



Hydrologic Benchmark Network Stations in the West-Central U.S. 1963-95 (USGS Circular 1173-C)

Abstract and Map Index	List of all HBN Stations	Introduction to Circular	Analytical Methods
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Castle Creek above Deerfield Reservoir, South Dakota (06409000)

This report details one of the approximately 50 stations in the Hydrologic Benchmark Network (HBN) described in the four-volume U.S. Geological Survey Circular 1173. The suggested citation for the information on this page is:

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All of the tables and figures are numbered as they appear in each circular. Use the navigation bar above to view the abstract, introduction and methods for the entire circular, as well as a map and list of all of the HBN sites. Use the table of contents below to view the information on this particular station.

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Site Characteristics and Land Use

The Castle Creek HBN Basin is within the Black Hills Section of the Great Plains physiographic province (Fenneman, 1946) in southwestern South Dakota ([Figure 21](#), *Map showing study area in Castle Creek Basin and photograph of Silver Creek*). The HBN station is about 4 km southwest of the dam on Deerfield Reservoir and about 23 km northwest of Hill City, S. Dak., at a latitude of 44°00'49" and a longitude of 103°49'48".

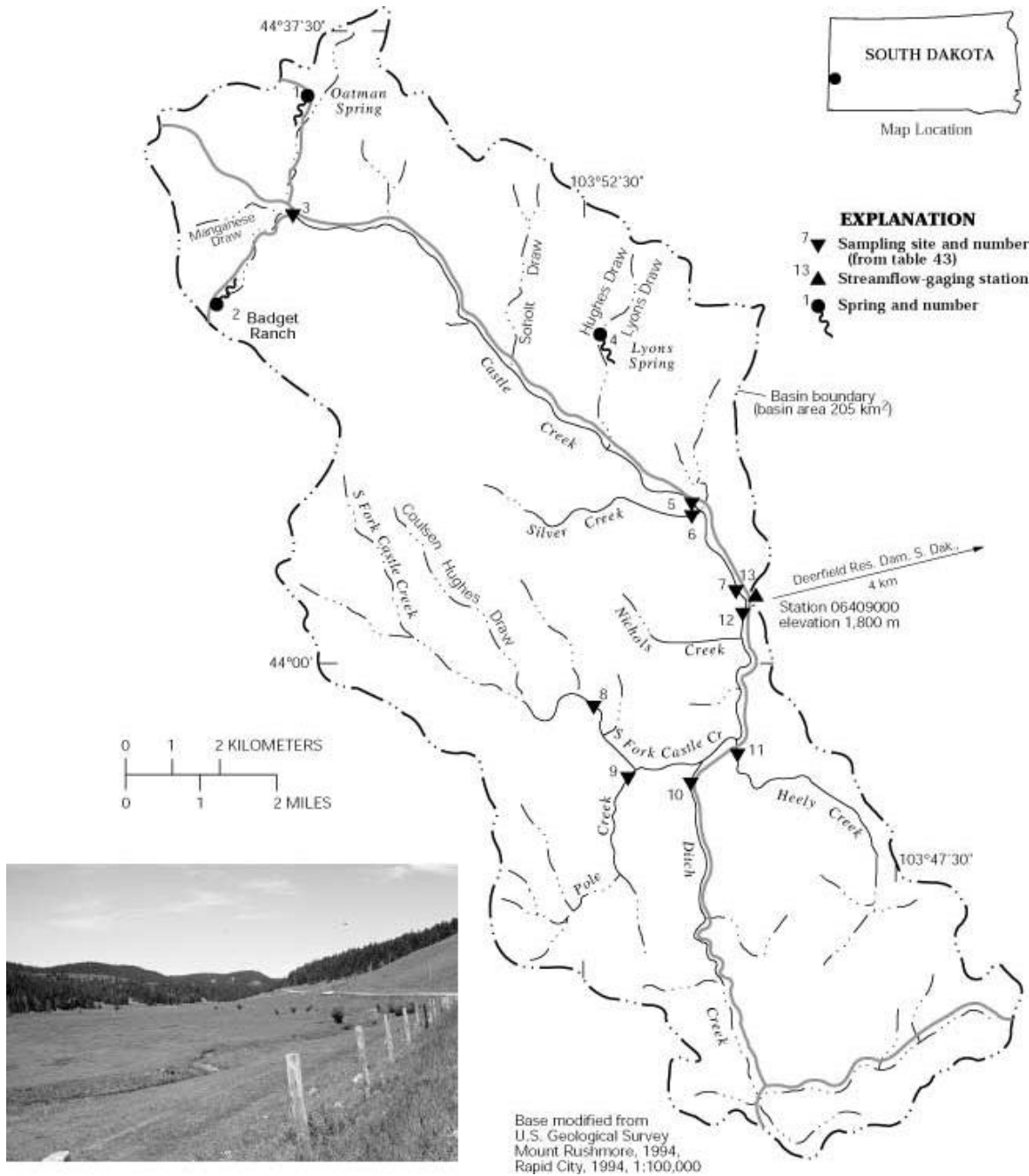


Figure 21. Map showing study area in Castle Creek Basin and photograph of Silver Creek

Castle Creek drains 205 km² of dissected, mountainous terrain. Elevations in the basin range from about 1,800 to about 2,170 m. The average stream slope is about 15 m/km (S.K. Sando, U.S. Geological Survey, written commun., 1998). The ecoregion of the basin is classified as the Black Hills Coniferous Forest Province (Bailey, 1995). A moderately dense Ponderosa pine forest covers most of the basin, and spruce, aspen, willows, and smaller trees and brush grow in the valley areas. Some of the valley floors have been cleared for pastures. Castle Creek is tributary to Rapid Creek, which drains into the Cheyenne River.

