WATER RESOURCES OF LAKE AND MOODY COUNTIES, SOUTH DAKOTA

By Donald S. Hansen

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4209

Prepared in cooperation with the

SOUTH DAKOTA GEOLOGICAL SURVEY,

LAKE AND MOODY COUNTIES, and the

EAST DAKOTA CONSERVANCY SUB-DISTRICT

Huron, South Dakota

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

The inch-pound units used in this report may be converted to metric (SI) units by the following conversion factors:

Multiply inch-pound unit	By	To obtain SI unit
inch	25.4	millimeter
foot (ft)	0.3048	meter
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.78543	liter
mile (mi)	1.609	kilometer
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per day (acre-ft/d)	1,233	cubic meter per day
acre	0.4047	hectare
gallons per minute (gal/min)	0.06308	liters per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot per day (ft/day)	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
square foot per day (ft^2/day)	0.0929	square meter per day

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

$$^{\circ}C = \frac{^{\circ}F - 32}{1.8}$$

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, called NGVD of 1929, is referred to as sea level in this report.

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ABSTRACT

The water resources of Lake and Moody Counties of eastern South Dakota consist of streams and lakes, and glacial and bedrock aquifers.

The primary sources of surface water in Lake and Moody Counties are the Big Sioux River and its intermittent tributaries, and Lakes Herman, Madison, and Brant. Seasonal variations in streamflow and lake levels are directly related to seasonal variations in precipitation. Dissolved-solids concentration in water from streams and lakes increases as streamflow decreases and lake levels decline.

Eight glacial aquifers and four bedrock aquifers were delineated in Lake and Moody Counties. The Big Sioux, North Skunk Creek, Pipestone Creek, Battle Creek, and East Fork Vermillion aquifers are composed of glacial outwash. These aquifers are generally less than 60 feet below land surface, and are in hydraulic connection with the river or creek of the same name. The Rutland, Ramona, and Howard aquifers are composed of glacial outwash and are overlain by 50 to 470 feet of till. The four bedrock aquifers are the Niobrara, Codell, Dakota, and quartzite wash.

The average thickness of the Big Sioux, Pipestone Creek, North Skunk Creek, Battle Creek, and East Fork Vermillion aquifers ranges from 14 feet for the Battle Creek aquifer to 39 feet for the North Skunk Creek aquifer. Recharge to the aquifers is from infiltration of precipitation. Reported discharge from wells screened in the Big Sioux, North Skunk Creek, and East Fork Vermillion aquifers ranges from 30 to 1,000 gallons per minute, and from those screened in the Pipestone Creek and Battle Creek aquifers ranges from 1 to 15 gallons per minute. Predominant chemical constituents in water from the Big Sioux, North Skunk Creek, and Pipestone Creek aquifers are calcium and bicarbonate. Predominant chemical constituents in the Battle Creek and East Fork Vermillion aquifers are calcium and sulfate. The average dissolved-solids concentration ranged from 480 milligrams per liter for the Pipestone Creek aquifer to 1,150 milligrams per liter for the East Fork Vermillion aquifer. Water from the aquifers is used for irrigation, municipal, and domestic purposes.

The average thickness of the Rutland, Ramona, and Howard aquifers ranges from 18 feet for the Ramona aquifer to 40 feet for the Howard aquifer. Recharge to the aquifers is by leakage from till. The Howard aquifer and quartzite wash aquifer are hydraulically connected in eastern Moody County. Reported discharge from wells screened in the aquifers ranges from 2 to 300 gallons per minute. Predominant chemical constituents in water from the aquifers are calcium, sulfate, and bicarbonate. The average dissolved-solids concentration for the Howard aquifer was 1,750 milligrams per liter, for the Rutland aquifer was 1,500 milligrams per liter, and for the Ramona aquifer was 1,360 milligrams per liter. Water from the aquifers is used primarily for domestic and stock purposes.

The average thickness of the bedrock aquifers ranges from 60 to 400 feet. The aquifers are under artesian conditions. The quartzite wash aquifer and the Codell aquifer are hydraulically connected in eastern Moody County. Water-quality data indicates recharge to the Codell aquifer from the quartzite wash aquifer in Moody County. The direction of water movement in the bedrock aquifers is from east to west. Predominant chemical constituents in water from the Niobrara aquifer are calcium, sodium, and sulfate; from the Codell and Dakota aquifers are sodium and sulfate; and from the quartzite wash aquifer are calcium, sulfate, and bicarbonate. Dissolved-solids concentration in water from the bedrock aquifers ranged from 1,200 to 2,290 milligrams per liter and averaged 1,650 milligrams per liter. Water from the bedrock aquifers is used for municipal, domestic, and stock purposes.

Water use in 1980 in Lake and Moody Counties was about 2.6 billion gallons. Ninety percent of the water used in the counties was withdrawn from the glacial aquifers and 10 percent was withdrawn from the bedrock aquifers.

INTRODUCTION

Lake and Moody Counties encompass 1,092 mi^2 of the east-central part of eastern South Dakota and are located in the southern part of the Coteau Des Prairies and eastern part of the James basin physiographic area (fig. 1). Land surface altitudes range from 1,490 ft above the National Geodetic Vertical Datum of 1929 (NGVD of 1929, which will be referred to as sea level in this report) in southern Moody County to 1,875 ft above sea level in northwestern Lake County.

The water resources of Lake and Moody 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.

Purpose and Scope

In July 1979, the South Dakota Geological Survey and the U.S. Geological Survey began a 4-year study to locate and describe the water resources and geology of Lake and Moody Counties. The purpose of this report is to provide hydrogeologic information needed for future water development and planning in Lake and Moody Counties. This study is part of an evaluation of the water resources and geology of eastern South Dakota (fig. 1).

The investigation included the collection and interpretation of drillers' logs, well inventories, test drilling, observation-well installation, measurement of static water levels, and chemical analysis of water samples. Figure 2 shows the test hole and geologic section locations and observation-well and water-quality sampling sites in Lake and Moody Counties. The wells and test holes are numbered according to the Federal land survey system (fig. 3).

Acknowledgments

The author would like to acknowledge the cooperation of residents of Lake and Moody Counties for providing information on their water wells, and of the local drilling companies for suppling test-hole information.

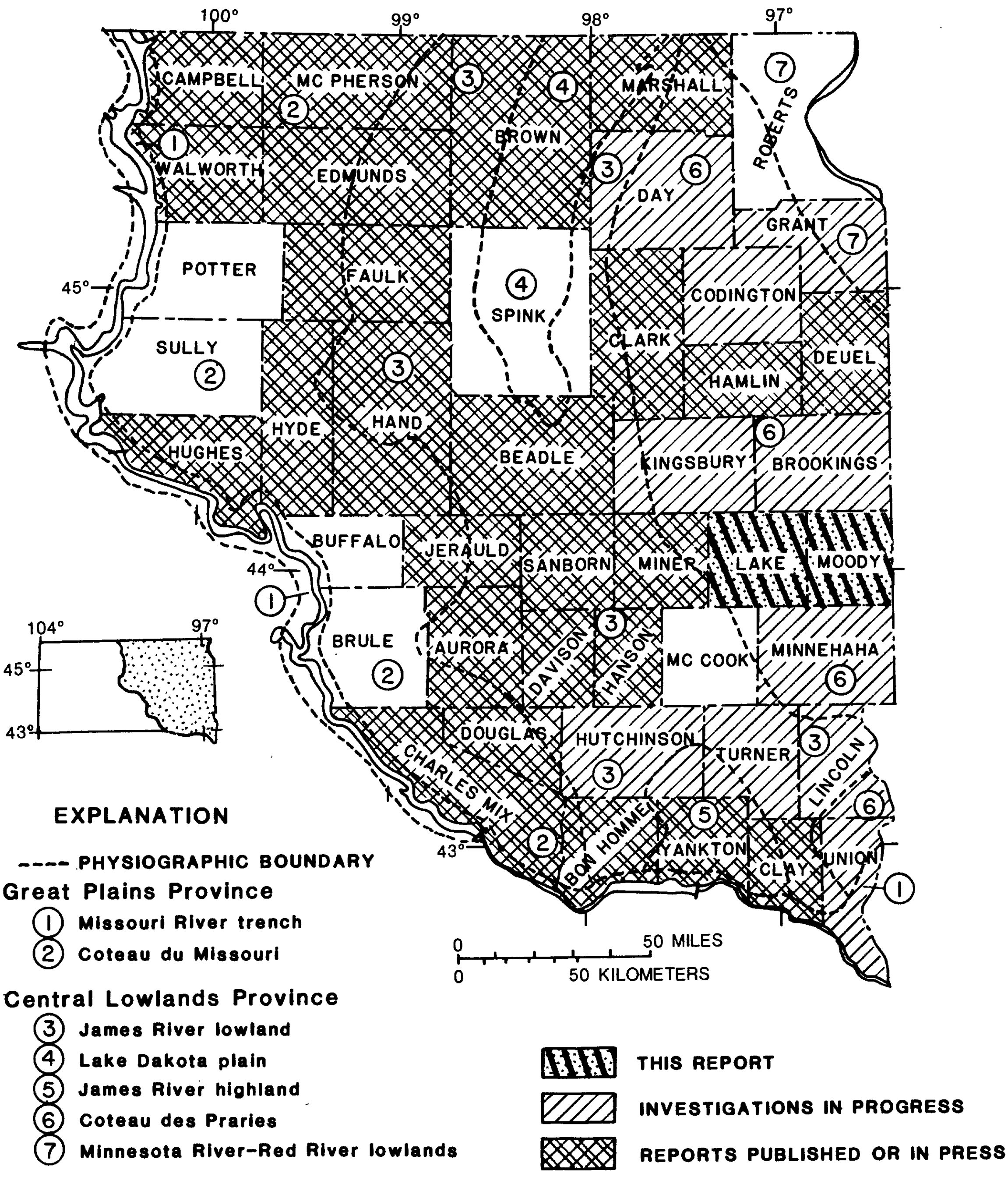
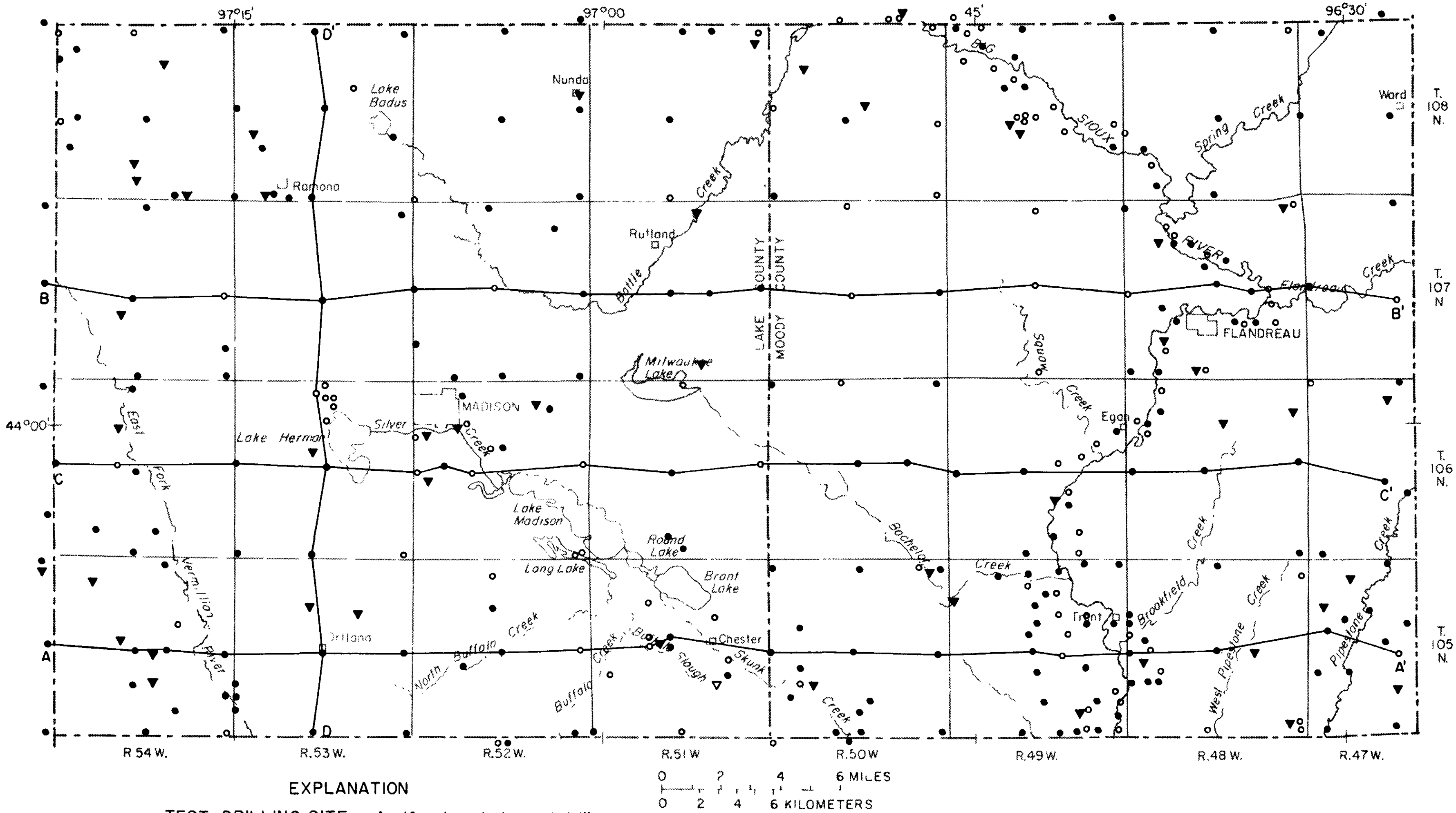


Figure 1.--Index map of eastern South Dakota showing area of this report, status of county investigations, and major physiographic divisions.



EXPLANATION

- ● TEST-DRILLING SITE--Aquifer description and drillers logs are available from U.S. Geological Survey
- ○ OBSERVATION-WELL SITE--Records of water-level measurements are available from U.S. Geological Survey
- ▼ WATER-QUALITY-SAMPLE SITE--Complete chemical analyses obtained for this study are available from U.S. Geological Survey
- A ●——● A' LINE OF GEOLOGIC SECTION

Figure 2.--Location of data sites and geologic sections in Lake and Moody Counties.

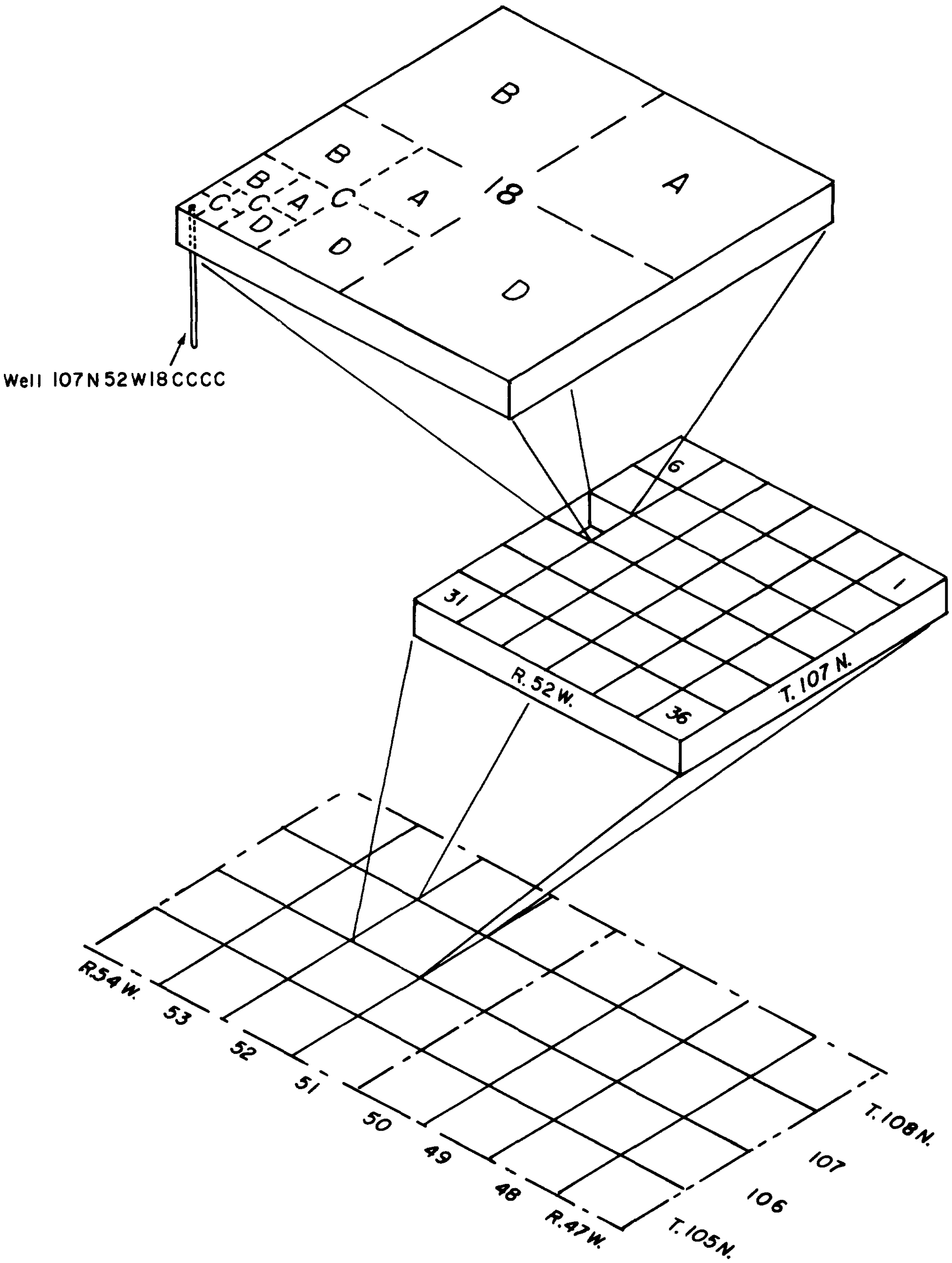


Figure 3.--Well-numbering diagram. The well number consists of township followed by "N," range followed by "W," and section number, followed by a maximum of four uppercase letters that indicate, respectively, the 160-, 40-, 10-, and 2½-acre tract in which the well is located. These letters are assigned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

WATER RESOURCES

The average annual precipitation of Lake and Moody Counties is 24 inches. About 97 percent of the precipitation is returned to the atmosphere by evaporation and transpiration. About 1 percent of the average annual precipitation becomes streamflow; however, this quantity may vary from year to year because of variations in precipitation. About 2 percent of the precipitation percolates into the ground to become ground water. The total volume of water in transient storage in aquifers is about 1.4 million acre-ft. In a given year, the water budget shows a change in ground-water storage which 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 zero, except where or if the ground-water discharge to wells increases.

Drainage in Lake and Moody Counties is primarily by the Big Sioux River and its intermittent tributaries (fig. 4). The western part of Lake County is drained by the East Fork of the Vermillion River. The balance of Lake County is drained by Battle and Skunk Creeks which flow to the Big Sioux River. Moody County is drained entirely by the Big Sioux River and its intermittent tributaries.

Surface Water

Streamflow

Streamflow is dependent upon the seasonal variation of precipitation, evapotranspiration, and ground-water storage. Rivers and creeks generally flow during the spring and early summer because of snowmelt and rainfall runoff and because of peak storage in aquifers. Creeks generally do not flow during late summer because of: (1) decreased runoff; (2) increased evaporation; and (3) decreased ground-water discharge. During years of above-normal precipitation, Skunk, Battle, and Flandreau Creeks may not go dry during late summer. The Big Sioux River receives an average of about 8 ft^3/s from ground water between the streamflow gaging station near Brookings and near Dell Rapids and rarely goes dry. The drought of 1976, however, caused zero flow within this reach. A summary of maximum, minimum, and average streamflow data for gaging stations on the Big Sioux River is given in table 1.

