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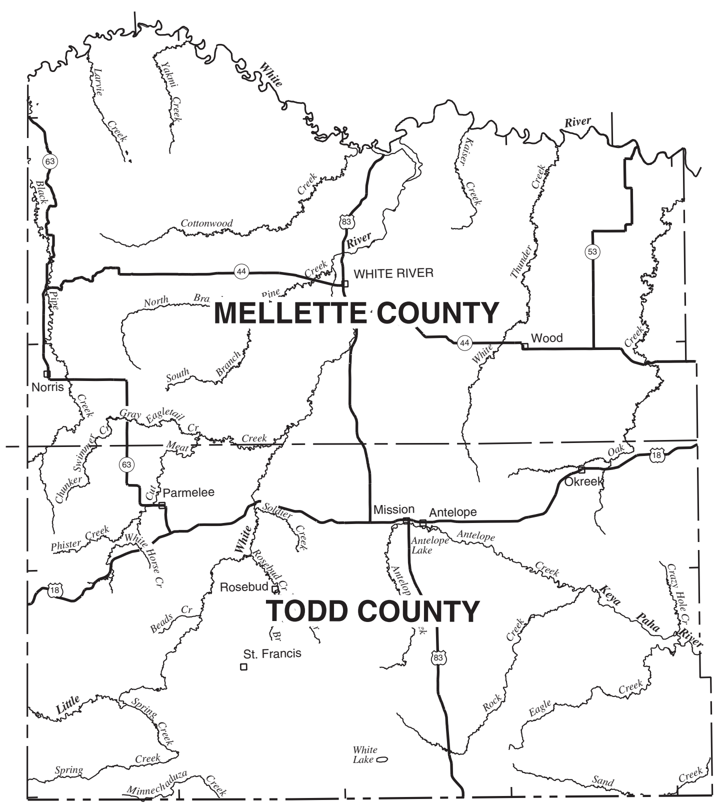
Water Resources of Mellette and Todd Counties, South Dakota

Water-Resources Investigations Report 98-4146



U.S. Department of the Interior
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By Janet M. Carter

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Bruce Babbitt, Secretary

U.S. Geological Survey

Thomas J. Casadevall, Acting Director

Rapid City, South Dakota: 1998

For additional information write to:

District Chief
U.S. Geological Survey
1608 Mt. View Road
Rapid City, SD 57702

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U.S. Geological Survey
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VERTICAL DATUM

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

Water Resources of Mellette and Todd Counties, South Dakota

By Janet M. Carter

ABSTRACT

Mellette and Todd Counties are located in south-central South Dakota and have a combined area of 2,694 square miles. The White River and its tributaries, which include the Little White River, drain Mellette County and about one-half of Todd County. Tributaries to the Niobrara River, which include the Keya Paha River, drain the other one-half of Todd County. The average discharge of the Little White River is about 56 cubic feet per second as the river enters Todd County and is about 131 cubic feet per second as it discharges to the White River in northern Mellette County. The average discharge of the Keya Paha River just outside Todd County is about 39 cubic feet per second. The average annual runoff for Mellette and Todd Counties ranges from 0.94 to 2.36 inches based on records from nine streamflow-gaging stations in and near the counties. The average annual runoff is 1.62 inches, which compares with the average annual precipitation of about 19 inches.

In Todd County, shallow wells completed in the alluvial, Ogallala, Arikaree, and White River aquifers generally can supply water that has low concentrations of dissolved solids, is fresh, and is soft to moderately hard. Ground water from shallow aquifers is limited in Mellette County; therefore, deep wells, often greater than 1,000 feet, are sometimes installed. The Pierre Shale often is used to supply rural domestic and stock wells in Mellette County even though well yields are low and the water has high dissolved solids, is moderately saline, and is very hard.

Alluvial aquifers are present in both counties and store an estimated 1.6 million acre-feet of water. The water quality of the alluvial aquifers is dependent on the underlying deposits, and generally the water has low concentrations of dissolved solids, is fresh, and is soft to moderately hard where underlain by the Ogallala and Arikaree Formations; has moderate concentrations of dissolved solids, is slightly saline, and is hard where underlain by the White River Group; and has high concentrations of dissolved solids, is saline, and is very hard where underlain by the Pierre Shale. Also, yields often are lower where the alluvial aquifers are underlain by the Pierre Shale.

The Ogallala aquifer is present in only Todd County, and the Arikaree aquifer is present throughout most of Todd County and southwestern and south-central Mellette County. The Ogallala aquifer contains an estimated 17 million acre-feet of water in storage, and the Arikaree aquifer contains an estimated 50 million acre-feet of water in storage. Both aquifers generally are suitable for irrigation, and yields from these aquifers are sometimes greater than 1,000 gallons per minute. Nitrate concentrations in 13 out of 92 water samples collected from the Ogallala aquifer exceeded the Primary Drinking Water Maximum Contaminant Level (MCL) of 10 milligrams per liter. In 11 out of 46 samples collected from the Arikaree aquifer, arsenic concentrations exceeded the MCL of 50 micrograms per liter.

The White River aquifer, where present, is usually the shallowest source of ground water in Mellette County. The White River aquifer also is used in northern Todd County where the Ogallala and Arikaree aquifers are not present. The White River aquifer contains an estimated 50 million acre-feet of water in storage. Reported yields from the aquifer range from 1 to 30 gallons per minute, which generally is insufficient to support irrigation in most areas. However, yields are sufficient for livestock-watering and rural-domestic purposes.

In both counties, the Pierre Shale is the shallowest bedrock aquifer and is exposed at the land surface throughout most of Mellette County. This aquifer is used primarily in Mellette County. Although the aquifer contains an estimated maximum of 1.5 million acre-feet of water in storage, it is not a viable source of ground water because the aquifer is relatively impermeable, yields are low, and water usually can be obtained from shallower sources, especially in Todd County. Reported yields from the Pierre Shale aquifer range from 1 to 8 gallons per minute.

Because few test holes and wells penetrate below the Pierre Shale, little is known about the extent of the deeper bedrock aquifers. All wells completed in the Dakota Sandstone, Inyan Kara, and Minnelusa and Madison aquifers in the counties are used for stock-watering purposes. High concentrations of dissolved solids and hard water are characteristic of the water quality in the bedrock aquifers. Depths to the top of the deeper bedrock aquifers range from 1,270 feet to greater than 2,000 feet below land surface.

INTRODUCTION

In 1992, the U.S. Geological Survey (USGS) in cooperation with the Rosebud Sioux Tribe, Mellette County, West River Water Development District, and the South Dakota Geological Survey, began a 5-year investigation to describe and quantify the water resources of Mellette and Todd Counties. This investigation was needed because of the limited information available on the surface- and ground-water resources in Mellette and Todd Counties. This information is needed by local, county, State, and Tribal officials to develop sound water-management plans.

Mellette and Todd Counties, which comprise the study area, are located in south-central South Dakota (fig. 1). Mellette County has an area of 1,306 square miles, and Todd County has an area of 1,388 square miles. According to the U.S. Census Bureau, the 1995 population was 2,002 in Mellette County and 9,105 in Todd County. The climate is subhumid, and the average annual precipitation is about 19 inches in both counties. Most of the land area is used for range or native hay production, and the main source of income in both counties is cattle ranching. Less than 15 percent of the land is used for crops, which include wheat, sorghum, oats, corn, and alfalfa.

The White River forms the northern boundary of Mellette County. Most of the area of the two counties is rolling, and numerous deep valleys drain into the White River to the north or into the Niobrara River to the south in Nebraska. The headwaters to the Keya Paha River are located in Todd County. All of Mellette County and the northern part of Todd County are in the Great Plains physiographic province. The southern part of Todd County is in the Sand Hills physiographic province (fig. 1).

The original boundaries of the Rosebud Indian Reservation included all or nearly all of Mellette, Todd, Gregory, and Tripp Counties, and a small portion of Lyman County. In the early 1900's, the Rosebud Reservation was opened for homesteading. As a result, scattered tracts of non-Indian owned land are present in both Mellette and Todd Counties. In 1975, the Rosebud Indian Reservation boundary was revised to include only Todd County (fig. 2).

Purpose and Scope

The results of a 5-year water-resources study of Mellette and Todd Counties are presented in this report. Specifically, this report includes descriptions of the quantity, quality, and availability of surface and ground water, the extent of the major shallow and bedrock aquifers, and surface- and ground-water uses in the two counties.

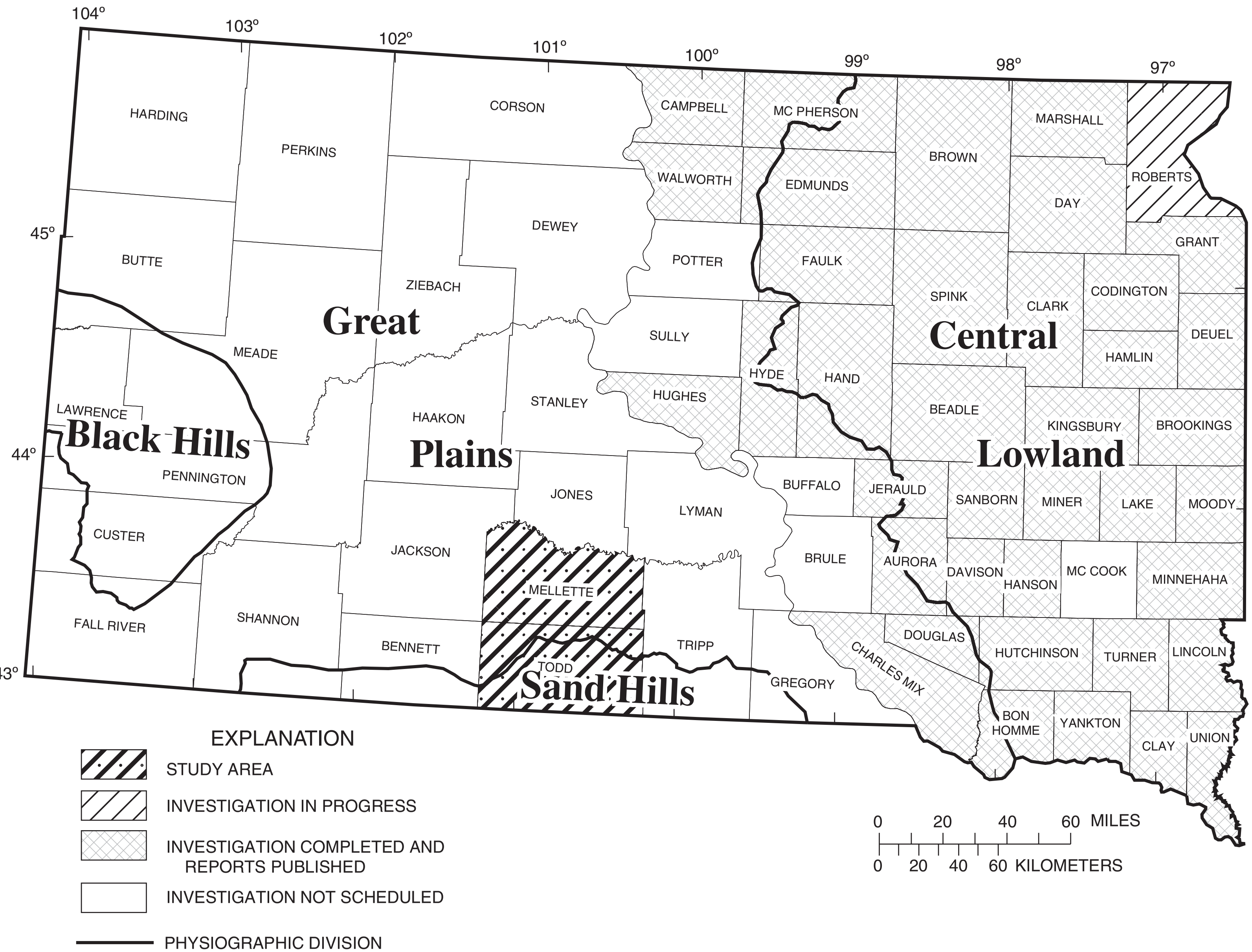


Figure 1. Index map of South Dakota showing location of Mellette and Todd Counties, status of county investigations, and locations of main physiographic divisions (physiographic divisions modified from Flint, 1955; Fenneman, 1946).

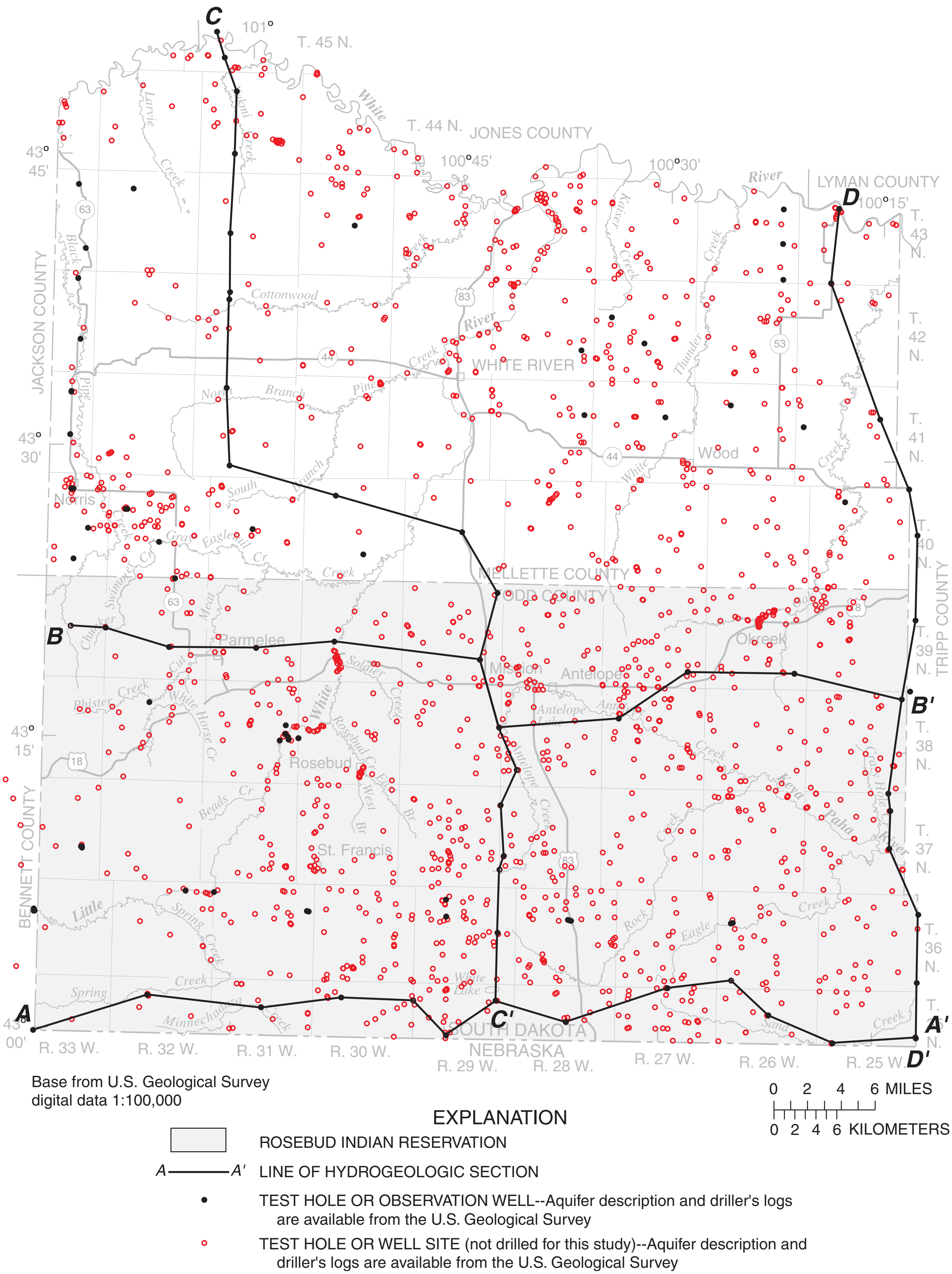


Figure 2. Locations of selected wells, test holes, and lines of hydrogeologic section in Mellette and Todd Counties.

