate concentrations contributed to the downward trend in specific conductance for the Powder River below Burger Draw (site P8). The CBNG production occurs in drainages upstream from site P8 on the Powder River, including the Burger Draw drainage basin, which is immediately upstream from site P8. Because coalbed waters typically do not contain large sulfate concentrations, discharges of CBNG-produced waters in the Burger Draw drainage basin may dilute sulfate concentrations in the Powder River below Burger Draw (site P8), particularly during low flows. Because flow is occurring more regularly in some of the plains ephemeral drainages, some flushing of surficial sulfate salts also may have occurred, which may decrease sulfate concentrations through time. Precipitation of barium sulfate also may contribute to the downward trend in flow-adjusted sulfate concentrations. Barium is a constituent commonly associated with CBNG-produced waters that will precipitate when mixed with sulfate in drainages (Wyoming Department of Environmental Quality, 2000; Brinck and others, 2008).

The seasonal Kendall test applied to major ion constituents indicated significant ($p<0.05$) downward trends in flow-adjusted sulfate concentrations downstream on the Powder River at Arvada (site P13) and at Moorhead (site P23), as well as on Clear Creek near Arvada (site P20); however, no trends were determined for flow-adjusted specific conductance values for these sites. Significant upward trends in flow-adjusted alkalinity concentrations were determined for the Powder River at Arvada (site P13) and at Moorhead (site P23). The CBNG-produced waters that typically have bicarbonate as their dominant anion may be the source affecting the upward trend in alkalinity on the Powder River at sites P13 and P23. Multiple approaches for assessing water quality indicate that some reaches of the Powder River may have been affected by CBNG-produced waters. Sharma and Frost (2008) used stable

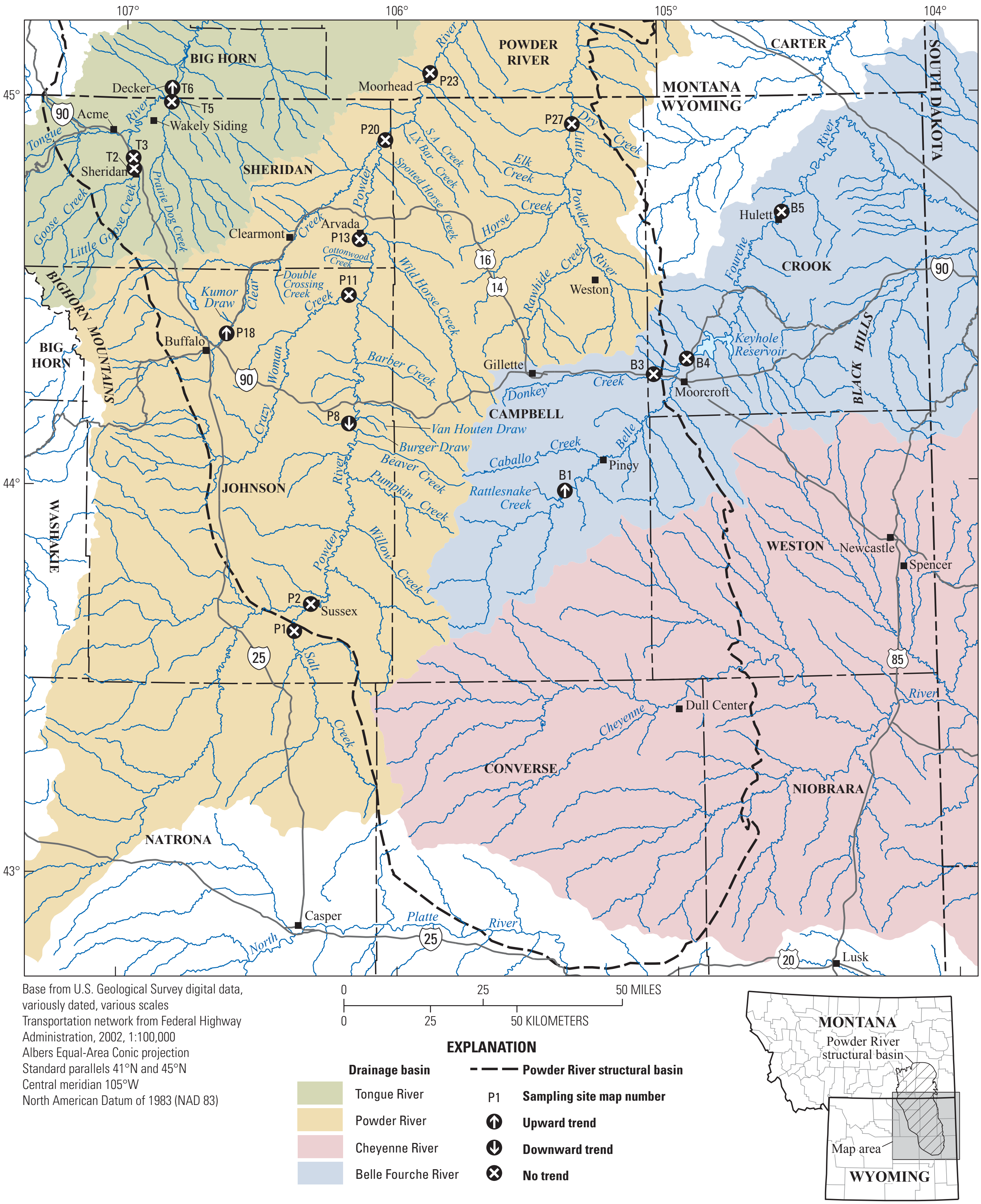

Figure 9. Trend results for flow-adjusted specific conductance at sites in the Tongue, Powder, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

isotopes of carbon as a tracer to determine that the reach of the Powder River downstream from Beaver Creek to near Moorhead, Mont., was affected by CBNG-produced waters. Isotope analysis results for the Powder River farther downstream in Montana generally reflected ambient conditions, indicating that waters were not affected by CBNG-produced waters. Peterson and others (2011) reported a decline in biological conditions in reaches of the Powder River between Barber Creek and Wild Horse Creek that may indicate cumulative effects from CBNG-produced waters, including effects from alkalinity. Barber Creek is one of the plains tributaries where CBNG-produced waters receive treatment to reduce concentrations of some of the dissolved constituents (Wyoming Department of Environmental Quality, 2011). Median dissolved sodium concentrations were substantially smaller for Barber Creek (site P10) compared to other drainages with CBNG development, such as Pumpkin Creek (site P4) and Burger Draw (site P7); however, median alkalinity concentrations were similar, although few samples from these sites were analyzed for anions (appendix 1).

In the Belle Fourche River drainage basin, a significant ($p<0.05$) upward trend in flow-adjusted specific conductance values was determined for the Belle Fourche River near Piney (site B1). No significant ($p>0.05$) trend in flow-adjusted specific conductance was determined for Donkey Creek (site B3) or for two sites downstream on the Belle Fourche River (sites B4 and B5).

Results of the seasonal Kendall test applied to major ion constituents indicated a significant ($p<0.05$) upward trend in flow-adjusted sodium concentrations contributed to the upward trend in specific conductance on the Belle Fourche River near Piney (site B1). Water production associated with CBNG development has been declining in the upper Belle Fourche River drainage basin since 2003 when it was at its peak (based on compilation of data retrieved from Wyoming and Gas Conservation Commission, 2011). Specific conductance values and sodium concentrations generally were smaller during water years 2001–10 compared to values reported by Peterson (1988) for water years 1975–81 for site B1. This indicates that CBNG-produced waters may have had a dilution effect on the water quality of the Belle Fourche River near Piney and as a result of declining CBNG production, concentrations are returning to larger levels that occurred prior to CBNG development.

Although no corresponding trends were determined for flow-adjusted specific conductance values, the seasonal Kendall test applied to major ion constituents indicated a significant ($p<0.05$) downward trend in flow-adjusted alkalinity concentrations on the Belle Fourche River below Moorcroft (site B4). Significant upward trends in flow-adjusted concentrations of calcium, magnesium, and chloride concentrations also were determined for Belle Fourche River below Moorcroft (site B4). Increases in chloride have been reported for Donkey Creek, and the Belle Fourche River downstream from Donkey Creek has been listed as impaired for chloride (Wyoming Department of Environmental Quality, 2010). One source potentially contributing to the upward trend in flow-adjusted magnesium and chloride concentrations may be magnesium chloride, which is used throughout the year in the Belle Fourche River drainage basin (Tetra Tech, Inc., 2011). During the winter, magnesium chloride is used as a de-icing agent for roads, and from May to October, as a dust suppressant applied to haul roads used to transport materials from extraction facilities.

Sodium Adsorption Ratios

Consistent basinwide patterns were not observed in trend results for SAR values for water years 2001–10 in the Tongue, Powder, and Belle Fourche River drainages basins (fig. 10). Significant ($p<0.05$) upward trends in flow-adjusted SAR values were determined at 2 sites and no significant ($p>0.05$) trends were determined for 15 sites.

In the Tongue River drainage basin, results of the seasonal Kendall test applied to flow-adjusted SAR values for water years 2001–10 indicated no significant ($p>0.05$) trends for Little Goose Creek (site T2), Goose Creek (site T3), Prairie Dog Creek near Acme (site T5), and the Tongue River at State line (site T6). As previously described for specific conductance trends, a significant ($p<0.05$) upward trend in flow-adjusted calcium was determined for site T6; however, a corresponding downward trend in flow-adjusted SAR was not determined. A downward trend was significant for unadjusted SAR values at site T6 (appendix 2).

In the Powder River drainage basin, results of the seasonal Kendall test applied to flow-adjusted SAR values for water years 2001–10 indicated a significant ($p<0.05$) upward trend on the Powder River at Arvada (site P13). The trend in flow-adjusted SAR values was not significant ($p>0.05$) for other sites on the Powder River, including at Sussex (site P2), below Burger Draw (site P8), and at Moorhead (site P23). No significant trends in flow-adjusted SAR values were determined for tributary sites in the Powder River drainage basin, including Salt Creek (site P1), Crazy Woman Creek (site P11), Clear Creek (site P18 and site P20), and the Little Powder River (site P27).

No significant trends ($p>0.05$) were determined for flow-adjusted concentrations of calcium, magnesium, and sodium for the Powder River at Arvada (site 13). Flow-adjusted calcium concentrations, which have an inverse relation with SAR, had a larger test statistic (tau = -0.310) than sodium (tau = 0.034) or magnesium (tau = -0.073) for the trend period, indicating the trend in flow-adjusted SAR values may be primarily the result of decreasing calcium concentrations. One of the geochemical effects of adding sodium bicarbonate produced waters to streams is the precipitation of calcium carbonate. This results in a decrease in calcium concentrations and a corresponding increase in SAR (Patz and others, 2004). Decreases in calcium concentrations in CBNG impoundments compared to CBNG outfalls also have been attributed to the precipitation of calcite (Jackson and Reddy, 2007b). The SAR trend, combined with the upward trend in flow-adjusted

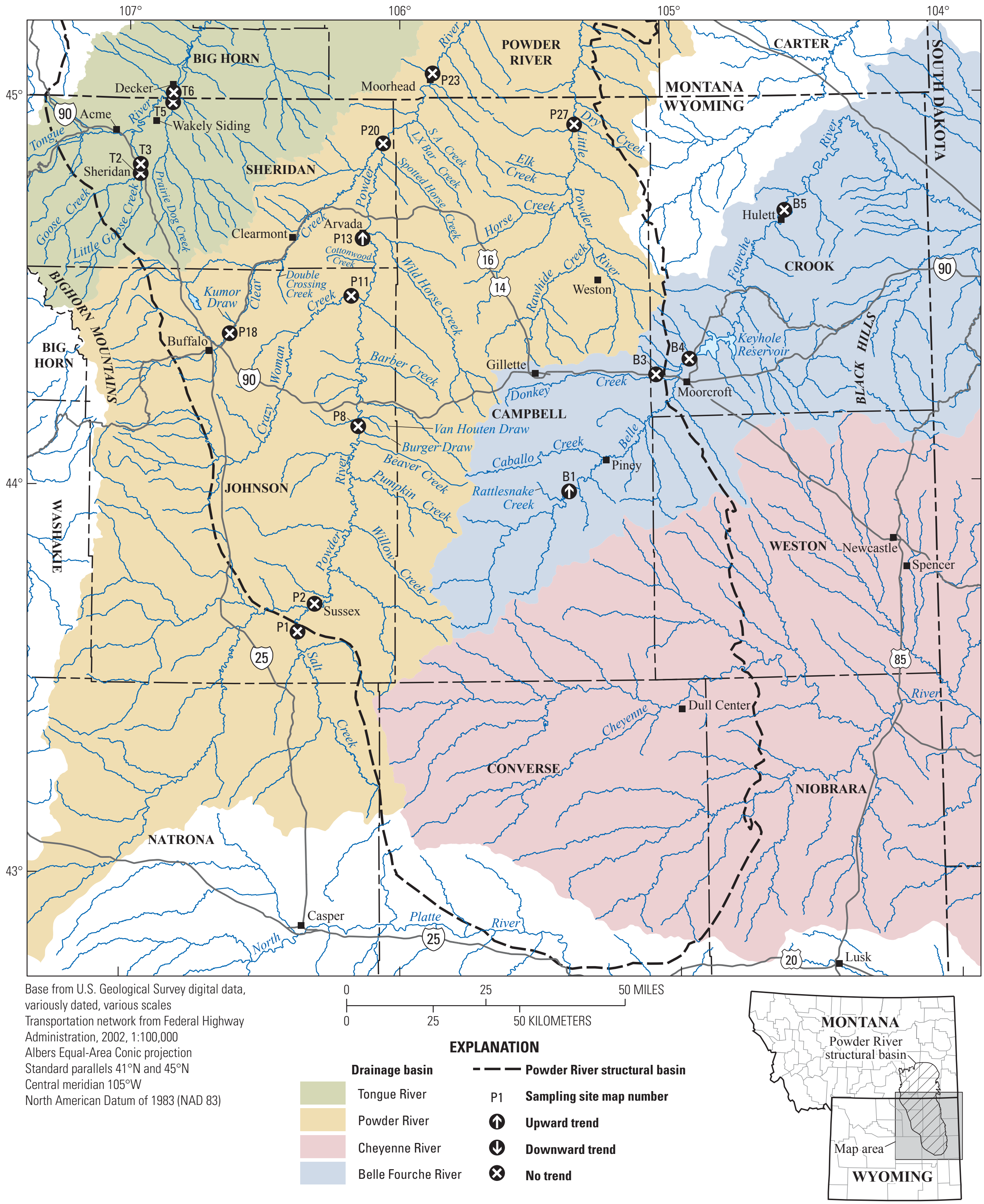

Figure 10. Trend results for flow-adjusted sodium adsorption ratios at sites in the Tongue, Powder, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

alkalinity concentration, is additional evidence that CBNG-produced waters may be causing the water-quality changes to the Powder River at Arvada (site P13) during water years 2001–10. Frost and others (2010) used strontium isotopes and mixing models to show that CBNG-produced waters account for less than 1 percent of the flow of the Powder River, but that it is possible for even a small amount of CBNG-produced waters to affect SAR values of the Powder River.

In the Belle Fourche River drainage basin, results of the seasonal Kendall test applied to flow-adjusted SAR values for water years 2001–10 indicated a significant ($p<0.05$) upward trend on the Belle Fourche River near Piney (site B1). Trends in flow-adjusted SAR values were not significant ($p>0.05$) for Donkey Creek (site B3) or downstream on the Belle Fourche River (site B4 and site B5). The upward SAR trend for site B1 corresponded with a significant upward trend in flow-adjusted sodium concentrations at that site. Because trends in flow-adjusted concentrations of calcium or magnesium were not significant, the increase in sodium, which is directly related to SAR, likely is the primary factor affecting the upward trend in SAR for the Belle Fourche River near Piney (site B1).

Trend Analysis for Water Years 2005–10

Trends were evaluated for the 6-year period of water years 2005–10 at sites in the Tongue River drainage basin (4 sites), the Powder River drainage basin (18 sites), the Cheyenne River drainage basin (1 site), and the Belle Fourche River drainage basin (3 sites). Sites that met data requirements for trend analyses for water years 2005–10 varied slightly compared to water years 2001–10 (table 2). Sampling frequency was decreased on Little Goose Creek (site T2), Goose Creek (site T3), and the Belle Fourche River below Hulett (site B5) and as a result, the number of observations in the ending period for those sites was not adequate to meet the trend test requirements. Two additional sites in the Tongue River drainage basin that were added to the monitoring network during water year 2004 (site T1 and site T4) were included in the trend analysis. Nine additional sites in the Powder River drainage basin (sites P4, P5 P6, P7, P15, P17, P19, P22, and P26) that were added to the monitoring network during water year 2004 were included in the trend analysis. One site in the Cheyenne River drainage basin that was added to the monitoring network during water year 2005 (site C2) was included in the trend analysis.

Trends were evaluated for specific conductance and SAR. In addition, trends were evaluated for dissolved concentrations of calcium, magnesium, sodium, alkalinity, chloride, and sulfate to determine which of the primary components may be contributing to a trend in specific conductance or SAR. For some sites, samples were analyzed only for cations (table 2); thus, trends in anions that may contribute to trends in specific conductance could not be evaluated for these sites.

Specific Conductance

Consistent basinwide patterns were not observed in trend results for specific conductance for water years 2005–10 in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins (fig. 11). Significant ($p<0.05$) upward trends in flow-adjusted specific conductance values were determined at 9 sites, downward trends were determined at 4 sites, and no significant ($p>0.05$) trends were determined for 13 sites (appendix 2).

In the Tongue River drainage basin, results of the seasonal Kendall test applied to flow-adjusted specific conductance values for water years 2005–10 indicated significant ($p<0.05$) upward trends on the Tongue River at Monarch (site T1), Prairie Dog Creek near Acme (site T5), and the Tongue River at State line (site T6). No significant ($p>0.05$) trend in flow-adjusted specific conductance values was determined for Prairie Dog Creek near Sheridan (site T4).

Results of the seasonal Kendall test applied to major ion constituents indicated upward trends for several constituents contributed to the upward trends in specific conductance. Significant ($p<0.05$) upward trends in flow-adjusted concentrations of magnesium, alkalinity, chloride, and sulfate were determined for the Tongue River at Monarch (site T1). Significant upward trends were determined in flow-adjusted concentrations of magnesium, sodium, alkalinity, chloride, and sulfate for Prairie Dog Creek near Acme (site T5). Upward trends in flow-adjusted concentrations of calcium, magnesium, alkalinity, chloride, and sulfate were significant for the Tongue River at State line (site T6). An upward trend in flow-adjusted chloride concentrations also was determined for Prairie Dog Creek near Sheridan (site T4), although no corresponding trend in flow-adjusted specific conductance was determined.

Determining the factors affecting trends in the Tongue River drainage basin for water years 2005–10 is complicated by several factors as previously described for water years 2001–10. Large concentrations of sodium and alkalinity typically are associated with coalbed waters; however, calcium, magnesium, chloride, and sulfate typically are not. In addition, the Tongue River at Monarch (site T1), which is upstream from CBNG development, generally had the same trends as downstream sites (T5 and T6). Studies that used other approaches to determine effects from CBNG developments in the Tongue River drainage basin were inconclusive. A study that used major ion composition and carbon isotopes to differentiate water sources found that surface waters were geochemically and isotopically distinct from CBNG-produced waters, particularly in the Prairie Dog Creek drainage basin where most of the development occurs (Quillinan and others, 2012). In addition, Peterson and others (2011) did not find substantial changes in biological conditions between sites upstream and downstream from CBNG development on the Tongue River and Prairie Dog Creek.

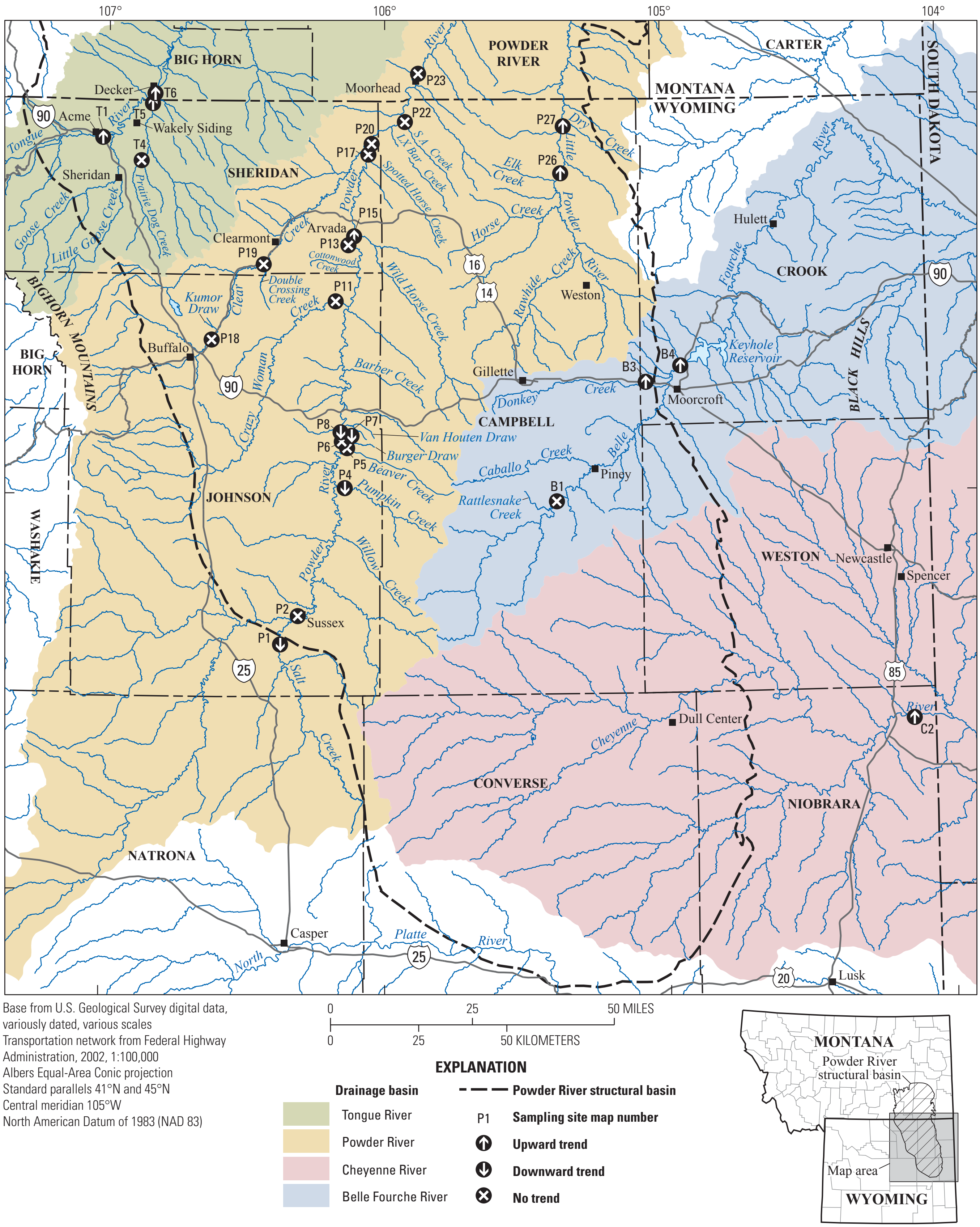

Figure 11. Trend results for flow-adjusted specific conductance at sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2005–10.

