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Information Pamphlet 49

MAJOR AQUIFERS IN LINCOLN AND UNION COUNTIES, SOUTH DAKOTA

by
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Prepared in cooperation with the
South Dakota Geological Survey and
Lincoln and Union Counties

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ABSTRACT

Ten glacial aquifers and one bedrock aquifer were delineated in Lincoln and Union Counties. The ten glacial aquifers have the potential to contain about 4 million acre-feet of water in storage, and the major bedrock aquifer has the potential to contain about 19.4 million acre-feet. The areal extent of the glacial aquifers was determined to range from 25 to 60 square miles for the Wall Lake, Parker-Centerville, Big Sioux, and Lower Vermillion-Missouri aquifers; to range from 85 to 90 square miles for the Harrisburg, Upper Vermillion-Missouri, and Newton Hills aquifers; to be 130 square miles for the Shindler aquifer; and to be 180 square miles each for the Brule Creek and Missouri aquifers. The areal extent of the only major bedrock aquifer, the Dakota, was determined to be 935 square miles.

The average cumulative 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 interaction with other glacial aquifers, by interaction with the Dakota aquifer, and by inflow from Brule Creek and its tributaries, from the Big Sioux River, and from the Missouri River 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.

Discharge from the glacial aquifers is by evapotranspiration where the aquifers are close to land surface; by withdrawals through stock, domestic, municipal, and irrigation wells; by interaction with 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. Average 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 an average 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 average cumulative thickness of 216 feet, and an average depth below land surface to the top of the aquifer of 281 feet. Discharge from the aquifer is by withdrawals through stock, domestic, municipal, and irrigation wells and probably by interaction with 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 an average dissolved-solids concentration of 1,800 milligrams per liter.

The total water use in Lincoln and Union Counties during 1990 was 15.80 million gallons per day. About 85 percent of the water used was for irrigation.

INTRODUCTION

This Information Pamphlet is one of a series of reports on water-resources studies of South Dakota counties. It is designed to acquaint the reader with the general distribution, quantity, and quality of ground water available from the major aquifers in Lincoln and Union Counties. Information in this pamphlet is based on data collected in Lincoln and Union Counties (figs. 1 and 2) by the U.S. Geological Survey and the South Dakota Geological Survey during 1982 through 1989. Available drill-log and observation-well data from other test holes, private wells, or public wells also were used for this study; some of this information is shown in figures 1 and 2. More detailed information on the water resources of Lincoln and Union Counties is contained in a report by Niehus (1994).

Copies of this publication and other similar county reports may be obtained from the South Dakota Geological Survey in Vermillion. Additional information about the hydrology and geology of Lincoln and Union Counties may be obtained from U.S. Geological Survey offices in Huron and Rapid City or the South Dakota Geological Survey in Vermillion.

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.

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

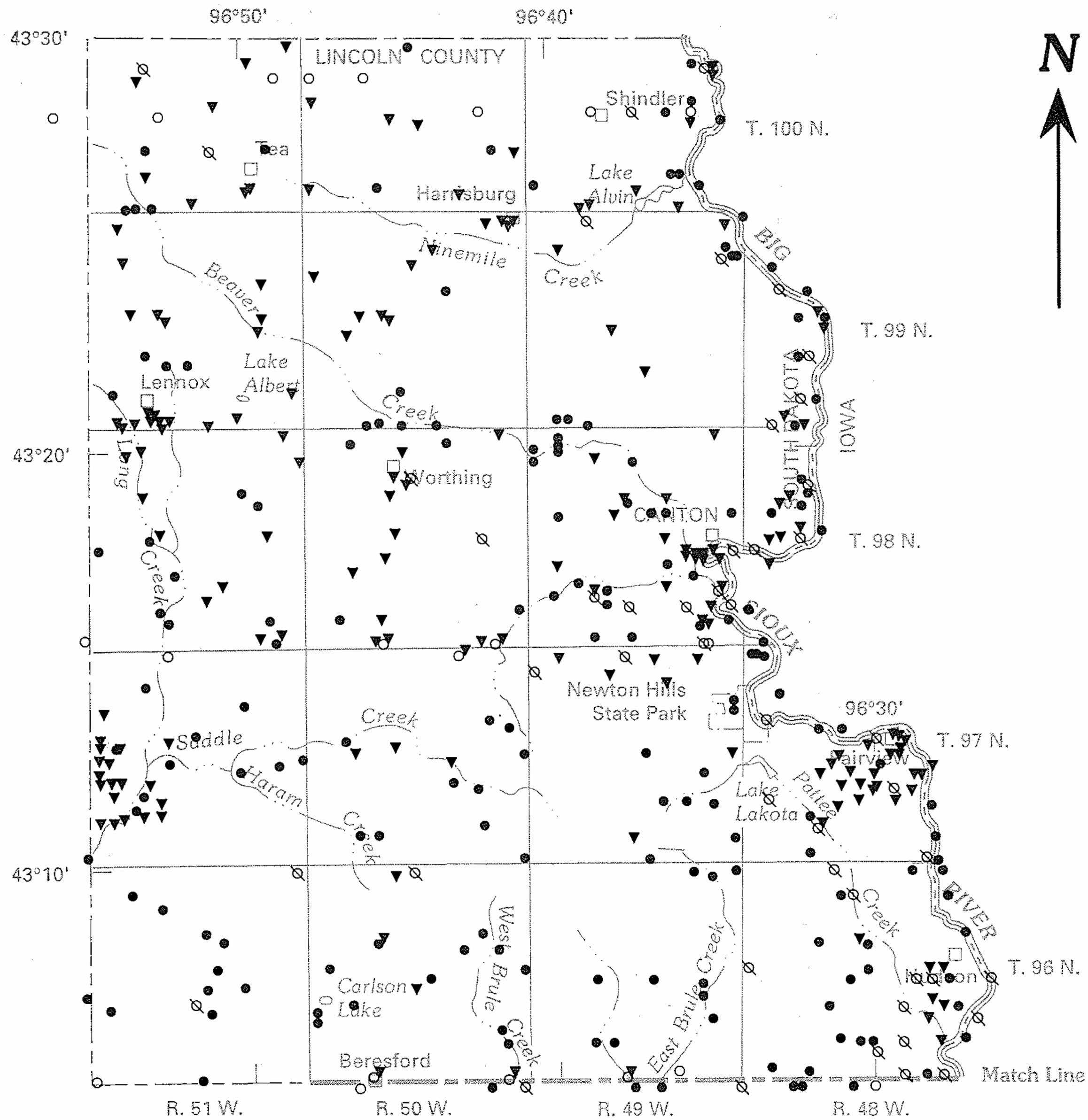
Multiply	By	To obtain
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
gallon per minute (gal/min)	0.0631	liter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
million gallons (Mgal)	3,785	cubic meter
million gallons per day (Mgal/d)	0.0438	cubic meter per second
square mile (mi^2)	2.590	square kilometer

DEFINITION OF TERMS

Alluvium: Material deposited by flowing water in river channels or on flood plains.

Aquifer: A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Artesian aquifer: A confined aquifer in which the water in a tightly cased well completed in the aquifer rises above the top of the aquifer.



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

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

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 1.--Location of selected ground-water data sites in Lincoln County.