Methods of Investigation

Methods of investigation included analyses of streamflow records, a well inventory, analyses of preexisting drillers' logs, test drilling and observation-well installation, measurement of static water levels, compilation of chemical analyses of surface- and ground-water samples, and analyses of water uses. Seventy-eight test holes were drilled; of these, 56 observation wells were installed for the study. Although the drilling was concentrated in Mellette and Todd Counties, a few of the test holes and wells were drilled in Bennett County just outside the western boundary of Todd County, in Jones County just outside the northern boundary of Mellette County, and in Tripp County just outside the eastern boundary of Todd County. The locations of test holes and observation wells drilled specifically for this study and the locations of four lines of hydrogeologic section are shown in figure 2. The locations of additional test holes and private or public wells used to help determine the structure contours of the formations and the extent, thickness, yield, potentiometric surface, and water quality of the aquifers also are shown in figure 2.

Many ground-water samples were collected and analyzed for this study. In 1990, 100 private domestic wells were sampled prior to the development of the water-resources investigation study. Between 1994 and 1996, samples were collected from 47 of the 56 observation wells installed for the study; between 1990 and 1994, an additional 12 wells, which included private and observation wells, were sampled for a nitrate study conducted by the USGS in Todd County. The sampling methods, quality-assurance procedures, and water-quality analyses for these studies are presented by Carter (1997). Between 1991 and 1995, samples were collected from 21 wells, which included community, private, and observation wells, for an arsenic study conducted by the USGS in Todd County. The sampling methods, quality-assurance procedures, and water-quality analyses for the arsenic study are presented by Carter and others (1998).

All data collection sites are numbered according to the Federal land survey system of western South Dakota (fig. 3). The local number consists of the 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 2.5-acre tract in which the well is located. These letters are assigned in a counterclockwise direction beginning with "A" in the northeast quarter. A serial number following the last letter is used to distinguish between wells in the same 2.5-acre tract. Thus, well 38N28W36ABCB is in the NW^1/4 of the SW^1/4 of the NW^1/4 of the NE^1/4 of section 36 in township 38 north and range 28 west.

Generalized Geology

As a result of different depositional environments in the past in western South Dakota, the geology in the study area consists mostly of marine, fluvial, and unconsolidated deposits ranging in age from the Precambrian to the present (table 1). In this report, descriptions of the geology is limited to deposits in Mellette and Todd Counties. Granitic rocks of Precambrian age dating to about 1,460 million years before present are located in a narrow strip across the southern edge of the study area (Richard Hammond, South Dakota Geological Survey, written commun., 1998); however, the rocks are not exposed at the surface. A geologic map showing the surficial deposits for Mellette and Todd Counties is shown in figure 4. Surficial deposits range from sedimentary rocks of Cretaceous age to unconsolidated deposits of Quaternary age.

Sedimentary rock sequences of Paleozoic and Mesozoic age were deposited by alternating transgressive and regressive seas. In the two counties, these rocks are composed mainly of limestone, dolomite, siltstone, sandstone, and shale. Rocks of Cambrian, Silurian, Devonian, Triassic, and Jurassic age are missing in the study area. The Red River and Winnipeg Formations, the Madison Limestone, and Minnelusa Formation are examples of transgressive seas. The study area was covered by seas from the Mississippian through the early Permian periods. From the late Permian period through the beginning of the Cretaceous period, deposits primarily were continental. Continental deposits are formed on land rather than in the sea and may include sediments of lake, swamp, wind, stream, or volcanic origin. Deposition and erosion of continental deposits prevailed throughout this time until another marine transgression occurred during the early Cretaceous period. Deposits during the Cretaceous period primarily were shale (Darton, 1905). Tertiary rocks generally consist of poorly consolidated claystones, siltstones, sandstones, and shale deposited in fluvial (stream/river) and lacustrine (lake) environments. Unconsolidated deposits of Quaternary age include terrace gravels, graded fluvial sand and gravels (alluvium), and eolian (windblown) sand. Glaciation during the Quaternary period did not affect the study area (Flint, 1955).

Table 1. Generalized stratigraphic column showing geologic units and some of their characteristics

Era	System	Formation or deposit	Thickness (feet)[1]	Description and origin[2]	Remarks[2]
Cenozoic	Quaternary	Alluvium	0-35	Brown, varies between clay, silts, fine to coarse sand, and gravel. Generally sandy along the Little White River and other streams that flow over deposits of Tertiary age. Generally clayey with some thin sand beds along intermittent streams that flow over the Pierre Shale. Fluvial.	Locally, deposits are moderately permeable along the Little White River and relatively impermeable along streams that flow over the Pierre Shale. Yields generally are adequate to supply domestic and stock wells except along streams that flow over the Pierre Shale. Water is fresh, low in concentrations of dissolved solids, and soft to moderately hard except in deposits underlain by the Pierre Shale.
		Windblown sand deposits	0-150	Brown, unconsolidated, very fine to medium grained, uniform, quartz sand; characterized by dune topography and blowouts. Eolian.	Generally very permeable and water bearing; yields are adequate to supply stock and domestic wells except where deposits are small.
		Terrace deposits	0-105	Brown, silty clay, sand, and gravel. Commonly, the silty and sandy layers are partly cemented, and the gravel and sand beds commonly are interbedded with laminated silty clay. Fluvial.	Generally water bearing in the basal portion of the deposits. Yields are usually adequate to supply stock and domestic wells. Water is fresh, low in concentrations of dissolved solids, and soft to moderately hard except in areas where the water-bearing deposits are underlain by the Pierre Shale.
	Tertiary	Ogallala Formation	0-240	Tan to olive, fine- to medium-grained sandstone with some silty clay. Upper unit of Ogallala Formation also is known as the Ash Hollow Formation and the lower unit as the Valentine Formation. Fluvial.	Permeable and generally water-bearing; yields are adequate to supply stock and domestic wells and can supply irrigation wells in some areas. Water is fresh, low in concentrations of dissolved solids, and soft to moderately hard.
		Arikaree Formation	0-620	Pinkish tan to red; consists of poorly consolidated, tuffaceous sandstone, siltstone, shale, and silty clay. The Rosebud Formation sometimes is differentiated as a unit within the Arikaree Formation. Basal unit is composed mostly of silts and sands. Fluvial.	The upper part of the formation generally is impermeable, but can yield small amounts of water from fractures, joints, and silty layers. The basal part is moderately permeable and can supply water for domestic and stock wells. Water is fresh, low in concentrations of dissolved solids, and soft to moderately hard.
		White River Group (undifferentiated)	0-470	Yellow to brown, poorly consolidated siltstone and claystone with some beds of fine-grained sand. Units of the White River Group sometimes are differentiated into the Brule and Chadron Formations. Fluvial.	Permeability varies from impermeable to moderately permeable, depending on the clay content. Yields are usually adequate to supply water to stock and domestic wells. Water is slightly saline, moderate in concentrations of dissolved solids, and hard depending on the proximity of the aquifer to the Pierre Shale.
Mesozoic	Cretaceous	Pierre Shale	600-1,395[3]	Bluish-black shale with some layers of bentonite. Marine.	Most of the formation is relatively impermeable. Can yield small amounts of water if fractures or sandy zones are present. Typically not considered an aquifer. Water is saline, high in concentrations of dissolved solids, and very hard.
		Niobrara Formation	125-175[4]	Tan to gray, highly calcareous shale. Commonly described by drillers as "chalk." Marine.	Water-bearing traits are largely unknown. May yield sufficient water for some purposes.

Mesozoic	Cretaceous	Carlile Shale	300-400[4]	Light grayish blue to black, noncalcareous shale. Marine.	Nearly impermeable. Water-bearing traits are largely unknown.
		Greenhorn Formation	100-120[4]	Tan, bluish, white, or gray calcareous shale. Marine.	Water-bearing traits are largely unknown.
		Graneros Shale	130-200[4]	Dark-gray non-calcareous shale. Marine.	Nearly impermeable. Water-bearing traits are largely unknown.
		Dakota Formation (Dakota Sandstone)	270-340[4]	Interbedded tan to white sandstone and dark-colored shale. Sandstone is composed of loose to well-cemented, very fine to coarse quartz sand; cement most commonly is calcium carbonate. Marine.	Permeable sandstone beds yield moderate quantities of water under artesian pressure for stock and domestic wells. The water is highly mineralized and cannot be used for irrigation purposes.
		Skull Creek Shale	95-150[4]	Dark bluish-gray shale. Marine.	Relatively impermeable. Water-bearing traits are largely unknown.
		Inyan Kara Group undifferentiated	100-275[4]	White to light-gray or tan sandstone and siltstone; contains beds of gray to black and reddish to buff shale. The Inyan Kara Group sometimes is divided into the Fall River and Lakota Formations. Continental to marginal marine.	Permeable sandstone beds yield moderate quantities of water under artesian pressure for stock and domestic wells. The water is highly mineralized and cannot be used for irrigation purposes.
Paleozoic	Permian and Pennsylvanian	Minnelusa Formation	300-530[4]	Consists of interbedded sandstone, siltstone, dolomite, limestone, anhydrite, and shale. Marine.	Permeable zones can yield adequate water for stock and domestic wells under artesian pressure. Water is lower in dissolved solids than the Dakota Sandstone and Inyan Kara aquifers. Can be used for irrigation on crops that are tolerant of salt with proper salinity management.
	Mississippian	Madison Formation	90-240[4]	Light gray to buff, varies from pure limestone to pure dolomite with various combinations of the two. Marine.	Permeable zones can yield adequate water for stock and domestic wells under artesian pressure. Water is lower in dissolved solids than the Dakota Sandstone and Inyan Kara aquifers. Can be used for irrigation on crops that are tolerant of salt with proper salinity management.
	Ordovician	Red River and Winnipeg Formations (undifferentiated)	0-170[4]	The Red River Formation mostly consists of dolomite, and the Winnipeg Formation mostly consists of sandstones[5]. Marine.	
Precambrian				Granite.	

[1]Based on interpretation and projection of data from electric logs and drillers' logs.
[2]Based on interpretation of data collected during study and from drillers' logs.
[3]From Ellis and others (1972).
[4]From Ellis and others (1971).
[5]From Agnew and Tychsen (1965).