In the Powder River drainage basin, results of the seasonal Kendall test applied to flow-adjusted specific conductance values for water years 2005–10 indicated significant ($p<0.05$) downward trends on Salt Creek (site P1), Pumpkin Creek (site P4), Burger Draw (site P7), and the Powder River below Burger Draw (site P8). Significant upward trends in flow-adjusted specific conductance were determined for Wild Horse Creek at mouth (site P15) and for two sites on the Little Powder River (sites P26 and P27). No significant ($p>0.05$) trends in flow-adjusted specific conductance values were determined for other sites on the Powder River (sites P2, P6, P13, P17, and P23), Beaver Creek (site P5), Crazy Woman Creek (site P11), Clear Creek (sites P18, P19, and P20), and SA Creek (site P22).

Results of the seasonal Kendall test applied to major ion constituents indicated significant ($p<0.05$) downward trends in flow-adjusted concentrations of sodium, alkalinity, and chloride contributed to the downward trend in flow-adjusted specific conductance for Salt Creek (site P1), despite upward trends in flow-adjusted concentrations of calcium and sulfate. Changes to traditional oil and gas development practices, such as decreased discharges of saline groundwaters that are associated with conventional gas and oil production, have historically affected water quality in the Salt Creek drainage basin (RETEC Group, Inc., 2004) and may be the cause of recent trends in Salt Creek; CBNG development likely is not the cause. Although no significant trend in flow-adjusted specific conductance was determined downstream from Salt Creek on the Powder River at Sussex (site P2), major ion trends for site P2 were similar to trends for site P1. Major ion trends included downward trends in flow-adjusted concentrations of sodium and chloride and an upward trend in flow-adjusted calcium concentrations, which illustrates the substantial effects that Salt Creek has on the water quality of the Powder River. An understanding of water-quality trends at sites upstream from CBNG development, including Salt Creek, is critical for defining constituent inputs to the Powder River; without an understanding of these trends, potential causes of water-quality trends at the Powder River main-stem sites that are downstream from Salt Creek could be misinterpreted.

Results of the seasonal Kendall test applied to major ion constituents indicated significant ($p<0.05$) downward trends in flow-adjusted sodium concentrations contributed to the downward trend in specific conductance for Burger Draw (site P7) and the Powder River below Burger Draw (site P8) for water years 2005–10. A significant downward trend in flow-adjusted magnesium concentrations also was determined at Burger Draw (site P7), and a significant downward trend in flow-adjusted alkalinity concentrations was determined for the Powder River below Burger Draw (site P8). Downward trends in sodium (sites P7 and P8) and alkalinity (site P8) are consistent with a decline in CBNG production in the Burger Draw drainage basin. Data retrieved and compiled from the Wyoming Oil and Gas Conservation Commission (2011) indicate that CBNG production in the Burger Draw drainage basin generally decreased after 2006 when production was at its peak. Changes to conventional oil and gas production in the Salt Creek drainage basin also may have affected sodium concentrations for the Powder River below Burger Draw (site P8).

Significant ($p<0.05$) upward trends in flow-adjusted calcium and magnesium contributed to the upward trend in specific conductance on Wild Horse Creek at mouth (site P15) and the Little Powder River below Elk Creek (site P26). Significant upward trends in flow-adjusted concentrations of calcium, magnesium, sodium, alkalinity, and sulfate were determined downstream for the Little Powder River above Dry Creek (site P27). Nearly all of the CBNG development during the 1990s in the Powder River drainage basin was in the Little Powder River drainage basin. In contrast, the volume of produced water in the Little Powder drainage basin during 2010 represented only 6 percent of the total volume of produced water for the Powder River drainage basin as a result of declining production in the Little Powder drainage basin during 2003—10 (based on compilation of data retrieved from Wyoming Oil and Gas Conservation Commission, 2011). CBNG-produced waters discharged in the Little Powder River drainage basin likely have relatively small dissolved solids because of the water quality of coalbeds in the eastern part of the structural basin (Rice and others, 2000); however, water-quality characteristics and determining the source of trends for the Little Powder River are complicated by coal-mine dewatering and streamflow contributions from groundwater, including groundwater that is affected by clinker deposits (Miller and others, 2005).

Although no corresponding trend in flow-adjusted specific conductance was determined for these sites, trends in major ion constituents were determined for some sites. Significant ($p<0.05$) downward trends in flow-adjusted concentrations of magnesium and sodium were determined for Beaver Creek (site P5). Significant upward trends in flow-adjusted concentrations of alkalinity and chloride were determined for Crazy Woman Creek (site P11). Upward trends in flow-adjusted alkalinity were determined for Clear Creek (sites P18 and P20) and the Powder River at Moorhead (site P23). A downward trend in flow-adjusted calcium concentrations was determined for Clear Creek near Clearmont (site P19).

In the Cheyenne River drainage basin, a significant ($p<0.05$) upward trend in flow-adjusted specific conductance values was determined for water years 2005–10 for the Cheyenne River near Spencer (site C2). Significant upward trends in flow-adjusted concentrations of calcium, magnesium, sodium, and sulfate contributed to the upward trend in specific conductance at that site. Because coalbeds in the eastern part of the Powder River structural basin generally have relatively small dissolved-solids concentrations, CBNG-produced waters can have a dilution effect on some streams with naturally large dissolved solids concentrations, like the Cheyenne River. The upward trend in flow-adjusted specific conductance and major ion constituents may reflect the decrease in CBNG production in this drainage basin during water years 2005–10 (based on compilation of data retrieved from Wyoming Oil and Gas Conservation Commission, 2011), although persistent drought conditions, which tend to increase salts at the surface, also have occurred in the basin.

In the Belle Fourche River drainage basin, significant ($p<0.05$) upward trends in flow-adjusted specific conductance values were determined for Donkey Creek (site B3) and the Belle Fourche River below Moorcroft (site B4). Significant upward trends in flow-adjusted concentrations of magnesium and sulfate were determined for Donkey Creek (site B3) during water years 2005–10. Significant upward trends in flow-adjusted concentrations of magnesium, sodium, and sulfate were determined for the Belle Fourche River below Moorcroft (site B4) for water years 2005–10. Like the Cheyenne River, CBNG-produced waters may have a dilution effect in the Belle Fourche River drainage basin. Upward trends in flow-adjusted concentrations of sodium and sulfate, in particular, may reflect the decrease in CBNG production in the Belle Fourche River drainage basins (based on compilation of data retrieved from Wyoming Oil and Gas Conservation Commission, 2011). As previously described in the "Trend Analysis for Water Years 2001–10" section, the use of magnesium chloride for de-icing and dust suppression may contribute to the upward trends in flow-adjusted magnesium concentrations in Donkey Creek and the Belle Fourche River.

Sodium Adsorption Ratios

Consistent basinwide patterns were not observed in trend results for SAR values for water years 2005–10 in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins (fig. 12). Significant ($p<0.05$) upward trends in flow-adjusted SAR values were determined at 4 sites, downward trends were determined at 5 sites, and no significant ($p>0.05$) trends were determined for 17 sites.

In the Tongue River drainage basin, results of the seasonal Kendall test applied to flow-adjusted SAR values for water years 2005–10 indicated that upward trends were significant ($p<0.05$) for Prairie Dog Creek (sites T4 and T5). The cation affecting the SAR trend for Prairie Dog Creek near Sheridan (site T4) was not isolated, because no significant trends ($p>0.05$) were determined for flow-adjusted calcium, magnesium, and sodium concentrations for water years 2005–10, although the trend for flow-adjusted sodium concentrations was nearly significant ($p=0.077$). Also, SAR is a computed constituent, and the relative proportions of cations may have varied slightly through time even though the magnitude of concentrations of individual cations did not significantly increase or decrease. Significant upward trends were determined for flow-adjusted magnesium and sodium concentrations for Prairie Dog Creek near Acme (site T5), indicating increases in sodium had a larger effect on increasing SAR values than increases in magnesium had in decreasing SAR values. As described for specific conductance trends, the factors affecting trends in the Tongue River drainage basin is difficult to isolate for several reasons. Most of the CBNG development in the Prairie Dog Creek drainage basin occurs downstream from site T4. Infiltration of CBNG-produced waters, as well as other land uses and drought conditions, could contribute to sodium concentrations. Continued monitoring for SAR and related constituents is important given the assimilative capacity for sodium is small for the Tongue River.

In the Powder River drainage basin, results of the seasonal Kendall test applied to flow-adjusted SAR values for water years 2005–10 indicated downward trends were significant ($p<0.05$) for Salt Creek (site P1), the Powder River at Sussex (site P2), Pumpkin Creek (site P4), the Powder River below Burger Draw (site P8), and Wild Horse Creek at mouth (site P15). Results of the seasonal Kendall test applied to flow-adjusted SAR values for water years 2005–10 indicated a significant upward trend for the Little Powder River above Dry Creek (site P27). No significant ($p>0.05$) trends in flow-adjusted SAR values were determined for Beaver Creek (site P5), Burger Draw (site P7), Crazy Woman Creek (site P11), Clear Creek (sites P18, P19, and P20), SA Creek (site P22), the Powder River at several sites (sites P6, P13, P17, and P23), and the Little Powder River below Elk Creek (site P26).

Significant ($p<0.05$) downward trends in flow-adjusted sodium concentrations contribute to downward trends in SAR for Salt Creek (site P1), the Powder River at Sussex (site P2), and the Powder River below Burger Draw (site P8). Significant upward trends in flow-adjusted calcium concentrations for Salt Creek (site P1) and the Powder River at Sussex (site P2) are consistent with the downward SAR trends. The trend in SAR values was not significant ($p>0.05$) farther downstream on the Powder River at Arvada (site P13) for water years 2005–10. Because an upward trend in flow-adjusted SAR values for the Powder River at Arvada (site P13) was significant for water years 2001–10 and not significant for water years 2005–10, the increase in flow-adjusted SAR values may have largely occurred before water year 2005. This may indicate that changes to Salt Creek could have an effect on the Powder River as far downstream as Arvada. For Pumpkin Creek (site P4), no significant trends were observed in flow-adjusted calcium, magnesium, or sodium. For Wild Horse Creek at mouth (site P15), significant upward trends in flow-adjusted concentrations of calcium and magnesium would both contribute to the downward trend in SAR at that site. The volume of CBNG-produced waters declined in the Wild Horse Creek drainage basin during 2008–10 (based on compilation of data retrieved from Wyoming Oil and Gas Conservation Commission, 2011). Significant upward trends in flow-adjusted concentrations of calcium, magnesium, and sodium were determined for the Little Powder River below Dry Creek (site P27). The tau test statistic (0.389) was largest for flow-adjusted sodium concentrations, indicating that the increase in sodium affected SAR values more than did increases in calcium and magnesium. As previously described for specific conductance, CBNG development decreased in the Little Powder River drainage basin during water years 2005–10 (based on compilation of data retrieved from Wyoming Oil and Gas Conservation Commission, 2011).

In the Cheyenne River drainage basin, results of the seasonal Kendall test applied to flow-adjusted SAR values

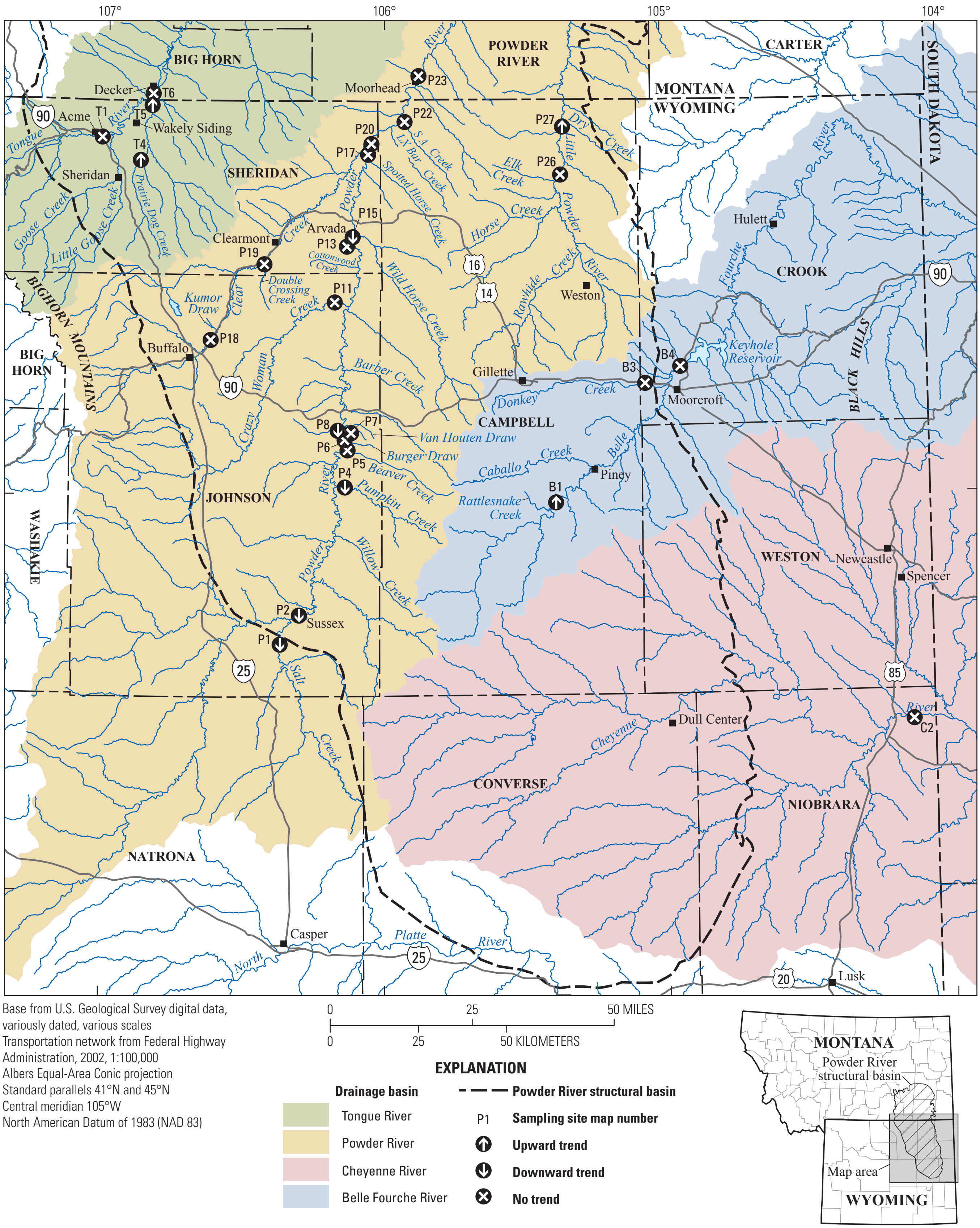

Figure 12. Trend results for flow-adjusted sodium adsorption ratios at sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2005–10.

for water years 2005–10 indicated no significant ($p>0.05$) trend for the Cheyenne River near Spencer (site C2). Significant ($p<0.05$) upward trends in flow-adjusted concentrations of calcium, magnesium, and sodium were determined at site C2, indicating that increases in sodium were coupled with increases in calcium and magnesium such that no increase in SAR occurred.

In the Belle Fourche River drainage basin, results of the seasonal Kendall test applied to flow-adjusted SAR values for water years 2005–10 indicated a significant ($p<0.05$) upward trend for the Belle Fourche River near Piney (site B1). No significant ($p>0.05$) trends for flow-adjusted SAR were determined for Donkey Creek (site B3) and the Belle Fourche River below Moorcroft (site B4). A significant upward trend in flow-adjusted sodium concentrations was determined for the Belle Fourche River near Piney (site B1), and no significant trends were determined for flow-adjusted concentrations of calcium and magnesium at site B1, indicating the increase in sodium likely caused the upward trend in SAR.

Trend Analysis for Water Years 1991–2010

The CBNG development was occurring in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins by 1999. Because CBNG development began before establishment of monitoring for CBNG effects in 2001, data for samples collected as part of other monitoring programs during 1991–2000 for selected sites were compiled to expand the temporal context of trends.

The suitability of the Powder River and its tributaries for irrigation water use was a concern prior to CBNG development. Upward trends in dissolved solids and SAR were reported by Cary (1991) for the Powder River at Arvada (site P13) for water years 1968–88 and 1975–88. To aid in water-management decisions for the Powder River, simulations using a computer model showed that removing oil and gas production water from Salt Creek had a positive effect on decreasing dissolved-solids concentrations in the Powder River (Lindner-Lunsford and others, 1992). During 1990, disposal of some of the saline groundwaters associated with conventional oil and gas production in the Salt Creek drainage basin was modified to include subsurface injection (RETEC Group, Inc., 2004). The change to subsurface injection substantially reduced the inputs from Salt Creek to the Powder River and decreased specific conductance in the Powder River as far downstream as Arvada, Wyo. (Clark and others, 2001). As a result of this time-specific change to the water quality in the Powder River drainage basin, water years 1991–2010 were selected as the long-term trend analysis period to exclude pre-1991 characteristics of water quality from Salt Creek on the Powder River that were related to conventional oil and gas production.

Many of the monitoring sites either did not have available data for water years 1991–2000, or data collection was inconsistent, thus making the sites ineligible for the trend analysis. Because of inconsistencies in data collection, trends were evaluated for a subset of constituents, including specific conductance, SAR, and the primary contributors to SAR (calcium, magnesium, and sodium). For some sites, only specific conductance was available for water years 1991–2000. Long-term trends in flow-adjusted specific conductance values were evaluated at 8 sites, and long-term trends in flow-adjusted SAR values were evaluated at 5 sites in the study area.

Specific Conductance

Sites analyzed for the trend period of 1991–2010 for specific conductance included 2 sites in the Tongue River drainage basin, 5 sites in the Powder River drainage basin, and 1 site on the Belle Fourche River (appendix 2). Results of the seasonal Kendall test applied to flow-adjusted specific conductance values for water years 1991–2010 indicated no significant ($p>0.05$) trends were determined for Goose Creek (site T3) and the Tongue River at the Stateline (site T6) in the Tongue River drainage basin. In the Powder River drainage basin, no significant trends in flow-adjusted specific conductance values were determined for Salt Creek (site P1), the Powder River at Sussex (site P2), the Powder River at Arvada (site P13), the Powder River at Moorhead (site P23), and the Little Powder River (site P27). No significant trend in flow-adjusted specific conductance values was determined for the Belle Fourche River below Moorcroft (site B4).

Sodium Adsorption Ratios

Sites analyzed for the trend period of 1991–2010 for SAR included four sites in the Powder River drainage basin and one site on the Belle Fourche River (appendix 2). In the Powder River drainage basin, results of the seasonal Kendall test applied to flow-adjusted SAR values indicated a significant ($p<0.05$) upward trend for the Powder River at Arvada (site P13) for water years 1991–2010. No significant ($p>0.05$) trend was determined for flow-adjusted SAR values for Salt Creek (site P1), the Powder River at Sussex (site P2), and the Little Powder River above Dry Creek (site P27). No significant trend was determined for flow-adjusted SAR values for the Belle Fourche River below Moorcroft (site B4) for water years 1991–2010.

Results of the seasonal Kendall test applied to flow-adjusted calcium and magnesium concentrations, which have an inverse relation with SAR, indicated significant ($p<0.05$) downward trends for the Powder River at Arvada (site P13) for water years 1991–2010. Results of the seasonal Kendall test applied to flow-adjusted sodium concentrations, which have a direct relation with SAR, indicated a significant upward trend for the Powder River at Arvada (site P13). Downward trends in calcium and magnesium concentrations may indicate precipitation of carbonate minerals, such as calcite and dolomite, as a result of CBNG development. Jackson and Reddy (2007b) observed a decrease in calcium concentrations, but not in magnesium concentrations, as a result of precipitation from CBNG outfalls to impoundments; however, their study was focused on geochemical reactions in ponds, which may have different chemistry and saturation characteristics than the Powder River at Arvada (site P13). The source of increased sodium likely is CBNG-produced waters that are discharged into tributary drainages of the Powder River upstream from Arvada, Wyo. Continued water-quality monitoring of the Powder River is important for determining whether these apparent CBNG effects will be relatively persistent or if other water-quality changes will occur as CBNG production declines, as well as whether changes in the water quality of Salt Creek during water years 2005–2010 will affect the Powder River at Arvada with the passage of additional time.

Although no significant ($p>0.05$) trend was determined for flow-adjusted SAR values for the Belle Fourche River below Moorcroft (site B4), an upward trend in flow-adjusted magnesium concentrations was significant ($p<0.05$) for water years 1991–2010. Trends in magnesium concentrations were significant for all three trend periods. As previously described, the source affecting the upward trend in flow-adjusted magnesium concentrations may be magnesium chloride, which is used throughout the year in the Belle Fourche River drainage basin (Tetra Tech, Inc., 2011) for de-icing and dust suppression.