Table 1.--Summary of streamflow data for gaging stations in Lake and Moody Counties

Station number	Station name and location	Drainage area (square miles)	Period of record	Discharge for period of record (cubic feet per second)		
				Maximum	Minimum	Average
06480000	Big Sioux River near Brookings	4,420	1953-81	33,900	0	159
06481000	Big Sioux River near Dell Rapids	5,060	1948-81	41,300	0	252
06480500	Big Sioux River near Flandreau	4,580	1928-32	5,200	0	97

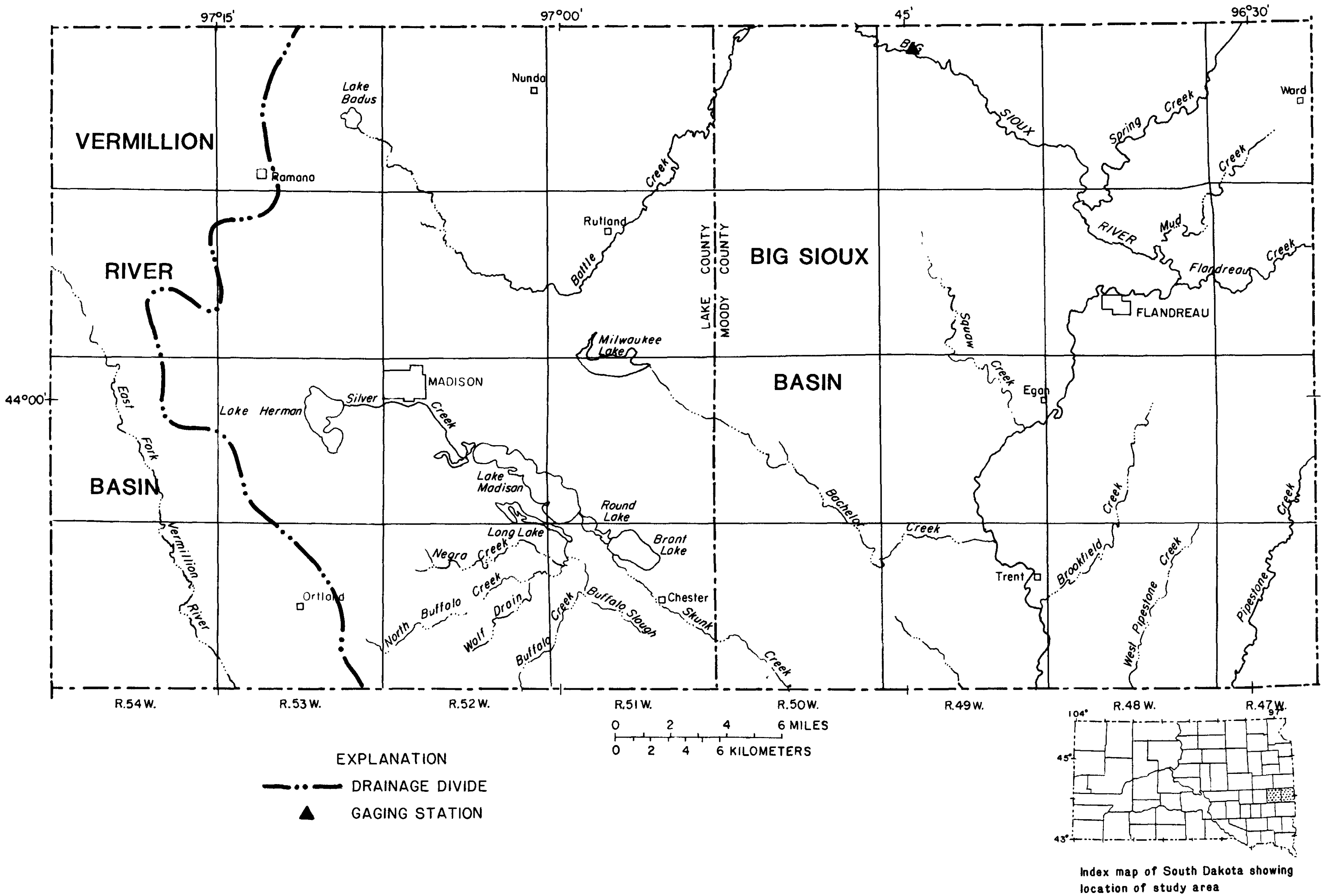


Figure 4.--Drainage basins in Lake and Moody Counties.

Floods

Extreme flooding in this area is a rare event, although valley bottoms and areas of internal drainage are flooded occasionally during the spring because of snowmelt and rainfall runoff. Maps of flood-prone areas along the Big Sioux River have been prepared by the U.S. Geological Survey. Such maps are available from the U.S. Geological Survey, Huron, SD 57350. The flood-prone areas are shown on topographic maps at a scale of about 2½ inches to the mile. These maps show areas subject to flooding by a flood that has a probability of 1 in 100 of occurring in any year.

Lakes and Ponds

Lake Madison, Lake Herman, and Brant Lake and ponds cover about 16 mi^2 or about 1 percent of the study area. The area of Lake Madison is 3.67 mi^2; Lake Herman 1.67 mi^2; and Brant Lake 1.33 mi^2. These lakes were formed by stagnant ice blocks positioned at the margin of the receding glacier (Hammond, 1982, written commun.).

Long-term records of lake-level fluctuations for Lake Madison indicate close correlation with departure from average annual precipitation (fig. 5). Lake Madison was dry in 1873, 1893 (South Dakota Lakes Preservation Committee, 1977), 1935, 1936, and 1940. These years corresponded to drought years. Lake levels rose from 1941 to 1945, 1959 to 1965, and from 1967 to 1969 because of above-normal precipitation. Lake levels remained constant from 1946 to 1951 with near-average precipitation, and declined from 1951 to 1959 and from 1965 to 1966 because of below-average precipitation.

Chemical Quality

Specific conductance of water from Lakes Herman and Madison generally decreases during the spring months because of dilution from spring rainfall and snowmelt runoff (table 2). Specific conductance is a measure of total dissolved material in the water. The average specific conductance of water collected from Lake Madison during the spring months was 1,350 micromhos per centimeter (μmhos/cm). The average specific conductance of water collected during the summer months was 1,490 μmhos/cm. The rise in specific conductance during the summer months is caused by reduced surface inflow and increased evaporation. The major chemical constituents in water from Lakes Herman and Madison are sulfate, calcium, and magnesium.

Dissolved-solids concentration in water from rivers and streams varies with the volume of streamflow. Figure 6 shows the relationship between specific conductance and discharge for the Big Sioux River near Brookings and near Dell Rapids. Specific conductance decreases as stream discharge increases because of dilution from rainfall and snowmelt runoff. The major chemical constituents in water from the Big Sioux River near Dell Rapids are sulfate and calcium.

Table 2.—Summary of chemical analyses for selected lakes in Lake and Moody Counties

[Analyses based on data collected from 1964-75, State Lakes Preservation Committee, 1977. Results in milligrams per liter except as indicated]

	Lake Herman			Lake Madison		
	Spring months average	Summer, fall, and winter months average	Annual range	Spring months average	Summer, fall, and winter months average	Annual range
Dissolved calcium	68	97	48-170	100	110	51-160
Dissolved magnesium	48	64	6-130	71	92.4	50-200
Dissolved sodium	40	48	23-80	98	120	59-140
Dissolved potassium	15	20	7-31	20	24	18-30
Dissolved chloride	6	8	1-25	120	130	79-180
Dissolved sulfate	310	380	190-920	510	500	280-730
Alkalinity, total	210	220	110-480	180	190	130-340
Dissolved phosphorus	.27	.43	0.08-1.53	.17	.21	0.02-0.48
Dissolved nitrogen	2.3	.88	<0.01-13.0	.54	.45	0.02-0.90
Dissolved solids	750	890	670-1,370	1,300	1,300	960-2,040
Specific conductance (micromhos per centimeter)	810	1,030	380-1,550	1,350	1,490	1,030-2,070
Dissolved oxygen	9.7	8.5	0.6-12.5	11.0	7.8	2.4-16
pH (units)	8.2	8.38	7.0-9.6	8.4	8.6	7.5-11.4
Temperature (°C)	8.7	14.0	0-27	9.8	13	0-26

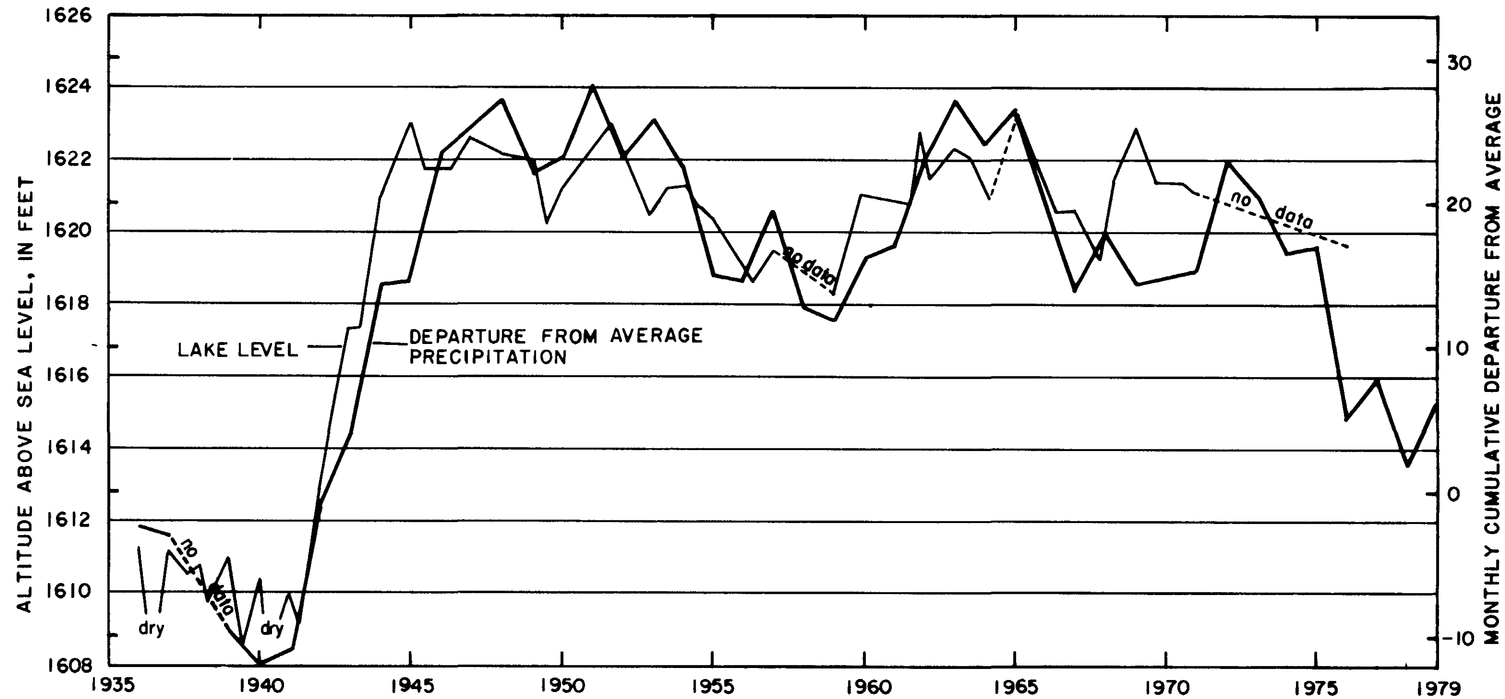


Figure 5.--Lake-level fluctuations for Lake Madison and departure from average precipitation (base period 1931-60) at Wentworth (dashed where data are unavailable).

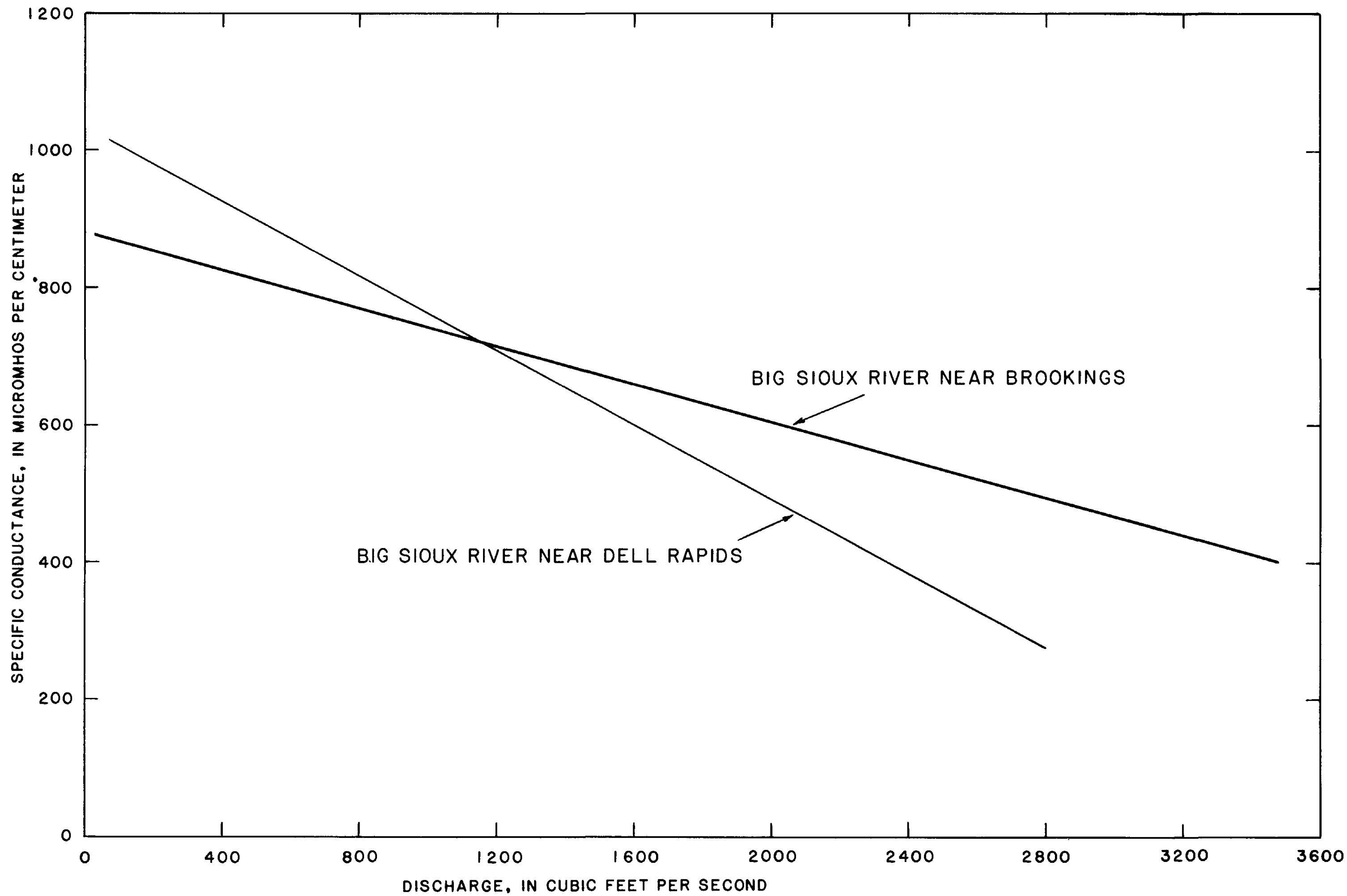


Figure 6.--The best fit line for instantaneous discharge-specific conductance data from the Big Sioux River near Dell Rapids and near Brookings.

Ground-Water Occurrence and Chemical Quality

Glacial Aquifers

Eight glacial aquifers were delineated in Lake and Moody Counties, and are shown in figures 8 and 9, and the hydrologic characteristics of each aquifer are discussed below. Glacial aquifers are unconsolidated sand and gravel outwash deposited by meltwaters from receding glaciers. The Big Sioux, Pipestone Creek, North Skunk Creek, Battle Creek, and East Fork Vermillion aquifers generally are less than 60 ft below land surface and are hydraulically connected to the river or creek of the same name. The Rutland, Ramona, and Howard aquifers are overlain by 50 to 470 ft of till. Till consists of grayish-blue clay with minor amounts of shale pebbles, sand, and silt. Till has a hydraulic conductivity of 5×10^{-4} ft/day (Henry, 1982) and will not yield a sufficient quantity of water for domestic use; however, locally it may contain thin, discontinuous sand and gravel lenses which may yield 2 to 3 gal/min to wells.

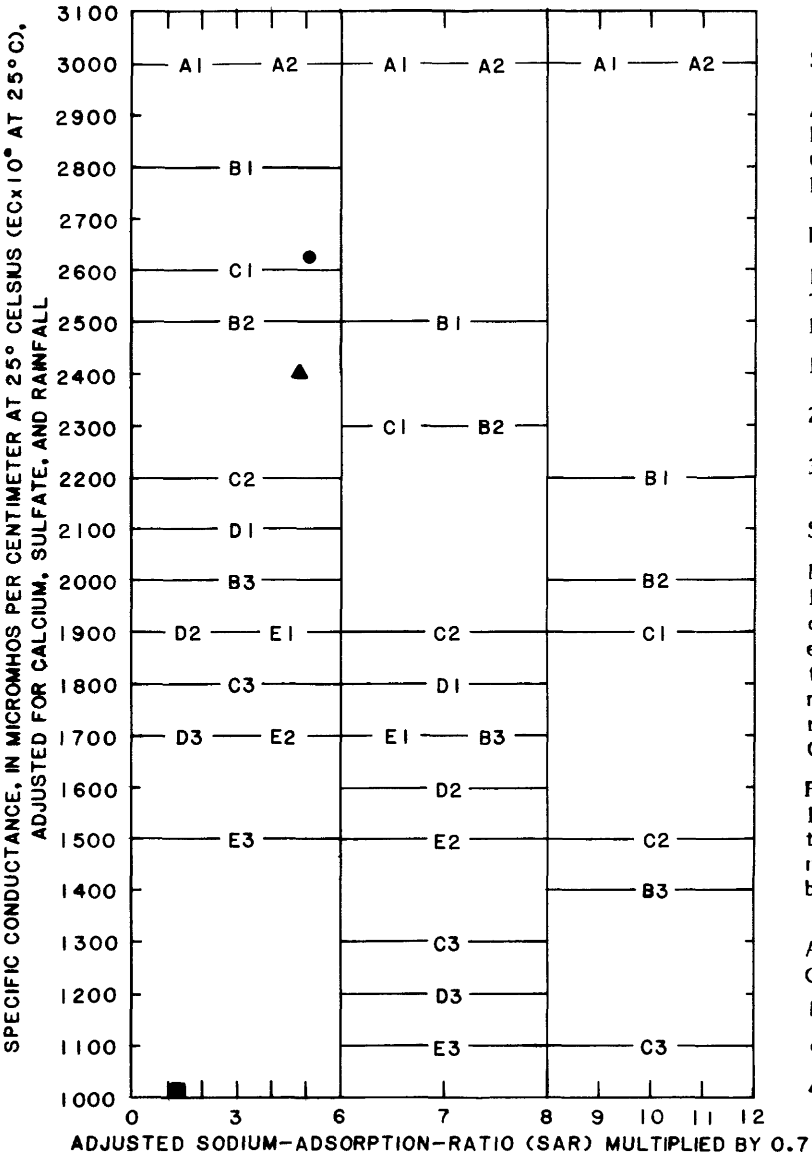
Water-level fluctuations in observation wells screened in the glacial aquifers are caused by seasonal changes in recharge and discharge. Water levels generally rise from February to June because recharge from snowmelt and spring rainfall is greater than discharge. Water levels generally decline from July to January because discharge from wells and evapotranspiration are greater than recharge. The subsurface outflow estimates for the 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.

Suitability of water for irrigation from the glacial and bedrock aquifers was determined from the South Dakota irrigation-water diagram (fig. 7) (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.

Big Sioux aquifer

The Big Sioux aquifer (fig. 8) ranges from a fine to medium, poorly sorted sand, to a well-sorted sand and medium gravel. Gravel as much as 1 inch in diameter was found in Township 108 North, Range 49 West, sections 5, 9, and 10. The aquifer is limited to the flood plain of the Big Sioux River and is underlain by till. The aquifer is generally under water-table conditions, however, in T. 105 N., R. 49 W., sections 10 and 25, the aquifer is confined by 8 to 10 ft of till. The water level in this area is about 3 ft above the top of the aquifer. Results of test drilling indicated that the confining till layer is not widespread or continuous. A geologic section of the aquifer is shown in figure 9. Hydrologic characteristics are given in table 3.