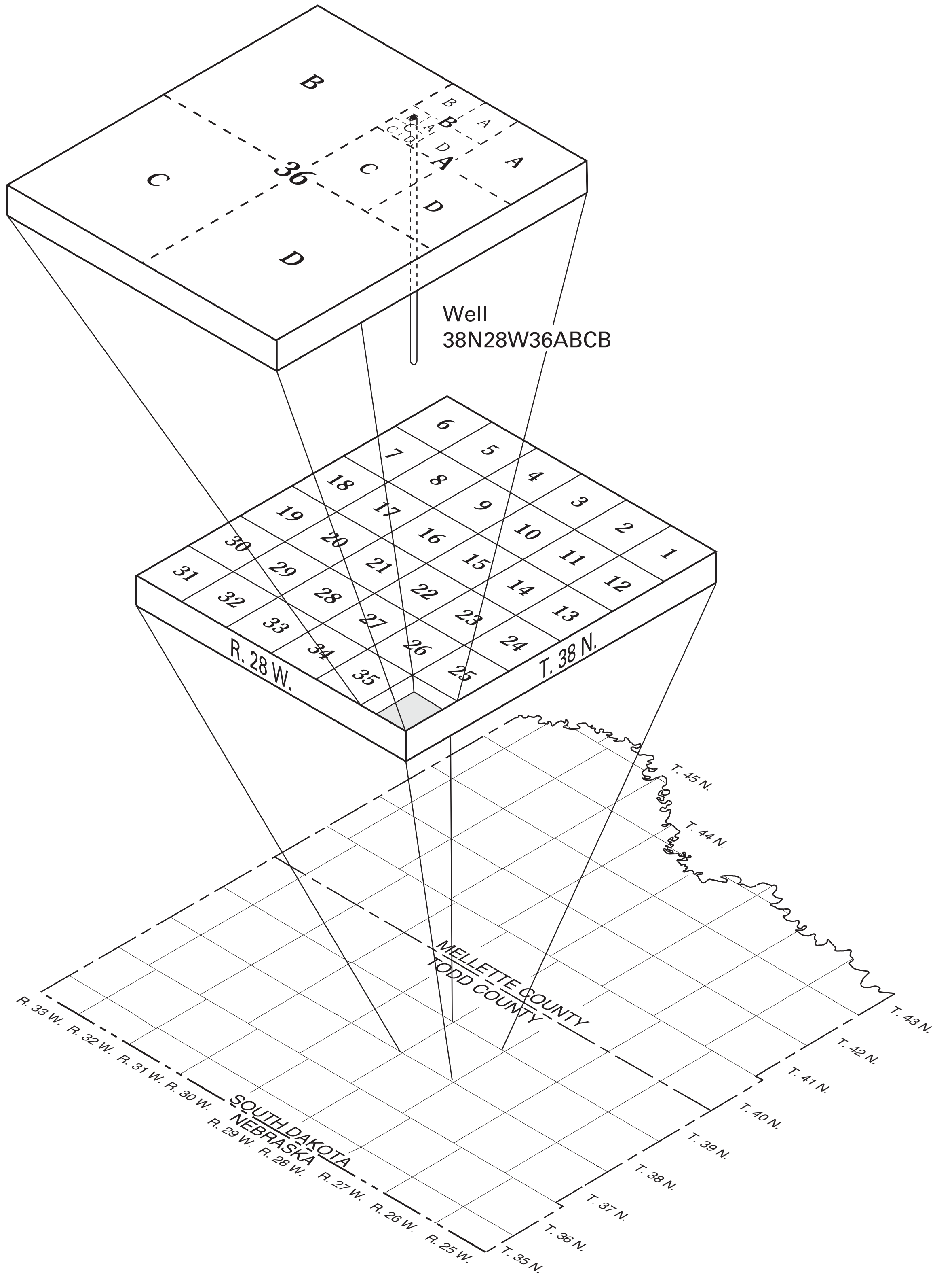
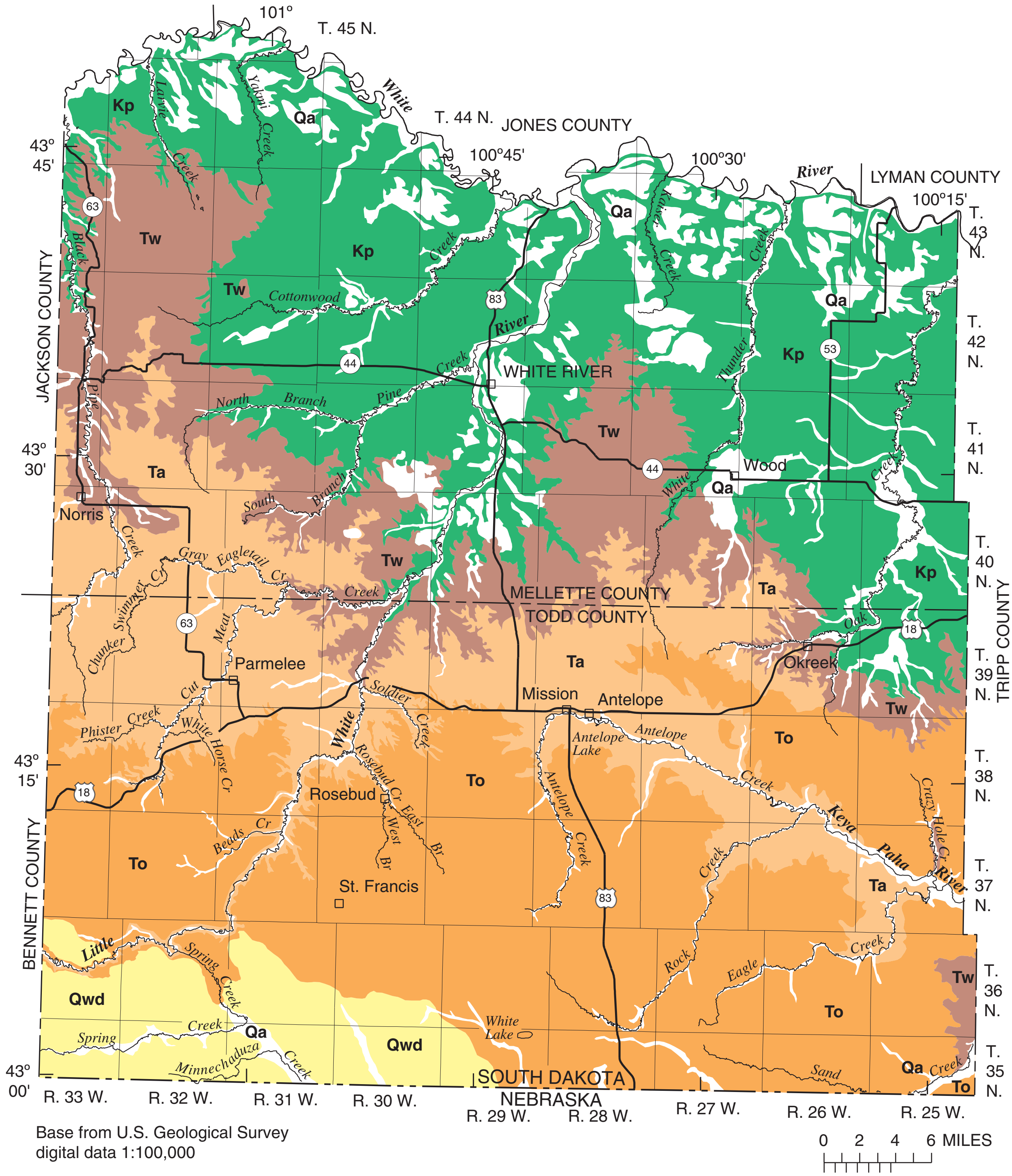


Figure 3. Well-numbering system. The well number consists of the township number, followed by “N,” the range number followed by “W,” and the section number followed by a maximum of four uppercase letters that indicate, respectively, the 160-, 40-, 10-, and 2 1/2-acre tract in which the well is located.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



Base from U.S. Geological Survey digital data 1:100,000

EXPLANATION

QUATERNARY UNCONSOLIDATED DEPOSITS
- Qa Alluvium
- Qwd Windblown sand deposits

TERTIARY SEDIMENTARY DEPOSITS
- To Ogallala Formation
- Ta Arikaree Formation
- Tw White River Group

CRETACEOUS SEDIMENTARY DEPOSITS
- Kp Pierre Shale

Figure 4. Generalized geologic map showing surficial geology of study area (modified from Ellis and others, 1971).

Known water-bearing bedrock formations in the study area include the Madison Limestone of Mississippian age, the Minnelusa Formation of Pennsylvanian and Permian age, and the Inyan Kara Group, Dakota Sandstone, and Pierre Shale of Cretaceous age (table 1). The youngest bedrock formation, the Pierre Shale, is exposed at land surface throughout most of Mellette County. The bedrock surface is the boundary between the bedrock formations and the overlying poorly consolidated Tertiary formations and surficial deposits. The Tertiary deposits in the study area are exposed at land surface (fig. 4), except where covered by unconsolidated deposits or where missing. The Tertiary deposits in the study area, from oldest to youngest, are the White River Group of Eocene and Oligocene age, the Arikaree Formation of Miocene age, and the Ogallala Formation of Pliocene age. A generalized map showing the unconsolidated deposits and outcrops of the Tertiary formations and Pierre Shale is shown in figure 4. Structure contour maps, which show the altitude of the tops of the formations, were constructed based on driller's logs and data collected during this study for the Pierre Shale (fig. 5), the White River Group (fig. 6), and the Arikaree Formation (fig. 7). Unconsolidated deposits of Quaternary age within the study area consist of alluvial, terrace, and windblown sand deposits.

Acknowledgments

Many people have assisted with the development and implementation of the study. In particular, Syed Huq, Charles Mack, and John Whiting of the Office of Water Resources of the Rosebud Sioux Tribe and Sena Lauritsen of the Mellette/Todd Water Resources Coordination Project provided valuable assistance with the collection of water-quality samples and other hydrologic data. The South Dakota Geological Survey drilled the test holes and installed the observation wells for the study. Dick Hammond and Patricia Hammond of the South Dakota Geological Survey provided valuable insight and technical guidance for the study. Appreciation is expressed to the Mellette County officials and the West River Water Development District personnel for their cooperation during this study. The cooperation of residents of Mellette and Todd Counties for providing information concerning their private wells is appreciated.

WATER RESOURCES

Precipitation

The average precipitation at Wood in Mellette County and at a precipitation station located 14 miles south of Mission in Todd County from 1961-90 was 18.96 inches and 19.32 inches, respectively (U.S. Department of Commerce, 1994). The total annual volume of water from precipitation in Mellette and Todd Counties is about 2,751,000 acre-feet. About 8 percent of the average annual precipitation becomes streamflow (230,000 acre-feet); however, this quantity varies from year to year and month to month because of climatic conditions.

Surface Water

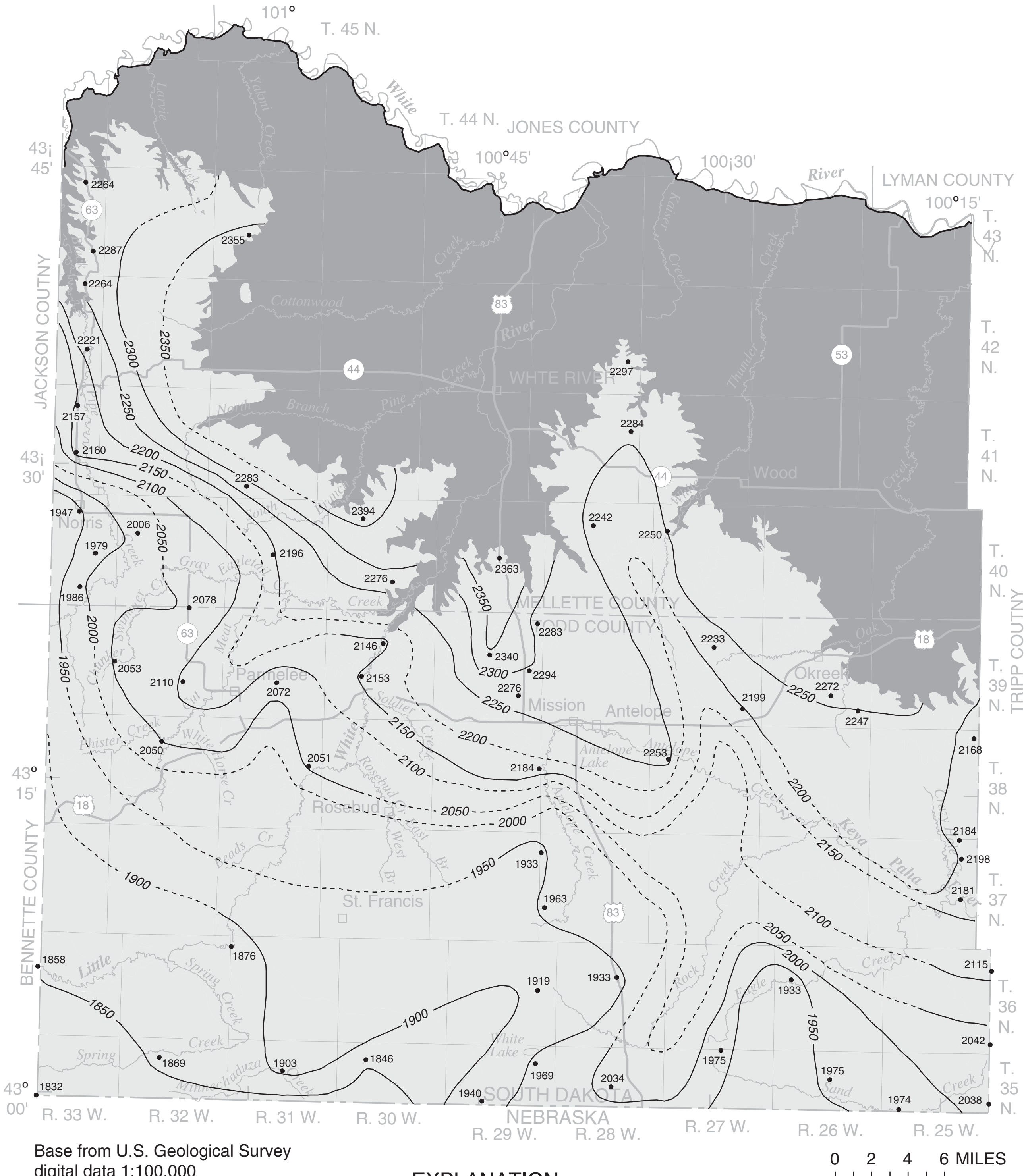
The surface-water resources in Mellette and Todd Counties include rivers, streams, and lakes. The major rivers are the White River, Little White River, and Keya Paha River. Some of the smaller streams include Blackpipe Creek, Antelope Creek, and Rosebud Creek. Two of the largest lakes in the study area are Antelope Lake (an artificial lake) and White Lake, which are located in Todd County.

Drainage Basins

The major drainage basins within the study area are the White River Basin and the Niobrara River Basin (fig. 8). The White River and Niobrara River, in Nebraska, flow easterly into the Missouri River. All of Mellette County and about 51 percent of Todd County is drained by the White River and its tributaries (1,306 square miles in Mellette County and about 710 square miles in Todd County). About 49 percent of Todd County is drained by tributaries of the Niobrara River (about 680 square miles), which include the Keya Paha River.

Streams

Four streamflow-gaging stations are located within the study area (fig. 8) and five gaging stations are located in adjacent counties. A summary of streamflow-gaging records for sites in and near Mellette and Todd Counties is presented in table 2.



EXPLANATION

APPROXIMATE AREA UNDERLAIN BY THE PIERRE SHALE (modified from Ellis and others, 1971)

APPROXIMATE AREA OF PIERRE SHALE EXPOSED AT LAND SURFACE (modified from Ellis and others, 1971)

—2300- - - STRUCTURE CONTOUR--Shows altitude of top of the Pierre Shale. Dashed where inferred. Contour interval 50 feet. Datum is sea level.

• 1940 WELL OR TEST HOLE THAT PENETRATED PIERRE SHALE--Number is altitude of the top of the Pierre Shale, in feet above sea level

Figure 5. Structure contour map for the top of the Pierre Shale.

