WATER RESOURCES OF LINCOLN AND UNION COUNTIES, SOUTH DAKOTA

By Colin A. Niehus

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
gallon per minute (gal/min)	0.0631	liter per second
inch (in.)	25.4	millimeter
million gallons per day (Mgal/d)	0.0438	cubic meter per second
square mile (mi^2)	2.590	square kilometer

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

$$°F = 9/5\ (°C) + 32$$

$$°C = 5/9\ (°F-32)$$

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

Water Resources of Lincoln and Union Counties, South Dakota

By Colin A. Niehus

ABSTRACT

The water resources of Lincoln and Union Counties occur as surface and ground water. Sources of surface water include the Missouri River, the Big Sioux River, and various minor streams and lakes. The Missouri River, which forms the southern border of Union County, is the primary source of surface water in Union County. At a streamflow-gaging station on the Missouri River south of Union County, the discharge averaged 32,380 cubic feet per second during water years 1966-89. Near the study area, the Missouri River is used for municipal and domestic water supplies and for irrigation especially close to the river. The Big Sioux River, which forms the eastern border of Lincoln and Union Counties, is also an important surface-water source. At a streamflow-gaging station on the Big Sioux River north of Lincoln County, the discharge averaged 523 cubic feet per second during water years 1972-89. Streamflow of the Big Sioux River and other minor streams in the study area is directly related to seasonal variations in precipitation and evapotranspiration. Dissolved-solids concentrations in water from these streams increase as stream discharges decrease. The flow of the Missouri River is less affected by seasonal variations in precipitation and evapotranspiration due to regulation (control) by upstream dams.

Ten glacial aquifers and one bedrock aquifer were delineated in Lincoln and Union Counties. The areal extent of the glacial aquifers was determined to be 25 to 60 square miles for the Wall Lake, Parker-Centerville, Big Sioux, and Lower Vermillion-Missouri aquifers; 85 to 90 square miles for the Harrisburg, Upper Vermillion-Missouri, and Newton Hills aquifers; 130 square miles for the Shindler aquifer; and 180 square miles each for the Missouri and Brule Creek aquifers.

The average thickness of the glacial aquifers ranges from 26 to 99 feet. Recharge to these aquifers mainly is from infiltration and subsequent percolation of precipitation. Recharge also occurs by leakage through till, by ground-water recharge from other glacial aquifers, by ground-water recharge from the Dakota aquifer, and by inflow from the Big Sioux and Missouri Rivers during high stages. The average depth below land surface to the top of the Parker-Centerville, Big Sioux, and Missouri aquifers ranges from 12 to 22 feet; the average depth below land surface to the top of the Harrisburg, Newton Hills, and Brule Creek aquifers ranges from 46 to 72 feet; the average depth below land surface to the top of the Wall Lake, Shindler, and Lower Vermillion-Missouri aquifers ranges from 103 to 106 feet; and the average depth below land surface to the top of the Upper Vermillion-Missouri aquifer is 162 feet. The buried aquifers are overlain by till and primarily are underlain by either till, Sioux Quartzite, Dakota Formation, Carlile Shale, or Niobrara Formation.

Discharge from the glacial aquifers is by evapotranspiration where the aquifers are close to land surface; by withdrawals from domestic, stock watering, irrigation, and municipal wells; by discharge to other aquifers; and by outflow to the Big Sioux and Missouri Rivers. Reported maximum well yields are largest (1,000 gallons per minute or more) from the Big Sioux, Lower Vermillion-Missouri, and Missouri aquifers.

Predominant chemical constituents are calcium, magnesium, sulfate, and bicarbonate in water from the

glacial aquifers. Mean dissolved-solids concentrations in water samples from the aquifers ranged from 777 to 2,400 milligrams per liter, except for the Harrisburg aquifer which had a mean of 4,075 milligrams per liter and the Lower Vermillion-Missouri aquifer which had dissolved-solids concentrations of 340 and 1,820 milligrams per liter in water samples from two wells.

The Dakota aquifer is a bedrock aquifer with an areal extent of 935 square miles, an average thickness of 216 feet, and an average depth below land surface to the top of the aquifer of 281 feet. The aquifer is overlain by Graneros Shale, the Lower Vermillion-Missouri aquifer, or the Missouri aquifer. The aquifer is underlain predominantly by several sandstones, shales, and dolostones of Cambrian, Ordovician, or Devonian age; by Sioux Quartzite wash; or by Sioux Quartzite. Discharge from the aquifer is by withdrawals from irrigation, municipal, domestic, and stock wells and probably by ground-water discharge to the Lower Vermillion-Missouri and Missouri aquifers. Reported well yields range from 10 to 1,200 gallons per minute. Predominant chemical constituents in water from the Dakota aquifer are calcium, sulfate, and bicarbonate. The water had a mean dissolved-solids concentration of 1,800 milligrams per liter.

The total water use in Lincoln and Union Counties during 1985 was 14.66 million gallons per day. About 76 percent of the water used was for irrigation.

INTRODUCTION

In 1982, the South Dakota Geological Survey and the U.S. Geological Survey began a 7-year comprehensive investigation of the water resources of Codington, Grant, Minnehaha, Lincoln, and Union Counties in order to develop a hydrologic data base and subsequently to develop digital models of the Big Sioux aquifer. This comprehensive investigation was needed because of the limited availability of information on the water resources of the Big Sioux River basin. Past water-resources studies of the Big Sioux River basin were undertaken for site-specific purposes and did not interrelate the hydrology of all the area's water resources. These studies often were water-supply investigations for individual cities or towns or investigations of individual aquifers. Water development has occurred at a rapid rate in some areas and at a slow rate in other areas. The end result has been a scattered development pattern that may not efficiently utilize the available water resources. As part of the comprehensive 7-year study, the South Dakota Geological Survey and Lincoln and Union Counties, South Dakota, cooperated with the U.S. Geological Survey in a 4-year study of water resources in Lincoln and Union Counties (fig. 1).

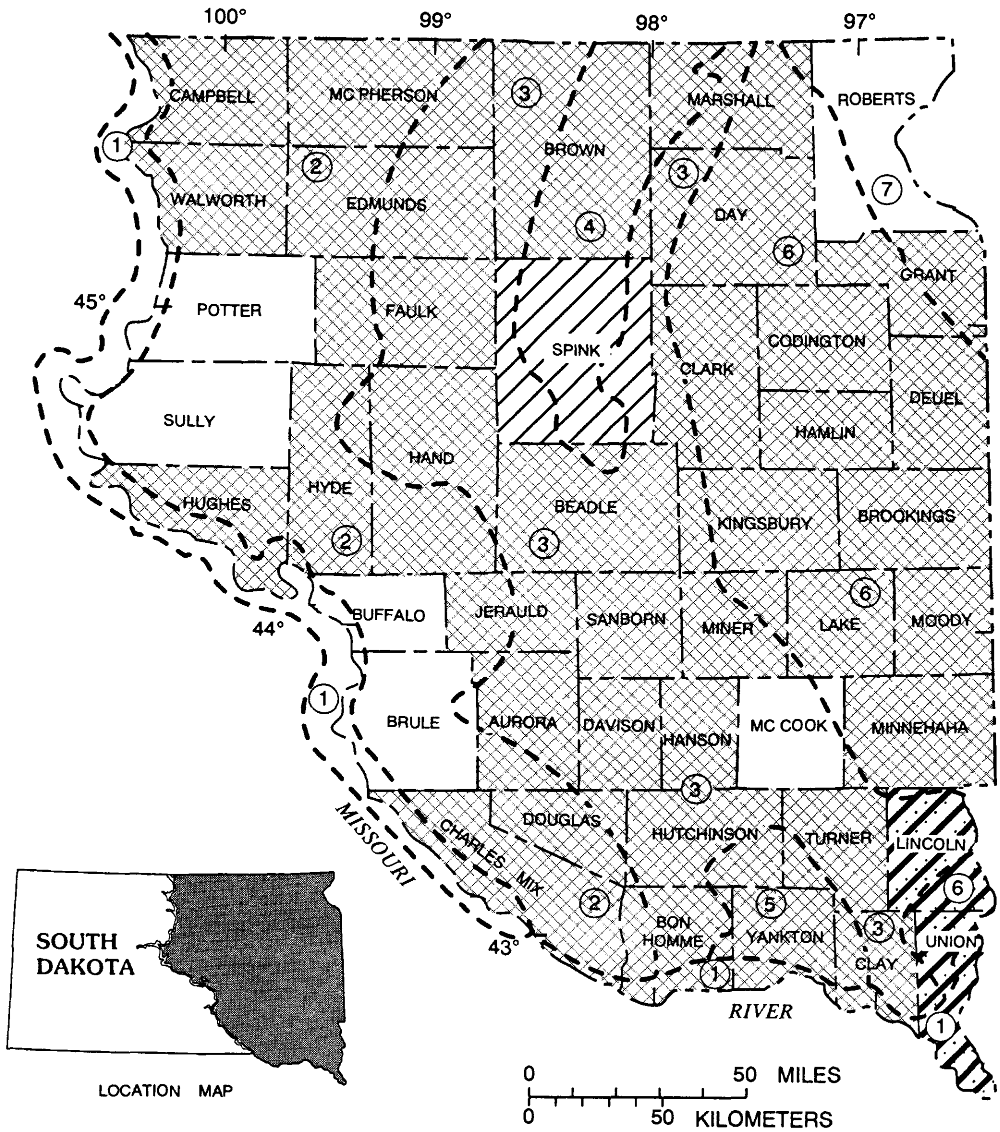
Purpose and Scope

This report describes the results of a 4-year study of the water resources of Lincoln and Union Counties. The report includes descriptions of: (1) The surface-water resources; (2) the extent of the major glacial and bedrock aquifers; (3) the recharge, movement, and discharge of water in the major glacial aquifers; (4) the quality of the surface and ground water; and (5) ground-water and surface-water uses in the two counties.

The study included collection and interpretation of drill logs, well inventories, test drilling, installation of observation wells, measurement of water levels, chemical analyses of ground water, and analysis of surface-water resources. The locations of test holes (drilled specifically for this study), observation wells, water-quality sampling sites, and geologic sections are shown in figure 2. Also shown are the locations of other test holes and private or public wells (having drill logs) that were used to draw the geologic sections. Available drill-log and observation-well data from other test holes, private wells, or public wells also were used for this study; however, their locations are not shown in figure 2. Data-collection sites are numbered according to the Federal land survey system, as shown in figure 3.

Physiography

Lincoln and Union Counties encompass 1,042 mi^2 of southeastern South Dakota (fig.1). The land surface ranges in altitude from 1,565 ft in southeastern



EXPLANATION

STUDY AREA

INVESTIGATION IN PROGRESS

INVESTIGATION COMPLETED AND REPORTS PUBLISHED OR IN PRESS

INVESTIGATION NOT SCHEDULED

- - - PHYSIOGRAPHIC BOUNDARY

GREAT PLAINS PROVINCE

1 Missouri River trench

2 Coteau du Missouri

CENTRAL LOWLANDS PROVINCE

3 James River lowland

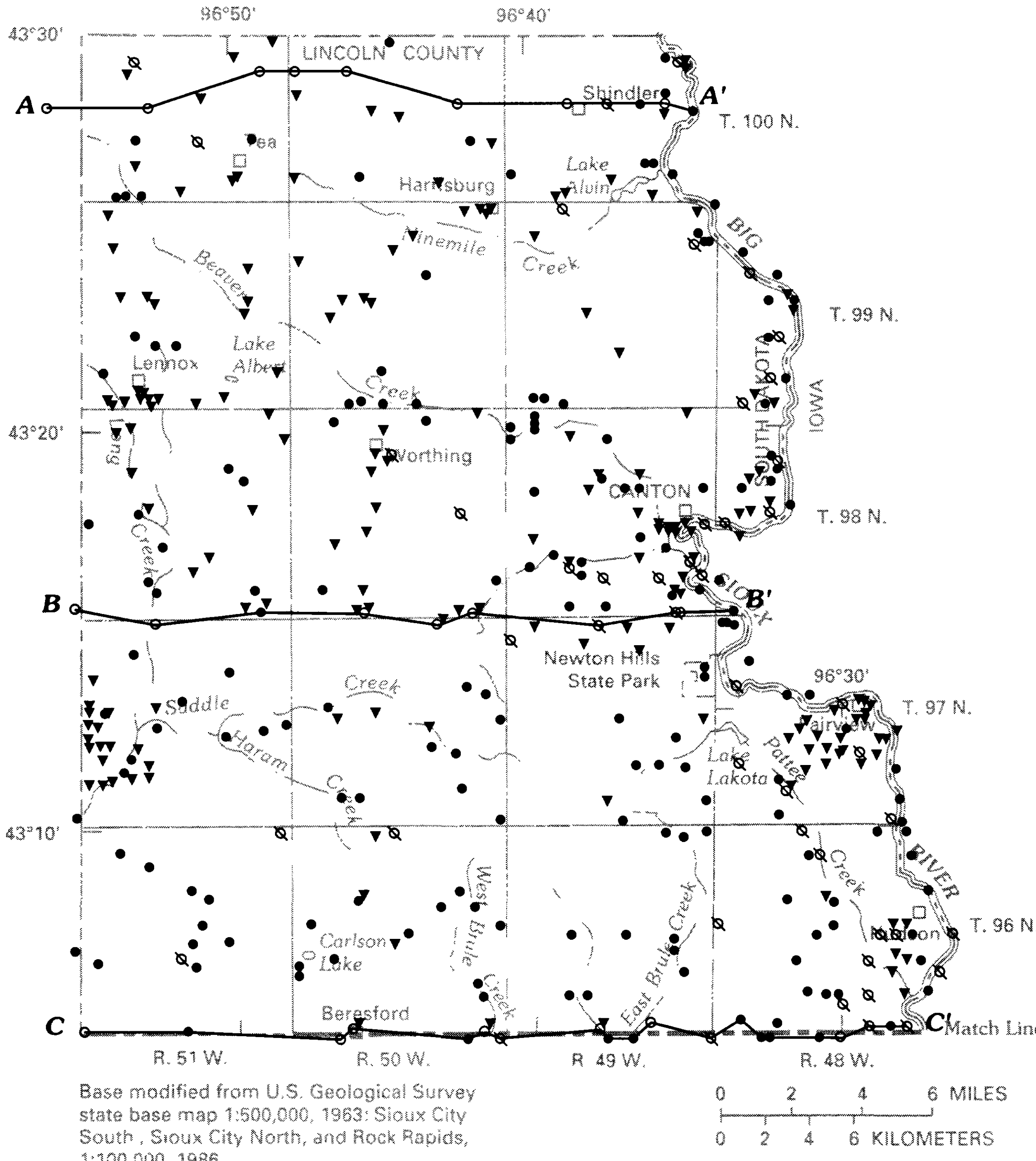
4 Lake Dakota plain

5 James River highland

6 Coteau des Prairies

7 Minnesota River-Red River lowlands

Figure 1.--Index map of eastern South Dakota showing location of area discussed in this report, status of county investigations, and locations of major physiographic divisions (physiographic divisions from Flint, 1955).



EXPLANATION

A———A' LINE OF GEOLOGIC SECTION

● TEST HOLE--Aquifer description and driller's logs are available from the U.S. Geological Survey

○ OTHER TEST HOLE OR WELL SITE (not drilled for this study)--Aquifer description and driller's logs are available from the U.S. Geological Survey

ꝋ OBSERVATION WELL--Records of water-level measurements are available from the U.S. Geological Survey

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

Figure 2.--Location of selected ground-water data sites and of geologic sections in Lincoln and Union Counties.

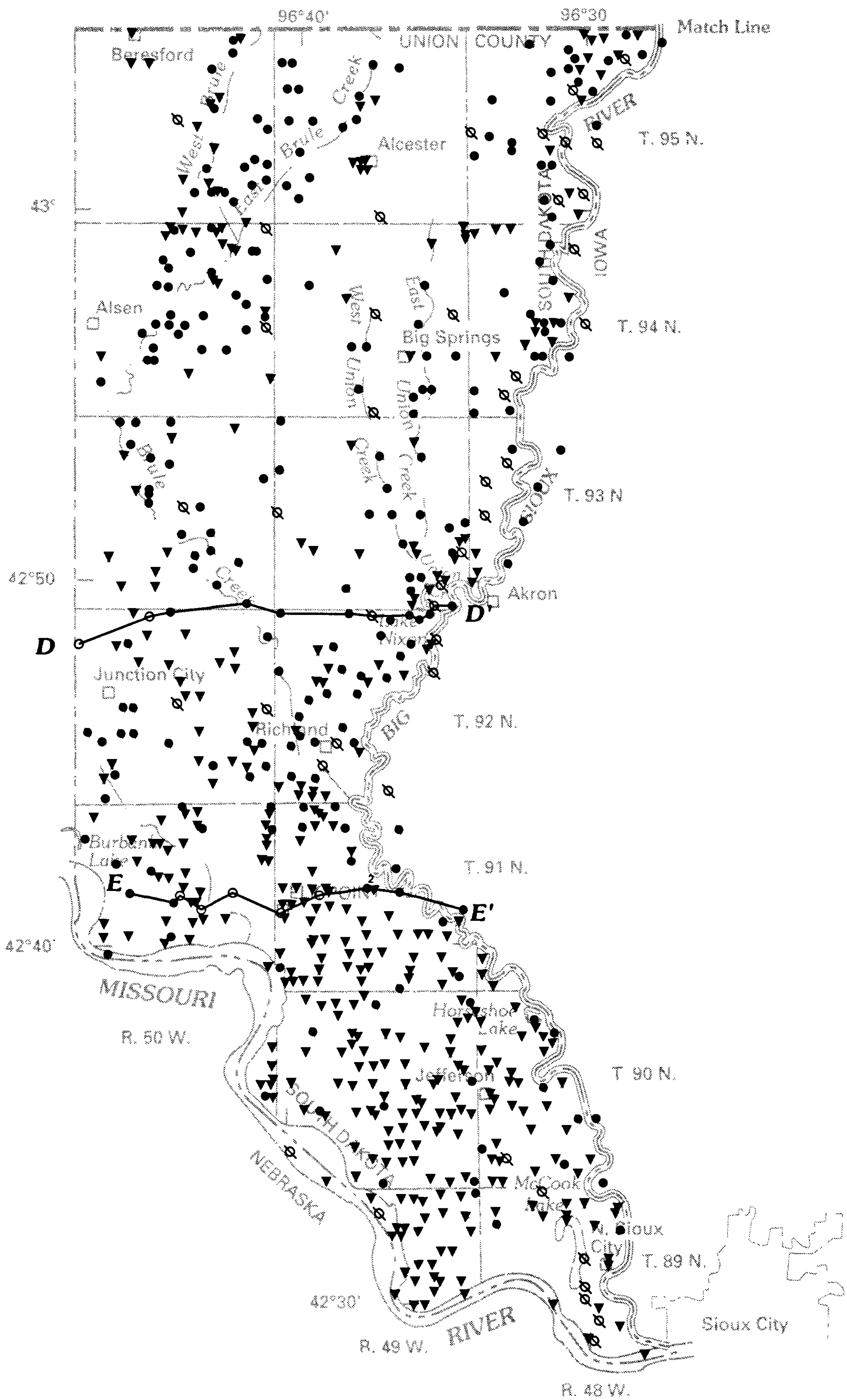


Figure 2.--Location of selected ground-water data sites and of geologic sections in Lincoln and Union Counties.--Continued

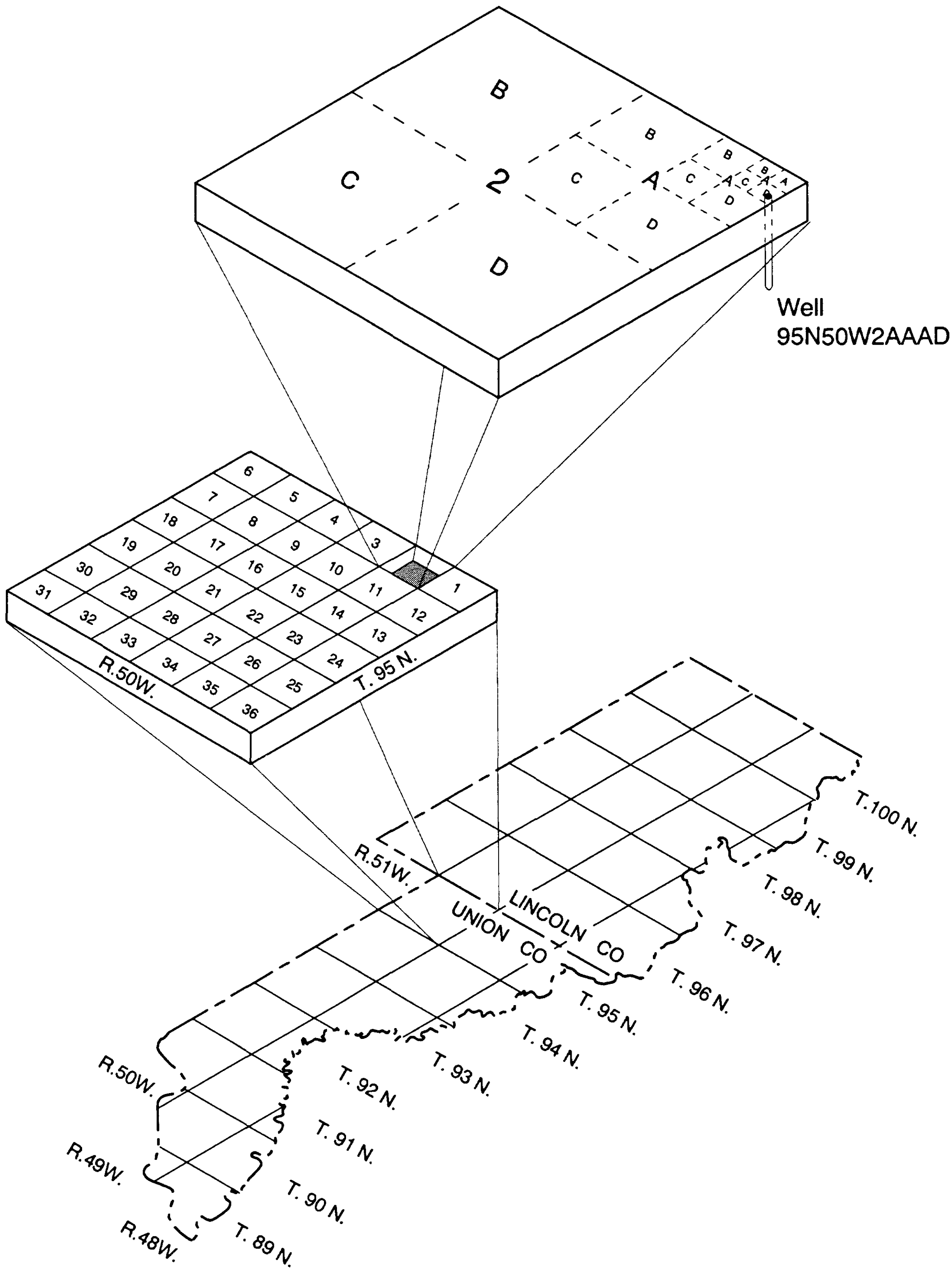


Figure 3.--Well-location diagram. The well number consists of the township, followed by "N," the range number followed by "W," and the section number, followed by a maximum of four uppercase letters that indicate, respectively, the 160-, 40-, 10-, and 2 1/2-acre tract in which the well is located. These letters are assigned in a counterclockwise direction beginning with "A" in the northeast quarter. A serial number following the last letter is used to distinguish between wells in the same 2 1/2-acre tract.

Lincoln County to 1,085 ft above sea level in the extreme southeastern tip of Union County. Northern and southeastern Lincoln County and northern Union County are within the Coteau des Prairies, a highland plateau between the Minnesota River lowland to the east and the James River lowland to the west. The Coteau des Prairies is characterized by an escarpment at its eastern slope. The Big Sioux River is the only major stream that drains the Coteau des Prairies. Central Lincoln County is in the James River lowland, which lies between the Coteau des Prairies and the Coteau du Missouri. Much of the James River lowland within the study area is drained southward by the Vermillion River. Southern Union County is in the Missouri River trench. The Missouri River trench and the James River lowland are stream-cut valleys; however, they differ markedly from each other. The James River lowland is many times wider, somewhat deeper, and smoother in relief. This difference is partly from age (the lowland is much older than the trench) and partly from degree of glaciation. The James River lowland has been repeatedly enlarged and smoothed by glacial action. The Missouri River trench bears lesser indications of glacial modification (Flint, 1955).

Geology

Lincoln and Union Counties are overlain primarily by Pleistocene glacial deposits and to a lesser extent by nonglacial loess (windblown sand and silt) and stream deposits. The glacial deposits can be divided into two categories--till and outwash. Till was deposited directly by and underneath glaciers without any subsequent reworking by the glaciers' water. It is a heterogeneous mixture of clay, silt, sand, gravel, and boulders of various sizes and shapes (Gary and others, 1972). Outwash was deposited from or by meltwater streams on top of the glacial ice or beyond the margin of the active glacial ice (Gary and others, 1972). It consists primarily of layers of clayey or silty sand and sandy gravel, interbedded with layers of sandy or gravelly silt or clay. The glacial deposits may be covered by nonglacial deposits of alluvium along streams and locally the deposits may be covered by loess. During the Pleistocene Epoch in South Dakota, the area east and north of the Missouri River was almost completely covered by glaciers. These glaciers left glacial deposits throughout eastern South Dakota. There was extensive glacial erosion of preglacial bedrock units in the region described as the James River lowland. This region had the thickest ice and therefore had the fastest moving glaciers. The glacial processes resulted in partially filled major valleys, forced the cutting of new valleys, and formed massive end moraines. One major result of the glaciers was major changes to the surface drainage. The drainage in eastern South Dakota is now predominantly southward because of this glaciation (Flint, 1955). The bedrock units directly underlying the glacial deposits and nonglacial loess and stream deposits in Lincoln and Union Counties are as follows: (1) Quartzite wash of Pre-Cretaceous age and the Sioux Quartzite of Precambrian age in northern Lincoln County; (2) Dakota Formation of Cretaceous age in southern Union County; and (3) in ascending order, the Graneros Shale, Greenhorn Limestone, Carlile Shale, and the Niobrara Formation of Late Cretaceous age over the rest of the counties. Several sandstones, shales, and dolostones of Cambrian, Ordovician, or Devonian age (Paleozoic) also underlie much of Union County. The bedrock geology in Lincoln and Union Counties is depicted in figures 4 and 5.