Summary

The Powder River structural basin in northeastern Wyoming and southeastern Montana is an area of ongoing coalbed natural gas (CBNG) development. Produced waters associated with CBNG development in Wyoming are managed with a variety of techniques, including surface impoundments and discharges into stream drainages. The interaction of CBNG-produced waters with the atmosphere and the semiarid soils of the Powder River structural basin can affect water chemistry in several ways. Specific conductance and sodium adsorption ratios (SAR) of CBNG-produced waters that are discharged to streams have been of particular concern because they have the potential to affect the use of the water for irrigation. Water-quality monitoring has been conducted since 2001 at main-stem and tributary sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins in response to concerns about CBNG effects. A study was conducted to summarize characteristics for stream-water quality for water years 2001–10 (October 1, 2000, to September 30, 2010), and examine trends in specific conductance, SAR, and primary constituents that contribute to specific conductance and SAR for changes through time (water years 1991–2010) that may have occurred as a result of CBNG development. Specific conductance and SAR are the focus characteristics of this report. Dissolved calcium, magnesium, and sodium, which are primary contributors to specific conductance and SAR, as well as dissolved alkalinity, chloride, and sulfate, which are other primary contributors to specific conductance, also are described.

Stream-water quality in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins was variable during water years 2001–10, in part because of variations in streamflow. In general, annual runoff was less than average during water years 2001–06 and near or above average during water years 2007–10. Streamflow measured during sampling events for the Tongue River near the Wyoming-Montana State line ranged from 10 cubic feet per second (ft^3/s) to 5,430 ft^3/s during water years 2001–10. Streamflow measured during sampling events for the Powder River at Moorhead, Mont., ranged from 0.57 to 5,220 ft^3/s. Streamflow ranged from 0.01 to 121 ft^3/s during sampling events for the Cheyenne River near Spencer, Wyo., during water years 2005–10 and from 0.02 to 599 ft^3/s for the Belle Fourche River downstream from Moorcroft, Wyo., during water years 2001–10.

The stream water of the Tongue River drainage basin had the smallest specific conductance values, sodium adsorption ratios, and major ion concentrations. Sites in the Tongue River drainage basin typically had the smallest range of specific conductance and SAR values. Median specific conductance values at sites in the Tongue River drainage basin ranged from 411 microsiemens per centimeter at 25°C (µS/cm at 25°C) for the Tongue River at Monarch, Wyo., during water years 2004–10 to 1,460 µS/cm at 25°C for Prairie Dog Creek near Acme, Wyo., during water years 2001–10. Median SAR values for sites in the Tongue River drainage basin ranged from 0.32 to 1.3. The Powder River drainage basin has the largest drainage area and most diverse site conditions among the four major drainage basins. Median specific conductance values in the basin ranged from 672 µS/cm at 25°C for Clear Creek near Buffalo, Wyo., during water years 2001–10 to 7,350 µS/cm at 25°C for SA Creek near Moorhead, Mont., during water years 2004–10. Sites in the Powder River drainage basin had the largest range of median SAR values (0.87 to 32.8) during water years 2001–10.

Trend analyses using the seasonal Kendall test with flow-adjusted concentrations were conducted to determine changes to water quality through time in sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins. Trends were evaluated for water years 2001–10 for 17 sites, which generally were on the main-stem streams and primary tributaries. Trends were evaluated for water years 2005–10 for 26 sites to increase the spatial coverage of sites. Trends were evaluated for water years 1991–2010 for eight sites to include water-quality data collected prior to widespread CBNG development and expand the temporal context of trends.

Consistent patterns were not observed in trend results for water years 2001–10 for flow-adjusted specific conductance and SAR values in the Tongue, Powder, and Belle Fourche River drainage basins. Significant (p-values less than 0.05) upward trends in flow-adjusted specific conductance values were determined for 3 sites, a downward trend was determined for 1 site, and no significant (p-value greater than 0.05) trends were determined for 13 sites. One of the sites with a significant upward trend in flow-adjusted specific conductance was the Tongue River at the Wyoming-Montana State line. Trend results for flow-adjusted concentrations of individual constituents indicated calcium, chloride, and sulfate contributed to the upward trend. Large concentrations of calcium, chloride, and sulfate typically are not associated with coalbed waters. Although no corresponding trends were determined for flow-adjusted specific conductance values, significant upward trends in flow-adjusted alkalinity concentrations were determined for the Powder River at Arvada, Wyo., and at Moorhead, Mont. Discharges of CBNG-produced waters, which typically are dominated by sodium and bicarbonate, likely are the sources affecting the upward trend in alkalinity; however, no corresponding upward trends in flow-adjusted sodium concentrations were determined. Significant (p-values less than 0.05) upward trends for water years 2001–10 in flow-adjusted SAR values were determined for 2 sites and no significant (p-value greater than 0.05) trends were determined for 15 sites. No trends in flow-adjusted SAR values were determined for the Tongue River at the Wyoming-Montana State line or for the Powder River at Moorhead, Mont. One of the sites with a significant upward trend in flow-adjusted SAR values was the Powder River at Arvada, Wyo.; however, no significant trends were determined for flow-adjusted concentrations of calcium, magnesium, and sodium.

For water years 2005–10, significant upward trends in flow-adjusted specific conductance values were determined for 9 sites, downward trends were determined for 4 sites, and no significant trends were determined for 13 sites. A significant upward trend was determined for flow-adjusted specific conductance values for the Tongue River at the Wyoming-Montana State line; however, a significant upward trend also was determined at a site on the Tongue River at Monarch, Wyo., which is upstream from CBNG development. Salt Creek, which has had a substantial effect on the water quality of the Powder River through time, had a downward trend in flow-adjusted specific conductance. Significant downward trends in flow-adjusted concentrations of sodium, alkalinity, and chloride contributed to the downward trend in specific conductance for Salt Creek. Several of the sites with upward trends in flow-adjusted specific conductance, including the Little Powder River, were in the plains in the eastern part of the study area. Significant upward trends in flow-adjusted SAR values for water years 2005–10 were determined for 4 sites, downward trends were determined for 5 sites, and no significant trends were determined for 17 sites. No trends in flow-adjusted SAR values were determined for the Tongue River at the Wyoming-Montana State line or for the Powder River at Moorhead, Mont.

Results of the seasonal Kendall test applied to flow-adjusted specific conductance values for water years 1991–2010 indicated no significant trend for eight sites in the Tongue, Powder, and Belle Fourche River drainage basins. No significant trend in flow-adjusted specific conductance was determined for the Tongue River at the Wyoming-Montana State line and the Powder River at Moorhead, Mont. Results of the seasonal Kendall test applied to flow-adjusted SAR values for water years 1991–2010 indicated an upward trend for one site and no significant trend for four sites in the Powder and Belle Fourche River drainage basins. The significant upward trend in flow-adjusted SAR values was determined for the Powder River at Arvada, Wyo., during water years 1991–2010. A significant upward trend in flow-adjusted sodium concentrations and significant downward trends in flow-adjusted concentrations of calcium and magnesium also were determined.

Results indicate that CBNG development in the Powder River structural basin may have contributed to some trends, such as the upward trend in flow-adjusted SAR for the Powder River at Arvada, Wyo., for water years 1991–2010. An upward trend in flow-adjusted alkalinity concentrations for water years 2001–10 also was determined for the Powder River at Arvada, Wyo. Trend results are consistent with changes that can occur from the addition of sodium and bicarbonate associated with CBNG-produced waters to the Powder River. Upward trends in constituents at other sites, including the Belle Fourche River, may be the result of declining CBNG development, indicating that CBNG-produced waters may have had a dilution effect on some streams. The factors affecting other trends could not be determined because multiple factors could have been affecting the stream-water quality or because trends were observed at sites upstream from CBNG development that may have affected water-quality trends at sites downstream from CBNG development.

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Appendixes

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
T1	06299980	Streamflow, instantaneous, ft^3/s	90	30	71	99	183	2,520
T1	06299980	pH, in standard units	89	7.7	8.1	8.3	8.5	8.8
T1	06299980	Specific conductance, in µS/cm	90	177	316	411	443	545
T1	06299980	Dissolved solids, in mg/L	90	106	187	243	271	337
T1	06299980	Dissolved solids, in tons per day	90	24.3	50.2	68.8	102	1,144
T1	06299980	Calcium, dissolved, in mg/L	90	22.1	36.2	46.7	50.2	67.7
T1	06299980	Magnesium, dissolved, in mg/L	90	6.67	15.0	20.1	22.2	30.8
T1	06299980	Sodium adsorption ratio (unitless)	90	0.12	0.26	0.32	0.38	0.79
T1	06299980	Sodium, dissolved, in mg/L	90	2.45	7.69	10.4	12.8	26.8
T1	06299980	Alkalinity, in mg/L as calcium carbonate	90	80.8	139	177	189	235
T1	06299980	Chloride, dissolved, in mg/L	90	0.54	1.21	1.51	1.86	3.60
T1	06299980	Sulfate, dissolved, in mg/L	90	8.26	28.8	44.3	54.3	110
T2	06304500	Streamflow, instantaneous, ft^3/s	103	2.1	20	31	44	1,180
T2	06304500	pH, in standard units	103	7.7	8.1	8.3	8.5	8.7
T2	06304500	Specific conductance, in µS/cm	103	124	553	643	690	984
T2	06304500	Dissolved solids, in mg/L	99	69.3	341	395	427	640
T2	06304500	Dissolved solids, in tons per day	99	3.70	23.2	31.9	44.5	593
T2	06304500	Calcium, dissolved, in mg/L	98	12.0	51.4	61.2	65.4	87.9
T2	06304500	Magnesium, dissolved, in mg/L	98	5.50	33.9	39.6	44.7	67.7
T2	06304500	Sodium adsorption ratio (unitless)	98	0.19	0.43	0.47	0.52	2.2
T2	06304500	Sodium, dissolved, in mg/L	98	3.16	16.5	19.5	22.2	89.4
T2	06304500	Alkalinity, in mg/L as calcium carbonate	99	52.2	206	246	268	318
T2	06304500	Chloride, dissolved, in mg/L	99	0.75	3.60	4.48	5.27	117
T2	06304500	Sulfate, dissolved, in mg/L	99	9.08	74.5	90.1	109	270
T3	06305500	Streamflow, instantaneous, ft^3/s	103	3.8	46	66	98	1,790
T3	06305500	pH, in standard units	103	7.8	8.1	8.3	8.5	8.9
T3	06305500	Specific conductance, in µS/cm	103	110	540	639	690	868
T3	06305500	Dissolved solids, in mg/L	98	75.4	347	410	448	571
T3	06305500	Dissolved solids, in tons per day	98	4.63	52.4	72.1	90.1	891
T3	06305500	Calcium, dissolved, in mg/L	98	10.5	50.6	59.4	64.0	75.8
T3	06305500	Magnesium, dissolved, in mg/L	98	4.39	30.9	37.1	42.1	49.6
T3	06305500	Sodium adsorption ratio (unitless)	98	0.19	0.51	0.57	0.63	1.0
T3	06305500	Sodium, dissolved, in mg/L	98	2.93	19.0	23.6	25.8	42.3
T3	06305500	Alkalinity, in mg/L as calcium carbonate	97	43.0	200	229	246	292
T3	06305500	Chloride, dissolved, in mg/L	98	0.71	4.97	6.27	8.06	20.7
T3	06305500	Sulfate, dissolved, in mg/L	98	10.4	91.6	110	125	190
T4	06306200	Streamflow, instantaneous, ft^3/s	87	0.53	9.0	13	29	116
T4	06306200	pH, in standard units	87	7.7	8.1	8.2	8.3	8.5

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
T4	06306200	Specific conductance, in µS/cm	87	425	670	936	1,030	1,240
T4	06306200	Dissolved solids, in mg/L	87	275	448	622	705	891
T4	06306200	Dissolved solids, in tons per day	87	1.27	17.8	22.8	36.7	177
T4	06306200	Calcium, dissolved, in mg/L	87	42.8	72.7	98.1	114	145
T4	06306200	Magnesium, dissolved, in mg/L	87	21.2	37.6	56.7	62.7	77.1
T4	06306200	Sodium adsorption ratio (unitless)	87	0.32	0.41	0.50	0.58	0.89
T4	06306200	Sodium, dissolved, in mg/L	87	10.7	17.2	26.3	31.4	44.8
T4	06306200	Alkalinity, in mg/L as calcium carbonate	86	118	214	286	321	423
T4	06306200	Chloride, dissolved, in mg/L	87	1.20	2.25	3.27	4.39	7.86
T4	06306200	Sulfate, dissolved, in mg/L	87	80.3	159	223	248	368
T5	06306250	Streamflow, instantaneous, ft^3/s	131	0.21	11	18	36	127
T5	06306250	pH, in standard units	129	7.6	8.0	8.2	8.3	8.5
T5	06306250	Specific conductance, in µS/cm	131	642	1,240	1,460	1,670	2,510
T5	06306250	Dissolved solids, in mg/L	131	427	912	1,089	1,301	2,157
T5	06306250	Dissolved solids, in tons per day	131	1.01	34.3	50.3	76.7	398
T5	06306250	Calcium, dissolved, in mg/L	131	37.5	111	135	152	209
T5	06306250	Magnesium, dissolved, in mg/L	131	20.5	71.1	88.2	105	167
T5	06306250	Sodium adsorption ratio (unitless)	131	0.57	1.1	1.3	1.6	3.6
T5	06306250	Sodium, dissolved, in mg/L	131	22.9	63.6	76.0	105	216
T5	06306250	Alkalinity, in mg/L as calcium carbonate	131	155	275	317	361	488
T5	06306250	Chloride, dissolved, in mg/L	131	1.93	3.94	4.79	5.95	9.03
T5	06306250	Sulfate, dissolved, in mg/L	131	163	406	506	639	1,156
T6	06306300	Streamflow, instantaneous, ft^3/s	149	10	131	181	310	5,430
T6	06306300	pH, in standard units	147	7.7	8.2	8.3	8.5	8.8
T6	06306300	Specific conductance, in µS/cm	149	186	488	636	725	1,280
T6	06306300	Dissolved solids, in mg/L	149	108	302	399	466	776
T6	06306300	Dissolved solids, in tons per day	149	21.0	151	186	297	3,580
T6	06306300	Calcium, dissolved, in mg/L	149	20.1	45.9	57.0	63.1	78.9
T6	06306300	Magnesium, dissolved, in mg/L	149	7.83	24.2	34.2	39.5	63.2
T6	06306300	Sodium adsorption ratio (unitless)	149	0.23	0.60	0.73	0.86	2.8
T6	06306300	Sodium, dissolved, in mg/L	149	4.97	20.4	28.2	35.4	124
T6	06306300	Alkalinity, in mg/L as calcium carbonate	149	73.1	170	214	239	356
T6	06306300	Chloride, dissolved, in mg/L	149	0.83	3.04	4.11	5.19	7.93
T6	06306300	Sulfate, dissolved, in mg/L	149	20.5	82.3	123	151	302
P1	06313400	Streamflow, instantaneous, ft^3/s	110	4.5	12	15	18	384
P1	06313400	pH, in standard units	110	7.7	8.1	8.2	8.4	8.9
P1	06313400	Specific conductance, in µS/cm	110	1,110	5,490	5,950	6,480	8,460
P1	06313400	Dissolved solids, in mg/L	110	792	3,720	3,948	4,276	5,529

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
P1	06313400	Dissolved solids, in tons per day	110	48.4	125	162	203	1,580
P1	06313400	Calcium, dissolved, in mg/L	110	50.2	119	154	203	287
P1	06313400	Magnesium, dissolved, in mg/L	110	21.3	56.0	64.8	73.9	144
P1	06313400	Sodium adsorption ratio (unitless)	110	4.9	14.2	18.0	20.8	30.0
P1	06313400	Sodium, dissolved, in mg/L	110	164	938	1,078	1,192	1,488
P1	06313400	Alkalinity, in mg/L as calcium carbonate	110	75.7	236	310	365	640
P1	06313400	Chloride, dissolved, in mg/L	110	39.2	890	1,046	1,203	1,646
P1	06313400	Sulfate, dissolved, in mg/L	110	341	1,093	1,222	1,425	2,325
P2	06313500	Streamflow, instantaneous, ft^3/s	195	3.7	53	110	160	1,410
P2	06313500	pH, in standard units	194	7.6	8.1	8.2	8.3	8.6
P2	06313500	Specific conductance, in µS/cm	195	545	1,960	2,270	2,940	6,240
P2	06313500	Dissolved solids, in mg/L	195	338	1,360	1,589	2,046	4,075
P2	06313500	Dissolved solids, in tons per day	195	40.7	264	428	603	5,924
P2	06313500	Calcium, dissolved, in mg/L	194	41.8	122	141	156	288
P2	06313500	Magnesium, dissolved, in mg/L	195	13.2	45.9	52.0	58.9	103
P2	06313500	Sodium adsorption ratio (unitless)	194	1.5	4.3	5.1	7.4	21.1
P2	06313500	Sodium, dissolved, in mg/L	195	43.3	220	281	423	1,128
P2	06313500	Alkalinity, in mg/L as calcium carbonate	195	82.9	183	213	236	330
P2	06313500	Chloride, dissolved, in mg/L	195	28.0	156	214	336	1,186
P2	06313500	Sulfate, dissolved, in mg/L	195	134	556	663	869	1,634
P3	06313540	Streamflow, instantaneous, ft^3/s	21	0.06	0.20	0.26	0.55	1.6
P3	06313540	pH, in standard units	21	7.9	8.1	8.2	8.4	8.7
P3	06313540	Specific conductance, in µS/cm	21	3,140	3,480	3,640	3,820	4,700
P3	06313540	Dissolved solids, in mg/L	21	2,215	2,534	2,592	2,718	3,429
P3	06313540	Dissolved solids, in tons per day	21	0.59	1.45	1.85	3.74	11.1
P3	06313540	Calcium, dissolved, in mg/L	21	17.5	57.6	86.4	152	271
P3	06313540	Magnesium, dissolved, in mg/L	21	32.1	65.6	69.3	77.5	117
P3	06313540	Sodium adsorption ratio (unitless)	21	8.5	11.0	13.0	16.1	25.3
P3	06313540	Sodium, dissolved, in mg/L	21	521	639	719	767	859
P3	06313540	Alkalinity, in mg/L as calcium carbonate	3	412	—	578	—	651
P3	06313540	Chloride, dissolved, in mg/L	3	18.3	—	26.7	—	26.9
P3	06313540	Sulfate, dissolved, in mg/L	3	1,319	—	1,827	—	2,035
P4	06313560	Streamflow, instantaneous, ft^3/s	63	0.10	1.6	3.5	4.6	14
P4	06313560	pH, in standard units	63	8.1	8.3	8.4	8.6	9.1
P4	06313560	Specific conductance, in µS/cm	63	2,010	3,220	3,600	3,850	5,250
P4	06313560	Dissolved solids, in mg/L	63	1,401	2,145	2,479	2,591	4,224
P4	06313560	Dissolved solids, in tons per day	63	0.60	12.3	21.7	28.2	56.2
P4	06313560	Calcium, dissolved, in mg/L	61	8.07	27.0	32.5	41.5	161

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
P4	06313560	Magnesium, dissolved, in mg/L	63	30.8	38.2	45.8	65.8	174
P4	06313560	Sodium adsorption ratio (unitless)	61	9.4	15.5	19.1	24.5	27.8
P4	06313560	Sodium, dissolved, in mg/L	63	390	687	774	871	1,037
P4	06313560	Alkalinity, in mg/L as calcium carbonate	4	385	—	1,245	—	1,548
P4	06313560	Chloride, dissolved, in mg/L	4	21.9	—	23.7	—	30.7
P4	06313560	Sulfate, dissolved, in mg/L	4	566	—	895	—	1,780
P5	06313585	Streamflow, instantaneous, ft³/s	75	0.45	1.3	2.8	6.0	16
P5	06313585	pH, in standard units	75	8.2	8.6	8.7	8.8	9.1
P5	06313585	Specific conductance, in µS/cm	75	1,180	1,590	2,560	2,840	3,820
P5	06313585	Dissolved solids, in mg/L	75	766	1,019	1,710	1,904	2,563
P5	06313585	Dissolved solids, in tons per day	75	2.30	6.89	12.3	16.2	35.5
P5	06313585	Calcium, dissolved, in mg/L	73	8.02	15.3	22.2	32.2	68.4
P5	06313585	Magnesium, dissolved, in mg/L	75	11.4	22.9	31.1	37.6	86.5
P5	06313585	Sodium adsorption ratio (unitless)	73	5.9	11.9	16.0	19.0	26.1
P5	06313585	Sodium, dissolved, in mg/L	75	201	336	560	634	774
P5	06313585	Alkalinity, in mg/L as calcium carbonate	6	469	502	621	642	816
P5	06313585	Chloride, dissolved, in mg/L	6	23.9	25.6	28.5	31.8	40.5
P5	06313585	Sulfate, dissolved, in mg/L	6	54.1	76.4	173	287	434
P6	06313590	Streamflow, instantaneous, ft³/s	88	0.07	41	115	186	761
P6	06313590	pH, in standard units	88	7.8	8.2	8.3	8.4	8.8
P6	06313590	Specific conductance, in µS/cm	88	723	1,995	2,340	2,935	5,310
P6	06313590	Dissolved solids, in mg/L	88	462	1,395	1,597	2,030	4,093
P6	06313590	Dissolved solids, in tons per day	88	0.77	230	483	722	2,858
P6	06313590	Calcium, dissolved, in mg/L	88	17.2	118	130	147	291
P6	06313590	Magnesium, dissolved, in mg/L	88	20.7	46.0	52.0	63.8	124
P6	06313590	Sodium adsorption ratio (unitless)	88	1.9	4.9	5.6	7.0	21.7
P6	06313590	Sodium, dissolved, in mg/L	88	66.5	256	303	410	770
P6	06313590	Alkalinity, in mg/L as calcium carbonate	88	122	188	227	275	1,158
P6	06313590	Chloride, dissolved, in mg/L	88	32.6	146	198	286	565
P6	06313590	Sulfate, dissolved, in mg/L	88	204	559	692	890	1,973
P7	06313604	Streamflow, instantaneous, ft³/s	71	0.04	0.53	0.99	1.8	2.8
P7	06313604	pH, in standard units	71	8.3	8.6	8.7	8.8	9.5
P7	06313604	Specific conductance, in µS/cm	71	1,940	3,260	3,430	3,740	3,900
P7	06313604	Dissolved solids, in mg/L	71	1,430	2,154	2,255	2,445	2,537
P7	06313604	Dissolved solids, in tons per day	71	0.22	3.14	6.40	11.6	18.9
P7	06313604	Calcium, dissolved, in mg/L	71	10.3	14.5	16.7	19.3	31.5
P7	06313604	Magnesium, dissolved, in mg/L	71	14.9	19.3	22.1	26.6	32.4
P7	06313604	Sodium adsorption ratio (unitless)	71	18.2	28.4	29.8	31.7	37.1