Recharge to the aquifer is by infiltration of rain and snowmelt through the overlying 1 to 2 ft of topsoil. In T. 105 N., R. 48 W., uncontrolled flowing wells, screened in the Howard aquifer, discharge on the land surface and subsequently recharge the aquifer. The general direction of water movement in the aquifer is to the south and toward the Big Sioux River, which flows from north to south (fig. 10). The gradient of the water-table surface is about 6 ft/mi; however, in the Trent area the gradient may be as much as 15 ft/mi. Results of test drilling in the Trent area showed fine to medium sand in the drill samples. The higher gradients in this area may be caused by decreased aquifer hydraulic conductivity because of the fine to medium sand in this area.



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

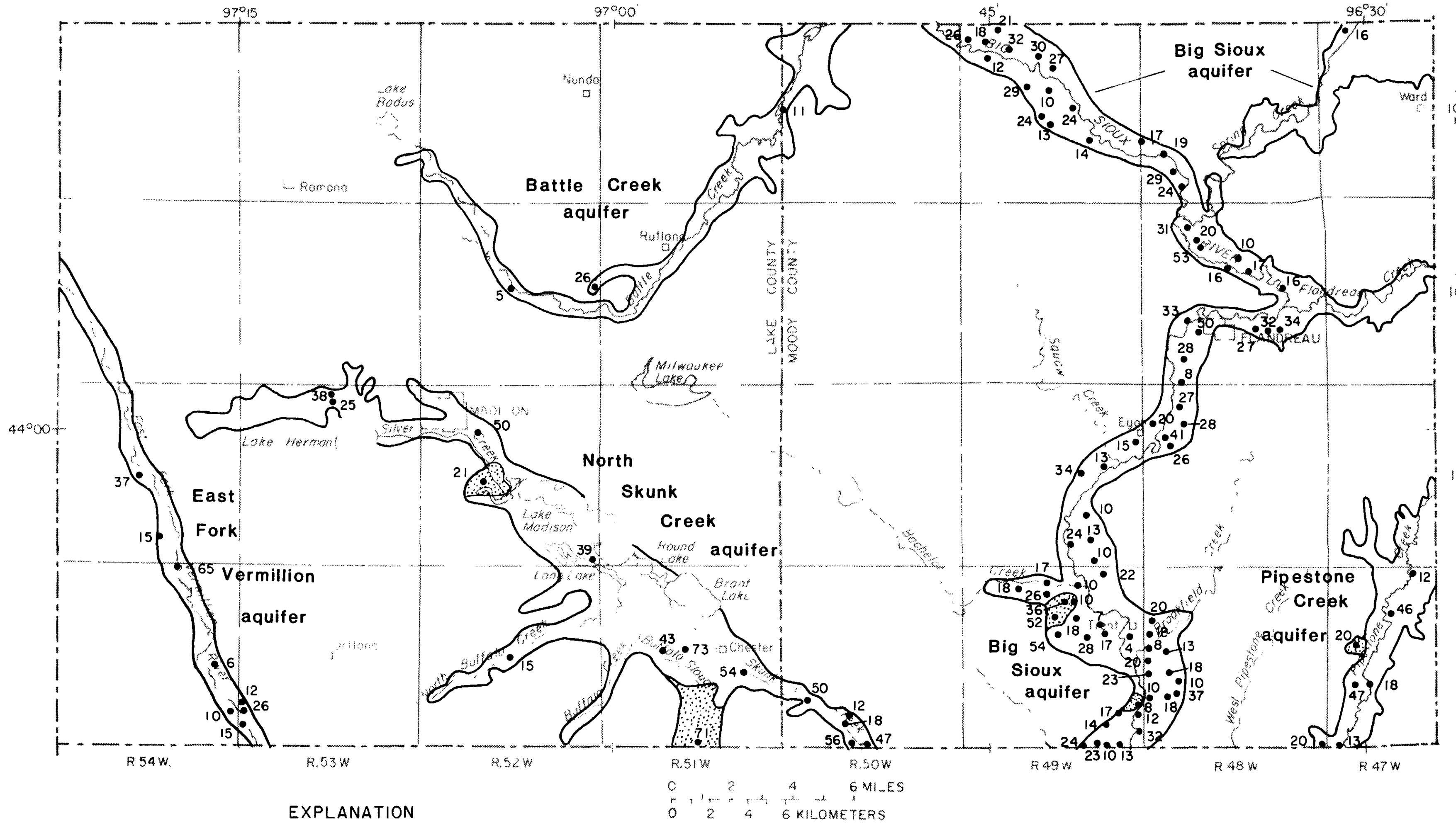
Maximum values are based on 12 inches or less of average rainfall during the frost-free season. For each additional 2 inches of rainfall the maximum values of $ECx10^6$ may be increased by 200. Average rainfall for Lake and Moody Counties is 18 inches.

For water having more than 10 meq/L of calcium and more than 20 meq/L of sulfate, the maximum value of $ECx10^6$ may be increased by 400.

AVERAGE CHEMICAL QUALITY OF WATER FROM THE:

■ BIG SIOUX AQUIFER
● HOWARD AQUIFER
▲ QUARTZITE WASH AQUIFER

Figure 7.--South Dakota irrigation-water classification diagram 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.



EXPLANATION

•43 TEST HOLE--Number is thickness of aquifer, in feet

AREA WHERE THE AQUIFER IS CONFINED BY TILL

AQUIFER BOUNDARY

Figure 8.--Extent and thickness of the East Fork Vermillion, North Skunk Creek, Battle Creek, Pipestone Creek, and Big Sioux aquifers in Lake and Moody Counties.

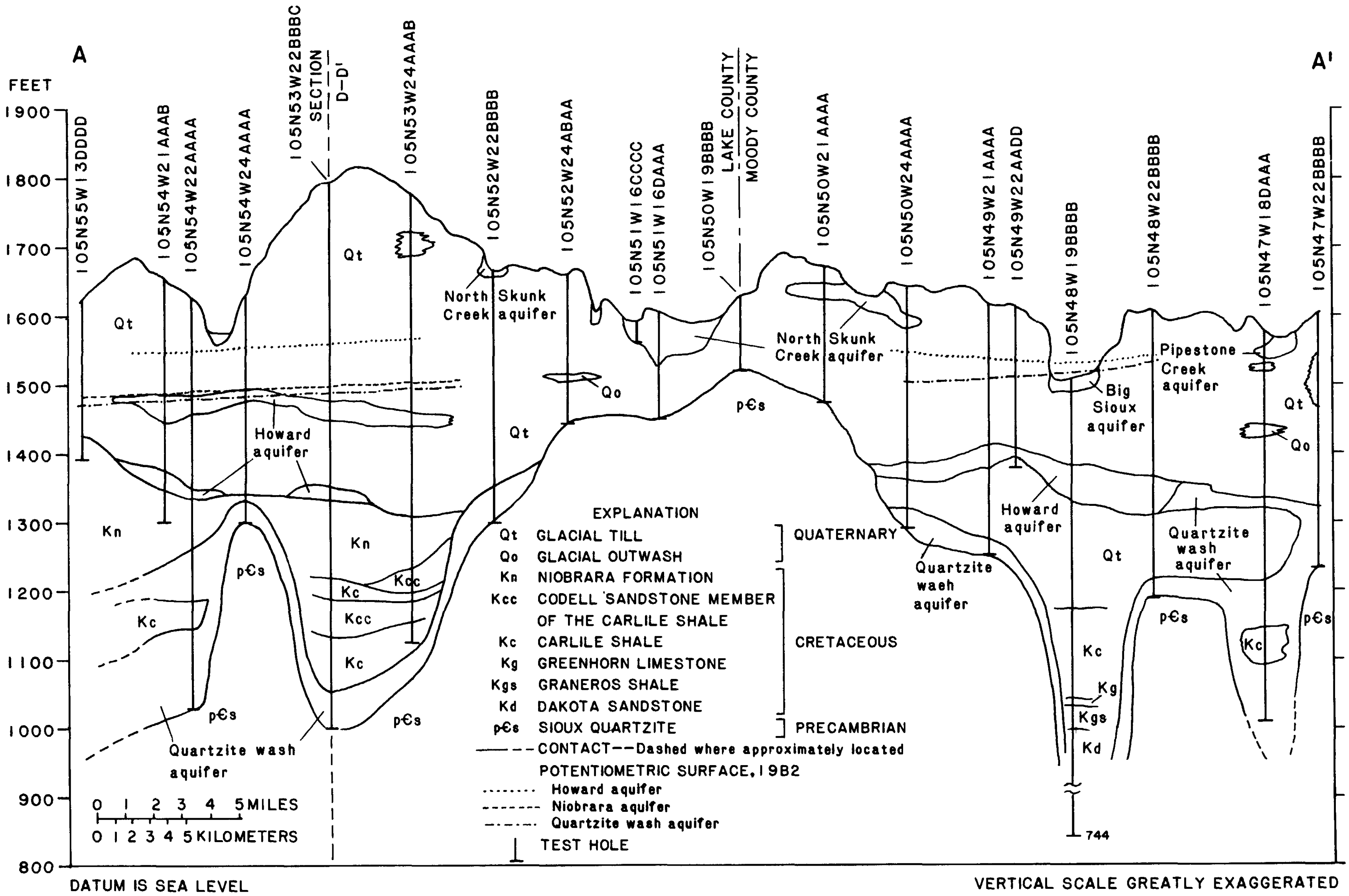


Figure 9.--Geologic section A-A' showing the Big Sioux, Pipestone Creek, North Skunk Creek, Howard, and quartzite wash aquifers. (Section A-A' is shown in figure 2.)

Table 3.--Summary of the hydrologic characteristics of the major aquifers

Aquifer name	Areal extent (square miles)	Maximum thickness (feet)	Average thickness (feet)	Range in depth below land surface (feet)	Range of ground-water level below land surface (feet)	Artesian (A) and (or) water table (WT) aquifer	Estimated volume of water in storage[2] (acre-feet)	Range of well discharges[1] (gallons per minute)	Suitability for irrigation[3]
				GLACIAL AQUIFERS					
Big Sioux	58	54	22	0-10	0.5-18	WT,A	163,000	100-800	Yes
Pipestone Creek	12	47	30	0-60	0-15	WT	46,000	5-15	Yes
North Skunk Creek	48	73	39	0-60	4-26	WT	196,000	100-1,000	Yes
Battle Creek	19	26	14	0-3	[1] 0-10	[1] WT	34,000	1-3	No
East Fork Vermillion	9	[1] 65	15	0-3	12-30	WT	15,000	30-950	Yes
Rutland	30	32	28	50-175	-10-58	A	110,000	2-5	No
Ramona	85	32	17	90-240	[1] 100-150	A	190,000	2-5	No
Howard	675	117	40	100-470	5-190	A	3.5 million	5-300	Yes
				BEDROCK AQUIFERS					
Niobrara	693	180	85	200-610	160-195	A	7.5 million	2-5	No
Codell	630	70	60	600-800	200-300	A	5.0 million	5-75	No
Dakota	700	--	[4] 400	[4] 700-1,000	[4] 50-250	A	3.6 million	5-20	No
Quartzite wash	291	210	76	100-760	-5-136	A	2.7 million	10-20	Yes

1/ Reported data.
2/ Storage was estimated by multiplying average thickness by areal extent and multiplying by specific yield of 0.2.
3/ Based on the South Dakota irrigation-water classification diagram (fig. 7).
4/ Based on data from Schoon, 1971.

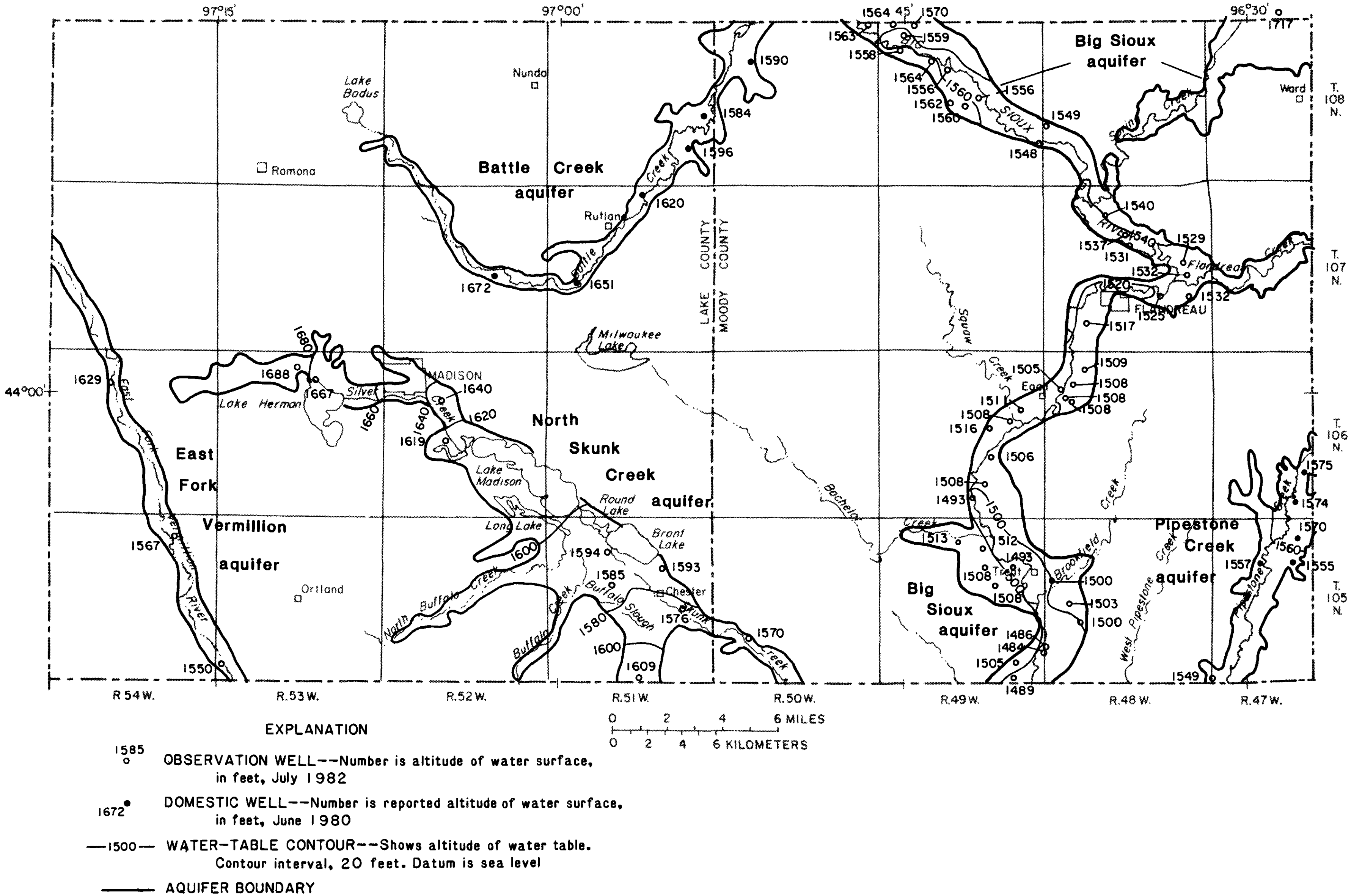


Figure 10.--Water-table surface of the East Fork Vermillion, North Skunk Creek, Battle Creek, Pipestone Creek, and Big Sioux aquifers in Lake and Moody Counties.

Discharge from the Big Sioux aquifer is from irrigation, domestic, municipal, and stock wells, evapotranspiration, and by ground-water leakage to the Big Sioux River. The average annual pumpage by irrigation and municipal wells screened in the aquifer from 1970 to 1979 was about 3,125 acre-ft. The maximum reported discharge from irrigation wells in the aquifer was about 5,200 acre-ft during the drought of 1976. Discharge from irrigation wells screened in the aquifer is as much as 800 gal/min. Records of long-term water-level fluctuations in well 106N48W5CCCC show close correlation with long-term trends in precipitation (fig. 11). The water-level rise during 1962, 1965, 1968-69, 1972, and 1977-79 was caused by above-average precipitation. The decline from 1963-64, 1966-68, 1970-71, 1973-76, and 1980-81 was caused by below-average precipitation.

Predominant chemical constituents in water from the Big Sioux aquifer are calcium, bicarbonate, and sulfate. The average concentration of dissolved calcium is 100 mg/L, the average concentration of bicarbonate is 260 mg/L, and the average concentration of dissolved sulfate is 180 mg/L. Dissolved-solids concentration ranged from 300 to 1,570 mg/L and averaged 540 mg/L. Hardness concentration calculated from laboratory analyses ranged from 240 to 600 mg/L and averaged 400 mg/L. In T. 105 N., R. 48 W., dissolved-solids and dissolved sulfate concentrations averaged 670 mg/L. Larger dissolved-solids and sulfate concentrations may be caused by uncontrolled flowing wells, screened in the Howard aquifer, that discharge on land surface and subsequently recharge the Big Sioux aquifer. A summary of chemical analyses of water from the aquifer is given in table 4. Water from the aquifer is used for municipal, irrigation, domestic, and stock purposes.

Pipestone Creek aquifer

The Pipestone aquifer (fig. 8) is composed of a medium to coarse sand and fine gravel. The aquifer is limited to the flood plain of Pipestone Creek. A geologic section of the aquifer is shown in figure 9 and hydrologic characteristics are given in table 3.

Recharge to the aquifer is by infiltration of precipitation and snowmelt on the flood plain of Pipestone Creek. The direction of water movement in the aquifer is from northeast to southwest and toward Pipestone Creek. The gradient of the potentiometric surface ranged from about 2 to 15 ft/mi (fig. 10).

Discharge from the Pipestone Creek aquifer results from evapotranspiration, withdrawal by domestic and stock wells, and seepage to Pipestone Creek. The average transmissivity of the aquifer is about 16,000 ft^2/d (Adolphson, 1983). Aquifer tests were conducted using two irrigation wells located in section 8, township 106 north, range 46 west. Subsurface outflow into Minnehaha County is about 9 acre-ft/d.

Water-level fluctuations in the aquifer are caused by seasonal changes in recharge and discharge (fig. 12). Water levels declined from July 1981 to January 1982 because discharge was greater than recharge. Water levels rose from February to June 1982 because recharge from snowmelt runoff and rainfall was greater than discharge. Water levels rose from August to November 1982 because of above-average precipitation.