Acknowledgments

The author acknowledges the cooperation of residents and municipal officials of Lincoln and Union Counties for providing information concerning the water wells they own or manage. The cooperation of the local drilling companies in supplying well logs and other data also is appreciated.

WATER RESOURCES

The water resources of Lincoln and Union Counties include surface and ground water. The major surface-water resources are the Missouri and Big Sioux Rivers. The major ground-water resources are in glacial aquifers, which contain about 4 million acre-ft of water in storage.

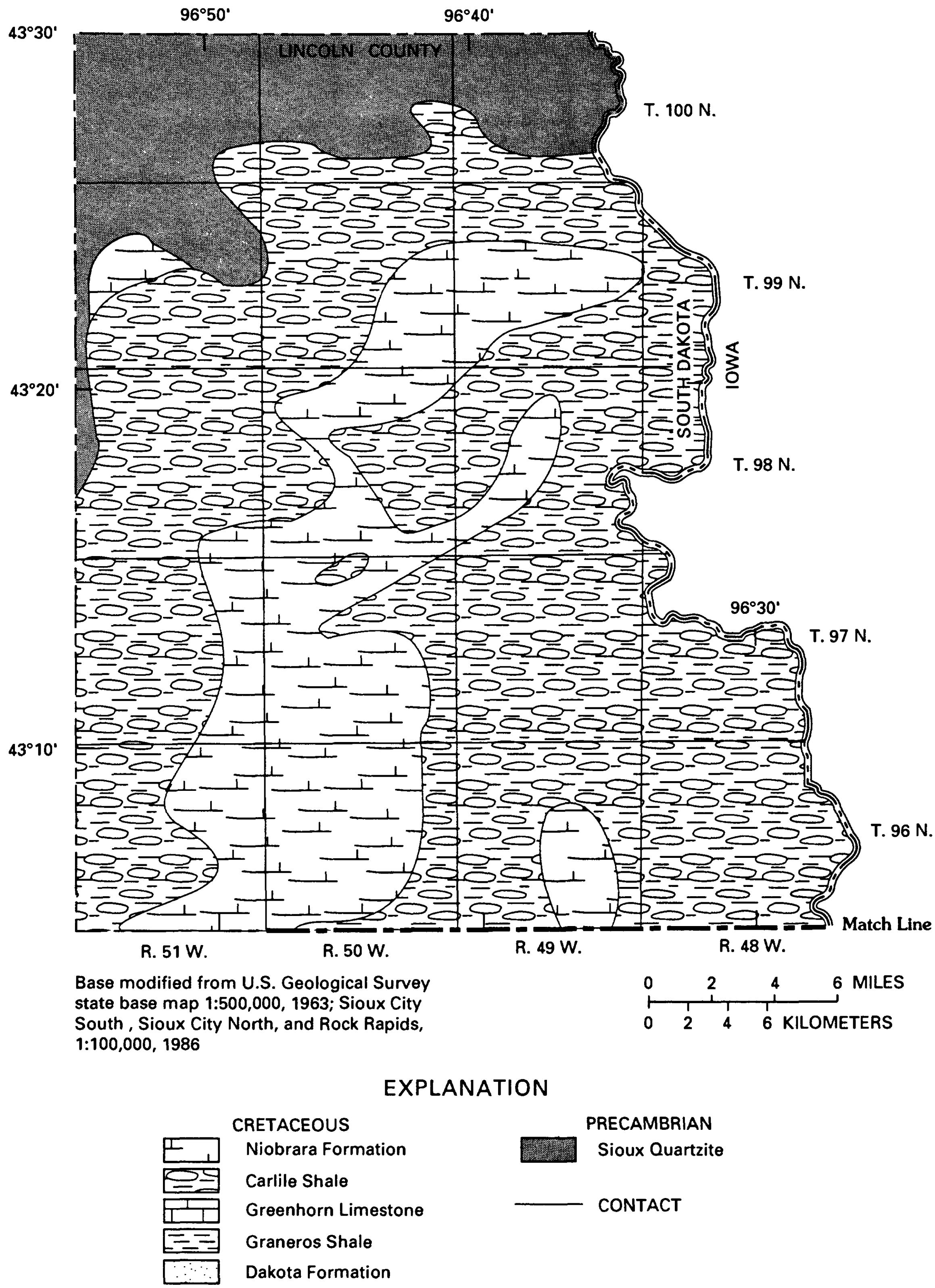


Figure 4.--Bedrock geology for Lincoln and Union Counties.

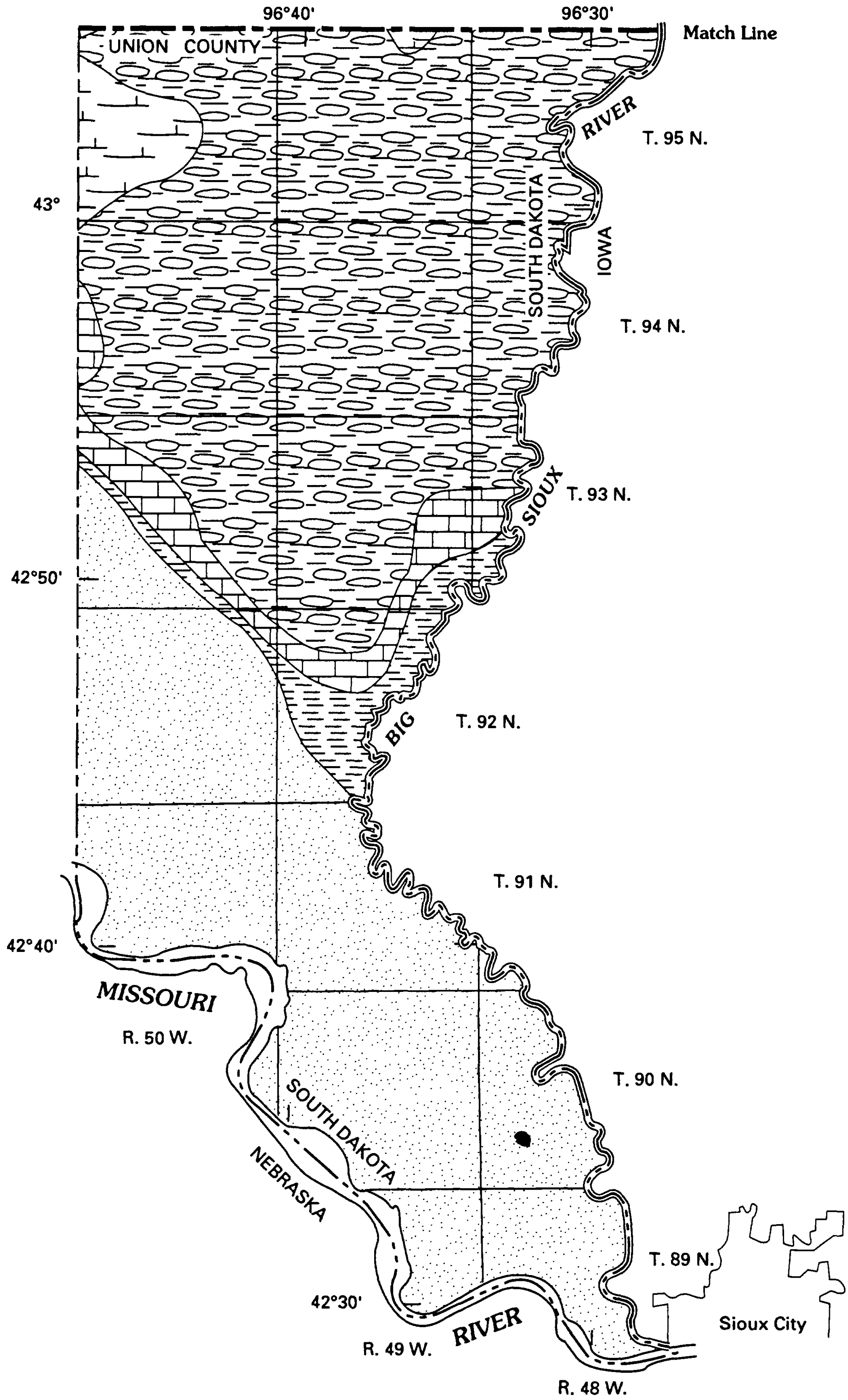
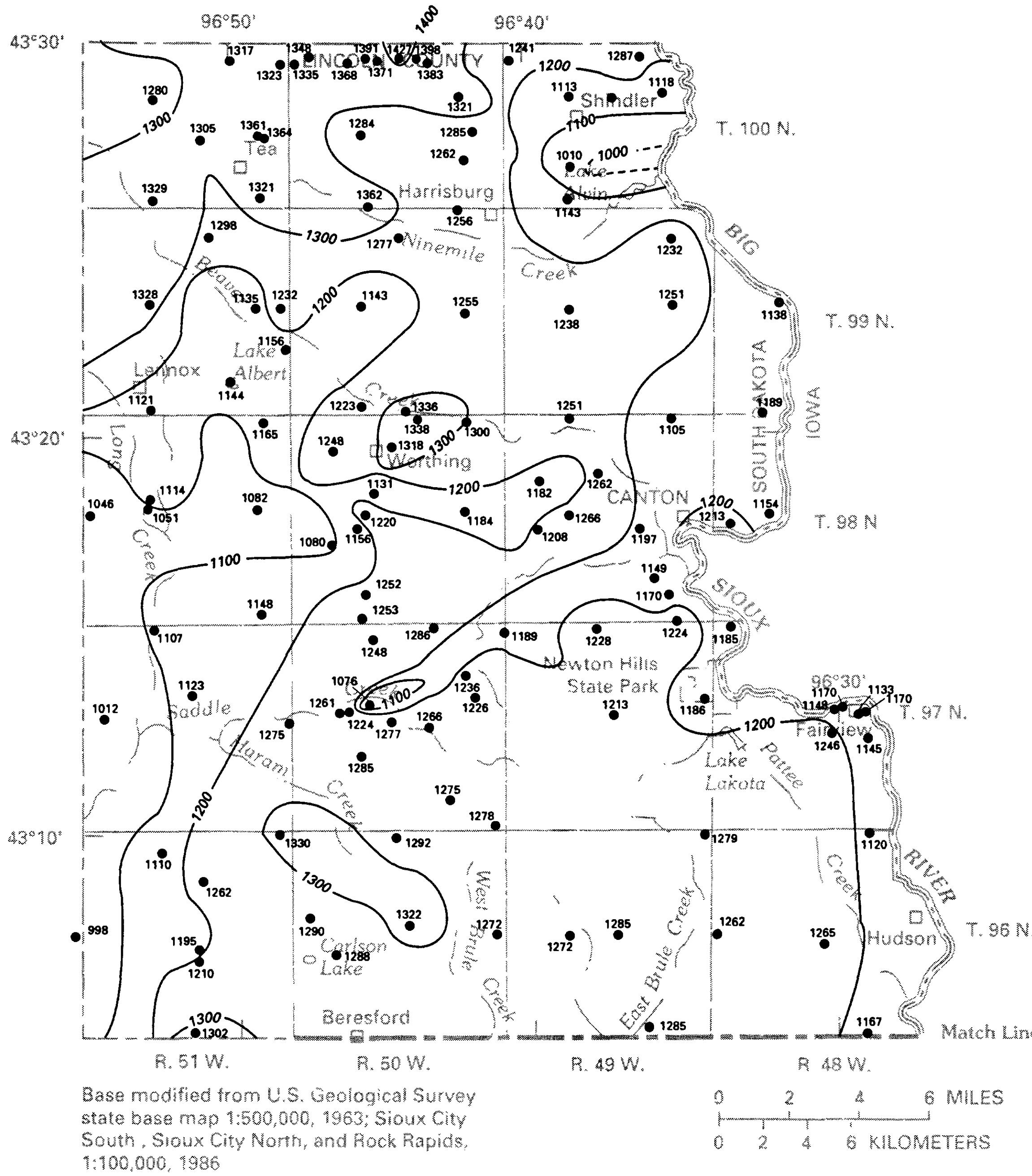


Figure 4.--Bedrock geology for Lincoln and Union Counties.--Continued



EXPLANATION

1200 - - - - STRUCTURE CONTOUR--Shows altitude of the bedrock surface. Dashed where limited data exist. Contour interval is100 feet. Datum is sea level.

1285 • TEST HOLE OR WELL SITE--Number is altitude of the bedrock surface, in feet. Datum is sea level.

Figure 5.--Structure contours of the bedrock surface for Lincoln and Union Counties.

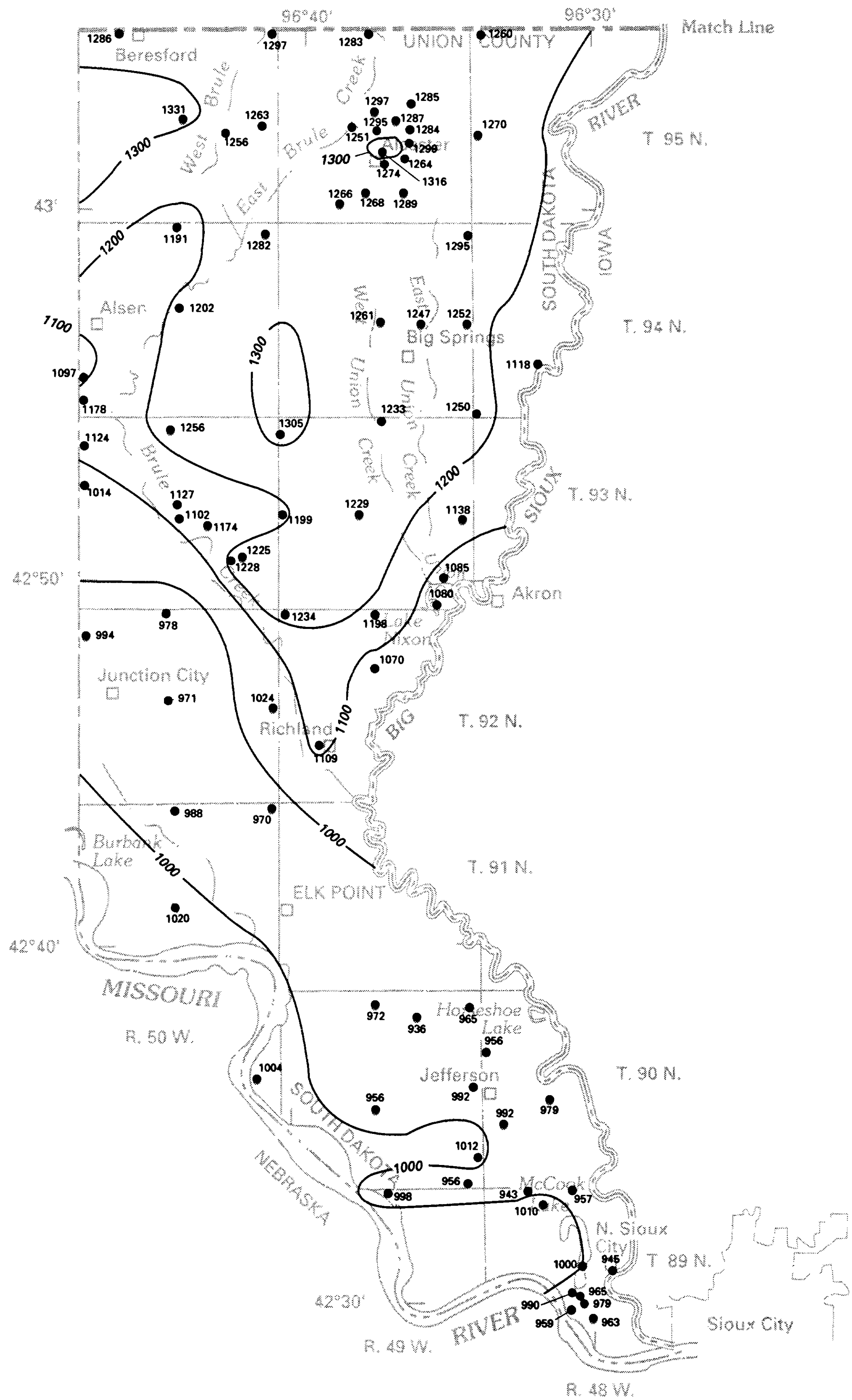


Figure 5.--Structure contours of the bedrock surface for Lincoln and Union Counties.--Continued

Precipitation

The average annual precipitation at Canton in Lincoln County and Centerville near the northwest corner of Union County from 1951 to 1980 was 24.05 and 24.70 in., respectively (U.S. National Oceanic and Atmospheric Administration, 1986). About 70 to 80 percent of the precipitation is returned to the atmosphere by evaporation and transpiration. About 10 percent of the average annual precipitation becomes streamflow; however, this quantity can 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 (Hansen, 1990).

Surface-Water Occurrence and Chemical Quality

The surface-water resources in Lincoln and Union Counties include rivers, streams, and lakes. The major rivers are the Missouri and Big Sioux Rivers. Three of the larger lakes are McCook Lake, Lake Alvin, and Lake Lakota.

Drainage Basins

Drainage in eastern and northern Lincoln County and most of Union County (fig. 6) is well developed and is primarily by the Big Sioux River and its tributaries (about 385 mi^2 in Lincoln County and 375 mi^2 in Union County). Drainage in western Lincoln County and the extreme northwestern part of Union County also is well developed and is primarily by the Vermillion River and its tributaries (about 200 mi^2 in Lincoln County and 5 mi^2 in Union County). The Missouri River and its minor tributaries directly drain extreme southern Union County (about 80 mi^2). More detailed information about the drainage of the Big Sioux River and the Vermillion River in eastern South Dakota can be found in U.S. Geological Survey reports by Amundson and others (1985) and by Benson and others (1988).

Missouri River

The Missouri River, the largest river in the area, forms the southeastern border of South Dakota with Nebraska. The Missouri River also forms the southern boundary of Union County. The river is regulated by a series of six main-stem dams and reservoirs stretching from Montana to the nearby Gavins Point Dam and its reservoir, the Lewis and Clark Lake. At streamflow-gaging station 06486000 at Sioux City, Iowa (fig. 6), the discharge averaged 32,380 ft^3/s during water years 1966-89. Although records also exist for this streamflow-gaging station prior to 1966, they were not used to calculate the average discharge because the Missouri River was not completely regulated by the present main-stem system.

Specific conductance, which can be used to estimate dissolved-solids concentrations in water because specific conductance is related to the number and types of ions in solution, is fairly constant for the Missouri River. For example, during water year 1988 the instantaneous flow at streamflow-gaging station 06467500 at Yankton, South Dakota, ranged from 18,000 to 39,500 ft^3/s, whereas the specific conductance only ranged from 700 to 870 $\mu S/cm$ (microsiemens per centimeter at 25°Celsius).

Near the study area, the Missouri River is used for municipal and domestic water supplies and for irrigation especially close to the river. The Missouri River is connected hydraulically to the Missouri aquifer in Union County and provides some inflow or outflow to this aquifer depending on the river stage (a more detailed discussion is presented later in this report). A summary of streamflow-gaging station records for sites in and near Lincoln and Union Counties is listed in table 1.

Big Sioux River

The Big Sioux River is the boundary between South Dakota and northwestern Iowa and the eastern border of Lincoln and Union Counties. Discharge averaged 1,030 ft^3/s during 1929-89 at streamflow-gaging station 06485500 at Akron, Iowa (table 1). The minimum daily discharge at this station (4.0 ft^3/s) occurred during January 1977, which was a period of drought. From October 1974 to September 1981, specific conductance of water at the Akron streamflow-gaging station ranged from 260 to 2,310 $\mu S/cm$. Specific conductance for water in the Big Sioux River is generally inversely related to discharge. During water year 1988 at Akron, the specific conductance for discharge greater than 1,000 ft^3/s averaged 640 µS/cm, whereas the specific conductance for discharge less than 1,000 ft^3/s averaged 950 µS/cm. The observed specific conductance of water from the Big Sioux River at Akron decreased from 1,100 µS/cm when the instantaneous discharge was 205 ft^3/s in December 1987 to 790 µS/cm when the instantaneous discharge was 1,960 ft^3/s in March 1988. A streamflow-gaging station also is located on the Big Sioux River at Sioux Falls, South Dakota, which is immediately north of Lincoln County. The Big Sioux River, which is connected hydraulically to the Big Sioux aquifer, receives ground-water inflow during most stages (a more detailed discussion is presented later in this report).

Other Streams

Other smaller streams in and near Lincoln and Union Counties at which flow records have been collected include Beaver Creek, Brule Creek, and the Vermillion River (fig. 6). A summary of streamflow-gaging station records for these streams is listed in table 1. Flow in these streams (as well as other ungaged streams) depends primarily on seasonal variations in precipitation, evapotranspiration, and ground-water storage. These streams generally have increased flow during spring and early summer because of snowmelt and rainfall runoff and because of the release of water stored in aquifers that are hydraulically connected to the streams. These streams generally have reduced flow or are dry during late fall and winter because of decreased rainfall runoff, decreased ground-water discharge, evaporation, and ice formation. Specific conductance of water from these small streams generally varies inversely with discharge because of dilution from snowmelt and rainfall runoff. For example, at Beaver Creek at Canton during water year 1988, the specific conductance was 970 µS/cm for the maximum sampled discharge of 30 ft^3/s, whereas the specific conductance was 2,110 µS/cm for the minimum sampled discharge of 0.77 ft^3/s. At Brule Creek at Elk Point during water year 1988, the specific conductance was 450 µS/cm for the maximum sampled discharge of 265 ft^3/s, whereas the specific conductance was 1,000 µS/cm for the minimum sampled discharge of 4.6 ft^3/s.

Table 1.--Summary of data for streamflow-gaging stations in and near Lincoln and Union Counties

Station number	Station name	Drainage area (square miles)	Period of record used (water year)	Discharge (cubic feet per second)		
				Maximum (instantaneous)	Minimum (daily)	Average
06467500[1]	Missouri River at Yankton, S. Dak.	279,500	1931-89	480,000	2,700	[2]29,940
06479000[1]	Vermillion River near Wakonda, S. Dak.	1,680	1946-83	9,880	0	125
06479010[1]	Vermillion River near Vermillion, S. Dak.	2,302	1984-89	21,400	4.9	413
06482020[1]	Big Sioux River at North Cliff Avenue, at Sioux Falls, S. Dak.	[3]5,216	[4]1972-89	21,600	.81	523
06482848	Beaver Creek at Canton, S. Dak.	124	1983-89	2,570	0	45.1
06485500	Big Sioux River at Akron, Ia.	[3]8,424	1929-89	80,800	4.0	1,030
06485696	Brule Creek near Elk Point, S. Dak.	204	1983-89	6,290	1.1	77.3
06486000	Missouri River at Sioux City, Ia.	314,600	1898-1989	441,000	2,500	[2]32,380

[1]Outside study area.
[2]Average is for the period 1966-89.
[3]Of this area, 1,487 square miles probably is noncontributing.
[4]U.S. Army Corps of Engineers has additional records for the period March 1962 to September 1971.

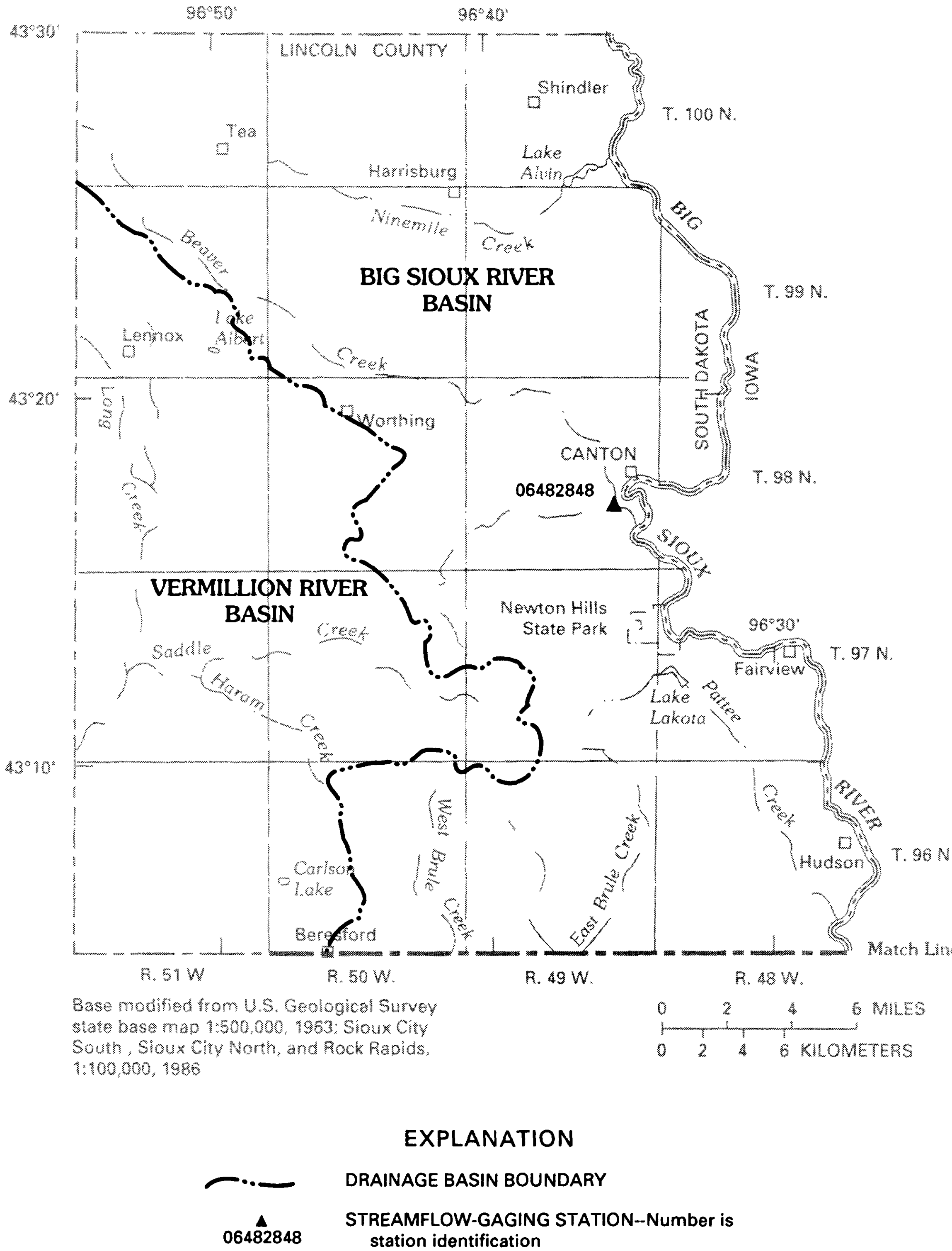


Figure 6.--Locations of drainage basins and U.S. Geological Survey streamflow-gaging stations in and near Lincoln and Union Counties.

