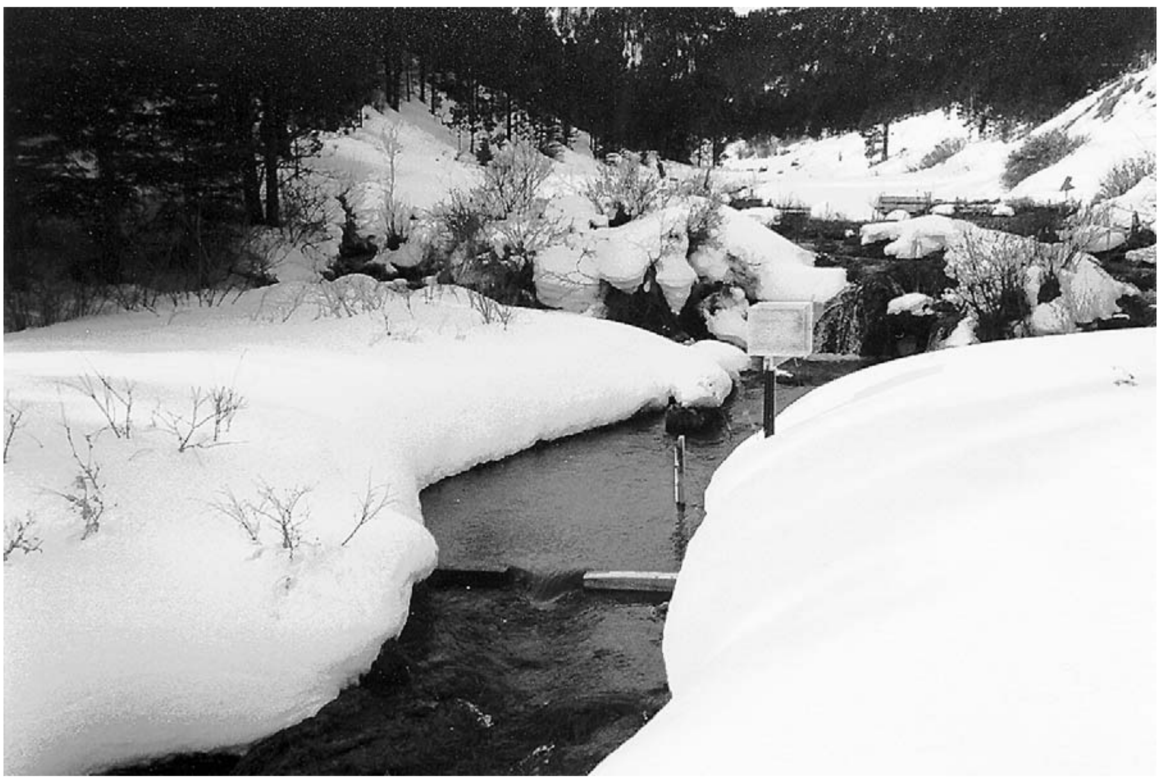
STREAMFLOW CHARACTERISTICS FOR THE BLACK HILLS OF SOUTH DAKOTA, THROUGH WATER YEAR 1993

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 97-4288



Prepared in cooperation with the
SOUTH DAKOTA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES and the
WEST DAKOTA WATER DEVELOPMENT DISTRICT

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By LISA D. MILLER and DANIEL G. DRISCOLL

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Rapid City, South Dakota
1998

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U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, Acting Director

For additional information write to:

District Chief
U.S. Geological Survey
1608 Mt. View Road
Rapid City, SD 57702

Copies of this report can be purchased from:

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Branch of Information Services
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CONTENTS

ILLUSTRATIONS

TABLES

CONTENTS OF SUPPLEMENTAL SECTIONS

Section F. Graphs showing variations in flow for stations with 10 or more years of daily record—Continued

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
Volume		
cubic foot (ft^3)	0.02832	cubic meter
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.001233	cubic hectometer
Flow rate		
inch per year (in/yr)	25.4	millimeter per year
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

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

$$°F = (1.8 \times °C) + 32$$

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

$$°C = (°F - 32) / 1.8$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Water year: In Geological Survey reports dealing with surface-water supply, water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends; thus, the water year ending September 30, 1993, is called the "1993 water year."

Streamflow Characteristics for the Black Hills of South Dakota, through Water Year 1993

By Lisa D. Miller *and* Daniel G. Driscoll

ABSTRACT

This report summarizes streamflow records and describes streamflow characteristics for streams draining the Black Hills of western South Dakota. Monthly and annual streamflow records are tabulated for all available years of record, through water year 1993, for 129 continuous-record gaging stations, including 111 stations for which records of daily flow are available and 18 stations for which only monthly records are available. Various summary statistics and graphics are presented for stations with sufficient periods of record. In addition to streamflow summaries, records of monthend contents are presented for five reservoirs operated by the Bureau of Reclamation in the Black Hills area.

Streamflow characteristics are described for four categories of hydrogeologic settings, including interior sedimentary basins, interior crystalline basins, interior basins downstream of loss zones (loss-zone basins), and exterior basins. All of the interior basins are located predominantly within the outermost extent of the outcrop of the Inyan Kara Group and the exterior basins are located predominantly beyond this outcrop.

Distinct differences in variability of annual and monthly streamflow are described for the four categories of hydrogeologic settings. The interior sedimentary basins, which are dominated by springflow from headwater areas, have the smallest variability in both annual and monthly flow, as a group. The exterior basins, as a group, have the largest variability in both annual and monthly flow. Streamflow variability for the interior crystalline basins, which are composed primarily of Precambrian and Tertiary igneous and metamorphic rocks, generally falls midway between the interior sedimentary and exterior basins. Loss-zone stations, which are located downstream of loss zones that occur where streams cross outcrops of the Madison Limestone and other overlying sedimentary units, exhibit the widest range in streamflow variability of any of the categories. Most of the loss-zone basins have springs located upstream of the gaging stations, but downstream of the loss zones. Flow at several of the loss-zone stations is dominated by large and consistent springflow; however, flow at other loss-zone stations is dominated by streamflow losses or by tributary inflows between the loss zones and the gaging stations, which results in extremely variable streamflow characteristics. It is demonstrated that springflow in Battle, Spring, Elk, and Bear Butte Creeks is much more variable than in Cascade Springs, Fall River, Beaver Creek, and Redwater River.

Interior crystalline basins and exterior basins are shown to be much more responsive to climatic conditions than the springflow-dominated basins. Zero-flow months have been recorded for all of the exterior basins and most of the interior crystalline basins; however, zero-flow months have not been recorded for any of the interior sedimentary basins. Zero-flow months have not been recorded for the loss-zone stations with large,

consistent springflow; however, zero-flow months are common for loss-zone stations with smaller, less consistent springs.

Direct surface runoff is demonstrated to be uncommon for outcrops of the Madison Limestone and Minnelusa Formation. Examination of streamflow records for two basins with large outcrops of these formations indicates that direct surface runoff seldom occurs.

Annual streamflow is shown to increase from south to north, which is consistent with climatic patterns for the area. Annual yield generally is larger for all of the interior categories than for the exterior basins; however, this is consistent with larger precipitation and smaller evapotranspiration rates at higher elevations. Annual yields generally are largest for the interior sedimentary basins; however, all of these basins are located in the northern Black Hills. Interior crystalline basins located in the northern Black Hills have annual yields that are comparable with interior sedimentary basins.

INTRODUCTION

The Black Hills area is an important resource center for the State of South Dakota. Not only do the Black Hills provide an economic base for western South Dakota through tourism, agriculture, the timber industry, and mineral resources; they also are an important source of water. Water originating in the area is used for municipal, industrial, agricultural, and recreational purposes throughout much of western South Dakota.

Population growth and resource development have the potential to affect the quantity, quality, and availability of water within the Black Hills area. Because of this concern, the Black Hills Hydrology Study was initiated in 1990 to assess the quantity, quality, and distribution of surface water and ground water in the Black Hills area of South Dakota (Driscoll, 1992). This long-term study is a cooperative effort between the U.S. Geological Survey (USGS); the South Dakota Department of Environment and Natural Resources; and the West Dakota Water Development District, which represents various local and county cooperators.

Purpose and Scope

One of the specific objectives of the Black Hills Hydrology Study is to describe streamflow for the Black Hills area. The purpose of this report is to fulfill that objective by summarizing streamflow records and describing streamflow characteristics for streams draining the Black Hills of South Dakota.

Description of Study Area

The Black Hills are situated between the Cheyenne and Belle Fourche Rivers (fig. 1). The Belle Fourche River, with a drainage area of 7,210 mi^2 at USGS gaging station 06438000, is the largest tributary to the Cheyenne River, which has a drainage area of 23,900 mi^2 at gaging station 06439300. The study area for the Black Hills Hydrology Study includes the topographically defined Black Hills, which is represented in figures 1 and 2 by the outer extent of the outcrop of the Inyan Kara Group.

Physiography and Climate

The Black Hills area is an elongated, domal feature, about 125 mi long and 60 mi wide, that was uplifted during the Laramide orogeny (Feldman and Heimlich, 1980). Elevations range from about 7,200 ft above sea level at the higher peaks to approximately 3,000 ft in the surrounding plains. Most of the higher elevations are heavily forested with ponderosa pine, which is the primary product of an active timber industry. White spruce, quaking aspen, paper birch, and other native trees and shrubs are found in cooler, wetter areas (Orr, 1959). The lower elevations surrounding the Hills are primarily urban, suburban, and agricultural. Numerous deciduous species such as cottonwood, ash, elm, oak, and willow are common along stream bottoms in the lower elevations. Rangeland, hayland, and winter wheat farming are the principal agricultural uses for dryland areas. Alfalfa, corn, and vegetables are produced in bottom lands and in irrigated areas. Various other crops, primarily for cattle fodder, are produced in both dryland areas and in bottom lands.

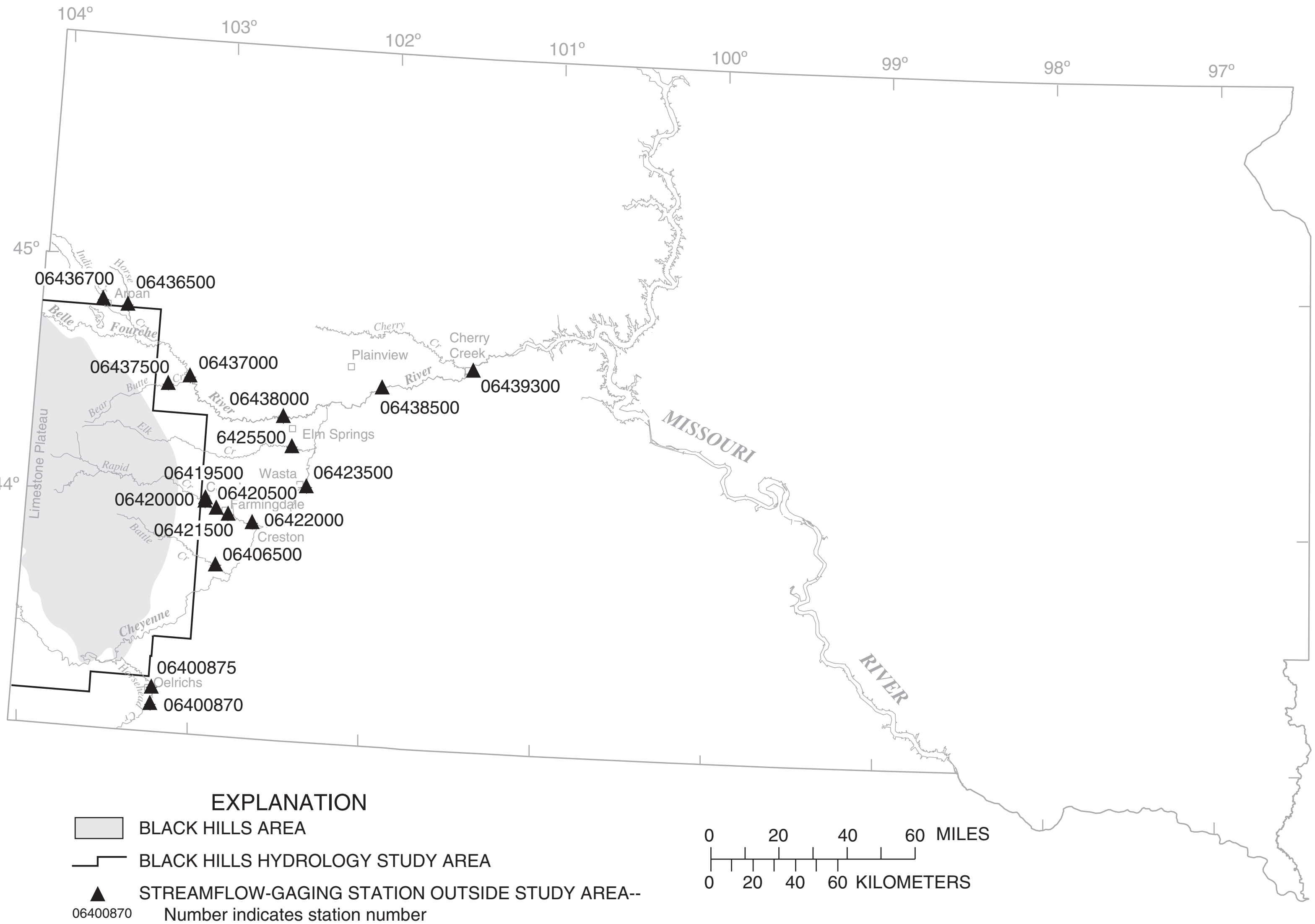
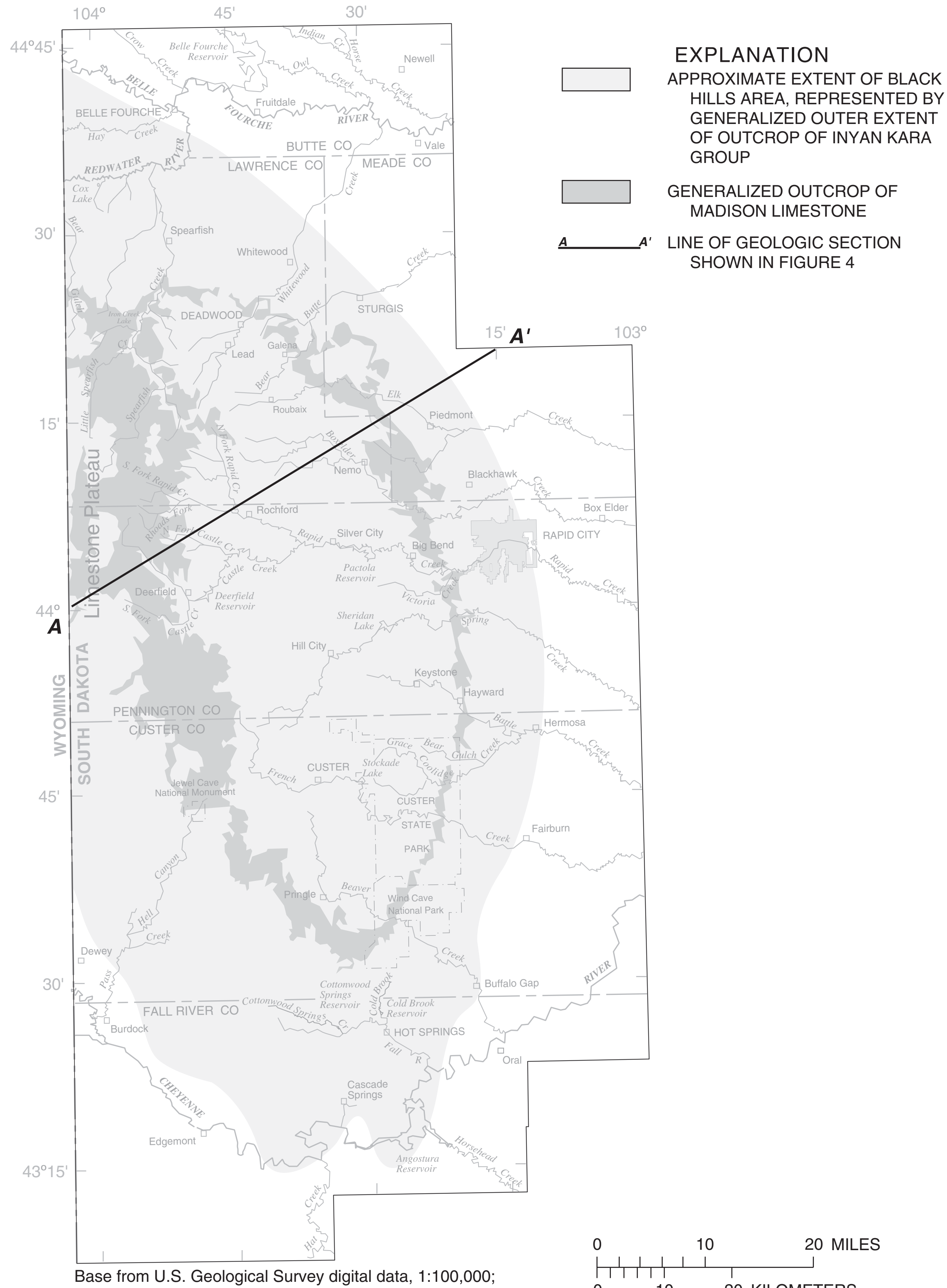


Figure 1. Area of investigation for Black Hills Hydrology Study showing locations of gaging stations outside of the study area for which data are presented.



Base from U.S. Geological Survey digital data, 1:100,000; Quadrangle maps 1:24,000; and City Engineers map, 1991

Figure 2. Generalized outcrop of Madison Limestone and outer extent of Inyan Kara Group, within study area for Black Hills Hydrology Study.

The overall climate of the Black Hills area is continental, with generally low precipitation amounts, hot summers, cold winters, and extreme variations in both precipitation and temperatures (Johnson, 1933). Climatic conditions are locally affected by topography, with generally lower temperatures and higher precipitation at the higher elevations. The average annual temperature (1961-90) for the Black Hills area is 43.9 degrees Fahrenheit (U.S. Department of Commerce, 1994), and ranges from 47.6 degrees at Hot Springs (fig. 2; elevation = 3,559 ft) to approximately 37 degrees near Deerfield Reservoir (elevation = 6,060 ft). Average annual precipitation is 21.30 in., and ranges from 15.08 in. at Hot Springs to 28.65 in. at Lead (elevation = 5,350 ft). Average annual precipitation also generally increases from south to north, by as much as 5 to 10 in/yr (Addison, 1991). Average annual evaporation generally exceeds average annual precipitation throughout the study area. Average pan evaporation for April through October (U.S. Department of Commerce, 1994) is about 30 in. at Pactola Reservoir (elevation = 4,720 ft) and about 50 in. at Oral (elevation = 2,960 ft).

Hydrogeology

Much of the surface-water hydrology of the Black Hills area is controlled by geologic features. The oldest geologic units in the stratigraphic sequence are the Precambrian metamorphic and igneous rocks (fig. 3), which are exposed in the central core of the Black Hills, extending from near Lead to south of Custer. The Precambrian rocks generally are of low permeability; however, localized fracture systems can provide adequate well yields for limited use. Various Tertiary intrusive rocks, with hydrogeologic characteristics similar to the Precambrian rocks, are exposed in the northern Black Hills.

