WATER RESOURCES OF HUTCHINSON AND TURNER COUNTIES, SOUTH DAKOTA

By Richard J. Lindgren and Donald S. Hansen

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

CONVERSION FACTORS

For readers who may prefer to use metric (International System) units rather than inch-pound units, the conversion factors for the terms in this report are listed below:

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

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

$$°C = \frac{°F - 32}{1.8}$$

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

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ABSTRACT

The water resources of Hutchinson and Turner Counties in southeastern South Dakota occur as surface water in streams, lakes, and ponds and as ground water in glacial and bedrock aquifers. The major surface-water sources are the James and Vermillion Rivers and their intermittent tributaries. Dissolved-solids concentrations of water from streams and lakes generally varies inversely with the magnitude of streamflow and with lake levels.

Ground water may be obtained from 11 major glacial and 3 major bedrock aquifers with an estimated 23 million acre-feet of water in storage in Hutchinson and Turner Counties. The glacial aquifers are composed primarily of unconsolidated sand and gravel and contain about 5.2 million acre-feet of water in storage. The Parker-Centerville, West Fork Vermillion, East Fork Vermillion, and Turkey Ridge Creek aquifers are shallow aquifers with depths to the top of the aquifers of less than 65 feet below land surface. The Choteau, Dolton, Turkey Ridge, Wall Lake, and Ethan aquifers are buried aquifers overlaid by 35 to 270 feet of till. The Upper Vermillion-Missouri aquifer is overlaid by as much as 355 feet of glacial till, except in southern Turner County in the Vermillion River flood plain where the aquifer occurs at or near land surface. The Lower James-Missouri aquifer is overlaid by as much as 245 feet of glacial till, except in southern Hutchinson County in the James River flood plain where the aquifer occurs at or near land surface. The average thickness of the glacial aquifers ranges from 18 feet for the Ethan aquifer to 69 feet for the Lower James-Missouri aquifer. Estimated maximum well yields range from 50 gallons per minute for the Turkey Ridge aquifer to 1,000 gallons per minute for the Parker-Centerville, Upper Vermillion-Missouri, Lower James-Missouri, and Choteau aquifers.

The predominant chemical constituents in water from the Parker-Centerville, West Fork Vermillion, East Fork Vermillion, Turkey Ridge Creek, Upper Vermillion-Missouri, Lower James-Missouri, Turkey Ridge, and Wall Lake aquifers are calcium and sulfate; from the Choteau and Ethan aquifers are sodium and sulfate; and from the Dolton aquifer are sodium, sulfate, and bicarbonate. Average dissolved-solids concentrations in water from the glacial aquifers ranged from 870 to 2,200 milligrams per liter and average hardness concentrations ranged from 280 to 1,400 milligrams per liter.

Three major bedrock aquifers, the Niobrara, Codell, and Dakota aquifers, store about 18 million acre-feet of water in Hutchinson and Turner Counties. Water in the aquifers is under confined conditions. The average thickness of the bedrock aquifers is 75 feet for the Niobrara aquifer, 40 feet for the Codell aquifer, and 81 feet for the Dakota aquifer. Estimated maximum well yields are 1,000 gallons per minute for the Niobrara aquifer, 100 gallons per minute for the Codell aquifer, and 250 gallons per minute for the Dakota aquifer. The predominant chemical constituents in water from the Niobrara and Dakota aquifers are calcium, sodium, and sulfate. The predominant chemical constituents in water from the Codell aquifer are sodium and sulfate. Average dissolved-solids concentrations in water from the bedrock aquifers ranged from 1,450 to 1,510 milligrams per liter and average hardness concentrations ranged from 230 to 670 milligrams per liter.

Water use from glacial and bedrock aquifers in Hutchinson and Turner Counties during 1985 was estimated to be about 3.9 billion gallons. Ninety-one percent of the water used was withdrawn from glacial aquifers and 9 percent of the water used was withdrawn from bedrock aquifers. Eighty-three percent of the water withdrawn from the aquifers was used for irrigation.

INTRODUCTION

Hutchinson and Turner Counties (fig. 1) include about 1,430 mi^2 located mostly in the James River lowland physiographic division (Flint, 1955). The southeastern corner of Hutchinson County and the southwestern part of Turner County are located in the James River highland physiographic division. The southwest corner of Hutchinson County is located in the Coteau du Missouri physiographic division, which is a plateau-like highland occupying the area between the Missouri River and the James River basins. Land surface altitudes range from 1,170 ft above sea level in the James River basin to 1,730 ft above sea level on Turkey Ridge and 1,900 ft above sea level in extreme southwestern Hutchinson County on the Coteau du Missouri.

The water resources of Hutchinson and Turner Counties consist of streams and lakes, and glacial and bedrock aquifers. The glacial aquifers consist of sand and gravel outwash, deposited by receding glaciers. The bedrock aquifers consist of late Cretaceous sandstones, siltstones, and marls.

In October 1982, the South Dakota Geological Survey and the U.S. Geological Survey began a 5-year cooperative study to evaluate the geology and water resources of Hutchinson and Turner Counties in southeastern South Dakota. This study is part of an evaluation of the water resources and geology of eastern South Dakota (fig. 1). "Study area," as it appears henceforth, refers to Hutchinson and Turner Counties.

Purpose and Scope

This report provides hydrogeologic information for Hutchinson and Turner Counties. Reliable and current data and analyses are needed for water-resources evaluation and for future water development and planning. This report emphasizes the ground-water resources because previous information about the extent and yield of glacial and bedrock aquifers generally was insufficient for water-resources evaluations.

Methods of Investigation

This investigation included an analysis of streamflow records and chemical analyses, a well inventory, analysis of available drillers' logs, test drilling and installation of observation wells, measurement of static water levels, and chemical analyses of water samples collected from wells. Hydrogeologic data from more than 320 test holes and 206 observation wells were analyzed to determine the areal extent, thickness, and yield of the glacial and bedrock aquifers. Water samples for chemical analyses were collected from 107 wells during the study. The test hole, observation well, and water-quality sampling sites in Hutchinson and Turner Counties are shown in figure 2. Wells, test holes, and sampling sites are numbered according to the Federal land survey system (fig. 3).

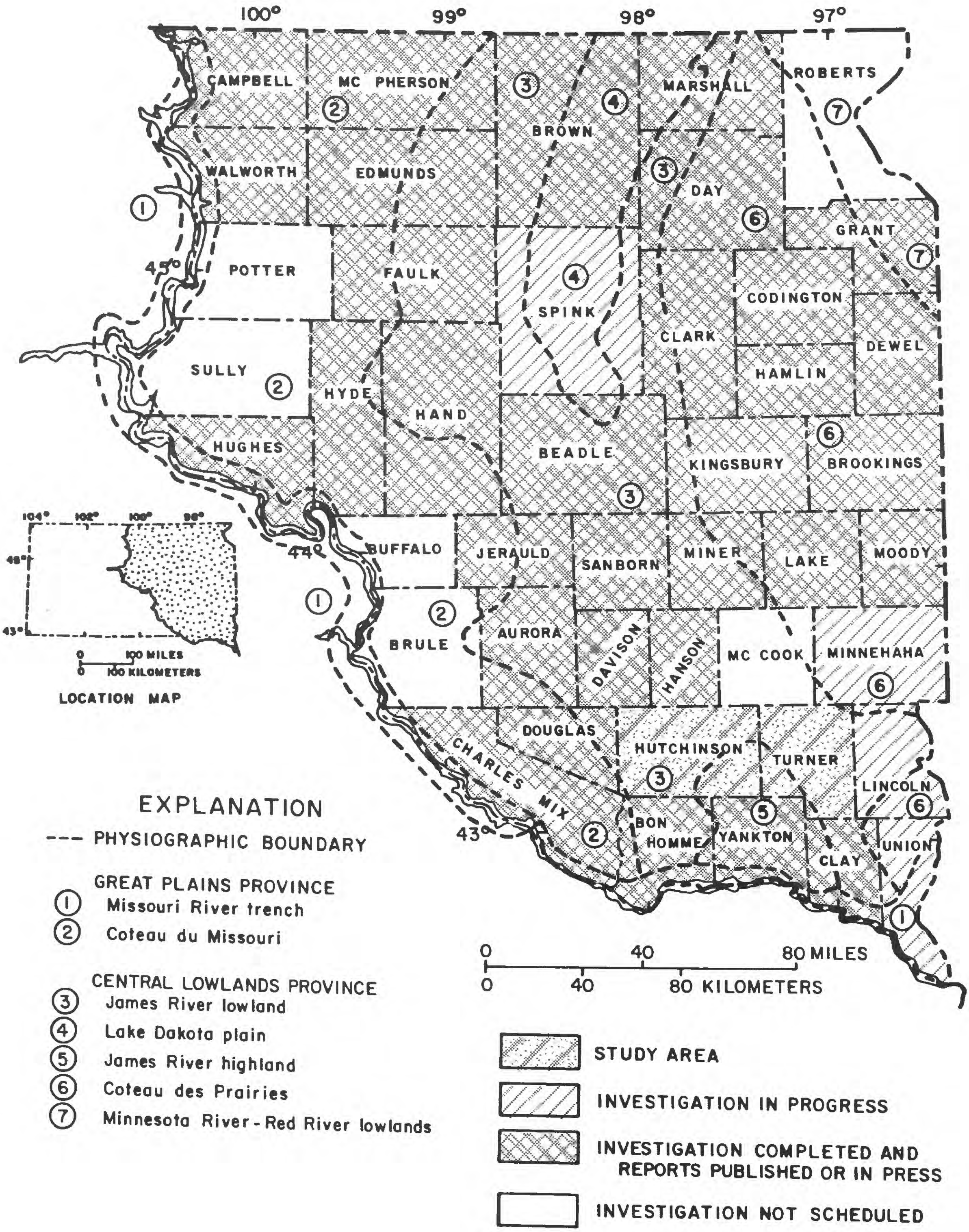
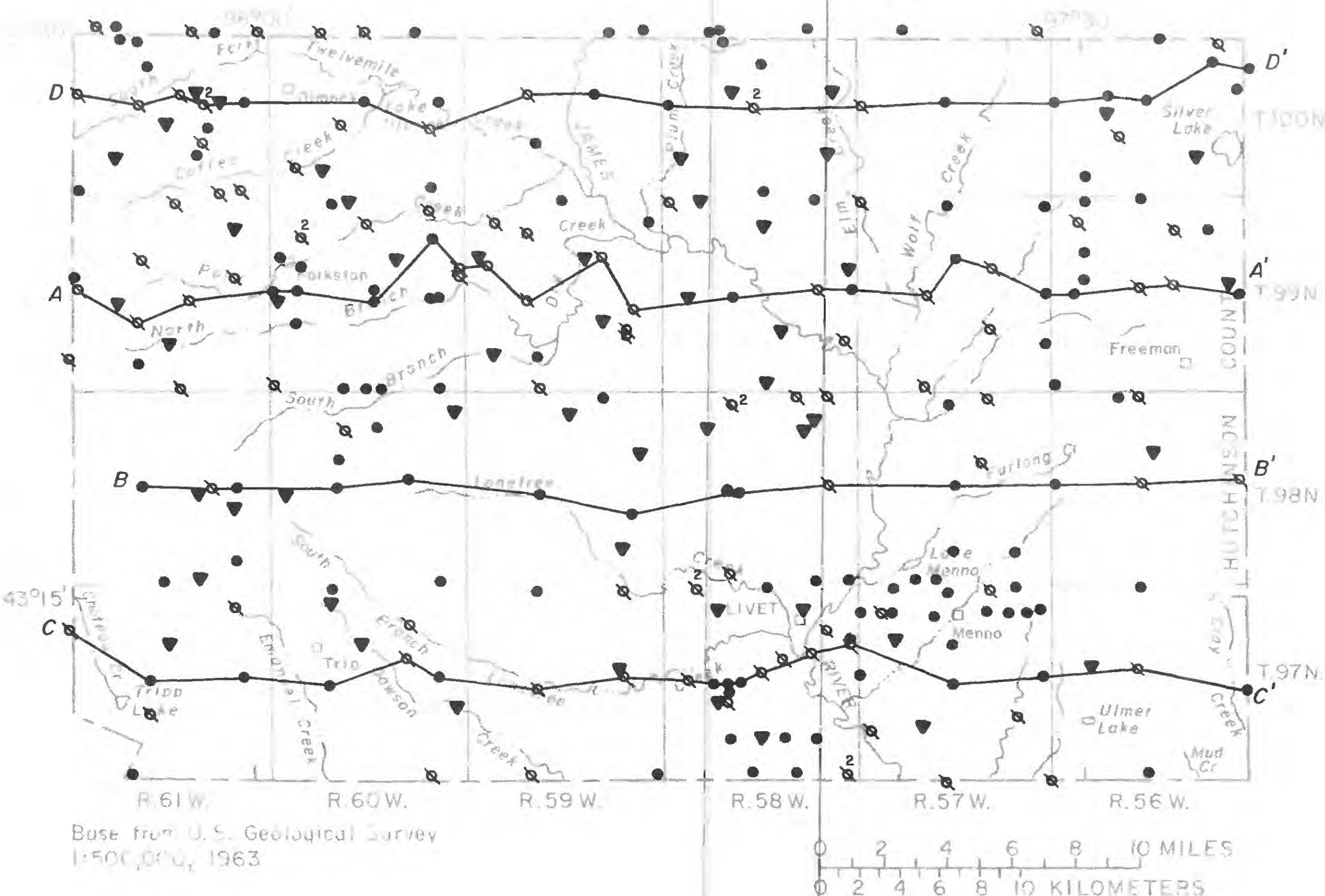


Figure 1.--Index map of eastern South Dakota showing area of this report, status of county investigations, and major physiographic division.



EXPLANATION

- ● TEST-DRILLING SITE--Aquifer description and drillers logs are available from U.S. Geological Survey
- ⊘² OBSERVATION-WELL SITE--Records of water-level measurements are available from U.S. Geological Survey. Number indicates number of wells at same site, if more than one
- ▼ WATER-QUALITY SAMPLE SITE--Complete chemical analyses obtained for this study are available from U.S. Geological Survey
- A—A'—A'' LINE OF GEOLOGIC SECTION

Figure 2.--Location of test holes, observation wells, ground-water-quality sampling sites, and geologic sections in Hutchinson and Turner Counties.

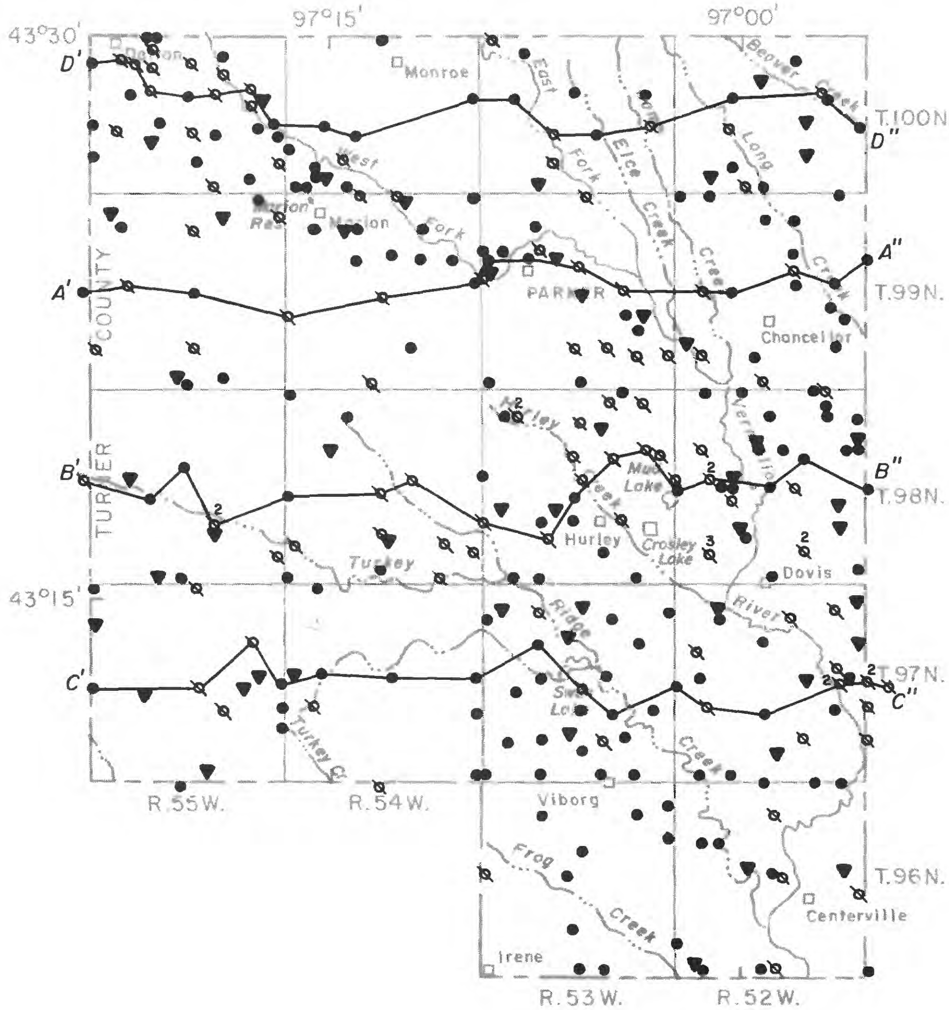


Figure 2.--Location of test holes, observation wells, ground-water-quality sampling sites, and geologic sections in Hutchinson and Turner Counties.--Continued

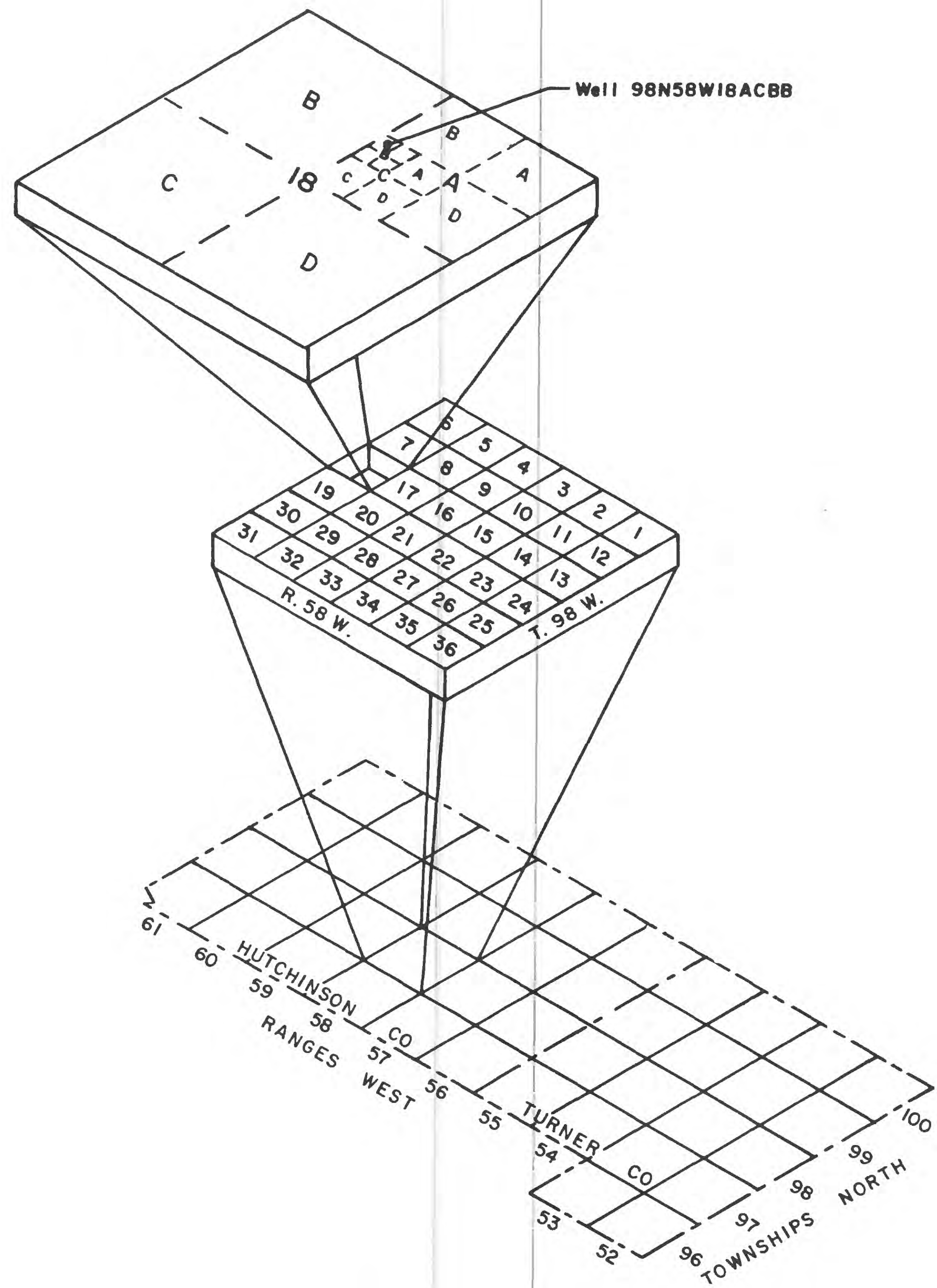


Figure 3.--Well-numbering diagram. The well number consists of township followed by "N," range followed by "W," and section number, followed by a maximum of four uppercase letters that indicate, respectively, the 160-, 40-, 10-, and 2½-acre tract in which the well is located. These letters are assigned in a counter clockwise 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.

Acknowledgments

The authors would like to acknowledge the cooperation of residents and municipal officials of Hutchinson and Turner Counties for providing information concerning the water wells they own or manage. Test-hole information provided by local drilling companies also is appreciated.

WATER RESOURCES

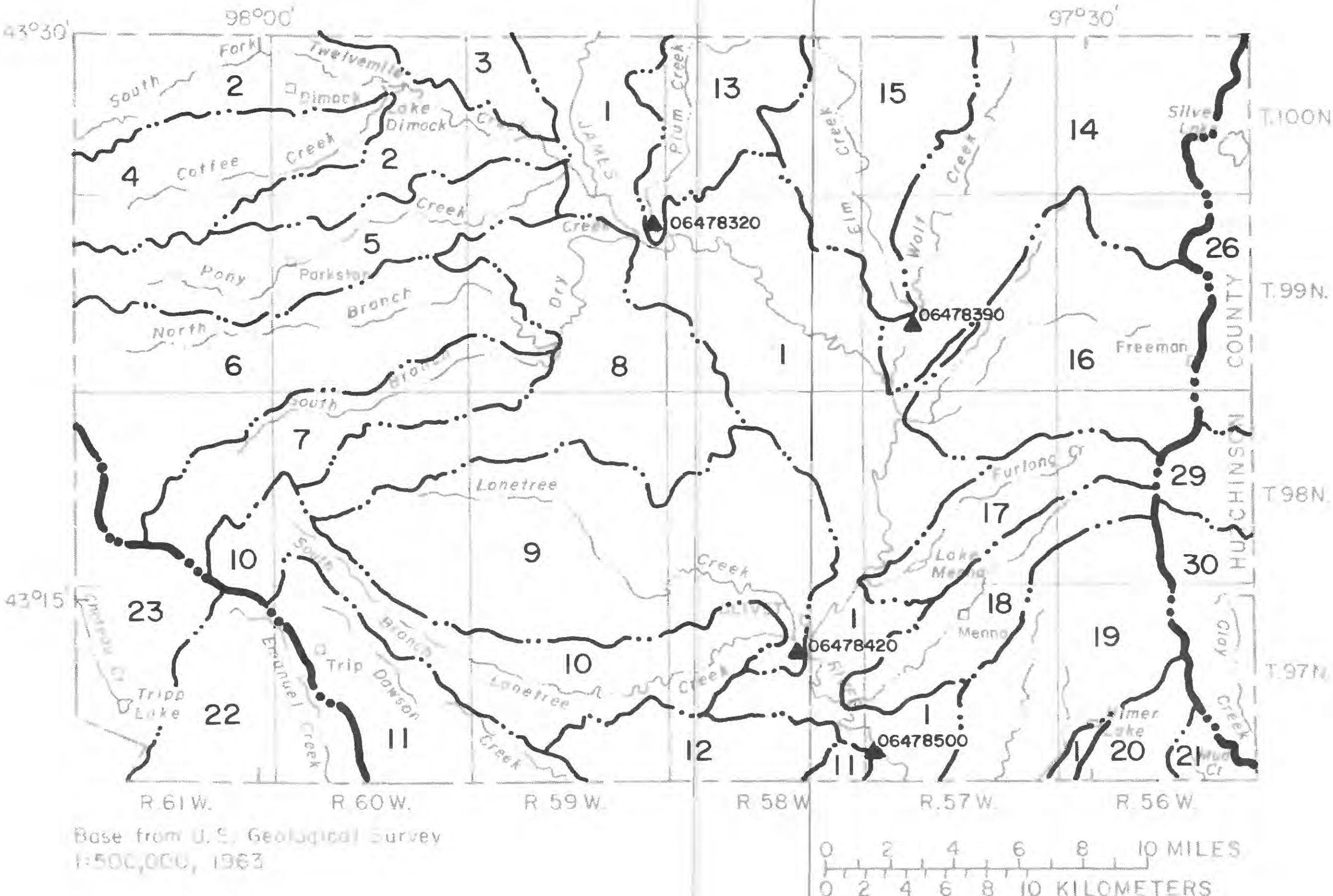
The average annual precipitation from 1951 through 1980 at Menno (Hutchinson County) was 23.4 inches and at Marion (Turner County) was 23.8 inches (U.S. National Oceanic and Atmospheric Administration, 1987). About 75 to 85 percent of the precipitation is returned to the atmosphere by evaporation and transpiration. About 5 percent of the average annual precipitation becomes streamflow; however, this quantity may vary from year to year because of climatic variations. Ten to 20 percent of the precipitation percolates through the root zone to become ground water. Changes in ground-water storage in a given year 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.

Surface Water

Drainage Basins

Two major streams flow from north to south through the study area, the James River in Hutchinson County and the Vermillion River in Turner County (fig. 4). The present drainage pattern is a result of glacial alterations of pre-glacial valleys. The James and Vermillion Rivers flow through the James River lowland (fig. 1), believed to have been formed by two major pre-glacial streams that incised broad valleys which were later widened and united by glacial erosion (Flint, 1955). The tributaries to the James and Vermillion Rivers are intermittent and occupy wide, shallow depressions between broad, low ridges built during the recession of a glacier that occupied the James River lowland. The James River trench was cut by the water escaping from the southern end of glacial Lake Dakota. The present-day Vermillion River trench was formed by meltwater from the most recent glacier which carved a deep trench in the glacial deposits which had previously been laid down. Turkey Ridge, a relatively resistant ridge of drift-covered bedrock (Niobrara Formation generally overlaid by Pierre Shale), forms the divide between the James and Vermillion Rivers in the southern part of the study area.

The James River and its tributaries drain about 731 mi^2 in Hutchinson County (Benson and others, 1987). Choteau and Emanuel Creeks are tributaries of the Missouri River that drain about 45 mi^2 in southwestern Hutchinson County. The Vermillion River and its tributaries drain about 645 mi^2, predominantly in Turner County (Benson and others, 1988). Tributaries of the Big Sioux River (Beaver and Skunk Creeks) drain a small area (9 mi^2) in the northeastern corner of Turner County (Amundson and others, 1985). The areas of the various drainages are listed in table 1.



EXPLANATION

BOUNDARIES

— · · — Drainage basin

— · · — Drainage subbasin

10 DRAINAGE BASIN DESIGNATION IN TABLE 1

▲ 06478500 STREAMFLOW-GAGING STATION -- Number is station identification

Figure 4.--Major streams and drainage-basin divides in Hutchinson and Turner Counties.

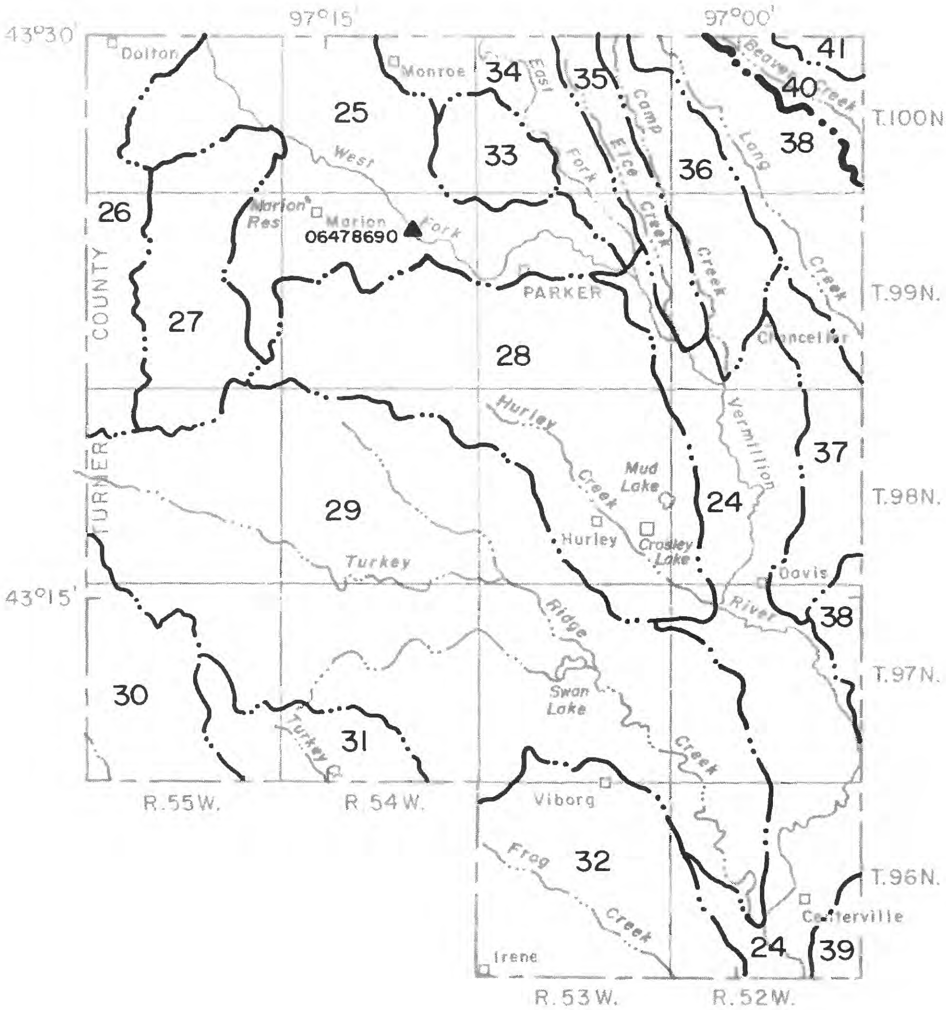


Figure 4.--Major streams and drainage-basin divides in Hutchinson and Turner Counties.--Continued

Table 1.--Areas of drainage basins shown in figure 4

Number	Drainage basin name	Drainage area in Hutchinson and Turner Counties (square miles[1])
	JAMES RIVER	
1	James River Direct	109
2	South Fork Twelvemile Creek	40
3	Twelvemile Creek	11
4	Coffee Creek	24
5	Pony Creek	32
6	North Branch Dry Creek	48
7	South Branch Dry Creek	25
8	Dry Creek	51
9	Lonetree Creek	74
10	South Branch Lonetree Creek	37
11	Dawson Creek	24
12	Lakeview School tributary	16
13	Plum Creek	19
14	Wolf Creek	64
15	Elm Creek	29
16	Zion Church tributary	49
17	Furlong Creek	17
18	Unnamed Menno tributary	21
19	Klaudt School tributary	31
20	Ulmer School tributary	6
21	Mud Creek	4
	Total	731
	MISSOURI RIVER	
22	Emanuel Creek	24
23	Choteau Creek	21
	Total	45
	VERMILLION RIVER	
24	Vermillion River Direct	67
25	West Fork Vermillion River	65
26	Dolton Township tributary	40
27	Rosefield Township tributary	24
28	Hurley Creek	75
29	Turkey Ridge Creek	170
30	Clay Creek	33
31	Turkey Creek	13
32	Frog Creek	40
33	Parker tributary	11
34	East Fork Vermillion River	21
35	Elce Creek	11
36	Camp Creek	22
37	Middletown Township tributary	18
38	Long Creek	32
39	Blind Creek	3
	Total	645
	BIG SIOUX RIVER	
40	Beaver Creek	6
41	Skunk Creek	3
	Total	9

[1]Rounded to nearest square mile.

Streamflow

Data from streamflow-gaging stations operated by the U.S. Geological Survey in and near the study area are summarized in table 2. The average discharge for the James River near Scotland for the period of record (1928-86) is 424 ft^3/s, or about 307,000 acre-ft/yr. The average discharge for the period of record (1945-83) for the Vermillion River near Wakonda, located 6.5 mi south of the Turner-Clay County line, is 125 ft^3/s, or about 90,500 acre-ft/yr.

The volume of streamflow depends on the amount of annual precipitation, intensity of precipitation, antecedent soil conditions, contributions to streamflow from ground-water discharge, 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 increased precipitation. Streamflow is least during the late summer, fall, and winter months because of decreased precipitation and increased evapotranspiration during the summer. Most of the streams in the study area experience periods of no flow during the year, including both the James and Vermillion Rivers during drought years.

The average annual runoff from the contributing drainage area of the James River near Scotland is 0.35 in/mi^2 (18.6 $acre\text{-}ft/mi^2$). The average annual runoff for the Vermillion River near Wakonda is 1.01 in/mi^2 (53.9 $acre\text{-}ft/mi^2$), for the West Fork Vermillion River near Parker is 1.31 in/mi^2 (70.11 $acre\text{-}ft/mi^2$), and for Wolf Creek near Clayton is 1.46 in/mi^2 (77.93 $acre\text{-}ft/mi^2$). These average annual runoff computations were based on the average discharge during the available period of record for each station. It is assumed that the record periods are representative of long-term conditions at each site. The average annual runoff is smaller for the James River near Scotland than for the other streams because: (1) For most of the drainage basin north of the gage site, the topography is relatively flat with gentle slopes, and (2) precipitation is less in the northern part of the James River drainage basin than further south. Conversely, for the Vermillion River, West Fork Vermillion River, and Wolf Creek, the topography generally is more rugged with steeper slopes and average precipitation over the drainage basins is greater.

The percentage of no-flow days for the James River near Scotland, the Vermillion River near Wakonda, the West Fork Vermillion River near Parker, and Wolf Creek near Clayton are shown in figure 5. A smaller percentage of no-flow days occurs for the James River near Scotland and the Vermillion River near Wakonda than for the other two sites because their contributing drainage areas are much larger. Wastewater from the city of Mitchell, 13 mi north of the Davison-Hutchinson County line, is a significant contribution to streamflow at the gage near Scotland during low-flow periods and may reduce the percentage of no-flow days. Ground water may discharge into Wolf Creek upstream from the streamflow gaging station near Clayton in T. 99 N., R. 57 W., sec. 4 and T. 100 N., R. 57 W., sec. 34. Lonetree Creek, Twelvemile Creek, East Fork Vermillion River, and Turkey Ridge Creek also receive minor amounts of ground-water discharge.

Table 2.--Summary of data for streamflow gaging stations in and near Hutchinson and Turner Counties

Station number	Station name and Federal land survey location	Drainage area (square miles)	Period of record	Discharge for period of record (cubic feet per second)		
				Maximum	Minimum	Average
06478000[1]	James River near Mitchell 103N59W30CB	19,800	[2]1953-58 1965-72	13,800 Apr. 11,1969	1 Oct. 9, 1956 Sept. 26-27, 1958	313
06478320	Plum Creek near Milltown 99N59W01CD	35.4	1981-83	774 June 20,1983	0 about half the time	[3]
06478390	Wolf Creek near Clayton 99N57W29AB	396	1975-86	6,520 June 21,1984	0 at times in 1976, 1977, and 1980-82	42.6
06478420	Lonetree Creek at Olivet 97N58W15AA	112	1981-83	1,090 Mar. 31,1983	0 many days in 1982 0.15 in 1983	[3]
06478500	James River near Scotland 97N57W30CC	20,653 (4,148 non-contributing)	1928-86	29,400 June, 23, 1984	0 many days in some years	424
06478690	West Fork Vermillion River near Parker 99N54W10AA	370	1961-86	4,800 June 16, 1984	0 many days in most years	35.8
06479000[4]	Vermillion River near Wakonda 94N52W02BC	1,680	1945-83	9,880 Apr. 8,1969	0 at times in 1951, 1956-59, 1975-77, and 1981	125

[1]Located 13.5 miles north of the Hutchinson-Davison County line.
[2]Published as "near Alexandria."
[3]Average not computed because of short period of record.
[4]Located 6.5 miles south of the Turner-Clay County line.

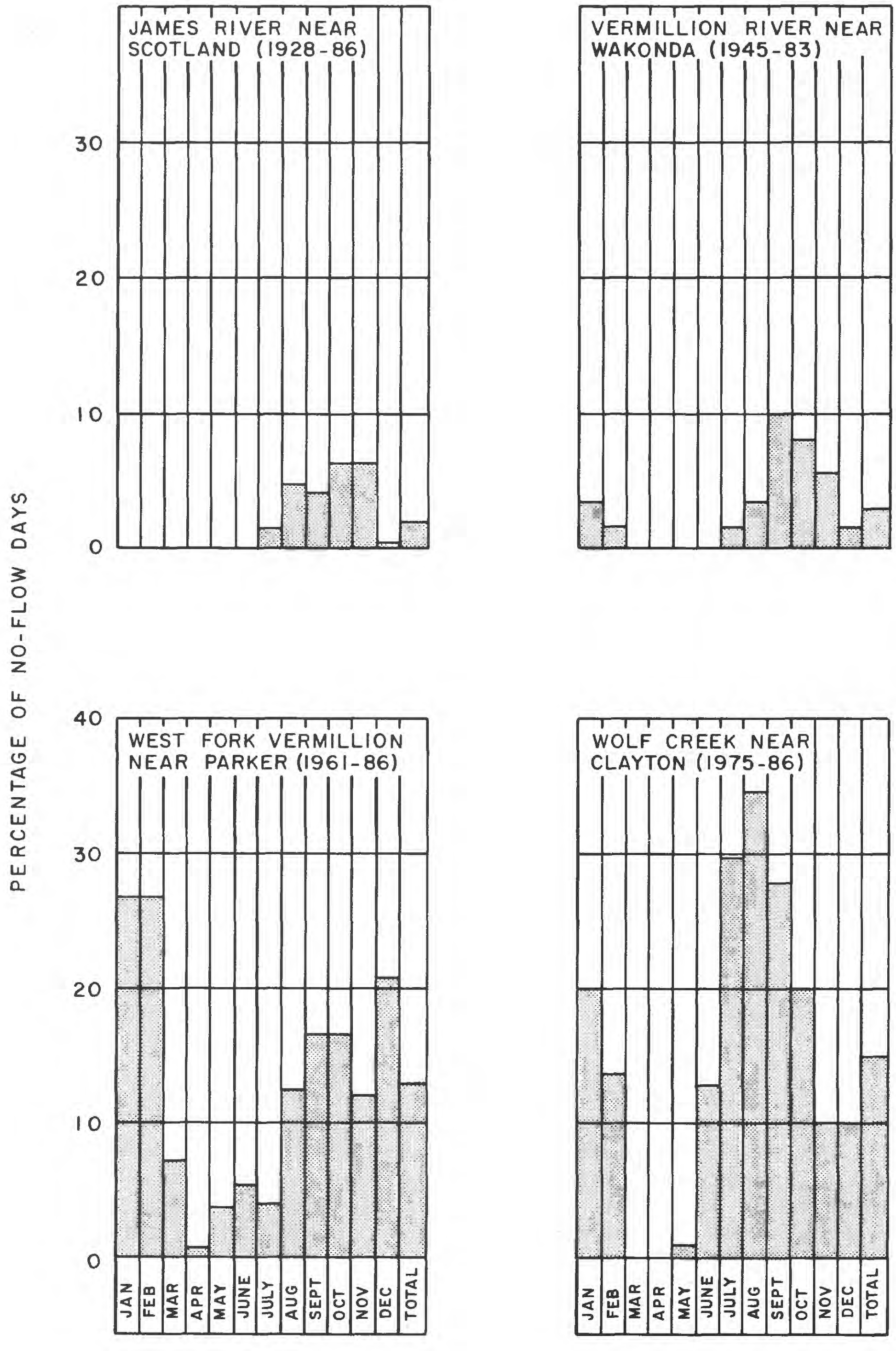


Figure 5.--Percentage of no-flow days for the James River near Scotland, Vermillion River near Wakonda, West Fork Vermillion River near Parker, and Wolf Creek near Clayton.