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
P7	06313604	Sodium, dissolved, in mg/L	71	446	772	813	851	1,007
P7	06313604	Alkalinity, in mg/L as calcium carbonate	4	1,037	—	1,486	—	1,955
P7	06313604	Chloride, dissolved, in mg/L	4	22.9	—	32.8	—	34.5
P7	06313604	Sulfate, dissolved, in mg/L	4	27.5	—	49.0	—	110
P8	06313605	Streamflow, instantaneous, ft³/s	114	1.4	52	110	172	1,030
P8	06313605	pH, in standard units	114	7.6	8.2	8.3	8.4	9.1
P8	06313605	Specific conductance, in µS/cm	114	726	2,050	2,375	2,870	5,790
P8	06313605	Dissolved solids, in mg/L	114	469	1,405	1,649	2,031	3,830
P8	06313605	Dissolved solids, in tons per day	114	9.64	277	441	676	5,796
P8	06313605	Calcium, dissolved, in mg/L	114	15.6	113	130	148	223
P8	06313605	Magnesium, dissolved, in mg/L	114	20.4	45.5	52.4	62.8	108
P8	06313605	Sodium adsorption ratio (unitless)	114	1.9	5.0	5.6	7.2	26.7
P8	06313605	Sodium, dissolved, in mg/L	114	67.5	259	307	404	1,037
P8	06313605	Alkalinity, in mg/L as calcium carbonate	114	103	210	248	304	2,091
P8	06313605	Chloride, dissolved, in mg/L	114	32.6	146	198	258	926
P8	06313605	Sulfate, dissolved, in mg/L	114	116	553	686	863	1,665
P9	06313633	Streamflow, instantaneous, ft³/s	46	0.03	0.20	1.2	1.9	3.6
P9	06313633	pH, in standard units	46	7.6	8.8	8.9	9.0	9.4
P9	06313633	Specific conductance, in µS/cm	46	1,050	1,310	1,370	1,650	4,840
P9	06313633	Dissolved solids, in mg/L	46	635	803	871	1,172	3,201
P9	06313633	Dissolved solids, in tons per day	46	0.05	1.04	2.70	4.33	9.28
P9	06313633	Calcium, dissolved, in mg/L	45	6.96	12.4	16.2	21.8	92.0
P9	06313633	Magnesium, dissolved, in mg/L	46	8.07	11.1	14.5	24.9	70.6
P9	06313633	Sodium adsorption ratio (unitless)	45	4.8	10.9	12.7	14.9	37.7
P9	06313633	Sodium, dissolved, in mg/L	46	196	271	291	325	1,160
P9	06313633	Alkalinity, in mg/L as calcium carbonate	3	175	—	475	—	484
P9	06313633	Chloride, dissolved, in mg/L	3	22.9	—	38.9	—	46.3
P9	06313633	Sulfate, dissolved, in mg/L	3	44.6	—	66.6	—	881
P10	06313750	Streamflow, instantaneous, ft³/s	52	0.03	0.32	0.66	1.6	15
P10	06313750	pH, in standard units	52	7.5	8.3	8.6	8.8	9.3
P10	06313750	Specific conductance, in µS/cm	52	776	1,220	1,635	2,160	3,690
P10	06313750	Dissolved solids, in mg/L	52	505	721	1,060	1,469	2,824
P10	06313750	Dissolved solids, in tons per day	52	0.11	0.67	1.94	6.51	35.0
P10	06313750	Calcium, dissolved, in mg/L	52	5.89	13.1	17.0	32.5	234
P10	06313750	Magnesium, dissolved, in mg/L	52	2.87	6.05	8.97	18.0	150
P10	06313750	Sodium adsorption ratio (unitless)	52	2.8	9.8	15.8	24.6	33.8
P10	06313750	Sodium, dissolved, in mg/L	52	115	238	327	500	768

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
P10	06313750	Alkalinity, in mg/L as calcium carbonate	5	923	—	1,188	—	1,283
P10	06313750	Chloride, dissolved, in mg/L	5	14.0	—	16.9	—	28.3
P10	06313750	Sulfate, dissolved, in mg/L	5	0.50	—	5.63	—	34.0
P11	06316400	Streamflow, instantaneous, ft^3/s	193	0.01	5.1	11	21	422
P11	06316400	pH, in standard units	193	7.4	8.0	8.1	8.3	8.6
P11	06316400	Specific conductance, in µS/cm	193	335	1,280	1,630	2,140	3,660
P11	06316400	Dissolved solids, in mg/L	193	245	1,028	1,316	1,834	3,363
P11	06316400	Dissolved solids, in tons per day	193	0.06	20.9	38.9	64.6	343
P11	06316400	Calcium, dissolved, in mg/L	193	32.2	121	150	192	336
P11	06316400	Magnesium, dissolved, in mg/L	193	12.8	62.3	80.0	107	207
P11	06316400	Sodium adsorption ratio (unitless)	193	0.45	1.6	1.9	2.5	5.7
P11	06316400	Sodium, dissolved, in mg/L	193	17.9	87.3	115	178	476
P11	06316400	Alkalinity, in mg/L as calcium carbonate	192	70.0	180	215	244	468
P11	06316400	Chloride, dissolved, in mg/L	193	1.69	6.12	8.26	10.5	61.0
P11	06316400	Sulfate, dissolved, in mg/L	193	94.3	531	702	1,009	1,948
P12	06316900	Streamflow, instantaneous, ft^3/s	40	0.01	0.01	0.03	0.06	7.1
P12	06316900	pH, in standard units	40	7.6	8.6	8.9	9.0	9.3
P12	06316900	Specific conductance, in µS/cm	40	1,150	2,080	2,740	3,085	4,110
P12	06316900	Dissolved solids, in mg/L	40	743	1,414	1,851	2,065	2,755
P12	06316900	Dissolved solids, in tons per day	40	0.02	0.06	0.15	0.28	20.8
P12	06316900	Calcium, dissolved, in mg/L	40	4.16	9.38	10.4	16.2	275
P12	06316900	Magnesium, dissolved, in mg/L	40	3.77	8.31	11.1	17.2	125
P12	06316900	Sodium adsorption ratio (unitless)	40	1.0	22.1	32.8	39.3	46.7
P12	06316900	Sodium, dissolved, in mg/L	40	57.3	410	640	729	1,009
P12	06316900	Alkalinity, in mg/L as calcium carbonate	1	—	—	—	—	140
P12	06316900	Chloride, dissolved, in mg/L	1	—	—	—	—	6.09
P12	06316900	Sulfate, dissolved, in mg/L	1	—	—	—	—	1,254
P13	06317000	Streamflow, instantaneous, ft^3/s	193	0.08	70	118	213	2,260
P13	06317000	pH, in standard units	193	7.3	8.1	8.3	8.4	8.9
P13	06317000	Specific conductance, in µS/cm	193	651	1,990	2,270	2,610	5,170
P13	06317000	Dissolved solids, in mg/L	193	412	1,398	1,595	1,874	4,101
P13	06317000	Dissolved solids, in tons per day	193	0.89	332	494	828	9,775
P13	06317000	Calcium, dissolved, in mg/L	191	40.8	105	126	149	307
P13	06317000	Magnesium, dissolved, in mg/L	193	18.0	45.7	54.8	63.9	133
P13	06317000	Sodium adsorption ratio (unitless)	191	1.9	4.7	5.5	6.5	11.8
P13	06317000	Sodium, dissolved, in mg/L	193	61.6	245	295	367	752
P13	06317000	Alkalinity, in mg/L as calcium carbonate	193	76.8	194	225	271	521

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
P13	06317000	Chloride, dissolved, in mg/L	193	22.5	130	175	221	514
P13	06317000	Sulfate, dissolved, in mg/L	193	179	557	689	823	2,010
P14	06317020	Streamflow, instantaneous, ft^3/s	71	0.01	0.76	2.8	5.0	43
P14	06317020	pH, in standard units	71	7.6	8.0	8.3	8.4	9.0
P14	06317020	Specific conductance, in µS/cm	71	252	2,180	2,680	3,270	4,580
P14	06317020	Dissolved solids, in mg/L	71	218	1,569	2,024	2,512	4,013
P14	06317020	Dissolved solids, in tons per day	71	0.08	3.62	13.8	24.7	181
P14	06317020	Calcium, dissolved, in mg/L	70	19.6	63.0	104	153	253
P14	06317020	Magnesium, dissolved, in mg/L	71	6.80	57.6	90.9	124	236
P14	06317020	Sodium adsorption ratio (unitless)	70	1.3	6.3	7.2	7.9	12.3
P14	06317020	Sodium, dissolved, in mg/L	71	25.4	348	410	475	808
P14	06317020	Alkalinity, in mg/L as calcium carbonate	71	44.1	441	529	615	1,009
P14	06317020	Chloride, dissolved, in mg/L	71	2.76	15.6	17.5	19.9	40.6
P14	06317020	Sulfate, dissolved, in mg/L	71	84.3	600	1,033	1,346	2,256
P15	06317030	Streamflow, instantaneous, ft^3/s	75	0.002	0.37	2.6	5.4	82
P15	06317030	pH, in standard units	75	7.6	8.3	8.4	8.5	8.9
P15	06317030	Specific conductance, in µS/cm	75	1,090	2,690	3,440	4,320	7,410
P15	06317030	Dissolved solids, in mg/L	75	749	1,983	2,597	3,561	7,139
P15	06317030	Dissolved solids, in tons per day	75	0.02	3.40	14.2	26.8	326
P15	06317030	Calcium, dissolved, in mg/L	74	33.0	71.4	101	146	343
P15	06317030	Magnesium, dissolved, in mg/L	75	27.6	86.9	130	174	507
P15	06317030	Sodium adsorption ratio (unitless)	74	4.3	7.2	8.0	10.2	17.7
P15	06317030	Sodium, dissolved, in mg/L	75	152	412	505	713	1,229
P15	06317030	Alkalinity, in mg/L as calcium carbonate	6	126	371	418	449	509
P15	06317030	Chloride, dissolved, in mg/L	6	6.07	15.1	23.4	27.0	32.5
P15	06317030	Sulfate, dissolved, in mg/L	6	547	1,942	2,433	3,132	3,510
P16	06317095	Streamflow, instantaneous, ft^3/s	29	0.001	0.01	0.10	0.43	42
P16	06317095	pH, in standard units	29	8.0	8.3	8.4	8.5	8.8
P16	06317095	Specific conductance, in µS/cm	29	1,730	1,900	4,000	5,290	7,950
P16	06317095	Dissolved solids, in mg/L	29	1,121	1,277	2,920	4,866	8,313
P16	06317095	Dissolved solids, in tons per day	29	0.01	0.06	0.66	6.41	146
P16	06317095	Calcium, dissolved, in mg/L	29	7.65	11.1	72.6	199	356
P16	06317095	Magnesium, dissolved, in mg/L	29	5.74	10.5	97.8	328	628
P16	06317095	Sodium adsorption ratio (unitless)	29	3.4	8.9	11.8	22.8	31.6
P16	06317095	Sodium, dissolved, in mg/L	29	187	451	657	909	1,416
P16	06317095	Alkalinity, in mg/L as calcium carbonate	1	—	—	—	—	338
P16	06317095	Chloride, dissolved, in mg/L	1	—	—	—	—	19.9
P16	06317095	Sulfate, dissolved, in mg/L	1	—	—	—	—	3,146

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
P17	06317100	Streamflow, instantaneous, ft^3/s	73	2.8	70	135	231	1,660
P17	06317100	pH, in standard units	75	7.2	8.2	8.3	8.4	8.6
P17	06317100	Specific conductance, in µS/cm	75	741	1,710	2,200	2,540	3,560
P17	06317100	Dissolved solids, in mg/L	75	485	1,365	1,591	1,794	2,616
P17	06317100	Dissolved solids, in tons per day	73	12.7	327	544	928	2,982
P17	06317100	Calcium, dissolved, in mg/L	74	52.2	101	119	136	210
P17	06317100	Magnesium, dissolved, in mg/L	74	20.2	46.9	56.6	65.5	101
P17	06317100	Sodium adsorption ratio (unitless)	74	1.5	4.4	5.6	6.4	8.8
P17	06317100	Sodium, dissolved, in mg/L	74	70.0	209	302	343	506
P18	06320210	Streamflow, instantaneous, ft^3/s	113	4.4	28	42	67	2,340
P18	06320210	pH, in standard units	113	7.5	7.9	8.2	8.4	9.2
P18	06320210	Specific conductance, in µS/cm	113	104	470	672	783	1,010
P18	06320210	Dissolved solids, in mg/L	108	85.2	316	466	549	717
P18	06320210	Dissolved solids, in tons per day	108	7.29	39.6	50.5	65.9	938
P18	06320210	Calcium, dissolved, in mg/L	108	9.54	46.3	67.4	80.5	98.3
P18	06320210	Magnesium, dissolved, in mg/L	108	3.37	19.4	27.9	32.9	45.1
P18	06320210	Sodium adsorption ratio (unitless)	108	0.30	0.73	0.87	1.0	1.4
P18	06320210	Sodium, dissolved, in mg/L	108	4.24	23.0	33.6	41.4	62.6
P18	06320210	Alkalinity, in mg/L as calcium carbonate	107	29.0	106	142	168	233
P18	06320210	Chloride, dissolved, in mg/L	107	0.87	2.86	3.79	4.97	13.6
P18	06320210	Sulfate, dissolved, in mg/L	107	20.3	139	206	245	331
P19	06323550	Streamflow, instantaneous, ft^3/s	75	27	55	90	142	2,045
P19	06323550	pH, in standard units	75	7.4	7.9	8.2	8.4	8.7
P19	06323550	Specific conductance, in µS/cm	75	136	658	725	789	972
P19	06323550	Dissolved solids, in mg/L	75	99.2	449	502	561	725
P19	06323550	Dissolved solids, in tons per day	75	44.2	83.1	116	166	548
P19	06323550	Calcium, dissolved, in mg/L	75	14.4	64.7	75.3	82.4	110
P19	06323550	Magnesium, dissolved, in mg/L	75	4.13	25.3	30.1	33.8	46.3
P19	06323550	Sodium adsorption ratio (unitless)	75	0.30	0.77	0.87	0.92	1.1
P19	06323550	Sodium, dissolved, in mg/L	75	4.99	29.4	35.2	38.5	52.4
P19	06323550	Alkalinity, in mg/L as calcium carbonate	1	—	—	—	—	180
P19	06323550	Chloride, dissolved, in mg/L	1	—	—	—	—	5.45
P19	06323550	Sulfate, dissolved, in mg/L	1	—	—	—	—	319
P20	06324000	Streamflow, instantaneous, ft^3/s	204	0.24	43	70	103	2,230
P20	06324000	pH, in standard units	204	7.6	8.0	8.2	8.4	8.8
P20	06324000	Specific conductance, in µS/cm	204	175	914	1,060	1,240	2,020
P20	06324000	Dissolved solids, in mg/L	203	90.3	654	787	940	1,663
P20	06324000	Dissolved solids, in tons per day	203	1.04	109	143	194	1,327

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
P20	06324000	Calcium, dissolved, in mg/L	203	17.7	90.3	108	127	189
P20	06324000	Magnesium, dissolved, in mg/L	203	5.49	39.3	48.0	56.8	105
P20	06324000	Sodium adsorption ratio (unitless)	203	0.33	1.1	1.2	1.3	2.6
P20	06324000	Sodium, dissolved, in mg/L	203	6.53	48.6	59.2	70.2	169
P20	06324000	Alkalinity, in mg/L as calcium carbonate	203	48.3	165	195	223	321
P20	06324000	Chloride, dissolved, in mg/L	203	0.69	3.10	3.72	4.31	6.82
P20	06324000	Sulfate, dissolved, in mg/L	203	32.9	297	372	455	878
P21	06324200	Streamflow, instantaneous, ft³/s	52	0.01	0.33	0.73	1.2	17
P21	06324200	pH, in standard units	52	8.1	8.5	8.6	8.7	9.0
P21	06324200	Specific conductance, in µS/cm	52	1,700	2,785	3,185	3,910	11,200
P21	06324200	Dissolved solids, in mg/L	52	1,284	1,917	2,171	2,981	11,310
P21	06324200	Dissolved solids, in tons per day	52	0.31	2.07	4.04	7.07	88.8
P21	06324200	Calcium, dissolved, in mg/L	50	9.58	22.6	36.9	85.2	366
P21	06324200	Magnesium, dissolved, in mg/L	51	8.51	34.6	57.0	139	788
P21	06324200	Sodium adsorption ratio (unitless)	50	4.6	12.4	15.3	20.4	32.6
P21	06324200	Sodium, dissolved, in mg/L	51	223	626	659	730	2,458
P21	06324200	Alkalinity, in mg/L as calcium carbonate	4	333	—	690	—	1,275
P21	06324200	Chloride, dissolved, in mg/L	4	8.51	—	18.0	—	22.5
P21	06324200	Sulfate, dissolved, in mg/L	4	195	—	1,135	—	2,050
P22	06324300	Streamflow, instantaneous, ft³/s	65	0.001	0.01	0.04	0.35	52
P22	06324300	pH, in standard units	65	6.6	7.8	7.9	8.1	8.6
P22	06324300	Specific conductance, in µS/cm	65	1,710	6,600	7,350	7,810	8,630
P22	06324300	Dissolved solids, in mg/L	65	1,286	5,895	7,194	7,676	8,741
P22	06324300	Dissolved solids, in tons per day	65	0.02	0.22	0.84	4.67	201
P22	06324300	Calcium, dissolved, in mg/L	65	63.7	251	286	322	369
P22	06324300	Magnesium, dissolved, in mg/L	65	70.2	363	416	446	540
P22	06324300	Sodium adsorption ratio (unitless)	64	4.3	9.9	10.5	11.1	13.1
P22	06324300	Sodium, dissolved, in mg/L	64	212	1,060	1,159	1,291	1,498
P22	06324300	Alkalinity, in mg/L as calcium carbonate	6	353	373	467	552	659
P22	06324300	Chloride, dissolved, in mg/L	6	12.2	16.6	33.4	39.0	41.9
P22	06324300	Sulfate, dissolved, in mg/L	6	1,906	2,651	4,780	5,405	5,423
P23	06324500	Streamflow, instantaneous, ft³/s	206	0.57	94	200	329	5,220
P23	06324500	pH, in standard units	202	7.6	8.2	8.3	8.4	8.7
P23	06324500	Specific conductance, in µS/cm	206	356	1,560	1,820	2,100	3,660
P23	06324500	Dissolved solids, in mg/L	206	231	1,132	1,313	1,556	2,817
P23	06324500	Dissolved solids, in tons per day	206	4.29	379	687	1,105	8,882
P23	06324500	Calcium, dissolved, in mg/L	206	30.9	97.8	117	137	295
P23	06324500	Magnesium, dissolved, in mg/L	206	10.1	45.1	54.0	65.1	160

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
P23	06324500	Sodium adsorption ratio (unitless)	206	1.1	3.4	4.1	4.5	9.0
P23	06324500	Sodium, dissolved, in mg/L	206	27.2	164	214	250	520
P23	06324500	Alkalinity, in mg/L as calcium carbonate	206	78.4	169	203	244	458
P23	06324500	Chloride, dissolved, in mg/L	206	5.67	62.3	97.5	121	307
P23	06324500	Sulfate, dissolved, in mg/L	206	80.3	487	577	730	1,770
P24	06324870	Streamflow, instantaneous, ft^3/s	34	0.07	0.35	0.75	2.4	7.2
P24	06324870	pH, in standard units	34	7.1	7.9	8.1	8.2	8.4
P24	06324870	Specific conductance, in µS/cm	34	2,130	3,210	3,850	4,420	5,410
P24	06324870	Dissolved solids, in mg/L	34	1,769	3,002	3,682	4,371	5,472
P24	06324870	Dissolved solids, in tons per day	34	1.03	4.28	8.21	19.9	65.5
P24	06324870	Calcium, dissolved, in mg/L	34	127	231	301	396	507
P24	06324870	Magnesium, dissolved, in mg/L	34	121	234	264	322	503
P24	06324870	Sodium adsorption ratio (unitless)	34	1.4	2.5	3.0	3.6	4.6
P24	06324870	Sodium, dissolved, in mg/L	34	138	213	292	370	586
P25	06324940	Streamflow, instantaneous, ft^3/s	24	0.03	1.5	3.9	7.5	50
P25	06324940	pH, in standard units	24	7.6	8.0	8.1	8.2	8.4
P25	06324940	Specific conductance, in µS/cm	24	648	2,015	2,980	3,578	5,600
P25	06324940	Dissolved solids, in mg/L	24	478	1,604	2,507	3,204	5,363
P25	06324940	Dissolved solids, in tons per day	24	0.25	9.50	16.7	51.2	289
P25	06324940	Calcium, dissolved, in mg/L	24	32.9	94.6	147	199	350
P25	06324940	Magnesium, dissolved, in mg/L	24	24.1	92.3	143	207	396
P25	06324940	Sodium adsorption ratio (unitless)	24	1.9	3.8	4.7	5.6	7.6
P25	06324940	Sodium, dissolved, in mg/L	24	58.0	236	342	486	868
P26	06324950	Streamflow, instantaneous, ft^3/s	75	0.01	1.5	3.2	13	130
P26	06324950	pH, in standard units	75	7.6	8.0	8.2	8.3	8.4
P26	06324950	Specific conductance, in µS/cm	75	588	2,160	3,070	3,640	4,600
P26	06324950	Dissolved solids, in mg/L	75	404	1,716	2,463	3,049	4,017
P26	06324950	Dissolved solids, in tons per day	75	0.09	9.71	22.2	56.6	479
P26	06324950	Calcium, dissolved, in mg/L	75	23.4	114	155	188	313
P26	06324950	Magnesium, dissolved, in mg/L	75	10.8	73.8	108	127	230
P26	06324950	Sodium adsorption ratio (unitless)	75	1.7	4.4	6.1	7.7	11.2
P26	06324950	Sodium, dissolved, in mg/L	75	49.6	249	434	543	672
P27	06324970	Streamflow, instantaneous, ft^3/s	123	0.01	1.0	3.1	9.9	314
P27	06324970	pH, in standard units	123	7.4	7.9	8.1	8.2	8.5
P27	06324970	Specific conductance, in µS/cm	123	358	2,470	3,330	3,770	5,250
P27	06324970	Dissolved solids, in mg/L	123	225	1,868	2,716	3,136	4,585
P27	06324970	Dissolved solids, in tons per day	123	0.07	6.77	24.1	62.1	671
P27	06324970	Calcium, dissolved, in mg/L	123	17.6	119	163	189	313
P27	06324970	Magnesium, dissolved, in mg/L	123	7.38	78.8	111	129	211