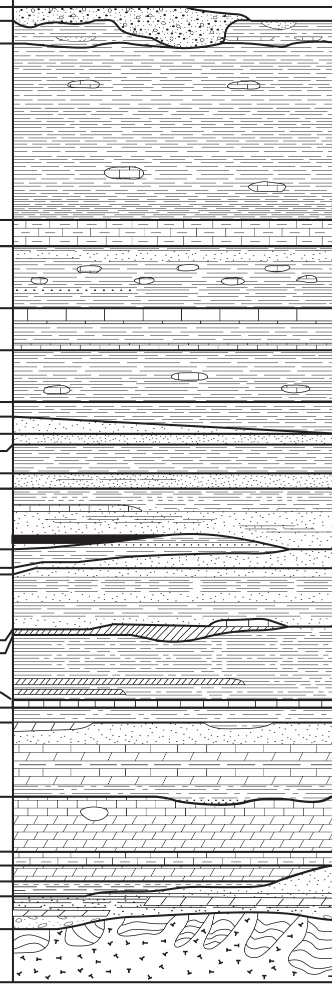
Surrounding the central core is a layered series of sedimentary rocks including limestones, sandstones, and shales that are exposed in roughly concentric rings around the uplifted flanks of the Black Hills (DeWitt and others, 1989). The generalized outcrop of the Madison Limestone, also known locally as the Pahasapa Limestone, is shown as an example in figure 2. The generalized outer extent of the outcrop of the Inyan Kara Group, which approximates the outer extent of the Black Hills uplift, also is shown in figure 2. The bedrock sedimentary formations typically dip away from the uplifted Black Hills at angles that approach or exceed 10 degrees near the outcrops, and decrease with distance from the uplift (fig. 4).

Many of the sedimentary units are aquifers, both within and beyond the study area. Recharge to these aquifers is from precipitation upon the outcrops and from stream infiltration along the flanks of the Black Hills (Greene, 1993; Kyllonen and Peter, 1987; Peter, 1985). Within the Paleozoic rock interval, aquifers in the Deadwood Formation, Madison Limestone, Minnelusa Formation, and Minnekahta Limestone are used extensively. These aquifers are collectively confined by the underlying Precambrian rocks and the overlying Spearfish Formation. Individually the aquifers are separated by minor confining layers, or by relatively impermeable layers within the individual formations. Leakance between these aquifers is extremely variable (Greene, 1993; Peter, 1985). Within the Mesozoic rock interval, aquifers in the Inyan Kara Group are used extensively. Aquifers in various other units within the Mesozoic interval are used locally to lesser degrees. As much as 4,000 ft of Cretaceous shales act as the upper confining layer to aquifers in the Mesozoic interval.

Artesian conditions generally exist within the aforementioned aquifers, where an upper confining layer is present. Under artesian conditions, water in a well will rise above the top of the aquifer in which it is completed. If the water level, or potentiometric surface, is above the land surface, a flowing well will result. Flowing wells and artesian springs that originate from confined aquifers are common around the periphery of the Black Hills. The hydrogeologic setting of the Black Hills area is schematically illustrated in figure 5.

Reservoirs and Water Use

Numerous agricultural, municipal, industrial, and recreational users utilize available water supplies in the Black Hills area. The natural flows of many streams within the study area are altered by regulation or diversions for these uses. Agricultural users in the area account for the largest consumptive uses of water, followed by municipal and industrial users. Major irrigation projects with large storage reservoirs are located along Rapid Creek and the Belle Fourche and Cheyenne Rivers. Significant irrigation diversions also occur from many other area streams.



ERATHEM	SYSTEM	ABBREVIATION FOR STRATIGRAPHIC INTERVAL	GEOLOGIC UNIT	THICKNESS IN FEET	DESCRIPTION
CENOZOIC	QUATERNARY & TERTIARY (?)	Qal, Qw, Qt	UNDIFFERENTIATED SANDS AND GRAVELS	0-50	Sand, gravel, and boulders
	TERTIARY [1]	Tw	WHITE RIVER GROUP	0-600	Light colored clays with sandstone channel fillings and local limestone lenses.
MESOZOIC	CRETACEOUS	Kp	PIERRE SHALE; Sharon Springs Mem.	1200-2000	Principal horizon of limestone lenses giving teepee buttes. Dark-gray shale containing scattered concretions. Widely scattered limestone masses, giving small teepee buttes. Black fissile shale with concretions.
		Kng	NIOBRARA FORMATION	100-225	Impure chalk and calcareous shale.
			CARLILE FORMATION; Turner Sand Member; Wall Creek Sands	400-750	Light-gray shale with numerous large concretions and sandy layers. Dark-gray shale
			GREENHORN FORMATION	(25-30) (200-350)	Impure slabby limestone. Weathers buff. Dark-gray calcareous shale, with thin Orman Lake limestone at base.
		Kb	GRANEROS GROUP: BELLE FOURCHE SHALE	300-550	Gray shale with scattered limestone concretions. Clay spur bentonite at base.
		Kms	GRANEROS GROUP: MOWRY SHALE	150-250	Light-gray siliceous shale. Fish scales and thin layers of bentonite.
			GRANEROS GROUP: MUDDY SANDSTONE: DYNNESON; NEWCASTLE	20-60	Brown to light yellow and white sandstone.
			GRANEROS GROUP: SKULL CREEK SHALE	170-270	Dark gray to black siliceous shale.
		KJim	INYAN KARA GROUP: FALL RIVER FORMATION	10-200	Massive to slabby sandstone.
			INYAN KARA GROUP: LAKOTA FM; Fuson Shale; Minnewaste Limestone	10-188; 0-25; 25-485	Coarse gray to buff cross-bedded conglomeratic sandstone, interbedded with buff, red, and gray clay, especially toward top. Local fine-grained limestone.
	JURASSIC		MORRISON FORMATION	0-220	Green to maroon shale. Thin sandstone.
			UNKPAPA SS	0-225	Massive fine-grained sandstone.
		Jsg	SUNDANCE FORMATION; Redwater Member; Lak Member; Hulett Member; Stockade Beaver; Canyon Spr Member	250-450	Greenish-gray shale, thin limestone lenses. Glauconltic sandstone; red sandstone near middle.
			GYPSUM SPRING FORMATION	0-45	Red siltstone, gypsum, and limestone.
	TRIASSIC	TRPs	SPEARFISH FORMATION; Goose Egg Equivalent	250-700	Red sandy shale, soft red sandstone and siltstone with gypsum and thin limestone layers. Gypsum locally near the base.
PALEOZOIC	PERMIAN	Pmo	MINNEKAHTA LIMESTONE	30-50	Massive gray, laminated limestone.
			OPECHE FORMATION	50-135	Red shale and sandstone.
	PENNSYLVANIAN	PIPm	MINNELUSA FORMATION	350-850	Yellow to red cross-bedded sandstone, limestone, and anhydrite locally at top. Interbedded sandstone, limestone, dolomite, shale, and anhydrite. Red shale with interbedded limestone and sandstone at base.
	MISSISSIPPIAN	MDpe	MADISON (PAHASAPA) LIMESTONE	300-630	Massive light-colored limestone. Dolomite in part. Cavernous in upper part.
	DEVONIAN		ENGLEWOOD LIMESTONE	30-60	Pink to buff limestone. Shale locally at base.
	ORDOVICIAN	OЄwd	WHITEWOOD (RED RIVER) FORMATION	0-60	Buff dolomite and limestone.
			WINNIPEG FORMATION	0-100	Green shale with siltstone.
	CAMBRIAN		DEADWOOD FORMATION	10-400	Massive to thin-bedded buff to purple sandstone. Greenish glauconitic shale flaggy dolomite and flatpebble limestone conglomerate. Sandstone, with conglomerate locally at the base.
PRECAMBRIAN		pЄu	UNDIFFERENTIATED METAMORPHIC AND IGNEOUS ROCKS		Schist, slate, quartzite, and arkosic grit. Intruded by diorite, metamorphosed to amphibolite, and by granite and pegmatite.

[1] Also may include intrusive igneous rocks

Modified from information furnished by the Department of Geology and Geological Engineering, South Dakota School of Mines and Technology (written commun., January 1994)

Figure 3. Stratigraphic section for the Black Hills.

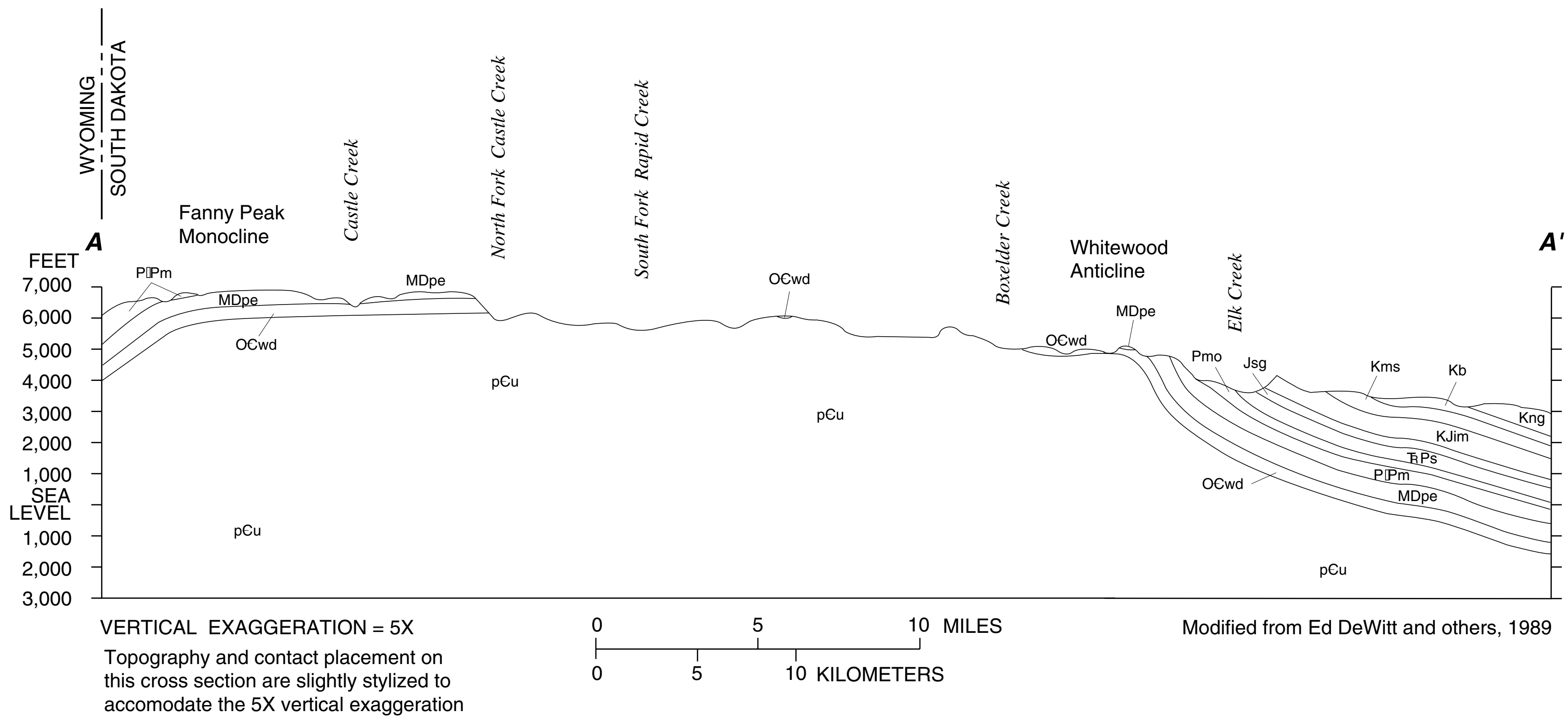


Figure 4. Generalized geologic section A-A'. (Location of section is shown in figure 2. Explanation of abbreviation for stratigraphic interval is shown in figure 3).

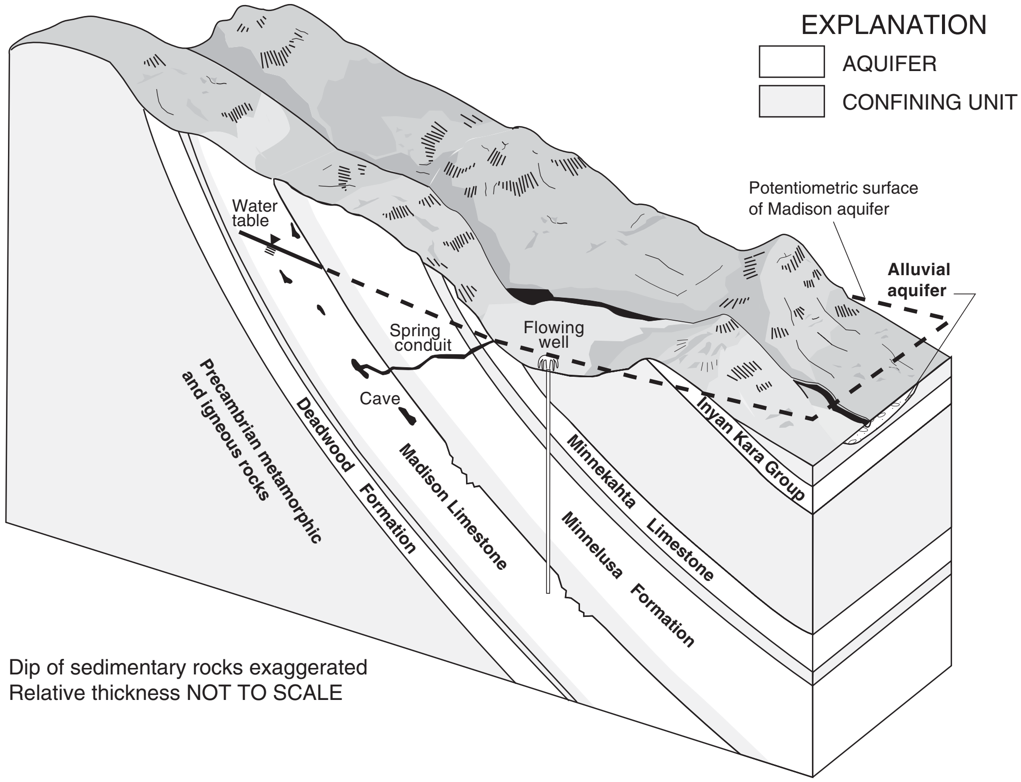


Figure 5. Schematic showing simplified hydrogeologic setting of the Black Hills area.

The USGS and the Bureau of Reclamation (Reclamation) have cooperated in collection and publication of storage information for five reservoirs (Angostura, Deerfield, Pactola, Keyhole, and Belle Fourche) in the Black Hills area. The USGS typically has assisted in collection of stage information, which is used by Reclamation for calculating records of reservoir contents. Records of monthend reservoir contents are provided by Reclamation for publication in USGS data reports. Records of monthend contents for Angostura, Deerfield, Pactola, Keyhole, and Belle Fourche Reservoirs, which have been published previously by the USGS, are summarized for all available years of record in Section A of the Supplemental Information section at the back of this report. The following paragraphs provide a brief description of each of these reservoirs.

Angostura Reservoir (fig. 2) is formed by a composite dam consisting of a concrete gravity structure and an earth embankment on the Cheyenne River. Water stored in the reservoir is used primarily for irrigation. Storage began in October 1949 and the dam was completed in December 1949. Live capacity is 122,100 acre-ft, of which active conservation capacity is 82,400 acre-ft and inactive capacity is 39,700 acre-ft. Dead storage (storage below lowest outlet point) is 8,600 acre-ft, and surcharge capacity (capacity above crest of spillway) is 56,400 acre-ft (Bureau of Reclamation, 1997).

Deerfield Reservoir (fig. 2) is formed by an earthfill dam on Castle Creek, a major tributary to Rapid Creek. Water from Deerfield Reservoir is used for municipal supply for Rapid City and for irrigation in the Rapid Valley Project downstream of Rapid City. Storage began in December 1945 and the dam was completed in 1947. Active conservation capacity is 15,504 acre-ft, dead storage is 151 acre-ft, and surcharge capacity is 26,655 acre-ft (Bureau of Reclamation, 1997).

Pactola Reservoir (fig. 2) is formed by an earthfill dam on Rapid Creek. Water from Pactola Reservoir is used for municipal supply for Rapid City and for irrigation in the Rapid Valley Project downstream of Rapid City. The dam was completed in August 1956, and storage began that same month. Active conservation capacity is 54,955 acre-ft, inactive capacity is

895 acre-ft, and dead storage is 122 acre-ft. Pactola Reservoir also provides 43,057 acre-ft of exclusive flood-control storage and 41,892 acre-ft of surcharge capacity (Bureau of Reclamation, 1997).

Keyhole Reservoir, which is located in Wyoming about 50 mi west of Spearfish, South Dakota, is formed by an earthfill dam on the Belle Fourche River. The reservoir provides supplemental irrigation storage for the Belle Fourche Project, which is located 146 river miles downstream. Keyhole Reservoir also supplies water for irrigation between the reservoir and the Belle Fourche Project. Storage began in February 1952, and the dam was completed in October 1952. Active conservation capacity is 185,801 acre-ft, inactive capacity is 7,226 acre-ft, and dead storage is 726 acre-ft. Surcharge capacity is 294,810 acre-ft, of which 140,462 acre-ft is designated as exclusive flood-control storage (Bureau of Reclamation, 1997).

Belle Fourche Reservoir (fig. 2) is an off-stream reservoir formed by an earthen dam on Owl Creek. Water is diverted from the Belle Fourche River through the Inlet Canal and is used for irrigation of project areas within and beyond the northern part of the study area. Storage began in May 1910 and the dam was completed in April 1911. Active conservation capacity is 185,277 acre-ft, dead storage is 6,800 acre-ft, and surcharge capacity is 86,139 acre-ft (Bureau of Reclamation, 1997).

Two small flood control reservoirs constructed by the U.S. Army Corps of Engineers are known to affect high flows of the Fall River near Hot Springs (fig. 2). Cold Brook Reservoir, with a capacity of 7,200 acre-ft, has regulated flows from Cold Brook since September 1952. Perennial flows occur into Cold Brook Reservoir; however, outflows are approximately equal to inflows, except when flood flows are stored (Kevin Grode, U.S. Army Corps of Engineers, written commun., Feb. 23, 1994). Cottonwood Springs Reservoir, with a capacity of 8,385 acre-ft, has regulated flows from Cottonwood Springs Creek since June 1969. Small, intermittent flows occur into Cottonwood Springs Reservoir; however, extended periods of zero inflow are common (Kevin Grode, U.S. Army Corps of Engineers, oral commun., Feb. 23, 1994).

Numerous other small reservoirs and stock dams are located within the study area. Most of these are operated as pass-through reservoirs under most conditions. The individual effects of such reservoirs on streamflow at various gaging stations generally are small. Potential, minor effects of small reservoirs generally are noted in station descriptions in USGS data reports.

The City of Rapid City is the largest municipal user of both surface and ground water in the Black Hills area. Numerous industries within Rapid City use modest quantities of water, most of which are obtained from the City's municipal supply. The largest industrial user in the Black Hills area is the Homestake Mining Company in Lead, which also supplies water to the Cities of Deadwood and Lead. An interbasin collection system is used to divert water to Whitewood Creek from Rapid, Elk, and Spearfish Creeks for these municipal and industrial uses. Homestake Mining Company also diverts water from Spearfish Creek for two hydropower stations; however, these flows are returned to Spearfish Creek.

Acknowledgments

The authors acknowledge the efforts of the West Dakota Water Development District for helping to develop the Black Hills Hydrology Study. West Dakota's coordination of various local and county cooperators has been a key element in making this study possible. The authors also recognize the numerous local and county cooperators represented by West Dakota, as well as the numerous private citizens who have helped provide guidance and support for the Black Hills Hydrology Study. In addition, the guidance and support of the South Dakota Department of Environment and Natural Resources is acknowledged.