Flow Duration

For most creeks within the study area, the duration of streamflow is reduced because of low precipitation, large evapotranspiration, rapid runoff, and relatively small contributions of ground-water discharge to streamflow. Daily flow-duration curves (fig. 6) show the percentage of time which a given flow is equaled or exceeded. For both the James River near Scotland and the Vermillion River near Wakonda, the average discharge (424 ft^3/s and 125 ft^3/s, respectively) is exceeded only about 20 percent of the time. This is typical of streams for which much of the annual flow occurs during the large runoff events associated with spring snowmelt and early summer thunderstorms. A daily mean discharge of 1,090 ft^3/s for the James River near Scotland, 225 ft^3/s for the Vermillion River near Wakonda, and 55 ft^3/s for Wolf Creek near Clayton may be expected to be equaled or exceeded 10 percent of the time. A discharge of 1 ft^3/s is exceeded more than 90 percent of the time for both the James River near Scotland and the Vermillion River near Wakonda.

Floods

Information on the magnitude and frequency of floods is important in decisions regarding land use. Periodic inundation of stream flood plains is common in the study area during the spring because of snowmelt runoff and precipitation. In many cases, flooding along the main channel of the James and Vermillion Rivers is increased by tributary inflow. Bankfull capacities, determined for the James River in Hutchinson County by the Missouri River Basin Commission (Missouri River Basin Commission, 1980a), range from 2,600 to 3,400 ft^3/s. Bankfull capacity of the James River in southern Hutchinson County (2,800 ft^3/s) can be expected to be exceeded an average of once in 10 years on any individual day during the 26 days from March 29 through April 23 (Benson, 1983).

Principal areas subject to flooding in the Vermillion River valley are limited to the Vermillion main stem downstream from Davis and small areas at the mouths of various tributaries. Small areas of Centerville and Davis are the only urban areas subject to flooding.

Lakes

The surface area of lakes totals about 1,000 acres in Hutchinson and Turner Counties. The lakes are small with average depths of less than 10 ft (table 3). Silver Lake is the largest lake, with a surface area of 431 acres and a storage capacity of 1,724 acre-ft.

In addition to bodies of water large enough to be classified as lakes, the study area is characterized by numerous small depressions and some small marshy areas which are used for stock watering and wildlife propagation. Dugouts and stock dams are used to collect surface runoff and are used for stock watering purposes. During periods of drought, most of the small depressions and dugouts are dry.

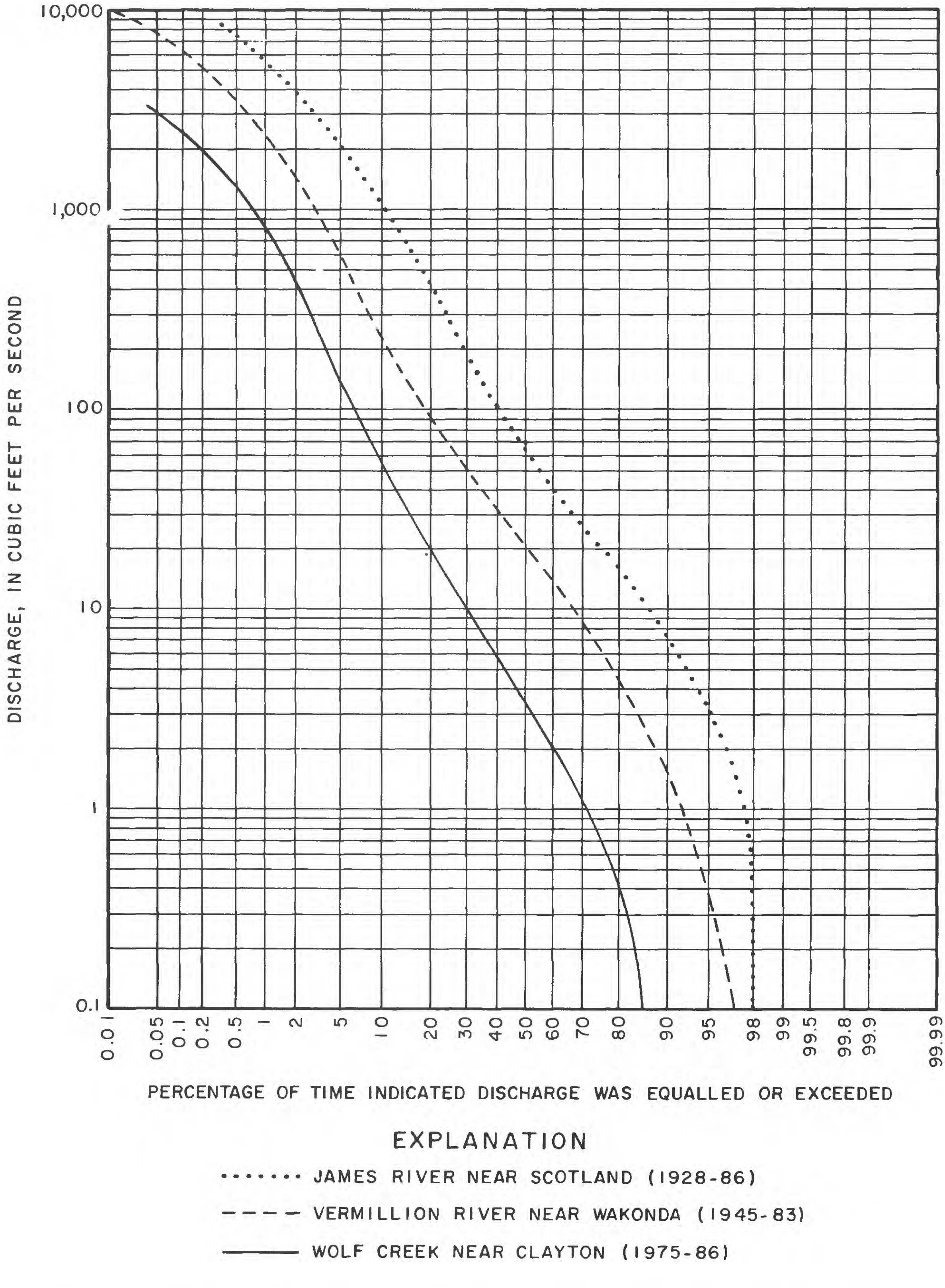


Figure 6.--Daily flow-duration curves for the James River near Scotland, Vermillion River near Wakonda, and Wolf Creek near Clayton.

Table 3.--Summary of lake data, Hutchinson and Turner Counties

[R, reservoir; N, natural lake]

Lake name	Location	Depth[1] (feet)		Surface area[1] (acres)	Storage capacity (acre-feet)	Classification for beneficial use[2]
		Maximum	Average			
Dimock (R)	100N60W15	15.5	7	75	525	6
Menno (R)	98N57W34	--	6	62	372	5
Silver (N)	100N56W25,36	7	4	431	1,724	6
Marion (R)	99N54W6	8	4	3	12	5,9
Mud (N)	98N53W13,24	5	3	45	135	9
	98N52W19					
Swan (R)	97N53W15,16	6	3.5	180	630	5
Tripp (R)	97N61W20	23	9.8	12.5	122	5
Crosley (N)	98N53W25	--	2.5	160	400	--

[1]Oral communication from South Dakota Department of Game, Fish, and Parks (1986).
[2]Classification:
5 - warm water semipermanent fish life propogation water
6 - warm water marginal fish life propogation waters
9 - wildlife propogation and stock watering waters.

Water Quality

Dissolved-solids concentration in water from streams generally varies inversely with the magnitude of streamflow. Dissolved-solids concentrations are generally smallest during the spring when streamflow is large because of snowmelt and rainfall. Specific conductance can be used to estimate dissolved-solids concentration in water because specific conductance is related to the number and types of ions in solution. The changes in specific conductance associated with seasonal variations in stream discharge for the James and Vermillion Rivers are shown in figure 7.

The predominant chemical constituents for the period of record in the James River near Scotland and in the Vermillion River near Wakonda were calcium and sulfate. Dissolved-solids (sum of constituents) concentrations ranged from 150 to 2,400 mg/L (milligrams per liter) and averaged 1,040 mg/L for the James River near Scotland. Dissolved-solids (sum of constituents) concentrations ranged from 270 to 1,200 mg/L and averaged 828 mg/L for the Vermillion River near Wakonda. The James River near Scotland had a much larger average sodium concentration (120 mg/L) than the Vermillion River near Wakonda (41 mg/L). The James River near Scotland also had larger average concentrations of chloride (62 mg/L) and boron (460 μg/L [micrograms per liter]) than the Vermillion River near Wakonda (9.0 mg/L and 170 μg/L, respectively). A summary of chemical analyses for the James and Vermillion Rivers is shown in table 4.

James River water increases in average hardness, dissolved solids, and calcium concentrations as it flows from north to south through Hutchinson County, as indicated by the comparative average concentrations near Mitchell and near Scotland (table 4). The data presented in table 4 were computed using available periods of record for the 3 stations and therefore assume records are representative of the same approximate average long-term conditions.

No water-quality data are available for lakes within the study area. However, from other studies, it is known that lakes exhibit seasonal variations in water-quality constituents and properties. Dissolved-solids concentration generally decreases in the spring as the lake water is diluted by snowmelt runoff and large precipitation amounts and increases during the summer as lake levels fall because of evapotranspiration losses and less precipitation.

Ground-Water Occurrence and Chemical Quality

Glacial Aquifers

Eleven glacial aquifers were delineated in Hutchinson and Turner Counties (figs. 8, 9, and 10), and hydrologic characteristics of each aquifer are discussed below. Glacial aquifers are unconsolidated sand and gravel outwash deposited by meltwaters from receding glaciers. The Parker-Centerville, West Fork Vermillion, East Fork Vermillion, and Turkey Ridge Creek aquifers (fig. 8) are at or near land surface and generally are under water-table conditions. The Upper Vermillion-Missouri, Lower James-Missouri, and Choteau aquifers (fig. 9) are overlaid by as much as 355 ft of till and generally are under artesian conditions. Till consists of grayish-blue clay with minor amounts of shale pebbles, sand, and silt. The hydraulic conductivity of till ranges from 10^{-4} to 10^{-8} ft/d (Henry, 1982). The Lower James-Missouri aquifer is at or near land surface in the James River flood plain in southern Hutchinson County and is under water-table conditions. The Dolton, Turkey Ridge, Wall Lake, and Ethan aquifers (fig. 10) are overlaid by 30 to 165 ft of till and generally are under artesian conditions.

Table 4.--Summary of chemical analyses of water from the James and Vermillion Rivers

[All units reported in milligrams per liter except as indicated; μg/L, micrograms per liter; μS/cm, microsiemens per centimeter at 25 °C; °C, °Celsius; --, no data]

Chemical constituent	James River near Mitchell[1] 06478000			
	Number of analyses	Maximum value	Minimum value	Mean
Specific conductance, lab (μS/cm)	0	--	--	--
Specific conductance, field (μS/cm)	1,305	2,970	370	1,350
pH, lab (standard units)	0	--	--	--
Hardness as $CaCO_3$	64	950	100	410
Alkalinity, lab	0	--	--	--
Solids, sum of constituents, dissolved	39	2,100	250	793
Solids, residue at 180 °C, dissolved	48	2,200	215	964
Calcium, dissolved	59	200	25	84
Magnesium, dissolved	59	110	9.5	47
Sodium, dissolved	64	360	24	140
Potassium, dissolved	59	33	8.4	17
Bicarbonate, field	64	590	110	330
Sulfate, dissolved	64	970	63	340
Chloride, dissolved	59	260	5.5	73
Fluoride, dissolved	42	.6	.2	.4
Silica, dissolved	38	25	2.5	14
Nitrogen, nitrate dissolved	32	4.0	.00	.76
Nitrogen, nitrate total	0	--	--	--
Nitrogen, NO2+NO3 dissolved	24	2.7	.02	1.0
Arsenic, dissolved (μg/L)	1	3	3	3
Boron, dissolved (μg/L)	59	3,400	80	550
Iron, dissolved (μg/L)	18	430	10	140
Iron, total recoverable (μg/L)	0	--	--	--
Manganese, dissolved (μg/L)	12	1,200	0	470
Manganese, total recoverable (μg/L)	11	570	0	160
Molybdenum, dissolved (μg/L)	0	--	--	--
Selenium, dissolved (μg/L)	0	--	--	--
Strontium, dissolved (μg/L)	0	--	--	--

[1]For period of record 1953-58, 1965-72.
[2]For period of record 1928-86.
[3]For period of record 1945-83.
[4]Median value.

James River near Scotland[2] 06478500				Vermillion River near Wakonda[3] 06479000			
Number of analyses	Maximum value	Minimum value	Mean	Number of analyses	Maximum value	Minimum value	Mean
26	2,450	490	1,640	0	--	--	--
369	3,010	270	1,430	131	4,040	340	1,140
45	8.5	7.3	[4]8.1	0	--	--	--
281	1,500	97	590	45	2,500	190	640
26	350	120	240	0	--	--	--
180	2,400	150	1,040	40	1,200	270	828
266	2,490	110	1,120	37	3,870	304	982
250	400	29	140	45	420	50	150
250	140	6.0	60	45	360	16	66
259	300	7.8	120	45	220	6.9	41
195	44	.4	17	45	35	5.6	9.7
211	520	79	300	45	810	110	280
259	1,300	45	490	45	2,200	110	480
248	260	4.2	62	45	30	.0	9.0
190	1.1	.0	.4	40	.9	.0	.3
178	30	.3	13	40	26	.3	15
49	5.8	.00	.43	16	4.8	.00	.56
1	.02	.02	.02	0	--	--	--
68	1.1	.00	.20	9	3.4	.00	.97
53	30	0	5	0	--	--	--
89	850	40	460	43	790	30	170
46	110	0	25	13	500	0	110
87	4,400	0	430	10	60	10	30
53	2,800	0	710	13	1,200	0	650
55	3,400	0	970	20	4,800	20	1,200
19	13	0	7	0	--	--	--
49	40	0	2	0	--	--	--
14	1,700	390	870	3	1,100	580	830

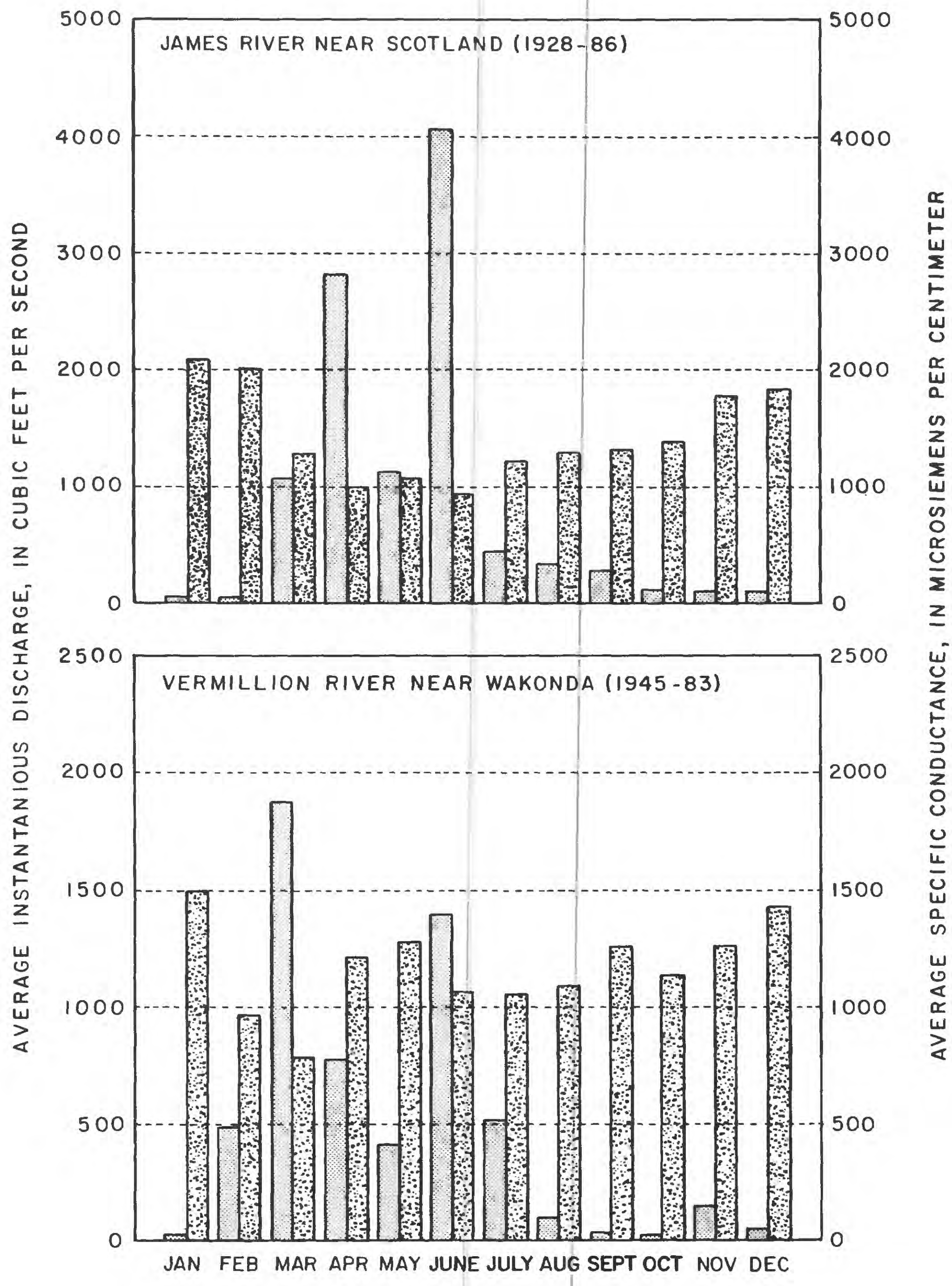
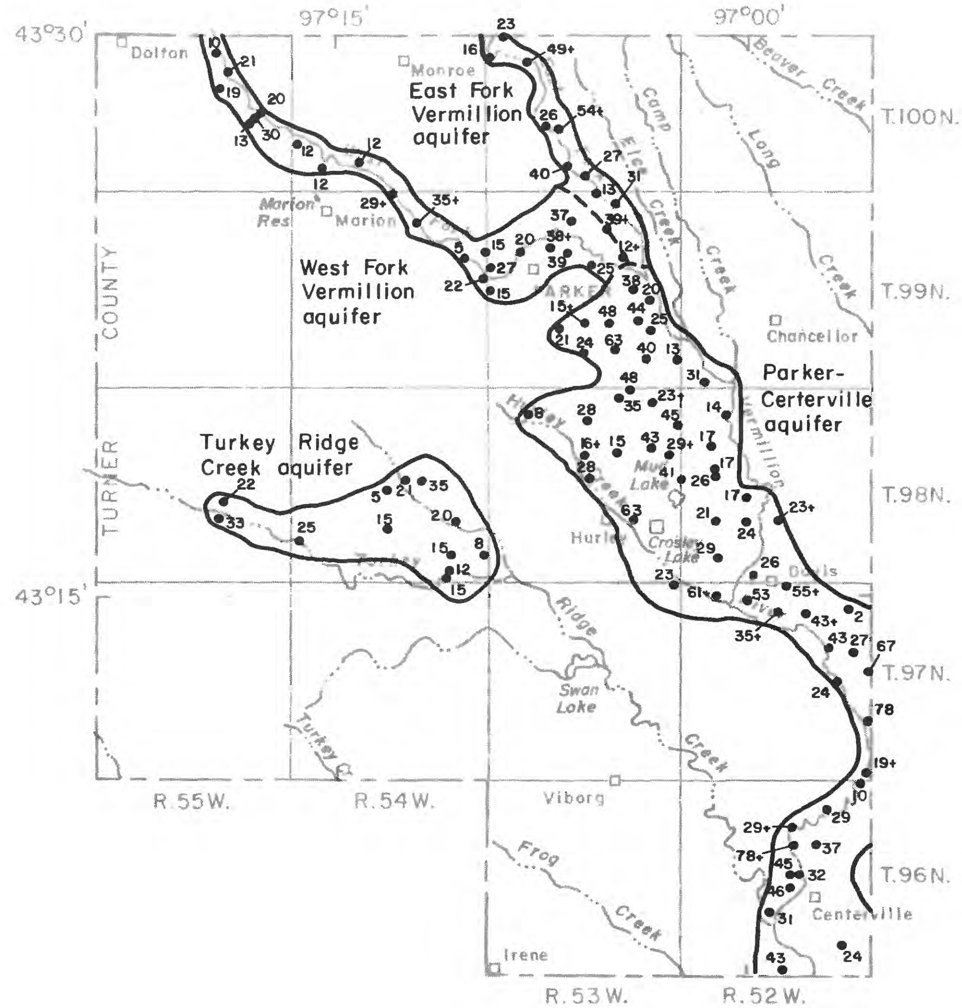


Figure 7.--Relation between instantaneous discharge and specific conductance for the James River near Scotland and the Vermillion River near Wakonda.

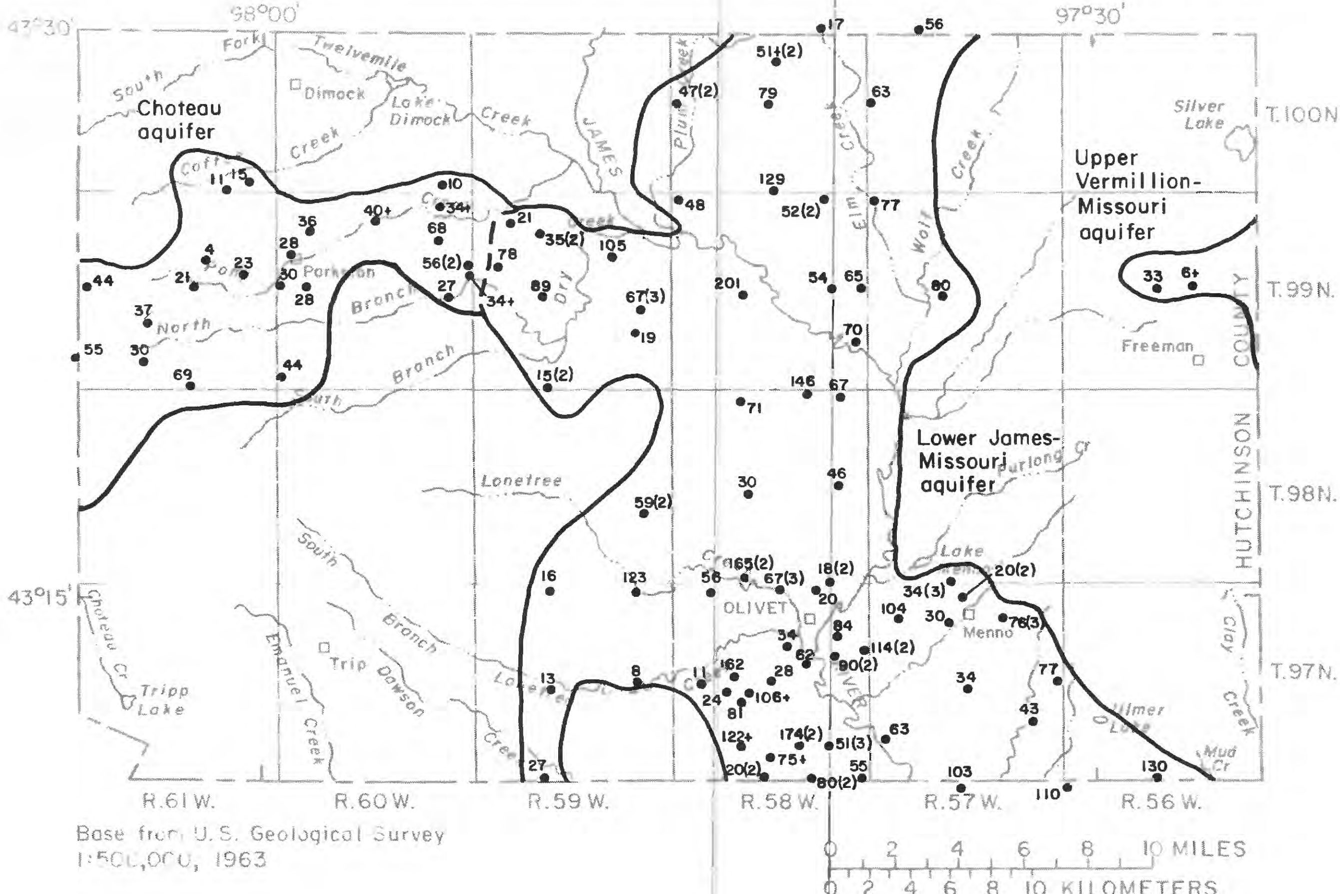


EXPLANATION

● 16+ TEST HOLE--Number is thickness of sand and gravel, in feet. A plus (+) indicates thickness greater than shown

——— – – AQUIFER BOUNDARY--Dashed where approximately located

Figure 8.--Areal extent and thickness of the Parker-Centerville, West Fork Vermillion, East Fork Vermillion, and Turkey Ridge Creek aquifers in Turner County.



EXPLANATION

● 56(2) TEST HOLE--Number is thickness of sand and gravel, in feet. Numbers in parenthesis refer 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 9.--Areal extent and thickness of the Upper Vermillion-Missouri, Lower James-Missouri, and Choteau aquifers in Hutchinson and Turner Counties.

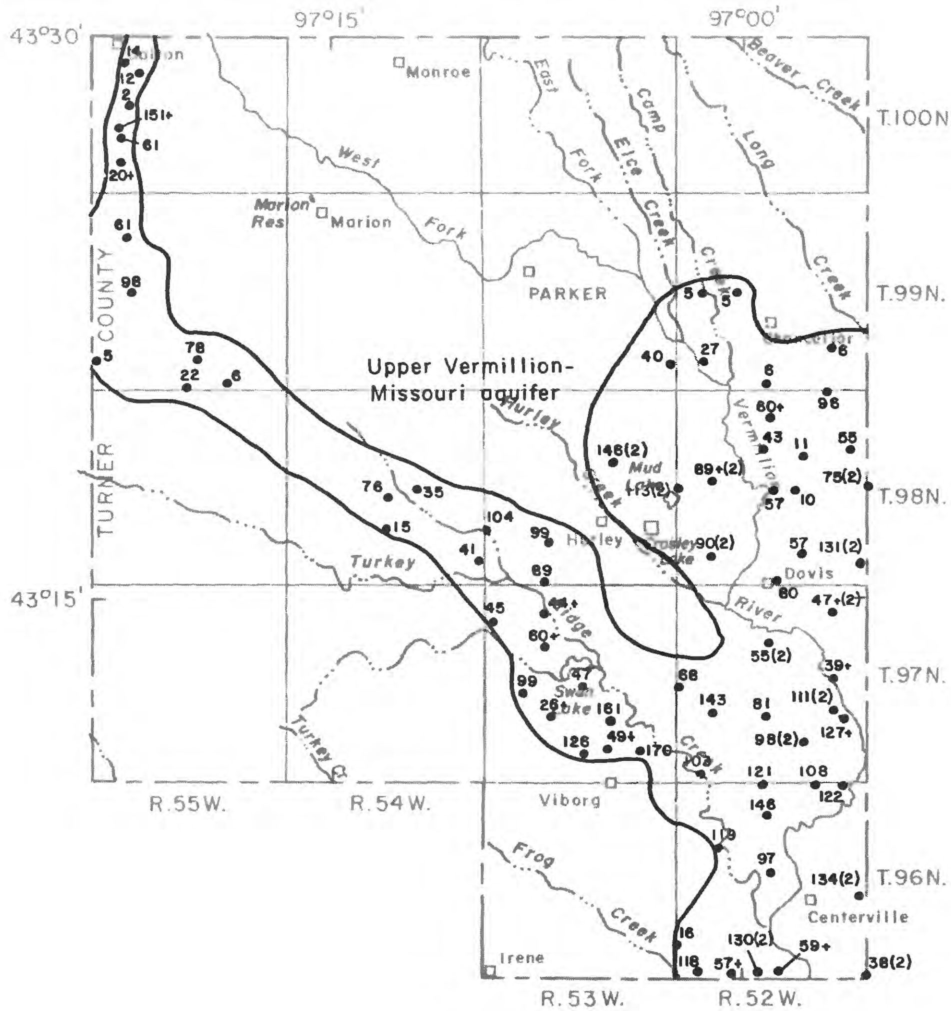
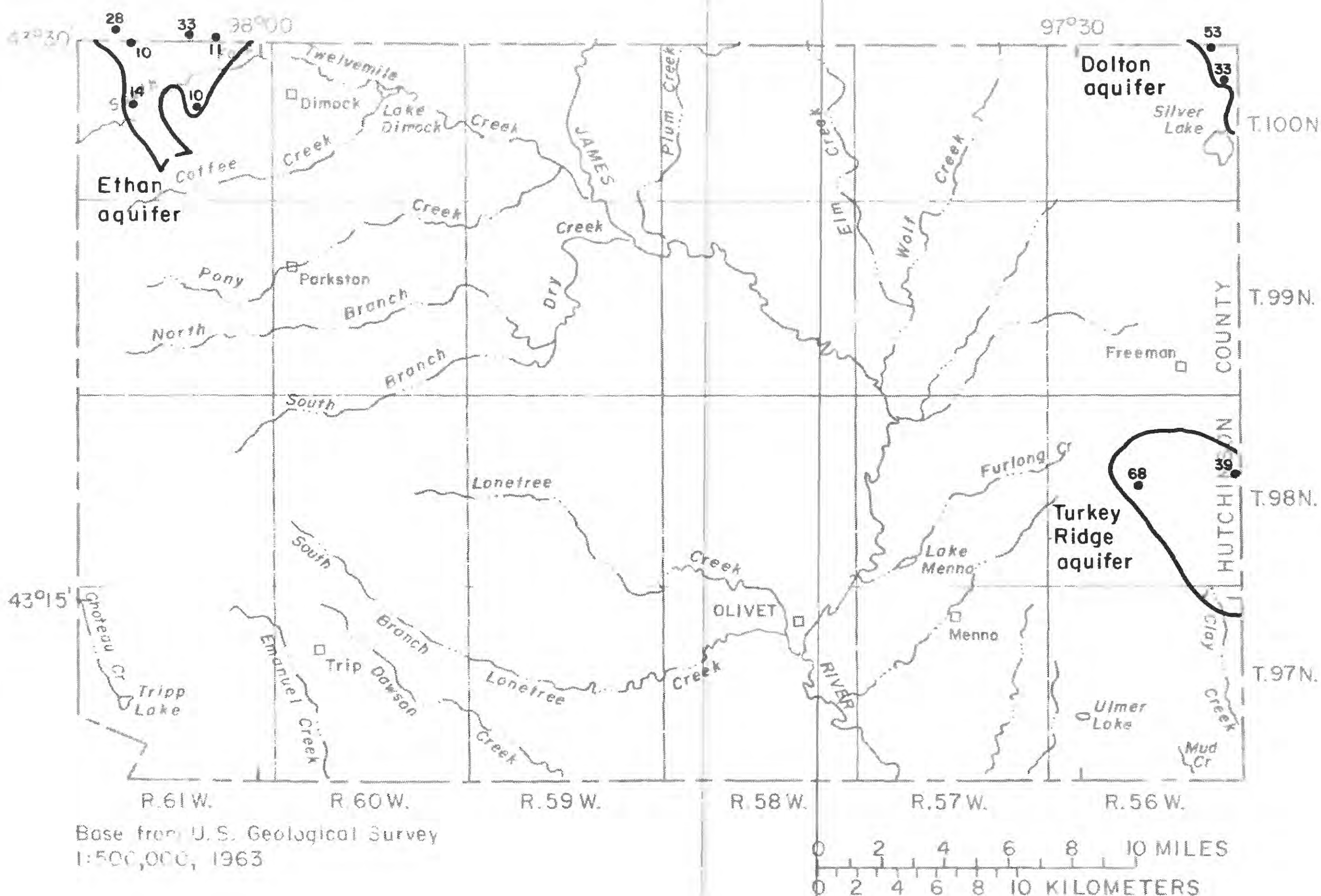


Figure 9.--Areal extent and thickness of the Upper Vermillion-Missouri, Lower James-Missouri, and Choteau aquifers in Hutchinson and Turner Counties.--Continued



EXPLANATION

● 14(2) TEST HOLE-- Number is thickness of sand and gravel, in feet. Numbers in parenthesis refer 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 10.--Areal extent and thickness of the Dolton, Turkey Ridge, Wall Lake, and Ethan aquifers in Hutchinson and Turner Counties.

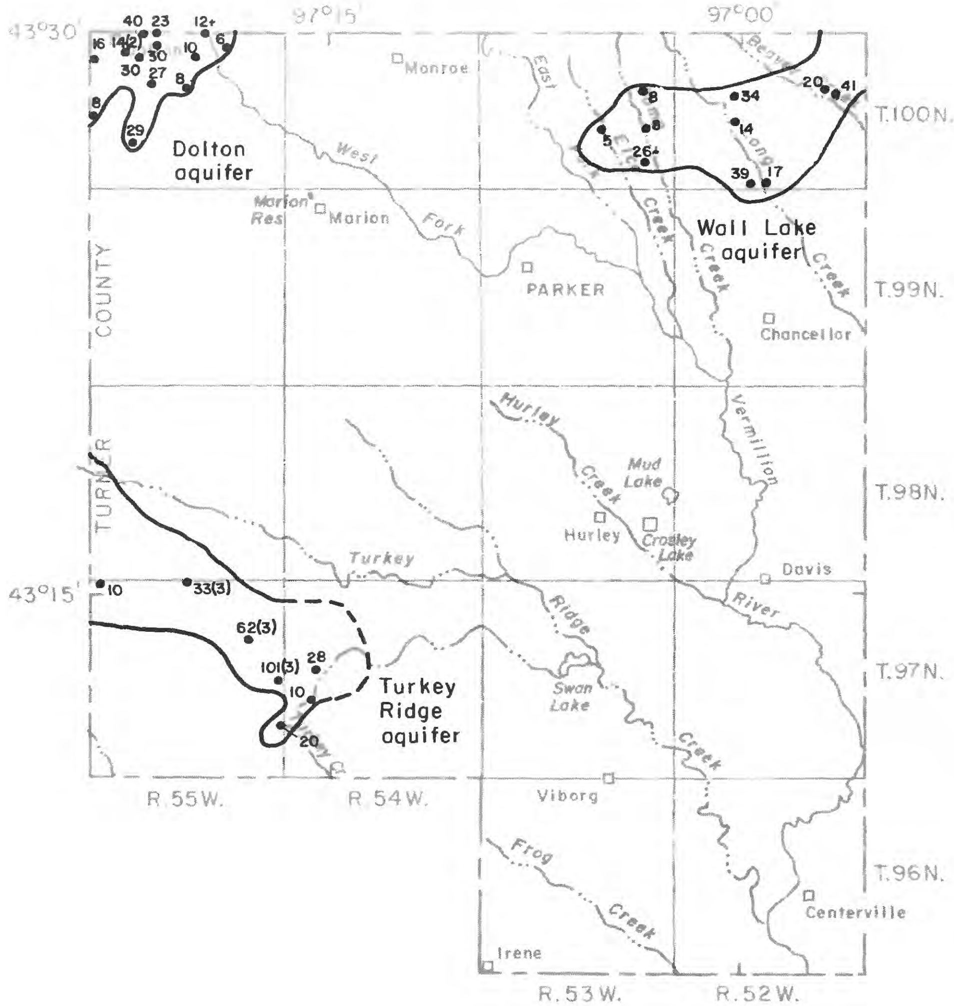


Figure 10.--Areal extent and thickness of the Dolton, Turkey Ridge, Wall Lake, and Ethan aquifers in Hutchinson and Turner Counties.--Continued

Water-level fluctuations in observation wells screened in the glacial aquifers are caused by seasonal variations in recharge and discharge. Water levels generally rise from February to June because recharge from snowmelt and spring rainfall is greater than discharge. Water levels generally decline from July to January because discharge from wells and evapotranspiration are greater than recharge. Subsurface outflow estimates for selected glacial aquifers were calculated by multiplying the cross-sectional area of the aquifer by the gradient of the water-table surface times the average hydraulic conductivity. The average hydraulic conductivity was estimated from test-hole logs that penetrated the aquifer.

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. Specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline in the water table. Porosity is a nondimensional value that expresses the ratio of the volume of pores to the total volume of a porous material.

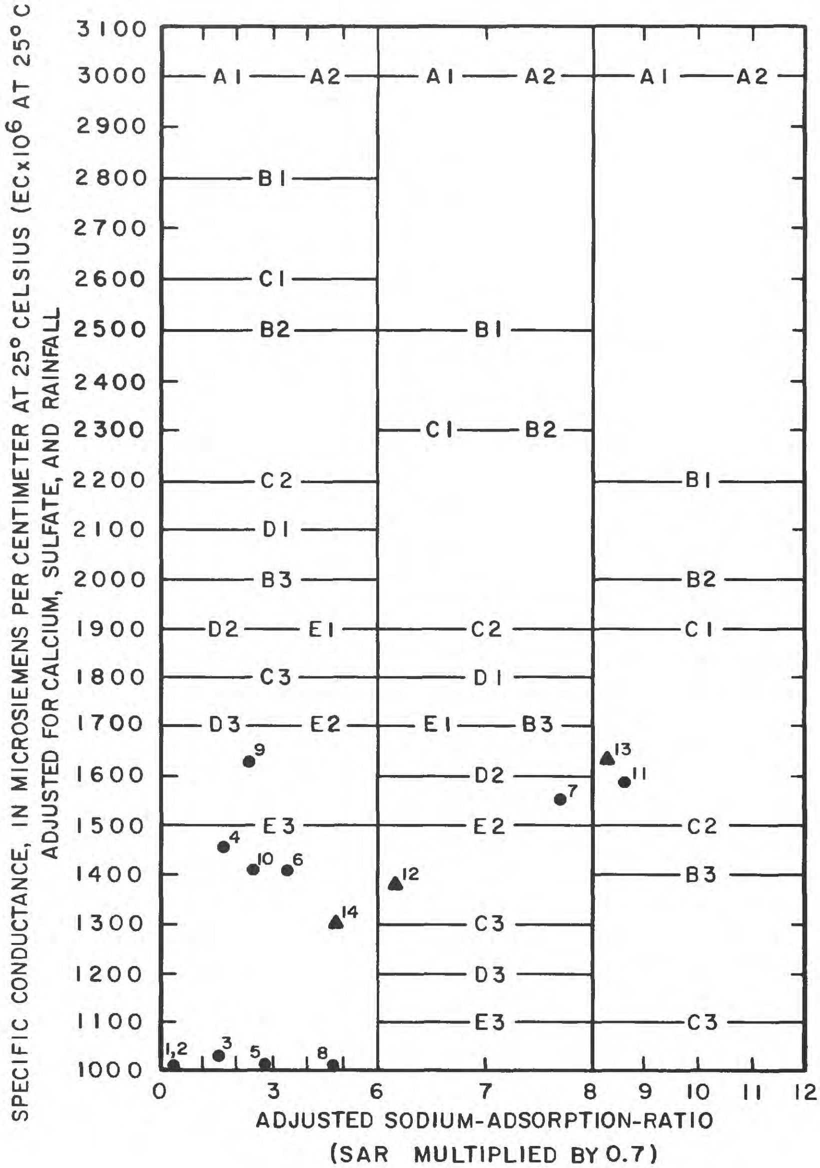
Suitability of water for irrigation from the glacial and bedrock aquifers was determined from the South Dakota irrigation-water diagram (fig. 11) (Koch, 1983). The diagram is based on South Dakota irrigation-water standards, revised January 7, 1982, and shows the State of South Dakota's water-quality and soil-texture requirements for the issuance of an irrigation permit.