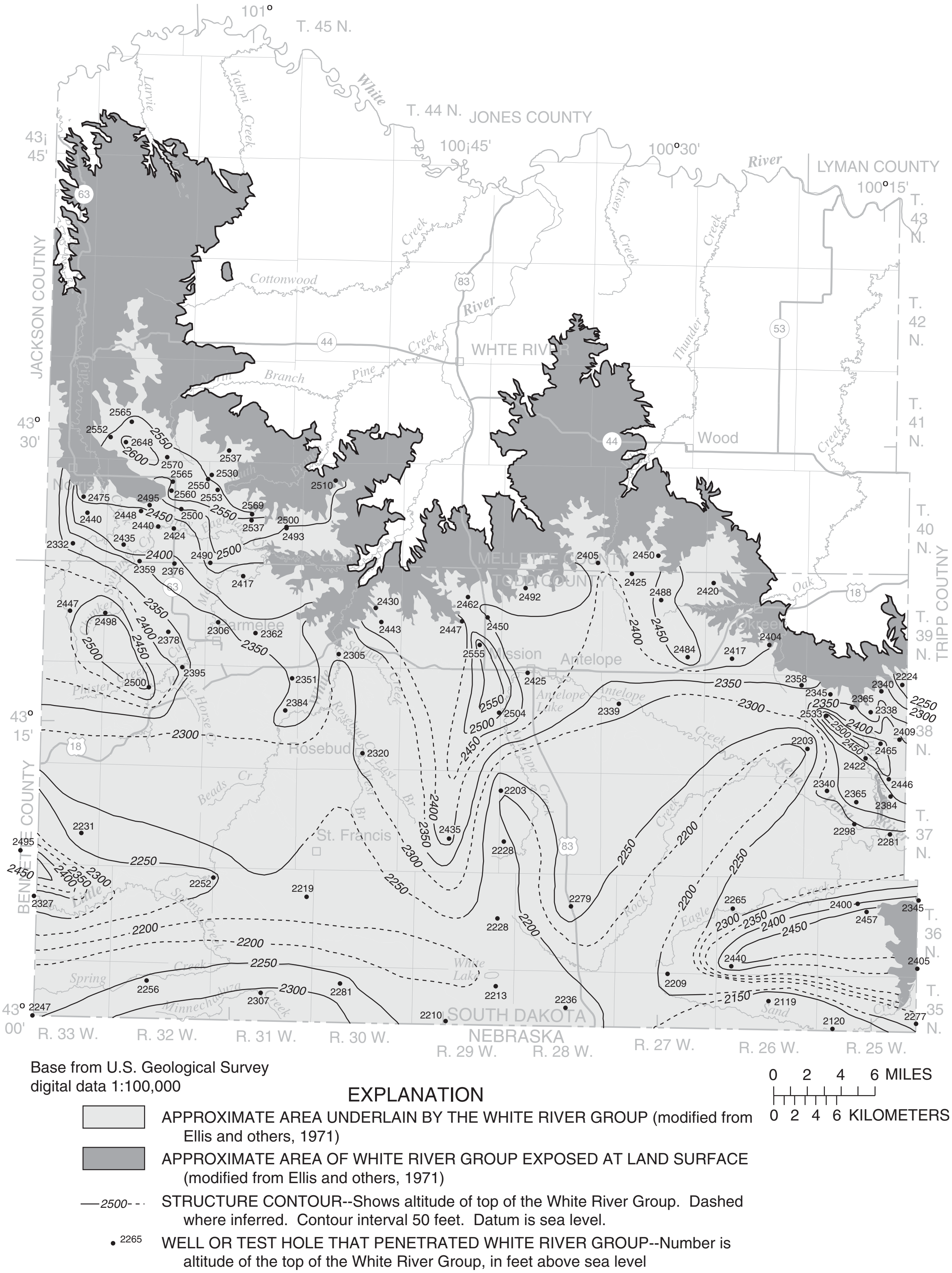
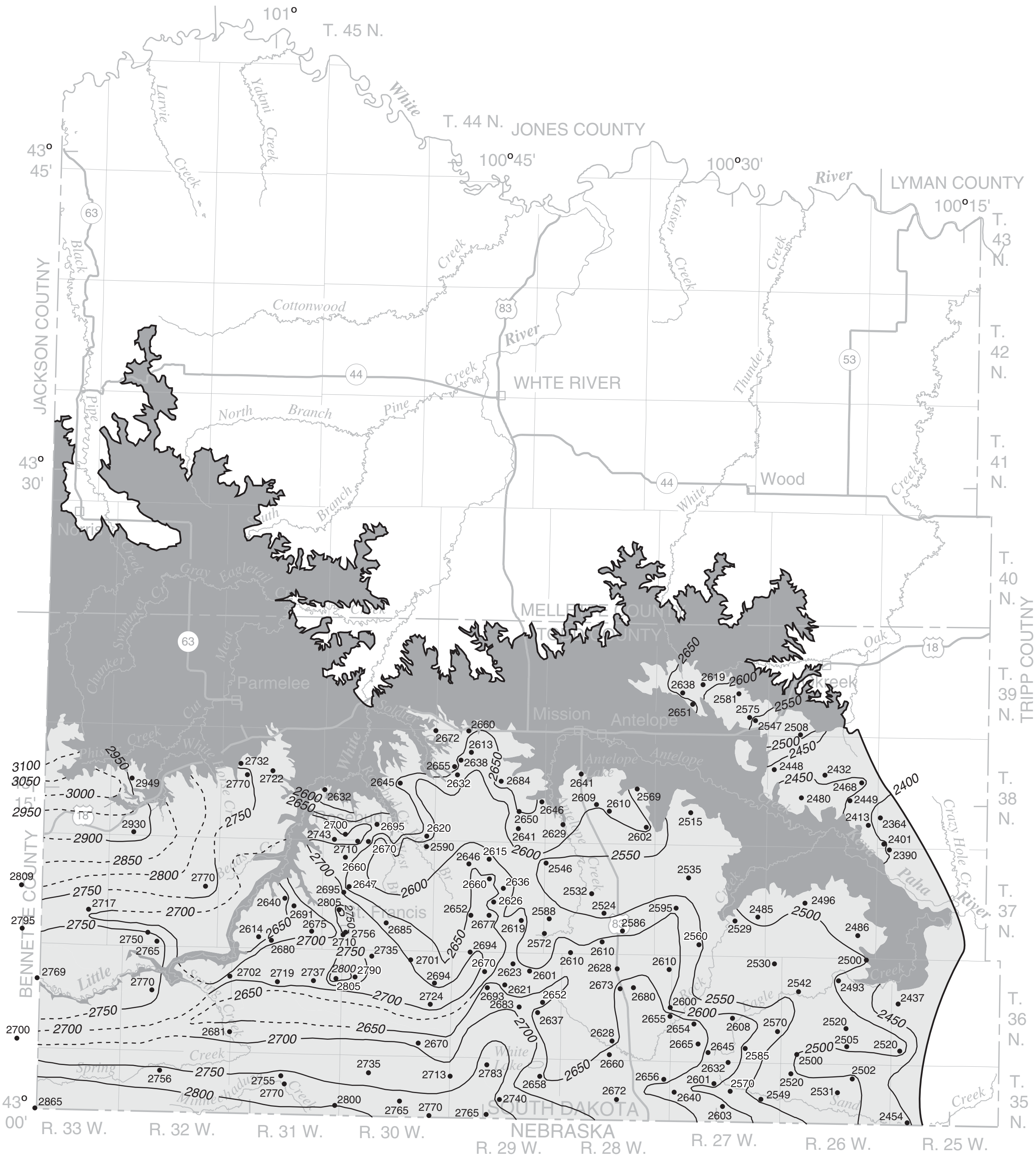


Figure 6. Structure contour map for the top of the White River Group.



Base from U.S. Geological Survey
digital data 1:100,000

0 2 4 6 MILES
0 2 4 6 KILOMETERS

EXPLANATION

APPROXIMATE AREA UNDERLAIN BY THE ARIKAREE FORMATION (modified from Ellis and others, 1971)

APPROXIMATE AREA OF ARIKAREE FORMATION EXPOSED AT LAND SURFACE (modified from Ellis and others, 1971)

—2700- - STRUCTURE CONTOUR--Shows altitude of top of the Arikaree Formation. Dashed where inferred. Contour interval 50 feet. Datum is sea level.

• 2770 WELL OR TEST HOLE THAT PENETRATED ARIKAREE FORMATION--Number is altitude of the top of the Arikaree Formation, in feet above sea level

Figure 7. Structure contour map for the top of the Arikaree Formation.

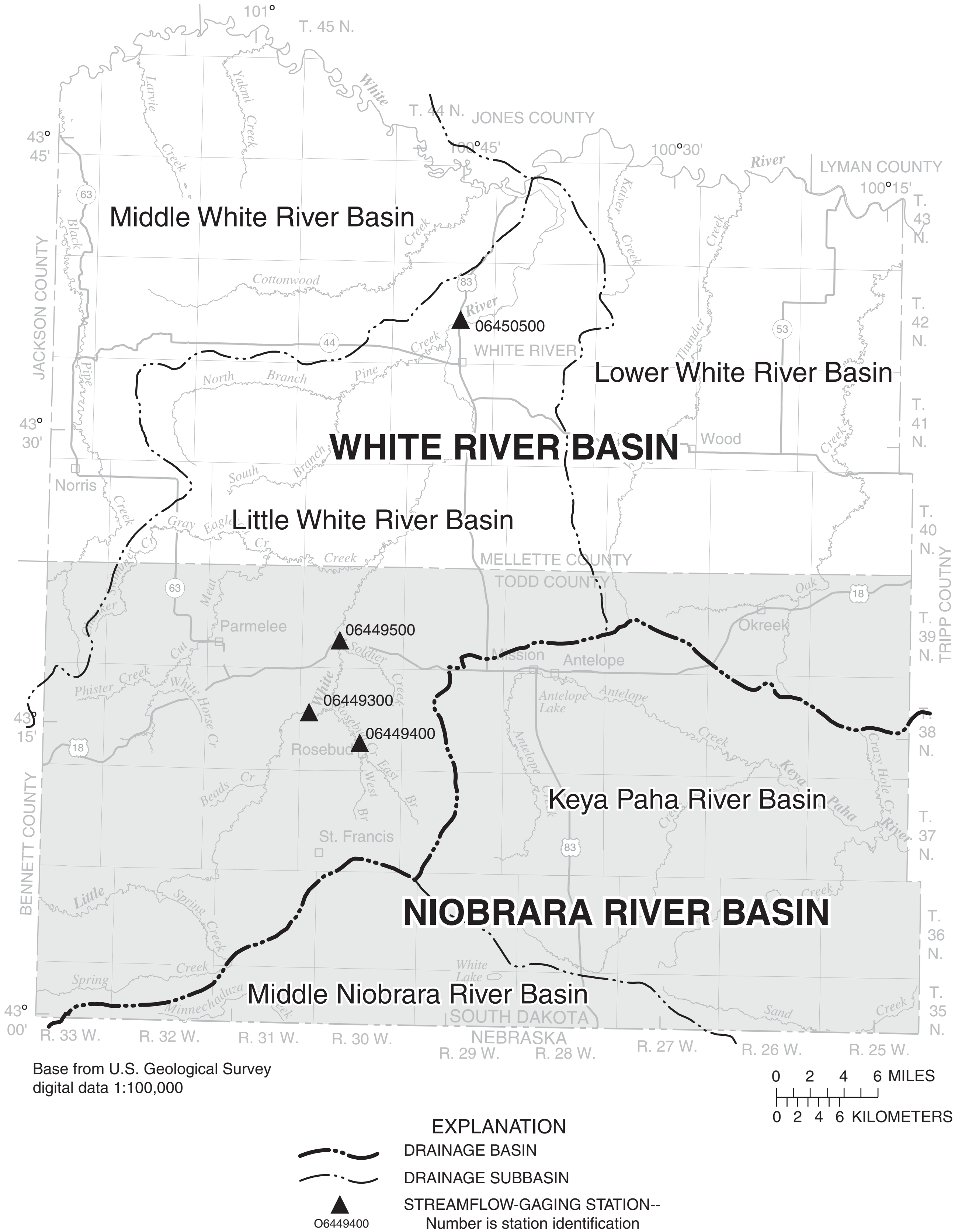


Figure 8. Locations of drainage basins and U.S. Geological Survey streamflow-gaging stations in Mellette and Todd Counties.

Table 2. Summary of data for streamflow-gaging stations in and near Mellette and Todd Counties

Station number	Station name	Drainage area (square miles)	Noncontributing drainage area (square miles)	Period of record used (water year)	Streamflow (cubic feet per second)					
					Extreme flow		Annual flow			
					Maximum instantaneous	Minimum daily	Average	25th percentile	Median 50th percentile	75th percentile
[1]06447230	Blackpipe Creek near Belvidere	250	0	1993-95	3,500	0.00	31.8	15.0	19.9	60.5
[1]06447500	Little White River near Martin	310	80	1939, 1963-95	1,190	0.60	20.1	15.6	18.8	22.5
[1]06449100	Little White River near Vetal	590	175	1960-95	3,540	9.0	55.7	45.8	56.3	65.0
06449300	Little White River above Rosebud	890	260	1982-95	2,190	20	110	94	111	124
06449400	Rosebud Creek at Rosebud	50.8	0	1975-95	670	.00	7.54	6.98	7.44	8.10
06449500	Little White River near Rosebud	1,020	260	1944-95	4,640	10	113	99	116	125
06450500	Little White River below White River	1,570	260	1950-95	13,700	7.0	131	100	128	149
[1]06464100	Keya Paha River near Keyapaha	466	0	1982-95	852	2.4	39.1	25.0	40.0	49.4
[1]06464500	Keya Paha River at Wewela	1,070	0	1939-95	5,430	.00	73.4	47.5	59.0	99.0

[1]Outside study area.

The average flow of the Little White River is about 56 cubic feet per second as the river enters Todd County near Vetal (station 06449100). The average flow of the Little White River is about 131 cubic feet per second as it discharges to the White River in northern Mellette County based on the average discharge of the most downstream gaging station (station 06450500). The Keya Paha River near Keyapaha (station 06464100) has an average flow of about 39 cubic feet per second.

The average annual runoff for the nine gaging stations ranges from 0.94 to 2.36 inches and averages 1.62 inches. The average annual runoff for the Little White River for the period of record is 1.18 inches (63 acre-feet per square mile) near Martin, 1.82 inches (97 acre-feet per square mile) near Vetal, 2.36 inches (126 acre-feet per square mile) above Rosebud, 2.03 inches (108 acre-feet per square mile) near Rosebud, and 1.37 inches (73 acre-feet per square mile) below White River. For Rosebud Creek, which is a tributary to the Little White River, the average annual runoff at Rosebud for the period of record is 2.03 inches (108 acre-feet per square mile). The average annual runoff for the period of record for the Keya Paha River near Keyapaha is 1.14 inches (61 acre-feet per square mile) and for the Keya Paha River at Wewela is 0.94 inches (50 acre-feet per square mile). The average annual runoff for Blackpipe Creek near Belvidere is 1.73 inches (92 acre-feet per square mile).