SUMMARY OF STREAMFLOW GAGING IN THE BLACK HILLS

Since the turn of the century, more than 100 continuous-record streamflow-gaging stations have been operated in the Black Hills area by the USGS. Over the years, this network has been adapted to meet specific needs of Federal, State, and local cooperators to provide streamflow data for a variety of purposes (Little and Matthews, 1985). The following sections describe the history of streamflow gaging and summarize available streamflow records for the study area.

History of Streamflow Gaging

A list of continuous-record gaging stations operated in the Black Hills area is presented in table 1. Stations are arranged by station numbers, which increase in a downstream direction, according to the USGS downstream order system. Collection of streamflow data began in 1903 under the authority of the Sundry Civil Bill. A total of 13 stations were installed in the area during the period from 1903 through 1906; however, the program was discontinued in 1907 (Larimer, 1970). Eight new stations, as well as several stations that had been operated previously, were installed during four periods (1912-15, 1928-29, 1932-34, and 1938) of modest growth in the gaging program. Several of the stations installed during 1928-29 were under authority of the Flood Control Act, which established many stations on the Missouri River and its major tributaries (Little and Matthews, 1985). Two stations have been operated continuously since 1934 (06423500 and 06438000) and constitute the longest continuous streamflow records in the Black Hills area.

Beginning in the 1940's, numerous additional gaging stations were installed and operated for various purposes. Several Federal programs such as the Hydrologic Bench-Mark Network, National Stream-Quality Accounting Network, and Missouri River Basin Program have supported numerous gaging stations, primarily on major tributaries to the Missouri River. Both the Hydrologic Bench-Mark Network and the National Stream-Quality Accounting Network were designed by the USGS to obtain hydrologic data at selected sites throughout the country. The Missouri River Basin Program is supported primarily by the Bureau of Reclamation and is used to manage water resources in the region. During the mid-1940's, many streamflow-gaging stations were established under the Pick-Sloan Plan for Missouri Basin development (Decker, 1991). Additional stations were established during the late 1940's through the early 1960's in the Black Hills area for management of the Rapid Valley and Belle Fourche irrigation projects. In 1980 and 1981, several stations were established along Rapid Creek in Rapid City as part of the U. S. Environmental Protection Agency's Nationwide Urban Runoff Program (Goddard and Lockner, 1989). A portion of Whitewood Creek and the adjacent flood plain was listed as an Interim Priority Site under the Comprehensive Environmental Response Compensation and Liability Act of 1980. As a result, stations were established along Whitewood Creek in the early-1980's to monitor and study potential environmental problems associated with mining activities upstream (Goddard, 1989).

Numerous stations have been operated in cooperation with various State and local agencies. Many stations have been operated for water-rights purposes since the 1940's, in cooperation with the South Dakota Department of Environment and Natural Resources. In 1988, numerous stations were established along Rapid Creek as part of a study of ground-water/surface-water interactions. Numerous stations also were established in Pennington and Lawrence Counties during the late 1980's and early 1990's, as part of hydrologic investigations in these counties. As of March 1994, nineteen continuous-record streamflow-gaging stations, including many of the aforementioned Pennington and Lawrence County gages, were being operated as part of the Black Hills Hydrology Study (Driscoll, 1994).

Prior to about 1940, continuous streamflow data were obtained primarily from daily water-stage (height of the water surface above a reference elevation) measurements made by observers. After the mid-1940's, most continuous records of stage have been obtained from water-stage recorders, which generally record stage on either a continuous basis or at selected time intervals. Stage-discharge relations are developed for specific stream locations from periodic discharge measurements made at known stages (Wahl and others, 1995). These relations, in combination with stage records, are used to calculate streamflow records.

Summary of Streamflow Records

Summaries of streamflow records are presented for 129 continuous-record gaging stations that have been operated by the USGS within, or downstream from, the study area for the Black Hills Hydrology Study. This includes 111 stations for which records of daily flow have been reported and 18 stations for which only monthly records are available. For the stations with records of daily flow, 32 have less than 5 years of record, 27 have between 5 and 9 years of record, and 52 have 10 or more years of record.

The following summaries generally are presented by water year, which is the standard format for publication of streamflow records by the USGS (Rantz and others, 1982). A water year is a 12-month period that extends from October 1 through September 30 and is designated by the calender year in which it ends.

Table 1. Continuous-record streamflow-gaging stations operated in Black Hills area

Station number	Station name	Period of record through water year 1993
06394500	Beaver Creek near Burdock	1905-07, 1928-32
06394600	Hell Canyon near Jewel Cave, near Custer	1978-80
06394605	Hell Canyon near Custer	1978-80
06395000	Cheyenne River at Edgemont	1903-07, 1928-33, 1947-93
06400000	Hat Creek near Edgemont	1905-06, 1951-93
06400497	Cascade Springs near Hot Springs	1976-93
06400500	Cheyenne River near Hot Springs	1915-20, 1943-72
06400870	Horsehead Creek near Oelrichs	1982-83
06400875	Horsehead Creek at Oelrichs	1983-93
06401500	Cheyenne River below Angostura Dam	1946-93
06402000	Fall River at Hot Springs	1938-93
06402430	Beaver Creek near Pringle	1991-93
06402470	Beaver Creek above Buffalo Gap	1991-93
06402500	Beaver Creek near Buffalo Gap	1938-93
06402600	Cheyenne River near Buffalo Gap	1969-80
06402990	French Creek below Custer	1991-92
06402995	French Creek above Stockade Lake, near Custer	1991-93
06403000	French Creek near Custer	1945-47
06403300	French Creek above Fairburn	1982-93
06403500	French Creek near Fairburn	1945-47
06404000	Battle Creek near Keystone	1945-47, 1962-93
06404500	Battle Creek near Hermosa	1945-47
06404800	Grace Coolidge Creek near Hayward	1989-93
06404998	Grace Coolidge Creek near Game Lodge, near Custer	1977-93
06405000	Grace Coolidge Creek near Custer	1945-47, 1967-76

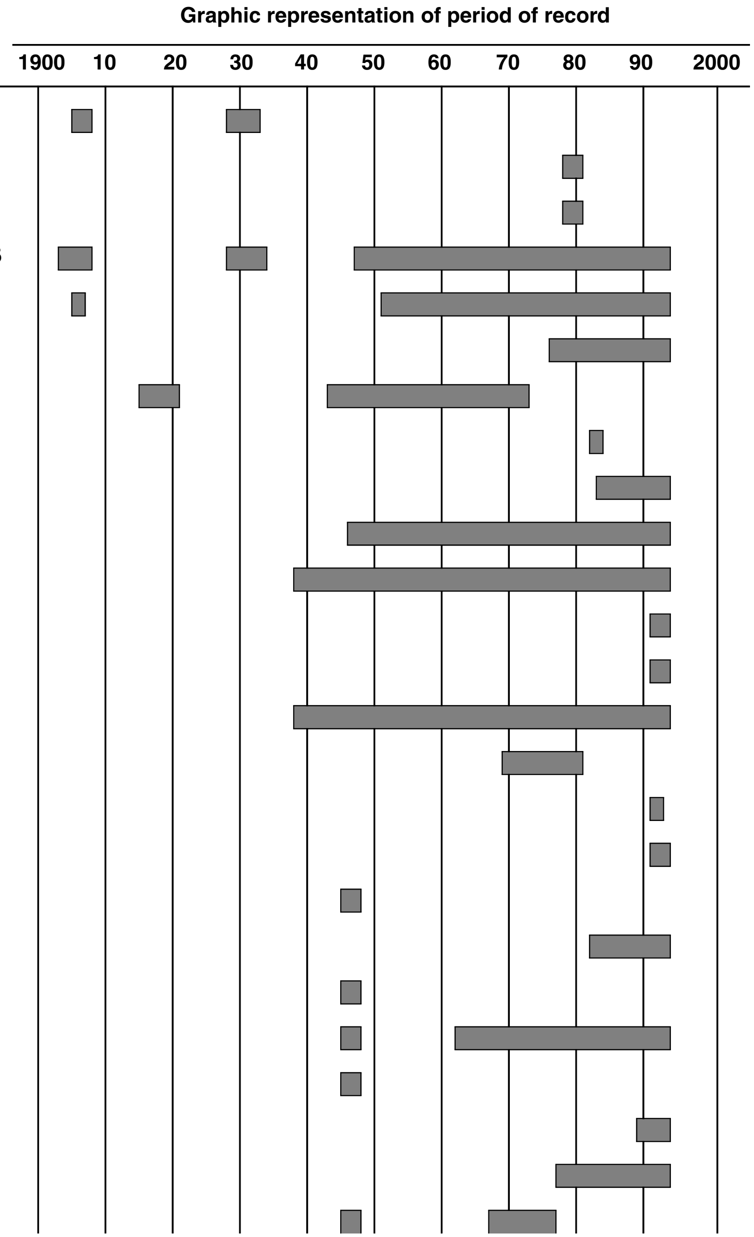


Table 1. Continuous-record streamflow-gaging stations operated in Black Hills area—Continued

Station number	Station name	Period of record through water year 1993
06405400	Grace Coolidge Creek near Fairburn	1978-80
06405500	Grace Coolidge Creek near Hermosa	1945-47, 1978-80
06405800	Bear Gulch near Hayward	1989-93
06406000	Battle Creek at Hermosa	1903, 1949-93
06406500	Battle Creek below Hermosa	1951-53, 1989-93
06406920	Spring Creek above Sheridan Lake, near Keystone	1991-93
06407000	Spring Creek near Hill City	1938-40
06407500	Spring Creek near Keystone	1945-47, 1987-93
06408000	Spring Creek near Rapid City	1903-06, 1945-47
06408500	Spring Creek near Hermosa	1949-93
06408700	Rhoads Fork near Rochford	1982-93
06408860	Rapid Creek near Rochford	1988-93
06409000	Castle Creek above Deerfield Reservoir, near Hill City	1948-93
06410000	Castle Creek below Deerfield Dam	1946-93
06410500	Rapid Creek above Pactola Reservoir, at Silver City	1954-93
06411500	Rapid Creek below Pactola Dam	1929-32, 1946-93
06412000	Rapid Creek at Big Bend	1915-17, 1932-43
06412200	Rapid Creek above Victoria Creek, near Rapid City	1989-93
06412500	Rapid Creek above Canyon Lake, near Rapid City	1946-93
06412510	Rapid Creek above Rapid City	1991
06412600	Cleghorn Springs main channel at Fish Hatchery, at Rapid City	1988-92
06412700	Cleghorn Springs south channel at Fish Hatchery, at Rapid City	1988-92
06412800	Cleghorn Springs north channel at Fish Hatchery, at Rapid City	1988-92
06412810	Cleghorn Springs at Rapid City	1993
06412900	Rapid Creek below Cleghorn Springs, at Rapid City	1988-93
06413000	Bennett Ditch at Rapid City	1946-51

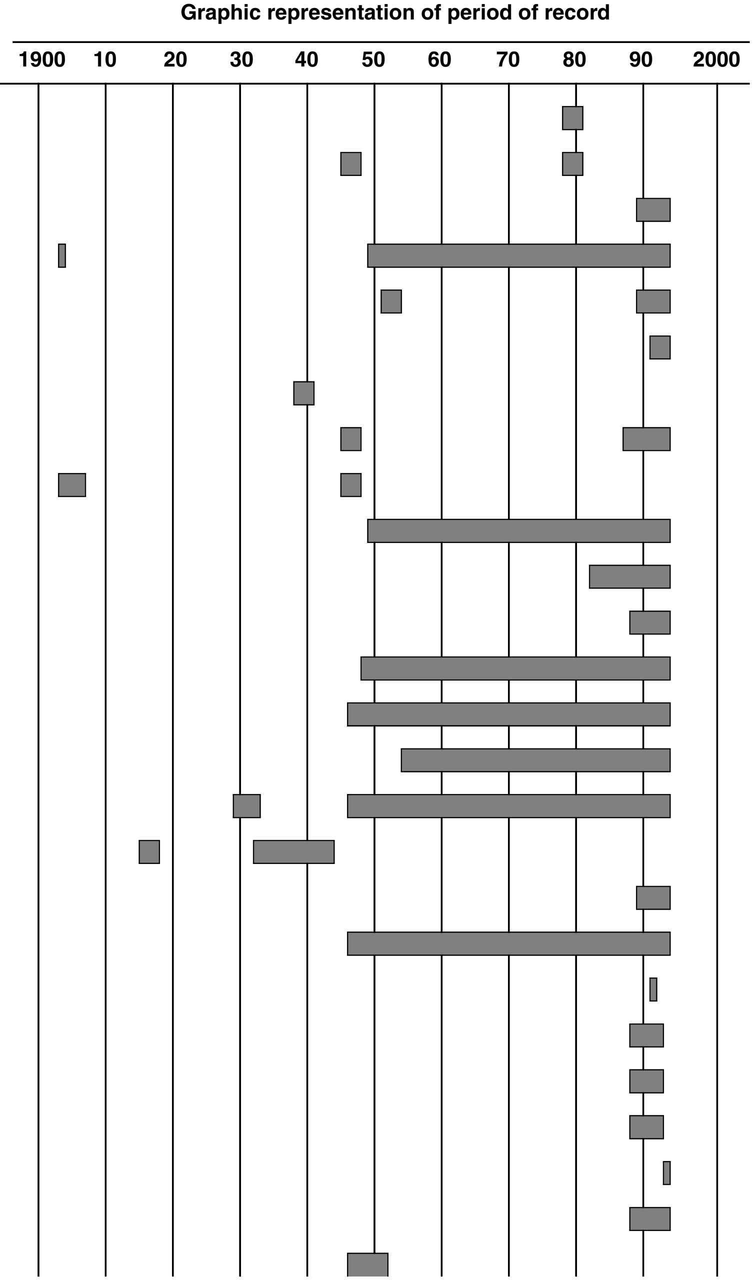


Table 1. Continuous-record streamflow-gaging stations operated in Black Hills area—Continued

Station number	Station name	Period of record through water year 1993
06413200	Rapid Creek below Park Drive, at Rapid City	1988-90
06413300	Leedy Ditch at headgate below Canyon Lake Dam, at Rapid City	1988-90
06413500	Leedy Ditch at Rapid City	1946-51
06413550	Leedy Ditch at mouth at Rapid City	1988-90
06413570	Rapid Creek above Jackson Boulvard, at Rapid City	1988-90
06413650	Lime Creek at mouth, at Rapid City	1981-82, 1988-93
06413660	Storybook Ditch at headgate, at Rapid City	1988-90
06413670	Storybook Ditch at mouth, at Rapid City	1988-90
06413700	Rapid Creek above Water Treat Plant, at Rapid City	1980-82, 1988-90
06413800	Deadwood Avenue Drain at mouth, at Rapid City	1981-82, 1987-90
06414000	Rapid Creek at Rapid City	1903-07, 1942-93
06414500	Iowa Ditch at Rapid City	1946-53
06414700	Rapid Creek at East Main Street, at Rapid City	1980-82
06415000	Lockart Ditch at Rapid City	1946-53
06415500	Hawthorne Ditch at Rapid City	1946-53, 1981-82
06416000	Rapid Creek below Hawthorne Ditch, at Rapid City	1946-53, 1980-82
06416300	Meade Street Drain at Rapid City	1980
06416500	Murphy Ditch near Rapid City	1946-53
06417000	Cyclone Ditch near Rapid City	1946-53
06417500	South Side Ditch near Rapid City	1946-53
06418000	Little Giant Ditch near Rapid City	1946-53
06418500	Rapid Creek below Little Giant Ditch, near Rapid City	1946-53
06418900	Rapid Creek below Sewage Plant, near Rapid City	1982-93
06419000	Lone Tree Ditch near Rapid City	1946-53
06419500	Saint Germain Ditch at Caputa	1946-53
06420000	Rapid Creek at Caputa	1946-53

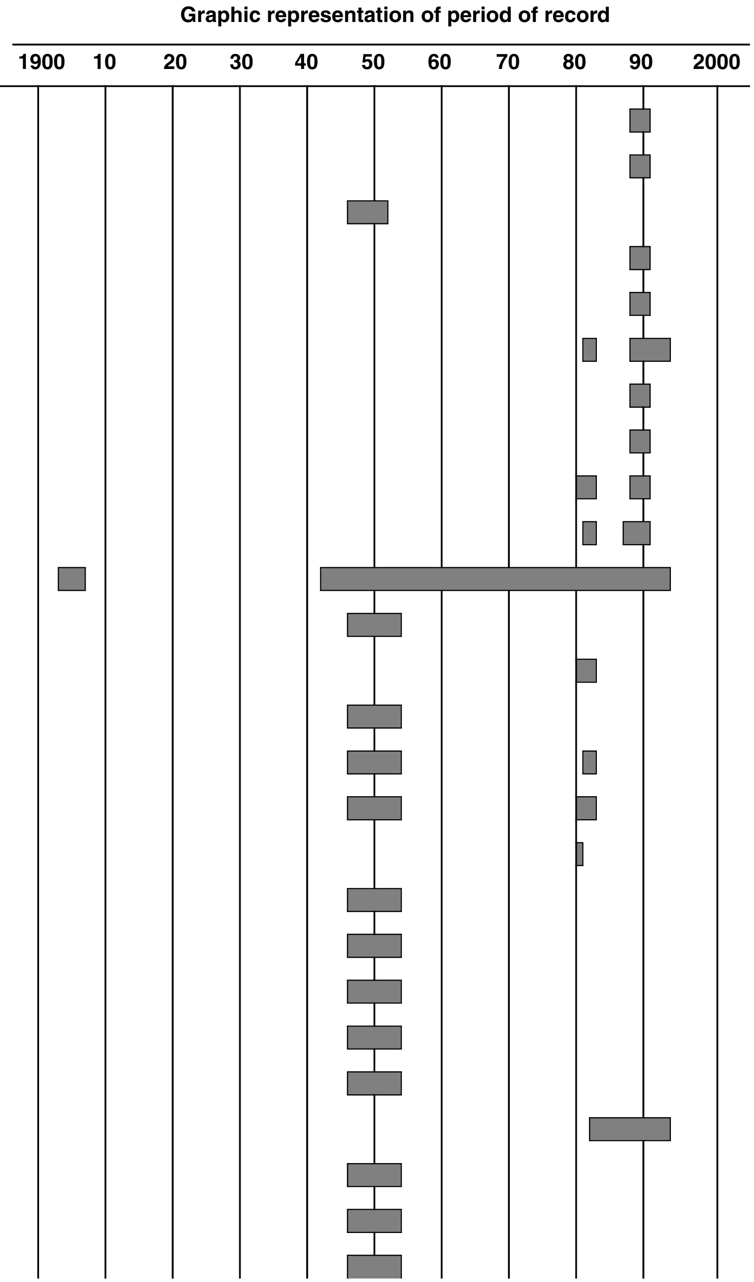
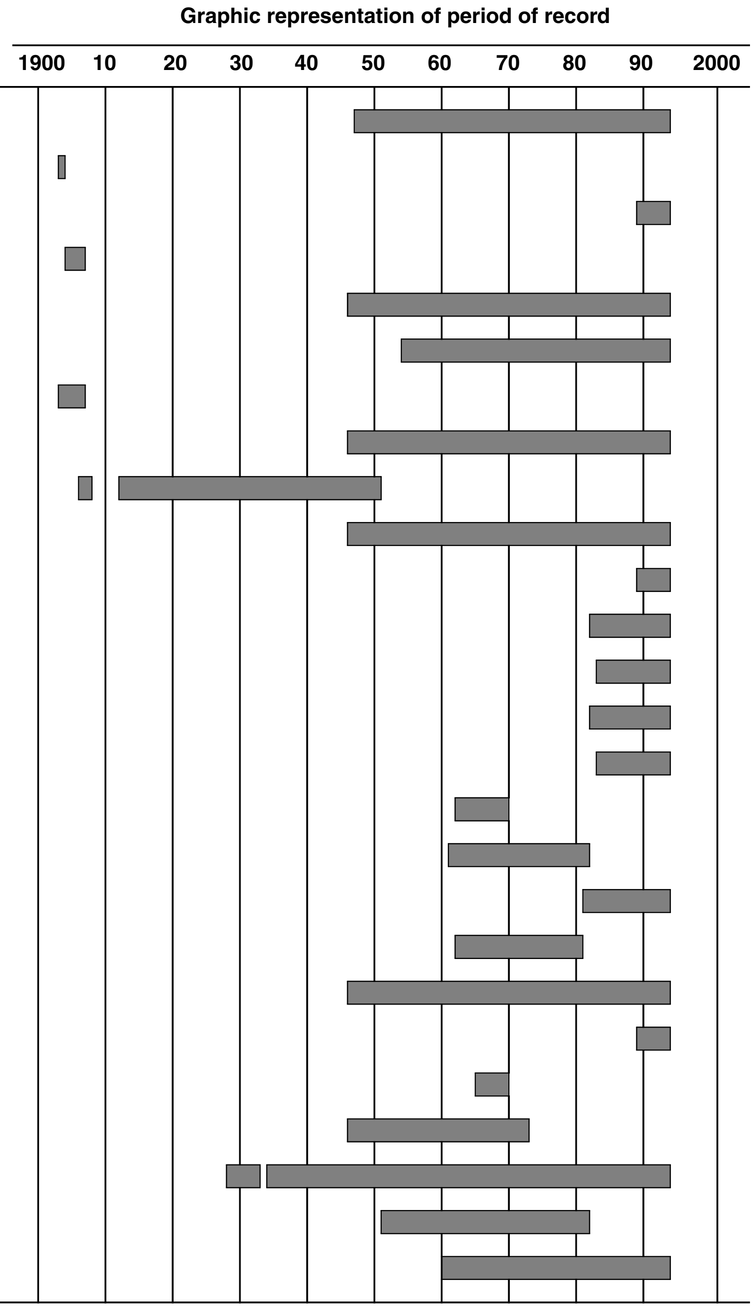