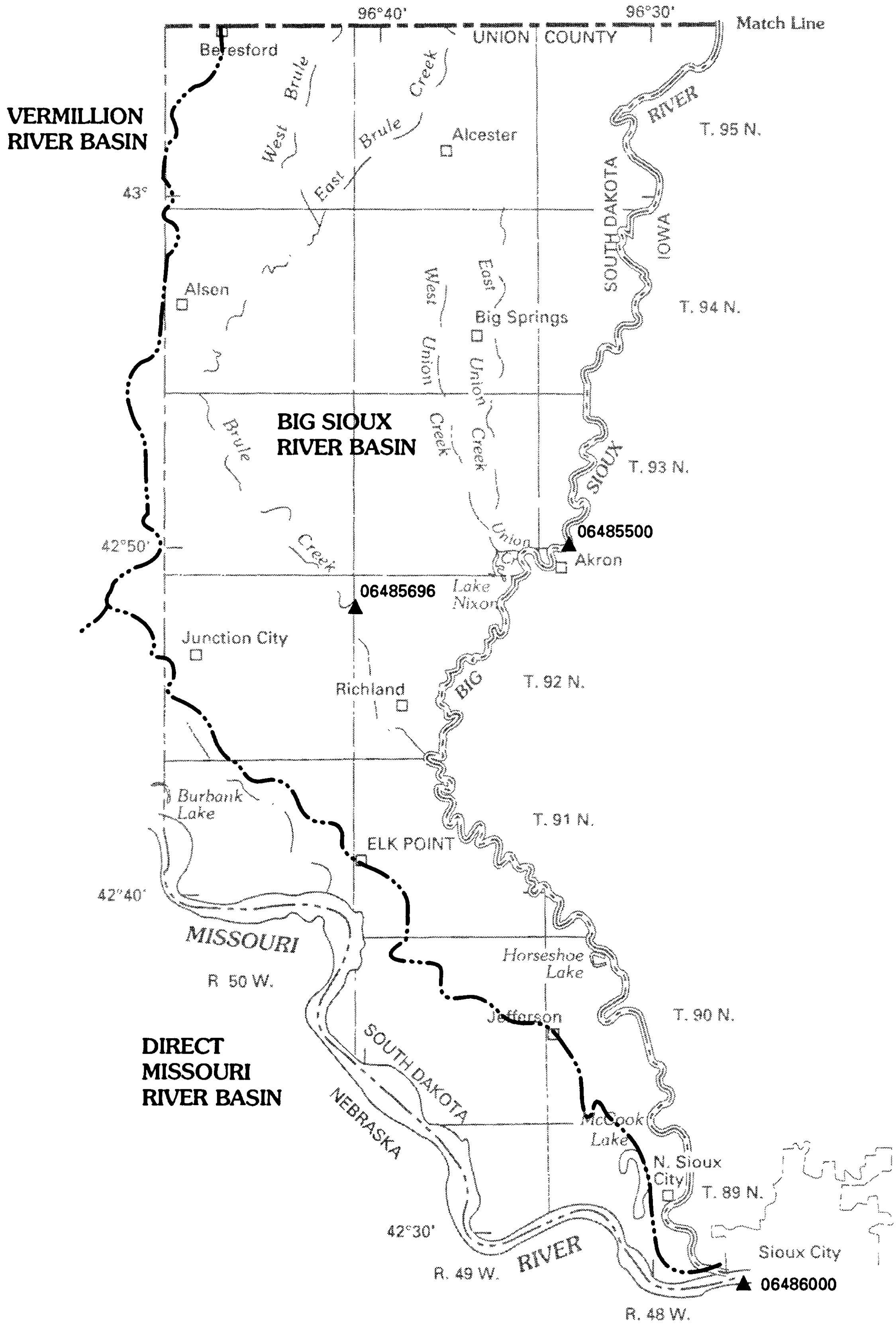


Figure 6.--Locations of drainage basins and U.S. Geological Survey streamflow-gaging stations in and near Lincoln and Union Counties.--Continued

Floods

With the exception of the Big Sioux River, flooding of large areas in Lincoln and Union Counties is uncommon because of the well-developed drainage system. However, major flooding can occur periodically along the larger creeks, notably Brule Creek in Union County and Beaver Creek in Lincoln County. Maps of flood-prone areas adjacent to the Big Sioux River are available from the U.S. Geological Survey. The flood-prone areas, shown on topographic maps at a scale of 1 to 24,000, are areas that have about a one in 100 chance, on the average, of being inundated during any year. Flooding is very unlikely for the areas bordering the Missouri River, because the flow in this river is regulated by a series of upstream dams and reservoirs.

Lakes

McCook Lake is located in extreme southeastern Union County in the flood plain of the Missouri River near North Sioux City (fig. 6). At a water-surface altitude of 1,092 ft above sea level, the surface area of this lake is about 290 acres.

Lake Alvin, located near Harrisburg in northern Lincoln County (fig. 6), has a surface area of about 100 acres at a water-surface altitude of 1,307 ft above sea level. Ninemile Creek, a tributary of the Big Sioux River, drains into the lake.

Lake Lakota is located near the Newton Hills State Park near Fairview in east-central Lincoln County (fig. 6) and is fed by Pattee Creek. It has a surface area of about 95 acres at a water-surface altitude of 1,384 ft above sea level.

Other natural or manmade smaller lakes in Lincoln and Union Counties include Lake Nixon, Burbank Lake, Horseshoe Lake, Carlson Lake, and Lake Albert. These lakes generally are all less than 50 acres in surface area. Many other small manmade ponds used for livestock watering also are in the study area.

Little water-quality data are available for lakes and ponds in the study area. However, it is known that lakes of this region have seasonal variations in water-quality constituents and properties (Lindgren and Niehus, 1992). Dissolved-solids concentrations generally decrease in the spring as the lake water is diluted by snowmelt and rainfall runoff and increase during the summer and fall as lake levels decline when evapotranspiration losses exceed inflow.

Ground-Water Occurrence and Chemical Quality

Glacial Aquifers

Ten glacial aquifers were delineated in Lincoln and Union Counties. A summary of selected hydrologic characteristics of these aquifers is given in table 2. The aquifers are discussed in the order shown in table 2, which generally is the order of occurrence from northern Lincoln County to southern Union County. Glacial aquifers are mostly unconsolidated sand and gravel outwash that were deposited by meltwaters from receding glaciers but locally can contain some alluvial deposits. Test drilling has shown that the aquifers are mostly overlain and underlain by till. Till in Lincoln and Union Counties generally consists of brown or gray clay with minor amounts of pebbles, sand, and silt. Till in eastern South Dakota has an average hydraulic conductivity of about 10^{-5} ft/d (Barari, 1985). The till generally will not yield a sufficient quantity of water to wells even for domestic use; however, locally it can contain thin, discontinuous sand and gravel lenses that yield 2 to 15 gal/min to domestic and stock-watering wells (Hansen, 1990).

Water-level fluctuations in observation wells screened in the Big Sioux, Newton Hills, Brule Creek, and Missouri glacial aquifers probably are caused by seasonal changes in recharge and discharge. Water levels generally rise from February through June because recharge from snowmelt and spring rainfall is greater than discharge (Hansen, 1990). Water levels generally decline from July through January because discharge from wells and evapotranspiration is greater than recharge. Hydrographs of observation wells screened in the Wall Lake, Harrisburg, Shindler, Upper Vermillion-Missouri, Parker-Centerville, and Lower Vermillion-Missouri glacial aquifers do not correspond closely with seasonal variations in precipitation.

Table 2.--Summary of selected hydrologic characteristics of the major aquifers in Lincoln and Union Counties

[--, not determined]

Aquifer name	Areal extent (square miles)	Maximum thickness (feet)	Average thickness[1] (feet)	Range in depth below land surface to top of aquifer (feet)	Average depth below land surface to top of aquifer[1] (feet)	Range of water level above (-) or below land surface[2] (feet)	Average water level below land surface[3] (feet)	Artesian (A) and (or) water-table (WT) aquifer (primarily)	Estimated volume of water in storage[4] (acre-feet)	Range of reported well discharges[5] (gallons per minute)	Suitability for irrigation[6]
GLACIAL AQUIFERS											
Wall Lake	40	92	32	6-178	106	20 - 88	56	A	120,000	--	Yes.
Harrisburg	90	63	26	8-170	59	35 - 90	64	WT	220,000	--	No.
Shindler	130	79	31	3-174	103	0 - 150	50	A	390,000	--	Yes.
Upper Vermillion-Missouri	85	116	41	106-240	162	110	110	A	330,000	--	No.
Parker-Centerville	25	53	35	0- 83	17	5 - 50	17	A	80,000	--	Yes.
Big Sioux	60	72	28	1-118	12	-7 - 48	13	WT	160,000	10-1,500	Yes.
Newton Hills	90	110	36	0-258	72	5 - 180	34	A	310,000	--	No.
Brule Creek	180	88	33	1-176	46	0 - 153	70	A	570,000	5- 250	Yes.
Lower Vermillion-Missouri	40	144	99	42-132	105	3 - 200	100	A	380,000	700-1,600	Yes.
Missouri	180	146	84	0-105	22	0 - 130	18	A, WT	1.5 million	10-1,800	Yes.
BEDROCK AQUIFER											
Dakota	935	423	[7]216	53-558	281	12 - 372	155	A	19.4 million	10-1,200	Yes.

[1]Arithmetic mean from test-hole data.
[2]A negative number indicates feet above land surface.
[3]Arithmetic mean from observation-well data.
[4]Storage was estimated by multiplying average thickness by areal extent and multiplying product by specific yield of 0.15.
[5]Reported data.
[6]Based on the South Dakota irrigation-water classification diagram (fig. 7).
[7]This average represents only Dakota wells and test holes that fully penetrate the aquifer.

The general suitability of water for irrigation from the glacial aquifers can be determined by use of 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. Water from seven of the glacial aquifers generally is suitable for most uses including irrigation.

Wall Lake aquifer

The composites of aquifer materials that comprise the Wall Lake aquifer (fig. 8) range from a fine to medium sand to a fine, medium, or coarse gravel. The aquifer is the southern extension of the Wall Lake aquifer described by Lindgren and Niehus (1992) and the eastern extension of the Wall Lake aquifer described by Lindgren and Hansen (1990). The aquifer underlies the northwestern corner of Lincoln County and generally is north and west of the Sioux Quartzite bedrock high. Analyses of test-drilling data and reported water levels indicate that the aquifer primarily is under artesian conditions. A geologic section of the aquifer is shown in figure 9, and selected hydrologic characteristics are given in table 2. A portion of the aquifer lies directly on Sioux Quartzite, and the aquifer mainly is overlain by till. Recharge to the Wall Lake aquifer is from fractures in the Sioux Quartzite in southern Minnehaha County, subsequent movement through these fractures, and then into the Wall Lake aquifer (Lindgren and Niehus, 1992). The general direction of water movement in the aquifer is southerly, based on data from observation wells 100N51W8DCCC and 100N51W27BBAA.

The relation between trends in precipitation and water-level fluctuations is not clear, based on limited water-level data from well 100N51W8DCCC (fig. 10). The only known discharge from the aquifer is through stock and domestic wells. Predominant chemical constituents in water from the Wall Lake aquifer are calcium and sulfate. A summary of chemical analyses of water from the aquifer is listed in table 3.

Harrisburg aquifer

The composites of unconsolidated materials that comprise the Harrisburg aquifer (fig. 8) range from a fine to medium sand to a mixture of fine to coarse sand and fine to medium gravel. The aquifer underlies northeast Lincoln County and generally is east of the Sioux Quartzite or Carlile Shale bedrock high. Analyses of test-drilling data and reported water levels indicate that the aquifer primarily is under water-table conditions. A geologic section of the aquifer is shown in figure 9, and selected hydrologic characteristics are listed in table 2. The aquifer is overlain by till and underlain mostly by till but in a few places is underlain by Sioux Quartzite, Carlile Shale, or Niobrara Formation. Less than 10 ft of till separates the Harrisburg aquifer from the underlying Shindler aquifer in the central part of the area underlain by the Harrisburg aquifer. Recharge to the Harrisburg aquifer probably is by downward leakage through till. The dissolved-solids concentration of five samples from U.S. Geological Survey (USGS) analyses averaged 4,075 mg/L (milligrams per liter). These high concentrations of dissolved solids could result, in part, from the thick cover of glacial till that overlies the aquifer (average depth below land surface to the top of the aquifer is 59 ft). As water leaks through the till to the aquifer, it dissolves solids from the till which could increase the concentrations of dissolved solids in the aquifer water.

Discharge from the aquifer is through withdrawals from stock, domestic, and irrigation wells; evaporation from the water-table surface where the aquifer is near land surface; seepage and flow from springs; and probably ground-water discharge to the underlying Shindler aquifer. Dissolved calcium, dissolved sodium, and dissolved sulfate concentrations in water from the Harrisburg aquifer averaged 660, 230, and 2,100 mg/L, respectively (from USGS analyses). The Harrisburg overlies much of the Shindler and in some places, the aquifers are separated vertically by less than 10 ft of till. Analyses of water-level fluctuations in well 99N49W32DCDC indicate no clear relation with trends in precipitation (fig. 10).

Predominant chemical constituents in water from the Harrisburg aquifer are calcium and sulfate. Specific conductance, determined from three onsite

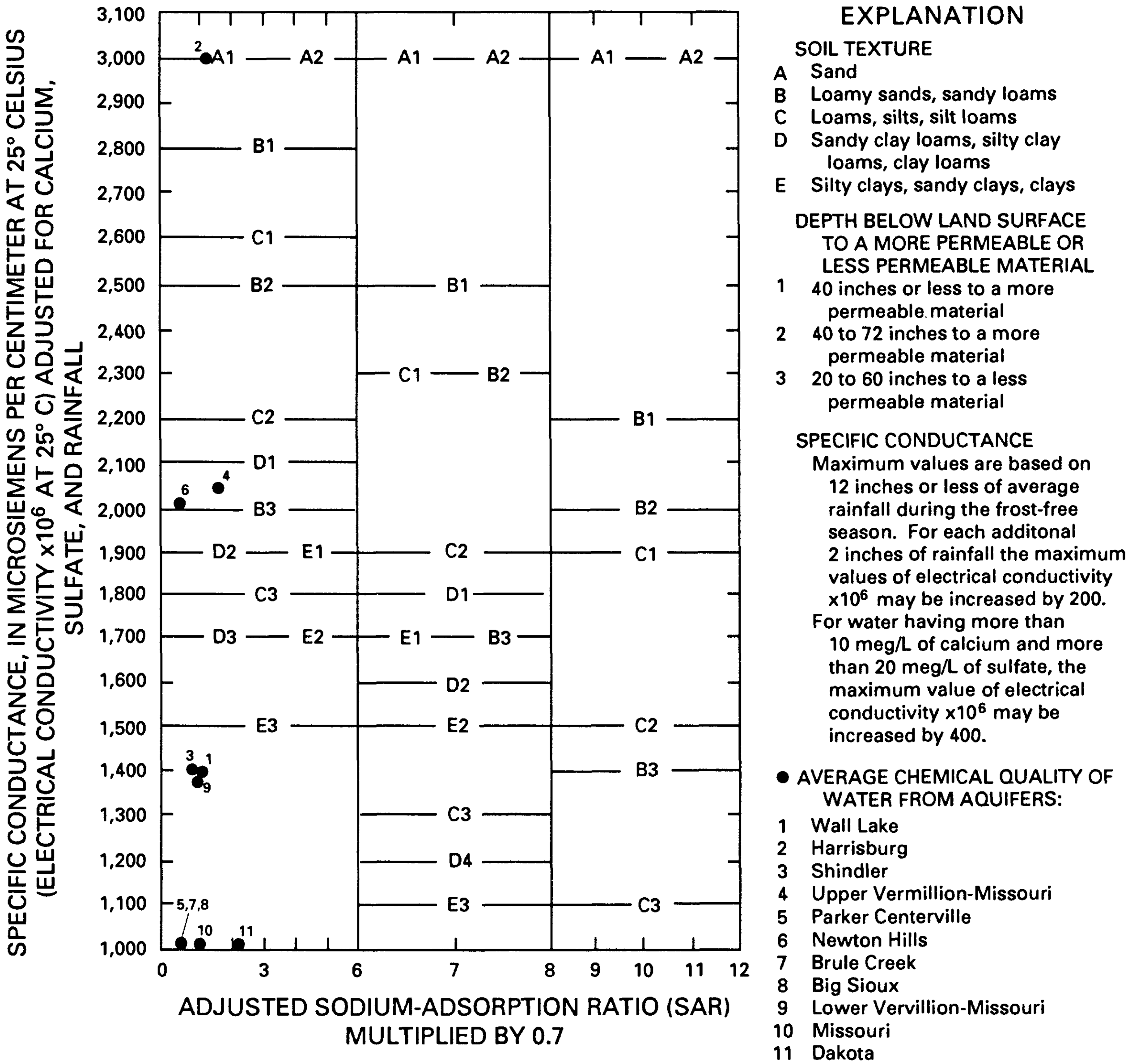
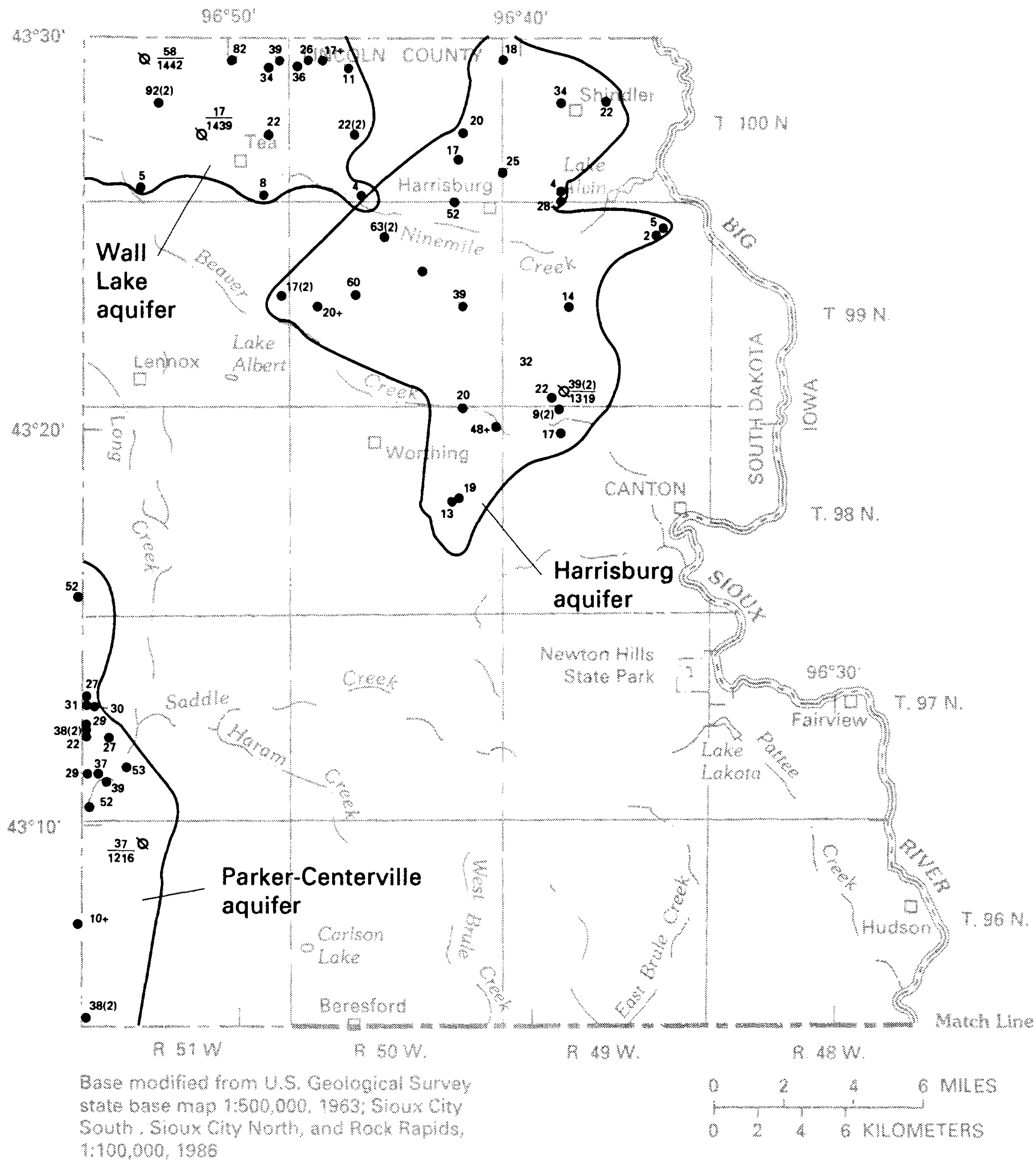


Figure 7.--South Dakota irrigation-water classification diagram (based on South Dakota standards (revised Jan. 7, 1982) for maximum allowable specific conductance and adjusted sodium-adsorption-ratio values for which an irrigation permit can be issued for applying water under various soil-texture conditions. Water can be applied for all soil-texture 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)).



EXPLANATION

APPROXIMATE AQUIFER BOUNDARY

20+ TEST HOLE--Number is the thickness of the aquifer, in feet. Number in parenthesis is number of aquifer units penetrated where more than one. A plus (+) indicates thickness of aquifer greater than shown.

39(2)/1319 OBSERVATION WELL--Upper number is the thickness of the aquifer, in feet. Lower number is the altitude of potentiometric surface, in feet, of the Wall Lake, Harrisburg, and Parker-Centerville aquifers during June 1987, October 1986, and December 1981, respectively. Number in parenthesis is the number of aquifer units penetrated where more than one (multiple units of one aquifer). Datum is sea level.

Figure 8.--Extent, thickness, and altitude of the potentiometric surface of the Wall Lake, Harrisburg, and Parker-Centerville aquifers in Lincoln County.

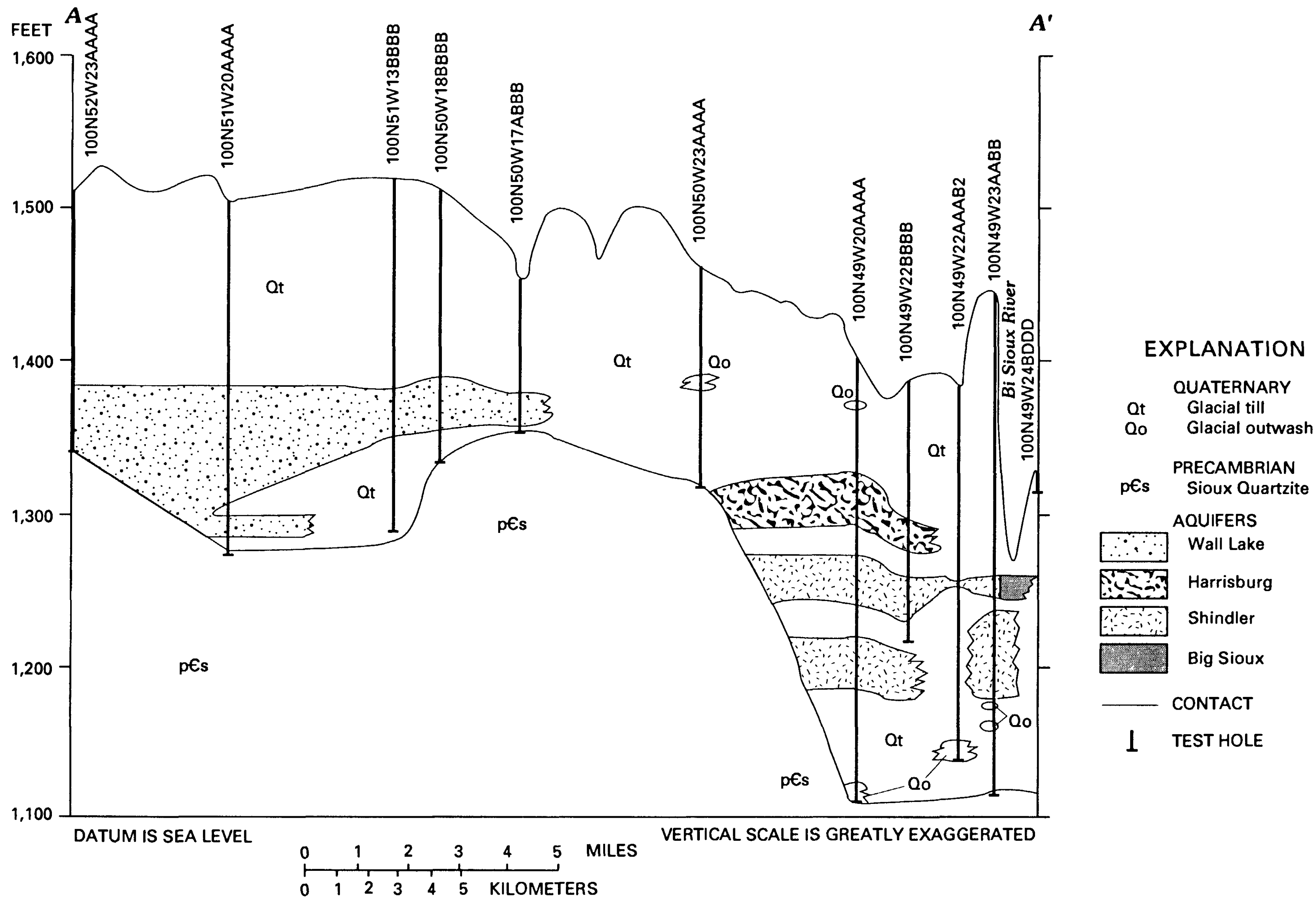


Figure 9.--Geologic section A-A' showing the Wall Lake, Harrisburg, Shindler, and Big Sioux aquifers in Lincoln County. (Section A-A' is shown in figure 2.)