Streamflow is directly affected by precipitation and evapotranspiration. Streams generally receive more than one-half of their flow from discharge from the aquifers, especially during the winter months, when the stage in the streams often is lower than the hydraulic heads in the aquifers. Numerous ephemeral springs occur along the Little White River.

Flow Duration

Daily-duration hydrographs for the indicated percentage of time daily mean streamflow is exceeded for the Little White River below White River (station 06450500) in Mellette County is shown in figure 9. The duration hydrographs show the maximum and minimum daily flows and the 20-, 50-, and 80-percent exceedance values for the period 1957-95. Streamflow for the indicated hydrographs can be expected to be equaled or exceeded 20, 50, and 80 percent of the time, respectively, on any individual day. For example, on April 1, a flow equal to or exceeding 113 cubic feet per second can be expected 80 percent of the time, a discharge equal to or exceeding 186 cubic feet per second can be expected 50 percent of the time, and a flow equal to or exceeding 249 cubic feet per second can be expected 20 percent of the time. Flows are highest during late winter and spring when runoff of snowmelt and rainfall are greatest. Streamflow gradually decreases during late spring and summer due to increasing evapotranspiration and decreasing precipitation. Flows are lowest from fall to mid-winter. There are no days when the flow was less than 10 cubic feet per second for the 39-year period shown.

Because there are no gaging stations within the study area on the Keya Paha River, daily-duration hydrographs for the indicated percentage of time daily mean streamflow is exceeded is shown in figure 10 for the Keya Paha River at Wewela (station 06464500) in southwest Tripp County. The period of record used to construct the duration hydrographs is 1957-95. Flows of the Keya Paha River are highest during late winter and spring and lowest from fall to mid-winter. Although a flow equal to or exceeding 10 cubic feet per second can be expected 80 percent of the time on any individual day, there are several days during some years when there was no flow at the Keya Paha River at Wewela station.

Flood Information

Flooding from snowmelt and rainfall during the spring is common along the White River and parts of the Little White River because of numerous ice jams. Flood-stage data are not available in Mellette and Todd Counties, but data are available for two gaging stations located on the White River outside the study area. At the gaging station located near Kadoka in Jackson County, flood stage of the White River is 13 feet (Tresté Huse, National Weather Service, Rapid City, S. Dak., written commun., 1997). Flood stage of the White River near Oacoma in Lyman County is 15 feet (Tresté Huse, National Weather Service, Rapid City, S. Dak., written commun., 1997). Maps of flood prone areas along the White River in Mellette County, at a scale of about 2.64 inches to the mile, can be obtained from the USGS District office in Rapid City, South Dakota.

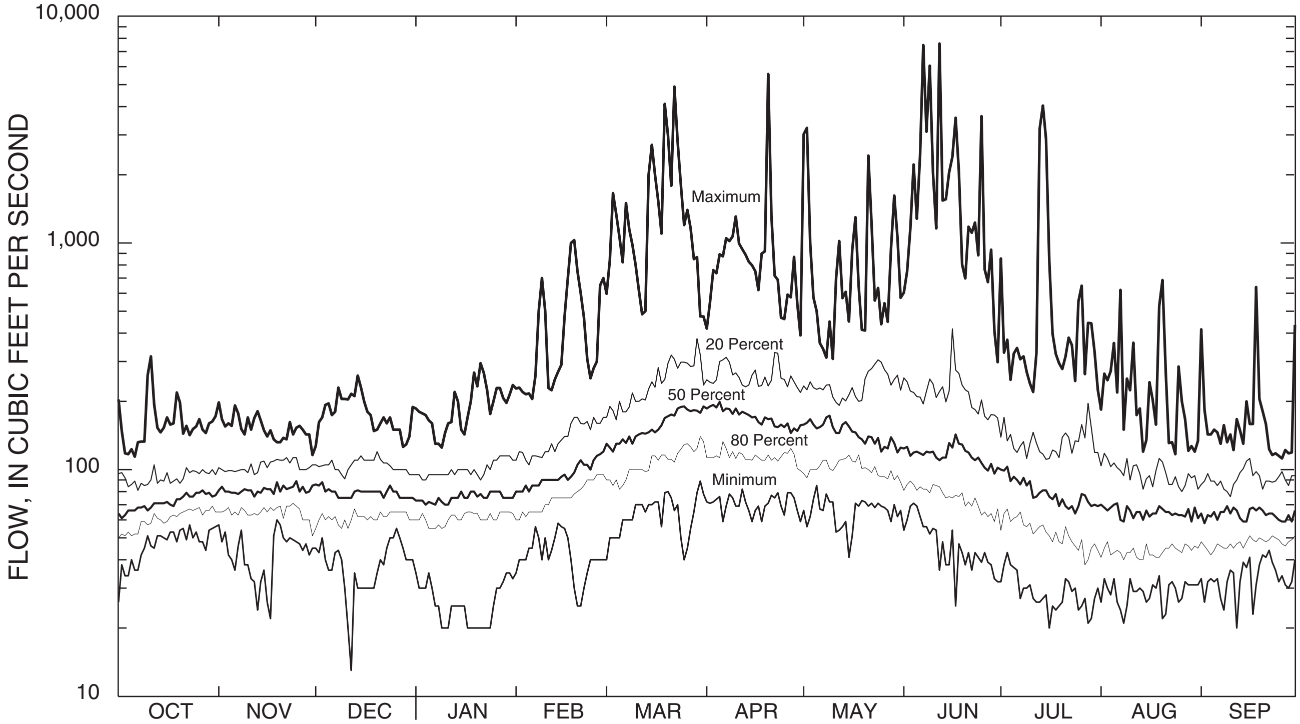


Figure 9. Daily-duration hydrographs for indicated percentage of time flow of the Little White River below White River (station 06450500) in Mellette County was equal to or greater than that shown, water years 1957-95.

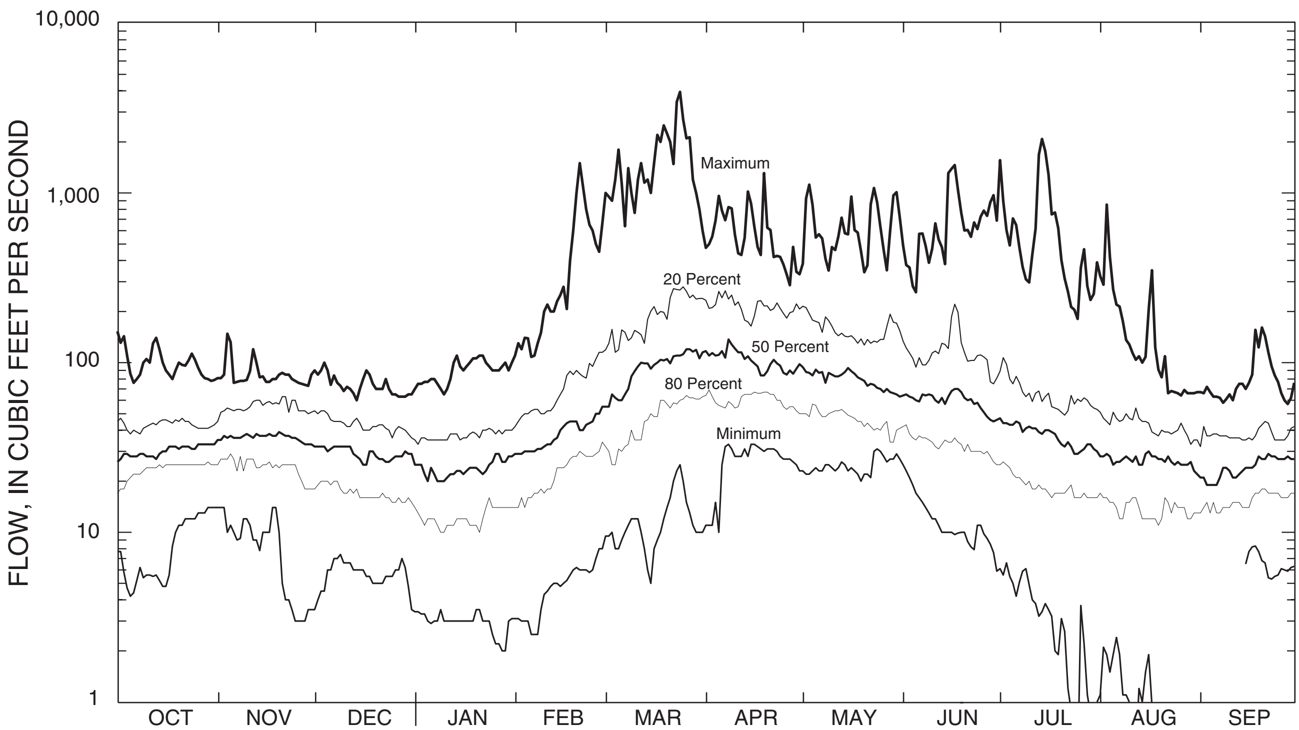


Figure 10. Daily-duration hydrographs for indicated percentage of time flow of the Keya Paha River at Wewela (station 06464500) in Tripp County was equal to or greater than that shown, water years 1957-95.

Lakes

Few natural lakes exist within the study area. Although many manmade lakes exist in the study area, most generally occupy less than 10 acres and are used for stock-watering purposes. White Lake, located in south-central Todd County near the South Dakota-Nebraska border (fig. 8), is the largest natural lake in the study area with a surface area of about 160 acres and an average elevation of 2,783 feet above sea level. Antelope Lake, an artificial lake located near Antelope in north-central Todd County (fig. 8), has a surface area of about 95 acres and an average elevation of 2,521 feet above sea level. Other lakes within the study area have a surface area of less than 50 acres.

Water Quality

Water-quality data are available in the USGS NWIS water-quality database for several stream sites located in Mellette and Todd Counties. Because little water-quality data are available for the lakes in the study area, this section discusses only the water-quality data from streams.

A summary of chemical analyses is shown in table 3 for the Little White River at the gaging stations above Rosebud (station 06449300) and below White River (station 06450500). The dominant chemical species in water are calcium and bicarbonate at the site above Rosebud and calcium, bicarbonate, and sulfate at the site below White River (fig. 11).

Specific conductance, a measure of total dissolved solids (TDS), data also are available for two streams that have gaging stations within 10 miles of the study area. The mean specific conductance was 760 µS/cm (microsiemens per centimeter at 25° Celsius) for 31 samples collected between 1992-95 on Blackpipe Creek near Belvidere (station 06447230), and 447 µS/cm for 144 samples collected between 1981-95 on the Keya Paha River near Keyapaha (station 06464100).

Most water-quality constituents and properties in streams vary with the volume of streamflow. For example, specific conductance shows a typical seasonal pattern due to variations in streamflow at Little White River above Rosebud (station 06449300) for the period of October 1981 through August 1995 (fig. 12). Conductance values are lowest in February and March, during the high flows of spring snowmelt, which causes dilution of TDS. The highest conductance values occur in November-January and are the result of low-flow and ice conditions. Conductance at this site ranged from 219 µS/cm on March 9, 1994, when the daily mean discharge was 684 cubic feet per second to 580 µS/cm on November 18, 1991, when the daily mean discharge was 111 cubic feet per second. Specific conductance at the site Little White River below White River (06450500) (not included in fig. 12) ranged from 210 µS/cm when the mean daily discharge was 2,000 cubic feet per second to 1,350 µS/cm when the mean daily discharge was 116 cubic feet per second. This cyclic pattern occurs at other sites along the Little White River and is similar to patterns shown by other water-quality constituents.

In addition to seasonal variability, specific conductance values varied between the sites located on the Little White River in Mellette and Todd Counties. Generally, specific conductance increases from upstream to downstream. For example, specific conductance increases from station 06449300 above Rosebud to station 06450500 below White River (fig. 13); the mean conductance was 312 µS/cm above Rosebud, 346 µS/cm at Rosebud Creek, 327 µS/cm near Rosebud, and 386 µS/cm below White River. The increase in conductance probably is at least partly attributed to the underlying geology. Three upstream sites overlie either the Arikaree or Ogallala Formations, which generally supply lower TDS; the downstream site overlies the Pierre Shale, which generally supplies higher TDS.

Ground Water

The shallow aquifers in the study area are the alluvial, Ogallala, Arikaree, and White River aquifers. The bedrock aquifers are the Pierre Shale, Dakota Sandstone, Inyan Kara, and Minnelusa and Madison aquifers.

In Todd County, ground water generally can be obtained from shallow wells (less than 300 feet) completed either in alluvial deposits or in deposits of Tertiary age (Ogallala Formation, Arikaree Formation, or White River Group). Ground water is more difficult to obtain in Mellette County because the Pierre Shale is exposed throughout much of the county (fig. 4), which means that the younger Tertiary deposits have been eroded and are not present in these areas. Water is difficult to obtain from the Pierre Shale, plus concentrations of dissolved solids are high and water is hard, thus deep wells (greater than 1,000 feet) are sometimes drilled in Mellette County to obtain ground water.