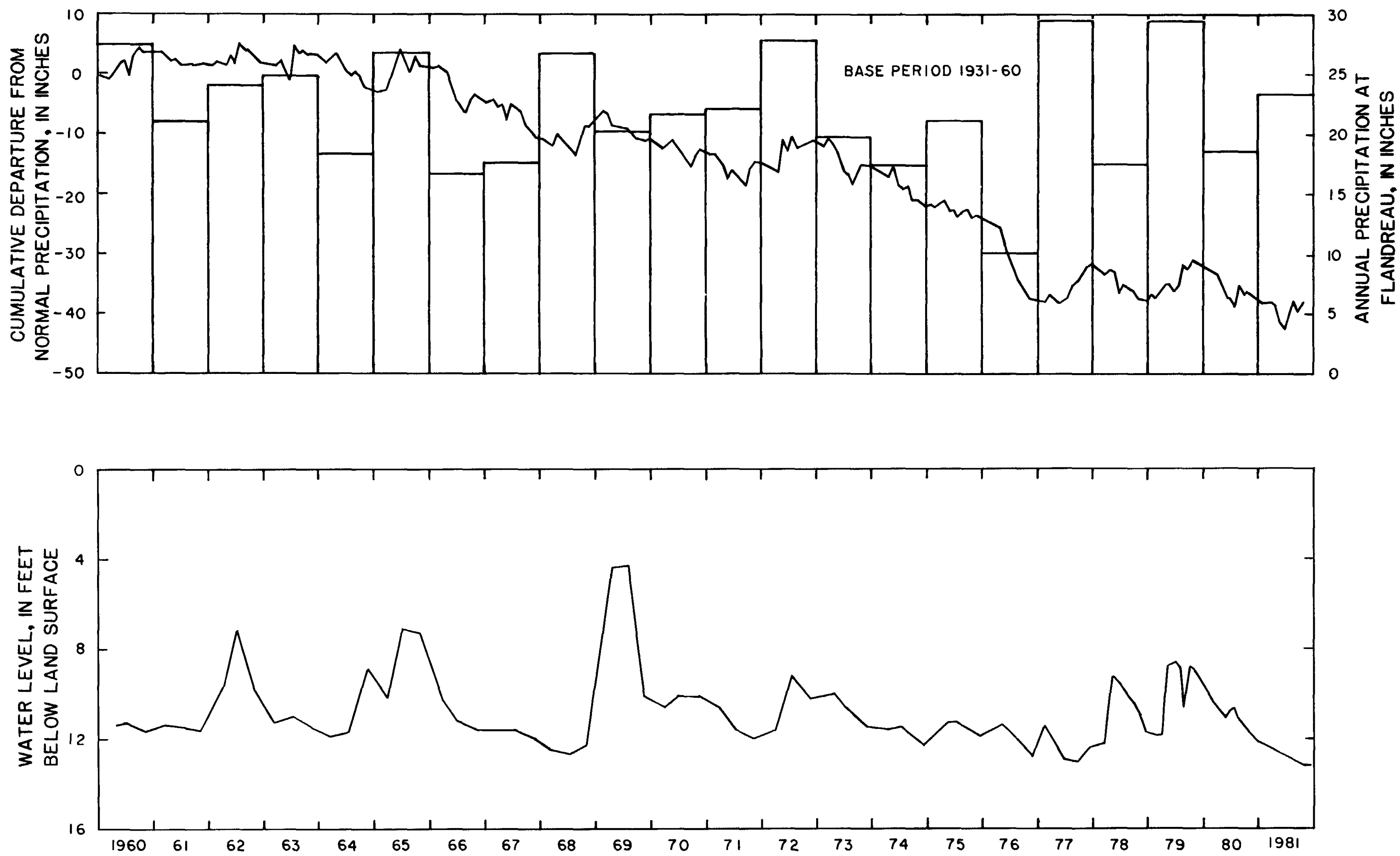


Figure 11.--Water-level fluctuations in the Big Sioux aquifer, annual precipitation, and cumulative departure from average precipitation (base period 1931-60) at Flandreau, S. Dak.

Table 4.--Summary of chemical analyses of water from the Big Sioux and Howard aquifers

[Analyses by South Dakota Geological Survey. Results in milligrams per liter except as indicated]

	Big Sioux aquifer				Howard aquifer			
	Number of samples	Mean	Minimum value	Maximum value	Number of samples	Mean	Minimum value	Maximum value
Dissolved calcium	17	100	57	200	24	260	160	350
Dissolved sodium	17	19	5	36	24	130	25	240
Dissolved magnesium	17	36	23	55	24	98	50	200
Dissolved potassium	17	3	2	5	16	15	7	28
Bicarbonate	17	260	120	350	16	380	260	510
Dissolved sulfate	17	180	45	812	24	950	500	1,600
Dissolved nitrate	17	6.3	.1	24	23	.24	.05	1.4
Dissolved chloride	17	11	2.0	40	24	14	2.0	31
Dissolved iron (micrograms per liter)	17	780	10	3,500	24	350	10	2,200
Dissolved manganese (micrograms per liter)	4	90	10	210	23	1,200	20	5,600
Dissolved fluoride	4	.3	.1	.4	23	.5	.2	1.0
Dissolved boron (micrograms per liter)	17	90	0	380	14	880	220	3,800
Dissolved solids	17	540	300	1,570	24	1,750	964	5,520
Specific conductance, field (micromhos per centimeter)	17	814	500	1,860	23	2,070	1,340	3,110
pH, field (units)	17	7.8	7.3	8.3	15	7.3	6.9	7.8
Temperature, water (degrees Celsius)	4	10.0	8.0	15.0	14	9.9	7.0	14.5

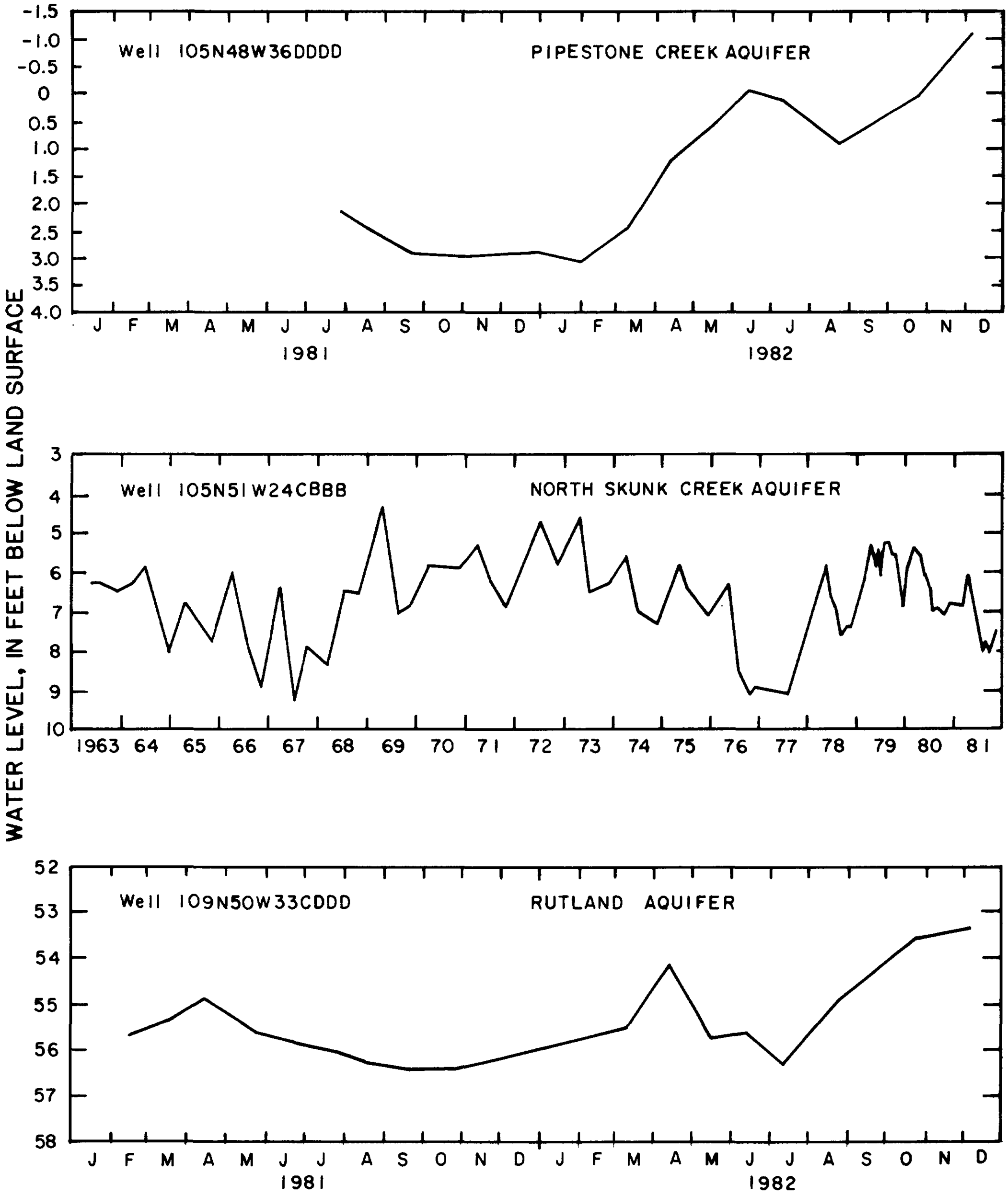


Figure 12.--Observation well hydrographs of the Pipestone Creek, North Skunk Creek, and Rutland aquifers.

Predominant chemical constituents in water from the Pipestone Creek aquifer are calcium and bicarbonate. Specific conductance, determined by onsite analyses, ranged from 550 to 2,360 µmhos/cm and averaged 1,180 µmhos/cm. Hardness concentration, determined by onsite analyses, ranged from 300 to 1,250 mg/L and averaged 600 mg/L. Laboratory analyses of water from the aquifer are given in table 5. Water from the aquifer is used primarily for domestic and stock purposes. The water is of suitable quality for irrigation based on South Dakota irrigation-water standards, revised January 1982.

North Skunk Creek aquifer

The North Skunk Creek aquifer (fig. 8) is composed of a poorly sorted, sandy gravel northwest of Lake Madison, and grades to a well sorted sand and gravel southeast of Lake Madison (Ellis and Adolphson, 1965). The aquifer is under water-table conditions in most areas, however, along the margin of the aquifer and in the south-central part of T. 105 N., R. 51 W., the aquifer is overlain by as much as 60 ft of till and is under artesian conditions. A geologic section of the aquifer is shown in figure 9 and hydrologic characteristics are given in table 3.

Recharge to the aquifer is by infiltration of precipitation and snowmelt. Water-level fluctuations in observation wells (fig. 12) and lake-level fluctuations (fig. 5) indicate that Lakes Madison, Herman, and Brant are hydraulically connected to the aquifer. Normal precipitation and snowmelt runoff during spring and early summer may cause the lake level to be higher than the water-table surface, thus the lakes may recharge the aquifer. Normal precipitation and evaporation during late summer and fall may cause the lake level to be lower than the water-table surface, thus the aquifer may discharge to the lake.

The general direction of water movement in the aquifer is to the southeast. In the south-central part of T. 105 N., R. 51 W., the direction of movement is to the north. The northward gradient may be caused by a possible recharge area located to the south, in Minnehaha County, where the aquifer is at or near land surface. The gradient of the water-table surface ranges from 4 to 20 ft/mi.

Discharge from the aquifer is: (1) By irrigation, municipal, stock, and domestic wells; (2) by evaporation directly from the water table surface where the aquifer is near land surface; (3) by transpiration; and (4) to Skunk Creek. Outflow to Minnehaha County is about 1.5 acre-ft/day. Average annual pan evaporation from Lakes Madison, Herman, and Brant is about 16,000 acre-ft.

Predominant chemical constituents in water from the North Skunk Creek aquifer are calcium and bicarbonate. Specific conductance, determined from onsite analyses, ranged from 560 to 2,060 µmhos/cm and averaged 1,250 µmhos/cm. Hardness concentration, determined by onsite analyses, ranged from 320 to 1,370 mg/L and averaged 710 mg/L. Laboratory analyses of water from the aquifer are given in table 5. Water from the aquifer is used for municipal, domestic, and stock purposes, and is suitable for irrigation based on South Dakota irrigation-water standards, revised January 1982. Withdrawal for irrigation in 1979 was 500 million gallons.

Table 5.--Chemical analyses of water from selected glacial aquifers

[Analyses by South Dakota Geological Survey Laboratory unless otherwise noted. Results in milligrams per liter except as indicated]

Location	Dissolved calcium	Dissolved sodium	Dissolved magnesium	Dissolved potassium	Bicarbonate	Dissolved sulfate	Dissolved nitrate	Dissolved chloride
				Pipestone Creek aquifer				
105N47W27BBBB	92	26	29	3	380	80	0.1	2
105N48W36DDDD	94	23	31	2	390	96	.1	2
				North Skunk Creek aquifer				
106N52W 8DAAA	220	94	98	—	--	580	.1	14
105N51W26BBBB	78	14	47	3	310	140	1.7	7
105N51W16CCDB	85	11	31	6	280	100	5.9	11
105N50W29BBBB	150	34	58	4	340	390	1.8	4
				Battle Creek aquifer				
107N51W 3AADB	107	26	68	3	230	370	6.3	10
108N50W 8CACD	180	28	59	4	310	480	1.2	13
				East Fork Vermillion aquifer				
107N55W12AB	180	48	58	4	410	490	.2	—
106N54W 9CCCC	200	51	83	9	460	550	.2	7
				Rutland aquifer				
109N50W35DDCC 1/	310	40	68	6	350	770	.1	3.0
108N50W15DDDD	300	51	84	10	450	610	17	--

1/ Analysis by U.S. Geological Survey Laboratory.

Table 5.--Chemical analyses of water from selected glacial aquifers--Continued

Location	Dissolved iron (micrograms per liter)	Dissolved manganese (micrograms per liter)	Dissolved fluoride	Dissolved boron (micrograms per liter)	Dissolved solids	Specific conductance (field) (micromhos per centimeter)	pH (field) (units)	Temperature (degrees Celsius)
Pipestone Creek aquifer								
105N47W27BBBB	350	170	0.4	220	460	700	7.5	9.0
105N48W36DDDD	380	620	.2	110	500	860	7.7	12.0
North Skunk Creek aquifer								
106N52W 8DAAA	200	400	.6	--	1,320	1,780	--	--
105N51W26BBBB	240	90	.9	250	480	700	7.2	14.5
105N51W16CCDB	100	440	.3	170	410	650	7.5	8.5
105N50W29BBBB	30	310	.2	180	850	1,180	7.4	13.0
Battle Creek aquifer								
107N51W 3AADB	20	10	1.0	180	763	1,040	7.2	10.5
108N50W 8CACD	210	450	.4	60	962	1,240	7.2	9.0
East Fork Vermillion aquifer								
107N55W12AB	200	900	.3	--	1,040	--	--	--
106N54W 9CCCC	1,000	820	.4	--	1,250	--	--	--
Rutland aquifer								
109N50W35DDCC[1/]	50	5,000	.3	500	1,430	1,850	7.2	14.0
108N50W15DDDD	10	2,300	.5	440	1,560	2,150	6.9	7.5

1/ Analysis by U.S. Geological Survey Laboratory.

Battle Creek aquifer

The Battle Creek aquifer (fig. 8) is composed of fine to medium sand with some fine gravel and is underlain by till. The aquifer is limited to the flood plain of Battle Creek. Test-drilling data and reported water-levels indicate that the aquifer is under water-table conditions. Hydrologic characteristics are given in table 3.

Recharge to the aquifer is by infiltration of precipitation and snowmelt. Reported water-levels indicate that the direction of water movement is toward Battle Creek and to the northeast. Discharge from the aquifer is: (1) from stock wells; (2) by evapotranspiration; (3) to Battle Creek; and (4) to the Big Sioux aquifer in T. 109 N., R. 50 W., Brookings County. Outflow to the Big Sioux aquifer is about 0.3 acre-ft/day.

Predominant chemical constituents in water from the aquifer are calcium, bicarbonate, and sulfate. Specific conductance, determined by onsite analyses, ranged from 610 to 2,300 µmhos/cm and averaged 1,160 µmhos/cm. Hardness concentrations, determined by onsite analyses, ranged from 440 to 1,300 mg/L and averaged 680 mg/L. Laboratory analyses of water from the aquifer are given in table 5. Water in the aquifer is used primarily for stock watering. The aquifer is not used for irrigation because wells screened in the aquifer will discharge only 1 to 3 gal/min.

East Fork Vermillion aquifer

The East Fork Vermillion aquifer (fig. 8) ranges from fine to medium sand to a well-sorted coarse sand and fine gravel. Clay layers as much as 10 ft thick are interbedded in the aquifer in T. 107 N., R. 54 W. In section 3 of T. 105 N., R. 54 W., coarse gravel and large rocks were reported. The aquifer is limited to the flood plain of the East Fork of the Vermillion River. Hydrologic characteristics of the aquifer are given in table 3.

Recharge to the aquifer is by infiltration of precipitation and snowmelt. The direction of water movement is toward the East Fork of the Vermillion River and to the southeast at a gradient of 3 to 12 ft/mi. Discharge from the aquifer is from irrigation and domestic wells and evapotranspiration. Outflow to McCook County is about 1.5 acre-ft/day.

Predominant chemical constituents in water from the aquifer are calcium, bicarbonate, and sulfate. Hardness concentration of water from two samples, table 5, was 680 and 840 mg/L. Laboratory analyses of water from the aquifer are given in table 5. Water in the aquifer is used for stock, domestic, and municipal purposes, and is suitable quality for irrigation use based on South Dakota irrigation-water standards, revised January 1982. Withdrawal for irrigation in 1979 was 55 million gallons.

Rutland and Ramona aquifers

The Rutland and Ramona aquifers (fig. 13) are composed of poorly sorted, medium to coarse sand, intermixed with fine to coarse gravel. The Rutland aquifer is 24 to 32 ft thick, and is overlain by as much as 175 ft of till. The Ramona aquifer is as much as 32 ft thick, and is overlain by as much as 240 ft of till. A geologic section of the aquifers is shown in figure 14. The extent of the Ramona aquifer is limited to Lake County and eastern Miner County (Koch and McGarvie, 1986). Both aquifers are under artesian conditions. Hydrologic characteristics are given in table 3.

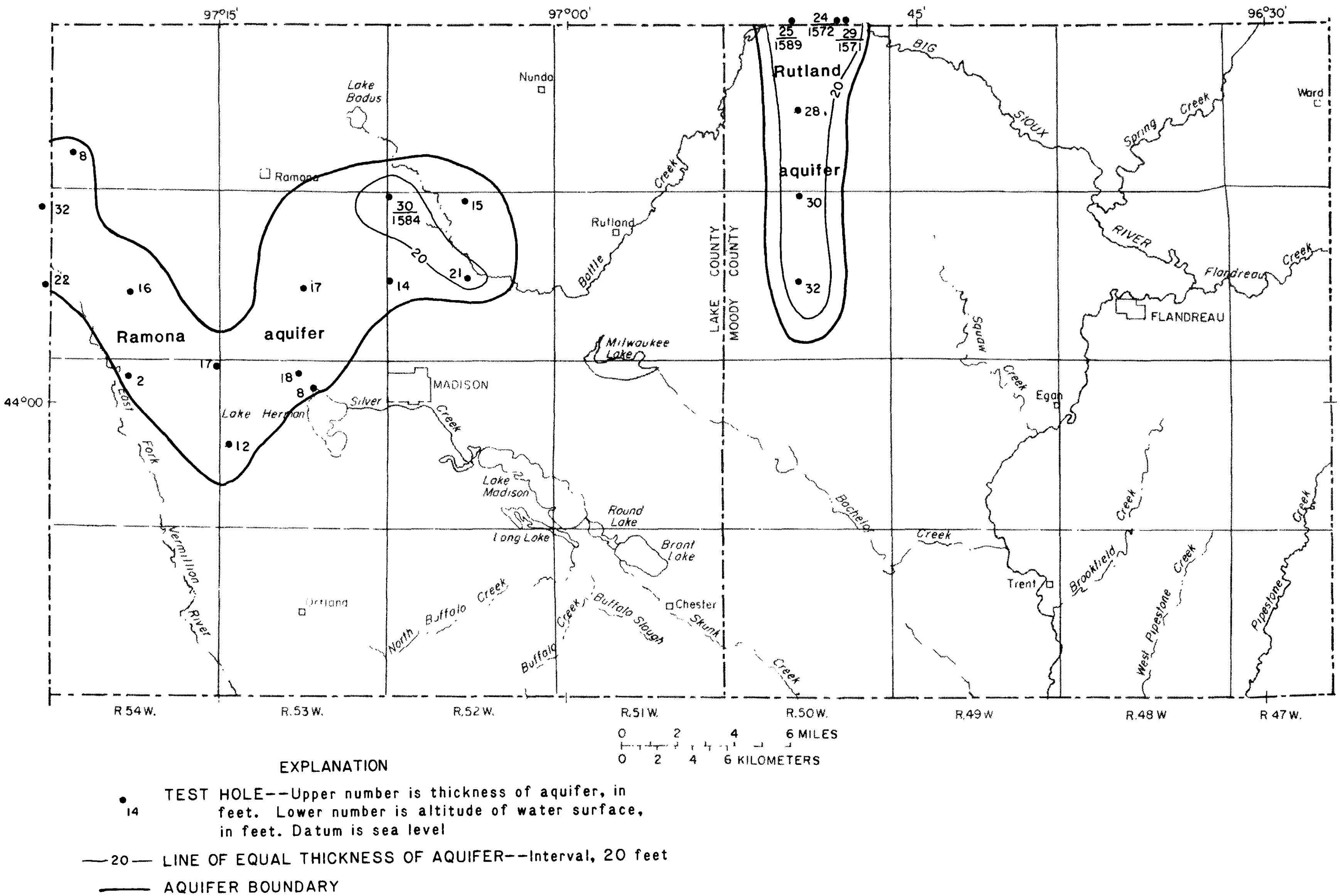


Figure 13.--Location, thickness, and water-surface altitude of the Rutland and Ramona aquifers, October 1982.