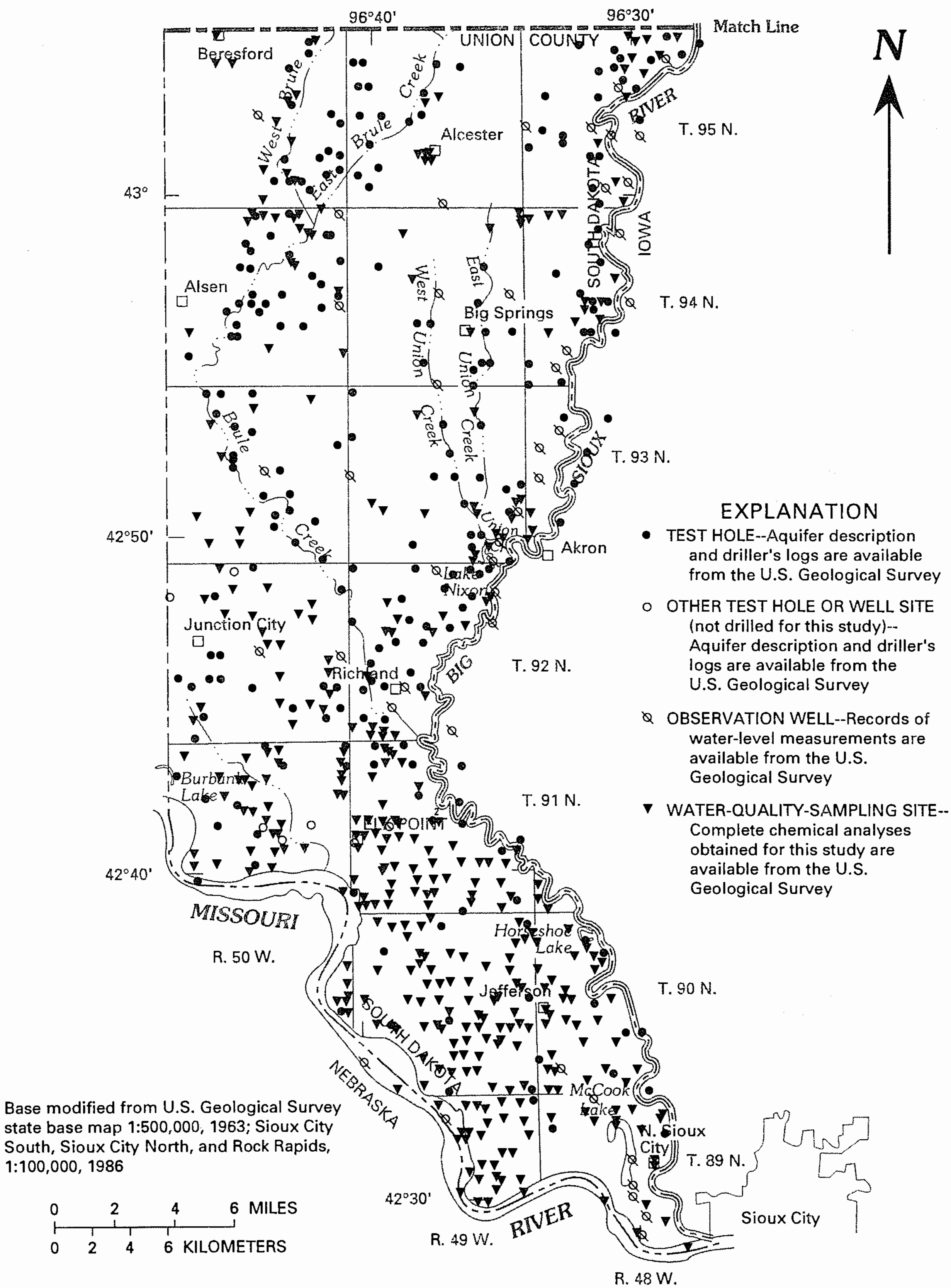


Figure 2.--Location of selected ground-water data sites in Union County.

Bedrock: A general term for the rock, usually consolidated, that underlies soil, sand, clay or other unconsolidated material. In Lincoln and Union Counties, the uppermost bedrock usually is shale, sandstone, siltstone, or quartzite.

Confined aquifer: An aquifer in which the water in a tightly cased well completed in the aquifer usually rises above the top of the aquifer.

Dissolved solids: The sum of all dissolved material in water, expressed as the weight (milligrams) of solute per unit volume (liter) of water.

Glacial aquifer: As used in this report, an aquifer consisting mainly of unconsolidated sand and gravel deposited as outwash from a glacier.

Glacial outwash: Gravel, sand, silt, and clay that was deposited by water from melting ice. In this report, the term is restricted to sand and gravel.

Hardness: Dissolved calcium and magnesium salts in water that decrease the lathering ability of soap and form scale in boilers and pipes. Hardness is reported as concentration of calcium carbonate and is classified by the U.S. Geological Survey as follows:

Water classification	Milligrams per liter	Grains per gallon
Soft	0- 60	0 - 3.5
Moderately hard	61-120	3.6- 7.0
Hard	121-180	7.1-10.5
Very hard	More than 180	More than 10.5

Large-capacity well: Defined by South Dakota law as a well capable of yielding at least 18 gallons per minute on a sustained basis.

Milligrams per liter (mg/L): A unit expressing the concentration of chemical constituents in solution as mass (milligrams) of solute per unit volume (liter) of water. One milligram per liter is approximately equal to one part per million.

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.

Specific conductance: The ability of water to conduct an electric current. Generally, this is a measure of the dissolved chemical constituents in water.

Till: A general term applied to all unsorted rock material (clay, silt, sand, gravel, and boulders) transported by glaciers and deposited directly on land or in the sea.

Unconfined aquifer: An aquifer in which the water table forms the upper boundary.

Water table: That water surface in an unconfined aquifer at which the pressure is atmospheric.

GLACIAL AQUIFERS

Ten glacial aquifers were delineated in Lincoln and Union Counties. The average thickness of the glacial aquifers ranges from 26 to 99 ft. The areal extent of the glacial aquifers was determined to range from 25 to 60 mi^2 for the Wall Lake, Parker-Centerville, Big Sioux, and Lower Vermillion-Missouri aquifers; to range from 85 to 90 mi^2 for the Harrisburg, Upper Vermillion-Missouri, and

Newton Hills aquifers; to be 130 mi^2 for the Shindler aquifer; and to be 180 mi^2 each for the Missouri and Brule Creek aquifers.

The average depth below land surface to the top of the Parker-Centerville, Big Sioux, and Missouri aquifers ranges from 12 to 22 ft; the average depth below land surface to the top of the Harrisburg, Newton Hills, and Brule Creek aquifers ranges from 46 to 72 ft; the average depth below land surface to the top of the Wall Lake, Shindler, and Lower Vermillion-Missouri aquifers ranges from 103 to 106 ft; and the average depth below land surface to the top of the Upper Vermillion-Missouri aquifer is 162 ft. The confined aquifers are overlain by till and primarily are underlain by either till, the Sioux Quartzite, the Dakota Formation, the Carlile Shale, or the Niobrara Formation. A summary of selected hydrologic characteristics of these aquifers is given in table 1.

Glacial aquifers are mostly unconsolidated sand and gravel outwash that was 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. 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).

Wall Lake Aquifer

The materials that comprise the Wall Lake aquifer (fig. 3) range from a fine to medium sand to 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 about 40 mi^2 in the northwestern corner of Lincoln County. The average cumulative thickness of the aquifer is 32 ft, and the average depth below land surface to the top of the aquifer is 106 ft. Analyses of test-drilling data and reported water levels indicate that the aquifer primarily is under artesian conditions. Selected hydrologic characteristics are given in table 1. A portion of the aquifer lies directly on the Sioux Quartzite, and the aquifer mainly is overlain by till.

Recharge to the Wall Lake aquifer is through fractures in the Sioux Quartzite in southern Minnehaha County (Lindgren and Niehus, 1992). The general direction of water movement in the aquifer is southerly, based on data from observation wells in sec. 8, T. 100 N., R. 51 W. and in sec. 27, T. 100 N., R. 51 W. The only known discharge from the aquifer is by withdrawals through stock and domestic wells.

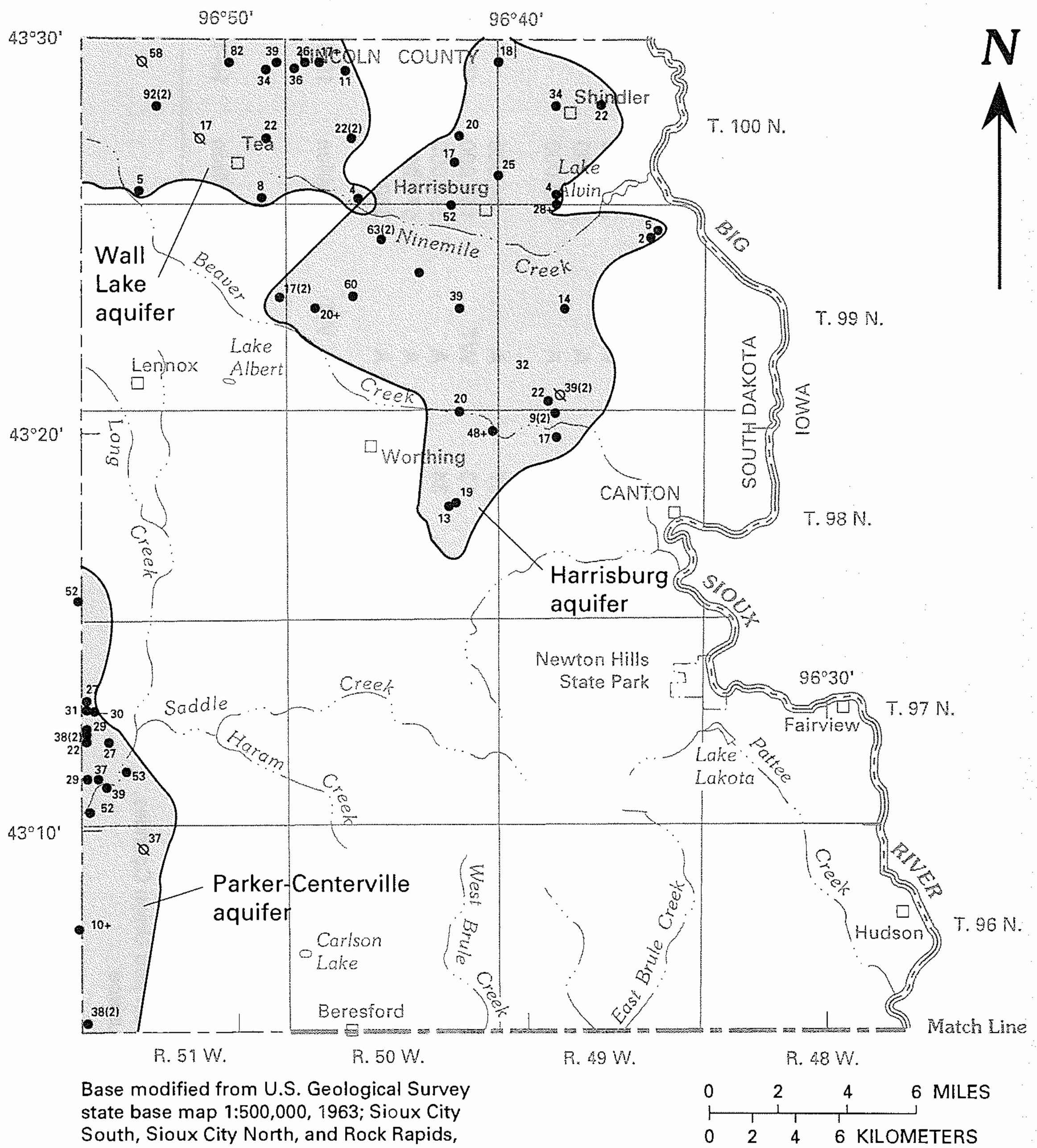
Predominant chemical constituents in water from the Wall Lake aquifer are calcium and sulfate. Dissolved-solids concentrations in five water samples from the aquifer ranged from 1,280 to 2,160 mg/L and averaged 1,620 mg/L. Hardness concentrations as calcium carbonate ($CaCO_3$) in six water samples from the aquifer ranged from 750 to 1,200 mg/L and averaged 990 mg/L.