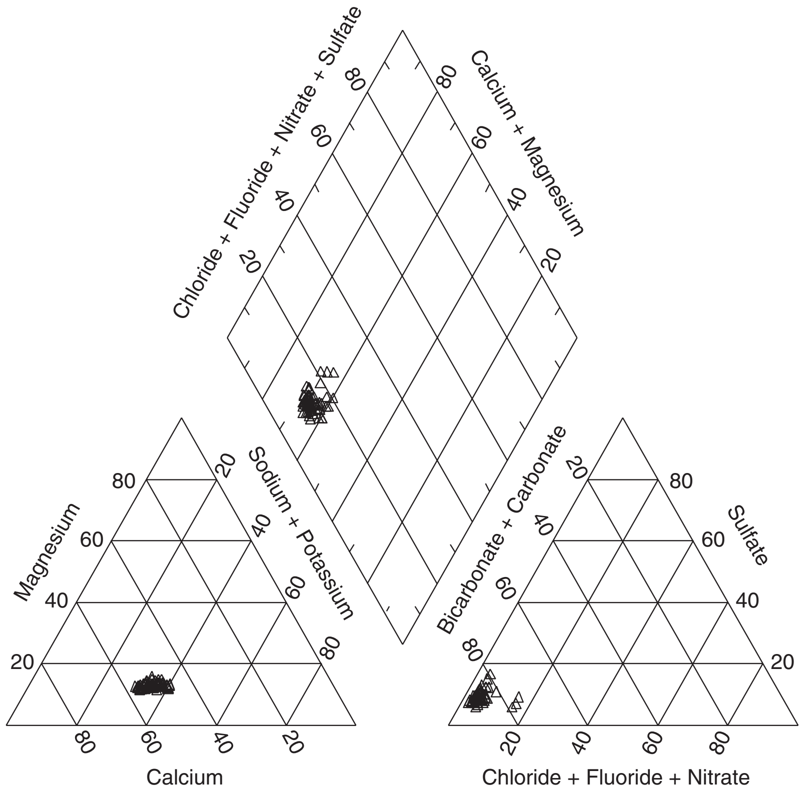
Table 3. Summary of chemical analyses for the Little White River at gaging stations above Rosebud and below White River, 1950-95

[Results based on data stored in USGS NWIS water-quality database. Results in milligrams per liter except as indicated. One milligram per liter (mg/L) is approximately equal to one part per million. One microgram per liter (µg/L) is equal to one part per billion; µS/cm, microsiemens per centimeter at 25° Celsius; --, not analyzed or not determined; <, less than indicated detection limit; ND, specifically analyzed for but not detected, and detection limit unknown]

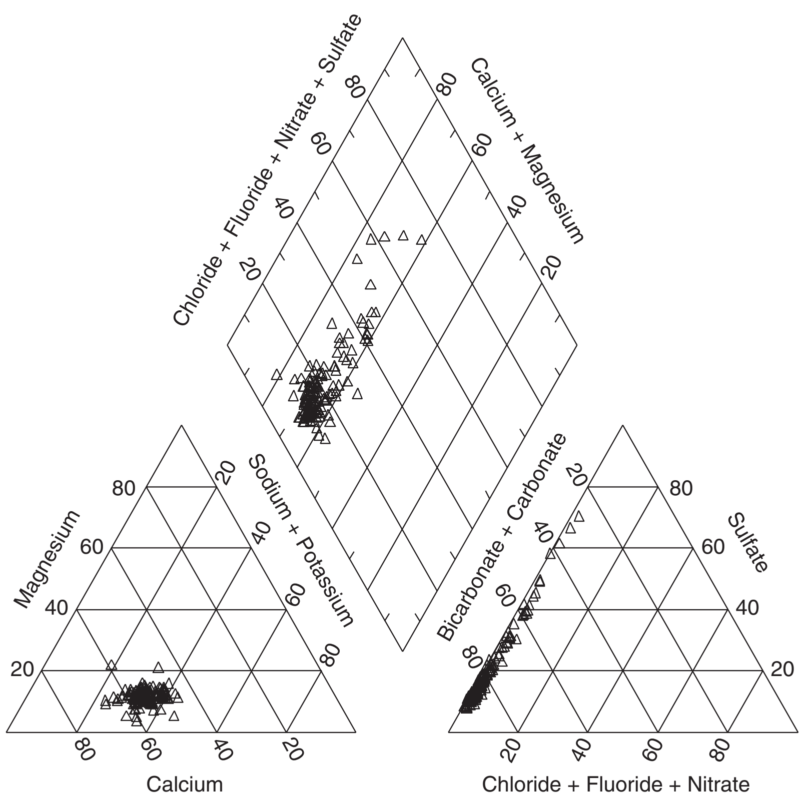
Property or dissolved constituent	06449300 Little White River above Rosebud (1981-95)				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance (µS/cm)	157	312	305	219	580
pH (standard units)	111	8.0	8.1	7.1	9.4
Hardness, as $CaCO_3$	60	113	114	66	134
Solids, residue at 180° C	61	234	232	151	292
Solids, sum of constituents	57	202	192	114	269
Calcium	60	36	37	21	43
Magnesium	62	6	6	3	8
Sodium	62	22	21	10	31
Potassium	62	10	9	6	14
Bicarbonate	1	167	167	167	167
Alkalinity	105	149	147	65	195
Sulfate	61	16	15	6	30
Chloride	62	4	3.2	0.8	17.0
Fluoride	27	0.5	0.5	0.3	0.7
Silica	23	49	49	38	56
Nitrogen, nitrate	22	0.6	0.5	0.1	1.6
Nitrite plus nitrate	61	0.6	0.5	<0.1	1.6
Phosphorus, orthophosphate	59	0.18	0.18	0.02	0.47
Aluminum (µg/L)	33	138	90	20	1,500
Arsenic (µg/L)	60	8	8	5	13
Barium (µg/L)	51	89	100	<2	180
Boron (µg/L)	57	45	40	30	80
Cadmium (µg/L)	60	<10	<10	<10	<10
Chromium (µg/L)	19	<1	<1	<1	1
Cobalt (µg/L)	16	<3	<3	<3	<3
Copper (µg/L)	62	4	3	<1	29
Iron (µg/L)	62	90	35	5	1,100
Lead (µg/L)	59	1	<1	<1	20
Lithium (µg/L)	33	21	19	<4	50
Manganese (µg/L)	62	7	5	1	48
Mercury (µg/L)	59	<0.1	<0.1	<0.1	3.8
Molybdenum (µg/L)	1	2	2	2	2
Nickel (µg/L)	18	1	<1	<1	5
Selenium (µg/L)	109	<1	<1	<1	1
Silver (µg/L)	19	<1	<1	<1	<1
Strontium (µg/L)	33	202	210	<0.5	250
Vanadium (µg/L)	1	9	9	9	9
Zinc (µg/L)	95	14	8	<3	150

Table 3. Summary of chemical analyses for the Little White River, 1950-95—Continued

Property or dissolved constituent	06450500 Little White River below White River (1950-95)				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance (µS/cm)	321	386	360	210	1350
pH (standard units)	147	7.7	7.8	7.0	8.9
Hardness, as $CaCO_3$	147	143	129	102	435
Solids, residue at 180° C	132	305	283	220	948
Solids, sum of constituents	92	283	258	174	915
Calcium	143	47	42	34	141
Magnesium	143	6	6	2	26
Sodium	147	30	27	18	109
Potassium	94	10	9	6	15
Bicarbonate	145	197	194	144	262
Alkalinity	0	--	--	--	--
Sulfate	144	46	28	14	445
Chloride	144	2	2	ND	9
Fluoride	75	0.5	0.4	0.2	1.1
Silica	79	51	53	5	84
Nitrogen, nitrate	0	--	--	--	--
Nitrite plus nitrate	0	--	--	--	--
Phosphorus, orthophosphate	0	--	--	--	--
Aluminum (µg/L)	0	--	--	--	--
Arsenic (µg/L)	47	ND	ND	ND	ND
Barium (µg/L)	0	--	--	--	--
Boron µg/L)	94	93	80	30	290
Cadmium (µg/L)	47	ND	ND	ND	ND
Chromium (µg/L)	0	--	--	--	--
Cobalt (µg/L)	47	ND	ND	ND	ND
Copper (µg/L)	0	--	--	--	--
Iron, total (µg/L)	17	34	20	ND	190
Lead (µg/L)	47	ND	ND	ND	ND
Lithium (µg/L)	0	--	--	--	--
Manganese, total (µg/L)	1	110	110	110	110
Mercury (µg/L)	0	--	--	--	--
Molybdenum (µg/L)	0	--	--	--	--
Nickel (µg/L)	0	--	--	--	--
Selenium (µg/L)	47	ND	ND	ND	80
Silver (µg/L)	0	--	--	--	--
Strontium (µg/L)	0	--	--	--	--
Vanadium (µg/L)	0	--	--	--	--
Zinc (µg/L)	0	--	--	--	--



LITTLE WHITE RIVER ABOVE ROSEBUD (station 06449300)



LITTLE WHITE RIVER BELOW WHITE RIVER (station 06450500)

Figure 11. Trilinear diagrams (Piper, 1944) showing proportional concentrations of major ions for the Little White River.

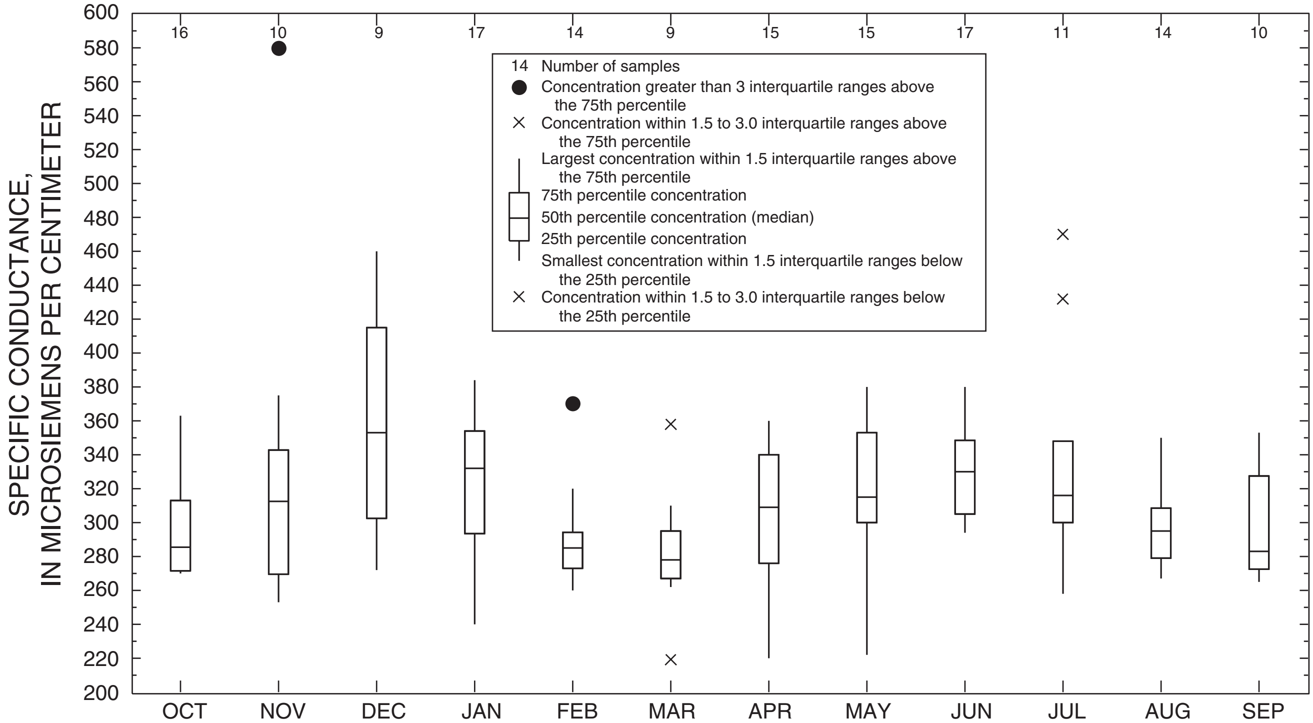


Figure 12. Monthly variations in specific conductance for the Little White River above Rosebud (station 06449300), 1981-95.

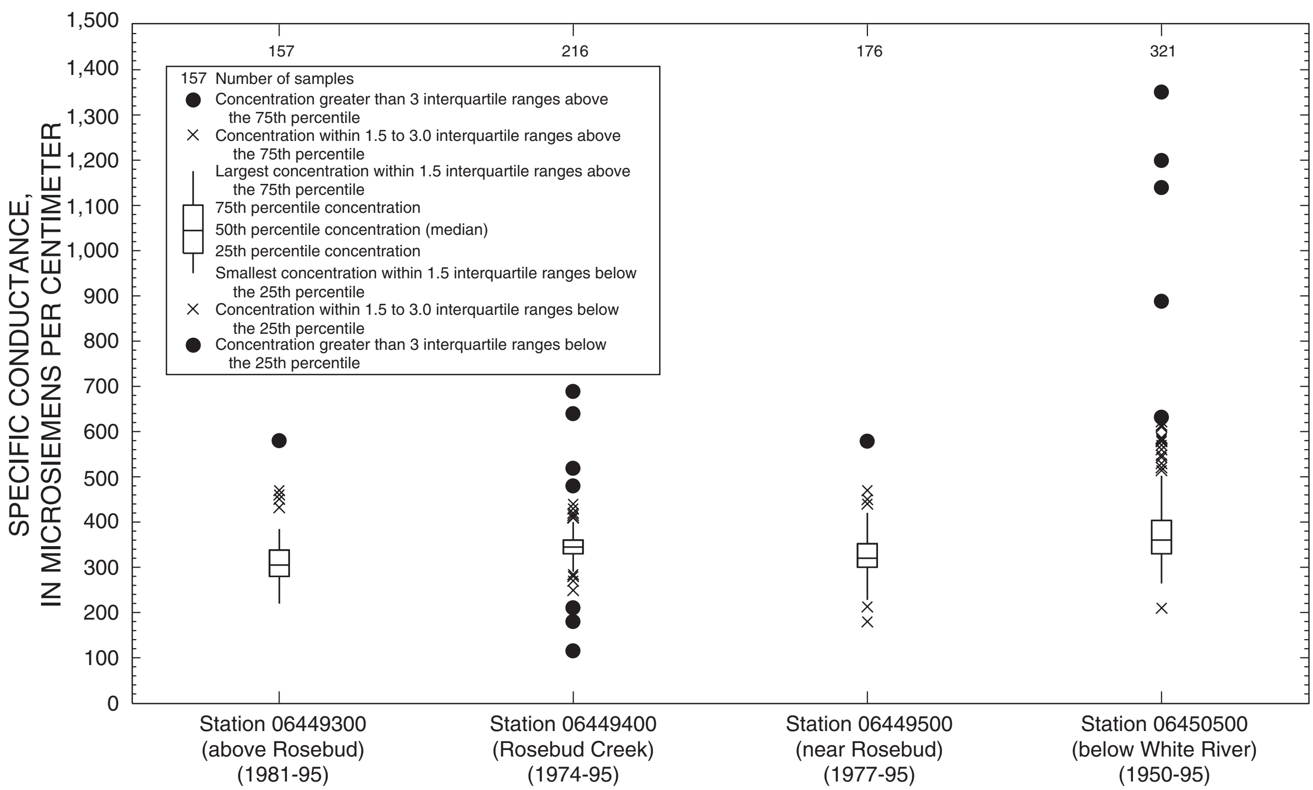


Figure 13. Variations in specific conductance at selected sites located on the Little White River, 1950-95.

