WATER RESOURCES OF MINNEHAHA COUNTY, SOUTH DAKOTA

By Richard J. Lindgren and Colin A. Niehus

U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
acre-foot per square mile (acre-ft/mi^2)	476.1	cubic meter per square kilometer
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
gallon	3.785	liter
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Temperature can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by the following equations:

$$°F = 9/5\ (°C) + 32$$
$$°C = 5/9\ (°F-32)$$

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

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ABSTRACT

The water resources of Minnehaha County occur as surface water in streams and lakes and as ground water in glacial and bedrock aquifers. The major surface-water sources are the Big Sioux River and its intermittent tributaries. Lakes in Minnehaha County are: (1) Small, less than 500 acres in areal extent, (2) shallow, less than 15 feet deep, and (3) restricted to the western one-third of the county. The predominant chemical constituents in water from the Big Sioux River near Dell Rapids; Big Sioux River at North Cliff Avenue, at Sioux Falls; Skunk Creek at Sioux Falls; and Split Rock Creek at Corson are calcium, sulfate, and bicarbonate. Dissolved-solids concentration of water from streams and lakes varies inversely with the volume of streamflow and with lake levels.

Large amounts of ground water may be obtained from nine major glacial and two major bedrock aquifers in Minnehaha County. The glacial aquifers are composed primarily of unconsolidated sand and gravel deposited as outwash from a glacier and contain about 725,000 acre-feet of water in storage. The Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, Brandon, and Colton aquifers are predominantly shallow, water-table aquifers with average cumulative thicknesses ranging from about 10 to 20 feet for the Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, and Colton aquifers to about 35 feet for the Brandon aquifer. Estimated maximum well yields are about 1,000 gallons per minute for the Big Sioux and Skunk Creek aquifers and about 500 gallons per minute for the Pipestone Creek, Beaver Creek, Brandon, and Colton aquifers. The predominant chemical constituents in water from the Big Sioux and Skunk Creek aquifers are calcium, sulfate, and bicarbonate; from the Colton aquifer are calcium, magnesium, and sulfate; and from the Pipestone Creek, Beaver Creek, and Brandon aquifers are calcium and bicarbonate.

The Wall Lake, Howard, and Valley Springs aquifers are buried, confined aquifers overlaid by 19 to 265 feet of till; the average cumulative thicknesses of these aquifers are about 33, 28, and 15 feet, respectively. Estimated maximum well yields are about 500 gallons per minute for the Wall Lake and Howard aquifers and about 200 gallons per minute for the Valley Springs aquifer. The predominant chemical constituents in water from the Wall Lake aquifer are calcium and sulfate and in water from the Howard and Valley Springs aquifers are calcium and bicarbonate. Average dissolved-solids concentrations ranged from 443 to 1,100 milligrams per liter, and average hardness concentrations (as calcium carbonate) ranged from 310 to 810 milligrams per liter in the major glacial aquifers.

Two major bedrock aquifers, the Split Rock Creek and Sioux Quartzite aquifers, are important sources of water in Minnehaha County. The Split Rock Creek aquifer contains about 855,000 acre-feet of water in storage with an average cumulative thickness of sand and gravel layers of about 48 feet. The Sioux Quartzite is a locally well-fractured and jointed crystalline rock that is used extensively as a source of water in western and east-central Minnehaha County. The amount of water contained in storage in the Sioux Quartzite aquifer is unknown because the depth and development of the fracture system is not well known. Estimated maximum well yields are about 500 gallons per minute for the Split Rock Creek aquifer and about 150 gallons per minute for the Sioux Quartzite aquifer. The predominant chemical constituents in water from the Split Rock Creek and Sioux Quartzite aquifers are calcium and sulfate. Average dissolved-solids concentrations were 890 and 1,030 milligrams per liter, and average hardness concentrations (as calcium carbonate) were 620 and 820 milligrams per liter in the Split Rock Creek and Sioux Quartzite aquifers, respectively.

Water use from glacial and bedrock aquifers in Minnehaha County in 1985 was estimated to be 5.87 billion gallons. Ninety-four percent of the water used was withdrawn from glacial aquifers and 6 percent of the water used was withdrawn from bedrock aquifers. Eighty-five percent of the water withdrawn from the aquifers in Minnehaha County was used for municipal purposes.

INTRODUCTION

In October 1982, the South Dakota Geological Survey and the U.S. Geological Survey began a 7-year cooperative study (Big Sioux basin hydrologic study) to evaluate the geology and water resources of five counties in the Big Sioux River basin in South Dakota. The five counties included in the Big Sioux basin hydrologic study are Codington, Grant, Minnehaha, Lincoln, and Union. This report encompasses Minnehaha County (fig. 1).

Minnehaha County has an area of 815 mi^2 and is located almost entirely in the Coteau des Prairies physiographic area, a plateau-like highland occupying the area between the Minnesota River-Red River lowland and the James River lowland (Flint, 1955). The extreme southwestern corner of Minnehaha County is located in the James River lowland. Land-surface altitudes range from 1,270 ft above sea level in the Big Sioux River flood plain in southeastern Minnehaha County to 1,820 ft in northwestern Minnehaha County.

Purpose and Scope

This report provides hydrogeologic information about the quantity and quality of available water supplies in Minnehaha County. Reliable and timely data and analyses are needed for water-resources evaluation and for future water development and planning for agriculture, rural water systems, and municipalities. This report describes the quantity and availability of surface and ground water, the hydrologic system as it affects water availability, and the quality of surface and ground water. Emphasis was on studying ground water because the extent and yield of glacial and bedrock aquifers has not been previously reported.

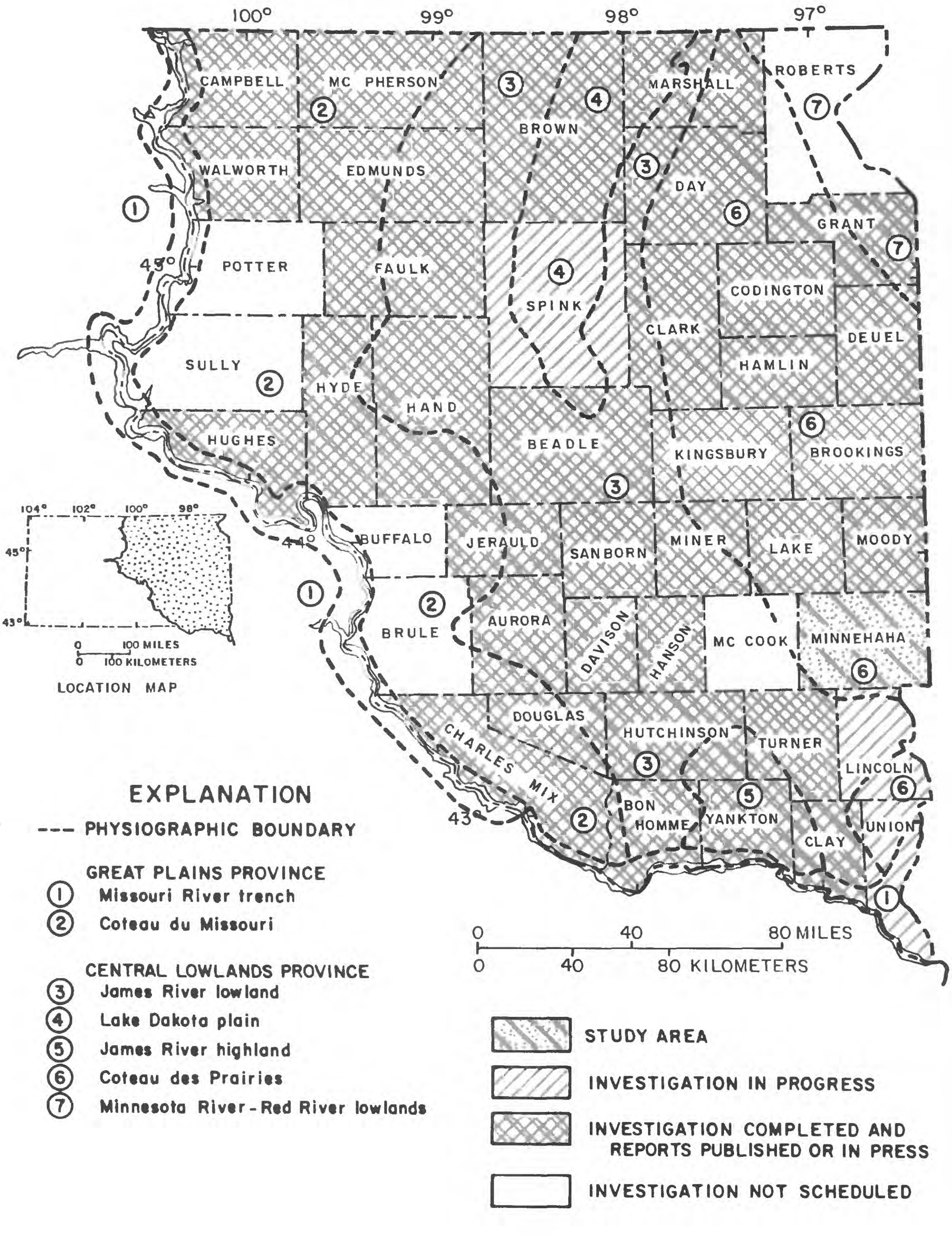


Figure 1.--Location of the study area, status of county investigations, and major physiographic divisions.

Methods of Investigation

Methods of investigation included analyses of surface-water streamflow records and chemical analyses of surface-water samples, a well inventory, analysis of pre-existing drillers' logs, test drilling and observation-well installation, measurement of static water levels, and chemical analyses of water samples collected from ground-water wells. Geohydrologic data from more than 350 test holes and 200 observation wells were analyzed to determine the areal extent, thickness, and yield of the glacial and bedrock aquifers. Water samples were collected from 34 ground-water wells during the study for detailed chemical analyses. The test hole, observation well, and water-quality sampling sites in Minnehaha County are shown in figures 2, 3, and 4. The test-hole sites shown include both holes drilled for this study (fig. 2) and other test holes drilled for previous studies (fig. 4). Wells, test holes, and sampling sites are numbered according to the Federal land survey system (fig. 5). Subsurface inflow and outflow to and from the study area were calculated by multiplying the hydraulic gradient by the transmissivity (hydraulic conductivity times thickness) by the aquifer length perpendicular to the direction of flow for each aquifer having a direction of flow predominantly perpendicular to the study area boundaries. Estimates of hydraulic conductivity were based on the lithology and particle size of the aquifer material. Hydraulic conductivity is the rate of flow of water transmitted through a porous medium of unit cross-sectional area under a unit hydraulic gradient at the prevailing kinematic viscosity. Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

Acknowledgments

The authors would like to acknowledge the residents and municipal officials for their cooperation in providing needed information on their water wells. Test-hole information provided by local drilling companies is also appreciated.

WATER RESOURCES

Water Budget

The average annual precipitation at Sioux Falls from 1951 to 1980 was 24.12 in. (U.S. National Oceanic and Atmospheric Administration, 1987). Seventy-five to 85 percent of the precipitation is returned to the atmosphere by evaporation and transpiration. From 5 to 10 percent of the average annual precipitation becomes streamflow; however, this quantity may vary from year to year because of climatic variations. Five to 20 percent of the precipitation percolates through the root zone to become ground water. In a given year, the water budget shows a change in ground-water storage that can be detected by, and calculated from, water-level changes in observation wells in the aquifers. The long-term (greater than 10 years) changes in storage are small, unless ground-water discharge to wells increases.

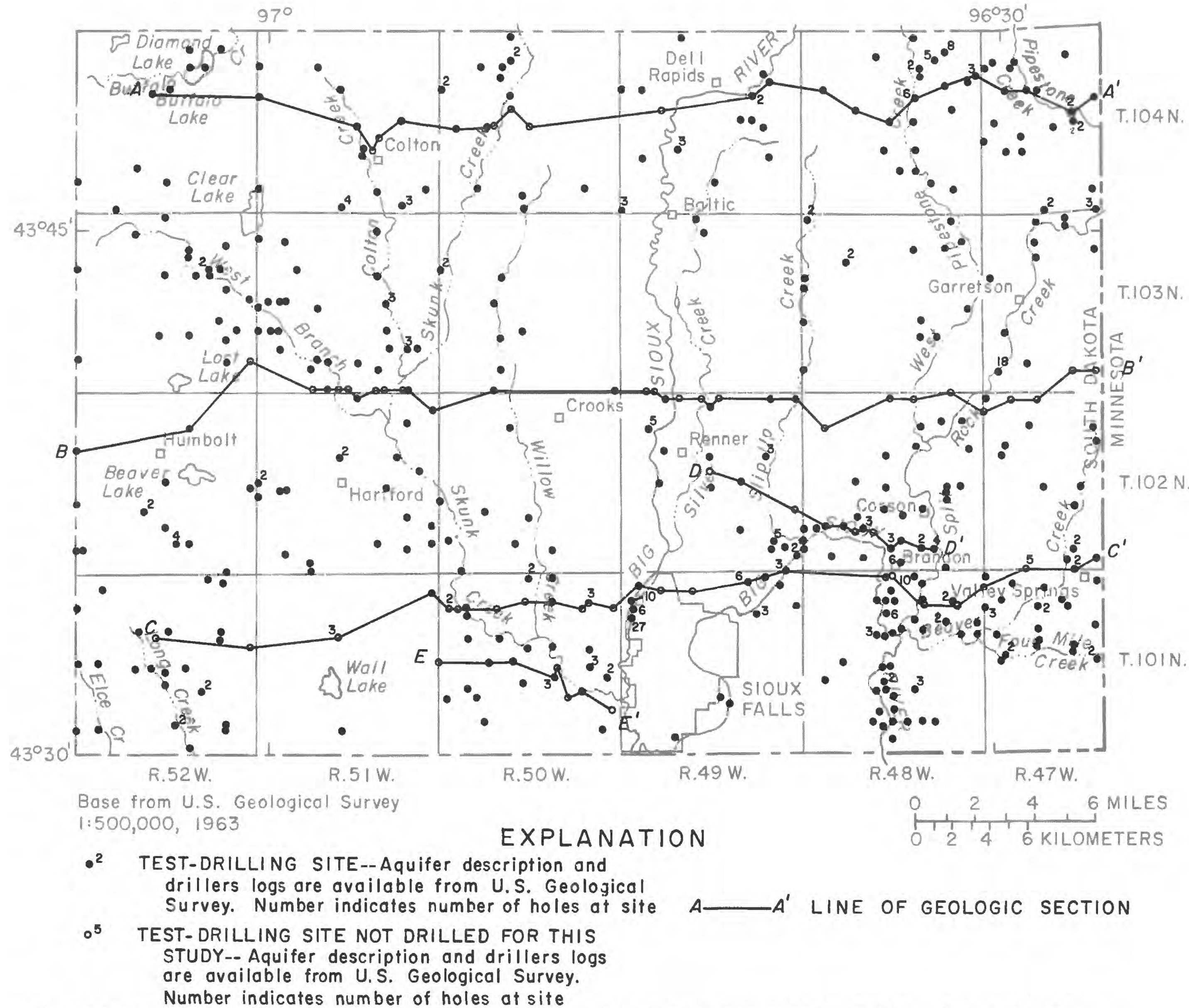
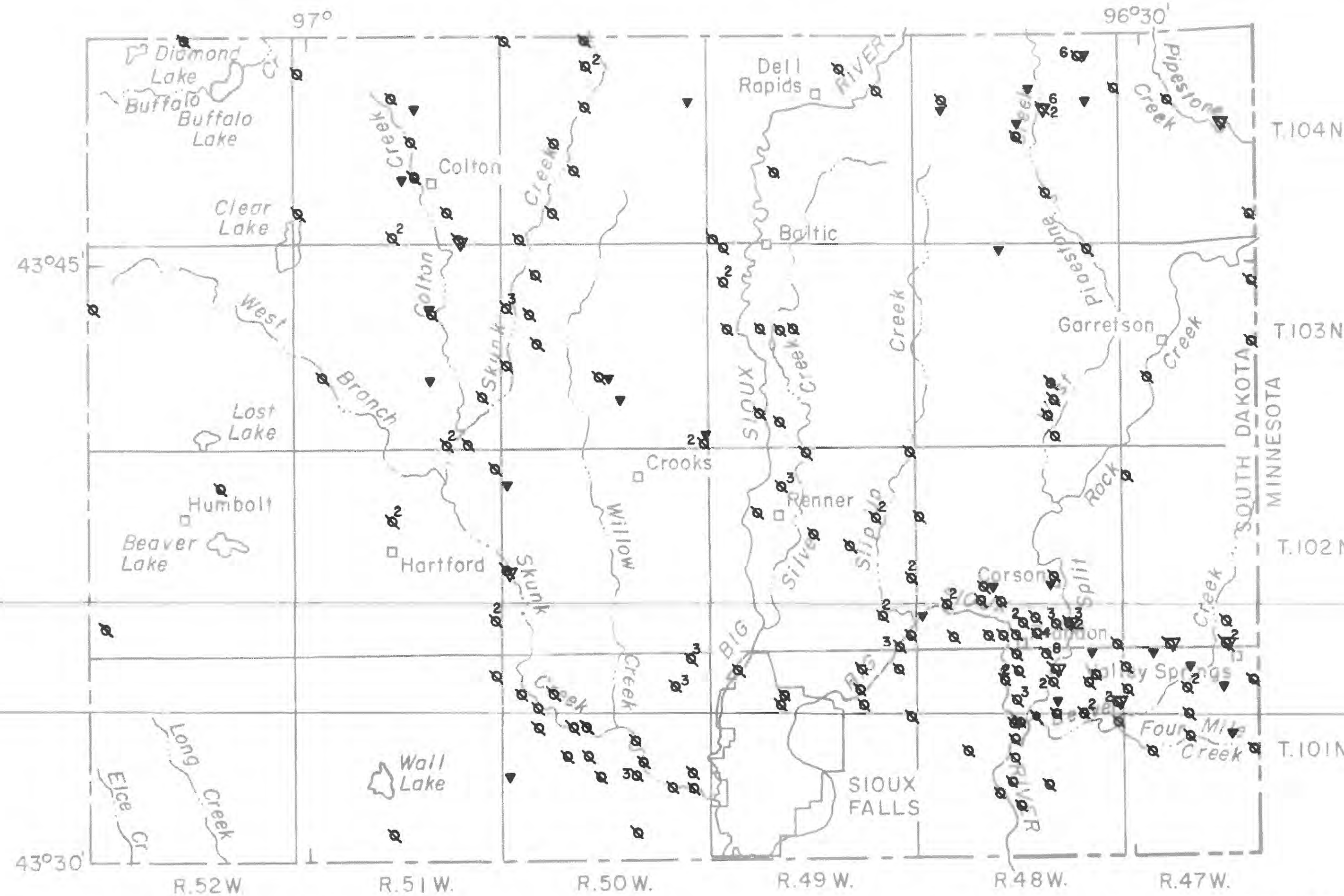


Figure 2.--Location of test-hole sites and geologic sections in Minnehaha County.



Base from U.S. Geological Survey
1:500,000, 1963

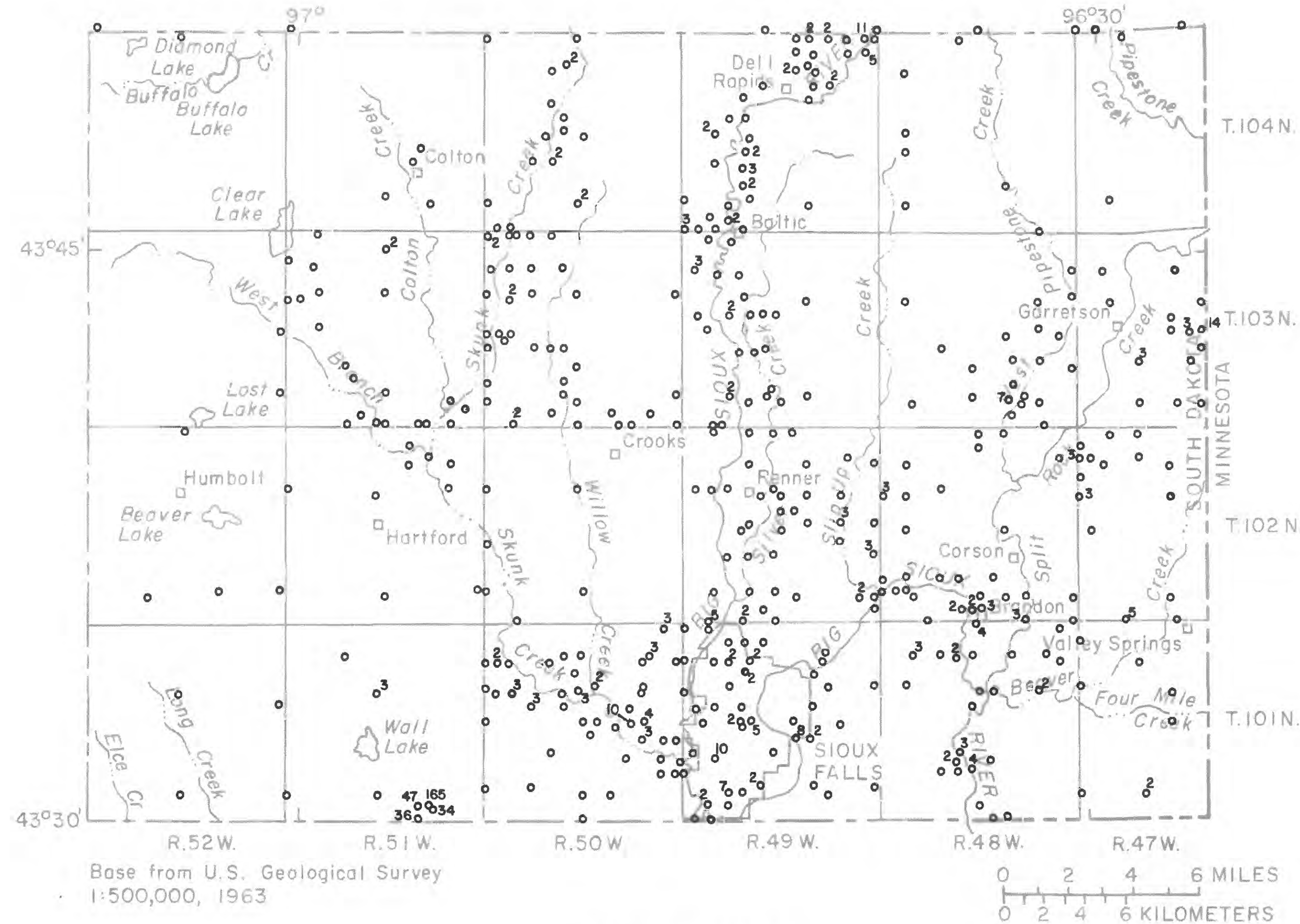
EXPLANATION

Ø² OBSERVATION-WELL SITE--Records of periodic water-level measurements are available from the U.S. Geological Survey. Number indicates number of wells at site

▼ WATER-QUALITY SAMPLE SITE--Complete chemical analyses obtained for this study are available from the U.S. Geological Survey

▼⁶₂ OBSERVATION-WELL AND WATER-QUALITY SAMPLE SITE--Upper number indicates number of observation wells at site. Lower number indicates number of water-quality wells at site

Figure 3.--Location of observation-well and ground-water-quality sampling sites in Minnehaha County.



EXPLANATION

o^2 TEST-DRILLING SITE--Aquifer description and drillers logs are available from U.S. Geological Survey. Number indicates number of wells or test holes at site

Figure 4.--Location of additional test-hole sites from other studies in Minnehaha County.

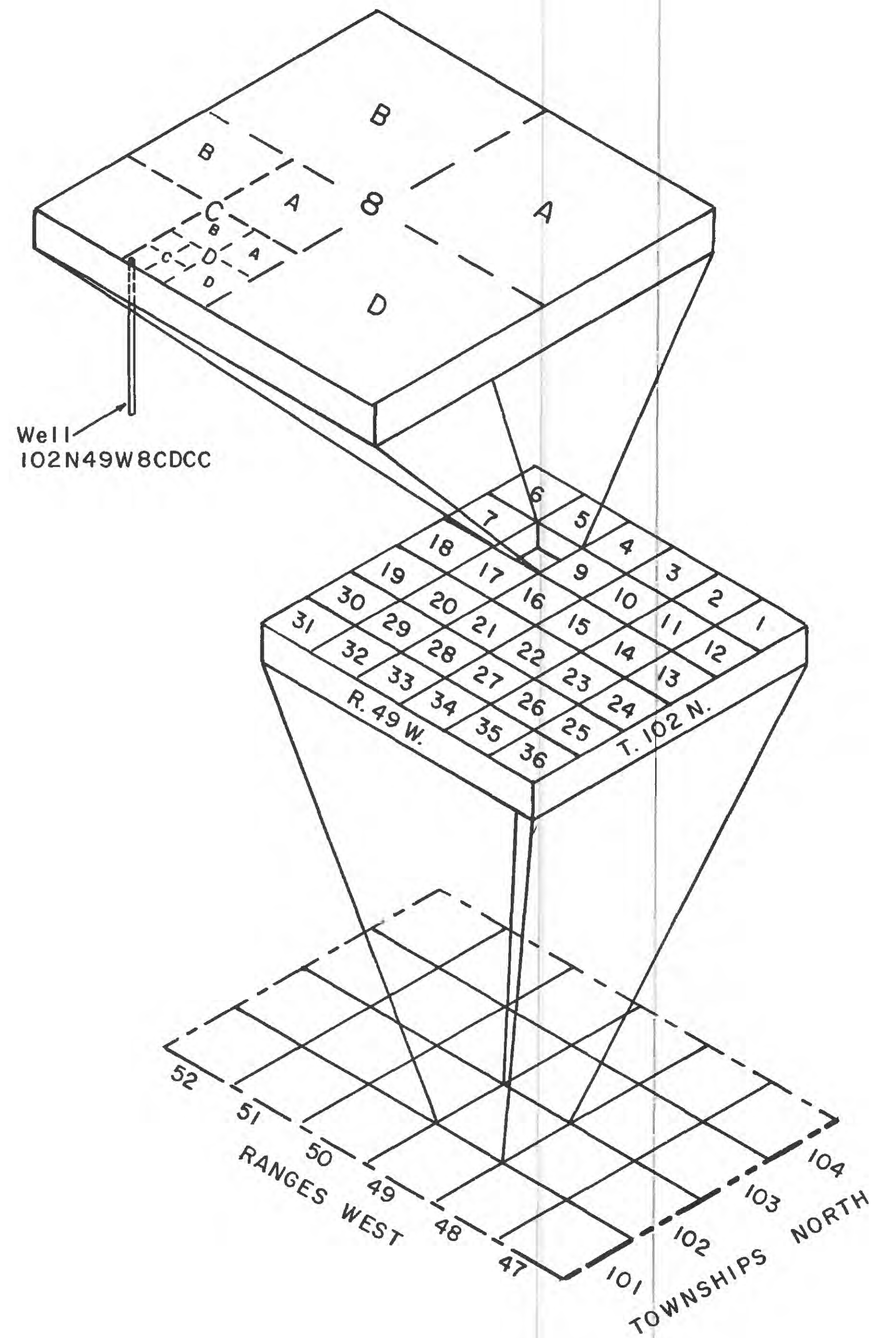


Figure 5.--Well-numbering diagram. The well number consists of township followed by "N," range followed by "W," and section number, followed by a maximum of four uppercase letters that indicate, respectively, the 160-, 40-, 10-, and 2½-acre tract in which the well is located. These letters are assigned in a counterclockwise direction beginning with "A" in the northeast quarter. A serial number following the last letter is used to distinguish between wells in the same 2½-acre tract.

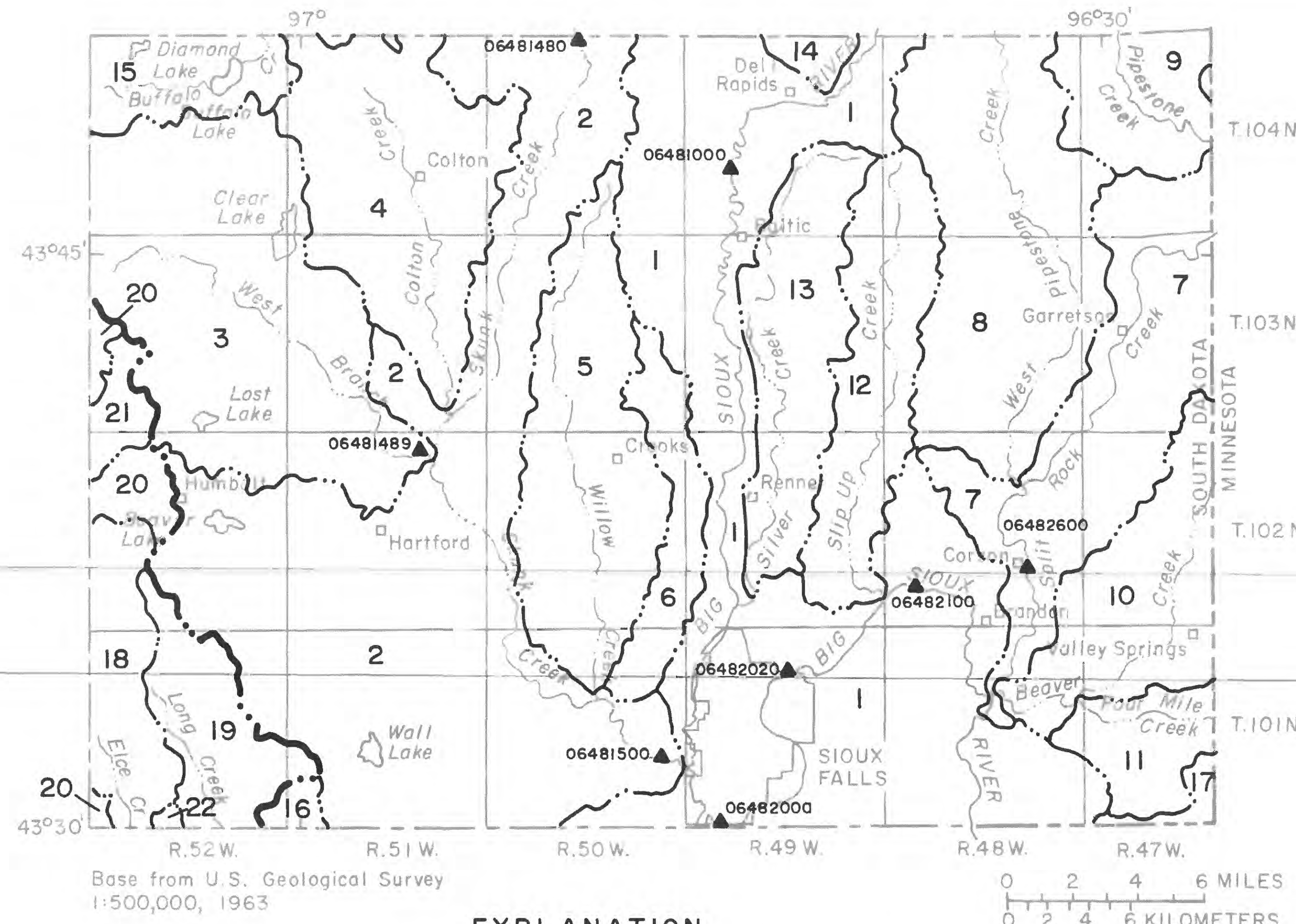
Surface Water

Drainage Basins

The Big Sioux River, which flows from north to south through the center of Minnehaha County, and its tributaries drain 94 percent of the land surface area of the county (fig. 6 and table 1). Tributaries of the Vermillion River drain the remaining 6 percent in southwestern and west-central Minnehaha County. The Big Sioux River valley was originally cut by glacial meltwater flowing southward confined between the two glacier lobes that flanked the Coteau des Prairies. The major tributaries of the Big Sioux River in Minnehaha County are Skunk and Split Rock Creeks. In the eastern two-thirds of the county the drainage system is well developed while in the western one-third the natural drainage is poorly defined.