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
P27	06324970	Sodium adsorption ratio (unitless)	123	1.9	5.6	6.9	7.9	10.6
P27	06324970	Sodium, dissolved, in mg/L	123	39.2	337	480	569	977
P27	06324970	Alkalinity, in mg/L as calcium carbonate	123	72.5	269	354	403	734
P27	06324970	Chloride, dissolved, in mg/L	123	6.09	38.8	55.7	90.2	298
P27	06324970	Sulfate, dissolved, in mg/L	123	75.9	986	1,436	1,726	2,555
C1	06365900	Streamflow, instantaneous, ft^3/s	48	0.002	0.02	0.03	0.06	4.3
C1	06365900	pH, in standard units	48	7.0	7.5	7.8	7.9	8.1
C1	06365900	Specific conductance, in µS/cm	48	263	3,170	3,645	4,085	5,590
C1	06365900	Dissolved solids, in mg/L	48	175	2,789	3,299	3,750	5,178
C1	06365900	Dissolved solids, in tons per day	48	0.02	0.13	0.32	0.51	2.05
C1	06365900	Calcium, dissolved, in mg/L	48	16.2	266	303	368	479
C1	06365900	Magnesium, dissolved, in mg/L	48	6.01	132	154	176	226
C1	06365900	Sodium adsorption ratio (unitless)	48	0.92	4.4	4.8	5.2	7.1
C1	06365900	Sodium, dissolved, in mg/L	48	17.1	357	410	490	732
C1	06365900	Alkalinity, in mg/L as calcium carbonate	48	46.0	301	348	386	465
C1	06365900	Chloride, dissolved, in mg/L	48	3.28	24.9	28.2	30.9	39.9
C1	06365900	Sulfate, dissolved, in mg/L	48	64.4	1,634	1,906	2,184	3,100
C2	06386500	Streamflow, instantaneous, ft^3/s	55	0.01	0.10	0.57	5.4	121
C2	06386500	pH, in standard units	54	7.6	8.0	8.2	8.4	8.4
C2	06386500	Specific conductance, in µS/cm	55	541	3,200	4,900	5,420	6,720
C2	06386500	Dissolved solids, in mg/L	55	363	2,607	4,093	4,597	5,986
C2	06386500	Dissolved solids, in tons per day	55	0.11	1.23	7.61	34.6	291
C2	06386500	Calcium, dissolved, in mg/L	55	31.2	149	243	307	407
C2	06386500	Magnesium, dissolved, in mg/L	55	10.7	71.0	110	132	174
C2	06386500	Sodium adsorption ratio (unitless)	55	2.3	7.3	10.4	11.5	13.7
C2	06386500	Sodium, dissolved, in mg/L	55	59.1	454	815	921	1,188
C2	06386500	Alkalinity, in mg/L as calcium carbonate	55	86.8	239	263	289	418
C2	06386500	Chloride, dissolved, in mg/L	55	5.27	65.3	97.1	113	148
C2	06386500	Sulfate, dissolved, in mg/L	55	150	1,508	2,467	2,809	3,491
B1	06425720	Streamflow, instantaneous, ft^3/s	87	0.02	0.50	1.5	2.8	23
B1	06425720	pH, in standard units	87	7.5	7.8	8.1	8.2	9.2
B1	06425720	Specific conductance, in µS/cm	87	1,680	2,570	2,860	3,260	6,210
B1	06425720	Dissolved solids, in mg/L	86	1,320	2,071	2,330	2,680	5,718
B1	06425720	Dissolved solids, in tons per day	86	0.18	3.72	8.93	15.5	108
B1	06425720	Calcium, dissolved, in mg/L	86	65.3	118	148	172	394
B1	06425720	Magnesium, dissolved, in mg/L	86	53.6	99.5	116	134	300
B1	06425720	Sodium adsorption ratio (unitless)	86	3.1	4.8	5.6	6.4	8.5
B1	06425720	Sodium, dissolved, in mg/L	86	173	312	372	438	825

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
B1	06425720	Alkalinity, in mg/L as calcium carbonate	80	90.1	243	300	366	778
B1	06425720	Chloride, dissolved, in mg/L	80	9.55	16.3	19.4	26.0	62.1
B1	06425720	Sulfate, dissolved, in mg/L	80	677	1,144	1,325	1,554	3,182
B2	06425900	Streamflow, instantaneous, ft^3/s	74	0.02	0.59	1.8	2.8	7.4
B2	06425900	pH, in standard units	74	7.4	8.1	8.2	8.3	8.8
B2	06425900	Specific conductance, in µS/cm	74	772	1,560	1,920	2,530	5,370
B2	06425900	Dissolved solids, in mg/L	74	511	1,096	1,400	2,033	5,383
B2	06425900	Dissolved solids, in tons per day	74	0.28	3.01	6.03	9.61	35.8
B2	06425900	Calcium, dissolved, in mg/L	74	27.2	64.2	93.9	148	392
B2	06425900	Magnesium, dissolved, in mg/L	74	19.9	44.8	71.2	109	335
B2	06425900	Sodium adsorption ratio (unitless)	74	1.8	4.0	4.9	5.7	7.5
B2	06425900	Sodium, dissolved, in mg/L	74	79.1	217	249	314	641
B2	06425900	Alkalinity, in mg/L as calcium carbonate	74	107	267	342	400	778
B2	06425900	Chloride, dissolved, in mg/L	74	10.9	16.8	24.5	46.9	121
B2	06425900	Sulfate, dissolved, in mg/L	74	234	429	684	1,109	3,215
B3	06426400	Streamflow, instantaneous, ft^3/s	115	0.05	1.6	3.1	7.6	46
B3	06426400	pH, in standard units	115	7.3	7.9	8.3	8.6	9.3
B3	06426400	Specific conductance, in µS/cm	115	1,020	2,440	2,780	2,990	4,540
B3	06426400	Dissolved solids, in mg/L	115	690	1,812	2,067	2,370	3,708
B3	06426400	Dissolved solids, in tons per day	115	0.40	8.15	17.1	39.1	179
B3	06426400	Calcium, dissolved, in mg/L	115	51.0	117	140	164	210
B3	06426400	Magnesium, dissolved, in mg/L	115	38.0	105	125	143	190
B3	06426400	Sodium adsorption ratio (unitless)	115	2.3	3.5	4.1	5.1	11.8
B3	06426400	Sodium, dissolved, in mg/L	115	88.0	244	281	337	798
B3	06426400	Alkalinity, in mg/L as calcium carbonate	115	98.9	226	286	341	626
B3	06426400	Chloride, dissolved, in mg/L	115	50.8	157	198	228	529
B3	06426400	Sulfate, dissolved, in mg/L	115	286	767	934	1,072	1,941
B4	06426500	Streamflow, instantaneous, ft^3/s	120	0.02	3.0	5.7	12	599
B4	06426500	pH, in standard units	120	7.3	8.0	8.3	8.6	9.2
B4	06426500	Specific conductance, in µS/cm	120	300	2,210	2,640	2,975	4,590
B4	06426500	Dissolved solids, in mg/L	120	203	1,617	1,983	2,334	3,784
B4	06426500	Dissolved solids, in tons per day	120	0.14	18.8	31.7	67.7	342
B4	06426500	Calcium, dissolved, in mg/L	119	21.4	102	120	143	266
B4	06426500	Magnesium, dissolved, in mg/L	119	8.76	83.3	105	131	178
B4	06426500	Sodium adsorption ratio (unitless)	119	1.2	4.0	5.1	5.8	8.7
B4	06426500	Sodium, dissolved, in mg/L	119	25.7	234	325	389	595
B4	06426500	Alkalinity, in mg/L as calcium carbonate	120	63.2	217	281	374	714

Appendix 1. Summary statistics for water-quality constituents for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–10.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius, mg/L, milligrams per liter; —, not calculated]

Site number (fig. 1)	USGS site identification number	Property or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
B4	06426500	Chloride, dissolved, in mg/L	120	3.42	98.3	138	184	414
B4	06426500	Sulfate, dissolved, in mg/L	120	70.6	729	945	1,148	1,738
B5	06428050	Streamflow, instantaneous, ft^3/s	104	3.4	9.7	20	55	245
B5	06428050	pH, in standard units	104	7.4	7.9	8.1	8.4	8.8
B5	06428050	Specific conductance, in µS/cm	104	646	1,640	1,900	2,040	2,490
B5	06428050	Dissolved solids, in mg/L	100	459	1,219	1,605	1,721	2,225
B5	06428050	Dissolved solids, in tons per day	100	20.4	44.5	79.5	187	638
B5	06428050	Calcium, dissolved, in mg/L	99	53.9	161	238	288	369
B5	06428050	Magnesium, dissolved, in mg/L	99	17.1	58.7	71.3	78.0	92.2
B5	06428050	Sodium adsorption ratio (unitless)	99	0.50	1.0	1.3	2.0	4.8
B5	06428050	Sodium, dissolved, in mg/L	99	24.1	69.6	92.2	136	258
B5	06428050	Alkalinity, in mg/L as calcium carbonate	100	72.7	156	177	204	276
B5	06428050	Chloride, dissolved, in mg/L	100	3.26	11.4	19.2	30.0	62.4
B5	06428050	Sulfate, dissolved, in mg/L	100	231	692	912	993	1,218

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.

[USGS, U.S. Geological Survey; —, not calculated; <, less than. Slope for unadjusted trends is the change per year in original measurement units; for flow-adjusted trends, the slopes reflect relative changes in units after adjustment for streamflow variability]

Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
T1	06299980	Unadjusted	2005–10	Specific conductance	63	0.085	0.495	2.21	No trend.
T1	06299980	Flow adjusted	2005–10	Specific conductance	63	0.324	0.005	0.022	Upward.
T1	06299980	Unadjusted	2005–10	Calcium	63	0.070	0.576	0.292	No trend.
T1	06299980	Flow adjusted	2005–10	Calcium	63	0.113	0.352	0.550	No trend.
T1	06299980	Unadjusted	2005–10	Magnesium	63	-0.028	0.852	-0.055	No trend.
T1	06299980	Flow adjusted	2005–10	Magnesium	63	0.268	0.022	0.326	Upward.
T1	06299980	Unadjusted	2005–10	Sodium adsorption ratio	63	-0.021	0.901	-0.001	No trend.
T1	06299980	Flow adjusted	2005–10	Sodium adsorption ratio	63	0.155	0.192	0.006	No trend.
T1	06299980	Unadjusted	2005–10	Sodium	63	-0.014	0.950	-0.018	No trend.
T1	06299980	Flow adjusted	2005–10	Sodium	63	0.155	0.192	0.272	No trend.
T1	06299980	Unadjusted	2005–10	Alkalinity	63	0.134	0.263	1.22	No trend.
T1	06299980	Flow adjusted	2005–10	Alkalinity	63	0.282	0.015	2.50	Upward.
T1	06299980	Unadjusted	2005–10	Chloride	63	0.282	0.015	0.040	Upward.
T1	06299980	Flow adjusted	2005–10	Chloride	63	0.296	0.011	0.065	Upward.
T1	06299980	Unadjusted	2005–10	Sulfate	63	0.028	0.852	0.261	No trend.
T1	06299980	Flow adjusted	2005–10	Sulfate	63	0.239	0.040	1.22	Upward.
T2	06304500	Unadjusted	2001–10	Specific conductance	56	-0.251	0.011	-9.75	Downward.
T2	06304500	Flow adjusted	2001–10	Specific conductance	56	0.064	0.523	1.97	No trend.
T2	06304500	Unadjusted	2001–10	Calcium	52	-0.220	0.073	-0.727	No trend.
T2	06304500	Flow adjusted	2001–10	Calcium	52	0.150	0.149	0.455	No trend.
T2	06304500	Unadjusted	2001–10	Magnesium	52	-0.130	0.341	-0.260	No trend.
T2	06304500	Flow adjusted	2001–10	Magnesium	52	0.120	0.371	0.223	No trend.
T2	06304500	Unadjusted	2001–10	Sodium adsorption ratio	52	-0.175	0.159	-0.004	No trend.
T2	06304500	Flow adjusted	2001–10	Sodium adsorption ratio	52	0.020	0.893	0.001	No trend.
T2	06304500	Unadjusted	2001–10	Sodium	52	-0.220	0.069	-0.287	No trend.
T2	06304500	Flow adjusted	2001–10	Sodium	52	0.030	0.787	0.059	No trend.
T2	06304500	Unadjusted	2001–10	Alkalinity	52	-0.020	0.872	-0.552	No trend.
T2	06304500	Flow adjusted	2001–10	Alkalinity	52	0.160	0.221	3.02	No trend.
T2	06304500	Unadjusted	2001–10	Chloride	52	-0.110	0.468	-0.042	No trend.
T2	06304500	Flow adjusted	2001–10	Chloride	52	0.220	0.163	0.060	No trend.
T2	06304500	Unadjusted	2001–10	Sulfate	52	-0.240	0.030	-2.83	Downward.
T2	06304500	Flow adjusted	2001–10	Sulfate	52	0.090	0.471	0.612	No trend.
T3	06305500	Unadjusted	1991–2010	Specific conductance	80	0.151	0.116	3.71	No trend.
T3	06305500	Flow adjusted	1991–2010	Specific conductance	80	-0.176	0.080	-2.56	No trend.
T3	06305500	Unadjusted	2001–10	Specific conductance	56	-0.277	0.039	-10.5	Downward.
T3	06305500	Flow adjusted	2001–10	Specific conductance	56	0.098	0.320	1.96	No trend.
T3	06305500	Unadjusted	2001–10	Calcium	52	-0.260	0.093	-0.946	No trend.
T3	06305500	Flow adjusted	2001–10	Calcium	52	-0.020	0.914	-0.093	No trend.
T3	06305500	Unadjusted	2001–10	Magnesium	52	-0.280	0.143	-0.771	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

[USGS, U.S. Geological Survey; —, not calculated; <, less than. Slope for unadjusted trends is the change per year in original measurement units; for flow-adjusted trends, the slopes reflect relative changes in units after adjustment for streamflow variability]

Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
T3	06305500	Flow adjusted	2001–10	Magnesium	52	0.030	0.878	0.063	No trend.
T3	06305500	Unadjusted	2001–10	Sodium adsorption ratio	52	-0.345	0.017	-0.011	Downward.
T3	06305500	Flow adjusted	2001–10	Sodium adsorption ratio	52	0.050	0.534	0.002	No trend.
T3	06305500	Unadjusted	2001–10	Sodium	52	-0.340	0.020	-0.653	Downward.
T3	06305500	Flow adjusted	2001–10	Sodium	52	0.030	0.765	0.019	No trend.
T3	06305500	Unadjusted	2001–10	Alkalinity	52	-0.290	0.101	-3.69	No trend.
T3	06305500	Flow adjusted	2001–10	Alkalinity	52	-0.060	0.665	-0.390	No trend.
T3	06305500	Unadjusted	2001–10	Chloride	52	-0.080	0.431	-0.062	No trend.
T3	06305500	Flow adjusted	2001–10	Chloride	52	0.190	0.071	0.131	No trend.
T3	06305500	Unadjusted	2001–10	Sulfate	52	-0.440	0.008	-4.00	Downward.
T3	06305500	Flow adjusted	2001–10	Sulfate	52	-0.070	0.596	-0.387	No trend.
T4	06306200	Unadjusted	2005–10	Specific conductance	71	0.046	0.699	3.50	No trend.
T4	06306200	Flow adjusted	2005–10	Specific conductance	71	0.097	0.377	0.008	No trend.
T4	06306200	Unadjusted	2005–10	Calcium	71	-0.017	0.912	-0.377	No trend.
T4	06306200	Flow adjusted	2005–10	Calcium	71	0.029	0.825	0.404	No trend.
T4	06306200	Unadjusted	2005–10	Magnesium	71	-0.074	0.508	-0.470	No trend.
T4	06306200	Flow adjusted	2005–10	Magnesium	71	0.109	0.321	0.518	No trend.
T4	06306200	Unadjusted	2005–10	Sodium adsorption ratio	71	0.189	0.076	0.008	No trend.
T4	06306200	Flow adjusted	2005–10	Sodium adsorption ratio	71	0.234	0.027	0.008	Upward.
T4	06306200	Unadjusted	2005–10	Sodium	71	0.086	0.440	0.345	No trend.
T4	06306200	Flow adjusted	2005–10	Sodium	71	0.189	0.077	0.470	No trend.
T4	06306200	Unadjusted	2005–10	Alkalinity	70	-0.071	0.536	-1.32	No trend.
T4	06306200	Flow adjusted	2005–10	Alkalinity	70	0.129	0.238	2.74	No trend.
T4	06306200	Unadjusted	2005–10	Chloride	71	0.554	<0.001	0.366	Upward.
T4	06306200	Flow adjusted	2005–10	Chloride	71	0.497	<0.001	0.327	Upward.
T4	06306200	Unadjusted	2005–10	Sulfate	71	0.109	0.321	2.80	No trend.
T4	06306200	Flow adjusted	2005–10	Sulfate	71	0.189	0.077	4.09	No trend.
T5	06306250	Unadjusted	2001–10	Specific conductance	60	-0.059	0.585	-8.17	No trend.
T5	06306250	Flow adjusted	2001–10	Specific conductance	60	0.081	0.366	6.24	No trend.
T5	06306250	Unadjusted	2001–10	Calcium	60	-0.007	0.970	-0.182	No trend.
T5	06306250	Flow adjusted	2001–10	Calcium	60	0.015	0.836	0.465	No trend.
T5	06306250	Unadjusted	2001–10	Magnesium	60	-0.007	0.972	-0.405	No trend.
T5	06306250	Flow adjusted	2001–10	Magnesium	60	0.126	0.127	0.797	No trend.
T5	06306250	Unadjusted	2001–10	Sodium adsorption ratio	60	0.100	0.353	0.007	No trend.
T5	06306250	Flow adjusted	2001–10	Sodium adsorption ratio	60	0.178	0.065	0.008	No trend.
T5	06306250	Unadjusted	2001–10	Sodium	60	0.037	0.727	0.737	No trend.
T5	06306250	Flow adjusted	2001–10	Sodium	60	0.148	0.081	1.00	No trend.
T5	06306250	Unadjusted	2001–10	Alkalinity	60	0.007	0.970	0.378	No trend.
T5	06306250	Flow adjusted	2001–10	Alkalinity	60	0.133	0.337	2.99	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

[USGS, U.S. Geological Survey; —, not calculated; <, less than. Slope for unadjusted trends is the change per year in original measurement units; for flow-adjusted trends, the slopes reflect relative changes in units after adjustment for streamflow variability]

Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
T5	06306250	Unadjusted	2001–10	Chloride	60	0.293	0.051	0.199	No trend.
T5	06306250	Flow adjusted	2001–10	Chloride	60	0.348	0.017	0.223	Upward.
T5	06306250	Unadjusted	2001–10	Sulfate	60	-0.081	0.490	-3.70	No trend.
T5	06306250	Flow adjusted	2001–10	Sulfate	60	0.074	0.419	3.17	No trend.
T5	06306250	Unadjusted	2005–10	Specific conductance	66	0.138	0.229	21.7	No trend.
T5	06306250	Flow adjusted	2005–10	Specific conductance	66	0.316	0.005	0.041	Upward.
T5	06306250	Unadjusted	2005–10	Calcium	66	-0.092	0.435	-1.42	No trend.
T5	06306250	Flow adjusted	2005–10	Calcium	66	0.092	0.435	1.28	No trend.
T5	06306250	Unadjusted	2005–10	Magnesium	66	0.092	0.435	1.74	No trend.
T5	06306250	Flow adjusted	2005–10	Magnesium	66	0.250	0.026	3.49	Upward.
T5	06306250	Unadjusted	2005–10	Sodium adsorption ratio	66	0.388	<0.001	0.050	Upward.
T5	06306250	Flow adjusted	2005–10	Sodium adsorption ratio	66	0.447	<0.001	0.069	Upward.
T5	06306250	Unadjusted	2005–10	Sodium	66	0.224	0.048	2.91	Upward.
T5	06306250	Flow adjusted	2005–10	Sodium	66	0.395	<0.001	5.63	Upward.
T5	06306250	Unadjusted	2005–10	Alkalinity	66	0.237	0.036	6.05	Upward.
T5	06306250	Flow adjusted	2005–10	Alkalinity	66	0.250	0.026	6.70	Upward.
T5	06306250	Unadjusted	2005–10	Chloride	66	0.579	<0.001	0.507	Upward.
T5	06306250	Flow adjusted	2005–10	Chloride	66	0.553	<0.001	0.511	Upward.
T5	06306250	Unadjusted	2005–10	Sulfate	66	0.184	0.105	18.9	No trend.
T5	06306250	Flow adjusted	2005–10	Sulfate	66	0.421	<0.001	33.4	Upward.
T6	06306300	Unadjusted	1991–2010	Specific conductance	78	0.253	0.006	5.40	Upward.
T6	06306300	Flow adjusted	1991–2010	Specific conductance	78	0.044	0.637	0.690	No trend.
T6	06306300	Unadjusted	2001–10	Specific conductance	58	-0.071	0.264	-4.33	No trend.
T6	06306300	Flow adjusted	2001–10	Specific conductance	58	0.233	0.040	9.24	Upward.
T6	06306300	Unadjusted	2001–10	Calcium	58	0.059	0.531	0.260	No trend.
T6	06306300	Flow adjusted	2001–10	Calcium	58	0.383	0.006	1.21	Upward.
T6	06306300	Unadjusted	2001–10	Magnesium	58	-0.036	0.613	-0.200	No trend.
T6	06306300	Flow adjusted	2001–10	Magnesium	58	0.233	0.051	0.650	No trend.
T6	06306300	Unadjusted	2001–10	Sodium adsorption ratio	58	-0.217	0.039	-0.014	Downward.
T6	06306300	Flow adjusted	2001–10	Sodium adsorption ratio	58	0.051	0.609	0.005	No trend.
T6	06306300	Unadjusted	2001–10	Sodium	58	-0.146	0.063	-0.503	No trend.
T6	06306300	Flow adjusted	2001–10	Sodium	58	0.075	0.390	0.289	No trend.
T6	06306300	Unadjusted	2001–10	Alkalinity	58	-0.130	0.156	-2.10	No trend.
T6	06306300	Flow adjusted	2001–10	Alkalinity	58	0.186	0.138	2.42	No trend.
T6	06306300	Unadjusted	2001–10	Chloride	58	0.059	0.633	0.041	No trend.
T6	06306300	Flow adjusted	2001–10	Chloride	58	0.375	0.020	0.135	Upward.
T6	06306300	Unadjusted	2001–10	Sulfate	58	0.020	0.808	0.335	No trend.
T6	06306300	Flow adjusted	2001–10	Sulfate	58	0.257	0.042	4.08	Upward.
T6	06306300	Unadjusted	2005–10	Specific conductance	59	0.000	1.000	0.000	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