Table 1. Continuous-record streamflow-gaging stations operated in Black Hills area—Continued

Station number	Station name	Period of record through water year 1993
06420500	Hammerquist Ditch near Farmingdale	1946-53
06421500	Rapid Creek near Farmingdale	1946-89, 1991-93
06422000	Rapid Creek at Creston	1929-32, 1990
06422398	Boxelder Creek at Nemo	1978-80
06422500	Boxelder Creek near Nemo	1945-47, 1966-93
06422600	Boxelder Creek at Camp Columbus, near Nemo	1978-80
06422650	Boxelder Creek at Doty School, near Blackhawk	1978-80
06423000	Boxelder Creek at Blackhawk	1903-06, 1945-47
06423010	Boxelder Creek near Rapid City	1978-93
06423500	Cheyenne River near Wasta	1914-15, 1928-32, 1934-93
06424000	Elk Creek near Roubaix	1945-47, 1992-93
06424500	Elk Creek above Piedmont	1945-47
06425100	Elk Creek near Rapid City	1979-93
06425500	Elk Creek near Elm Springs	1949-93
06428500	Belle Fourche River at Wyoming-South Dakota State line	1947-93
06429000	Belle Fourche River at Belle Fourche	1903-06
06429997	Murray Ditch above headgate, at Wyoming-South Dakota State line	1987-93
06430000	Murray Ditch at Wyoming-South Dakota State line	1954-87
06430500	Redwater Creek at Wyoming-South Dakota State line	1929-31, 1936-37, 1954-93
06430540	Cox Lake outlet near Beulah, WY	1991-93
06430770	Spearfish Creek near Lead	1989-93
06430800	Annie Creek near Lead	1989-93
06430850	Little Spearfish Creek near Lead	1989-93
06430898	Squaw Creek near Spearfish	1989-93
06430900	Spearfish Creek above Spearfish	1989-93
06431000	Spearfish Creek near Spearfish	1904-07

Table 1. Continuous-record streamflow-gaging stations operated in Black Hills area—Continued

Station number	Station name	Period of record through water year 1993
06431500	Spearfish Creek at Spearfish	1947-93
06432000	Spearfish Creek at Toomey Ranch near Spearfish	1903
06432020	Spearfish Creek below Spearfish	1989-93
06432500	Redwater Canal at Minnesala	1904-06
06433000	Redwater River above Belle Fourche	1946-93
06433500	Hay Creek at Belle Fourche	1954-93
06434000	Redwater Creek at Belle Fourche	1903-06
06434500	Inlet Canal near Belle Fourche	1946-93
06435500	Belle Fourche River near Belle Fourche	1906-07, 1912-50
06436000	Belle Fourche River near Fruitdale	1946-93
06436156	Whitetail Creek at Lead	1989-93
06436170	Whitewood Creek at Deadwood	1982-93
06436180	Whitewood Creek above Whitewood	1983-93
06436190	Whitewood Creek near Whitewood	1982-93
06436198	Whitewood Creek above Vale	1983-93
06436500	Horse Creek near Newell	1962-69
06436700	Indian Creek near Arpan	1961-81
06436760	Horse Creek above Vale	1981-93
06436800	Horse Creek near Vale	1962-80
06437000	Belle Fourche River near Sturgis	1946-93
06437020	Bear Butte Creek near Deadwood	1989-93
06437200	Bear Butte Creek near Galena	1965-69
06437500	Bear Butte Creek near Sturgis	1946-72
06438000	Belle Fourche River near Elm Springs	1928-32, 1934-93
06438500	Cheyenne River near Plainview	1951-81
06439300	Cheyenne River at Cherry Creek	1960-93



Streamflow records in this report are summarized from the first available year of record through water year 1993 (WY 1993). Different types of summaries are presented in the Supplemental Information section for each of four categories, including: (1) Stations for which only monthly records are available; (2) stations with less than 5 years of daily record; (3) stations with 5 to 9 years of daily record; and (4) stations with 10 or more years of daily record. Within each category, stations are arranged by station numbers, which increase in a downstream direction.

Streamflow records for South Dakota have been published in a variety of USGS publications. During WY 1966-93, streamflow records have been published in a series of annual, state-wide "Water Resources Data" reports for South Dakota (U.S. Geological Survey, 1967-94). During WY 1961-65, streamflow records for South Dakota were included in joint annual reports for North Dakota and South Dakota (U.S. Geological Survey, 1962-66). Prior to water year 1961, streamflow records for South Dakota were published in a series of annual USGS Water-Supply Papers that contained streamflow records for the Missouri River Basin. Streamflow records for the Missouri River Basin through WY 1970 have been summarized in a series of multi-year compilations for water years through 1950, WY 1951-60, WY 1961-65, and WY 1965-70 (U.S. Geological Survey, 1959, 1964, 1969, and 1973).

Most of the streamflow records that are summarized in this report are obtained from the USGS's computerized data base known as the Automated Data Processing System (ADAPS). ADAPS is part of the National Water Information System (NWIS), which is used by the USGS to store and process water-related data (Dempster, 1990). Various ADAPS application programs were used to develop statistical summaries of streamflow records.

Stations With Records of Only Monthly Mean Flow

Descriptions of stations for which only monthly streamflow records are available are presented in table 2. Stations located within the study area for the Black Hills Hydrology Study are shown in figure 6. Stations 06419500, 06420000, and 06420500, which

Table 2. Site information for gaging stations for which only monthly streamflow records are available

[NA, drainage area not applicable; --, drainage area undetermined]

Station number	Period of record (water years)	Station name	Area (square miles)	Latitude	Longitude
				(degrees, minutes, seconds)	
06413000	1946-51	Bennett Ditch at Rapid City	NA	440330	1031640
06413500	1946-51	Leedy Ditch at Rapid City	NA	440320	1031640
06414500	1946-53	Iowa Ditch at Rapid City	NA	440500	1031200
06415000	1946-53	Lockart Ditch at Rapid City	NA	440420	1031130
06416500	1946-53	Murphy Ditch near Rapid City	NA	440340	1031000
06417000	1946-53	Cyclone Ditch near Rapid City	NA	440320	1031000
06417500	1946-53	South Side Ditch near Rapid City	NA	440240	1030800
06418000	1946-53	Little Giant Ditch near Rapid City	NA	440240	1030730
06418500	1946-51	Rapid Creek below Little Giant Ditch, near Rapid City	--	440230	1030730
06419000	1946-53	Lone Tree Ditch near Rapid City	NA	440120	1030400
06419500	1946-53	Saint Germain Ditch at Caputa	NA	435950	1025950
06420000	1946-54	Rapid Creek at Caputa	509	435920	1025940
06420500	1946-53	Hammerquist Ditch near Farmingdale	NA	435800	1025530
06429000	1903-06	Belle Fourche River at Belle Fourche	3,360	444030	1035120
06431000	1904-07	Spearfish Creek near Spearfish	157	442840	1035200
06432000	1903	Spearfish Creek at Toomey Ranch, near Spearfish	179	443310	1035230
06432500	1904-06	Redwater Canal at Minnesala	NA	443900	1034800
06434000	1903-06	Redwater Creek at Belle Fourche	1,020	444020	1035010

An electronic copy of figure 6 is not available. For more information, please contact Dan Driscoll (605) 355-4560.

Figure 6. Location of gaging stations within study area for which only monthly records are available.

are located beyond the study area boundary, are shown in figure 1. Monthly streamflow values for these stations are summarized in Section B of the Supplemental Information section. Annual streamflow values also are presented for several stations; however, most stations were operated only on a seasonal basis. All streamflow values for these stations are presented in acre-feet. Records for several of the stations also were published as mean values in cubic feet per second in previous compilations (U.S. Geological Survey, 1959, 1964). All other streamflow records in subsequent Supplemental Information sections are presented in cubic feet per second.

Stations With Less Than 5 Years of Daily Record

Descriptions of stations with less than 5 years of daily record are presented in table 3. Stations located within the study area for the Black Hills Hydrology Study are shown in figure 7. Station 06400870, which is located beyond the study area boundary, is shown in figure 1. Monthly and annual streamflow values for these stations are summarized in Section C of the Supplemental Information section. Daily flow values for all of these stations are available in various, previous USGS publications.

Stations With 5 to 9 Years of Daily Record

Descriptions of stations with 5 to 9 years of record are presented in table 4. Stations located within the study area for the Black Hills Hydrology Study are shown in figure 8. Stations 06406500, 06422000, and 06436500, which are located beyond the study area boundary, are shown in figure 1. Monthly and annual streamflow values for these stations are presented in Section D of the Supplemental Information section. A limited set of summary statistics also is presented for most stations in Section D. Maxima, minima, and means are presented for monthly and annual values where 5 or more years of consecutive, complete record are available. In tables with sufficient record for computation of summary statistics, the period of record used for computations is shown.

Stations With 10 or More Years of Daily Record

Descriptions of stations with 10 or more years of daily record are presented in table 5. Stations located within the study area for the Black Hills Hydrology Study are shown in figure 9. Ten stations, which are located beyond the study area boundary, are shown in figure 1. A summary of tabular information for each station is presented in Section E of the Supplemental Information section. Graphical representations of variations in annual, monthly, and daily flow for each station are presented in Section F of the Supplemental Information section.

The tabular information for each station includes a table of monthly and annual mean flows for the entire period of record and five additional tables of selected summary information for a selected, consistent period of record. The summary information includes summary statistics for monthly and annual mean flows, correlation coefficients for 1-year serial correlations for monthly mean flows, correlation matrices for monthly mean flow, low-flow tables, and high-flow tables. Graphical representations include graphs of annual mean flow, distribution of monthly mean flow, a duration curve of daily mean flow, and duration hydrographs of daily mean flow for each station. More detailed descriptions of tabular and graphical information are presented in subsequent discussions.

The summary information and graphical representations generally are presented only for consecutive, complete years of hydrologically consistent record for each station. The period of record used for summary information and graphical representations is shown as the "Period of statistics record" in table 5. Using station 06400000, Hat Creek near Edgemont as an example, statistics are not computed for WY 1905-06 because of the large break in record from 1907-50 (tables E2.1-2.6).

Months of missing record are common during the first year of record for many stations or for stations that have been operated seasonally. Such years of incomplete record generally are excluded from statistical computations. Station 06400497, Cascade Springs near Hot Springs (table 5), is an example of a station for which the first year of incomplete record is excluded from statistical computations (tables E3.1-3.6). Station 06395000, Cheyenne River near Edgemont, is an example of a station with seasonal records (tables E1.1-1.6).

Months of missing record within a period of consistent record are uncommon. Occasional years with months of missing record within a year generally are included in statistical computations because of problems with excluding intermediate years in applications programs for statistical computations. An example is station 06402000, Fall River near Hot Springs, for which statistics are computed for WY 1939-93, in spite of 3 months of incomplete record during WY 1947 (tables E7.1-7.6).

Table 3. Site information for gaging stations with less than 5 years of daily record

[NA, drainage area not applicable; --, drainage area undetermined]

Station number	Period of record (water year)	Station name	Area (square miles)	Latitude	Longitude
				(degrees, minutes, seconds)	
06394600	1978-80	Hell Canyon near Jewel Cave, near Custer	--	434256	1035005
06394605	1978-80	Hell Canyon near Custer	--	433700	1035327
06400870	1982-83	Horsehead Creek near Oelrichs	108	430657	1031342
06402430	1991-93	Beaver Creek near Pringle	45.8	433453	1032834
06402470	1991-93	Beaver Creek above Buffalo Gap	111	433120	1032123
06402990	1991-92	French Creek below Custer	53.4	434614	1033304
06402995	1991-93	French Creek above Stockade Lake, near Custer	68.7	434610	1033210
06403000	1945-47	French Creek near Custer	98.0	434250	1032820
06403500	1945-47	French Creek near Fairburn	129	434050	1031610
06404500	1945-47	Battle Creek near Hermosa	108	434950	1031340
06405400	1978-80	Grace Coolidge Creek near Fairburn	--	434613	1032028
06406920	1991-93	Spring Creek above Sheridan Lake, near Keystone	127	435739	1032918
06407000	1938-40	Spring Creek near Hill City	142	435900	1032600
06408000	[1]1903-06, 1945-47	Spring Creek near Rapid City	171	435920	1031555
06412510	1991	Rapid Creek above Rapid City	371	440310	1031841
06412810	1993	Cleghorn Springs at Rapid City	--	440332	1031749
06413200	1988-90	Rapid Creek below Park Drive, at Rapid City	384	440333	1031702
06413300	1988-90	Leedy Ditch at headgate below Canyon Lake Dam, at Rapid City	NA	440327	1031712
06413550	1988-90	Leedy Ditch at mouth, at Rapid City	NA	440349	1031618
06413570	1988-90	Rapid Creek above Jackson Boulevard, at Rapid City	391	440355	1031621
06413660	1988-90	Storybook Ditch at headgate, at Rapid City	NA	440404	1031615
06413670	1988-90	Storybook Ditch at mouth, at Rapid City	NA	440429	1031544
06414700	1980-82	Rapid Creek at East Main Street, at Rapid City	416	440445	1031212
06415500	[1]1946-53, 1981-82	Hawthorne Ditch at Rapid City	NA	440429	1031130
06416000	[1]1946-54, 1980-82	Rapid Creek below Hawthorne Ditch, at Rapid City	418	440400	1031025
06416300	1980	Meade Street Drain at Rapid City	3.15	440351	1031132
06422398	1978-80	Boxelder Creek at Nemo	--	441148	1033014
06422600	1978-80	Boxelder Creek at Camp Columbus, near Nemo	--	440730	1032530
06422650	1978-80	Boxelder Creek at Doty School, near Blackhawk	--	440703	1032154
06423000	[1]1903-06, 1945-47	Boxelder Creek at Blackhawk	128	440750	1031910
06424500	1945-47	Elk Creek above Piedmont	49	441605	1032430
06430540	1991-93	Cox Lake outlet near Beulah, WY	0.07	443356	1035937

[1]Only monthly values available for early period.

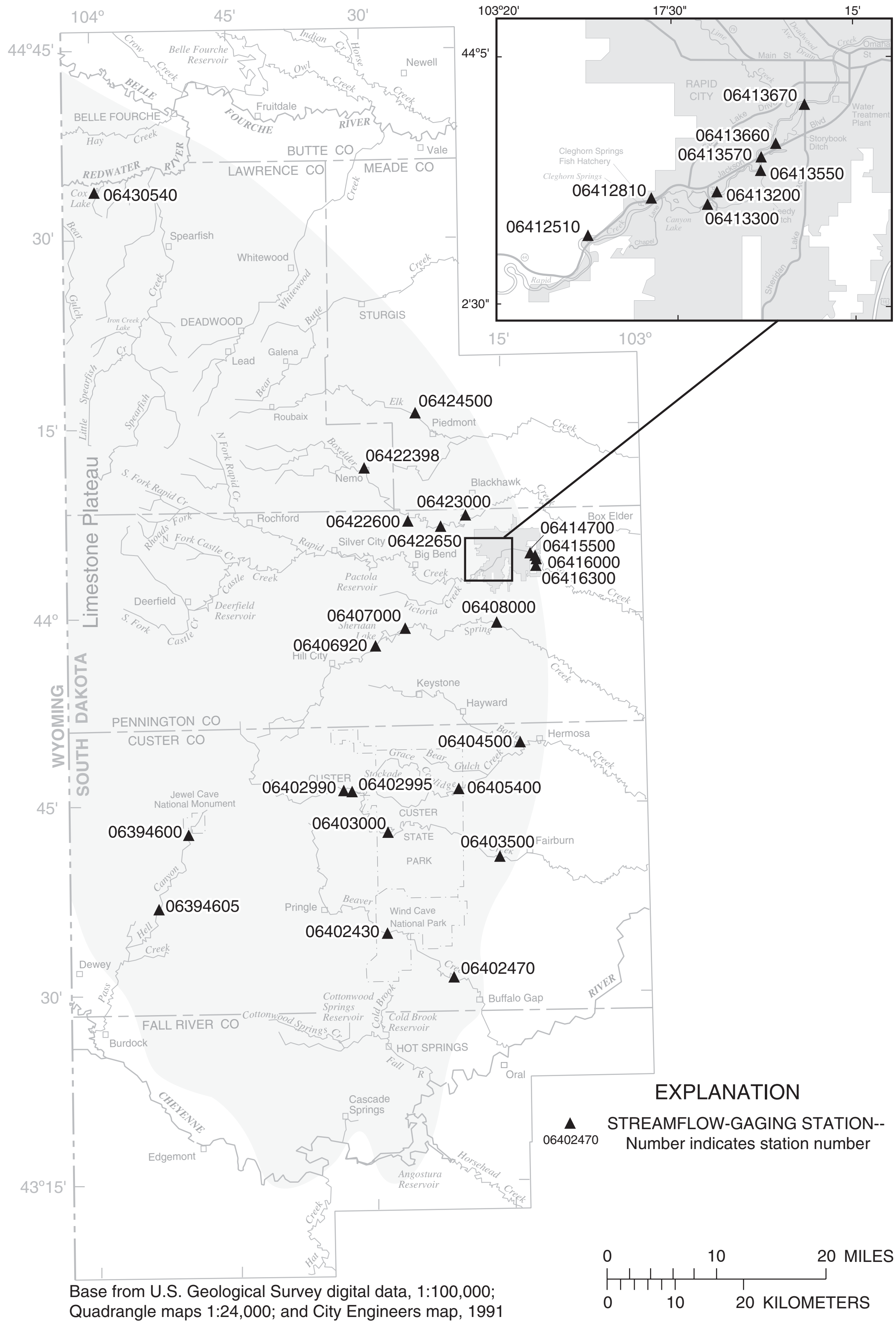


Figure 7. Location of gaging stations within study area with less than 5 years of daily record.

