WATER RESOURCES OF DEUEL AND HAMLIN COUNTIES, SOUTH DAKOTA

By Jack Kume

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4069

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CONVERSION FACTORS

For those readers interested in using metric units rather than inch-pound units, the conversion factors for the terms in this report are listed below.

Multiply	By	To obtain
acre	4,047	square meter
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per year (ft/yr)	0.3048	meter per year
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06308	liter per second
inch	25.40	millimeter
inch	2.54	centimeter
mile (mi)	1.609	kilometer
micromho per centimeter (μmho/cm)	1.000	microsiemens
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square foot per day (ft^2/d)	0.09290	square meter per day
square mile (mi^2)	2.590	square kilometer

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ABSTRACT

The water resources of Deuel and Hamlin Counties are relatively undeveloped. In 1975, only about 6,000 acre-feet of water was used for irrigation, stock, domestic, and public supplies; most of this usage came from ground water. Average surface-water runoff from the area is about 37,000 acre-feet annually. At least 95 percent of the 1.43 million acre-feet of precipitation in an average year is lost to evapotranspiration.

An estimated 8.4 million acre-feet of water is stored in three major and several minor aquifers in the glacial drift. The Big Sioux aquifer, underlying the valley of the Big Sioux River and some of its tributaries, contains an estimated 0.5 million acre-feet of water in storage, but is, along with other small, surficial aquifers, the most easily developed source of good-quality ground water. These aquifers can yield enough to supply large-capacity wells in many areas. The Big Sioux, and other surficial aquifers, are hydraulically connected with the Big Sioux River or other streams and some of the many lakes in the area, so that these aquifers can receive recharge from or discharge water to those streams and lakes.

The other two major aquifers in the drift are the Prairie Coteau aquifer, buried beneath 3 to 360 feet of till, and the Altamont aquifer, buried beneath 150 to 820 feet of till and commonly overlying the bedrock surface. The Prairie Coteau aquifer contains an estimated 5 million acre-feet of water ranging from good to poor in quality; locally, wells capable of producing as much as 1,000 gallons per minute from this aquifer are possible. The Altamont aquifer contains an estimated 2.9 million acre-feet of water ranging from fair to poor in quality; locally, wells capable of producing as much as 500 gallons per minute could be constructed.

The only known aquifer in the bedrock is the sandstone of the Dakota Formation, which contains an estimated 5 million acre-feet of saline water.

INTRODUCTION

In eastern South Dakota, ground water supplies most of the domestic and stock water as well as much of the water needed to meet the rapidly expanding requirements for irrigation. Rapid increase in the use of water has resulted in a need for more information about ground water--its occurrence, quantity and quality, and its availability for irrigation, industrial, livestock, domestic, and municipal use. An additional concern in Deuel and Hamlin Counties is the effects that ground-water withdrawals may have on some surface-water resources, such as Lake Poinsett or the Big Sioux River, and, conversely, the effects on ground-water supplies of natural or man-caused changes in the levels of lakes or the flow of streams. This report summarizes information obtained during a cooperative study of the two-county area made by the South Dakota State Geological Survey and the U.S. Geological Survey at the request of and in cooperation with the Deuel and Hamlin County Boards of Commissioners and the East Dakota Conservancy Sub-District.

Deuel and Hamlin Counties, an area of about 1,184 mi^2, lie across the rolling glacial upland of the Coteau des Prairies division of the Central Lowlands physiographic province (fig. 1). Part of northeastern Deuel County is in the Minnesota River-Red River Lowland division. The 16- to 20-mi wide south-southeast trending valley of the Big Sioux River crosses the eastern two-thirds of Hamlin County. The valley is asymetrical, deepest near its eastern edge (from about 1,630 ft above sea level on the south to 1,690 ft in the north), rising gradually to the west and more rapidly to the east to about 1,700 to 1,750 ft (southern and northern county lines, respectively). This broad, shallow trough is paralleled on the west by a broad, moderately higher upland whose crest is somewhat above 1,800 ft altitude (maximum about 1,930 ft) and is paralleled on the east by a higher, somewhat more rugged highland whose crest has an altitude of about 2,000 ft (maximum about 2,035 ft). Northeast of the crest of the eastern highland, the land surface slopes steeply to the valley of the Minnesota River, which has an altitude of about 1,150 ft in Deuel County.

The physiography and geology of Deuel and Hamlin Counties have been described in detail by Beissel (in press). Other investigations of geology or hydrology that included all or parts of Deuel and Hamlin Counties are listed in the Selected References.

Glacial drift of Pleistocene age and alluvium of Holocene age comprise the surficial deposits. Except for the Precambrian basement rocks, the consolidated rock in the county is Cretaceous in age and includes in order of increasing age the Pierre Shale, Niobrara Formation, Carlile Shale, Greenhorn Formation, Graneros Shale, and Dakota Formation.

Data used in the preparation of this report may be examined at the U.S. Geological Survey, Federal Building, Huron, S. Dak., and at the South Dakota Geological Survey, Science Center, University of South Dakota, Vermillion, S. Dak.

The author gratefully acknowledges help from the well drillers, county and town officials, and ranchers and farmers of Deuel and Hamlin Counties and adjacent areas. Special thanks are due to Mr. Jerry L. Siegel and the East Dakota Conservancy Sub-District personnel, who provided water data including many measurements of lake stage and of water levels in observation wells.

During this investigation, an onsite field inventory of more than 2,700 private and public wells was made; more than 733 test holes were drilled; more than 230 partial and 118 complete chemical analyses were made; and data from 4 aquifer tests were collected and analyzed.

All wells and data sites (which include test holes, sampling sites, observation wells, and streamflow-measurement sites) are numbered according to a system based on the Federal land-survey system used in eastern South Dakota (fig. 2).

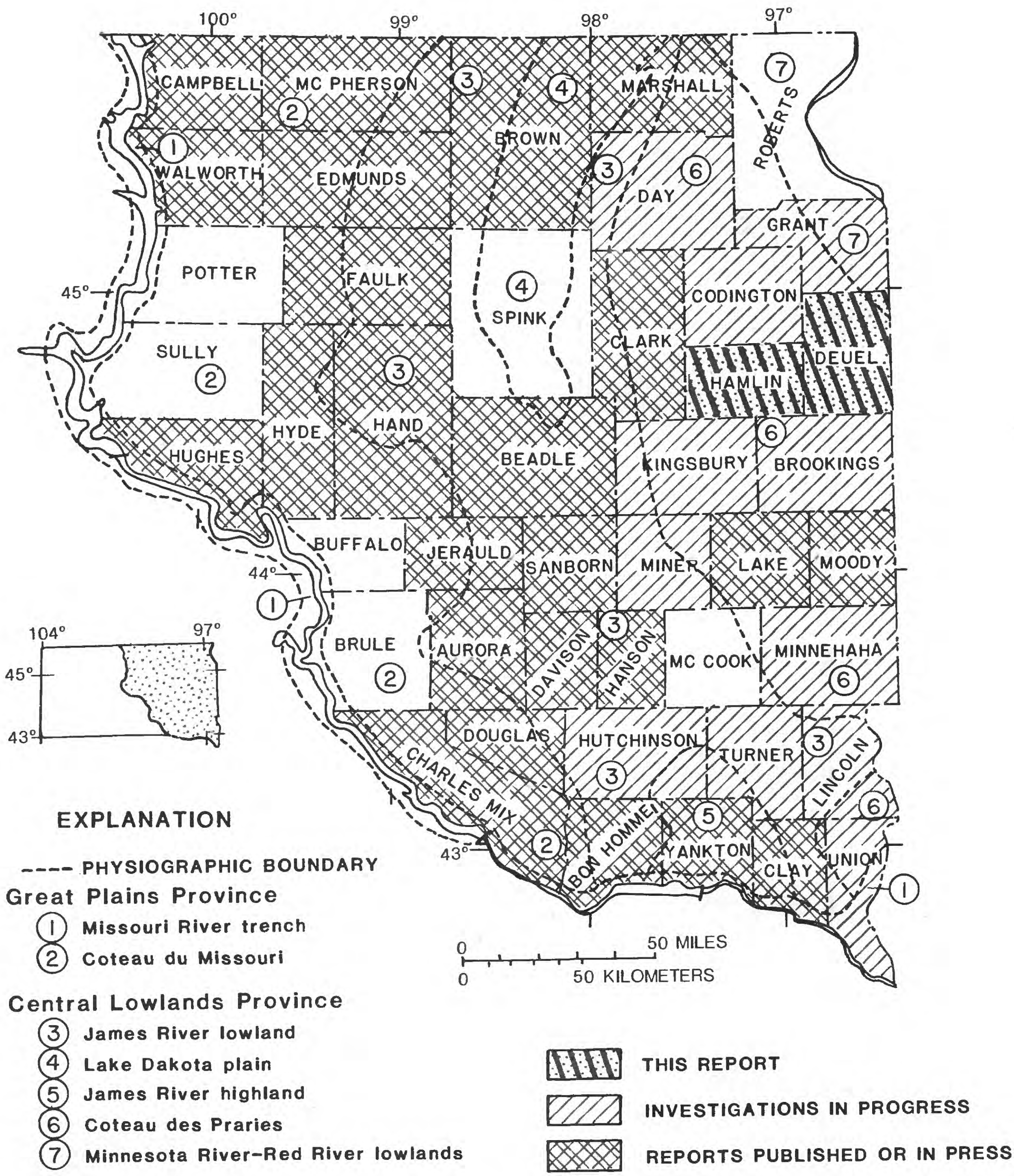
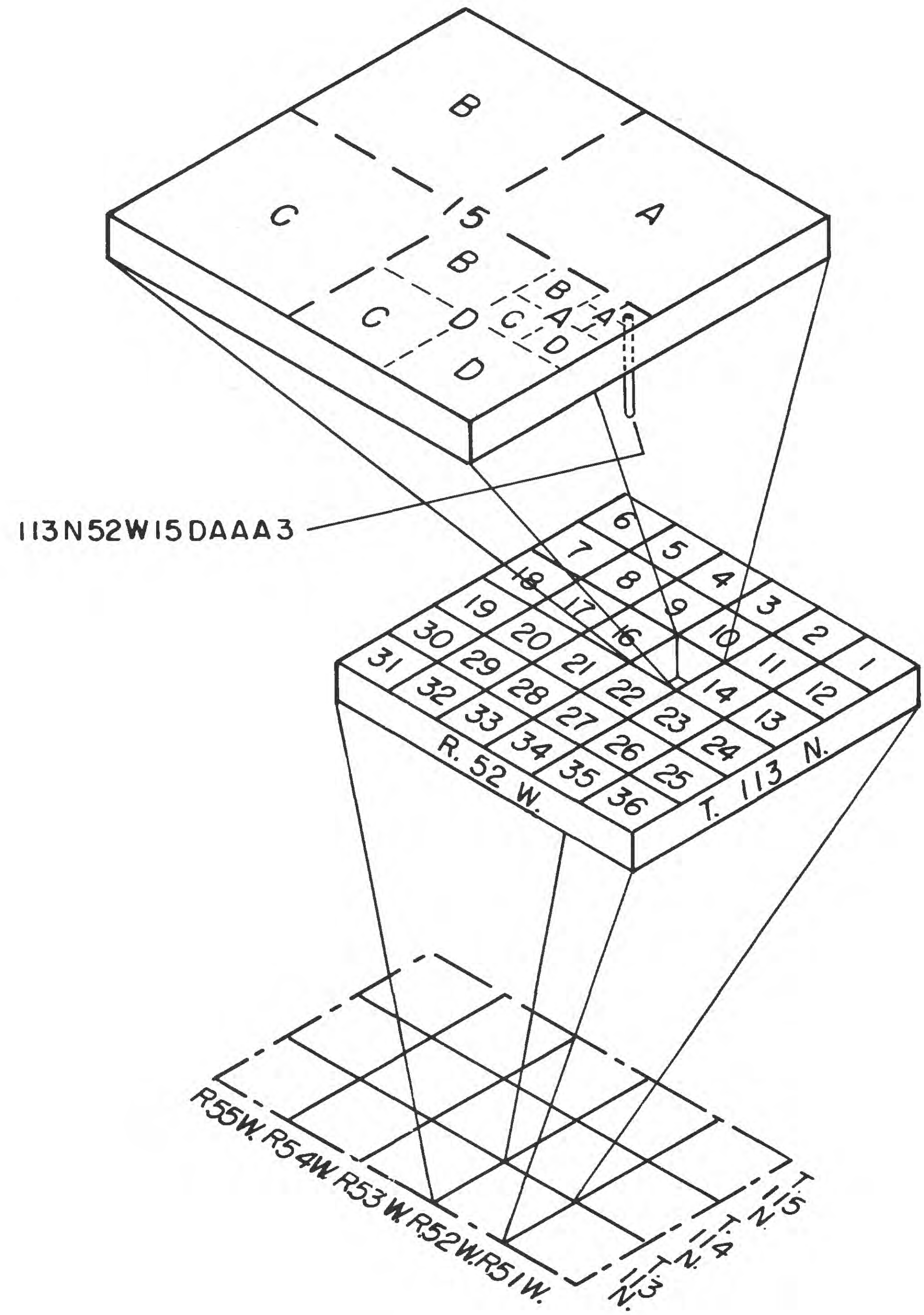


Figure 1.--Location of the area discussed in this report, the status of the county water-resources study program, and the major physiographic divisions of the area (after Flint, 1955).



EXPLANATION

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

Figure 2.--Well-numbering diagram.

HYDROLOGY

Water in Deuel and Hamlin Counties is present in streams, lakes, ponds, and reservoirs and in the interconnected pore space of unconsolidated surficial deposits and of bedrock strata. Most of the surface water and ground water in surficial deposits comes from precipitation in Deuel and Hamlin Counties and adjacent areas. The estimated average annual hydrologic budget for the study area is shown in figure 3.

The average annual hydrologic budget illustrates inflow and outflow of water for Deuel and Hamlin Counties. About 1,470,000 acre-ft (479 billion gallons) of water per year move through the area. About 95 percent (1.4 million acre-ft) of the water is returned to the atmosphere by evaporation and transpiration. About 82 percent of the annual lake-evaporation rate of 33.7 inches occurs during the May to October growing season (Kohler and others, 1959). Only about 2.6 percent of the precipitation becomes streamflow or aquifer outflow from the area. Average surface-water runoff from the area is about 37,500 acre-ft. Less than 4 percent of the precipitation percolates downward to become ground water. Much of this ground water moves laterally in local flow systems before being discharged by springs to lakes and streams and by evapotranspiration. In any given year, the water budget probably would show a change in ground-water storage, which can be detected by and calculated from changes in water levels in observation wells completed in the aquifers. Over the long term, however, changes in storage will be zero except where, or if, ground-water discharge to wells significantly increases. In 1975 only about 6,000 acre-ft of water was used for irrigation, stock, domestic, and public supplies; most of this usage came from ground water.

The lakes, streams, and aquifers in the two-county area are hydrologically connected in a complex pattern. Water moves back and forth between surface- and ground-water paths in its movement through the counties. The present study disclosed the broad features of this relationship. A recent study discloses and quantifies the hydrologic system of the Big Sioux River and Big Sioux aquifer (Koch, 1980). Koch (1980) included design and verification of a digital model of the hydrologic system that will predict the effects of changes in precipitation, evapotranspiration, and location and magnitude of pumpage from the river or aquifer on streamflow and on water levels in, recharge to, and evaporation from the aquifer.

Surface Water

The surface-water resources of Deuel and Hamlin Counties are outlined and summarized in figure 4 and tables 1 and 2. All of Hamlin County and much of Deuel County lie in the drainage basin of the Big Sioux River, a tributary of the Missouri River. Northeastern and eastern Deuel County lie in the basin of the Minnesota River, a tributary of the upper Mississippi River. About 34 percent of the area does not usually contribute water to either the Big Sioux or Minnesota Rivers, but is in basins of internal drainage. Runoff from land within basins of internal drainage flows to sloughs, lakes, or ponds and evaporates or infiltrates to aquifers. The area of internal drainage varies greatly from year to year depending on the quantity and temporal distribution of precipitation.

All streams in the two-county area, with the possible exception of the West Branch of the Lac qui Parle River, have periods of no flow ranging from a week to at least 10 to 11 months per year for smaller ephemeral streams or more about 1 year in

Precipitation 1,428,000 acre-feet + Inflow in rivers and streams 42,500 acre-feet + Ground-water inflow 531 acre-feet = Outflow in rivers and streams 80,000 acre-feet +

Ground-water outflow 985 acre-feet ± Changes in ground-water storage 0 acre-feet + Consumptive use 6,000 acre-feet + Evapotranspiration 1,384,000 acre-feet

