

Contents

Summary of Major Findings	1
Precipitation.....	1
Ground Water	1
Surface Water.....	2
Water Quality.....	2
Hydrologic Budgets	3
Introduction	4
Purpose and Scope.....	4
Description of Study and Study Area	4
Overview of Study	4
Description of Study Area.....	8
Hydrologic Processes and Framework	10
Hydrologic Processes	10
Local Hydrologic Framework	12
Climate	12
Geology.....	15
Ground Water	24
Surface Water	26
Regional Ground-Water Framework.....	35
Water Resources	36
Ground-Water Resources	36
Characteristics of Major Aquifers.....	36
Overview of Other Aquifers	55
Ground-Water Levels.....	55
Temporal Trends.....	56
Comparisons between Madison and Minnelusa Aquifers	57
Comparisons for Other Aquifers	58
Responses to Climatic Conditions	59
Ground-Water Quality.....	59
Background.....	59
General Characteristics for Major Aquifers.....	63
General Characteristics for Minor Aquifers.....	70
Susceptibility to Contamination	71
Ground-Water Quality Relative to Water Use	72
Surface-Water Resources	72
Streamflow Characteristics	72
Streamflow Variability	73
Annual Yield Characteristics	75
Surface-Water Quality.....	80
Standards and Criteria	80
General Characteristics	82
Human Influences on Water Quality.....	86
Surface-Water Quality Relative to Water Use	92
Hydrologic Budgets	94
Methods for Estimating Basin Yield and Recharge	94
Ground-Water Budgets	95
Surface-Water Budgets	100
Combined Ground-Water and Surface-Water Budget.....	100
Madison and Minnelusa Flow System.....	102
Flowpaths	102
Springs.....	108
Future Information Needs.....	113
References	114
Definition of Terms	118