Castle Creek is a perennial stream with a small range of mean monthly discharges from 0.23 m³/s in January to 0.47 m³/s in May (Burr and others, 1996). The average annual precipitation received at the Deerfield 3 SE weather station (5.4 km southeast of the HBN station) is 51 cm. The upper basin receives enough snow to sustain a snowpack through most of the winter (B.C. Engle, U.S. Geological Survey, written commun., 1997). Average annual runoff is about 5 cm (Burr and others, 1996). The area has cold winters and mild summers. Mean monthly temperatures ranged from -7.3°C in December to 15.5°C in July during the period 1981–95 (National Climatic Data Center, 1996).

The Black Hills are a dome-shaped uplift, dissected by streams. The central core rocks of the Black Hills underlie the area near the HBN station and are composed of Precambrian micaceous schist and phyllite. The upstream part of the Castle Creek HBN Basin drains predominantly Paleozoic carbonate rocks of the Limestone Plateau, including the Madison Limestone of Mississippian age, an important regional aquifer. Lithologic types are cliff-forming dolomitic limestones, dolomites, limestones, shale, and siltstone (DeWitt and others, 1986; DeWitt and others, 1989). Important characteristics of the Madison Limestone, locally known as the Pahasapa Limestone, are its karstic features, including numerous fractures, solution cavities, and springs. The caverns of Jewel Cave National Monument and Wind Cave National Park formed in the Madison Limestone, south and east of the Castle Creek HBN Basin. The Madison is a key factor in the surface-water hydrology of the Black Hills area. Many streams lose all or part of their flow to the sinkholes; resurgent springs are located farther downstream (Driscoll, 1992). The soils in the basin are silty, generally deep, well drained, and gently sloping to steep. Soils are formed in materials weathered from limestone (U.S. Department of Agriculture, 1990). There is very little alluvium in the stream valleys.