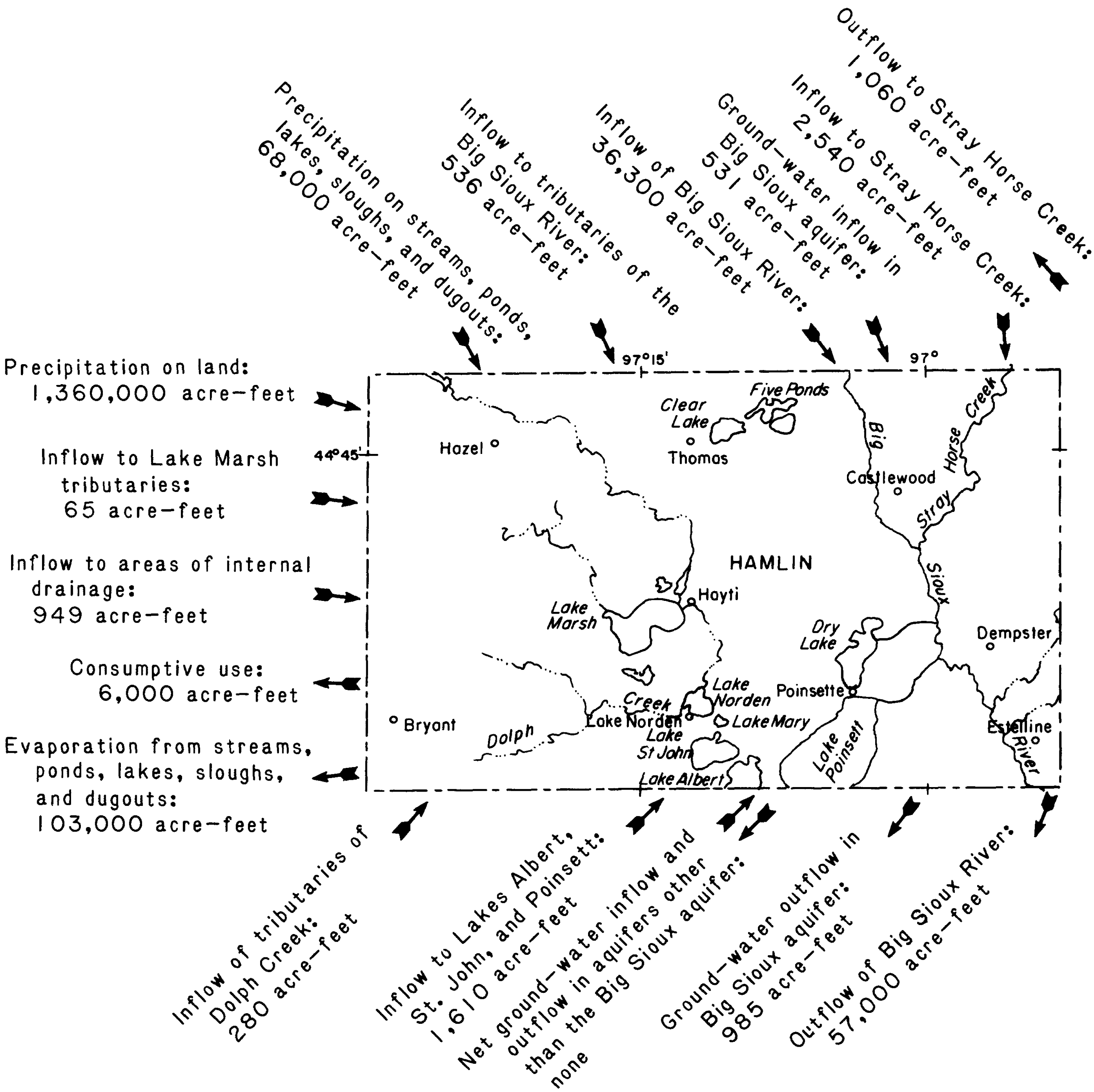
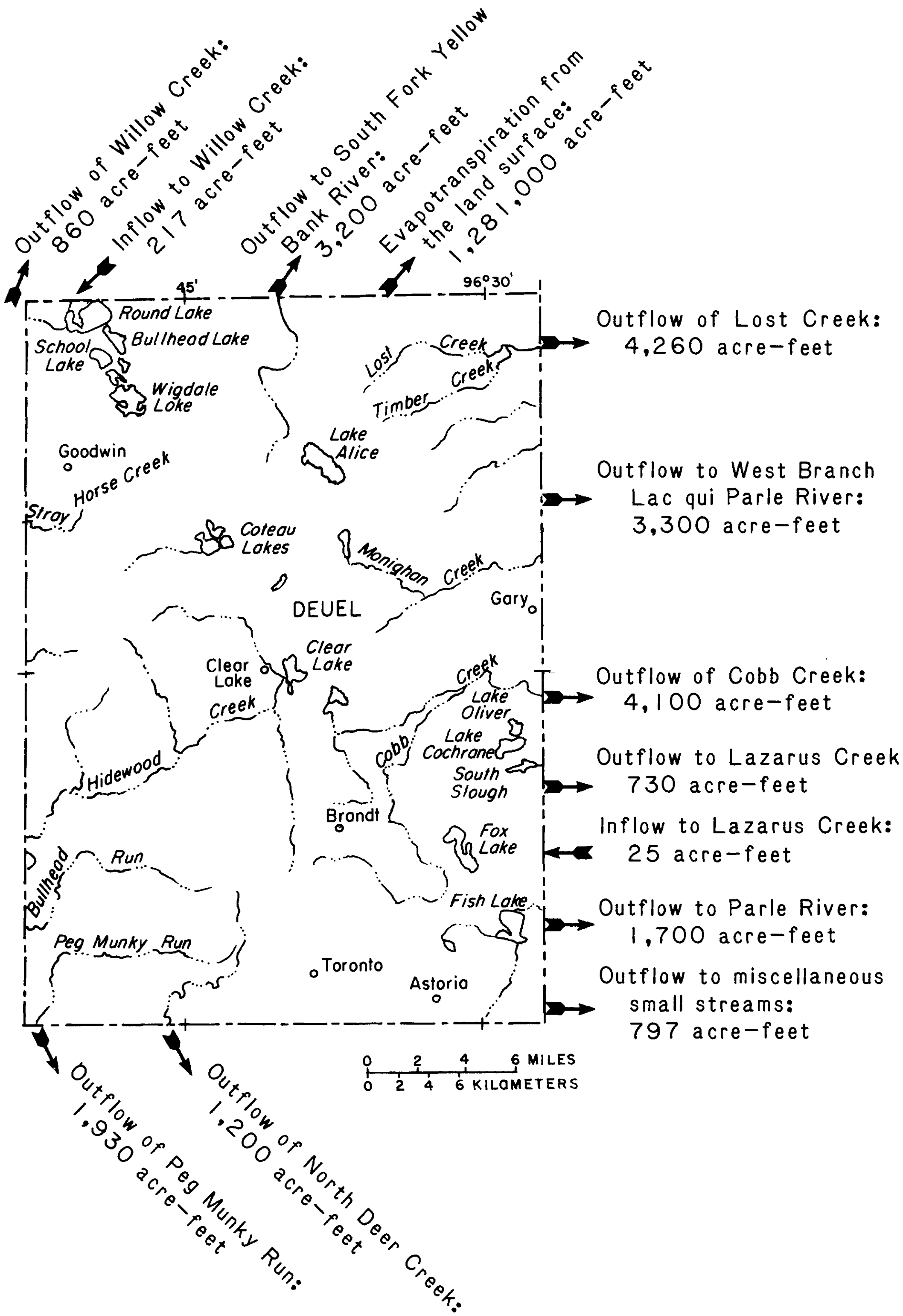


Figure 3.--Estimated average annual hydrologic budget.


Outflow of Willow Creek:
860 acre-feet
Inflow to Willow Creek:
217 acre-feet
Outflow to South Fork Yellow
Bank River:
3,200 acre-feet
Evapotranspiration from
the land surface:
1,281,000 acre-feet
45'
96°30'
Round Lake
Bullhead Lake
School Lake
Wigdale Lake
Goodwin
Horse Creek
Stray
Lost Creek
Timber Creek
Lake Alice
Coteau Lakes
Monighan Creek
DEUEL
Gary
Clear Lake
Clear Lake
Creek
Hidewood
Cobb Creek
Lake Oliver
Lake Cochrane
South Slough
Brandt
Fox Lake
Bullhead Run
Fish Lake
Peg Munky Run
Toronto
Astoria
Outflow of Lost Creek:
4,260 acre-feet
Outflow to West Branch
Lac qui Parle River:
3,300 acre-feet
Outflow of Cobb Creek:
4,100 acre-feet
Outflow to Lazarus Creek:
730 acre-feet
Inflow to Lazarus Creek:
25 acre-feet
Outflow to Parle River:
1,700 acre-feet
Outflow to miscellaneous
small streams:
797 acre-feet
0 2 4 6 MILES
0 2 4 6 KILOMETERS
Outflow of Peg Munky Run:
1,930 acre-feet
Outflow of North Deer Creek:
1,200 acre-feet

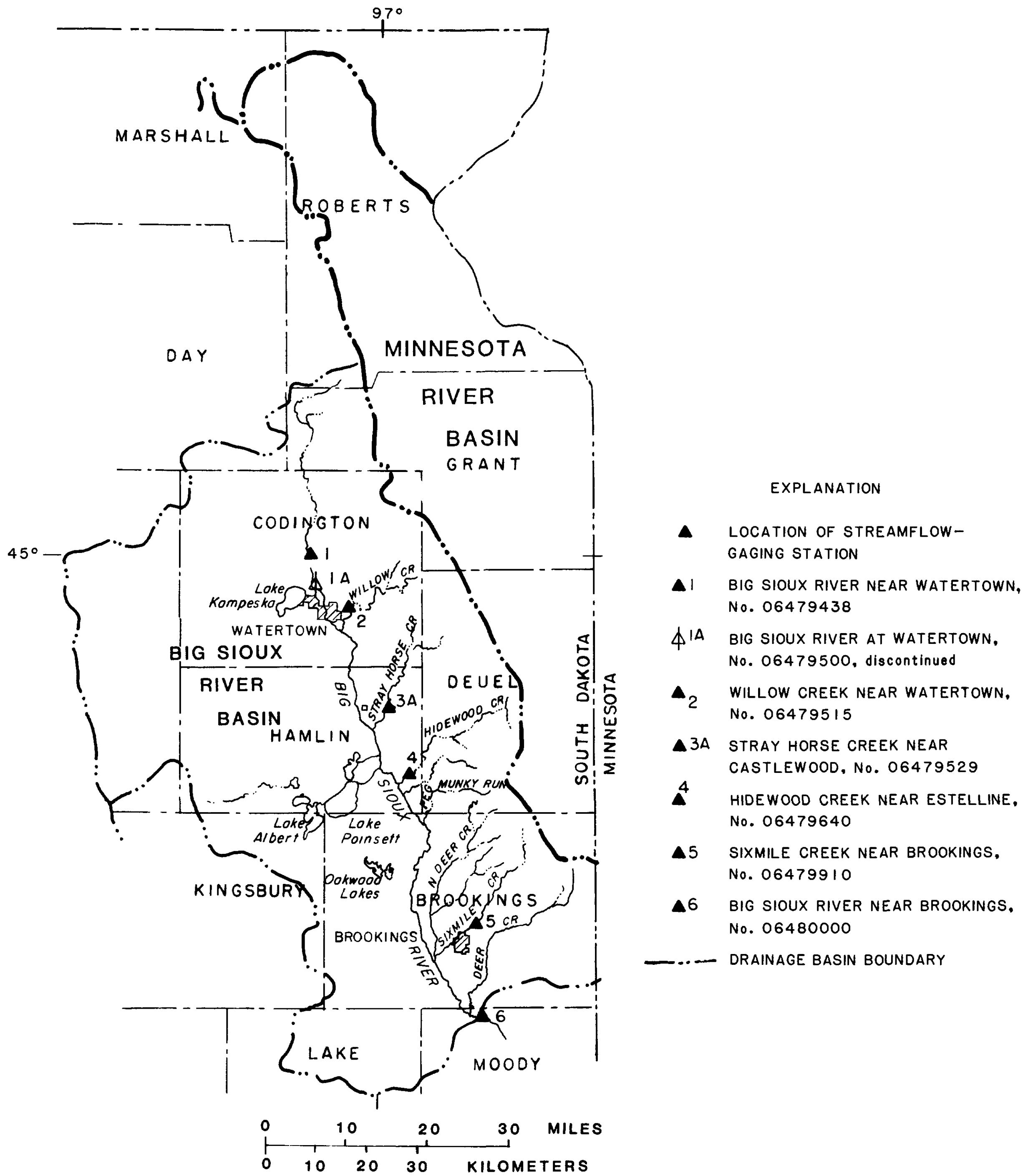


Figure 4.--Drainage basins and locations of streamflow-gaging stations.

Table 1.--Estimated average annual streamflows of selected drainage basins

[Estimated using the method of Larimer (1970)]

	Drainage basin or stream name	Drainage area (square miles)	Average annual streamflow 1/		
			Acre-feet per square mile	Cubic feet per second	Acre-feet
1	Lake Marsh	68.5	67.0	6.3	4,600
2	Lake Norden	59.5	65.0	5.3	3,900
3	Dolph Creek	46.3	67.6	4.3	3,100
4	Lakes Mary, St. John, Albert, and Poinsett	74.1	63.3	6.4	2/ 4,700
5	Willow Creek	13.8	63.0	1.2	860
6	Stray Horse Creek	78.7	73.4	8.0	3/ 8,330
7	Hidewood Creek	123.1	66.3	11.3	3/ 18,980
8	Bullhead Run	15.5	68.4	1.5	1,100
9	Peg Munky Run	29.2	66.1	2.7	2,000
10	North Deer Creek	20.1	59.7	1.7	1,200
11	South Fork of the Yellow Bank River	45.7	68.1	4.3	3,200
12	Lost Creek	57.8	71.6	5.7	4,200
13	Crow Timber Creek	12.2	88.5	1.5	1,100
14	West Branch of the Lac qui Parle River	43.8	75.8	4.6	3,300
15	Monighan Creek	25.6	74.6	2.6	1,900
16	Cobb Creek	56.0	72.3	5.6	4,100
17	Lazarus Creek	8.7	83.2	1.0	730
18	Parle River	20.5	80.0	2.27	1,700

1/ Does not include precipitation on permanent lakes.
2/ Total flow of streams into the lakes. Evaporation from the lakes exceeds stream inflow plus precipitation on the lakes by more than 13,000 acre-feet.
3/ Estimated from 7 years of streamflow records.

Table 2.--Average size and volume of water stored in selected lakes

[Data from State Lakes Preservation Committee (1977), except as noted]

Lake or pond	Surface area (acres)	Average depth (feet)	Volume stored (acre-feet)
Hamlin County:			
Albert	3,610	4	14,440
Clear	704	4	2,816
Dry	1,958	4	7,832
Five Ponds	1,043	2	2,086
Florence	150	3	450
St. John	1,184	4	4,736
Marsh	1,594	4	6,376
Mary	198	2	396
Norden	742	6	4,452
Poinsett	7,866	10	78,660
734 stock ponds and dugouts	1/ 367	8.7	1/ 3,180
Miscellaneous other small natural ponds	1/ 13,180	2.8	1/ 26,900
Total, Hamlin County	32,596		160,324
Deuel County:			
Alice	1,082	6	6,492
Astoria	80	2	160
Briggs	75	4	300
Bullhead	339	7	2,373
Clear	531	4	2,124
Cochrane	365	11	4,015
Coteau, E	121	2	242
Coteau, N	101	2	202
Coteau, S	224	4	896
Coteau, W	89	2	178
Fish	812	4	3,248
Fox	224	2	448
Francis	110	2	220
Ketchum	83	4	332
Lone Tree	186	4	744
Oliver	154	5	770
Round	941	4	3,764
Rush	139	2	278
Salt	211	2	422
School	326	3	978
School, S	220	2	440
Silver	78	2	156
South Slough	251	2	302
Sutton	88	2	176

Table 2.--Average size and volume of water stored in selected lakes--Continued

Lake or pond	Surface area (acres)	Average depth (feet)	Volume stored (acre-feet)
Deuel County (Cont):			
Wigdale	710	2	1,420
765 stock ponds and dugouts	1/ 383	8.7	1/ 3,312
Miscellaneous other small natural ponds	1/ 690	2.8	1/ 1,932
Total, Deuel County	8,913		35,924

1/ Estimated from information supplied by the U.S. Dept. of Agriculture, Soil Conservation Service (written commun.).

seven for the Big Sioux River. During periods of extended drought, most streams may be dry all or most of the year and the Big Sioux River may be dry for as long as 7 or 8 weeks. The West Branch of the Lac qui Parle River is spring fed and appears to have a continuous base flow.

The Big Sioux River originates in northeastern South Dakota (fig. 4) and drains an area of less than 500 mi^2 of glacial till and outwash plains before it flows into Hamlin County. It has a nearly uniform slope of about 16 inches per mile of channel through Hamlin County.

The estimated flows of selected streams and the estimated collective flows of several streams in selected basins are summarized in table 1. The flow volumes given were calculated for points where the streams crossed the county line, where they joined the Big Sioux River, or where they discharged into a lake. Collective flows were calculated where several small streams discharged into a lake (such as Lake Marsh) or where several tributaries left the study area before joining the main stream (such as the South Fork of the Yellow Bank River). For the basins that include Lake Marsh, Lake Norden, and Lake Poinsett, the flows given in the table are those of the streams that flow into the lakes, not the outflow from the respective lakes. Evaporation loss from the lakes is very large. For example, in the basin that includes Lake Poinsett, Lake Albert, Lake Mary, and Lake St. John, the average annual evaporation from the lakes' surfaces is about 13,000 acre-ft greater than the stream inflow to the lakes. Therefore, this basin contributes surface- and ground-water outflow to the Big Sioux River and Big Sioux aquifer only during periods of snowmelt runoff and spring rain, during prolonged wet spells, or unusually heavy storms in summer. The "deficit" of 13,000 acre-ft is met by discharge to the lakes of shallow ground-water aquifers in the basin and (mostly) by inflow from the Big Sioux River and the Big Sioux aquifer whenever the level of Lake Poinsett is lower than the level of the Big Sioux River or lower than the water table in the Big Sioux aquifer.

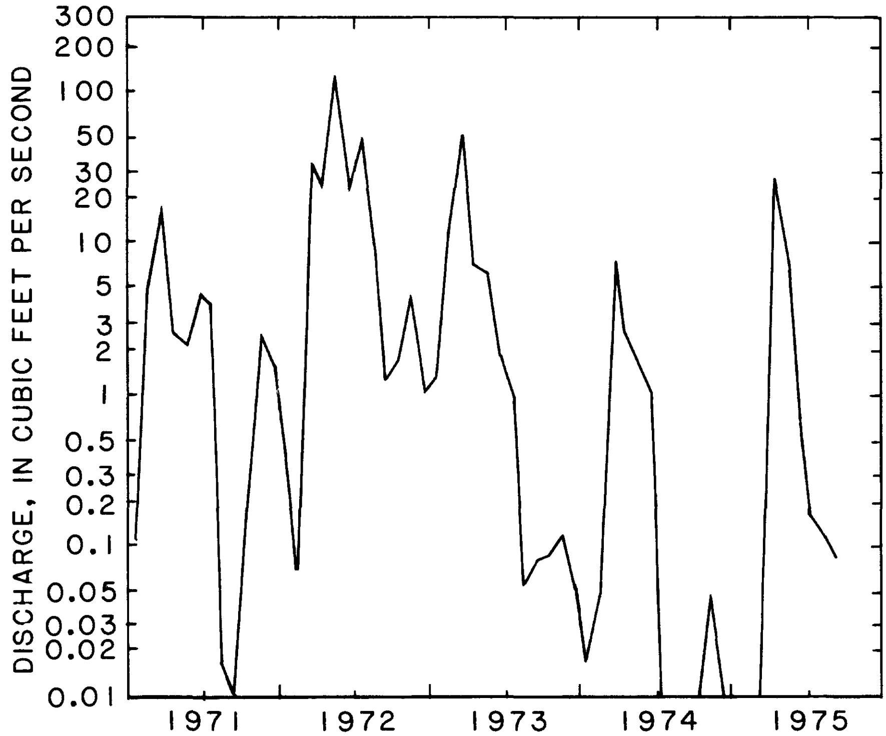
The total area of open water (lakes, ponds, sloughs) is estimated as 32,596 acres in Hamlin County and 8,913 acres in Deuel County, based on information supplied by the U.S. Soil Conservation Service (written commun.) and the State Lakes Preservation Committee (1977). Many of these lakes are shallow, the average depth under average conditions ranging from 2 ft for many lakes to 10 or 12 ft for Lake Poinsett (State Lakes Preservation Committee, 1977; and Barari, 1971a) (see table 2). The areas and storage volumes of the lakes, ponds, and sloughs varies greatly from year to year. Lake Poinsett, for example, contains at least 110,000 acre-ft of water when lake level is as high as the discharge outlet, but maximum storage on record was more than 135,000 acre-ft (1969) and minimum storage was less than 4,000 acre-ft (1936).

The area of open water (lakes and ponds) probably is increasing slowly as many farmers install ditches and drainage tile to remove surplus water from fields in spring to improve tillability and to increase tillable acreage. The drained water flows more rapidly to lakes and ponds or to through-draining streams. Stockponds commonly are present at low points in the local topography both to intercept more water for stock use and to act as "sumps" for farmland drainage. In a few locations such ponds store enough water, or are adequately fed by aquifers, to be a suitable source of irrigation water.

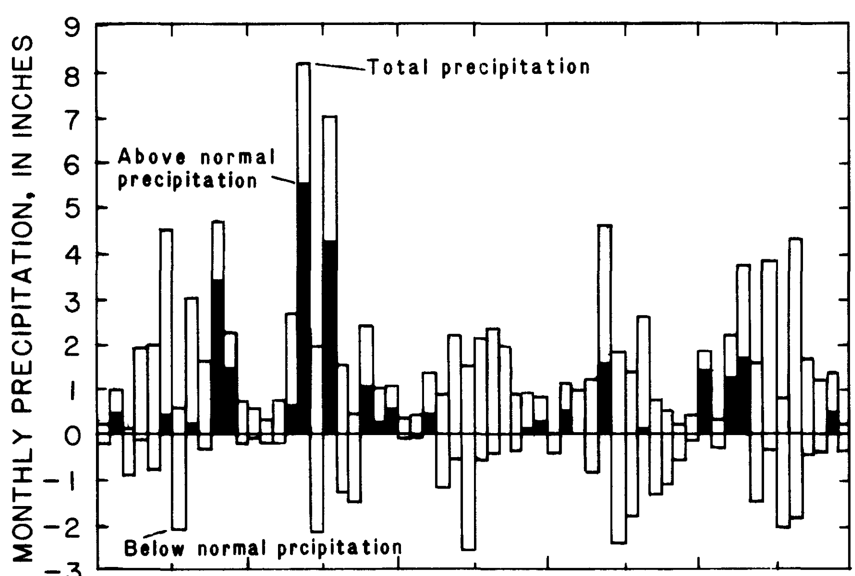
To assist the user of surface-water information to place the "average" values in context and also to gain insight into the magnitude and frequency of deviations from average, hydrologists prepare various kinds of graphs. Streamflow hydrographs for Stray Horse Creek and for Hidewood Creek are shown in figures 5 and 6. Flow-probability curves for the Big Sioux River at the gage sites near Watertown and near Brookings are shown in figure 7.