[USGS, U.S. Geological Survey; —, not calculated; <, less than. Slope for unadjusted trends is the change per year in original measurement units; for flow-adjusted trends, the slopes reflect relative changes in units after adjustment for streamflow variability]

Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
T6	06306300	Flow adjusted	2005–10	Specific conductance	59	0.354	0.003	16.1	Upward.
T6	06306300	Unadjusted	2005–10	Calcium	59	-0.062	0.649	-0.517	No trend.
T6	06306300	Flow adjusted	2005–10	Calcium	59	0.262	0.032	0.933	Upward.
T6	06306300	Unadjusted	2005–10	Magnesium	59	-0.046	0.745	-0.182	No trend.
T6	06306300	Flow adjusted	2005–10	Magnesium	59	0.308	0.011	0.689	Upward.
T6	06306300	Unadjusted	2005–10	Sodium adsorption ratio	59	-0.223	0.068	-0.022	No trend.
T6	06306300	Flow adjusted	2005–10	Sodium adsorption ratio	59	0.185	0.134	0.007	No trend.
T6	06306300	Unadjusted	2005–10	Sodium	59	-0.169	0.172	-0.780	No trend.
T6	06306300	Flow adjusted	2005–10	Sodium	59	0.154	0.216	0.864	No trend.
T6	06306300	Unadjusted	2005–10	Alkalinity	59	0.015	0.948	0.550	No trend.
T6	06306300	Flow adjusted	2005–10	Alkalinity	59	0.308	0.011	5.06	Upward.
T6	06306300	Unadjusted	2005–10	Chloride	59	0.062	0.649	0.080	No trend.
T6	06306300	Flow adjusted	2005–10	Chloride	59	0.308	0.011	0.232	Upward.
T6	06306300	Unadjusted	2005–10	Sulfate	59	0.031	0.845	0.314	No trend.
T6	06306300	Flow adjusted	2005–10	Sulfate	59	0.338	0.005	5.80	Upward.
P1	06313400	Unadjusted	1991–2010	Specific conductance	75	-0.073	0.517	-13.3	No trend.
P1	06313400	Flow adjusted	1991–2010	Specific conductance	75	-0.057	0.529	-8.36	No trend.
P1	06313400	Unadjusted	1991–2010	Calcium	76	-0.130	0.291	-1.41	No trend.
P1	06313400	Flow adjusted	1991–2010	Calcium	76	-0.188	0.131	-2.91	No trend.
P1	06313400	Unadjusted	1991–2010	Magnesium	76	-0.192	0.134	-1.11	No trend.
P1	06313400	Flow adjusted	1991–2010	Magnesium	76	-0.243	0.062	-1.12	No trend.
P1	06313400	Unadjusted	1991–2010	Sodium adsorption ratio	76	0.141	0.272	0.175	No trend.
P1	06313400	Flow adjusted	1991–2010	Sodium adsorption ratio	76	0.140	0.207	0.157	No trend.
P1	06313400	Unadjusted	1991–2010	Sodium	76	0.010	0.942	—	No trend.
P1	06313400	Flow adjusted	1991–2010	Sodium	76	0.020	0.853	1.36	No trend.
P1	06313400	Unadjusted	2001–10	Specific conductance	58	-0.079	0.567	-48.3	No trend.
P1	06313400	Flow adjusted	2001–10	Specific conductance	58	-0.087	0.416	-39.1	No trend.
P1	06313400	Unadjusted	2001–10	Calcium	58	0.429	0.027	8.68	Upward.
P1	06313400	Flow adjusted	2001–10	Calcium	58	0.286	0.097	6.53	No trend.
P1	06313400	Unadjusted	2001–10	Magnesium	58	0.254	0.071	1.05	No trend.
P1	06313400	Flow adjusted	2001–10	Magnesium	58	0.159	0.234	0.857	No trend.
P1	06313400	Unadjusted	2001–10	Sodium adsorption ratio	58	-0.294	0.094	-0.727	No trend.
P1	06313400	Flow adjusted	2001–10	Sodium adsorption ratio	58	-0.214	0.158	-0.380	No trend.
P1	06313400	Unadjusted	2001–10	Sodium	58	-0.087	0.545	-13.5	No trend.
P1	06313400	Flow adjusted	2001–10	Sodium	58	-0.119	0.360	-10.8	No trend.
P1	06313400	Unadjusted	2001–10	Alkalinity	58	-0.056	0.698	-1.70	No trend.
P1	06313400	Flow adjusted	2001–10	Alkalinity	58	-0.159	0.243	-4.40	No trend.
P1	06313400	Unadjusted	2001–10	Chloride	58	-0.111	0.494	-19.4	No trend.
P1	06313400	Flow adjusted	2001–10	Chloride	58	-0.032	0.848	-2.23	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

[USGS, U.S. Geological Survey; —, not calculated; <, less than. Slope for unadjusted trends is the change per year in original measurement units; for flow-adjusted trends, the slopes reflect relative changes in units after adjustment for streamflow variability]

Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P1	06313400	Unadjusted	2001–10	Sulfate	58	0.143	0.332	18.7	No trend.
P1	06313400	Flow adjusted	2001–10	Sulfate	58	0.127	0.406	13.8	No trend.
P1	06313400	Unadjusted	2005–10	Specific conductance	72	-0.367	<0.001	-192	Downward.
P1	06313400	Flow adjusted	2005–10	Specific conductance	72	-0.322	0.002	-0.021	Downward.
P1	06313400	Unadjusted	2005–10	Calcium	72	0.544	<0.001	15.3	Upward.
P1	06313400	Flow adjusted	2005–10	Calcium	72	0.489	<0.001	14.3	Upward.
P1	06313400	Unadjusted	2005–10	Magnesium	72	0.300	0.004	1.78	Upward.
P1	06313400	Flow adjusted	2005–10	Magnesium	72	0.122	0.255	1.04	No trend.
P1	06313400	Unadjusted	2005–10	Sodium adsorption ratio	72	-0.544	<0.001	-1.83	Downward.
P1	06313400	Flow adjusted	2005–10	Sodium adsorption ratio	72	-0.433	<0.001	-1.55	Downward.
P1	06313400	Unadjusted	2005–10	Sodium	72	-0.439	<0.001	-64.4	Downward.
P1	06313400	Flow adjusted	2005–10	Sodium	72	-0.356	0.001	-50.8	Downward.
P1	06313400	Unadjusted	2005–10	Alkalinity	72	-0.311	0.003	-21.7	Downward.
P1	06313400	Flow adjusted	2005–10	Alkalinity	72	-0.389	<0.001	-16.4	Downward.
P1	06313400	Unadjusted	2005–10	Chloride	72	-0.367	<0.001	-56.2	Downward.
P1	06313400	Flow adjusted	2005–10	Chloride	72	-0.289	0.006	-34.2	Downward.
P1	06313400	Unadjusted	2005–10	Sulfate	72	0.411	<0.001	55.8	Upward.
P1	06313400	Flow adjusted	2005–10	Sulfate	72	0.233	0.026	41.7	Upward.
P2	06313500	Unadjusted	1991–2010	Specific conductance	80	0.079	0.425	8.54	No trend.
P2	06313500	Flow adjusted	1991–2010	Specific conductance	80	0.013	0.898	0.693	No trend.
P2	06313500	Unadjusted	1991–2010	Calcium	80	0.017	0.850	—	No trend.
P2	06313500	Flow adjusted	1991–2010	Calcium	80	-0.120	0.247	-0.674	No trend.
P2	06313500	Unadjusted	1991–2010	Magnesium	80	-0.018	0.871	-0.025	No trend.
P2	06313500	Flow adjusted	1991–2010	Magnesium	80	-0.108	0.326	-0.152	No trend.
P2	06313500	Unadjusted	1991–2010	Sodium adsorption ratio	80	0.157	0.163	0.047	No trend.
P2	06313500	Flow adjusted	1991–2010	Sodium adsorption ratio	80	0.111	0.294	0.037	No trend.
P2	06313500	Unadjusted	1991–2010	Sodium	80	0.121	0.273	2.31	No trend.
P2	06313500	Flow adjusted	1991–2010	Sodium	80	0.066	0.528	1.21	No trend.
P2	06313500	Unadjusted	2001–10	Specific conductance	58	-0.024	0.749	-4.76	No trend.
P2	06313500	Flow adjusted	2001–10	Specific conductance	58	0.079	0.540	15.8	No trend.
P2	06313500	Unadjusted	2001–10	Calcium	58	0.063	0.620	0.506	No trend.
P2	06313500	Flow adjusted	2001–10	Calcium	58	0.175	0.221	1.80	No trend.
P2	06313500	Unadjusted	2001–10	Magnesium	58	-0.048	0.630	-0.118	No trend.
P2	06313500	Flow adjusted	2001–10	Magnesium	58	0.183	0.141	0.553	No trend.
P2	06313500	Unadjusted	2001–10	Sodium adsorption ratio	58	-0.063	0.570	-0.034	No trend.
P2	06313500	Flow adjusted	2001–10	Sodium adsorption ratio	58	-0.056	0.670	-0.034	No trend.
P2	06313500	Unadjusted	2001–10	Sodium	58	-0.008	0.960	-0.692	No trend.
P2	06313500	Flow adjusted	2001–10	Sodium	58	0.024	0.872	0.907	No trend.
P2	06313500	Unadjusted	2001–10	Alkalinity	58	0.063	0.539	1.36	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

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Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P2	06313500	Flow adjusted	2001–10	Alkalinity	58	0.270	0.073	2.96	No trend.
P2	06313500	Unadjusted	2001–10	Chloride	58	-0.048	0.720	-1.65	No trend.
P2	06313500	Flow adjusted	2001–10	Chloride	58	0.063	0.600	1.78	No trend.
P2	06313500	Unadjusted	2001–10	Sulfate	58	-0.040	0.637	-2.62	No trend.
P2	06313500	Flow adjusted	2001–10	Sulfate	58	0.095	0.421	4.20	No trend.
P2	06313500	Unadjusted	2005–10	Specific conductance	72	-0.211	0.044	-90.6	Downward.
P2	06313500	Flow adjusted	2005–10	Specific conductance	72	-0.156	0.143	-0.018	No trend.
P2	06313500	Unadjusted	2005–10	Calcium	72	0.067	0.551	1.24	No trend.
P2	06313500	Flow adjusted	2005–10	Calcium	72	0.233	0.026	2.53	Upward.
P2	06313500	Unadjusted	2005–10	Magnesium	72	-0.100	0.357	-0.752	No trend.
P2	06313500	Flow adjusted	2005–10	Magnesium	72	0.122	0.255	0.770	No trend.
P2	06313500	Unadjusted	2005–10	Sodium adsorption ratio	72	-0.256	0.015	-0.281	Downward.
P2	06313500	Flow adjusted	2005–10	Sodium adsorption ratio	72	-0.222	0.034	-0.237	Downward.
P2	06313500	Unadjusted	2005–10	Sodium	72	-0.300	0.004	-14.7	Downward.
P2	06313500	Flow adjusted	2005–10	Sodium	72	-0.244	0.020	-9.53	Downward.
P2	06313500	Unadjusted	2005–10	Alkalinity	72	-0.156	0.143	-5.14	No trend.
P2	06313500	Flow adjusted	2005–10	Alkalinity	72	0.056	0.625	1.23	No trend.
P2	06313500	Unadjusted	2005–10	Chloride	72	-0.344	0.001	-18.0	Downward.
P2	06313500	Flow adjusted	2005–10	Chloride	72	-0.256	0.015	-7.00	Downward.
P2	06313500	Unadjusted	2005–10	Sulfate	72	-0.011	0.957	-1.08	No trend.
P2	06313500	Flow adjusted	2005–10	Sulfate	72	0.133	0.212	6.90	No trend.
P4	06313560	Unadjusted	2005–10	Specific conductance	63	-0.386	0.001	-103	Downward.
P4	06313560	Flow adjusted	2005–10	Specific conductance	63	-0.241	0.038	-0.015	Downward.
P4	06313560	Unadjusted	2005–10	Calcium	61	0.215	0.074	2.18	No trend.
P4	06313560	Flow adjusted	2005–10	Calcium	61	0.067	0.609	0.656	No trend.
P4	06313560	Unadjusted	2005–10	Magnesium	63	0.352	0.002	2.73	Upward.
P4	06313560	Flow adjusted	2005–10	Magnesium	63	0.214	0.067	2.55	No trend.
P4	06313560	Unadjusted	2005–10	Sodium adsorption ratio	61	-0.452	<0.001	-1.35	Downward.
P4	06313560	Flow adjusted	2005–10	Sodium adsorption ratio	61	-0.304	0.011	-0.834	Downward.
P4	06313560	Unadjusted	2005–10	Sodium	63	-0.379	0.001	-32.8	Downward.
P4	06313560	Flow adjusted	2005–10	Sodium	63	-0.186	0.112	-17.5	No trend.
P5	06313585	Unadjusted	2005–10	Specific conductance	72	-0.761	<0.001	-326	Downward.
P5	06313585	Flow adjusted	2005–10	Specific conductance	72	-0.189	0.074	-0.014	No trend.
P5	06313585	Unadjusted	2005–10	Calcium	70	-0.141	0.196	-1.00	No trend.
P5	06313585	Flow adjusted	2005–10	Calcium	70	-0.094	0.399	-1.07	No trend.
P5	06313585	Unadjusted	2005–10	Magnesium	72	-0.744	<0.001	-5.45	Downward.
P5	06313585	Flow adjusted	2005–10	Magnesium	72	-0.322	0.002	-1.39	Downward.
P5	06313585	Unadjusted	2005–10	Sodium adsorption ratio	70	-0.529	<0.001	-1.79	Downward.
P5	06313585	Flow adjusted	2005–10	Sodium adsorption ratio	70	-0.071	0.536	-0.157	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

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Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P5	06313585	Unadjusted	2005–10	Sodium	72	-0.744	<0.001	-76.0	Downward.
P5	06313585	Flow adjusted	2005–10	Sodium	72	-0.211	0.045	-8.93	Downward.
P6	06313590	Unadjusted	2005–10	Specific conductance	71	-0.269	0.011	-70.0	Downward.
P6	06313590	Flow adjusted	2005–10	Specific conductance	71	-0.143	0.185	-0.013	No trend.
P6	06313590	Unadjusted	2005–10	Calcium	71	-0.097	0.377	-2.32	No trend.
P6	06313590	Flow adjusted	2005–10	Calcium	71	-0.029	0.825	-0.175	No trend.
P6	06313590	Unadjusted	2005–10	Magnesium	71	-0.211	0.047	-1.73	Downward.
P6	06313590	Flow adjusted	2005–10	Magnesium	71	-0.109	0.321	-0.585	No trend.
P6	06313590	Unadjusted	2005–10	Sodium adsorption ratio	71	-0.280	0.008	-0.250	Downward.
P6	06313590	Flow adjusted	2005–10	Sodium adsorption ratio	71	-0.143	0.185	-0.150	No trend.
P6	06313590	Unadjusted	2005–10	Sodium	71	-0.269	0.011	-16.3	Downward.
P6	06313590	Flow adjusted	2005–10	Sodium	71	-0.189	0.077	-9.72	No trend.
P6	06313590	Unadjusted	2005–10	Alkalinity	71	-0.114	0.294	-5.35	No trend.
P6	06313590	Flow adjusted	2005–10	Alkalinity	71	0.040	0.741	2.31	No trend.
P6	06313590	Unadjusted	2005–10	Chloride	71	-0.314	0.003	-15.7	Downward.
P6	06313590	Flow adjusted	2005–10	Chloride	71	-0.177	0.098	-6.09	No trend.
P6	06313590	Unadjusted	2005–10	Sulfate	71	-0.166	0.122	-18.4	No trend.
P6	06313590	Flow adjusted	2005–10	Sulfate	71	-0.051	0.659	-6.24	No trend.
P7	06313604	Unadjusted	2005–10	Specific conductance	68	-0.809	<0.001	-130	Downward.
P7	06313604	Flow adjusted	2005–10	Specific conductance	68	-0.630	<0.001	-0.024	Downward.
P7	06313604	Unadjusted	2005–10	Calcium	68	-0.160	0.149	-0.645	No trend.
P7	06313604	Flow adjusted	2005–10	Calcium	68	-0.210	0.057	-0.600	No trend.
P7	06313604	Unadjusted	2005–10	Magnesium	68	-0.679	<0.001	-2.40	Downward.
P7	06313604	Flow adjusted	2005–10	Magnesium	68	-0.568	<0.001	-1.54	Downward.
P7	06313604	Unadjusted	2005–10	Sodium adsorption ratio	68	0.160	0.149	0.274	No trend.
P7	06313604	Flow adjusted	2005–10	Sodium adsorption ratio	68	0.111	0.327	0.146	No trend.
P7	06313604	Unadjusted	2005–10	Sodium	68	-0.383	<0.001	-22.8	Downward.
P7	06313604	Flow adjusted	2005–10	Sodium	68	-0.284	0.009	-15.7	Downward.
P8	06313605	Unadjusted	2001–10	Specific conductance	59	-0.307	0.030	-67.0	Downward.
P8	06313605	Flow adjusted	2001–10	Specific conductance	59	-0.203	0.034	-36.9	Downward.
P8	06313605	Unadjusted	2001–10	Calcium	59	-0.303	0.049	-4.13	Downward.
P8	06313605	Flow adjusted	2001–10	Calcium	59	-0.211	0.131	-2.66	No trend.
P8	06313605	Unadjusted	2001–10	Magnesium	59	-0.272	0.036	-1.56	Downward.
P8	06313605	Flow adjusted	2001–10	Magnesium	59	-0.126	0.244	-0.521	No trend.
P8	06313605	Unadjusted	2001–10	Sodium adsorption ratio	59	-0.126	0.313	-0.043	No trend.
P8	06313605	Flow adjusted	2001–10	Sodium adsorption ratio	59	-0.004	1.000	-0.001	No trend.
P8	06313605	Unadjusted	2001–10	Sodium	59	-0.264	0.045	-9.46	Downward.
P8	06313605	Flow adjusted	2001–10	Sodium	59	-0.119	0.122	-4.58	No trend.
P8	06313605	Unadjusted	2001–10	Alkalinity	59	0.042	0.732	1.05	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

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Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P8	06313605	Flow adjusted	2001–10	Alkalinity	59	0.310	0.067	6.30	No trend.
P8	06313605	Unadjusted	2001–10	Chloride	59	-0.211	0.129	-4.74	No trend.
P8	06313605	Flow adjusted	2001–10	Chloride	59	0.027	0.811	0.788	No trend.
P8	06313605	Unadjusted	2001–10	Sulfate	59	-0.379	0.007	-24.9	Downward.
P8	06313605	Flow adjusted	2001–10	Sulfate	59	-0.218	0.038	-12.0	Downward.
P8	06313605	Unadjusted	2005–10	Specific conductance	72	-0.333	0.001	-78.8	Downward.
P8	06313605	Flow adjusted	2005–10	Specific conductance	72	-0.267	0.011	-0.025	Downward.
P8	06313605	Unadjusted	2005–10	Calcium	72	-0.033	0.786	-0.775	No trend.
P8	06313605	Flow adjusted	2005–10	Calcium	72	0.089	0.416	0.759	No trend.
P8	06313605	Unadjusted	2005–10	Magnesium	72	-0.189	0.074	-1.32	No trend.
P8	06313605	Flow adjusted	2005–10	Magnesium	72	-0.067	0.551	-0.603	No trend.
P8	06313605	Unadjusted	2005–10	Sodium adsorption ratio	72	-0.378	<0.001	-0.296	Downward.
P8	06313605	Flow adjusted	2005–10	Sodium adsorption ratio	72	-0.344	0.001	-0.222	Downward.
P8	06313605	Unadjusted	2005–10	Sodium	72	-0.311	0.003	-16.1	Downward.
P8	06313605	Flow adjusted	2005–10	Sodium	72	-0.256	0.015	-12.4	Downward.
P8	06313605	Unadjusted	2005–10	Alkalinity	72	-0.278	0.008	-10.5	Downward.
P8	06313605	Flow adjusted	2005–10	Alkalinity	72	-0.211	0.045	-5.50	Downward.
P8	06313605	Unadjusted	2005–10	Chloride	72	-0.322	0.002	-12.4	Downward.
P8	06313605	Flow adjusted	2005–10	Chloride	72	-0.200	0.058	-4.98	No trend.
P8	06313605	Unadjusted	2005–10	Sulfate	72	-0.167	0.116	-13.9	No trend.
P8	06313605	Flow adjusted	2005–10	Sulfate	72	-0.078	0.481	-6.02	No trend.
P11	06316400	Unadjusted	2001–10	Specific conductance	58	-0.349	0.017	-63.1	Downward.
P11	06316400	Flow adjusted	2001–10	Specific conductance	58	-0.048	0.698	-4.76	No trend.
P11	06316400	Unadjusted	2001–10	Calcium	58	-0.377	0.014	-5.76	Downward.
P11	06316400	Flow adjusted	2001–10	Calcium	58	-0.167	0.293	-1.23	No trend.
P11	06316400	Unadjusted	2001–10	Magnesium	58	-0.310	0.012	-3.05	Downward.
P11	06316400	Flow adjusted	2001–10	Magnesium	58	-0.087	0.536	-0.427	No trend.
P11	06316400	Unadjusted	2001–10	Sodium adsorption ratio	58	-0.179	0.126	-0.040	No trend.
P11	06316400	Flow adjusted	2001–10	Sodium adsorption ratio	58	-0.008	0.970	-0.001	No trend.
P11	06316400	Unadjusted	2001–10	Sodium	58	-0.262	0.041	-4.27	Downward.
P11	06316400	Flow adjusted	2001–10	Sodium	58	-0.048	0.696	-0.238	No trend.
P11	06316400	Unadjusted	2001–10	Alkalinity	58	-0.159	0.191	-3.28	No trend.
P11	06316400	Flow adjusted	2001–10	Alkalinity	58	0.087	0.460	0.571	No trend.
P11	06316400	Unadjusted	2001–10	Chloride	58	-0.230	0.068	-0.209	No trend.
P11	06316400	Flow adjusted	2001–10	Chloride	58	-0.079	0.488	-0.044	No trend.
P11	06316400	Unadjusted	2001–10	Sulfate	58	-0.341	0.024	-31.9	Downward.
P11	06316400	Flow adjusted	2001–10	Sulfate	58	-0.095	0.432	-4.41	No trend.
P11	06316400	Unadjusted	2005–10	Specific conductance	71	-0.120	0.270	-36.0	No trend.
P11	06316400	Flow adjusted	2005–10	Specific conductance	71	0.154	0.151	0.014	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