Parker-Centerville aquifer

The Parker-Centerville aquifer (fig. 8) underlies 74 mi^2 of eastern Turner County and is the most extensive shallow aquifer in the study area. The aquifer is composed of fine sand to coarse-pebble gravel with some cobble gravel in southern T. 96 N., R. 52 and 53 W. Depth to the top of the aquifer ranges from land surface in the Vermillion River valley to 50 ft below land surface in the southeastern corner of T. 96 N., R. 52 W. where the aquifer is overlaid by till. The Parker-Centerville aquifer lies on till and is separated from the underlying Upper Vermillion-Missouri aquifer by a layer of till ranging in thickness from 7 to 97 ft. Maximum till thickness occurs in the northern and central parts of the aquifer. Water in the Parker-Centerville aquifer is under water-table conditions except near the western boundary and the southeastern corner of T. 96 N., R. 52 W. where water in the aquifer is confined by till. Geologic sections of the aquifer are shown in figures 12, 13, and 14 and hydrologic characteristics are given in table 5.

Recharge to the Parker-Centerville aquifer is from: (1) Direct infiltration of precipitation where the aquifer is at or near land surface, (2) the West Fork Vermillion aquifer, (3) the East Fork Vermillion aquifer, and (4) seepage from the Vermillion River when river stage is higher than the water-table surface in the aquifer. River stage may be higher than the water-table surface in the aquifer when the water table is lowered because of irrigation pumpage during the growing season or when river stage is high because of spring snowmelt or storm events.

The flow of water in the Parker-Centerville aquifer is generally toward the Vermillion River and to the south at an average gradient of about 6 ft/mi (fig. 15). The gradient decreases to about 3 ft/mi in the southern part of the aquifer in T. 96 N., R. 52 W.



EXPLANATION

SOIL TEXTURE

A Sand
B Loamy sands, sandy loams
C Loams, silts, silt loams
D Sandy clay loams, silty clay loams, clay loams
E Silty clays, sandy clays, clays

DEPTH BELOW LAND SURFACE TO A MORE-PERMEABLE OR LESS-PERMEABLE MATERIAL

1 40 inches or less to a more-permeable material
2 40 to 72 inches to a more-permeable material
3 20 to 60 inches to a less-permeable material

SPECIFIC CONDUCTANCE

Maximum values are based on 12 inches or less of average rainfall during the frost-free season. For each additional 2 inches of rainfall the maximum values of EC x 10^6 may be increased by 200.

For water having more than 10 meg/L of calcium and more than 20 meg/L of sulfate, the maximam value of EC x 10^6 may be increased by 400.

AVERAGE CHEMICAL QUALITY OF WATER FROM AQUIFERS

● GLACIAL AQUIFERS
1 Parker-Centerville
2 West Fork Vermillion
3 East Fork Vermillion
4 Turkey Ridge Creek
5 Upper Vermillion-Missouri
6 Lower James-Missouri
7 Choteau
8 Dolton
9 Turkey Ridge
10 Wall Lake
11 Ethan

▲ BEDROCK AQUIFERS
12 Niobrara
13 Codell
14 Dakota

Figure 11.--South Dakota irrigation-water classification based on South Dakota standards (revised Jan. 7, 1982) for maximum allowable specific conductance and adjusted sodium-adsorption-ratio values for which an irrigation permit can be issued for applying water under various soil texture conditions. Water can be applied under all conditions at or above the plotted point but not below it provided other conditions as defined by the State Conservation Commission are met. (From Koch, 1983.)

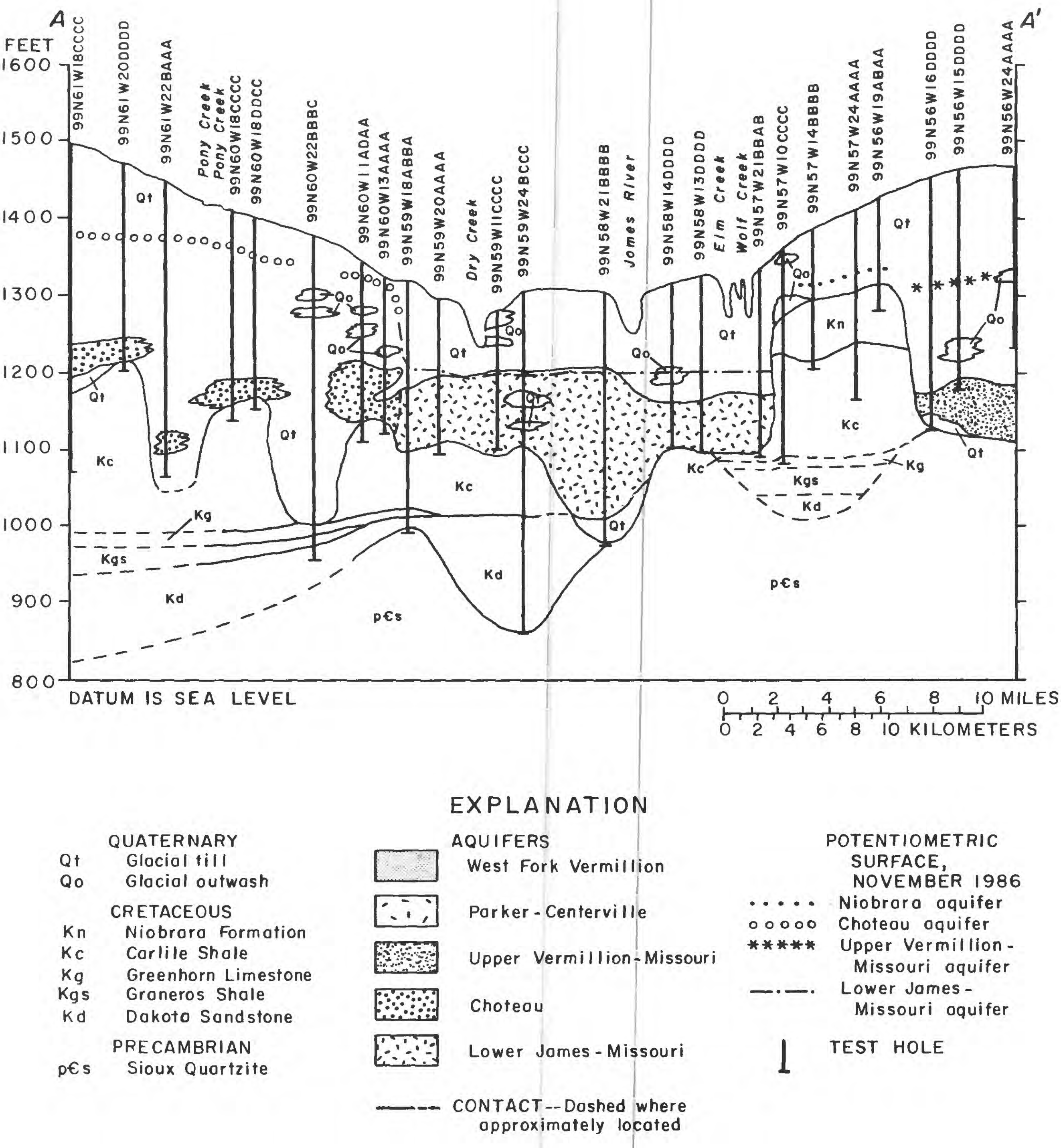


Figure 12.--Geologic section A-A" showing the Parker-Centerville, West Fork Vermillion, Upper Vermillion-Missouri, Choteau, Lower James-Missouri, Niobrara, and Dakota aquifers. (Line of section is shown in figure 2.)

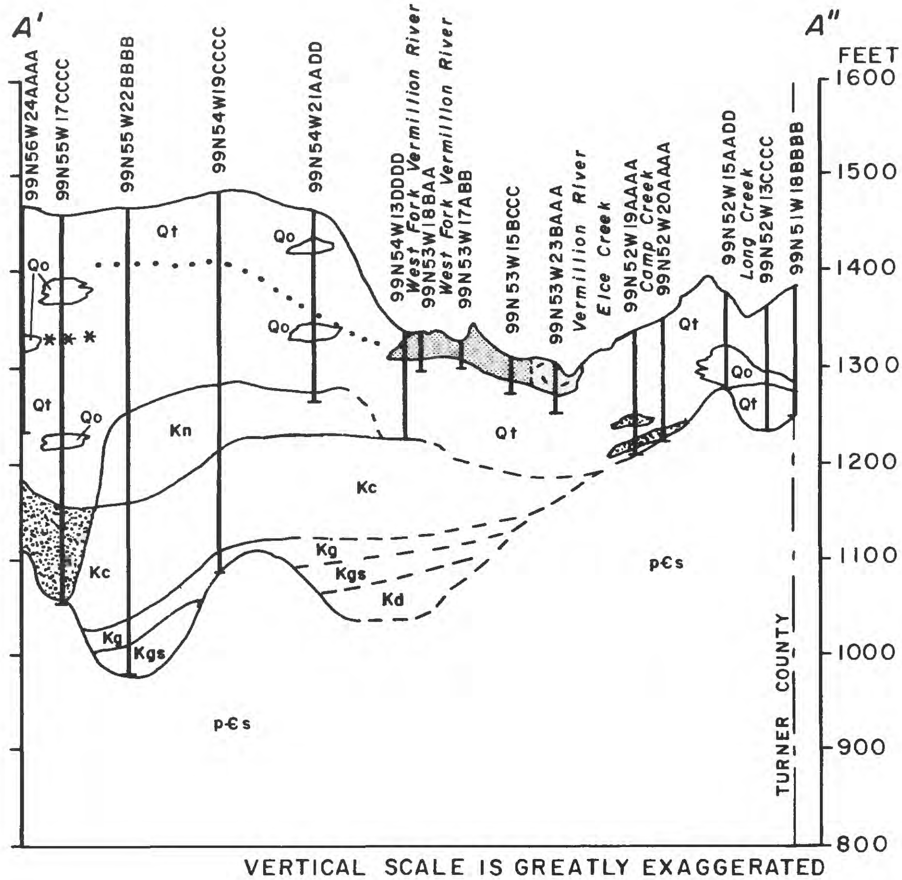


Figure 12.--Geologic section A-A" showing the Parker-Centerville, West Fork Vermillion, Upper Vermillion-Missouri, Choteau, Lower James-Missouri, Niobrara, and Dakota aquifers.--Continued

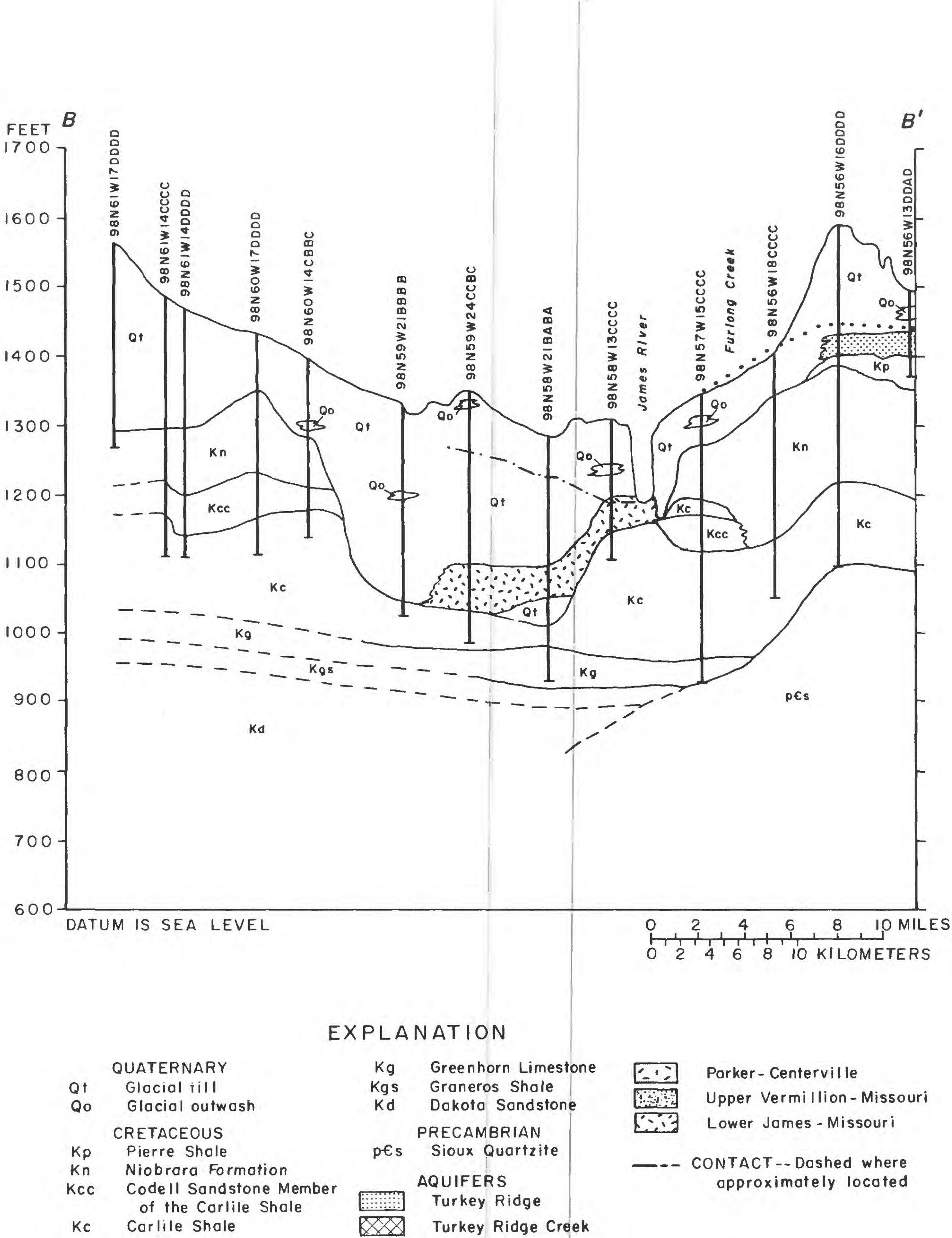
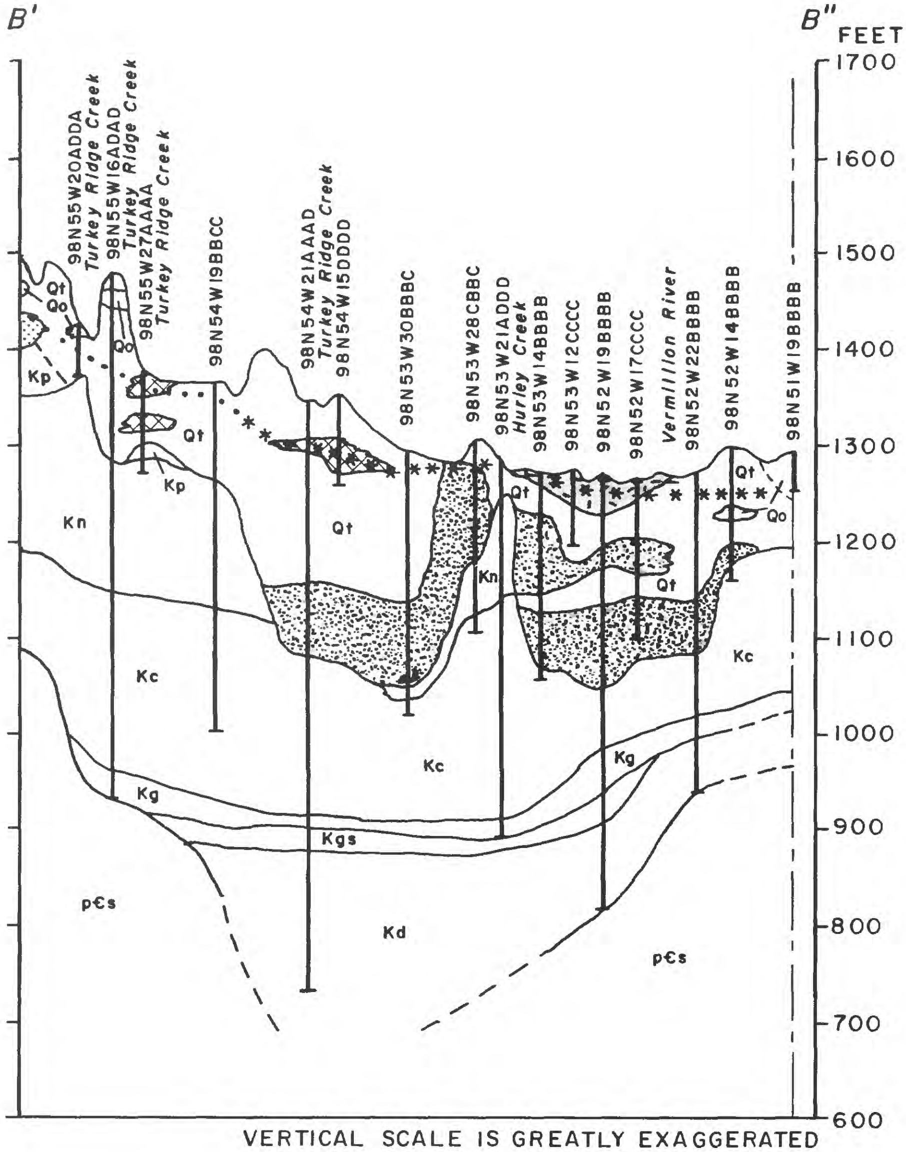


Figure 13.--Geologic section B-B" showing the Turkey Ridge, Turkey Ridge Creek, Parker-Centerville, Upper Vermillion-Missouri, Lower James-Missouri, Niobrara, Codell, and Dakota aquifers. (Section B-B" is shown in figure 2.)



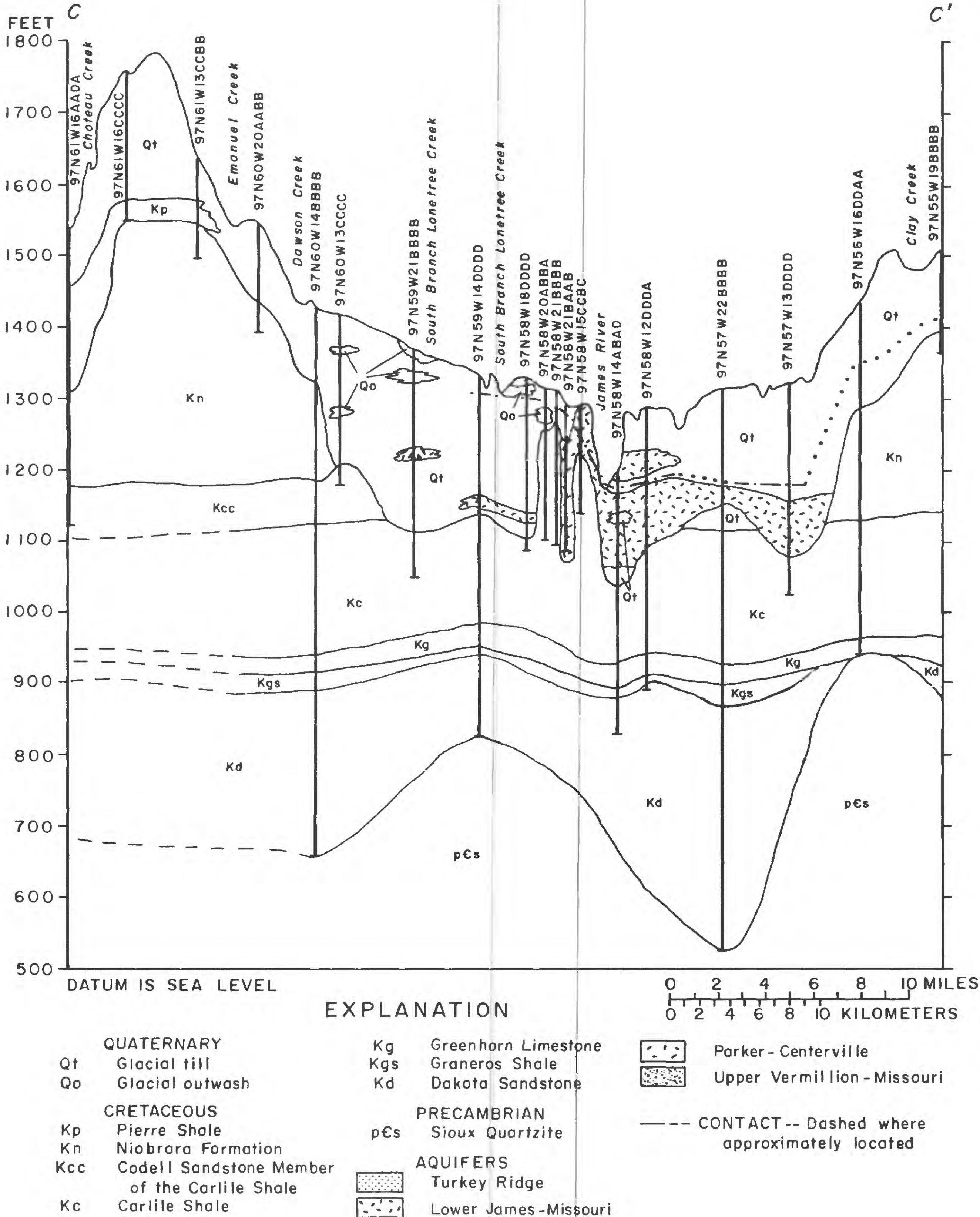
EXPLANATION - cont.

POTENTIOMETRIC SURFACE, NOVEMBER 1986

- ...... Niobrara aquifer
- **** Upper Vermillion-Missouri aquifer
- —·—· Lower James-Missouri aquifer
- — — — Parker-Centerville aquifer

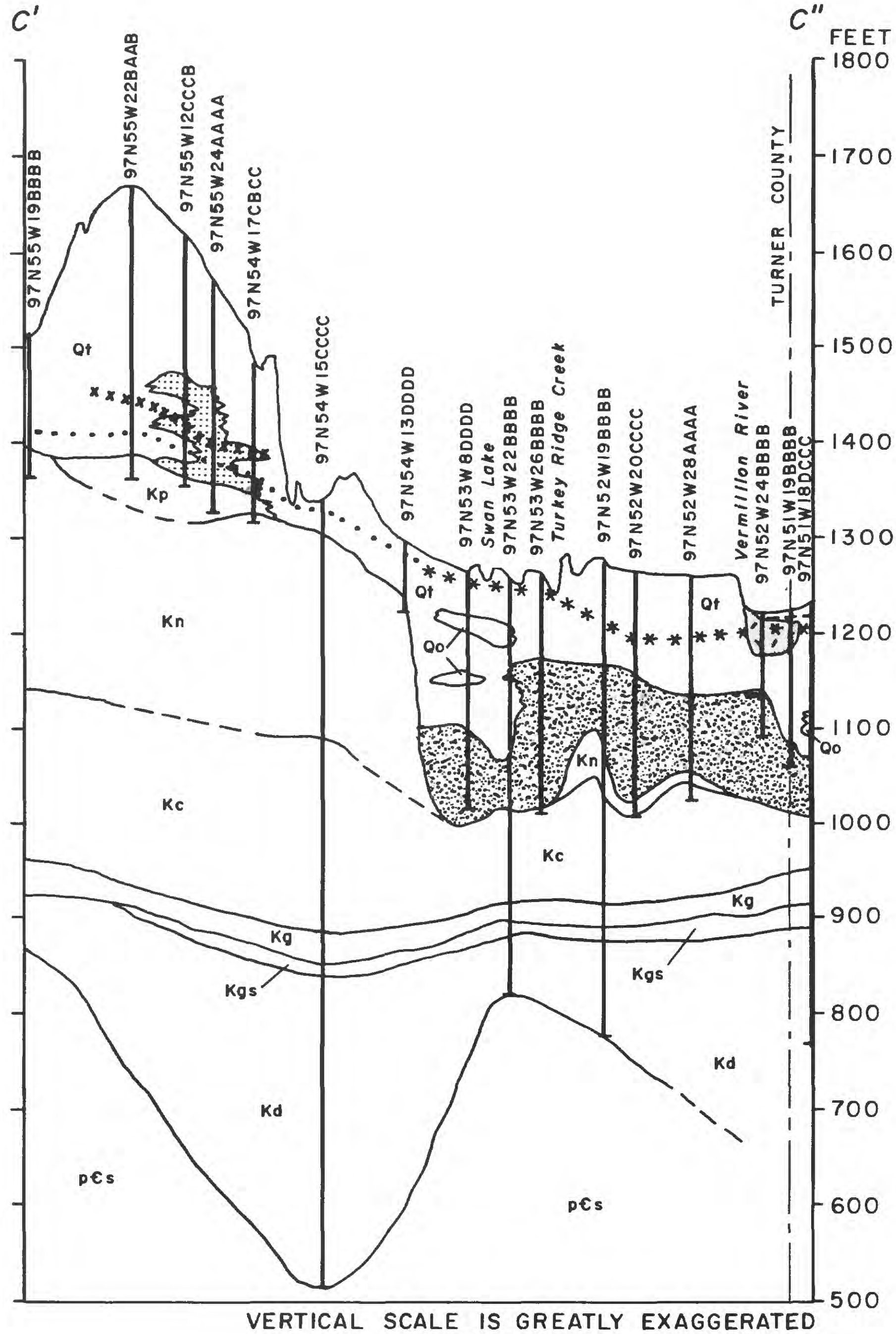
TEST HOLE

Figure 13.--Geologic section B-B" showing the Turkey Ridge, Turkey Ridge Creek, Parker-Centerville, Upper Vermillion-Missouri, Lower James-Missouri, Niobrara, Codell, and Dakota aquifers.--Continued



EXPLANATION

Figure 14.--Geologic section C-C" showing the Turkey Ridge, Lower James-Missouri, Parker-Centerville, Upper Vermillion-Missouri, Niobrara, Codell, and Dakota aquifers. (Section C-C" is shown in figure 2.)



EXPLANATION - cont.

POTENTIOMETRIC SURFACE, NOVEMBER 1986

xxxxx Turkey Ridge aquifer

• • • • • Niobrara aquifer

—·—· Lower James - Missouri aquifer

**** Upper Vermillion - Missouri aquifer

— — — Parker - Centerville aquifer

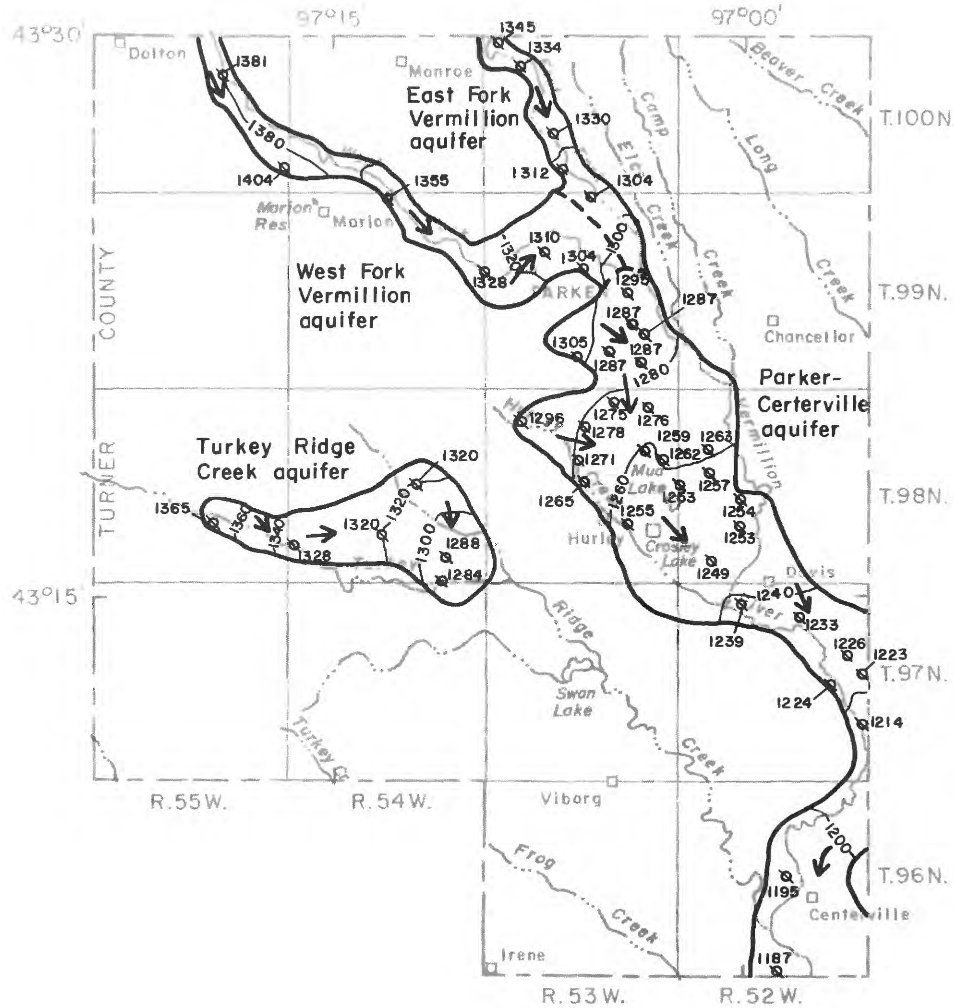
TEST HOLE

Figure 14.--Geologic section C-C" showing the Turkey Ridge, Lower James-Missouri, Parker-Centerville, Upper Vermillion-Missouri, Niobrara, Codell, and Dakota aquifers.--Continued

Table 5.--Summary of the hydrologic characteristics of major aquifers in Hutchinson and Turner Counties

Aquifer name	Areal extent (square miles)	Maximum thickness[1] (feet)	Average thickness (feet)	Range of depth of top of aquifer unit below land surface[1] (feet)	Range of water level below land surface[1] (feet)	Water-table (WT) and/or artesian (A) aquifer	Estimated maximum volume of water in storage[2] (acre-feet)	Estimated maximum well yield (gallons per minute)
GLACIAL AQUIFERS								
Parker-Centerville	74	78+	34	0 - 50	0 - 20	WT,A	322,000	1,000
West Fork Vermillion	18	39+	22	0 - 45	7 - 15	WT,A	51,000	500
East Fork Vermillion	6	54+	29	0 - 5	4 - 14	WT	22,000	500
Turkey Ridge Creek	18	35	19	0 - 65	0 - 36	WT,A	44,000	500
Upper Vermillion-Missouri	207	170	68	0 - 355	6 - 179	A	1,802,000	1,000
Lower James-Missouri	268	201	69	0 - 245	0 - 134	WT,A	2,367,000	1,000
Choteau	65	69	33	105 - 270	F[3] - 144	A	275,000	1,000
Dolton	12	53	22	45 - 165	5 - 93	A	34,000	400
Turkey Ridge	44	101	41	55 - 160	27 - 219	WT,A	231,000	50
Wall Lake	24	41	21	35 - 140	5 - 63	A	65,000	500
Ethan	9	33	18	50 - 115	40 - 53	A	21,000	400
Total of glacial aquifers							5,234,000	
BEDROCK AQUIFERS								
Niobrara	729	370	75	0 - 510	F[3] - 235	A	6,998,000	1,000
Codell	230	80	40	0 - 500+	23 - 235	A	1,178,000	100
Dakota	949	341	81	180 - 900+	F[3] - 187	A	9,839,000	250
Total of bedrock aquifers							18,015,000	
Total							23,249,000	

[1]A "+" indicates value greater than shown.
[2]Storage was estimated by multiplying average aquifer thickness times areal extent times an estimated porosity of 0.2 (U.S. Bureau of Reclamation, 1977).
[3]F indicates flowing well.



EXPLANATION

1328 OBSERVATION WELL--Number is altitude of water surface, in feet. Datum is sea level

—1300- - POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 20 feet

——- - - AQUIFER BOUNDARY--Dashed where approximately located

←—— DIRECTION OF GROUND-WATER MOVEMENT

Figure 15.--Potentiometric surface of the Parker-Centerville, West Fork Vermillion, East Fork Vermillion, and Turkey Ridge Creek aquifers in Turner County (November 1986).

Discharge from the Parker-Centerville aquifer is: (1) By evapotranspiration where the aquifer is at or near land surface, (2) by leakage to the underlying Upper Vermillion-Missouri aquifer, (3) by seepage to the Vermillion River when river stage is lower than the water table in the aquifer, and (4) by withdrawal from irrigation, municipal, stock, and domestic wells. Subsurface outflow to Clay County is about 660 acre-ft/yr.

Water-level fluctuations in observation wells screened in the Parker-Centerville aquifer are caused by seasonal changes in recharge and discharge, primarily irrigation pumpage. Comparatively high water levels observed in well 96N52W22BAAA during 1969, 1978-80, and 1983-86 (fig. 16) were caused by above-normal precipitation, and the comparatively low water levels observed during 1970-72, 1976-77, and 1980-82 were caused by below-normal precipitation and large pumpage. Water-level fluctuations in well 98N53W1CBBB were similar to those in well 96N52W22BAAA.

The hydrographs for three observation wells located in T. 98 N., R. 52 W., sec. 32 are shown in figure 17. At this location, the Parker-Centerville aquifer is underlaid by the Upper Vermillion-Missouri aquifer. The Upper Vermillion-Missouri aquifer is composed of two layers of sand and gravel separated by 32 ft of till. A 34-ft layer of silty clay acts as a confining layer between the Parker-Centerville and the Upper Vermillion-Missouri aquifers. The water level in the Parker-Centerville aquifer generally was from 3 to 4 ft higher than the water levels in the sand and gravel layers of the Upper Vermillion-Missouri aquifer during the spring and was about 10 to 14 ft higher during the summer in 1985 and 1986. The water level in the Parker-Centerville aquifer rose about 3 ft in the spring of 1985 and about 4 ft in the spring of 1986. The water level in the observation wells screened in both the upper and lower sand and gravel layers of the Upper Vermillion-Missouri aquifer rose about 2.5 ft from September 1985 to May 1986, whereas the water level in the well screened in the Parker-Centerville aquifer rose only about 0.5 ft during the same time period. Water levels in all three wells rose in response to the cessation of irrigation withdrawals during the falls of 1985 and 1986.

Predominant chemical constituents in water from the Parker-Centerville aquifer are calcium, sulfate, and bicarbonate (fig. 18). The mean dissolved cation and anion concentrations were used to compute the percent of total milliequivalents per liter of each cation and anion plotted in figure 18. Dissolved-solids concentrations ranged from 407 to 6,760 mg/L and averaged 1,840 mg/L. Hardness concentrations (as $CaCO_3$) ranged from 270 to 1,700 mg/L and averaged 680 mg/L. Hardness concentrations were generally greater than 1,000 mg/L in the northwestern part of the aquifer. A summary of chemical analyses of water from the aquifer is given in table 6.

Water from the Parker-Centerville aquifer is used for stock watering, domestic, municipal, and irrigation purposes. The water generally is suitable for irrigation under all soil texture conditions based on the South Dakota irrigation-water classification diagram (fig. 11).

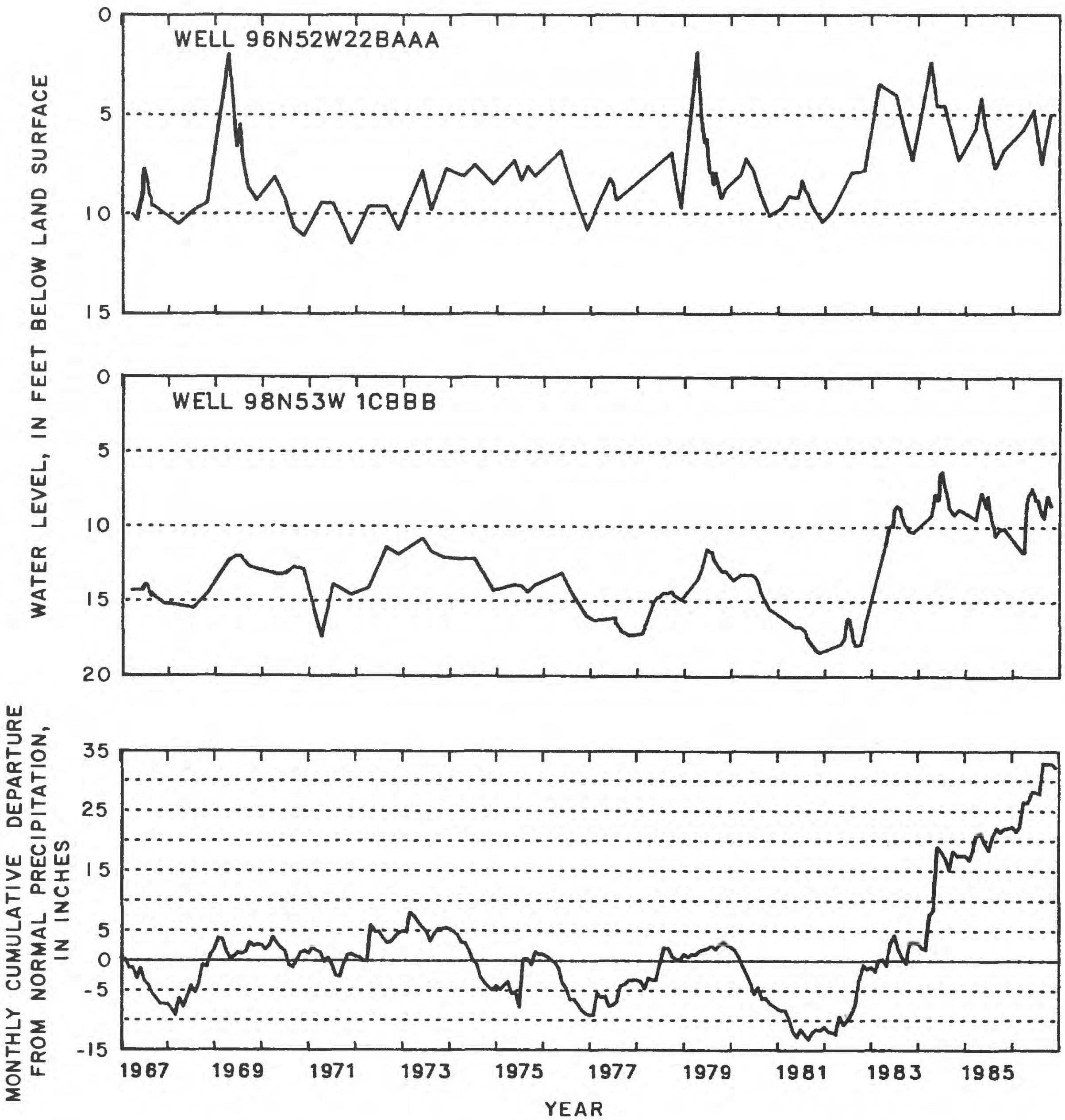


Figure 16.--Water-level fluctuations in the Parker-Centerville aquifer and cumulative monthly departure from normal precipitation at Marion.