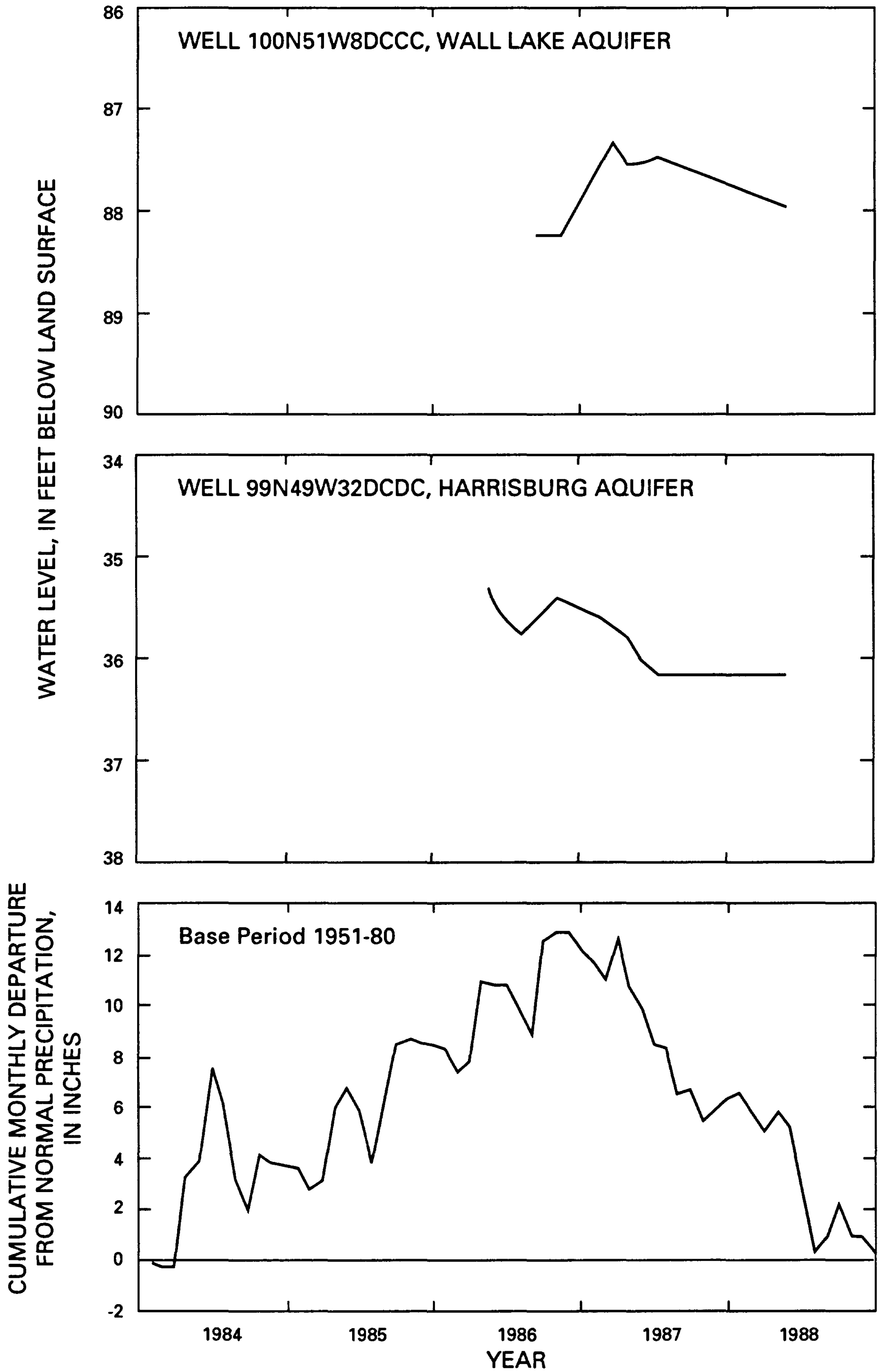


Figure 10.--Water-level fluctuations in the Wall Lake and Harrisburg aquifers and the cumulative monthly departure from normal precipitation at Canton.

Table 3.--Summary of chemical analyses of water from the Wall Lake and Harrisburg aquifers in Lincoln County

[Analyses by U.S. Geological Survey, South Dakota Geological Survey, and others. Results in milligrams per liter except as indicated; µg/L, micrograms per liter; --, not analyzed; -, not computed; <, less than; ND, not detected. For the statistical analysis of physical properties of water and chemical constituents in this table, the following assumptions were used: (1) Values of zero were assigned to constituents that were not detected. The detection limits for these constituents were unknown. (2) Values equal to the detection limits (that is, constituent <.1) were assigned to constituents that were less than specific values. (3) Average values were assigned to constituents when there were multiple-date analyses at a specific site. These average values were then averaged with other site location's constituents to arrive at mean values. This was done to avoid skewing the data]

	Wall Lake aquifer				Harrisburg aquifer			
	Number of samples	Mean	Minimum value	Maximum value	Number of samples	Mean	Minimum value	Maximum value
Specific conductance, field (microsiemens per centimeter at 25°C)	2	-	1,450	2,150	1	-	3,800	3,800
pH, field (units)	2	-	7.2	7.7	1	-	7.1	7.1
Temperature, water (°C)	0	--	--	--	0	--	--	--
Alkalinity, field (as $CaCO_3$)	2	-	152	410	1	-	490	490
Hardness (as $CaCO_3$)	6	990	750	1,200	5	2,700	2,000	3,400
Dissolved solids, residue at 180°C	5	1,620	1,280	2,160	5	4,075	3,600	4,750
Dissolved calcium	6	277	230	320	5	660	520	850
Dissolved magnesium	6	74	43	94	5	260	170	320
Dissolved sodium	6	122	68	200	5	230	110	310
Sodium absorption ratio	6	1.7	1	3	5	2	0.9	3
Dissolved potassium	2	-	7	14	1	-	22	22
Bicarbonate, field (as HCO_3)	2	-	180	500	1	-	600	600
Dissolved sulfate	6	900	730	1,200	5	2,100	1,400	2,700
Dissolved chloride	6	7	3	10	5	18	<1.0	45
Dissolved fluoride	4	0.26	0.22	0.30	3	0.45	0.24	0.62
Nitrogen, nitrate (as N)	5	0.33	<0.10	1.24	5	12	ND	36
Dissolved nitrogen, NO_2+NO_3	0	--	--	--	0	--	--	--
Dissolved iron (µg/L)	0	--	--	--	0	--	--	--
Iron, recoverable (µg/L)	5	2,750	ND	8,400	5	6,000	450	21,000
Dissolved manganese (µg/L)	0	--	--	--	0	--	--	--
Manganese, recoverable (µg/L)	4	2,475	1,900	2,900	4	3,230	220	6,200

analyses, ranged from 1,260 to 3,280 μS/cm and averaged 2,570 μS/cm. Hardness concentration, determined from three onsite analyses, ranged from 700 to 2,020 mg/L and averaged 1,580 mg/L. Onsite analyses (mentioned above and later in the text) only represent field analyses (specific conductance and hardness) done by the South Dakota District (USGS) for samples that were not submitted for laboratory analyses. These data are not included in the tables, which include field conductance and chemical analyses results for samples sent to the U.S. Geological Survey National Water Quality laboratory in Denver, Colorado. A summary of chemical analyses of water from the Harrisburg aquifer is given in table 3.

Shindler aquifer

The composites of aquifer materials that comprise the Shindler aquifer (fig. 11) range from a mixture of fine to very coarse sand to a fine to coarse gravel. The aquifer underlies northeast Lincoln County. The aquifer is connected hydraulically with the Big Sioux aquifer on its southeastern boundary (figs. 9, 12, and 13). Analyses of test-drilling data and reported water levels indicate that the aquifer primarily is under artesian conditions. Geologic sections of the aquifer are shown in figures 9 and 13, and selected hydrologic characteristics are given in table 2. The Harrisburg aquifer overlies most of the Shindler aquifer. These two aquifers are separated by less than 10 ft of till in the central area of the Shindler aquifer. The Shindler aquifer is underlain at various locations by till, Niobrara Formation, Carlile Shale, or Sioux Quartzite.

Dissolved calcium, dissolved sodium, and dissolved sulfate concentrations (from USGS analyses) averaged 660, 230, and 2,100 mg/L for the Harrisburg, and 350, 123, and 1,200 mg/L for the Shindler aquifer. The Harrisburg aquifer probably contributes some recharge through till to the underlying Shindler aquifer. The high concentrations of dissolved solids (mean of 2,220 mg/L) in the water in the Shindler aquifer probably are due in part to the thick cover of glacial till that overlies the aquifer (the depth below land surface to the top of the aquifer averages 103 ft). As water leaks through the till to the aquifer, it dissolves solids from the till which could increase the concentration of dissolved solids in the aquifer water. The general direction of water movement in the Shindler aquifer is easterly toward the Big Sioux River.

Discharge from the aquifer is through withdrawals from stock and domestic wells and by ground-water discharge to the Big Sioux aquifer. Water-quality data from the Shindler and Big Sioux aquifers support this hydraulic connection. This connection is discussed in more detail in the section on the Big Sioux aquifer. Specific conductance, and dissolved calcium, dissolved sodium, and dissolved sulfate averaged 2,200 μS/cm, 350 mg/L, 123 mg/L, and 1,200 mg/L for water from the Shindler aquifer. Analyses of records of water-level fluctuations in well 99N49W11AAAA2 show some correlation with trends in precipitation (fig. 14) for the last half of 1985 and all of 1986.

Predominant chemical constituents in water from the Shindler aquifer are calcium and sulfate. Specific conductance, determined from seven onsite analyses, ranged from 1,320 to 3,650 μS/cm and averaged 2,560 μS/cm. Hardness concentration, determined from seven onsite analyses, ranged from 700 to 2,330 mg/L and averaged 1,440 mg/L. A summary of chemical analyses of water from the aquifer is listed in table 4.

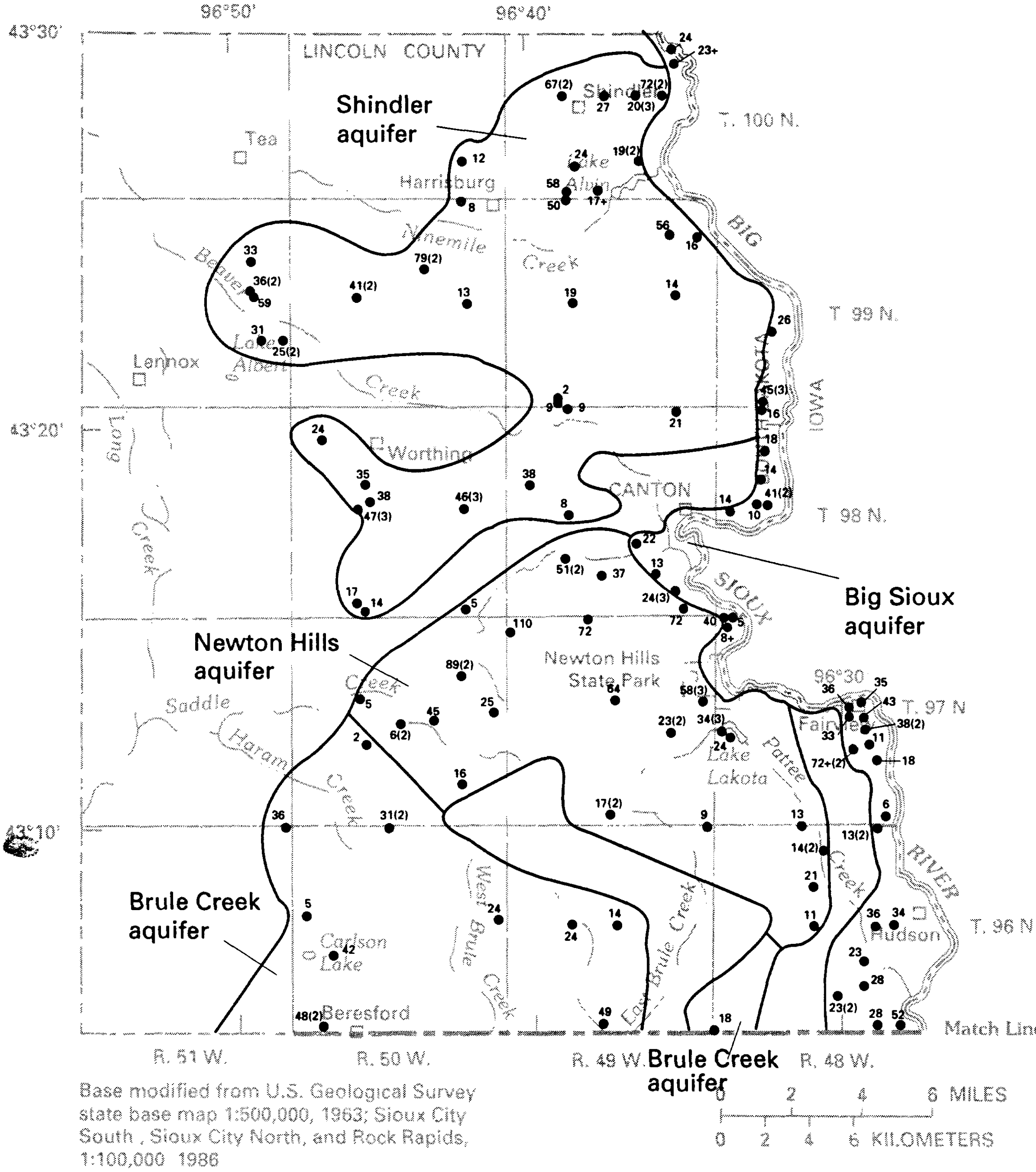
Upper Vermillion-Missouri aquifer

The Upper Vermillion-Missouri aquifer (fig. 15) is composed of a mixture of fine to coarse sand and fine to coarse gravel. The aquifer is the eastern extension of the Upper Vermillion-Missouri aquifer described by Lindgren and Hansen (1990). The aquifer underlies extreme western Lincoln County, on the western side of the Niobrara Formation bedrock high. A reported water level at well 99N50W17DDDD2 indicates that the aquifer probably is under artesian conditions. A geologic section of the aquifer is shown in figure 13, and selected hydrologic characteristics are listed in table 2. The aquifer overlies Sioux Quartzite or Carlile Shale in most areas and is overlain by till.

Table 4.--Summary of chemical analyses of water from the Shindler and Upper Vermillion-Missouri aquifers in Lincoln County

[Analyses by U.S. Geological Survey, South Dakota Geological Survey, and others. Results in milligrams per liter except as indicated; µg/L, micrograms per liter; --, not analyzed; -, not computed; <, less than; ND, not detected. For the statistical analysis of physical properties in water and chemical constituents in this table, the following assumptions were used: (1) Values of zero were assigned to constituents that were not detected. The detection limits for these constituents were unknown. (2) Values equal to the detection limits (that is, constituent <.1) were assigned to constituents that were less than specific values. (3) Average values were assigned to constituents when there were multiple-date analyses at a specific site. These average values were then averaged with other site location's constituents to arrive at mean values. This was done to avoid skewing the data]

	Shindler aquifer				Upper Vermillion-Missouri aquifer			
	Number of samples	Mean	Minimum value	Maximum value	Number of samples	Mean	Minimum value	Maximum value
Specific conductance, field (microsiemens per centimeter at 25°C)	4	2,200	1,750	2,700	6	2,840	1,760	3,800
pH, field (units)	2	-	6.7	7.6	7	7.5	7.1	7.8
Temperature, water (°C)	2	-	9	11	0	--	--	--
Alkalinity, field (as $CaCO_3$)	2	307	267	347	6	296	84	488
Hardness (as $CaCO_3$)	8	1,255	810	1,900	9	1,300	800	2,000
Dissolved solids, residue at 180°C	8	2,220	1,380	3,150	8	2,400	1,300	3,600
Dissolved calcium	8	350	220	495	9	350	220	630
Dissolved magnesium	8	90	35	155	9	102	51	190
Dissolved sodium	8	123	58	230	8	194	103	320
Sodium absorption ratio	8	1.4	0.7	3	8	2.5	2	4
Dissolved potassium	3	13.8	6.4	20	6	17	11	25
Bicarbonate, field (as HCO_3)	2	-	330	420	6	360	100	600
Dissolved sulfate	8	1,200	630	1,900	9	1,400	620	2,200
Dissolved chloride	8	9	<3.0	23	9	13	3	27
Dissolved fluoride	7	0.28	0.15	0.37	0	--	--	--
Nitrogen, nitrate (as N)	6	0.09	0.03	0.10	8	0.48	ND	1.95
Dissolved nitrogen, NO_2+NO_3	2	-	0.1	0.4	0	--	--	--
Dissolved iron (µg/L)	2	-	200	5,150	0	--	--	--
Iron, recoverable (µg/L)	6	4,200	270	14,000	9	3,600	80	10,000
Dissolved manganese (µg/L)	2	-	1,100	1,800	0	--	--	--
Manganese, recoverable (µg/L)	5	1,490	290	4,400	3	2,200	2,100	2,400



EXPLANATION

APPROXIMATE AQUIFER BOUNDARY

72+(2)
TEST HOLE--Number is the thickness of the aquifer, in feet. Number in parenthesis is number of aquifer units penetrated where more than one. A plus (+) indicates thickness of aquifer greater than shown.

Figure 11.--Extent and thickness of the Shindler, Big Sioux, Newton Hills, Brule Creek, Lower Vermillion-Missouri, and Missouri aquifers in Lincoln and Union Counties.

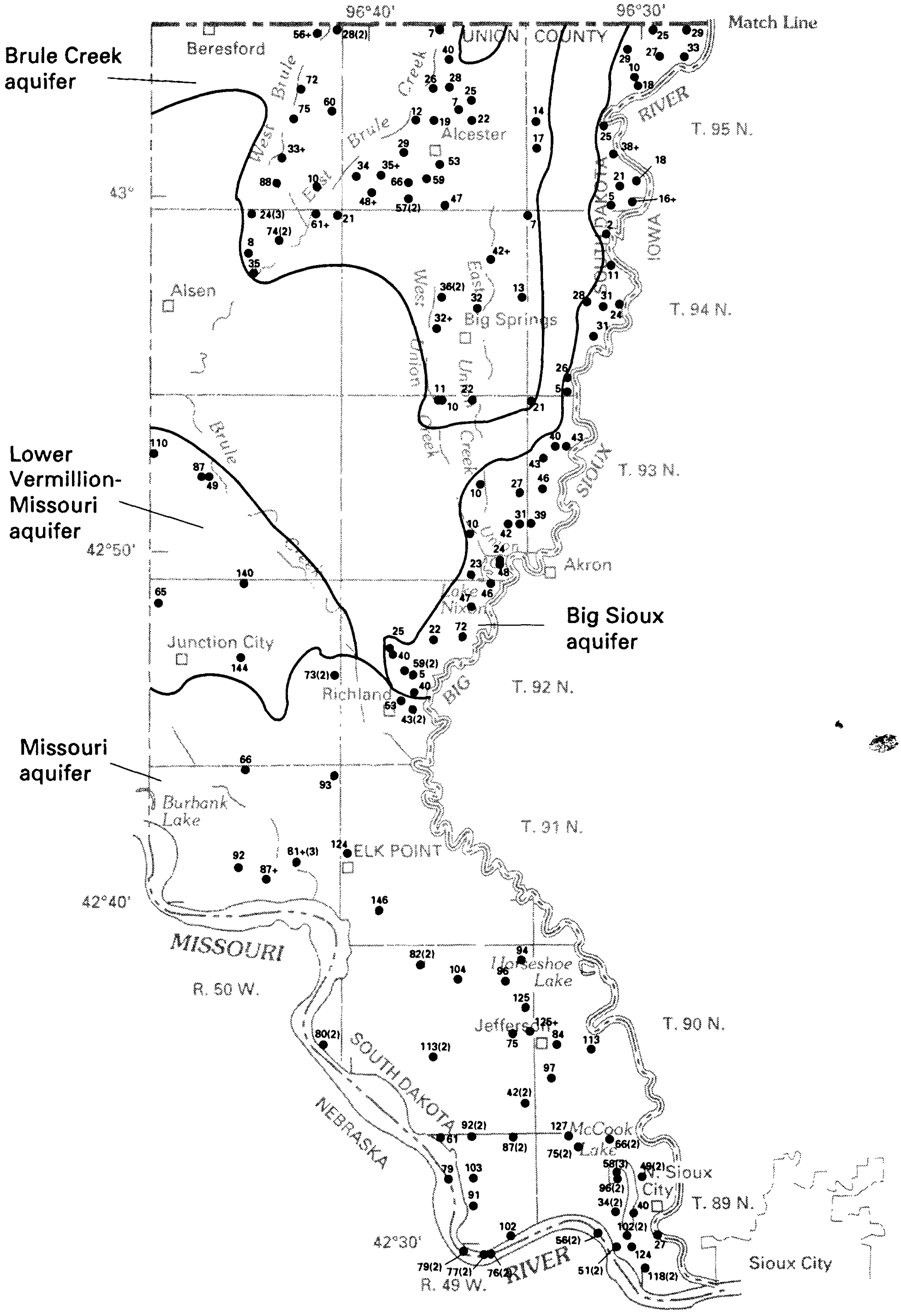
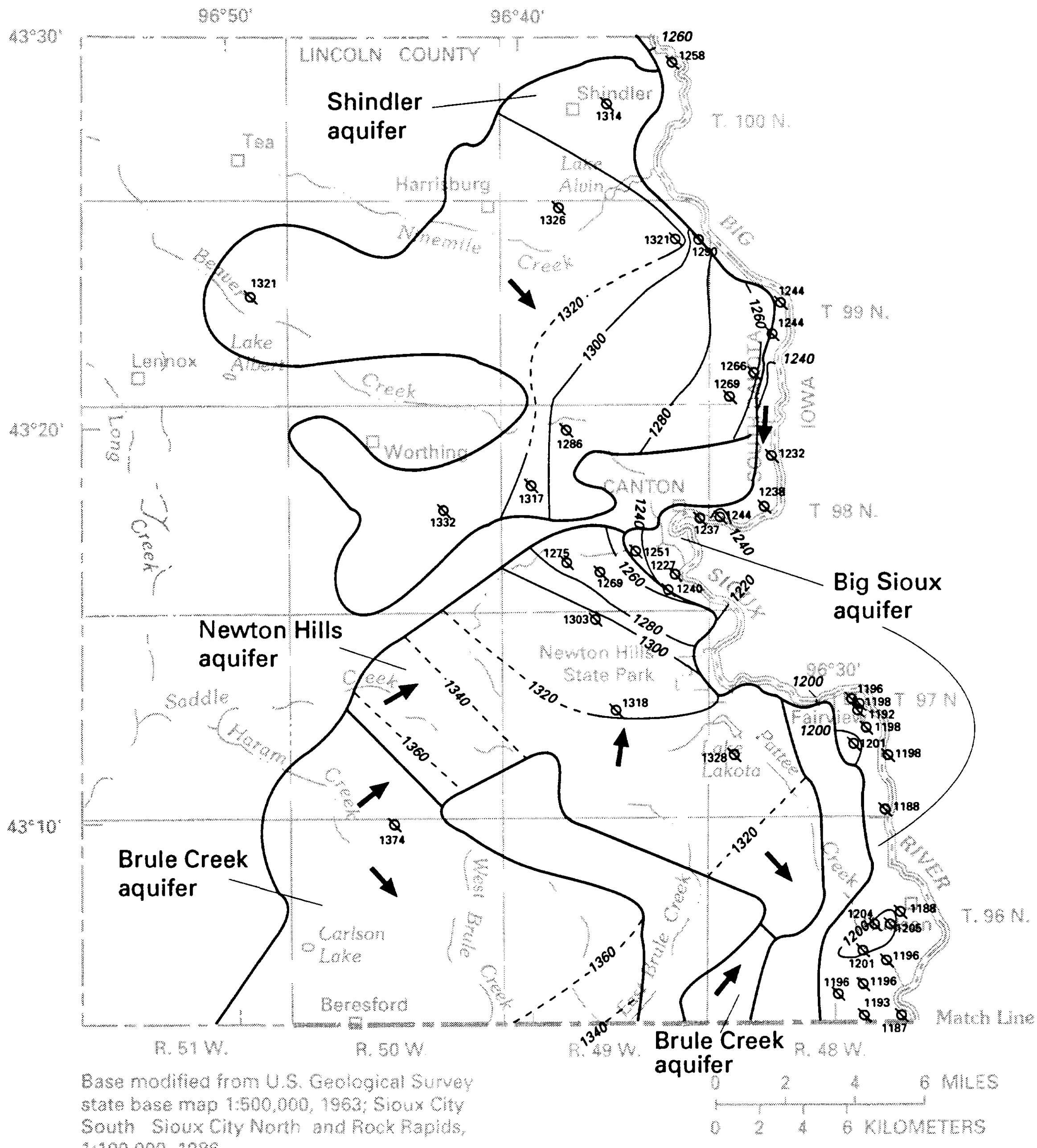


Figure 11.--Extent and thickness of the Shindler, Big Sioux, Newton Hills, Brule Creek, Lower Vermillion-Missouri, and Missouri aquifers in Lincoln and Union Counties.--Continued



EXPLANATION

— 1300 - - - POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly closed wells for aquifers: Shindler, May 1988; Big Sioux, Sept. 1986; Newton Hills and Brule Creek, May 1988; and Lower Vermillion-Missouri and Missouri, Sept. 1986. Contour interval is 20 feet, except for Lower Vermillion-Missouri and Missouri aquifers where it is 10 feet. Dashed where approximately located. Datum is sea level.