The Castle Creek HBN station is in Pennington County. The basin lies entirely within the Black Hills National Forest, although some of the land along the valley floors is privately owned. Much of the drainage area can be accessed by improved paved roads and light-duty gravel and dirt roads. Foot trails provide access to areas farther up the drainages. The HBN station can be accessed by vehicle during all seasons, weather permitting. Manmade features in the basin include a gravel pit, roads, trails, and a campground. An established Forest Service campground is in the Ditch Creek drainage. Timber harvest has occurred one or more times throughout the basin. Cattle and horses graze throughout the basin. Hay and oats are grown in the pastures along the valley bottoms. Recreational uses in the basin include four-wheel-drive vehicle use, fishing, hiking, hunting, and camping. Winter recreation in the upper basin includes skiing and

snowmobiling. The basin sees substantial tourism because of its location within the popular Black Hills and its close proximity to Mount Rushmore National Monument. There is a gravel mine in the South Fork Castle Creek drainage, and Black Hills gold is mined lower in the Castle Creek drainage downstream from the HBN study area.

Historical Water-Quality Data and Time-Series Trends

The data set analyzed for the Castle Creek HBN station includes 240 water-quality samples that were collected from December 1964 through August 1995. Sampling frequency is described on the basis of water year, which begins on October 1 and ends on September 30. Sampling frequency was quarterly from 1965 through 1967 and increased to 10–13 samples collected annually during the period 1968 to 1982. After 1982, samples generally were collected quarterly. Samples were analyzed at USGS district water-quality laboratories until the early 1970's. After 1973, with the creation of the USGS Central Laboratory System, all samples were analyzed at the water-quality laboratory (now called NWQL) in Arvada, Colo. The period of record for discharge is from water year 1948 to current year (2000). Daily water temperature was recorded from May 1964 to September 1984.

Data quality was checked using ion balances and time-series plots. Calculated ion balances for samples with complete major-ion analyses are shown in [Figures 22a](#) and [22b](#). *Temporal variation of discharge, field pH, major dissolved constituents, and ion balance at Castle Creek, South Dakota*. More than 95 percent of the samples had ion balances within the ± 10 percent range, indicating that the major-ion analytical results were of good quality and that unmeasured constituents, such as organic anions, do not contribute much to the ionic composition of Castle Creek. Time-series plots of ion concentrations were inspected for evidence of influences that are related to analytical method changes (fig. 22). Calcium, magnesium, and sodium show a similar pattern of having more scatter in the early part of the record and a decrease in scatter after 1983. This decrease coincides with a change in the analytical method for these analytes from AA spectroscopy to ICP spectroscopy (U.S. Geological Survey Office of Water Quality Technical Memorandum No. 82.18, 1982). Several samples had high sulfate concentrations in the late 1970's. The decrease in scatter of sulfate concentrations after 1982 corresponds with the change from a methylthymol blue procedure to a turbidimetric titration method (U.S. Geological Survey Office of Water Quality Technical Memorandum No. 83.07, 1983). Changes also were made in meters and electrodes used for field pH determinations during the study period. When changes in methods or instrumentation result in improved precision or elimination of measurement bias, time-series data can exhibit less scatter or a directional shift, respectively. The time-series data, therefore, may reflect the method or instrument change rather than an environmental change.