Table 1.--Areas of drainage basins in Minnehaha County

Drainage basin number (fig. 6)	Drainage basin name	Drainage area in Minnehaha County (square miles)
	BIG SIOUX RIVER BASIN	
1	Big Sioux River (direct)	145.9
2	Skunk Creek	157.3
3	West Branch Skunk Creek	77.2
4	Colton Creek	49.2
5	Willow Creek	47.1
6	Unnamed Skunk Creek tributary	15.3
7	Split Rock Creek	54.3
8	West Pipestone Creek	66.7
9	Pipestone Creek	18.7
10	Beaver Creek east	32.5
11	Four Mile Creek	13.3
12	Slip-up Creek	32.5
13	Silver Creek	32.0
14	Unnamed Big Sioux River tributary	3.2
15	Buffalo Creek	15.0
16	Beaver Creek west	3.0
17	Blood Run Creek	2.2
	VERMILLION RIVER BASIN	
18	Elce Creek	18.0
19	Long Creek	18.4
20	East Fork Vermillion River	7.1
21	Lost Lake	5.6
22	Camp Creek	.5
	Total	815



EXPLANATION

BOUNDARIES
Drainage basin
Drainage subbasin

10 DRAINAGE BASIN DESIGNATION IN TABLE 1

06482000 STREAMFLOW-GAGING STATION--Number is station identification

Figure 6.--Drainage basins in Minnehaha County.

Streamflow

A summary of streamflow data for streamflow-gaging stations operated by the U.S. Geological Survey in Minnehaha County is presented in table 2. The average annual discharge for the period of record is 328 ft^3/s for the Big Sioux River near Dell Rapids; 547 ft^3/s for the Big Sioux River at North Cliff Avenue, at Sioux Falls; 70.7 ft^3/s for Skunk Creek at Sioux Falls; and 103 ft^3/s for Split Rock Creek at Corson. Annual runoff depends on the amount of annual precipitation, the intensity of individual storm events throughout the year, and the size and physical characteristics of the drainage basin. Seasonal variations in streamflow reflect seasonal variations in precipitation. Streamflow is greatest during the spring and early summer because of snowmelt and precipitation or following a heavy rainfall and least during the late summer and winter months because of low precipitation and high evapotranspiration rates during the summer. Most of the streams in Minnehaha County experience periods of no flow during the year, including the Big Sioux River during some dry years.

The average annual runoff for the period of record is 1.48 in. (79 acre-ft/mi^2) for the Big Sioux River near Dell Rapids; 1.99 in. (106 acre-ft/mi^2) for the Big Sioux River at North Cliff Avenue, at Sioux Falls; 1.57 in. (83 acre-ft/mi^2) for Skunk Creek at Sioux Falls; and 3.02 in. (161 acre-ft/mi^2) for Split Rock Creek at Corson. The generally higher average annual runoffs per square mile for the Big Sioux River basin as compared to those for the James River near Scotland, about 40 mi southwest of the study area (19 acre-ft/mi^2), and the Vermillion River near Wakonda, about 35 mi south of the study area (54 acre-ft/mi^2), for example, are caused by slightly higher precipitation, a better developed drainage system, and greater contributions to streamflow from ground-water storage.

The monthly percentage of no-flow days for the Big Sioux River near Dell Rapids, Skunk Creek at Sioux Falls, and Split Rock Creek at Corson is shown in figure 7. The percentage of no-flow days is relatively small (less than 7 percent) for all three sites because of ground-water discharge to the streams. The Big Sioux River at North Cliff Avenue, at Sioux Falls had no days with zero flow for the period of record because streamflow was augmented by treated water from the city of Sioux Falls that flowed into the river upstream from the gage.

Flow Duration

Flow-duration curves (fig. 8) show the percentage of time that a given discharge is equaled or exceeded. The average discharge for the Big Sioux River near Dell Rapids and for the Big Sioux River at North Cliff Avenue, at Sioux Falls is exceeded only about 20 to 25 percent of the time. The average discharge for Skunk Creek at Sioux Falls and for Split Rock Creek at Corson is exceeded only about 15 percent of the time. The average discharge is exceeded a low percentage of the time (as compared to rivers in more humid climates) because much of the flow occurs during the high runoffs associated with spring snowmelt and spring and early summer thunderstorms. A daily mean discharge of 737 ft^3/s for the Big Sioux River near Dell Rapids, 1,500 ft^3/s for the Big Sioux River at Sioux Falls, 127 ft^3/s for Skunk Creek at Sioux Falls, and 165 ft^3/s for Split Rock Creek at Corson may be expected to be exceeded only 10 percent of the time. Streamflow in the Big Sioux River at North Cliff Avenue at Sioux Falls was augmented by treated water from the city of Sioux Falls that flowed into the river upstream from the gage at a rate of 14.1 ft^3/s from 1970 to 1979 (Koch, 1982), probably causing the flatter slope in the duration curve at discharges from about 13 to 20 ft^3/s. In general, a less steep slope for the daily flow-duration curve indicates less variable flow and more dependable low flows.

Table 2.--Summary of streamflow data for gaging stations in and near Minnehaha County

[--, average not computed because of short period of record]

Station number	Station name	Drainage area (square miles)	Period of record	Discharge for period of record (cubic feet per second) Maximum	Minimum	Average
06481000	Big Sioux River near Dell Rapids	4,483 (1,479 non-contributing)	1948-88	41,300 Apr. 9, 1969	0 Aug. 25 to Oct. 17, 1976	328
06481480	Skunk Creek near Chester	53.2	1984-87	1,060 Sept. 21, 1986	0.42 Jan. 2, 1986	--
06481489	West Branch Skunk Creek near Hartford	80.5	1984-86	740 Mar. 16, 1985	0.09 Feb. 9, 1985	--
06481500	Skunk Creek at Sioux Falls	622 (8.51 non-contributing)	1948-88	29,400 June 17, 1957	0 at times in many years	70.7
06482020	Big Sioux River at North Cliff Avenue, at Sioux Falls	5,216 (1,487 non-contributing)	[1]1962-71 1971-88	21,600 June 22, 1984 [2]40,700 Apr. 10, 1969	0.81 Feb. 13, 1982	[3]547
06482100	Big Sioux River near Brandon	5,810 (1,970 non-contributing)	1959-72	36,800 Apr. 10, 1969	5.0 Jan. 7, 1968	361
06482610	Split Rock Creek at Corson	464	[1]1951-65 1965-88	17,800 Apr. 8, 1969 [2]19,300 June 17, 1957	0 at times some years	[4]103

[1]Gage heights and discharge measurements only in files of U.S. Army Corps of Engineers.
[2]Extreme outside U.S. Geological Survey period of record.
[3]Average computed for 1971-88 only.
[4]Average computed for 1965-88 only.

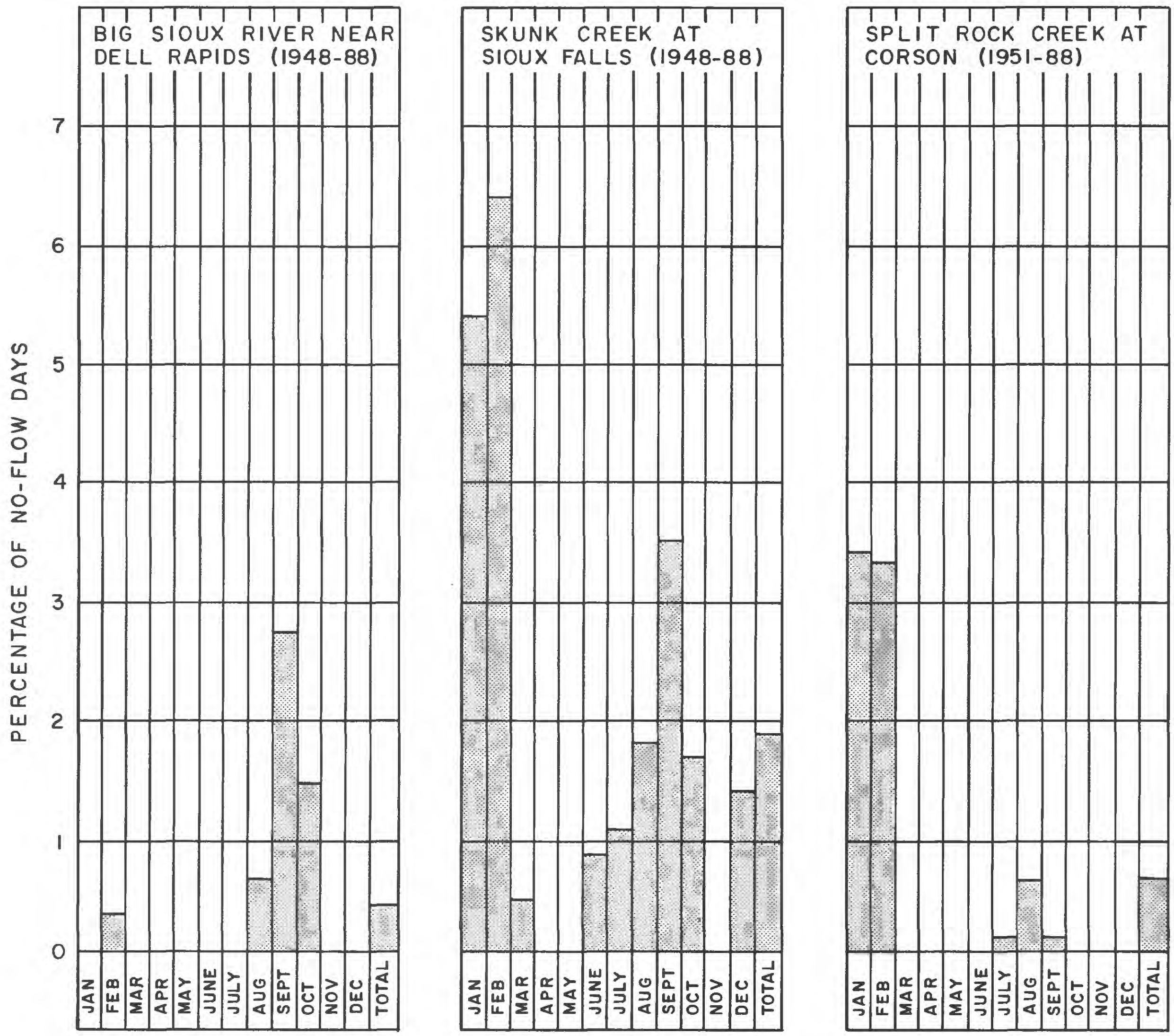


Figure 7.--Percentage of no-flow days for the Big Sioux River near Dell Rapids, Skunk Creek at Sioux Falls, and Split Rock Creek at Corson.

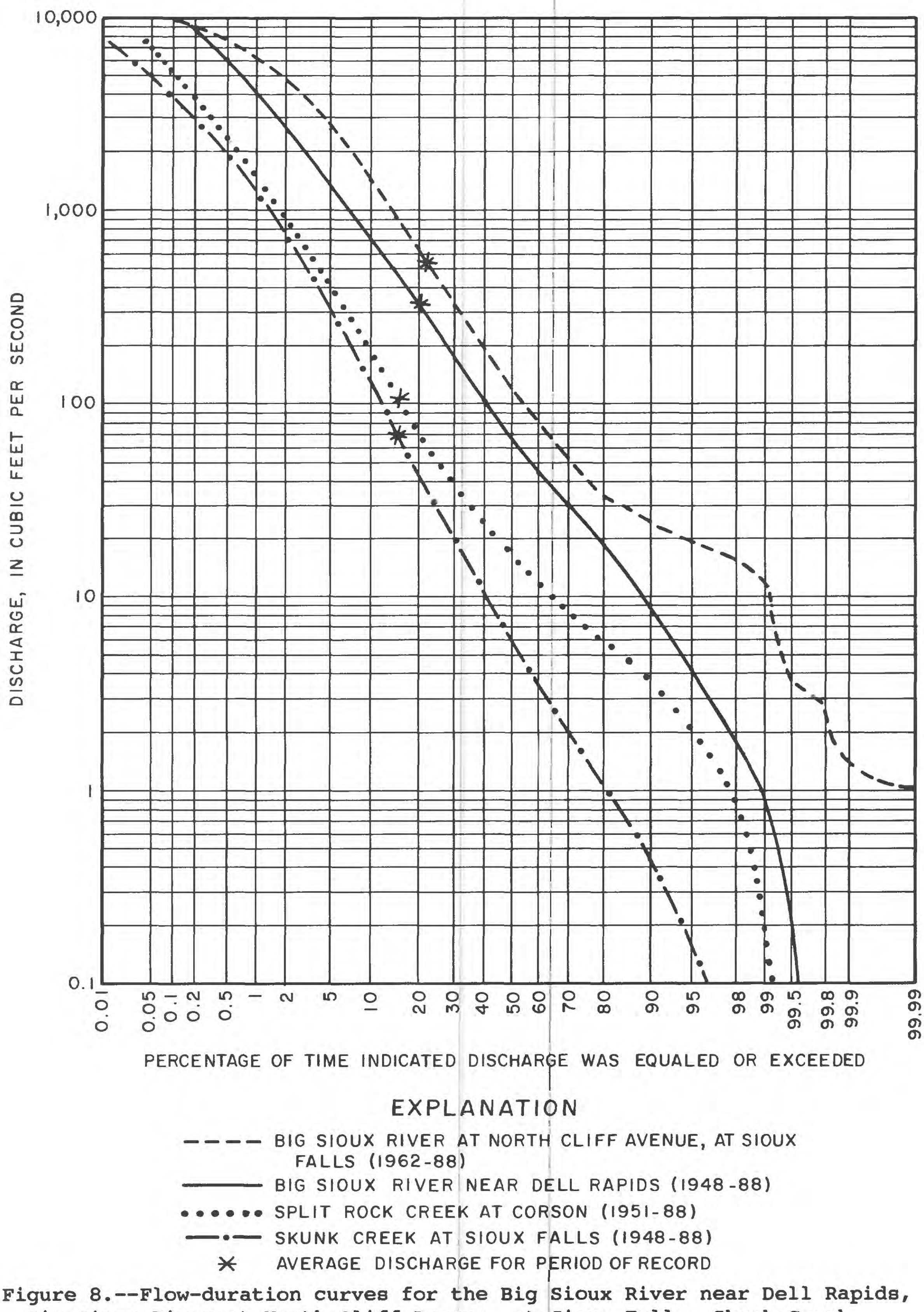


Figure 8.--Flow-duration curves for the Big Sioux River near Dell Rapids, Big Sioux River at North Cliff Avenue, at Sioux Falls, Skunk Creek at Sioux Falls, and Split Rock Creek at Corson.

Flood Frequency

Periodic flooding of stream valley bottoms during the spring because of snowmelt runoff and precipitation is common in Minnehaha County. Flooding along the main channel of the Big Sioux River, especially in the southern part of the county, may be increased by tributary inflow. The two major tributaries to the Big Sioux River in Minnehaha County, Skunk and Split Rock Creeks, both enter the main stem near Sioux Falls. Statistical flood-frequency analyses of peak flows for selected streams in Minnehaha County are presented in table 3.

Lakes

Available information about lakes in Minnehaha County is summarized in table 4. In the western one-third of Minnehaha County, the drainage system is poorly developed with many small lakes, sloughs, and marshy areas. The lakes in Minnehaha County are restricted to this part of the county and all have surface areas of less than 500 acres and average depths of less than 10 ft. Clear Lake has the largest surface area (472 acres) and Beaver Lake has the largest storage capacity (2,560 acre-ft). Wall Lake is located about 10 mi west of Sioux Falls and is used extensively for recreation.

In addition to bodies of water large enough to be classified as lakes, Minnehaha County has numerous small depressions and marshy areas which are used for stock watering and wildlife propagation. Dugouts and stock dams are used to collect surface-water runoff and are used for stock watering purposes. During periods of extended drought most of the small depressions and dugouts are dry.

Chemical Quality

Dissolved-solids concentrations of water from streams generally varies inversely with the volume of streamflow. Dissolved-solids concentrations generally are lowest in the spring when streamflow is at a maximum because of spring snowmelt and precipitation. Specific conductance can be used to approximate dissolved-solids content in the water because specific conductance is related to the number and specific chemical types of ions in solution. The relation between specific conductance and discharge for the Big Sioux River, Skunk Creek, and Split Rock Creek, is shown in figure 9.

Chemical analyses for the Big Sioux River, Skunk Creek, and Split Rock Creek are shown in table 5. The predominant chemical constituents in water from the Big Sioux River near Dell Rapids, Big Sioux River at North Cliff Avenue, at Sioux Falls, Skunk Creek at Sioux Falls, and Split Rock Creek at Corson are calcium, sulfate, and bicarbonate. Sodium and chloride also are present in significant quantities in water from the Big Sioux River at North Cliff Avenue, at Sioux Falls. The high sodium and chloride concentrations observed in water from the Big Sioux River at North Cliff Avenue, at Sioux Falls probably are caused by treated sewage from the city of Sioux Falls which flows into the river upstream from the gage. The natural water-quality characteristics of the Big Sioux River probably are better illustrated by water from the Big Sioux River near Dell Rapids where the chemical composition of the river water is not significantly affected by the discharge of treated sewage. The average concentration of dissolved solids (sum of constituents) was 560 mg/L (milligrams per liter) for the period of record for the Big Sioux River near Dell Rapids, 570 mg/L for Skunk Creek at Sioux Falls, and 360 mg/L for Split Rock Creek at Corson. The average hardness

Table 3.--Magnitude and probability of instantaneous annual peak flows at streamflow-gaging stations and other sites in and near Minnehaha County

[Method used to make estimates: A, U.S. Water Resources Council (1981); B, Becker (1980)]

Station number and/or name	Number of drainage basin (fig. 6)	Contributing drainage area (square miles)	Method	Discharge, in cubic feet per second, for indicated recurrence intervals, in years					
				2	5	10	25	50	100
06481000 Big Sioux River nr Dell Rapids	[1]1	3,004	A	3,180	8,640	14,000	22,900	31,100	40,400
06481489 West Branch Skunk Creek nr Hartford	[1]3	80.5	B	110	345	645	1,240	1,910	2,720
06481500 Skunk Creek at Sioux Falls	[1]2	613.5	A	1,410	4,470	7,870	14,000	20,100	27,500
06482020 Big Sioux River at North Cliff Avenue, at Sioux Falls	[1]1	3,729	A	3,890	8,220	12,000	17,900	23,100	28,900
06482610 Split Rock Creek at Corson	[1]7	464	A	2,480	5,700	8,750	13,800	18,400	23,800
Colton Creek at confluence with Skunk Creek	[1]4	49.8	B	75	230	420	800	1,200	1,690
Willow Creek at confluence with Skunk Creek	5	47.1	B	75	235	430	810	1,220	1,720
Silver Creek at confluence with Big Sioux River	13	32.0	B	55	160	285	535	790	1,100
Slip-up Creek at confluence with Big Sioux River	12	32.5	B	80	240	440	825	1,240	1,740
West Pipestone Creek at confluence with Split Rock Creek	[1]8	86.8	B	110	345	640	1,250	1,920	2,730

[1]Only a portion of the total drainage area is in Minnehaha County.

Table 4.--Summary of lake data

Lake name	Location	Depth (feet) Maximum	Depth (feet) Average	Surface area[1] (acres)	Storage capacity (acre-feet)	Classification for beneficial use[2]
Wall Lake	101N51W21,28	14	7	220	1,540	5,7,8,9
Lost Lake	103N52W34	7	5	120	600	--
Clear Lake	103N51W6 103N52W1 104N51W31 104N52W36	7	3.5	472	1,652	--
Beaver Lake	102N52W14,15	11	8	320	2,560	--
Diamond Lake	104N52W5	8	6	256	1,536	--

[1]Oral communication from South Dakota Department of Game, Fish, and Parks.

[2]The following classifications for beneficial use are from South Dakota Water Quality Standards effective Feb. 19, 1981:

5 - Warm water semipermanent fish life propagation water
7 - Immersion recreation waters
8 - Limited contact recreation waters
9 - Wildlife propagation and stock watering waters

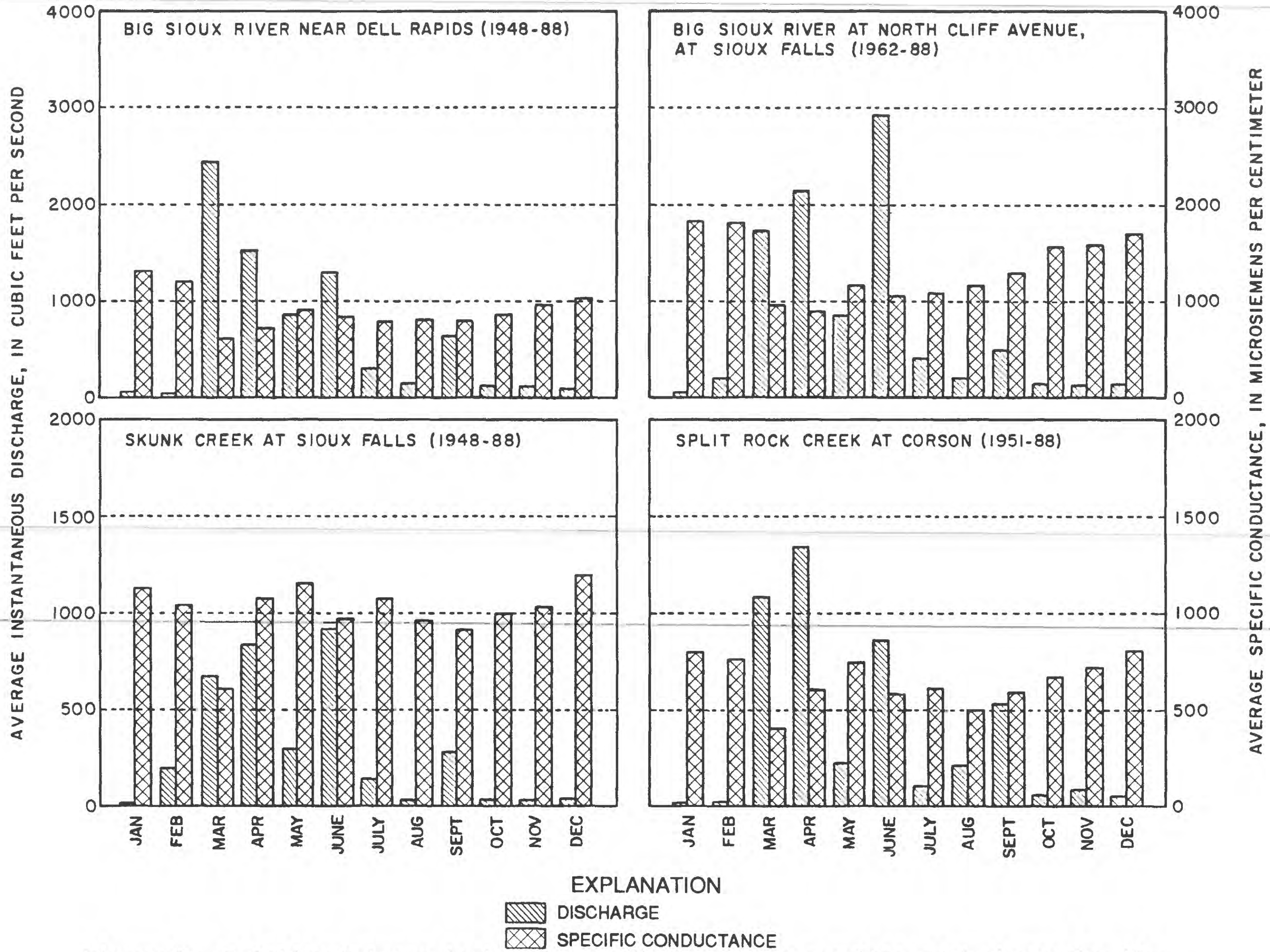


Figure 9.--Relation between instantaneous discharge and specific conductance for the Big Sioux River at Dell Rapids, Big Sioux River at North Cliff Avenue, at Sioux Falls, Skunk Creek at Sioux Falls, and Split Rock Creek at Corson.

concentration, as $CaCO_3$ (calcium carbonate), was 400 mg/L for the Big Sioux River near Dell Rapids, 440 mg/L for Skunk Creek at Sioux Falls, and 280 mg/L for Split Rock Creek at Corson. The higher average dissolved-solids and hardness concentrations for the Big Sioux River near Dell Rapids and Skunk Creek at Sioux Falls as compared to Split Rock Creek at Corson probably are caused by a greater contribution to streamflow from ground water.

Lakes exhibit seasonal variations in water-quality parameters. Dissolved-solids concentrations generally decrease in the spring as the volume of lake water increases from snowmelt runoff and precipitation and increase during the summer as lake levels decline because of evapotranspiration losses.

Table 5.--Summary of chemical analyses for the Big Sioux River, Skunk Creek, and Split Rock Creek

[Analyses by U.S. Geological Survey Laboratory. Units reported in milligrams per liter (mg/L) except as indicated. μg/L, micrograms per liter; μS/cm, microsiemens per centimeter at 25 °Celsius]

	06481000 Big Sioux River near Dell Rapids			
Constituent	Number of analyses	Maximum	Minimum	Mean
Specific conductance, field (μS/cm)	336	1,900	151	847
pH, field (pH units)	291	9.1	6.6	7.9
Hardness, total, as $CaCO_3$	233	940	58	400
Hardness, noncarbonate, as $CaCO_3$	233	540	0	170
Alkalinity, field, as $CaCO_3$	187	460	51	220
Dissolved solids, sum of constituents	210	1,400	77	560
Dissolved solids, residue at 180°C	198	1,540	109	600
Dissolved calcium	232	210	15	88
Dissolved magnesium	232	100	5	43
Dissolved sodium	232	180	2.1	35
Dissolved potassium	231	26	3	8
Bicarbonate, field	176	560	61	270
Dissolved sulfate	233	690	12	209
Dissolved chloride	232	260	0	27
Dissolved fluoride	214	1.5	.1	.3
Dissolved silica	210	28	.1	11
Dissolved nitrogen, nitrate, as N	76	19	0	4.9
Dissolved boron (μg/L)	214	780	30	140
Iron, total recoverable (μg/L)	67	4,800	0	770
Manganese, total recoverable (μg/L)	72	830	0	290

Table 5.--Summary of chemical analyses for the Big Sioux River, Skunk Creek, and Split Rock Creek--Continued

	06482020 Big Sioux River at North Cliff Avenue, at Sioux Falls			
Constituent	Number of analyses	Maximum	Minimum	Mean
Specific conductance, field ($\mu S/cm$)	242	3,200	108	1,290
pH, field (pH units)	166	8.9	6.6	7.8
Hardness, total, as $CaCO_3$	46	610	130	390
Hardness, noncarbonate, as $CaCO_3$	46	390	31	170
Alkalinity, field, as $CaCO_3$	43	390	74	220
Dissolved solids, sum of constituents	48	1,800	170	859
Dissolved solids, residue at 180°C	155	2,050	114	930
Dissolved calcium	46	150	32	88
Dissolved magnesium	46	60	11	42
Dissolved sodium	46	460	7.7	140
Dissolved potassium	46	29	8	13
Bicarbonate, field	37	470	90	270
Dissolved sulfate	46	400	42	237
Dissolved chloride	46	670	8.7	190
Dissolved fluoride	17	1.4	.3	.6
Dissolved silica	46	24	.9	14
Dissolved nitrogen, nitrate, as N	17	8.9	0	2.3
Dissolved boron ($\mu g/L$)	0	--	--	--
Iron, total recoverable ($\mu g/L$)	51	7,900	190	1,000
Manganese, total recoverable ($\mu g/L$)	55	890	160	380

Table 5.--Summary of chemical analyses for the Big Sioux River, Skunk Creek, and Split Rock Creek--Continued

Constituent	06481500 Skunk Creek at Sioux Falls			
	Number of analyses	Maximum	Minimum	Mean
Specific conductance, field ($\mu S/cm$)	164	1,540	148	960
pH, field (pH units)	43	8.4	6.5	7.8
Hardness, total, as $CaCO_3$	43	870	56	440
Hardness, noncarbonate, as $CaCO_3$	43	510	0	190
Alkalinity, field, as $CaCO_3$	39	360	83	240
Dissolved solids, sum of constituents	35	1,100	74	570
Dissolved solids, residue at 180°C	33	1,220	100	589
Dissolved calcium	43	170	16	94
Dissolved magnesium	43	110	3.9	49
Dissolved sodium	43	65	1.2	23
Dissolved potassium	43	18	6	10
Bicarbonate, field	43	450	57	280
Dissolved sulfate	43	540	12	234
Dissolved chloride	43	58	0	14
Dissolved fluoride	35	.5	.1	.3
Dissolved silica	35	25	.9	10
Dissolved nitrogen, nitrate, as N	31	8.9	0	2.4
Dissolved boron ($\mu g/L$)	40	160	20	80
Iron, total recoverable ($\mu g/L$)	14	150	10	60
Manganese, total recoverable ($\mu g/L$)	20	1,300	0	330

Table 5.--Summary of chemical analyses for the Big Sioux River, Skunk Creek, and Split Rock Creek--Continued

Constituent	06482610 Split Rock Creek at Corson			
	Number of analyses	Maximum	Minimum	Mean
Specific conductance, field ($\mu S/cm$)	134	980	180	612
pH, field (pH units)	12	8.6	7.4	8.1
Hardness, total, as $CaCO_3$	12	380	120	280
Hardness, noncarbonate, as $CaCO_3$	12	100	23	74
Alkalinity, field, as $CaCO_3$	12	280	95	200
Dissolved solids, sum of constituents	12	470	160	360
Dissolved solids, residue at 180°C	2	421	409	--
Dissolved calcium	12	86	29	59
Dissolved magnesium	12	40	11	32
Dissolved sodium	12	31	7.7	24
Dissolved potassium	12	9	4	5
Bicarbonate, field	12	340	120	240
Dissolved sulfate	12	120	27	91
Dissolved chloride	12	38	11	24
Dissolved fluoride	12	.6	.3	.4
Dissolved silica	12	7.8	.1	3.3
Dissolved nitrogen, nitrate, as N	2	.13	.04	--
Dissolved boron ($\mu g/L$)	9	130	60	90
Iron, total recoverable ($\mu g/L$)	1	650	650	--
Manganese, total recoverable ($\mu g/L$)	1	150	150	--

Ground-water Occurrence and Quality

Ground water in Minnehaha County may be obtained from nine major glacial aquifers and two major bedrock aquifers with an estimated 1.58 million acre-ft of water in storage, excluding the Sioux Quartzite aquifer (table 6). The amount of ground water in storage in the Sioux Quartzite aquifer is unknown because the depth and development of the fracture system is not well known. The glacial aquifers contain about 725,000 acre-ft of water in storage. The bedrock Split Rock Creek aquifer contains about 855,000 acre-ft of water in storage. The storage was calculated by multiplying the areal extent of each aquifer by the average thickness by an estimated porosity of 20 percent. Porosity is the percentage of a unit volume of aquifer material that is occupied by voids.