Table 1. Summary of selected hydrologic characteristics of the major aquifers in Lincoln and Union Counties

[--, not determined]

Aquifer name	Areal extent (square miles)	Maximum cumulative thickness (feet)	Average cumulative 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 potential volume of water in storage[4] (acre-feet)	Range of reported well discharges[5] (gallons per minute)
GLACIAL AQUIFERS										
Wall Lake	40	92	32	6-178	106	20 - 88	56	A	120,000	--
Harrisburg	90	63	26	8-170	59	35 - 90	64	WT	220,000	--
Shindler	130	79	31	3-174	103	0 - 150	50	A	390,000	--
Upper Vermillion-Missouri	85	116	41	106-240	162	110	110	A	330,000	--
Parker-Centerville	25	53	35	0- 83	17	5 - 50	17	A	84,000	--
Big Sioux	60	72	28	1-118	12	-7 - 48	13	WT	160,000	10-1,500
Newton Hills	90	110	36	0-258	72	5 - 180	34	A	310,000	--
Brule Creek	180	88	33	1-176	46	0 - 153	70	A	570,000	5- 250
Lower Vermillion-Missouri	40	144	99	42-132	105	3 - 200	100	A	380,000	700-1,600
Missouri	180	146	84	0-105	22	0 - 130	18	A, WT	1.5 million	10-1,800
BEDROCK AQUIFER										
Dakota	935	423	[6]216	53-558	281	12 - 372	155	A	19.4 million	10-1,200

[1] Arithmetic mean from test-hole data within Lincoln and Union Counties.
[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] This average represents only Dakota wells and test holes that fully penetrate the aquifer.



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

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) OBSERVATION WELL--Number is the thickness of the aquifer, in feet. Number in parenthesis is the number of aquifer units penetrated where more than one (multiple units of one aquifer).

Figure 3.--Extent and thickness of the Wall Lake, Harrisburg, and Parker-Centerville aquifers in Lincoln County.

Harrisburg Aquifer

The unconsolidated materials that comprise the Harrisburg aquifer (fig. 3) range from a fine to medium sand to a mixture of fine to coarse sand and fine to medium gravel. The aquifer underlies about 90 mi^2 of northeast Lincoln County and generally is east of a Sioux Quartzite or Carlile Shale bedrock high. The average cumulative thickness of the aquifer is 26 ft, and the average depth below land surface to the top of the aquifer is 59 ft. Analyses of test-drilling data and reported water levels indicate that the aquifer primarily is under water-table conditions. Selected hydrologic characteristics are listed in table 1. The aquifer is overlain by till and underlain mostly by till but in a few places is underlain by the Sioux Quartzite, the Carlile Shale, or the Niobrara Formation. Less than 10 ft of till separates the Harrisburg aquifer from the underlying Shindler aquifer in the central part of the Harrisburg aquifer.

Recharge to the Harrisburg aquifer probably is by downward leakage through till. Discharge from the aquifer is by withdrawals through stock, domestic, and irrigation wells; evapotranspiration from the water-table surface where the aquifer is near land surface; seepage and flow from springs; and probably interaction with the underlying Shindler aquifer.

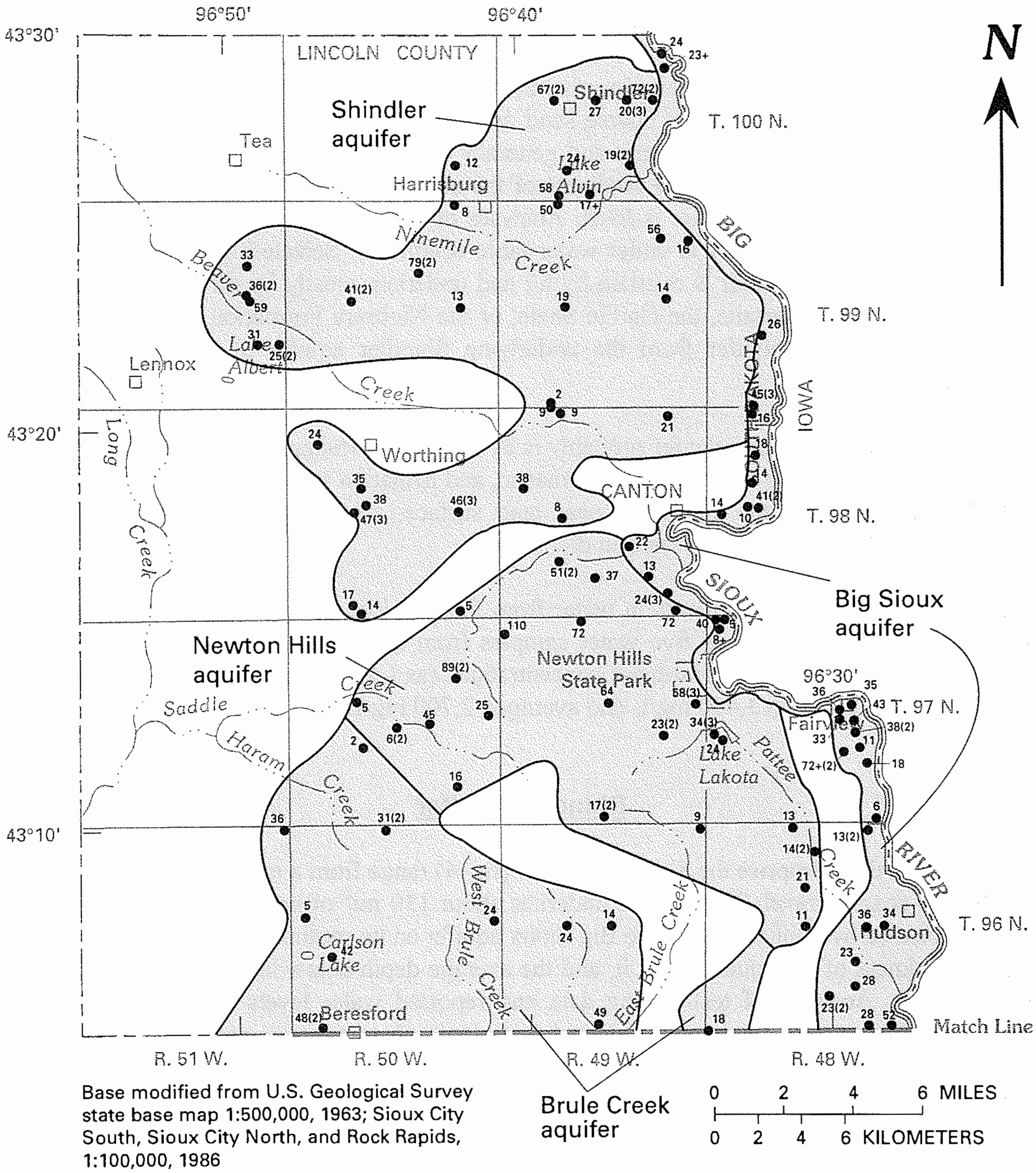
Predominant chemical constituents in water from the Harrisburg aquifer are calcium and sulfate. Dissolved-solids concentrations in five water samples from the aquifer ranged from 3,600 to 4,750 mg/L and averaged 4,075 mg/L. Hardness concentrations (as $CaCO_3$) in five water samples from the aquifer ranged from 2,000 to 3,400 mg/L and averaged 2,700 mg/L.