APPROXIMATE AQUIFER BOUNDARY

1374 OBSERVATION WELL--Number is altitude of potentiometric surface, in feet. Datum is sea level.

DIRECTION OF GROUND-WATER MOVEMENT

Figure 12.--Altitude of the potentiometric surfaces of the Shindler, Big Sioux, Newton Hills, Brule Creek, Lower Vermillion-Missouri, and Missouri aquifers in Lincoln and Union Counties.

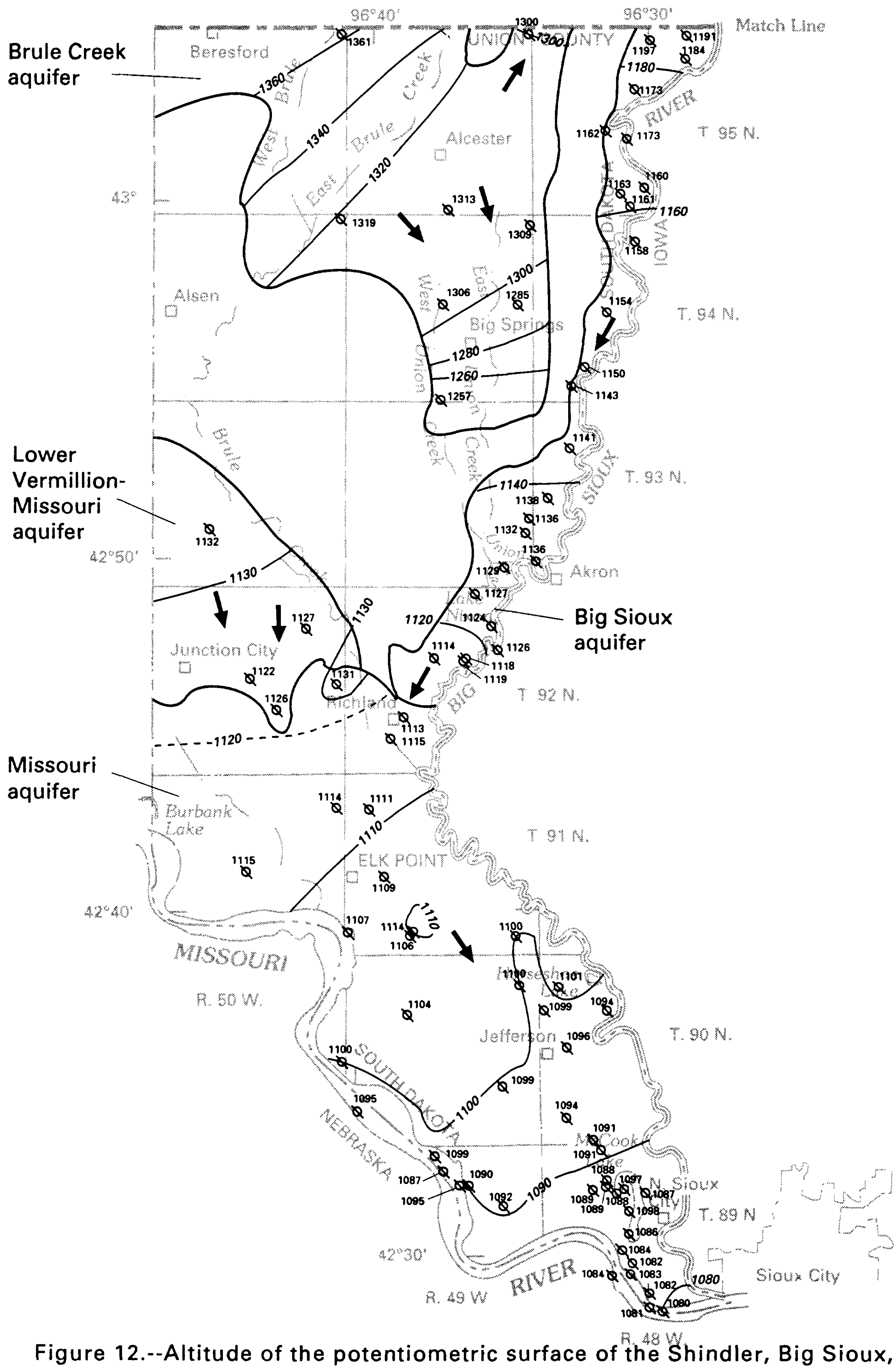


Figure 12.--Altitude of the potentiometric surface of the Shindler, Big Sioux, Newton Hills, Brule Creek, Lower Vermillion-Missouri, and Missouri aquifers in Lincoln and Union Counties.--Continued

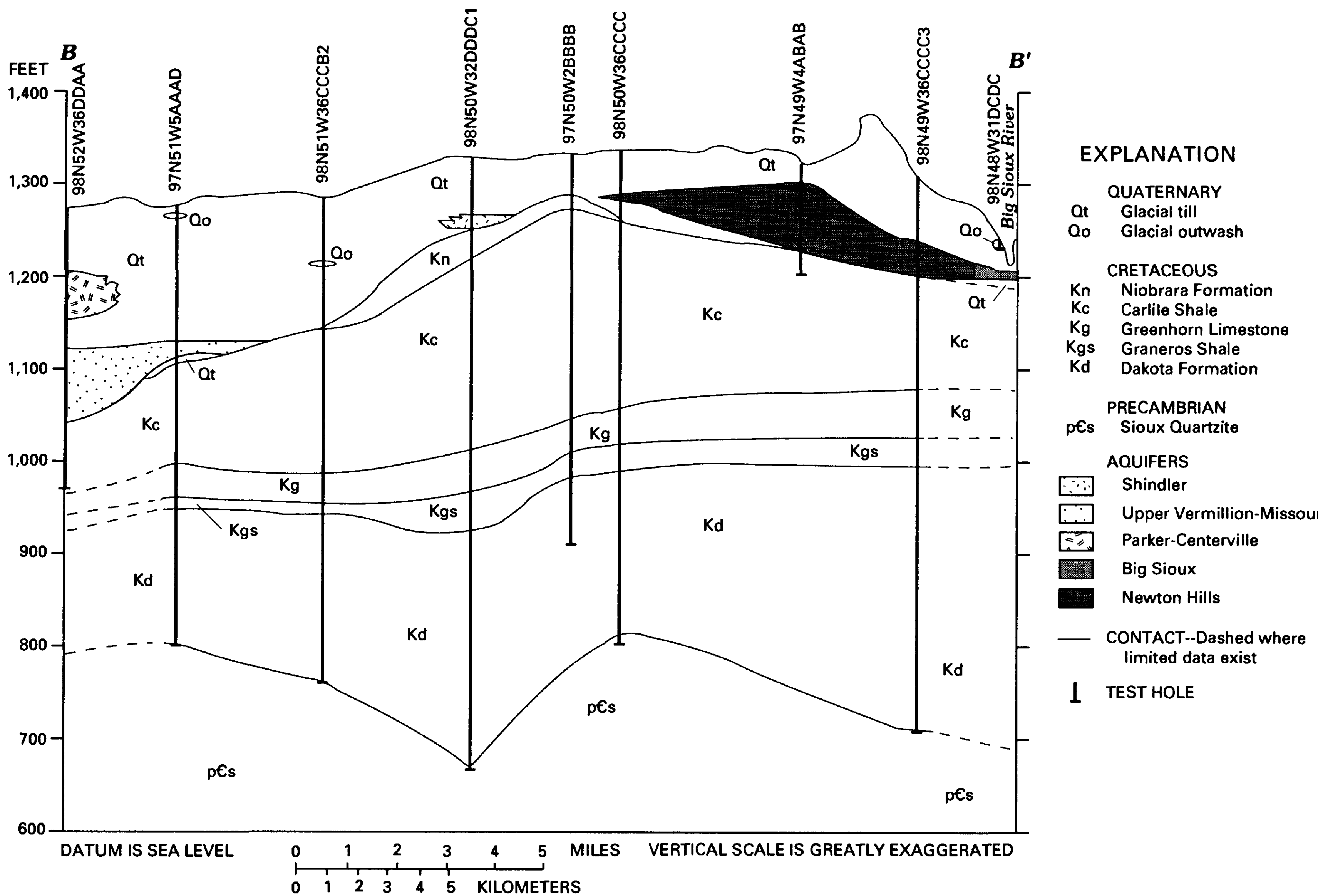


Figure 13.--Geologic section B-B' showing the Shindler, Upper Vermillion-Missouri, Parker-Centerville, Big Sioux, and Newton Hills aquifers in Lincoln County, South Dakota. (Section B-B' is shown in figure 3.)

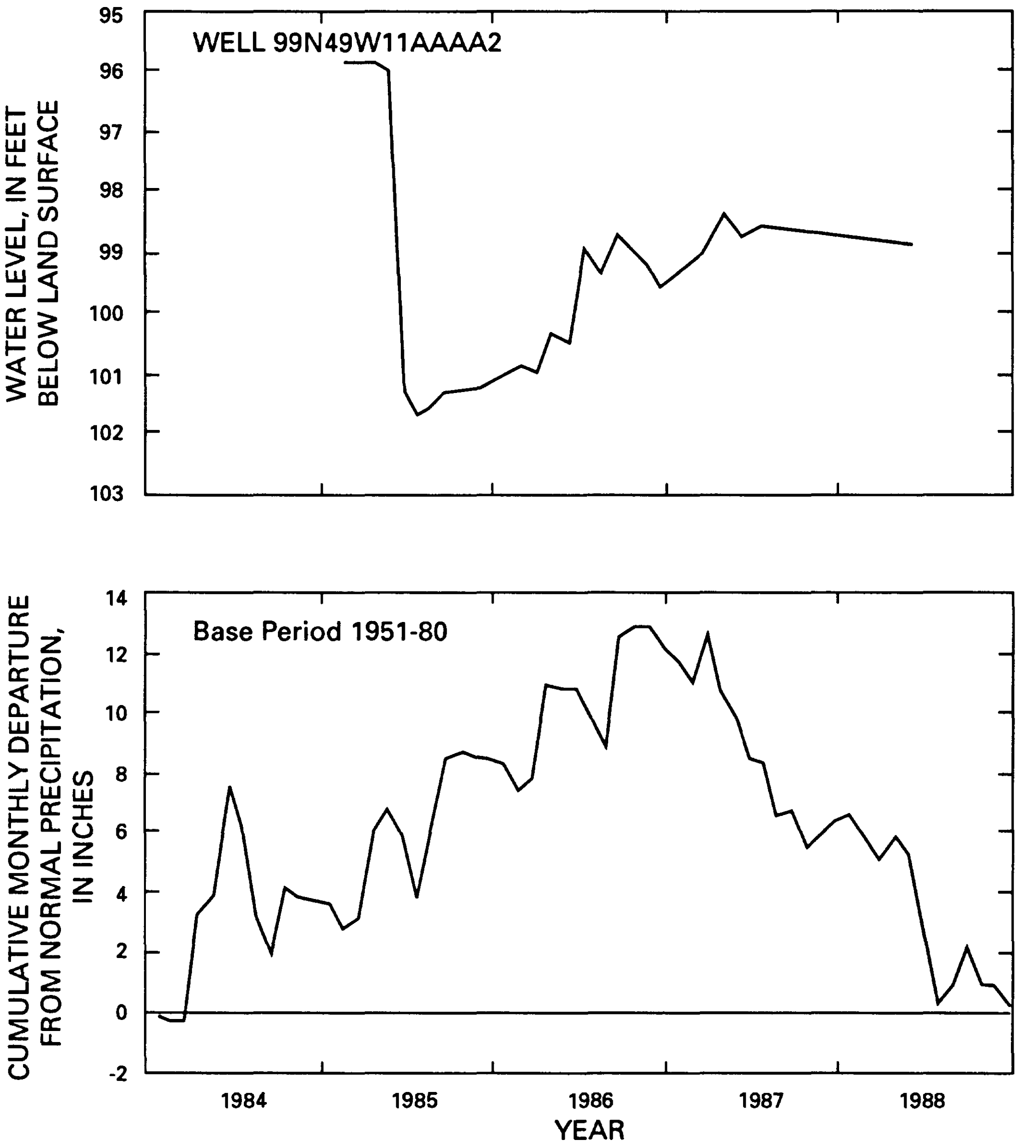
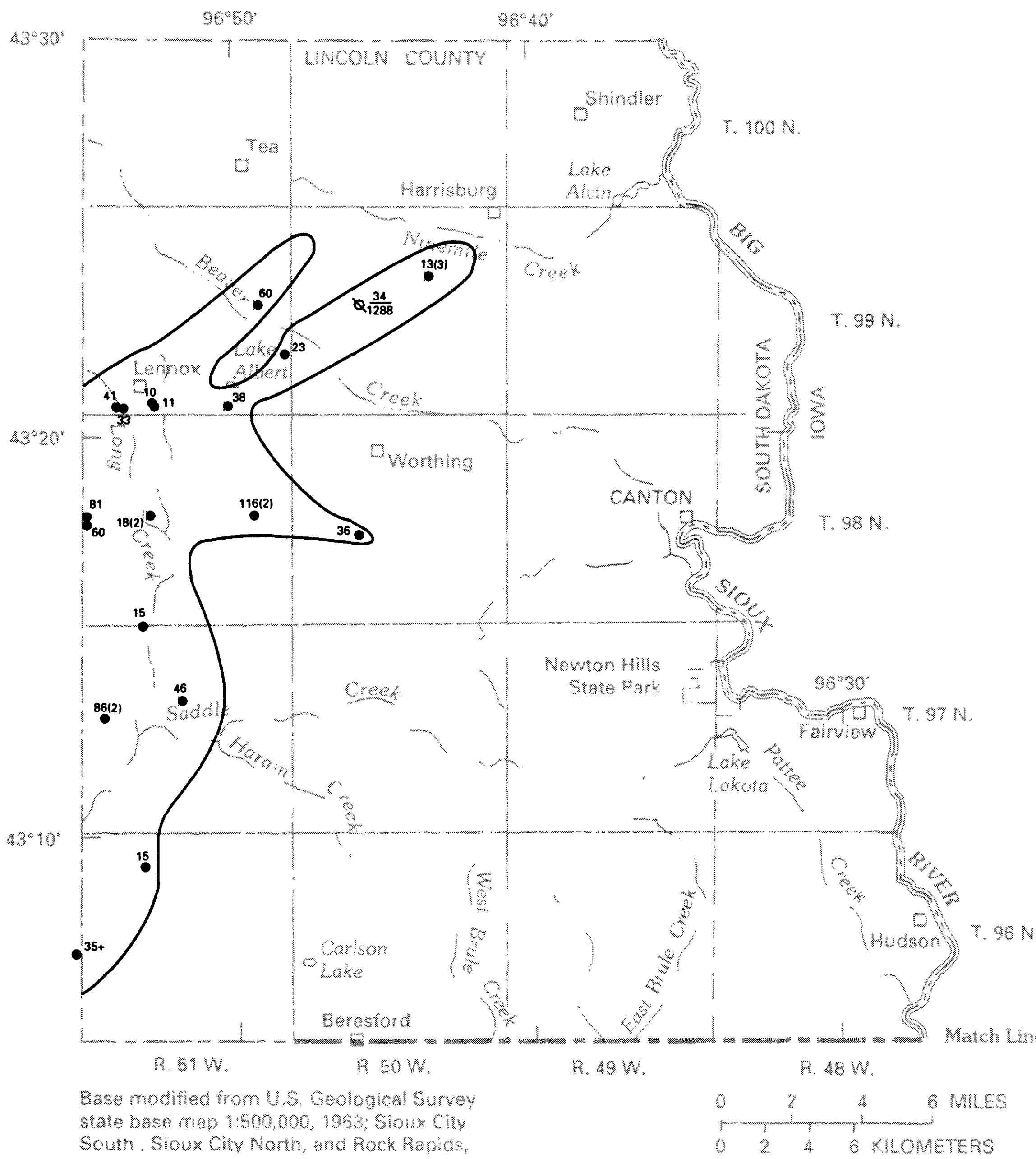


Figure 14.--Water-level fluctuations in the Shindler aquifer and the cumulative monthly departure from normal precipitation at Canton.



Base modified from U.S. Geological Survey state base map 1:500,000, 1963; Sioux City South , Sioux City North, and Rock Rapids, 1:100,000, 1986

EXPLANATION

APPROXIMATE AQUIFER BOUNDARY

35+ TEST HOLE--Number is the thickness of the aquifer, in feet. Number in parenthesis is number of aquifer units penetrated where more than one. A plus (+) indicates thickness of aquifer greater than shown.

34/1288 OBSERVATION WELL--Upper number is the thickness of the aquifer, in feet. Lower number is the altitude of potentiometric surface, in feet, of the Upper Vermillion-Missouri aquifer during October 1981. Datum is sea level.

Figure 15.--Extent, thickness, and altitude of the potentiometric surface of the Upper Vermillion-Missouri aquifer in Lincoln County.

The overlying Parker-Centerville aquifer probably contributes some recharge to the Upper Vermillion-Missouri aquifer. Less than 10 ft of till separates the Upper Vermillion-Missouri aquifer from the Parker-Centerville aquifer at well 96N51W8AAAA. The specific conductance of water in the Upper Vermillion-Missouri aquifer at well 97N51W19BBBB2, where it underlies the Parker-Centerville aquifer, was 1,760 µS/cm (from USGS analyses). In parts of the Upper Vermillion-Missouri not underlying the Parker-Centerville, the specific conductance of water in the Upper Vermillion-Missouri aquifer averaged 3,000 µS/cm (from USGS analyses). This could be expected because the average specific conductance of water in the Parker-Centerville was much lower than the average specific conductance (2,840 µS/cm from USGS analyses) of water in the Upper Vermillion-Missouri aquifer. Therefore, in areas of recharge, water from the Parker-Centerville aquifer could cause a lower specific conductance of water in the Upper Vermillion-Missouri aquifer than where the Parker-Centerville aquifer does not overlie the Upper Vermillion-Missouri aquifer. Discharge from the aquifer is through withdrawals from stock, domestic, and municipal wells.

Predominant chemical constituents in water from the aquifer are calcium and sulfate. Specific conductance, determined from four onsite analyses, ranged from 1,660 to 2,300 µS/cm and averaged 2,040 µS/cm. Hardness concentration, determined from four onsite analyses, ranged from 650 to 1,180 mg/L and averaged 880 mg/L. A summary of chemical analyses of water from the aquifer is given in table 4.

Parker-Centerville aquifer

The Parker-Centerville aquifer (fig. 8), which underlies the extreme southwestern edge of Lincoln County, is composed of a mixture of fine to coarse sand and fine to coarse gravel. The aquifer is the eastern extension of the Parker-Centerville aquifer described by Lindgren and Hansen (1990). Analyses of test-drilling data and reported water levels indicate that the aquifer primarily is under artesian conditions. Geologic sections of the aquifer are shown in figures 13 and 16, and selected hydrologic characteristics are given in table 2. The aquifer is overlain in most areas by till. At well 96N51W8AAAA, less than 10 ft of till separates the Parker-Centerville aquifer from the underlying Upper Vermillion-Missouri aquifer. Recharge to the Parker-Centerville aquifer is by infiltration and subsequent percolation of rainfall and snowmelt in areas where the aquifer is at or near land surface. Laboratory chemical analyses of water samples (by USGS) support this conclusion, as the average specific conductance of water from the aquifers was only 755 µS/cm. Also, in Turner County the Parker-Centerville aquifer is close to land surface and is recharged by the Vermillion River (Bardwell, 1984), which could cause lower specific conductances in the aquifer in Lincoln County.

Discharge from the aquifer is: (1) through withdrawals from stock, domestic, and municipal wells, (2) by seepage and flow from springs, (3) by evapotranspiration where the aquifer is near land surface, and (4) probably by discharge to the Upper Vermillion-Missouri aquifer. This conclusion is supported by the fact that water obtained from the Upper Vermillion-Missouri aquifer had a specific conductance of 1,750 µS/cm (from USGS laboratory analyses) at well 97N51W19BBBB2 (an area where the Upper Vermillion-Missouri aquifer underlies the Parker-Centerville aquifer) whereas the specific conductance averaged about 3,000 µS/cm (from USGS analyses) in parts of the Upper Vermillion-Missouri not underlying the Parker-Centerville. This would be expected since the average specific conductance of the Parker-Centerville (755 µS/cm from USGS analyses) was much lower than the average specific conductance (2,840 µS/cm from USGS analyses) of the Upper Vermillion-Missouri aquifer.

Predominant chemical constituents in water from the Parker-Centerville aquifer are calcium, magnesium, sulfate, and bicarbonate. A summary of chemical analyses of water from the aquifer is given in table 5. No onsite analyses for specific conductance or hardness were performed.

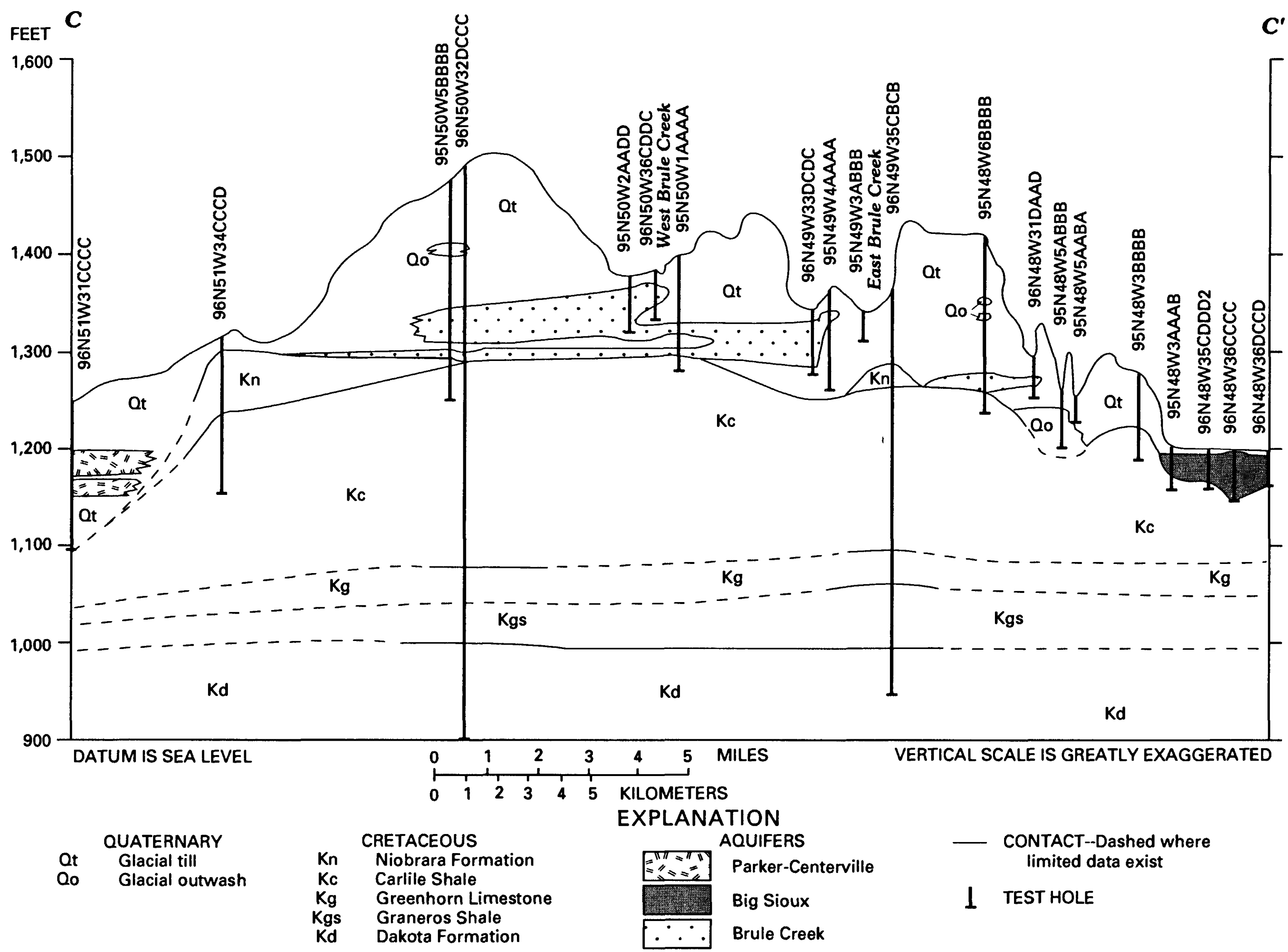


Figure 16.--Geologic section C-C' showing the Parker-Centerville, Big Sioux, and Brule Creek aquifers in Lincoln and Union Counties. (Section C-C' is shown in figure 2.)