Average dissolved-solids concentrations ranged from 443 to 1,100 mg/L, and average hardness concentrations (as $CaCO_3$) ranged from 310 to 810 mg/L in the major glacial aquifers. Maximum hardness concentrations (as $CaCO_3$) were greater than 1,000 mg/L for the Skunk Creek, Colton, and Wall Lake aquifers and less than 1,000 mg/L for the rest of the major glacial aquifers. Average concentrations of dissolved solids were 890 and 1,030 mg/L, and average hardness concentrations (as $CaCO_3$) were 620 and 820 mg/L in the Split Rock Creek and Sioux Quartzite aquifers, respectively.

Suitability of water for irrigation from the glacial and bedrock aquifers was determined from the South Dakota irrigation-water diagram (Koch, 1983). The diagram is based on South Dakota irrigation-water standards, revised January 7, 1982, and shows the State of South Dakota's water-quality and soil-texture requirements for the issuance of an irrigation permit. Water from all the major aquifers in Minnehaha County has average specific conductances (adjusted for calcium, sulfate, and rainfall) less than 1,000 μS/cm (microsiemens per centimeter) and adjusted sodium-adsorption ratios less than 6. Water from each aquifer is therefore generally suitable for irrigation under all soil texture conditions, provided other conditions as defined by the State Conservation Commission are met.

Glacial Aquifers

Glacial aquifers, primarily unconsolidated sand and gravel deposited as outwash by meltwater from receding glaciers, underlie about 215 mi^2 (about 26 percent) of Minnehaha County. Outwash deposits can be at land surface or be buried by till or alluvium. Till is an unsorted, unstratified mixture of clay, silt, sand, gravel, and boulders deposited by a glacier. Till has a very low hydraulic conductivity and therefore is a poor source of water. Locally, however, the till can contain thin, discontinuous sand and gravel lenses that can yield as much as 5 gal/min to wells. Depths to the top of the aquifers range from land surface to 265 ft for the major glacial aquifers in Minnehaha County. The average cumulative thickness of sand and gravel ranges from about 10 to 35 ft.

The Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, Brandon, and Colton aquifers are predominantly shallow, water-table aquifers. Average cumulative thicknesses range from about 10 to 20 ft for the Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, and Colton aquifers to about 35 ft for the Brandon aquifer. The Wall Lake, Howard, and Valley Springs aquifers are buried, confined aquifers overlaid by from 19 to 265 ft of till. The average cumulative thicknesses of these aquifers are 33, 28, and 15 ft, respectively.

Table 6.--Summary of the hydrologic characteristics of major aquifers in Minnehaha County

[--, no data; >, greater than]

Aquifer name	Areal extent (square miles)	Maximum thickness (feet)	Average cumulative thickness (feet)	Range of depth below land surface (feet)	Average depth below land surface (feet)	Range of water level above (+) or below land surface (feet)	Artesian (A) and/or water table (WT) aquifer (predominantly)	Estimated volume of water in storage[1] (acre-feet)	Estimated maximum well yield (gallons per minute)
GLACIAL AQUIFERS									
Big Sioux	68	[2]71	22	0-82	10	2-42	WT	190,000	1,000
Skunk Creek	43	[2]84	21	0-93	9	2-86	WT	115,000	1,000
Pipestone Creek	19	>36	15	1-52	11	1-23	WT	35,000	500
Beaver Creek	11	49	17	0-118	22	6-29	WT	25,000	500
Brandon	6	[2]62	35	0-24	7	11-56	WT	25,000	500
Colton	8	26	12	1-57	20	4-18	WT	10,000	500
Wall Lake	58	88	33	19-205	106	9-156	A	245,040	500
Howard	15	63	28	123-265	202	5-49	A	55,000	500
Valley Springs	14	[2]26	15	93-207	131	20-147	A	25,000	200
Total								725,000	
BEDROCK AQUIFERS									
Split Rock Creek	139	[2]222	48	21-337	160	10-187	A	855,000	500
Sioux Quartzite	815	--	--	2-510	120	0-300	A	([3])	150

[1]Storage was estimated by multiplying average thickness times areal extent times an estimated porosity of 20 percent.
[2]Includes multiple layers.
[3]Storage unknown because the depth and development of the fracture system is not well known.

The Big Sioux aquifer is a continuation of the same-named aquifer in Moody County (Hansen, 1984). The Skunk Creek aquifer is a continuation of the North Skunk Creek aquifer in Moody County (Hansen, 1984). The Pipestone Creek aquifer is a continuation of the same-named aquifer in Moody County (Hansen, 1984).

Big Sioux Aquifer

The Big Sioux aquifer underlies about 68 mi^2 near the Big Sioux River in Minnehaha County (fig. 10). Most of the aquifer is under the flood plain of the Big Sioux River. Geologic sections of the aquifer are shown in figures 11, 12, 13, and 14, and hydrologic characteristics are given in table 6. In T. 101 N., R. 49 W. and T. 104 N., R. 49 W., Sioux Quartzite crops out at the surface in the Big Sioux River flood plain, and the aquifer is not present. This isolates the northern Big Sioux aquifer in T. 104 N., R. 49 W. from the southern Big Sioux aquifer. Depth to the top of the aquifer ranges from land surface in the Big Sioux River flood plain to 67 ft in northeastern T. 101 N., R. 50 W. and 82 ft near the eastern boundary of the aquifer in T. 102 N., R. 49 W., where the aquifer is overlaid by till. The average depth below land surface is about 10 ft. The maximum cumulative thickness is 71 ft and the average cumulative thickness is about 22 ft. The cumulative thickness ranges from 25 to 35 ft for most of the Big Sioux aquifer between Sioux Falls and the Sioux Quartzite outcrop in T. 104 N., R. 49 W. The cumulative thickness usually is less than 15 ft in T. 104 N., R. 49 W. (fig. 10), north of the Sioux Quartzite outcrop. The Big Sioux aquifer is composed of fine to coarse, poorly sorted sand and fine to coarse pebble gravel with thin (3- to 5-ft thick) interbedded clay and till layers in some areas. The aquifer is underlaid by: (1) Till, (2) siltstones and shales of the Split Rock Creek Formation in northern T. 101 N., R. 48 W., southern T. 102 N., R. 48 W., and southeastern T. 102 N., R. 49 W., and (3) Sioux Quartzite in northern T. 104 N., R. 49 W., northeastern T. 101 N., R. 49 W., and southern T. 101 N., R. 48 W. Properly constructed wells completed in the Big Sioux aquifer may yield as much as 1,000 gal/min where the thickness exceeds 25 ft.

Recharge to the Big Sioux aquifer is from: (1) Infiltration of precipitation in the flood plain of the Big Sioux River, (2) seepage from the Big Sioux River when river stage is higher than the potentiometric surface in the aquifer because of spring snowmelt or storm events, (3) the Skunk Creek aquifer, (4) the Beaver Creek aquifer, (5) the Brandon aquifer, (6) the Split Rock Creek aquifer in northern T. 101 N., R. 48 W., southern T. 102 N., R. 48 W., and southeastern T. 102 N., R. 49 W., (7) the Wall Lake aquifer in southwestern T. 101 N., R. 49 W., and (8) the Sioux Quartzite aquifer in northern T. 104 N. and southern T. 101 N., R. 48 W. Using a ground-water flow computer model, Koch (1982) determined the computer-simulated recharge to the Big Sioux aquifer between Dell Rapids and Sioux Falls under equilibrium (steady-state) conditions. Infiltration of precipitation constituted 53 percent (6.9 in/yr) of the total recharge to the aquifer, and seepage from the Big Sioux River constituted 47 percent of the total recharge. Recharge from the Big Sioux River occurs during spring snowmelt and storm event peak flows and by pumping wells that lower the aquifer head below the river head. Recharge to the Big Sioux aquifer from the Brandon aquifer is minor because the cross-sectional area at the juncture between the aquifers near the southern end of Split Rock Creek is very small. Subsurface inflow southward from Moody County is about 450 acre-ft/yr.

EXPLANATION

10(2) TEST HOLE--Number is thickness of sand and gravel, in feet. Number in parenthesis refers to number of layers of sand and gravel, if more than one layer is present. A plus (+) indicates thickness greater than shown

AQUIFER BOUNDARY

Figure 10.--Areal extent and thickness of the Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, Brandon, Colton, Slip Up Creek, and Four Mile Creek aquifers in Minnehaha County.

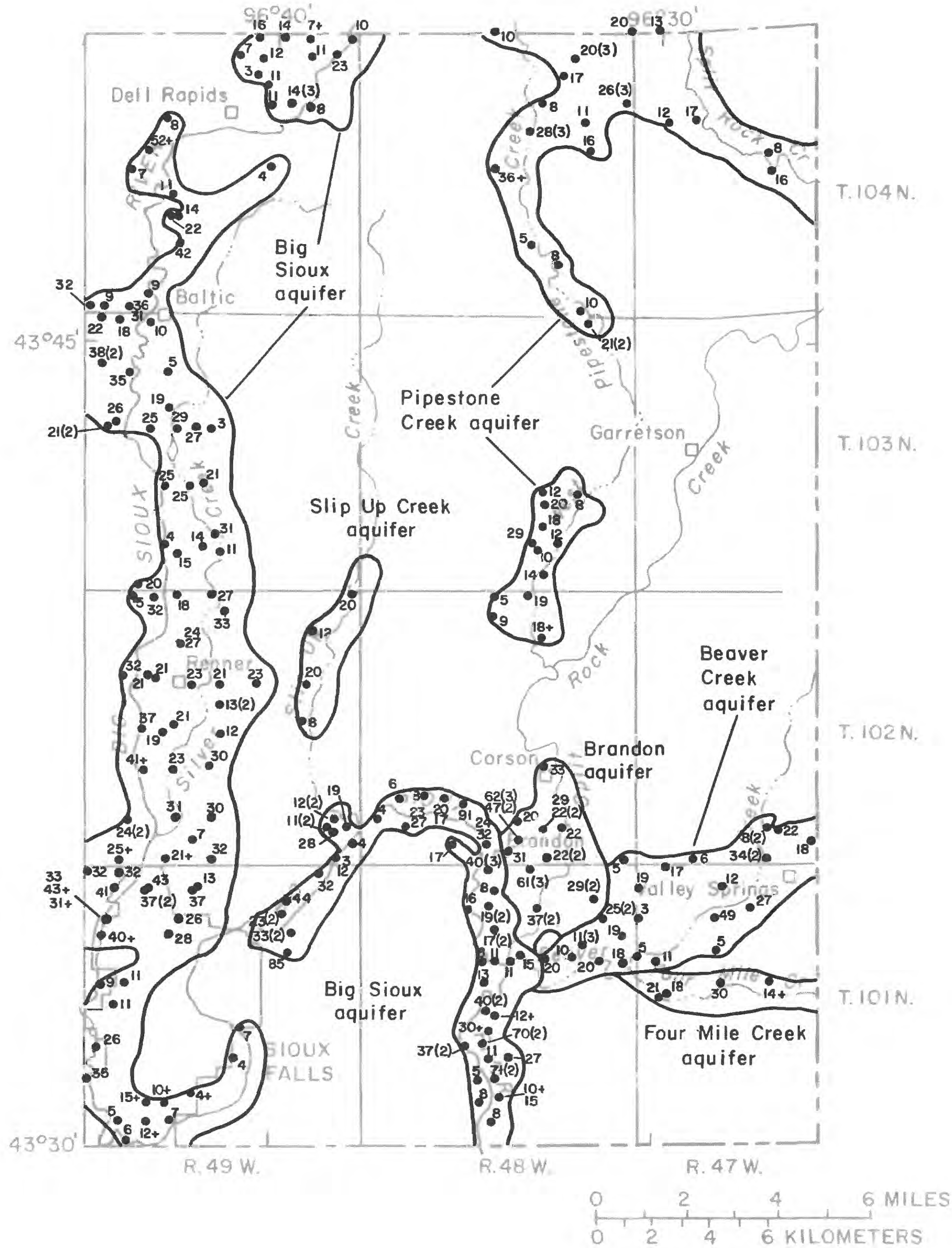


Figure 10.--Areal extent and thickness of the Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, Brandon, Colton, Slip Up Creek, and Four Mile Creek aquifers in Minnehaha County--Continued.

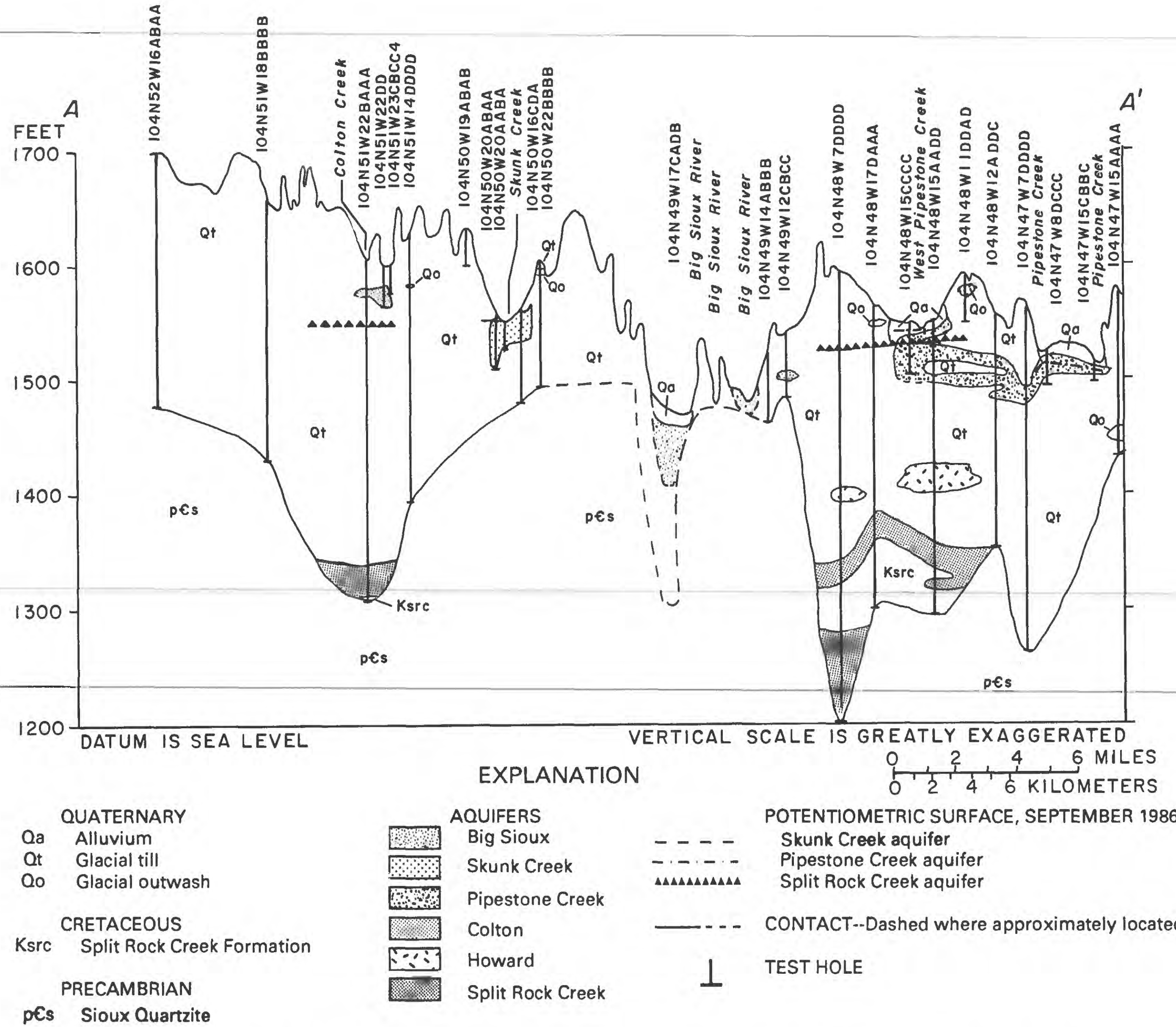


Figure 11.--Geologic section A-A' showing the Big Sioux, Skunk Creek, Pipestone Creek, Colton, Howard, Split Rock Creek, and Sioux Quartzite aquifers. (Section A-A' is shown in figure 2.)

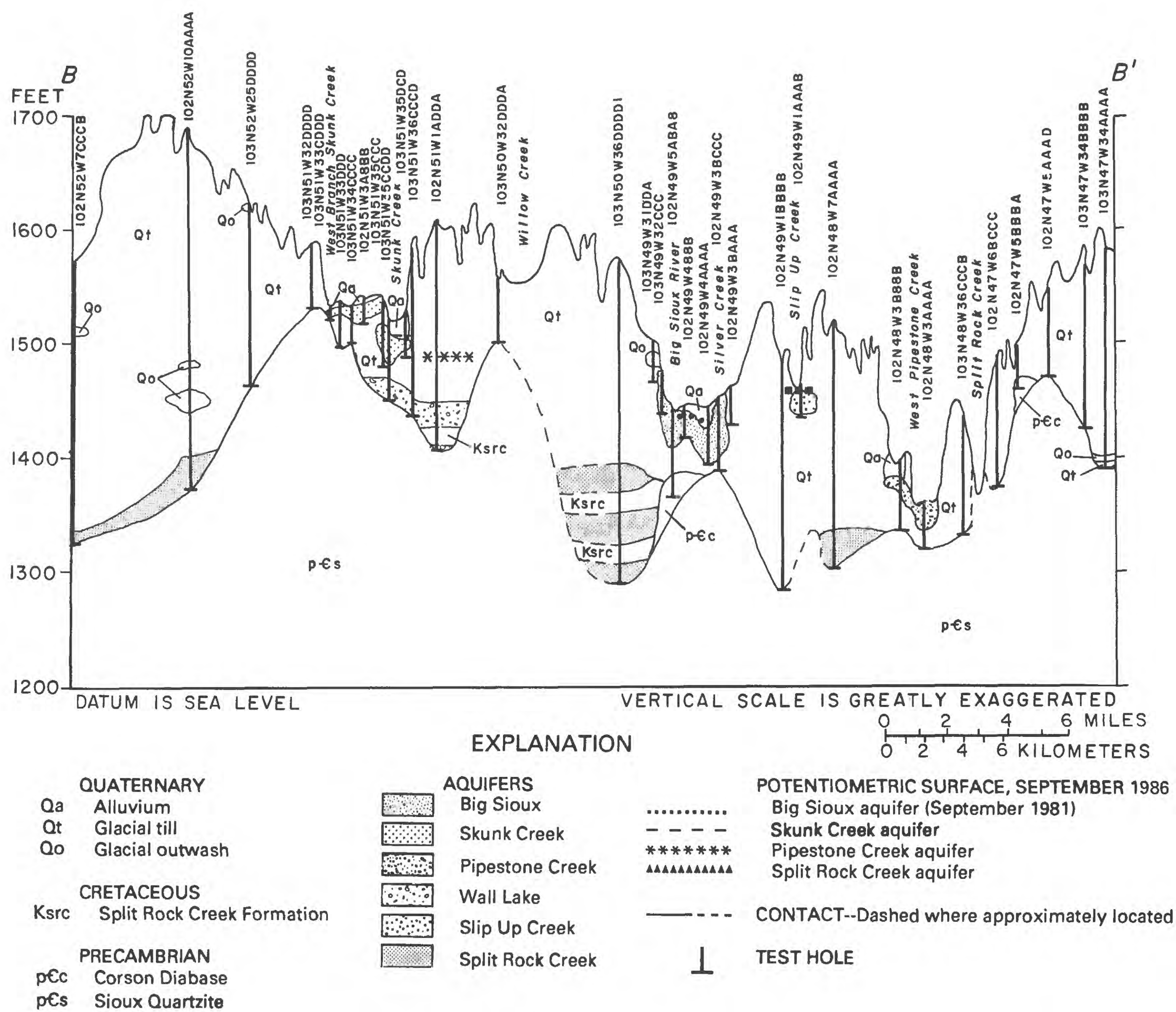


Figure 12.--Geologic section B-B' showing the Big Sioux, Skunk Creek, Pipestone Creek, Wall Lake, Slip Up Creek, Split Rock Creek, and Sioux Quartzite aquifers. (Section B-B' is shown in figure 2.)

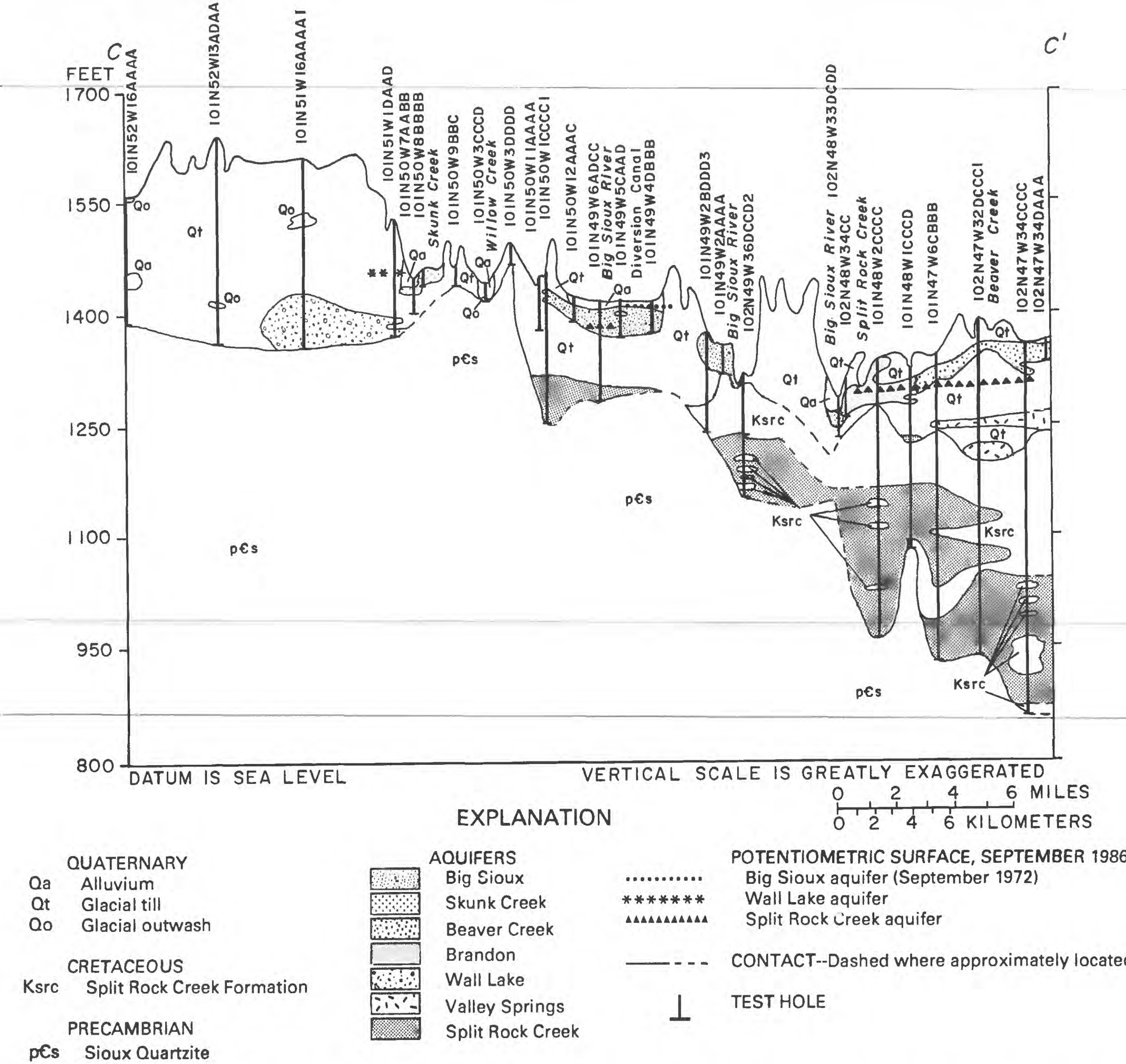


Figure 13.--Geologic section C-C' showing the Big Sioux, Skunk Creek, Beaver Creek, Brandon, Wall Lake, Valley Springs, Split Rock Creek, and Sioux Quartzite aquifers. (Section C-C' is shown in figure 2.)

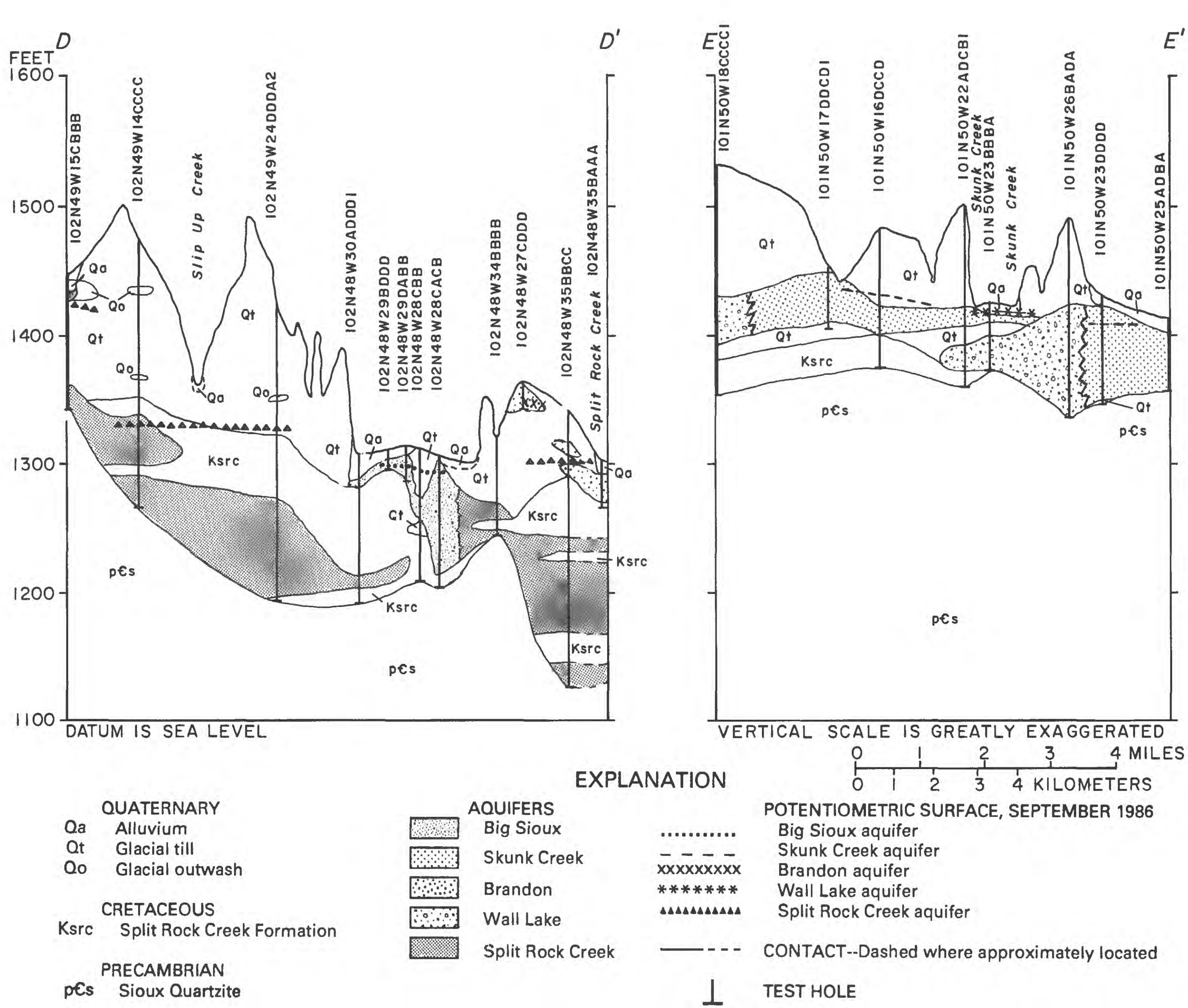
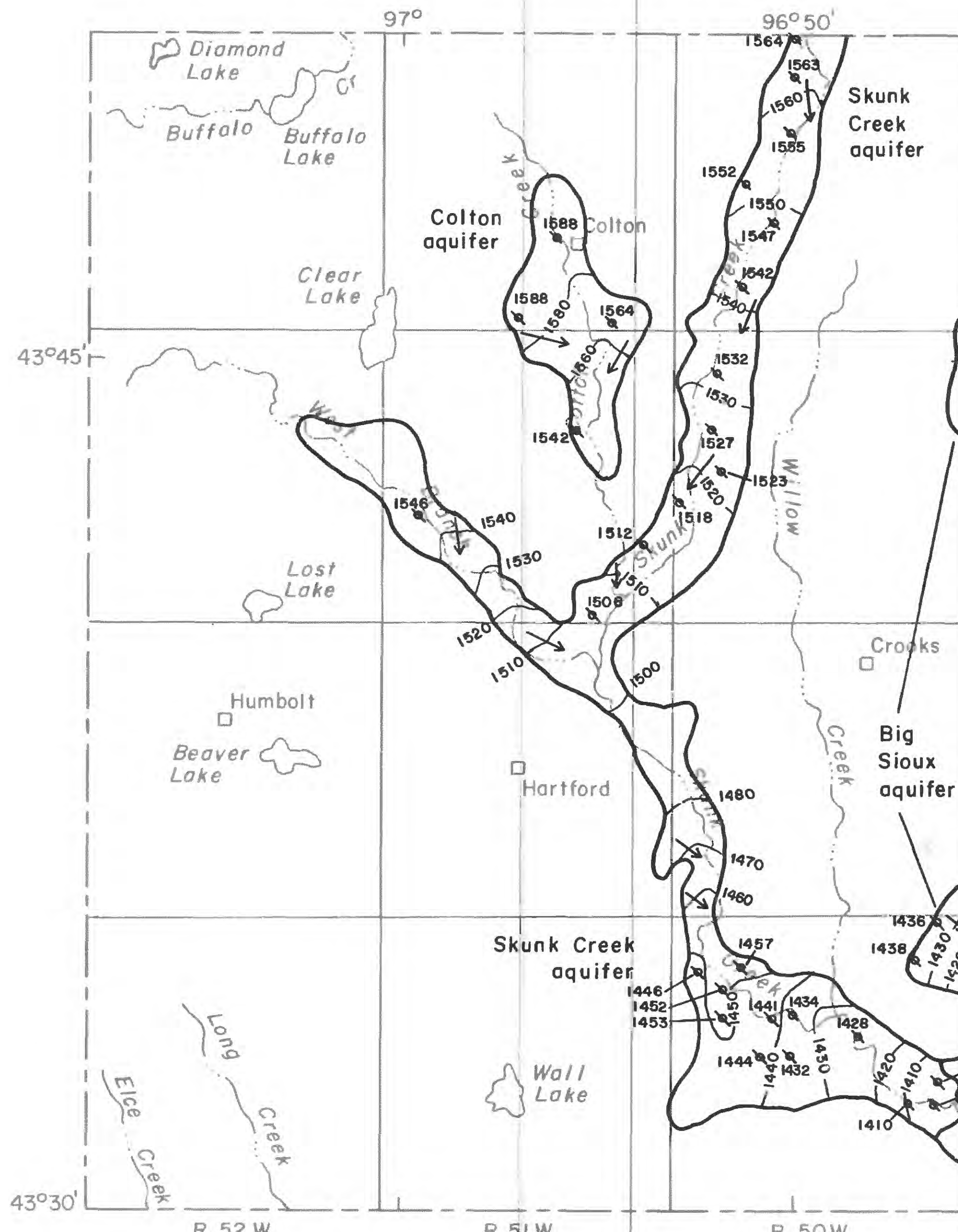


Figure 14.--Geologic sections D-D' and E-E' showing the Big Sioux, Skunk Creek, Brandon, Wall lake, Split Rock Creek, and Sioux Quartzite aquifers. (Sections D-D' and E-E' are shown in figure 2.)