Shindler Aquifer

The materials that comprise the Shindler aquifer (fig. 4) range from a mixture of fine to very coarse sand to fine to coarse gravel. The aquifer underlies about 130 mi^2 of northeast Lincoln County. The aquifer is connected hydraulically with the Big Sioux aquifer on its southeastern boundary. The average cumulative thickness of the aquifer is 31 ft, and the average depth below land surface to the top of the aquifer is 103 ft. Analyses of test-drilling data and reported water levels indicate that the aquifer primarily is under artesian conditions. Selected hydrologic characteristics are given in table 1. The Harrisburg aquifer overlies much 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, the Niobrara Formation, the Carlile Shale, or the Sioux Quartzite.

The Harrisburg aquifer probably contributes some recharge through till to the underlying Shindler aquifer. The general direction of water movement in the Shindler aquifer is easterly toward the Big Sioux River. Discharge from the aquifer is by withdrawals through stock and domestic wells and by interaction with the Big Sioux aquifer. Water-quality data from the Shindler and Big Sioux aquifers are consistent with this hydraulic connection.

Predominant chemical constituents in water from the Shindler aquifer are calcium and sulfate. Dissolved-solids concentrations in eight water samples from the aquifer ranged from 1,380 to 3,150 mg/L and averaged 2,220 mg/L. Hardness concentrations (as $CaCO_3$) in eight water samples from the aquifer ranged from 810 to 1,900 mg/L and averaged 1,255 mg/L.



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 4.--Extent and thickness of the Shindler, Big Sioux, Newton Hills, and Brule Creek aquifers in Lincoln County.

Upper Vermillion-Missouri Aquifer

The materials that comprise the Upper Vermillion-Missouri aquifer (fig. 5) range from a mixture of fine to coarse sand to 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 about 85 mi^2 of extreme western Lincoln County. The average cumulative thickness of the aquifer is 41 ft, and the average depth below land surface to the top of the aquifer is 162 ft. A reported water level at a well in sec. 17, T. 99 N., R. 50 W. indicates that the aquifer probably is under artesian conditions. Selected hydrologic characteristics are listed in table 1. The aquifer overlies the Sioux Quartzite or the Carlile Shale in most areas and is overlain by till.

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 a well in sec. 8, T. 96 N., R. 51 W. Discharge from the aquifer is by withdrawals through stock, domestic, and municipal wells.

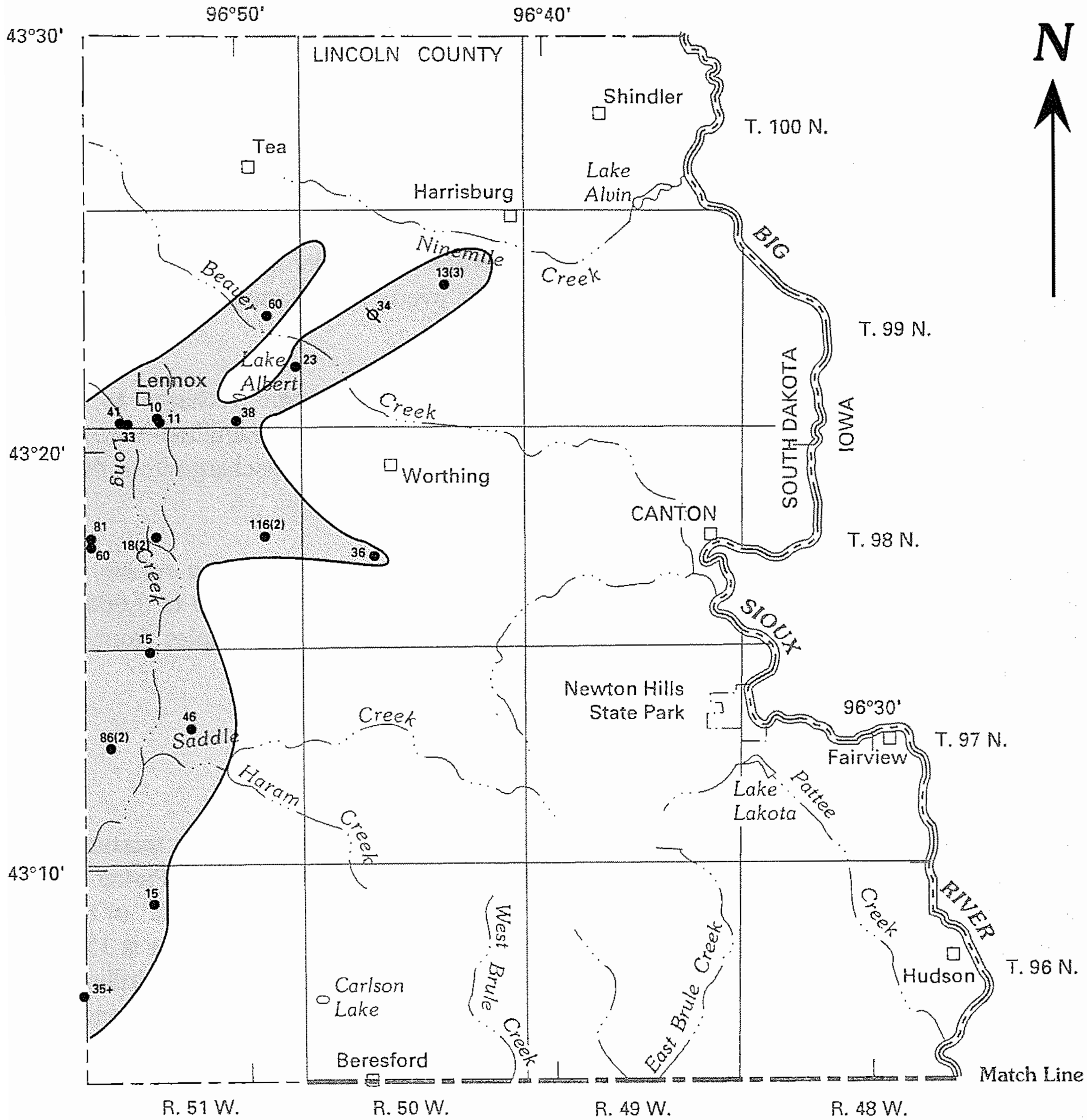
Predominant chemical constituents in water from the aquifer are calcium and sulfate. Dissolved-solids concentrations in eight water samples from the aquifer ranged from 1,300 to 3,600 mg/L and averaged 2,400 mg/L. Hardness concentrations (as $CaCO_3$) in nine water samples from the aquifer ranged from 800 to 2,000 mg/L and averaged 1,300 mg/L.

Parker-Centerville Aquifer

The materials that comprise the Parker-Centerville aquifer (fig. 3) range from a mixture of fine to coarse sand to fine to coarse gravel. The aquifer is the eastern extension of the Parker-Centerville aquifer described by Lindgren and Hansen (1990). The aquifer underlies about 25 mi^2 of the extreme southwestern edge of Lincoln County. The average cumulative thickness of the aquifer is 35 ft, and the average depth below land surface to the top of the aquifer is 17 ft. Analyses of test-drilling data and reported water levels indicate that the aquifer primarily is under artesian conditions. Selected hydrologic characteristics are given in table 1. The aquifer is overlain in most areas by till. At a well in sec. 8, T. 96 N., R. 51 W., 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. Discharge from the aquifer is: (1) by withdrawals through 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 interaction with the Upper Vermillion-Missouri aquifer.

Predominant chemical constituents in water from the Parker-Centerville aquifer are calcium, magnesium, sulfate, and bicarbonate. Dissolved-solids concentrations in 11 water samples from the aquifer ranged from 404 to 2,060 mg/L and averaged 777 mg/L. Hardness concentrations (as $CaCO_3$) in 11 water samples from the aquifer ranged from 370 to 1,400 mg/L and averaged 600 mg/L.



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

● 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 OBSERVATION WELL--Number is the thickness of the aquifer, in feet.

Figure 5.--Extent and thickness of the Upper Vermillion-Missouri aquifer in Lincoln County.

Big Sioux Aquifer

The materials that comprise the Big Sioux aquifer (figs. 4 and 6) range from fine sand to very coarse gravel. The aquifer underlies about 60 mi^2 of the flood plain of the Big Sioux River. The Big Sioux aquifer is connected hydraulically with the Shindler, Newton Hills, and Missouri aquifers and with the Big Sioux River. The average cumulative thickness of the aquifer is 28 ft, and the average depth below land surface to the top of the aquifer is 12 ft. Analyses of test-drilling data and reported water levels indicate that the aquifer primarily is under water-table conditions. Selected hydrologic characteristics are given in table 1. 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. Reported well discharges range from 10 to 1,500 gal/min.