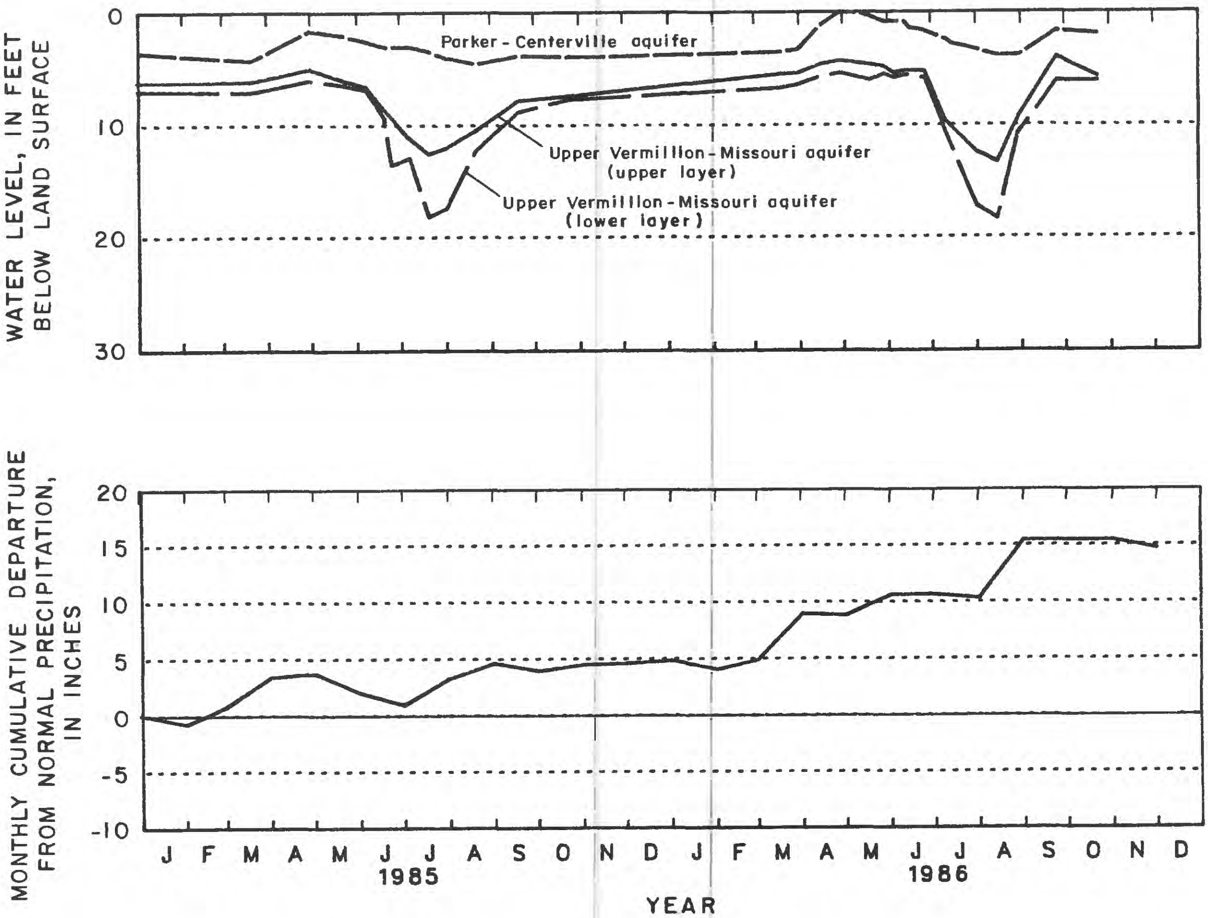


Figure 17.--Water-level fluctuations in the Parker-Centerville and Upper Vermillion-Missouri aquifers and cumulative monthly departure from normal precipitation at Marion.

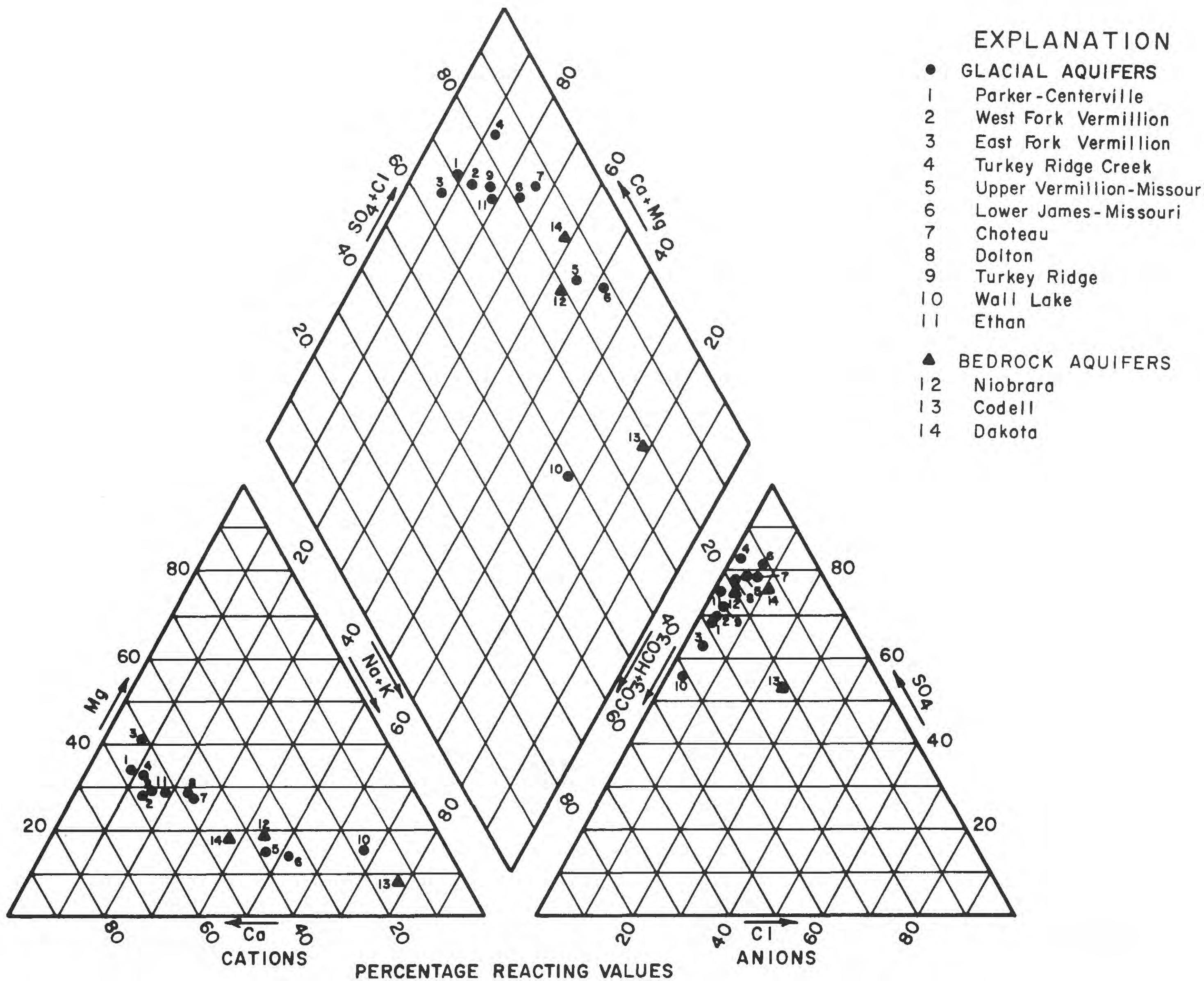


Figure 18.--Predominant chemical constituents in water from major aquifers.

Table 6.--Summary of chemical analyses of water from glacial and bedrock aquifers in Hutchinson and Turner Counties

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

	Glacial aquifers							
	Parker-Centerville aquifer				West Fork Vermillion aquifer			
Constituent	Number of samples	Maximum	Minimum	Mean	Number of samples	Maximum	Minimum	Mean
Specific conductance, lab (μS/cm)	25	2,800	540	1,130	6	1,780	785	1,240
pH, lab[1] (pH units)	21	8.0	7.5	[2]7.8	6	8.1	7.6	[2]7.7
Hardness, as $CaCO_3$	25	1,700	270	680	6	930	410	670
Hardness, noncarbonate, as $CaCO_3$	21	1,600	62	420	6	2,500	160	750
Alkalinity, lab, as $CaCO_3$	21	420	90	230	6	330	230	270
Dissolved solids	24	6,760	407	1,840	6	1,200	550	870
Calcium, dissolved	25	430	56	180	6	200	98	150
Magnesium, dissolved	25	140	16	58	6	110	41	70
Sodium, dissolved	25	110	6	30	6	48	16	30
Potassium, dissolved	21	14	3	7	6	14	3.9	6.4
Bicarbonate, lab, as $CaCO_3$	15	440	110	250	1	310	310	310
Sulfate, dissolved	25	1,700	140	450	6	690	210	400
Chloride, dissolved	25	90	2	13	6	82	5.2	23
Fluoride, dissolved	4	.6	.3	.4	2	.3	.2	.2
Silica, dissolved	4	30	21	27	5	34	24	28
Nitrogen, dissolved	4	8.5	<.10	--	5	21	<.10	--
Boron, dissolved[1] (μg/L)	14	370	40	180	3	110	80	97
Iron, dissolved[1] (μg/L)	4	7,000	20	2,000	5	900	6	270
Iron, total[3] (μg/L)	14	3,800	50	780	1	10	10	10
Manganese, dissolved[1] (μg/L)	4	1,300	5	680	5	620	17	280
Manganese, total[3] (μg/L)	4	2,200	50	1,100	0	--	--	--
Selenium, dissolved[1] (μg/L)	2	<1	<1	<1	2	<1	<1	<1
Strontium, dissolved[1] (μg/L)	2	1,300	320	810	2	540	60	300

Table 6.--Summary of chemical analyses of water from glacial and bedrock aquifers in Hutchinson and Turner Counties--Continued

	Glacial aquifers							
	East Fork Vermillion aquifer				Turkey Ridge Creek aquifer			
Constituent	Number of samples	Maximum	Minimum	Mean	Number of samples	Maximum	Minimum	Mean
Specific conductance, lab ($\mu S/cm$)	4	2,050	1,400	1,640	5	2,800	2,150	2,460
pH, lab[1] (pH units)	4	8.0	7.4	[2]7.6	5	8.1	7.0	[2]7.6
Hardness, as $CaCO_3$	4	1,100	730	850	5	1,700	1,000	1,400
Hardness, noncarbonate, as $CaCO_3$	4	760	430	560	5	1,500	880	1,100
Alkalinity, lab, as $CaCO_3$	4	320	230	290	5	450	140	300
Dissolved solids	4	1,600	930	1,260	5	2,800	1,900	2,200
Calcium, dissolved	4	290	180	230	5	420	260	360
Magnesium, dissolved	4	87	55	67	5	170	91	130
Sodium, dissolved	4	91	34	59	5	110	43	82
Potassium, dissolved	4	12	3.7	8.7	5	34	5.1	18
Bicarbonate, lab, as $CaCO_3$	2	360	280	320	2	300	170	230
Sulfate, dissolved	4	890	410	640	5	1,600	1,100	1,300
Chloride, dissolved	4	29	6	16	5	12	3.4	6.8
Fluoride, dissolved	1	.4	.4	.4	1	.3	.3	.3
Silica, dissolved	2	29	27	28	3	32	29	30
Nitrogen, dissolved	2	23	.5	12	3	<.10	<.10	<.10
Boron, dissolved[1] ($\mu g/L$)	2	490	340	420	3	1,100	460	710
Iron, dissolved[1] ($\mu g/L$)	2	40	20	30	3	9,300	30	3,900
Iron, total[3] ($\mu g/L$)	1	800	800	800	2	1,500	60	780
Manganese, dissolved[1] ($\mu g/L$)	2	2,800	160	1,500	3	2,100	840	1,600
Manganese, total[3] ($\mu g/L$)	0	--	--	--	0	--	--	--
Selenium, dissolved[1] ($\mu g/L$)	1	<1	<1	<1	1	<1	<1	<1
Strontium, dissolved[1] ($\mu g/L$)	1	1,500	1,500	1,500	1	2,700	2,700	2,700

Table 6.--Summary of chemical analyses of water from glacial and bedrock aquifers in Hutchinson and Turner Counties--Continued

	Glacial aquifers							
	Upper Vermillion-Missouri aquifer				Lower James-Missouri aquifer			
Constituent	Number of samples	Maximum	Minimum	Mean	Number of samples	Maximum	Minimum	Mean
Specific conductance, lab (µS/cm)	38	3,410	700	1,600	34	4,450	1,150	2,010
pH, lab[1] (pH units)	35	8.4	7.4	[2]7.9	33	8.5	7.2	[2]7.8
Hardness, as $CaCO_3$	37	1,500	71	740	35	2,700	430	920
Hardness, noncarbonate, as $CaCO_3$	35	1,200	110	540	35	2,300	280	720
Alkalinity, lab, as $CaCO_3$	36	420	78	220	34	420	71	200
Dissolved solids	38	8,600	528	1,720	35	3,300	776	1,630
Calcium, dissolved	38	390	12	190	35	490	110	240
Magnesium, dissolved	38	120	10	63	35	360	26	78
Sodium, dissolved	38	300	15	110	35	290	20	140
Potassium, dissolved	36	42	4.8	15	35	31	7	18
Bicarbonate, lab, as $CaCO_3$	19	420	95	180	12	330	87	140
Sulfate, dissolved	38	1,800	180	710	35	1,500	430	900
Chloride, dissolved	38	46	1.5	12	35	440	4	56
Fluoride, dissolved	8	.5	.2	.4	7	1.3	.2	.4
Silica, dissolved	17	48	23	31	23	33	20	29
Nitrogen, dissolved	17	1.8	<.10	--	22	150	<.10	--
Boron, dissolved[1] (µg/L)	28	2,300	130	690	19	1,800	140	830
Iron, dissolved[1] (µg/L)	17	10,000	30	2,600	23	15,000	6	2,600
Iron, total[3] (µg/L)	15	5,500	40	1,500	2	200	60	130
Manganese, dissolved[1] (µg/L)	17	3,400	570	1,400	23	6,200	10	2,700
Manganese, total[3] (µg/L)	2	2,300	2,300	2,300	0	--	--	--
Selenium, dissolved[1] (µg/L)	8	<1	<1	<1	7	15	<1	--
Strontium, dissolved[1] (µg/L)	8	2,200	460	1,500	7	3,900	230	2,100

Table 6.--Summary of chemical analyses of water from glacial and bedrock aquifers in Hutchinson and Turner Counties--Continued

Constituent	Glacial aquifers							
	Choteau aquifer				Dolton aquifer			
	Number of samples	Maximum	Minimum	Mean	Number of samples	Maximum	Minimum	Mean
Specific conductance, lab ($\mu S/cm$)	14	2,490	1,850	2,150	6	2,200	850	1,440
pH, lab[1] (pH units)	14	8.4	7.4	[2]7.8	6	8.6	7.5	[2]8.2
Hardness, as $CaCO_3$	14	1,000	320	620	6	810	60	280
Hardness, noncarbonate, as $CaCO_3$	14	910	56	450	2	640	130	280
Alkalinity, lab, as $CaCO_3$	14	320	79	170	6	540	170	380
Dissolved solids	14	2,570	1,380	1,720	5	2,110	610	1,190
Calcium, dissolved	14	290	80	180	6	210	19	64
Magnesium, dissolved	14	76	14	43	6	71	3	30
Sodium, dissolved	14	420	190	290	6	350	180	260
Potassium, dissolved	14	36	16	24	6	20	8	13
Bicarbonate, lab, as $CaCO_3$	7	340	100	180	4	540	210	370
Sulfate, dissolved	14	1,700	730	1,000	6	1,200	26	420
Chloride, dissolved	14	130	28	74	5	26	4	15
Fluoride, dissolved	3	.7	.5	.6	0	--	--	--
Silica, dissolved	7	37	17	29	2	32	30	31
Nitrogen, dissolved	7	2.5	<.10	--	2	.11	<.10	--
Boron, dissolved[1] ($\mu g/L$)	10	2,500	820	2,100	5	1,800	1,400	1,500
Iron, dissolved[1] ($\mu g/L$)	7	1,700	90	600	2	2,600	500	1,600
Iron, total[3] ($\mu g/L$)	7	1,200	90	510	0	--	--	--
Manganese, dissolved[1] ($\mu g/L$)	7	5,500	760	2,800	2	380	110	240
Manganese, total[3] ($\mu g/L$)	0	--	--	--	0	--	--	--
Selenium, dissolved[1] ($\mu g/L$)	3	<1	<1	<1	1	<1	<1	<1
Strontium, dissolved[1] ($\mu g/L$)	3	2,500	1,500	2,100	1	540	540	540

Table 6.--Summary of chemical analyses of water from glacial and bedrock aquifers in Hutchinson and Turner Counties--Continued

	Glacial aquifers							
	Turkey Ridge aquifer				Wall Lake aquifer			
Constituent	Number of samples	Maximum	Minimum	Mean	Number of samples	Maximum	Minimum	Mean
Specific conductance, lab (μS/cm)	5	2,810	1,830	2,230	4	2,290	1,250	2,020
pH, lab[1] (pH units)	5	7.3	6.9	[2]7.1	4	8.0	7.4	[2]7.8
Hardness, as $CaCO_3$	5	1,500	930	1,200	4	1,300	700	1,000
Hardness, noncarbonate, as $CaCO_3$	5	1,000	520	760	4	970	320	690
Alkalinity, lab, as $CaCO_3$	5	540	240	420	4	380	320	340
Dissolved solids	5	2,400	1,300	1,780	4	1,800	1,200	1,550
Calcium, dissolved	5	420	250	320	4	350	180	270
Magnesium, dissolved	5	120	74	93	4	110	60	90
Sodium, dissolved	5	140	35	88	4	160	31	100
Potassium, dissolved	5	17	6.8	10	4	17	5.9	11
Bicarbonate, lab, as $CaCO_3$	0	--	--	--	0	--	--	--
Sulfate, dissolved	5	1,400	550	950	4	1,000	450	860
Chloride, dissolved	5	12	4.9	8	4	19	1.7	11
Fluoride, dissolved	3	.3	.2	.2	2	.4	.4	.4
Silica, dissolved	5	48	31	38	4	34	25	29
Nitrogen, dissolved	5	5.5	<.10	--	4	4.8	<.10	--
Boron, dissolved[1] (μg/L)	3	970	260	530	2	700	360	530
Iron, dissolved[1] (μg/L)	5	7,200	56	3,900	4	6,600	40	2,500
Iron, total[3] (μg/L)	0	--	--	--	0	--	--	--
Manganese, dissolved[1] (μg/L)	5	8,800	330	2,700	4	1,500	240	812
Manganese, total[3] (μg/L)	0	--	--	--	0	--	--	--
Selenium, dissolved[1] (μg/L)	3	2	<1	--	2	<1	<1	<1
Strontium, dissolved[1] (μg/L)	3	2,800	1,500	1,900	2	1,800	990	1,400

Table 6.--Summary of chemical analyses of water from glacial and bedrock aquifers in Hutchinson and Turner Counties--Continued

Constituent	Glacial aquifer				Bedrock aquifer			
	Ethan aquifer				Niobrara aquifer			
	Number of samples	Maximum	Minimum	Mean	Number of samples	Maximum	Minimum	Mean
Specific conductance, lab (μS/cm)	3	2,870	2,380	2,580	20	2,850	993	1,990
pH, lab[1] (pH units)	3	8.1	7.2	[2]7.7	18	7.9	6.4	[2]7.4
Hardness, as $CaCO_3$	3	1,300	590	840	20	1,300	110	650
Hardness, noncarbonate, as $CaCO_3$	3	1,100	230	530	15	970	40	490
Alkalinity, lab, as $CaCO_3$	3	360	160	290	19	380	96	270
Dissolved solids	3	2,700	1,800	2,100	20	2,490	560	1,510
Calcium, dissolved	3	390	170	250	20	390	30	170
Magnesium, dissolved	3	79	40	54	20	120	8	55
Sodium, dissolved	3	350	260	320	20	470	23	220
Potassium, dissolved	3	45	18	29	19	31	7.1	20
Bicarbonate, lab, as $CaCO_3$	1	200	200	200	6	390	120	240
Sulfate, dissolved	3	1,500	940	1,100	20	1,400	200	800
Chloride, dissolved	3	80	32	50	20	110	2.5	24
Fluoride, dissolved	1	.6	.6	.6	5	2	.2	.9
Silica, dissolved	2	31	28	30	13	30	7.8	16
Nitrogen, dissolved	2	3.9	<.10	--	13	3.2	<.10	--
Boron, dissolved[1] (μg/L)	2	3,000	500	1,800	10	5,500	3	2,100
Iron, dissolved[1] (μg/L)	2	1,800	1,000	1,400	12	45,000	7	4,400
Iron, total[3] (μg/L)	1	780	780	780	2	3,500	880	2,200
Manganese, dissolved[1] (μg/L)	2	1,000	470	740	12	1,100	10	160
Manganese, total[3] (μg/L)	0	--	--	--	1	800	800	800
Selenium, dissolved[1] (μg/L)	2	<1	<1	<1	4	<1	<1	<1
Strontium, dissolved[1] (μg/L)	1	2,300	2,300	2,300	4	3,500	1,000	2,100

Table 6.--Summary of chemical analyses of water from glacial and bedrock aquifers in Hutchinson and Turner Counties--Continued

Constituent	Bedrock aquifers							
	Codell aquifer				Dakota aquifer			
	Number of samples	Maximum	Minimum	Mean	Number of samples	Maximum	Minimum	Mean
Specific conductance, lab ($\mu S/cm$)	9	2,440	2,050	2,260	14	2,660	900	1,910
pH, lab[1] (pH units)	9	8.0	7.4	[2]7.9	14	8.1	7.2	[2]7.4
Hardness, as $CaCO_3$	9	440	85	230	15	1,200	250	670
Hardness, noncarbonate, as $CaCO_3$	5	330	0	--	15	1,100	21	500
Alkalinity, lab, as $CaCO_3$	9	420	110	290	14	300	76	170
Dissolved solids	9	1,720	1,270	1,450	15	2,100	784	1,460
Calcium, dissolved	9	120	23	55	15	360	50	190
Magnesium, dissolved	9	50	6.8	23	15	82	20	51
Sodium, dissolved	9	470	250	400	15	510	86	180
Potassium, dissolved	9	31	12	19	15	25	13	20
Bicarbonate, lab, as $CaCO_3$	4	410	130	210	2	120	93	110
Sulfate, dissolved	9	1,100	130	580	15	1,300	360	800
Chloride, dissolved	9	400	38	200	15	140	8	81
Fluoride, dissolved	2	1.2	.5	.8	6	2.3	.8	1.6
Silica, dissolved	5	9.1	8.1	8.6	13	27	6.4	10
Nitrogen, dissolved	5	2.1	<.10	--	11	2.6	<.10	--
Boron, dissolved[1] ($\mu g/L$)	6	5,900	2,500	4,000	8	2,700	290	1,100
Iron, dissolved[1] ($m\mu/L$)	5	5,800	20	1,300	12	5,300	6	800
Iron, total[3] ($\mu g/L$)	3	1,800	120	1,000	0	--	--	--
Manganese, dissolved[1] ($\mu g/L$)	5	60	10	24	12	780	11	170
Manganese, total[3] ($\mu g/L$)	0	--	--	--	0	--	--	--
Selenium, dissolved[1] ($\mu g/L$)	2	<1	<1	<1	5	<1	<1	<1
Strontium, dissolved[1] ($\mu g/L$)	2	3,100	750	1,900	5	9,000	1,400	4,800

[1]Analyses by U.S. Geological Survey Laboratory only.
[2]Median value.
[3]Analyses by South Dakota Geological Survey Laboratory only.

West Fork Vermillion aquifer

The West Fork Vermillion aquifer (fig. 8) underlies 18 mi^2 of northern Turner County and is composed of fine sand to coarse-pebble gravel. The aquifer is at or near land surface and under water-table conditions in the West Fork Vermillion River flood plain. In T. 99 N., R. 53 W., north of the West Fork Vermillion River, the aquifer is confined by as much as 45 ft of till and is under artesian conditions. Hydrologic characteristics are given in table 5, and geologic sections of the aquifer are shown in figures 12 and 19.

Recharge to the West Fork Vermillion aquifer is by direct infiltration of precipitation in the West Fork Vermillion River flood plain where the aquifer is at or near land surface. The general direction of water movement in the aquifer is toward the West Fork Vermillion River and to the southeast at a gradient of about 6 ft/mi (fig. 15). Discharge from the West Fork Vermillion aquifer is: (1) To the Parker-Centerville aquifer, (2) to the West Fork Vermillion River, (3) by evapotranspiration where the aquifer is at or near land surface, and (4) by withdrawal from irrigation, municipal, stock, and domestic wells. Subsurface inflow from McCook County is about 100 acre-ft/yr.

Records of long-term water-level fluctuations in well 99N53W15BCBC, located in the West Fork Vermillion River flood plain, show close correlation with long-term trends in precipitation (fig. 20). The water level declined about 5 ft during 1981 because of below-normal precipitation and increased irrigation withdrawals. The water level rose about 17 ft from 1982 to 1984 because of above-normal precipitation. Water-level fluctuations in wells completed in areas where the West Fork Vermillion aquifer is under confined conditions were similar to the fluctuations observed in well 99N53W15BCBC but were about 1 to 2 ft greater in magnitude.

Predominant chemical constituents in water from the West Fork Vermillion aquifer are calcium, sulfate, and bicarbonate (fig. 18). Dissolved-solids concentrations ranged from 550 to 1,200 mg/L and averaged 870 mg/L. Hardness concentrations ranged from 410 to 930 mg/L and averaged 670 mg/L. A summary of chemical analyses of water from the aquifer is given in table 6. Water from the West Fork Vermillion aquifer is used for domestic, municipal, irrigation, and stock-watering purposes. Water from the aquifer generally is suitable for irrigation under all soil texture conditions based on the South Dakota irrigation-water classification diagram (fig. 11).

East Fork Vermillion aquifer

The East Fork Vermillion aquifer (fig. 8) underlies about 6 mi^2 of northeastern Turner County. The aquifer is composed of fine sand to medium-pebble gravel, is limited to the flood plain of the East Fork Vermillion River, and is at or near land surface (fig. 19). The aquifer is underlaid by till; however, near the McCook-Turner County line, the aquifer lies directly on Sioux Quartzite. Hydrologic characteristics of the aquifer are given in table 5.

Recharge to the East Fork Vermillion aquifer is by direct infiltration of precipitation and snowmelt. Subsurface inflow from McCook County is about 240 acre-ft/yr. The direction of water movement in the aquifer is to the East Fork Vermillion River (fig. 15).

Discharge from the East Fork Vermillion aquifer is: (1) To the Parker-Centerville aquifer, (2) to the East Fork Vermillion River, (3) by evapotranspiration, and (4) by withdrawal from irrigation, stock, and domestic wells.

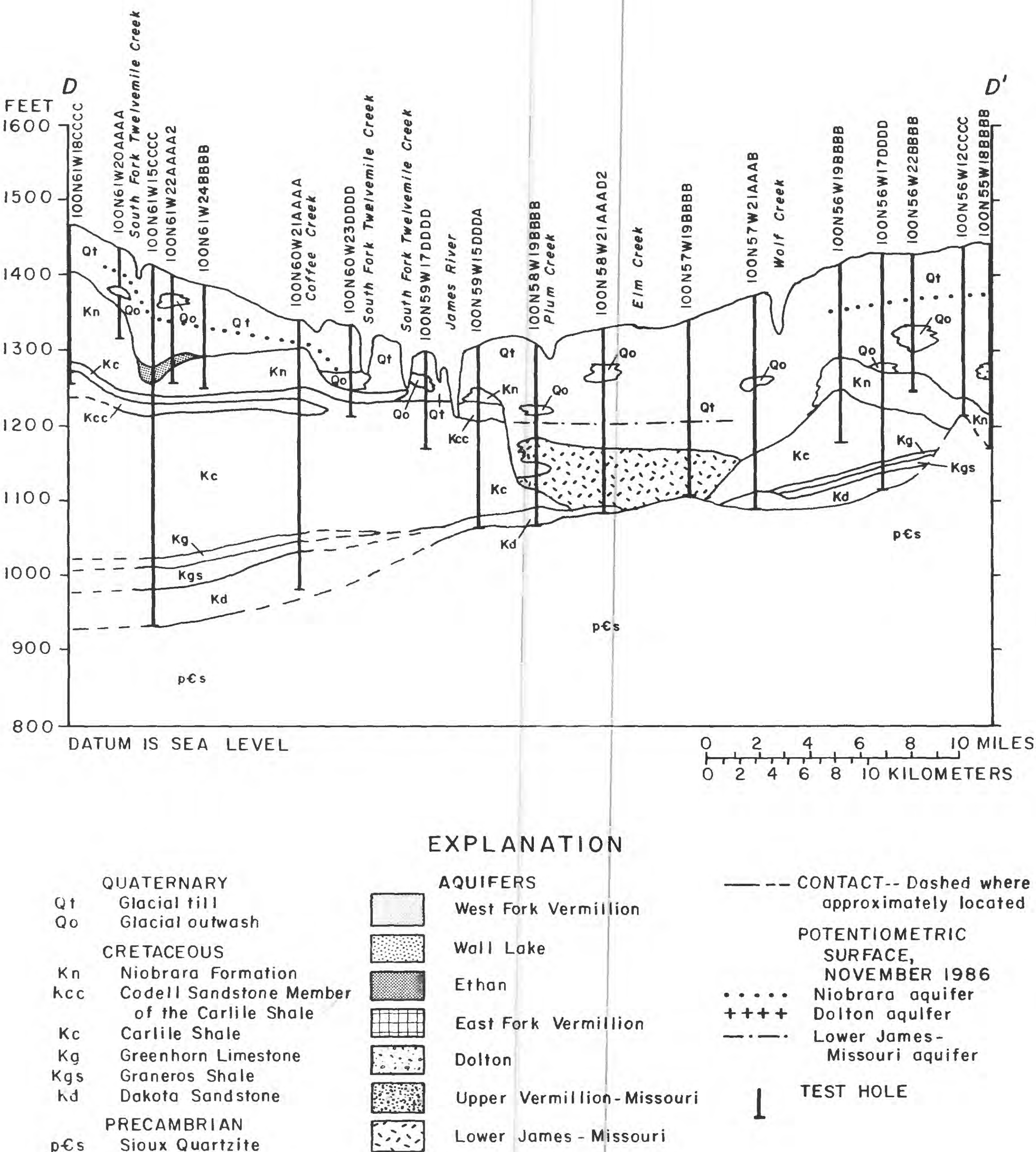


Figure 19.--Geologic section D-D" showing the West Fork Vermillion, Wall Lake, Ethan, East Fork Vermillion, Dolton, Upper Vermillion-Missouri, Lower James-Missouri, Niobrara, Codell, and Dakota aquifers. (Section D-D" is shown in figure 2.)

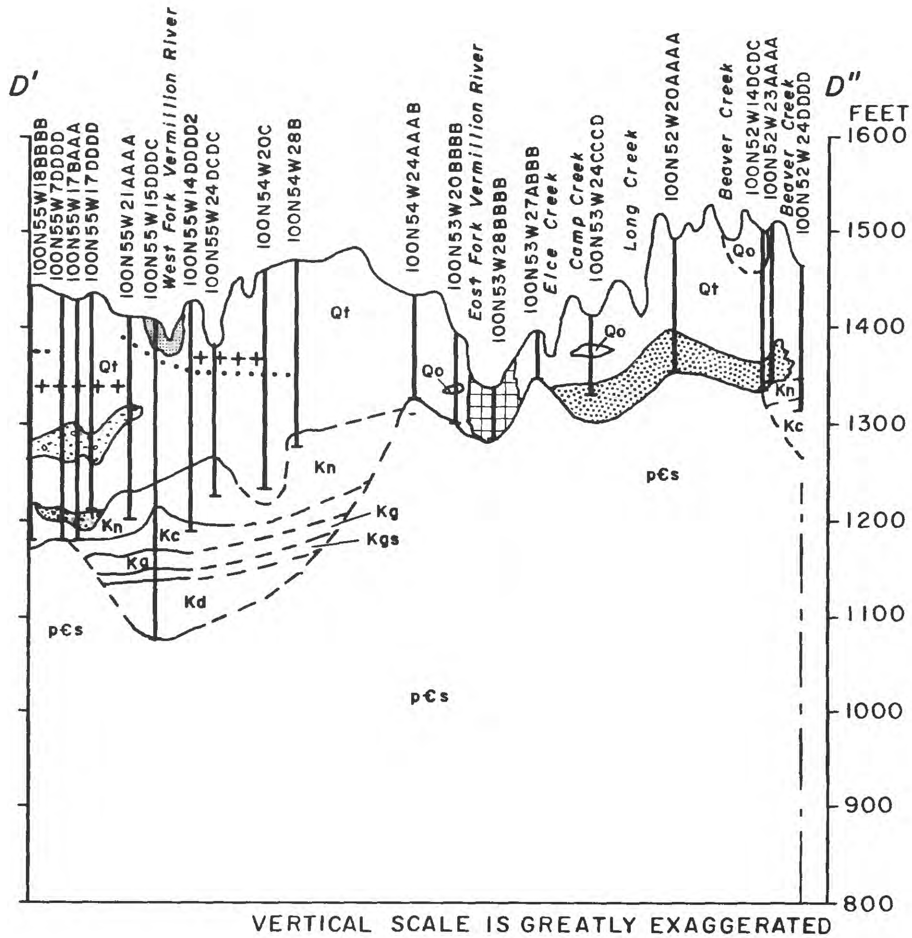


Figure 19.--Geologic section D-D" showing the West Fork Vermillion, Wall Lake, Ethan, East Fork Vermillion, Dolton, Upper Vermillion-Missouri, Lower James-Missouri, Niobrara, Codell, and Dakota aquifers.--Continued

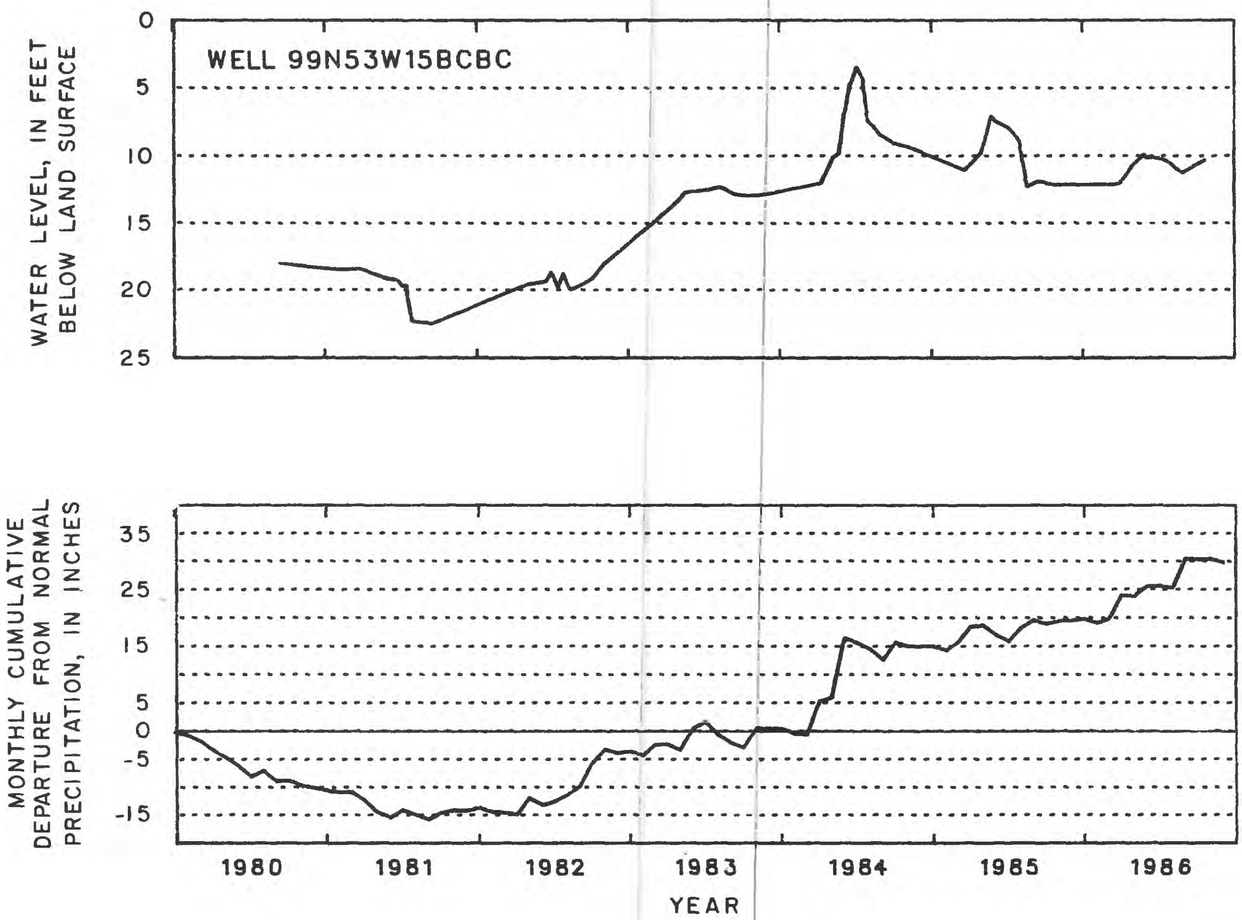


Figure 20.--Water-level fluctuations in the West Fork Vermillion aquifer and cumulative monthly departure from normal precipitation at Marion.

Water-level fluctuations in observation wells screened in the East Fork Vermillion aquifer are caused by seasonal changes in recharge and irrigation pumpage (fig. 21). Above-normal precipitation and snowmelt during the spring months of 1983-86 caused the peak water level in well 99N53W3BBAA to be about 4 ft higher than the peak water level observed during the spring months of 1978-82. Similar water levels observed during the fall months for the period of record may indicate hydraulic connection between the East Fork Vermillion River and the aquifer. Well 99N53W3BBAA is only about 0.5 mi from the river and the water level in the well closely parallels river stage. An irrigation well located about 1.5 mi to the northwest of the observation well had little or no effect on the water level in the observation well.

Predominant chemical constituents in water from the East Fork Vermillion aquifer are calcium, sulfate, and bicarbonate (fig. 18). Dissolved-solids concentrations ranged from 930 to 1,600 mg/L and averaged 1,260 mg/L. Hardness concentrations ranged from 730 to 1,100 mg/L and averaged 850 mg/L. Dissolved sodium and sulfate concentrations increased from north to south, possibly because of recharge from the Wall Lake aquifer in the southern part of the East Fork Vermillion aquifer. A summary of chemical analyses of water from the aquifer is given in table 6.

Water from the East Fork Vermillion aquifer is used for stock watering, domestic, and irrigation purposes. Water from the aquifer generally is suitable for irrigation under all soil texture conditions based on the South Dakota irrigation-water classification diagram (fig. 11).

Turkey Ridge Creek aquifer

The Turkey Ridge Creek aquifer (fig. 8) underlies about 18 mi^2 of southwestern Turner County. The aquifer is composed of fine sand to coarse-pebble gravel that lies directly on till. In southern T. 98 N., R. 54 W. and R. 55 W., a layer of till or Pierre Shale as little as 15 ft thick separates the Turkey Ridge Creek aquifer from the Niobrara Formation. Water in the Turkey Ridge Creek aquifer is under water-table conditions near Turkey Ridge Creek and under confined conditions away from the creek where the aquifer is overlaid by as much as 65 ft of till. The depth to water in wells ranged from land surface in the southeastern part of the aquifer near Turkey Ridge Creek to 36 ft below land surface where the aquifer is confined by till. A geologic section of the aquifer is shown in figure 13 and hydrologic characteristics are given in table 5.

Recharge to the Turkey Ridge Creek aquifer is: (1) By direct infiltration of precipitation near Turkey Ridge Creek where the aquifer is at or near land surface and (2) possibly from the underlying Niobrara aquifer.

The direction of water movement in the aquifer is toward Turkey Ridge Creek and to the east at a gradient of about 12 to 13 ft/mi in the western part of the aquifer and to the south and southeast at a gradient of 12 to 16 ft/mi in the eastern part of the aquifer (fig. 15).

Discharge from the Turkey Ridge Creek aquifer is: (1) By evapotranspiration where the aquifer is at or near land surface, (2) to Turkey Ridge Creek in the southern part of the aquifer, and (3) by withdrawal from stock and domestic wells. Discharge from the aquifer to Turkey Ridge Creek in T. 98 N., R. 54 W., sections 14, 15, 25, and 26, probably does not occur because the aquifer and streambed are separated by 20 ft of till.