Base from U.S. Geological Survey
1:500,000, 1963

EXPLANATION

1413* OBSERVATION WELL --Number is altitude of water surface, in feet. An asterisk (*) indicates an October 1986 water level. Datum is sea level

—1500— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, variable

AQUIFER BOUNDARY

DIRECTION OF GROUND-WATER MOVEMENT

Figure 15.--Potentiometric surface of the Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, Brandon, Colton, Slip Up Creek, and Four Mile Creek aquifers, September 1986, in Minnehaha County.

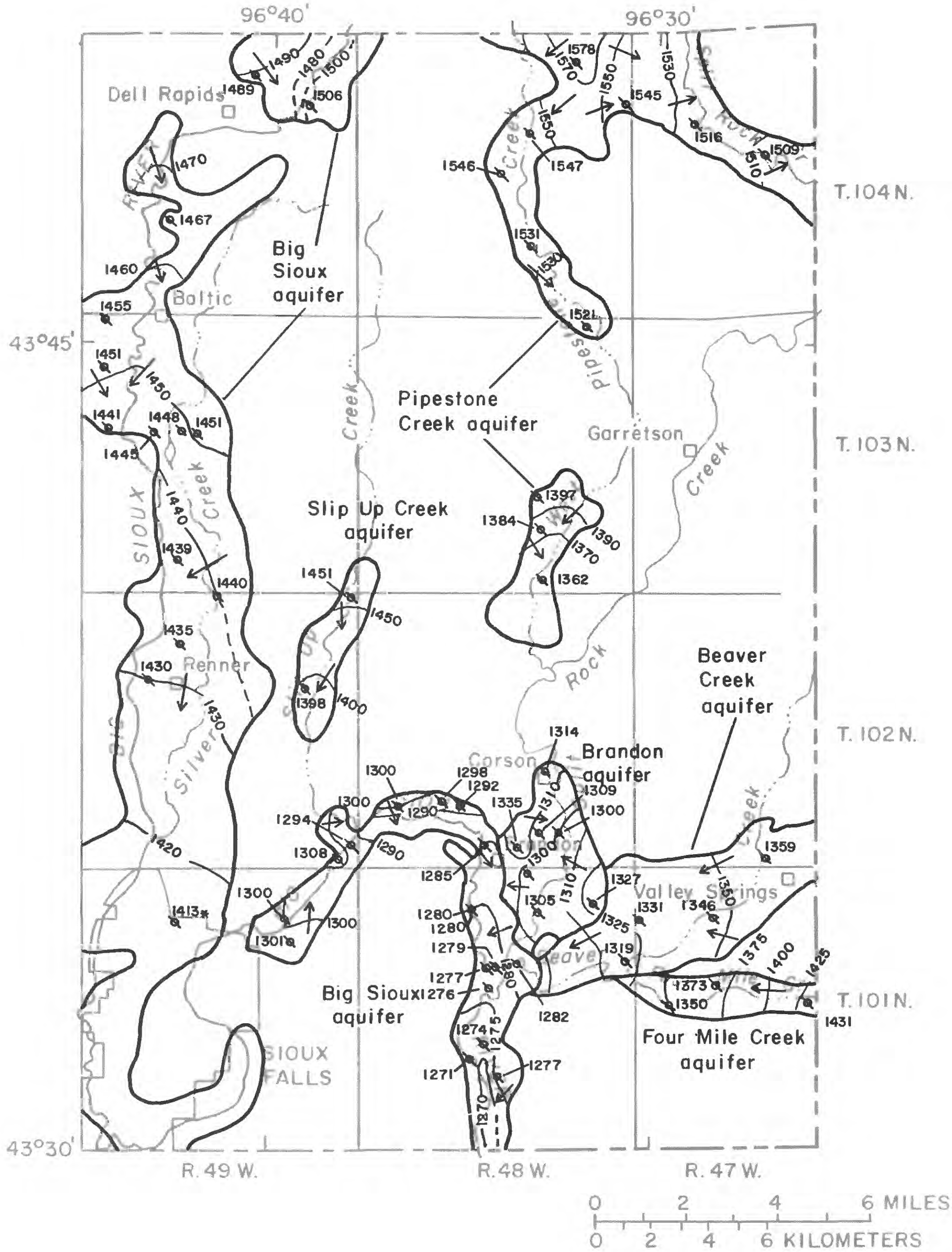


Figure 15.--Potentiometric surface of the Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, Brandon, Colton, Slip Up Creek, and Four Mile Creek aquifers, September 1986, in Minnehaha County--Continued.

The direction of water movement in the Big Sioux aquifer generally is to the south and towards the Big Sioux River (fig. 15). In southern Minnehaha County where the Big Sioux River meanders to the north and east, the direction of water movement in the aquifer also is to the north and east. In northern T. 101 N., R. 49 W. and southern T. 102 N., R. 49 W., the general flow pattern in the aquifer is altered by pumpage from the Sioux Falls municipal well field. Withdrawal of water by the municipal wells results in a cone of depression in the vicinity of the municipal well field, a localized movement of water towards the pumping municipal wells, and a localized flow pattern that differs from the regional flow pattern. The gradient of the water-table surface is about 4 to 6 ft/mi southward north of Sioux Falls and as much as 22 ft/mi in the vicinity of the Sioux Falls municipal well field. East of Sioux Falls, the gradient of the water-table surface is about 3 ft/mi.

The Big Sioux aquifer is under water-table conditions except in northeastern T. 101 N., R. 50 W. and near the eastern boundary in T. 102 N., R. 49 W. where the aquifer is overlaid by till and is under confined conditions. The depth to water in wells generally is less than 10 ft below land surface in the Big Sioux River flood plain and ranges from 9 to 42 ft in areas where the aquifer is overlaid by till.

Discharge from the Big Sioux aquifer is: (1) By evapotranspiration where the aquifer is at or near land surface, (2) by seepage to the Big Sioux River when river stage is lower than the water table in the aquifer, as is generally the case except during spring snowmelt and storm event peak flows, and (3) by pumping wells. Koch (1982) determined the computer-simulated discharge from the Big Sioux aquifer between Dell Rapids and Sioux Falls under equilibrium conditions to be 62 percent by pumping wells, 35 percent by seepage to the Big Sioux River, and 3 percent by evapotranspiration from the aquifer. Subsurface outflow to Lincoln County, which borders the study area to the south, is less than 100 acre-ft/yr.

Water-level fluctuations in observation wells completed in the Big Sioux aquifer are caused mainly by seasonal changes in recharge. Water levels in wells generally rise during the spring and early summer because of recharge from snowmelt and rainfall and decline during the summer and fall because of lower recharge from precipitation, increased evapotranspiration, and seepage losses to the Big Sioux River. Long-term records of water-level fluctuations in wells show a close correlation with long-term trends in precipitation (fig. 16). The comparatively high water levels measured in wells 101N48W16ADDA and 103N49W17DBDC during 1962, 1965, 1969, 1978-79, and 1983-86 were caused by above-normal precipitation. The comparatively low water levels measured during 1958-59, 1963-64, 1966-68, 1974-77, and 1980-81 were caused by below-normal precipitation and increased withdrawals by wells.

Water-level fluctuations in well 101N48W28BAAA located about 300 ft from the Big Sioux River are shown in figure 17. Water-level fluctuations in the well show a close correlation with fluctuations in river stage measured from a nearby bridge. The water level in the well generally is about 1 ft higher than river stage, indicating discharge from the aquifer to the Big Sioux River. During the spring of 1985 and 1986 and September 1986, river stage was higher than the potentiometric surface of the aquifer, indicating recharge from the Big Sioux River to the aquifer. The relatively high water levels measured during September 1986 were caused by precipitation in September that was about 6.5 in. above normal.

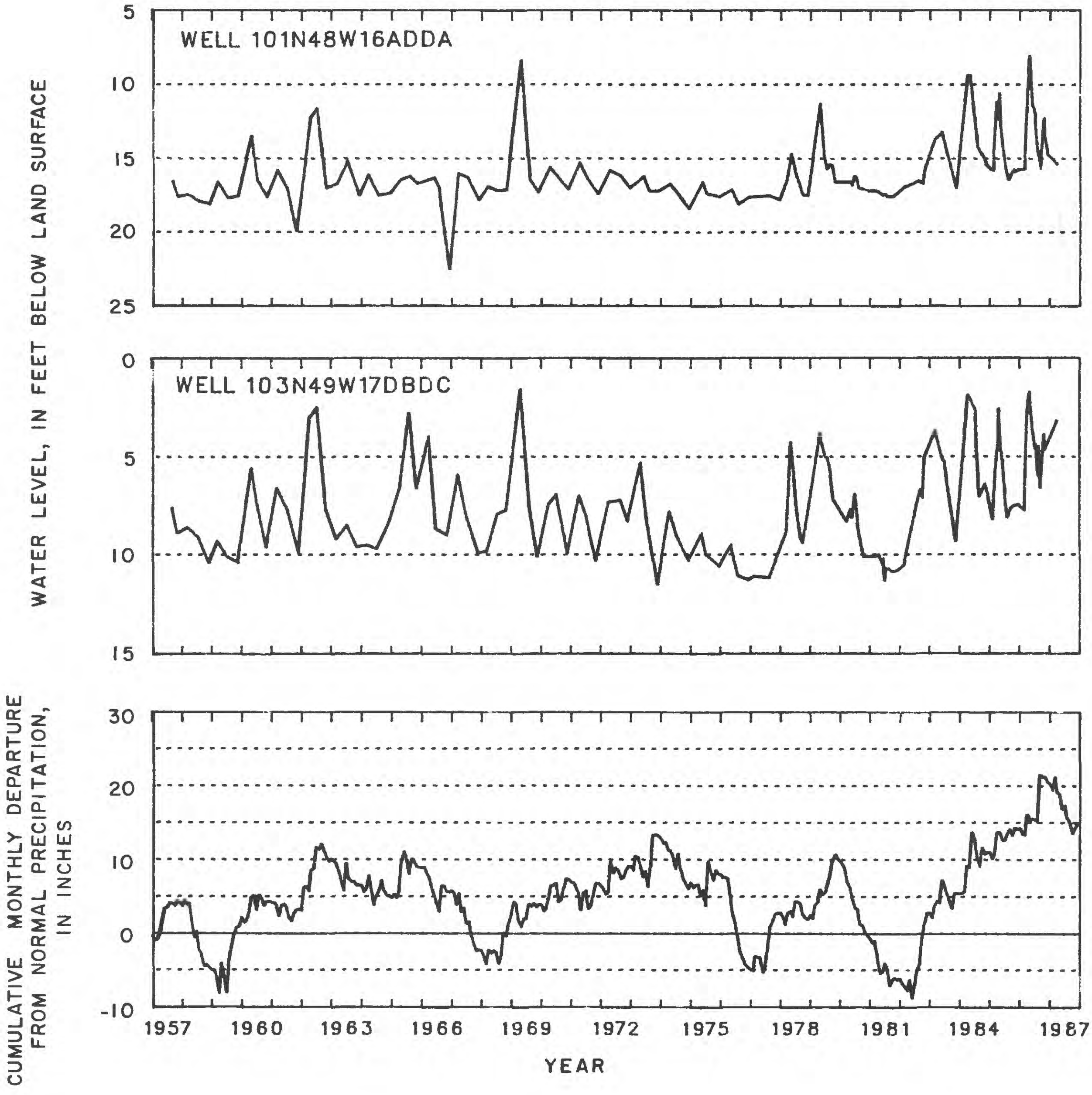


Figure 16.--Water-level fluctuations in the Big Sioux aquifer and cumulative monthly departure from normal precipitation at Sioux Falls.

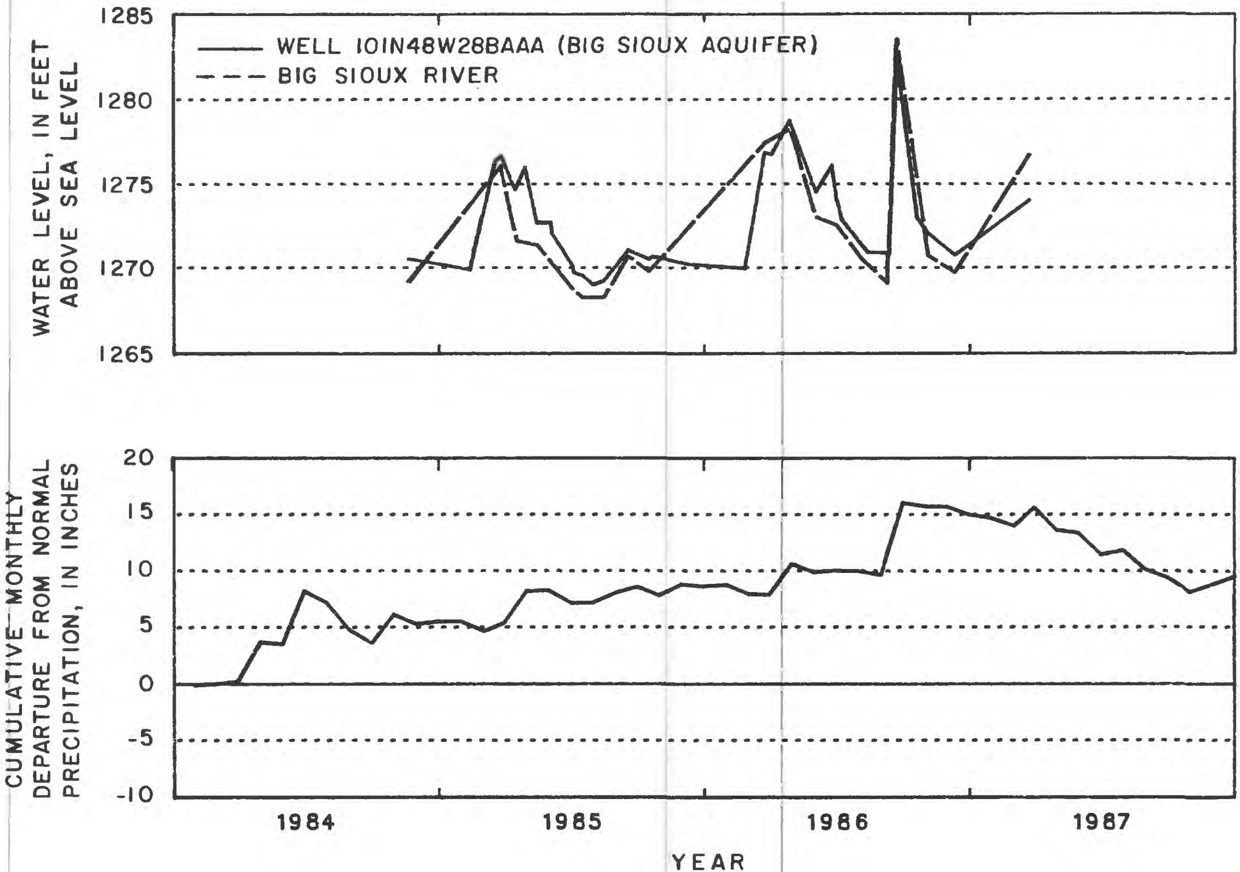


Figure 17.--Water-level fluctuations in the Big Sioux aquifer, river-stage fluctuations in the Big Sioux River, and cumulative monthly departure from normal precipitation at Sioux Falls.

The predominant chemical constituents in water from the Big Sioux aquifer are calcium, sulfate, and bicarbonate. A summary of chemical analyses of water from the aquifer is given in table 7. Concentrations of dissolved solids ranged from 260 to 1,540 mg/L and averaged 490 mg/L. Hardness concentrations (as $CaCO_3$) ranged from 180 to 840 mg/L and averaged 350 mg/L. Mixing of water from the Big Sioux and Split Rock Creek aquifers in some areas in R. 48 W. may be indicated by lower sulfate percentages, less than 30 percent compared to greater than 45 percent for most of both the Big Sioux and Split Rock Creek aquifers, and higher bicarbonate percentages, greater than 60 percent compared to less than 50 percent (fig. 18).

Water from the Big Sioux aquifer is used for stock watering, domestic, municipal, and irrigation purposes. The principal user of water withdrawn from the Big Sioux aquifer in Minnehaha County is the city of Sioux Falls, using about 91 percent (about 4,665 million gallons per year) of the total water withdrawn from the aquifer.

Table 7.--Summary of chemical analyses of water from glacial and bedrock aquifers

[Summary includes analyses by both the U.S. Geological Survey Laboratory and the South Dakota Geological Survey Laboratory unless otherwise noted. Units reported in milligrams per liter (mg/L) except as indicated; μg/L, micrograms per liter; μS/cm, microsiemens per centimeter at 25 °Celsius]

	Big Sioux aquifer			
Constituent	Number of samples	Maximum	Minimum	Mean
Specific conductance, lab (μS/cm)	22	1,630	430	725
pH[1], lab (pH units)	22	8.2	7.4	8.0
Hardness, as $CaCO_3$	22	840	180	350
Alkalinity, lab, as $CaCO_3$	21	350	110	195
Dissolved solids	22	1,540	260	490
Dissolved calcium	22	210	36	80
Dissolved magnesium	22	90	8	35
Dissolved sodium	22	76	10	22
Dissolved potassium	21	25	2	5
Bicarbonate, lab	19	430	130	225
Dissolved sulfate	22	690	28	175
Dissolved chloride	22	52	2.0	16
Dissolved fluoride	0	--	--	--
Dissolved nitrate	16	6.5	.01	1.3
Dissolved nitrogen	0	--	--	--
Dissolved boron (μg/L)	19	220	10	110
Dissolved iron[2] (μg/L)	4	4,900	590	1,900
Iron, total[1] (μg/L)	0	--	--	--

See footnotes at end of table.

Table 7.--Summary of chemical analyses of water from glacial and bedrock aquifers--Continued

Constituent	Number of samples	Maximum	Minimum	Mean
		Skunk Creek aquifer		
Specific conductance, lab ($\mu S/cm$)	11	1,020	340	682
pH[1], lab (pH units)	10	8.1	7.3	7.9
Hardness as $CaCO_3$	11	1,100	150	407
Alkalinity, lab, as $CaCO_3$	10	580	120	230
Dissolved solids	11	750	180	460
Dissolved calcium	11	280	37	99
Dissolved magnesium	11	95	15	39
Dissolved sodium	11	62	7.0	24
Dissolved potassium	10	5	1	3
Bicarbonate (lab)	8	400	140	220
Dissolved sulfate	11	260	7	150
Dissolved chloride	11	34	2.0	8
Dissolved fluoride	0	--	--	--
Dissolved nitrate	7	2.6	.02	.8
Dissolved nitrogen	1	.16	.16	--
Dissolved boron ($\mu g/L$)	7	180	10	110
Dissolved iron[2] ($\mu g/L$)	2	2,500	38	--
Iron, total[1] ($\mu g/L$)	0	--	--	--
		Beaver Creek aquifer		
Specific conductance, lab ($\mu S/cm$)	3	1,290	707	910
pH[1], lab (pH units)	3	7.4	7.2	7.3
Hardness as $CaCO_3$	3	680	370	480
Alkalinity, lab, as $CaCO_3$	3	400	300	340
Dissolved solids	3	880	450	593
Dissolved calcium	3	180	98	126
Dissolved magnesium	3	55	30	40
Dissolved sodium	3	33	11	18
Dissolved potassium	3	4	1	2
Bicarbonate (lab)	0	--	--	--
Dissolved sulfate	3	320	96	170
Dissolved chloride	3	23	2.3	11
Dissolved fluoride	0	--	--	--
Dissolved nitrate	0	--	--	--
Dissolved nitrogen	3	6.7	2.5	4.5
Dissolved boron ($\mu g/L$)	1	60	60	--
Dissolved iron[2] ($\mu g/L$)	3	47	7	31
Iron, total[1] ($\mu g/L$)	0	--	--	--

See footnotes at end of table.

Table 7.--Summary of chemical analyses of water from glacial and bedrock aquifers--Continued

Constituent	Number of samples	Maximum	Minimum	Mean
	Brandon aquifer			
Specific conductance, lab ($\mu S/cm$)	3	798	758	772
pH[1], lab (pH units)	3	8.0	7.4	7.6
Hardness as $CaCO_3$	3	380	370	380
Alkalinity, lab, as $CaCO_3$	3	360	310	320
Dissolved solids	3	480	410	443
Dissolved calcium	3	100	92	96
Dissolved magnesium	3	34	32	33
Dissolved sodium	3	15	14	15
Dissolved potassium	3	3	1	2
Dissolved sulfate	3	110	30	72
Dissolved chloride	3	7.2	3.9	5.3
Dissolved fluoride	0	--	--	--
Dissolved nitrate	0	--	--	--
Dissolved nitrogen	3	8.9	.1	5.0
Dissolved boron ($\mu g/L$)	0	--	--	--
Dissolved iron[2] ($\mu g/L$)	3	20	4	9
Iron, total[1] ($\mu g/L$)	0	--	--	--
	Pipestone Creek aquifer			
Specific conductance, lab ($\mu S/cm$)	3	1,480	705	1,220
pH[1], lab (pH units)	3	7.5	7.2	7.4
Hardness as $CaCO_3$	3	840	370	560
Alkalinity, lab, as $CaCO_3$	3	560	270	430
Dissolved solids	3	860	480	733
Dissolved calcium	3	170	79	120
Dissolved magnesium	3	100	22	63
Dissolved sodium	3	150	16	67
Dissolved potassium	3	3	1	2
Bicarbonate, lab	0	--	--	--
Dissolved sulfate	3	190	130	160
Dissolved chloride	3	60	1.2	35
Dissolved fluoride	0	--	--	--
Dissolved nitrate	0	--	--	--
Dissolved nitrogen	3	64	.1	28
Dissolved boron ($\mu g/L$)	2	140	90	--
Dissolved iron[2] ($\mu g/L$)	3	2,700	7	910
Iron, total[1] ($\mu g/L$)	0	--	--	--

See footnotes at end of table.

Table 7.--Summary of chemical analyses of water from glacial and bedrock aquifers--Continued

Constituent	Number of samples	Colton aquifer Maximum	Minimum	Mean
Specific conductance, lab ($\mu S/cm$)	4	2,710	1,070	1,590
pH[1], lab (pH units)	4	7.7	7.1	7.4
Hardness as $CaCO_3$	4	1,400	560	810
Alkalinity, lab, as $CaCO_3$	4	340	260	300
Dissolved solids	4	2,000	690	1,100
Dissolved calcium	4	280	130	180
Dissolved magnesium	4	180	56	92
Dissolved sodium	4	86	17	40
Dissolved potassium	4	7	3	5
Bicarbonate, lab	1	414	414	--
Dissolved sulfate	4	1,100	240	480
Dissolved chloride	4	140	15	65
Dissolved fluoride	0	--	--	--
Dissolved nitrate	1	11	11	--
Dissolved nitrogen	3	30	1.8	16
Dissolved boron ($\mu g/L$)	0	--	--	--
Dissolved iron[2] ($\mu g/L$)	4	70	4	20
Iron, total[1] ($\mu g/L$)	0	--	--	--
		Wall Lake aquifer		
Specific conductance, lab ($\mu S/cm$)	8	1,710	707	1,240
pH[1], lab (pH units)	5	7.9	7.5	7.7
Hardness as $CaCO_3$	9	1,000	340	660
Alkalinity, lab, as $CaCO_3$	5	360	84	200
Dissolved solids	9	1,500	420	1,010
Dissolved calcium	9	270	88	170
Dissolved magnesium	9	79	30	56
Dissolved sodium	9	74	16	49
Dissolved potassium	5	13	2	7
Bicarbonate (lab)	3	160	100	130
Dissolved sulfate	9	820	33	460
Dissolved chloride	8	10	2.5	5.5
Dissolved fluoride	0	--	--	--
Dissolved nitrate	3	.1	.1	.1
Dissolved nitrogen	3	2.3	.02	.8
Dissolved boron ($\mu g/L$)	3	480	100	340
Dissolved iron[2] ($\mu g/L$)	5	1,300	9	350
Iron, total[1] ($\mu g/L$)	1	210	210	--

See footnotes at end of table.

Table 7.--Summary of chemical analyses of water from glacial and bedrock aquifers--Continued

Constituent	Number of samples	Maximum	Minimum	Mean
	Valley Springs aquifer			
Specific conductance, lab (μS/cm)	4	1,280	741	942
pH[1], lab (pH units)	4	8.0	7.1	7.5
Hardness as $CaCO_3$	4	640	320	440
Alkalinity, lab, as $CaCO_3$	4	400	330	350
Dissolved solids	4	920	450	620
Dissolved calcium	4	150	86	110
Dissolved magnesium	4	64	26	41
Dissolved sodium	4	60	30	40
Dissolved potassium	4	8	7	7
Bicarbonate, lab	2	410	400	--
Dissolved sulfate	4	360	63	170
Dissolved chloride	4	12	3.8	7.7
Dissolved fluoride	0	--	--	--
Dissolved nitrate	2	.1	.1	--
Dissolved nitrogen	2	4.0	.1	--
Dissolved boron (μg/L)	1	430	430	--
Dissolved iron[2] (μg/L)	4	250	40	140
Iron, total[1] (μg/L)	0	--	--	--
	Split Rock Creek aquifer			
Specific conductance, lab (μS/cm)	19	2,700	440	1,170
pH[1], lab (pH units)	20	8.2	7.2	7.7
Hardness as $CaCO_3$	20	1,700	180	620
Alkalinity, lab, as $CaCO_3$	20	390	92	240
Dissolved solids	20	2,300	230	890
Dissolved calcium	20	490	28	150
Dissolved magnesium	20	120	16	58
Dissolved sodium	20	80	9.6	39
Dissolved potassium	20	15	1	6
Bicarbonate, lab	9	380	110	200
Dissolved sulfate	20	1,500	26	440
Dissolved chloride	20	18	.9	6.9
Dissolved fluoride	0	--	--	--
Dissolved nitrate	8	3.5	.01	1.8
Dissolved nitrogen	11	17	.10	2.4
Dissolved boron (μg/L)	13	570	50	310
Dissolved iron[2] (μg/L)	15	8,000	5	2,300
Iron, total[1] (μg/L)	0	--	--	--

See footnotes at end of table.

Table 7.--Summary of chemical analyses of water from glacial and bedrock aquifers--Continued

Constituent	Sioux Quartzite aquifer			
	Number of samples	Maximum	Minimum	Mean
Specific conductance, lab ($\mu S/cm$)	13	3,130	610	1,370
pH[1], lab (pH units)	9	8.4	7.1	7.4
Hardness as $CaCO_3$	14	3,000	280	820
Alkalinity, lab, as $CaCO_3$	9	410	130	310
Dissolved solids	14	3,300	320	1,030
Dissolved calcium	14	820	64	210
Dissolved magnesium	14	220	27	68
Dissolved sodium	14	96	14	36
Dissolved potassium	9	9	2	4
Bicarbonate, lab	5	440	160	350
Dissolved sulfate	14	1,700	21	430
Dissolved chloride	14	98	2.5	20
Dissolved fluoride	0	--	--	--
Dissolved nitrate	10	22	.10	4.3
Dissolved nitrogen	5	59	.10	13
Dissolved boron ($\mu g/L$)	1	80	80	--
Dissolved iron[2] ($\mu g/L$)	12	55,000	3	8,000
Iron, total[1] ($\mu g/L$)	1	20	20	--

[1]South Dakota Geological Survey.
[2]U.S. Geological Survey.