The boundaries of five aquifers were delineated for this study: the alluvial, Ogallala, Arikaree, White River, and Pierre Shale aquifers. Because little information is available regarding the deeper aquifers in the study area (including the Dakota Sandstone, Inyan Kara, and Minnelusa and Madison aquifers), only their hydraulic properties will be discussed. For purposes of this report, alluvial aquifers include saturated portions of terrace and windblown deposits. The Minnelusa and Madison aquifers will be discussed together because the deepest wells in the study area are completed in both aquifers. A summary of the aquifers in the study area is presented in table 4.

Shallow Aquifers

The shallow aquifers in the study area consist primarily of unconsolidated sand and gravel or poorly consolidated sandstones and siltstones. Alluvial aquifers are found in both Mellette and Todd Counties; however, the water has high dissolved solids, is moderately saline, and is very hard in Mellette County where alluvial deposits are underlain by the Pierre Shale. The Ogallala aquifer is present in only Todd County. The Arikaree aquifer is present throughout most of Todd County and in only small areas of Mellette County. The White River aquifer is present in both counties, but the aquifer primarily is used only in Mellette County because shallower water usually can be obtained in Todd County.

Because the aquifer material within each of the formations can vary greatly even within a section of land, it was not possible to delineate specific water-bearing deposits within each formation. All formations were assumed to be fully saturated. Therefore, in the following discussions, the term “aquifer” refers to the entire formation where saturated and not to any particular interval within that formation. The following paragraph describes some of the other aquifer and formation names used in other reports to describe the shallow geologic units in the study area.

The High Plains aquifer system is a regional aquifer that consists mainly of deposits of Quaternary and Tertiary age that are hydraulically connected (Dugan and others, 1994). The High Plains aquifer system extends from southern South Dakota to Texas.

Table 4. Summary of the characteristics of major aquifers in Mellette and Todd Counties

[--, data insufficient for estimate]

Aquifer name	Estimated areal extent (square miles)	Maximum thickness (feet)	Average thickness[1] (feet)	Range in depth below land surface to top of aquifer (feet)	Range of water level (feet below or above (+) land surface	Estimated amount of water in storage[2] (million acre-feet)	Range in reported well yields (gallons per minute)	Suitable for irrigation[3]
Alluvial	440	104	29	0 - 94	0 - 94	1.6	1 - 125	Yes[4]
Ogallala	950	239	137	0 - 164	3 - 164	17	1 - 1,250	Yes
Arikaree	1,360	618	290	0 - 406	+18 - 170	50	1 - 1,005	Yes
White River	1,720	469	229	0 - 789	+6 - 261	50	1 - 30	Yes[4]
Pierre Shale	2,694	1,294	900	0 - 1,204	2 - 200	[5]1.5	1 - 8	No
Dakota Sandstone	2,694	336	[6]236	1,270 - 2,348	+102 - 450	[7]81	10 - 100	No
Inyan Kara	--	275	[6]136	[8]1,915 - 2,450	+289 - 300	--	9 - 160	No
Minnelusa and Madison	--	882	[6]608	[8]2,105 - 2,448	+79 - 44	--	25 - 40	Yes[9]

[1]Arithmetic mean from test-hole data; all formations assumed to be fully saturated.

[2]Storage estimated by multiplying average thickness times areal extent times a porosity of 0.20 for all aquifers except Pierre Shale; a porosity of 0.001 was used in storage calculation for Pierre Shale.

[3]Based on irrigation-water classification diagram (fig. 31).

[4]Though water quality generally is suitable for irrigation, in most places yields will be insufficient to support irrigation.

[5]Maximum value because saturated thickness probably is much less than average thickness.

[6]Average thickness greater than indicated because not all test holes fully penetrated the aquifer.

[7]Minimum value because average thickness greater than indicated.

[8]Minimum values because no information available on depths in Todd County.

[9]Though generally suitable for irrigation, in some places the water in the aquifer is not suitable.

The principal aquifer in this system is the Ogallala; the Arikaree and Brule aquifers also are included in this system. The Brule Formation is the upper unit of the White River Group and the Chadron Formation is the lower unit. In some studies, it has been possible to distinguish between the two units of the White River Group; however, because the lithologic units could not be distinguished in most of the study area, the White River Group was not subdivided in this report. Additionally, references are sometimes made to the Rosebud Formation, which is part of the Arikaree Formation, and to the Ash Hollow and Valentine Formations, which are part of the Ogallala Formation.

In the following sections, monthly precipitation data were compiled from annual summaries (U.S. Department of Commerce, 1957-94) to determine the cumulative departure from normal precipitation. The National Weather Service station at Valentine, Nebraska, located 10 miles south of the South Dakota-Nebraska border on highway 83, was used because it had a more complete record than the stations at Wood and Mission.

Alluvial Aquifers

The major alluvial deposits are located along the Keya Paha, Little White, and White Rivers and associated tributaries, and are considered aquifers where saturated. Generally, the alluvial aquifers that overlie the Pierre Shale are essentially impermeable because of the high percentage of clay and supply only a small amount of water. Also, some alluvial aquifers along the White River are not in hydraulic connection with the river (Ellis and others, 1971), and therefore do not yield an adequate supply of water.

The composition of the alluvial deposits varies from clayey silt to gravel. Deposits that overlie Tertiary deposits are composed mainly of sand and gravel in comparison to deposits that overlie the Pierre Shale, which generally contain a greater percentage of clay. Alluvial aquifers underlie about 440 square miles of the study area and contain an estimated 1.6 million acre-feet of water in storage. The saturated thickness of the alluvial deposits along streams generally ranges from about 10 to 40 feet (fig. 14) and averages 29 feet. The thicknesses of two terrace deposits in Mellette County exceeded 100 feet, although only about 10 feet of these deposits were saturated. The general direction of ground-water flow in the alluvial aquifers is toward the streams and rivers and downstream (fig. 15). Water in alluvial aquifers along the Little White River, Blackpipe, Oak, and White Thunder Creeks generally flows north; water in aquifers along the Keya Paha and White Rivers generally flows east.

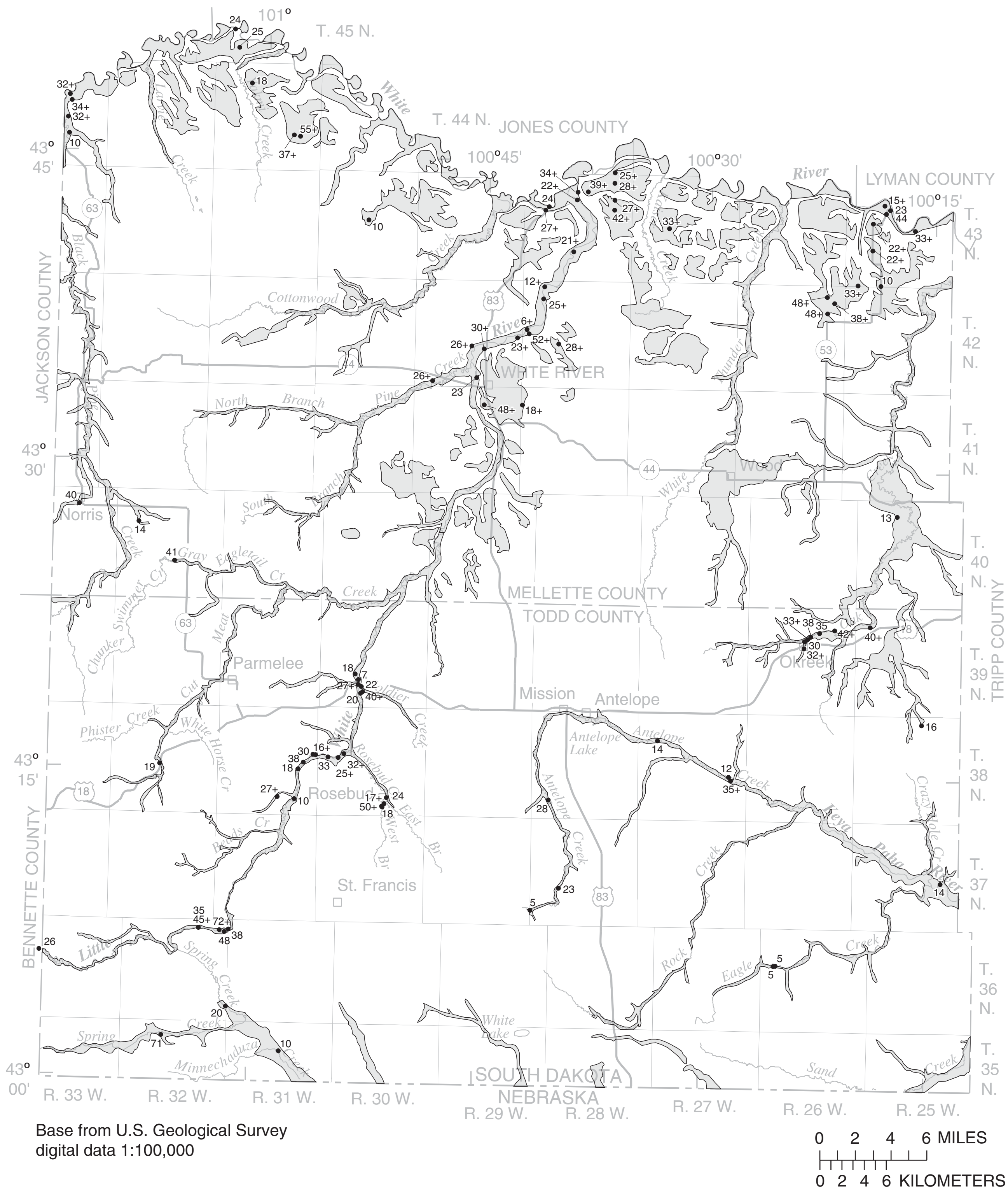
Records of long-term water-level fluctuations in well 43N28W8CCDC in Mellette County and well 38N28W32BBBB in Todd County (fig. 16) correlate well with long-term precipitation data, although the correlation is more evident in the Mellette County well. The water-level decline from 1974-76 was caused by below-normal precipitation. The increase in water levels from 1991-95 was caused by above-normal precipitation.

Recharge to the alluvial aquifers is by infiltration of precipitation, stream loss when the stream stage is higher than the hydraulic head in the aquifer, and discharge from springs originating in Tertiary aquifers. Generally, the greatest recharge occurs in the spring after snowmelt. Infiltration rates generally range between 1 and 6 inches/hour in the alluvial deposits (U.S. Soil Conservation Service, 1974, 1975), so precipitation is a major source of recharge to these deposits. Discharge from the aquifer is by withdrawals of water from domestic and stock wells and by evapotranspiration from the aquifer. The cyclic pattern of recharge and discharge is evident in the water-level fluctuations of well 38N28W32BBBB (fig. 16). Every year, the water level is highest in the spring due to snowmelt and high streamflows, and is lowest during the summer and fall months when potential evapotranspiration is the greatest and precipitation decreases.

The only available information concerning the hydraulic properties of the alluvial aquifers in the study area was specific capacity data stored in the USGS NWIS ground-water database for eight wells completed in alluvial deposits. The specific capacity of a well is the rate of discharge of water from a well divided by the drawdown of the water level within the well (Lohman and others, 1972). The specific capacity of the 8 alluvial wells ranged from 6 to 900 square feet per day with an average of 400 square feet per day.

Ogallala Aquifer

The Ogallala aquifer is present throughout most of Todd County, but not in Mellette County. A hydrogeologic section (A-A') across the southern boundary of Todd County (fig. 17) shows the Ogallala aquifer and the underlying Arikaree and White River aquifers. The Ogallala Formation is overlain by unconsolidated deposits consisting of alluvium and windblown sand deposits in the southwestern part of Todd County.

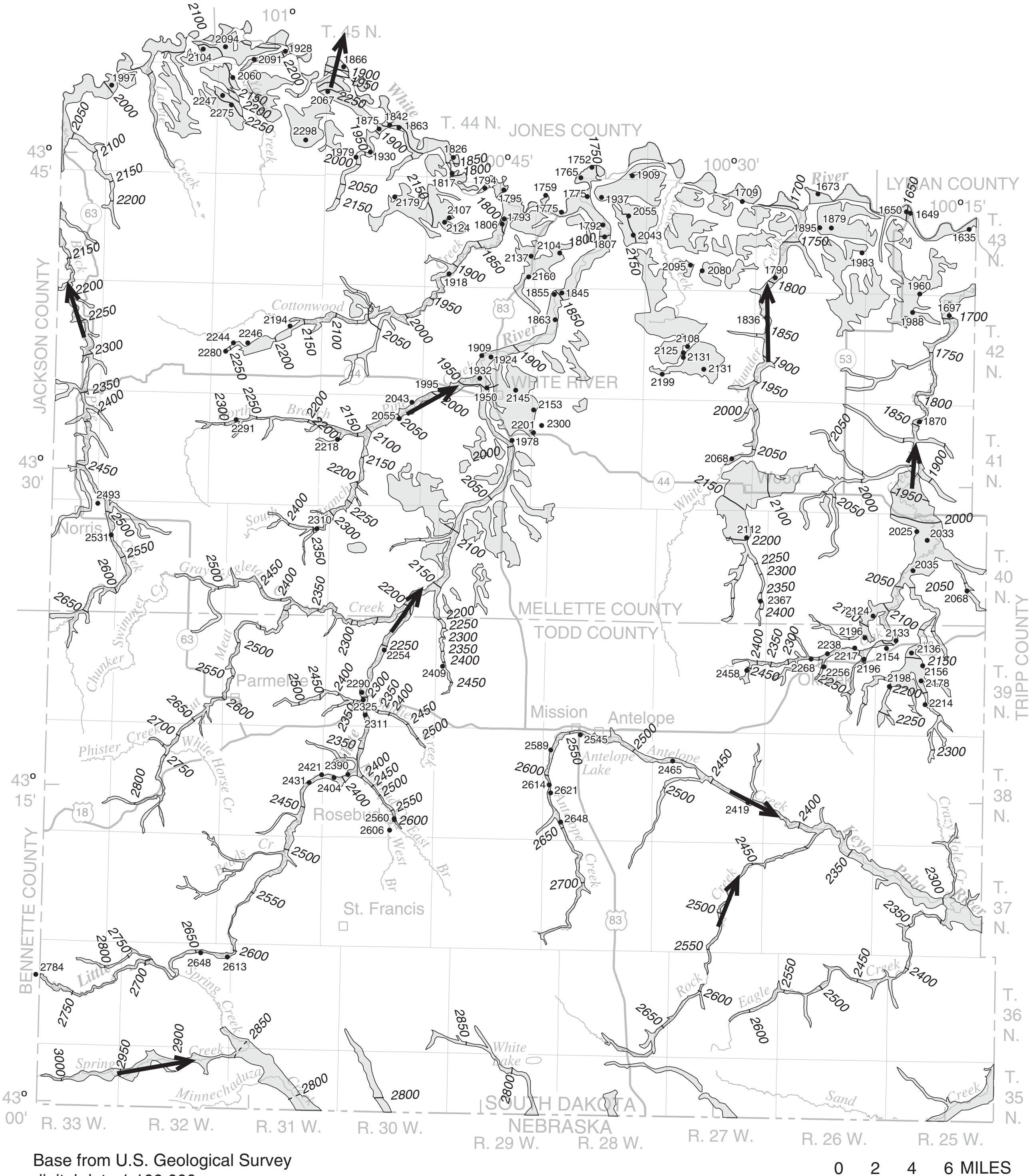


EXPLANATION

APPROXIMATE AREA UNDERLAIN BY ALLUVIAL AQUIFERS (modified from Ellis and others, 1971)

• 32+ WELL OR TEST HOLE--Numbers are saturated thickness, in feet, of aquifer. A plus (+) indicates a thickness greater than shown.