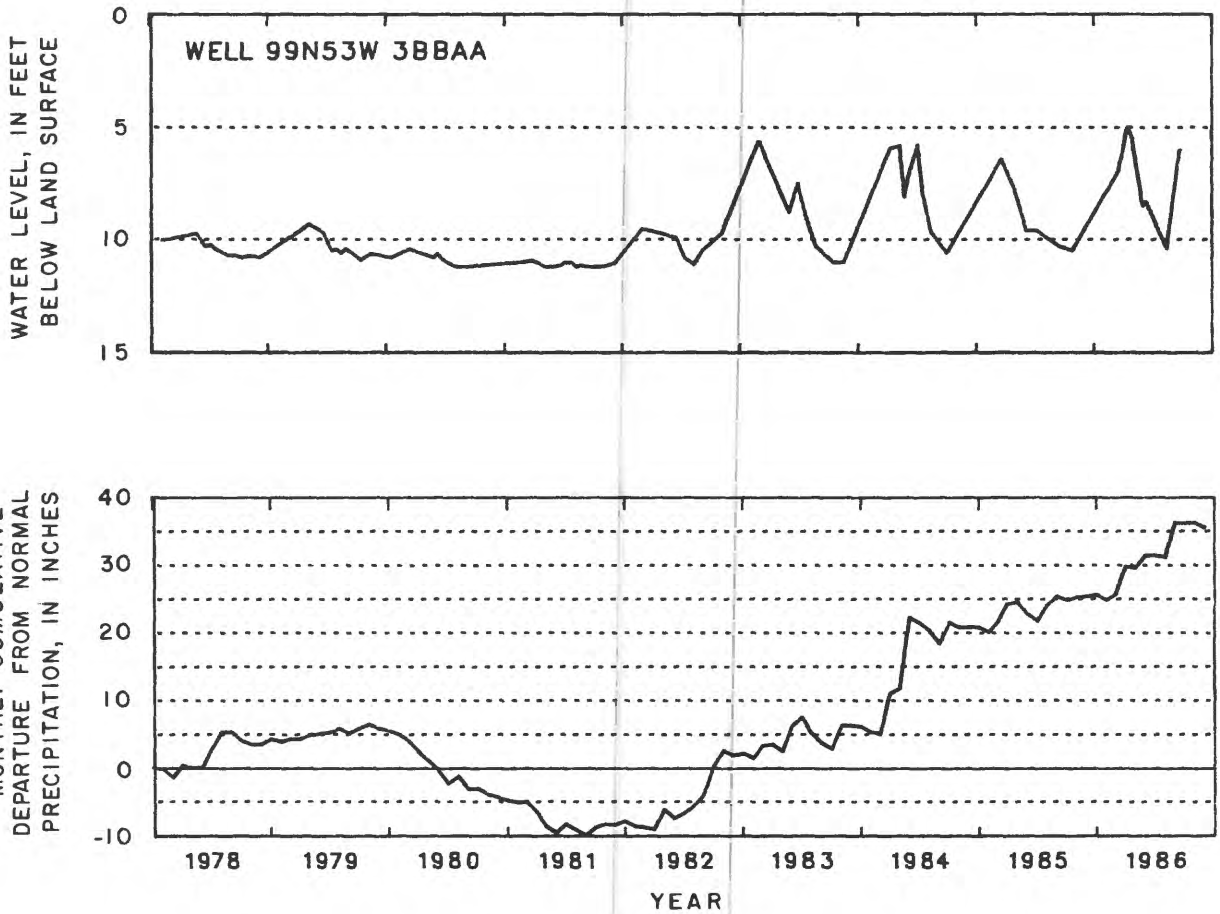


Figure 21.--Water-level fluctuations in the East Fork Vermillion aquifer and cumulative monthly departure from normal precipitation at Marion.

Water-level fluctuations in observation wells screened in the Turkey Ridge Creek aquifer are caused by seasonal changes in recharge (fig. 22). The comparatively low water levels in well 98N54W15DDDD from 1980-82 were caused by below-normal precipitation. The water level rises from 1983-84 were caused by above-normal precipitation.

The predominant chemical constituents in water from the Turkey Ridge Creek aquifer are calcium and sulfate (fig. 18). Dissolved-solids concentrations ranged from 1,900 to 2,800 mg/L and averaged 2,200 mg/L. Hardness concentrations ranged from 1,000 to 1,700 mg/L and averaged 1,400 mg/L. Specific conductance increased from 2,150 μS/cm (microsiemens per centimeter at 25 °Celsius) in the western part of the aquifer to 2,800 μS/cm in the southeastern part. A summary of chemical analyses of water from the aquifer is given in table 6.

Water from the Turkey Ridge Creek aquifer is used for stock watering and domestic purposes. The water generally is suitable for irrigation under all soil texture conditions based on the South Dakota irrigation-water classification diagram (fig. 11).

Upper Vermillion-Missouri aquifer

The Upper Vermillion-Missouri aquifer (fig. 9) is composed of fine sand to medium-pebble gravel, and the thickness generally exceeds 100 ft in the southeastern part of T. 96 N., R. 52 W. where the aquifer is composed primarily of cobble gravel. In T. 98 N., R. 52 W., the aquifer occurs as two layers of medium sand and gravel separated by as much as 40 ft of till (fig. 13). The aquifer is at or near land surface in T. 96 N., R. 52 W. at the Clay-Turner County line and is in hydraulic connection with the Parker-Centerville aquifer. In T. 99 N., R. 55 W. (fig. 12), the aquifer is as much as 355 ft below land surface. The aquifer generally is underlaid by Carlile Shale (fig. 13); however, in T. 99 N., R. 52 W., the aquifer is underlaid by Sioux Quartzite. In western Turner County, the aquifer trends northwest-southeast, lies on a preglacial bedrock channel (George Duchossois, South Dakota Geological Survey, written commun., 1985), and is underlaid by the Niobrara Formation (figs. 13 and 19) and Sioux Quartzite (fig. 12).

Recharge to the Upper Vermillion-Missouri aquifer is: (1) From the Niobrara aquifer in Turner County (figs. 13, 14, and 19), (2) by direct infiltration of precipitation in T. 96 N., R. 52 W. where the aquifer is at or near land surface, and (3) from fractures in the Sioux Quartzite in the northern part of the aquifer (T. 99 N., R. 52, 55, 56 W.). The Sioux Quartzite outcrops in northeastern Turner County and is recharged by direct infiltration of precipitation. Subsurface inflow from McCook County is about 110 acre-ft/yr.

The direction of water movement in the Upper Vermillion-Missouri aquifer is to the south and southeast at a gradient of about 4 ft/mi (fig. 23). The gradient in the western part of T. 97 N., R. 52 W. increases to about 15 ft/mi where the northwest-trending channel merges with the remainder of the aquifer.

Discharge from the Upper Vermillion-Missouri aquifer is by withdrawal from irrigation, municipal, stock, and domestic wells. Subsurface outflow into Clay County is about 2,900 acre-ft/yr.

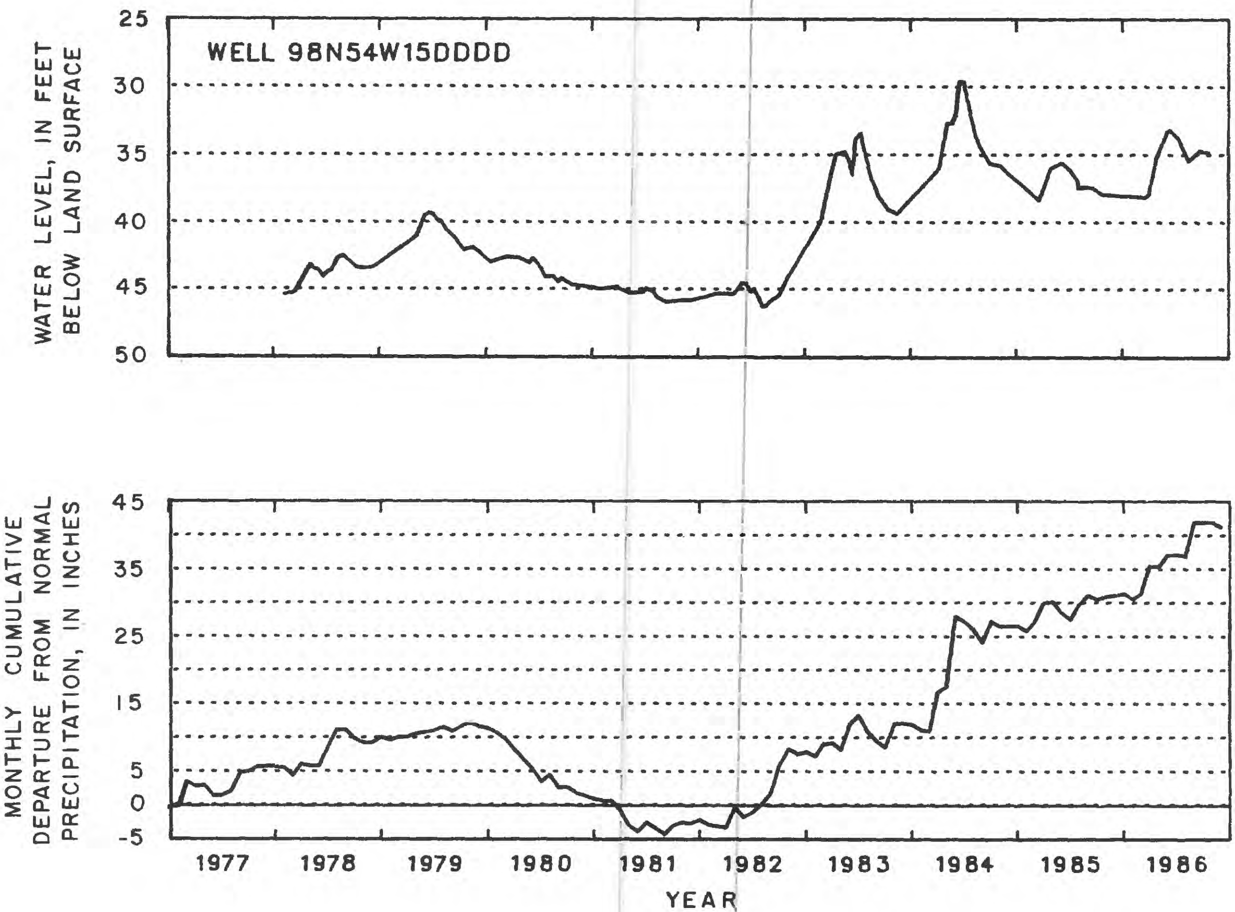


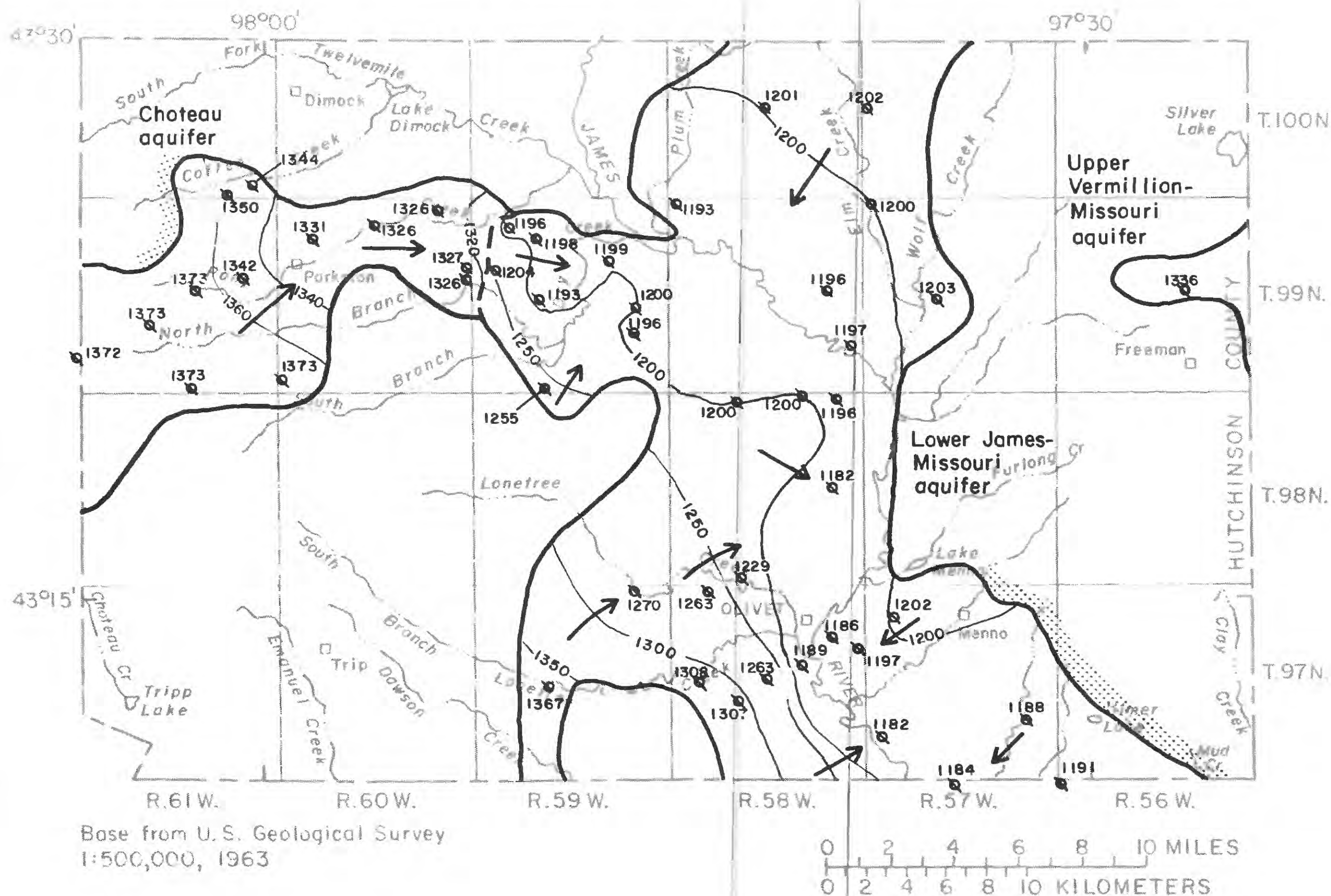
Figure 22.--Water-level fluctuations in the Turkey Ridge Creek aquifer and cumulative monthly departure from normal precipitation at Marion.

Water-level fluctuations in observation wells screened in the Upper Vermillion-Missouri aquifer are caused by seasonal fluctuations in recharge and discharge primarily from irrigation pumpage (fig. 24). Records of long-term water-level fluctuations in well 98N52W32BBBB2 show close correlation with long-term trends in precipitation. Annual water-level declines caused by irrigation withdrawals ranged from about 13 ft during 1983-86 to about 17 ft in 1980. Water-level declines in observation wells in the southern part of the aquifer generally were less than 10 ft, because the aquifer is under water-table conditions and irrigation withdrawals were less in the southern than in the northern part of the aquifer. The water level in well 100N55W30AABB located in the northwest-trending bedrock channel was about 5 to 7 ft higher in 1984-86 than in 1982-83 because of above-normal precipitation (fig. 24).

Two wells were completed in the Upper Vermillion-Missouri aquifer at 98N52W32BBBB where the aquifer is comprised of two layers of sand and gravel separated by 32 ft of glacial till (fig. 17). In 1985 and 1986, the water level in the upper sand and gravel layer was 1 to 2 ft higher during the spring and about 5 ft higher during the summer than the water level in the lower sand and gravel layer (fig. 17). The rise and decline of the water level in each layer was similar. Water levels in both layers declined 10 to 15 ft during June and July of 1985 and 1986 because of irrigation withdrawals, rose rapidly to within a few feet of pre-pumping levels soon after pumping ceased, and then continued to rise slowly (1 to 2 ft) from September to March. Irrigation wells in the area withdraw water from both sand and gravel layers, but the majority withdraw water from the lower sand and gravel layer, which is generally thicker than the upper layer.

The predominant chemical constituents in water from the Upper Vermillion-Missouri aquifer are calcium and sulfate (fig. 18). The water-quality characteristics of water from the Upper Vermillion-Missouri aquifer have complex areal variations that may be caused by mixing of water from other aquifers. Dissolved-solids concentrations ranged from 528 to 8,600 mg/L and averaged 1,720 mg/L. Hardness concentrations ranged from 71 to 1,500 mg/L and averaged 740 mg/L. Dissolved-solids and hardness concentrations generally were largest in the northeastern part of the aquifer near the Turner-Lincoln County line. Hardness concentrations increased from 71 mg/L near the northern part of the northwest-trending channel to as much as 1,100 mg/L near the southern part. The smaller hardness concentrations near the northern part may be because of recharge from fractures in the Sioux Quartzite. A summary of chemical analyses of water from the aquifer is given in table 6.

Patterns in specific conductance and hardness concentrations may indicate leakage from the Parker-Centerville aquifer to the Upper Vermillion-Missouri aquifer. Specific conductance and hardness concentrations of water from the Parker-Centerville aquifer generally were smaller than in the Upper Vermillion-Missouri aquifer. Specific conductance averaged 1,310 μS/cm and hardness concentrations averaged 620 mg/L in areas where the aquifer is overlaid by the Parker-Centerville aquifer. In areas where the Upper Vermillion-Missouri aquifer is not overlaid by the Parker-Centerville aquifer, specific conductance averaged 1,980 μS/cm and hardness concentrations averaged 950 mg/L.



EXPLANATION

1331 OBSERVATION WELL--Number is altitude of water surface, in feet. Datum is sea level

—1300— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Contour intervals, 20 feet for the Choteau and Upper Vermillion-Missouri aquifers and 50 feet for the Lower James-Missouri aquifer

— — — AQUIFER BOUNDARY--Dashed where approximately located

BOUNDARIES WHERE THE GLACIAL AQUIFERS ARE HYDRAULICALLY CONNECTED WITH AND RECEIVE RECHARGE FROM THE NIOBRARA AQUIFER

←— DIRECTION OF GROUND-WATER MOVEMENT

Figure 23.--Potentiometric surface of the Upper Vermillion-Missouri, Lower James-Missouri, and Choteau aquifers in Hutchinson and Turner Counties (November 1986).

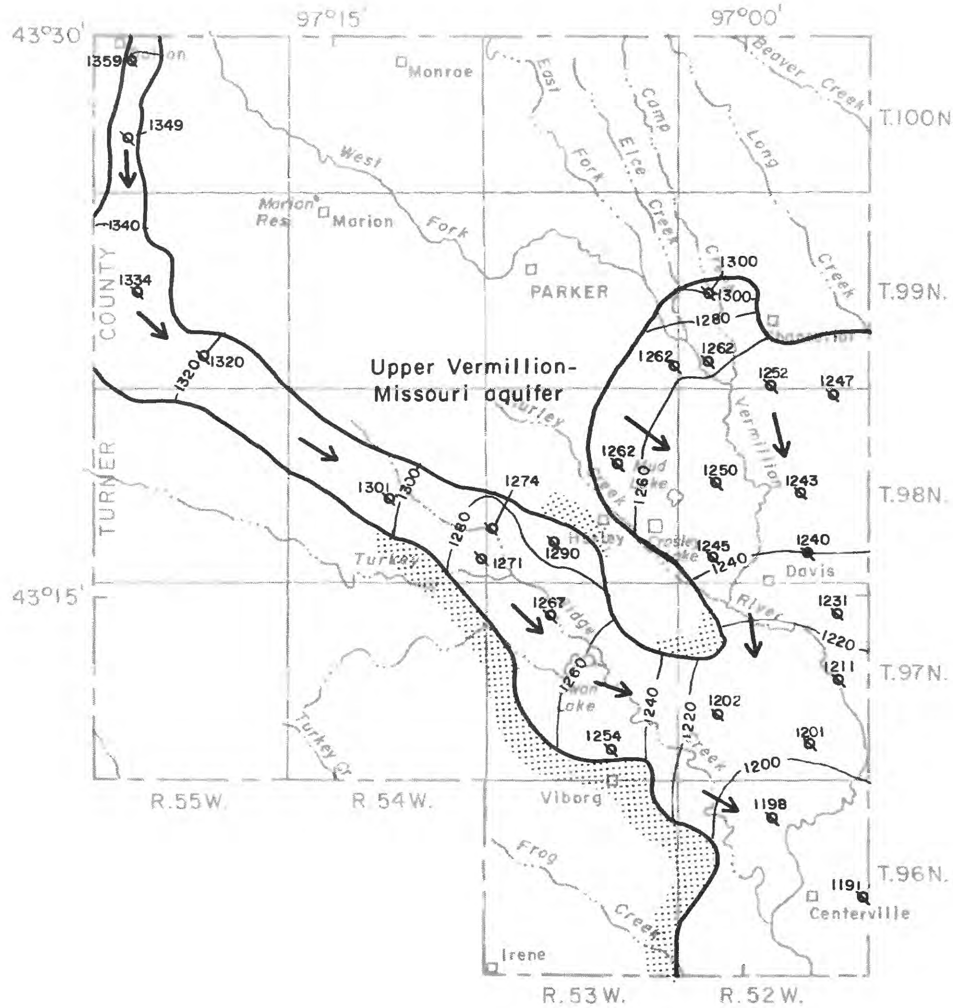


Figure 23.--Potentiometric surface of the Upper Vermillion-Missouri, Lower James-Missouri, and Choteau aquifers in Hutchinson and Turner Counties (November 1986)--Continued.

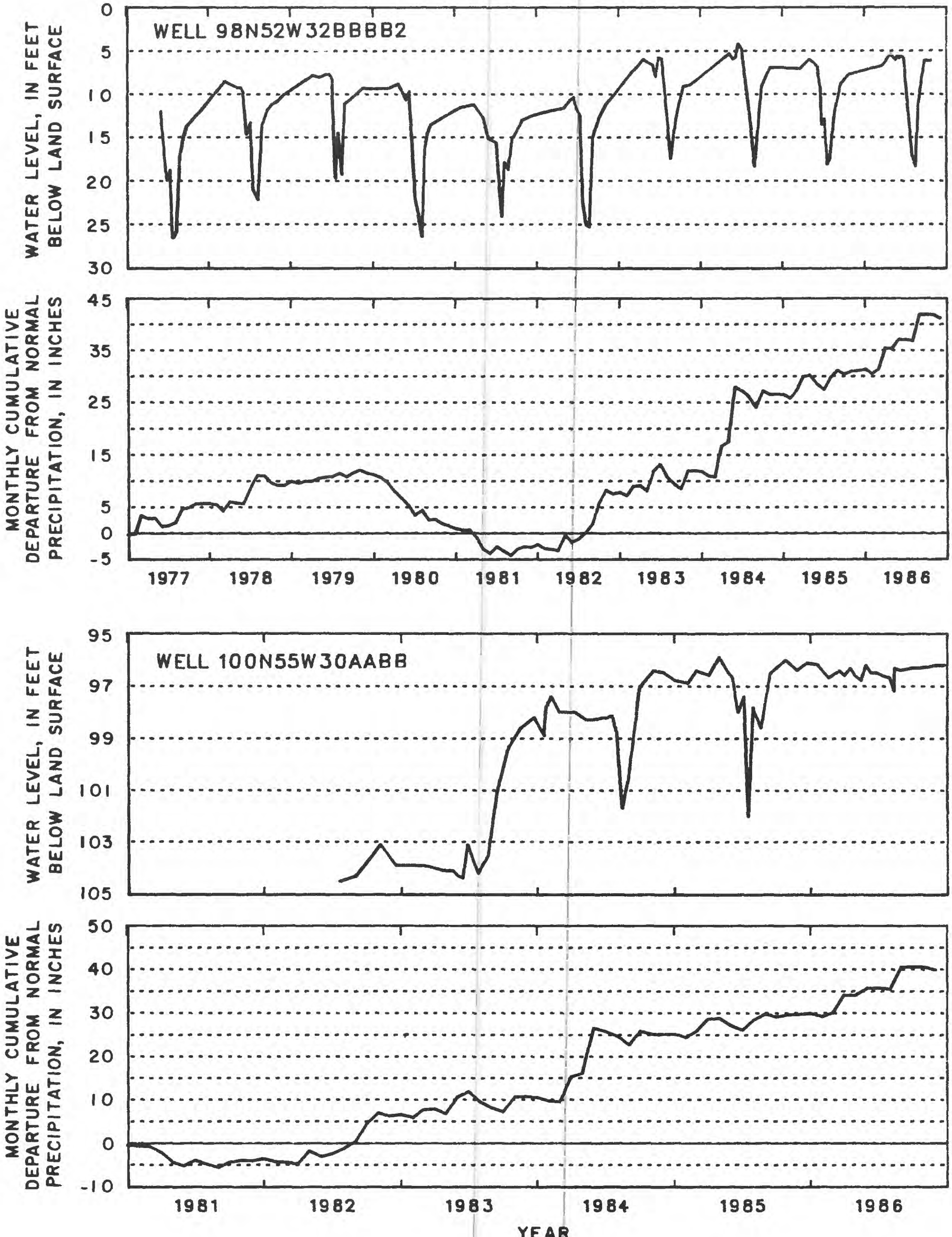


Figure 24.--Water-level fluctuations in the Upper Vermillion-Missouri aquifer and cumulative monthly departure from normal precipitation at Marion.

Dissolved-sodium concentrations were greater than 100 mg/L east of the Vermillion River in T. 97 N., T. 98 N., and T. 99 N. and in the northwest-trending channel. The larger concentrations in the northwest-trending channel may be caused by mixing with water from the Niobrara aquifer. The predominant chemical constituents in water from well 100N55W7DDDD located in the northern part of the northwest-trending channel were sodium, sulfate, and bicarbonate.

Water from the Upper Vermillion-Missouri aquifer is used for stock watering, domestic, municipal, and irrigation purposes. Water from the aquifer generally is suitable for irrigation under all soil texture conditions based on the South Dakota irrigation-water classification diagram (fig. 11).

Lower James-Missouri aquifer

The Lower James-Missouri aquifer (fig. 9) underlies about 268 mi^2 of Hutchinson County and areally is the most extensive glacial aquifer in the study area. The aquifer is composed of fine sand to cobble gravel intermixed in some places with discontinuous layers of till as much as 25 ft thick. The aquifer generally is underlaid by till or Carlile Shale; however, northeast of the James River, the aquifer lies on Sioux Quartzite (fig. 19), and in northern T. 97 N., R. 57 W. and northwestern T. 99 N., R. 59 W., the aquifer lies on the Niobrara Formation. Depth to the top of the aquifer ranges from land surface in the James River flood plain in T. 97 N. and T. 98 N. to 245 ft below land surface. Water in the aquifer is under confined conditions east of the James River valley and near its western boundary and generally under water-table conditions elsewhere. Depth to water in wells ranged from less than 1 ft in the James River flood plain to 134 ft below land surface in the northern part of the aquifer. Geologic sections of the aquifer are shown in figures 12, 13, 14, and 19 and hydrologic characteristics are given in table 5.

Recharge to the Lower James-Missouri aquifer is: (1) From the Choteau aquifer in T. 99 N., R. 59 W., (2) by direct infiltration of precipitation on the James River flood plain in T. 97 and 98 N. where the aquifer is at or near land surface, (3) from fractures in the Sioux Quartzite and the Dakota aquifer northeast of the James River in southern T. 99 N. and northern T. 98 N., R. 58 W., and (4) from the Niobrara aquifer in the northern part of T. 97 N., R. 57 W. Subsurface inflow from Hanson County is about 4,600 acre-ft/yr.

The direction of water movement in the Lower James-Missouri aquifer is toward the James River (fig. 23). East of the James River, the gradient of the potentiometric surface is about 2 ft/mi. West of the James River near the boundary with the Choteau aquifer, the gradient is about 23 ft/mi. The gradient decreases to about 7 ft/mi in the northern part of T. 98 N., R. 58 W. and is as much as about 60 ft/mi in T. 97 N. west of the James River where the aquifer is underlaid by Carlile Shale.

Discharge from the Lower James-Missouri aquifer is: (1) By seepage to the James River in T. 97 N. and T. 98 N., (2) by evapotranspiration in the James River flood plain in T. 97 N. and T. 98 N. where the aquifer is at or near land surface, and (3) by withdrawal from irrigation, stock, and domestic wells.

Water-level fluctuations in observation wells screened in the Lower James-Missouri aquifer are caused by seasonal fluctuations in recharge and discharge primarily by irrigation wells (fig. 25). The water level in well

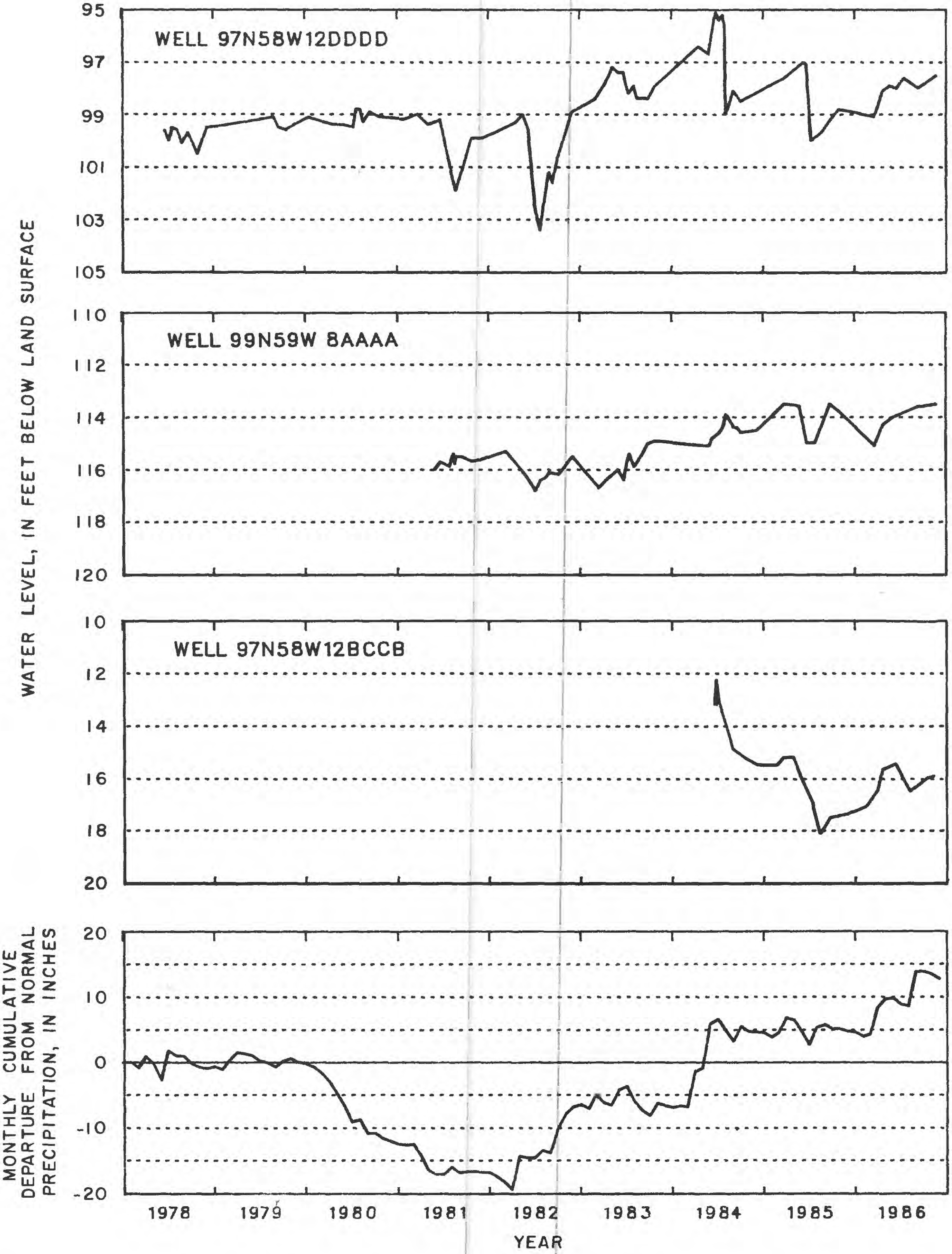


Figure 25.--Water-level fluctuations in the Lower James-Missouri aquifer and cumulative monthly departure from normal precipitation at Marion.

97N58W12DDDD, located east of the James River near an irrigation well, declined 3 to 4 ft from June to August during 1981 and 1982 because of irrigation withdrawals. Water levels generally rose from 1983-86 because of above-normal precipitation and subsequently declined from June to August in 1985 because of irrigation withdrawals. The water level in well 99N59W8AAAA was about 2 ft higher from 1984-86 than from 1982-83 because of above-normal precipitation. The water level in well 97N58W12BCCB declined about 3 ft from June 1984 to February 1985, rose about 0.3 ft from February to April 1985 because of infiltration of snowmelt and precipitation, declined about 3 ft from April to August 1985 because of irrigation withdrawals and less recharge, and rose about 2.5 ft from August 1985 to June 1986 because of spring recharge and the cessation of irrigation withdrawals. The comparatively high water level during early summer 1984 was caused by above-normal spring and early summer precipitation.

The predominant chemical constituents in water from the Lower James-Missouri aquifer are calcium and sulfate (fig. 18). Dissolved-solids concentrations ranged from 776 to 3,300 mg/L and averaged 1,630 mg/L. Hardness concentrations ranged from 430 to 2,700 mg/L and averaged 920 mg/L. The water-quality characteristics of water from the Lower James-Missouri aquifer have complex areal variations that may be associated with recharge and mixing with water from other aquifers. Hardness concentrations generally ranged from 500 to 1,000 mg/L; however, in T. 98 N., R. 58 W. and T. 99 N., R. 58 W., hardness concentrations ranged from about 1,000 to 2,700 mg/L. The hardness concentrations in some parts of the aquifer may be caused by recharge from sources of water with comparatively small hardness concentrations. The percentage of sodium in water from the northwestern and southern part of the aquifer is greater than in the eastern part. The greater sodium percentage in water from the northwestern part of the Lower James-Missouri aquifer may be caused by mixing of water from the Choteau aquifer. Dissolved-chloride concentrations as much as 440 mg/L in southern T. 99 N. and northern T. 98 N. may indicate mixing with water from the Dakota aquifer. A summary of chemical analyses of water from the aquifer is given in table 6.

Water from the Lower James-Missouri aquifer is used for stock watering, domestic, and irrigation purposes. Water from the aquifer generally is suitable for irrigation under all soil texture conditions based on the South Dakota irrigation-water classification diagram (fig. 11).

Choteau aquifer

The Choteau aquifer (fig. 9) underlies about 65 mi^2 in northwestern Hutchinson County and is composed of fine sand to fine-pebble gravel with some medium-pebble gravel near the eastern boundary and is overlaid by gray pebbly till (fig. 12). Test drilling indicated that the central part of the aquifer contains interbedded gravelly till layers. Depth to the top of the aquifer ranges from 105 ft in the eastern part of the aquifer to 270 ft near the Douglas-Hutchinson County line. In the eastern part of the aquifer near the boundary with the Lower James-Missouri aquifer, two layers of sand and gravel were separated by 9 ft of till in test hole 99N60W13AAAA. Hydraulic connection between the layers in the western part of the aquifer is indicated by similar water levels in observation wells screened in the two layers. The difference between water levels in observation wells 99N61W20DDDD screened in the upper layer and 99N61W22BAAA screened in the lower layer is less than 1 ft. The Choteau aquifer lies directly on impermeable Carlile Shale or till over most of its area; however, in the northern one-half of T. 99 N., R. 61 W., the aquifer is underlaid by the Niobrara aquifer. Test-hole data from 99N60W7AAAA and 99N61W32ABAA indicate that the Choteau aquifer is separated from the Codell aquifer by 6 ft of till. Hydrologic characteristics are given in table 5.

Recharge to the Choteau aquifer is from the Codell aquifer in northwestern T. 99 N., R. 60 W. and from the Niobrara aquifer in the north-central part of T. 99 N., R. 61 W.

The general direction of water movement in the Choteau aquifer is to the east; however, water levels in observation wells screened in the Choteau aquifer in Douglas County indicate that the direction of water movement is to the west near the Hutchinson-Douglas County line. The direction of movement of water in the aquifer in Douglas County is to the south (Jim Goodman, South Dakota Department of Water and Natural Resources, written commun., 1990). The gradient of the potentiometric surface is about 2 ft/mi (fig. 23); however, in the central part of the aquifer the gradient is about 20 ft/mi. The boundary between the Choteau and the Lower James-Missouri aquifer is indicated by a decline in the potentiometric surface of about 105 ft. The head decline may be the result of the change from confined conditions in the Choteau aquifer to water-table conditions in the Lower James-Missouri aquifer. Depth to water in wells ranges from 0 to 144 ft below land surface and increases from east to west. Wells in the Choteau aquifer near the eastern boundary may flow during the spring and early summer months.

Discharge from the Choteau aquifer is: (1) To the Lower James-Missouri aquifer; (2) by irrigation, municipal, domestic, and stock wells; (3) possibly to the Niobrara aquifer in the northwestern part of T. 98 N., R. 60 W.; and (4) to the Codell aquifer in northern T. 98 N., R. 61 W. and southern T. 99 N., R. 61 W. and in southeastern T. 100 N., R. 61 W. and northeastern T. 99 N., R. 61 W.

Water-level fluctuations in observation wells screened in the Choteau aquifer are caused by seasonal changes in discharge (fig. 26). Water levels in observation wells generally rise from late fall to early summer because of recovery from irrigation pumpage and recharge from spring snowmelt and decline during the summer and early fall months because of irrigation pumpage. Records of long-term water-level fluctuations in well 99N60W4DDAD show close correlation with long-term trends in precipitation. The water-level declines from 1967-68, 1975-77, and 1980-81 in well 99N60W4DDAD were caused by below-normal precipitation. The water-level rises in 1978-79 and 1983-86 were caused by above-normal precipitation. The water level in well 99N61W20DDDD rose by about 12 ft from the fall of 1981 to the fall of 1986 (fig. 26) because of above-normal precipitation.

Predominant chemical constituents in water from the northern part of the Choteau aquifer are sodium and sulfate. The predominant chemical constituents in water in the west-central part of the aquifer are calcium and sulfate. Dissolved-solids concentrations ranged from 1,380 to 2,570 mg/L and averaged 1,720 mg/L. Hardness concentrations ranged from 320 to 1,000 mg/L and averaged 620 mg/L. Mixing of water between the Codell aquifer and the Choteau aquifer may occur in northern T. 99 N., R. 60 and 61 W. and southeastern T. 100 N., R. 61 W. where the two aquifers are in hydraulic connection. The hardness concentration in water from well 100N61W36CBBB in the Choteau aquifer was 460 mg/L. The hardness concentration in water from well 99N60W7AAAA in the Codell aquifer was 440 mg/L. Predominant chemical constituents in water from the Codell aquifer are similar to the Choteau aquifer (fig. 18) which would further indicate the hydraulic connection. A summary of chemical analyses of water from the aquifer is given in table 6.

Water from the Choteau aquifer is used for stock watering, domestic, municipal, and irrigation purposes. Suitability of water from the Choteau aquifer for irrigation is limited to certain soil texture conditions based on the South Dakota irrigation-water classification diagram (fig. 11).