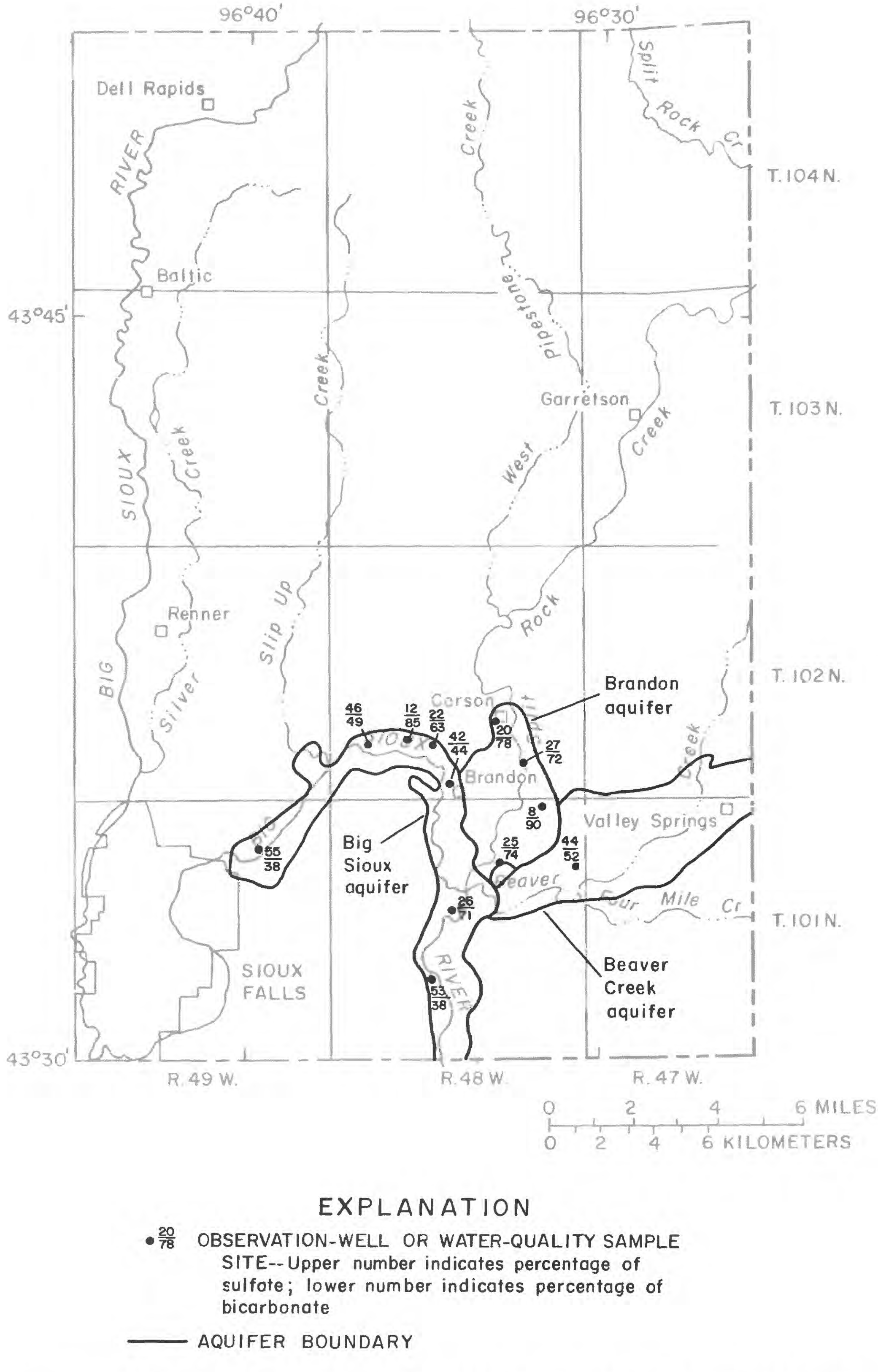


Figure 18.--Sulfate and bicarbonate percentages for parts of the Big Sioux, Beaver Creek, and Brandon aquifers.

Skunk Creek Aquifer

The Skunk Creek aquifer underlies about 43 mi^2 near Skunk and West Branch Skunk Creeks in western Minnehaha County (fig. 10). Geologic sections of the aquifer are shown in figures 11, 12, 13, and 14, and hydrologic characteristics are given in table 6. Depth to the top of the aquifer ranges from land surface in the Skunk Creek flood plain to 93 ft, south of Skunk Creek in T. 101 N., R. 50 W. where the aquifer is overlaid by till. The average depth below land surface is about 9 ft. The maximum cumulative thickness is 84 ft and the average cumulative thickness is about 21 ft. The cumulative thickness is greatest in T. 101 N., R. 50 W. near the Big Sioux River, in the southwestern part of the aquifer in T. 101 N., R. 50 W., and in T. 104 N., R. 50 W. near the Minnehaha-Moody County line. The Skunk Creek aquifer ranges from a fine to coarse, poorly sorted sand and fine to medium pebble gravel to a well-sorted sand and gravel with thin (2 to 6 ft thick) interbedded silty clay layers in some areas. The aquifer is underlaid by: (1) Till, (2) shale near the southwestern aquifer boundary in T. 101 N., R. 50 W., and (3) Sioux Quartzite in T. 102 N., R. 51 W., section 11. Properly constructed wells completed in the Skunk Creek aquifer may yield as much as 1,000 gal/min where the thickness exceeds 25 ft.

Recharge to the Skunk Creek aquifer is from infiltration of precipitation in the flood plain of Skunk Creek and from the Wall Lake aquifer in southeastern T. 101 N., R. 50 W. Subsurface inflow from the north out of Moody County is about 550 acre-ft/yr.

The direction of water movement in the Skunk Creek aquifer is to the south and southeast and towards Skunk Creek (fig. 15). The potentiometric gradient of the water-table surface in T. 103 N. and T. 104 N. is about 5 ft/mi underlying Skunk Creek and about 12 ft/mi underlying West Branch Skunk Creek. The potentiometric gradient is about 5 ft/mi in northwestern T. 101 N., R. 50 W. and about 10 ft/mi for the rest of the aquifer in T. 101 N. and T. 102 N.

The Skunk Creek aquifer is under water-table conditions except south of the Skunk Creek flood plain in T. 101 N., R. 50 W. where the aquifer is overlaid by till and is under confined conditions. The depth to water in wells is less than 8 ft below land surface north of the confluence of Skunk Creek and West Branch Skunk Creek. South of the confluence of Skunk Creek and West Branch Skunk Creek the depth to water in wells ranges from 5 ft below land surface in the Skunk Creek flood plain to 86 ft below land surface where the aquifer is overlaid by till.

Discharge from the Skunk Creek aquifer is: (1) By evapotranspiration in the Skunk Creek flood plain where the aquifer is at or near land surface, (2) by seepage to Skunk Creek, (3) to the Big Sioux aquifer, and (4) to stock, domestic, and irrigation wells.

Water-level fluctuations in observation wells completed in the Skunk Creek aquifer are caused by seasonal changes in recharge and irrigation withdrawals (fig. 19). Water levels in wells generally rise during the spring and early summer because of recharge from snowmelt and rainfall. Water levels generally decline during the summer and early fall because of lower recharge from precipitation, increased evapotranspiration, seepage losses to Skunk Creek, and irrigation withdrawals. The 5-ft rise in water level measured in well 101N50W7ABAB during the fall of 1986 was caused by September precipitation that was about 6.5 in. above normal. Long-term records of

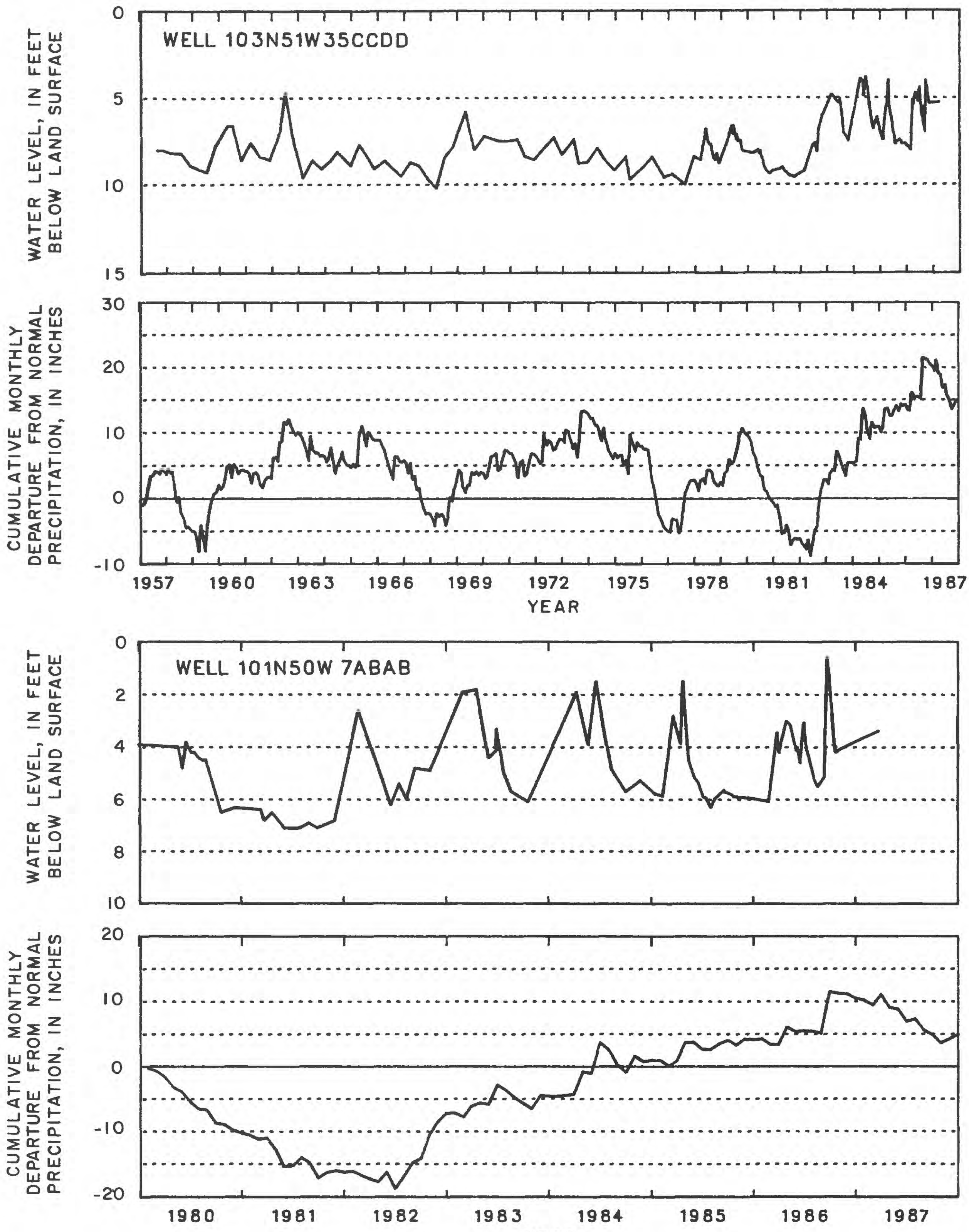


Figure 19.--Water-level fluctuations in the Skunk Creek aquifer and cumulative monthly departure from normal precipitation at Sioux Falls.

water-level fluctuations in well 103N51W35CCDD show a close correlation with long-term trends in precipitation. The comparatively high water levels measured during 1962, 1969, 1978-79, and 1983-86 were caused by above-normal precipitation. The comparatively low water levels measured during 1958-59, 1966-68, 1974-77, and 1980-81 were caused by below-normal precipitation.

Water-level fluctuations in well 101N50W16BAAA located about 200 ft from Skunk Creek are shown in figure 20. Water-level fluctuations in the well show a close correlation with fluctuations in creek stage measured from a nearby bridge. The water level in the well was always 2 to 3 ft higher than creek stage during 1985-87, indicating discharge from the aquifer to Skunk Creek. In contrast to the observed conditions for the Big Sioux River-Big Sioux aquifer system, creek stage was lower than the potentiometric surface of the Skunk Creek aquifer even during high spring flows, indicating no recharge from Skunk Creek to the Skunk Creek aquifer. Measurements of creek stages and water levels in nearby wells at seven additional sites also indicated that creek stage was always lower than the potentiometric surface of the aquifer near Skunk Creek.

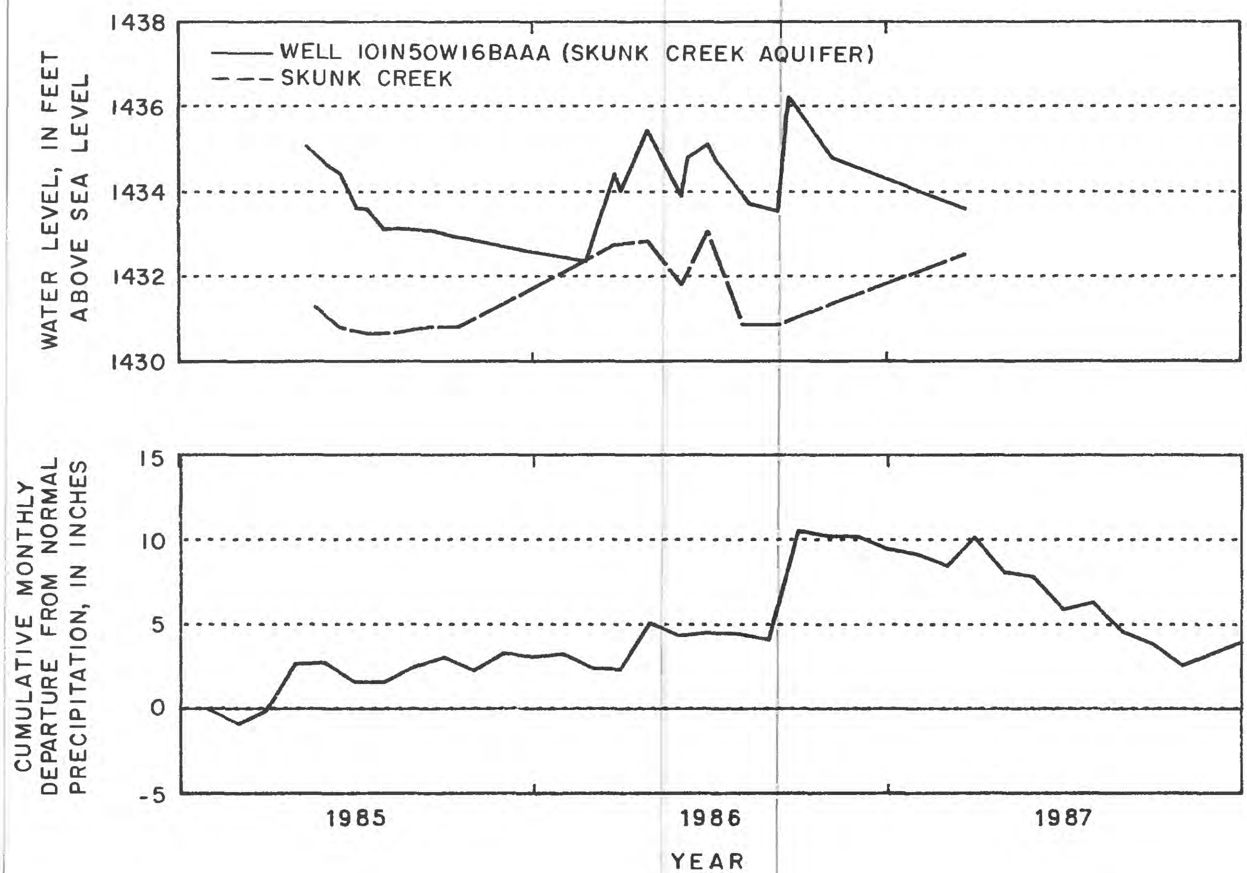


Figure 20.--Water-level fluctuations in the Skunk Creek aquifer, river-stage fluctuations in Skunk Creek, and cumulative monthly departure from normal precipitation at Sioux Falls.

The predominant chemical constituents in water from the Skunk Creek aquifer are calcium, sulfate, and bicarbonate. A summary of chemical analyses of water from the aquifer is given in tables 7 and 8. Concentrations of dissolved solids ranged from 180 to 750 mg/L and averaged 460 mg/L. Hardness concentrations (as $CaCO_3$) ranged from 150 to 1,100 mg/L and averaged 407 mg/L. Recharge to the Skunk Creek aquifer from the Wall Lake aquifer in southeastern T. 101 N., R. 50 W. may be indicated by specific conductances and dissolved-solids concentrations for the Skunk Creek aquifer greater than 1,000 μS/cm and 700 mg/L, respectively, compared to an average value of about 650 μS/cm and 430 mg/L, respectively, for the remainder of the Skunk Creek aquifer.

Water from the Skunk Creek aquifer is used for stock watering, domestic, and irrigation purposes. About 172 million gallons of water were pumped from the Skunk Creek aquifer in 1985 for irrigation, accounting for about 75 percent of the total water use from the Skunk Creek aquifer.

Pipestone Creek Aquifer

The Pipestone Creek aquifer underlies about 19 mi^2 near Pipestone and West Pipestone Creeks in northeastern and east-central Minnehaha County (fig. 10). A geologic section of the aquifer is shown in figures 11 and 12, and hydrologic characteristics are given in table 6. The Pipestone Creek aquifer is not present in northeastern T. 103 N., R. 48 W. where the Sioux Quartzite crops out near West Pipestone Creek. Depth to the top of the aquifer ranges from near land surface in the Pipestone and West Pipestone Creeks' flood plains to 52 ft in northern T. 104 N. where the aquifer is overlaid by till. The average depth below land surface is about 11 ft. The maximum cumulative thickness is greater than 36 ft and the average cumulative thickness is about 15 ft. The cumulative thickness generally is greatest near West Pipestone Creek in T. 104 N. and mostly less than 15 ft elsewhere. The Pipestone Creek aquifer is composed of fine to coarse sand and fine to coarse pebble gravel with 5- to 10-ft-thick interbedded silty clay layers in the extreme northern part of the aquifer. The aquifer is underlaid by till north of the Sioux Quartzite outcrop in northeastern T. 103 N., R. 48 W. and by Sioux Quartzite south of the outcrop. Properly constructed wells completed in the Pipestone Creek aquifer may yield as much as 500 gal/min but typically yield less than 100 gal/min because the average thickness is only about 15 ft.

Recharge to the Pipestone Creek aquifer is from infiltration of precipitation where the aquifer is at or near land surface. Subsurface inflow from the north out of Moody County is about 425 acre-ft/yr.

The direction of water movement in the Pipestone Creek aquifer is to the south and southeast and towards West Pipestone Creek and Pipestone Creek (fig. 15). Near the Minnehaha-Moody County line in northeastern T. 104 N., R. 48 W., water moves to the southeast towards Pipestone Creek and to the southwest towards West Pipestone Creek from a topographic and potentiometric high at a gradient of 15 to 25 ft/mi. The potentiometric gradient near Pipestone Creek is to the southeast at about 5 ft/mi. The potentiometric gradient near West Pipestone Creek is towards the south at: (1) About 0.5 ft/mi in northern T. 104 N., (2) about 7 ft/mi in southern T. 104 N., and (3) about 25 ft/mi in T. 103 N.

Table 8.--Chemical analyses of water collected from

[Analyses by U.S. Geological Survey Laboratory. Units as indicated. µg/L, micrograms per liter; µS/cm,

Location	Specific conductance (field) (µS/cm)	pH (field) (units)	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$	Dissolved solids, sum of constituents	Dissolved calcium	Dissolved magnesium	Dissolved sodium
				GLACIAL AQUIFERS				
				Skunk Creek aquifer				
101N50W19BCCB	980	7.2	510	272	650	130	44	21
				Beaver Creek aquifer				
101N47W 5ADDC	--	--	390	303	450	98	35	11
101N48W11CBBA	--	--	370	306	450	100	30	11
101N48W12ADDD	1,230	7.1	680	402	880	180	55	33
				Brandon aquifer				
101N48W 1BBB	735	7.3	370	356	410	92	34	15
102N48W27AACA	765	7.2	380	312	440	100	32	14
102N48W35ABBB2	740	8.1	380	307	480	97	33	15
				Pipestone Creek aquifer				
104N47W15CBAB	--	--	840	451	860	170	100	36
104N48W 1CBBD	--	--	370	270	480	110	22	16
104N48W15CBCB	1,480	--	470	558	860	79	67	150
				Colton aquifer				
104N51W35DDDA	1,370	7.6	660	279	830	140	76	32
104N51W27BBAB	3,000	7.1	1,400	263	2,000	280	180	86
103N51W10DDAA	1,050	7.4	560	323	690	130	58	17
				Four Mile Creek				
101N47W15CBDB	890	8.0	430	322	510	92	49	25
				Wall Lake aquifer				
102N50W 6CCBB	730	--	340	360	420	88	30	20
102N50W19CBBB	1,090	--	570	299	730	140	53	18
				Howard aquifer				
104N48W15AADD2	765	--	310	303	470	73	30	40
				Valley Springs aquifer				
101N47W 9AADC	--	--	640	399	920	150	64	60
102N47W32DCCC	730	8.9	320	337	450	86	26	30
				BEDROCK AQUIFERS				
				Split Rock Creek aquifer				
103N50W36ADDB	1,930	8.3	1,100	336	1,500	290	100	51
101N47W 6AAAA	835	7.7	410	319	540	110	33	24
101N48W 2CBBB	--	--	310	264	350	86	24	9.6
102N47W34CCCC	730	--	360	302	450	98	27	20
102N48W30CCCB	--	--	890	371	1,200	210	88	51
104N48W10CABB	960	--	470	394	510	91	60	23
104N48W12CCCD	1,070	--	400	264	730	100	36	69
104N48W18AAAA	2,100	--	1,200	255	1,700	270	120	80
104N51W15BABD	--	--	1,700	210	2,300	490	110	60
102N48W28BBCD	890	7.5	410	370	560	100	38	36
103N50W22CCCD	1,780	7.4	1,000	359	1,400	260	86	36
				Sioux Quartzite aquifer				
103N50W27BDDC	--	--	1,200	343	1,600	290	110	48
103N48W 4ABCC	430	7.6	300	319	360	74	27	19
103N51W22DDDA	1,630	7.1	780	408	800	190	74	30
104N50W12DCAD	865	7.2	420	342	510	100	41	21

glacial and bedrock aquifers for this study

reported in milligrams per liter (mg/L) except microsiemens per centimeter at 25 °Celsius]

Dissolved potassium	Dissolved sulfate	Dissolved chloride	Dissolved fluoride	Dissolved nitrogen	Dissolved boron (µg/L)	Dissolved iron (µg/L)	Dissolved manganese (µg/L)	Dissolved strontium (µg/L)	Dissolved selenium (µg/L)
5	260	2.6	--	0.16	--	38	420	--	--
1	96	6.6	--	6.7	--	7	6	--	--
2	98	2.3	0.3	2.5	60	39	7	330	7
4	320	23	--	4.3	--	47	3	--	--
1	30	4.7	--	5.9	--	4	<1	--	--
3	76	7.2	--	8.9	--	19	2	--	--
3	110	3.9	--	<.10	--	5	36	--	--
2	190	60	.4	64	90	25	5	650	2
3	130	1.2	.4	<.10	140	2,700	460	530	<1
1	160	43	--	19	--	7	<1	--	--
5	340	53	--	16	--	6	440	--	--
7	1,100	40	--	30	--	70	1,300	--	--
3	250	15	--	1.8	--	4	410	--	--
1	110	20	.6	11	50	9	1	440	5
2	33	2.5	--	2.3	--	54	9	--	--
4	300	2.7	--	<.10	--	9	110	--	--
9	110	3.8	.4	<.10	400	8	56	600	<1
7	360	12	.2	4.0	430	45	300	1,200	6
7	63	3.8	--	<.10	--	52	260	--	--
9	800	3.1	.4	<.10	490	1,700	590	2,200	<1
4	150	3.0	--	<.10	--	6,500	310	--	--
2	39	3.9	.3	8.0	50	6	<1	270	4
4	99	3.2	.5	<.10	140	8	260	540	<1
7	630	10	.5	<.10	470	1,800	500	1,700	<1
1	51	18	.6	17	80	5	3	500	<1
11	300	18	--	<.10	--	6,200	310	--	--
15	990	12	--	.10	--	5,600	2,200	--	--
12	1,500	.9	.4	<.10	570	8,000	2,100	2,600	<1
4	120	4.1	--	.29	--	230	240	--	--
8	740	12	--	<.10	--	8	840	--	--
9	880	3.2	--	<.10	--	5,500	650	--	--
4	21	2.5	--	.12	--	5	4	--	--
5	130	98	--	59	--	<3	1	--	--
3	110	6.4	--	5.3	--	5	1	--	--

The Pipestone Creek aquifer is under water-table conditions in the Pipestone and West Pipestone Creeks' flood plains and under confined conditions outside the flood plains where the aquifer is overlaid by till. The depth to water in wells generally is less than 12 ft below land surface with a maximum depth to water of 23 ft. Wells completed in the Pipestone Creek aquifer in the Pipestone Creek flood plain near the Minnehaha-Moody County line may flow during years with above-normal precipitation and during the spring months when water levels in wells are high.

Discharge from the Pipestone Creek aquifer is: (1) By evapotranspiration where the aquifer is at or near land surface, (2) by seepage to Pipestone and West Pipestone Creeks, and (3) to stock and domestic wells. Subsurface outflow eastward to Minnesota is about 250 acre-ft/yr.

Water-level fluctuations in observation wells completed in the Pipestone Creek aquifer are caused by seasonal changes in recharge (fig. 21). Water levels in wells generally rise during the spring and early summer because of recharge from snowmelt and rainfall. Water levels mainly decline during the summer because of lower recharge from precipitation, increased evapotranspiration, and seepage losses to Pipestone and West Pipestone Creeks. The water-level rise measured during the fall in 1986 in well 104N47W15CBBC was caused by above-normal precipitation in September.

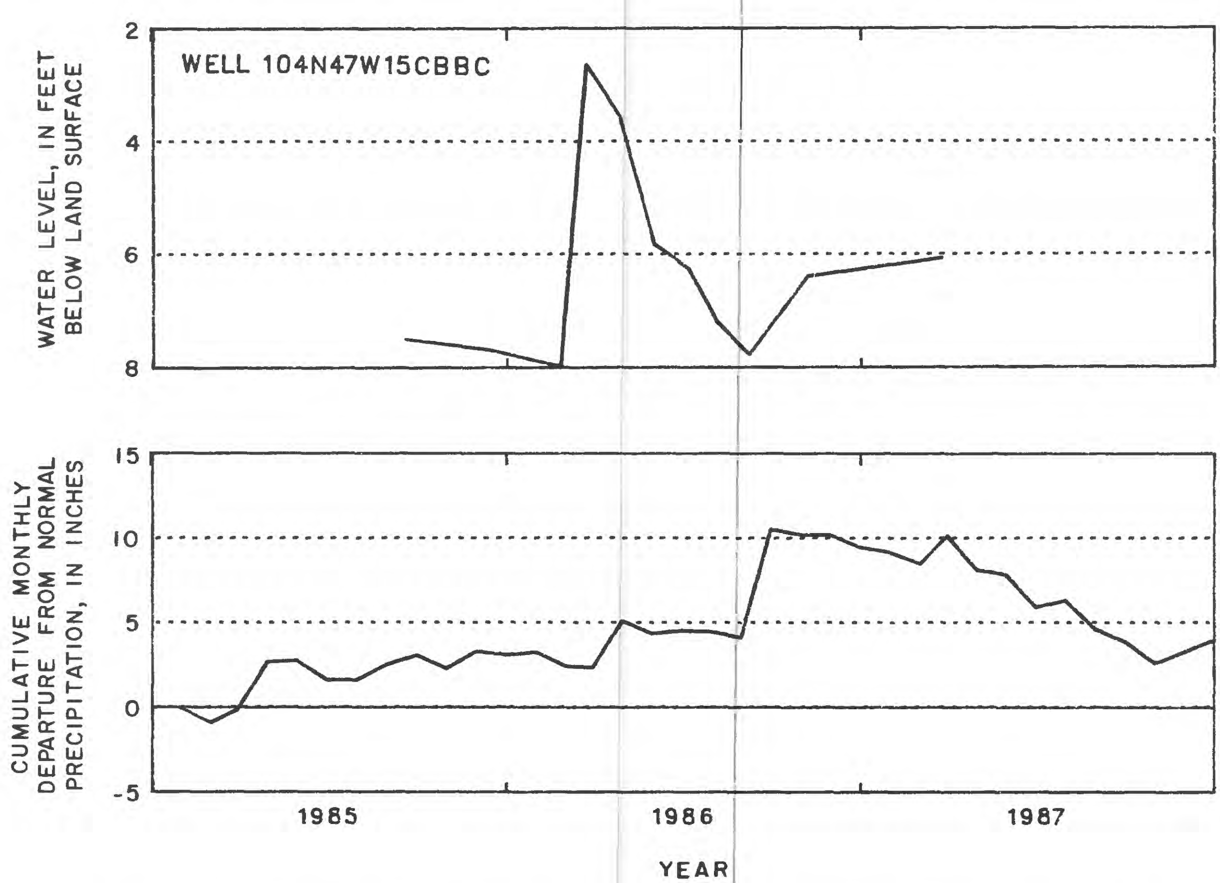


Figure 21.--Water-level fluctuations in the Pipestone Creek aquifer and cumulative monthly departure from normal precipitation at Sioux Falls.

The predominant chemical constituents in water from the Pipestone Creek aquifer are calcium and bicarbonate. A summary of chemical analyses of water from the aquifer is given in tables 7 and 8. Concentrations of dissolved solids for water from three wells completed in the Pipestone Creek aquifer were 480, 860, and 860 mg/L. Hardness concentrations (as $CaCO_3$) from the same three wells were 370, 470, and 840 mg/L.

Water from the Pipestone Creek aquifer is used for stock watering and domestic purposes.