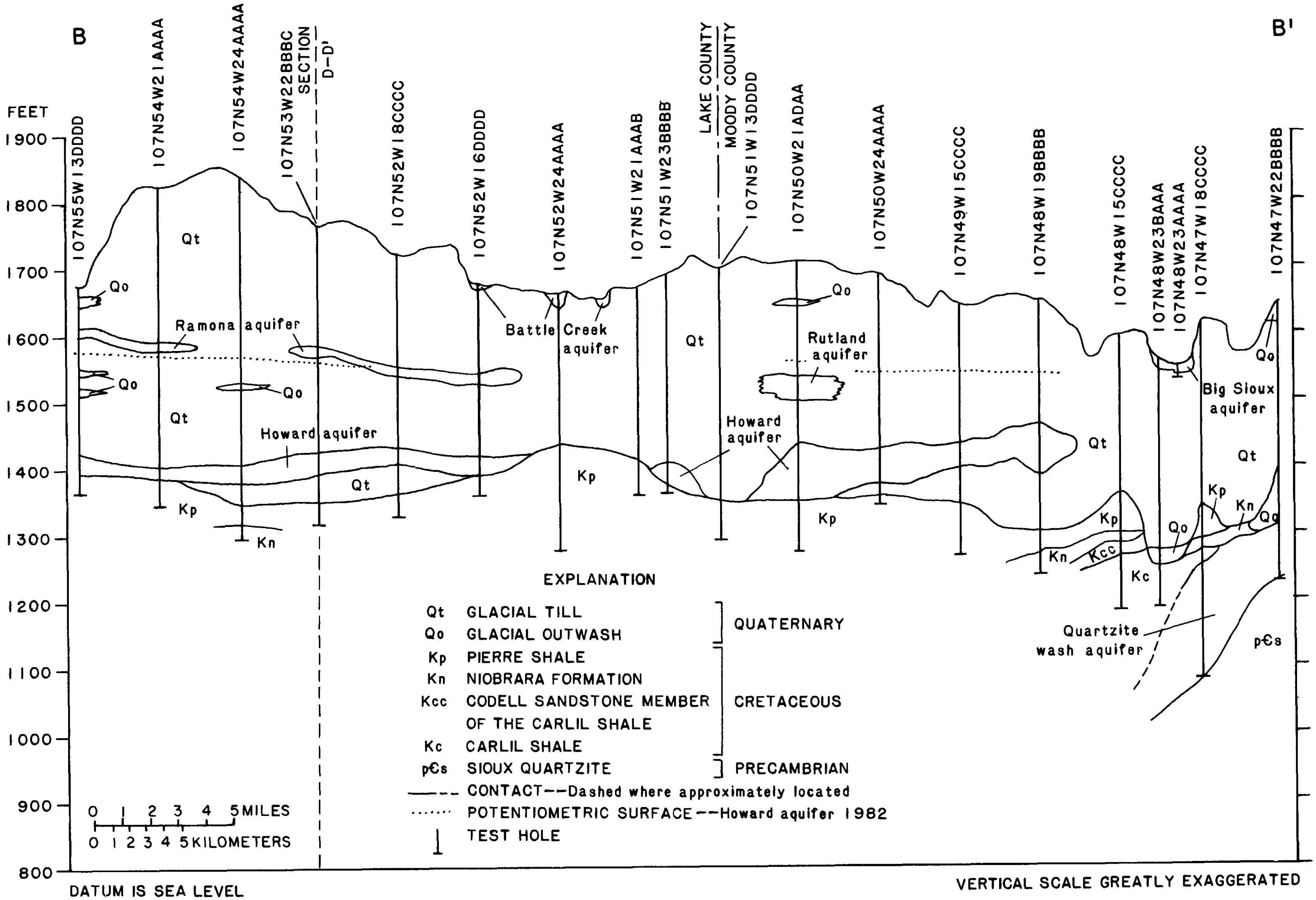


Figure 14.--Geologic section B-B' showing the Rutland and Ramona aquifers. (Section B-B' is shown in figure 2.)

Recharge to the Rutland and Ramona aquifers is by leakage from the till. Water-level fluctuations from observation wells in the Rutland aquifer (fig. 12) indicate that there are seasonal changes in recharge, however, the recharge area is probably in Brookings County (fig. 1). Water-level fluctuations from observation wells in the Ramona aquifer do not indicate seasonal changes in recharge. Discharge from the aquifers is from domestic and stock wells.

Predominant chemical constituents in water from the Rutland aquifer are calcium, sulfate, and bicarbonate. Specific conductance, determined by onsite analyses, in water from the Rutland aquifer ranged from 2,270 to 2,690 µmhos/cm and averaged 2,430 µmhos/cm. Hardness concentration, determined by onsite analyses, in water from the Rutland aquifer ranged from 1,330 to 1,900 µmhos/cm and averaged 1,500 µmhos/cm. Laboratory analyses of water from the Rutland aquifer are given in table 5. Specific conductance of water from the Ramona aquifer, determined by onsite analyses, ranged from 1,500 to 3,600 µmhos/cm and averaged 2,100 µmhos/cm. The average dissolved-solids concentration, calculated from the field specific conductance, in water from the Ramona aquifer was 1,360 mg/L. Hardness concentration of water from the Ramona aquifer, determined by onsite analyses, ranged from 620 to 2,600 mg/L and averaged 1,200 mg/L. Water from the Ramona and Rutland aquifers is used for domestic and stock purposes.

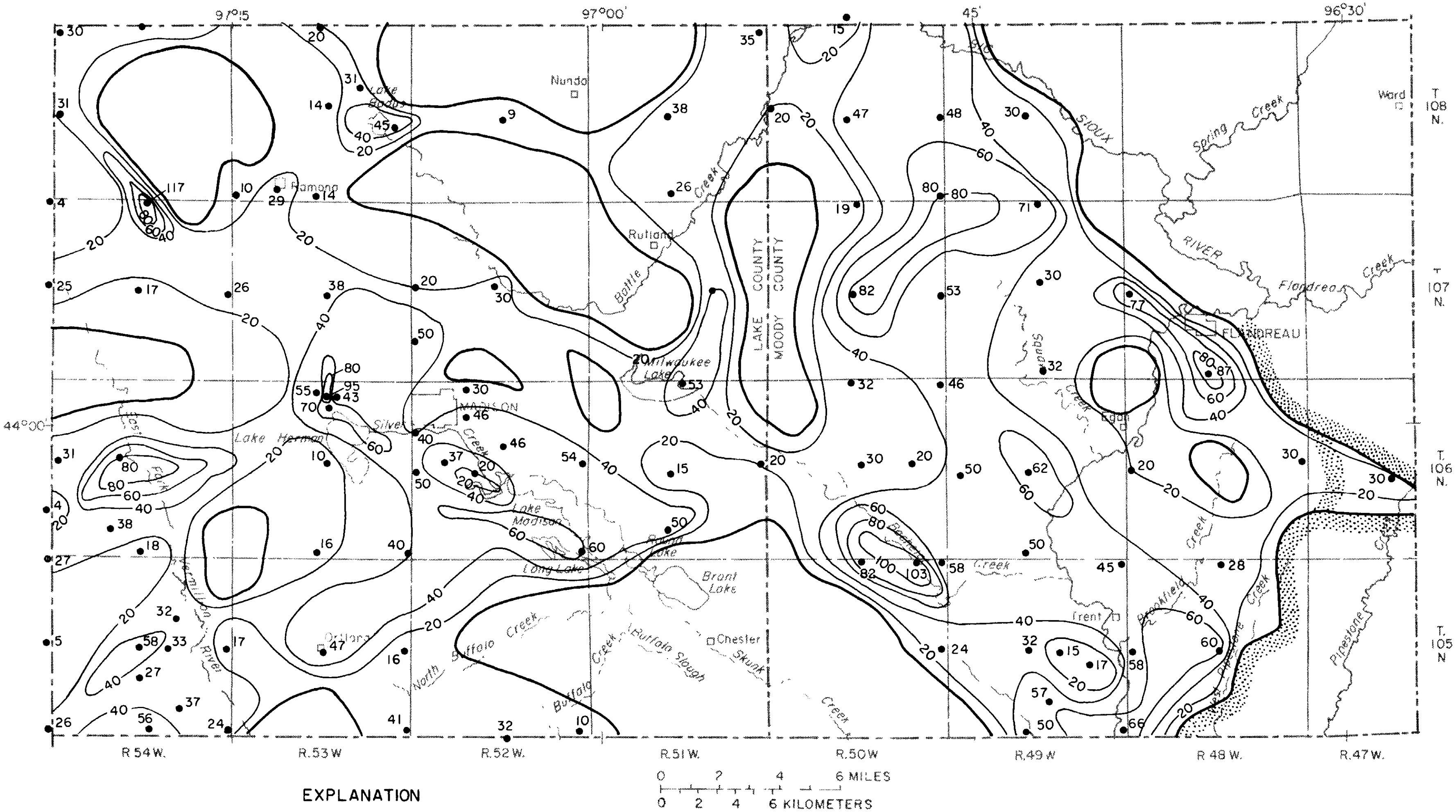
Howard aquifer

The Howard aquifer (fig. 15) ranges from a fine to medium quartzose sand in southeast Moody County to a medium to coarse sand and fine gravel in Lake and northern Moody Counties. The aquifer is composed of angular, coarse quartzose gravel in the northeast part of T. 105 N., R. 50 W. The aquifer is at about 1,400 ft above sea level and is overlain by as much as 470 ft of till. A geologic section of the aquifer is shown in figures 14 and 16. Hydrologic characteristics are given in table 3.

Recharge to the Howard aquifer in Lake and Moody Counties probably is by leakage from the till. Recharge to the aquifer by infiltration of precipitation through the till probably does not occur in Lake and Moody Counties because as much as 470 ft of till overlies the aquifer. The recharge area probably is north of the study area, in Kingsbury and Brookings Counties. Water-level fluctuations in observation wells in Lake and Moody Counties show seasonal changes in recharge and discharge. Results of test drilling suggest that the Howard aquifer and the quartzite wash aquifer may be hydraulically connected (fig. 15) in eastern Moody County.

The direction of water movement in the aquifer (fig. 17) is shown by arrows perpendicular to potentiometric contours. Movement in Lake County generally is from northwest to southeast, however, in southwest Lake County movement is southwest, into Miner and McCook Counties. The direction of water movement in Moody County is from north to south.

Discharge from the aquifer is: (1) To fractures in the Sioux Quartzite in southern Lake and Moody Counties and to the Dell Rapids quarry located 2 mi south of well 105N49W36DDDD; (2) from municipal wells, domestic wells, and uncontrolled, flowing stock wells in T. 105 N., R. 48 and 49 W.; and (3) by leakage to the underlying Niobrara aquifer in the southwest and central part of Lake County.



EXPLANATION

- TEST HOLE--Number is thickness of aquifer, in feet
- —20— LINE OF EQUAL THICKNESS OF AQUIFER--Interval, 20 feet
- AREA WHERE QUARTZITE WASH AND THE HOWARD AQUIFERS ARE HYDRAULICALLY CONNECTED
- AQUIFER BOUNDARY

Figure 15.--Extent and thickness of the Howard aquifer in Lake and Moody Counties.

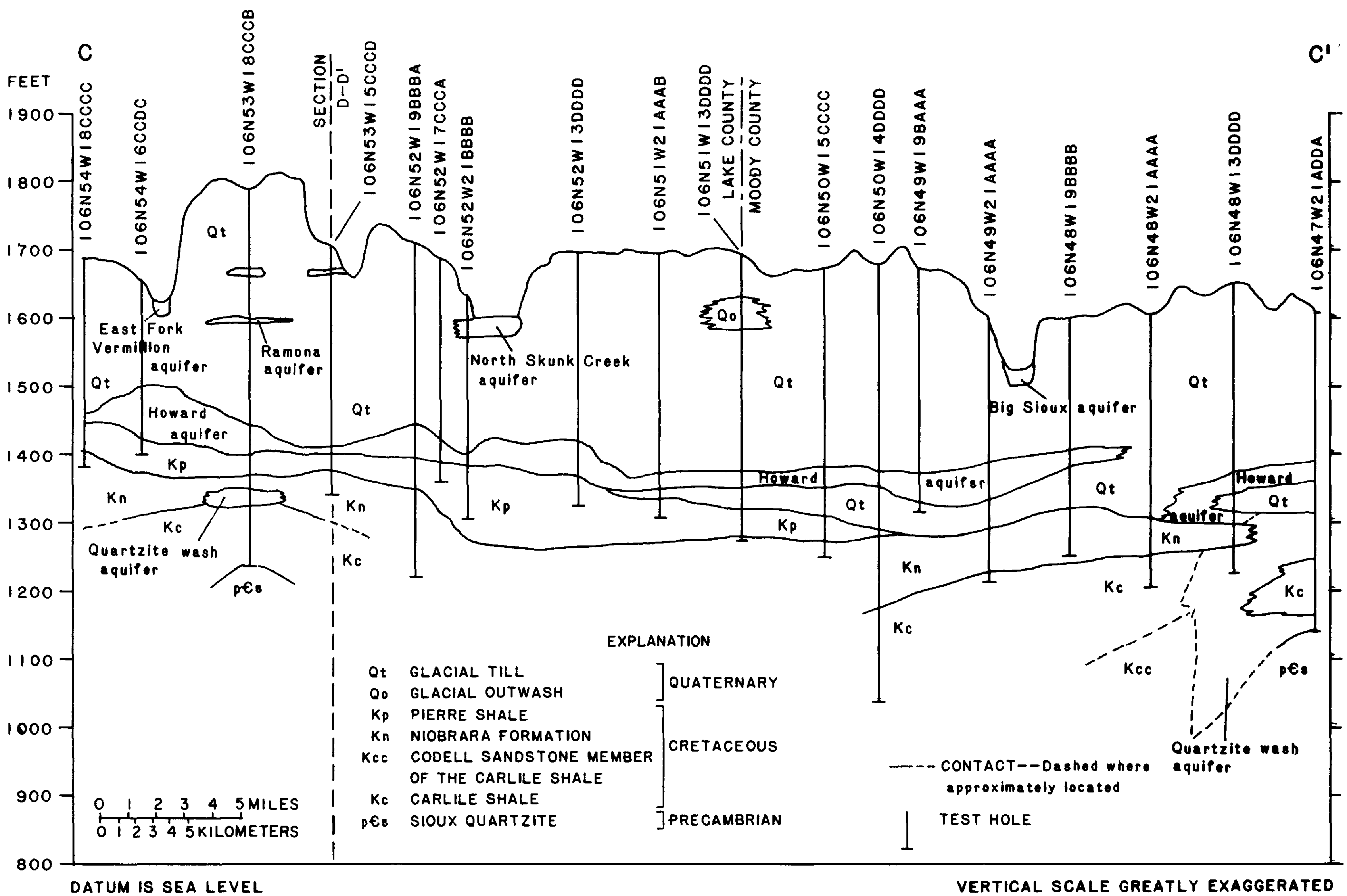
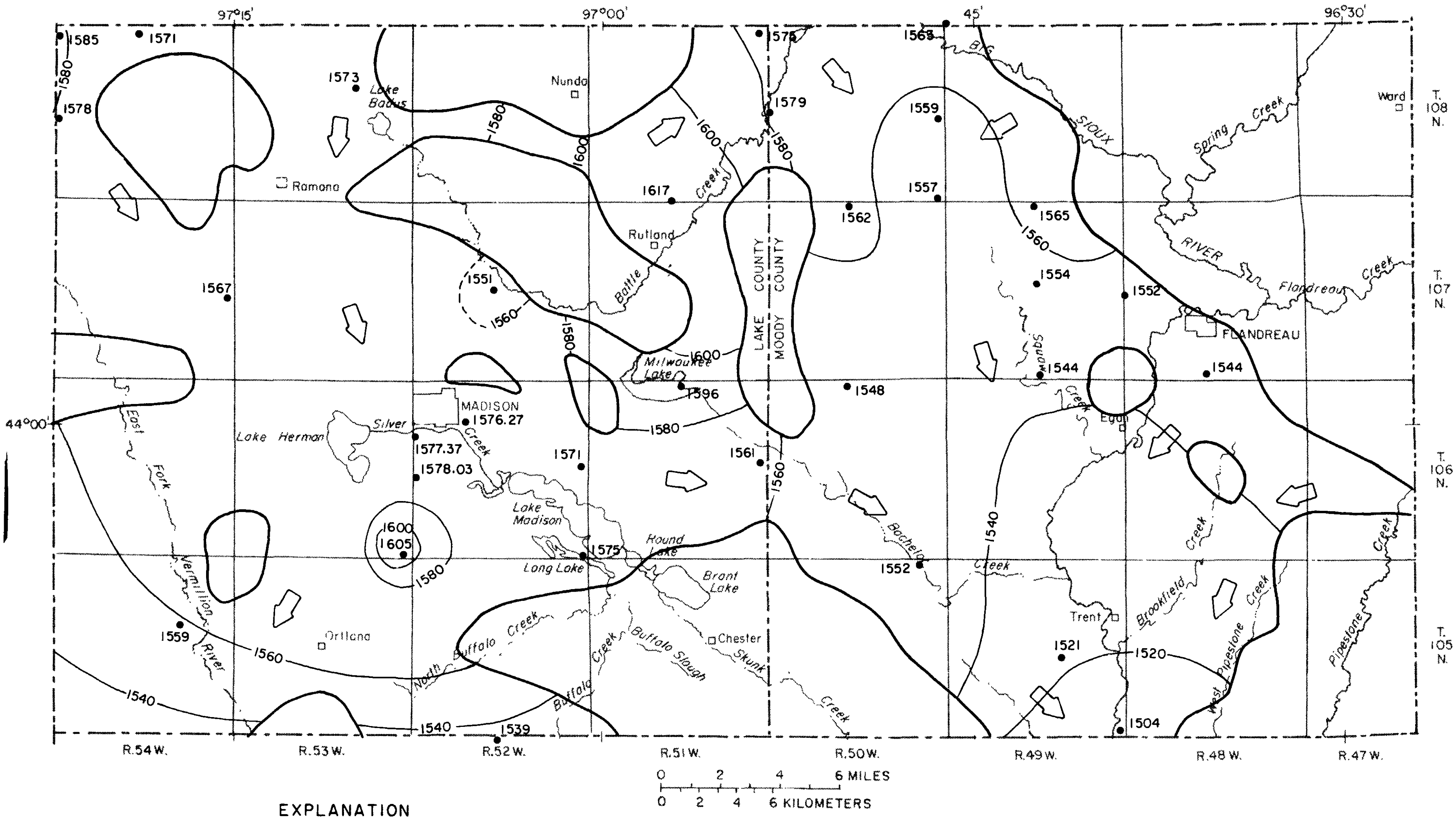


Figure 16.--Geologic section C-C' showing the Howard aquifer. (Section C-C' is shown in figure 2.)



EXPLANATION

1521 ● OBSERVATION WELL--Number is altitude of water surface, in feet. Datum is sea level

—1520-- POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 20 feet. Datum is sea level

——— AQUIFER BOUNDARY

⇨ DIRECTION OF GROUND-WATER MOVEMENT

Figure 17.--Potentiometric surface of the Howard aquifer, October 1982.

Water-level fluctuations (fig. 18) are caused by seasonal changes in recharge and discharge. Water levels in observation wells generally rose from November 1981 to June 1982 because of recharge from snowmelt and spring rainfall. Below-average precipitation from April to May 1981 caused water levels to decline about 1.5 ft. Above-average precipitation from September to December 1982 caused water levels to rise about 0.5 ft.