The hydrographs shown in figures 5 and 6 are based on measurements made at stream gages on the respective streams. Although these hydrographs are for monthly mean flows, such graphs can be prepared for almost any length time period. Also shown in figures 5 and 6 are graphs of precipitation for weather stations in or near the respective stream basins. Comparison of the precipitation to streamflow shows the relationship between the two. The departure (difference) from normal (average) is shown on the precipitation graph. Streamflow and precipitation were highest in spring, lower during the summer, and lowest during fall and winter. Both streams had periods of no flow during fall and winter in some years.

The flow-probability curves shown in figure 7 also are based on measurements made at stream gages and are plotted as 10-day averages. But these graphs show the probability that a particular stream discharge (rate of flow) will be equaled or exceeded at any time of the year. As shown by the example on each graph, the percent of the time that flow will be more or less than a specific value can be determined for any day of the year.



MONTHLY MEAN DISCHARGE OF STRAY HORSE CREEK NEAR CASTLEWOOD NO. 06479529



TOTAL PRECIPITATION AND DEPARTURE FROM NORMAL AT CASTLEWOOD, SOUTH DAKOTA.

Figure 5.--Monthly mean discharge of Stray Horse Creek near Castlewood and precipitation at Castlewood.

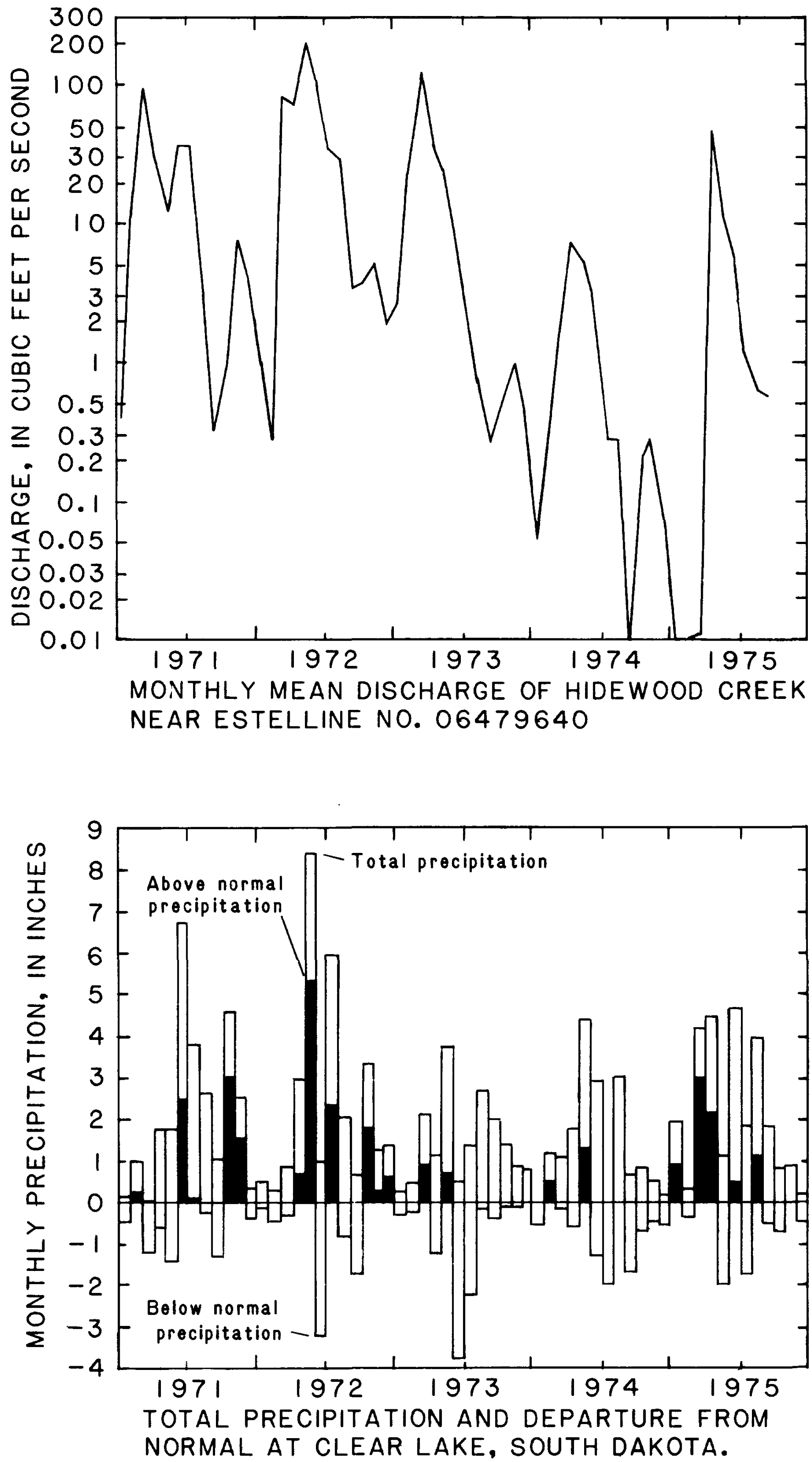
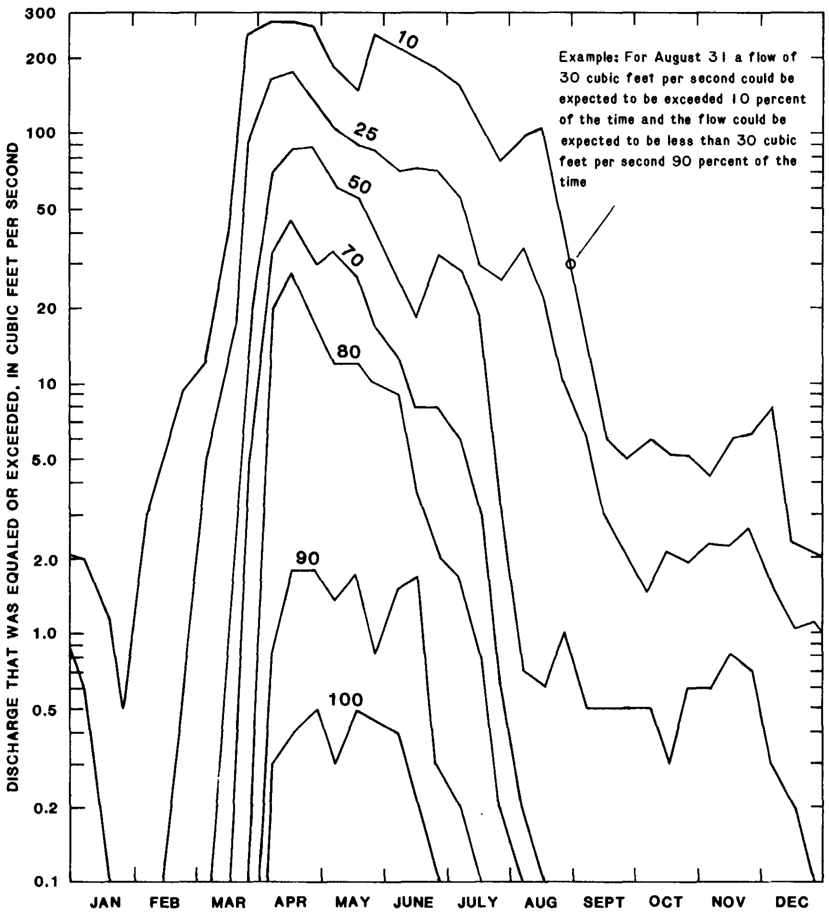
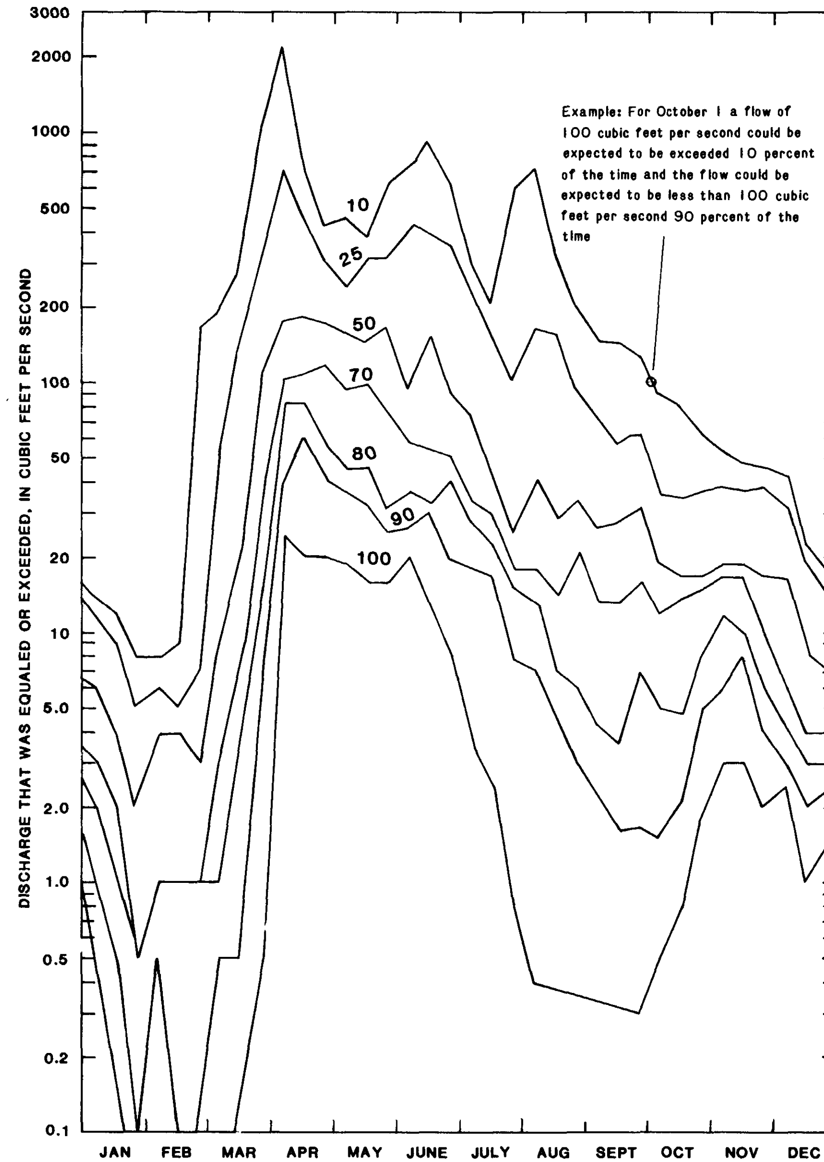


Figure 6.--Monthly mean discharge of Hidewood Creek near Estelline and precipitation at Clear Lake.



Gaging station near Watertown based on data from 1945-65.



Gaging station near Brookings based on data from 1953-65.

Figure 7.--Flow-probability curves for the Big Sioux River at the gaging stations near Watertown and Brookings.

Ground Water

The ground-water resources of Deuel and Hamlin Counties include three major aquifers in the glacial drift (the Big Sioux, Prairie Coteau, and Altamont aquifers), a major aquifer in the bedrock (the Dakota Formation), and several minor aquifers in glacial drift and alluvium.

The geology of Deuel and Hamlin Counties is described in detail by Beissel (in press), so it is discussed very briefly in this report. The stratigraphic column (table 3) shows the various formations and deposits and summarizes age, depth, thickness, and other characteristics of the rocks. Pleistocene (glacial) drift and Holocene (post-glacial) alluvium, ranging from about 170 ft to 820 ft in thickness, comprise the surficial deposits. The bedrock is Late Cretaceous in age and includes in order of increasing age the Pierre Shale, Niobrara Formation, Carlile Shale, Greenhorn Formation, Graneros Shale, and Dakota Formation. The Dakota Formation is underlain by Precambrian basement rocks. A summary of the hydrologic characteristics of the major aquifers is shown in table 4.

Glacial Aquifers

Glacial aquifers are those in the unconsolidated deposits of glacial and alluvial origin. These deposits range from about 170 ft to more than 800 ft in thickness as shown in figure 8, and are composed of alluvial valley fill, glacial till (end moraine, ground moraine, and stagnation moraine), and outwash (valley-train outwash, collapsed outwash, and undifferentiated outwash). The till, an unsorted, unstratified mixture of clay, silt, sand, and gravel, makes up more than 80 percent of the surficial material. Numerous deposits of outwash sand and gravel are present either at land surface or buried beneath till. Many such deposits are lenticular, thin, and discontinuous, but where tapped by a well, they commonly provide adequate water supplies suitable for domestic and stock use. The alluvium and drift contain three major aquifers, the Big Sioux aquifer, the Prairie Coteau aquifer, and the Altamont aquifer.

Big Sioux aquifer.--The most readily available ground water is present in surficial outwash bodies, the largest and most productive of which is the Big Sioux aquifer (table 4). The Big Sioux aquifer underlies an area of 178 mi^2, mostly in the valleys of the Big Sioux River and its major tributaries (fig. 9). The aquifer is composed mainly of glacial-meltwater stream deposits except in the areas of Dry, Marsh, and Clear Lakes where it is a hummocky, collapsed (ice-contact) outwash. Throughout its extent, the Big Sioux aquifer is underlain by till and commonly is overlain by alluvial silt and clay (fig. 10). In the Big Sioux River valley-Lake Poinsett area, the outwash ranges in thickness from about 2 to 123 ft and averages 30 ft. The outwash is at the land surface or it may be overlain by from 1 to 4 ft of alluvium. In the Lake Marsh area, the outwash ranges in thickness from about 2 to 65 ft and averages 30 ft. Near the town of Clear Lake the outwash ranges in thickness from 3 to 88 ft and averages about 20 ft. Estimated storage in the Big Sioux aquifer is 480,000 acre-ft.

Water levels in the Big Sioux aquifer range from land surface to about 18 ft below land surface and generally are highest in June, although in some parts of the aquifer they are highest in March or April. This high is in response to recharge from snowmelt and from spring rain and from floods or high water level of the Big Sioux River. Low water levels in the aquifer usually occur in September or October except for a few areas where the annual lows may occur in August or in December. The low

Table 3.--Generalized stratigraphic column for Deuel and Hamlin Counties

[Stratigraphic column modified from Beissel (1974)]

Era	Period	Epoch	Unit	Thickness (feet)	Description
Cenozoic	Quaternary	Holocene (approximately the last 10,000 years)	Alluvium	0-35	Silt, clay, and sand. Minor aquifers are sand lenses at, or near, land surface.
		Pleistocene (approximately the last 2 million years)	Glacial Drift	170-820	Till, outwash, and lake deposits. Major aquifers are sand and gravel deposits at the land surface and buried at various depths within the till.
Mesozoic	Cretaceous	Late Cretaceous (approximately 63 to 96 million years ago)	Pierre Shale	0-120	Shale, medium- to dark-gray, contains limestone and ironstone concretions, many thin bentonite beds. Not an aquifer but a barrier to the movement of water.
			Niobrara Formation	0-85	Shale, light- to dark-gray, highly calcareous; white-speckled with microfossils. Not used as a source for water; unknown water-yielding capability.
			Carlile Shale	210-240	Shale, medium- to dark-gray, contains ironstone concretions and stringers of fine-grained sandstone. Shale is not an aquifer but a barrier to the movement of water; sandstone stringers have an unknown water-yielding capability.
			Greenhorn Formation	About 30	Shale, white to light-gray, highly calcareous, fossiliferous. Not an aquifer.
			Graneros Shale	40-60	Shale, dark-gray, contains ironstone concretions. Not an aquifer but a barrier to the movement of water.
			Dakota Formation	56-80	Sandstone, white, fine- to medium-grained, friable to consolidated. Major aquifer.
Precambrian			Crystalline rocks		Granite, schist. Not an aquifer.

Table 4.--Summary of hydrologic information for the aquifers

Aquifer	Lithology and type	Depth below land surface, in feet		Thickness, in feet		Area acres	Effective porosity	Estimated storage, in acre-feet
		Range	Average	Range	Average			
Big Sioux	Sand and gravel; unconfined.	0-40	5	2-123	30	113,920	0.15	480,000
Other surface outwash.	Sand and gravel; unconfined.	0-39	6	1-72	17	31,360	.15	52,000
Prairie Coteau	Sand and gravel; confined.	3-364	94	4-144	47	698,880	.15	5,000,000
Altamont	Sand and gravel; confined.	150-820	475	3-101	35	557,000	.15	2,900,000
Other drift and alluvium.	Sandy, silty-clay; stony clay (till); unconfind to confined.	0-93	57	--	--	--	--	--
Dakota	Sandstone; confined.	384-1,333	1,083	56-83	66	757,760	.10	5,000,000

Table 4.--Summary of hydrologic information for the aquifers--Continued

Aquifer	Potential for development		Present development				Suitable for irrigation
	Estimated yield, range in gallons per minute	Will support additional development	Number of wells inventoried (1971-74)	Average well depth, in feet	Average depth to water, in feet	Average potential yield of wells, in gallons per minute	
Big Sioux	50->1,000	Major amount	353	29	14	500	Yes.
Other surface outwash.	<10-150	Minor amount	59	34	18	3	Varies.
Prairie Coteau	<50-1,000	Major amount	989	117	52	250	Generally yes for wells less than 250 feet deep.
Altamont	<50-500	Major amount	31	472	139	50	Locally yes.
Other drift and alluvium.	<1->3	Minor amount	185	57	29	.3	Locally yes.
Dakota	20->60	Major amount	10	1,303	280	30	No.