Beaver Creek Aquifer

The Beaver Creek aquifer underlies about 11 mi^2 near Beaver Creek in southeastern Minnehaha County (fig. 10). A geologic section of the aquifer is shown in figure 13 and hydrologic characteristics are given in table 6. Depth to the top of the aquifer ranges from land surface in the Beaver Creek flood plain to 49 ft near the southern boundary, to 118 ft near the northeast boundary where the aquifer is overlaid by till. The maximum cumulative thickness is 49 ft and the average cumulative thickness is about 17 ft. The cumulative thickness generally is less than 20 ft in the western part of the aquifer and generally greater than 20 ft in the eastern part. The Beaver Creek aquifer is composed of fine to coarse sand and fine to coarse pebble gravel. The aquifer is underlaid by till and, in the western part, by the shales and siltstones of the Split Rock Creek Formation. Properly constructed wells completed in the Beaver Creek aquifer may yield as much as 500 gal/min where the thickness exceeds 25 ft. Yield from wells completed in the western part of the aquifer generally are less than 300 gal/min because the thickness is less than 20 ft.

Recharge to the Beaver Creek aquifer is from infiltration of precipitation in the flood plain of Beaver Creek. Subsurface inflow from the east out of Minnesota is about 600 acre-ft/yr.

The direction of water movement in the Beaver Creek aquifer is to the west and towards Beaver Creek (fig. 15). The potentiometric gradient is about 7 ft/mi in the eastern part of the aquifer and about 13 ft/mi in the central and western parts of the aquifer. The potentiometric gradient in the northwestern part of the aquifer near the boundary with the Brandon aquifer is only about 3 to 4 ft/mi.

The Beaver Creek aquifer is under water-table conditions except in the northwestern part and near the southern boundary where the aquifer is overlaid by till and is under confined conditions. The depth to water in wells ranges from 6 ft in the flood plain of Beaver Creek to 29 ft where the aquifer is overlaid by till.

Discharge from the Beaver Creek aquifer is: (1) By evapotranspiration where the aquifer is at or near land surface, (2) by seepage to Beaver Creek, (3) to the Big Sioux aquifer, (4) to the Brandon aquifer, and (5) to stock and domestic wells.

Water-level fluctuations in observation wells completed in the Beaver Creek aquifer are caused by seasonal changes in recharge (fig. 22). Water levels in wells generally rise during the spring and early summer because of recharge from snowmelt and rainfall. Water levels generally decline during the summer because of lower recharge from precipitation, increased evapotranspiration, and seepage losses to Beaver Creek. The 1.5-ft rise in water level measured in well 102N47W34CCCC2 from September 1986 to November 1986 was caused by September precipitation that was about 6.5 in. above normal. The water-level rises measured in well 101N48W12DADD2 during the fall in both 1985 and 1986 were caused by above-normal fall precipitation. The spring and early summer peak water level was lower in 1985 than in 1986 and 1987 because of less precipitation during the winter of 1984 and spring of 1985.

The predominant chemical constituents in water from the Beaver Creek aquifer are calcium and bicarbonate. A summary of chemical analyses of water from the aquifer is given in tables 7 and 8. Concentrations of dissolved solids for water from 3 wells completed in the Beaver Creek aquifer were 450, 450, and 880 mg/L. Hardness concentrations (as $CaCO_3$) for water from the same 3 wells were 370, 390, and 680 mg/L.

Water from the Beaver Creek aquifer is used for stock watering and domestic purposes.

Brandon Aquifer

The Brandon aquifer underlies about 6 mi^2 near Split Rock Creek in southeastern Minnehaha County (fig. 10). A geologic section of the aquifer is shown in figures 13, 14, and 15, and hydrologic characteristics are given in table 6. North of the Brandon aquifer in T. 102 N., R. 48 W., Split Rock Creek is underlaid by Sioux Quartzite and no outwash is present. Depth to the top of the aquifer ranges from land surface in and west of the Split Rock Creek flood plain to 24 ft where the aquifer is overlaid by till. The average depth below land surface is about 7 ft. The maximum cumulative thickness is 62 ft and the average cumulative thickness is about 35 ft. The Brandon aquifer is composed of fine to coarse, poorly sorted sand and fine to coarse pebble gravel with about 10 ft interbedded clay layers in most areas. The aquifer is underlaid by the siltstones and shales of the Split Rock Creek Formation and by till near the western and eastern boundaries. Properly constructed wells completed in the Brandon aquifer may yield as much as 500 gal/min where the thickness exceeds 20 ft. Yields from wells for most of the aquifer are less than 100 gal/min because the thickness is less than 20 ft.

Recharge to the Brandon aquifer is from infiltration of precipitation, from the Beaver Creek aquifer, from the Split Rock Creek aquifer in the flood plain of Split Rock Creek, and probably through fractures in the Sioux Quartzite from Sioux Quartzite outcrop areas located near the northern boundary of the Brandon aquifer.

The direction of water movement in the Brandon aquifer is to the south and towards Split Rock Creek (fig. 15). The sand and gravel of the Brandon aquifer generally occurs at a higher elevation than the sand and gravel of the bordering Big Sioux aquifer and therefore the hydraulic connection between the two aquifers is poor (fig. 13). A poor hydraulic connection between the aquifers is indicated by a large head difference in two wells located about 0.25 mi apart in the Big Sioux and Brandon aquifers in T. 102 N., R. 48 W., section 33.

The potentiometric gradient ranges from about 20 to 35 ft/mi towards Split Rock Creek from the northwestern and eastern aquifer boundaries. The potentiometric gradient towards Split Rock Creek from the west-central and southwestern aquifer boundaries is only about 5 ft/mi.

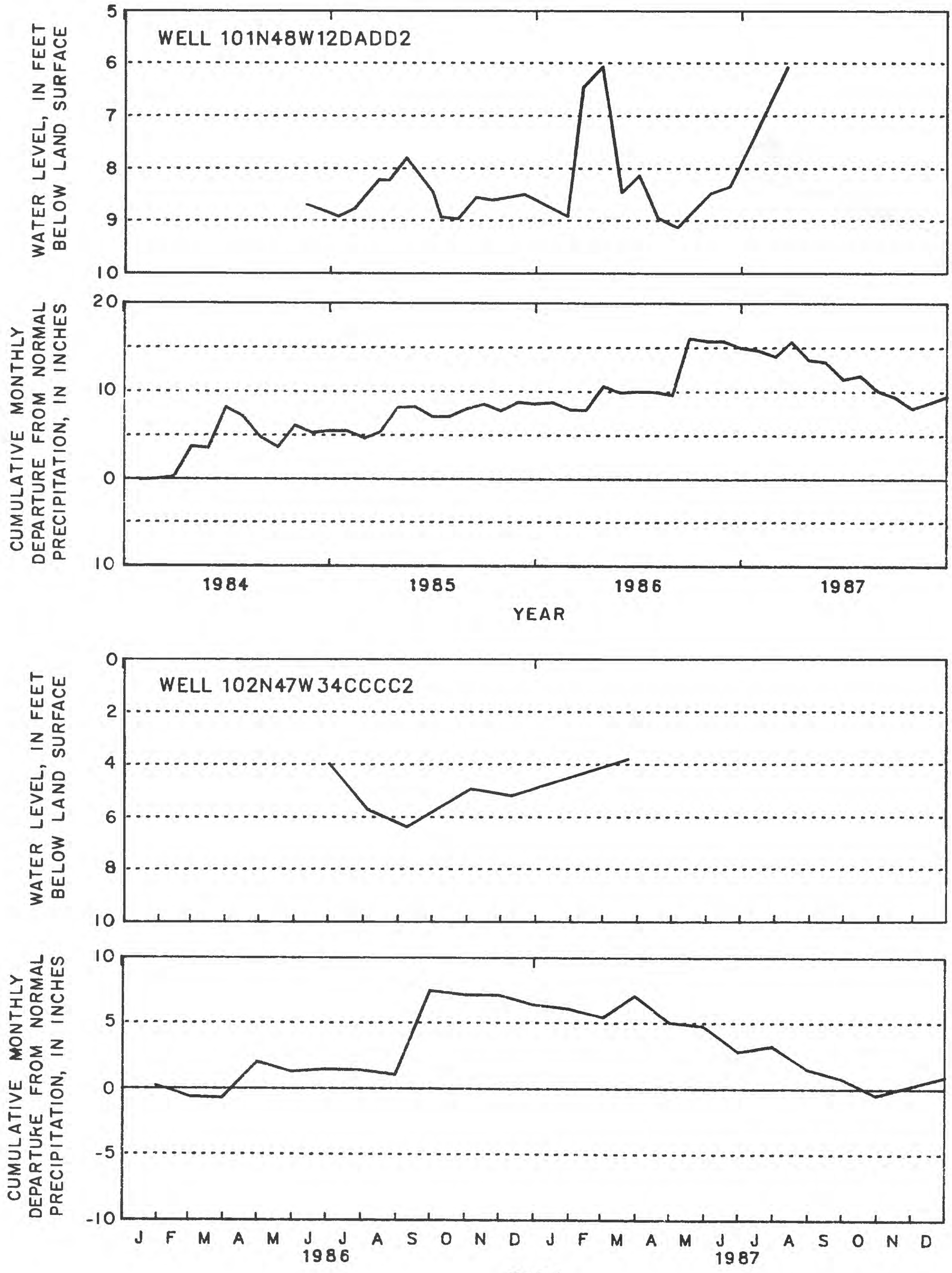


Figure 22.--Water-level fluctuations in the Beaver Creek aquifer and cumulative monthly departure from normal precipitation at Sioux Falls.

The Brandon aquifer is under water-table conditions except near the eastern boundary in T. 101 N., R. 48 W. where the aquifer is overlaid by till and is under confined conditions. The depth to water in wells ranges from 11 ft in the Split Rock Creek flood plain to 39 ft east of Split Rock Creek where the aquifer is overlaid by till and to 56 ft on the topographic high west of the flood plain.

Discharge from the Brandon aquifer is: (1) By evapotranspiration where the aquifer is at or near land surface, (2) by seepage to Split Rock Creek, (3) to the Big Sioux aquifer, and (4) to stock, domestic, and municipal wells.

Water-level fluctuations in observation wells completed in the Brandon aquifer are caused mainly by seasonal changes in recharge (fig. 23). Water levels in wells generally rise during the spring and early summer because of recharge from snowmelt and rainfall. Water levels decline during the summer because of lower recharge from precipitation, increased evapotranspiration, and seepage losses to Split Rock Creek. The water-level rises measured in wells during the fall of 1986 were caused by September precipitation that was about 6.5 in. above normal.

Water-level fluctuations in well 102N48W35ABBB2 located about 50 ft from Split Rock Creek show a close correlation with fluctuations in creek stage measured from a nearby bridge. The water level in the well was always 1 to 3 ft higher than creek stage during 1985-87, indicating discharge from the aquifer to Split Rock Creek. Creek stage was lower than the potentiometric surface of the Brandon aquifer near Split Rock Creek even during high spring flows, indicating no recharge from Split Rock Creek to the Brandon aquifer.

The predominant chemical constituents in water from the Brandon aquifer are calcium and bicarbonate. A summary of chemical analyses of water from the aquifer is given in tables 7 and 8. Concentrations of dissolved solids for water from three wells completed in the Brandon aquifer were 410, 440, and 480 mg/L. Hardness concentrations (as $CaCO_3$) for water from the same three wells were 370, 380, and 380 mg/L. Mixing of water from the Brandon and Split Rock Creek aquifers may be indicated by the similar percentages of sulfate and bicarbonate for the Brandon aquifer and the Split Rock Creek aquifer in the eastern part of R. 48 W. (fig. 18). The relatively high bicarbonate percentages may also indicate recharge through fractures in the Sioux Quartzite from Sioux Quartzite outcrop areas located near the northern boundary of the Brandon aquifer.

Water from the Brandon aquifer is used for stock watering, domestic, municipal, and irrigation purposes. About 83 percent of the water withdrawn from the Brandon aquifer is used by the city of Brandon.

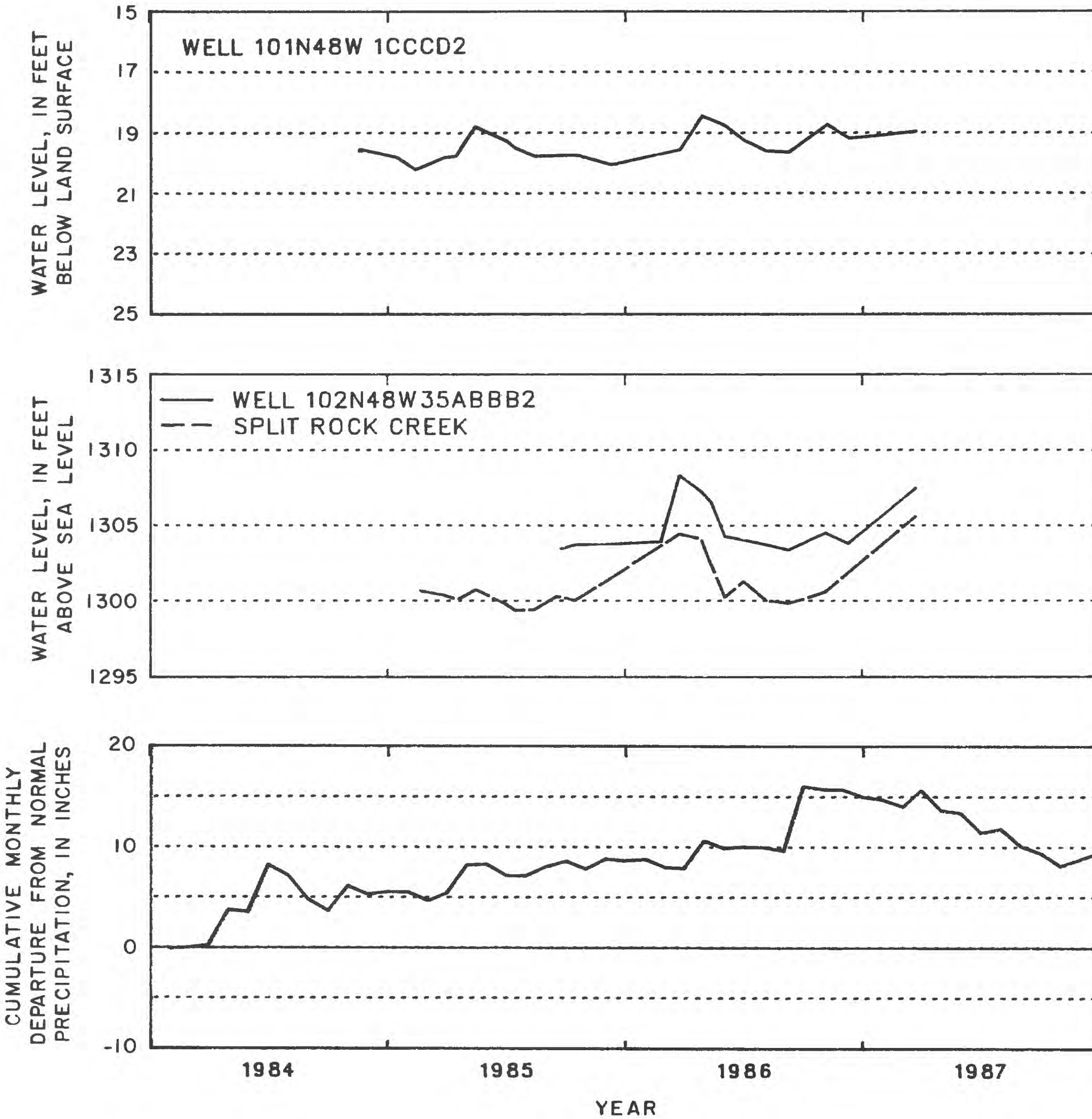


Figure 23.--Water-level fluctuations in the Brandon aquifer, river-stage fluctuations in Split Rock Creek, and cumulative monthly departure from normal precipitation at Sioux Falls.

Colton Aquifer

The Colton aquifer underlies about 8 mi^2 near Colton Creek in northwestern Minnehaha County (fig. 10). Hydrologic characteristics of the aquifer are given in table 6. Depth to the top of the aquifer averages about 20 ft below land surface. The maximum cumulative thickness is 26 ft in the central part of the aquifer and decreases to the north and to the south. The average cumulative thickness is about 12 ft. The Colton aquifer is composed of fine to coarse sand and fine to coarse pebble gravel. The aquifer is underlaid by till. Properly constructed wells completed in the Colton aquifer may yield as much as 500 gal/min where the thickness exceeds 20 ft. Well yields typically are less than 100 gal/min, however, because of small (less than 20 ft) thicknesses.

Recharge to the Colton aquifer is from infiltration of precipitation. The direction of water movement in the Colton aquifer is to the south and towards Colton Creek at a gradient of about 10 ft/mi (fig. 15).

The Colton aquifer is under water-table conditions. The depth to water in wells generally is less than 10 ft below land surface with a maximum depth to water of 18 ft.

Discharge from the Colton aquifer is: (1) By evapotranspiration where the aquifer is at or near land surface, (2) by seepage to Colton Creek, and (3) to stock, domestic, and municipal wells.

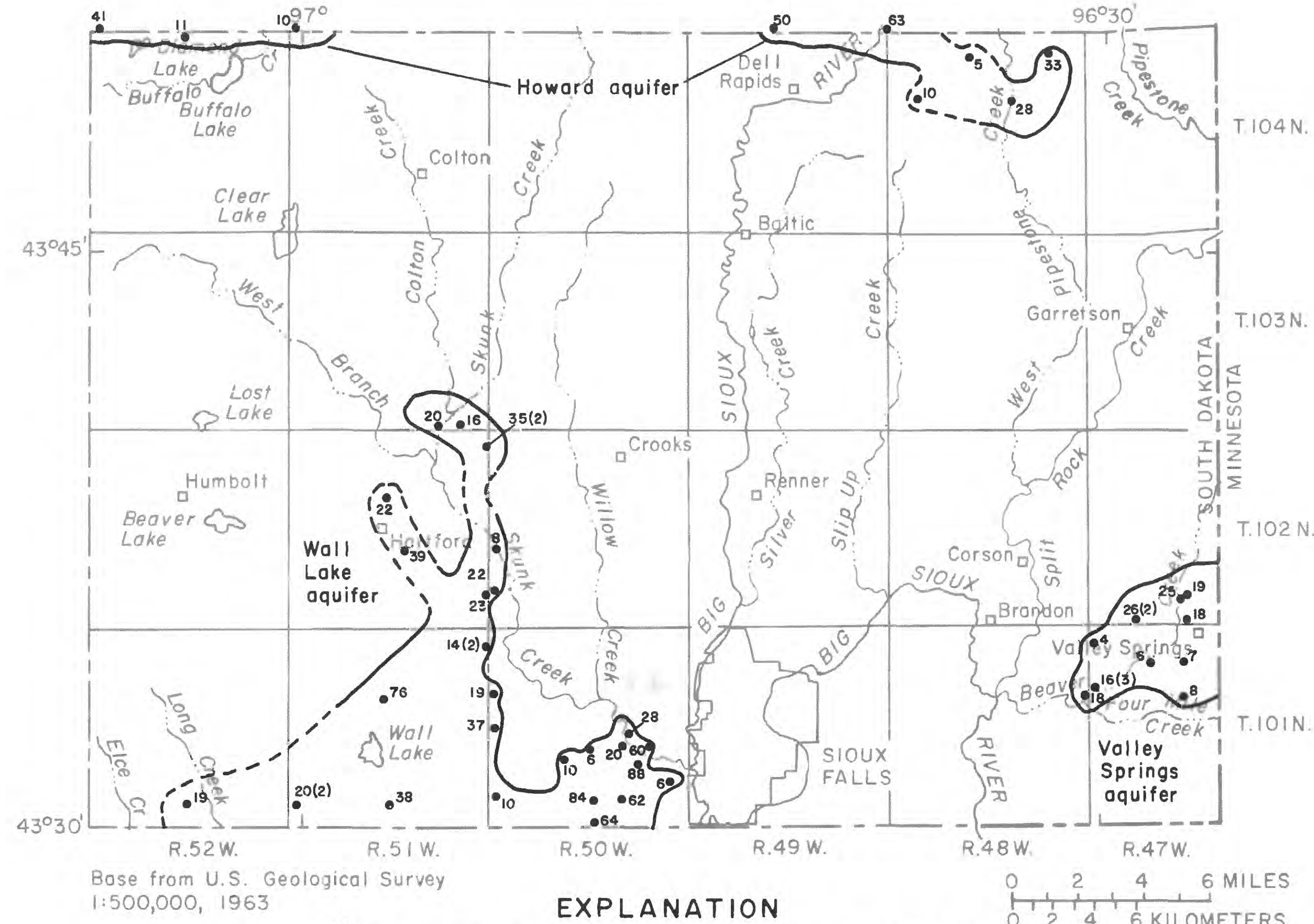
Water-level fluctuations in observation wells completed in the Colton aquifer are caused by seasonal changes in recharge. Water levels in wells generally rise during the spring and early summer because of recharge from snowmelt and rainfall. Water levels decline during the summer because of lower recharge from precipitation, increased evapotranspiration, and seepage losses to Colton Creek. Water levels in three observation wells completed in the Colton aquifer rose 1.7 to 2.8 ft from September 1986 to March 1987 and declined 1.3 to 2.4 ft from March to July 1987.

The predominant chemical constituents in water from the Colton aquifer are calcium, magnesium, and sulfate. A summary of chemical analyses of water from the aquifer is given in tables 7 and 8. Concentrations of dissolved solids ranged from 690 to 2,000 mg/L and averaged 1,100 mg/L. Hardness concentrations (as $CaCO_3$) ranged from 560 to 1,400 mg/L and averaged 810 mg/L. The greatest dissolved-solids and hardness (as $CaCO_3$) concentrations (2,000 and 1,400 mg/L, respectively) occurred in the northern part of the aquifer west of Colton Creek. Elsewhere in the aquifer, dissolved-solids and hardness (as $CaCO_3$) concentrations were less than 1,000 and 700 mg/L, respectively.

Water from the Colton aquifer is used for stock watering, domestic, and municipal purposes. About 60 percent of the water withdrawn from the Colton aquifer is used by the city of Colton.

Wall Lake Aquifer

The Wall Lake aquifer underlies about 58 mi^2 in southwestern Minnehaha County (fig. 24). Due to lack of adequate data, the western boundary of the aquifer is an approximation. A geologic section of the aquifer is shown in figures 12, 13, and 14, and hydrologic characteristics are given in table 6. Depth to the top of the aquifer ranges from 19 ft near Skunk Creek to 205 ft



EXPLANATION

16(3) TEST HOLE--Number is thickness of sand and gravel, in feet. Number in parenthesis refers to number of layers of sand and gravel, if more than one layer is present

AQUIFER BOUNDARY--Dashed where approximately located

Figure 24.--Areal extent and thickness of the Wall Lake, Howard, and Valley Springs aquifers in Minnehaha County.

and averages about 106 ft. The maximum cumulative thickness is 88 ft and the average cumulative thickness is about 33 ft. The cumulative thickness exceeds 60 ft for much of the southeast part of the aquifer and generally is less than 25 ft for the remainder of the aquifer. The Wall Lake aquifer is composed of fine to coarse well-sorted quartzose sand and fine pebble gravel with interbedded 2- to 3-ft-thick clay layers in some areas. The aquifer generally is underlaid by Sioux Quartzite and is overlaid by till. In some parts of southern T. 101 N., the aquifer is underlaid by till or shale. Properly constructed wells completed in the Wall Lake aquifer may yield as much as 500 gal/min where the thickness exceeds 50 ft. Well yields generally are less than 250 gal/min for much of the western part of the aquifer where the thickness is 25 ft or less.

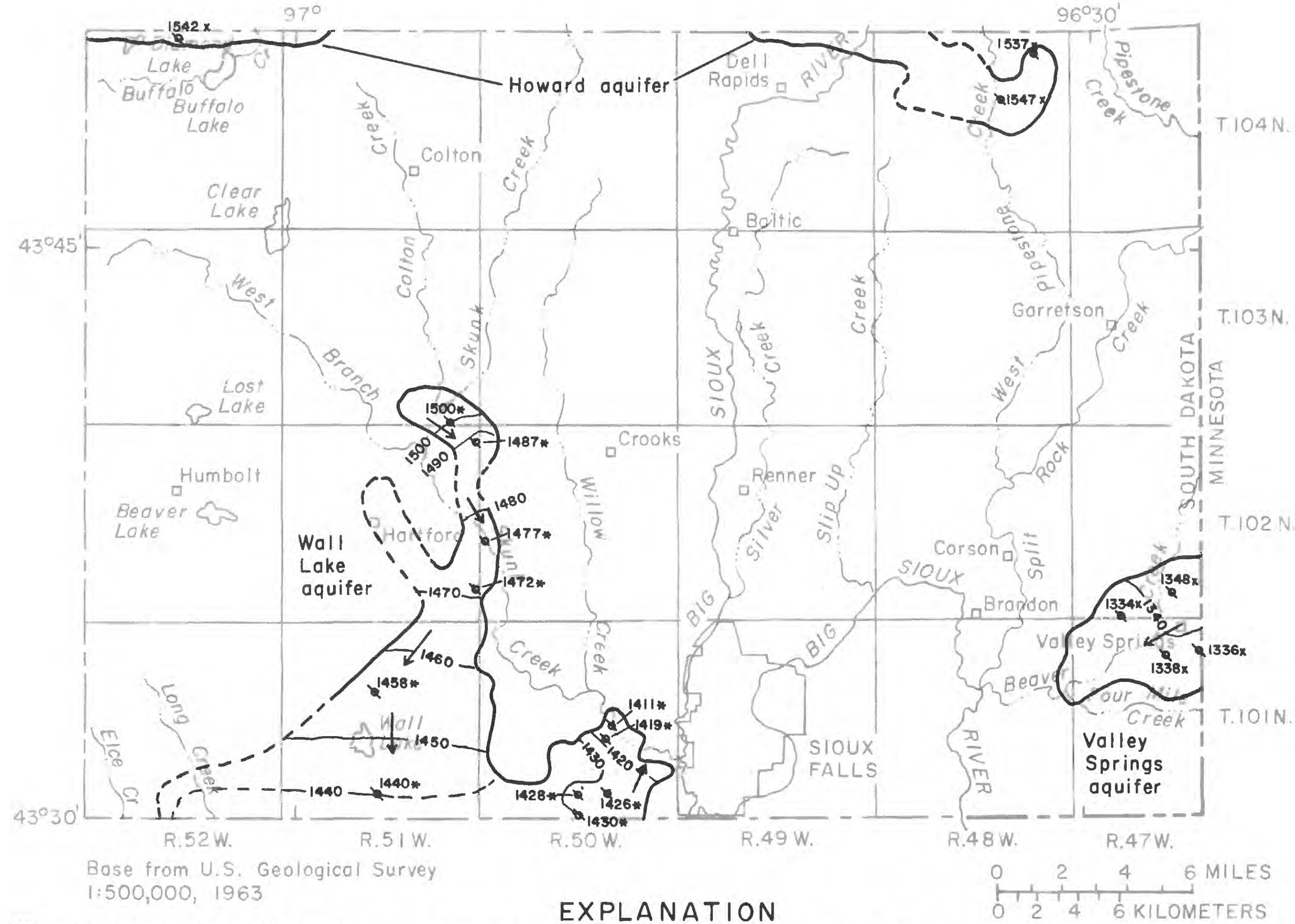
Recharge to the Wall Lake aquifer probably is from infiltration of precipitation into fractures in the Sioux Quartzite near the northwestern part of the Wall Lake aquifer where the Sioux Quartzite is at or near land surface. Water subsequently moves southward from the Sioux Quartzite topographic high through fractures in the Sioux Quartzite and then into the directly overlying Wall Lake aquifer. Although some subsurface inflow occurs from the south out of Lincoln County, the source of the water probably is the recharge area in Minnehaha County, because there is no known source of recharge to the Wall Lake aquifer in Lincoln County.

The direction of water movement in the Wall Lake aquifer is to the south in the western part of the aquifer and to the northeast towards Skunk Creek and the Big Sioux River in the eastern part of the aquifer (fig. 25). The gradient of the potentiometric surface is about 7 ft/mi in the northwestern and eastern parts of the aquifer and about 4 ft/mi in the southwestern part.

The Wall Lake aquifer is under confined conditions except in eastern T. 101 N., R. 50 W. near the Big Sioux and Skunk Creek aquifers where it is under water-table conditions (fig. 14). The depth to water in wells ranges from 9 ft below land surface near Skunk Creek in the eastern part of the aquifer to 156 ft below land surface in the western part and exceeds 75 ft below land surface for most of the aquifer.

Discharge from the Wall Lake aquifer is to: (1) The Big Sioux aquifer near the confluence of Skunk Creek and the Big Sioux River, (2) the Skunk Creek aquifer, and (3) stock and domestic wells. Near Skunk Creek in the eastern part of the aquifer the sand and gravel of the Wall Lake aquifer is at elevations from about 1,350 ft to about 1,425 ft above sea level whereas the sand and gravel of the Skunk Creek aquifer is at elevations from about 1,400 ft to about 1,425 ft above sea level, indicating a hydraulic connection between the aquifers. A thin layer (less than 10 ft) of till separates the Wall Lake and Skunk Creek aquifers in the western part of the area common to the two aquifers. Near the confluence of Skunk Creek and the Big Sioux River, the thickness of sand and gravel increases, the till layer that is to the northwest does not exist, and the Wall Lake, Skunk Creek, and Big Sioux aquifers are in hydraulic connection and form a single aquifer. Subsurface outflow southward to Turner County is about 600 acre-ft/yr.

Long-term records of water-level fluctuations in wells completed in the Wall Lake aquifer show a close correlation with long-term trends in precipitation (fig. 26). The comparatively high water levels measured in observation wells 101N50W34AAAD and 101N51W16AAAA2 during 1983-86 were caused by above-normal precipitation and the comparatively low water levels observed during 1981-82 were caused by below-normal precipitation.



EXPLANATION

1440 OBSERVATION WELL--Number is altitude of water surface, in feet. An (x) indicates a July 1987 water level. An (*) indicates a September 1987 water level. Datum is sea level

—1340-- POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 10 feet

AQUIFER BOUNDARY--Dashed where approximately located

DIRECTION OF GROUND-WATER MOVEMENT

Figure 25.--Potentiometric surface of the Wall Lake, Howard, and Valley Springs aquifers, July and September 1987, in Minnehaha County.