Recharge to the Big Sioux aquifer is by infiltration and subsequent percolation of snowmelt and rainfall 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 aquifer also may receive some recharge from the Brule Creek aquifer through the till in T. 93 N. (fig. 6). Water-level data from observation wells and chemical analyses of water from the two aquifers support this interpretation. The Big Sioux and Brule Creek aquifers have similar chemical water quality. Possibly, the Big Sioux aquifer also receives some recharge from the Newton Hills and Brule Creek aquifers in T. 96 N. (fig. 6). The general direction of water movement in the aquifer is to the south.

Discharge from the aquifer is: (1) by withdrawals through stock, domestic, municipal, and irrigation wells, (2) by evapotranspiration from the aquifer where it is near land surface, and (3) by interaction with 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 boundary.(T. 92 N., fig. 6) where the Big Sioux and Missouri flood plains intersect.

Predominant chemical constituents in water from the Big Sioux aquifer are calcium, sulfate, and bicarbonate. Dissolved-solids concentrations in 47 water samples from the aquifer ranged from 384 to 7,150 mg/L and averaged 991 mg/L. Hardness concentrations (as $CaCO_3$) in 53 water samples from the aquifer ranged from 260 to 1,900 mg/L and averaged 620 mg/L.

Newton Hills Aquifer

The materials that comprise the Newton Hills aquifer (fig. 4) range from fine sand to medium gravel. The aquifer underlies about 90 mi^2 of southeast Lincoln County and is connected hydraulically with the Brule Creek and Big Sioux aquifers. This aquifer is actually the northern extension of the Brule Creek aquifer. The average cumulative thickness of the aquifer is 36 ft, and the average depth below land surface to the top of the aquifer is 72 ft. 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. Selected hydrologic characteristics are given in table 1. 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.

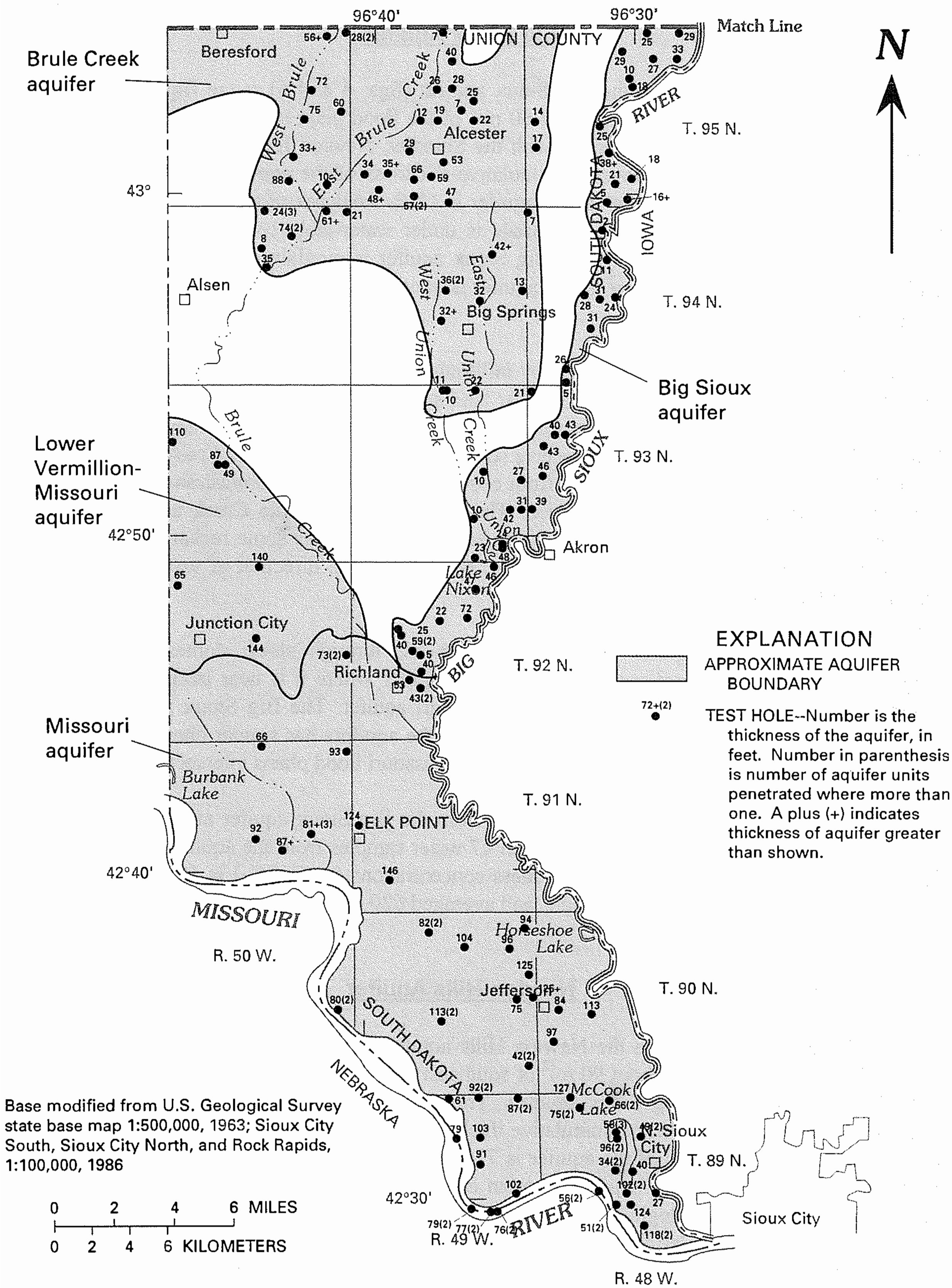


Figure 6.--Extent and thickness of the Big Sioux, Brule Creek, Lower Vermillion-Missouri, and Missouri aquifers in Union County.

Recharge to the Newton Hills 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 of till over the aquifer (average depth below land surface is 72 ft), the water from the aquifer has relatively high concentrations of dissolved solids. Recharge to the aquifer also is from the Brule Creek aquifer along the southwestern boundary of the Newton Hills aquifer. The general direction of water movement in the aquifer is northeast towards the Big Sioux aquifer.

Discharge from the aquifer is: (1) by withdrawals through stock and domestic wells, (2) by seepage and flow from springs, (3) by evapotranspiration where the aquifer is near land surface, and (4) by interaction with the Big Sioux aquifer in southeastern Lincoln County.

Predominant chemical constituents in water from the Newton Hills aquifer are calcium and sulfate. Dissolved-solids concentrations in three water samples from the aquifer ranged from 1,200 to 1,290 mg/L and averaged 1,230 mg/L. Hardness concentrations (as $CaCO_3$) in four water samples from the aquifer ranged from 800 to 1,500 mg/L and averaged 1,050 mg/L.

Brule Creek Aquifer

The Brule Creek aquifer (figs. 4 and 6) contains both glacial and nonglacial sands and gravels which range from medium sand to coarse gravel. The aquifer underlies about 180 mi^2 of southern Lincoln and northern Union Counties. It is connected hydraulically with the Newton Hills aquifer. The average cumulative thickness of the aquifer is 33 ft, and the average depth below land surface to the top of the aquifer is 46 ft. 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. Selected hydrologic characteristics are given in table 1. The aquifer is overlain by till and underlain primarily by the Niobrara Formation or the Carlile Shale. Reported well discharges range from 5 to 250 gal/min.

The general direction of water movement in the Brule Creek aquifer is southerly, except at its northeastern and northwestern boundaries where the aquifer is connected hydraulically to the Newton Hills aquifer and water movement is to the northeast. Recharge to the aquifer is by infiltration and subsequent percolation of rainfall and snowmelt in areas where the aquifer is near land surface and by inflow from Brule Creek and its tributaries. Discharge from the aquifer is: (1) by withdrawals through stock, domestic, municipal, and irrigation wells; (2) by evapotranspiration where the aquifer is near land surface; (3) by interaction with the Newton Hills aquifer and possibly with the Big Sioux aquifer through till at the southern boundary (T. 93 N., fig. 6) of the aquifer; and (4) by flow from springs.

Predominant chemical constituents in water from the Brule Creek aquifer are calcium, sulfate, and bicarbonate. Dissolved-solids concentrations in 16 water samples from the aquifer ranged from 480 to 3,212 mg/L and averaged 1,285 mg/L. Hardness concentrations (as $CaCO_3$) in 30 water samples from the aquifer ranged from 340 to 2,000 mg/L and averaged 690 mg/L.

Lower Vermillion-Missouri Aquifer

The materials that comprise the Lower Vermillion-Missouri aquifer (fig. 6) range from coarse sand to coarse gravel. The aquifer underlies about 40 mi^2 and is west and north of the Big Sioux River flood plain and north of the Missouri River flood plain in central Union County. The average cumulative thickness of the aquifer is 99 ft, and the average depth below land surface to the top of the aquifer is 105 ft. Analyses of test-drilling data and reported water levels indicate that the aquifer is under artesian conditions. Selected hydrologic characteristics are given in table 1. 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). Reported well discharges range from 700 to 1,600 gal/min.