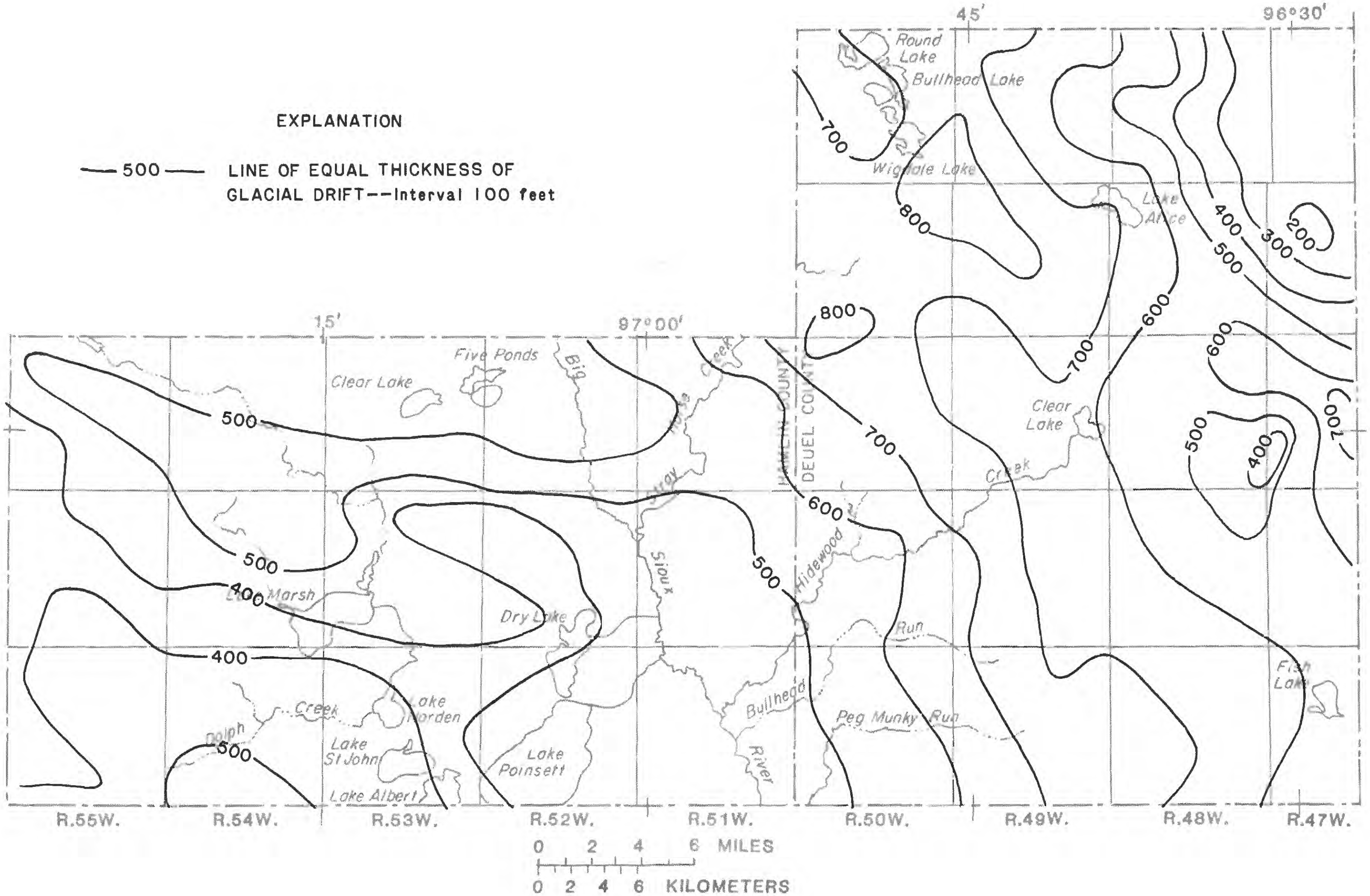


Figure 8.--Thickness of glacial drift.

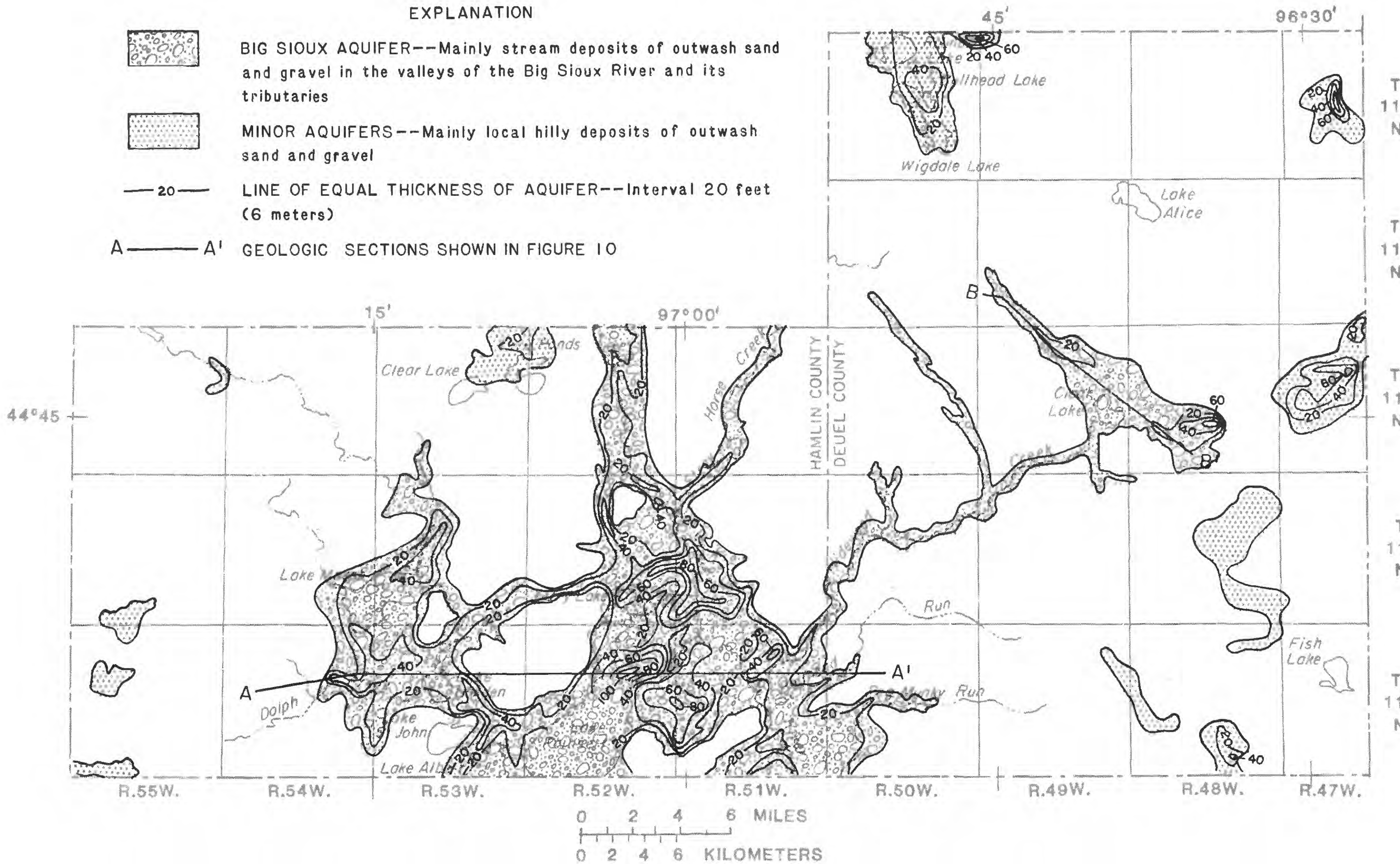


Figure 9.--Extent and thickness of the Big Sioux aquifer and other surface or near-surface outwash aquifers.

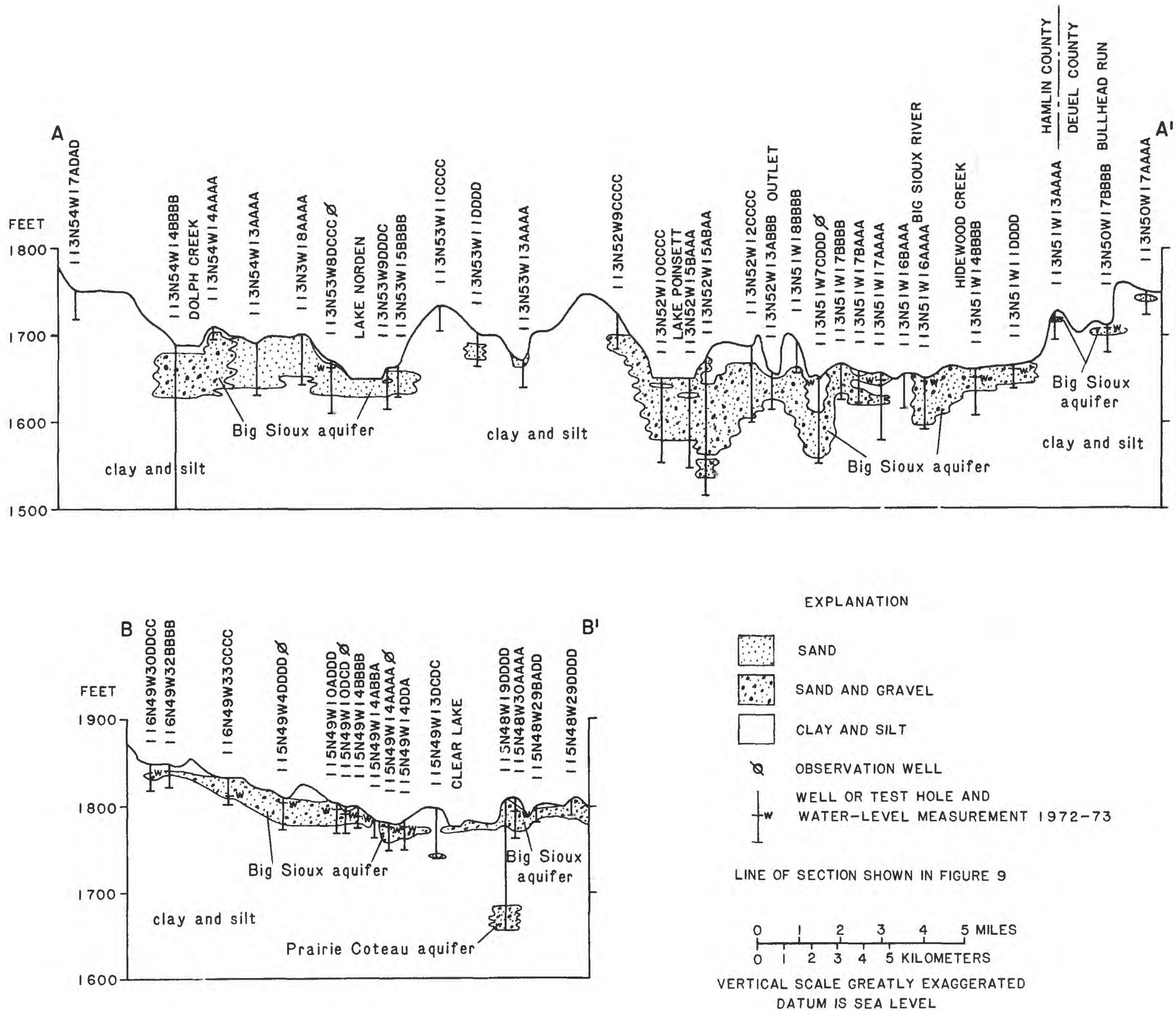


Figure 10.--Geologic sections showing the Big Sioux aquifer and other surface or near-surface outwash aquifers.

is in response to large growing-season losses to evapotranspiration, to much reduced recharge in late summer and fall due to small amounts of precipitation, and to continued discharge to lakes and the Big Sioux River.

The largest fluctuation in water level measured in a well during any 1 year was 5 ft in 1969. This was caused by a very high spring flood in the Big Sioux River. Generally, fluctuations in water levels are only 2 or 3 ft/yr.

The altitude of the water table in the Big Sioux aquifer for July 18, 1974, is shown in figure 11. The altitude of the water table ranged from a high of about 1,839 ft, near South Coteau Lake, to a low of about 1,639 ft, at the Brookings County line near Estelline. A hydrograph of water-level fluctuations in a well completed in the Big Sioux aquifer is shown in figure 12.

Aquifer tests have been made at four wells, one each near Castlewood and Clear Lake, and two near Estelline, to determine transmissivity and storage coefficient for the Big Sioux aquifer. The results of the tests are summarized in table 5. Barari (1971, p. 16) made two of the tests (wells 113N51W3DACC and 113N51W26ACAA). The transmissivities determined ranged from 13,000 to 43,000 ft^2/d; storage coefficients ranged from 0.004 to 0.18. Also, transmissivities were estimated for all test holes based on particle size in well cuttings; values as high as 75,000 ft^2/d were estimated. For that part of the aquifer underlying the main valley of the Big Sioux River, an "average" transmissivity of 20,000 ft^2/d and average storage coefficient of 0.15 would not be unreasonable estimates; therefore, in this area, the aquifer could yield as much as 1,000 gal/min to properly constructed wells.

Recharge by infiltration of precipitation on the surface of the outwash and alluvial deposits that comprise the aquifer is estimated to be 48,000 acre-ft/yr. There is also recharge from runoff from adjacent areas onto the surface of the aquifer deposits, leakage from adjacent till, and infiltration from the Big Sioux River when the level of water in the river is higher than the water level in the underlying and adjacent aquifer. There is an estimated subsurface inflow of 531 acre-ft/yr (fig. 3) to the Big Sioux aquifer in Deuel and Hamlin Counties from Codington County.

Discharge from the Big Sioux aquifer is to the Big Sioux River (estimated as an average net discharge of 6,800 acre-ft/yr), and to many lakes and ponds (estimated average net discharge of about 13,000 acre-ft/yr), by discharge to wells (about 2,400 acre-ft/yr), and by evapotranspiration (estimated to average more than 35,000 acre-ft/yr). Aquifer outflow to Brookings County is estimated to be 985 acre-ft/yr.

The water from the Big Sioux aquifer generally is of good quality for domestic, stock, municipal, and irrigation use and is used widely for those applications.

Prairie Coteau aquifer.--Buried beneath till and within the thick layer of glacial drift that blankets the area are numerous lenticular bodies of outwash. Many of these deposits are included in what is herein named the Prairie Coteau aquifer. Generally, those outwash deposits buried beneath 30 ft or more of till and not otherwise part of a surface or near-surface aquifer, and not part of the Altamont aquifer at the base of the drift, are included in the Prairie Coteau aquifer.

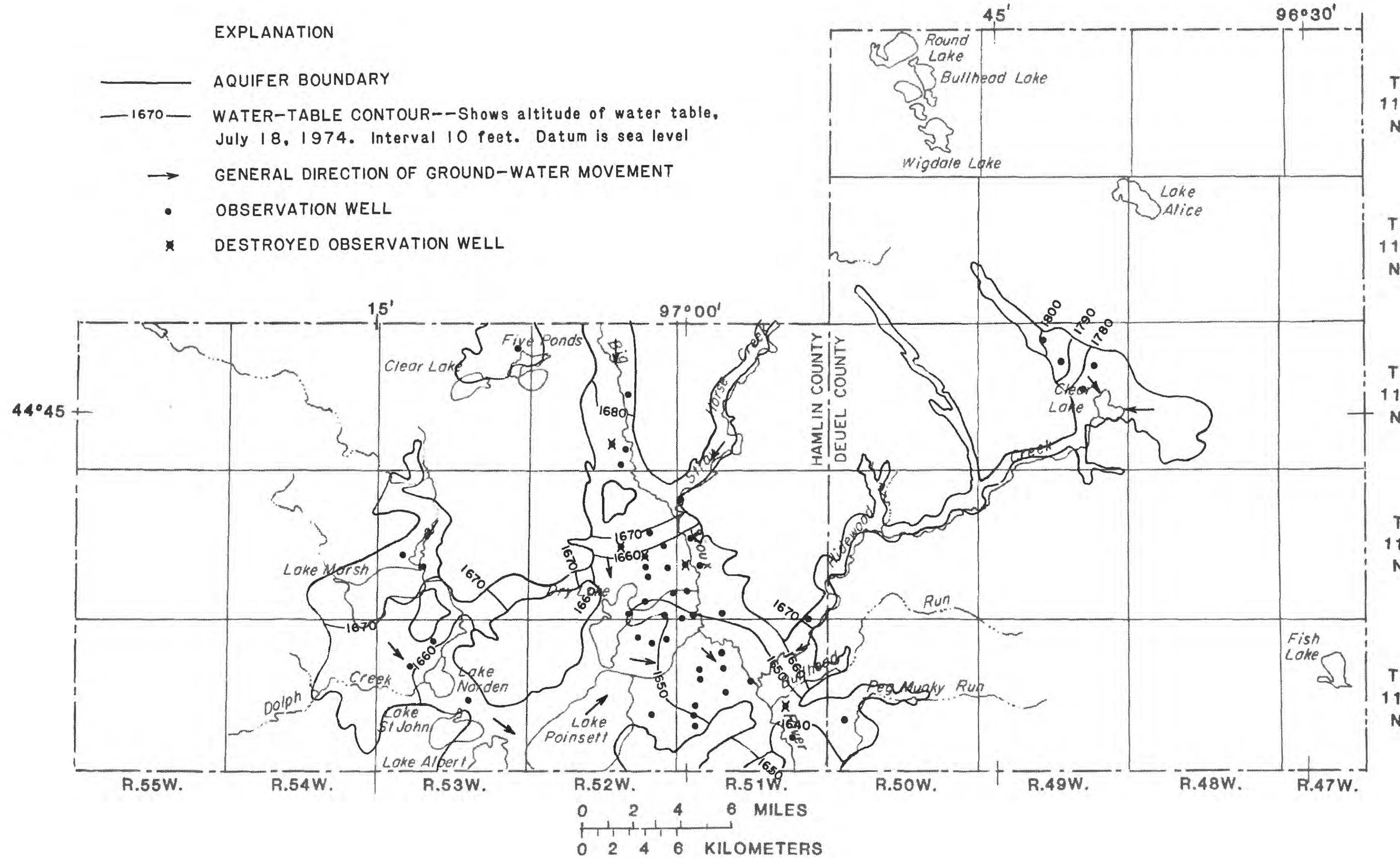


Figure 11.--Altitude of the water table in the Big Sioux aquifer.

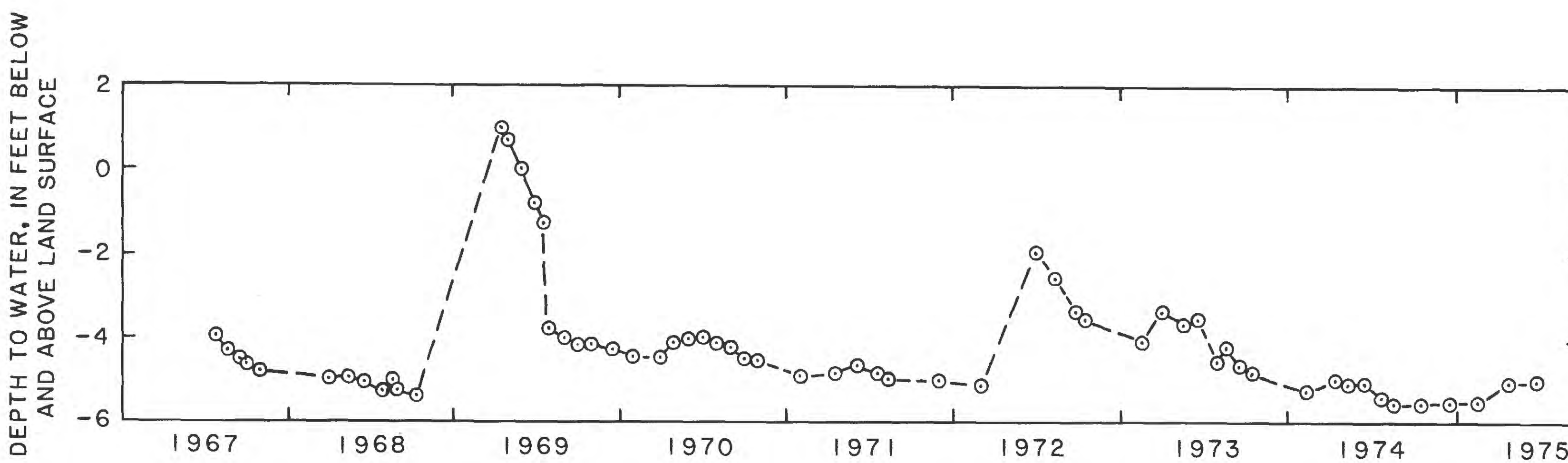


Figure 12.--Water-level fluctuations in well 114N52W25AAAA, completed in the Big Sioux aquifer.

Table 5.--Aquifer-test data for the Big Sioux aquifer

Location	Use of well	Test pumping time (hours)	Average Discharge (gallons per minute)	Aquifer transmissivity (feet squared per day)	Aquifer storage coefficient	Aquifer thickness (feet)	Aquifer material
113N51W26ACAA[1/]	Irrigation	72	810	43,000	0.10	28	Sand and gravel, very coarse-grained, well sorted.
113N51W3DACC[1/]	Irrigation	42	710	20,000	.10	40	Sand and gravel.
115N52W35CCCC	Observation	8	140	24,000	.18	20	Sand, gravelly, fine- to medium-grained, silty.
115N49W4DDDD	Observation	8	125	13,000	.004	26	Sand and gravel, medium- to coarse-grained, silty, and clayey.

1/ Data from Barari (1971a).