Table 5.--Summary of chemical analyses of water from the Parker-Centerville and Big Sioux aquifers in Lincoln and Union Counties

[Analyses by U.S. Geological Survey, South Dakota Geological Survey, and others. Results in milligrams per liter except as indicated; µg/L, micrograms per liter; --, not analyzed; <, less than; ND, not detected. For the statistical analysis of physical properties in water and chemical constituents in this table, the following assumptions were used: (1) Values of zero were assigned to constituents that were not detected. The detection limits for these constituents were unknown. (2) Values equal to the detection limits (that is, constituent <.1) were assigned to constituents that were less than specific values. (3) Average values were assigned to constituents when there were multiple-date analyses at a specific site. These average values were then averaged with other site location's constituents to arrive at mean values. This was done to avoid skewing the data]

	Parker-Centerville aquifer				Big Sioux aquifer			
	Number of samples	Mean	Minimum value	Maximum value	Number of samples	Mean	Minimum value	Maximum value
Specific conductance, field (microsiemens per centimeter at 25°C)	4	755	678	897	15	1,200	620	4,640
pH, field (units)	4	7.7	7.3	7.9	24	7.4	6.6	8.0
Temperature, water (°C)	0	--	--	--	7	10	9	10
Alkalinity, field (as $CaCO_3$)	4	275	226	299	23	318	60	504
Hardness (as $CaCO_3$)	11	600	370	1,400	53	620	260	1,900
Dissolved solids, residue at 180°C	11	777	404	2,060	47	991	384	7,150
Dissolved calcium	11	131	89	260	53	164	34	600
Dissolved magnesium	11	71	36	190	53	51	19	170
Dissolved sodium	11	34	15	78	48	36	5	340
Sodium absorption ratio	11	0.6	0.3	0.9	48	0.6	0.1	4
Dissolved potassium	4	3	2	4	39	5.8	0.4	25
Bicarbonate, field (as HCO_3)	4	335	275	360	17	430	220	610
Dissolved sulfate	11	360	140	1,300	53	303	23	1,600
Dissolved chloride	11	18	ND	79	51	23	ND	480
Dissolved fluoride	0	--	--	--	36	0.3	ND	0.5
Nitrogen, nitrate (as N)	11	3	0.18	15	18	6	ND	25
Dissolved nitrogen, NO_2+NO_3	0	--	--	--	24	2.17	0.05	13.5
Dissolved iron (µg/L)	0	--	--	--	36	590	10	3,500
Iron, recoverable (µg/L)	11	1,490	<50	6,000	24	1,100	ND	14,000
Dissolved manganese (µg/L)	0	--	--	--	23	800	50	3,600
Manganese, recoverable (µg/L)	11	1,200	<50	4,000	18	2,300	ND	36,000

Big Sioux aquifer

The composites of aquifer materials that comprise the Big Sioux aquifer (fig. 11) range from a fine sand to very coarse gravel. The aquifer underlies the flood plain of the Big Sioux River. The Big Sioux aquifer is connected hydraulically with the Shindler, Newton Hills, and Missouri aquifers and to the Big Sioux River. Analyses of test-drilling data and reported water levels indicate that the aquifer primarily is under water-table conditions. Geologic sections of the aquifer are shown in figures 9, 13, 16, and 17, and selected hydrologic characteristics are given in table 2. The Big Sioux aquifer is overlain either by alluvium or till and underlain mostly by till. In most areas, the aquifer is at or near land surface. Based on previous aquifer tests (Koch, 1980), the Big Sioux aquifer has an average hydraulic conductivity of 400 ft/d and an average specific yield of 0.12 (Niehus, U.S. Geological Survey, written commun., 1992). Also, Koch (1980) determined specific yields for this aquifer ranging from 0.10 to 0.17.

Recharge to the aquifer is by infiltration and subsequent percolation of rainfall and snowmelt in areas where the aquifer is at or near land surface. Recharge to the aquifer also is from the Shindler aquifer in northeastern Lincoln County and from the Newton Hills aquifer in southeastern Lincoln County. The chemical quality of Big Sioux aquifer water is quite different where the Big Sioux, Shindler, and Newton Hills aquifers are connected hydraulically than from the central and southern parts of the Big Sioux aquifer (south of T. 97 N.). Where the Big Sioux aquifer is in hydraulic connection with the Shindler aquifer, the specific conductance, and dissolved calcium, dissolved sodium, dissolved sulfate, and bicarbonate concentrations of the Big Sioux aquifer averaged 2,920 µS/cm, 310 mg/L, 95 mg/L, 765 mg/L, and 415 mg/L, respectively, while in the central and southern parts of the Big Sioux aquifer, the respective parameters averaged 815 µS/cm, 110 mg/L, 20 mg/L, 110 mg/L, and 480 mg/L (from USGS analyses). Where the Big Sioux aquifer is in hydraulic connection with the Newton Hills aquifer, the dissolved calcium, dissolved sodium, and dissolved sulfate concentrations of the Big Sioux aquifer averaged 265 mg/L, 72 mg/L, and 766 mg/L, respectively. In the central and southern parts of the Big Sioux aquifer, the average concentrations were 110 mg/L, 20 mg/L, and 110 mg/L (from USGS analyses). The Shindler and Newton Hills aquifers could contribute to these higher concentrations.

The Big Sioux aquifer also may receive some recharge from the Brule Creek aquifer through the till in T. 93 N. Water-level data from observation wells and chemical analyses of water from the two aquifers support this conclusion. The Big Sioux and Brule Creek aquifers have similar chemical water quality. The specific conductances, and dissolved calcium, dissolved sodium, dissolved sulfate, and bicarbonate concentrations of the Big Sioux aquifer averaged 1,200 µS/cm, 164 mg/L, 36 mg/L, 303 mg/L, and 430 mg/L (from USGS analyses). Possibly, the Big Sioux aquifer also receives some recharge from the Newton Hills and Brule Creek aquifers in T. 96 N., as evidenced by the flow directions shown in figure 12.

The general direction of water movement in the aquifer is to the south (fig. 12). The gradient of the water-table surface generally is about 2.5 ft/mi.

Discharge from the aquifer is: (1) through withdrawals from irrigation, municipal, domestic, and stock wells, (2) by evapotranspiration from the aquifer where it is near land surface, and (3) by discharge to the Big Sioux River and the Missouri aquifer. The Big Sioux aquifer is connected hydraulically to the Missouri aquifer, and water from the aquifers has similar chemical quality at their contact boundary (T. 92 N.). For example, dissolved calcium, dissolved sodium, and dissolved sulfate concentrations (from USGS analyses) were 94 mg/L, 20 mg/L, and 58 mg/L in the Big Sioux aquifer at well 92N49W16AAAA and 69 mg/L, 9 mg/L, and 58 mg/L in the Missouri aquifer at well 92N49W28ACB.

Analyses of records of water-level fluctuations in well 95N48W3ABAA show some correlation with seasonal variations in precipitation (fig. 18). The water levels rise early in the year when precipitation is highest.

Predominant chemical constituents in water from the Big Sioux aquifer are calcium, sulfate, and bicarbonate. Specific conductance, determined from

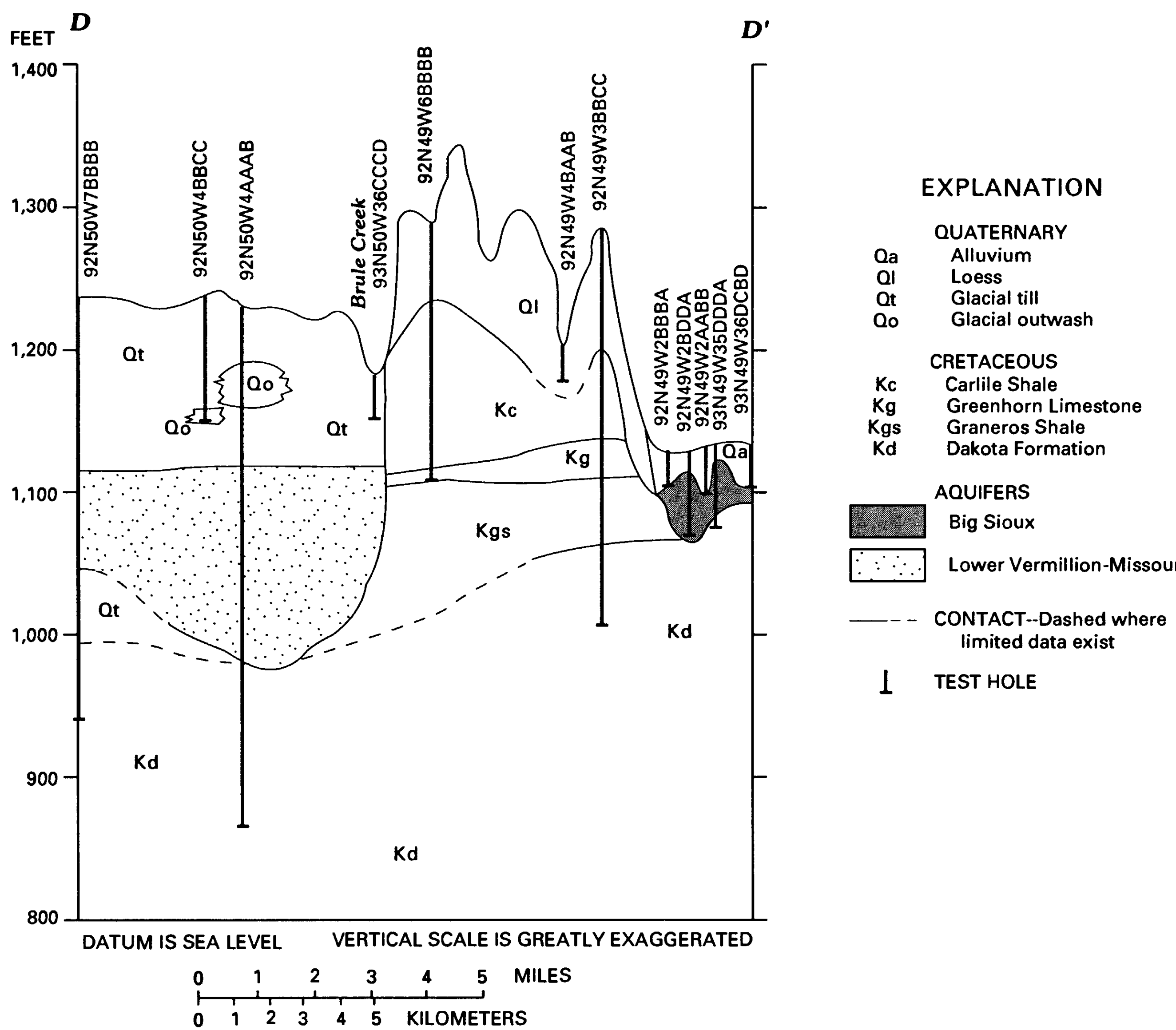


Figure 17.--Geologic section D-D' showing the Big Sioux and Lower Vermillion-Missouri aquifers in Union County. (Section D-D' is shown in figure 2.)

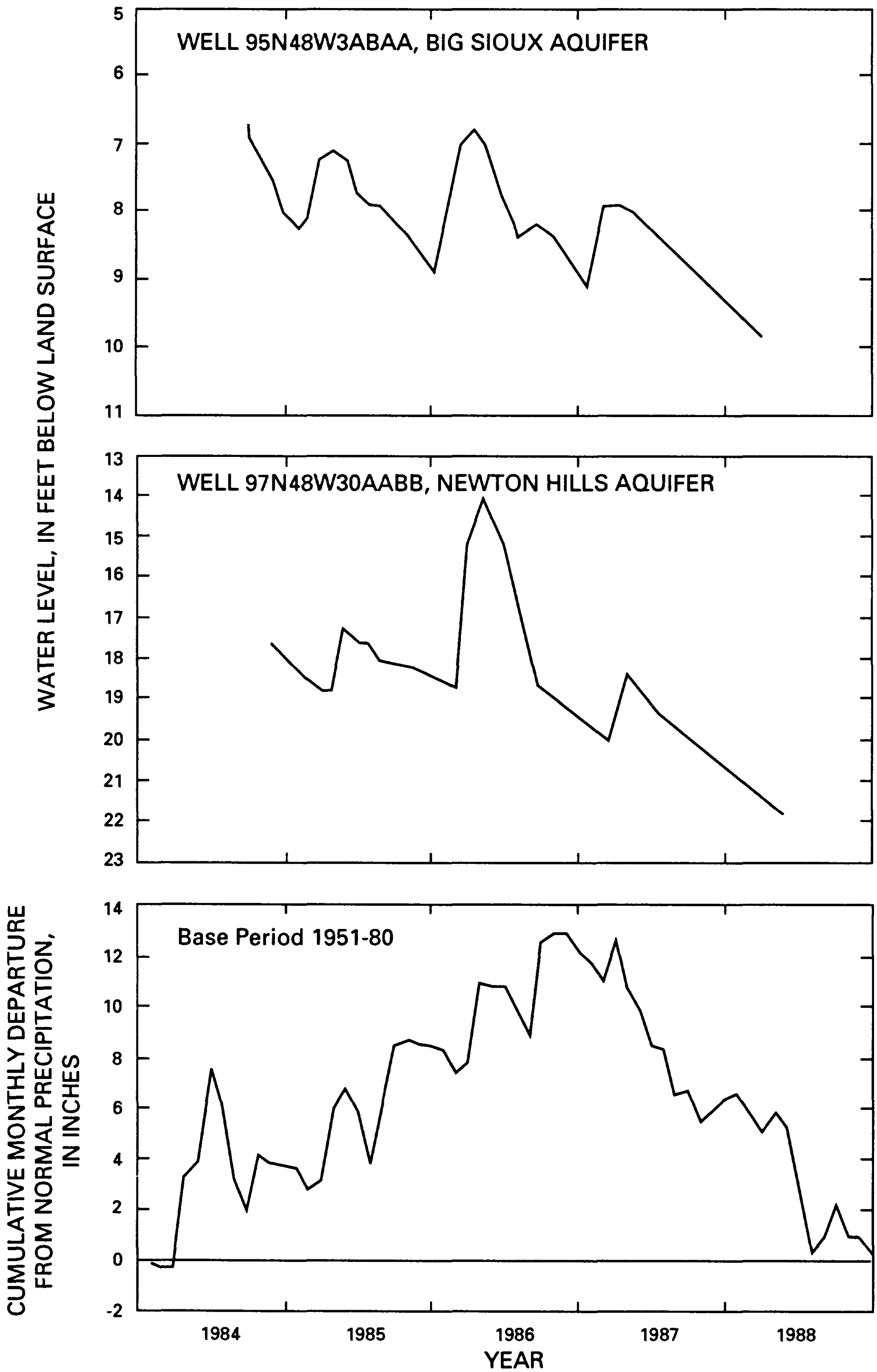


Figure 18.--Water-level fluctuations in the Big Sioux and Newton Hills aquifers and the cumulative monthly departure from normal precipitation at Canton.

19 onsite analyses, ranged from 710 to 2,310 µS/cm and averaged 1,390 µS/cm. Hardness concentration, determined from 19 onsite analyses, ranged from 210 to 1,540 mg/L and averaged 545 mg/L. A summary of chemical analyses of water from the aquifer is given in table 5.

Newton Hills aquifer

The composites of aquifer materials that comprise the Newton Hills aquifer (fig. 11) range from a fine sand to a medium gravel. The aquifer underlies southeast Lincoln County and is connected hydraulically with the Brule Creek and Big Sioux aquifers. Analyses of test-drilling data and reported water levels indicate that the aquifer is under artesian conditions except in areas where the aquifer is near land surface. A geologic section of the aquifer is shown in figure 13, and selected hydrologic characteristics are given in table 2. The aquifer is overlain by till and underlain mostly by till or Carlile Shale. The aquifer is near land surface at its extreme northeastern and southeastern boundaries.

Recharge to the aquifer is by infiltration and subsequent percolation of rainfall and snowmelt in areas where the aquifer is near land surface. However, because of the thick cover over the aquifer (average depth below land surface is 72 ft), the water from the Newton Hills aquifer has relatively high concentrations of dissolved solids. The specific conductances from USGS analyses ranged from 2,280 to 2,550 µS/cm, and the dissolved solids averaged 1,230 mg/L. Recharge to the Newton Hills aquifer also is from the Brule Creek aquifer along the southwestern boundary of the Newton Hills aquifer. Analyses of water levels in observation wells and test-hole logs lead to the conclusion that the Newton Hills and Brule Creek aquifers are connected hydraulically. Chemical analyses of water from these aquifers were inconclusive in substantiating the hydraulic connection. The general direction of water movement in the aquifer is northeast towards the Big Sioux aquifer (fig. 12).

Discharge from the aquifer is: (1) through withdrawals from domestic and stock wells, (2) by seepage and flow from springs, (3) by evapotranspiration where the aquifer is near land surface, and (4) by discharge to the Big Sioux aquifer in southeastern Lincoln County. Chemical data supporting the hydraulic connection between the Newton Hills and Big Sioux aquifers were discussed previously.

Analyses of records of water-level fluctuations in well 97N48W30AABB show there are seasonal changes in recharge (fig. 18). Analyses of these records indicate some relation with trends in precipitation, especially the decline in water levels in 1987 and 1988.

Predominant chemical constituents in water from the Newton Hills aquifer are calcium and sulfate. Specific conductance, determined from 10 onsite analyses, ranged from 900 to 4,850 µS/cm and averaged 2,450 µS/cm. Hardness concentration, from 10 onsite analyses, ranged from 120 to 3,050 mg/L and averaged 1,330 mg/L. A summary of chemical analyses of water from the aquifer is given in table 6.

Brule Creek aquifer

The Brule Creek aquifer (fig. 11) contains both glacial and nonglacial sands and gravels which range from a medium sand to a coarse gravel. The aquifer underlies southern Lincoln and northern Union Counties. It is connected hydraulically with the Newton Hills aquifer. Analyses of test-drilling data and reported water levels indicate that the aquifer is under artesian conditions except in areas where the aquifer is near the land surface. A geologic section of the aquifer is shown in figure 16, and selected hydrologic characteristics are given in table 2. The aquifer is overlain by till and underlain primarily by Niobrara Formation or Carlile Shale.

Recharge to the aquifer is by infiltration and subsequent percolation of rainfall and snowmelt in areas where the aquifer is near land surface. Laboratory chemical analyses by the USGS of water from the aquifer support this conclusion. The average specific conductance of 24 water samples from the aquifer was 1,200 µS/cm. The average depth below land surface of the top of the aquifer is 46 ft.

The general direction of water movement in the aquifer is southerly, except at its northeastern and

Table 6.--Summary of chemical analyses of water from the Newton Hills and Brule Creek aquifers in Lincoln and Union Counties

[Analyses by U.S. Geological Survey, South Dakota Geological Survey, and others. Results in milligrams per liter except as indicated; µg/L, micrograms per liter; --, not analyzed; -, not computed; <, less than; ND, not detected. For the statistical analysis of physical properties in water and chemical constituents in this table, the following assumptions were used: (1) Values of zero were assigned to constituents that were not detected. The detection limits for these constituents were unknown. (2) Values equal to the detection limits (that is, constituent <.1) were assigned to constituents that were less than specific values. (3) Average values were assigned to constituents when there were multiple-date analyses at a specific site. These average values were then averaged with other site location's constituents to arrive at mean values. This was done to avoid skewing the data]

	Newton Hills aquifer				Brule Creek aquifer			
	Number of samples	Mean	Minimum value	Maximum value	Number of samples	Mean	Minimum value	Maximum value
Specific conductance, field (microsiemens per centimeter at 25°C)	2	-	2,280	2,550	24	1,200	550	3,200
pH, field (units)	5	7.0	6.9	7.3	27	7.6	6.9	8.4
Temperature, water (°C)	1	-	15.5	15.5	3	9.3	7.5	10.5
Alkalinity, field (as $CaCO_3$)	0	--	--	--	21	318	204	534
Hardness (as $CaCO_3$)	4	1,050	800	1,500	30	690	340	2,000
Dissolved solids, residue at 180°C	3	1,230	1,200	1,290	16	1,285	480	3,212
Dissolved calcium	4	310	240	400	30	180	60	520
Dissolved magnesium	4	68	24	130	30	56	26	160
Dissolved sodium	2	-	35	59	30	35	10	150
Sodium absorption ratio	2	-	0.5	0.7	30	0.6	0.2	2
Dissolved potassium	2	-	8.4	13	29	5	2	11
Bicarbonate, field (as HCO_3)	0	--	--	--	21	400	250	650
Dissolved sulfate	4	570	280	1,400	30	430	70	1,600
Dissolved chloride	2	-	5.6	65	30	12	1	92
Dissolved fluoride	1	-	0.35	0.35	10	0.8	ND	2.2
Nitrogen, nitrate (as N)	0	--	--	--	10	7.44	0.07	24
Dissolved nitrogen, NO_2+NO_3	2	-	0.13	38	5	2.1	<0.1	9.3
Dissolved iron (µg/L)	2	-	50	180	5	1,300	25	4,600
Iron, recoverable (µg/L)	2	ND	ND	ND	15	675	ND	2,400
Dissolved manganese (µg/L)	2	-	50	50	5	607	3	1,600
Manganese, recoverable (µg/L)	0	--	--	--	7	75	ND	450

northwestern boundaries where the aquifer is connected hydraulically to the Newton Hills aquifer and water movement is to the northeast (fig. 12). Discharge from the aquifer is: (1) through withdrawals from irrigation, municipal, domestic, and stock wells; (2) by evapotranspiration where the aquifer is near land surface; and (3) by discharge to the Newton Hills aquifer and possibly to the Big Sioux aquifer through till at the southern boundary (T. 93 N.) of the aquifer. The possible hydraulic connection between the Brule Creek aquifer and the Newton Hills and Big Sioux aquifers was discussed previously. Water-level fluctuations in well 94N49W34CCCC reflect seasonal changes in recharge (fig. 19).

Predominant chemical constituents in water from the Brule Creek aquifer are calcium, sulfate, and bicarbonate. Specific conductance, determined from 29 onsite analyses, ranged from 760 to 4,100 µS/cm and averaged 1,598 µS/cm. Hardness concentration, from 29 onsite analyses, ranged from 340 to 2,280 mg/L and averaged 733 mg/L. A summary of chemical analyses of water from the aquifer is given in table 6.

Lower Vermillion-Missouri aquifer

The composites of aquifer materials that comprise the Lower Vermillion-Missouri aquifer (fig. 11) range from a coarse sand to a coarse gravel. The aquifer is west and north of the Big Sioux River flood plain and north of the Missouri River flood plain in central Union County. Analyses of test-drilling data and reported water levels indicate that the aquifer is under artesian conditions. A geologic section of the aquifer is shown in figure 17, and selected hydrologic characteristics are given in table 2. The aquifer is overlain primarily by till and underlain primarily by the Dakota Formation. The aquifer is the eastern extension of the Lower Vermillion-Missouri aquifer described by Stephens (1967).

Analyses of water-level measurements from observation wells and test-hole logs support the hypothesis that recharge to the aquifer probably is from the underlying Dakota aquifer. However, chemical analyses of water from these aquifers were inconclusive in indicating that the aquifers are connected hydraulically. Specific conductances from 14 USGS analyses averaged 1,781 µS/cm for the Lower Vermillion-Missouri aquifer. The Lower Vermillion-Missouri aquifer may also receive some recharge from percolation of precipitation and snowmelt through till although the average depth below land surface of the top of the aquifer is 105 ft. This may explain the lower mean concentration of dissolved solids observed in the Lower Vermillion-Missouri aquifer as compared to the Dakota aquifer. The Lower Vermillion-Missouri aquifer in neighboring Clay County (fig. 1) is near land surface and receives recharge from the Vermillion River along with percolation of precipitation and snowmelt (Christensen, 1967).

The general direction of water movement in the aquifer is southerly. The gradient of the potentiometric surface generally is about 2.5 ft/mi (fig. 12).

Discharge from the Lower Vermillion-Missouri aquifer is through withdrawals from irrigation, domestic, and stock wells and by discharge to the Missouri aquifer. Analyses of water-level measurements from observation wells and chemical analyses of water from the Lower Vermillion-Missouri and Missouri aquifers support this conclusion. The Lower Vermillion-Missouri and the northern part of the Missouri aquifer (Tps. 91 and 92 N.) have similar chemical water quality. The specific conductances of water samples from the Lower Vermillion-Missouri aquifer and the northern part of the Missouri aquifer averaged 1,781 µS/cm and 1,450 µS/cm, respectively, while the specific conductance of water samples from the southern part of the Missouri aquifer (Tps. 89 and 90 N.) averaged about 1,150 µS/cm (from USGS analyses). Analyses of records of water-level fluctuations in well 93N50W29AAAA show little correlation with trends in precipitation (fig. 20).

Predominant chemical constituents in water samples from the Lower Vermillion-Missouri aquifer are calcium and sulfate. Specific conductance, determined from 13 onsite analyses, ranged from 1,330 to 2,260 µS/cm and averaged 1,910 µS/cm. Hardness concentration, determined from 13 onsite analyses, ranged from 210 to 1,165 mg/L and averaged 550 mg/L. A summary of chemical analyses of water from the aquifer is given in table 7.

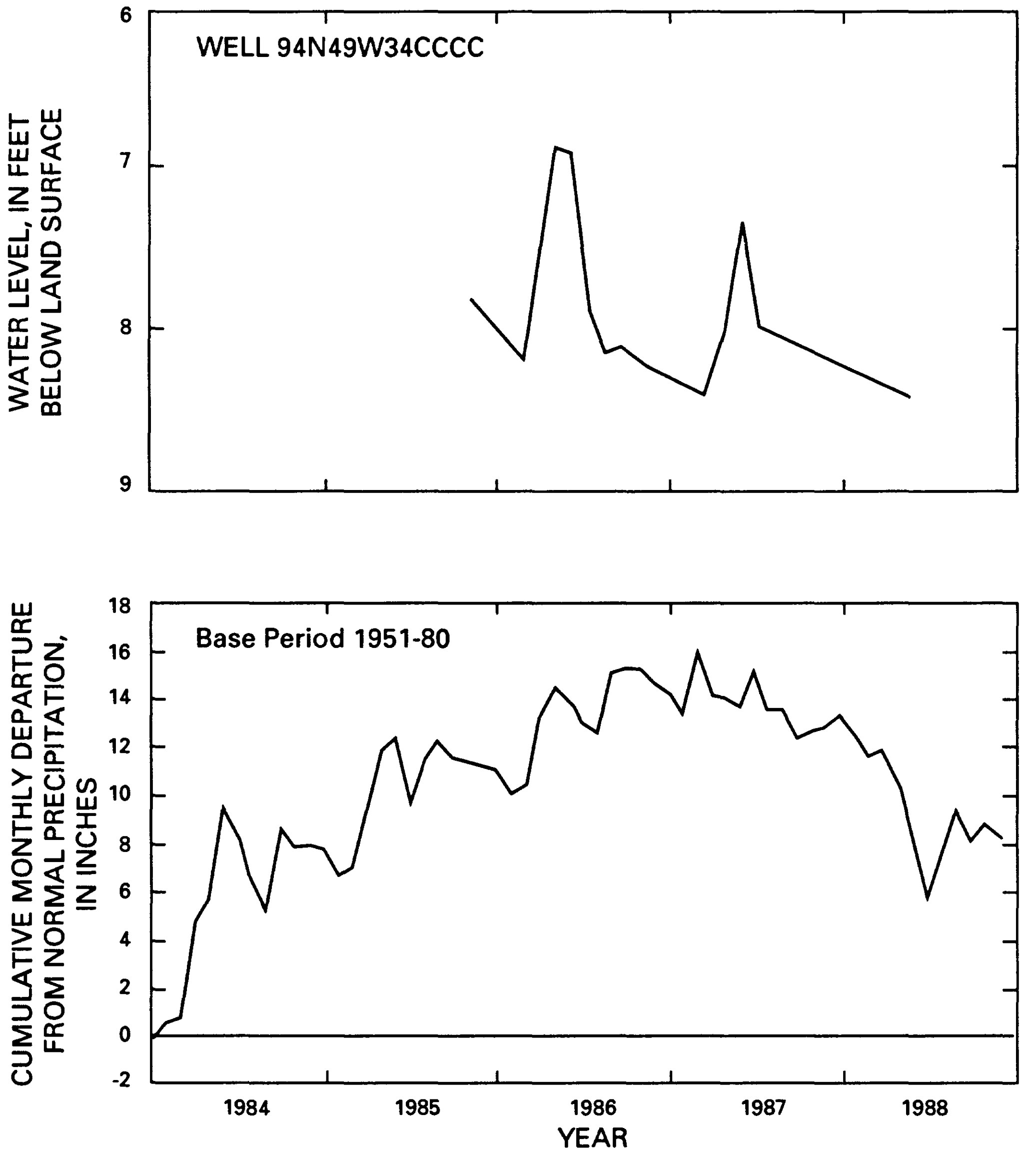


Figure 19.--Water-level fluctuations in the Brule Creek aquifer and the cumulative monthly departure from normal precipitation at Centerville.