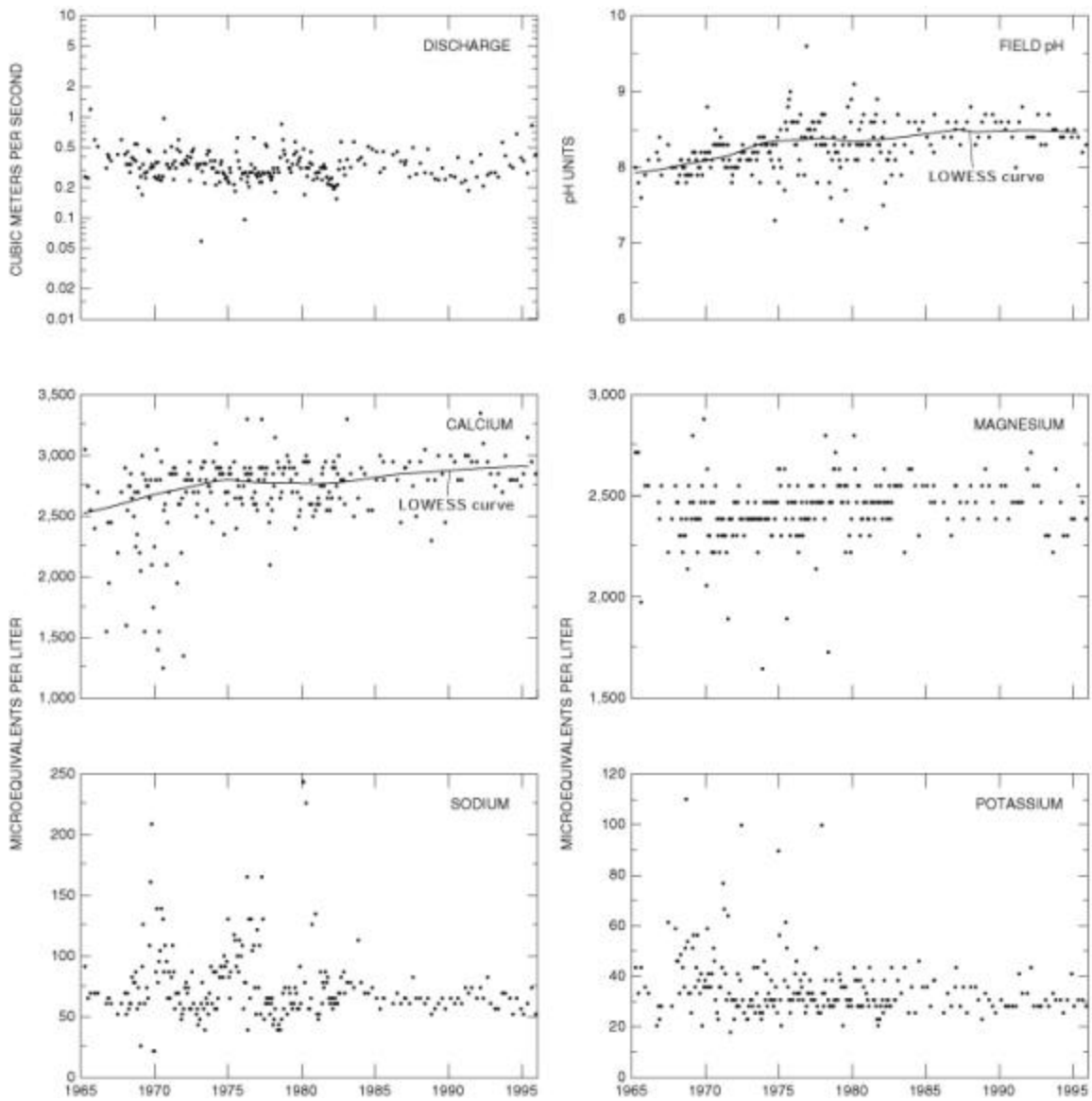


Figure 22a. Temporal variation of discharge, field pH, major dissolved constituents, and ion balance at Castle Creek, South Dakota