Recharge to the Lower Vermillion-Missouri aquifer probably is from the underlying Dakota aquifer. The aquifer may also receive some recharge from percolation of snowmelt and spring runoff through till, although the top of the aquifer is relatively deep (42-132 ft). The general direction of water movement in the aquifer is southerly.

Discharge from the Lower Vermillion-Missouri aquifer is by withdrawals through stock, domestic, and irrigation wells and by interaction with the Missouri aquifer. The Lower Vermillion-Missouri and the northern part of the Missouri aquifer (T. 91 N. and T. 92 N., fig. 6) have similar chemical water quality.

Predominant chemical constituents in water samples from the Lower Vermillion-Missouri aquifer are calcium and sulfate. Dissolved-solids concentrations in two water samples from the aquifer were 340 and 1,820 mg/L. Hardness concentrations (as $CaCO_3$) in 14 water samples from the aquifer ranged from 360 to 1,200 mg/L.

Missouri Aquifer

The unconsolidated materials that comprise the Missouri aquifer (fig. 6) range from fine sand to very coarse gravel. The aquifer underlies about 180 mi^2 of the flood plains of the Missouri and Big Sioux Rivers in southern Union County. The average cumulative thickness of the aquifer is 84 ft, and the average depth below land surface to the top of the aquifer is 22 ft. Analyses of test-drilling data and reported water levels indicate that the aquifer is under artesian conditions in the northwestern part of the aquifer and under water-table conditions in the southern part. Selected hydrologic characteristics are listed in table 1. 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. Reported well discharges range from 10 to 1,800 gal/min.

Recharge to the Missouri aquifer is by infiltration and subsequent percolation of snowmelt and spring runoff 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.

Recharge also occurs at times from the underlying Dakota aquifer. Analyses of limited water-level measurements from observation wells and chemical analyses indicate a hydraulic connection. Some recharge to the aquifer also is from the Missouri River during periods of high flow and stage. The general direction of water movement in the aquifer is to the southeast.

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

Predominant chemical constituents in water from the Missouri aquifer are calcium, sulfate, and bicarbonate. Dissolved-solids concentrations in 68 water samples from the aquifer ranged from 230 to 1,800 mg/L and averaged 850 mg/L. Hardness concentrations (as $CaCO_3$) in 251 water samples from the aquifer ranged from 17 to 1,400 mg/L and averaged 613 mg/L.

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, the Sioux Quartzite wash, the Carlile Shale, and the Niobrara Formation are minor bedrock 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 are not aquifers in these counties.

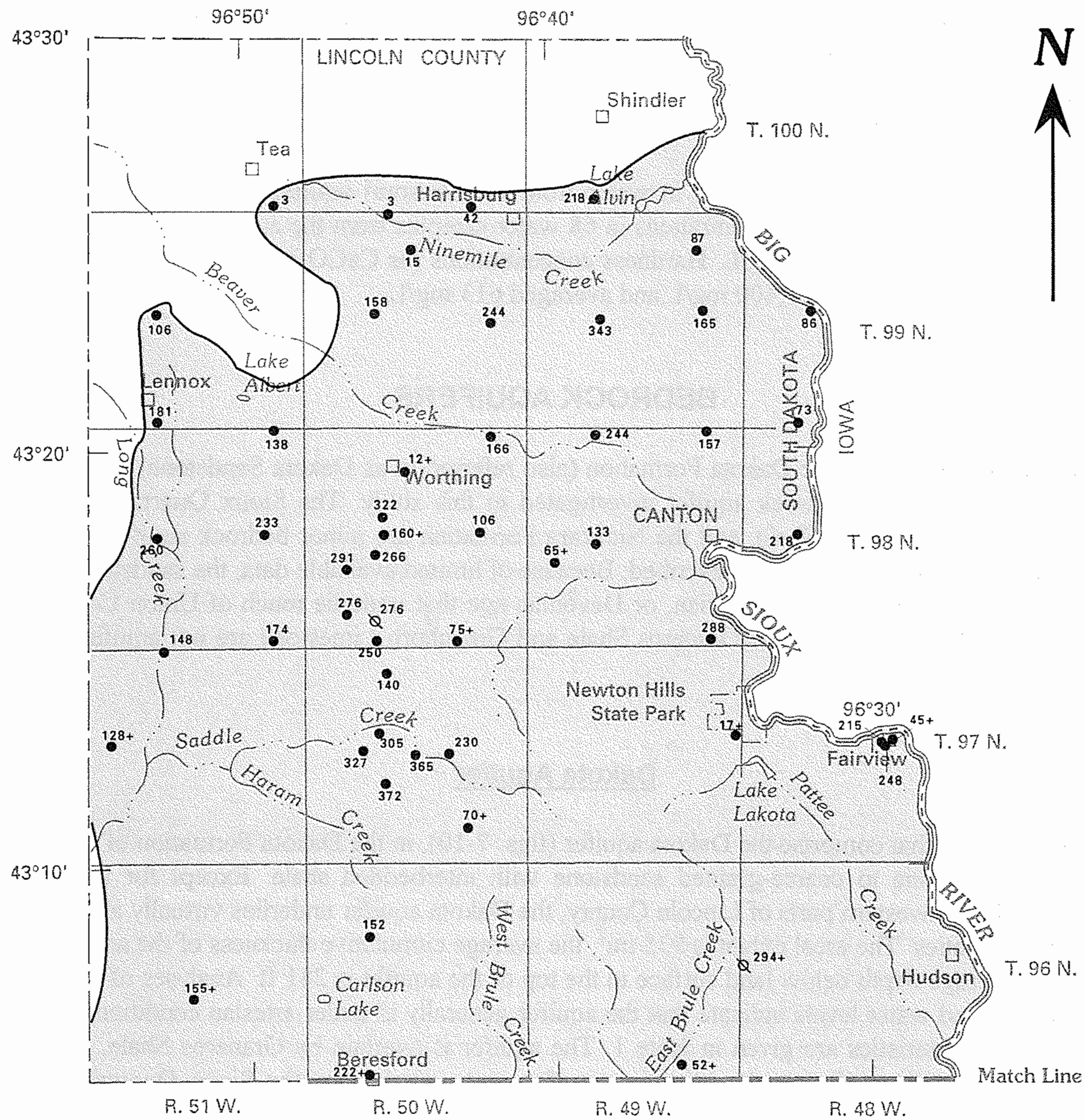
Dakota Aquifer

The materials that comprise the Dakota aquifer (figs. 7-10), in the Dakota Formation of Cretaceous age, range from fine to coarse-grained sandstone with interbedded shale. Except for the extreme northern and northwestern parts of Lincoln County, the Dakota aquifer underlies virtually all of Lincoln and Union Counties. The areal extent is 935 mi^2, the average cumulative thickness of the aquifer is 216 ft, and the average depth below land surface to the top of the aquifer is 281 ft. Analyses of test-drilling data and reported water levels indicate that the aquifer generally is under artesian conditions. Selected hydrologic characteristics are given in table 1. The aquifer is overlain by Graneros Shale, the Lower Vermillion-Missouri aquifer, or the Missouri aquifer, and underlain by the Sioux Quartzite; several sandstones, shales, and dolostones of Cambrian, Ordovician, or Devonian age; or the Sioux Quartzite wash. The general direction of water movement in the aquifer is southerly. Reported well discharges range from 10 to 1,200 gal/min.

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). In parts of Lincoln and Union Counties, the Dakota aquifer may also receive some recharge from the overlying Missouri aquifer.

Discharge from the Dakota aquifer is by withdrawals through stock, domestic, municipal, and irrigation wells and probably by interaction with the overlying Lower Vermillion-Missouri and Missouri aquifers. The aquifer probably also discharges to fractures in the underlying Sioux Quartzite.

Predominant chemical constituents in water from the Dakota aquifer are calcium, sulfate, and bicarbonate. Dissolved-solids concentrations in 64 water samples from the aquifer ranged from 405 to



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.

ø 294+ OBSERVATION WELL--Number is the thickness of the aquifer, in feet. A plus (+) indicates thickness of aquifer greater than shown.

Figure 7.--Extent and thickness of the Dakota aquifer in Lincoln County.