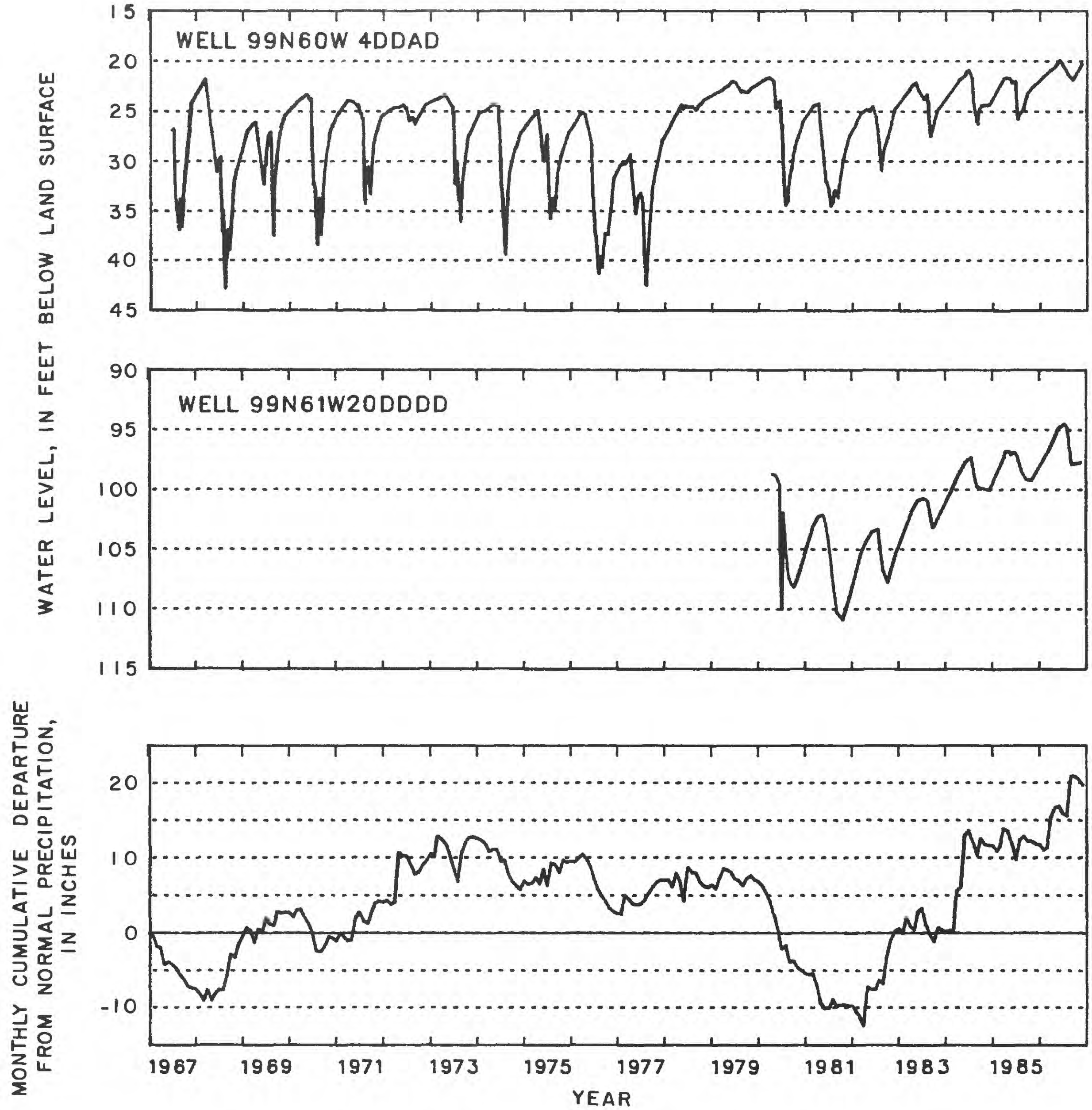
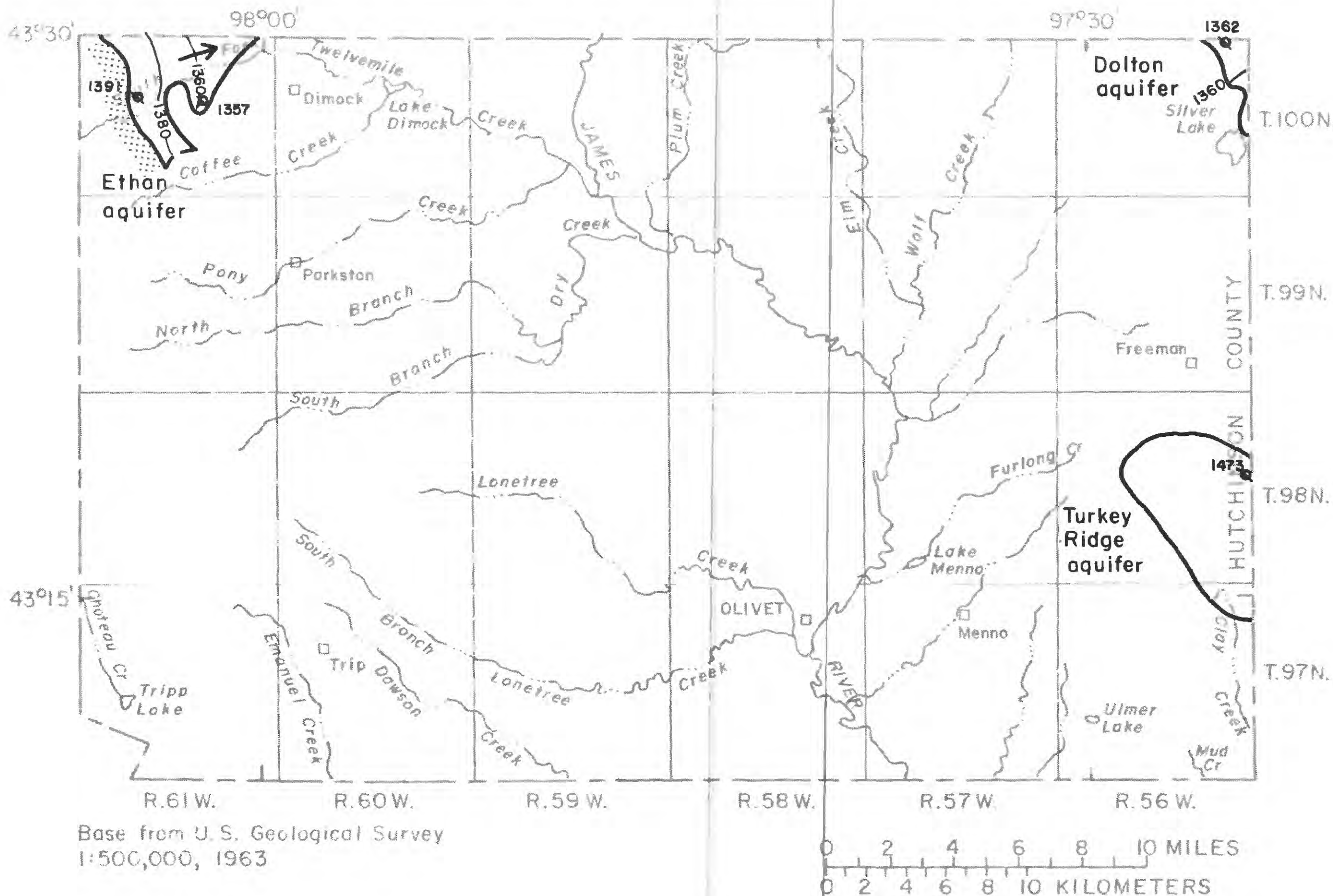


Figure 26.--Water-level fluctuations in the Choteau aquifer and cumulative monthly departure from normal precipitation at Menno.



EXPLANATION

1432 OBSERVATION WELL--Number is altitude of water surface, in feet. Datum is sea level

—1400-- POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 20 feet

AQUIFER BOUNDARY--Dashed where approximately located

BOUNDARIES WHERE THE GLACIAL AQUIFERS ARE HYDRAULICALLY CONNECTED WITH AND RECEIVE RECHARGE FROM THE NIOBRARA AQUIFER

DIRECTION OF GROUND-WATER MOVEMENT

Figure 27.--Potentiometric surface of the Dolton, Turkey Ridge, Wall Lake, and Ethan aquifers in Hutchinson and Turner Counties (November 1986).

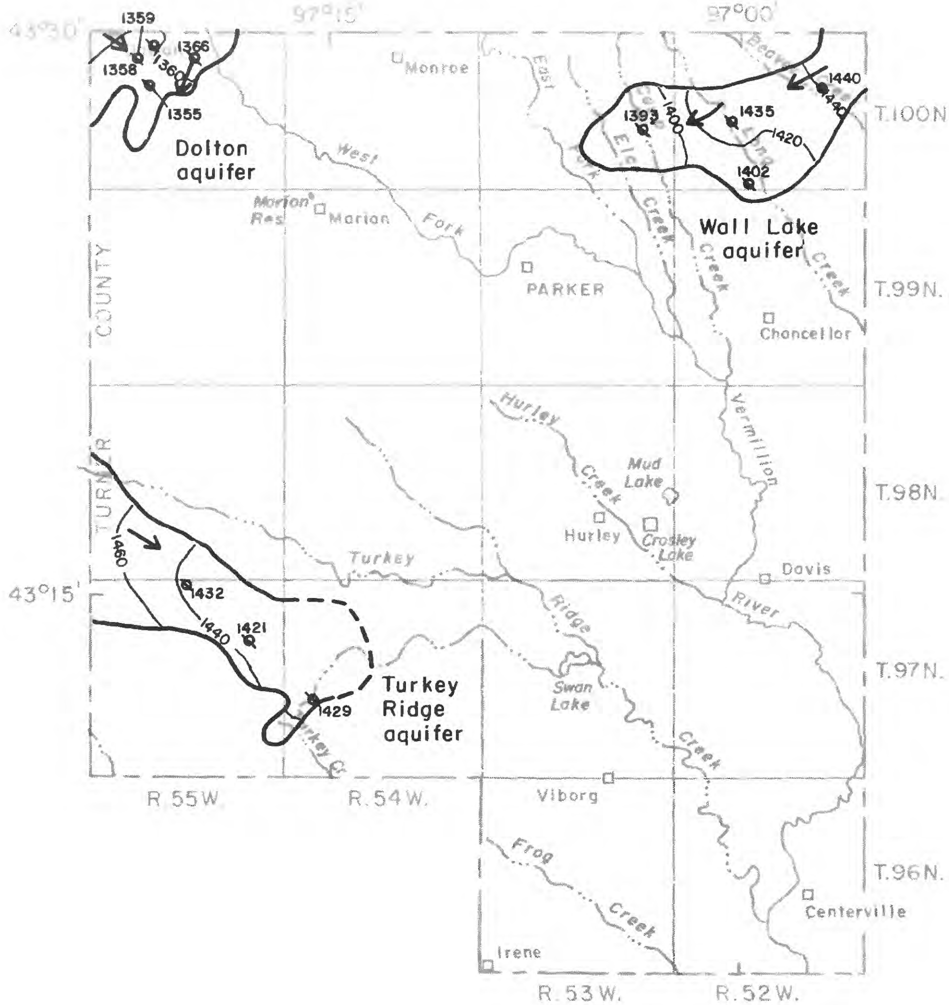


Figure 27.--Potentiometric surface of the Dolton, Turkey Ridge, Wall Lake, and Ethan aquifers in Hutchinson and Turner Counties (November 1986).--Continued

Dolton aquifer

The Dolton aquifer (fig. 10) underlies 12 mi^2 of northwestern Turner County and the extreme northeastern corner of Hutchinson County, is composed of fine sand to medium-pebble gravel, and is overlaid by gray, pebbly till. Depth to the top of the aquifer ranges from 45 ft before land surface near the West Fork Vermillion River to 165 ft below land surface near the western and southern aquifer boundaries (fig. 19). The depth to water in wells ranged from 5 ft near the West Fork Vermillion River to 93 ft in the south-central part of the aquifer and averaged about 75 ft. Hydrologic characteristics are given in table 5.

Recharge to the Dolton aquifer probably is by leakage from till. Subsurface inflow from McCook County is about 260 acre-ft/yr. The direction of water movement in the Dolton aquifer is to the south and southeast (fig. 27). Discharge from the Dolton aquifer is by withdrawal from municipal, stock, and domestic wells.

The principal source of discharge from the Dolton aquifer is rural water system wells, located near the Turner-McCook County line, which began pumping during the summer of 1985. Even though precipitation was greater than normal during 1984-86, the water level in observation well 100N55W17DDDD declined about 7 ft from the fall of 1984 to the fall of 1985 and about 3 ft from the fall of 1985 to the fall of 1986 (fig. 28). This would indicate that discharge from the aquifer exceeded recharge to the aquifer during that time period.

Predominant chemical constituents in water from the Dolton aquifer are sodium, sulfate, and bicarbonate (fig. 18). Dissolved-solids concentrations ranged from 610 to 2,110 mg/L and averaged 1,190 mg/L. Hardness concentrations ranged from 60 to 810 mg/L and averaged 280 mg/L. A summary of chemical analyses of water from the aquifer is given in table 6.

Water from the Dolton aquifer is used for stock watering, domestic, and municipal purposes. Water from the aquifer generally is suitable for irrigation under all soil texture conditions based on the South Dakota irrigation-water classification diagram (fig. 11).

Turkey Ridge aquifer

The Turkey Ridge aquifer (fig. 10) underlies 44 mi^2 in southwestern Turner and southeastern Hutchinson Counties and is composed of fine sand to fine-pebble gravel. The Turkey Ridge aquifer generally is underlaid by Pierre Shale and is under water-table conditions. The northwestern part of the aquifer is composed of fine to medium sand interbedded with thin silty clay layers. In the northeastern part of T. 97 N., R. 55 W. and south-central part of T. 98 N., R. 55 W., an upper, medium sand and gravel layer overlies a layer of fine to coarse sand separated by silty clay layers. The upper sand and gravel layer generally is dry. In the northwestern and the southeastern parts of the aquifer, the lower sand unit is absent; water in the upper layer is confined by gray, pebbly till, and water in the aquifer is under artesian conditions. Depth to the top of the aquifer ranges from 55 ft in well 98N56W13DDAD to 160 ft in well 97N55W12CCCB located on Turkey Ridge (figs. 13 and 14). The depth to water in wells ranged from 27 ft in the northwestern part of the aquifer to 219 ft on Turkey Ridge in the southwestern part of the aquifer. Hydrologic characteristics are given in table 5.

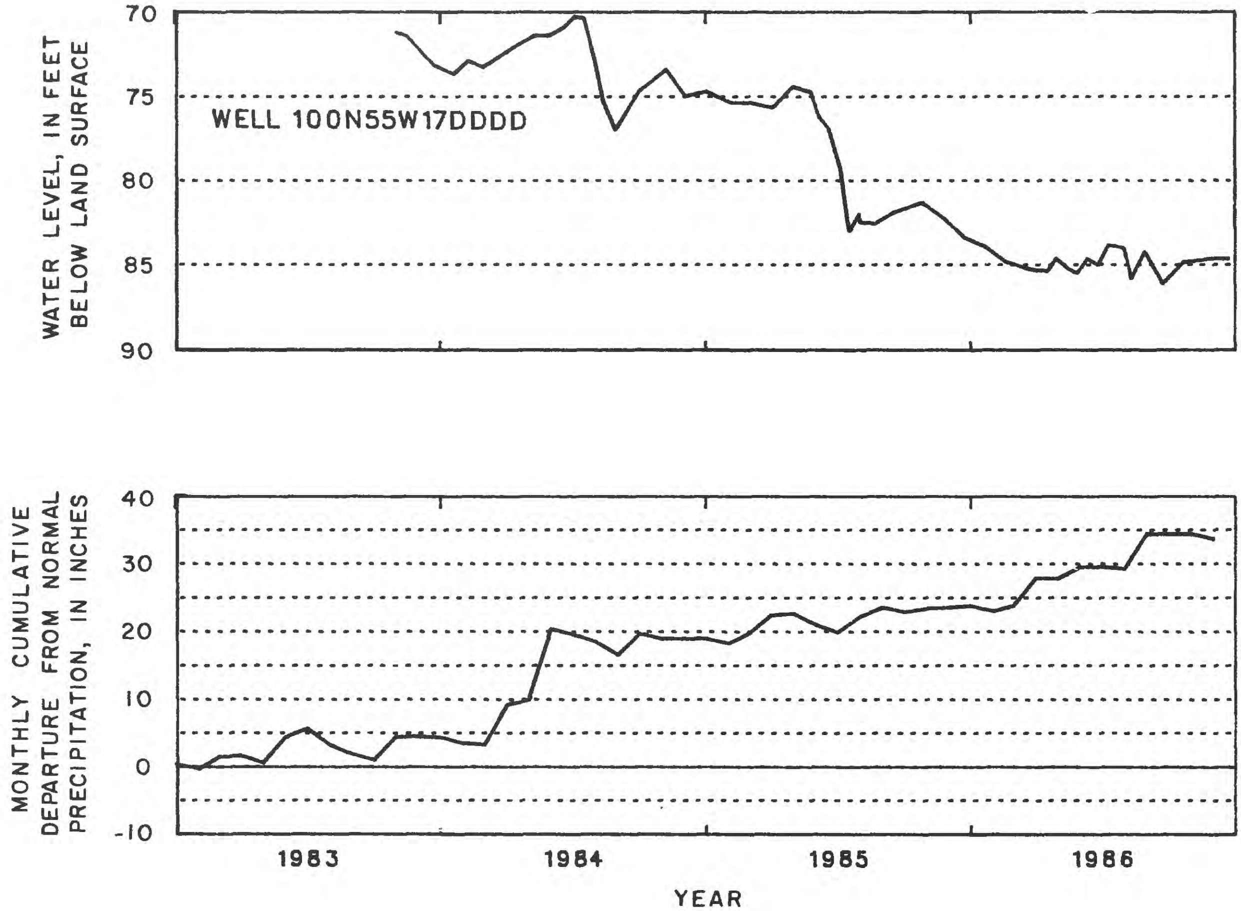


Figure 28.--Water-level fluctuations in the Dolton aquifer and cumulative monthly departure from normal precipitation at Marion.

Recharge to the Turkey Ridge aquifer may be by leakage from an overlying sand and gravel layer located in the flood plain of Turkey Ridge Creek in the east-central part of T. 98 N., R. 56 W.

The direction of water movement in the Turkey Ridge aquifer is to the southeast (fig. 27). The gradient of the potentiometric surface is about 8 ft/mi. Although test-hole data did not indicate hydraulic connection between the Turkey Ridge aquifer and the sand and gravel underlying Turkey Ridge Creek in northwestern T. 97 N., R. 54 W., the sand and gravel in the southeastern part of the Turkey Ridge aquifer about 1.5 mi from the creek coincides with the elevation of the streambed of Turkey Ridge Creek. Discharge from the Turkey Ridge aquifer is by withdrawal from stock and domestic wells.

Water levels in well 98N56W13DDDA (fig. 29), located in the valley of Turkey Ridge Creek, rose during the spring and early summer because of recharge from snowmelt and precipitation. The water-level rise was about 4 ft in 1984, less than 0.5 ft in 1985, and about 1.5 ft in 1986. The 4-ft water-level rise in 1984 was caused by above-normal precipitation. Water levels in wells in the Turkey Ridge aquifer generally fluctuated less than 1 ft annually from 1984-86.

The predominant chemical constituents in water from the Turkey Ridge aquifer are calcium and sulfate (fig. 18). Dissolved-solids concentrations ranged from 1,300 to 2,400 mg/L and averaged 1,780 mg/L. Hardness concentrations ranged from 930 to 1,500 mg/L and averaged 1,200 mg/L. Specific conductance averaged about 1,850 μS/cm in the northern part of the aquifer and 2,500 μS/cm in the southern part. Percent sulfate in water from the aquifer increased from 54 percent in the northwestern part of the aquifer to 78 percent in the southeastern part of the aquifer, with a corresponding decrease in percent bicarbonate from 44 percent to 21 percent. A summary of chemical analyses of water from the aquifer is given in table 6.

Water from the Turkey Ridge aquifer is used for stock watering and domestic purposes. Although water from the aquifer is suitable for irrigation under most soil texture conditions (fig. 11), the yield to wells (table 5) is not sufficient to supply enough water for irrigation purposes.

<u>Wall Lake aquifer</u>

The Wall Lake aquifer (fig. 10) underlies 24 mi^2 in northeastern Turner County. Depth to the top of the aquifer ranges from 35 ft near the western and southern aquifer boundaries to 140 ft below land surface near the Lincoln-Turner County line. The aquifer is composed of fine sand to fine-pebble gravel, overlies the Sioux Quartzite, and is overlaid by gray, pebbly till (fig. 19). Depth to water in wells ranged from 5 ft below land surface in the north-central part of the aquifer to 63 ft in the eastern part. Hydrologic characteristics are given in table 5.

Recharge of the Wall Lake aquifer is from fractures in the Sioux Quartzite in Minnehaha County. Recharge through fractures in the Sioux Quartzite may also originate near the McCook-Turner County line where the Sioux Quartzite is at or near land surface. Subsurface inflow from Minnehaha County was estimated to be about 330 acre-ft/yr. Subsurface inflow from Lincoln County was estimated to be about 100 acre-ft/yr.

The direction of water movement in the Wall Lake aquifer is to the southwest at a gradient of about 8 ft/mi (fig. 27). Discharge from the Wall Lake aquifer is by stock and domestic wells and possibly leakage to fractures in the Sioux Quartzite (fig. 19).

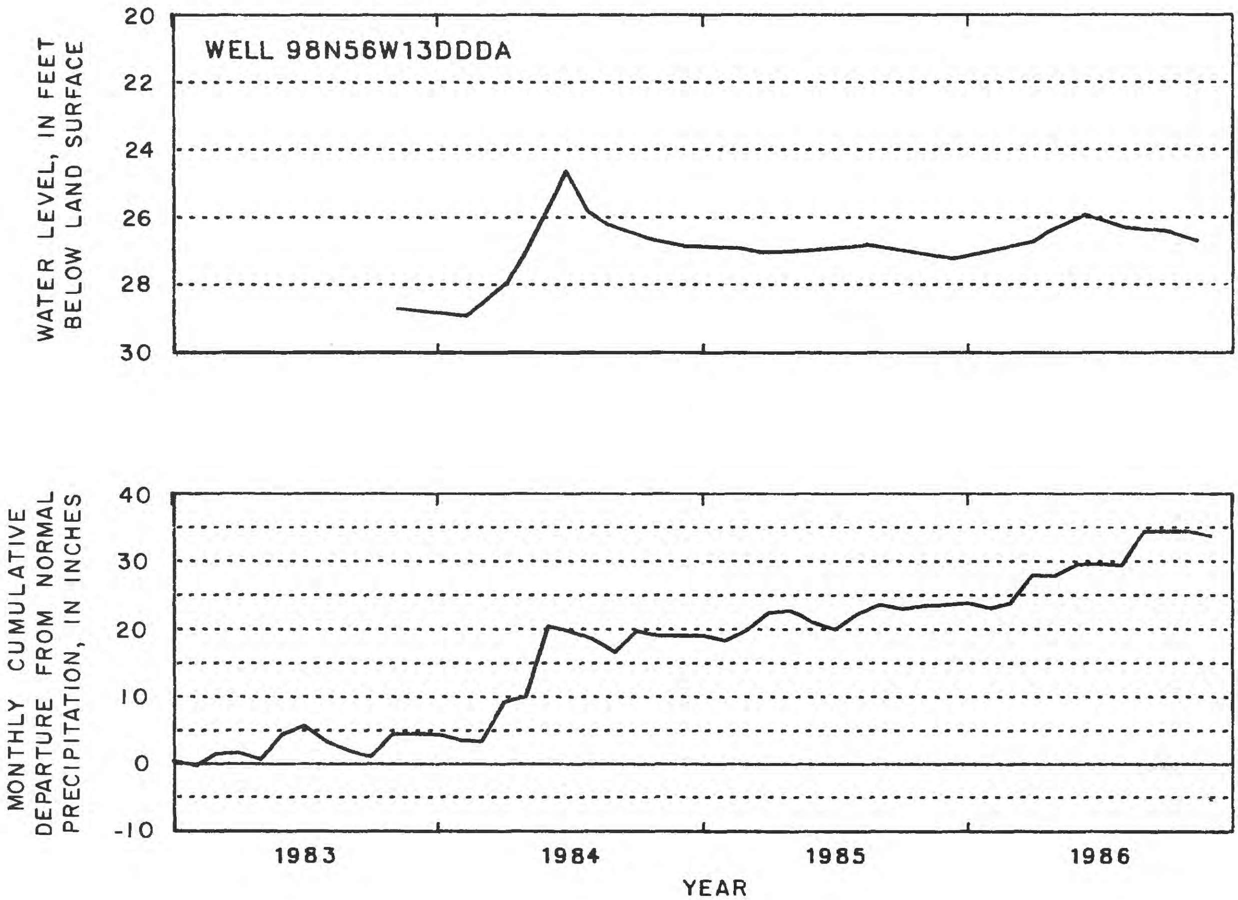


Figure 29.--Water-level fluctuations in the Turkey Ridge aquifer and cumulative monthly departure from normal precipitation at Marion.

Water-level fluctuations in observation wells screened in the Wall Lake aquifer are caused by seasonal changes in recharge (fig. 30). Water levels in wells rose from spring to early summer because of recharge from snowmelt and spring rainfall. Records of long-term water-level fluctuations show correlation to long-term precipitation trends. Water levels in well 100N52W33CCDC3 rose from 1983-86 because of above-normal precipitation.

The predominant chemical constituents in water from the Wall Lake aquifer are calcium and sulfate (fig. 18). Dissolved-solids concentrations ranged from 1,200 to 1,800 mg/L and averaged 1,550 mg/L. Hardness concentrations ranged from 700 to 1,300 mg/L and averaged 1,000 mg/L. A summary of chemical analyses of water from the aquifer is given in table 6.

Water from the Wall Lake aquifer is used for stock watering and domestic purposes. Water from the aquifer generally is suitable for irrigation under all soil texture conditions based on the South Dakota irrigation-water classification diagram (fig. 11).

Ethan aquifer

The Ethan aquifer (fig. 10) underlies about 9 mi^2 in northwestern Hutchinson County. Depth to the top of the aquifer ranges from 50 ft near the Davison-Hutchinson County line to 115 ft near the southern aquifer boundary (fig. 19). The aquifer is composed of fine sand to fine-pebble gravel and is overlaid by gray pebbly till. The aquifer lies in a buried, bedrock valley directly on the Niobrara Formation (fig. 19). Near its southern boundary, the Ethan aquifer is underlaid by till. Test-hole data indicate that the Ethan aquifer and Choteau aquifer may be in hydraulic connection in T. 100 N., R. 61 W. Depth to water in wells ranged from 40 to 53 ft below land surface and increased southward from the Davison-Hutchinson County line. A properly constructed well screened in both the Ethan and Niobrara aquifers may yield as much as 1,000 gal/min in areas where fractures and solution cavities in the Niobrara Formation are sufficiently developed. Hydrologic characteristics are given in table 5.

Recharge to the Ethan aquifer is from the Niobrara aquifer as indicated by similar water-quality characteristics observed in samples analyzed for the two aquifers. Recharge to the Ethan aquifer also occurs by infiltration of precipitation in Davison County where the aquifer is at or near land surface (Hansen, 1983).

The direction of water movement in the Ethan aquifer is to the east, northeast at a gradient of about 20 ft/mi (fig. 27). Discharge from the Ethan aquifer is by withdrawal from stock and domestic wells.

Water-level fluctuations in observation wells screened in the Ethan aquifer are caused by seasonal changes in recharge to the Niobrara aquifer and by irrigation pumpage (fig. 31). Water levels in wells completed in both aquifers at 100N61W22AAAA differed by less than 0.75 ft. Water levels in observation wells screened in the Ethan aquifer rose during the spring and early summer months because of recharge from snowmelt and rainfall to the Niobrara aquifer north of the Davison-Hutchinson County line. Water levels in wells declined from early summer to late fall because of irrigation withdrawals north of the Davison-Hutchinson County line. The Ethan aquifer is underlaid by the Niobrara aquifer, and the potentiometric surfaces of the two aquifers are similar. The water-level decline in 1980 in well 100N61W8AAAA was caused by below-normal precipitation and increased irrigation withdrawals. Water levels in the Ethan aquifer rose 5 ft from late summer of 1981 to late summer of 1982 because of above-normal

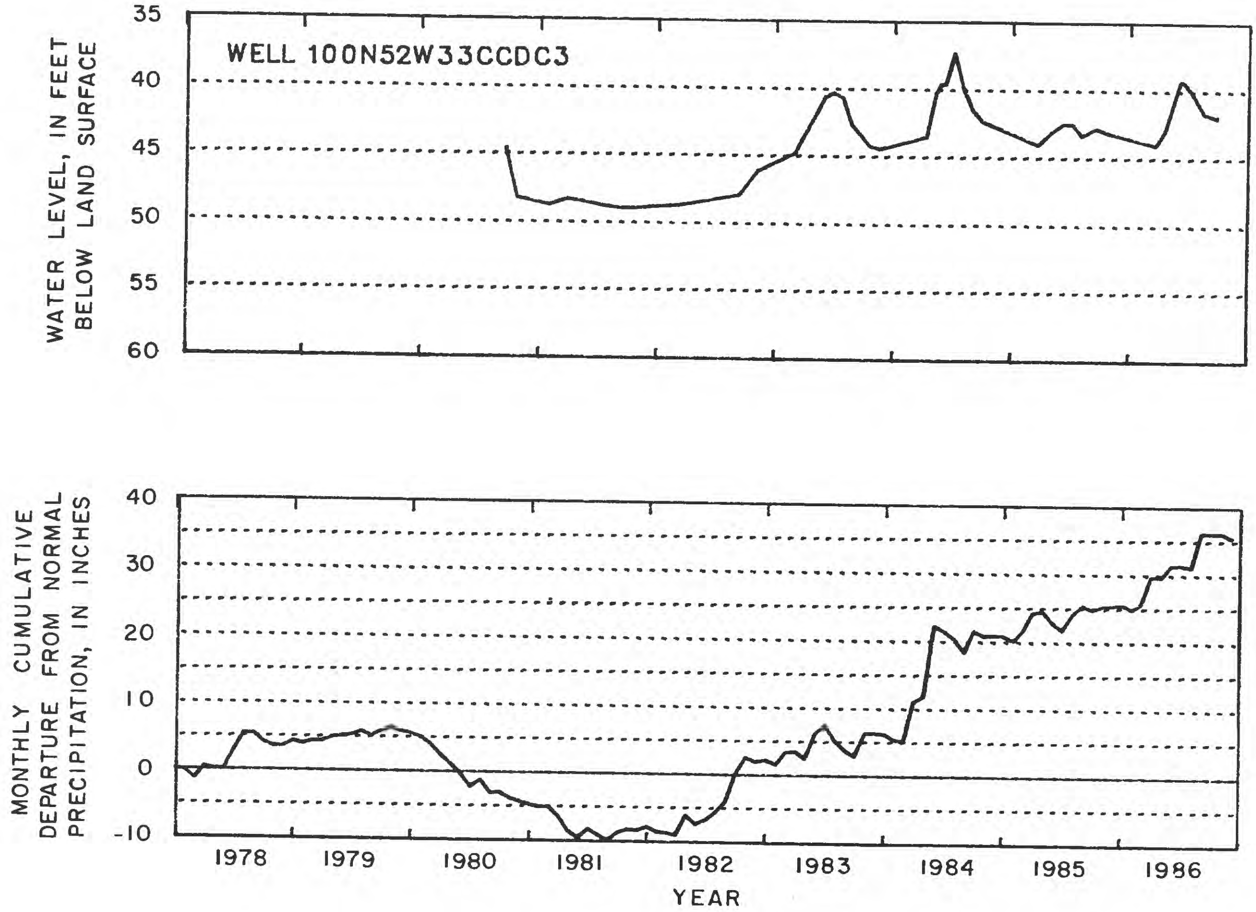


Figure 30.--Water-level fluctuations in the Wall Lake aquifer and cumulative monthly departure from normal precipitation at Marion.

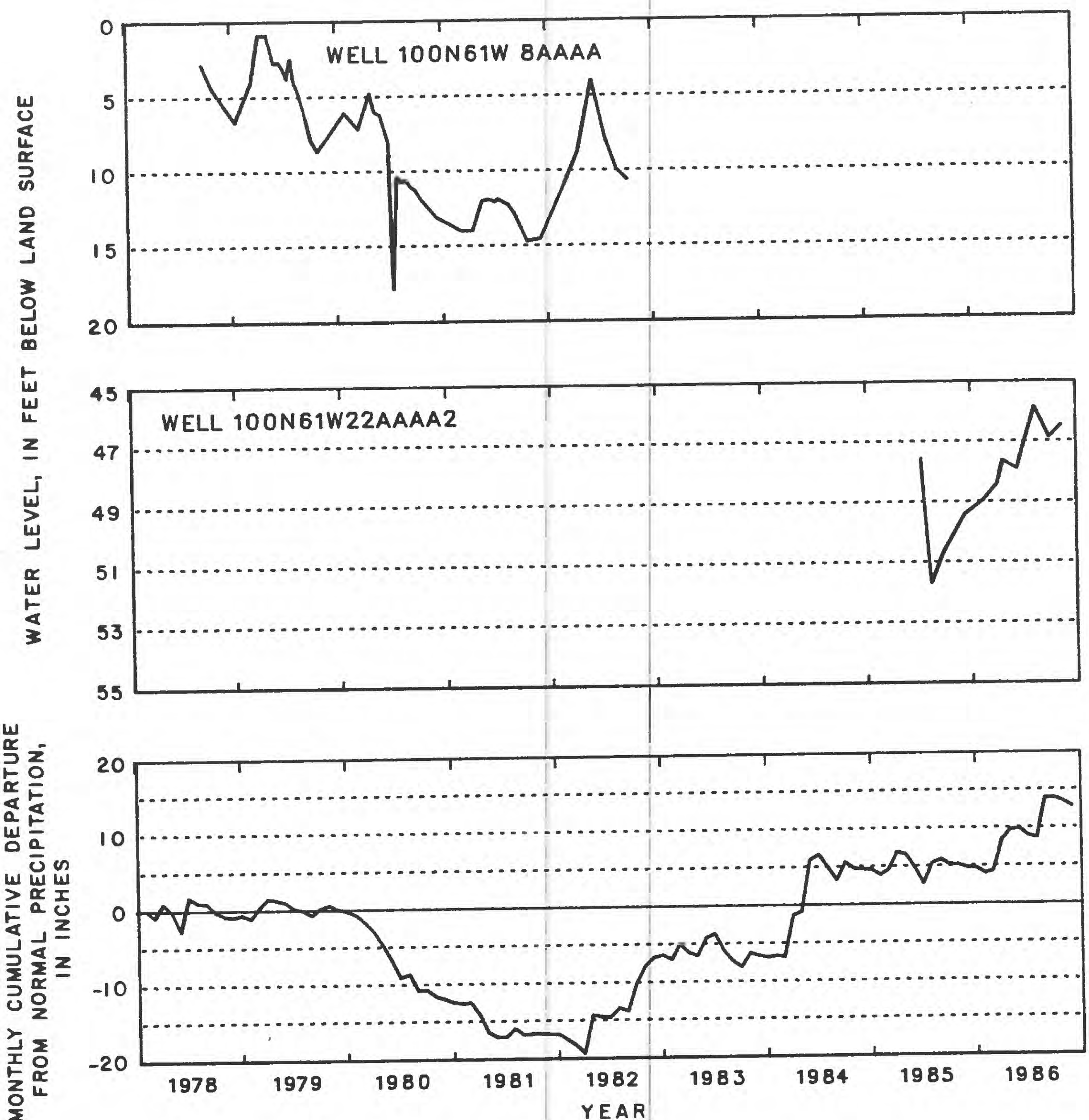


Figure 31.--Water-level fluctuations in the Ethan aquifer and cumulative monthly departure from normal precipitation at Menno.

precipitation. The water level in well 100N61W22AAAA2 declined 4 ft from July to August 1985 because of below-normal precipitation and increased irrigation withdrawals and rose 5.2 ft from August 1985 to November 1986 because of above-normal precipitation.

Predominant chemical constituents in water from the Ethan aquifer are sodium and sulfate. Chemical analyses of water from the Ethan and Niobrara aquifers indicate that water from the Ethan aquifer is mixing with water from the Niobrara aquifer (fig. 18). The predominant chemical constituents in water from wells 100N61W15DCDD and 100N61W21DACC screened in the Ethan aquifer where it is underlaid by the Niobrara aquifer were sodium and sulfate, as was the case for water from wells in the Niobrara aquifer in the area to the west of the Ethan aquifer. The predominant chemical constituents in water from well 100N61W8AAAA in the Ethan aquifer where it is underlaid by till were calcium and sulfate. Dissolved-solids concentrations in the Ethan aquifer ranged from 1,800 to 2,700 mg/L and averaged 2,100 mg/L. Hardness concentrations ranged from 590 to 1,300 mg/L and averaged 840 mg/L. A summary of chemical analyses of water from the aquifer is given in table 6.

Water from the Ethan aquifer is used for stock watering and domestic purposes. Suitability of water from the aquifer for irrigation is limited to certain soil texture conditions because of its relatively high sodium-adsorption ratio (fig. 11).

Bedrock Aquifers

Three major bedrock aquifers, in order of increasing geologic age, underlie much of the study area: the Niobrara aquifer in the Upper Cretaceous Niobrara Formation, the Codell aquifer in the Upper Cretaceous Codell Sandstone Member of the Carlile Shale, and the Dakota Sandstone (table 7). The bedrock aquifers store about 18 million acre-ft of water (table 5) which is more than three times the volume of water stored in all the glacial aquifers. The Codell aquifer occurs only in western Hutchinson County except for a few small areas east of the James River. The Codell aquifer is the major source of water in southwestern Hutchinson County because there are no major glacial aquifers present. The Niobrara and Dakota aquifers underlie about 50 and 66 percent of the study area, respectively, and are extensively used in eastern Hutchinson and western Turner Counties where major glacial aquifers underlie only a small percentage of the area. Ground-water storage in the Dakota aquifer was estimated to be about 9.8 million acre-ft, about 1.9 times the volume stored in the major glacial aquifers.

The Sioux Quartzite is a pink, well-fractured orthoquartzite. Reported yield to wells from the Sioux Quartzite may be as much as 100 gal/min. The yield to wells depends on the number and size of fractures and joints that are present and the relation of the fracture system to sources of recharge to the Sioux Quartzite. The Sioux Quartzite is a minor aquifer that is utilized as a source of water in northern Turner County.

Table 7.--Generalized stratigraphic column for Hutchinson and Turner Counties

System	Series	Geologic unit	Lithology	Maximum thickness (feet)	Water-yielding characteristics
Quaternary	Pleistocene and Holocene	Alluvium and glacial drift	Clay, yellowish-brown, silty; contains outwash deposits of sand and gravel.	435	Outwash deposits are very permeable, form major aquifers.
Cretaceous		Pierre Shale	Shale, dark-gray to black; may contain bentonite or marl.	150	Relatively impermeable. Locally wells may yield 1 to 5 gallons per minute.
		Niobrara Formation	Marl and chalk, shaly.	215	Slightly to very permeable. May yield up to 1,000 gallons per minute where solution cavities well developed.
		Codell Sandstone Member	Sandstone, fine to medium-grained; interbedded with siltstone and shale.	80	Permeable. Wells may yield as much as 100 gallons per minute.
		Carlile Shale	Shale, locally may contain sand lenses.	200	Relatively impermeable.
		Greenhorn Limestone	Limestone and calcareous shale, fossiliferous.	50	
		Graneros Shale	Shale, gray, silty.	35	Relatively impermeable.
		Dakota Formation	Sandstone, very fine to medium-grained; interbedded with shale.	250	Permeable. Wells may yield as much as 250 gallons per minute.
Precambrian		Quartzite wash	Quartzose sand, pink, very fine to coarse-grained; interbedded with shale in western Turner County.	125	Permeable. Wells may yield as much as 250 gallons per minute.
		Sioux Quartzite	Quartzite.	?	Locally well fractured and jointed. Utilized for domestic supplies.
		Igneous and metamorphic rocks	Granites, andesites, rhyolites, shists.	?	Locally might be possible to obtain water from fractures.

Niobrara aquifer

The Niobrara aquifer (fig. 32) underlies about 729 mi^2, or about 50 percent of Hutchinson and Turner Counties. The aquifer is composed of a fractured, calcareous marl, interbedded with calcareous claystone and is referred to as "chalkrock" by local drillers. The Niobrara Formation is not present in the bedrock channels occupied by the Choteau, Lower James-Missouri, and Upper Vermillion-Missouri aquifers. In the western part of area A and in area B (fig. 32) the Niobrara Formation generally lies directly on the Codell Sandstone Member of the Carlile Shale and is overlaid by till. In the southwestern part of area B, the Niobrara is overlaid by Pierre Shale. In the eastern part of area A, Carlile Shale, 10 to 45 ft thick, separates the Niobrara aquifer from the underlying Codell Sandstone Member of the Carlile Shale (fig. 19).

In areas C and D, the Niobrara aquifer generally overlies Carlile Shale and is overlaid by till or, in T. 97 N. and T. 98 N. in area C, by Pierre Shale. In T. 100 N., R. 54 W. and the northeastern corner of T. 100 N., R. 56 W., the Niobrara aquifer lies directly on Sioux Quartzite (fig. 19). Hydrologic characteristics are given in table 5.