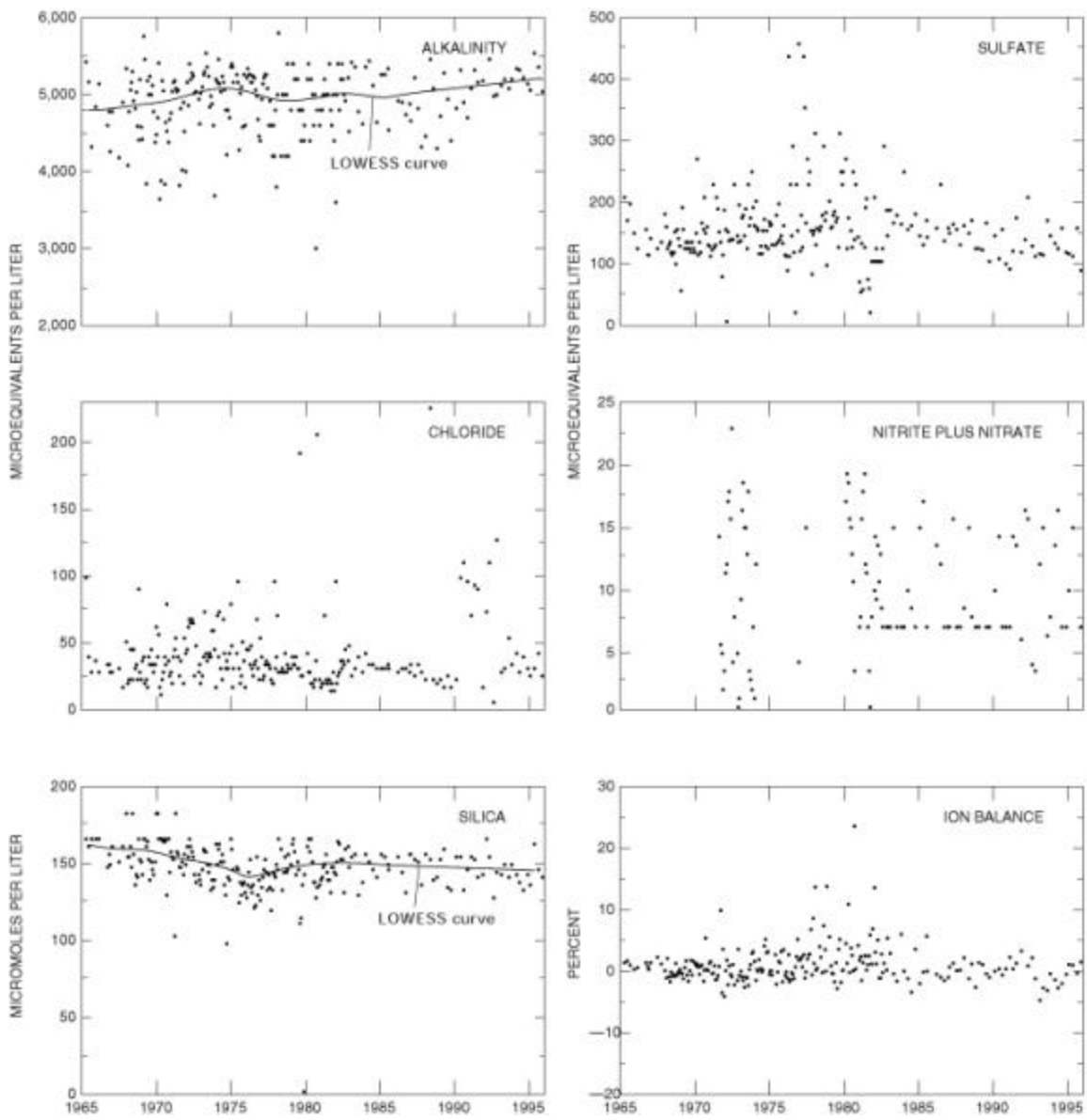


Figure 22b. Temporal variation of discharge, field pH, major dissolved constituents, and ion balance at Castle Creek, South Dakota - Continued

Table 40. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major ions measured in water-quality samples from Castle Creek, South Dakota, 1965—95, and volume-weighted mean concentrations in wet precipitation collected at the New Castle Station, Wyoming, 1981—95

[Parameters in units of microequivalents per liter, except for discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VWM, volume-weighted mean; spec. cond., specific conductance; --, not reported; <, less than]

Parameter	Stream Water						Precipitation VWM
	Minimum	First quartile	Median	Third quartile	Maximum	n	
Discharge	0.06	0.26	0.31	0.40	1.2	240	--
Spec. cond., field	304	439	467	485	715	239	--
pH, field	7.2	8.1	8.3	8.5	9.6	237	5.3 ^a
Calcium	1,200	2,600	2,800	2,900	3,400	240	15
Magnesium	1,600	2,400	2,500	2,600	2,900	239	2.9
Sodium	22	61	65	83	240	237	3.0
Potassium	18	28	31	38	110	238	.87
Ammonium	<.7	.7	1.4	4.3	14	72	13
Alkalinity, laboratory	3,000	4,700	5,000	5,200	5,800	239	--
Sulfate	6.2	120	150	170	460	239	18
Chloride	5.6	25	34	42	230	236	2.5
Nitrite plus nitrate	<.7	7.1	8.6	15	23	114	15 ^b
Silica	1.7	140	150	160	180	239	--

^a Laboratory pH.