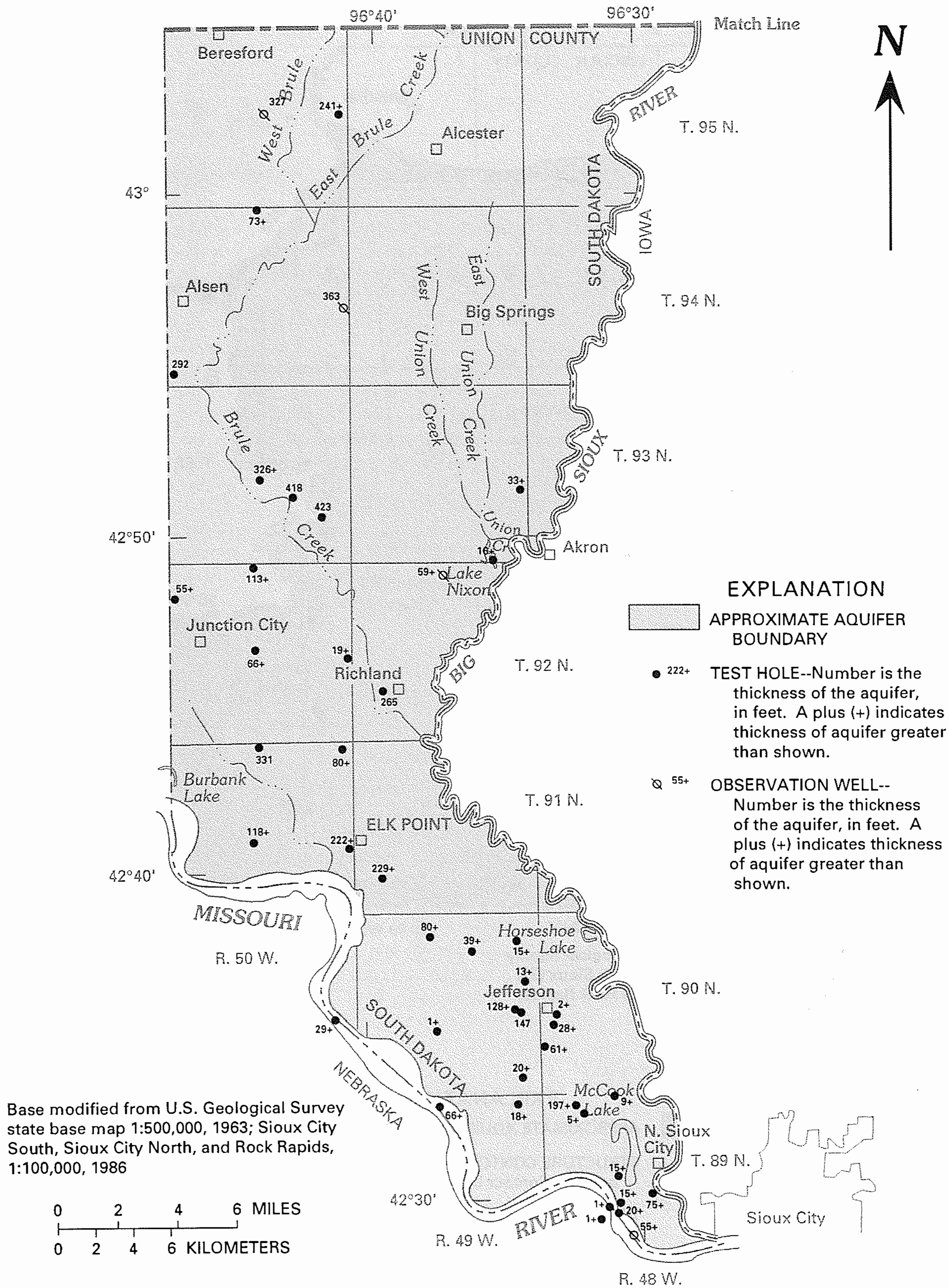
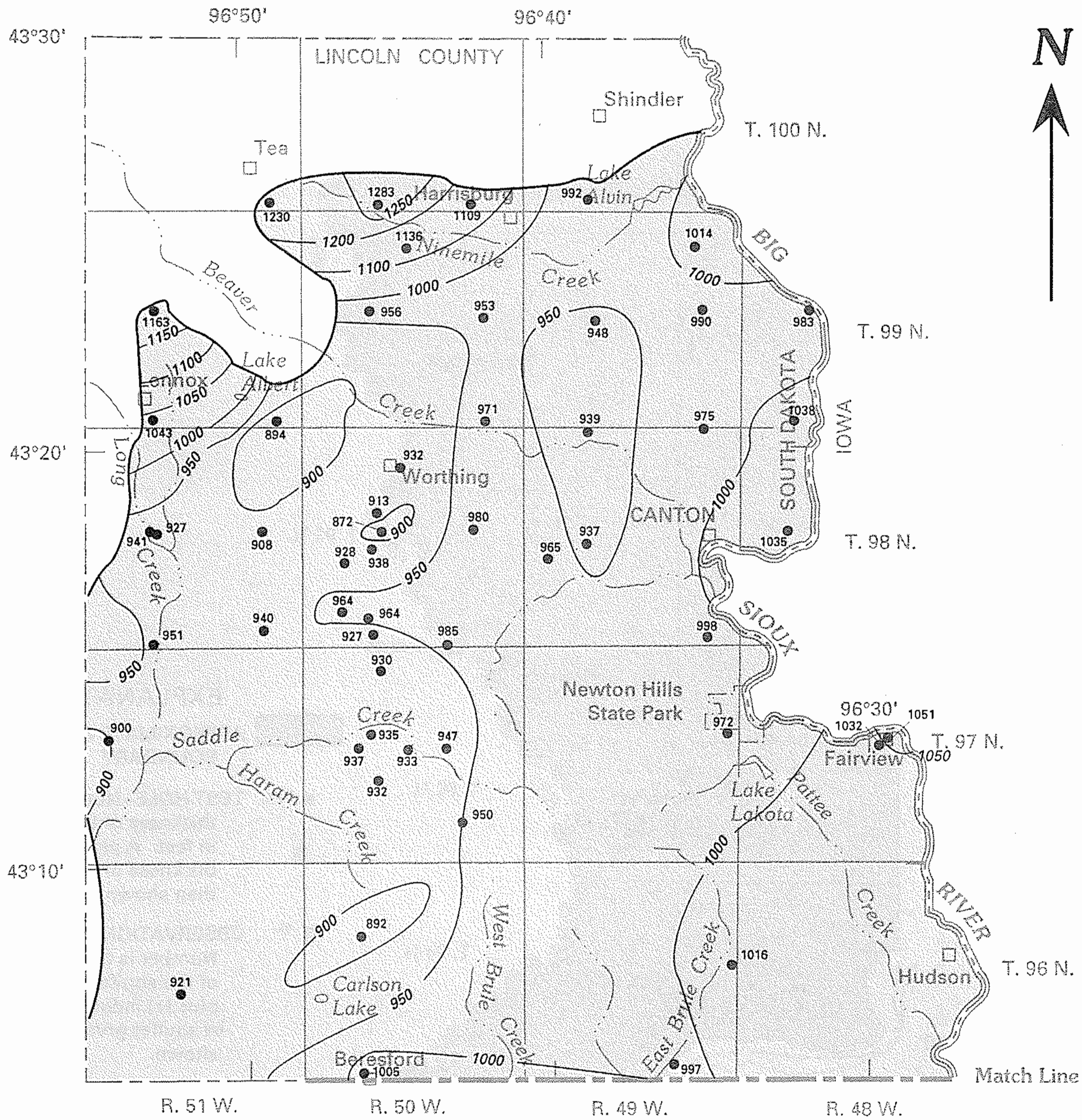


Figure 8.--Extent and thickness of the Dakota aquifer in Union County.



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

900 STRUCTURE CONTOUR--Shows altitude of the top of the aquifer. Contour interval is variable. Datum is sea level.

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

Figure 9.--Structure contours on the top of the Dakota aquifer in Lincoln County.