Table 4. Site information for gaging stations with 5 to 9 years of daily record

[NA, drainage area not applicable; --, drainage area undetermined]

Station number	Period of record (water years)	Station name	Area (square miles)	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)
06394500	1905-07, 1929-32	Beaver Creek near Burdock	1,540	432655	1040055
06404800	1989-93	Grace Coolidge Creek near Hayward	7.48	434807	1032603
06405500	1945-47, 1978-80	Grace Coolidge Creek near Hermosa	27.5	434629	1031942
06405800	1989-93	Bear Gulch near Hayward	4.23	434731	1032049
06406500	1951-53, 1989-93	Battle Creek below Hermosa	285	434330	1025415
06408860	1989-93	Rapid Creek near Rochford	101	440617	1033835
06412200	1988-93	Rapid Creek above Victoria Creek, near Rapid City	355	440248	1032106
06412600	1988-92	Cleghorn Springs main channel at Fish Hatchery, at Rapid City	--	440332	1031754
06412700	1988-92	Cleghorn Springs south channel at Fish Hatchery, at Rapid City	--	440331	1031756
06412800	1988-92	Cleghorn Springs north channel at Fish Hatchery, at Rapid City	--	440332	1031750
06412900	1988-93	Rapid Creek below Cleghorn Springs, at Rapid City	378	440333	1031749
06413650	1981-82, 1988-93	Lime Creek at mouth, at Rapid City	10.0	440430	1031600
06413700	1980-82, 1988-90	Rapid Creek above Water Treatment Plant, at Rapid City	404	440429	1031534
06413800	1981-82, 1987-90	Deadwood Avenue Drain at mouth, at Rapid City	2.18	440458	1031522
06422000	1929-32, 1990	Rapid Creek at Creston	710	435447	1024222
06424000	1945-47, 1992-93	Elk Creek near Roubaix	21.5	441741	1033547
06429997	1987-93	Murray Ditch above headgate at Wyoming-South Dakota State line	NA	443435	1040320
06430770	1989-93	Spearfish Creek near Lead	63.5	441756	1035202
06430800	1989-93	Annie Creek near Lead	3.55	441937	1035338
06430850	1989-93	Little Spearfish Creek near Lead	25.8	442058	1035608
06430898	1989-93	Squaw Creek near Spearfish	6.95	442404	1035335
06430900	1989-93	Spearfish Creek above Spearfish	139	442406	1035340
06432020	1989-93	Spearfish Creek below Spearfish	204	443448	1035337
06436156	1989-93	Whitetail Creek at Lead	6.15	442036	1034557
06436500	1962-69	Horse Creek near Newell	67.0	444753	1033228
06437020	1989-93	Bear Butte Creek near Deadwood	16.6	442008	1033806
06437200	1965-69	Bear Butte Creek near Galena	47.6	442332	1033511

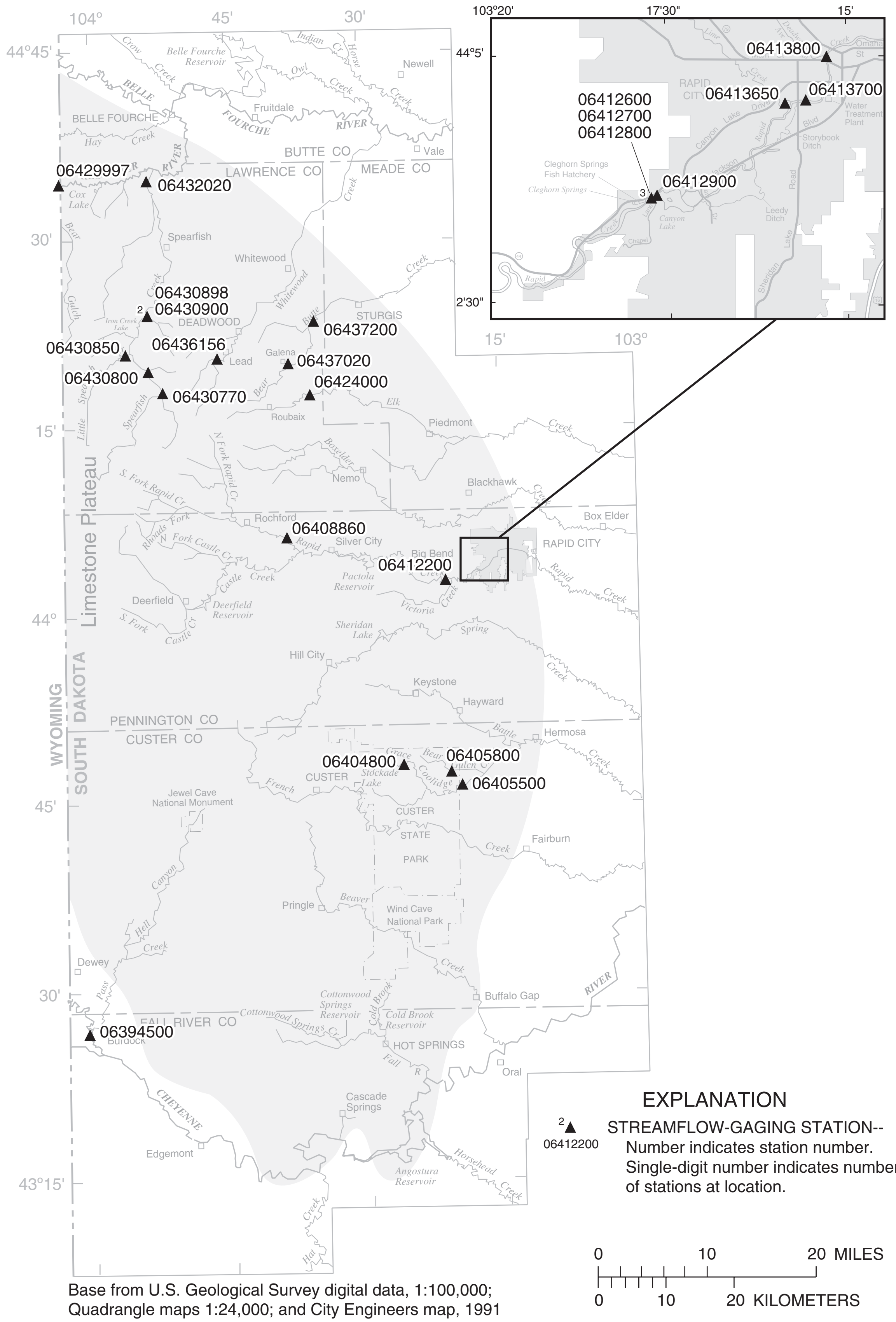


Figure 8. Location of gaging stations within study area with 5 to 9 years of daily record.

Table 5. Site information for gaging stations with 10 or more years of daily record

[NA, drainage area not applicable; --, drainage area undetermined]

Station number	Period of record (water years)	Station name	Area (square miles)	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Period of statistics record (water years)
06395000	1903-07, 1928-33, 1947-93	Cheyenne River at Edgemont	7,143	431820	1034914	1947-93
06400000	1905-06, 1951-93	Hat Creek near Edgemont	1,044	431424	1033516	1951-93
06400497	1976-93	Cascade Springs near Hot Springs	0.47	432010	1033307	1977-93
06400500	1915-20, 1943-72	Cheyenne River near Hot Springs	8,710	431819	1033343	[1]1944-72
06400875	1983-93	Horsehead Creek at Oelrichs	187	431117	1031334	1984-93
06401500	1946-93	Cheyenne River below Angostura Dam	9,100	432308	1032420	1953-78
06402000	1938-93	Fall River at Hot Springs	137	432550	1032833	[1]1939-93
06402500	1938-93	Beaver Creek near Buffalo Gap	130	432800	1031820	[1]1939-93
06402600	1969-80	Cheyenne River near Buffalo Gap	9,810	433005	1030423	1969-80
06403300	1982-93	French Creek above Fairburn	105	434302	1032203	[1]1983-93
06404000	1945-47, 1962-93	Battle Creek near Keystone	66.0	435221	1032010	1962-93
06404998	1977-93	Grace Coolidge Creek near Game Lodge, near Custer	25.2	434540	1032149	1977-93
06405000	1945-47, 1967-76	Grace Coolidge Creek near Custer	25.3	434540	1032142	1968-76
06406000	[2]1903, 1949-93	Battle Creek at Hermosa	178	434941	1031144	1950-93
06407500	1945-47, 1987-93	Spring Creek near Keystone	163	435845	1032025	1987-93
06408500	1949-93	Spring Creek near Hermosa	199	435631	1030932	1950-93
06408700	1982-93	Rhoads Fork near Rochford	7.95	440812	1035129	[1]1983-93
06409000	1948-93	Castle Creek above Deerfield Reservoir, near Hill City	79.2	440049	1034948	1949-93
06410000	1946-93	Castle Creek below Deerfield Dam	96.0	440145	1034653	1948-83
06410500	1954-93	Rapid Creek above Pactola Reservoir, at Silver City	292	440505	1033448	1954-93
06411500	1929-32, 1946-93	Rapid Creek below Pactola Dam	320	440436	1032854	1964-93
06412000	1915-17, 1932-43	Rapid Creek at Big Bend	332	440400	1032400	1933-42
06412500	1946-93	Rapid Creek above Canyon Lake, near Rapid City	371	440310	1031841	1964-93
06414000	1903-07, 1942-93	Rapid Creek at Rapid City	410	440509	1031431	1964-93
06418900	1982-93	Rapid Creek below Sewage Plant, near Rapid City	452	440124	1030543	1982-93
06421500	1946-89, 1991-93	Rapid Creek near Farmingdale	602	435631	1025112	1964-93
06422500	1945-47, 1966-93	Boxelder Creek near Nemo	96.0	440838	1032716	1967-93

Table 5. Site information for gaging stations with 10 or more years of daily record—Continued

[NA, drainage area not applicable; --, drainage area undetermined]

Station number	Period of record (water years)	Station name	Area (square miles)	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Period of statistics record (water years)
06423010	1978-93	Boxelder Creek near Rapid City	128	440754	1031754	1979-93
06423500	1914-15, 1928-32, 1934-93	Cheyenne River near Wasta	12,800	440452	1022403	1957-93
06425100	1979-93	Elk Creek near Rapid City	190	441425	1030903	[1]1980-93
06425500	1949-93	Elk Creek near Elm Springs	540	441454	1023010	1950-93
06428500	1947-93	Belle Fourche River at Wyoming-South Dakota State line	3,280	444459	1040249	1953-93
06430000	1954-87	Murray Ditch at Wyoming-South Dakota State line	NA	443435	1040258	1961-86
06430500	1929-31, 1936-37, 1954-93	Redwater Creek at Wyoming-South Dakota State line	471	443426	1040254	1955-93
06431500	1947-93	Spearfish Creek at Spearfish	168	442857	1035140	1947-93
06433000	1946-93	Redwater River above Belle Fourche	920	444002	1035020	1947-93
06433500	1954-93	Hay Creek at Belle Fourche	121	444001	1035046	1954-93
06434500	1946-93	Inlet Canal near Belle Fourche	NA	444214	1034923	1946-93
06435500	1906-07, [3]1912-45	Belle Fourche River near Belle Fourche	4,310	444130	1034930	1913-45
06436000	1946-93	Belle Fourche River near Fruitdale	4,540	444127	1034414	[1]1947-93
06436170	1982-93	Whitewood Creek at Deadwood	40.6	442248	1034325	1982-93
06436180	1983-93	Whitewood Creek above Whitewood	56.3	442632	1033744	[1]1984-93
06436190	1982-93	Whitewood Creek near Whitewood	77.4	443230	1033416	1982-93
06436198	1983-93	Whitewood Creek above Vale	102	443704	1032852	[1]1984-93
06436700	1961-81	Indian Creek near Arpan	315	444851	1034122	1962-81
06436760	1981-93	Horse Creek above Vale	464	443908	1032159	1981-93
06436800	1962-80	Horse Creek near Vale	530	443930	1032017	[1]1963-80
06437000	1946-93	Belle Fourche River near Sturgis	5,870	443047	1030811	[1]1947-93
06437500	1946-72	Bear Butte Creek near Sturgis	192	442835	1031550	1946-72
06438000	1928-32, 1934-93	Belle Fourche River near Elm Springs	7,210	442211	1023356	[1]1935-93
06438500	1951-81	Cheyenne River near Plainview	21,600	443116	1015934	1951-81
06439300	1960-93	Cheyenne River at Cherry Creek	23,900	443559	1012951	1961-93

[1]Low-flow statistics include previous year.
[2]Indicates only gage-height records available for 1903.
[3]Additional records for water years 1946-50, which were computed by combing records for stations 06434500 and 06436000, were published in Water Supply Paper 1309 (U.S. Geological Survey, 1959).

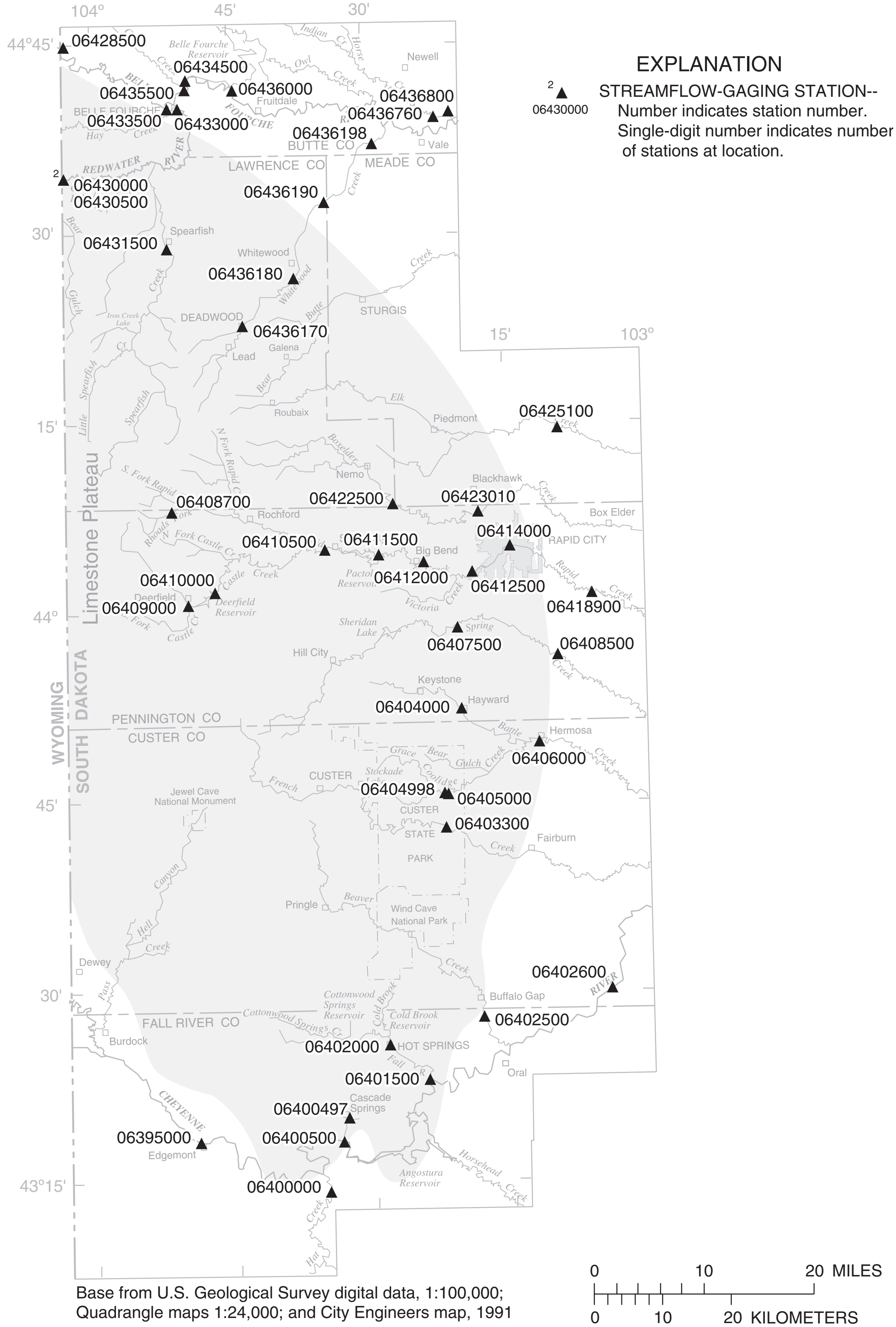


Figure 9. Location of gaging stations within study area with 10 or more years of daily record.

For some stations, large periods of record have been excluded from statistical computations because streamflow characteristics have been altered by reservoir operations. Table 6 presents storage information for reservoirs that have changed streamflow characteristics within periods of record for gaging stations with 10 or more years of record (table 5). These reservoirs were described in a previous section titled "Reservoirs and water use." Records of monthend contents for these reservoirs (if available) are summarized in Section A of the Supplemental Information section. Monthend contents are those that have been reported by the USGS in various data reports (relative to the same capacities reported in table 6). Storage capacities have been subject to occasional changes, based on updated reservoir capacity allocations by the Bureau of Reclamation. Changes in storage capacity generally result from sedimentation or structural modifications.

Stations for which changes in reservoir operations were a major consideration in selecting periods of record for statistical computations are listed in table 7. The rationale for selection of hydrologically consistent periods of record for statistical computations also is described in table 7. Statistics generally are computed for periods subsequent to filling of reservoirs, except as discussed in the following paragraphs.

Construction of Cold Brook and Cottonwood Springs Reservoirs (table 6) altered the high-flow characteristics for station 06402000, Fall River at Hot Springs (table 7). The effects on other streamflow characteristics are unknown. The annual flow of the Fall River has declined somewhat, through the period of record (table E7.1, fig. F7A). Peterlin (1990) hypothesized that construction of the two reservoirs could be responsible for the decline; however, effects of storage within the reservoirs are minimal. Thus, with the exception of high-flow statistics, the entire period of record is used for statistical computations.

Table 6. Summary of storage information for selected large reservoirs in Black Hills area

[Storage information obtained from various U.S. Geological Survey reports and Bureau of Reclamation reservoir capacity allocations. --, undetermined or not applicable]

Station number	Station or reservoir name	Dates (in month and year) of first storage and effective filling[1]		Reported capacities[2], in acre-feet, above given invert elevation, in feet	
		First storage	First filled		
06401000	Angostura Reservoir near Hot Springs	10/49	[1]06/52	A	[3]136,300
				B	[3]122,100
				C	3,139.75
06409500	Deerfield Reservoir near Hill City	12/45	[1]05/47	A	15,153
				B	15,504
				C	5839.0
06411000	Pactola Reservoir near Silver City	08/56	06/63	A	55,700
				B	54,955
				C	4,456.1
06427000	Keyhole Reservoir near Moorcroft, WY	02/52	03/72	A	[3]199,900
				B	[3]193,027
				C	4,036.0
06435000	Belle Fourche Reservoir near Belle Fourche	05/10	04/19	A	185,200
				B	185,277
				C	2,927.0
--	Cold Brook Reservoir	05/52	--	A	[4]7,200
				B	--
				C	--
--	Cottonwood Springs Reservoir	06/69	--	A	[4]8,385
				B	--
				C	--

[1]Not completely filled; however, filled to level at which typical releases were initiated.