Figures

1.	Map showing area of investigation for the Black Hills Hydrology Study	4
2.	Map showing data-collection network for the Black Hills Hydrology Study	6
3.	Graph showing population growth, by county, for incorporated and unincorporated areas	8
4.	Photographs of Calamity Peak near Custer and large-scale mines	8
5.	Map showing distribution of 1990 land use in the Black Hills area	9
6.	Schematic diagram illustrating hydrologic processes	10
7.	Schematic diagram showing (A) porosity and permeability; and (B) aquifers and confining beds	11
8.	Photograph of development of the Lime Creek observation well	11
9.	Map showing monthly precipitation distribution for October 1995	12
10.	Map showing distribution of average annual precipitation for the Black Hills area, water years 1950-98	13
11.	Boxplots showing distribution of annual precipitation for the study area and counties within the study area, water years 1931-98	13
12.	Boxplots and pie chart showing distribution of monthly precipitation and average annual precipitation	14
13.	Graph showing mean monthly precipitation for the study area and selected counties, water years 1931-98	14
14.	Graphs showing long-term trends in precipitation for the Black Hills area, water years 1931-98	14
15.	Stratigraphic column for the Black Hills	16
16.	Photograph of folds and fractures in Precambrian rock near Rochford	16
17.	Schematic diagrams and photographs showing (A) anticline and syncline, (B) monocline, (C) fault, and (D) dome	17
18.	Photograph of Bear Butte	17
19.	Map showing distribution of hydrogeologic units	18
20.	Geologic cross section A-A'	19
21-29.	Photographs of:	
21.	Towering cliff of the Deadwood Formation	19
22.	The Madison Limestone	20
23.	Large cave openings in the Madison Limestone at Jewel Cave	20
24.	The Minnelusa Formation	21
25.	Collapse breccia and a breccia pipe in the Minnelusa Formation	21
26.	The Minnekahta Limestone	22
27.	Red cliffs of the Spearfish Formation	22
28.	Massive gypsum and a sinkhole in the Spearfish Formation	22
29.	The Inyan Kara Group	23
30.	Schematic diagram showing simplified hydrologic setting of the Black Hills area	24
31.	Photographs of cave lakes	25
32.	Photograph of Cox Lake	26
33.	Photograph of the Pierre Shale	26
34.	Map showing hydrogeologic settings for the Black Hills area	27
35.	Photographs of headwater springflow along Beaver Creek and Cold Springs Creek	28
36.	Photograph of headwater springflow along Rhoads Fork	29
37.	Schematic diagram showing various spring types found in the limestone headwater area	29
38.	Schematic diagram illustrating interactions between ground water and surface water in the combined loss zone and artesian spring settings	30
39-43.	Photographs of:	
39.	Downstream progression of channel conditions along Grace Coolidge Creek	31
40.	Ash bars and large deltas of fine-grained sediment following the Galena Fire	32
41.	Cascade Springs	33
42.	Artesian springflow along Sand Creek and the Redwater River	33
43.	Pactola Reservoir	34
44.	Maps showing approximate extent of rocks containing regional aquifers in the Northern Great Plains area	34
45.	Map showing general direction of ground-water flow in regional aquifers within Paleozoic rock units	35
46.	Photograph of fractured and weathered Precambrian rocks	36
47.	Boxplots showing distribution of well yields from selected aquifers	37
48-52.	Maps showing depth to top of:	
48.	Deadwood Formation	38
49.	Madison Limestone	39
50.	Minnelusa Formation	40
51.	Minnekahta Limestone	41
52.	Inyan Kara Group	42
53-57.	Maps showing generalized thickness of:	
53.	Deadwood Formation	43
54.	Madison Limestone and Englewood Formation	44
55.	Minnelusa Formation	45
56.	Minnekahta Limestone	46
57.	Inyan Kara Group	47
58-62.	Maps showing potentiometric surface of:	
58.	Deadwood aquifer	48
59.	Madison aquifer and locations of major artesian springs	49
60.	Minnelusa aquifer and locations of major artesian springs	50
61.	Minnekahta aquifer	51
62.	Inyan Kara aquifer	52
63.	Map showing saturated thickness of the Madison aquifer	53
64.	Map showing saturated thickness of the Minnelusa aquifer	54
65.	Map showing location of observation wells for which hydrographs are presented	55