^b Nitrate only.

The median and range of major-ion concentrations in stream water collected at the Castle Creek HBN station and VWM concentrations in wet precipitation measured at the Newcastle, Wyo., NADP station are presented in table 40. The NADP station is about 43 km southwest of the HBN station. Precipitation chemistry at the NADP station was dilute

and slightly acidic with VWM pH of 5.3 during the period of record, 1981–95. The dominant cation in precipitation was calcium, accounting for about 38 percent of the cation concentration. About 33 percent of the total cation concentration was contributed by ammonium. Sulfate and nitrate contributed about 51 and 42 percent, respectively, to the total anion concentration in precipitation.

Stream water in Castle Creek is an alkaline, calcium bicarbonate type. The sum of ion concentrations ranged from about 7,600 to about 12,000 meq/L. Alkalinity ranged from 3,000 to 5,800 meq/L, and bicarbonate was the primary contributor to alkalinity at this station. Dissolved calcium and magnesium contributed over 98 percent of the median cation concentration in stream water, and bicarbonate contributed 96 percent of the median anion concentration. The predominance of these constituents is typical of a geologic setting containing limestones and dolomites. Carbonate rocks generally are more soluble than silica-rich rocks, including sandstones, granite, and schists; greater solubility of rock increases dissolved-solids concentrations in streams (Biasecker and Leifeste, 1975). Specific conductance (304 to 715 mS/cm) is an indicator of dissolved solids at this station. Median concentrations of ammonium and nitrate were lower in the stream water than in the precipitation, indicating that nitrogen generally is retained by the biomass in the basin.

Table 41. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major ions, Castle Creek, South Dakota, 1980 through 1995

[Q, discharge; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO₄, sulfate; Cl, chloride; SiO₂, silica; --, not applicable]

	Q	pH	Ca	Mg	Na	K	Alk	SO ₄	Cl
pH	-0.086	--	--	--	--	--	--	--	--
Ca	-.224	0.140	--	--	--	--	--	--	--
Mg	-.244	.138	0.404	--	--	--	--	--	--
Na	.011	.056	.068	0.084	--	--	--	--	--
K	.095	-.128	.115	-.058	0.278	--	--	--	--
Alk	-.208	-.004	.702	.307	.097	0.197	--	--	--
SO ₄	.217	.153	.126	.081	.158	.100	0.039	--	--
Cl	.055	-.112	.113	-.057	.138	.172	.192	0.156	--
SiO ₂	-.084	-.350	.299	.227	.024	.376	.270	-.053	0.088

Correlations among dissolved constituents and discharge were determined for Castle Creek (table 41). Base cations and anions showed weak and mixed, positive and inverse correlations with stream discharge. The lack of strong correlations with discharge probably is due to the narrow range of discharge associated with the well-drained soils and the karstic nature of underlying carbonates, which allows precipitation to infiltrate quickly. The magnitude of the minimum values of calcium (1,200 meq/L) and magnesium (1,600 meq/L) compared to precipitation indicates that most of the cations in stream water are contributed from ground-water sources that have been in contact with geologic materials. The stream solutes also showed weak correlations with each other, except for calcium and alkalinity (rho value = 0.702). The fact that calcium and magnesium are not strongly correlated, nor magnesium and alkalinity, may indicate that the calcium-alkalinity relationship is controlled by the limestones rather than the dolomites.

Results of the seasonal Kendall test for trends in discharge and major dissolved constituents for Castle Creek from 1965 through 1995 are presented in table 42. Statistically significant upward trends ($\alpha = 0.01$) occurred in pH, calcium, and alkalinity. A significant downward trend in unadjusted silica concentrations was observed. After the statistical test was adjusted for discharge, only the upward trends remained in concentrations of calcium and alkalinity. This indicates that stream discharge may have been controlling the pH and silica trends, but not the calcium and alkalinity trends. Regional precipitation chemistry shows a widespread decline in calcium concentrations for the period 1980–92 (Lynch and others, 1995). The decrease in calcium in precipitation is not consistent with the upward trend in calcium in stream water. However, carbonate rock rather than precipitation is the predominant control on the calcium in the stream water. Variations in timber harvest is one land-use change that has occurred in the basin.