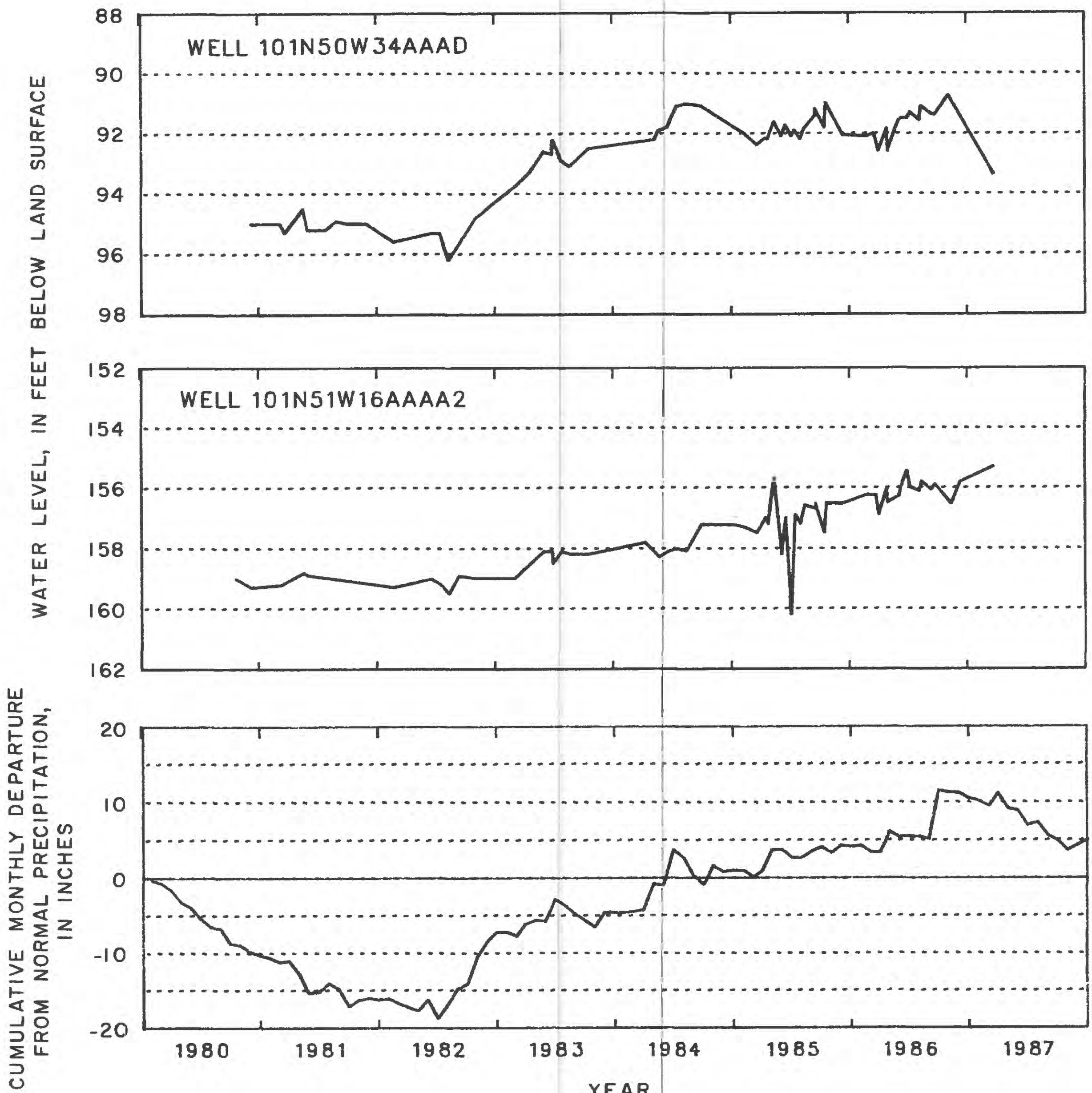


Figure 26.--Water-level fluctuations in the Wall Lake aquifer and cumulative monthly departure from normal precipitation at Sioux Falls.

The predominant chemical constituents in water from the Wall Lake aquifer generally are calcium and sulfate. Calcium and bicarbonate were the predominant chemical constituents in water from well 102N50W6CCBB. A summary of chemical analyses of water from the aquifer is given in tables 7 and 8. Concentrations of dissolved solids ranged from 420 to 1,500 mg/L and averaged 1,010 mg/L. Hardness concentrations (as $CaCO_3$) ranged from 340 to 1,000 mg/L and averaged 660 mg/L. The concentrations of dissolved solids and hardness generally are lowest in the northwestern part of the aquifer near the probable source of recharge from fractures in the Sioux Quartzite. The percentage of bicarbonate is greatest and the percentage of sulfate is lowest in the northwestern part of the Wall Lake aquifer (near well 102N50W6CCBB), also possibly indicating recharge to the Wall Lake aquifer through fractures in the Sioux Quartzite in the northwestern part of the aquifer.

Water from the Wall Lake aquifer is used for stock watering and domestic purposes.

Howard Aquifer

The Howard aquifer underlies about 15 mi^2 in extreme northeast and northwest Minnehaha County (fig. 24). Due to lack of adequate data, the areal extent of the aquifer in the northeast is approximated. The main body of the aquifer is to the north in Lake and Moody Counties. A geologic section of the aquifer is shown in figure 11, and hydrologic characteristics are given in table 6. Depth to the top of the aquifer ranges from 123 to 265 ft and averages 202 ft. The maximum cumulative thickness is 63 ft and the average cumulative thickness is about 28 ft. The cumulative thickness is greatest in the northeastern part of the aquifer along the Minnehaha-Moody County border. The Howard aquifer is composed of fine to coarse sand and fine to medium pebble gravel. The aquifer is underlaid by till or Sioux Quartzite and overlaid by till. Yield from properly constructed wells completed in the Howard aquifer may be as much as 500 gal/min in the extreme northeast part of the aquifer but generally is less than 100 gal/min.

There is no known source of recharge to the Howard aquifer in Minnehaha County. The Howard aquifer is overlaid by the Pipestone Creek aquifer in the Pipestone Creek flood plain in the northeast part of the aquifer. However, the two aquifers are hydraulically separated by more than 75 ft of till. In northeastern Minnehaha County, the Howard aquifer is separated from the Split Rock Creek aquifer by 35 to 50 ft of till. The recharge area for the Howard aquifer probably is located to the north of the study area. The direction of water movement in the Howard aquifer in northeastern Minnehaha County is from east to west towards the Dell Rapids quarry (fig. 25).

The Howard aquifer is under confined conditions. The depth to water in wells ranges from 6 to 49 ft below land surface in northeastern Minnehaha County and from 99 to 146 ft below land surface in northwestern Minnehaha County. Discharge from the Howard aquifer in Minnehaha County is: (1) To fractures in the Sioux Quartzite and to the Dell Rapids quarry and (2) to stock and domestic wells. The predominant chemical constituents in water from one well completed in the Howard aquifer in Minnehaha County were calcium and bicarbonate (table 8). Concentrations of dissolved solids and hardness (as $CaCO_3$) were 470 and 310 mg/L, respectively. Water from the Howard aquifer is used for stock-watering and domestic purposes.

Valley Springs Aquifer

The Valley Springs aquifer underlies about 14 mi^2 near the city of Valley Springs in southeastern Minnehaha County (fig. 24). A geologic section of the aquifer is shown in figure 13, and hydrologic characteristics are given in table 6. Depth to the top of the aquifer ranges from 93 ft in the Beaver Creek flood plain to 207 ft, south of the Beaver Creek flood plain near the South Dakota-Minnesota State line. The average depth below land surface is about 131 ft. The maximum cumulative thickness is 26 ft and the average cumulative thickness is about 15 ft. The cumulative thickness is greatest in the northern part of the aquifer and generally is less than 10 ft for the rest. The Valley Springs aquifer is composed of fine to coarse sand and fine to medium pebble gravel with layers of interbedded silty clay and till 5 to 10 ft thick in some areas. The aquifer is underlaid by the siltstones and shales of the Split Rock Creek Formation and overlaid by till. Yield from properly constructed wells completed in the Valley Springs aquifer may be as much as 200 gal/min in the northern part of the aquifer but generally is less than 10 gal/min in the south-central part where the thickness is less than 10 ft.

There is no known source of recharge to the Valley Springs aquifer in Minnehaha County. The Valley Springs aquifer is overlaid by the Beaver Creek aquifer in the Beaver Creek flood plain but the two aquifers are hydraulically separated by about 50 ft of till. The recharge area for the Valley Springs aquifer probably is located to the east of the study area in Minnesota because the gradient of the potentiometric surface is to the southwest at a gradient of 7 to 8 ft/mi (fig. 25). Subsurface inflow from Minnesota is about 1,175 acre-ft/yr. The direction of water movement in the Valley Springs aquifer is to the southwest.

The Valley Springs aquifer is under confined conditions. The depth to water in wells ranges from about 20 to 147 ft below land surface, generally increasing in depth from the western to the eastern part of the aquifer.

Discharge from the Valley Springs aquifer is to stock, domestic, and municipal wells and possibly to the Split Rock Creek aquifer. The layer of siltstones and shales separating the Valley Springs aquifer from the underlying sand of the Split Rock Creek aquifer ranges in thickness from 7 ft near the southwestern boundary of the Valley Springs aquifer to about 200 ft near the South Dakota-Minnesota State line. These siltstones and shales are often fractured and downward leakage of water from the Valley Springs aquifer to the Split Rock Creek aquifer may occur, particularly near the southwestern boundary of the Valley Springs aquifer where the layer of siltstones and shales is thinnest.

Water-level fluctuations in observation wells completed in the Valley Springs aquifer show a close correlation with trends in precipitation (fig. 27). The water level in observation well 102N47W34BBAB rose about 2.5 ft from March 1986 to March 1987 because of above-normal precipitation.

The predominant chemical constituents in water from the Valley Springs aquifer are calcium and bicarbonate. A summary of chemical analyses of water from the aquifer is given in tables 7 and 8. Concentrations of dissolved solids ranged from 450 to 920 mg/L and averaged 620 mg/L. Hardness concentrations (as $CaCO_3$) ranged from 320 to 640 mg/L and averaged 440 mg/L.

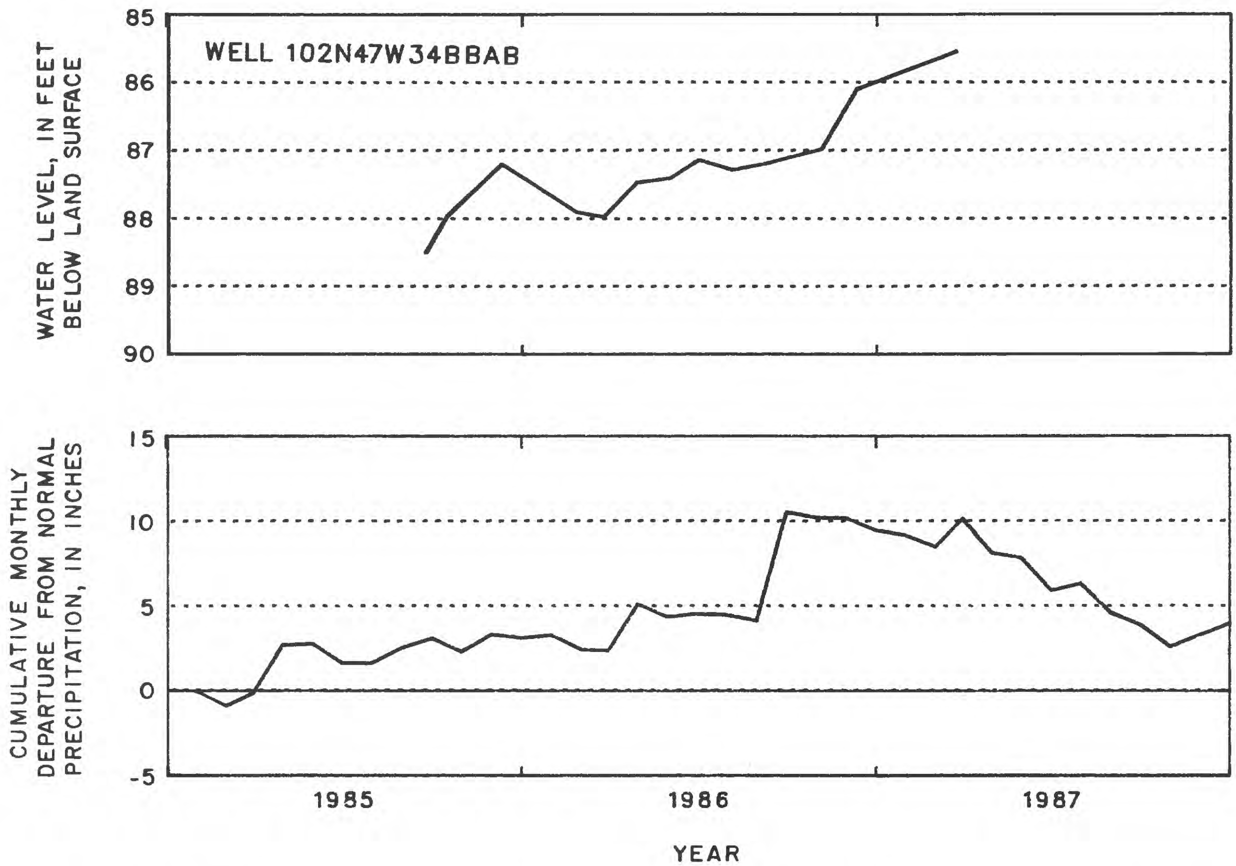


Figure 27.--Water-level fluctuations in the Valley Springs aquifer and cumulative monthly departure from normal precipitation at Sioux Falls.

Water from the Valley Springs aquifer is used for stock watering, domestic, and municipal purposes. About 90 percent of the water withdrawn from the Valley Springs aquifer is used by the city of Valley Springs.

Minor Glacial Aquifers

The Slip Up Creek and Four Mile Creek aquifers are classified as minor aquifers in Minnehaha County (fig. 10). The sand and gravel deposits are present underlying the flood plains of Slip Up and Four Mile Creeks. The deposits are small in areal extent, less than 5 mi^2, with cumulative thicknesses generally of less than 20 ft. A chemical analysis of water from a well completed in Four Mile Creek aquifer is given in table 8.

There also are a few small areas of outwash about 1 mi^2 or less in areal extent near the city of Garretson (Hilton and Barari, 1984) and underlying the flood plain of Split Rock Creek near Sherman.

Bedrock Aquifers

The major bedrock aquifers present in Minnehaha County, in decreasing order, are the Split Rock Creek and Sioux Quartzite aquifers. The Split Rock Creek aquifer lies in valleys in the Sioux Quartzite (Precambrian) surface and is composed of layers of predominantly quartz sand interbedded with layers of siltstone, shale, and silty clay of the Split Rock Creek Formation. The Sioux Quartzite yields moderate amounts of water to wells in areas where fractures are well developed and interconnected. The Sioux Quartzite is extensively used as a source of water in areas where glacial or the Split Rock Creek aquifers are not present, including much of western and east-central Minnehaha County.

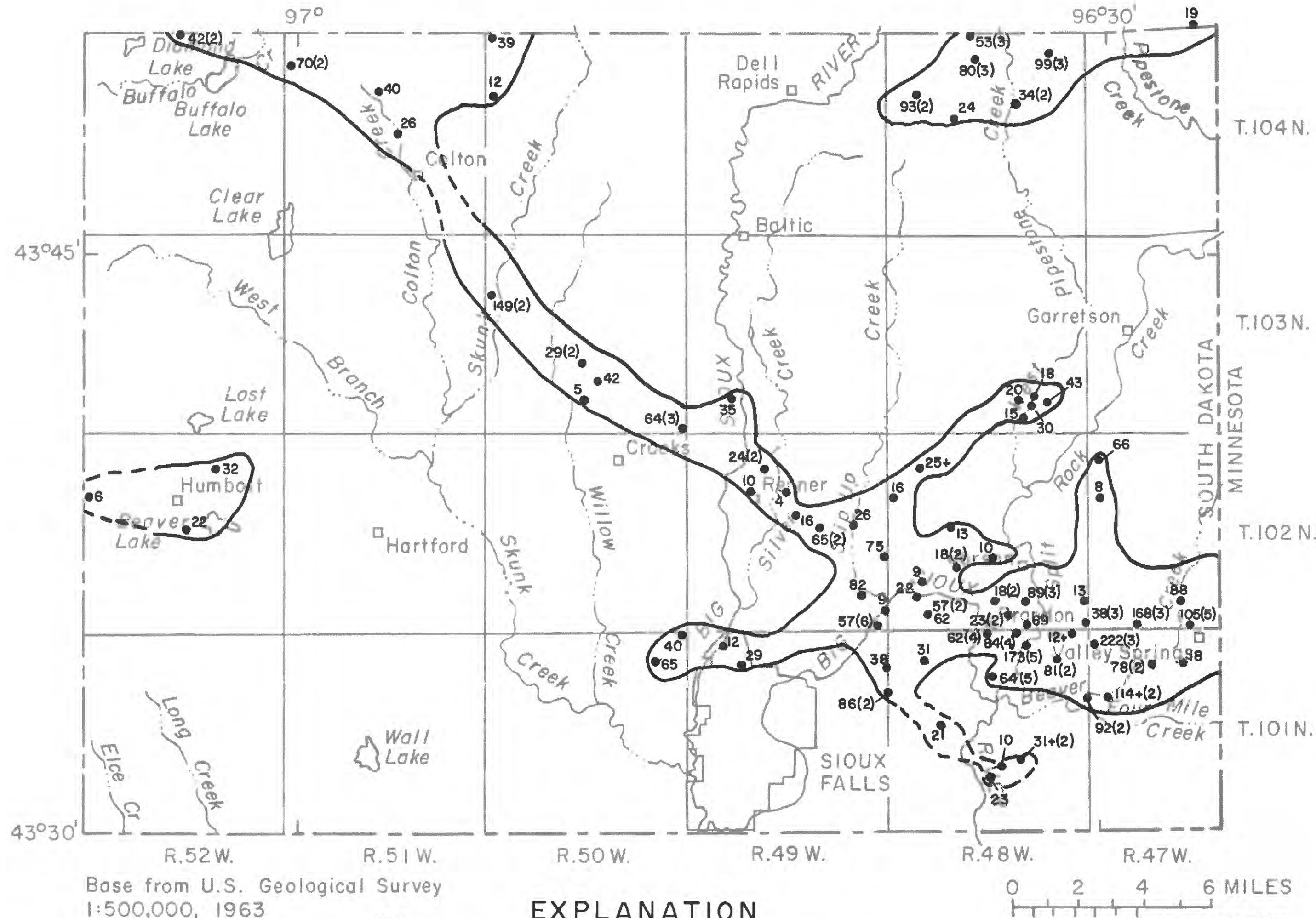
During pre-Cretaceous time, the Sioux Quartzite was a topographic high and subject to erosion. Either wave action or streams reworked sediment from the weathered quartzite and deposited the Split Rock Creek Formation in the valleys and throughout the Cretaceous sediments. The Split Rock Creek aquifer is composed of coarse quartzose sands and is interbedded in the Cretaceous bedrock in Minnehaha County; thus, the age of the aquifer is Cretaceous.

Split Rock Creek Aquifer

The Split Rock Creek aquifer underlies about 139 mi^2 in Minnehaha County, predominantly in the southeastern part of the county (fig. 28). A geologic section of the aquifer is shown in figures 11, 12, 13, and 14, and hydrologic characteristics are given in table 6. Depth to the top of the aquifer ranges from 21 ft in T. 103 N., R. 48 W. to 337 ft near the Minnehaha-Lake County line. Depth to the top of the aquifer generally is from 250 to 335 ft in T. 104 N. near the South Dakota-Minnesota State line in southeastern Minnehaha County and in T. 103 N., R. 50 W. and is from 100 to 200 ft for most of the rest of the aquifer. The maximum cumulative thickness of the sand and gravel (predominantly sand) layers of the Split Rock Creek aquifer is 222 ft and the average cumulative thickness is about 48 ft. The cumulative thickness of sand and gravel is: (1) Greater than 150 ft in the major valley in the Sioux Quartzite surface between Brandon and Valley Springs and near the Minnehaha-Lake County line, (2) generally greater than 90 ft in the northern part of T. 104 N., R. 48 W., and (3) generally less than 50 ft for the parts of the aquifer not included in (1) or (2) above.

The Split Rock Creek aquifer is composed predominantly of 1 to 5 layers of fine to coarse well-sorted quartzose sand interbedded with 4- to 45-ft-thick layers of siltstone, shale, and claystone of the Split Rock Creek Formation. The aquifer is underlaid by Sioux Quartzite and generally is overlaid by till. Properly constructed wells may yield as much as 500 gal/min where the cumulative thickness exceeds 75 ft, but yields usually are much less because of smaller thicknesses, interbedded layers of silt and clay, and cementation of the sand grains.

Recharge to the Split Rock Creek aquifer probably is from infiltration of precipitation that falls on Sioux Quartzite outcrops and subsequently moves along fractures in the quartzite and into the Split Rock Creek aquifer. Sioux Quartzite outcrops occur to the north, south, and west of the aquifer in southeastern Minnehaha County. Split Rock Creek also is a source of recharge to the Sioux Quartzite in Palisades State Park and in some areas to the south where water in the creek flows directly over the quartzite. The aquifer may also receive recharge from the Valley Springs aquifer.



EXPLANATION

64(5) TEST HOLE--Number is thickness of sand and gravel, in feet. Number in parenthesis refers to number of layers of sand and gravel, if more than one layer is present. A plus (+) indicates thickness greater than shown

AQUIFER BOUNDARY--Dashed where approximately located

Figure 28.--Areal extent and thickness of the Split Rock Creek aquifer in Minnehaha County.

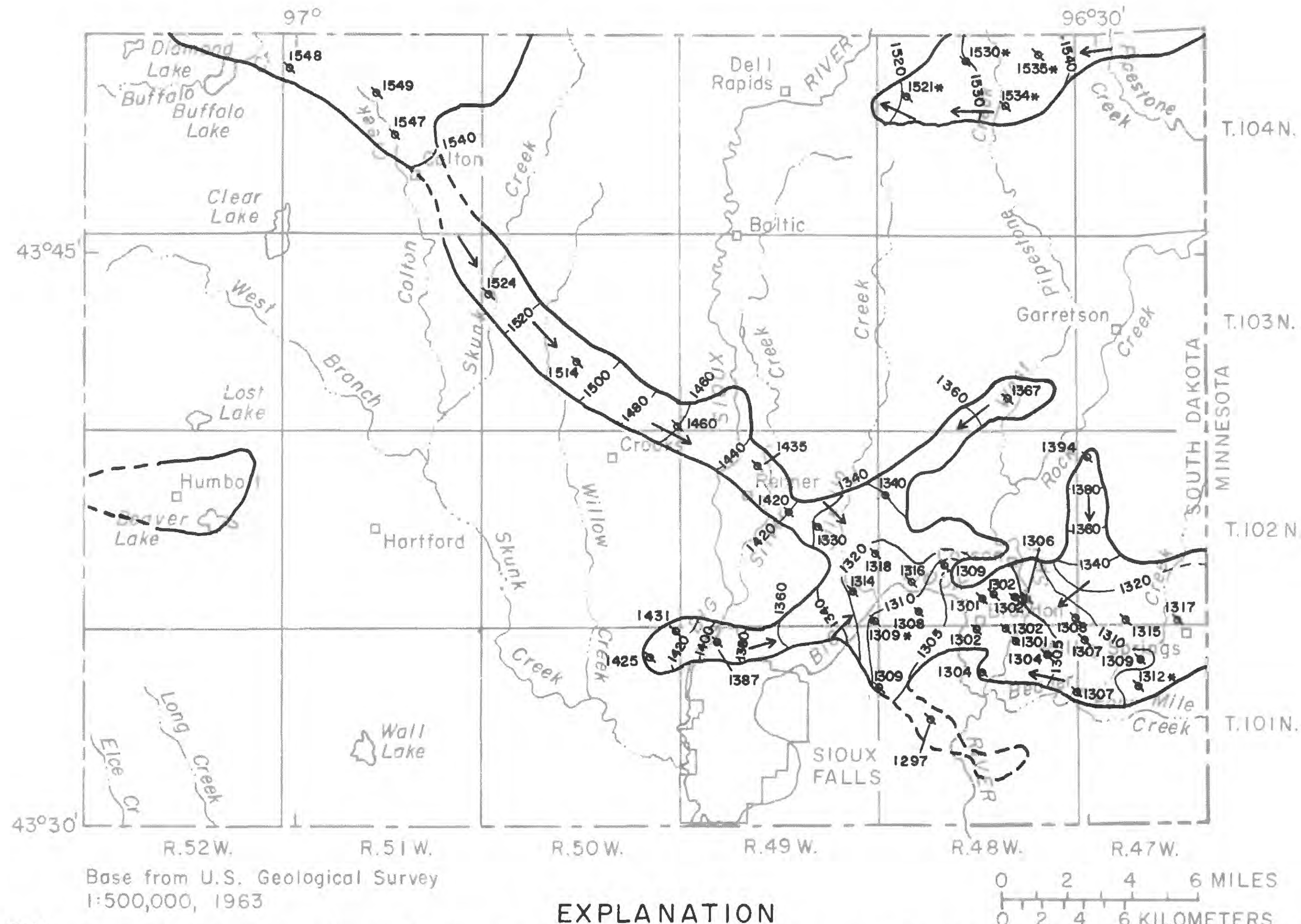
Subsurface inflow from Minnesota is about 1,375 acre-ft/yr. Subsurface inflow from Moody County is minimal because the direction of flow is predominantly parallel to the Minnehaha-Moody County line.

The direction of water movement in the Split Rock Creek aquifer (fig. 29) generally is towards discharge areas in southeastern Minnehaha County near the Big Sioux River and Split Rock Creek where water moves upward through fractured siltstones and claystones into the Big Sioux and Brandon aquifers. The gradient of the potentiometric surface is to the southeast at about 2 to 3 ft/mi in western T. 102 N., R. 48 W. just north of the Big Sioux River where the flow discharges upward. East of this discharge area, there is a similar gradient to the west at 2 to 3 ft/mi in the major valley in the Sioux Quartzite surface between Brandon and Valley Springs where the cumulative thickness is greater than 150 ft. The potentiometric surface between the Big Sioux River and Split Rock Creek is nearly flat, indicating little horizontal flow; flow is presumably upward towards the overlying aquifer enroute to discharging into the rivers. The gradient of the potentiometric surface is much larger, ranging from about 10 to 35 ft/mi, and is 1 mi wide in the narrow, lower transmissivity, arm-like extensions radiating to the west, northwest, and north of the main body of the aquifer. The direction of water movement in the Split Rock Creek aquifer in northeastern Minnehaha County is to the west towards the Dell Rapids Quarry at a gradient of about 5 ft/mi and in northwestern Minnehaha County is to the northwest at a gradient of less than 0.5 ft/mi.

The Split Rock Creek aquifer is under confined conditions except near observation well 102N49W14CCCC where it is under water-table conditions (D-D′, fig. 14). Water levels in wells range from 10 ft above to 187 ft below land surface. Wells completed in the Split Rock Creek aquifer in the Big Sioux River flood plain in the southwestern part of T. 102 N., R. 48 W. flow most of the time. Water also flowed from a test hole drilled to Sioux Quartzite at 101N48W15ABBB in which 18 ft of siltstone was present but no sand was present. The depth to water in the majority of wells completed in the Split Rock Creek aquifer is 50 to 100 ft below land surface.

Discharge from the Split Rock Creek aquifer is: (1) To the Big Sioux aquifer in northern T. 101 N., R. 48 W., southern T. 102 N., R. 48 W., and southeastern T. 102 N., R. 49 W, (2) to the Brandon aquifer, and (3) to stock, domestic, and municipal wells. Subsurface outflow north to Lake County is minimal because the direction of flow is nearly parallel to the Minnehaha-Lake County line and the potentiometric gradient is very small.

Water-level fluctuations in observation wells completed in the Split Rock Creek aquifer are caused by seasonal changes in recharge (figs. 30 and 31). Water levels in wells generally rise 1 to 2 ft during the spring and early summer because of recharge from snowmelt and rainfall that infiltrates into the Sioux Quartzite at outcrop areas and subsequently moves along fractures in the quartzite and into the Split Rock Creek aquifer. Water levels in wells generally decline during the summer and fall because of lower recharge from precipitation. The water-level rise observed in wells during the fall of 1986 was caused by September precipitation that was about 6.5 in. above normal. Long-term records of water-level fluctuations in wells show a close correlation with long-term trends in precipitation. The comparatively high water levels measured in wells during 1983-86 were caused by above-normal precipitation and the comparatively low water levels measured during 1980-82 were caused by below-normal precipitation.



EXPLANATION

1312* OBSERVATION WELL--Number is altitude of water surface, in feet. An asterisk (*) indicates a July 1987 water level. Datum is sea level

—1310-- POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, variable

AQUIFER BOUNDARY--Dashed where approximately located

DIRECTION OF GROUND-WATER MOVEMENT

Figure 29.--Potentiometric surface of the Split Rock Creek aquifer, September 1986, in Minnehaha County.