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Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P11	06316400	Unadjusted	2005–10	Calcium	71	-0.211	0.047	-5.22	Downward.
P11	06316400	Flow adjusted	2005–10	Calcium	71	0.120	0.270	2.02	No trend.
P11	06316400	Unadjusted	2005–10	Magnesium	71	-0.154	0.151	-2.31	No trend.
P11	06316400	Flow adjusted	2005–10	Magnesium	71	0.177	0.098	1.10	No trend.
P11	06316400	Unadjusted	2005–10	Sodium adsorption ratio	71	-0.046	0.699	-0.014	No trend.
P11	06316400	Flow adjusted	2005–10	Sodium adsorption ratio	71	0.143	0.185	0.026	No trend.
P11	06316400	Unadjusted	2005–10	Sodium	71	-0.109	0.321	-2.93	No trend.
P11	06316400	Flow adjusted	2005–10	Sodium	71	0.143	0.185	2.79	No trend.
P11	06316400	Unadjusted	2005–10	Alkalinity	71	-0.097	0.377	-3.77	No trend.
P11	06316400	Flow adjusted	2005–10	Alkalinity	71	0.223	0.036	2.70	Upward.
P11	06316400	Unadjusted	2005–10	Chloride	71	-0.006	1.000	-0.004	No trend.
P11	06316400	Flow adjusted	2005–10	Chloride	71	0.291	0.006	0.271	Upward.
P11	06316400	Unadjusted	2005–10	Sulfate	71	-0.074	0.508	-9.28	No trend.
P11	06316400	Flow adjusted	2005–10	Sulfate	71	0.154	0.151	11.2	No trend.
P13	06317000	Unadjusted	1991–2010	Specific conductance	79	0.007	0.954	—	No trend.
P13	06317000	Flow adjusted	1991–2010	Specific conductance	79	-0.004	0.970	-1.03	No trend.
P13	06317000	Unadjusted	1991–2010	Calcium	79	-0.364	<0.001	-2.64	Downward.
P13	06317000	Flow adjusted	1991–2010	Calcium	79	-0.457	<0.001	-2.75	Downward.
P13	06317000	Unadjusted	1991–2010	Magnesium	79	-0.286	0.007	-0.769	Downward.
P13	06317000	Flow adjusted	1991–2010	Magnesium	79	-0.412	<0.001	-0.896	Downward.
P13	06317000	Unadjusted	1991–2010	Sodium adsorption ratio	79	0.335	0.002	0.100	Upward.
P13	06317000	Flow adjusted	1991–2010	Sodium adsorption ratio	79	0.317	<0.001	0.085	Upward.
P13	06317000	Unadjusted	1991–2010	Sodium	79	0.161	0.092	3.00	No trend.
P13	06317000	Flow adjusted	1991–2010	Sodium	79	0.198	0.005	2.56	Upward.
P13	06317000	Unadjusted	2001–10	Specific conductance	59	-0.153	0.317	-36.7	No trend.
P13	06317000	Flow adjusted	2001–10	Specific conductance	59	-0.073	0.493	-19.8	No trend.
P13	06317000	Unadjusted	2001–10	Calcium	59	-0.379	0.054	-4.76	No trend.
P13	06317000	Flow adjusted	2001–10	Calcium	59	-0.310	0.056	-2.96	No trend.
P13	06317000	Unadjusted	2001–10	Magnesium	59	-0.195	0.205	-1.13	No trend.
P13	06317000	Flow adjusted	2001–10	Magnesium	59	-0.073	0.578	-0.391	No trend.
P13	06317000	Unadjusted	2001–10	Sodium adsorption ratio	59	0.011	0.948	0.006	No trend.
P13	06317000	Flow adjusted	2001–10	Sodium adsorption ratio	59	0.172	0.036	0.088	Upward.
P13	06317000	Unadjusted	2001–10	Sodium	59	-0.119	0.432	-3.42	No trend.
P13	06317000	Flow adjusted	2001–10	Sodium	59	0.034	0.726	0.935	No trend.
P13	06317000	Unadjusted	2001–10	Alkalinity	59	0.387	0.010	7.41	Upward.
P13	06317000	Flow adjusted	2001–10	Alkalinity	59	0.402	0.010	8.86	Upward.
P13	06317000	Unadjusted	2001–10	Chloride	59	-0.165	0.308	-5.50	No trend.
P13	06317000	Flow adjusted	2001–10	Chloride	59	-0.057	0.661	-0.895	No trend.
P13	06317000	Unadjusted	2001–10	Sulfate	59	-0.349	0.042	-21.2	Downward.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

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Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P13	06317000	Flow adjusted	2001–10	Sulfate	59	-0.272	0.031	-16.5	Downward.
P13	06317000	Unadjusted	2005–10	Specific conductance	71	-0.251	0.017	-90.0	Downward.
P13	06317000	Flow adjusted	2005–10	Specific conductance	71	-0.017	0.912	-0.003	No trend.
P13	06317000	Unadjusted	2005–10	Calcium	71	-0.154	0.151	-2.61	No trend.
P13	06317000	Flow adjusted	2005–10	Calcium	71	-0.029	0.825	-0.326	No trend.
P13	06317000	Unadjusted	2005–10	Magnesium	71	-0.234	0.027	-1.54	Downward.
P13	06317000	Flow adjusted	2005–10	Magnesium	71	-0.086	0.440	-0.251	No trend.
P13	06317000	Unadjusted	2005–10	Sodium adsorption ratio	71	-0.217	0.041	-0.182	Downward.
P13	06317000	Flow adjusted	2005–10	Sodium adsorption ratio	71	-0.074	0.508	-0.039	No trend.
P13	06317000	Unadjusted	2005–10	Sodium	71	-0.280	0.008	-12.2	Downward.
P13	06317000	Flow adjusted	2005–10	Sodium	71	-0.006	1.000	-0.588	No trend.
P13	06317000	Unadjusted	2005–10	Alkalinity	71	0.017	0.912	0.645	No trend.
P13	06317000	Flow adjusted	2005–10	Alkalinity	71	0.189	0.077	4.68	No trend.
P13	06317000	Unadjusted	2005–10	Chloride	71	-0.383	<0.001	-13.9	Downward.
P13	06317000	Flow adjusted	2005–10	Chloride	71	-0.189	0.077	-3.73	No trend.
P13	06317000	Unadjusted	2005–10	Sulfate	71	-0.143	0.185	-19.7	No trend.
P13	06317000	Flow adjusted	2005–10	Sulfate	71	0.006	1.000	0.959	No trend.
P15	06317030	Unadjusted	2005–10	Specific conductance	72	0.078	0.481	56.7	No trend.
P15	06317030	Flow adjusted	2005–10	Specific conductance	72	0.211	0.045	0.042	Upward.
P15	06317030	Unadjusted	2005–10	Calcium	71	0.326	0.002	12.3	Upward.
P15	06317030	Flow adjusted	2005–10	Calcium	71	0.394	<0.001	11.5	Upward.
P15	06317030	Unadjusted	2005–10	Magnesium	72	0.111	0.303	8.11	No trend.
P15	06317030	Flow adjusted	2005–10	Magnesium	72	0.289	0.006	11.1	Upward.
P15	06317030	Unadjusted	2005–10	Sodium adsorption ratio	71	-0.291	0.006	-0.416	Downward.
P15	06317030	Flow adjusted	2005–10	Sodium adsorption ratio	71	-0.371	<0.001	-0.275	Downward.
P15	06317030	Unadjusted	2005–10	Sodium	72	0.000	1.000	0.000	No trend.
P15	06317030	Flow adjusted	2005–10	Sodium	72	0.144	0.175	11.3	No trend.
P17	06317100	Unadjusted	2005–10	Specific conductance	72	-0.189	0.074	-43.3	No trend.
P17	06317100	Flow adjusted	2005–10	Specific conductance	70	0.053	0.655	0.005	No trend.
P17	06317100	Unadjusted	2005–10	Calcium	71	-0.246	0.020	-2.85	Downward.
P17	06317100	Flow adjusted	2005–10	Calcium	69	0.048	0.690	0.430	No trend.
P17	06317100	Unadjusted	2005–10	Magnesium	71	-0.211	0.047	-1.48	Downward.
P17	06317100	Flow adjusted	2005–10	Magnesium	69	0.108	0.333	0.556	No trend.
P17	06317100	Unadjusted	2005–10	Sodium adsorption ratio	71	-0.074	0.508	-0.033	No trend.
P17	06317100	Flow adjusted	2005–10	Sodium adsorption ratio	69	0.133	0.232	0.053	No trend.
P17	06317100	Unadjusted	2005–10	Sodium	71	-0.120	0.270	-5.03	No trend.
P17	06317100	Flow adjusted	2005–10	Sodium	69	0.096	0.393	3.52	No trend.
P18	06320210	Unadjusted	2001–10	Specific conductance	58	-0.103	0.477	-6.83	No trend.
P18	06320210	Flow adjusted	2001–10	Specific conductance	58	0.310	0.032	12.7	Upward.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

[USGS, U.S. Geological Survey; —, not calculated; <, less than. Slope for unadjusted trends is the change per year in original measurement units; for flow-adjusted trends, the slopes reflect relative changes in units after adjustment for streamflow variability]

Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P18	06320210	Unadjusted	2001–10	Calcium	54	-0.056	0.731	-0.537	No trend.
P18	06320210	Flow adjusted	2001–10	Calcium	54	0.324	0.032	1.24	Upward.
P18	06320210	Unadjusted	2001–10	Magnesium	54	0.028	0.895	0.054	No trend.
P18	06320210	Flow adjusted	2001–10	Magnesium	54	0.343	0.039	0.657	Upward.
P18	06320210	Unadjusted	2001–10	Sodium adsorption ratio	54	-0.093	0.606	-0.007	No trend.
P18	06320210	Flow adjusted	2001–10	Sodium adsorption ratio	54	0.306	0.067	0.010	No trend.
P18	06320210	Unadjusted	2001–10	Sodium	54	-0.065	0.723	-0.439	No trend.
P18	06320210	Flow adjusted	2001–10	Sodium	54	0.333	0.069	0.702	No trend.
P18	06320210	Unadjusted	2001–10	Alkalinity	54	-0.083	0.599	-0.798	No trend.
P18	06320210	Flow adjusted	2001–10	Alkalinity	54	0.398	0.024	2.96	Upward.
P18	06320210	Unadjusted	2001–10	Chloride	54	-0.074	0.699	-0.027	No trend.
P18	06320210	Flow adjusted	2001–10	Chloride	54	0.269	0.083	0.101	No trend.
P18	06320210	Unadjusted	2001–10	Sulfate	54	-0.074	0.629	-1.53	No trend.
P18	06320210	Flow adjusted	2001–10	Sulfate	54	0.287	0.063	4.60	No trend.
P18	06320210	Unadjusted	2005–10	Specific conductance	72	-0.167	0.116	-15.2	No trend.
P18	06320210	Flow adjusted	2005–10	Specific conductance	72	0.078	0.481	0.003	No trend.
P18	06320210	Unadjusted	2005–10	Calcium	72	-0.178	0.093	-1.09	No trend.
P18	06320210	Flow adjusted	2005–10	Calcium	72	-0.033	0.786	-0.197	No trend.
P18	06320210	Unadjusted	2005–10	Magnesium	72	-0.178	0.093	-0.878	No trend.
P18	06320210	Flow adjusted	2005–10	Magnesium	72	-0.078	0.481	-0.133	No trend.
P18	06320210	Unadjusted	2005–10	Sodium adsorption ratio	72	-0.189	0.074	-0.014	No trend.
P18	06320210	Flow adjusted	2005–10	Sodium adsorption ratio	72	0.022	0.871	0.000	No trend.
P18	06320210	Unadjusted	2005–10	Sodium	72	-0.167	0.116	-1.00	No trend.
P18	06320210	Flow adjusted	2005–10	Sodium	72	-0.044	0.704	-0.142	No trend.
P18	06320210	Unadjusted	2005–10	Alkalinity	72	-0.056	0.625	-1.24	No trend.
P18	06320210	Flow adjusted	2005–10	Alkalinity	72	0.244	0.020	1.89	Upward.
P18	06320210	Unadjusted	2005–10	Chloride	72	-0.056	0.625	-0.030	No trend.
P18	06320210	Flow adjusted	2005–10	Chloride	72	0.144	0.175	0.059	No trend.
P18	06320210	Unadjusted	2005–10	Sulfate	72	-0.200	0.058	-4.87	No trend.
P18	06320210	Flow adjusted	2005–10	Sulfate	72	-0.067	0.551	-0.616	No trend.
P19	06323550	Unadjusted	2005–10	Specific conductance	72	-0.361	0.001	-29.5	Downward.
P19	06323550	Flow adjusted	2005–10	Specific conductance	72	-0.144	0.175	-0.010	No trend.
P19	06323550	Unadjusted	2005–10	Calcium	72	-0.400	<0.001	-3.26	Downward.
P19	06323550	Flow adjusted	2005–10	Calcium	72	-0.222	0.034	-1.22	Downward.
P19	06323550	Unadjusted	2005–10	Magnesium	72	-0.333	0.001	-1.30	Downward.
P19	06323550	Flow adjusted	2005–10	Magnesium	72	-0.100	0.357	-0.318	No trend.
P19	06323550	Unadjusted	2005–10	Sodium adsorption ratio	72	-0.322	0.002	-0.021	Downward.
P19	06323550	Flow adjusted	2005–10	Sodium adsorption ratio	72	-0.133	0.212	-0.009	No trend.
P19	06323550	Unadjusted	2005–10	Sodium	72	-0.389	<0.001	-1.48	Downward.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

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Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P19	06323550	Flow adjusted	2005–10	Sodium	72	-0.200	0.058	-0.665	No trend.
P20	06324000	Unadjusted	2001–10	Specific conductance	60	-0.300	0.050	-38.0	No trend.
P20	06324000	Flow adjusted	2001–10	Specific conductance	60	-0.133	0.080	-8.01	No trend.
P20	06324000	Unadjusted	2001–10	Calcium	60	-0.333	0.038	-3.56	Downward.
P20	06324000	Flow adjusted	2001–10	Calcium	60	-0.074	0.416	-0.751	No trend.
P20	06324000	Unadjusted	2001–10	Magnesium	60	-0.311	0.044	-1.99	Downward.
P20	06324000	Flow adjusted	2001–10	Magnesium	60	-0.111	0.130	-0.526	No trend.
P20	06324000	Unadjusted	2001–10	Sodium adsorption ratio	60	-0.289	0.059	-0.024	No trend.
P20	06324000	Flow adjusted	2001–10	Sodium adsorption ratio	60	-0.022	0.830	-0.002	No trend.
P20	06324000	Unadjusted	2001–10	Sodium	60	-0.281	0.065	-2.30	No trend.
P20	06324000	Flow adjusted	2001–10	Sodium	60	-0.067	0.320	-0.618	No trend.
P20	06324000	Unadjusted	2001–10	Alkalinity	60	-0.148	0.167	-2.57	No trend.
P20	06324000	Flow adjusted	2001–10	Alkalinity	60	0.141	0.136	1.92	No trend.
P20	06324000	Unadjusted	2001–10	Chloride	60	-0.052	0.680	-0.019	No trend.
P20	06324000	Flow adjusted	2001–10	Chloride	60	0.104	0.450	0.036	No trend.
P20	06324000	Unadjusted	2001–10	Sulfate	60	-0.348	0.033	-17.6	Downward.
P20	06324000	Flow adjusted	2001–10	Sulfate	60	-0.193	0.034	-8.01	Downward.
P20	06324000	Unadjusted	2005–10	Specific conductance	72	-0.128	0.231	-14.2	No trend.
P20	06324000	Flow adjusted	2005–10	Specific conductance	72	0.022	0.871	0.004	No trend.
P20	06324000	Unadjusted	2005–10	Calcium	72	-0.244	0.020	-2.97	Downward.
P20	06324000	Flow adjusted	2005–10	Calcium	72	0.022	0.871	0.277	No trend.
P20	06324000	Unadjusted	2005–10	Magnesium	72	-0.178	0.093	-0.910	No trend.
P20	06324000	Flow adjusted	2005–10	Magnesium	72	-0.089	0.416	-0.299	No trend.
P20	06324000	Unadjusted	2005–10	Sodium adsorption ratio	72	-0.044	0.703	-0.007	No trend.
P20	06324000	Flow adjusted	2005–10	Sodium adsorption ratio	72	0.178	0.093	0.019	No trend.
P20	06324000	Unadjusted	2005–10	Sodium	72	-0.100	0.357	-0.747	No trend.
P20	06324000	Flow adjusted	2005–10	Sodium	72	0.056	0.625	0.769	No trend.
P20	06324000	Unadjusted	2005–10	Alkalinity	72	-0.022	0.871	-0.320	No trend.
P20	06324000	Flow adjusted	2005–10	Alkalinity	72	0.256	0.015	3.92	Upward.
P20	06324000	Unadjusted	2005–10	Chloride	72	0.133	0.212	0.082	No trend.
P20	06324000	Flow adjusted	2005–10	Chloride	72	0.200	0.058	0.130	No trend.
P20	06324000	Unadjusted	2005–10	Sulfate	72	-0.167	0.116	-9.20	No trend.
P20	06324000	Flow adjusted	2005–10	Sulfate	72	-0.100	0.357	-4.30	No trend.
P22	06324300	Unadjusted	2005–10	Specific conductance	62	0.224	0.060	68.3	No trend.
P22	06324300	Flow adjusted	2005–10	Specific conductance	62	-0.060	0.650	-0.005	No trend.
P22	06324300	Unadjusted	2005–10	Calcium	62	0.328	0.005	12.2	Upward.
P22	06324300	Flow adjusted	2005–10	Calcium	62	0.164	0.173	4.72	No trend.
P22	06324300	Unadjusted	2005–10	Magnesium	62	0.209	0.080	8.22	No trend.
P22	06324300	Flow adjusted	2005–10	Magnesium	62	0.045	0.746	1.73	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

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Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P22	06324300	Unadjusted	2005–10	Sodium adsorption ratio	61	0.054	0.690	0.012	No trend.
P22	06324300	Flow adjusted	2005–10	Sodium adsorption ratio	61	-0.194	0.110	-0.055	No trend.
P22	06324300	Unadjusted	2005–10	Sodium	61	0.295	0.014	23.3	Upward.
P22	06324300	Flow adjusted	2005–10	Sodium	61	0.039	0.790	3.01	No trend.
P23	06324500	Unadjusted	1991–2010	Specific conductance	76	0.070	0.516	4.29	No trend.
P23	06324500	Flow adjusted	1991–2010	Specific conductance	76	0.026	0.785	1.52	No trend.
P23	06324500	Unadjusted	2001–10	Specific conductance	57	-0.284	0.024	-53.7	Downward.
P23	06324500	Flow adjusted	2001–10	Specific conductance	57	-0.152	0.096	-14.8	No trend.
P23	06324500	Unadjusted	2001–10	Calcium	57	-0.510	0.008	-5.23	Downward.
P23	06324500	Flow adjusted	2001–10	Calcium	57	-0.267	0.096	-2.14	No trend.
P23	06324500	Unadjusted	2001–10	Magnesium	57	-0.358	0.014	-1.91	Downward.
P23	06324500	Flow adjusted	2001–10	Magnesium	57	-0.119	0.187	-0.552	No trend.
P23	06324500	Unadjusted	2001–10	Sodium adsorption ratio	57	-0.053	0.626	-0.017	No trend.
P23	06324500	Flow adjusted	2001–10	Sodium adsorption ratio	57	0.070	0.474	0.020	No trend.
P23	06324500	Unadjusted	2001–10	Sodium	57	-0.160	0.148	-4.32	No trend.
P23	06324500	Flow adjusted	2001–10	Sodium	57	-0.062	0.513	-1.79	No trend.
P23	06324500	Unadjusted	2001–10	Alkalinity	57	0.243	0.078	5.20	No trend.
P23	06324500	Flow adjusted	2001–10	Alkalinity	57	0.333	0.024	5.79	Upward.
P23	06324500	Unadjusted	2001–10	Chloride	57	-0.276	0.038	-4.97	Downward.
P23	06324500	Flow adjusted	2001–10	Chloride	57	-0.226	0.055	-3.04	No trend.
P23	06324500	Unadjusted	2001–10	Sulfate	57	-0.432	0.006	-26.7	Downward.
P23	06324500	Flow adjusted	2001–10	Sulfate	57	-0.317	0.006	-18.0	Downward.
P23	06324500	Unadjusted	2005–10	Specific conductance	71	-0.211	0.047	-29.2	Downward.
P23	06324500	Flow adjusted	2005–10	Specific conductance	71	0.086	0.440	16.6	No trend.
P23	06324500	Unadjusted	2005–10	Calcium	71	-0.291	0.006	-4.17	Downward.
P23	06324500	Flow adjusted	2005–10	Calcium	71	0.086	0.440	1.14	No trend.
P23	06324500	Unadjusted	2005–10	Magnesium	71	-0.280	0.008	-1.83	Downward.
P23	06324500	Flow adjusted	2005–10	Magnesium	71	0.051	0.659	0.214	No trend.
P23	06324500	Unadjusted	2005–10	Sodium adsorption ratio	71	-0.017	0.912	-0.009	No trend.
P23	06324500	Flow adjusted	2005–10	Sodium adsorption ratio	71	0.097	0.377	0.041	No trend.
P23	06324500	Unadjusted	2005–10	Sodium	71	-0.109	0.321	-2.73	No trend.
P23	06324500	Flow adjusted	2005–10	Sodium	71	0.097	0.377	4.02	No trend.
P23	06324500	Unadjusted	2005–10	Alkalinity	71	0.200	0.061	7.50	No trend.
P23	06324500	Flow adjusted	2005–10	Alkalinity	71	0.291	0.006	8.56	Upward.
P23	06324500	Unadjusted	2005–10	Chloride	71	-0.280	0.008	-6.61	Downward.
P23	06324500	Flow adjusted	2005–10	Chloride	71	-0.097	0.377	-2.04	No trend.
P23	06324500	Unadjusted	2005–10	Sulfate	71	-0.211	0.047	-16.8	Downward.
P23	06324500	Flow adjusted	2005–10	Sulfate	71	0.040	0.741	5.25	No trend.
P26	06324950	Unadjusted	2005–10	Specific conductance	72	0.206	0.051	113	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