[2]Capacities which unless otherwise noted consist of active conservation capacity at: (A) Original construction; and (B) as of water year 1993; relative to (C) invert elevation.

[3]Capacity consists of active conservation capacity and inactive capacity.

[4]Total capacity.

Table 7. Rationale for selection of statistics period for selected gaging stations

Station number	Station name	Period of record (water years)	Period of statistics record (water years)	Rationale for selection of statistics period
06401500	Cheyenne River below Angostura Dam	1946-93	1953-78	First complete water year after filling of Angostura Reservoir.
06402000	Fall River at Hot Springs	1938-93	[1]1939-93 [2]1970-93	High-flow statistics are run only for water years subsequent to completion of Cottonwood Springs Reservoir.
06410000	Castle Creek below Deerfield Dam	1946-93	1948-93	First complete water year after filling of Deerfield Reservoir.
06411500	Rapid Creek below Pactola Dam	1929-32 1946-93	1964-93	First complete water year after filling of Pactola Reservoir.
06412500	Rapid Creek above Canyon Lake	1946-93	1964-93	First complete water year after filling of Pactola Reservoir.
06414000	Rapid Creek at Rapid City	1903-07 1942-93	1964-93	First complete water year after filling of Pactola Reservoir.
06421500	Rapid Creek near Farmingdale	1946-89 1991-93	1964-93	First complete water year after filling of Pactola Reservoir.
06423500	Cheyenne River near Wasta	1914-15 1928-32 1934-93	1957-93	First complete water year after first storage in Pactola Reservoir.
06428500	Belle Fourche River at WY-SD State line	1947-93	1953-93	First complete water year after first storage in Keyhole Reservoir.
06435500	Belle Fourche River near Belle Fourche	1906-07 [3]1912-45	1913-45	First complete water year of record.

[1]Period of record for majority of statistics; low-flow statistics include previous year.
[2]Period of record for high-flow statistics.
[3]Additional records for water years 1946-50, which were computed by combing records for stations 06434500 and 06436000, were published in Water Supply Paper 1309 (U.S. Geological Survey, 1959).

Statistics for most stations downstream from Deerfield and Pactola Reservoirs are computed for periods subsequent to filling of the reservoirs (table 7). The statistics period selected for station 06423500, Cheyenne River near Wasta, begins with WY 1957, which is the first year of storage in Pactola Reservoir. Operations of Pactola Reservoir do affect streamflow of the Cheyenne River; however, effects of initially filling storage in Pactola Reservoir are small, relative to annual flow of the Cheyenne River.

Keyhole Reservoir has affected streamflow of the Belle Fourche River since storage began in February 1952; however, Keyhole Reservoir has been full only during March 1972 (table 6) and during 1978 (table A4). Because normal operating levels are much less than capacity, the first complete year of storage (WY 1953) is used for the beginning of the statistics period for station 06428500, Belle Fourche River at Wyoming-South Dakota State line.

Belle Fourche Reservoir has affected streamflow of the Belle Fourche River since storage began in May 1910 (table 6). The reservoir did not fill until April 1919; however, storage during 1913 was larger than in many subsequent years (table A5). Thus, WY 1913 is used as the beginning of the statistics period for station 06435500, Belle Fourche River near Belle Fourche.

Six tables are presented in Section E of the Supplemental Information section for each station having a sufficient period of record. The first table of each series for each station contains monthly and annual mean values for the entire period of available record. The following five tables of each series are for a selected, hydrologically consistent period of record.

The second table in each series presents statistics for monthly and annual mean flow for the selected statistics period. This table includes the total number of months used in the analysis; the maximum; 75th, 50th, and 25th percentiles; minimum; mean; standard deviation; skewness; and coefficient of variation for each column; and the percent of annual flow contributed by each month. This table also presents a serial correlation for annual flows, which is a correlation coefficient for a series comparing annual flow from one year to the next. The correlation coefficient is a measure of the strength of the linear relationship between the dependent and independent variable (Ott, 1988). Coefficients approaching zero represent a very weak correlation and correlations approaching +1 or -1 represent a strong positive or negative correlation.

The third table presents a serial correlation matrix for monthly flows lagged by 1 year. The fourth table of each series presents a correlation matrix for monthly mean flow. This matrix contains a correlation coefficient for each month, relative to monthly flow for other months.

The fifth table of each series presents the lowest mean flow and ranking, by year, for 1, 3, 7, 14, 30, 60, 90, 120, and 183 consecutive-day periods. A low-flow water year from April 1 to March 31 is used for the low-flow table. Thus, low-flow water year 1992 (April 1, 1992-March 31, 1993) is the last year reported in the low-flow tables. In addition, the low-flow statistics period for some stations includes a partial first year of record, which is excluded from other statistical computations. Such cases are footnoted in table 5. Station 0640200, Fall River at Hot Springs, is an example (tables E7.1-7.6). The final table of each series presents a high-flow table, which uses the standard water year (October 1-September 30).

Section F of the Supplemental Information section presents graphical representations of variations in annual, monthly, and daily mean flow for each station. Each figure contains four graphs labeled A, B, C, and D. Graphs for station 06400000, Hat Creek near Edgemont (table 5), are described as an example (fig. F2). Graph A shows annual mean flow values for the entire period of record, with the occasional exception of stations such as this, with short periods of record that are highly separated from the statistics period. Graph B shows the distribution of monthly mean flows in the form of boxplots. For October, the maximum monthly flow of record is 13.0 ft^3/s. Ninety percent of the October means are less than 4.12 ft^3/s, 75 percent are less than 1.00 ft^3/s, and 50 percent are less than 0.077 ft^3/s. The 25th percentile, 10th percentile, and the minimum are not shown because values of 0.00 cannot be plotted on a logarithmic scale. Graph C shows the duration curve of daily mean flow. For the example station, daily flow exceeds 0.25 ft^3/s 50 percent of the time, and flow exceeds 0.01 ft^3/s about 63 percent of the time. Graph D shows duration hydrographs of daily mean flow for five exceedance percentiles. For the example station, 20 percent of the time flow exceeds about 1.20 ft^3/s for the first day of November, and flow of less than 0.01 ft^3/s has been recorded for all days of the year.

STREAMFLOW CHARACTERISTICS FOR SELECTED BASINS

Streamflow within the study area is affected by both topography and geology. The base flow of most Black Hills streams originates in the higher elevations, where relatively large precipitation and small evapotranspiration result in more water being available for springflow and streamflow. Numerous streams have significant headwater springs originating from large outcrops of Paleozoic rocks (fig. 3) on the western side of the study area (fig. 4), which is known locally as the "Limestone Plateau" (fig. 2). Several streams, most notably Rapid Creek and Spearfish Creek, derive consistent base flow from large headwater springs on the eastern fringe of the Limestone Plateau. By comparison, stream reaches originating within the central Precambrian core of the Hills are more responsive to precipitation, with high flows during wet periods and low flows during dry periods (Addison, 1991). Most Black Hills streams generally lose all or part of their flow as they cross the outcrop of the Madison Limestone (Driscoll, 1994; Rahn and Gries, 1973). Karst features of the Madison Limestone, including sinkholes, collapse features, solution cavities, and caves are responsible for the Madison's capacity to accept recharge from streamflow. Large streamflow losses also occur within the outcrop of the Minnelusa Formation in many locations. A number of large artesian springs exist downgradient from streamflow-loss zones, most commonly within outcrops of the Spearfish Formation, near the contact with the Minnekahta Limestone. Artesian springs with discharges ranging from about 1 to 30 ft^3/s are common, providing an important source of base flow in many streams beyond the periphery of the Black Hills (Rahn and Gries, 1973).

The following sections present summaries of streamflow characteristics for streams grouped according to various hydrogeologic settings. Various analyses are presented to demonstrate the effects of hydrogeologic setting and climate on streamflow characteristics.

Methods for Categorizing Basins

A system for categorizing the hydrogeologic setting and degree of regulation of streams draining the Black Hills area is presented in table 8. Table 8 includes all gaging stations in the Black Hills area with 10 or more years of record, as well as several stations with less than 10 years of record, which are included because they provide important information in critical areas. The hydrogeologic settings for three categories are determined on the basis of geologic conditions within the drainage basins upstream of the gaging stations; however, a fourth category is based on locations of gaging stations, as described in a subsequent discussion. Stations that are categorized as having multiple hydrogeologic settings generally are excluded from subsequent analyses. Stations that are classified as highly regulated, in any of three categories, also are excluded from analyses. Locations of selected stations, relative to selected outcrops, are shown in figure 10.

Methods for categorizing the hydrogeologic setting for each station (table 8) are somewhat subjective. The drainage basin for each gaging station is first categorized as either interior or exterior. Interior basins are located predominantly within the uplifted Black Hills area, which is defined for this purpose as within the generalized, outermost extent of the outcrop of the Inyan Kara Group (fig. 10). Exterior basins are those for which the majority of the drainage area lies beyond the outer extent of the outcrop of the Inyan Kara Group. Basins are categorized as both interior and exterior if a predominant drainage area is not apparent. For example, station 06400500, Cheyenne River near Hot Springs (fig. 9), is categorized as both interior and exterior, and thus, is excluded from subsequent analyses. In comparison, station 06395000, Cheyenne River at Edgemont (fig. 10), also has tributaries draining both interior and exterior areas; however, influence from the interior area is relatively minor and the station is categorized as exterior. Station 06437500, Bear Butte Creek near Sturgis, is the only station categorized as both interior and exterior that is included in subsequent analyses.

Interior basins are further categorized as either upstream or downstream of loss zones. This category is less subjective, and is based strictly on whether a gaging station is located upstream, or downstream, of streamflow-loss zones that typically occur within outcrops of the Madison Limestone (fig. 10) and other overlying sedimentary units. Station 06405000, Grace Coolidge Creek near Custer, was determined to be located within a loss zone, and was subsequently replaced by station 06404998, Grace Coolidge Creek near Game Lodge, which is located just upstream of the original station. Thus, this station is categorized as upstream of a loss zone, but is not used in subsequent analyses. Station 06431500, Spearfish Creek at Spearfish, is located downstream of a loss zone, but flow is diverted around the loss zone. Thus, this station is categorized as upstream of the loss zone and is included in subsequent analyses. With these exceptions, all other interior basins are categorized as either upstream or downstream of a loss zone. Several stations categorized as downstream of loss zones are located beyond the outer extent of the outcrop of the Inyan Kara Group, but have only small percentages of their drainage areas within the exterior area.

Interior basins upstream of loss zones are further categorized as either sedimentary or crystalline, based on the predominant outcrops within each basin. The interior sedimentary basins are dominated by outcrops of Paleozoic units (fig. 3), and are located within headwater areas of the Limestone Plateau (fig. 10). The interior crystalline basins are dominated by outcrops of metamorphic or igneous rocks, most of which are crystalline, and are located within the central core of the Black Hills. This category also can include Tertiary intrusive rocks. Some subjectivity is involved because few basins are located entirely within outcrops of sedimentary or crystalline rocks. Basins are categorized as both sedimentary and crystalline if a predominant outcrop type is not apparent.

Stations also are categorized relative to the degree of regulation (high, medium, low, or negligible) from reservoir operations, irrigation diversions, and municipal and industrial diversions within each basin (table 8). Highly regulated basins are excluded from subsequent analyses of streamflow characteristics, because streamflow may no longer be representative of geologic conditions. Methods for categorizing the degree of regulation are somewhat subjective, but are based on the degree to which streamflow characteristics for each stream are affected by regulation. General criteria for categorizing the degree of regulation are presented in table 9.

Streamflow characteristics for numerous stations along Rapid Creek and the Belle Fourche and Cheyenne Rivers are highly affected (table 8) by operations of several major reservoirs that are described in previous sections. Station 06402000, Fall River at Hot Springs, is categorized as having medium regulation

Table 8. Hydrogeologic setting and degree of regulation for selected long-term gaging stations (generally those with 10 or more years of record)

[Interior, majority of drainage area within Black Hills; exterior, majority of drainage area outside Black Hills; sed, predominantly sedimentary; cry, predominantly crystalline. Degrees of regulation: H, high; M, medium; L, low; N, negligible or none]

Station number[1]	Station name	Hydrogeologic setting				Degree of regulation											
		Interior			Exterior	Reservoir operation				Irrigation diversion				Municipal and industrial diversions			
		Upstream of loss zone		Down-stream of loss zone													
		Sed	Cry			H	M	L	N	H	M	L	N	H	M	L	N
06395000	Cheyenne River at Edgemont				X			X				X					X
06400000	Hat Creek near Edgemont				X			X				X					X
06400497	Cascade Springs near Hot Springs			X					X				X				X
06400500	Cheyenne River near Hot Springs			X	X			X				X					X
06400875	Horsehead Creek at Oelrichs				X			X				X					X
06401500	Cheyenne River below Angostura Dam			X	X	X				X							X
06402000	Fall River at Hot Springs			X			X						X			X	
06402500	Beaver Creek near Buffalo Gap			X					X		X						X
06402600	Cheyenne River near Buffalo Gap			X	X	X				X							X
06403300	French Creek above Fairburn		X				X						X		X		
06404000	Battle Creek near Keystone		X						X				X			X	
06404998	Grace Coolidge Creek near Game Lodge, near Custer		X					X					X				X
06405000	Grace Coolidge Creek near Custer		[2]X					X					X				X
06406000	Battle Creek at Hermosa			X					X		X					X	
06407500	Spring Creek near Keystone		X				X						X			X	
06408500	Spring Creek near Hermosa			X			X					X					X
06408700	Rhoads Fork near Rochford	X							X				X				X
06409000	Castle Creek above Deerfield Reservoir, near Hill City	X							X				X				X
06410000	Castle Creek below Deerfield Dam	X				X							X				X
06410500	Rapid Creek above Pactola Reservoir, at Silver City	X	X			X							X			X	
06411500	Rapid Creek below Pactola Dam	X	X			X							X			X	
06412000	Rapid Creek at Big Bend	X	X						X				X			X	
06412500	Rapid Creek above Canyon Lake, near Rapid City			X		X							X			X	
06414000	Rapid Creek at Rapid City			X		X						X		X			
06418900	Rapid Creek below Sewage Plant, near Rapid City			X		X				X					X		

Table 8. Hydrogeologic setting and degree of regulation for selected long-term gaging stations (generally those with 10 or more years of record)—Continued

[Interior, majority of drainage area within Black Hills; exterior, majority of drainage area outside Black Hills; sed, predominantly sedimentary; cry, predominantly crystalline. Degrees of regulation: H, high; M, medium; L, low; N, negligible or none]

Station number[1]	Station name	Hydrogeologic setting				Degree of regulation											
		Interior			Exterior	Reservoir operation				Irrigation diversion				Municipal and industrial diversions			
		Upstream of loss zone		Down-stream of loss zone													
		Sed	Cry			H	M	L	N	H	M	L	N	H	M	L	N
06421500	Rapid Creek near Farmingdale			X		X				X					X		
06422500	Boxelder Creek near Nemo		X						X				X				X
06423010	Boxelder Creek near Rapid City			X					X				X				X
06423500	Cheyenne River near Wasta			X	X	X				X						X	
06425100	Elk Creek near Rapid City			X				X				X				X	
06425500	Elk Creek near Elm Springs				X			X				X				X	
06428500	Belle Fourche River at Wyo.-S. Dak. State line			X	X	X					X						X
06430000	Murray Ditch at Wyo.-S. Dak. State line			X					X	X							X
06430500	Redwater Creek at Wyo.-S. Dak. State line			X				X			X						X
[3]06430770	Spearfish Creek near Lead	X							X				X		X		
[3]06430800	Annie Creek near Lead		X						X				X				X
[3]06430850	Little Spearfish Creek near Lead	X							X				X				X
[3]06430898	Squaw Creek near Spearfish		X						X				X				X
06431500	Spearfish Creek at Spearfish	[4]X							X				X		X		
06433000	Redwater River above Belle Fourche			X				X			X					X	
06433500	Hay Creek at Belle Fourche				X			X				X				X	
06434500	Inlet Canal near Belle Fourche			X	X	X				X						X	
06435500	Belle Fourche River near Belle Fourche			X	X	X				X						X	
06436000	Belle Fourche River near Fruitdale			X	X	X				X						X	
[3]06436156	Whitetail Creek at Lead		X						X				X				X
06436170	Whitewood Creek at Deadwood	X	X						X				X	X			
06436180	Whitewood Creek above Whitewood			X					X				X	X			
06436190	Whitewood Creek near Whitewood			X					X			X		X			
06436198	Whitewood Creek above Vale			X				X				X		X			
06436700	Indian Creek near Arpan				X			X				X					X

Table 8. Hydrogeologic setting and degree of regulation for selected long-term gaging stations (generally those with 10 or more years of record)—Continued

[Interior, majority of drainage area within Black Hills; exterior, majority of drainage area outside Black Hills; sed, predominantly sedimentary; cry, predominantly crystalline. Degrees of regulation: H, high; M, medium; L, low; N, negligible or none]

Station number[1]	Station name	Hydrogeologic setting				Degree of regulation											
		Interior			Exterior	Reservoir operation				Irrigation diversion				Municipal and industrial diversions			
		Upstream of loss zone		Down-stream of loss zone													
		Sed	Cry			H	M	L	N	H	M	L	N	H	M	L	N
06436760	Horse Creek above Vale				X	X				X							X
06436800	Horse Creek near Vale				X	X				X							X
06437000	Belle Fourche River near Sturgis			X	X	X				X						X	
[3]06437020	Bear Butte Creek near Deadwood		X						X				X				X
06437500	Bear Butte Creek near Sturgis			X	X			X				X				X	
06438000	Belle Fourche River near Elm Springs			X	X	X				X							X
06438500	Cheyenne River near Plainview			X	X	X				X							X
06439300	Cheyenne River at Cherry Creek			X	X	X				X							X

[1]Stations that are used for analyses are shaded.
[2]Station is categorized as upstream of loss zone, although station actually was located within loss zone; replaced with station 06404998 during October 1976.
[3]Station with less than ten years of record.
[4]Station located downstream of the loss zone; however, baseflow is diverted around the loss zone. Thus, station is treated as being upstream of loss zone.