Table 42. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major-ion concentrations, Castle Creek, South Dakota, 1965 through 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, and silica in micromoles per liter per year; p-value, attained significance level; --, not calculated; <, less than]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	-0.01	0.592	--	--
pH	.01	<.001	(^b)	--
Calcium	10	<.001	9	<0.001
Magnesium	<.01	.018	3	.048
Sodium	<.01	.327	(^b)	--
Potassium	-.2	.013	(^b)	--
Alkalinity	10	.001	9	.003
Sulfate	-.6	.122	-0.4	.188
Chloride	<.01	.750	(^b)	--
Nitrite plus nitrate ^a	<.01 ^a	.306	--	--
Silica	-.3	.002	(^b)	--

^a Trend test for highly censored data was used.

^b Concentration-flow model not significant at $\alpha = 0.10$.

An upward trend in flow-adjusted sulfate concentrations and increasing levels of sulfur-dioxide emissions were reported by Smith and Alexander (1983) for the mid- to late 1960's to 1981. Annual precipitation and runoff data for Castle Creek indicate that evapotranspiration can account for about a tenfold increase in stream-water concentrations compared to precipitation, which indicates precipitation is the primary contributor of sulfate in stream water. The lack of a trend for the period 1965–95 indicates that sulfate deposition may have decreased in the area since that study.

Synoptic Water-Quality Data

Results of a surface-water synoptic sampling conducted June 12–14, 1993, in the Castle Creek Basin are presented in table 43, and locations of the sampling sites are shown in figure 21. Discharge at the HBN station (site 13) was $0.96 \text{ m}^3/\text{s}$ compared to the mean monthly discharge of $0.40 \text{ m}^3/\text{s}$ for the month of June (Burr and others, 1996). The sum of ions ranged from 1,100 (site 2) to 11,000 meq/L at several sites, including the HBN station (site 13). Concentrations of dissolved constituents in tributaries and springs generally were within the range of dissolved constituent concentrations for the Castle Creek HBN station (table 40) with the exception of site 2, which had a smaller concentration of calcium, magnesium, and bicarbonate than the minimum value recorded at the HBN station. Water in the basin is generally a calcium-magnesium bicarbonate or calcium bicarbonate type. Water sampled from the tributaries and springs were near neutral to alkaline. The percent difference of cations and anions ranged from 0.1 to 7.1 percent for all sites, indicating that unmeasured ions did not contribute substantially to the ionic composition of the water.

Two samples that were collected in the headwaters of the Castle Creek drainage were from springs (sites 1 and 2). The first location of sustained flow in the Castle Creek channel was noted at site 3. The concentrations of constituents were more dilute in Badget Ranch Spring (site 2). The exact location of the contact between the Madison Limestone and the Minnelusa Formation of Permian age is unknown in the area near this spring. The Minnelusa Formation includes sandstone, breccia, limestone, and shale. The geochemical composition of the Badget Ranch sample is more characteristic of a geologic environment containing silica-rich rocks like the Minnelusa Formation than a predominantly limestone environment. The different water quality at the two springs also could be the result of different residence time. Samples that were collected from areas draining metamorphosed tuffaceous shale tend to have higher concentrations of sodium and sulfate (sites 7, 11, 12, and 13). Precipitation chemistry can account for the nitrate concentrations in samples that were collected during the synoptic sampling.