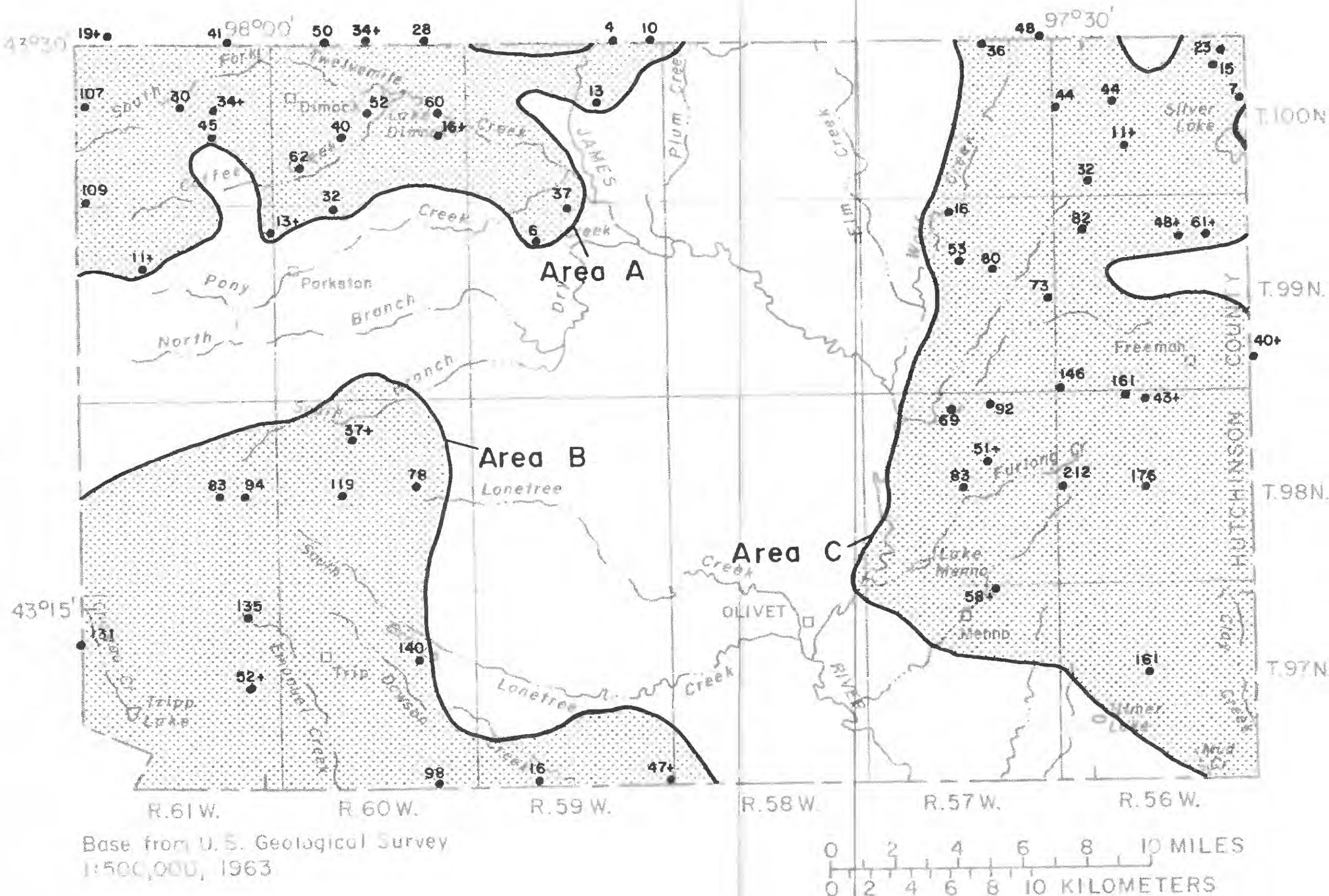
The aquifer is at or near land surface in the vicinity of Wolf Creek, northeastern Hutchinson County, and is as much as 510 ft below land surface in southwestern Hutchinson County. Test drilling showed that aquifer thickness generally is less than 100 ft; however, in T. 97 N. and T. 98 N. thickness ranges from 150 to 210 ft. Cross-section C-C′ indicates, however, that aquifer thickness may be as much as 370 ft in southwestern Hutchinson County.

Depth to water in observation wells ranged from about 5 ft in T. 98 N., R. 53 W. and near the Davison-Hutchinson County line to 235 ft in the southwestern part of Hutchinson County. Wells screened in the Niobrara aquifer in T. 97 N. and T. 98 N. near the James River valley and in the Turkey Ridge Creek flood plain in southwestern Turner County may flow.

Recharge to the Niobrara aquifer is: (1) By direct infiltration of precipitation on the outcrop area located in the flood plain of the North Fork of Twelve Mile Creek, 3 mi north of the Hutchinson-Davison County line (Hansen, 1983); (2) possibly from fractures in the Sioux Quartzite near the eastern boundary of the aquifer in T. 100 N., (fig. 19); and (3) by leakage from till.

The direction of water movement in the Niobrara aquifer varies for each area depending on local areas of recharge and discharge (fig. 33). In area A, the direction of water movement is to the east and southeast toward the South Fork of Twelve Mile Creek at a gradient of about 10 ft/mi in the western part, increasing to about 15 ft/mi in the eastern part. In area B, the direction of water movement is to the southwest at a gradient of about 4 ft/mi.

In the northern part of area C, the direction of water movement is toward Wolf Creek at a gradient of about 10 ft/mi. In the southern part of area C, the direction of water movement is to the southwest toward the Lower James-Missouri aquifer at a gradient of about 20 ft/mi and to the east toward the Upper Vermillion-Missouri aquifer and Turkey Ridge Creek at a gradient of about 10 ft/mi. In area D, the general direction of water movement is to the southeast at a gradient of about 10 to 15 ft/mi in the northern part and about 2 ft/mi in the southern part.



EXPLANATION

● 13+ TEST HOLE--Number is thickness of sand and gravel, in feet. A plus (+) indicates thickness greater than shown

AQUIFER BOUNDARY

AREA OF AQUIFER AS DISCUSSED IN TEXT

Figure 32.--Areal extent and thickness of the Niobrara aquifer in Hutchinson and Turner Counties.

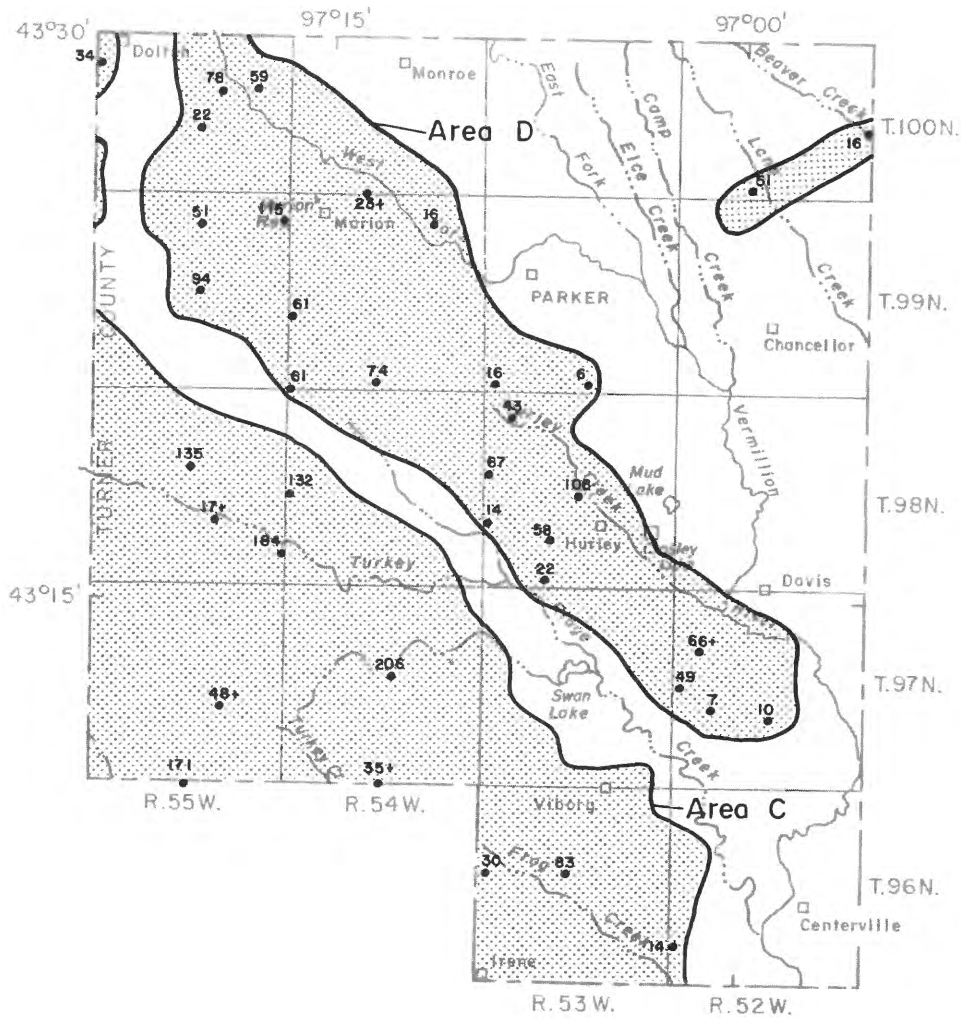
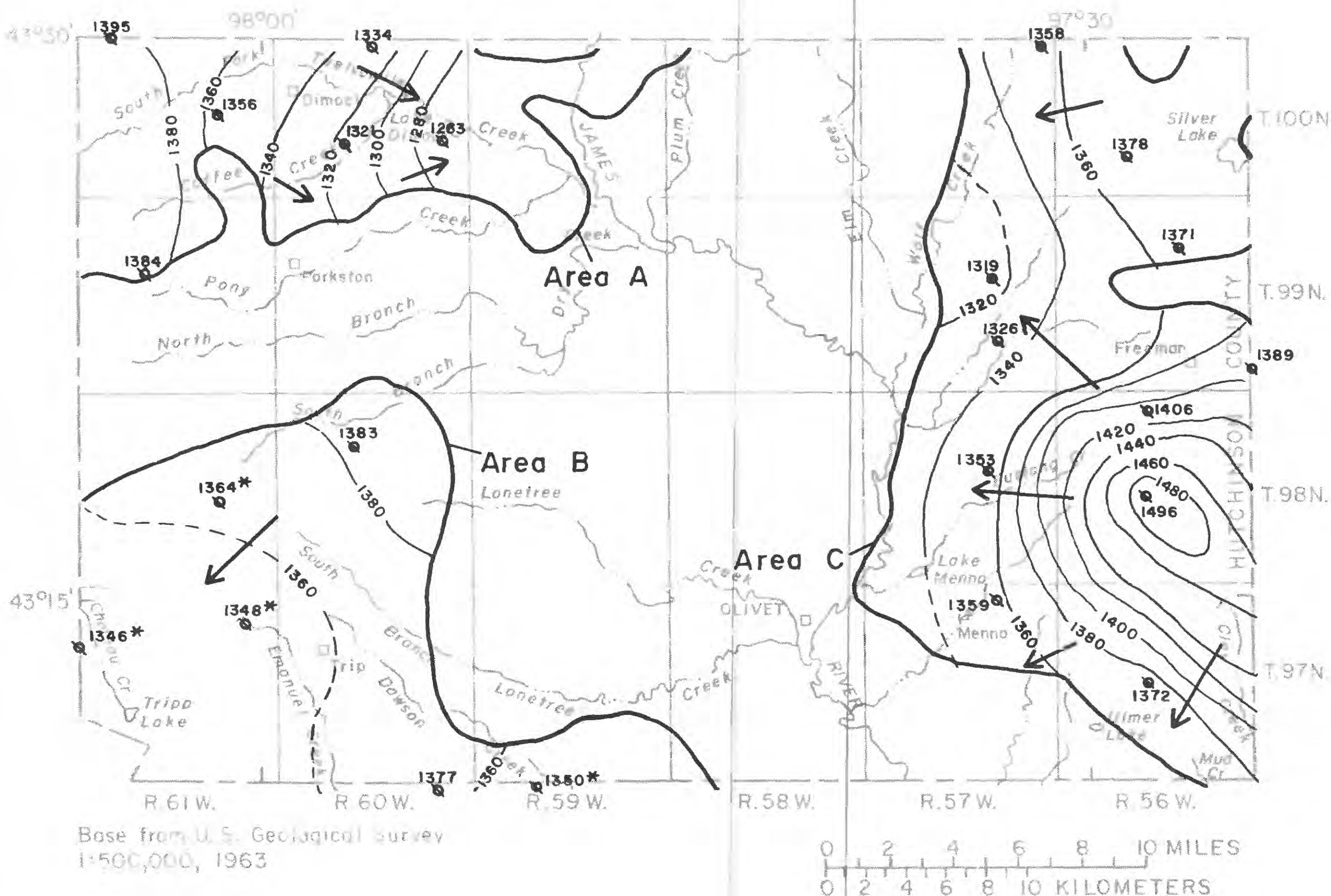


Figure 32.--Areal extent and thickness of the Niobrara aquifer in Hutchinson and Turner Counties.--Continued



EXPLANATION

1364* OBSERVATION WELL--Number is altitude of water surface, in feet. Asterisk (*) indicates water level is for well completed in Codell aquifer. Datum is sea level

—1300-- POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour intervals, 20 feet for Areas A, B, D, and 40 feet for Area C

——— AQUIFER BOUNDARY

←—— DIRECTION OF GROUND-WATER MOVEMENT

Figure 33.--Potentiometric surface of the Niobrara aquifer in Hutchinson and Turner Counties (November 1986).

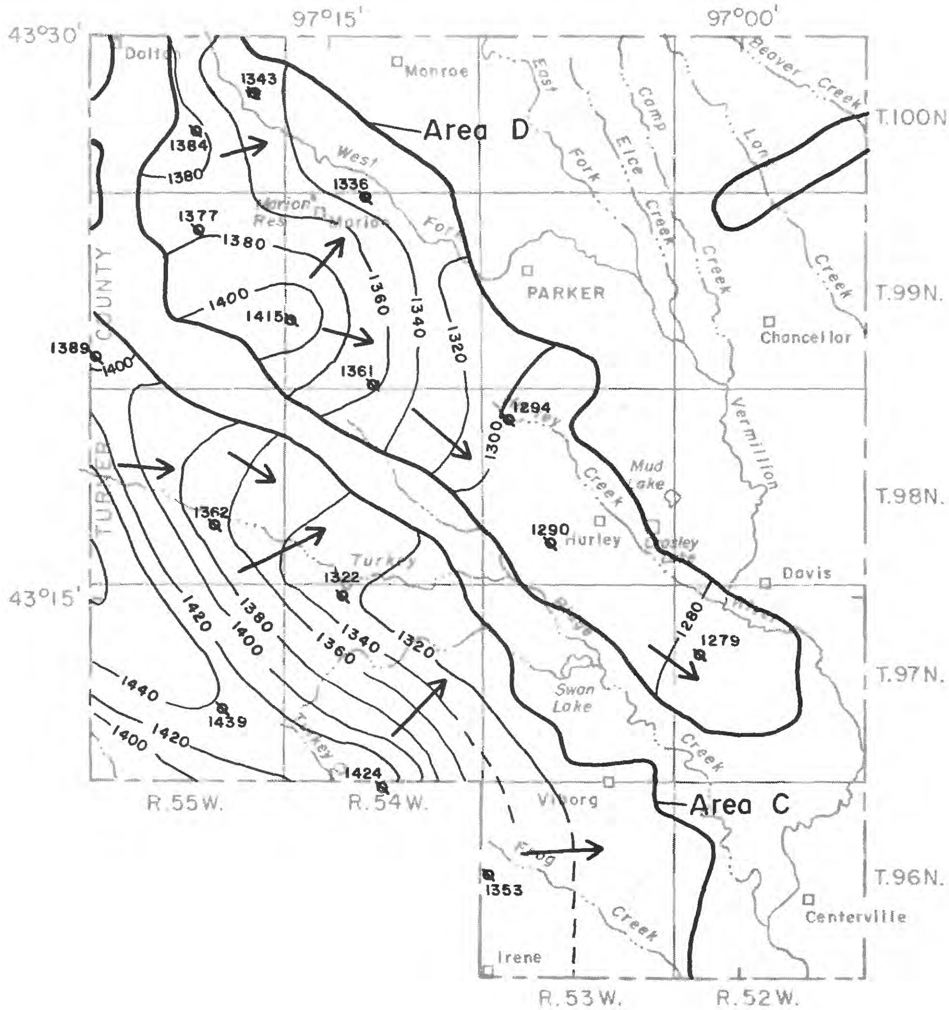


Figure 33.--Potentiometric surface of the Niobrara aquifer in Hutchinson and Turner Counties (November 1986).--Continued

Discharge from the Niobrara aquifer in area A is: (1) To the Ethan aquifer, (2) to the unnamed sand and gravel outwash underlying the South Fork of Twelve Mile Creek in T. 100 N., R. 60 W., (3) to the underlying Codell aquifer, and (4) to the Choteau aquifer in the north-central part of T. 99 N., R. 61 W. Discharge from the Niobrara aquifer in area C is: (1) To Wolf Creek where the Niobrara Formation crops out, (2) to the Lower James-Missouri aquifer in the northern part of T. 97 N., R. 57 W., (3) to the Upper Vermillion-Missouri aquifer in T. 96 N., T. 97 N., and T. 98 N., and (4) possibly to the Turkey Ridge Creek aquifer in southwestern T. 98 N., R. 54 W. where the intervening till layer is about 15 ft thick. Discharge from the Niobrara aquifer in southern T. 98 N., R. 53 W. and northeastern T. 97 N., R. 53 W. is to the Parker-Centerville aquifer. Discharge from the aquifer in T. 97 N., R. 52 W. is to the Upper Vermillion-Missouri aquifer. Discharge from the Niobrara aquifer is also by withdrawal from municipal, stock, and domestic wells.

Water-level fluctuations in observation wells screened in the Niobrara aquifer are caused by seasonal changes in recharge and irrigation withdrawals. Records of long-term water-levels show close correlation to long-term precipitation trends. The water level in well 100N60W21CCBC rose 1 to 2 ft during the spring and early summer of 1979, 1983-84, and 1986 and rose about 4 ft during the fall of 1982 (fig. 34) because of direct infiltration of rainfall and snowmelt in the outcrop area 2 mi north of the Davison-Hutchinson County line. The water level declined about 5 ft from 1980-82 because of below-normal precipitation. The water level in well 99N57W26BBBB in area C rose about 10 ft from fall 1982 to fall 1984 because of above-normal precipitation (fig. 35). The water level in well 100N55W14DDDD2 in the Niobrara aquifer declined 8 to 9 ft during the summer months of 1983 and 1985 and 4 to 5 ft during the summer of 1984 and 1986 (fig. 35) because of an irrigation well located 0.50 mi to the northeast.

Predominant chemical constituents in water from the Niobrara aquifer are calcium, sodium, and sulfate (fig. 18). Dissolved-solids concentrations ranged from 560 to 2,490 mg/L and averaged 1,510 mg/L. Hardness concentrations ranged from 110 to 1,300 mg/L and averaged 650 mg/L. Predominant chemical constituents in water from the eastern part of area A, the southeastern part of area B, and most of area C and area D were calcium and sulfate. Predominant chemical constituents in water from the western part of area A and all except the southeastern part of area B were sodium and sulfate, indicating possible mixing of water from the Codell aquifer. Predominant chemical constituents in water from the northern parts of areas C and D and northwestern T. 97 N., R. 55 W. were also sodium and sulfate. A summary of chemical analyses of water from the aquifer is given in table 6 and selected chemical analyses are given in table 8.

Water from the Niobrara aquifer is used for stock watering, domestic, municipal, and irrigation purposes. Suitability of water from the aquifer for irrigation is limited to certain soil texture conditions because of its relatively high sodium-adsorption ratio (fig. 11).

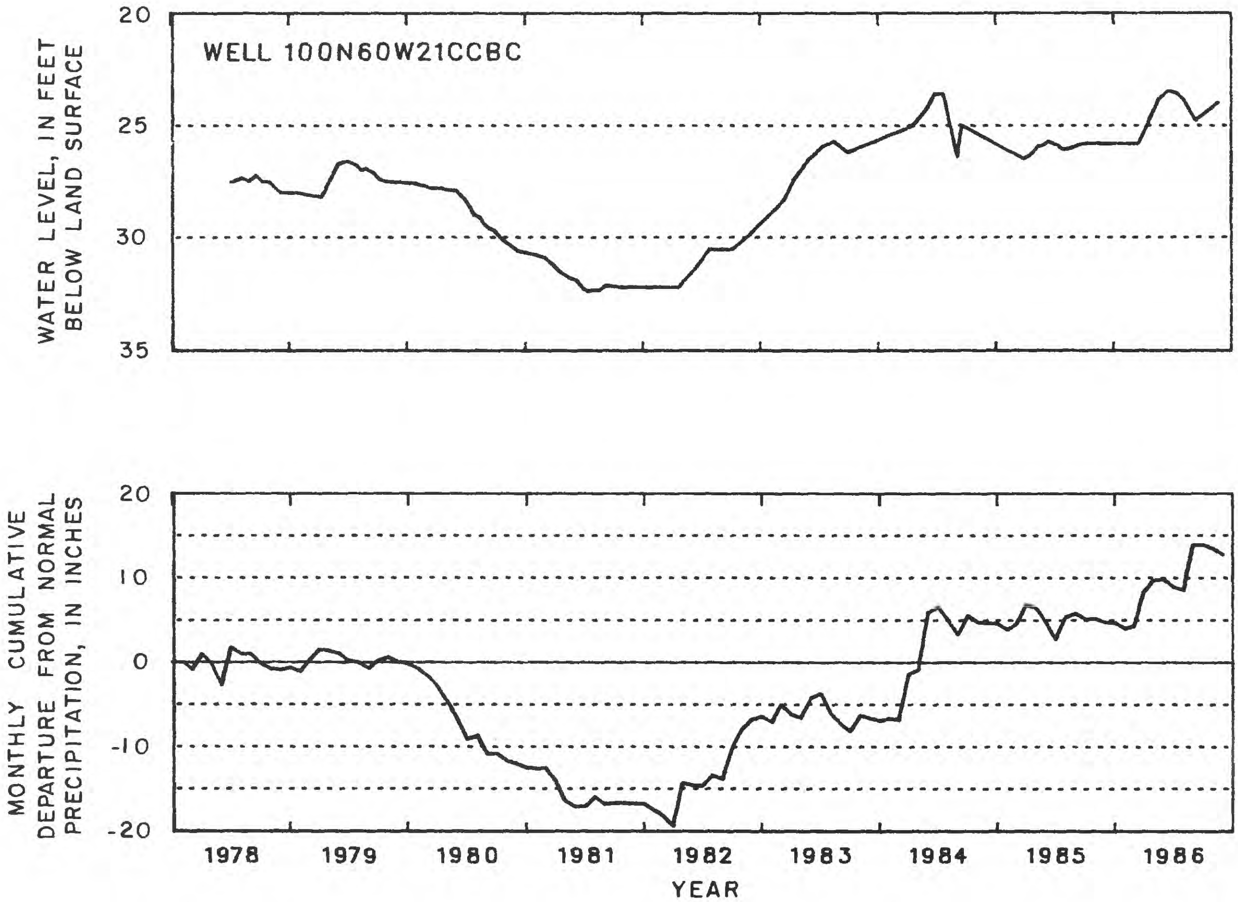


Figure 34.--Water-level fluctuations in the Niobrara aquifer and cumulative monthly departure from normal precipitation at Menno.

Table 8.--Selected chemical analyses of water from bedrock aquifers

[All units reported in milligrams per liter except as indicated; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 °Celsius]

Well number	Specific conductance (field) (µS/cm)	pH (field) (units)	Hardness as $CaCO_3$	Alkalinity	Dissolved solids, sum of constituents	Calcium	Magnesium	Sodium	Potassium
				Niobrara aquifer					
97N55W 7BBBA	1,440	7.8	210	250	980	57	17	240	22
97N55W20ABCD	1,560	7.1	680	320	1,100	180	57	92	25
97N56W17CABD	--	6.9	1,300	370	2,100	340	100	150	27
97N60W 9DCDD	1,960	7.4	680	270	1,400	190	51	170	22
98N53W21CDDD	2,380	--	1,300	380	2,100	390	90	35	7
98N55W17CCAB	955	7.1	490	350	640	140	33	23	11
98N60W19BABD	1,960	7.5	200	320	1,300	53	16	380	17
98N61W22AABC	2,310	7.5	310	270	1,600	78	27	370	17
99N53W22BBBC	1,930	7.1	1,300	310	1,600	310	120	27	7
99N55W 2CBBC	1,480	7.5	200	280	1,000	56	14	260	14
100N56W26DCBD	2,050	--	440	220	1,500	120	33	310	21
100N61W23BAAC	2,540	7.4	510	310	1,800	140	38	360	21
100N61W29CCCA	2,200	7.7	110	340	1,400	30	8.0	470	18
				Codell aquifer					
97N60W 5ACDC	2,310	7.7	100	400	1,300	27	8.6	410	13
97N61W 9DDD	2,300	7.8	92	420	1,300	25	7.1	450	13
98N61W23ADAC	2,120	7.8	110	420	1,300	30	9.2	420	12
98N61W34DDC	2,250	7.7	85	420	1,300	23	6.8	470	17
100N60W32ABBB	2,510	--	370	230	1,700	94	31	400	23
				Dakota aquifer					
97N52W 5CDCA	1,600	7.6	250	220	1,000	64	23	250	19
97N53W 3CBBC	1,880	7.8	300	200	1,300	73	27	300	22
97N55W23AAAD	1,930	--	560	99	1,400	150	46	190	23
97N59W14DDDD	2,660	7.3	980	--	2,000	270	74	120	23
97N60W24DCAC	2,530	7.1	1,200	120	2,100	360	81	130	23
98N52W24CBBA	1,510	7.5	450	300	1,000	110	43	160	22
98N54W 8CDCC	1,310	7.6	270	250	880	77	20	180	13
98N58W11ABBA	2,390	7.4	1,100	130	2,000	310	77	160	24
98N59W 3CBBD	2,480	7.2	1,200	130	2,000	360	82	120	23
98N60W 1ADCB	2,300	7.3	1,200	130	1,800	330	78	130	21
99N54W 8AADB	1,300	7.3	540	300	930	150	40	100	16
99N57W31DBAD	2,550	7.4	250	140	1,800	68	20	510	14
100N56W20ADDA	1,220	--	350	240	800	93	29	110	25

Bicarbonate (field)	Sulfate	Chloride	Fluoride	Dissolved nitrogen	Dissolved boron (μg/L)	Dissolved iron (μg/L)	Dissolved manganese (μg/L)	Dissolved selenium (μg/L)	Dissolved strontium (μg/L)
310	460	16	2.0	<0.10	5,500	1,100	14	<1	1,700
270	550	16	--	.40	--	290	170	--	--
360	1,200	12	.4	<.10	1,900	--	--	<1	3,500
440	750	35	--	<.10	--	45,000	310	--	--
440	1,300	7.9	--	3.2	--	40	20	--	--
270	200	4.5	--	<.10	--	200	120	--	--
420	510	95	--	<.10	--	520	20	--	--
400	880	30	.9	<.10	3,400	440	10	<1	2,200
--	900	6.2	.2	<.10	100	1,200	1,100	<1	1,000
--	450	22	--	1.0	--	7	36	--	--
--	830	25	--	<.10	--	780	20	--	--
--	980	33	--	<.10	--	2,900	60	--	--
--	600	110	--	<.10	--	270	20	--	--
500	180	400	1.2	2.0	5,200	20	20	<1	750
540	160	380	--	<.10	--	140	10	--	--
540	330	240	--	2.1	--	620	10	--	--
540	130	400	--	1.1	--	20	20	--	--
380	980	61	.5	<.10	3,400	5,800	60	<1	3,100
330	480	71	--	.25	--	6	72	--	--
310	610	100	1.7	2.6	2,700	50	72	<1	2,500
130	770	99	--	<.10	--	4,500	98	--	--
--	1,300	140	2.3	--	290	--	--	--	--
190	1,300	130	--	--	--	2,200	160	--	--
440	420	54	--	<.10	--	5,300	290	--	--
330	390	24	--	<.10	--	190	780	--	--
210	1,200	120	1.8	<.10	720	2,800	110	<1	8,600
190	1,200	130	--	<.10	--	1,800	190	--	--
210	1,100	56	2.0	<.10	630	1,800	90	<1	9,000
360	420	13	.8	.12	640	1,700	110	<1	1,400
170	980	110	--	<.10	--	620	90	--	--
290	360	26	1.3	.11	2,300	210	11	<1	2,600

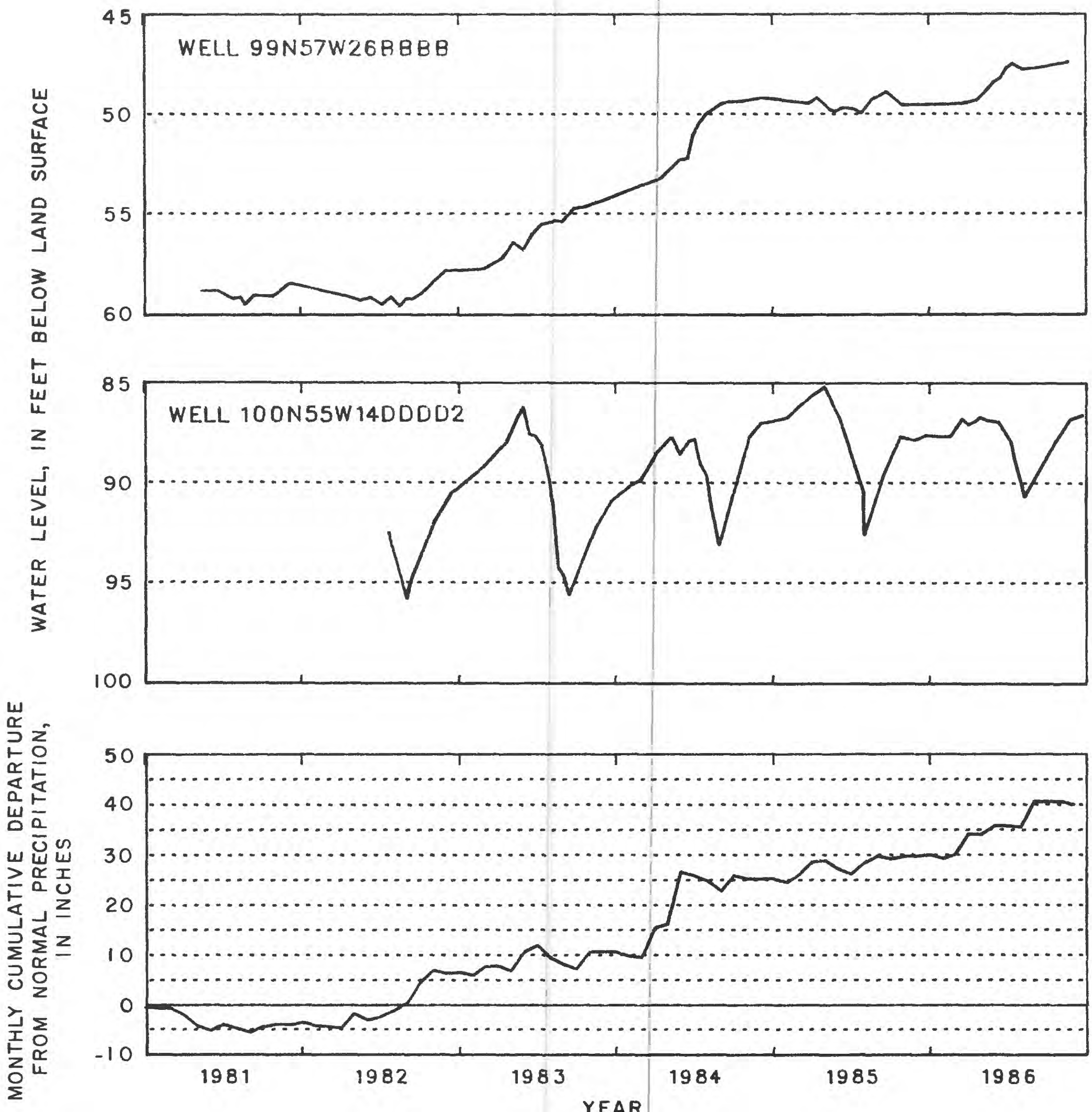


Figure 35.--Water-level fluctuations in the Niobrara aquifer and cumulative monthly departure from normal precipitation at Marion.

Codell aquifer

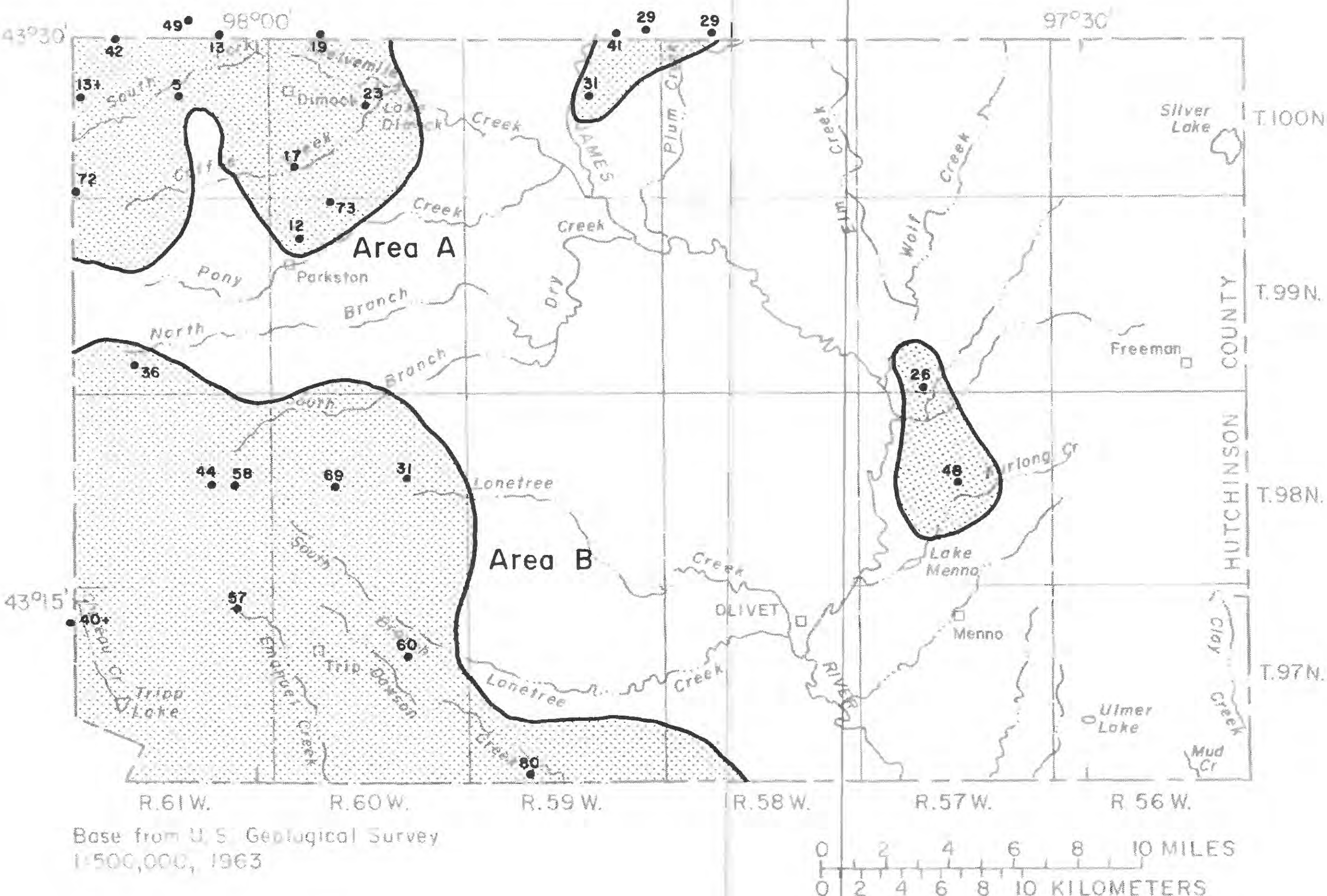
The Codell aquifer underlies about 230 mi^2 (about 28 percent) of Hutchinson County (fig. 36). Depth to the top of the aquifer ranges from land surface near the James River in central and northern Hutchinson County where the Codell Sandstone crops out to 95 ft in northwestern Hutchinson County and more than 500 ft in southwestern Hutchinson County (figs. 13, 14, and 19). The aquifer is composed of a fine- to medium-grained, moderately cemented sandstone interbedded with layers of siltstone and mudstone. In southwestern Hutchinson County, the aquifer is interbedded with a discontinuous 10- to 15-ft claystone layer and is overlaid primarily by the Niobrara aquifer; however, in T. 99 N., R. 61 W., the Codell is overlaid by the Choteau aquifer. In northwestern Hutchinson County, the Codell aquifer generally is overlaid by: (1) The Niobrara Formation or a 10-ft thick, discontinuous layer of Carlile Shale in the western part, (2) a continuous layer of Carlile Shale 10 to 45 ft thick in the eastern part which hydraulically separates the Codell aquifer from the Niobrara aquifer, and (3) the Choteau aquifer in the southeastern part. Hydrologic characteristics are given in table 5.

Depth to water in wells ranged from 23 ft in the eastern part of area A to 235 ft in area B. Water levels in observation wells screened in the Niobrara aquifer in T. 100 N., R. 61 W. were higher than water levels in wells screened in the Codell aquifer. Water-level differences may be caused by discontinuous shale layers in the Codell aquifer and the more shaly composition of the Niobrara aquifer. Yields from wells screened in the Codell aquifer in southwest Hutchinson County range from 2 to 10 gal/min because 50 percent of the aquifer thickness is siltstone and mudstone.

Recharge to the Codell aquifer is by leakage from the overlying Niobrara aquifer and from the Choteau aquifer in northwestern Hutchinson County where the Codell and Choteau aquifers are in hydraulic connection. The Choteau aquifer directly overlies the Codell aquifer in the northern one-third of T. 98 N., R. 60 and 61 W. Water levels in wells screened in the Choteau aquifer in this area are higher than the water levels in wells screened in the Codell aquifer, indicating movement of water from the Choteau aquifer to the Codell aquifer.

The general direction of water movement in the Codell aquifer in northwest Hutchinson County is to the east at a gradient of about 6 ft/mi (fig. 37). Test-hole data indicated that the Choteau aquifer occurs at the same elevation as the Codell aquifer in southwestern T. 100 N., R. 60 W., indicating possible hydraulic connection between the aquifers. Water levels in wells in the Choteau aquifer are higher than water levels in wells completed in the Codell aquifer in this area, which would indicate movement of water from the Choteau aquifer to the Codell aquifer. The direction of water movement in the Codell aquifer in southwestern Hutchinson County is to the southwest at a gradient of about 4 ft/mi. Discharge from the Codell aquifer is by withdrawal from municipal, stock, and domestic wells.

Long-term trends of water-level fluctuations show close correlation with long-term trends in precipitation. The water level in well 100N61W18CCCC declined about 4 ft from early summer 1980 to January 1981 because of below-normal precipitation and rose about 5 ft from October 1982 to May 1984 because of above-normal precipitation (fig. 38). The Codell aquifer is in hydraulic connection with the Choteau aquifer in T. 99 N., R. 60 W. A similar water-level decline was observed in an observation well screened in the Codell aquifer and an observation well in the Choteau aquifer at 99N60W7AAAA. The water-level decline was caused by withdrawals from irrigation wells screened in the Choteau aquifer. The similar water-level decline in the wells at the same location may indicate that the aquifers are in hydraulic connection.