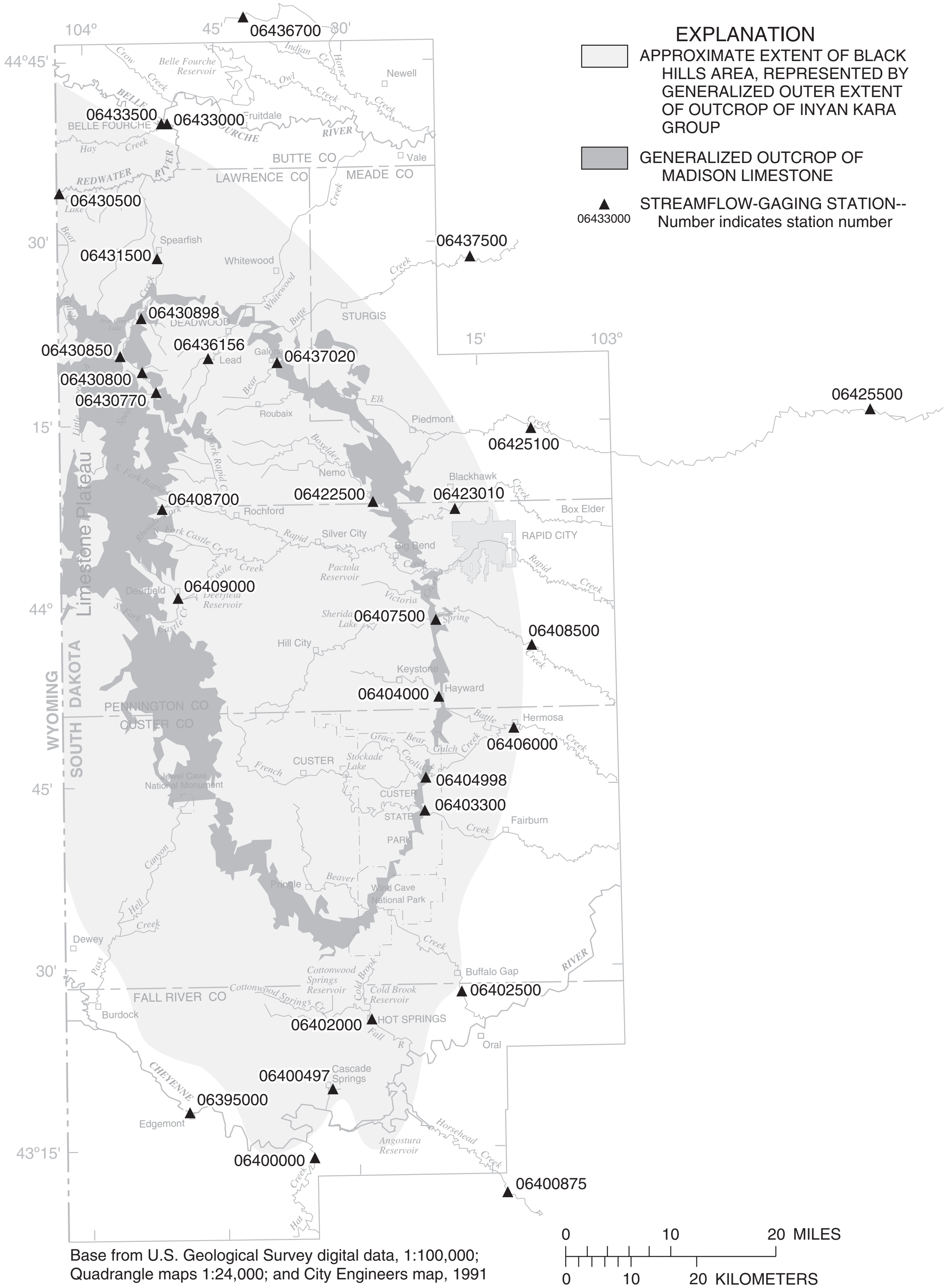


Figure 10. Location of selected gaging stations relative to selected geologic outcrops.

Table 9. Criteria for categorizing degree of regulation for Black Hills streams

Category	Criteria for assigning category
High	Streamflow measurably affected by regulation majority of time and most streamflow characteristics highly affected majority of time
Medium	Streamflow is measurably affected by regulation; however, many streamflow characteristics are not highly affected
Low	Streamflow is seldom measurably affected by regulation or most streamflow characteristics seldom affected
Negligible	Effects of regulation are nonexistent, or nearly nonexistent

because of two flood-storage reservoirs in the basin (Cold Brook and Cottonwood Springs Reservoirs), which primarily affect high-flow statistics. Stations 06403300, French Creek above Fairburn, 06407500, Spring Creek near Keystone, and 06408500, Spring Creek near Hermosa, also are categorized as having medium regulation because of occasional releases from upstream reservoirs, with potential to affect monthly streamflow values. Releases from Stockade Lake on French Creek, and Sheridan Lake on Spring Creek are increased for short periods (generally less than 1 month) during some years, in an effort to provide flow through downstream loss zones. Basins with small, pass-through reservoirs and large numbers of small stock dams generally are categorized as having low regulation because effects on most streamflow characteristics generally are small. Basins with few small dams or reservoirs are categorized as having negligible regulation.

Most stations that are highly regulated by reservoir operations also are highly affected by irrigation diversions. In addition, two stations along Horse Creek (stations 06436760 and 06436800) are highly affected by irrigation return flows originating from diversions from the Belle Fourche Reservoir. Several stations are categorized as having medium regulation because streamflow characteristics can be utilized for comparisons, in spite of sizeable irrigation withdrawals. Numerous stations are categorized as having low regulation from irrigation diversions. In most of these cases, irrigation methods are limited to spreader systems that are operational only during high flows or to small pumps.

Most effects from municipal or industrial diversions are small, relative to flow of affected streams. During low-flow conditions, municipal diversions by the City of Rapid City can be large, relative to the flow of Rapid Creek. Diversions by Homestake Mining Company from Rapid Creek, Elk Creek, and Spearfish Creek are categorized as low to medium; however, return flows to Whitewood Creek, subsequent to municipal and industrial usage, are categorized as high, relative to the natural flow of Whitewood Creek. Other basins are categorized as having negligible to medium regulation, depending on sizes of communities and relative effects of community water and wastewater systems on streamflow.

Comparison of Streamflow Characteristics for Selected Hydrogeologic Settings

Comparison statistics are presented in table 10 for selected stations in four categories of hydrogeologic settings, including interior sedimentary basins, interior crystalline basins, interior basins downstream of loss zones, and exterior basins. Stations for which comparison statistics are presented were selected from table 8 by generally excluding basins that have multiple hydrogeologic settings and highly regulated basins for which natural streamflow characteristics cannot be determined. Comparison statistics include: the coefficient of variation for annual flows; the ratio of minimum to maximum annual flow; the ratio of minimum to maximum mean monthly flow; the ratio of minimum to maximum monthly flow; and the annual yield, expressed in inches (per unit area). Most of the data for calculation of comparison statistics were taken from Section E of the Supplemental Information section, which presents summary statistics for stations with 10 or more years of record. Data for stations with less than 10 years of record were obtained from Section D of the Supplemental Information section. Readers are cautioned that comparison statistics presented in table 10 are based on various periods of record, which are not consistent from station to station.

The comparison statistics presented in table 10 provide numerous insights regarding the variability of streamflow in different hydrogeologic settings. The first statistic considered is the coefficient of variation for annual flows, which is a measure of the variability in annual mean flows over the period of record. A small value for this coefficient indicates low variability from one year to the next and a large value indicates high variability.

Table 10. Comparison statistics for selected stations with various hydrogeologic settings

[--, not computed]

Station number	Station name	Area (square miles)	Period of record (water years)	Coefficient of variation for annual flow	Annual minimum/ maximum ratio	Mean monthly minimum/ maximum ratio	Monthly minimum/ maximum ratio	Annual yield (inches)
			Interior sedimentary basins					
06408700	Rhoads Fork near Rochford	7.95	1983-93	0.22	0.531	0.912	0.420	8.51
06409000	Castle Creek above Deerfield Reservoir, near Hill City	79.2	1949-93	.25	.304	.507	.079	1.83
06430770	Spearfish Creek near Lead	63.5	1989-93	.10	.785	.622	.383	3.34
06430850	Little Spearfish Creek near Lead	25.8	1989-93	.04	.893	.843	.643	6.90
06431500	Spearfish Creek at Spearfish[1]	168	1947-93	.25	.321	.407	.045	4.13
			Mean	.17	.567	.658	.314	4.94
			Median	.22	.531	.622	.383	4.13
			Interior crystalline basins					
06403300	French Creek above Fairburn	105	1983-93	.62	.074	.070	.003	.84
06404000	Battle Creek near Keystone	66.0	1962-93	.70	.033	.028	.000	1.70
06404998	Grace Coolidge Creek near Game Lodge, near Custer	25.2	1977-93	.70	.067	.082	.000	1.94
06407500	Spring Creek near Keystone	163	1987-93	.96	.035	.041	.000	1.12
06422500	Boxelder Creek near Nemo	96.0	1967-93	.73	.069	.077	.002	2.17
06430800	Annie Creek near Lead	3.55	1989-93	.38	.309	.023	.000	3.10
06430898	Squaw Creek near Spearfish	6.95	1989-93	.37	.315	.041	.025	4.07
06436156	Whitetail Creek at Lead	6.15	1989-93	.25	.493	.081	.036	5.59
06437020	Bear Butte Creek near Deadwood	16.6	1989-93	.55	.301	.046	.006	3.77
			Mean	.58	.188	.062	.008	2.70
			Median	.62	.074	.070	.002	2.17
			Interior basins downstream of loss zones					
06400497	Cascade Springs near Hot Springs	.47	1977-93	.07	.762	.955	.589	567
06402000	Fall River at Hot Springs	137	1939-93	.13	.661	.947	.369	2.39
06402500	Beaver Creek near Buffalo Gap	130	1939-93	.21	.341	.363 [2].920	.009 [2].270	.73
06406000	Battle Creek at Hermosa	178	1950-93	.79	.037	.086	.001	.70

Table 10. Comparison statistics for selected stations with various hydrogeologic settings—Continued

[--, not computed]

Station number	Station name	Area (square miles)	Period of record (water years)	Coefficient of variation for annual flow	Annual minimum/ maximum ratio	Mean monthly minimum/ maximum ratio	Monthly minimum/ maximum ratio	Annual yield (inches)
			Interior basins downstream of loss zones—Continued					
06408500	Spring Creek near Hermosa	199	1950-93	1.45	0.000	0.027	0.000	0.33
06423010	Boxelder Creek near Rapid City	128	1979-93	1.75	.000	.000	.000	.10
06425100	Elk Creek near Rapid City	190	1980-93	1.06	.000	.034	.000	.34
06430500	Redwater Creek at Wyoming-South Dakota State line	471	1955-93	.28	.320	.421 [2].935	.048 [2].351	.94
06433000	Redwater River above Belle Fourche	920	1947-93	.31	.262	.174 [2].854	.002 [2].256	1.91
06437500	Bear Butte Creek near Sturgis[3]	192	1946-72	1.06	.000	.030	.000	.99
			Mean	--	--	--	--	--
			Median	--	--	--	--	--
			Exterior basins					
06395000	Cheyenne River at Edgemont[4]	7,143	1947-93	.94	.028	.024	.000	.16
06400000	Hat Creek near Edgemont	1,044	1951-93	1.20	.001	.013	.000	.22
06400875	Horsehead Creek at Oelrichs	187	1984-93	1.41	.000	[5].000	.000	.58
06425500	Elk Creek near Elm Springs[4]	540	1950-93	1.05	.000	.010	.000	.53
06433500	Hay Creek at Belle Fourche	121	1954-93	1.00	.002	.017	.000	.16
06436700	Indian Creek near Arpan	315	1962-81	1.07	.003	.001	.000	.86
06437500	Bear Butte Creek near Sturgis[3]	192	1946-72	1.06	.000	.030	.000	.99
			Mean	1.10	.006	.011	.000	.50
			Median	1.06	.002	.012	.000	.53

[1]Station is located downstream of loss zone; however, streamflow characteristics are most representative of "interior sedimentary" basins.

[2]Ratio calculated using only the period from December through March.

[3]Streamflow characteristics are representative of both "loss-zone" and "exterior" basins.

[4]Small percentage of drainage area is within "interior" of Black Hills; however, streamflow characteristics are most representative of "exterior" basins.

[5]Actual value is 0.0003.

Coefficients of variation for annual flow, by hydrogeologic setting, are presented in graph A of figure 11. The interior sedimentary basins, which are dominated by springflow from headwater areas of the Limestone Plateau (fig. 10), have the smallest variability in annual flow, as a group. The coefficient of variation is less than or equal to 0.25 for all interior sedimentary basins (table 10). The exterior basins, as a group, have the largest variability in annual flow, with all coefficients of variation for this group approaching or exceeding 1.0. Coefficients of variation for the interior crystalline basins generally fall midway between the interior sedimentary and exterior basins, with slight overlap at each end of the range. In comparison, the interior basins downstream of loss zones (loss-zone basins) span the widest range of variability in annual flow. At the lower end of the range, variability in annual flow for loss-zone basins is comparable to variability for the interior sedimentary basins that are dominated by springflow. At the higher end of the range, variability in annual flow for loss-zone basins is comparable to variability for the exterior basins.

The wide range of variability in flow characteristics for loss-zone basins justifies further discussion of factors influencing the variability. The stations representative of loss-zone basins generally have two commonalities. First, stream channels at some point upstream of the gaging stations generally are dry during low-flow periods, or experience substantial losses during high-flow periods, in crossing outcrops of the Madison Limestone and other sedimentary units. The only exception is station 06400497, Cascade Springs near Hot Springs, which is downgradient from the Madison outcrop, but has no loss zone in its small (0.47 mi^2) drainage basin. Several streams have multiple tributaries that experience losses. The second commonality is that all of the loss-zone basins have perennial or ephemeral springs between the loss zones and gaging stations. Station 06423010, Boxelder Creek near Rapid City, is somewhat of an exception. Several springs occur within the loss zone of Boxelder Creek (Rahn and Gries, 1973); however, springflow seldom occurs between the loss zone and the gaging station. Several streams have multiple tributaries with springs.

Additional factors that influence streamflow variability in loss-zone basins are the sizes of drainage basins and the range of hydrogeologic conditions existing upstream and downstream of the loss zones. In some cases, loss-zone basins can be subjected to all of the factors that influence variability in the three other hydrogeologic settings, in addition to variability introduced by streamflow losses. Basins with large, consistent, perennial springs, and minor influence from loss zones or from tributary inflow downstream of loss zones, are likely to have the least variability in annual flow. Cascade Springs is an example. Basins with small, inconsistent, ephemeral springs, and large influence from loss zones or from tributary inflow downstream of loss zones, are likely to have the largest variability in annual flow. Battle, Spring, Boxelder, Elk, and Bear Butte Creeks are examples. Bear Butte Creek (station 06437500) is treated as both a loss-zone and exterior basin.

Mean and median values are calculated for the coefficient of variation, for each category of hydrogeologic setting, with the exception of the loss-zone basins (table 10). Means and medians are not calculated for any of the comparison statistics for loss-zone basins, because this category includes at least three distinctly different populations: (1) Those which are dominated by loss-zone characteristics; (2) those which are dominated by springflow characteristics; and (3) those which are dominated by a blend of these characteristics.

The second statistic presented in table 10 is the ratio of the minimum annual flow to the maximum annual flow for each station. The "annual minimum/maximum ratio" is shown by hydrogeologic setting in graph B of figure 11. This ratio provides information that is similar to the coefficient of variation; however, the two statistics generally are inversely proportional. The annual ratios tend to increase with decreasing variability, so springflow-dominated streams with relatively constant discharge tend to have relatively large ratios. Thus, the interior sedimentary basins and those loss-zone basins that are dominated by consistent springflow tend to have the largest ratios. The annual minimum/maximum ratios are more sensitive than the coefficients of variation, to the extremities of the range of annual values for each station. As an example, two of the interior crystalline basins (stations 06403300, French Creek above Fairburn, and 06437020, Bear Butte Creek near Deadwood) have very similar coefficients of variation of 0.62 and 0.55, respectively; however, the annual ratio for French Creek (0.074) is much smaller than for Bear Butte Creek (0.301). In addition, stations at which zero-flow has been recorded for an entire water year are readily identified by a ratio of 0.0.

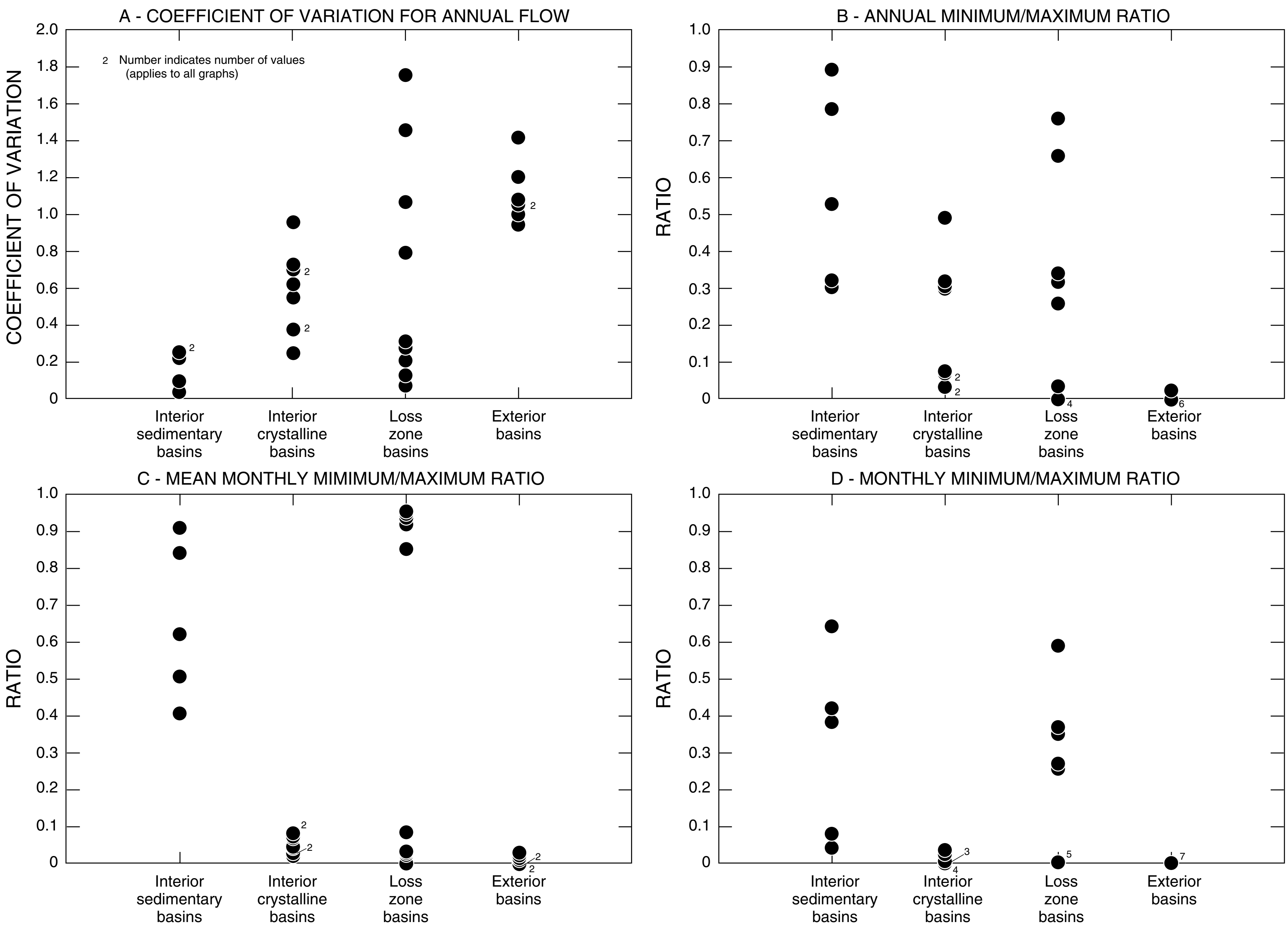


Figure 11. Distribution of streamflow variability for selected gaging stations in selected hydrogeologic settings (see table 10 for data).