Predominant chemical constituents in water from the aquifer are calcium and sulfate. Dissolved-solids concentration ranged from 964 to 5,520 mg/L and averaged 1,750 mg/L. Hardness concentrations ranged from 605 to 1,697 mg/L and averaged 1,050 mg/L. Dissolved sulfate concentration ranged from 500 to 1,600 mg/L and dissolved calcium concentration ranged from 160 to 350 mg/L. Water from the aquifer in southern Moody County generally had higher dissolved-solids concentrations. Dissolved sulfate concentration ranged from 900 to 1,500 mg/L and dissolved calcium concentration ranged from 240 to 350 mg/L. A summary of the chemical analyses of water from the Howard aquifer is given in table 4.

Water from the aquifer is used for domestic, municipal, and stock purposes. The water is of suitable quality for irrigation, based on South Dakota irrigation-water standards, revised January 1982. The average concentration of chemical constituents (table 4) in water from the Howard aquifer was used to plot the datum point on the South Dakota irrigation-water classification diagram (fig. 7).

Bedrock Aquifers

The bedrock aquifers in Lake and Moody Counties, in order of increasing age, are the Niobrara, Codell, and Dakota aquifers (fig. 19). These aquifers are absent in southeast Lake County and in the southern, eastern, and the northeast quarter of Moody County, where they pinch out against the Precambrian Sioux Quartzite. All of the bedrock aquifers are under artesian conditions.

During pre-Cretaceous time, the Sioux Quartzite was a topographic high and subject to erosion. Valleys as much as 600 ft were incised in the quartzite in southern Lake and Moody Counties. At the same time, either wave action or streams reworked sediment from the weathered quartzite and deposited coarse quartzose sand in the valleys and throughout the Cretaceous sediments. The quartzose sand was named the Sioux Quartzite wash aquifer (Hansen, 1983) in Hanson and Miner Counties and is referred to as the quartzite wash aquifer in this report. The aquifer is interbeded in the Cretaceous bedrock in southern Lake and eastern Moody Counties, thus, the age of the aquifer is pre-Cretaceous or Cretaceous, depending on the area.

Niobrara aquifer

The Niobrara aquifer in the Upper Cretaceous Niobrara Formation (fig. 20) is a fractured, dark gray to white, calcareous chalk that contains numerous solution cavities. Fractures in the Niobrara have developed enough in the southwest quarter of Lake County to provide sufficient water for stock and domestic wells. Local fractures and solution zones may be present in the aquifer in other parts of the county. The Niobrara aquifer is in hydraulic connection with the quartzite wash aquifer in eastern and northern Moody County (fig. 16). Hydrologic characteristics of the aquifer are given in table 3.

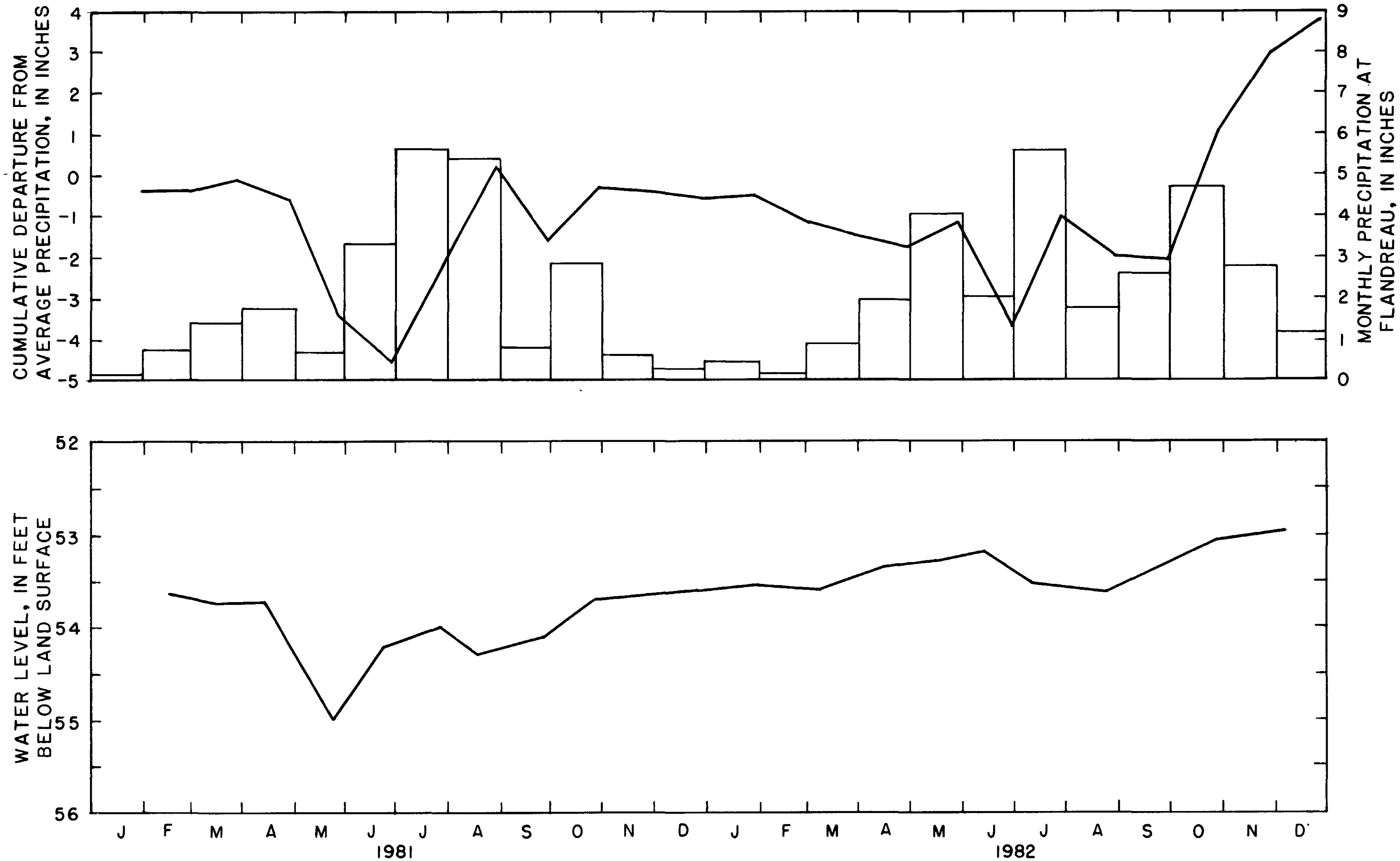


Figure 18.--Water-level fluctuations in the Howard aquifer, monthly precipitation, and cumulative departure from average precipitation at Flandreau, S. Dak.

System	Series	Geologic unit	Thickness (feet)	Water-bearing unit	Description
Quaternary	Pleistocene and Holocene	Alluvium and glacial drift	15 to 535	Buried outwash deposits (sand and gravel)	Clay, yellowish-brown, silty; contains sand and gravel; sand and gravel may occur in large concentrations.
Cretaceous	Cretaceous	Pierre Shale	0 to 265		Shale, dark-gray to black; may contain bentonite or marl.
		Niobrara Formation	0 to 120	Solution fractures in Niobrara Formation	Chalky marl, light-brown to gray; contains some pyrite, gypsum, and shell fragments.
		Quartzite wash	0 to 40	Quartzite wash	Quartzite sand, pink to light-brown, well rounded, coarse, well sorted. Probably derived from the Precambrian Sioux Quartzite.
		Codell Sandstone Member	0 to 100	Codell Sandstone	Sandstone, yellow, fine-grained; contains gray-brown silts, shale, and some pyrite.
		Carlile Shale	0 to 130	Sand lenses	Shale, gray-brown to black, greasy; contains some pyrite; locally sandy.
		Greenhorn Limestone	0 to 30	Greenhorn Limestone	Limestone and calcareous shale, light-gray, fossiliferous.
		Graneros Shale	0 to 135		Shale, gray, silty; some concretion zones.
	Lower Cretaceous	Dakota Formation	0 to 400	Dakota sands	Sandstone, light-brown to gray, fine to coarse-grained; interbedded with carboante and gray shale.
Precambrian		Sioux Quartzite	0 to 105	Quartzite wash	Quartzite sand, pink to light-brown, subrounded; highly weathered. Material overlying the Sioux Quartzite.
			0 to ?	Joints in Sioux Quartzite	Quartzite sand, well cemented, massive, well fractured and jointed.
		Igneous and metamorphic	0 to ?		Granites, andesites, rhyolites, shists.

Figure 19.--Generalized stratigraphic column for Lake and Moody Counties.

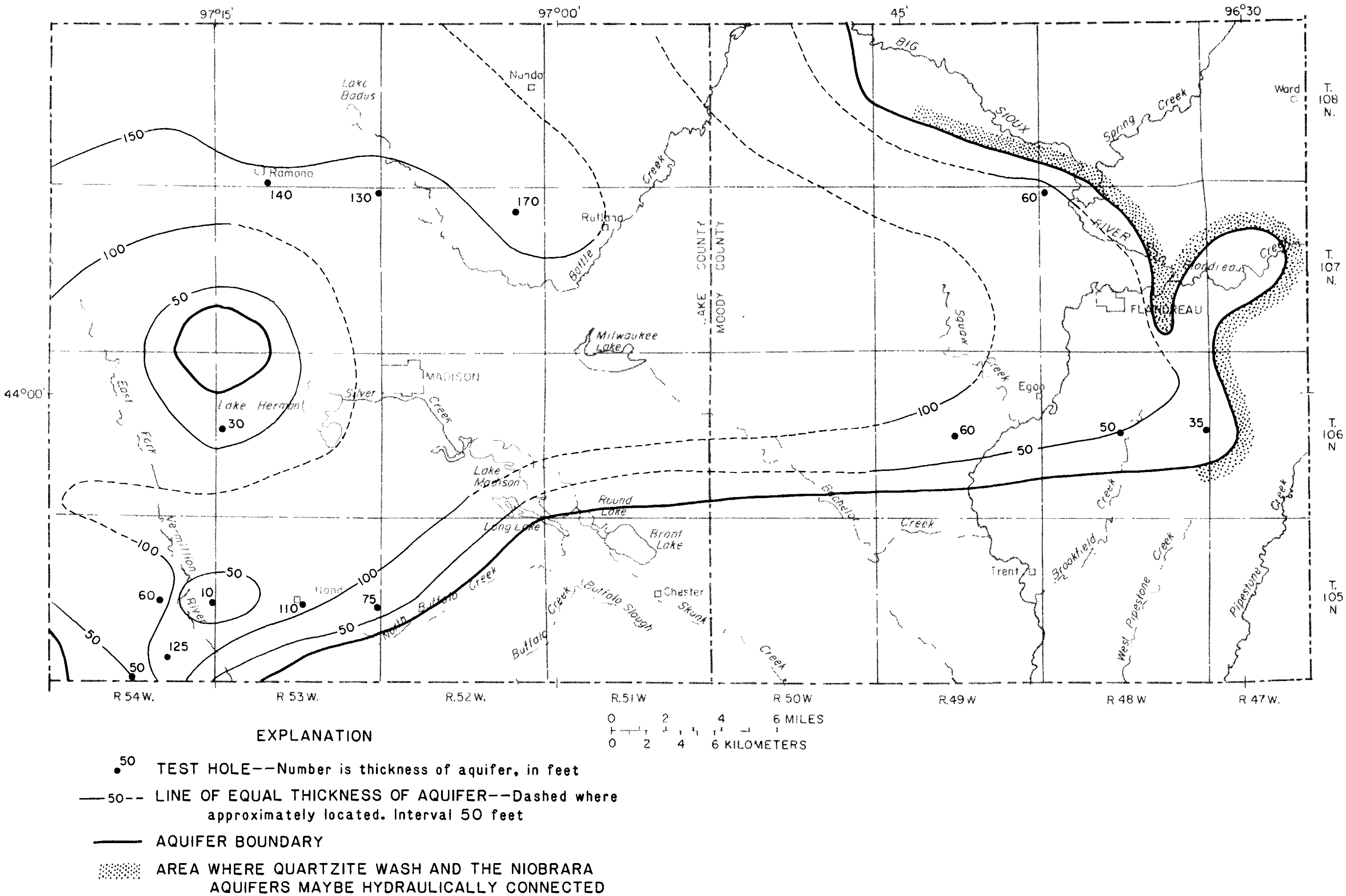


Figure 20.--Extent and thickness of the Niobrara aquifer.

Recharge to the Niobrara aquifer is by leakage from the overlying Howard aquifer in southwest and central Lake County and by leakage from the overlying till. Water-level fluctuations in observation well 105N55W13DDDD did not show seasonal changes in recharge and discharge.

The direction of water movement in the aquifer (fig. 21) is to the southwest at a gradient of about 2 ft/mi. Three observation wells in western Lake County indicate that the direction of water movement and the gradient of the potentiometric surface are similar to the direction of water movement and the gradient of the potentiometric surface in Miner County (Koch and McGarvie, 1986). Since the Niobrara and quartzite wash aquifers are hydraulically connected in eastern Moody County, the 1,540 and 1,560 potentiometric contours for the Niobrara aquifer (fig. 20) were approximately located by extrapolating potentiometric contours from the quartzite wash aquifer.

Discharge from the aquifer is from stock and domestic wells. Water from the aquifer is not extensively used because of the availability of water from shallow glacial aquifers and rural water systems. The regional discharge area for the Niobrara aquifer is probably the James River (Koch and McGarvie, 1986).

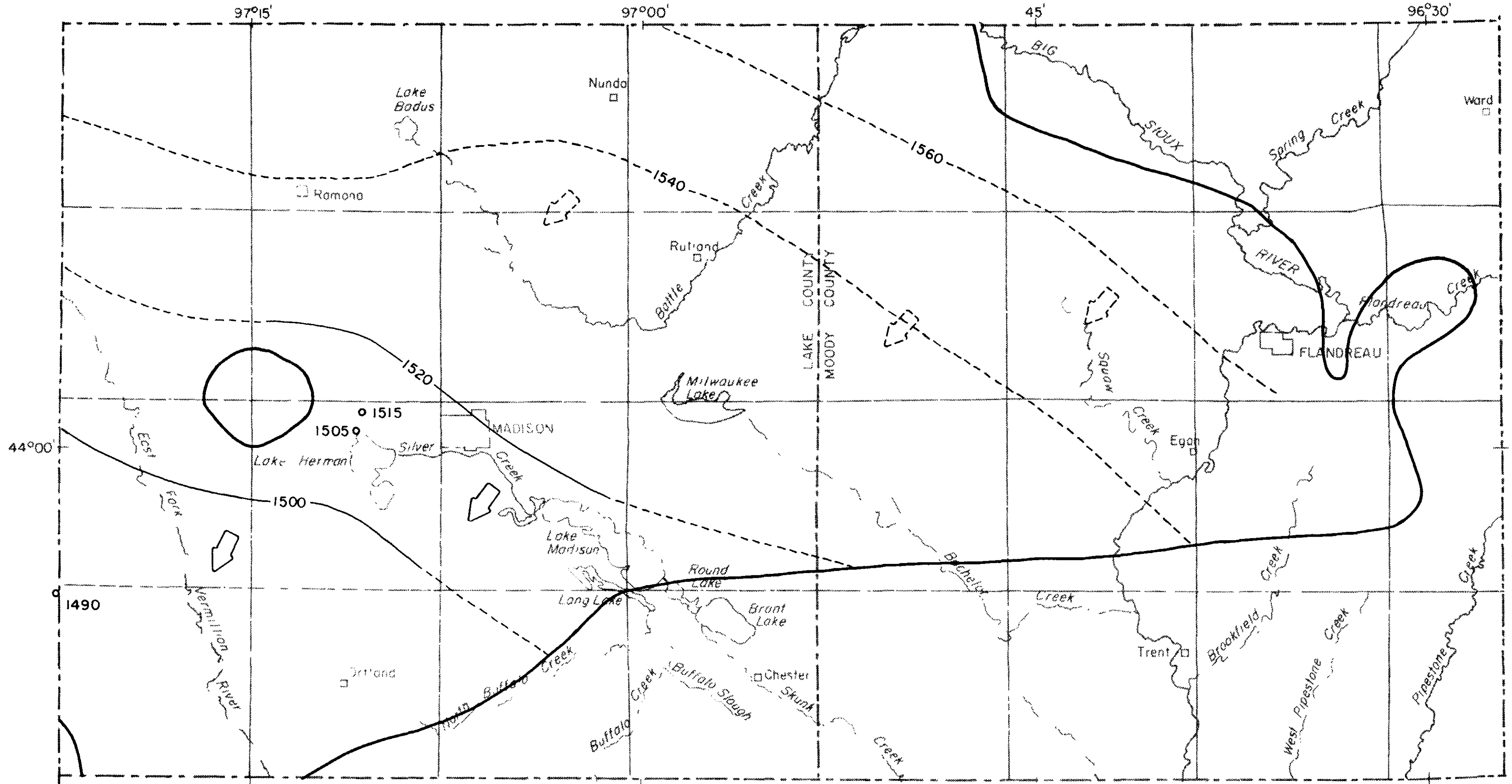
Predominant chemical constituents in water from the aquifer, sampled from observation well 105N55W1AAAA (table 6), are calcium, sodium, and sulfate.

Codell aquifer

The Codell aquifer in the Upper Cretaceous Codell Sandstone Member of the Carlile Shale (fig. 22) is composed of a white to yellow-brown, well-sorted, medium sandstone. The aquifer is the primary source of water for municipal, domestic, and stock use in northwestern Lake County. The aquifer is about 800 ft below land surface in northern Lake County and about 600 ft below land surface in southern Lake County (fig. 23). The aquifer pinches out against the Sioux Quartzite in southern Lake County. Hydrologic characteristics of the aquifer are given in table 3.

Test-drilling data in eastern Moody County indicates that the Codell aquifer may be hydraulically connected to the quartzite wash aquifer (fig. 16). Specific conductance and hardness concentration (fig. 24) of water from the Codell aquifer, determined by onsite analyses, indicates recharge from the quartzite wash aquifer. Recharge to the Codell aquifer also may occur by leakage from the underlying Dakota aquifer (Schoon, 1971). The direction of water movement in the Codell aquifer is to the southwest at a gradient of about 4 ft/mi (fig. 22). Discharge from the aquifer is primarily by municipal, domestic, and stock wells.

Predominant chemical constituents in water from the Codell aquifer are sodium and sulfate. Specific conductance and hardness concentration, determined by onsite analyses, are shown in figure 24. Northwest of the dashed line in Lake County (fig. 24), specific conductance ranged from 2,250 to 3,870 µmhos/cm and averaged 2,800 µmhos/cm. Hardness concentration ranged from 120 to 325 mg/L and averaged 210 mg/L. Southeast of the dashed line in Lake County, specific conductance ranged from 1,660 to 3,250 µmhos/cm and averaged 2,600 µmhos/cm. Hardness concentration ranged from 460 to 1,440 mg/L and averaged 820 mg/L. The average dissolved-solids concentration of water from the aquifer was 1,970 mg/L.



EXPLANATION

1505 o — OBSERVATION WELL--Number is altitude of water surface, in feet. Datum is sea level

——1500-- — POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 20 feet. Datum is sea level

——— — AQUIFER BOUNDARY

DIRECTION OF GROUND-WATER MOVEMENT--Dashed where approximately located

Figure 21.--Potentiometric surface of the Niobrara aquifer, October 1982.