Figures—Continued

66-70.	Hydrographs illustrating:	
66.	Temporal trends in ground-water levels	56
67.	General similarities in water levels for some colocated Madison/Minnelusa wells with confined conditions	57
68.	Large hydraulic separation for colocated Madison/Minnelusa wells with unconfined conditions	57
69.	Generally separated water levels for some colocated Madison/Minnelusa wells	58
70.	Colocated Minnelusa/Minnekahta and Deadwood/Madison wells	58
71-77.	Maps showing:	
71.	Water temperature in the Madison aquifer	63
72.	Specific conductance in the Madison aquifer	64
73.	Specific conductance in the Minnelusa aquifer	65
74.	Specific conductance in the Inyan Kara aquifer	66
75.	Hardness in the Inyan Kara aquifer	67
76.	Sulfate concentrations in the Minnelusa aquifer	68
77.	Radon concentrations in the Deadwood aquifer	69
78.	Boxplots of concentrations of nitrite plus nitrate for selected aquifers	70
79.	Photographs of potential sources of nitrogen in ground water	71
80.	Graphs showing duration curves of daily mean streamflow	73
81.	Graphs showing variations in mean monthly streamflow for basins representative of hydrogeologic settings	74
82.	Map showing basin yields for selected streamflow-gaging stations	75
83.	Map showing comparison between surface-drainage areas and contributing ground-water areas for streamflow-gaging stations in Limestone Plateau area	76
84.	Schematic diagram illustrating recharge and streamflow characteristics for selected outcrop types	77
85.	Map showing generalized average annual yield efficiency, water years 1950-98	78
86.	Map showing estimated annual yield potential for the Black Hills area, water years 1950-98	79
87.	Graph showing relations between dissolved solids and specific conductance by hydrogeologic setting	82
88.	Graph showing relations between specific conductance and streamflow for a selected site within each hydrogeologic setting	83
89.	Diagrams of median concentrations of common ions by hydrogeologic setting	83
90.	Map showing median sulfate concentrations in surface water	84
91.	Map showing median uranium concentrations in surface water	85
92.	Photographs of activities that can impact surface-water quality	86
93.	Map showing maximum selenium concentrations in surface water	87
94.	Graph showing downstream progression of pH for selected streams influenced by acid-mine drainage	88
95.	Photographs of an abandoned mine, acid-mine drainage, and a bog-iron area	89
96.	Graph showing changes in sulfate and sodium concentrations at Bear Butte Creek near Deadwood	89
97.	Graph showing comparison of dissolved copper concentrations to hardness-adjusted chronic and acute aquatic criteria for Bear Butte Creek near Deadwood	89
98.	Map showing maximum arsenic concentrations in surface water	90
99.	Graph showing nitrite plus nitrate concentrations in Annie Creek near Lead, 1988-97	91
100.	Boxplots of concentrations of dissolved nitrite plus nitrate by hydrogeologic setting, with Annie Creek separated from other crystalline core sites	91
101.	Boxplots of concentrations of dissolved nitrite plus nitrate within the Rapid Creek Basin	92
102.	Pie chart showing evapotranspiration, runoff, and precipitation recharge as percentages of annual precipitation	94
103.	Schematic showing components considered for ground-water budgets	95
104.	Photograph of headwater springflow in the Limestone Plateau area	96
105.	Photograph of artesian springflow at Evans Plunge	96
106.	Pie charts showing percentages of average annual budget components for bedrock aquifers for water years 1950-98	97
107.	Pie charts showing percentages of average annual budget components for the Madison and Minnelusa aquifers in South Dakota and Wyoming for water years 1950-98	98
108.	Pie chart showing percentages of water use from the Madison and Minnelusa aquifers, by category, for South Dakota counties in the Black Hills area for water years 1987-96	99
109.	Graph showing annual recharge to the Madison and Minnelusa aquifers, in the Black Hills of South Dakota and Wyoming, water years 1931-98	99
110.	Photographs of the Cheyenne and Belle Fourche Rivers	100
111.	Schematic diagram showing average hydrologic budget components for the study area, water years 1950-98	101
112.	Schematic diagram showing generalized average streamflow relative to surface geology and depletions, water years 1950-98	101
113.	Schematic diagram showing fractionation of stable oxygen isotopes	102
114.	Map showing generalized flowpaths in the Madison aquifer in the Black Hills area of South Dakota and Wyoming	103
115.	Graph showing estimated tritium concentrations in precipitation for the Black Hills area and decay curves for selected years	104
116.	Boxplots of tritium concentrations for selected ground-water and surface-water samples collected during 1990-98 in the Black Hills area	104
117.	Map showing tritium occurrence for selected sample sites in the Black Hills area	105
118.	Map showing concentrations of $\delta^{18}\text{O}$ in Madison and Minnelusa aquifers in the Rapid City area	106
119.	Photographs of dye testing along Boxelder Creek	107
120.	Graph showing long-term streamflow and precipitation trends for gaging station 06409000, Castle Creek above Deerfield Reservoir	108
121.	Graph showing long-term streamflow trends for gaging station 06402000, Fall River at Hot Springs	109
122.	Photograph of red sediment at Cascade Springs	110
123.	Schematic diagrams illustrating the development and abandonment of an artesian spring at the Mammoth Site of Hot Springs	111