Two different ratios involving monthly values are presented in table 10. These ratios also are shown, by hydrogeologic setting, in graphs C and D of figure 11. The “mean monthly minimum/maximum ratio” is obtained by comparing only the 12 mean monthly values for each station, and calculating the ratio of the smallest mean to the largest mean. The “monthly minimum/maximum ratio” is obtained by comparing all monthly values for the period of record for each station, and calculating the ratio of the smallest month to the largest month. Thus, the monthly minimum/maximum ratio for a station will be 0.0 if a zero-flow month has ever been recorded; however, the mean monthly minimum/maximum ratio will be 0.0 only if flow has never been recorded during a given month. Station 06423010, Boxelder Creek near Rapid City, which is a loss-zone station, is the only station which fits this category. Flow has never been recorded at this station for the months of October through March, for the entire period of record.

Several of the loss-zone basins included in table 10 are subject to considerable variability as a result of moderate to large irrigation withdrawals. The natural variability for stations 06402500, Beaver Creek near Buffalo Gap, 06430500, Redwater Creek at Wyoming-South Dakota State line, and 06433000, Redwater River above Belle Fourche, is much less than indicated by the coefficient of variation and the annual minimum/maximum ratio. It is not possible to alter these statistics to better reflect the natural variability of these streams; however, comparison statistics for the monthly ratios for these stations have been modified to reduce effects caused by irrigation diversions. For these stations, the monthly ratios also are calculated using only the months of December through March (table 10), which provides a much better indication of the small, natural variability in monthly streamflow for these springflow-dominated streams. The monthly ratios shown in figure 11, for these stations, are the modified ratios.

The annual yield for each station, which is calculated by dividing mean annual flow by drainage area and converting to inches, also is shown in table 10. Annual yields are calculated using the periods of record shown in table 10; thus, annual yields are not representative of any consistent period of record. Annual yields for several stations actually are somewhat larger than shown in table 10. Relatively large flows are diverted from upper Spearfish Creek to Whitewood Creek. Thus, actual annual yields are larger than indicated for stations 06430770, Spearfish Creek near Lead, and 06431500, Spearfish Creek at Spearfish. Irrigation diversions reduce the calculated annual yields for many of the loss-zone basins and exterior basins.

Annual yields for all stations except loss-zone stations, which may not be representative of annual yield for the drainage areas, are shown in figure 12. Annual yields generally increase from south to north, with the largest yields generally occurring in streams draining the higher elevations of the northern Black Hills. This is consistent with precipitation patterns for the Black Hills area.

Two effects of geologic conditions on annual yield are readily identifiable for several of the loss-zone basins. One effect is the reduction in yield that results from streamflow losses. For example, annual yield is reduced from 2.17 in. at station 06422500, Boxelder Creek near Nemo, to 0.10 in. at station 06423010, Boxelder Creek near Rapid City (table 10). Another effect can be identified for loss-zone basins that are dominated by springflow, which can produce flow originating from outside the surface drainage area, as evidenced by annual yields for two stations. The annual yield of 567 in. for station 06400497, Cascade Springs near Hot Springs, is at least two orders of magnitude larger than what would be expected for drainages in the southern Black Hills. The annual yield of 2.4 in. for station 06402000, Fall River at Hot Springs, also is somewhat larger than for other interior or exterior basins in the southern Black Hills.

Contributing subsurface areas for the springflow-dominated interior sedimentary basins also may be different than the surface drainages. Stations 06408700, Rhoads Fork near Rochford, and 06409000, Castle Creek above Deerfield Reservoir, are located relatively close together, with many hydrogeologic and climatic similarities. The differences in annual yields for these two stations (8.5 and 1.8 in., respectively) are much larger than would be expected as a result of climatic differences. It is likely that the contributing subsurface and surface drainage areas do not coincide, for one or both of these basins.

The effects of geologic conditions on annual yield in other hydrogeologic settings are more difficult to assess, because it is difficult to separate effects of geologic conditions from effects of climatic conditions. Annual yields for the two categories of interior basins (sedimentary and crystalline) generally are larger than for exterior basins (table 10, fig. 12); however, wetter climatic conditions within the interior Black Hills area

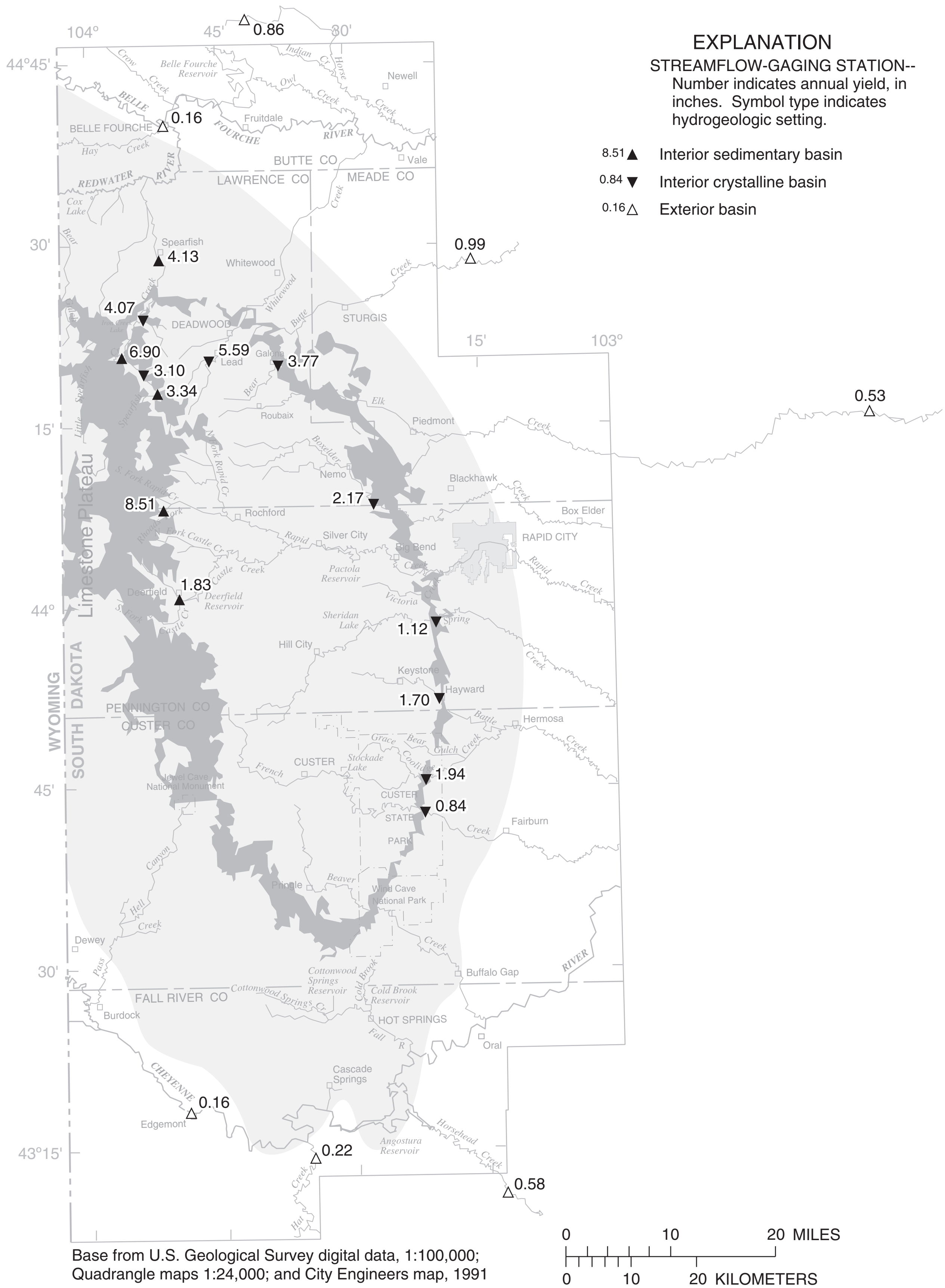


Figure 12. Distribution of annual yield for gaging stations representative of selected hydrogeologic settings.

probably are at least partially responsible for the larger yields. Annual yields for the interior sedimentary basins are larger, as a group, than for the interior crystalline basins; however, annual yields for interior crystalline basins located in the northern Black Hills are comparable with yields for the interior sedimentary basins, all of which are located in the northern Black Hills (fig. 12). Thus, it cannot necessarily be concluded that the interior sedimentary basins produce higher yields than crystalline basins.

Factors Affecting Streamflow Variability

A number of factors have been identified that affect variability of streamflow in the Black Hills area. Variations in climatic conditions have the potential to affect the timing and amount of streamflow in any given location. Annual yield is shown to generally increase from south to north and also is shown to be larger for interior sedimentary basins and interior crystalline basins, than for exterior basins. These variations in annual yield are consistent with climatic patterns for the Black Hills area, including: (1) Increasing precipitation from south to north; (2) increasing precipitation with increasing elevation; and (3) decreasing evapotranspiration rates with increasing elevation. Thus, in many cases, potential effects of geologic conditions on annual yield are difficult to separate from effects of climatic patterns.

Geologic conditions are shown to have a large effect on the annual and monthly variability of streamflow. Interior crystalline basins and exterior basins are shown to have large variations in annual and monthly flows. All of the exterior basins are prone to extended periods of zero flow, as indicated by the monthly minimum/maximum ratios, which are 0.0 for all exterior basins, and by the annual minimum/maximum ratios, which approach 0.0 for all exterior basins (table 10). Although interior crystalline basins exhibit large variability in annual and monthly flows, these basins are somewhat less prone to extended periods of zero flow. Zero-flow months have been recorded for about one-half of the crystalline basins, but zero-flow years have not been recorded for any of the crystalline basins listed in table 10. Larger precipitation and smaller evapotranspiration rates over the interior of the Black Hills probably are factors that decrease zero-flow periods, relative to exterior basins. In addition, it is possible that interior crystalline basins have larger shallow storage capacity than exterior basins, because of geologic factors such as fracturing.

Streams that are dominated by consistent springflow are shown to be relatively unresponsive to short-term variations in climatic conditions. As a group, the interior sedimentary basins exhibit the smallest variability in streamflow because of geologic constraints on both low and high flows. These basins derive large and consistent base flow from headwater areas of the Limestone Plateau, in the northwestern Black Hills, where most of the outcrops consist of the Madison Limestone and Minnelusa Formation. Direct surface runoff from these highly permeable outcrops is uncommon. As an example, the maximum daily flow for station 06408700, Rhoads Fork near Rochford, is 8.50 ft^3/s (table E17.6, fig. F17), which is less than twice the average flow of 4.98 ft^3/s (table E17.2), and less than three times the minimum daily flow of 3.10 ft^3/s (table E17.5).

Loss-zone basins that are dominated by large artesian springflow also have small variability in flow. An example is station 06400497, Cascade Springs near Hot Springs, where the maximum daily flow of 25 ft^3/s (table E3.6) is less than twice the minimum daily flow of 14 ft^3/s (table E3.5). Other springflow-dominated streams such as the Fall River, Beaver Creek, and the Redwater River also have small variability in springflow; however, the variability of measured streamflow is increased by effects of surface runoff and withdrawals. The source for many of the larger, more consistent artesian springs generally is discharge from the Madison and/or Minnelusa aquifers (Klemp, 1995; Whalen, 1994).

Several of the other streams that have been classified as loss-zone basins (Battle, Spring, Elk, and Bear Butte Creeks) have relatively small springs with large variability in flow characteristics. These streams are prone to low- or zero-flow conditions during extended dry periods, which indicates that these smaller springs are more responsive to short-term climatic and recharge conditions than some of the larger, more consistent springs. Additional variability in streamflow at these stations is caused by occasional large flows through the loss zones and by tributary inflow from intervening drainage areas between the loss zones and gaging locations.

Station 06423010, Boxelder Creek near Rapid City, has less influence from springflow than the other loss-zone stations. Several springs occur within the loss zone of Boxelder Creek (Rahn and Gries, 1973);

however, measurable flow at the gaging station generally occurs only when flow is sufficient to pass through the loss zone. The drainage area between the next station upstream (06422500, Boxelder Creek near Nemo) and this station increases by 32 mi^2. Much of this area consists of relatively large expanses of the Madison Limestone, Minnelusa Formation, and other sedimentary units. Examination of streamflow records for these stations (tables E27.1 and E28.1) indicates that monthly mean flow at the downstream station never exceeded corresponding flow at the upstream station during WY 1978-93. The largest daily flow for this period of record at the downstream site (114 ft^3/s on June 7, 1991) is smaller than the daily flow at the upstream site for the same date (151 ft^3/s). This provides additional evidence of the infrequent occurrence of direct surface runoff from the Madison Limestone and Minnelusa Formation.

Streamflow variability also can be affected, to some degree, by drainage area. Streamflow variability for the interior sedimentary basins can be increased by outcrops of crystalline rocks. Similarly, variability for the crystalline basins can be decreased by outcrops of sedimentary rocks. As a generality, larger drainages have more opportunity for integrated effects from multiple hydrogeologic settings. As an example, station 06431500, Spearfish Creek at Spearfish, is classified as an interior sedimentary basin (table 10). Variability for this station is larger than for two upstream stations that also are classified as interior sedimentary basins (stations 06430770, Spearfish Creek near Lead, and 06430850, Little Spearfish Creek near Lead). Part of the increased variability is a result of crystalline-rock outcrops within the basin. Two stations within the Spearfish Creek drainage (06430800, Annie Creek near Lead, and 06430898, Squaw Creek near Spearfish) are classified as predominantly crystalline; however, these basins have smaller variability than some of the other crystalline basins because of sedimentary-rock outcrops within their drainages.

SUMMARY AND CONCLUSIONS

This report summarizes streamflow records for all USGS gaging stations that have been operated within, or immediately downstream from the Black Hills of western South Dakota. In addition, streamflow characteristics are described for four categories of hydrogeologic settings that are identified for the area.

Streamflow records through WY 1993 are summarized for 129 continuous-record gaging stations. Collection of streamflow records in the Black Hills area began during WY 1903, with the operation of eight USGS gaging stations. The longest continuous records in the Black Hills area are for stations 06423500, Cheyenne River near Wasta, and 06438000, Belle Fourche River near Elm Springs, which span WY 1934-93. Monthly and annual means are tabulated for all available years of record for all 129 gaging stations, including 111 stations for which records of daily flow are available and 18 stations for which only monthly records are available. For the stations with records of daily flow, 32 have less than 5 years of record, 27 have between 5 and 9 years of record, and 52 have 10 or more years of record. Maxima, minima, and means for the monthly and annual values are summarized for the 27 stations with 5 to 9 years of record. For the 52 stations with 10 or more years of record, extensive summary information is presented in a series of six tables for each station. The first table of each series presents monthly and annual values for the station and the second table presents extensive summary statistics for these values. The third and fourth tables present correlation coefficients for 1-year serial correlations for monthly values and a correlation matrix for monthly mean flows. The fifth and sixth tables of each series present low- and high-flow values and rankings for 1, 3, 7, 14, 30, 60, 90, 120, and 183 consecutive-day periods. A series of four graphs also is presented for each station with 10 or more years of record, including graphs of annual mean flow, distribution of monthly mean flow, a duration curve of daily mean flow, and duration hydrographs of daily mean flow. In addition to streamflow summaries, records of monthend contents are presented for five reservoirs operated by the Bureau of Reclamation in the Black Hills area.

Streamflow characteristics are described for four categories of hydrogeologic settings that are identified for the Black Hills area. Stations with long-term records (generally 10 or more years) and with minimal effects from reservoir operations, irrigation diversions, and municipal and industrial diversions, are used to examine the effects of the various hydrogeologic settings on streamflow variability.

The four categories of hydrogeologic settings that are identified are interior sedimentary basins, interior crystalline basins, interior basins downstream of loss zones (loss-zone basins), and exterior basins. The interior basins are located predominantly within the outermost extent of the outcrop of the Inyan Kara Group and the exterior basins are located predominantly beyond this outcrop. The interior sedimentary basins generally are located within headwater areas of the Limestone Plateau and are dominated by outcrops of the Madison Limestone and Minnelusa Formation. The interior crystalline basins are located within the uplifted central core of the Black Hills and are dominated by Precambrian metamorphic and igneous rocks or Tertiary intrusive rocks. The loss-zone basins generally have gaging stations located downstream of loss zones that occur where streams cross outcrops of the Madison Limestone and other overlying sedimentary units. Most of the loss-zone basins have springs located upstream of the gaging stations, but downstream of the loss zones.

Distinct differences in variability of annual and monthly streamflow are identified for the four categories of hydrogeologic settings. The interior sedimentary basins, which are dominated by springflow from headwater areas of the Limestone Plateau, have the smallest variability in both annual and monthly flow, as a group. The exterior basins, as a group, have the largest variability in both annual and monthly flow. Variability in annual and monthly flow for the interior crystalline basins generally falls midway between the interior sedimentary and exterior basins. Variability for the interior crystalline basins generally decreases as the areal extent of sedimentary-rock outcrops within a basin increases. Conversely, outcrops of crystalline rocks within interior sedimentary basins tend to increase streamflow variability. Loss-zone basins exhibit the widest range in streamflow variability of any of the categories. Flow at several of the loss-zone stations is dominated by flow from large, artesian springs, with very little variability in flow. Cascade Springs, Fall River, Beaver Creek, and Redwater River demonstrate the most consistent springflow within this category. Flow at other loss-zone stations is dominated by streamflow losses or by tributary inflows between the loss zones and the gaging stations. Variability in flow at such stations can be larger than for interior sedimentary or exterior basins. The variability caused by streamflow losses or tributary inflows for such stations tends to mask the natural variability in springflow at such stations; however, it is shown that springflow in Battle, Spring, Elk, and Bear Butte Creeks is much more variable than in Cascade Springs, Fall River, Beaver Creek, and Redwater River.

Relations between climatic conditions and streamflow are not quantified in this report; however, it is shown that the interior crystalline basins and exterior basins are much more responsive to climatic conditions than the springflow-dominated basins. Zero-flow months have been recorded for all of the exterior basins and most of the interior crystalline basins; however, zero-flow months have not been recorded for any of the interior sedimentary basins. Zero-flow months have not been recorded for the loss-zone stations with large, consistent springflow; however, zero-flow months are common for loss-zone stations with smaller, less consistent springs. Thus, it is concluded that the smaller, less consistent springs are more responsive to short-term climatic and recharge conditions than the larger, more consistent springs.

Direct surface runoff is demonstrated to be uncommon for outcrops of the Madison Limestone and Minnelusa Formation. For station 06408700, Rhoads Fork near Rochford (drainage area equals 7.95 mi^2), the ratio of maximum to mean daily flow is less than 2.0 and the ratio of maximum to minimum daily flow is less than 3.0. The drainage area between stations 06422500, Boxelder Creek near Nemo, and 06423010, Boxelder Creek near Rapid, increases by 32 mi^2, with large outcrops of the Madison Limestone and Minnelusa Formation; however, monthly and daily flow at the downstream station (06423010) have not exceeded corresponding flow at the upstream station during WY 1978-93.

Annual streamflow generally increases from south to north, which is consistent with climatic patterns for the area. Annual yield generally is larger for all of the interior categories than for the exterior basins; however, this is consistent with larger precipitation and smaller evapotranspiration rates at higher elevations. Annual yields generally are largest for the interior sedimentary basins; however, all of these basins are located in the northern Black Hills. Interior crystalline basins located in the northern Black Hills have annual yields that are comparable with interior sedimentary basins.

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