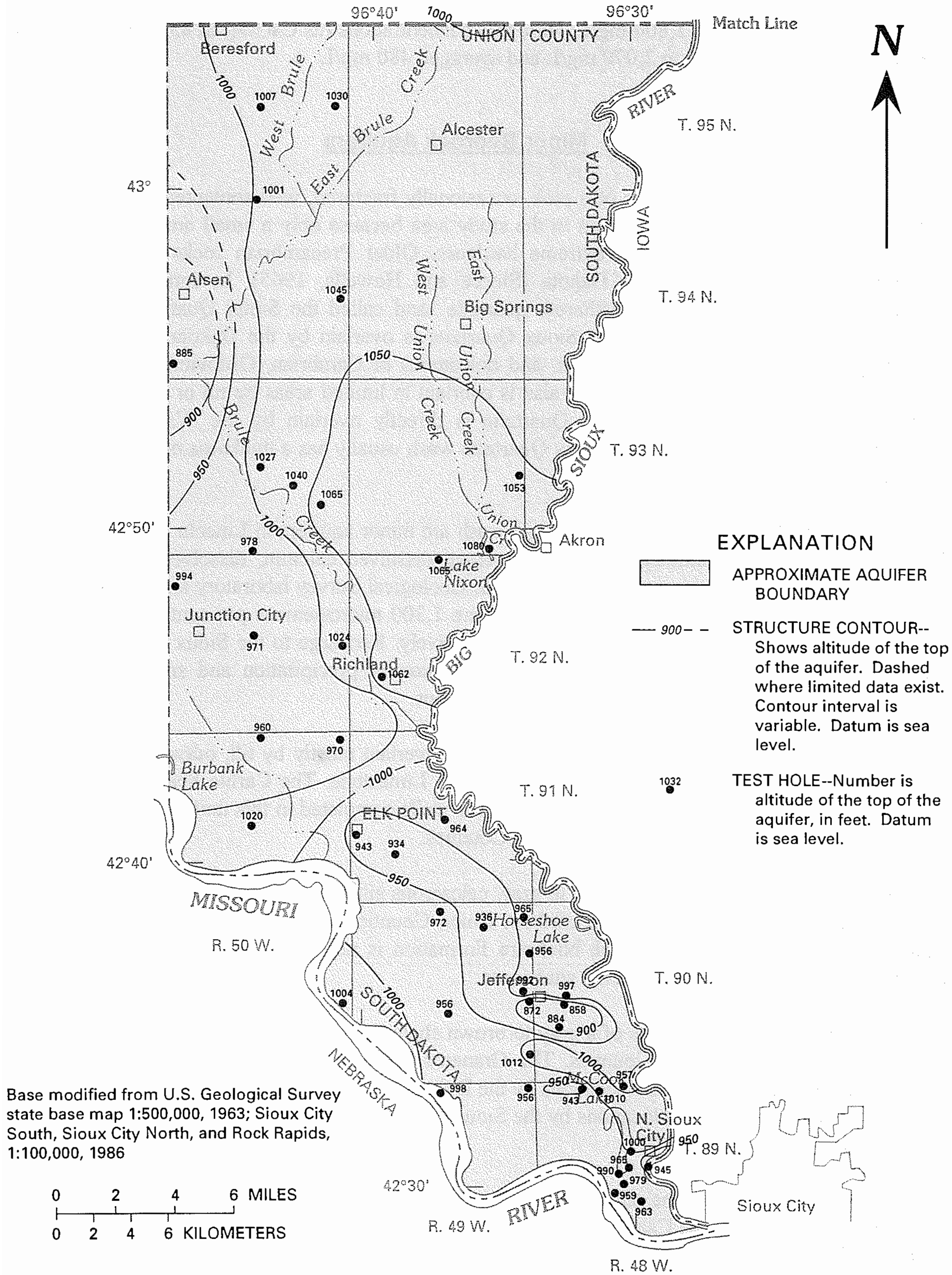


Figure 10.--Structure contours on the top of the Dakota aquifer in Union County.

7,640 mg/L and averaged 1,800 mg/L. Hardness concentrations (as $CaCO_3$) in 83 water samples from the aquifer ranged from 52 to 2,070 mg/L and averaged 480 mg/L.

Minor Bedrock Aquifers

The Sioux Quartzite consists of a pink, occasionally 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). 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 the 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 the Carlile Shale. In northern Lincoln County, the Sioux Quartzite is directly overlain by the Wall Lake and Upper Vermillion-Missouri aquifers. The Sioux Quartzite wash usually has a thickness of less than 5 ft based on examination of test-hole logs.

The Sioux Quartzite and 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 U.S. Geological Survey laboratory analyses of water from approximately 10 sites in the Sioux Quartzite were 1,300 microsiemens per centimeter ($\mu S/cm$), 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 by infiltration of precipitation and snowmelt 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 the Greenhorn Limestone. The Carlile Shale is relatively thick (greater than 250 ft in some areas). There are some wells completed in this unit, 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.

LARGE-CAPACITY WELLS

The best possibilities for developing large-capacity wells capable of supplying more than 500 gal/min are in the areas where the aquifers are composed of coarse sand and gravel and are more than 20 ft thick. Before supply wells are constructed, test holes often are drilled to determine the thickness of the aquifer and to provide samples for determining the grain size of the aquifer material. This information helps in the selection of the proper slot size and length of screen to be used in the construction of a well. Controlled pumping of the well for at least several hours indicates the yield of the aquifer at the locality and provides a representative water sample for chemical analysis. Measurement of the recovery of the water level in the well provides information that is useful for estimating the yield of a well during longer pumping periods. If the well is to be used for irrigation, knowledge of the type of soil, subsoil, and topography are also important in selecting the most suitable irrigation system. Intensive ground-water development may cause water-level declines and, especially in stream valleys, decreases in streamflow.

WATER USE

Total water use in Lincoln and Union Counties in 1990 was 15.80 Mgal/d. Eighty-five percent (13.47 Mgal/d) of the total amount of water used in Lincoln and Union Counties during 1990 was for irrigation (table 2). Ground water was the source of 94 percent (12.60 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.

Table 2. Water use in Lincoln and Union Counties in 1990

[From F.D. Amundson, U.S. Geological Survey, written commun., 1995. 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	0.22	0.75	0	0.02	0.34	1.33
Surface water	.33	0	0	0	.26	.59
Union County						
Ground water	.18	.41	.09	.05	12.26	12.99
Surface water	.28	0	0	0	.61	.89
Total	1.01	1.16	.09	.07	13.47	15.80

SUMMARY

Ten glacial aquifers and one bedrock aquifer were delineated in Lincoln and Union Counties. The ten glacial aquifers have the potential to contain about 4 million acre-ft of water in storage, and the major bedrock aquifer has the potential to contain about 19.4 million acre-ft.

The areal extent of the glacial aquifers was determined to range from 25 to 60 mi^2 for the Wall Lake, Parker-Centerville, Big Sioux, and Lower Vermillion-Missouri aquifers; to range from 85 to 90 mi^2 for the Harrisburg, Upper Vermillion-Missouri, and Newton Hills aquifers; to be 130 mi^2 for the Shindler aquifer; and to be 180 mi^2 each for the Missouri and Brule Creek aquifers. The areal extent of the only major bedrock aquifer, the Dakota, was determined to be 935 mi^2.

The average cumulative 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 southern Minnehaha County. Recharge to the Upper Vermillion-Missouri aquifer probably occurs from the overlying Parker-Centerville aquifer. Recharge to the Parker-Centerville aquifer is by infiltration and subsequent percolation of snowmelt and spring rainfall where the aquifer is near land surface. 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 stock, domestic, and municipal wells. The Parker-Centerville aquifer also has some discharge by seepage and flow from springs, by evapotranspiration where the aquifer is near land surface, and probably by interaction with the Upper Vermillion-Missouri aquifer.

The average cumulative 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 downward leakage through till. Recharge to the Shindler aquifer probably is from the overlying Harrisburg aquifer. Discharge from the Harrisburg aquifer is through stock, domestic, and irrigation wells; by evapotranspiration where the aquifer is near land surface; by seepage and flow from springs; and probably by interaction with the underlying Shindler aquifer. Discharge from the Shindler aquifer is through stock and domestic wells, and interaction with the Big Sioux aquifer.

The average cumulative 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 aquifers are near land surface and to the Brule Creek aquifer by inflow from Brule Creek and its tributaries. The Newton Hills aquifer also receives recharge from the Brule Creek aquifer. Discharge from the Newton Hills aquifer is through stock and domestic wells, by seepage and flow from springs, by evapotranspiration where the aquifer is near land surface, and by interaction with the Big Sioux aquifer in southeastern Lincoln County. Discharge from the Brule Creek aquifer is by withdrawals through stock, domestic, municipal, and irrigation wells; by evapotranspiration where the aquifer is near land surface; and by interaction with the Newton Hills aquifer and possibly with the Big Sioux aquifer through till in T. 93 N.; and by seepage and flow from springs.

The average cumulative 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 runoff where the aquifer is near land surface; from the Lower Vermillion-Missouri and the Big Sioux aquifers in the north; from the underlying Dakota aquifer; and from the Missouri River during periods of high flow and stage. Recharge to the Big Sioux aquifer is by infiltration and subsequent percolation of snowmelt and rainfall where the aquifer is near land surface and by interaction with the Shindler, Newton Hills, and possibly the Brule Creek aquifers. Discharge from the Lower Vermillion-Missouri aquifer is by withdrawals through stock, domestic, and irrigation wells and by interaction with the Missouri aquifer. Discharge from the Missouri aquifer is by withdrawals through stock, domestic, municipal, and irrigation wells; by evapotranspiration where the aquifer is near land surface; by interaction with the Missouri and Big Sioux Rivers during periods of low flow and stage; and by interaction with the Dakota aquifer. Discharge from the Big Sioux aquifer is by withdrawals through stock, domestic, municipal, and irrigation wells; by evapotranspiration where the aquifer is near land surface; and by interaction with the Big Sioux River and the Missouri aquifer.

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 at times from the overlying Missouri aquifer. Discharge from the Dakota aquifer is through stock, domestic, municipal, and irrigation wells; probably by interaction with the Lower Vermillion-Missouri and Missouri aquifers; and probably at times by discharge to fractures in the underlying Sioux Quartzite. Predominant chemical constituents are calcium, sulfate, and bicarbonate. The mean dissolved-solids concentration in water from the Dakota aquifer was 1,800 mg/L.

Total water use in Lincoln and Union Counties during 1990 was 15.80 Mgal/d. Eighty-five percent of total water use in Lincoln and Union Counties was for irrigation, of which 94 percent was from ground-water sources.

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