The Prairie Coteau aquifer underlies about 1,100 mi^2 of Deuel and Hamlin Counties. The areal extent and aggregate thickness of the aquifer complex are shown in figure 13. At any given site, the aquifer usually is composed of several layers of sand and gravel separated by clayey till and enclosed within a thick section of till (fig. 14). The beds of outwash at a given site probably are not connected hydraulically.

Aggregate thickness of the Prairie Coteau aquifer ranges from 4 to 144 ft and averages about 47 ft. The thickness shown in figure 13 generally is not for one bed, but is the total thickness of several beds. For example, the maximum thickness of 144 ft, at test hole 116N49W23CCCC, is the sum of the thicknesses of six beds that range from 5 to 39 ft thick. These beds are separated by 11 to 157 ft of till. The outwash deposits that make up the Prairie Coteau aquifer commonly are thickest where the glacial drift is thickest, as near Altamont and near Gary. Estimated ground-water storage in the Prairie Coteau aquifer is 5,000,000 acre-ft.

Water in the Prairie Coteau aquifer is under artesian conditions. Only one observation well (115N48W21DDDD) in the area monitors the water level in the aquifer complex. The water level is about 148 ft below land surface. The maximum difference between the high and low water level for the 8-year period of record is 2.53 ft. No annual trend is evident.

Evaluation of test hole data and commerical driller's logs indicates that the aquifer complex can yield as much as 250 gal/min to properly constructed wells.

Water from the Prairie Coteau aquifer is used throughout the area for stock. In some places the water is used for irrigation, domestic, and municipal supplies, but because of poor quality even in nearby areas, it is not suitable for these uses everywhere.

Altamont aquifer.—A sheet of outwash forms the base of the drift in most of Deuel County and much of Hamlin County. These outwash deposits, which lie directly on the bedrock surface or are separated from it by only a thin layer of till, are herein named the Altamont aquifer. Throughout most of its extent, the sheet of outwash seems to be continuous, but in a few places the basal outwash may not be continuous and may not have hydraulic connection with the rest of the basal outwash.

The Altamont aquifer underlies an area of 870 mi^2 in Deuel and Hamlin Counties. The areal extent and thickness of the aquifer is shown in figure 15. Depth to the top of the Altamont is from 150 to 820 ft and averages about 475 ft. The thickness of the Altamont aquifer ranges from 3 to 101 ft and averages about 35 ft. Estimated ground-water storage in the aquifer is 2,900,000 acre-ft. The relationship of the Altamont aquifer to overlying aquifers and to the bedrock surface can be seen on the geologic section in figure 14.

Water in the Altamont aquifer is under artesian conditions. Only one observation well (114N47W32AAAA) in the area monitors the water level in the aquifer; the water level is about 146 ft below land surface or about 313 ft above the top of the aquifer. The maximum water-level change for 7 years of record was about 2.8 ft. There appears a slight tendency for the annual high water level to occur in spring or early summer and for the annual low water level to occur in middle to late fall.

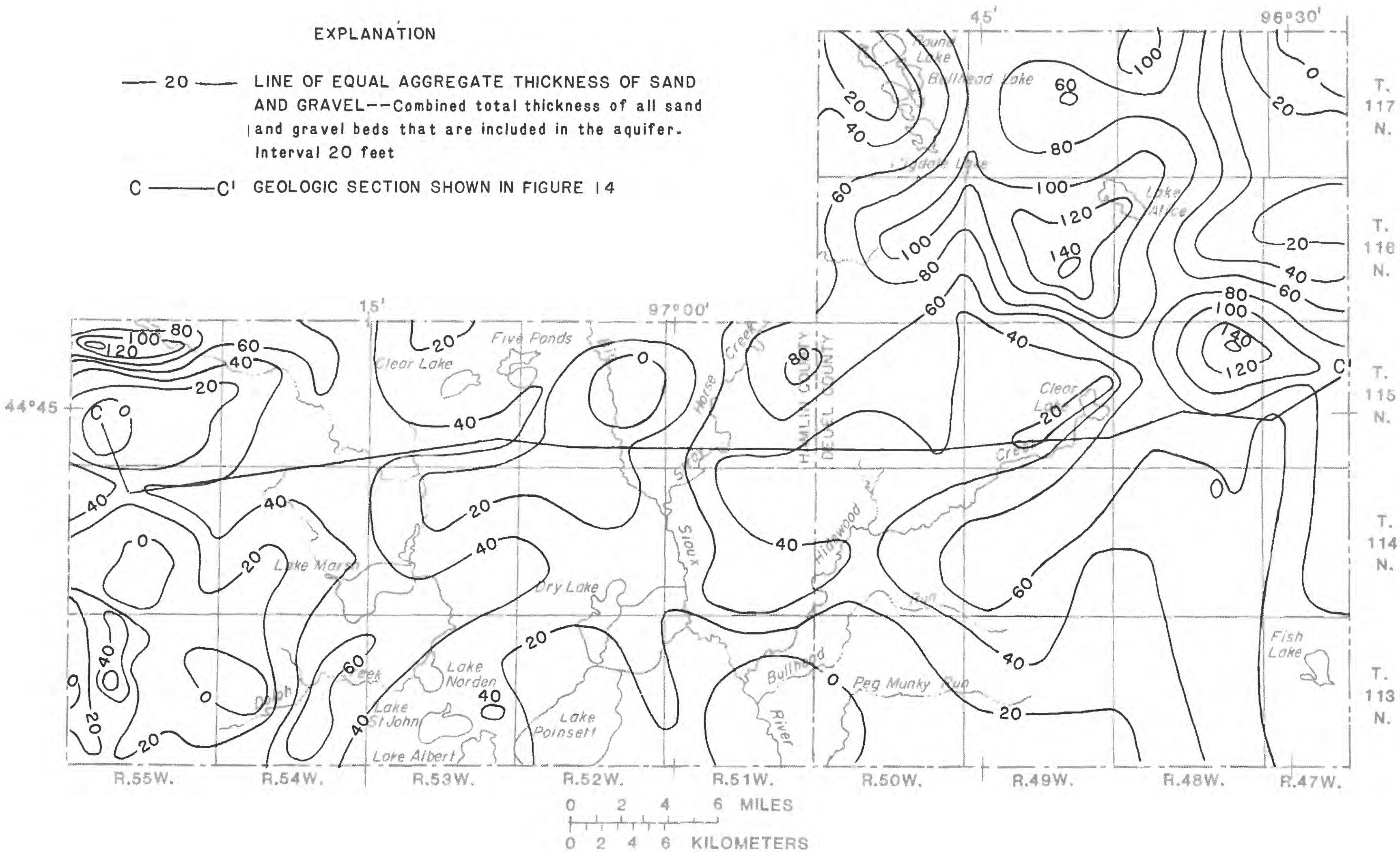


Figure 13.--Areal extent and thickness of the Prairie Coteau aquifer.

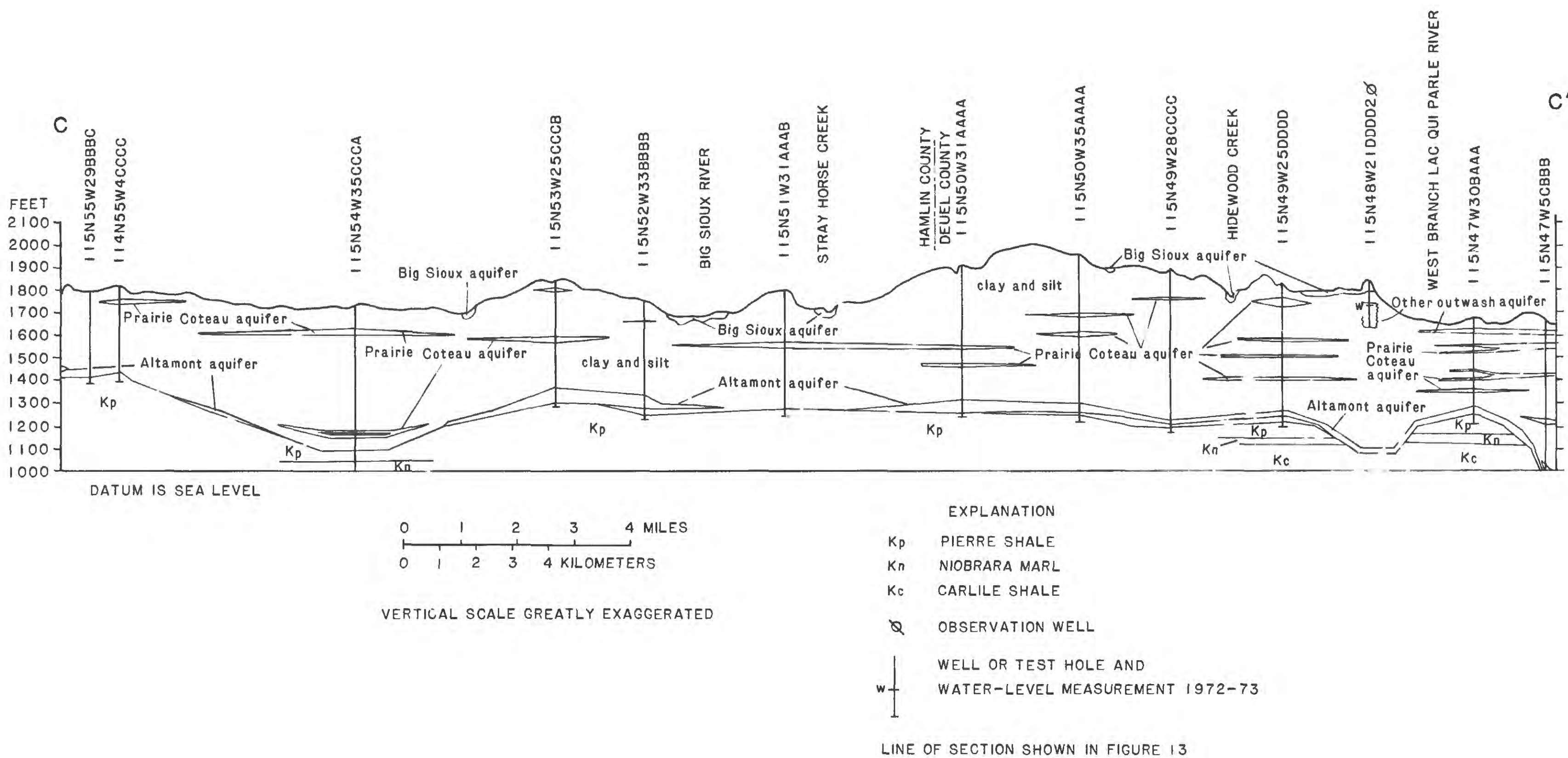


Figure 14.--Geologic section showing the Prairie Coteau aquifer.

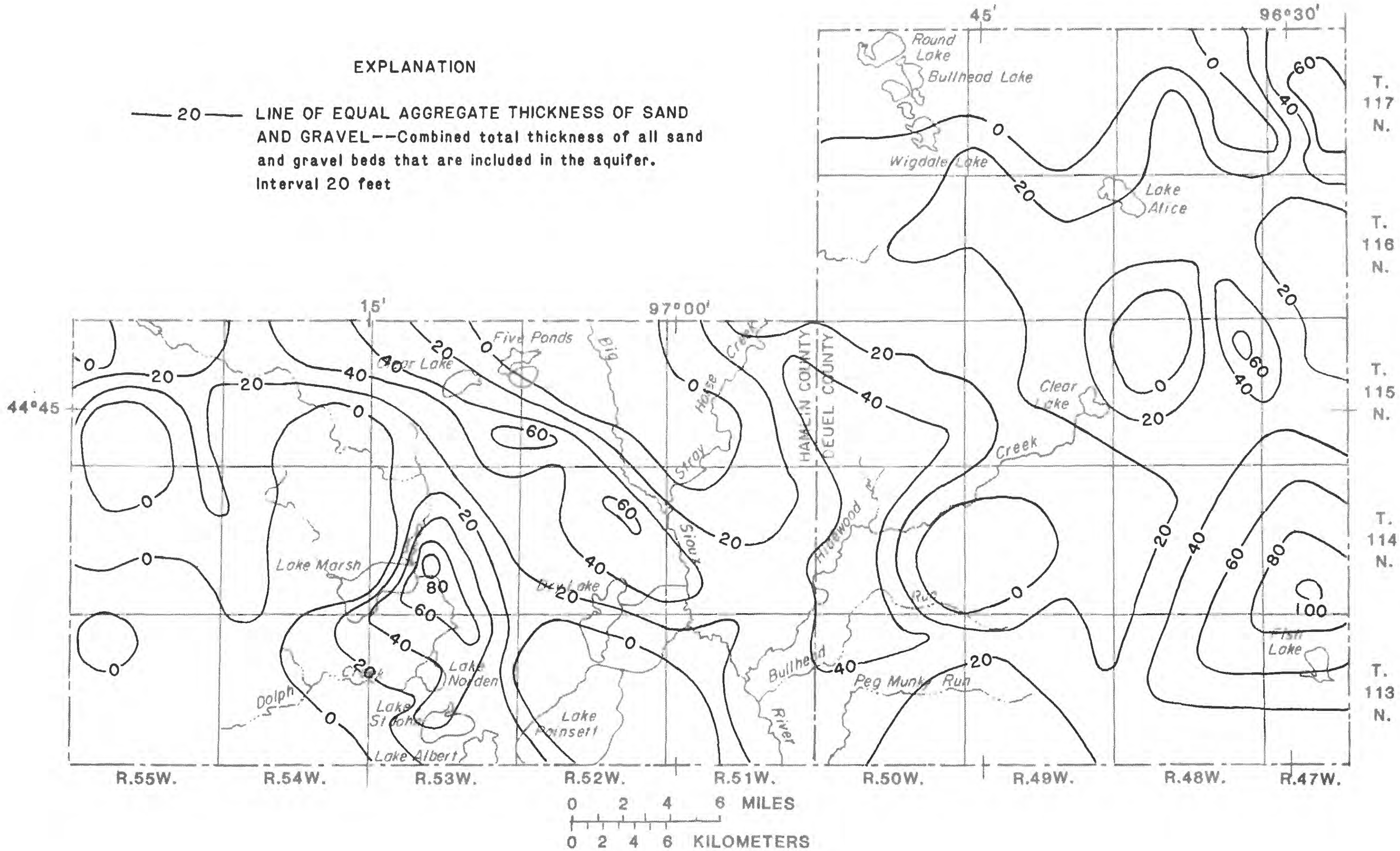


Figure 15.--Areal extent and thickness of the Altamont aquifer.

Evaluation of test hole data and commercial driller's logs indicates that the aquifer can yield as much as 500 gal/min to properly constructed wells.

Water quality in the Altamont aquifer generally is not suitable to use for irrigation, although it may be acceptable in some places. Elsewhere the water ranges from marginally acceptable to unsatisfactory for use as a domestic or public supply. Although little used for livestock supplies, the water is acceptable for such use and is a major potential source of stock water.

Minor aquifers.--Minor aquifers include surface or near surface deposits of outwash and alluvium other than the Big Sioux aquifer and those isolated, buried, lenses of outwash that are not in the Prairie Coteau aquifer. The distribution, extent, and thickness of these aquifers, which underlie about 49 mi^2, are shown in figure 9. Commonly, the deposits are made up of hummocky, collapsed outwash, but they do include some meltwater-channel outwash and buried outwash.

Thickness of the 11 minor aquifers ranges from 1 to 72 ft and averages about 17 ft. Five of the minor aquifers have maximum thicknesses of less than 20 ft. The estimated volume of ground water stored in the minor aquifers is about 52,000 acre-ft.

Bedrock Aquifers

About 500 ft of consolidated bedrock formations overlie the Precambrian basement rocks. The configuration of the surface of the bedrock strata in contact with the drift, and the distribution of the exposures of these formations at that contact, are shown in figure 16.

The bedrock formations in Deuel and Hamlin Counties, summarized in table 3, contain only one known aquifer, the Dakota Formation, and two units that might contain aquifers, the Niobrara Formation and the Carlile Shale. In part of the James River valley south of Spink County, and some other areas in eastern South Dakota, a zone at or near the base of the Niobrara Formation and the Codell Sandstone Member of the Carlile Shale are important and widely developed aquifers. No wells completed in either aquifer were found in Deuel and Hamlin Counties, nor was any other information found that would indicate the potential of these units as sources of usable supplies of water.

Dakota Formation.--Interpretation of the scanty information available indicates that the Dakota Formation underlies all of Deuel and Hamlin Counties. The Dakota, a fine- to medium-grained, white, variably cemented sandstone interbedded with dark shale, ranges in thickness from 56 to 83 ft and averages about 66 ft. Estimated ground-water storage in the aquifer within the two-county area is 5 million acre-ft. Flow measurements of existing and former productive wells completed in the Dakota show that yields range from 20 to more than 60 gal/min.

Water level in the Dakota aquifer has declined since about 1880, but much less so than in other parts of South Dakota. Darton (1909, pl. 15), for example, mapped the potentiometric surface of the Dakota as it was in about 1898. On the Deuel and Hamlin County part of the map, reproduced in figure 17, he showed that the potentiometric surface ranged from slightly above 1,200 ft above sea level in the northeastern corner of Deuel County to slightly above 1,600 ft in the western quarter of Hamlin County, which indicates that water in the Dakota was moving from west to east. In some other parts of the State, the decline in artesian head in the Dakota has been more than 700 ft since development began.