Tables

1. List of individuals involved with the Black Hills Hydrology Study steering committee	5
2. List of U.S. Geological Survey reports published as part of the Black Hills Hydrology Study	7
3. Geologic history of the Black Hills area	15
4. Summary of loss thresholds from Black Hills streams to bedrock aquifers.....	31
5. Summary of the characteristics of major aquifers in the study area.....	36
6. Water-quality criteria, standards, or recommended limits for selected properties and constituents	60
7. Surface-water-quality standards for selected physical properties and constituents	81
8. Estimates of average precipitation, precipitation recharge, runoff, total yield, and evapotranspiration for the study area, water years 1950-98	94
9. Recharge factors and outcrop areas for bedrock aquifers.....	95
10. Average ground-water budgets for bedrock aquifers, water years 1950-98	96
11. Detailed average hydrologic budgets for the Madison and Minnelusa aquifers, water years 1950-98	99
12. Average surface-water budgets for study area, water years 1950-98	100
13. Selected hydraulic and chemical information for large artesian springs	109

Conversion Factors and Vertical Datum

Multiply	By	To obtain
acre	4,047	square meter
acre	0.4047	hectare
acre-foot	1,233	cubic meter
acre-foot	0.001233	cubic hectometer
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
gallon per minute	0.06309	liter per second
inch	2.54	centimeter
inch	25.4	millimeter
inch per year	25.4	millimeter per year
mile	1.609	kilometer
square mile	259.0	hectare
square mile	2.590	square kilometer
ton per day	0.9072	metric ton per day
ton per day	0.9072	megagram per day

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

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$$

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: Water year is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends. Thus, the water year ending September 30, 1998, is called the “1998 water year.”

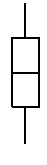
In the text, the first occurrence of terms included in the “Definition of terms” section are in boldface type.

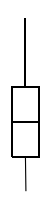
Other Abbreviations, Acronyms, and Symbols Used

mg/L	milligrams per liter
µg/L	micrograms per liter
mL	milliliters
µS/cm	microsiemens per centimeter at 25 degrees Celsius
pCi/L	picocuries per liter
‰	per mil
TU	tritium units
<	less than
>	greater than
≥	greater than or equal to
≈	approximately equal to
δ ¹⁸ O	isotopic ratio of oxygen-18 (¹⁸ O) to oxygen-16 (¹⁶ O)

DENR	South Dakota Department of Environment and Natural Resources
GIS	Geographic information system
GWSI	Ground Water Site Inventory database
USEPA	U.S. Environmental Protection Agency
MCL	Maximum Contaminant Level
MSL	Mean sea level
SMCL	Secondary Maximum Contaminant Level
USGS	U.S. Geological Survey

Boxplots are a useful and concise graphical display for summarizing the distribution of a data set. Two different types of boxplots are used in this report. In both types, the center of the data (known as the median) is shown as the center line of the box. The variation or spread of the data (known as the interquartile range) is shown by the box height.

	<ul style="list-style-type: none"> • Maximum 90th percentile 75th percentile Median 25th percentile 10th percentile ◦ Minimum 	<p>The first type is a truncated boxplot, and is used for all boxplots that do not show water-quality data. In the truncated boxplot, the whiskers are drawn only to the 90th and 10th percentiles of the data set. Thus, values included in largest 10 percent and the smallest 10 percent of the data are not shown. The maximum and minimum values for the data set are shown.</p>
---	--	---

	<ul style="list-style-type: none"> ◦ Outlier data value more than 3 times the interquartile range outside the quartile × Outlier data value less than or equal to 3 and more than 1.5 times the interquartile range outside the quartile Data value less than or equal to 1.5 times the interquartile range outside the quartile 75th percentile Median 25th percentile Data value less than or equal to 1.5 times the interquartile range outside the quartile 	<p>The second type is a standard boxplot, and is used for all boxplots that show water-quality data. In the standard boxplot, the whiskers are drawn only to the last data value that is within 1.5 times the interquartile range (height of the box). Values outside 1.5 times the interquartile range are called "outliers." For water-quality data, these outliers are of interest when comparing to water-quality standards and general distribution of extreme values.</p>
---	--	---

- ♣ Spring
- ▾ Water table