Table 6.--Chemical analyses of water from bedrock aquifers

[Analyses by South Dakota Geological Survey Laboratory unless otherwise noted. Results in milligrams per liter except as indicated]

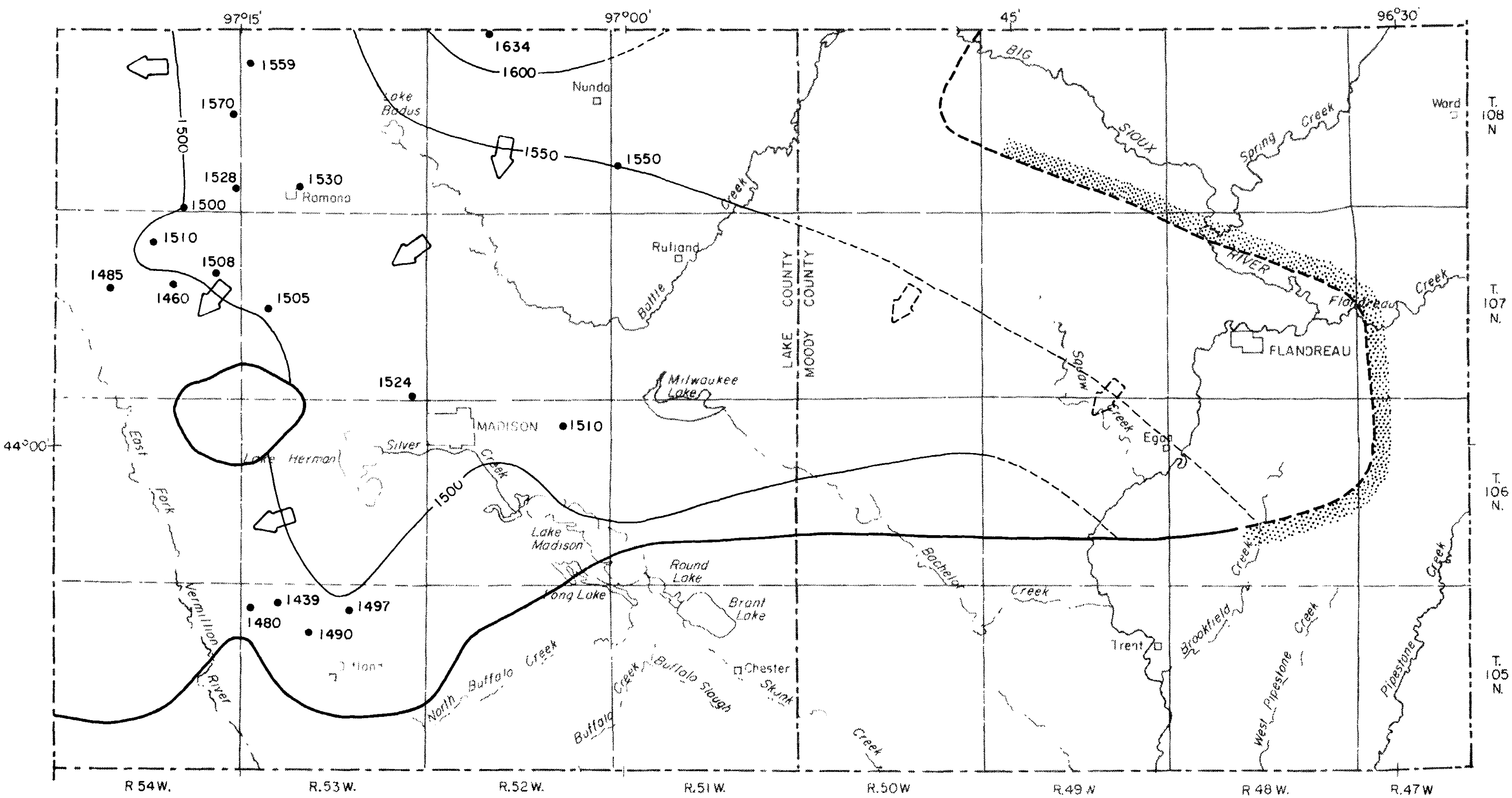
Location	Dissolved calcium	Dissolved sodium	Dissolved magnesium	Dissolved potassium	Bicarbonate	Dissolved sulfate	Dissolved nitrate	Dissolved chloride
Niobrara aquifer								
105N55W 1AAAA	210	200	79	18	400	950	1.6	7.0
Codell aquifer								
106N52W 2CDDC	150	450	44	--	--	1,100	.01	40
108N53W19DDAA	26	590	9.4	15	500	770	1.6	160
108N54W35CCAC	23	600	8.1	10	490	780	.05	130
108N53W32C	39	590	79	26	480	910	.20	96
108N52W13A	180	430	61	26	420	1,300	.10	36
Dakota aquifer								
106N52W 2CDDD	59	610	39	--	--	1,200	.10	43
Quartzite wash aquifer								
105N53W 9DAAA	210	120	70	21	310	780	.1	4
105N48W23BCBB	240	150	92	11	350	930	.1	35
105N54W27BABB	200	170	69	15	400	850	.5	23
105N47W 5CADD	200	120	89	9	250	880	.1	17
106N47W 4DDDA	140	97	94	6	230	720	.1	14
105N48W36DDDD	150	170	58	14	330	630	.1	50
108N49W21AAAA	240	110	120	11	440	940	.1	12
107N48W 1AAAA 1/	190	48	78	7	370	570	.1	4
105N54W 5CCCB	190	120	56	9	420	600	.5	4
105N47W 7DADA	210	43	74	8	410	590	.1	4

1/ Analysis by U.S. Geological Survey Laboratory.
2/ The average dissolved-solids concentration in water from the bedrock aquifers was 1,650 milligrams per liter.

Table 6.--Chemical analyses of water from bedrock aquifers--Continued

Location	Dissolved iron (micrograms per liter)	Dissolved manganese (micrograms per liter)	Dissolved fluoride	Dissolved boron (micrograms per liter)	Dissolved solids 2/	Specific conductance (field) (micromhos per centimeter)	pH (field) (units)	Temperature (degrees Celsius)
				Niobrara aquifer				
105N55W 1AAAA	520	--	--	920	1,840	2,750	--	--
				Codell aquifer				
106N52W 2CDDC	5,200	70	1.2	--	2,010	2,690	--	--
108N53W19DDAA	10	30	1.9	420	1,860	2,930	8.0	7.0
108N54W35CCAC	2,300	250	1.8	450	1,820	2,720	7.9	9.5
108N53W32C	400	20	1.7	--	1,860	--	7.8	--
108N52W13A	1,600	70	1.1	--	2,290	--	--	--
				Dakota aquifer				
106N52W 2CDDD	4,800	330	.3	--	2,210	3,026	--	--
				Quartzite wash aquifer				
105N53W 9DAAA	80	270	.1	930	1,440	1,720	7.5	10.5
105N48W23BCBB	1,700	460	.4	480	1,690	2,030	7.0	11.5
105N54W27BABB	110	1,800	1.2	1,200	1,580	2,030	7.0	7.5
105N47W 5CADD	6,200	520	.4	380	1,540	1,850	7.1	8.0
106N47W 4DDDA	3,800	990	.4	260	1,300	1,680	7.2	8.0
105N48W36DDDD	630	380	.9	710	1,250	1,800	7.5	13.5
108N49W21AAAA	1,600	1,600	.5	730	1,730	2,200	7.0	14.5
107N48W 1AAAA 1/	50	1,500	.6	410	1,200	1,500	8.5	10.0
105N54W 5CCCB	1,900	490	.3	660	1,270	1,530	7.3	11.5
105N47W 7DADA	950	120	.4	290	1,240	1,620	7.3	5.5

1/ Analysis by U.S. Geological Survey Laboratory.
2/ The average dissolved-solids concentration in water from the bedrock aquifers was 1,650 milligrams per liter.



EXPLANATION

1485 ● DOMESTIC WELL--Number is reported altitude of water surface, in feet. Datum is sea level

---1500--- POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 50 feet. Datum is sea level

AQUIFER BOUNDARY--Dashed where approximately located

DIRECTION OF GROUND-WATER MOVEMENT--Dashed where approximately located

AREA WHERE QUARTZITE WASH AND THE CODELL AQUIFERS ARE HYDRAULICALLY CONNECTED

Figure 22.--Extent and potentiometric surface of the Codell aquifer, June 1980.

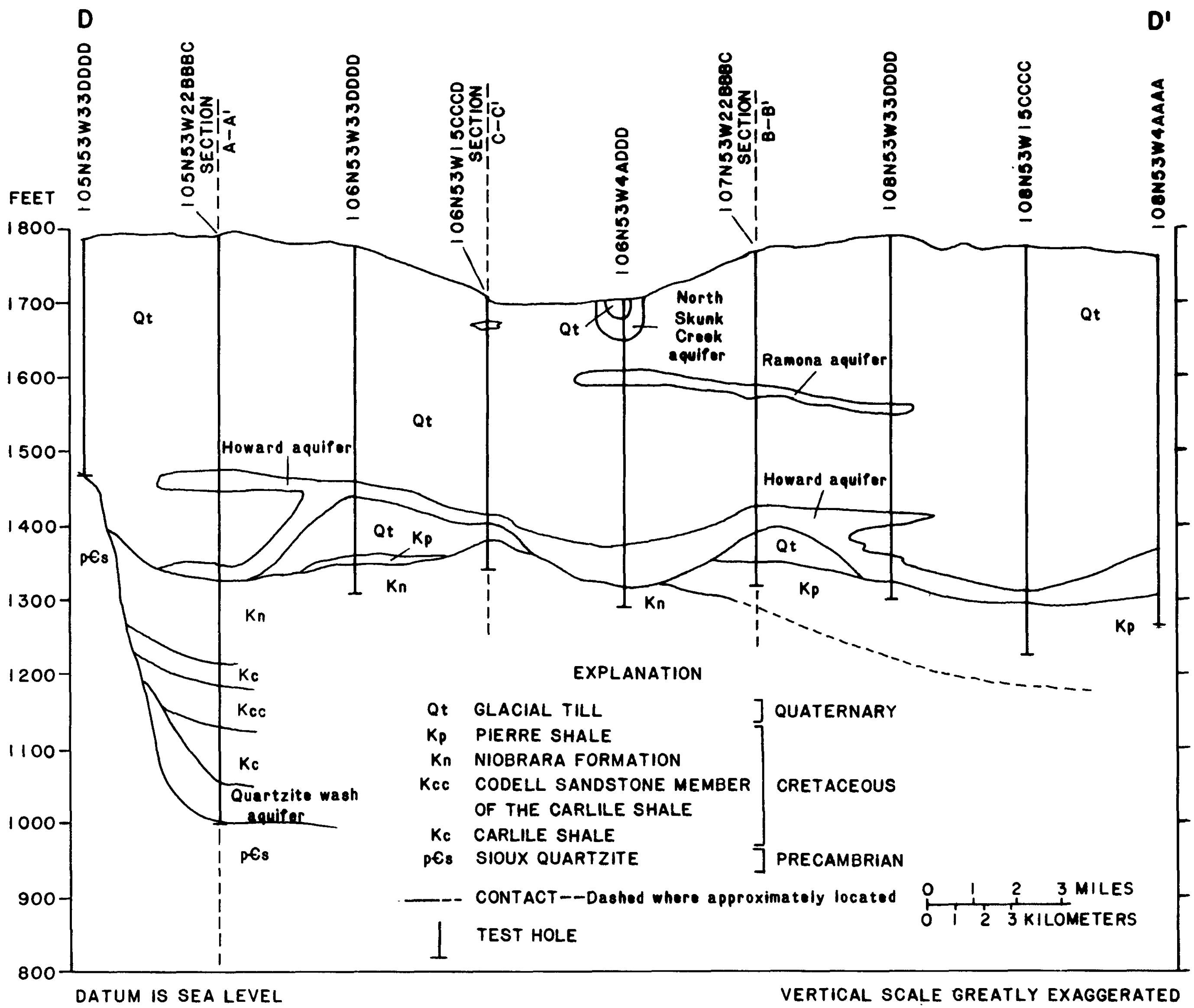
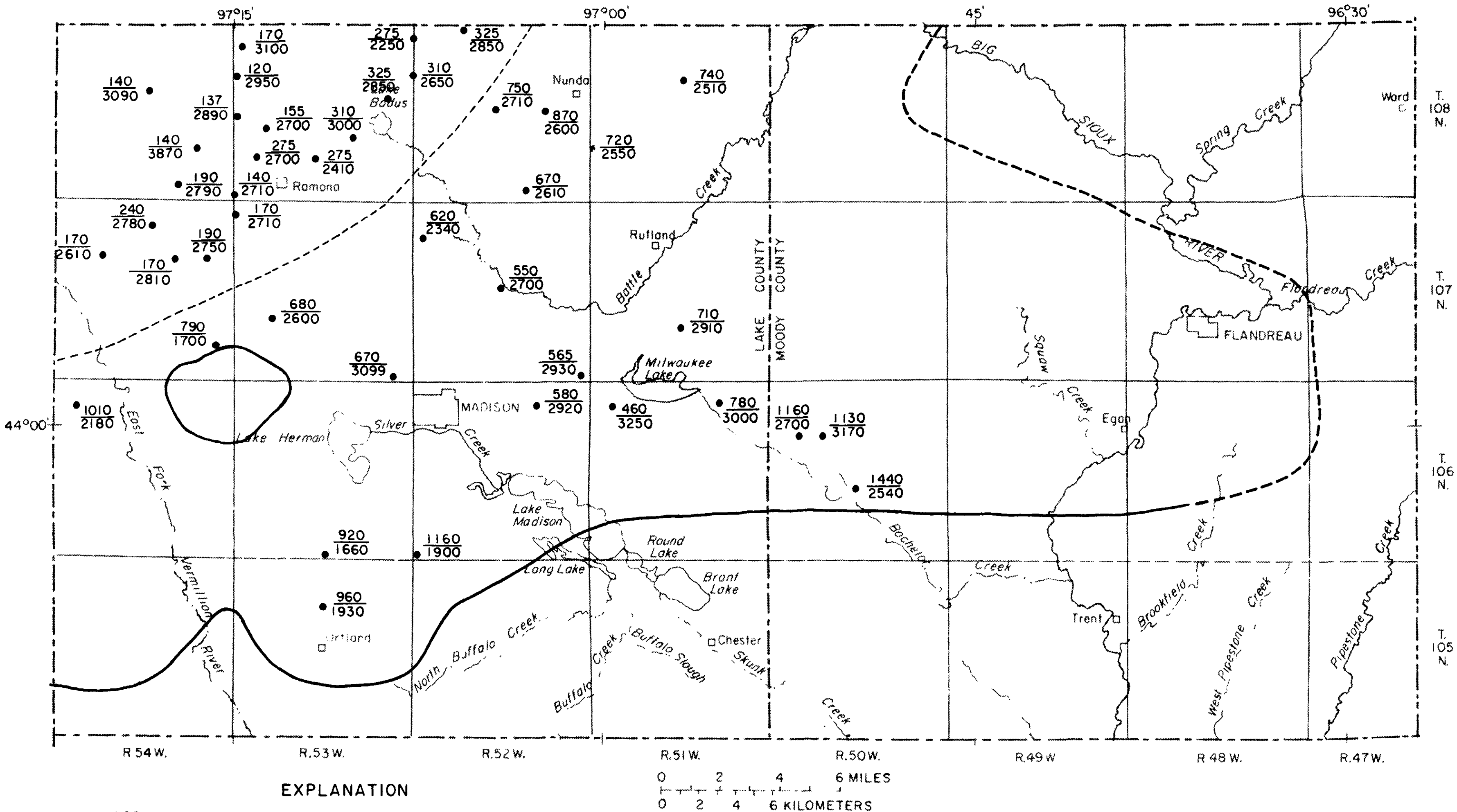


Figure 23.--Geologic section D-D' showing the Codell aquifer. (Section D-D' is shown in figure 2.)



EXPLANATION

- • $\frac{960}{1930}$ DOMESTIC WELL--Upper number is hardness concentration in mg/L. Lower number is specific conductance in mhos/cm
- AQUIFER BOUNDARY--Dashed where approximately located
- APPROXIMATE NORTHWEST EXTENT OF MIXING OF WATER FROM THE SIOUX QUARTZITE WASH AQUIFER AND THE CODELL AQUIFER

Figure 24.--Specific conductance and hardness concentration of water from the Codell aquifer, June 1980, determined by onsite analyses.

Chemical analyses of water from the Codell and quartzite wash aquifers (table 6) indicate that water from the quartzite wash aquifer is mixing with water from the Codell aquifer. Predominant chemical constituents in water from the quartzite wash aquifer are calcium and sulfate. The mixed water is predominantly calcium, sodium, and sulfate. The percentage reacting values of the major chemical constituents in water from the Codell and quartzite wash aquifers are shown in figure 25.

Dakota aquifer

The Dakota aquifer in the Cretaceous Dakota Formation is composed of a fine-grained, gray to brown sandstone that contains interbedded shale layers. The top of the aquifer is reported to be 800 to 1,000 ft below land surface. Data are available from only one test hole, one domestic well (106N52W2CDDD), and the Madison city well, thus, the aquifer extent (fig. 26) was determined from test holes that were drilled to Precambrian in which the Dakota aquifer was missing.

A reported water level of 1,500 ft above sea level in well 106N52W2CDDD and reported water levels in eastern Miner County of about 1,475 ft above sea level (Koch and McGarvie, 1986) indicate that the direction of water movement is to the west. Discharge from the aquifer is from domestic and stock wells and from uncontrolled flowing wells located in the James Basin (fig. 1) (Koch and McGarvie, 1986; Schoon, 1971). Predominant chemical constituents in water from the aquifer are sodium and sulfate (table 6). The city of Madison has discontinued use of the well completed in the Dakota aquifer.

Quartzite wash aquifer

The quartzite wash aquifer (fig. 27) is composed of an uncemented, coarse, well-rounded, well-sorted, pink, quartzose sand. The aquifer overlies the Sioux Quartzite at most locations, however, the aquifer is interbedded in the Cretaceous bedrock (figs. 9, 14 and 16) in eastern Moody County and western Lake County. Deposition of the quartzite wash aquifer probably occurred during pre-Cretaceous and Cretaceous time. The western boundary of the aquifer in Moody County and the northern boundary of the aquifer in Lake County were approximated because test holes did not penetrate the entire thickness of the Cretaceous sedimentary rocks.

Recharge to the aquifer occurs at the Sioux Quartzite outcrop area 3 mi east of the South Dakota-Minnesota state line. Water movement occurs through fractures in the Sioux Quartzite to the quartzite wash aquifer. Local quarries show extensive horizontal and vertical fractures in the quartzite. The quartzite wash aquifer in southeastern Lake County is probably in hydraulic connection to the quartzite wash aquifer in southern Moody County by the fractures in the quartzite (fig. 9).

The direction of water movement in the aquifer (fig. 28) is to the southwest at a gradient of about 4 ft/mi. Gradients as great as 12 ft/mi occur near the quarry at Dell Rapids, located 6 mi south of Trent, South Dakota. Discharge from the aquifer is: (1) To the Dell Rapids Quarry; (2) to stock and domestic wells; and (3) to the Codell aquifer. Water-level fluctuations in observation wells screened in the aquifer for 1982 did not indicate a definite trend or correlation with seasonal changes in recharge.