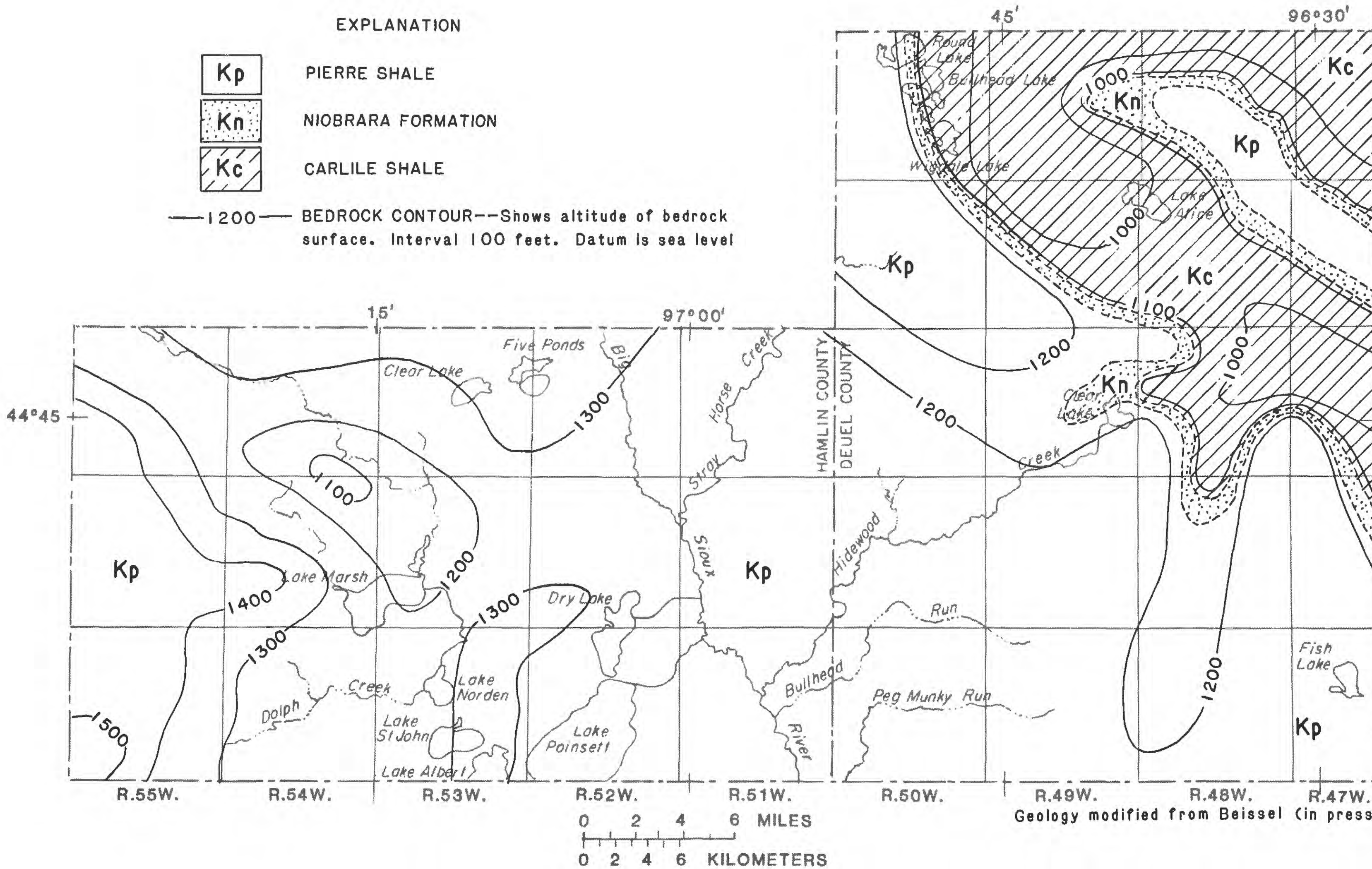
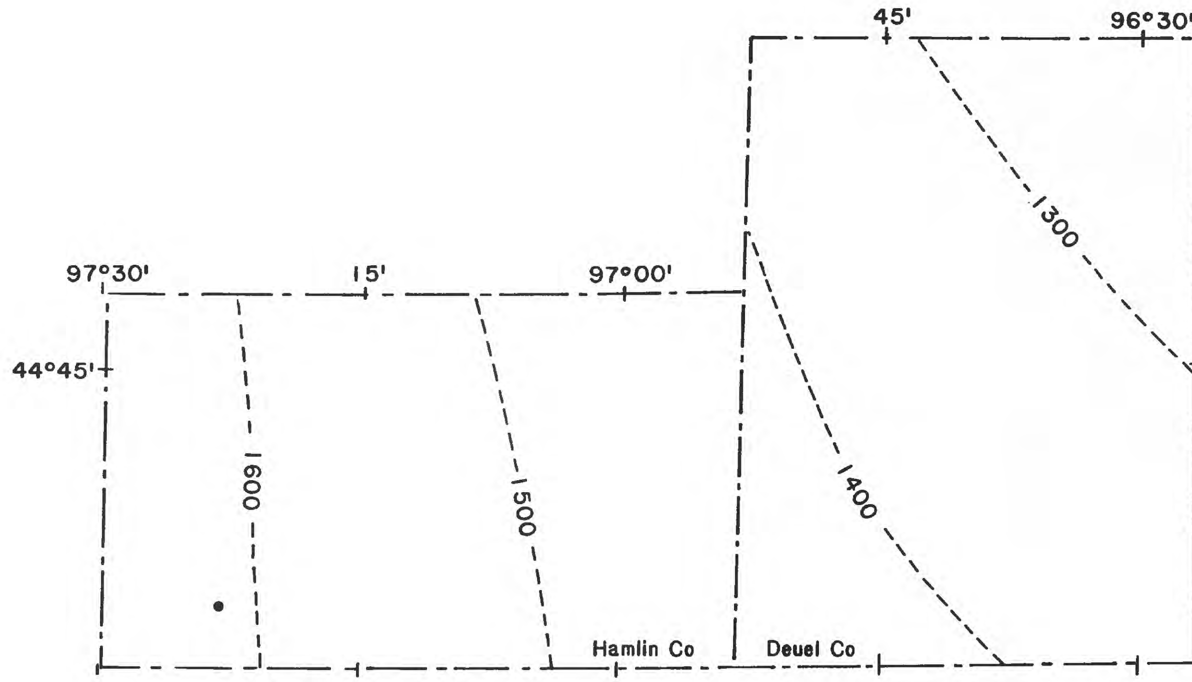


Figure 16.--Altitude of the bedrock surface and the subcrop of the bedrock formations.



EXPLANATION

---1400--- POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased well, 1898. Approximately located. Contour interval 100 feet. Datum is sea level

• WELL 113N55W23BBA--Water level on July 22, 1976, was 1502 feet above sea level

0 3 6 MILES

0 3 6 KILOMETERS

Figure 17.--Potentiometric surface of the Dakota aquifer about 1898 (after N. H. Darton, 1909).

The only observation well that monitors water level in the Dakota in Deuel and Hamlin Counties is well 113N55W23BBA, east of Bryant. In 1976 the potentiometric surface at this well was about 1,502 ft above sea level, only about 100 ft lower than in 1898 according to Darton's map. The water level in the well from 1963 to 1976, during which time the water level declined 18 ft from about 291 to 309 ft below land surface, is shown in figure 18.

Recharge to the aquifer in the Dakota Formation in Deuel and Hamlin Counties is by inflow from the Dakota in adjacent areas to the west. The origin of the water in the Dakota Formation has been the subject of speculation and study for many years. Some hydrologists have suggested that the water is derived from the expansion of the water and the compaction of the aquifer resulting from release of artesian pressure or the dewatering of confining shale beds by compaction resulting from release of artesian pressure (see, for example, Howells, 1965). Others have argued that the water is moving upward from the carbonate rocks of the Madison Group through successive aquifers at and near formational pinchouts in the central part of the State (Davis and others, 1961; Howells, 1974). This probably is the major source of recharge to the Dakota today. A possible past source of recharge to the Dakota suggested by J. S. Downey (1969) is the movement of water into the Dakota aquifer from beneath the continental glaciers during glacial maxima in areas where the Dakota was at the bedrock surface. Preliminary evaluation of geochemical data collected for a regional study of aquifers in the bedrock indicates that Downey's hypothesis may be valid (Lewis Howells, U.S. Geological Survey, written commun.).

Discharge of water from the Dakota aquifer in Deuel and Hamlin Counties is by movement into the aquifer in adjacent areas and by discharge to wells.

Water Quality

The standards for municipal water supplies are set by the U.S. Environmental Protection Agency (1975). These standards contain both mandatory and recommended limits for dissolved or suspended materials in drinking water. Some of these standards are shown in table 6, which summarizes the significance of the many chemical and physical properties of water.

Water used by livestock is subject to quality limitations of the same type as those relating to the quality of drinking water for human consumption. Livestock can, however, generally tolerate a larger concentration of dissolved solids in their water than can humans.

The characteristics that determine the suitability of water for irrigation are its dissolved-solids concentration, boron concentration, the concentration of calcium and magnesium relative to the concentration of sodium, and the chemical changes that may take place in the soil and water after the water has been applied.

Large concentrations of dissolved solids in irrigation water may adversely affect plant growth. The tolerances of crops to the concentration of dissolved solids varies widely, and can vary for the same crop variety depending upon such factors as temperature, soil type, soil fertility, subsoil permeability, and rainfall (U.S. Salinity Laboratory Staff, 1954).

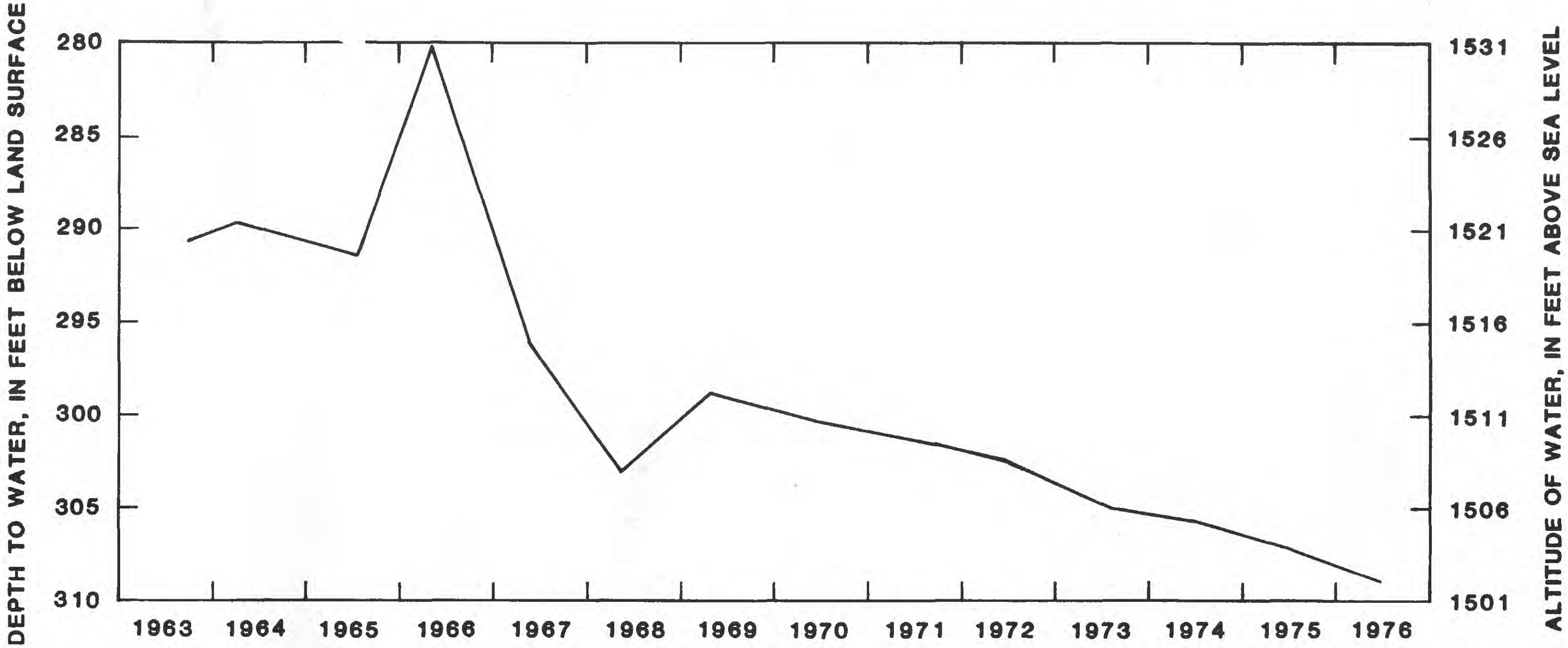


Figure 18.--Depth to water in observation well 113N55W23BBAB, completed in the Dakota aquifer.

Table 6.--Significance of chemical and physical properties of water

[Of considerable use in compiling the significance column was the California State Water Resources Control Board publication 3A, "Water Quality Criteria," 2d edition, by J. E. McKee and Harold Wolf, 548 pages, 1963. Limits, where given are those set forth by the U.S. Environmental Protection Agency (1975). Milligrams per liter (mg/L) are approximately equivalent to parts per million. Micrograms per liter (µg/L) are approximately equivalent to parts per billion.]

Constituent or property	Recommended limit (mg/L) (*mandatory limit)	Significance
Temperature		Affects the usefulness of water for many purposes. Generally, users prefer water of uniformly low temperature. Temperature of ground water tends to increase with increasing depth to the aquifer.
Silica (SiO_2)		Forms hard scale in pipes and boilers and may form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	0.3	Forms rust-colored sediment; stains laundry, utensils, and fixtures reddish brown. Objectionable for food and beverage processing.
Manganese (Mn)	.05	Causes gray or black stains on porcelain, enamel, and fabrics. Can promote growth of certain kinds of bacteria.
Calcium (Ca) and magnesium (Mg)		Cause most of the hardness and scale-forming properties of water (see hardness).
Sodium (Na) and potassium (K)		Large amounts may limit use of water for irrigation and industrial use and, in combination with chloride, give water a salty taste. Abnormally high concentrations may indicate natural brines, industrial brines, or sewage.
Bicarbonate (HCO_3)		In combination with calcium and magnesium forms carbonate hardness.

Table 6.--Significance of chemical and physical properties of water--Continued

Constituent or property	Recommended limit (mg/L) (*mandatory limit)	Significance
Sulfate (SO_4)	250	Sulfates of calcium and magnesium form hard scale. Large amounts of sulfate have a laxative effect on some people and, in combination with other ions, give water a bitter taste.
Chloride (Cl)	250	Large amounts increase the corrosiveness of water and, in combination with sodium, give water a salty taste.
Fluoride (F)	1.5	Reduces incidence of tooth decay when optimum fluoride content is present in water consumed by children during the period of tooth calcification. Excessive amounts of fluoride may cause mottling of teeth.
Nitrate (NO_3) (as N)	* 45 * 10	Concentrations higher than local average may indicate pollution by feedlot runoff, sewage, or fertilizers. Concentrations higher than 45 mg/L may be injurious when used in feeding infants.
Boron (B)		Essential to plant growth, but may be toxic to crops when present in excessive concentrations in irrigation water. Sensitive plants may show damage when irrigation water contains more than 670 µg/L and even tolerant plants may be damaged when boron exceeds 2,000 µg/L.
Dissolved solids	500	The total of all dissolved mineral constituents, usually expressed in milligrams per liter or in parts per million of weight. The concentration of dissolved solids may affect the taste of water. Water that contains more than 1,000 mg/L is unsuitable for many industrial uses. Some dissolved mineral matter is desirable, otherwise the water would have a flat taste.

Table 6.--Significance of chemical and physical properties of water--Continued

Constituent or property	Recommended limit (mg/L) (*mandatory limit)	Significance
Hardness as $CaCO_3$		Related to the soap-consuming power of water; results in formation of scum when soap is added. May cause deposition of scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate in water is called carbonate hardness; hardness in excess of this amount is called non-carbonate hardness. Water that has a hardness less than 61 mg/L is considered soft; 61-120 mg/L moderately hard; 121-180 mg/L, hard; and more than 180 mg/L, very hard.
Percent sodium (% Na)		Ratio of sodium to total cations in equivalents per million (epm) expressed as a percentage. Important in irrigation waters; the higher the percent sodium, the less suitable the water for irrigation.
Sodium-adsorption ratio (SAR)		A ratio used to express the relative activity of sodium ions in exchange reactions with soil. Important in irrigation water; the higher the SAR, the less suitable the water for irrigation.
Residual sodium carbonate (RSC)		The amount, expressed in epm, of carbonate and bicarbonate a water would contain after the removal of an equivalent amount of calcium and magnesium. RSC is a measure of the "black alkali" hazard of water. Water having an RSC greater than 2.5 epm is not considered suitable for irrigation; an RSC of 1.25 to 2.5 epm is considered marginal; and an RSC of less than 1.25 epm is considered "probably safe" for irrigation.

Table 6.--Significance of chemical and physical properties of water--Continued

Constituent or property	Recommended limit (mg/L) (*mandatory limit)	Significance
Specific conductance		A measure of the ability of a unit cube of water to conduct an electrical current; varies with temperature, therefore reported at 25°C (77°F). Values are reported in micromhos per centimeter. Magnitude depends on concentration, kind, and degree of ionization of dissolved constituents; can be used to determine the approximate concentration of dissolved solids.
pH		A measure of the hydrogren ion concentration; pH of 7.0 indicates a neutral solution, pH values lower than 7.0 indicate acidity, pH values higher than 7.0 indicate alkalinity. Water generally becomes more corrosive with decreasing pH; however, excessively alkaline water also may be corrosive.

Sodium hazard is a measure of the capacity of irrigation water to permit replacement, on soil particles, of exchangeable calcium and magnesium by sodium. Soil that has a high content of exchangeable sodium is undesirable for agriculture as it tends to deflocculate or "puddle," to develop a hard crust, and to become nearly impermeable to water. This effect may result when the percent sodium in irrigation water rises considerably above 50 (Wilcox, 1949). The sodium hazard is expressed in either of two ways: as percent sodium (%Na) or as sodium-adsorption ratio (SAR). The classification, with respect to salinity hazard and sodium hazard, of representative samples of water from the various aquifers is shown in figure 19.

Boron is essential to proper plant growth and nutrition, but a small excess over the needed amount is toxic to some plants. Sensitive plants may be damaged when the boron concentration in water exceeds 670 µg/L (micrograms per liter); very tolerant plants may have damage when the boron concentration exceeds 3,000 µg/L (Scofield, 1936).

"Black Alkali" or sodium carbonate may form in soils by evaporation of some types of water and result in an unfavorably high soil pH. The tendency for black alkali to form is called the alkali hazard and is related to the residual sodium carbonate (RSC) in the irrigation water. Eaton (1950) concluded that the RSC had to exceed 1.25 before soil structure would deteriorate.

Representative chemical analyses of surface and ground water from Deuel and Hamlin Counties are shown in table 7.

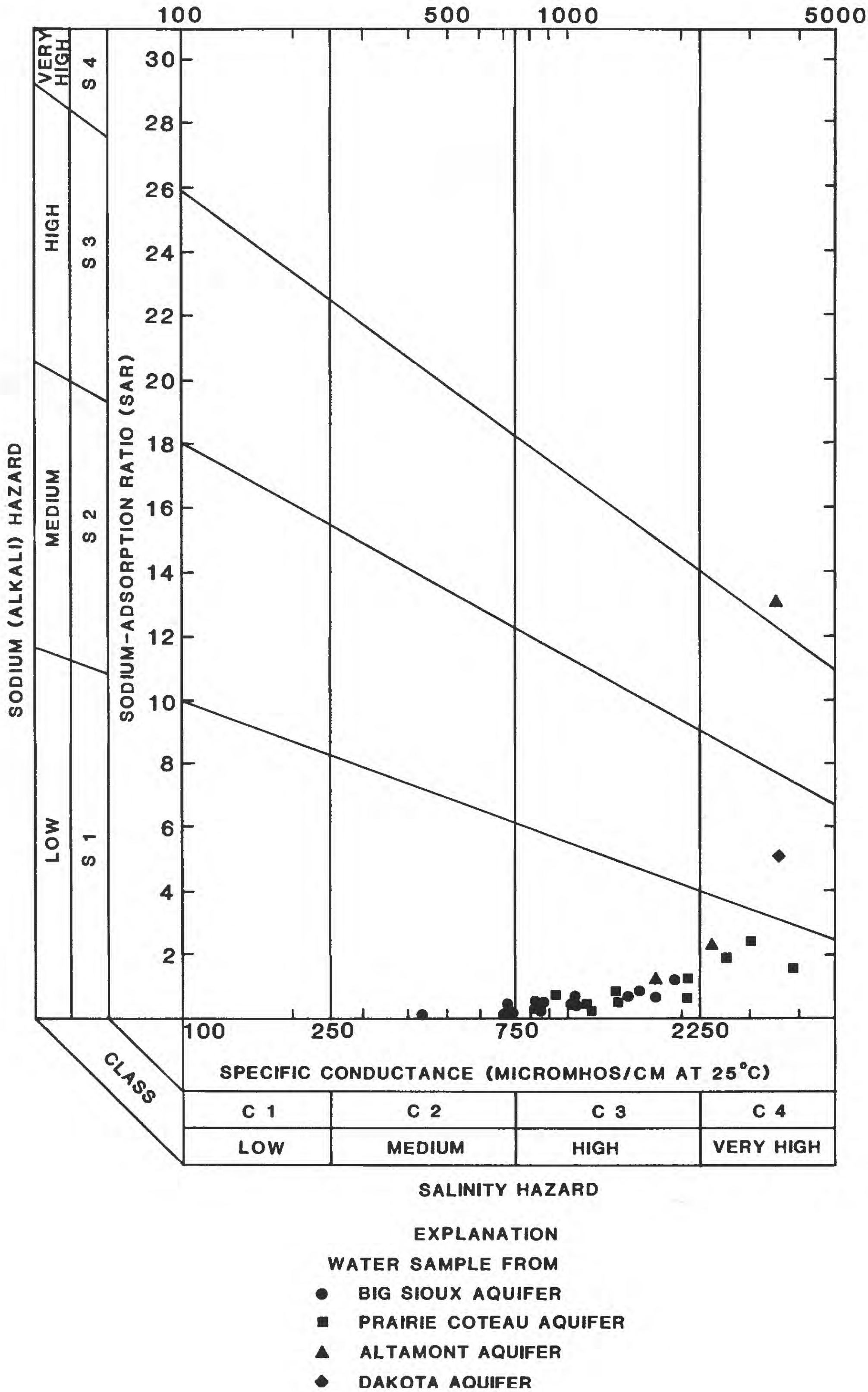


Figure 19.--Classification of ground water for irrigation use (classification developed by U.S. Salinity Laboratory Staff, 1954).