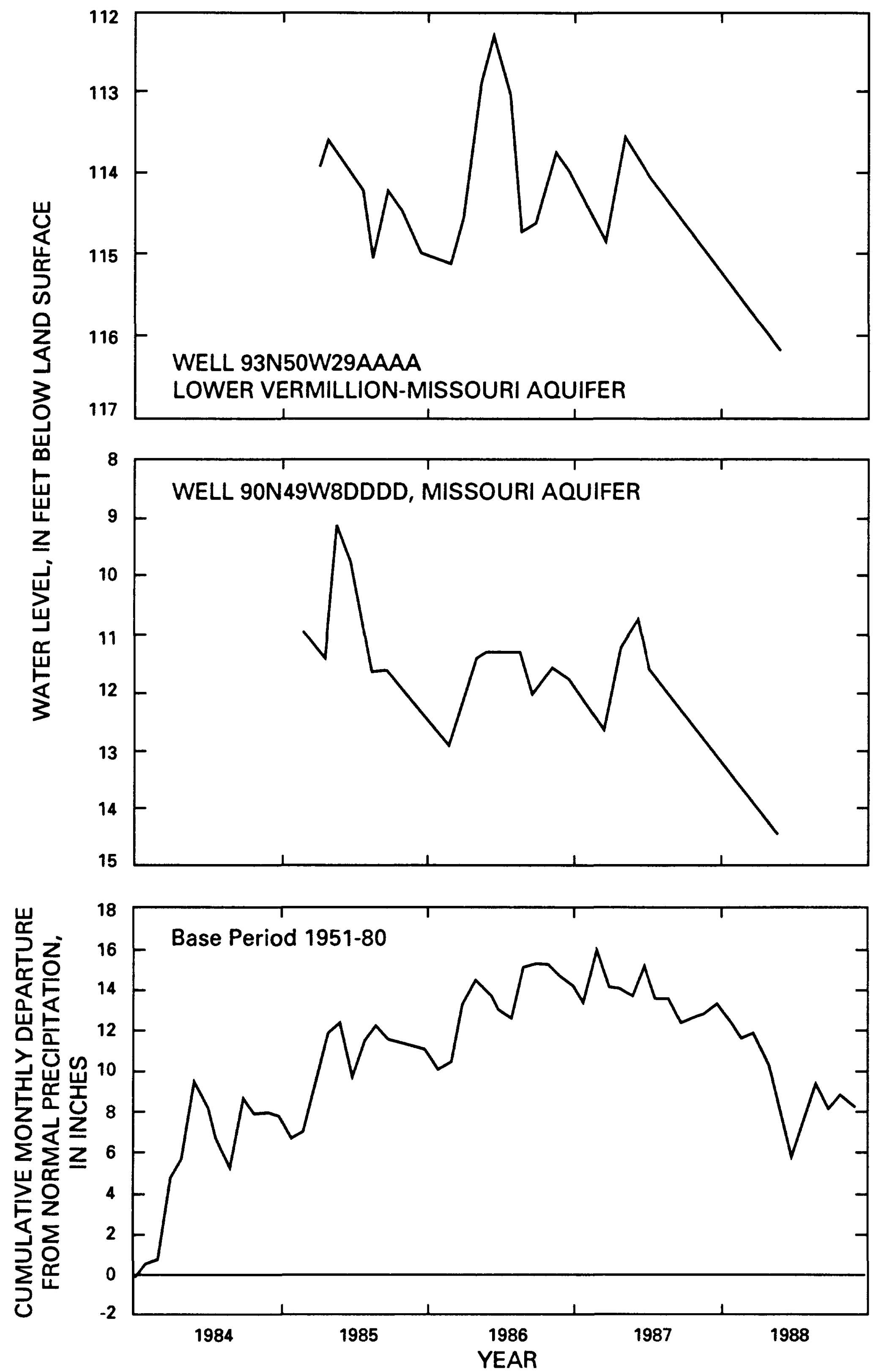


Figure 20.--Water-level fluctuations in the Lower Vermillion-Missouri and Missouri aquifers and the cumulative monthly departure from normal precipitation at Centerville.

Table 7.--Summary of chemical analyses of water from the Lower Vermillion-Missouri and Missouri aquifers in Union County

[Analyses by U.S. Geological Survey, South Dakota Geological Survey, and others. Results in milligrams per liter except as indicated; µg/L, micrograms per liter; --, not analyzed; -, not computed; <, less than; ND, not detected. For the statistical analysis of physical properties of water and chemical constituents in this table, the following assumptions were used: (1) Values of zero were assigned to constituents that were not detected. The detection limits for these constituents were unknown. (2) Values equal to the detection limits (that is, constituent <.1) were assigned to constituents that were less than specific values. (3) Average values were assigned to constituents when there were multiple-date analyses at a specific site. These average values were then averaged with other site location's constituents to arrive at mean values. This was done to avoid skewing the data]

	Lower Vermillion-Missouri aquifer				Missouri aquifer			
	Number of samples	Mean	Minimum value	Maximum value	Number of samples	Mean	Minimum value	Maximum value
Specific conductance, field (microsiemens per centimeter at 25°C)	14	1,781	791	2,250	215	1,290	440	2,640
pH, field (units)	14	7.4	7.0	8.2	217	7.4	6.6	8.4
Temperature, water (°C)	1	-	11.5	11.5	20	11.9	9	15
Alkalinity, field (as $CaCO_3$)	14	251	148	368	218	425	122	801
Hardness (as $CaCO_3$)	14	-	360	1,200	251	613	17	1,400
Dissolved solids, residue at 180°C	2	-	340	1,820	68	850	230	1,800
Dissolved calcium	14	260	100	355	252	160	3	400
Dissolved magnesium	14	60	24	82	252	53	ND	293
Dissolved sodium	14	103	17	150	252	78	8	410
Sodium absorption ratio	14	1.5	0.4	3	251	1.5	0.2	46
Dissolved potassium	13	15	5	24	209	12.6	1.7	370
Bicarbonate, field (as HCO_3)	14	310	180	450	213	520	130	980
Dissolved sulfate	14	735	6	1,100	252	295	<25	1,100
Dissolved chloride	14	60	2	160	249	20	ND	410
Dissolved fluoride	0	--	--	--	19	0.55	0.30	0.94
Nitrogen, nitrate (as N)	2	-	0.26	1.60	64	1.81	0.05	33
Dissolved nitrogen, NO_2+NO_3	0	--	--	--	10	0.7	<0.1	4
Dissolved iron (µg/L)	0	--	--	--	11	1,582	2	12,000
Iron, recoverable (µg/L)	3	1,080	30	1,600	76	4,020	<10	33,800
Dissolved manganese (µg/L)	0	--	--	--	11	780	10	2,800
Manganese, recoverable (µg/L)	1	-	1,600	1,600	51	1,184	<2	6,000

Missouri aquifer

The composites of unconsolidated materials that comprise the Missouri aquifer (fig. 11) range from a fine sand to a very coarse gravel. The aquifer underlies the flood plains of the Missouri and Big Sioux Rivers in southern Union County. Analyses of test-drilling data and reported water levels indicate that the aquifer is under artesian conditions in the northwestern part of the area underlain by the aquifer and under water-table conditions in the southern part. A geologic section of the aquifer is shown in figure 21, and selected hydrologic characteristics are listed in table 2. The aquifer is overlain by alluvium and underlain primarily by the Dakota Formation. The Missouri aquifer contains about 1.5 million acre-ft of water in storage.

Recharge to the aquifer is by infiltration and subsequent percolation of rainfall and snowmelt in areas where the aquifer is near land surface. Recharge to the aquifer also is from the Lower Vermillion-Missouri aquifer at the northern boundary of the Missouri aquifer and from the Big Sioux aquifer at the extreme northeastern boundary of the Missouri aquifer. The Missouri aquifer is a southern extension of the Big Sioux and Lower Vermillion-Missouri aquifers. Water from the Missouri and Big Sioux aquifers has similar chemical quality at their boundary (T. 92 N.). This similarity was previously discussed in the sections on the Big Sioux and Lower Vermillion-Missouri aquifers.

Recharge also occurs from the underlying Dakota aquifer. Analyses of limited water-level measurements from observation wells and chemical analyses indicate a hydraulic connection. The specific conductance and the dissolved calcium, dissolved sodium, dissolved sulfate, and bicarbonate concentrations of the Missouri aquifer averaged 1,290 μS/cm, 160 mg/L, 78 mg/L, 295 mg/L, and 520 mg/L, respectively (from USGS analyses).

Some recharge to the aquifer also is from the Missouri River during periods of high flow and stage. Lower specific conductances, which averaged 1,150 μS/cm in the southern part of the Missouri aquifer (Tps. 89 and 90 N.), probably are a result of good hydraulic connection with the Missouri River and the fact that the aquifer is near land surface in this area.

The general direction of water movement in the aquifer is to the southeast (fig. 12). The gradient of the potentiometric surface generally is about 1.5 ft/mi.

Discharge from the aquifer is: (1) through withdrawals from irrigation, municipal, domestic, and stock wells; (2) by evapotranspiration where the aquifer is near land surface; (3) by discharge to the Big Sioux and Missouri Rivers during periods of low flow and stage; and (4) by discharge to the underlying Dakota aquifer.

Analyses of records for well 90N49W8DDDD show a correlation between water-level fluctuations and seasonal trends in precipitation (fig. 20). Above-normal precipitation in 1986 and early 1987 are correlated with water-level rises and below-normal precipitation in late 1987 and 1988 are correlated with declines in water levels.

Predominant chemical constituents in water from the Missouri aquifer are calcium, sulfate, and bicarbonate. Specific conductance, determined from 28 onsite analyses, ranged from 780 to 2,400 μS/cm and averaged 1,440 μS/cm. Hardness concentration, determined from 29 onsite analyses, ranged from 140 to 770 mg/L and averaged 360 mg/L. A summary of chemical analyses of water from the aquifer is given in table 7.

Bedrock Aquifers

The Dakota aquifer in the Dakota Formation (also referred to as Dakota Sandstone) of Cretaceous age was the only major bedrock aquifer investigated in this study. The Sioux Quartzite, Sioux Quartzite wash, Carlile Shale, and the Niobrara Formation are minor aquifers in Lincoln and Union Counties and are briefly described. Because of limited available data, the sandstones, shales, and dolostones of Cambrian, Ordovician, or Devonian age that underlie much of Union County were not investigated in this study. The Graneros Shale and Greenhorn Limestone were not aquifers in these counties.

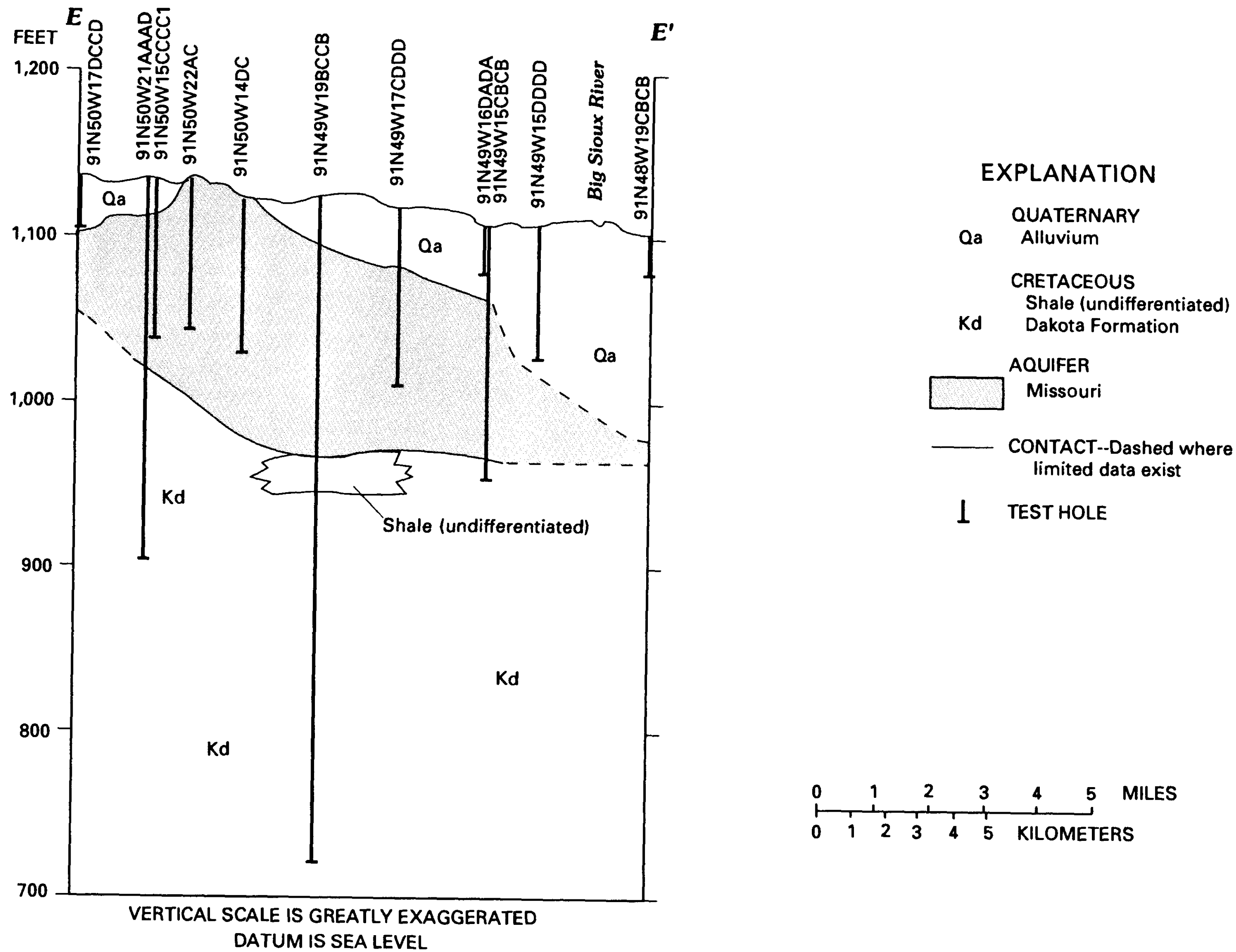


Figure 21.--Geologic section E-E' showing the Missouri aquifer in Union County. (Section E-E' is shown in figure 2.)

Dakota aquifer

The Dakota aquifer (figs. 22 and 23), in the Dakota Formation of Cretaceous age, is composed of a fine to coarse-grained sandstone with interbedded shale. The aquifer underlies Lincoln and Union Counties except for the extreme northern part of Lincoln County. Analyses of test-drilling data and reported water levels indicate that the aquifer generally is under artesian conditions. Geologic sections of the aquifer are shown in figures 13, 16, 17, and 21, and selected hydrologic characteristics are given in table 2. The aquifer is overlain by Graneros Shale, the Lower Vermillion-Missouri aquifer, or the Missouri aquifer and underlain by Sioux Quartzite; several sandstones, shales, and dolostones of Cambrian, Ordovician, or Devonian age; or Sioux Quartzite wash. The general direction of water movement in the aquifer is southerly.

Recharge to the Dakota aquifer is from underlying formations in the western part of South Dakota, especially the Madison Formation and other formations that crop out in the Black Hills (Schoon, 1971). The Dakota aquifer may also receive some recharge from the overlying Missouri aquifer.

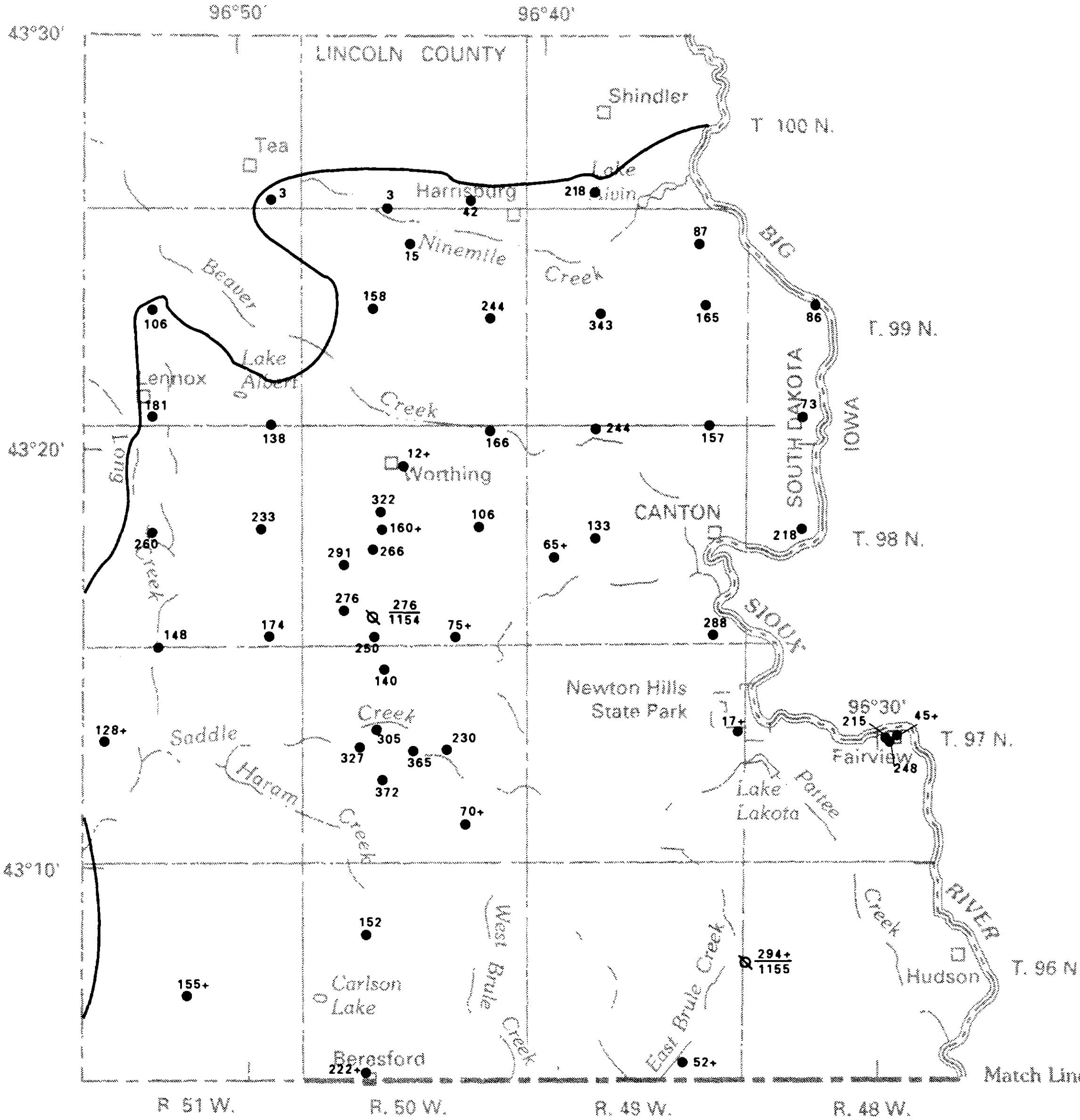
Discharge from the aquifer is through withdrawals for irrigation, municipal, domestic, and stock wells and probably by discharge to the overlying Lower Vermillion-Missouri and Missouri aquifers. Analyses of water-level measurements from observation wells and test-hole logs support this hypothesis. However, chemical analyses of water from the Dakota and Lower Vermillion-Missouri aquifers were inconclusive in indicating that the aquifers are connected hydraulically. Analyses of limited water-level measurements from observation wells and chemical analyses indicate a hydraulic connection between the Dakota and Missouri aquifers. The specific conductance and the dissolved calcium, dissolved sodium, dissolved sulfate, and bicarbonate concentrations of the Dakota aquifer averaged 1,325 μS/cm, 131 mg/L, 120 mg/L, 360 mg/L, and 342 mg/L, respectively (from USGS analyses). The Dakota aquifer probably also discharges to fractures in the underlying Sioux Quartzite.

Analyses of records of long-term water-level fluctuations in well 93N50W4DAA generally correlate with long-term fluctuations in precipitation (fig. 24), especially the period 1967 through 1988.

The Dakota aquifer's water chemistry is derived from water originating in the Madison Limestone and traveling upward and laterally through intervening Pennsylvanian, Jurassic, and Lower Cretaceous units from the west until it reaches the Dakota Formation near mid-State (L.W. Howells, U.S. Geological Survey, written commun., 1980). Predominant chemical constituents in water from the Dakota aquifer are calcium, sulfate, and bicarbonate. Specific conductance, determined from 85 onsite analyses, ranged from 680 to 2,500 μS/cm and averaged 1,190 μS/cm. Hardness concentration, determined from 85 onsite analyses, ranged from 50 to 2,700 mg/L and averaged 320 mg/L. A summary of chemical analyses of water from the aquifer is given in table 8. Water from the Dakota aquifer generally is suitable for most uses.

Minor bedrock aquifers

The Sioux Quartzite consists of a pink, sometimes fractured, well-cemented orthoquartzite. The thickness of the quartzite is unknown in the study area because only a small amount of drilling was done in this bedrock due to its extreme hardness. Older Precambrian rocks underlie the Sioux Quartzite in southeastern South Dakota (Steece and Howells, 1965). These older rocks are pink, red, and gray granites which are intruded by gabbro dikes (Petsch, 1962). In some areas, the Sioux Quartzite is overlain by pink, weathered, quartzite sand called the Sioux Quartzite wash (Hansen, 1983). However, in most areas, the Sioux Quartzite is overlain by Dakota Formation (Lincoln County) and several sandstones, shales, and dolostones of Cambrian, Ordovician, or Devonian age (most of Union County). The quartzite also is overlain in limited areas by till or Carlile Shale. In northern Lincoln County, the Sioux Quartzite is directly overlain by the glacial Wall Lake and Upper Vermillion-Missouri aquifers. The Sioux Quartzite wash usually has a thickness less than 5 ft based on analyses of test-hole logs.



Base modified from U.S. Geological Survey state base map 1:500,000, 1963; Sioux City South, Sioux City North, and Rock Rapids, 1:100,000, 1986

0 2 4 6 MILES

0 2 4 6 KILOMETERS

EXPLANATION

APPROXIMATE AQUIFER BOUNDARY

20+ TEST HOLE--Number is the thickness of the aquifer, in feet. A plus (+) indicates thickness of aquifer greater than shown.

363/1144 OBSERVATION WELL--Upper number is the thickness of the aquifer, in feet. Lower number is the altitude of potentiometric surface, in feet, of the Dakota aquifer during October 1986. Datum is sea level.

Figure 22.--Extent, thickness, and altitude of the potentiometric surface of the Dakota aquifer in Lincoln and Union Counties.