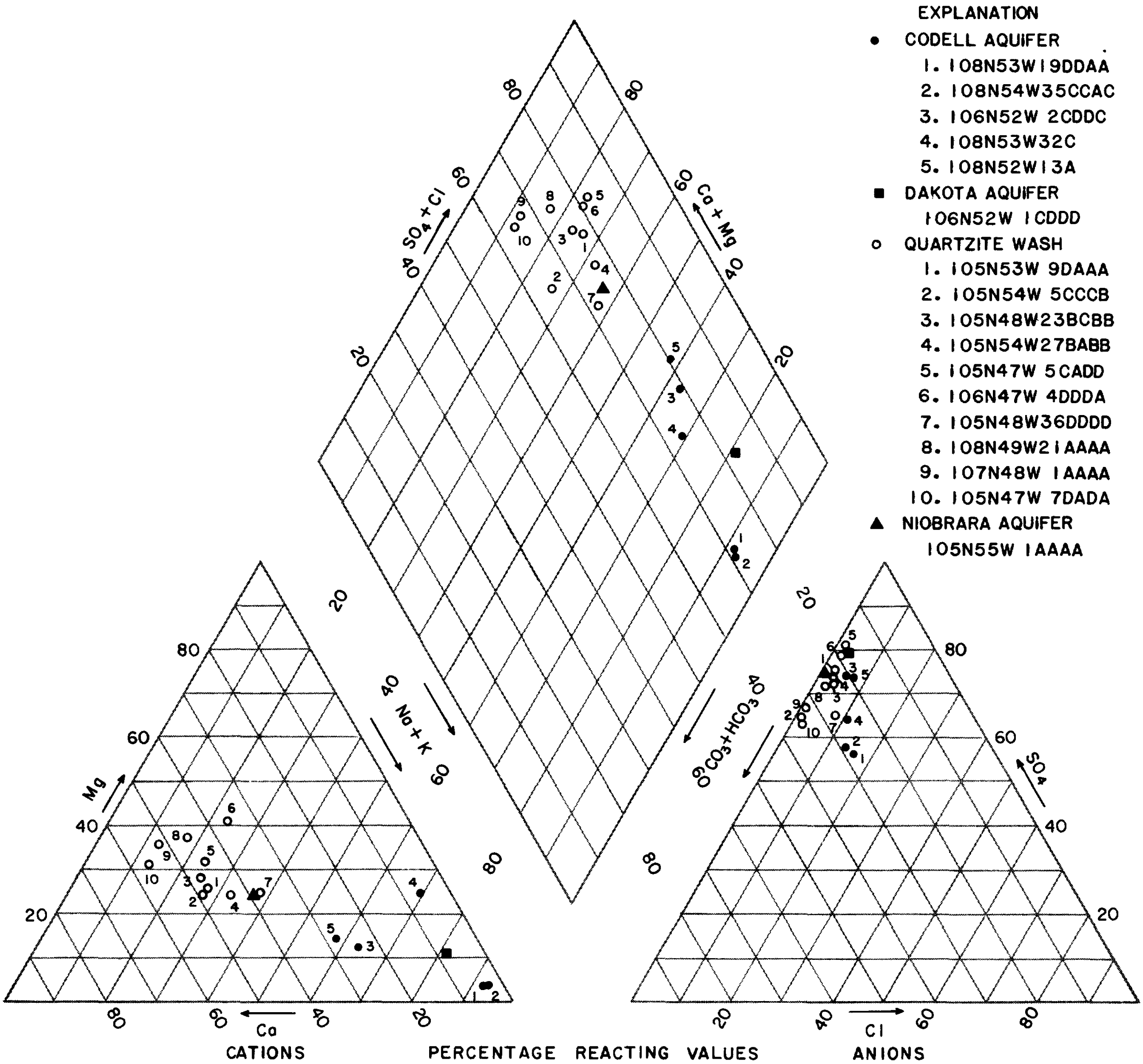
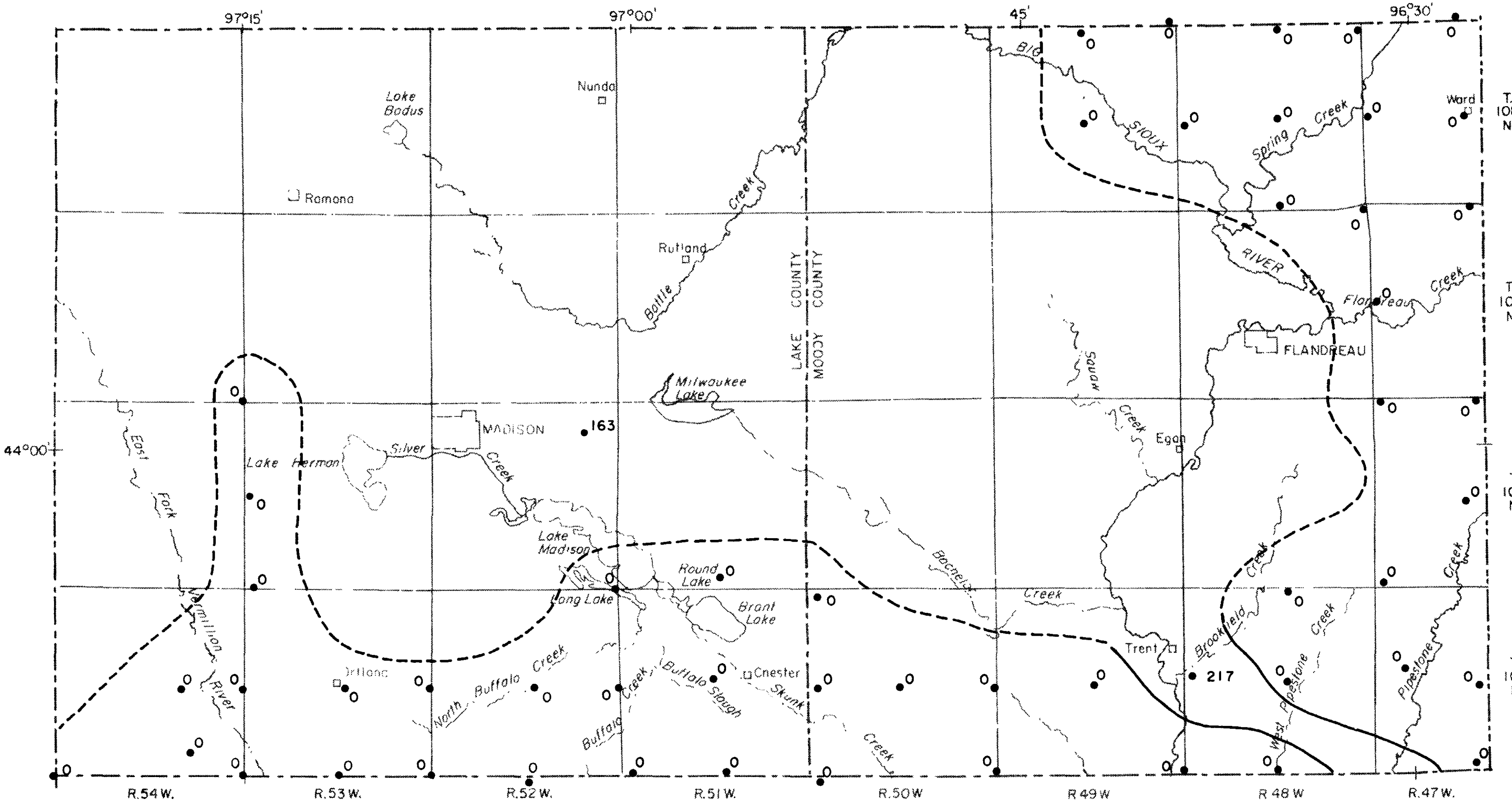


Figure 25.--Predominant chemical constituents in water from the Codell aquifer are sodium and sulfate, and from the quartzite wash aquifer are calcium and sulfate. The mixed water is calcium, sodium, and sulfate.

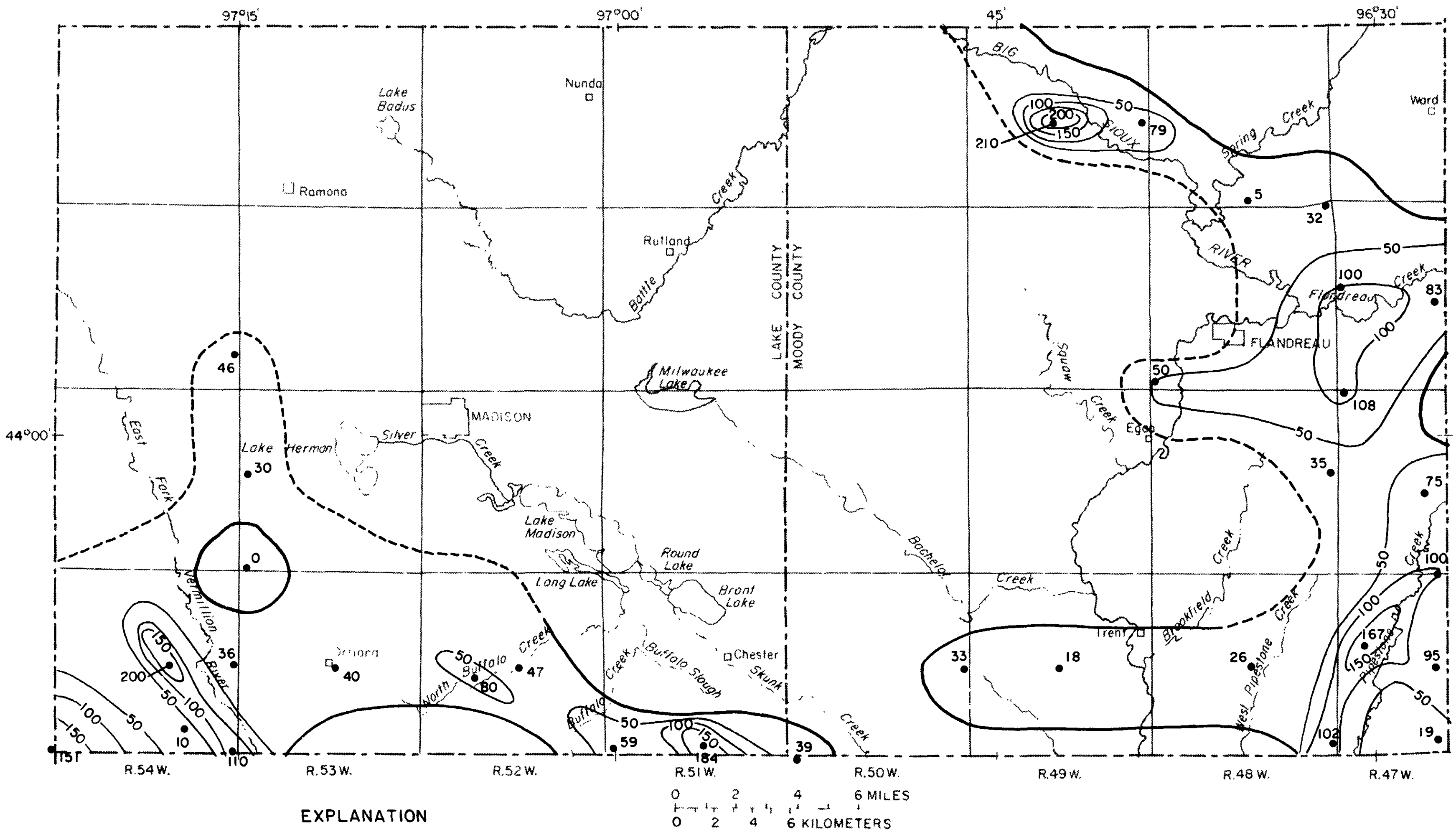


EXPLANATION

•163 TEST HOLE--Number is thickness of aquifer, in feet

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

Figure 26.--Approximate extent of the Dakota aquifer. (Extent determined from test holes completed in Precambrian that did not penetrate the aquifer.)



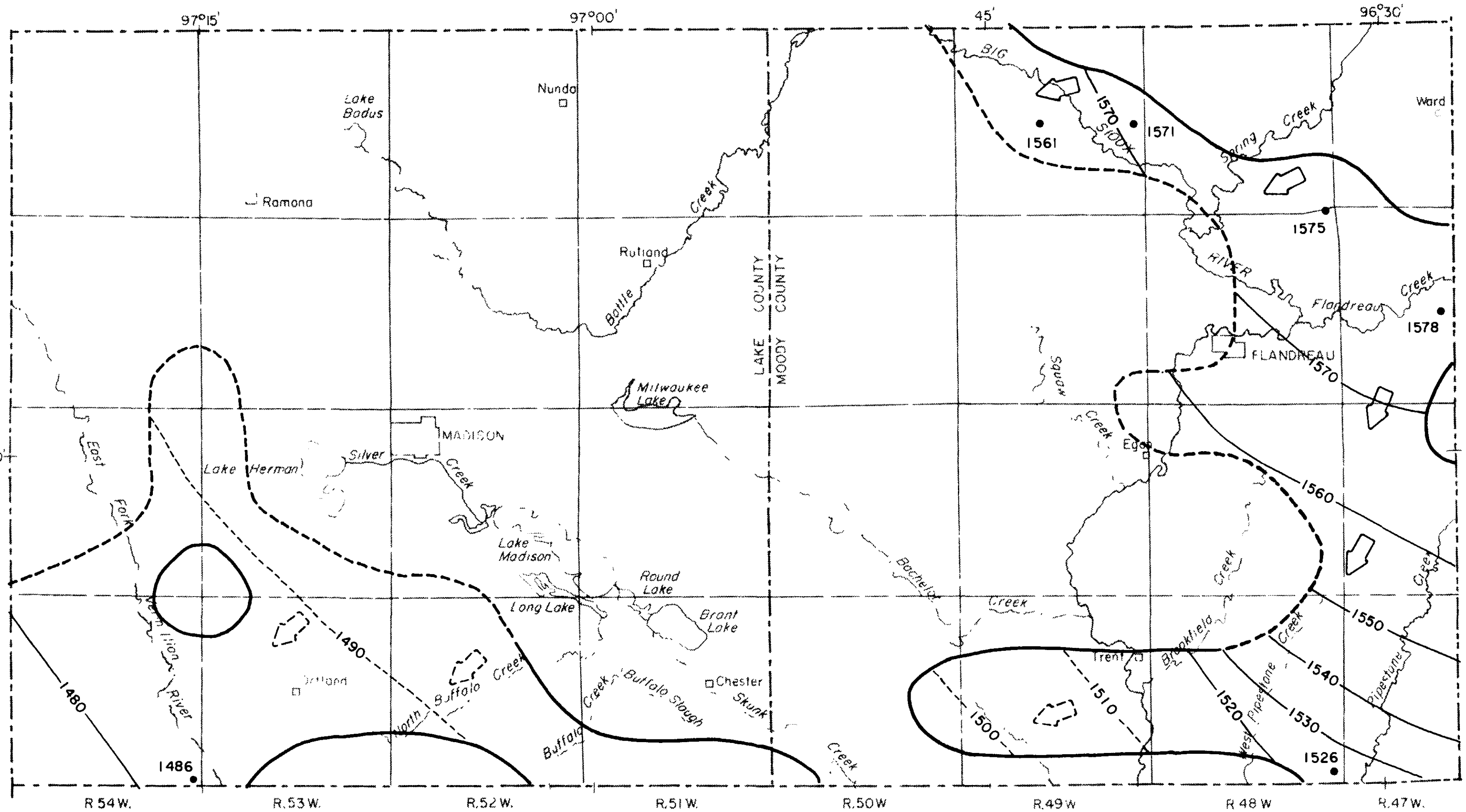
EXPLANATION

33● TEST HOLE--Number is thickness of aquifer, in feet

—50— LINE OF EQUAL THICKNESS OF AQUIFER--Interval, 50 feet

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

Figure 27.--Extent and thickness of the quartzite wash aquifer.



EXPLANATION

1526 • OBSERVATION WELL--Number is altitude of water surface, in feet. Datum is sea level

—— 1530 - - - POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 10 feet. Datum is sea level

AQUIFER BOUNDARY--Dashed where approximately located

DIRECTION OF GROUND-WATER MOVEMENT--Dashed where approximately located

Figure 28.--Potentiometric surface of the quartzite wash aquifer, October 1982.

Predominant chemical constituents in water from the quartzite wash aquifer are calcium and sulfate. Dissolved calcium concentration ranged from 140 to 240 mg/L and averaged 200 mg/L. Dissolved sulfate concentration ranged from 570 to 940 mg/L and averaged 750 mg/L. The average dissolved-solids concentration in water from the aquifer was 1,420 mg/L. Complete chemical analyses are given in table 6. Water from the aquifer is used primarily for stock and domestic purposes. Water from the aquifer is suitable for irrigation as indicated by the South Dakota irrigation-water standards shown in figure 7.

WATER USE

Water use from glacial and bedrock aquifers in Lake and Moody Counties was estimated to be about 2.6 billion gallons in 1980 (table 7). Ninety percent of water used is from glacial aquifers and 10 percent of the water used is from bedrock aquifers. Seventy-five percent of the total water use is from the Big Sioux and North Skunk Creek aquifers. Sixty-seven percent of the water used for stock and domestic use is withdrawn from the Howard and quartzite wash aquifers. The volume of water withdrawn from the Howard and quartzite wash aquifers is declining because of the installation of rural water systems.

Table 7.--Estimates of ground-water withdrawal in million gallons per year for Lake and Moody Counties

[Data based on 1980 water use unless otherwise noted]

Aquifers	Total	Municipal	Rural domestic	Livestock	Irrigation
GLACIAL					
Big Sioux	1,175	90	10	25	1/ 1,050
Pipestone	15	--	5	10	--
North Skunk Creek	780	220	20	40	1/ 500
Battle Creek	7	--	2	5	--
East Fork Vermillion	62	--	2	5	1/ 55
Rutland	15	--	5	10	--
Ramona	9	--	3	6	--
Howard	290	20	80	190	--
BEDROCK					
Niobrara	3	--	1	2	--
Codell	68	8	20	40	--
Dakota	6	--	2	4	--
Quartzite wash	170	--	50	120	--

1/ Based on reported, 1979 irrigation data.

SUMMARY

The primary sources of surface water in Lake and Moody Counties are the Big Sioux River and its intermittent tributaries and Lakes Herman, Madison, and Brant. Seasonal variations in streamflow and lake levels are directly related to seasonal variations in precipitation. Long-term lake levels correlate with departure from average precipitation. Specific conductance in water from streams and lakes is inversely related to stream discharge and lake levels, respectively. Dissolved-solids concentration in water from streams and lakes increases as stream discharge decreases and lake levels decline.

Eight glacial outwash aquifers and four bedrock aquifers were delineated in Lake and Moody Counties. The Big Sioux, Pipestone Creek, North Skunk Creek, Battle Creek, and East Fork Vermillion aquifers are composed of glacial outwash and are generally less than 60 feet below land surface. The Rutland, Ramona, and Howard aquifers are composed of glacial outwash and are overlain by 50 to 470 feet of till. The bedrock aquifers are the Niobrara, Codell, Dakota, and the quartzite wash.

The average thickness of the Big Sioux, Pipestone Creek, North Skunk Creek, Battle Creek, and East Fork Vermillion aquifers ranges from 14 to 32 feet. Recharge is predominantly from infiltration of snowmelt and spring rainfall. Discharge from the aquifers is by evapotranspiration, domestic, stock, irrigation, and municipal wells, and outflow to the river or creek of the same name. Major chemical constituents in water from the Big Sioux, Pipestone Creek, and North Skunk Creek aquifers are calcium and bicarbonate. Major chemical constituents in water from the Battle Creek and East Fork Vermillion aquifers are calcium and sulfate. The dissolved-solids concentration of the aquifers ranged from 300 to 1,320 milligrams per liter. With the exception of the Battle Creek aquifer, water from the unconfined glacial aquifers is of suitable quality for irrigation.

The average thickness of the Rutland, Ramona, and Howard aquifers ranges from 18 to 40 feet. Recharge to the Howard aquifer is by infiltration of precipitation, however, the recharge area probably is to the north, in Kingsbury and Brookings Counties. Recharge to the aquifers is by leakage from the till. Discharge from the aquifers is from stock, municipal, and domestic wells. Discharge from the Howard aquifer is also by outflow to fractures in the underlying Sioux Quartzite and leakage to the Niobrara aquifer. Reported well discharge from the Rutland, Ramona, and Howard aquifers ranged from 2 to 300 gallons per minute. Predominant chemical constituents in water from the aquifers are calcium and sulfate. Predominant chemical constituents in water from the Rutland aquifer are calcium and bicarbonate. The dissolved-solids concentration in the Howard and Rutland aquifers ranged from 964 to 5,520 milligrams per liter. Water from the Howard aquifer may be of suitable quality for irrigation use, provided the dissolved chemical constituents and soil texture meet South Dakota irrigation-water standards, revised 1982.

The average thickness of the bedrock aquifers ranges from 60 to 400 feet. With the exception of the Quartzite wash aquifer, the aquifers are absent in the extreme southern part of Lake and Moody Counties and in eastern Moody County. Recharge to the Niobrara is by leakage from the overlying Howard aquifer. Recharge to the Codell aquifer may be from the quartzite wash aquifer in eastern Moody and southwestern Lake Counties. Leakage from the underlying Dakota aquifer may be a source of recharge to the Codell aquifer. The direction of water movement in the aquifers is predominantly from east to west. Discharge from the aquifers is to domestic,

municipal, and stock wells. Predominant chemical constituents in water from the Niobrara aquifer are calcium, sodium and sulfate. Predominant chemical constituents in water from the Codell and Dakota aquifers are sodium and sulfate. Predominant chemical constituents in water from the quartzite wash aquifer are calcium, sulfate, and bicarbonate. The average dissolved-solids concentration of water from the quartzite wash aquifer was 1,420 milligrams per liter and from the Codell aquifer was 1,970 milligrams per liter.

Total 1980 water use in Lake and Moody Counties was about 2.6 billion gallons. Ninety percent of the water consumption in the counties was from the glacial aquifers.

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