Table 7.--Selected chemical analyses

[Analyses by U.S. Geological Survey Laboratory unless otherwise noted. Results reported as milligrams per liter (mg/L) except as indicated. One milligram per liter is approximately equivalent to one part per million. One microgram per liter (µg/L) is approximately equal to one part per million. µmhos/cm, micromhos per centimeter at 25°C.]

Location	Source of water	Date of collection	Depth of well (feet)	Temperature °C	Silica (SiO_2)	Iron (Fe) (µg/L)	Manganese (Mn) (µg/L)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrite plus nitrate, dissolved as N	Phosphorus, total as P	Boron (B) (µg/L)	Dissolved solids: Residue at 180°C	Dissolved solids: Calculated	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium-adsorption ratio (SAR)	Specific conductance (µmhos/cm)	pH
Surface water																										
113N51W35BABA	Big Sioux River 1/	6- 4-74	--	28.0	17	--	--	93	45	40	7.6	310	200	33	1.5	0.33	0.47	190	--	592	420	160	17	0.9	940	7.9
115N52W15ABAB	Big Sioux River 2/	6- 4-74	--	27.0	21	--	--	76	36	52	7.7	292	130	59	.4	.37	1.6	240	--	537	340	88	25	1.2	860	8.5
115N47W3BAAC	West Branch Lac qui Parle River 3/.	6- 4-74	--	14.0	26	--	--	120	44	14	5.3	374	190	11	1.4	.33	.23	80	--	598	480	170	6	.3	910	8.0
113N52W14ADDA	Lake Poinsett	9-26-73	--	16.0	2.4	--	--	48	81	75	24	299	310	30	.2	.03	.25	340	--	719	450	210	25	1.5	1,120	8.2
114N53W19DDAA	Lake Marsh	5-14-74	--	9.5	12	--	--	320	190	170	44	121	1,700	21	.3	.01	.24	1,000	--	2,520	1,600	1,500	18	1.9	3,020	7.7
117N47W3CBBC	Salt Lake	5-29-74	--	17.6	1.2	--	--	330	390	2,800	87	323	6,800	1,100	.2	.00	.07	17,000	--	11,700	2,400	2,200	71	25	13,700	8.3
117N50W10CAAC	Bullhead Lake	5-21-74	--	16.0	13	--	--	53	150	25	24	311	510	11	.3	.06	.15	130	--	940	750	490	7	.4	1,370	8.3
Ground water																										
113N50W29BBBB	Big Sioux River	10-12-72	25	12.8	--	--	--	88	58	13	1.6	488	68	7.0	--	.23	--	70	504	481	460	58	6	.3	864	7.4
113N51W6BABB	do.	4-22-64	27	11.1	21	--	--	90	34	16	2.3	297	131	11	.2	.0	--	110	474	458	364	120	9	.4	713	7.3
113N51W26BAAC	do.	6- 6-74	11	14.0	24	20	0	84	38	8.8	2.3	327	53	9.5	.6	11	--	80	--	430	370	98	5	.2	710	7.8
113N52W15AADA	do.	7- 3-74	34	12.5	29	20	1,200	130	57	36	5.0	412	310	2.5	.3	.03	.01	180	--	775	560	220	12	.7	1,120	7.8
113N52W31CCBA	do.	7- 2-74	72	14.1	30	10	2,700	270	61	100	12	226	900	16	.3	.14	--	680	--	1,500	930	740	19	1.4	1,940	7.4
113N53W17ABDA	do.	8-10-74	40	9.5	29	20	1,500	190	77	45	12	400	560	7.3	.2	.19	.02	290	--	1,121	790	460	11	.7	1,500	7.6
114N50W16DACA	do.	8-22-74	18	9.5	24	30	770	140	56	21	3.3	451	180	53	.1	1.6	--	50	--	708	580	210	7	.4	1,110	7.2
114N51W7BBBB	do.	4-21-64	25	8.9	18	--	--	108	42	16	6.1	266	223	16	.2	.0	--	120	601	563	444	226	7	.3	854	7.2
114N52W14AACA	do.	10-12-72	28	--	30	20	10	220	100	43	3.9	648	170	110	--	56.0	--	210	--	1,240	960	430	9	.6	1,890	7.2
114N52W14BCAA	do.	10-12-72	70	--	--	--	--	96	30	18	2.8	405	74	2.5	--	.52	--	90	444	424	360	31	10	.4	715	7.4
114N53W20CADC	do.	8-28-73	40	9.5	--	--	--	180	91	62	22	481	560	46	--	.00	--	350	1,240	1,202	820	430	14	.9	1,600	7.9
114N53W28BBDB	do.	10-11-72	20	10.0	30	40	700	110	40	24	5.6	326	160	40	.3	1.8	--	130	--	579	440	170	10	.5	886	7.2
115N49W23ABAA	do.	8-16-73	13	15.0	--	--	--	73	24	5.3	.0	230	55	2.8	--	7.9	--	70	350	309	280	92	4	.1	430	8.1
115N49W23ACCD	do.	10-13-72	31	10.0	27	80	--	140	46	50	5.3	323	140	130	.3	3.4	--	70	--	693	540	270	11	.6	1,160	7.4
115N52W23BBAA	do.	10-12-72	15	10.0	--	--	--	110	43	20	3.2	321	210	5.5	--	.01	--	80	612	552	450	190	9	.4	864	7.4
113N48W20CCCD	Surface outwash	6-19-74	18	7.0	23	10	0	99	31	7.4	.9	322	120	6.1	.5	.04	--	50	--	447	370	110	4	.2	744	7.8
115N47W17BBCC	do.	10-12-72	47	10.8	--	--	--	99	32	6.0	3.0	402	60	1.4	--	.16	--	60	422	404	380	49	3	.1	689	7.4
115N53W1DDDD	do.	10-11-72	26	10.0	--	--	--	76	48	9.9	2.7	5/ 301	130	12	--	8.4	--	70	496	466	390	140	5	.2	759	7.7
115N55W24BDDD 4/	do.	- -70	25	--	--	70	90	120	35	5/ 16		5/ 313	160	17	--	8.0	--	--	540	--	440	187	7	.3	--	8.4
117N47W17DDBA	do.	9-28-73	60	9.0	30	5,200	390	260	86	53	9.9	433	720	5.5	.2	.02	--	510	--	1,380	1,000	650	10	.7	1,800	7.3
113N49W35DDDC	Prairie Coteau	8-22-74	348	9.0	19	50	590	380	120	200	10	380	1,500	1.8	.3	.13	--	380	--	2,420	1,400	1,100	23	2.3	2,920	7.2
113N49W35DDDC2	do.	8-22-74	30	10.6	30	30	40	130	66	23	4.0	427	220	32	.8	12	--	80	--	770	600	250	8	.4	1,180	7.4
113N53W36ABAB	do.	6-27-74	88	10.4	--	--	1,100	160	73	54	13	5/ 403	470	5.3	--	.01	--	200	1,060	978	700	370	14	.9	1,400	7.7
113N55W29BBBC 4/	do.	- -64	255	--	--	100,000	--	330	56	5/ 38		5/ 573	630	20	--	--	--	--	1,370	--	800	585	7	.5	2,040	7.4
113N55W29DDDD 4/	do.	- -64	55	--	--	1,500	--	500	360	5/ 174		5/ 1,770	1,500	72	--	--	--	--	3,490	--	1,700	1,280	12	1.5	4,010	6.9
115N47W19BAB	do.	6- 9-73	245	9.0	30	50	430	120	40	33	4.3	437	190	2.0	.3	.05	--	290	--	636	460	110	13	.7	946	7.5
115N51W34CDCC	do.	6-27-74	288	8.9	31	110	1,100	300	140	170	6.4	5/ 685	1,100	5.5	.3	.24	--	560	--	2,090	1,300	760	22	2.0	2,620	7.3
115N54W12BAAC 6/	do.	4- -67	217	--	--	310	--	230	42	35	5.9	5/ 463	440	15	.4	.09	--	--	--	997	740	360	9	.6	1,440	7.5
115N55W11DDAD 4/	do.	- -70	80	--	--	150	200	420	99	--	--	--	1,800	26	1.5	28.8	--	--	2,580	--	1,500	--	--	--	--	7.7
116N50W5DDCD	do.	9-19-73	30	8.0	22	20	280	160	80	19	2.8	464	370	11	.6	.73	--	90	--	;898	730	350	5	.3	1,240	7.2
117N48W8BCDB	do.	8-21-74	160	10.0	29	50	1,600	270	75	100	12	272	950	6.9	.3	.02	--	990	--	1,580	980	760	18	1.4	2,040	7.3
113N55W7CDCD 7/	Altamont	- -64	385	--	--	7,600	1,500	450	220	840	--	5/ 1,030	2,700	140	1.0	2.9	--	--	4,800	--	2,000	1,180	25	2.2	2,310	--
115N54W14DBC	do.	8- 6-74	500	--	33	20	210	120	48	650	12	411	1,200	250	.2	3.5	--	1,700	--	2,530	500	160	73	13	3,620	7.7
116N48W13DDC	do.	8-22-74	480	12.5	33	30	50	170	86	84	13	421	630	3.8	.3	.05	--	1,100	--	1,230	780	430	19	1.3	1,710	7.3
113N55W23BBA	Dakota	6-18-74	1,325	10.1	5.4	200	40	8.9	2.9	810	6.4	5/ 349	1,100	280	3.5	.02	--	3,700	--	2,390	35	0	98	60	3,590	7.9
115N55W34CCCC 7/	do.	- -70	1,236	--	--	800	0	28	18	1,400	--	5/ 590	1,100	1,100	3.0	.00	--	--	3,900	--	140	0	95	51	--	--

1/ Streamflow, 25 cubic feet per second.
2/ Streamflow, 6.5 cubic feet per second.
3/ Streamflow, 2.3 cubic feet per second.
4/ South Dakota Geological Survey, Vermillion, S. Dak.
5/ Calculated.
6/ Water Resources Research Institute, Brookings, S. Dak.
7/ South Dakota State Chemical Laboratory, Vermillion, S. Dak.

Surface Water

Rivers and streams contained good-quality water, usually of calcium sulfate or calcium bicarbonate type. In the 10 samples collected, dissolved-solids concentration ranged from 510 to 1,060 mg/L (milligrams per liter) and the average concentration was about 600 mg/L. Hardness ranged from about 340 to 790 mg/L and averaged about 780 mg/L. Thus the water, though very hard, is fresh to moderately saline, is low in sodium hazard, low in boron, and is acceptable to very good for livestock and irrigation use. However, during the occasional runoffs that may occur during a drought or during the early runoff period following a drought, the water may be more saline and may carry a much larger concentration of some constituents such as nitrate. During a major drought, of course, most streams will go dry including, occasionally, the Big Sioux River.

More than one-half of the lakes (16) contained magnesium or magnesium-calcium sulfate type water; five lakes contained magnesium bicarbonate type water. Five lakes contained calcium or calcium-magnesium bicarbonate, two lakes contained calcium or calcium-magnesium sulfate type water, and one lake (Salt Lake) contained sodium sulfate type water. Analyses of samples from 29 lakes ranged widely in quality. Dissolved-solids concentration ranged from about 300 mg/L (Wigdale Lake) to 11,700 mg/L (Salt Lake), but only seven lakes had concentrations larger than 1,000 mg/L (Salt, Marsh, and Clear Lakes in Hamlin Co.; Culver, Cochrane, Oliver, and Alice Lakes in Deuel Co.). Hardness ranged from about 240 to 2,400 mg/L, and only the seven lakes previously listed exceeded 800 mg/L hardness. The sodium hazard was low in all but Salt Lake (SAR 25) and Clear Lake in Hamlin County (SAR 3.8). Boron concentration was large enough to be important in only Salt Lake, a source that is already unsatisfactory for most uses because of high salinity and high sodium hazard. Thus, 21 of the 29 lakes tested contain fresh, though very hard, water suitable for livestock and irrigation use. Most of the samples collected for this study were collected in spring and early summer when water quality usually is at or near its best. During dry spells or prolonged droughts, water quality can be much worse--little or no inflow combined with high evaporation loss can increase the dissolved-solids concentration of a lake markedly (by a factor of more than 10). The increase will be greatest for those lakes or ponds in areas of internal drainage, for water bodies that receive insufficient inflow to cause outflow, and for those lakes and ponds that receive little or no ground-water inflow and have little or no ground-water outflow.

Ground Water

The Big Sioux aquifer and other surface outwash aquifers generally yield good-quality water of calcium bicarbonate or calcium sulfate type. The distribution of dominant ions and of dissolved-solids concentration are shown in figure 20. Although water in many of the lakes associated with or overlying the Big Sioux aquifer contains magnesium as the dominant cation, this was true for only three of the well-water samples analyzed. Dissolved-solids concentration ranged from 293 to 5,070 mg/L; however, the only samples that contained more than 1,300 mg/L were the old wells for the city of Clear Lake. These wells, replaced about 1950, probably were subjected to infiltration from refuse dumps and by sewage. Dissolved-solids concentrations greater than about 800 mg/L in water in the western part of the Big Sioux aquifer (from the eastern side of Lake Poinsett to north and west of Lake Marsh) are caused mainly by the high evaporation rate from the overlying lakes. Because the lakes and the aquifer are integral parts of a single hydrologic system, the more saline lake water can move freely into the aquifer.

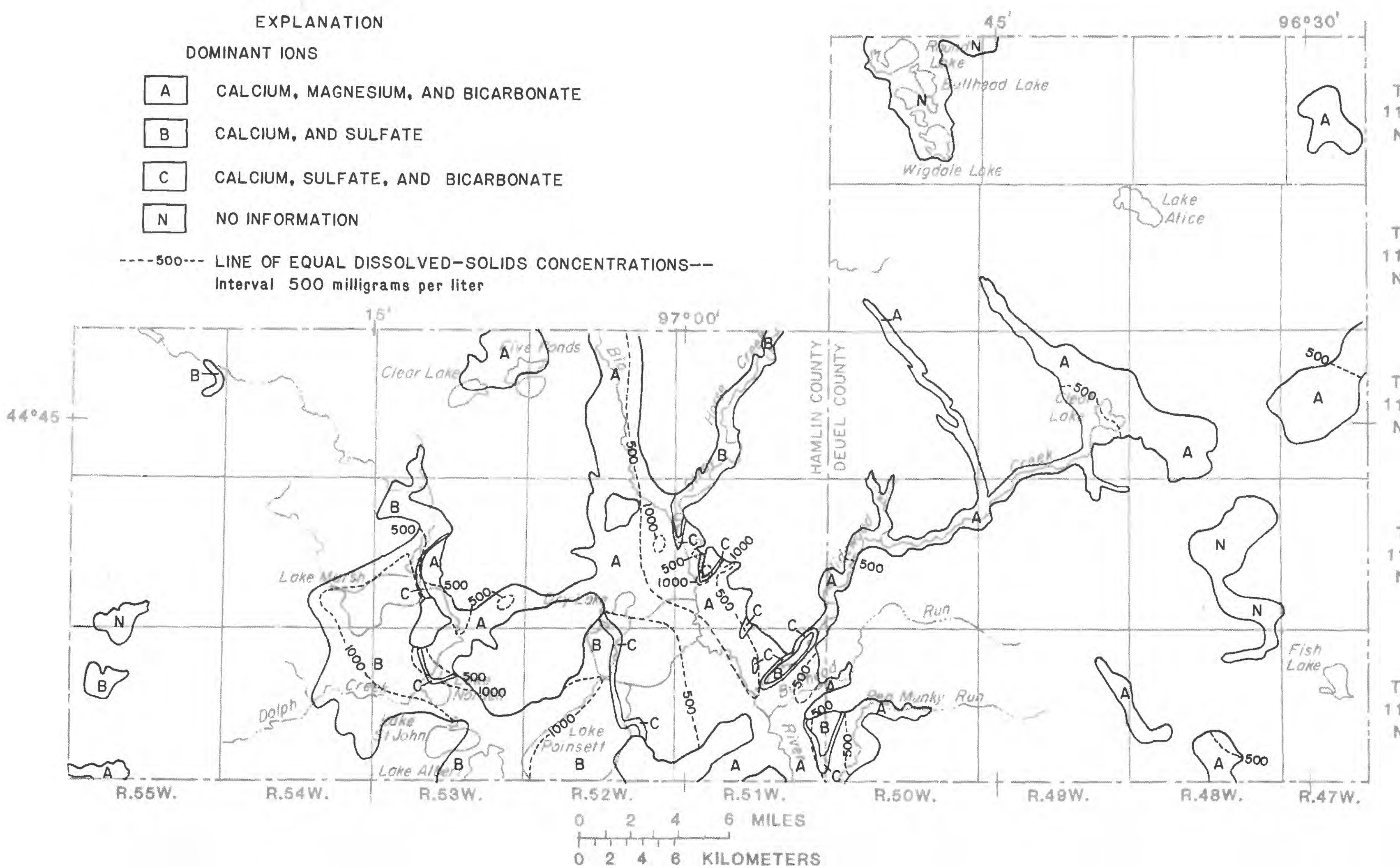


Figure 20.--Distribution of dominant ions and of dissolved-solids concentrations in water from the Big Sioux aquifer and other surficial aquifers.

Waste-disposal systems, such as for towns and lake-shore developments, can contribute seepage with large dissolved-solids concentration to the ground water, as can barnyards, feedlots, and fertilizer applied to crops. Such sources as these contribute to the larger dissolved-solids concentrations found around Lake Poinsett, and probably are the cause of dissolved-solids concentrations greater than 700 mg/L found in the Big Sioux aquifer from Castlewood to the Brookings County line. The presence of seepage from water disposal systems, barnyards, feedlots, and fertilizer generally can be detected because these sources usually contain soluble nitrates and nitrites (nitrites are more common in industrial and commercial waste water than in domestic and farm waste) and cause nitrate concentrations greater than is "normal" for the area. ("Normal" is here considered as less than 1 mg/L of nitrate.) The geographic pattern of nitrate concentration is shown in figure 21. The areas where the nitrate concentrations are largest are the housing strip around Lake Poinsett, the towns of Clear Lake and Estelline, four clusters of farm wells between Dempster and Castlewood, and a scattering of individual farm wells. Areas of less intense but apparently identifiable pollution are the towns of Castlewood and Lake Norden. Water supplies polluted by a local source, such as a septic drainfield or a barnyard, probably can be "cleaned up" by relocating the well by as little as 100 yards, provided that the new location is not in the ground-water flow path of the polluting seepage.

Hardness of the water generally was from 200 to 600 mg/L and is classified as very hard. Water samples from only two wells contained more than 670 μg/L of boron (the threshold for damage to sensitive plants); one well was northwest of Castlewood and the other was southwest of Lake Poinsett. Fluoride concentration was less than the level recommended as optimum for drinking water. Thus, water from the Big Sioux aquifer and other surficial outwash aquifers is from good to excellent in quality for livestock and irrigation supplies and good quality for domestic water supplies except locally where large concentrations of constituents, such as nitrates, are present. The major disadvantage of the water for domestic use is its hardness and, in some areas, a large dissolved-solids concentration.