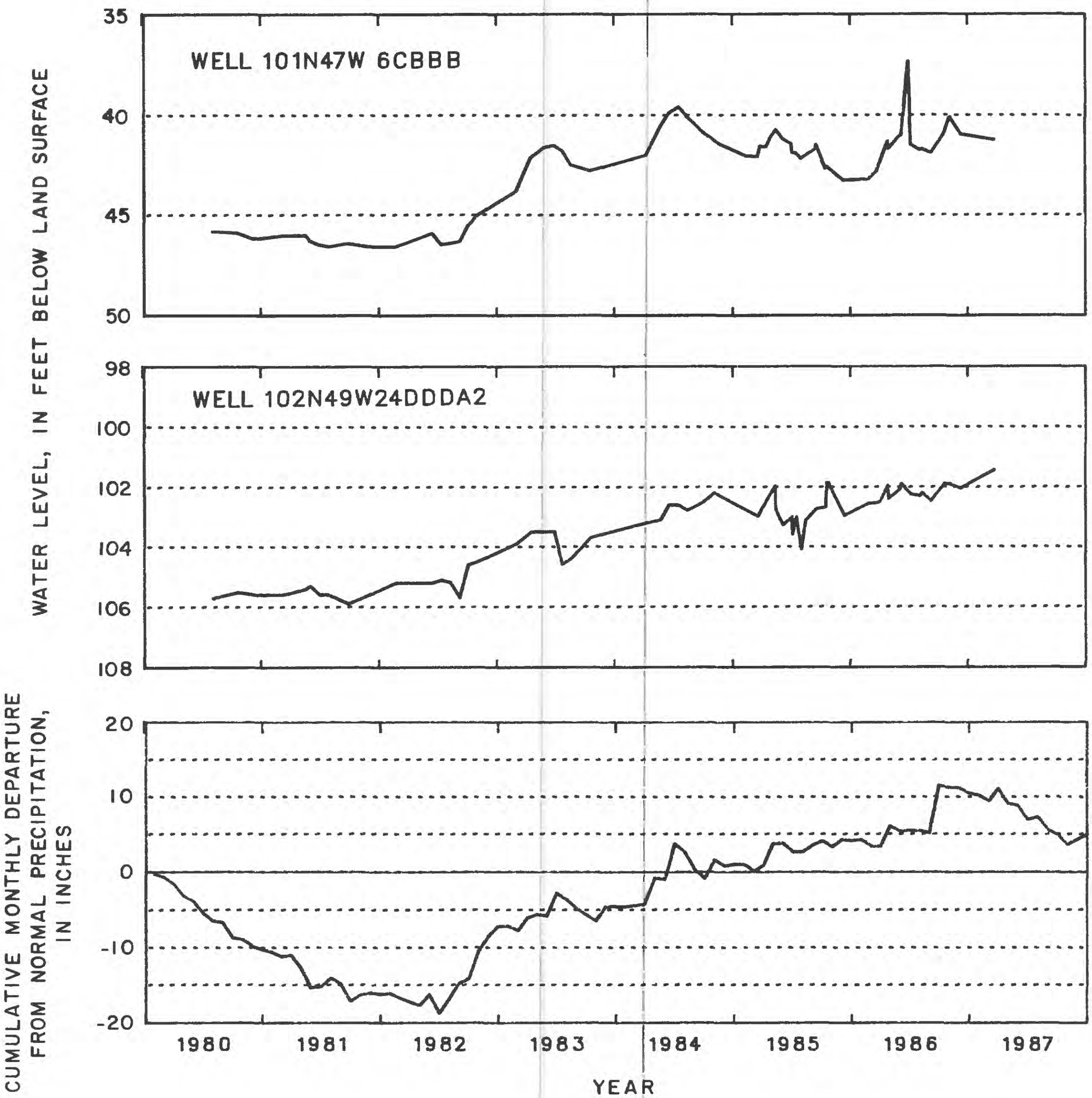


Figure 30.--Water-level fluctuations in the Split Rock Creek aquifer and cumulative monthly departure from normal precipitation at Sioux Falls.

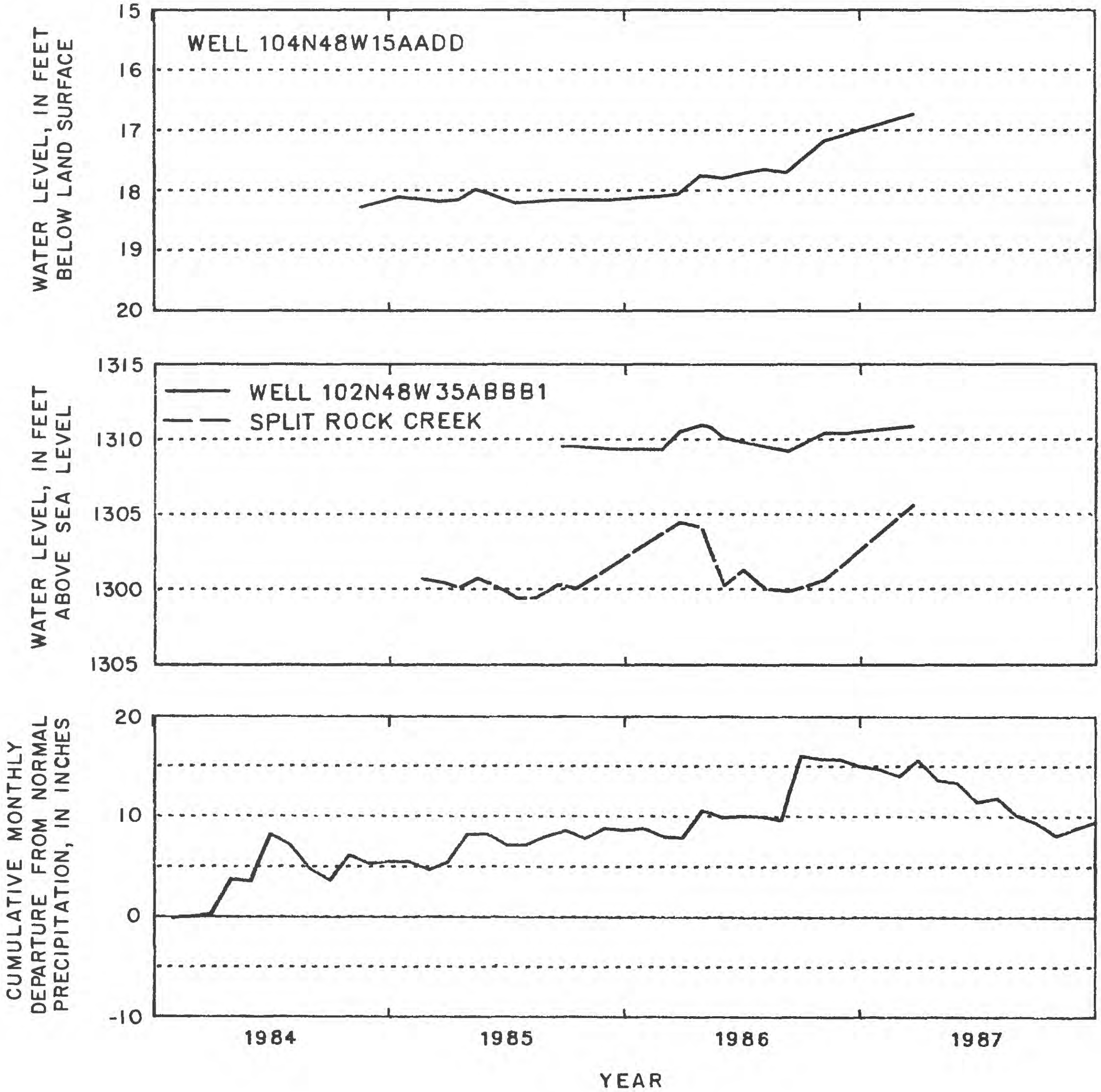


Figure 31.--Water-level fluctuations in the Split Rock Creek aquifer, river-stage fluctuations in Split Rock Creek, and cumulative monthly departure from normal precipitation at Sioux Falls.

Water-level fluctuations in well 102N48W35ABBB1 (fig. 31), located about 50 ft from Split Rock Creek, show a close correlation with fluctuations in creek stage measured from a nearby bridge. The water level in the well was always much higher than creek stage during 1985-87, indicating discharge from the aquifer to Split Rock Creek.

The predominant chemical constituents in water from the Split Rock Creek aquifer are calcium and sulfate. A summary of chemical analyses of water from the aquifer is given in tables 7 and 8. Concentrations of dissolved solids ranged from 230 to 2,300 mg/L and averaged 890 mg/L. Hardness concentrations (as $CaCO_3$) ranged from 180 to 1,700 mg/L and averaged 620 mg/L. Recharge to the Split Rock Creek aquifer from infiltration of precipitation that falls on Sioux Quartzite outcrops and subsequently moves along fractures in the quartzite and into the Split Rock Creek aquifer may be indicated by relatively high bicarbonate and relatively low sulfate percentages in areas of the Split Rock Creek aquifer near Sioux Quartzite outcrops. Bicarbonate percentages generally exceed 70 percent in the areas near Sioux Quartzite outcrops and are less than 35 percent in areas such as the northwest to southeast-trending channel that are not close to outcrop areas and probably receive comparatively less rapid recharge from fractures in the Sioux Quartzite (fig. 32). Concentrations of dissolved solids generally are lower in areas of the Split Rock Creek aquifer near Sioux Quartzite outcrops, generally being less than 600 mg/L compared to greater than 1,000 mg/L for other areas, further indicating comparatively rapid recharge through fractures in the Sioux Quartzite.

Water from the Split Rock Creek aquifer is used for stock watering and domestic purposes. The city of Brandon has a municipal well completed in the aquifer, but the well usually is not used.

Sioux Quartzite Aquifer

The Sioux Quartzite aquifer underlies all of Minnehaha County. An altitude map of the top of the Sioux Quartzite is shown in figure 33. The hydrologic characteristics of the aquifer are given in table 6. The Sioux Quartzite is a locally well-fractured and jointed crystalline rock that will yield water to wells in amounts sufficient for domestic and municipal supplies. In some places, the Sioux Quartzite is directly overlaid by a discontinuous layer of fine to coarse well-sorted quartzose sand that is derived from weathering of the Sioux Quartzite. The depth and development of the fracture system in the Sioux Quartzite is unknown but water-supply wells commonly penetrate the quartzite to a depth of 200 ft or less. Depth to the top of the Sioux Quartzite aquifer ranges from at or near land surface to 510 ft below land surface, often with large changes in depth in a short distance. Depth to the top of the Sioux Quartzite aquifer exceeds 300 ft in the northwestern, northeastern, and southeastern parts of Minnehaha County. The Sioux Quartzite aquifer is overlaid by: (1) Till, (2) Pierre Shale in southwestern Minnehaha County, (3) the Big Sioux aquifer in northern T. 104 N., R. 49 W., northeastern T. 101 N., R. 49 W., and southern T. 101 N., R. 48 W., (4) the Skunk Creek aquifer near the Sioux Quartzite outcrop area in T. 101 N., R. 51 W., section 11, (5) the Pipestone Creek aquifer south of the Sioux Quartzite outcrop area in northeastern T. 103 N., R. 48 W., (6) the Wall Lake aquifer, and (7) the Split Rock Creek aquifer. Reported yields from properly constructed wells completed in the Sioux Quartzite aquifer are as much as 150 gal/min but generally are less than 50 gal/min. The yield to wells depends on the extent of the local fracturing and interconnection of fractures in the Sioux Quartzite.

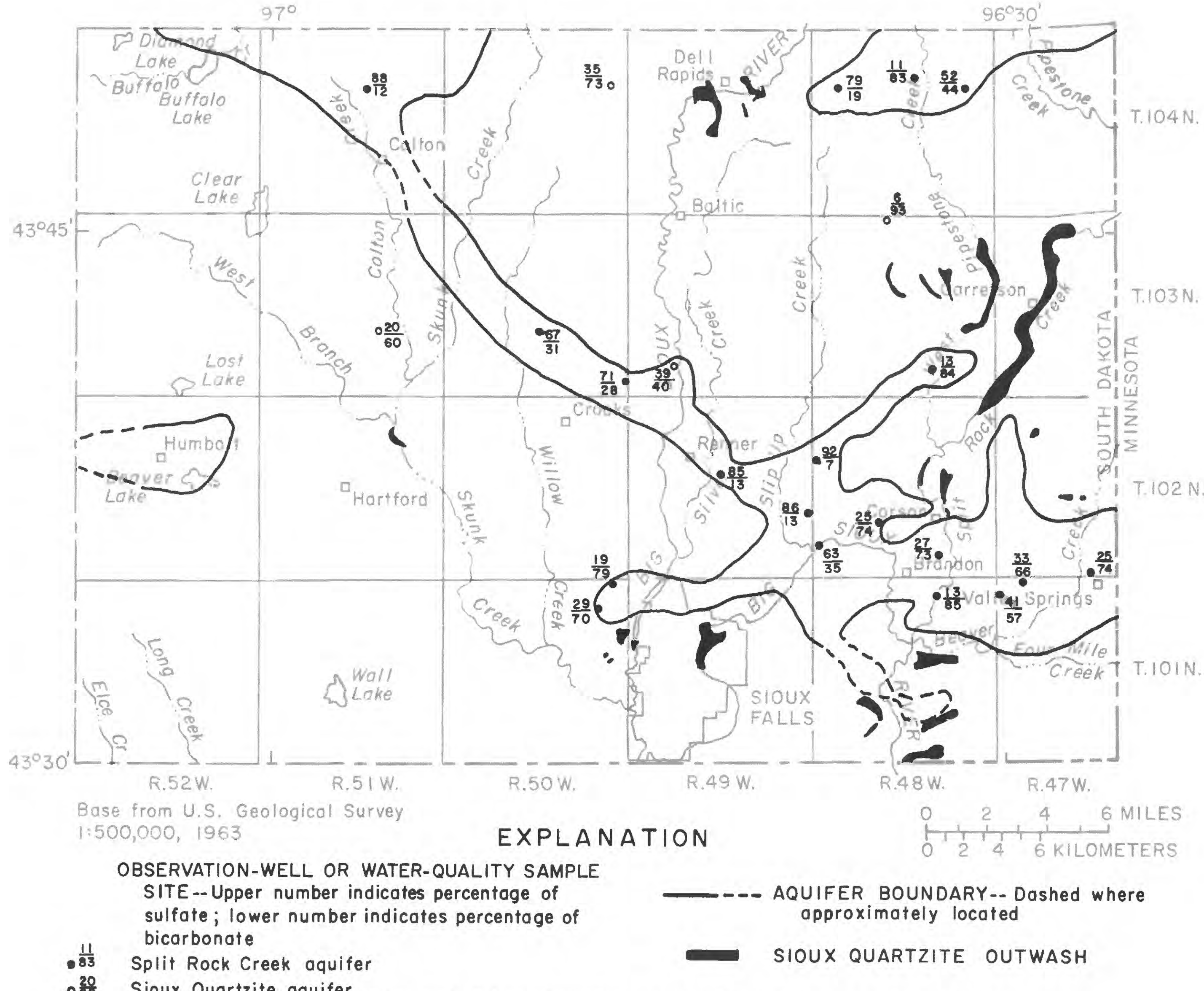
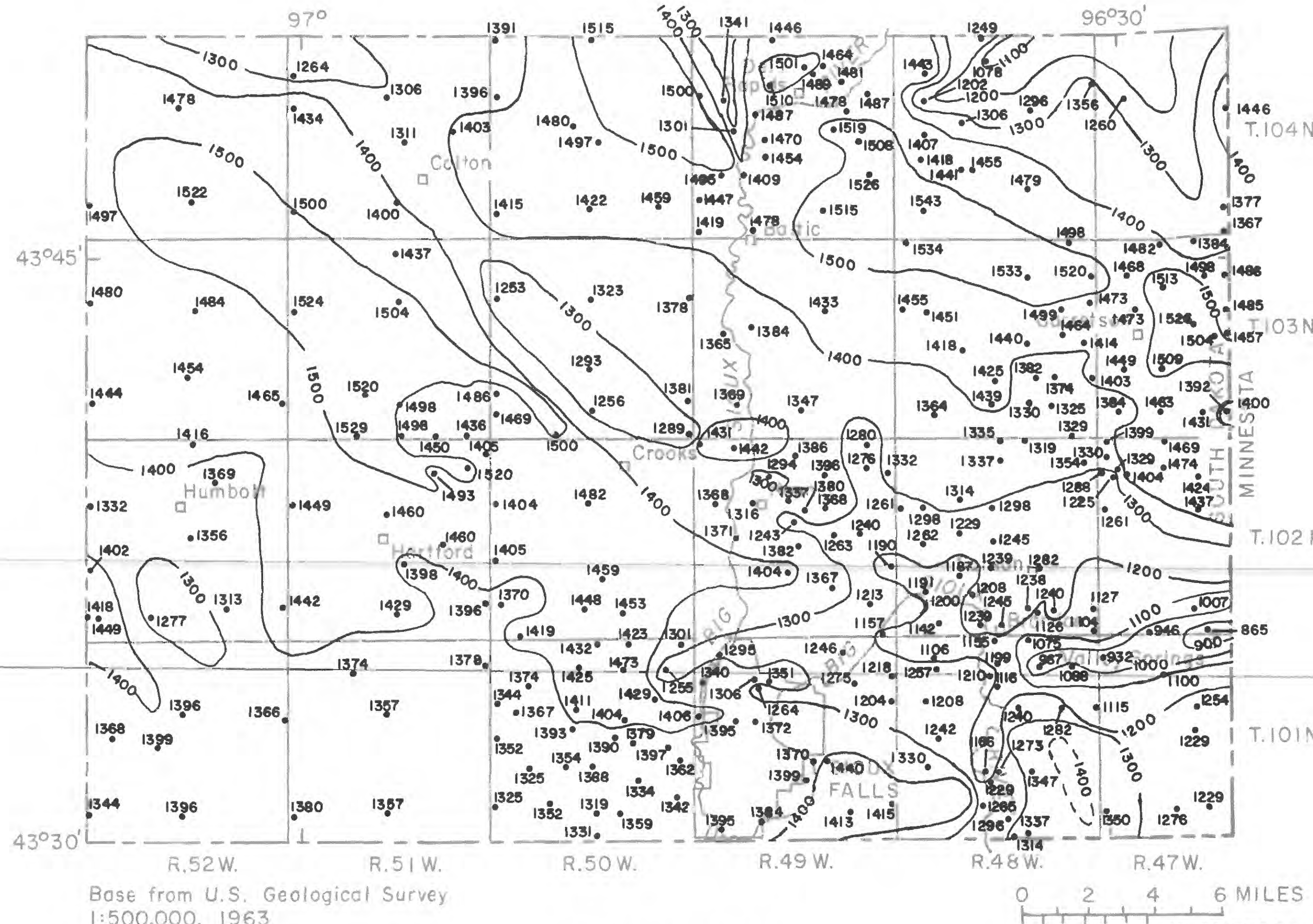


Figure 32.--Sulfate and bicarbonate percentages for parts of the Split Rock Creek and Sioux Quartzite aquifers.



EXPLANATION

1330 TEST HOLE--Number is altitude of the top of the aquifer, in feet. Datum is sea level

—1400— STRUCTURE CONTOUR--Shows altitude of the top of the aquifer. Contour interval, 100 feet

Figure 33.--Altitude and configuration of the top of the Sioux Quartzite aquifer in Minnehaha County.

Recharge to the Sioux Quartzite aquifer is from infiltration of snowmelt and rainfall in areas where the Sioux Quartzite is at or near land surface. Split Rock Creek probably is also a source of recharge to the Sioux Quartzite aquifer in Palisades State Park and in some areas to the south where water in the creek flows directly over the quartzite surface.

Based predominantly on reported water levels, water enters the Sioux Quartzite aquifer at outcrop areas and subsequently moves predominantly to the south and southwest following the regional dip in the Sioux Quartzite surface. The general flow pattern is altered in some areas by the movement of water towards other aquifers in the valleys in the Sioux Quartzite surface. The predominant source of water-level data for the Sioux Quartzite aquifer was reported water levels from private wells and was not considered reliable enough by the authors to construct a potentiometric surface map or to calculate potentiometric gradients. The reported water-level data was used, however, to determine the general flow pattern in the Sioux Quartzite aquifer.

The Sioux Quartzite aquifer is under water-table conditions near the Sioux Quartzite outcrop areas and generally is under confined conditions elsewhere in Minnehaha County. The depth to water in wells ranges from land surface at the outcrop areas to 300 ft below land surface in west-central Minnehaha County.

Discharge from the Sioux Quartzite aquifer is to: (1) The Big Sioux aquifer in northern T. 104 N. and southern T. 101 N., R. 48 W., (2) the Brandon aquifer, (3) the Wall Lake aquifer, (4) the Split Rock Creek aquifer, and (5) stock-watering, domestic, and municipal wells.

Water-level fluctuations in observation wells completed in the Sioux Quartzite aquifer show a close correlation with long-term trends in precipitation (fig. 34). The comparatively high water levels measured in well 103N49W29CDCC during 1983-86 were caused by above-normal precipitation and the comparatively low water levels measured during 1980-82 were caused by below-normal precipitation. Water-level rises measured during the spring, which were caused by seasonal recharge, ranged from about 1 to 2.5 ft from 1983-86. The water-level rise measured in most observation wells in Minnehaha County during the fall of 1986 was also measured in well 103N49W29CDCC.

The predominant chemical constituents in water from the Sioux Quartzite aquifer are calcium and sulfate. A summary of chemical analyses of water from the aquifer is given in tables 7 and 8. Concentrations of dissolved solids ranged from 320 to 3,300 mg/L and averaged 1,030 mg/L. Hardness concentrations (as $CaCO_3$) ranged from 280 to 3,000 mg/L and averaged 820 mg/L. The available data indicate that dissolved-solids and hardness concentrations in water from wells completed in the Sioux Quartzite aquifer are lowest near Sioux Quartzite outcrop (recharge) areas and increase with increasing distance from the outcrop areas. The available data also indicate that bicarbonate percentages are greatest (greater than 60 percent) and sulfate percentages are lowest (less than 30 percent) near the Sioux Quartzite outcrop areas (fig. 32). The percentages of bicarbonate and sulfate decrease to less than 40 percent and increase to more than 50 percent, respectively, as distance from the outcrop areas increases.

Water from the Sioux Quartzite aquifer is used for stock watering, domestic, and municipal purposes. About 48 percent of the water withdrawn

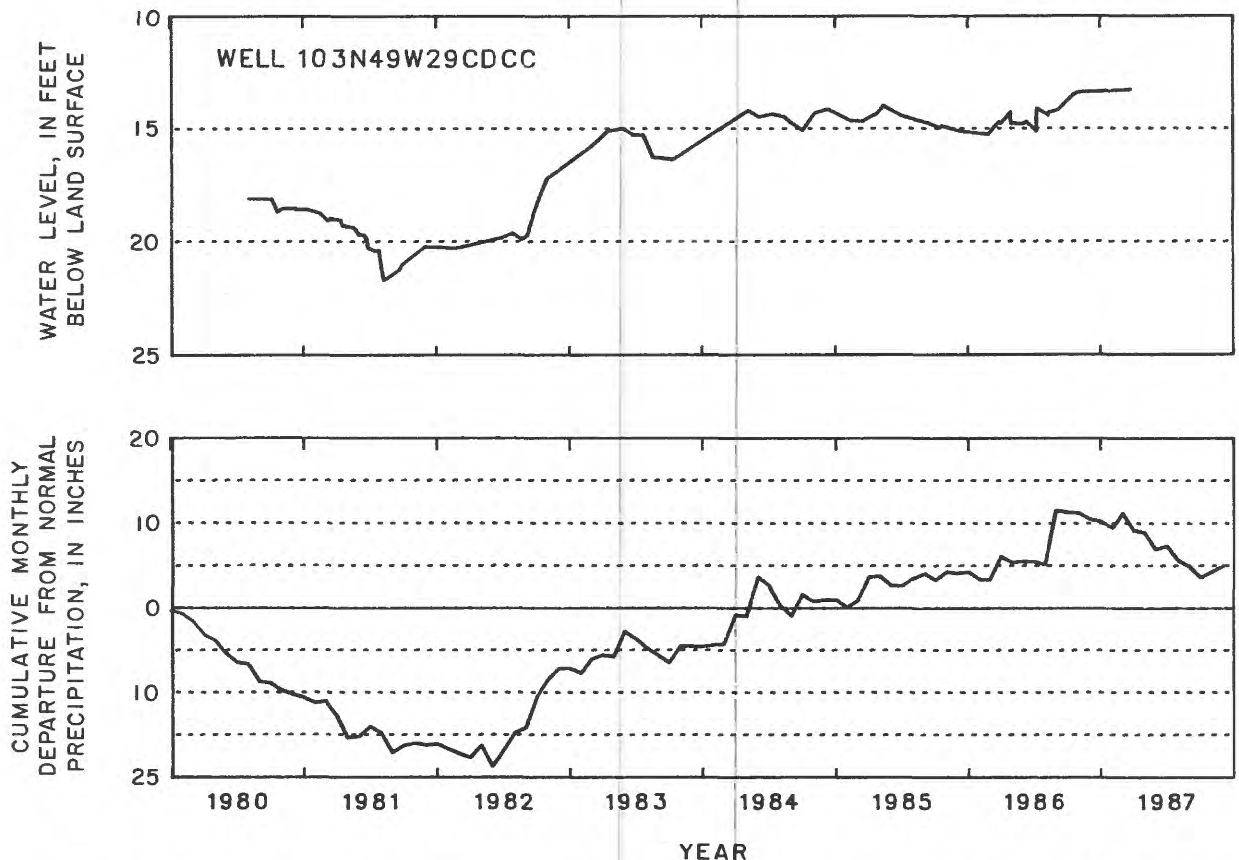


Figure 34.--Water-level fluctuations in the Sioux Quartzite aquifer and cumulative monthly departure from normal precipitation at Sioux Falls.

WATER USE

Surface water in Minnehaha County is used predominantly for stock-watering and irrigation purposes. Total surface-water use in Minnehaha County in 1985 was about 416 million gallons. About 60 percent of the total was for stock-watering purposes and about 40 percent was for irrigation.

Water use from glacial and bedrock aquifers in Minnehaha County in 1985 was estimated to be about 5.87 billion gallons (table 9). About 94 percent of the water used was withdrawn from glacial aquifers and about 6 percent of the water used was withdrawn from bedrock aquifers. Eighty-five percent of the water withdrawn from the aquifers in Minnehaha County was used for municipal purposes and 94 percent of the water withdrawn for municipal purposes was used by the city of Sioux Falls. About 347 million gallons (6 percent of the estimated 1985 water use) of water were withdrawn from the Big Sioux, Skunk Creek, and Brandon aquifers in 1985 for irrigation purposes. About 35 percent of the water withdrawn from the aquifers for rural domestic purposes was withdrawn from the Sioux Quartzite aquifer.

Table 9.--Estimated ground-water withdrawal in 1985

[Reported in million gallons]

Aquifers	Total	Municipal	Rural-domestic	Livestock	Irrigation[1]
GLACIAL					
Big Sioux	5,130	4,764	182	17	167
Skunk Creek	230	0	39	19	172
Pipestone Creek	17	0	11	6	0
Beaver Creek	9	0	6	3	0
Brandon	91	76	5	2	8
Colton	31	19	8	4	0
Wall Lake	10	0	7	3	0
Howard	--	--	--	--	--
Valley Springs	21	19	1	1	0
BEDROCK					
Split Rock Creek	29	0	19	10	0
Sioux Quartzite	302	86	145	71	0
Total	5,870	4,964	423	136	347

[1]Based on reported 1985 irrigation data.

SUMMARY

The water resources of Minnehaha County occur as surface water in streams and lakes and as ground water in glacial and bedrock aquifers. The major surface-water sources are the Big Sioux River and its intermittent tributaries. Seasonal variations in streamflow reflect seasonal variations in precipitation and snowmelt, being greatest during the spring and early summer and least during late summer and winter. The Big Sioux River, Skunk Creek, Split Rock Creek, Beaver Creek, Pipestone Creek, West Pipestone Creek, and Colton Creek receive discharge from ground-water storage. For the Big Sioux River near Dell Rapids and at North Cliff Avenue at Sioux Falls, the average annual flow is exceeded only about 20 to 25 percent of the time and for Skunk Creek at Sioux Falls and Split Rock Creek at Corson the average annual flow is exceeded only about 16 percent of the time. Lakes in Minnehaha County are: (1) Small, less than 500 acres in areal extent, (2) shallow, less than 15 ft deep, and (3) restricted to the western one-third of the county.

The predominant chemical constituents in water from the Big Sioux River near Dell Rapids, Big Sioux River at North Cliff Avenue, at Sioux Falls, Skunk Creek at Sioux Falls, and Split Rock Creek at Corson are calcium, sulfate, and bicarbonate. Dissolved-solids concentrations of water from streams and lakes varies inversely with the volume of streamflow and with lake levels.

Large amounts of ground water may be obtained from nine major glacial and two major bedrock aquifers in Minnehaha County. The glacial aquifers are composed primarily of unconsolidated sand and gravel deposited as outwash and contain about 725,000 acre-ft of water in storage. The Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, Brandon, and Colton aquifers are predominantly shallow, water-table aquifers with average cumulative thicknesses ranging from about 10 to 20 ft for the Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, and Colton aquifers to about 35 ft for the Brandon aquifer. The Big Sioux, Skunk Creek, Pipestone Creek, Beaver Creek, and Brandon aquifers extend beyond the flood plains of the streams they underlie in some small areas and are overlaid by as much as 100 ft of till. In the areas where the aquifers are overlaid by till, confined conditions exist. Estimated maximum well yields are about 1,000 gal/min for the Big Sioux and Skunk Creek aquifers and about 500 gal/min for the Pipestone Creek, Beaver Creek, Brandon, and Colton aquifers.

Recharge to the shallow, water-table aquifers primarily is by infiltration of precipitation in the flood plains of the overlying streams where the aquifers are at or near land surface. The Big Sioux aquifer also receives recharge from: (1) Seepage from the Big Sioux River when river stage is higher than the potentiometric surface in the aquifer, (2) the Skunk Creek aquifer, (3) the Beaver Creek aquifer, (4) the Brandon aquifer, (5) the Split Rock Creek aquifer, and (6) the Wall Lake aquifer. The Skunk Creek aquifer also receives recharge from the Wall Lake aquifer. The Brandon aquifer also receives recharge from the Beaver Creek, Split Rock Creek, and probably the Sioux Quartzite aquifers. Discharge from the shallow, water-table aquifers is: (1) By evapotranspiration where the aquifers are at or near land surface, (2) by seepage to the streams the aquifers underlie, (3) to adjacent hydraulically connected aquifers, and (4) to stock, domestic, municipal, and irrigation wells.

The predominant chemical constituents in water from the Big Sioux and Skunk Creek aquifers are calcium, sulfate, and bicarbonate; from the Colton aquifer are calcium, magnesium, and sulfate; and from the Pipestone Creek, Beaver Creek, and Brandon aquifers are calcium and bicarbonate. The average dissolved-solids concentrations ranged from 443 to 1,100 mg/L, and the average hardness concentrations (as $CaCO_3$) ranged from 350 to 810 mg/L in these aquifers.

The Wall Lake, Howard, and Valley Springs aquifers are buried, predominantly confined aquifers overlaid by 19 to 265 ft of till with average cumulative thicknesses of about 33, 28, and 15 ft, respectively. Estimated maximum well yields are about 500 gal/min for the Wall Lake and Howard aquifers and about 200 gal/min for the Valley Springs aquifer.

Recharge to the Wall Lake aquifer probably is from infiltration of precipitation on Sioux Quartzite outcrops to the north of the aquifer and subsequent movement of the water to the south through fractures in the Sioux Quartzite and then into the Wall Lake aquifer. The recharge area for the Howard aquifer probably is located to the north of the study area. The recharge area for the Valley Springs aquifer probably is located to the east of Minnehaha County in Minnesota. Discharge from the Wall Lake aquifer is to: (1) The Skunk Creek aquifer, (2) the Big Sioux aquifer, and (3) stock and domestic wells. Discharge from the Howard aquifer is to fractures in the Sioux Quartzite, to the Dell Rapids quarry, and to stock and domestic wells. Discharge from the Valley Springs aquifer is to stock, domestic, and municipal wells and possibly to the Split Rock Creek aquifer.

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