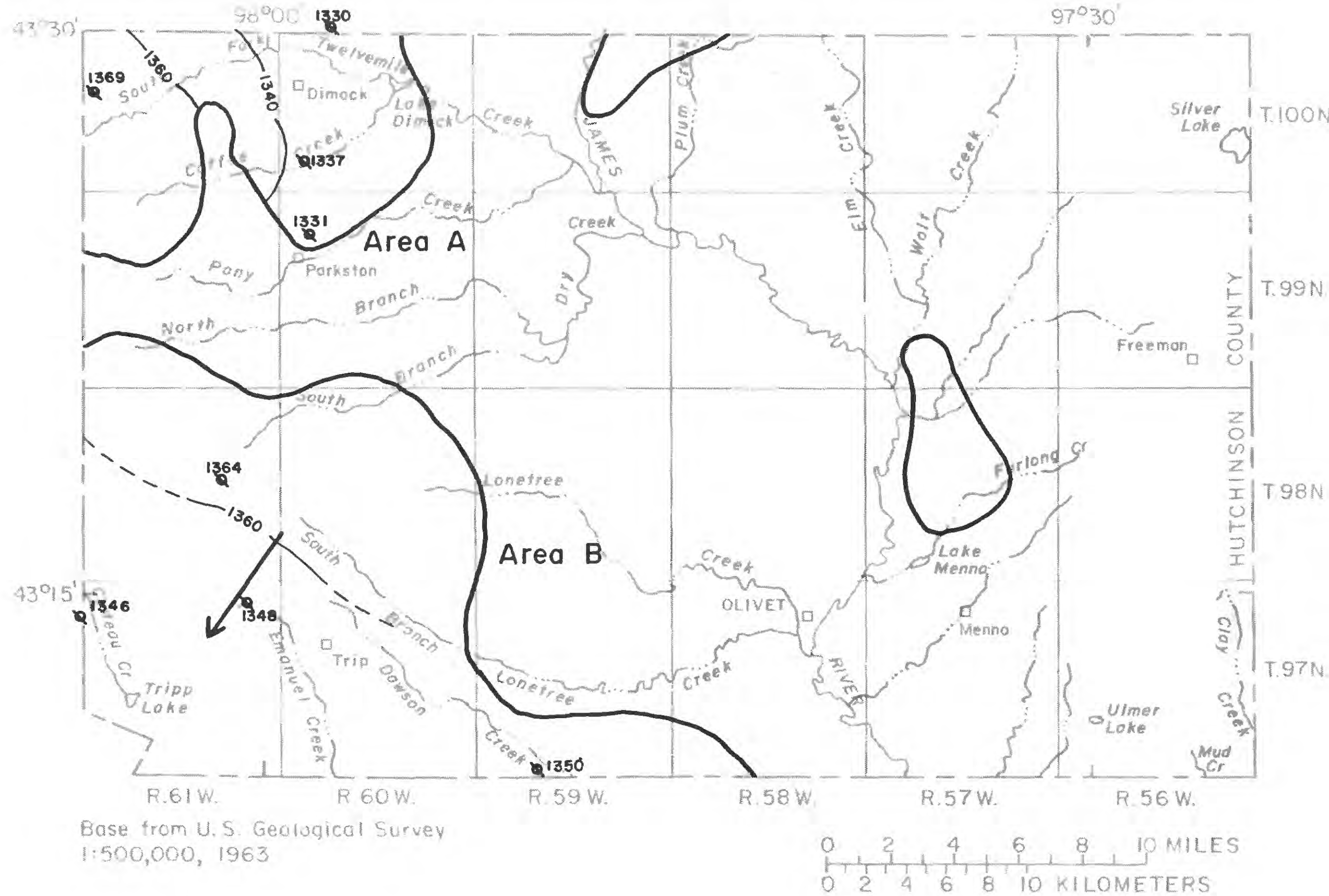
EXPLANATION

● 40+ TEST HOLE -- Number is thickness of sand and gravel, in feet. A plus (+) indicates thickness greater than shown

AQUIFER BOUNDARY

AREA OF AQUIFER AS DISCUSSED IN TEXT

Figure 36.--Areal extent and thickness of the Codell aquifer in Hutchinson County.



EXPLANATION

1330 OBSERVATION WELL -- Number is altitude of water surface, in feet. Datum is sea level

—1360-- POTENTIOMETRIC CONTOUR -- Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 20 feet

——— AQUIFER BOUNDARY

←—— DIRECTION OF GROUND-WATER MOVEMENT

Figure 37.--Potentiometric surface of the Codell aquifer in Hutchinson County (November 1986).

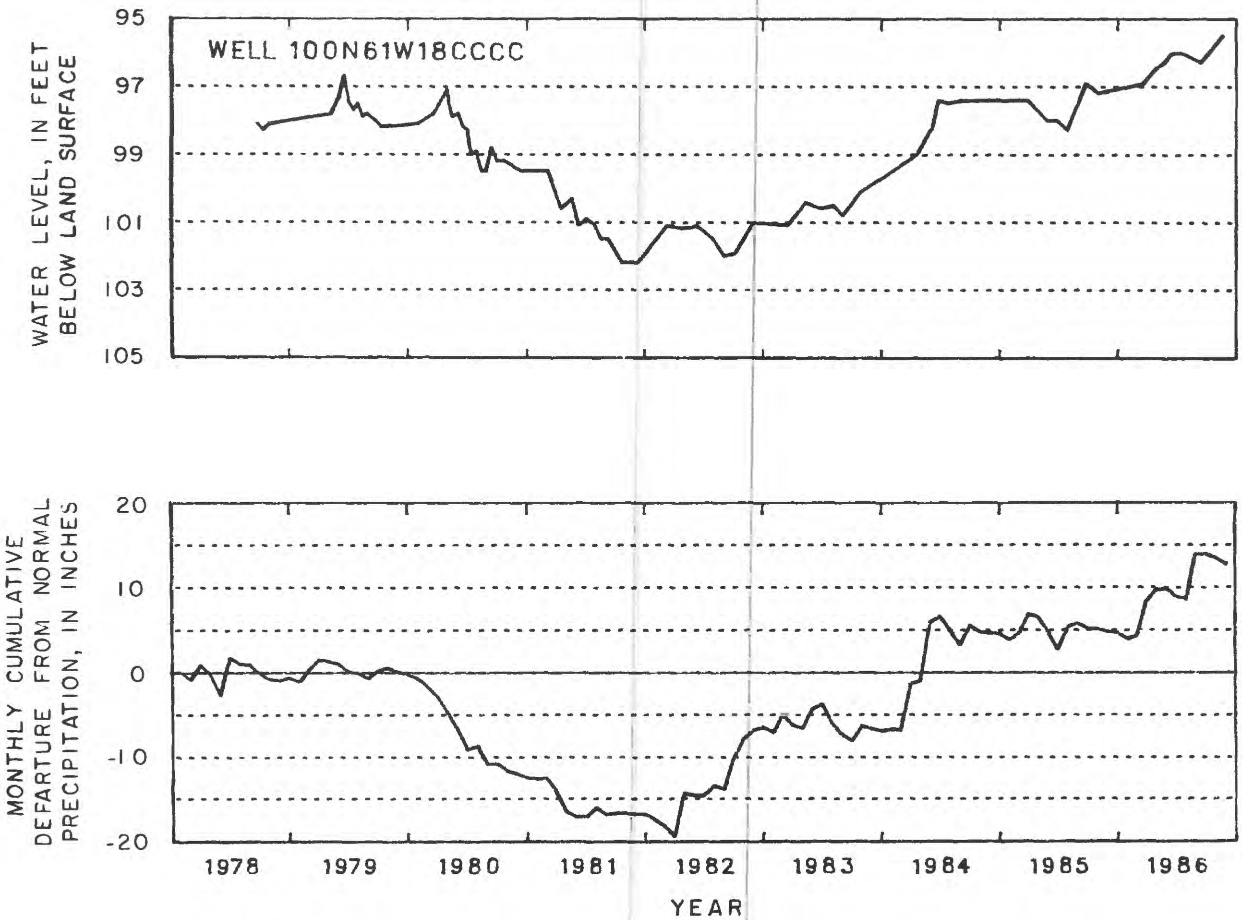


Figure 38.--Water-level fluctuations in the Codell aquifer and cumulative monthly departure from normal precipitation at Menno.

Predominant chemical constituents in water from the Codell aquifer are sodium and sulfate (fig. 18). Dissolved-solids concentrations ranged from 1,270 to 1,720 mg/L and averaged 1,450 mg/L. Hardness concentrations ranged from 85 to 440 mg/L and averaged 230 mg/L. Hardness concentrations in the southeastern area A ranged from 320 to 440 mg/L, compared to an average concentration of 160 mg/L for the rest of the Codell aquifer. The larger hardness concentrations were probably caused by mixing with water from the Choteau aquifer. A larger percentage composition of sulfate and a smaller percentage of sodium was observed in water from wells in the Codell aquifer in the southeastern part of T. 100 N., R. 60 W. as compared to the rest of the aquifer. The observed differences in composition further indicate that water from the Codell aquifer is mixing with water from the Choteau aquifer in that area.

Mixing of water from the Niobrara and Codell aquifers may occur since the predominant chemical constituents in water from the Niobrara aquifer in the western part of area A were also sodium and sulfate. A summary of chemical analyses is given in table 6, and selected chemical analyses of water from the aquifer are included in table 8.

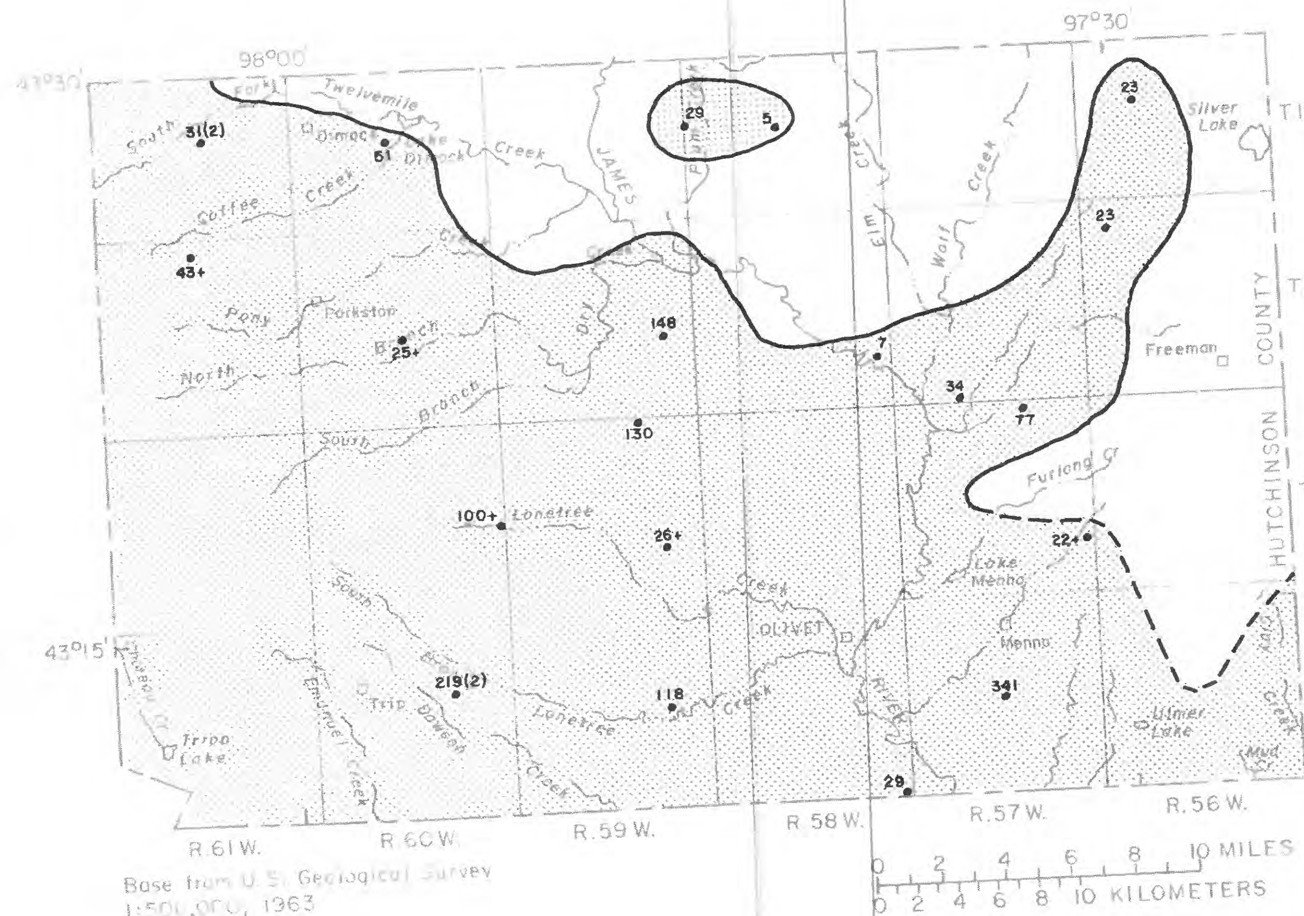
Water from the Codell aquifer is used for stock watering, domestic, and municipal purposes. Water from the aquifer generally is not used for irrigation because of small well yields and large dissolved-sodium concentrations.

Dakota aquifer

The Dakota aquifer underlies about 949 mi^2, or about 66 percent of Hutchinson and Turner Counties (fig. 39). The aquifer is composed of a very fine- to medium-grained, friable to well-cemented, quartzose sandstone interbedded with claystone layers as much as 70 ft thick. A pink, very fine to coarse-grained quartzose sand underlies the Dakota and overlies the Sioux Quartzite. In western Hutchinson and northern and southeastern Turner Counties, the aquifer is characterized by two sand layers; in southwestern Turner County, the aquifer is characterized by four sand layers; and elsewhere one sand layer. The lower sand layers in western Hutchinson and southwestern Turner Counties thin to the east and pinch out against Sioux Quartzite. Depth to the top of the aquifer ranges from 180 ft near the James River in T. 99 N. to more than 900 ft in southwestern Hutchinson County and is greater than 400 ft for most of the areal extent of the aquifer. The thickness is as much as 341 ft in the southern part of the aquifer and decreases to the north because the elevation of the Sioux Quartzite surface generally increases from south to north in the study area. Geologic sections of the aquifer are shown in figures 12, 13, 14, and 19, and hydrologic characteristics are given in table 5.

The Dakota aquifer is overlaid by the Lower James-Missouri aquifer in parts of T. 100 N., R. 58 W., T. 99 N., R. 58 W., T. 99 N., R. 59 W., and possibly northern T. 98 N., R. 58 W. and northwestern T. 98 N., R. 57 W.

Water levels in wells in the Dakota aquifer, east of the James River flood plain, ranged from 65 to about 190 ft below land surface. Water levels generally are less than 100 ft below land surface in Turner County. Wells in the Dakota aquifer in the James River flood plain and west of the flood plain usually flow.



EXPLANATION

• 31(2) TEST HOLE -- Number is thickness of sand and gravel, in feet. Numbers in parenthesis refer 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

AREA OF AQUIFER AS DISCUSSED IN TEXT

Figure 39.--Areal extent and thickness of the Dakota aquifer in Hutchinson and Turner Counties.

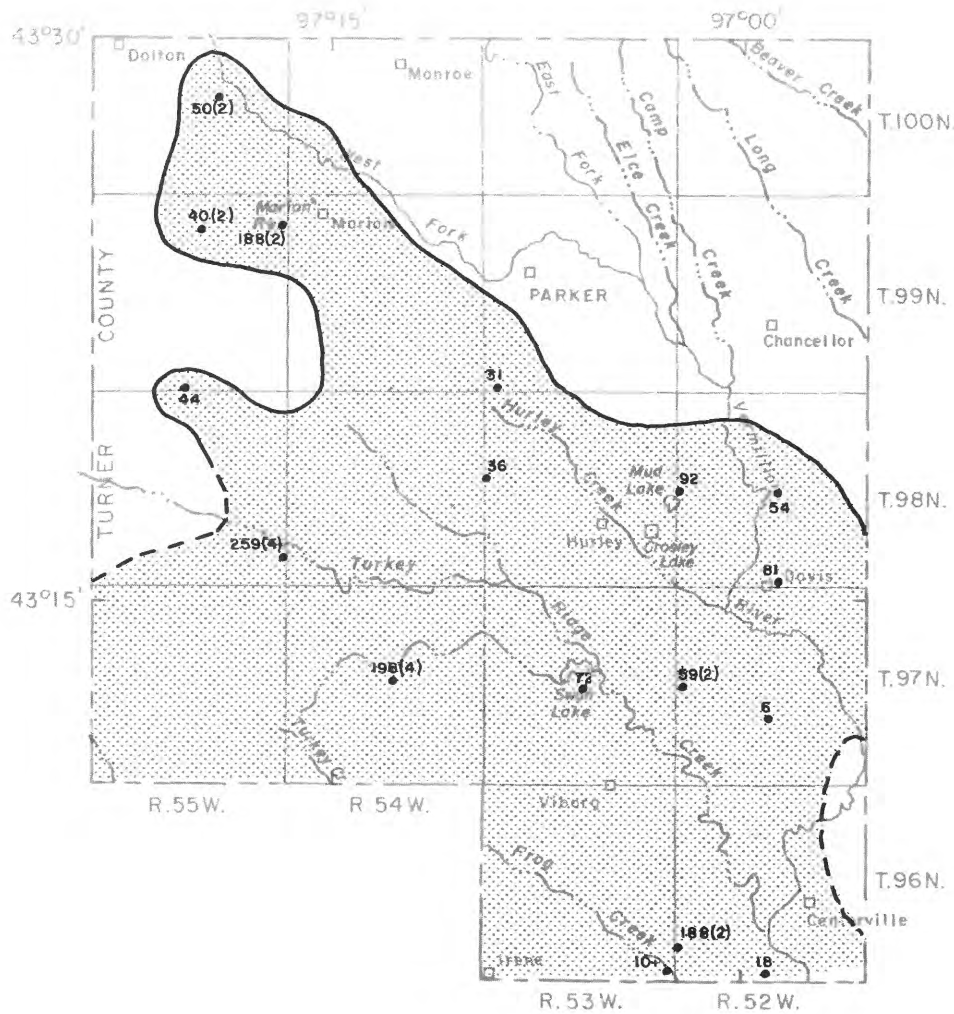
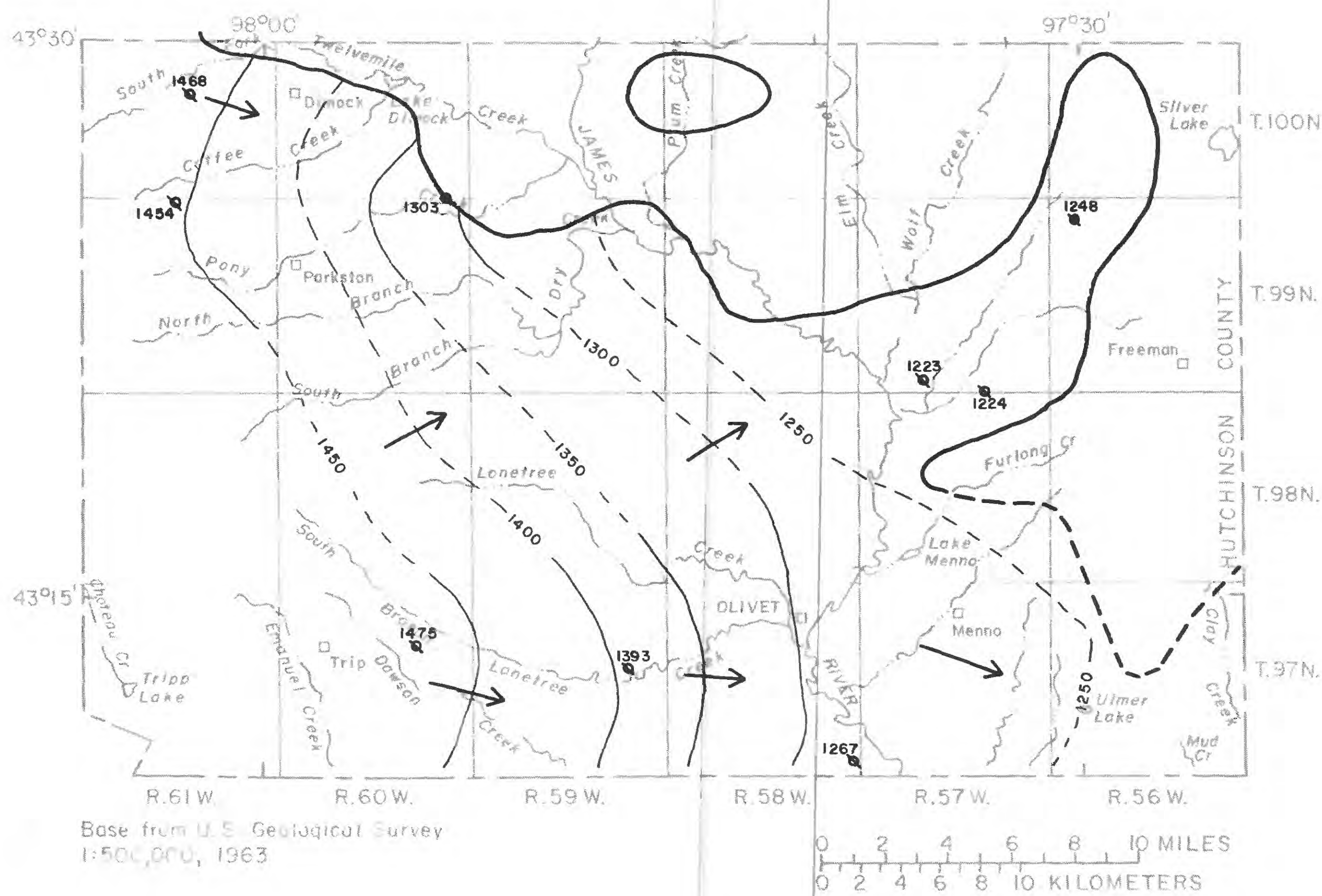


Figure 39.--Areal extent and thickness of the Dakota aquifer in Hutchinson and Turner Counties.--Continued



EXPLANATION

1475 OBSERVATION WELL--Number is altitude of water surface, in feet. Datum is sea level

—1400-- POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 50 feet

——-- AQUIFER BOUNDARY--Dashed where approximately located

← DIRECTION OF GROUND-WATER MOVEMENT

Figure 40.--Potentiometric surface of the Dakota aquifer in Hutchinson and Turner Counties (November 1986).

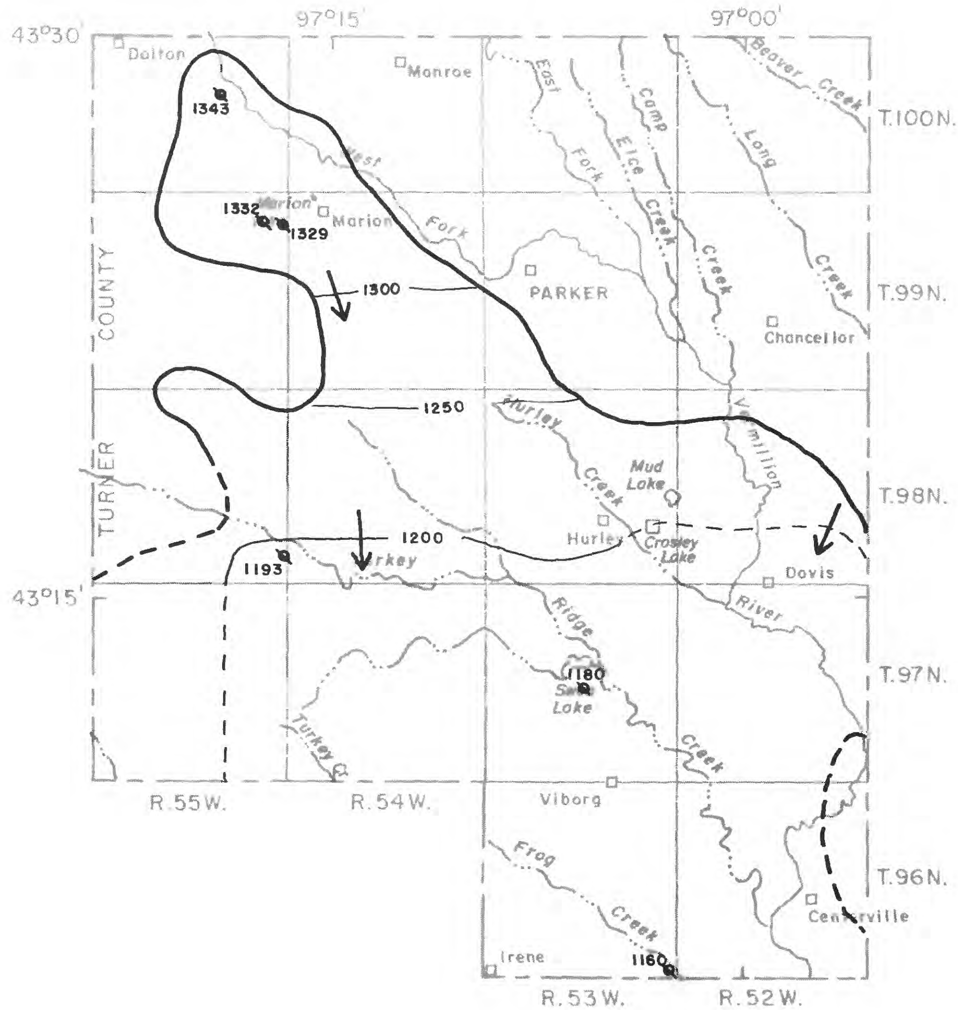


Figure 40.--Potentiometric surface of the Dakota aquifer in Hutchinson and Turner Counties (November 1986).--Continued

Recharge to the Dakota aquifer may be from the underlying Sioux Quartzite in northeastern Hutchinson County and northern Turner County. The general direction of water movement in the Dakota aquifer in Hutchinson County is to the east toward the James River at a gradient of about 15 ft/mi (fig. 40). The direction of water movement in northeastern Hutchinson County is to the southwest. The direction of water movement in Turner County is to the south at a gradient of about 3 ft/mi.

Discharge from the Dakota aquifer is: (1) To the Lower James-Missouri aquifer northeast of the James River, (2) possibly to the Lower James-Missouri aquifer in southern T. 99 N., R. 58 W. and northern T. 98 N., R. 57 and 58 W., and (3) by withdrawal from municipal, stock, and domestic wells. The major discharge areas for the Dakota aquifer in southeastern South Dakota are the Lower Vermillion-Missouri aquifer in Clay County (Stephens, 1967) and the Missouri aquifer in Union County.

Water-level fluctuations in observation well 97N58W36DDDD2 screened in the Dakota aquifer show a close correlation with long-term trends in precipitation (fig. 41). The water level rose about 9 ft from 1981-86 because of above-normal precipitation. The water level in well 100N55W15DDDC declined 1 to 3 ft during the summer in 1984-86, similar to but smaller in magnitude than the summer water-level declines in well 100N55W14DDDD2 screened in the Niobrara aquifer about 1 mi to the east (fig. 35). The similarity in water levels and summer declines in water level in the two wells may indicate a hydraulic connection between the Niobrara and Dakota aquifers in the area between the two well sites. Wells in the Dakota aquifer elsewhere do not show a similar summer water-level decline. The water level in the wells in the Niobrara aquifer is about 1 to 2 ft higher during winter, fall, and spring than the water level in the well in the Dakota aquifer and about 2 to 3 ft lower during the summer.

Predominant chemical constituents in water from the Dakota aquifer are calcium, sodium, and sulfate (fig. 18). Dissolved-solids concentrations ranged from 784 to 2,100 mg/L and averaged 1,460 mg/L; hardness concentrations ranged from 250 to 1,200 mg/L and averaged 670 mg/L. A summary of chemical analyses is given in table 6, and selected chemical analyses of water from the aquifer are included in table 8.

Specific conductance and hardness concentrations ranged from 2,150 to 2,660 μS/cm and 980 to 1,200 mg/L, west of the James River and from 900 to 1,960 μS/cm and 250 to 560 mg/L, east of the James River. Smaller specific conductance and hardness concentrations east of the James River may be dilution effects caused by recharge from rainfall and snowmelt to fractures in the Sioux Quartzite and subsequent movement to the Dakota aquifer. The quartzite is at or near land surface near the McCook-Turner County line and northeast of the study area. Predominant chemical constituents in water from the Dakota aquifer west of the James River were calcium and sulfate and the predominant chemical constituents east of the James River were calcium and sulfate or sodium and sulfate.

Water from the Dakota aquifer is used for stock watering, domestic, and municipal purposes. Although water from the aquifer generally is suitable for irrigation under all soil texture conditions based on the South Dakota irrigation-water classification diagram (fig. 11), the yield to wells generally is not sufficient to supply enough water for irrigation purposes.

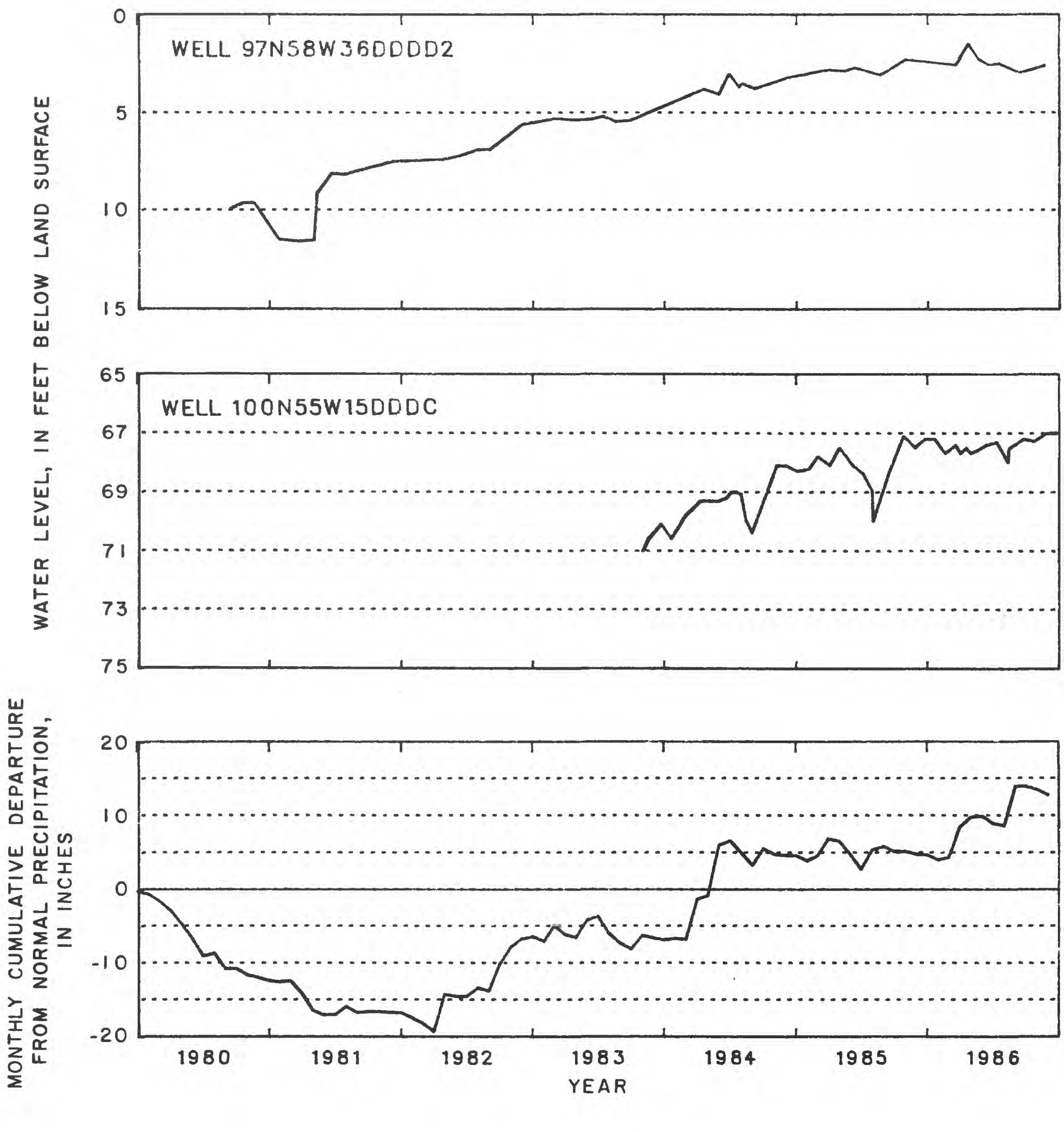


Figure 41.--Water-level fluctuations in the Dakota aquifer and cumulative monthly departure from normal precipitation at Menno.

WATER USE

Surface water in Hutchinson and Turner Counties is used for domestic, stock-watering, and irrigation purposes. Total surface-water withdrawals during 1985 were about 365 million gallons in Hutchinson County and about 240 million gallons in Turner County (R. D. Benson, U.S. Geological Survey, written commun., 1986). About 25 percent of the total surface-water use in Hutchinson County and about 5 percent of the total surface-water use in Turner County was for irrigation.

Use of water from glacial and bedrock aquifers in Hutchinson and Turner Counties in 1985 was estimated to be about 3.9 billion gallons (table 9). Ninety-one percent of the water used was withdrawn from glacial aquifers and 9 percent was withdrawn from bedrock aquifers. Eighty-three percent of the water withdrawn from the aquifers was used for irrigation. Eighty-seven percent of the water used for irrigation was withdrawn from the Parker-Centerville and Upper Vermillion-Missouri aquifers. Twenty-six percent of the water used for stock and rural domestic purposes was withdrawn from the Lower James-Missouri and Upper Vermillion-Missouri aquifers and 56 percent was withdrawn from the bedrock aquifers.

The Sioux Quartzite is also used as a source of water in northern Turner County. Water from the Sioux Quartzite is used for stock-watering, domestic, and municipal purposes.

Table 9.--Estimated ground-water withdrawal in 1985 for Hutchinson and Turner Counties

[Reported in million gallons; --, no data]

Aquifers	Total	Municipal	Rural domestic	Livestock	Irrigation
GLACIAL					
Parker-Centerville	2,124	11	4	7	[1]2,102
Vermillion West Fork	163	15	2	4	[1]142
Vermillion East Fork	27	--	2	3	[1]22
Turkey Ridge Creek	3	--	1	2	--
Upper Vermillion-Missouri	837	33	21	38	[1]745
Lower James-Missouri	244	--	20	35	[1]189
Choteau	87	38	7	13	[1]29
Dolton	69	49	5	5	[1]10
Turkey Ridge	11	--	4	7	--
Wall Lake	9	--	3	6	--
Ethan	5	--	2	3	--
Subtotal	3,579	146	71	123	3,239
BEDROCK					
Niobrara	180	35	46	83	[1]16
Codell	61	19	15	27	--
Dakota	98	19	28	51	--
Subtotal	339	73	89	161	16
Total	3,918	219	160	284	3,255

[1]South Dakota Department of Water and Natural Resources, written commun., 1985.

SUMMARY

The water resources of Hutchinson and Turner Counties in southeastern South Dakota occur as surface water in streams, lakes, and ponds and as ground water in glacial and bedrock aquifers. The major surface-water sources in the 1,430-mi^2 study area are the James and Vermillion Rivers and their intermittent tributaries. Seasonal variations in streamflow correspond to seasonal variations in precipitation, snowmelt, and evapotranspiration. The average annual runoff for the James River near Scotland (18.6 acre-ft/mi^2) is much less than the average annual runoff (greater than 50 acre-ft/mi^2) for the major streams in the study area. The James River, Vermillion River, West Fork Vermillion River, Wolf Creek (upstream from the gaging station near Clayton), Lonetree Creek, Twelvemile Creek, East Fork Vermillion River, and Turkey Ridge Creek receive discharge from ground-water storage. The average discharge is exceeded only about 20 percent of the time for both the James River near Scotland and the Vermillion River near Wakonda. Dissolved-solids concentration of water from streams and lakes generally varies inversely with the volume of streamflow and lake levels.

Ground water may be obtained from 11 major glacial and 3 major bedrock aquifers with an estimated 23 million acre-ft of water in storage in Hutchinson and Turner Counties. The glacial aquifers are composed primarily of unconsolidated sand and gravel deposited as outwash and contain about 5.2 million acre-ft of water in storage. The Parker-Centerville, West Fork Vermillion, East Fork Vermillion, and Turkey Ridge Creek aquifers are shallow aquifers with depths to the top of the aquifers of less than 65 ft below land surface. The Choteau, Dolton, Turkey Ridge, Wall Lake, and Ethan aquifers are buried aquifers overlaid by from 35 to 270 ft of till. The Upper Vermillion-Missouri and Lower James-Missouri aquifers are predominantly buried aquifers overlaid by as much as 355 and 245 ft of glacial till, respectively. However, in southern Turner County, the Upper Vermillion-Missouri aquifer is at or near land surface in the Vermillion River flood plain. The Lower James-Missouri aquifer occurs at or near land surface in southern Hutchinson County in the James River flood plain.

The Parker-Centerville, West Fork Vermillion, East Fork Vermillion, and Turkey Ridge Creek aquifers have average thicknesses ranging from 19 to 34 ft. Water in the aquifers is under water-table conditions except for small areas where the aquifers extend beyond the flood plain. Estimated maximum well yields for the Parker-Centerville aquifer are 1,000 gal/min and for the West Fork Vermillion, East Fork Vermillion, and Turkey Ridge Creek aquifers are 500 gal/min. Recharge to the aquifers is primarily by infiltration of precipitation where the aquifers are at or near land surface. The predominant chemical constituents in water from the shallow aquifers are calcium and sulfate. The average dissolved-solids concentrations in water from the shallow (Parker-Centerville, West Fork Vermillion, East Fork Vermillion, and Turkey Ridge Creek) aquifers ranged from 870 to 2,200 mg/L, and average hardness concentrations ranged from 670 to 1,400 mg/L.

Water in the Upper Vermillion-Missouri, Choteau, Dolton, Wall Lake, and Ethan aquifers is under confined conditions. The average thickness for these aquifers ranges from 18 to 68 ft. Water in the Lower James-Missouri and Turkey Ridge aquifers is under both water-table and confined conditions. The average thickness of the Lower James-Missouri aquifer is 69 ft, and the average thickness of the Turkey Ridge aquifer is 41 ft. Estimated maximum well yields for the Upper-Vermillion Missouri, Lower James-Missouri, and Choteau aquifers are 1,000 gal/min; for the Wall Lake aquifer are 500 gal/min; for the Dolton and Ethan aquifers are 400 gal/min; and for the Turkey Ridge aquifer are 50 gal/min.

The predominant chemical constituents in water from the Upper Vermillion-Missouri, Lower James-Missouri, Turkey Ridge, and Wall Lake aquifers are calcium and sulfate; from the Choteau and Ethan aquifers are sodium and sulfate; and from the Dolton aquifer are sodium, sulfate, and bicarbonate. The average dissolved-solids concentrations in water from the buried (Upper Vermillion-Missouri, Lower James-Missouri, Choteau, Dolton, Turkey Ridge, Wall Lake, and Ethan) aquifers ranged from 1,190 to 2,100 mg/L, and average hardness concentrations ranged from 280 to 1,200 mg/L.

Three major bedrock aquifers, the Niobrara, Codell, and Dakota aquifers store about 18 million acre-ft of water in Hutchinson and Turner Counties. Water in the aquifers is under confined conditions. The average thicknesses of the bedrock aquifers are about 75 ft for the Niobrara aquifer, 40 ft for the Codell aquifer, and 81 ft for the Dakota aquifer.

Estimated maximum well yields are 1,000 gal/min for the Niobrara aquifer. Estimated maximum well yields are 100 gal/min for the Codell aquifer and 250 gal/min for the Dakota aquifer.

The predominant chemical constituents in water from the Niobrara and Dakota aquifers are calcium, sodium, and sulfate. The predominant chemical constituents in water from the Codell aquifer are sodium and sulfate. The average dissolved-solids concentrations were 1,510, 1,450, and 1,460 mg/L for water from the Niobrara, Codell, and Dakota aquifers, respectively. The average hardness concentrations were 650, 230, and 670 mg/L for water from the Niobrara, Codell, and Dakota aquifers, respectively.

Water use from glacial and bedrock aquifers in Hutchinson and Turner Counties during 1985 was estimated to be about 3.9 billion gallons. Ninety-one percent of the water used was withdrawn from glacial aquifers and 9 percent of the water used was withdrawn from bedrock aquifers. Eighty-three percent of the water withdrawn from the aquifers was used for irrigation and 87 percent of the water used for irrigation was withdrawn from the Parker-Centerville and Upper Vermillion-Missouri aquifers.

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