Table 43. Physical properties and major-ion concentrations in surface-water samples collected at sites in the Castle Creek Basin, June 12-14, 1993

[Site locations shown in fig. 21; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO₄, sulfate; Cl, chloride; NO₃, nitrate; SiO₂, silica; concentrations in microequivalents per liter, except silica is in micromoles per liter; --, not measured; <, less than; criteria used in selection of sampling sites: BG = bedrock geology, TRIB = major tributary]

Site	Identification number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO ₄	Cl	NO ₃	SiO ₂	Criteria
1	440650103570000	--	458	7.8	3,800	1,500	52	44	5,000	25	<2.8	7.5	350	BG
2	440414103583000	--	50	7.2	380	100	52	49	480	8.3	17	2	230	BG
3	440521103571600	--	407	--	2,800	1,800	39	14	4,400	58	8.5	37	180	BG
4	440400103521100	--	476	8.3	2,800	2,500	52	22	5,300	56	14	6.4	150	BG
5	440156103504300	0.39	483	8.4	3,000	2,300	61	31	5,200	180	34	4.9	160	TRIB
6	440148103504100	.04	481	8.5	3,000	2,500	57	28	5,300	100	17	6.9	140	TRIB
7	440055103495900	.55	491	8.4	3,100	2,400	78	33	5,200	230	62	7.8	170	TRIB
8	435930103521900	.02	463	8.4	3,200	2,100	48	19	5,000	56	45	4.8	130	BG
9	435847103513900	.01	460	8.5	3,000	2,200	57	31	5,100	63	17	4.9	150	TRIB
10	435832103504400	.09	477	8.5	3,200	2,200	52	20	4,900	65	31	9.5	150	TRIB
11	435856103500000	.06	501	8.4	2,800	2,600	87	72	5,400	200	25	1.6	160	BG
12	440039103495100	.25	449	8.5	2,800	2,200	87	46	4,600	120	25	1.9	170	TRIB
13	06409000	.96	476	8.5	3,000	2,300	83	36	5,100	190	51	6	170	--

References Cited

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U.S. Geological Survey, 1983, Analytical methods—Sulfate determinations: Office of Water Quality Technical Memorandum No. 83.07, accessed December 27, 1999, at URL <http://water.usgs.gov/admin/memo/>.

Appendix A. List of Map References

- a. U.S. Geological Survey topographic maps:
 - Crooks Tower, South Dakota (1:24,000), 1956
 - Crows Nest Peak, South Dakota (1:24,000), 1956
 - Deerfield, South Dakota (1:24,000), 1979, streamflow-gaging station
 - Ditch Creek, South Dakota (1:24,000), 1956
 - Mount Rushmore, South Dakota (1:100,000), 1977
 - Preacher Spring, South Dakota (1:24,000), 1956
 - Rapid City, South Dakota (1:100,000), 1980

- b. Geologic maps:
 - DeWitt, E., Redden, J.A., Busher, D., and Wilson, A.B., 1989, Geologic map of the Black Hills area, South Dakota and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1910, 1 pl., scale 1:250,000.
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- c. Soil surveys:
 - U.S. Department of Agriculture, 1990, Soil survey of Custer and Pennington Counties, Black Hills parts, South Dakota: U.S. Department of Agriculture, Soil Conservation Service, 295 p.

- d. Other maps:
 - Black Hills National Forest map, 1988, U.S. Department of Agriculture.

Appendix B. NWIS Site-Identification Numbers

Table B-1. NWIS site-identification numbers and site names for water-quality sampling sites.

Site	Identification Number	Site Name
1	440650103570000	OATMAN SPRING
2	440414103583000	SPRING NEAR BADGET RANCH
3	440521103571600	SPRING BELOW MANGANESE DRAW NEAR CASTLE CREEK HEADWATERS
4	440400103521100	LYONS SPRING
5	440156103504300	CASTLE CREEK ABOVE SILVER CREEK
6	440148103504100	SILVER CREEK
7	440055103495900	CASTLE CREEK ABOVE SOUTH FORK
8	435930103521900	SOUTH FORK CASTLE CREEK ABOVE POLE CREEK
9	435847103513900	POLE CREEK
10	435832103504400	DITCH CREEK
11	435856103500000	HEELY CREEK
12	440039103495100	SOUTH FORK CASTLE CREEK
13	06409000	CASTLE CREEK AT GAGE