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Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P26	06324950	Flow adjusted	2005–10	Specific conductance	72	0.344	0.001	0.042	Upward.
P26	06324950	Unadjusted	2005–10	Calcium	72	0.333	0.001	8.14	Upward.
P26	06324950	Flow adjusted	2005–10	Calcium	72	0.444	<0.001	9.76	Upward.
P26	06324950	Unadjusted	2005–10	Magnesium	72	0.367	<0.001	8.80	Upward.
P26	06324950	Flow adjusted	2005–10	Magnesium	72	0.400	<0.001	9.54	Upward.
P26	06324950	Unadjusted	2005–10	Sodium adsorption ratio	72	-0.044	0.704	-0.061	No trend.
P26	06324950	Flow adjusted	2005–10	Sodium adsorption ratio	72	-0.011	0.957	-0.007	No trend.
P26	06324950	Unadjusted	2005–10	Sodium	72	0.106	0.328	6.60	No trend.
P26	06324950	Flow adjusted	2005–10	Sodium	72	0.200	0.058	15.2	No trend.
P27	06324970	Unadjusted	1991–2010	Specific conductance	80	0.057	0.528	13.9	No trend.
P27	06324970	Flow adjusted	1991–2010	Specific conductance	80	-0.039	0.688	-8.74	No trend.
P27	06324970	Unadjusted	1991–2010	Calcium	80	0.108	0.181	1.53	No trend.
P27	06324970	Flow adjusted	1991–2010	Calcium	80	0.055	0.483	0.404	No trend.
P27	06324970	Unadjusted	1991–2010	Magnesium	80	0.108	0.204	1.10	No trend.
P27	06324970	Flow adjusted	1991–2010	Magnesium	80	0.026	0.788	0.203	No trend.
P27	06324970	Unadjusted	1991–2010	Sodium adsorption ratio	80	-0.016	0.867	-0.015	No trend.
P27	06324970	Flow adjusted	1991–2010	Sodium adsorption ratio	80	-0.147	0.139	-0.037	No trend.
P27	06324970	Unadjusted	1991–2010	Sodium	80	0.037	0.675	1.54	No trend.
P27	06324970	Flow adjusted	1991–2010	Sodium	80	-0.055	0.578	-2.19	No trend.
P27	06324970	Unadjusted	2001–10	Specific conductance	60	0.030	0.821	12.8	No trend.
P27	06324970	Flow adjusted	2001–10	Specific conductance	60	0.215	0.096	69.4	No trend.
P27	06324970	Unadjusted	2001–10	Calcium	60	0.007	0.969	0.024	No trend.
P27	06324970	Flow adjusted	2001–10	Calcium	60	0.193	0.116	2.44	No trend.
P27	06324970	Unadjusted	2001–10	Magnesium	60	0.059	0.615	0.447	No trend.
P27	06324970	Flow adjusted	2001–10	Magnesium	60	0.230	0.082	2.84	No trend.
P27	06324970	Unadjusted	2001–10	Sodium adsorption ratio	60	0.000	1.000	0.000	No trend.
P27	06324970	Flow adjusted	2001–10	Sodium adsorption ratio	60	0.126	0.311	0.078	No trend.
P27	06324970	Unadjusted	2001–10	Sodium	60	0.022	0.866	1.52	No trend.
P27	06324970	Flow adjusted	2001–10	Sodium	60	0.207	0.108	8.77	No trend.
P27	06324970	Unadjusted	2001–10	Alkalinity	60	0.052	0.603	1.48	No trend.
P27	06324970	Flow adjusted	2001–10	Alkalinity	60	0.148	0.095	6.04	No trend.
P27	06324970	Unadjusted	2001–10	Chloride	60	0.037	0.767	0.786	No trend.
P27	06324970	Flow adjusted	2001–10	Chloride	60	0.193	0.131	2.27	No trend.
P27	06324970	Unadjusted	2001–10	Sulfate	60	-0.007	0.973	-1.82	No trend.
P27	06324970	Flow adjusted	2001–10	Sulfate	60	0.163	0.245	24.9	No trend.
P27	06324970	Unadjusted	2005–10	Specific conductance	72	0.111	0.303	85.8	No trend.
P27	06324970	Flow adjusted	2005–10	Specific conductance	72	0.289	0.006	0.062	Upward.
P27	06324970	Unadjusted	2005–10	Calcium	72	0.111	0.303	3.35	No trend.
P27	06324970	Flow adjusted	2005–10	Calcium	72	0.278	0.008	11.7	Upward.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

[USGS, U.S. Geological Survey; —, not calculated; <, less than. Slope for unadjusted trends is the change per year in original measurement units; for flow-adjusted trends, the slopes reflect relative changes in units after adjustment for streamflow variability]

Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
P27	06324970	Unadjusted	2005–10	Magnesium	72	0.222	0.034	5.52	Upward.
P27	06324970	Flow adjusted	2005–10	Magnesium	72	0.333	0.001	9.15	Upward.
P27	06324970	Unadjusted	2005–10	Sodium adsorption ratio	72	0.067	0.551	0.063	No trend.
P27	06324970	Flow adjusted	2005–10	Sodium adsorption ratio	72	0.256	0.015	0.202	Upward.
P27	06324970	Unadjusted	2005–10	Sodium	72	0.144	0.175	15.2	No trend.
P27	06324970	Flow adjusted	2005–10	Sodium	72	0.389	<0.001	28.1	Upward.
P27	06324970	Unadjusted	2005–10	Alkalinity	72	0.100	0.357	7.64	No trend.
P27	06324970	Flow adjusted	2005–10	Alkalinity	72	0.278	0.008	13.3	Upward.
P27	06324970	Unadjusted	2005–10	Chloride	72	0.022	0.871	1.99	No trend.
P27	06324970	Flow adjusted	2005–10	Chloride	72	0.144	0.175	2.05	No trend.
P27	06324970	Unadjusted	2005–10	Sulfate	72	0.178	0.093	83.2	No trend.
P27	06324970	Flow adjusted	2005–10	Sulfate	72	0.333	0.001	130	Upward.
C2	06386500	Unadjusted	2005–10	Specific conductance	55	-0.124	0.362	-60.0	No trend.
C2	06386500	Flow adjusted	2005–10	Specific conductance	55	0.314	0.016	0.028	Upward.
C2	06386500	Unadjusted	2005–10	Calcium	55	-0.010	1.000	-0.200	No trend.
C2	06386500	Flow adjusted	2005–10	Calcium	55	0.333	0.010	11.6	Upward.
C2	06386500	Unadjusted	2005–10	Magnesium	55	0.000	1.000	0.000	No trend.
C2	06386500	Flow adjusted	2005–10	Magnesium	55	0.410	0.001	5.17	Upward.
C2	06386500	Unadjusted	2005–10	Sodium adsorption ratio	55	-0.162	0.226	-0.150	No trend.
C2	06386500	Flow adjusted	2005–10	Sodium adsorption ratio	55	0.200	0.131	0.270	No trend.
C2	06386500	Unadjusted	2005–10	Sodium	55	-0.048	0.762	-13.9	No trend.
C2	06386500	Flow adjusted	2005–10	Sodium	55	0.314	0.016	33.3	Upward.
C2	06386500	Unadjusted	2005–10	Alkalinity	55	0.238	0.070	4.95	No trend.
C2	06386500	Flow adjusted	2005–10	Alkalinity	55	0.219	0.096	3.43	No trend.
C2	06386500	Unadjusted	2005–10	Chloride	55	0.105	0.450	1.69	No trend.
C2	06386500	Flow adjusted	2005–10	Chloride	55	0.238	0.070	4.69	No trend.
C2	06386500	Unadjusted	2005–10	Sulfate	55	-0.048	0.762	-4.54	No trend.
C2	06386500	Flow adjusted	2005–10	Sulfate	55	0.352	0.007	98.3	Upward.
B1	06425720	Unadjusted	2001–10	Specific conductance	50	0.204	0.156	33.3	No trend.
B1	06425720	Flow adjusted	2001–10	Specific conductance	50	0.277	0.041	36.6	Upward.
B1	06425720	Unadjusted	2001–10	Calcium	50	-0.016	0.938	-0.180	No trend.
B1	06425720	Flow adjusted	2001–10	Calcium	50	0.016	0.937	0.133	No trend.
B1	06425720	Unadjusted	2001–10	Magnesium	50	-0.047	0.713	-0.445	No trend.
B1	06425720	Flow adjusted	2001–10	Magnesium	50	-0.026	0.872	-0.483	No trend.
B1	06425720	Unadjusted	2001–10	Sodium adsorption ratio	50	0.372	0.030	0.169	Upward.
B1	06425720	Flow adjusted	2001–10	Sodium adsorption ratio	50	0.455	0.020	0.149	Upward.
B1	06425720	Unadjusted	2001–10	Sodium	50	0.309	0.045	8.08	Upward.
B1	06425720	Flow adjusted	2001–10	Sodium	50	0.466	0.019	8.27	Upward.
B1	06425720	Unadjusted	2005–10	Specific conductance	57	0.047	0.744	10.0	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

[USGS, U.S. Geological Survey; —, not calculated; <, less than. Slope for unadjusted trends is the change per year in original measurement units; for flow-adjusted trends, the slopes reflect relative changes in units after adjustment for streamflow variability]

Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
B1	06425720	Flow adjusted	2005–10	Specific conductance	57	0.203	0.103	0.028	No trend.
B1	06425720	Unadjusted	2005–10	Calcium	57	-0.156	0.216	-4.76	No trend.
B1	06425720	Flow adjusted	2005–10	Calcium	57	-0.172	0.171	-4.86	No trend.
B1	06425720	Unadjusted	2005–10	Magnesium	57	-0.188	0.134	-3.60	No trend.
B1	06425720	Flow adjusted	2005–10	Magnesium	57	-0.078	0.557	-1.96	No trend.
B1	06425720	Unadjusted	2005–10	Sodium adsorption ratio	57	0.500	<0.001	0.256	Upward.
B1	06425720	Flow adjusted	2005–10	Sodium adsorption ratio	57	0.625	<0.001	0.343	Upward.
B1	06425720	Unadjusted	2005–10	Sodium	57	0.219	0.078	9.56	No trend.
B1	06425720	Flow adjusted	2005–10	Sodium	57	0.578	<0.001	19.7	Upward.
B3	06426400	Unadjusted	2001–10	Specific conductance	59	-0.038	0.636	-10.0	No trend.
B3	06426400	Flow adjusted	2001–10	Specific conductance	59	0.172	0.063	25.2	No trend.
B3	06426400	Unadjusted	2001–10	Calcium	59	0.218	0.007	2.70	Upward.
B3	06426400	Flow adjusted	2001–10	Calcium	59	0.157	0.062	2.18	No trend.
B3	06426400	Unadjusted	2001–10	Magnesium	59	0.234	0.020	2.35	Upward.
B3	06426400	Flow adjusted	2001–10	Magnesium	59	0.218	0.052	3.14	No trend.
B3	06426400	Unadjusted	2001–10	Sodium adsorption ratio	59	-0.318	0.025	-0.182	Downward.
B3	06426400	Flow adjusted	2001–10	Sodium adsorption ratio	59	-0.080	0.389	-0.013	No trend.
B3	06426400	Unadjusted	2001–10	Sodium	59	-0.241	0.052	-9.54	No trend.
B3	06426400	Flow adjusted	2001–10	Sodium	59	0.065	0.490	2.55	No trend.
B3	06426400	Unadjusted	2001–10	Alkalinity	59	-0.372	0.013	-12.5	Downward.
B3	06426400	Flow adjusted	2001–10	Alkalinity	59	-0.172	0.094	-4.08	No trend.
B3	06426400	Unadjusted	2001–10	Chloride	59	-0.065	0.557	-1.45	No trend.
B3	06426400	Flow adjusted	2001–10	Chloride	59	0.142	0.215	3.12	No trend.
B3	06426400	Unadjusted	2001–10	Sulfate	59	0.096	0.291	11.5	No trend.
B3	06426400	Flow adjusted	2001–10	Sulfate	59	0.165	0.119	20.7	No trend.
B3	06426400	Unadjusted	2005–10	Specific conductance	72	0.056	0.625	10.0	No trend.
B3	06426400	Flow adjusted	2005–10	Specific conductance	72	0.222	0.034	0.032	Upward.
B3	06426400	Unadjusted	2005–10	Calcium	72	0.261	0.012	4.68	Upward.
B3	06426400	Flow adjusted	2005–10	Calcium	72	0.200	0.058	4.46	No trend.
B3	06426400	Unadjusted	2005–10	Magnesium	72	0.311	0.003	6.50	Upward.
B3	06426400	Flow adjusted	2005–10	Magnesium	72	0.289	0.006	5.82	Upward.
B3	06426400	Unadjusted	2005–10	Sodium adsorption ratio	72	-0.344	0.001	-0.193	Downward.
B3	06426400	Flow adjusted	2005–10	Sodium adsorption ratio	72	0.100	0.357	0.018	No trend.
B3	06426400	Unadjusted	2005–10	Sodium	72	-0.178	0.093	-8.14	No trend.
B3	06426400	Flow adjusted	2005–10	Sodium	72	0.200	0.058	5.77	No trend.
B3	06426400	Unadjusted	2005–10	Alkalinity	72	-0.422	<0.001	-26.1	Downward.
B3	06426400	Flow adjusted	2005–10	Alkalinity	72	-0.178	0.093	-10.3	No trend.
B3	06426400	Unadjusted	2005–10	Chloride	72	-0.133	0.212	-4.32	No trend.
B3	06426400	Flow adjusted	2005–10	Chloride	72	0.089	0.416	3.00	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

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Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
B3	06426400	Unadjusted	2005–10	Sulfate	72	0.333	0.001	59.0	Upward.
B3	06426400	Flow adjusted	2005–10	Sulfate	72	0.367	<0.001	61.7	Upward.
B4	06426500	Unadjusted	1991–2010	Specific conductance	76	0.118	0.167	22.9	No trend.
B4	06426500	Flow adjusted	1991–2010	Specific conductance	76	0.050	0.610	9.15	No trend.
B4	06426500	Unadjusted	1991–2010	Calcium	52	0.202	0.080	2.03	No trend.
B4	06426500	Flow adjusted	1991–2010	Calcium	52	0.205	0.075	1.29	No trend.
B4	06426500	Unadjusted	1991–2010	Magnesium	52	0.292	0.021	2.45	Upward.
B4	06426500	Flow adjusted	1991–2010	Magnesium	52	0.314	0.026	2.08	Upward.
B4	06426500	Unadjusted	1991–2010	Sodium adsorption ratio	52	-0.247	0.094	-0.086	No trend.
B4	06426500	Flow adjusted	1991–2010	Sodium adsorption ratio	52	-0.218	0.111	-0.039	No trend.
B4	06426500	Unadjusted	1991–2010	Sodium	52	-0.048	0.708	-2.02	No trend.
B4	06426500	Flow adjusted	1991–2010	Sodium	52	-0.006	0.979	-0.251	No trend.
B4	06426500	Unadjusted	2001–10	Specific conductance	60	0.048	0.573	9.17	No trend.
B4	06426500	Flow adjusted	2001–10	Specific conductance	60	0.170	0.212	34.9	No trend.
B4	06426500	Unadjusted	2001–10	Calcium	60	0.222	0.033	3.64	Upward.
B4	06426500	Flow adjusted	2001–10	Calcium	60	0.244	0.048	3.44	Upward.
B4	06426500	Unadjusted	2001–10	Magnesium	60	0.178	0.074	3.12	No trend.
B4	06426500	Flow adjusted	2001–10	Magnesium	60	0.356	0.021	3.82	Upward.
B4	06426500	Unadjusted	2001–10	Sodium adsorption ratio	60	-0.274	0.031	-0.135	Downward.
B4	06426500	Flow adjusted	2001–10	Sodium adsorption ratio	60	-0.052	0.669	-0.015	No trend.
B4	06426500	Unadjusted	2001–10	Sodium	60	-0.126	0.204	-6.97	No trend.
B4	06426500	Flow adjusted	2001–10	Sodium	60	0.089	0.500	2.30	No trend.
B4	06426500	Unadjusted	2001–10	Alkalinity	60	-0.333	0.014	-14.0	Downward.
B4	06426500	Flow adjusted	2001–10	Alkalinity	60	-0.267	0.033	-10.2	Downward.
B4	06426500	Unadjusted	2001–10	Chloride	60	0.141	0.267	6.07	No trend.
B4	06426500	Flow adjusted	2001–10	Chloride	60	0.481	0.005	7.39	Upward.
B4	06426500	Unadjusted	2001–10	Sulfate	60	0.096	0.425	17.5	No trend.
B4	06426500	Flow adjusted	2001–10	Sulfate	60	0.215	0.138	24.1	No trend.
B4	06426500	Unadjusted	2005–10	Specific conductance	72	0.022	0.871	25.0	No trend.
B4	06426500	Flow adjusted	2005–10	Specific conductance	72	0.222	0.034	0.031	Upward.
B4	06426500	Unadjusted	2005–10	Calcium	71	0.120	0.270	1.95	No trend.
B4	06426500	Flow adjusted	2005–10	Calcium	71	0.166	0.122	2.51	No trend.
B4	06426500	Unadjusted	2005–10	Magnesium	71	0.177	0.098	3.60	No trend.
B4	06426500	Flow adjusted	2005–10	Magnesium	71	0.406	<0.001	6.03	Upward.
B4	06426500	Unadjusted	2005–10	Sodium adsorption ratio	71	-0.097	0.377	-0.070	No trend.
B4	06426500	Flow adjusted	2005–10	Sodium adsorption ratio	71	0.177	0.098	0.058	No trend.
B4	06426500	Unadjusted	2005–10	Sodium	71	-0.051	0.659	-2.35	No trend.
B4	06426500	Flow adjusted	2005–10	Sodium	71	0.223	0.036	9.45	Upward.
B4	06426500	Unadjusted	2005–10	Alkalinity	72	-0.178	0.093	-5.76	No trend.

Appendix 2. Trend results for selected water-quality constituents for selected sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 1991–2010.—Continued

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Site number (fig. 1)	USGS site identification number	Type of value used in trend test	Trend period (water years)	Property or constituent	Sample size	Tau value	p-value	Slope	Trend direction
B4	06426500	Flow adjusted	2005–10	Alkalinity	72	0.033	0.786	1.91	No trend.
B4	06426500	Unadjusted	2005–10	Chloride	72	-0.233	0.026	-11.2	Downward.
B4	06426500	Flow adjusted	2005–10	Chloride	72	0.100	0.357	1.85	No trend.
B4	06426500	Unadjusted	2005–10	Sulfate	72	0.278	0.008	53.3	Upward.
B4	06426500	Flow adjusted	2005–10	Sulfate	72	0.444	<0.001	66.0	Upward.
B5	06428050	Unadjusted	2001–10	Specific conductance	56	-0.230	0.059	-28.0	No trend.
B5	06428050	Flow adjusted	2001–10	Specific conductance	56	-0.200	0.108	-20.1	No trend.
B5	06428050	Unadjusted	2001–10	Calcium	52	0.210	0.169	3.58	No trend.
B5	06428050	Flow adjusted	2001–10	Calcium	52	0.280	0.165	7.84	No trend.
B5	06428050	Unadjusted	2001–10	Magnesium	52	0.030	0.838	0.171	No trend.
B5	06428050	Flow adjusted	2001–10	Magnesium	52	0.030	0.792	0.235	No trend.
B5	06428050	Unadjusted	2001–10	Sodium adsorption ratio	52	-0.380	0.067	-0.103	No trend.
B5	06428050	Flow adjusted	2001–10	Sodium adsorption ratio	52	-0.380	0.097	-0.099	No trend.
B5	06428050	Unadjusted	2001–10	Sodium	52	-0.410	0.047	-7.69	Downward.
B5	06428050	Flow adjusted	2001–10	Sodium	52	-0.390	0.079	-6.39	No trend.
B5	06428050	Unadjusted	2001–10	Alkalinity	52	-0.130	0.369	-1.67	No trend.
B5	06428050	Flow adjusted	2001–10	Alkalinity	52	0.000	1.000	0.000	No trend.
B5	06428050	Unadjusted	2001–10	Chloride	52	-0.410	0.033	-1.92	Downward.
B5	06428050	Flow adjusted	2001–10	Chloride	52	-0.290	0.112	-1.69	No trend.
B5	06428050	Unadjusted	2001–10	Sulfate	52	0.030	0.811	1.76	No trend.
B5	06428050	Flow adjusted	2001–10	Sulfate	52	0.110	0.359	6.23	No trend.

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