The Prairie Coteau aquifer yield good to poor quality water in which calcium or calcium and magnesium are the dominant cations and either sulfate or bicarbonate is the dominant anion. A few samples were mixed bicarbonate-sulfate anion type. One well in western Hamlin County yields sodium sulfate type water. The locations of wells for which chemical analyses are available, and the dominant ions for each, are shown in figure 22. Because calcium and magnesium are the major cations, the water is very hard. Hardness ranged from 300 to 3,000 mg/L and averaged about 1,200 mg/L. All samples in which bicarbonate was the main anion were from wells less than 180 ft deep; all but four samples were from wells less than 100 ft deep. Only three samples of bicarbonate water contained more than 900 mg/L dissolved solids. Nitrate concentration had been measured in two of these three samples and in both it exceeded 10 mg/L. All samples in which sulfate was the main anion contained more than 900 mg/L dissolved solids; about three-fourths of the samples with large sulfate concentration contained more than 2,000 mg/L dissolved solids. Most samples with large sulfate concentration were from wells more than 100 ft deep and all were from wells more than 50 ft deep. Dissolved-solids concentrations in samples ranged from 393 to 4,940 mg/L and averaged about 1,500 mg/L. The water was fresh (less than 1,000 mg/L dissolved solids) in only one-third of the samples, all from wells less than 250 ft deep. Of the samples analyzed for nitrate, almost one-half contained more than 10 mg/L and two-thirds contained more than 1.0 mg/L. Based on the sparse information available, the most likely causes of above normal nitrate concentrations may be local to each well. The shallower wells may be receiving nitrate from infiltration of

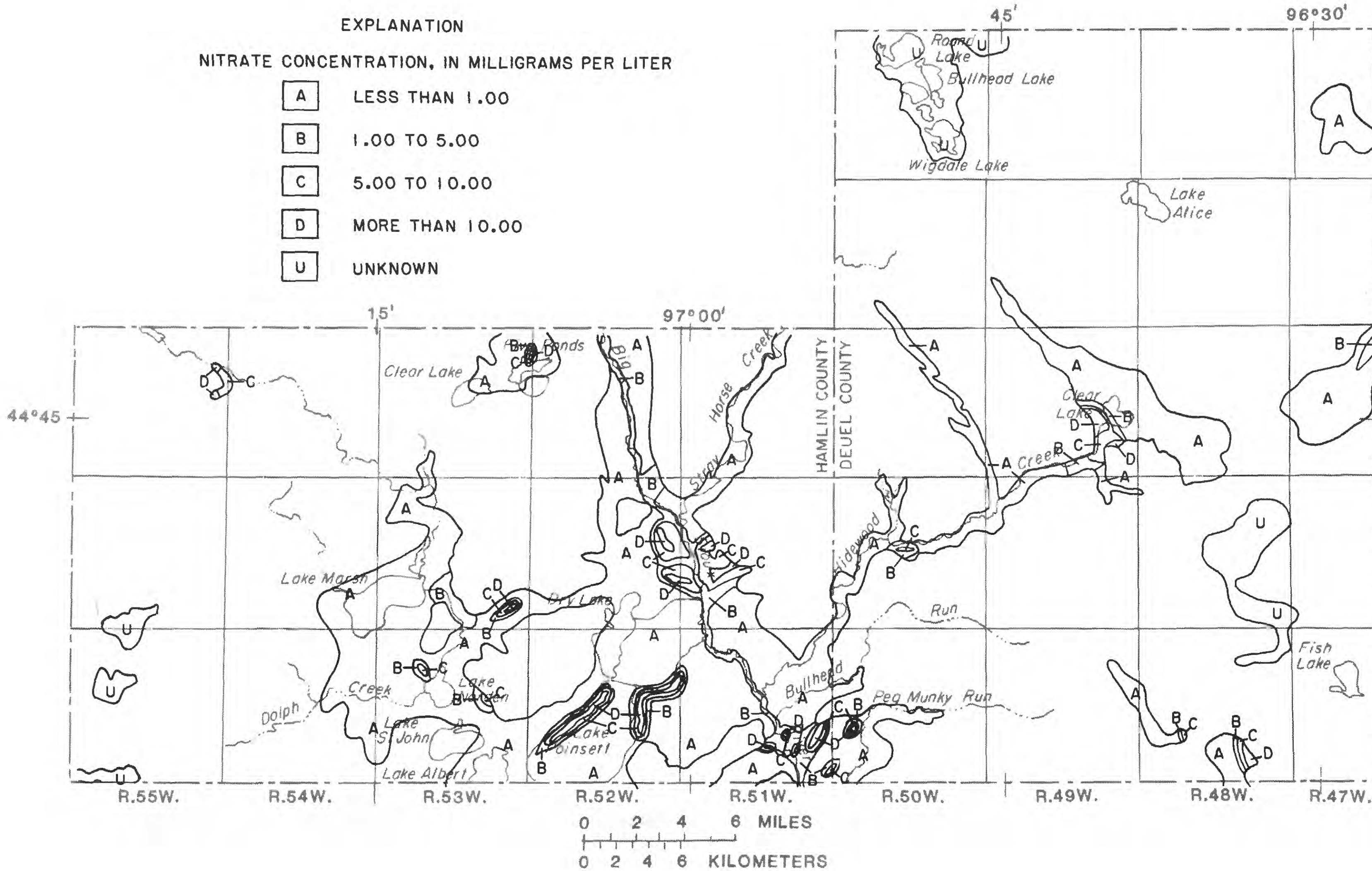


Figure 21.--Distribution of nitrate concentrations in the Big Sioux aquifer and other surficial aquifers.

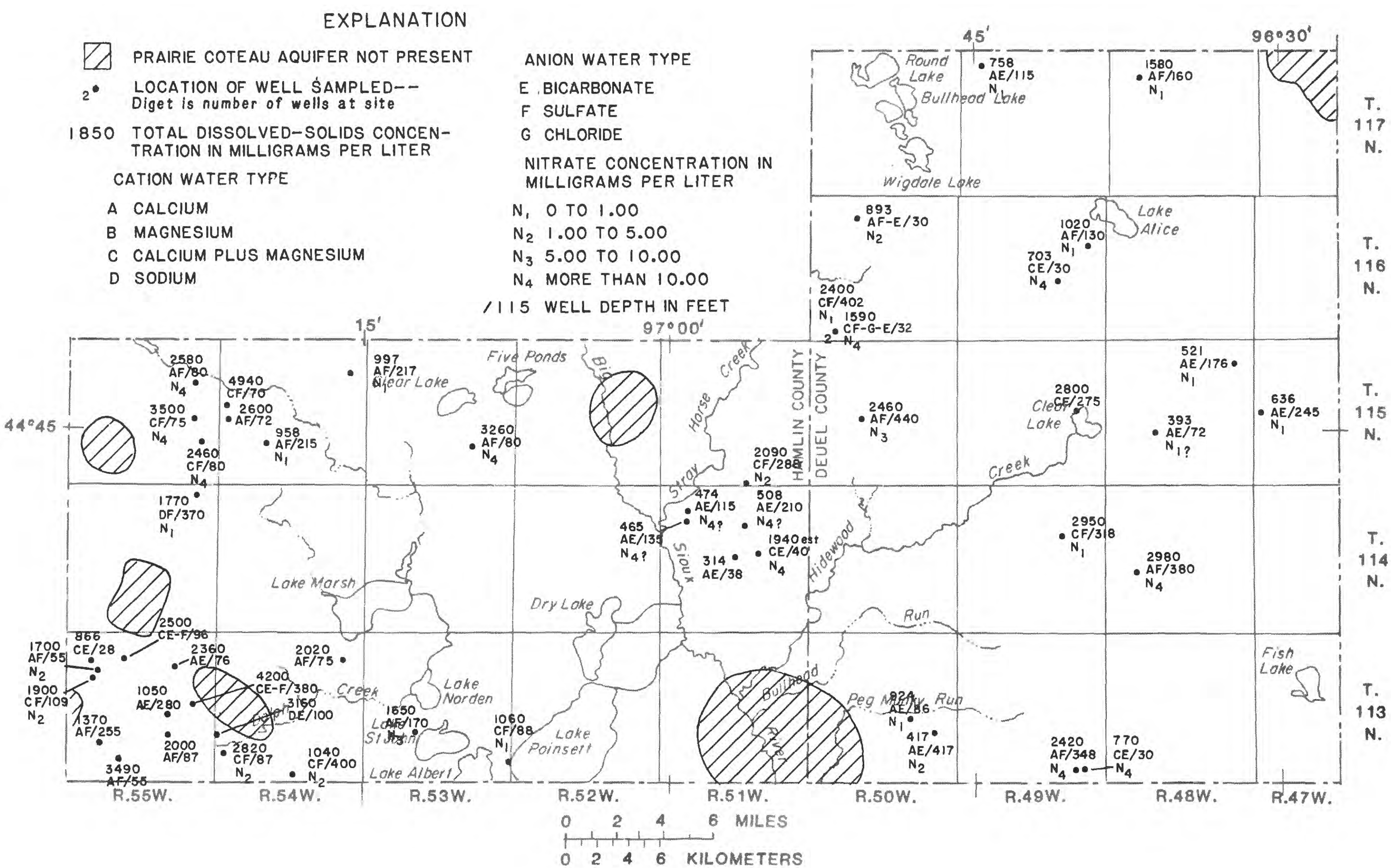


Figure 22.--Locations of wells completed in the Prairie Coteau aquifer for which chemical analyses were obtained.

crop fertilizer as well as barnyard seepage or sewage. For the deeper wells, particularly those completed in aquifers buried beneath 100 ft or more of relatively impermeable glacial till, general infiltration of nitrates in the area seems less likely--the 100 years since settlement probably is not long enough for the infiltration to the aquifer of nitrate-rich recharge. For these wells the path most likely followed by the nitrate-rich water is the well bore itself or the bore of a nearby abandoned well. The water may enter the well through holes or leaky joints in the casing; it may seep down the imperfectly sealed annulus between the casing and the wall of the drill hole; and it can seep into an abandoned well and hence into the aquifer or into a higher permeable zone where it can flow laterally until it reaches the bore of an existing well. Boron concentration exceeded 670 µg/L (the threshold for sensitive plants) only in samples from wells more than 300 ft deep. Fluoride concentration was less than the level recommended as optimum for drinking water. Fluoride exceeded 1.0 mg/L only in wells from 50 to 100 ft deep; the significance of this, if any, is unknown. Thus, water from the Prairie Coteau aquifer is from good to poor for livestock, good to unacceptable for irrigation, and good to unacceptable for domestic supplies. The major disadvantage of the water for domestic use (where its overall quality is best) is its hardness; elsewhere, large concentrations of dissolved solids, sulfate, and, locally, nitrate can make the water less desirable to unacceptable for use.

The Altamont aquifer yields good to poor quality water that varies widely in the proportions of major ions. Of the 11 wells for which chemical analyses are available, in five the water is calcium magnesium sulfate water, in two it is sodium sulfate, one each of sodium chloride and sodium bicarbonate, and one each are the mixed types sodium chloride, sulfate and sodium bicarbonate, chloride. The locations of wells for which chemical analyses are available, and the dominant ions for each are shown in figure 23. The water is very hard; hardness ranged from 240 to 2,000 mg/L. Dissolved-solids concentration ranged from 914 to 4,800 mg/L. All but two samples contained more than 1.0 mg/L nitrate (six samples contained more than 10 mg/L). The very sparse information available seems to indicate that the contamination is local for each well. In all but one sample the boron concentration exceeded 670 µg/L, the threshold of damage for sensitive plants. Fluoride concentration in all samples was less than the level recommended as optimum for drinking water. Thus, water from the Altamont aquifer is from good to poor for livestock, fair to unacceptable for irrigation, and good to unacceptable for domestic supplies. The major disadvantages of the water for domestic use is its hardness, its generally higher than desirable dissolved-solids and sulfate concentrations, and, locally, its high nitrate concentrations.

The Dakota aquifer contains poor quality water throughout Hamlin and Deuel Counties. Although analyses from only four wells (all in western Hamlin County) were available from the study area, some analyses were available in adjacent counties of South Dakota and Minnesota. The dominant cation is sodium; the dominant anion is sulfate or sulfate and chloride. The water is soft to very hard; hardness ranges from 35 to more than 400 mg/L. Dissolved-solids concentration ranges from about 2,400 to more than 3,900 mg/L. The natural concentration of nitrate in the aquifer is less than 0.2 mg/L. Boron exceeds 3,500 µg/L in all analyses. Fluoride probably exceeds the recommended limit throughout the area; the lowest concentration measured was 3.5 mg/L. Thus, water from the Dakota aquifer throughout Deuel and Hamlin Counties probably is acceptable to poor quality for livestock, unacceptable for irrigation, and poor for domestic use.

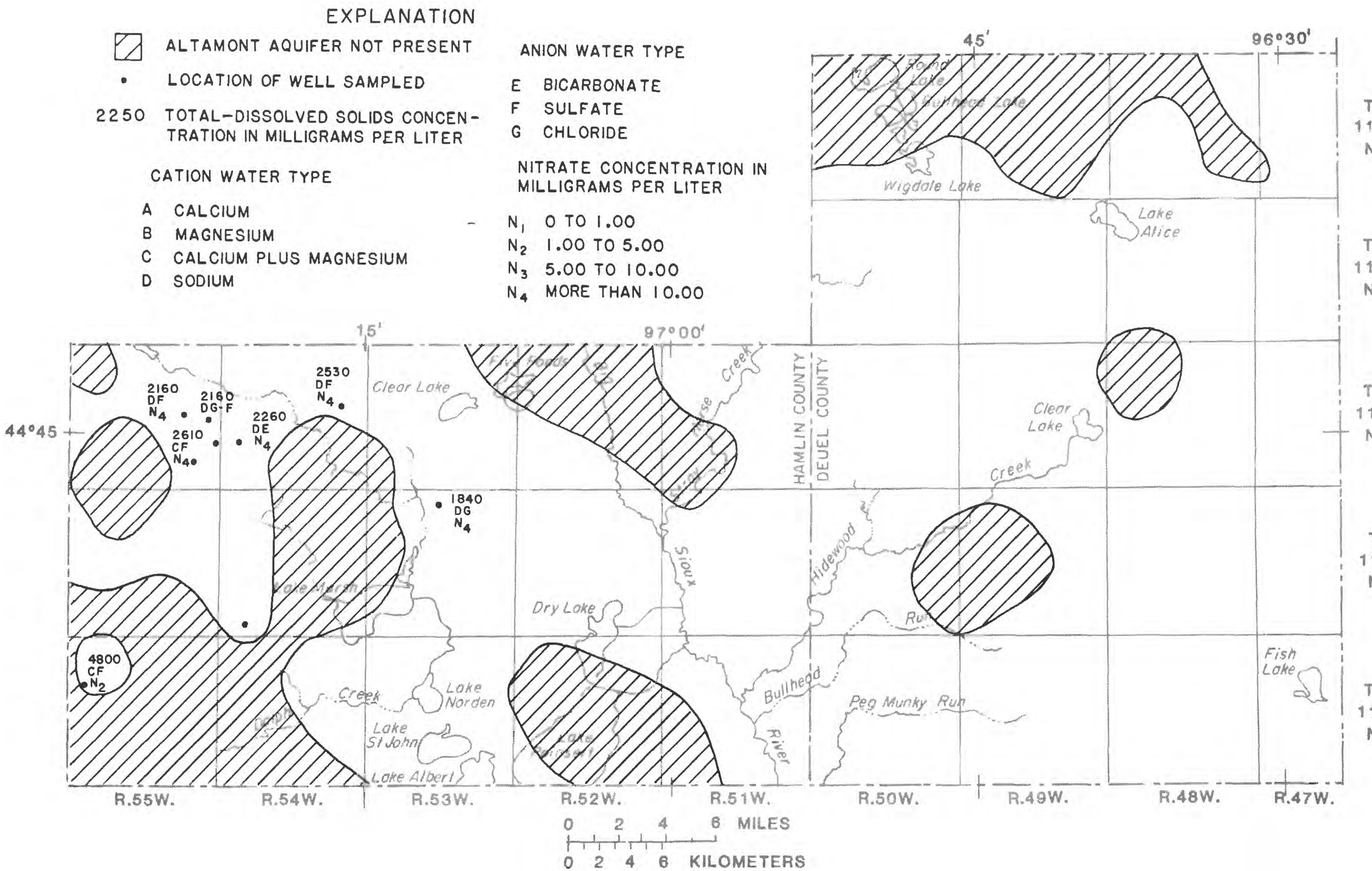


Figure 23.--Locations of wells completed in the Altamont aquifer for which chemical analyses were obtained.

SUMMARY

Deuel and Hamlin Counties have widely distributed and relatively undeveloped surface-water and ground-water resources. These resources probably could not support large-scale uses such as irrigation in at least three-fourths of the area.

The largest and most reliable source of surface water is the Big Sioux River. Its average annual inflow to the two-county area is about 36,300 acre-feet, and it has an average annual net gain in flow of about 20,700 acre-feet as it crosses the study area. Flow from the river helps to maintain the levels of several lakes, such as Lake Poinsett, and the river contributes recharge to adjacent parts of the Big Sioux aquifer. The river also is the source of water for several irrigation withdrawals.

Other streams are used mostly for stock water, as sources to fill stock dugouts and stock ponds, and, except for the West Fork of the Lac qui Parle River, are usually dry except at times of spring snowmelt or heavy rain.

The many lakes in the two counties have little direct use as water supplies, except for livestock and for recreation. Many of the lakes are parts of the hydrologic systems of aquifers and have an important roll in the complex interaction of surface water and ground water. When lake level is high, from runoff, a given lake may be a major source of recharge to an aquifer, but at other times, when streamflow is low and evaporation is high, the lake may be a major area of discharge for the aquifer.

Although some lakes are moderately saline to saline, the water of most lakes normally contains less than 1,000 milligrams per liter dissolved solids.

Ground water, the source of most water used in Deuel and Hamlin Counties, can support more intensive development. The Big Sioux aquifer and several other surficial, minor aquifers, underlie about 227 square miles, contain an estimated 0.5 million acre-feet of water in storage, and are the most widely distributed sources of good-quality ground water. In some areas these aquifers can support wells of at least 1,000 gallons per minute capacity. Water in the surficial aquifers is easily susceptible to contamination from barnyards, feedlots, dumpgrounds, septic disposal fields, and crop fertilizer because the aquifers are near the land surface and are covered with permeable material.

The Prairie Coteau aquifer, buried beneath a cover of clay till, underlies about 1,100 square miles, and contains an estimated 5 million acre-feet of water. This aquifer can supply as much as 1,000 gallons per minute to wells in a few areas, but drilling costs and pumping lifts will be greater than for wells completed in surficial aquifers. Also, the water quality generally is poorer, though good quality water can be obtained in some areas. Of the wells sampled, many were high in nitrate, but the elevated nitrate levels probably are due to inadequate sealing of the casing or well bore to surface or near-surface drainage rather than to naturally high nitrate in the aquifer or to large-scale areal infiltration of nitrate.

The Altamont aquifer, the most deeply buried aquifer in the glacial drift, underlies about 870 square miles and stores an estimated 2.9 million acre-feet of water. This aquifer can, in a few areas, supply as much as 500 gallons per minute to wells, but the drilling costs will be greater than for the other aquifers in the drift. Pumping lifts will average more than twice those for the Prairie Coteau aquifer, and the average quality of the water is the poorest of the aquifers in the drift. The water

generally is saline, very hard, and high in sulfate. Water from many of the sampled wells was high in nitrate, but this probably is due to leakage of surface or near surface drainage into the well bore.

The Dakota Formation is the only bedrock unit found to contain an aquifer. The Dakota underlies the entire area and contains an estimated 5 million acre-feet of saline water. Due to its depth, and therefore, the high cost of well construction, high pumping lifts (averaging about 280 feet), and generally poor quality water, the Dakota probably will not be developed in the foreseeable future. The water is high in boron, fluoride, sodium, sulfate, and, in some areas, chloride.

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