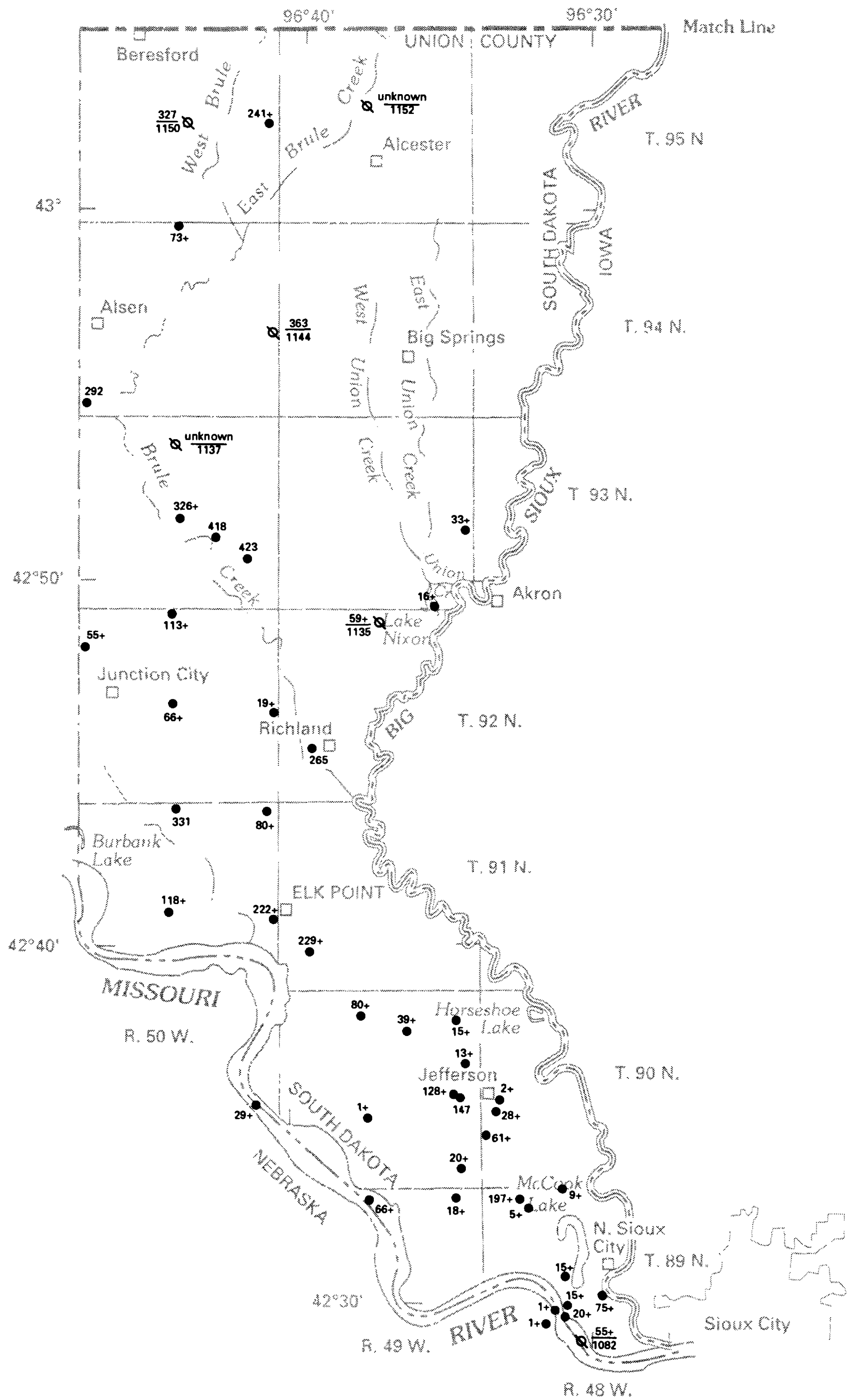
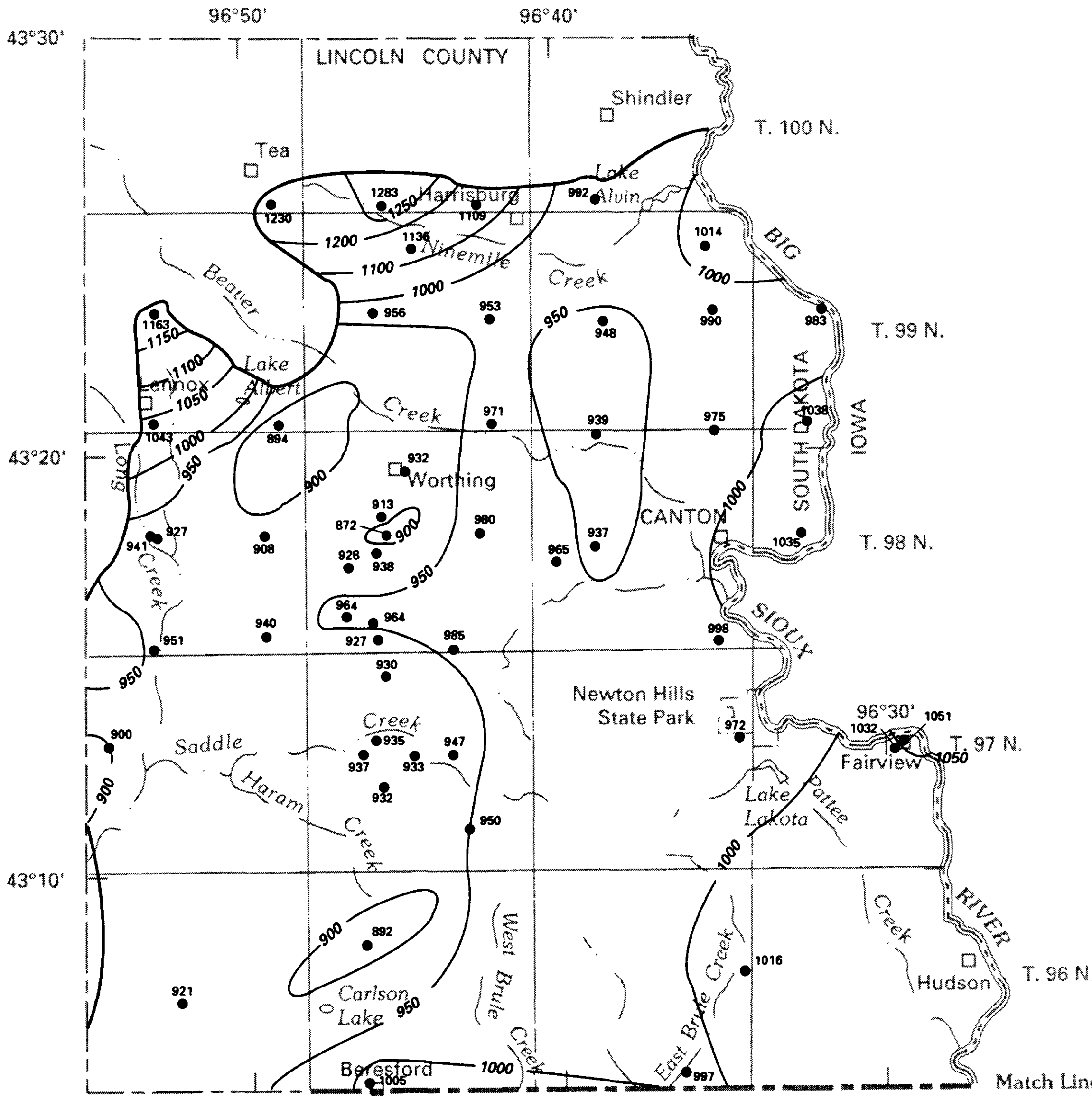


Figure 22.--Extent, thickness, and altitude of the potentiometric surface of the Dakota aquifer in Lincoln and Union Counties.--Continued



Base modified from U.S. Geological Survey state base map 1:500,000, 1963; Sioux City South , Sioux City North, and Rock Rapids, 1:100,000, 1986

0 2 4 6 MILES

0 2 4 6 KILOMETERS

EXPLANATION

900 — STRUCTURE CONTOUR--Shows altitude of the top of the aquifer. Dashed where limited data exist. Contour interval is variable. Datum is sea level.

APPROXIMATE AQUIFER BOUNDARY

1001 TEST HOLE--Number is altitude of the top of the aquifer, in feet. Datum is sea level.

Figure 23.--Structure contours on the top of the Dakota aquifer in Lincoln and Union Counties.

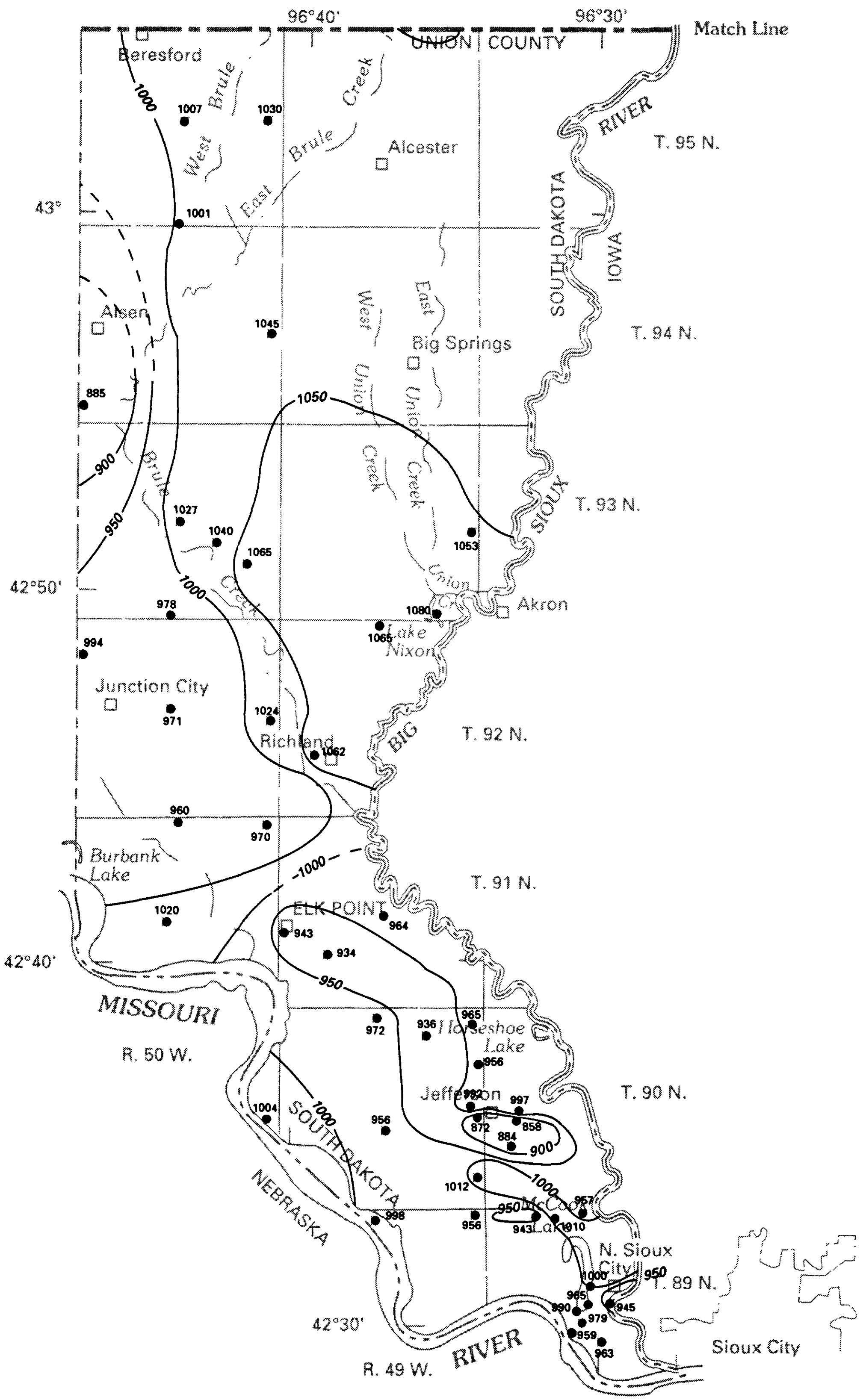


Figure 23.--Structure contours on the top of the Dakota aquifer in Lincoln and Union Counties.--Continued

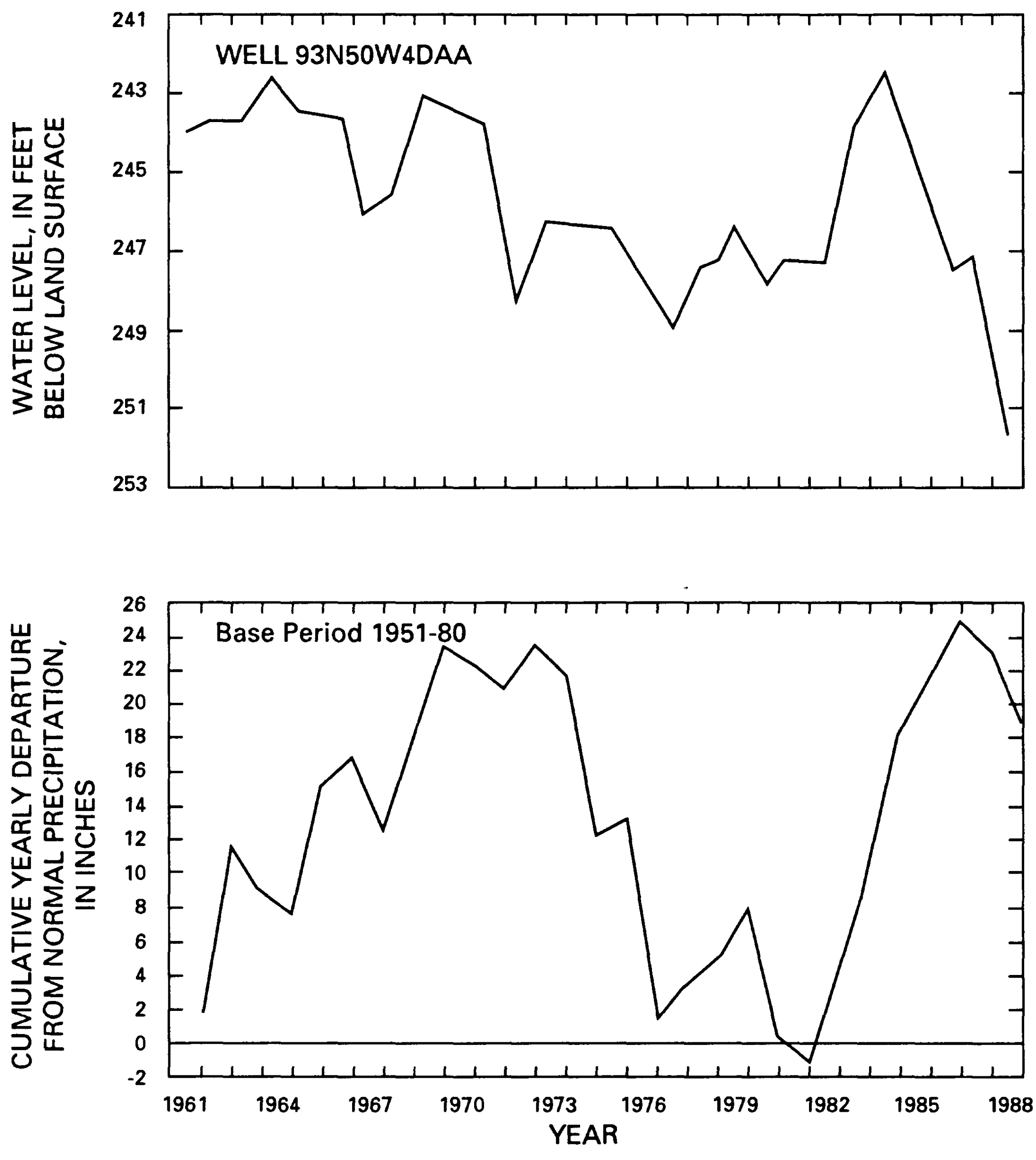


Figure 24.--Water-level fluctuations in the Dakota aquifer and the cumulative yearly departure from normal precipitation at Centerville.

Table 8.--Summary of chemical analyses of water from the Dakota aquifer in Lincoln and Union Counties

[Analyses by U.S. Geological Survey, South Dakota Geological Survey, and others. Results in milligrams per liter except as indicated; µg/L, micrograms per liter; --, not analyzed; -, not computed; <, less than; ND, not detected. For the statistical analysis of physical properties of water and chemical constituents in this table, the following assumptions were used: (1) Values of zero were assigned to constituents that were not detected. The detection limits for these constituents were unknown. (2) Values equal to the detection limits (that is, constituent <.1) were assigned to constituents that were less than specific values. (3) Average values were assigned to constituents when there were multiple-date analyses at a specific site. These average values were then averaged with other site location's constituents to arrive at mean values. This was done to avoid skewing the data]

	Number of samples	Mean	Minimum value	Maximum value
Specific conductance, field (microsiemens per centimeter at 25°C)	65	1,325	505	7,630
pH, field (units)	51	7.6	6.7	8.3
Temperature, water (°C)	20	12	6.00	17
Alkalinity, field (as $CaCO_3$)	61	280	80	560
Hardness (as $CaCO_3$)	83	480	52	2,070
Dissolved solids, residue at 180°C	64	1,800	405	7,640
Dissolved calcium	83	131	14	590
Dissolved magnesium	83	37	3	138
Dissolved sodium	78	120	49	250
Sodium absorption ratio	78	3.2	0.9	10
Dissolved potassium	45	17	10	26
Bicarbonate, field (as HCO_3)	60	342	98	680
Dissolved sulfate	83	360	30	1,700
Dissolved chloride	83	28.3	1.5	270
Dissolved fluoride	47	1.5	0.3	4
Nitrogen, nitrate (as N)	54	1	ND	25
Dissolved nitrogen, NO_3+NO_3	2	-	<0.1	<0.1
Dissolved iron (µg/L)	6	3,370	380	12,000
Iron, recoverable (µg/L)	77	1,760	ND	23,500
Dissolved manganese (µg/L)	3	90	70	105
Manganese, recoverable (µg/L)	67	190	ND	2,400

The Sioux Quartzite and the Sioux Quartzite wash are minor aquifers in Lincoln and Union Counties. The average specific conductance and the average dissolved calcium, dissolved sodium, dissolved sulfate, and bicarbonate concentrations from USGS laboratory (approximately 10 sites) analyses of water from the Sioux Quartzite were 1,300 µS/cm, 170 mg/L, 115 mg/L, 525 mg/L, and 425 mg/L, respectively. Recharge to the Sioux Quartzite and Sioux Quartzite wash aquifers probably occurs in southern Minnehaha County where the Sioux Quartzite crops out.

The Carlile Shale is a gray to brown shale. It is overlain mostly by till, outwash, or the Niobrara Formation and underlain primarily by Greenhorn Limestone. The Carlile Shale is relatively thick (greater than 250 ft in some areas). There are some wells located in the formation, but overall the Carlile Shale is a minor aquifer in Lincoln and Union Counties.

The Niobrara Formation is a white to gray, calcareous siltstone that may contain layers of chalk. It covers parts of Lincoln and extreme northern Union Counties and is overlain by till or outwash and underlain by the Carlile Shale. The Niobrara Formation is not thick (generally less than 50 ft) or extensive and is a minor aquifer in the study area.

The Graneros Shale consists of a gray to brown shale. It is relatively thin (less than 50 ft in most areas) in Lincoln and Union Counties. The Graneros Shale primarily is overlain by the Greenhorn Limestone and underlain in most locations by the Dakota Formation except in northern Lincoln County where it is underlain in some locations by the Sioux Quartzite. The Graneros Shale is not an aquifer in Lincoln and Union Counties.

The Greenhorn Limestone consists of a white to brown, very calcareous shale and limestone. The formation is overlain by the Carlile Shale and underlain by the Graneros Shale. It is relatively thin (less than 50 ft in most areas) in Lincoln and Union Counties. Although the Greenhorn Limestone is an aquifer in some parts of South Dakota (Kume and Howells, 1987), it is not an aquifer in Lincoln and Union Counties.

WATER USE

Seventy-six percent (11.2 Mgal/d) of the total amount of water used in Lincoln and Union Counties during 1985 was for irrigation (table 9). Ground water was the source of 96 percent (10.7 Mgal/d) of the water used for irrigation. Analyses of well-inventory data indicate that the primary source of ground water for irrigation is the Missouri aquifer. All the withdrawals in Lincoln and Union Counties for public-water supplies were from ground water and were primarily from the Dakota, Brule Creek, Missouri, and Big Sioux aquifers. About 60 percent of the water used for stock watering was derived from surface-water sources and 40 percent from ground-water sources. Well-inventory data indicate that the primary sources of ground water for stock watering are the Dakota, Brule Creek, and Missouri aquifers. Total water use in Lincoln and Union Counties in 1985 was 14.66 Mgal/d.

Table 9.--Water use in Lincoln and Union Counties in 1985

[From R.D. Benson, U.S. Geological Survey, written commun., 1986. All values in million gallons per day]

	Livestock	Public water supply	Self-supplied domestic	Self-supplied commercial/ industrial/ gravel mining	Irrigation	Total
Lincoln County						
Ground water	0.31	0.97	0.12	0.02	0.67	2.09
Surface water	.47	0	0	.03	.07	.57
Union County						
Ground water	.24	.62	.29	.04	10.03	11.22
Surface water	.35	0	0	0	.43	.78
Total	1.37	1.59	.41	.09	11.20	14.66

SUMMARY

The water resources of Lincoln and Union Counties occur as surface and ground water. Major sources of surface water include the Big Sioux and Missouri Rivers. At a streamflow-gaging station on the Missouri River south of Union County, the discharge averaged 32,380 ft^3/s during water years 1966-89. At a streamflow-gaging station on the Big Sioux River north of Lincoln County, the discharge averaged 523 ft^3/s during water years 1972-89. Streamflow of the Big Sioux River and other minor streams in the study area is directly related to seasonal variations in precipitation and evapotranspiration. Dissolved-solids concentrations in water from these streams increase as stream discharges decrease. The flow of the Missouri River is less affected by seasonal variations in precipitation and evapotranspiration due to regulation (control) by upstream dams. Near the study area, the Missouri River is used for municipal and domestic water supplies and for irrigation especially close to the river.

Ten glacial aquifers and one bedrock aquifer were delineated in Lincoln and Union Counties. The average thickness of the Wall Lake, Upper Vermillion-Missouri, and Parker-Centerville aquifers is 32, 41, and 35 ft, respectively. The average depth below land surface to the top of the aquifer is 106 ft for the Wall Lake aquifer, 162 ft for the Upper Vermillion-Missouri aquifer, and 17 ft for the Parker-Centerville aquifer. Recharge to the Wall Lake aquifer is from fractures in the Sioux Quartzite in Minnehaha County. Recharge to the Parker-Centerville aquifer is by infiltration and subsequent percolation of snowmelt and spring rainfall where the aquifer is near land surface. The aquifer also is recharged by the Vermillion River in Turner County. The Parker-Centerville aquifer probably contributes some recharge to the Upper Vermillion-Missouri aquifer. Discharge from the Wall Lake aquifer is through domestic and stock-watering wells. Discharge from the Upper Vermillion-Missouri and Parker-Centerville aquifers is through domestic, stock watering, and municipal wells. The Parker-Centerville aquifer also has some discharge by evapotranspiration where the aquifer is near land surface and by seepage and flow from springs.

The average thickness of the Harrisburg and Shindler aquifers is 26 and 31 ft, respectively. The average depth below land surface to the top of the aquifer is 59 ft for the Harrisburg aquifer, which overlies the Shindler aquifer, and 103 ft for the Shindler aquifer. Recharge to the Harrisburg aquifer probably is by leakage through till. Recharge to the Shindler aquifer probably is from the overlying Harrisburg aquifer. Discharge from the Harrisburg aquifer is by domestic wells, stock watering, irrigation, and evaporation where the aquifer is near land surface, seepage and flow from springs, and probably by discharge to the underlying Shindler aquifer. Discharge from the Shindler aquifer is by domestic wells, stock watering, and discharge to the Big Sioux aquifer.

The average thickness of the Newton Hills and Brule Creek aquifers is 36 and 33 ft, respectively. The average depth below land surface to the top of the aquifer is 72 ft for the Newton Hills aquifer and 46 ft for the Brule Creek aquifer. Recharge to these aquifers is by infiltration and subsequent percolation of snowmelt and spring runoff where the aquifer is near land surface. The Newton Hills aquifer also receives ground water from the Brule Creek aquifer. Discharge for the Newton Hills aquifer is through domestic wells and stock watering, by seepage and flow from springs, by evapotranspiration, and by discharge to the Big Sioux aquifer. Discharge for the Brule Creek aquifer is through domestic wells, stock watering, by evapotranspiration, municipal wells, and irrigation, and by discharge to the Newton Hills aquifer in the north and possibly the Big Sioux aquifer in T. 93 N.

The average thickness of the Lower Vermillion-Missouri, Missouri, and Big Sioux aquifers is 99, 84, and 28 ft, respectively. The average depth below land surface to the top of the aquifer is 105 ft for the Lower Vermillion-Missouri aquifer, 22 ft for the Missouri aquifer, and 12 ft for the Big Sioux aquifer. Recharge to the Lower Vermillion-Missouri aquifer probably is from the underlying Dakota aquifer. Recharge to the Missouri aquifer is by infiltration and subsequent percolation of snowmelt and spring rainfall where the aquifer is near land surface, and by ground-water recharge from the Lower Vermillion-Missouri and the

Big Sioux aquifers in the north, the underlying Dakota aquifer, and the Missouri River. Recharge to the Big Sioux aquifer is by infiltration and subsequent percolation of snowmelt and spring rainfall where the aquifer is near land surface and recharge from the Shindler, Newton Hills, and possibly the Brule Creek aquifers. Discharge for the Lower Vermillion-Missouri aquifer is through domestic wells, stock watering, irrigation, and by discharge to the Missouri aquifer. Discharge for the Missouri aquifer is through domestic wells, stock watering, municipal wells, irrigation, by evapotranspiration, by discharge to the Missouri and Big Sioux Rivers, and by discharge to the Dakota aquifer. Discharge for the Big Sioux aquifer is through domestic wells, stock watering, municipal wells, irrigation, by evapotranspiration, and by discharge to the Missouri aquifer and to the Big Sioux River.

Predominant chemical constituents are calcium, magnesium, sulfate, and bicarbonate in water from the glacial aquifers. Average dissolved-solids concentrations for water from the Parker-Centerville, Missouri, and Big Sioux aquifers ranged from 777 to 991 mg/L; from the Newton Hills, Brule Creek, and Wall Lake aquifers ranged from 1,230 to 1,620 mg/L; and from the Shindler and Upper Vermillion-Missouri aquifers ranged from 2,220 to 2,400 mg/L. Water in the Harrisburg aquifer had an average dissolved-solids concentration of 4,075 mg/L. The dissolved-solids concentrations of water from two wells in the Lower Vermillion-Missouri aquifer was 340 and 1,820 mg/L.

The depth below land surface to the top of the Dakota aquifer averages 281 ft in Lincoln and Union Counties. Recharge to the Dakota aquifer is from the underlying formations in the western part of South Dakota, especially the Madison Formation and other formations that crop out in the Black Hills. The Dakota aquifer may also receive some recharge from the overlying Missouri aquifer. Discharge from the Dakota aquifer is through domestic wells, stock watering, irrigation, municipal wells, and by ground-water discharge to the Lower Vermillion-Missouri and Missouri aquifers, and probably discharge to fractures in the underlying Sioux Quartzite. Predominant chemical constituents are calcium, sulfate, and bicarbonate. The average dissolved-solids concentration in water from the Dakota aquifer was 1,800 mg/L.

Total water use in Lincoln and Union Counties during 1985 was 14.66 Mgal/d. The primary users of water in Lincoln and Union Counties are irrigators. Seventy-six percent of total water use was for irrigation, of which 96 percent was ground water.

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