Figure 14. Extent and thickness of alluvial aquifers.



Base from U.S. Geological Survey digital data 1:100,000

EXPLANATION

APPROXIMATE AREA OF ALLUVIAL AQUIFERS (modified from Ellis and others, 1971)

2500 POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased, nonpumping wells in 1996. Dashed where inferred. Contour interval 50 feet. Datum is sea level.

• 2431 WELL--Number is altitude of water level, in feet above sea level

GENERAL DIRECTION OF GROUND-WATER FLOW

Figure 15. Potentiometric surface of alluvial aquifers.

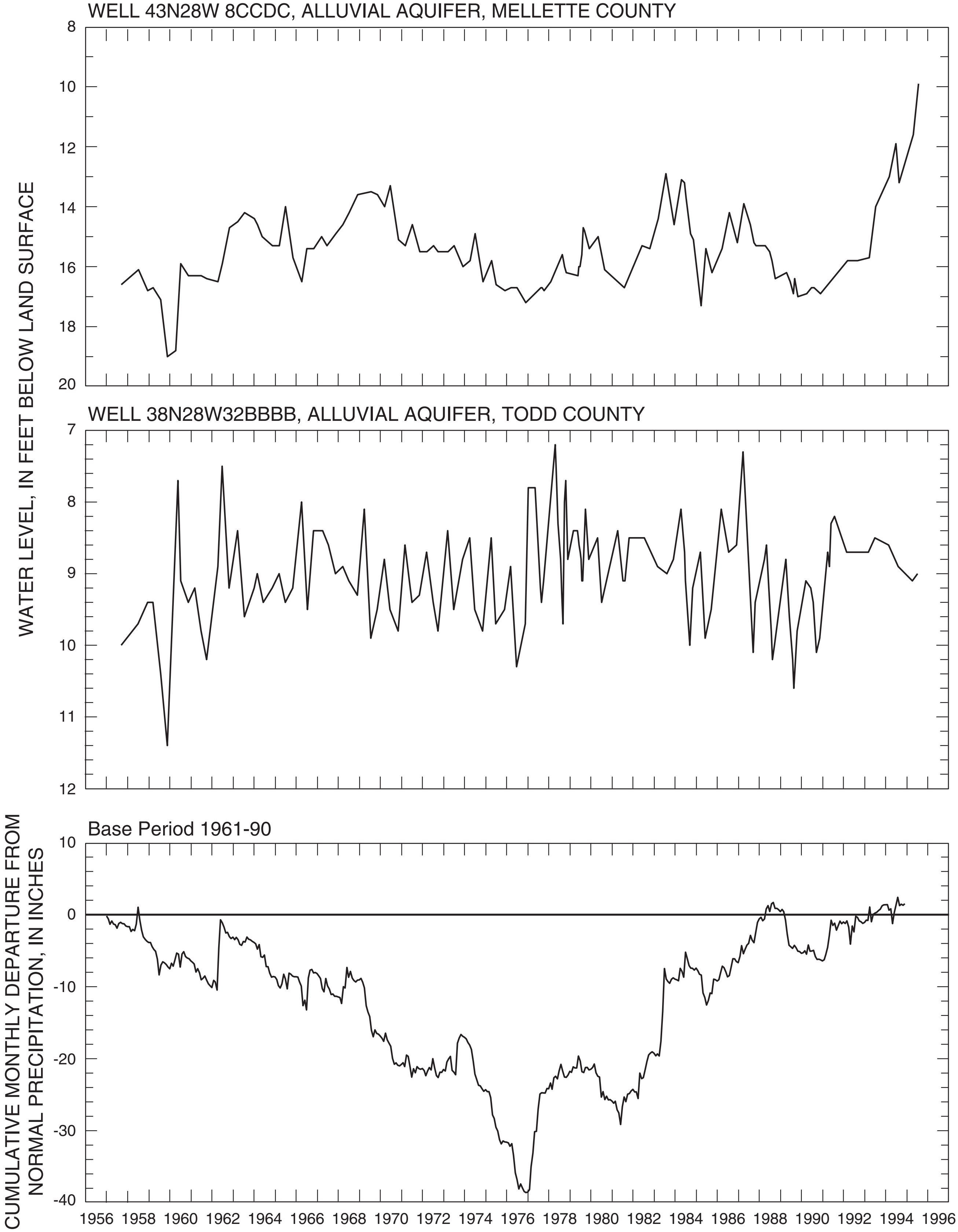


Figure 16. Water-level fluctuations in alluvial aquifers and cumulative monthly departure from normal precipitation at Valentine, Nebraska.

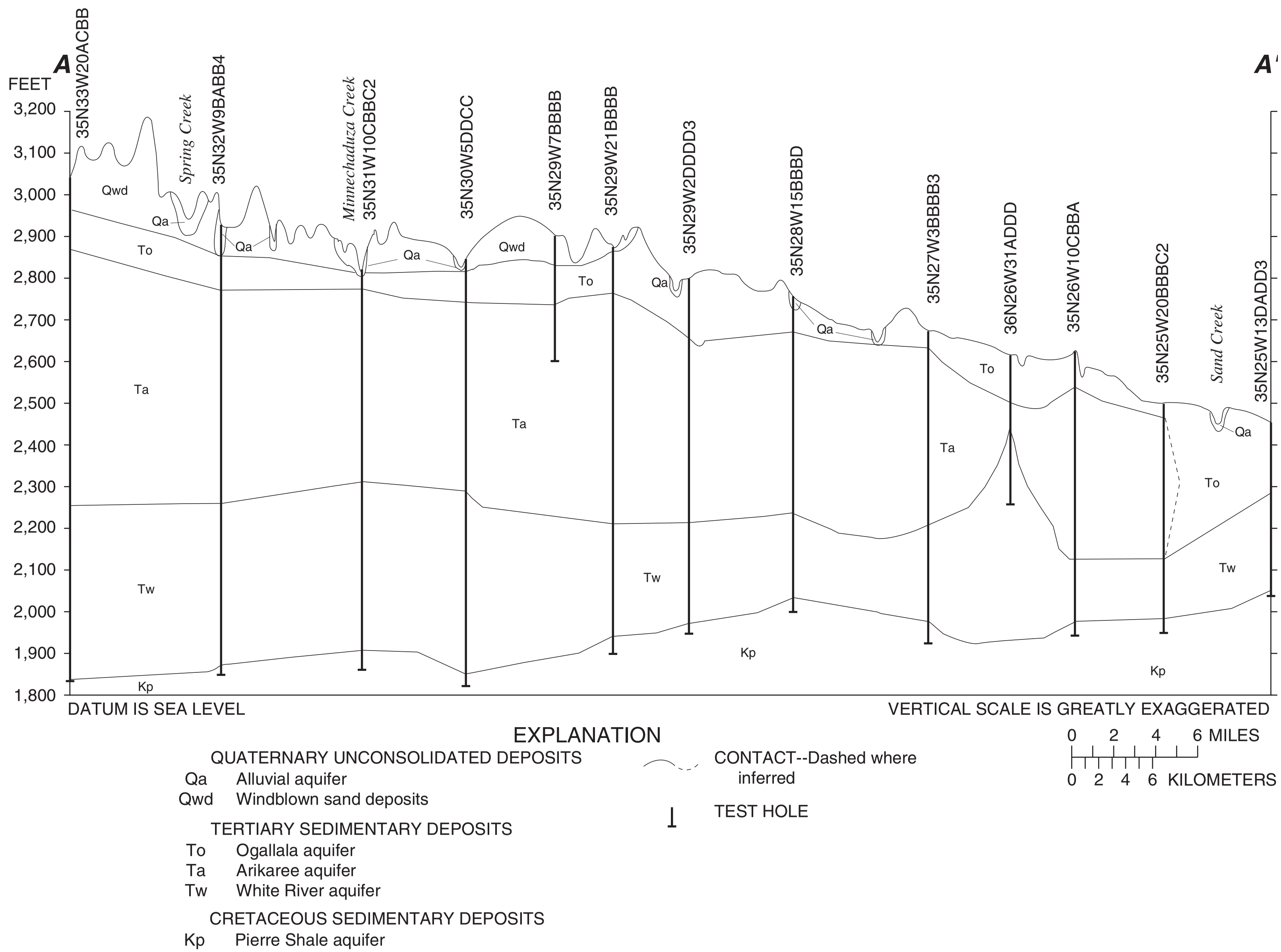


Figure 17. Hydrogeologic section A-A′ showing aquifers of Quaternary, Tertiary, and Cretaceous age in Todd County. (The location of section A-A′ is shown in fig. 2).

The Ogallala Formation consists primarily of poorly consolidated, fine- to medium-grained sandstone with some interbedded clay and silt. The saturated sandstones and silt of the Ogallala Formation make up the Ogallala aquifer. The depth to the top of the aquifer ranges from 0 to 164 feet below land surface, and the average thickness is 137 feet (table 4). The aquifer underlies about 950 square miles in Todd County and contains about 17 million acre-feet of water in storage. Generally, the aquifer is thickest in the central portion of Todd County, where use of the aquifer for irrigation is highest. The potentiometric surface of the Ogallala aquifer is shown in figure 18. Most of the aquifer is under water-table conditions, except in the southwest part of Todd County where the aquifer is confined by well-cemented or concretion beds in the upper part of the Ogallala Formation. The depth to water in wells generally is less than 10 feet below land surface where the aquifer is confined. Under water-table conditions, the depth to water ranges from 3 to greater than 150 feet below land surface. The aquifer has the highest yield potential of the aquifers in the study area; the maximum reported well yield is 1,250 gallons per minute (table 4).

Records of long-term water-level fluctuations in well 36N30W13BBBB and well 37N28W21CCCC (fig. 19) correlate well with long-term precipitation data prior to 1990. The water-level decline in 1981 was caused by below-normal precipitation. The increase in water levels from 1982 to 1984 was caused by above-normal precipitation. However, the water-level decline in both wells since 1990 does not correspond with below-normal precipitation; rather, the decline probably was caused by increased withdrawals of water for irrigation. In general, regional studies of the Ogallala aquifer indicate that water levels have not substantially declined in South Dakota due to irrigational development (Dugan and others, 1994). Predictions for further development of the Ogallala aquifer in South Dakota indicate that the water-level declines through 2020 generally will be less than 10 feet in most areas of Todd County (Luckey and others, 1988).

Recharge to the Ogallala aquifer primarily is by infiltration of precipitation on outcrops of the Ogallala Formation or overlying windblown sand deposits (fig. 4) and by stream loss as streams cross the outcrop of the Ogallala Formation when the stream stage is higher than the hydraulic head in the aquifer. Infiltration rates generally are greater than 2 inches/hour in the Ogallala Formation and generally are greater than 6 inches/hour in the overlying windblown sand deposits (U.S. Soil Conservation Service, 1974), so precipitation is a major source of recharge to the aquifer. Discharge from the aquifer is through withdrawals from domestic, public, stock, and irrigation wells; by loss to streams and springs; and by evapotranspiration from the aquifer where the aquifer is at or near land surface.

Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman and others, 1972). Transmissivities of the Ogallala aquifer were estimated for the water-bearing sediments of 10 test holes along the boundary between Todd County and Nebraska; transmissivities ranged from 800 to 9,200 square feet per day, with an average of 2,800 square feet per day (Newport, 1959). Additionally, specific capacity data stored in the USGS NWIS ground-water database were available for 65 wells completed in the Ogallala aquifer. The specific capacity ranged from 2 to 2,400 square feet per day, with an average of 600 square feet per day. Hydraulic conductivity is the volume of water an aquifer will transmit under a unit hydraulic gradient, through a unit cross-sectional area, measured at right angles to the direction of flow (Lohman, 1972). Transmissivity is equal to the hydraulic conductivity times the saturated thickness of the aquifer. Average hydraulic conductivities of the Ogallala aquifer in south-central South Dakota, estimated from 205 well logs, ranged from 3.6 to 160 feet per day, with an average of 30 feet per day (Kolm and Case, 1983).

Arikaree Aquifer

The Arikaree aquifer is present throughout most of Todd County, but is present in only a small part of southwestern Mellette County. The Arikaree Formation is not present along the eastern boundary of Todd County (fig. 7). The absence of the Arikaree aquifer in eastern Todd County also is shown in the hydrogeologic section B-B' (fig. 20).

The Arikaree Formation is predominantly composed of pinkish-tan to red, clayey, tuffaceous siltstones and sandstones. The Arikaree aquifer is composed primarily of the saturated sandstones and siltstones within the Arikaree Formation. The depth to the top of the aquifer ranges from 0 to 406 feet below land surface, and the average thickness is 290 feet (table 4). The aquifer underlies approximately 1,360 square miles of the study area and contain about

Base from U.S. Geological Survey digital data 1:100,000

EXPLANATION

APPROXIMATE AREA UNDERLAIN BY THE OGALLALA AQUIFER (modified from Ellis and others, 1971)

2900 POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased, nonpumping wells in 1996. Dashed where inferred. Contour interval 50 feet. Datum is sea level.

• 2745 WELL--Number is altitude of water level, in feet above sea level

GENERAL DIRECTION OF GROUND-WATER FLOW

Figure 18. Potentiometric surface of the Ogallala aquifer.

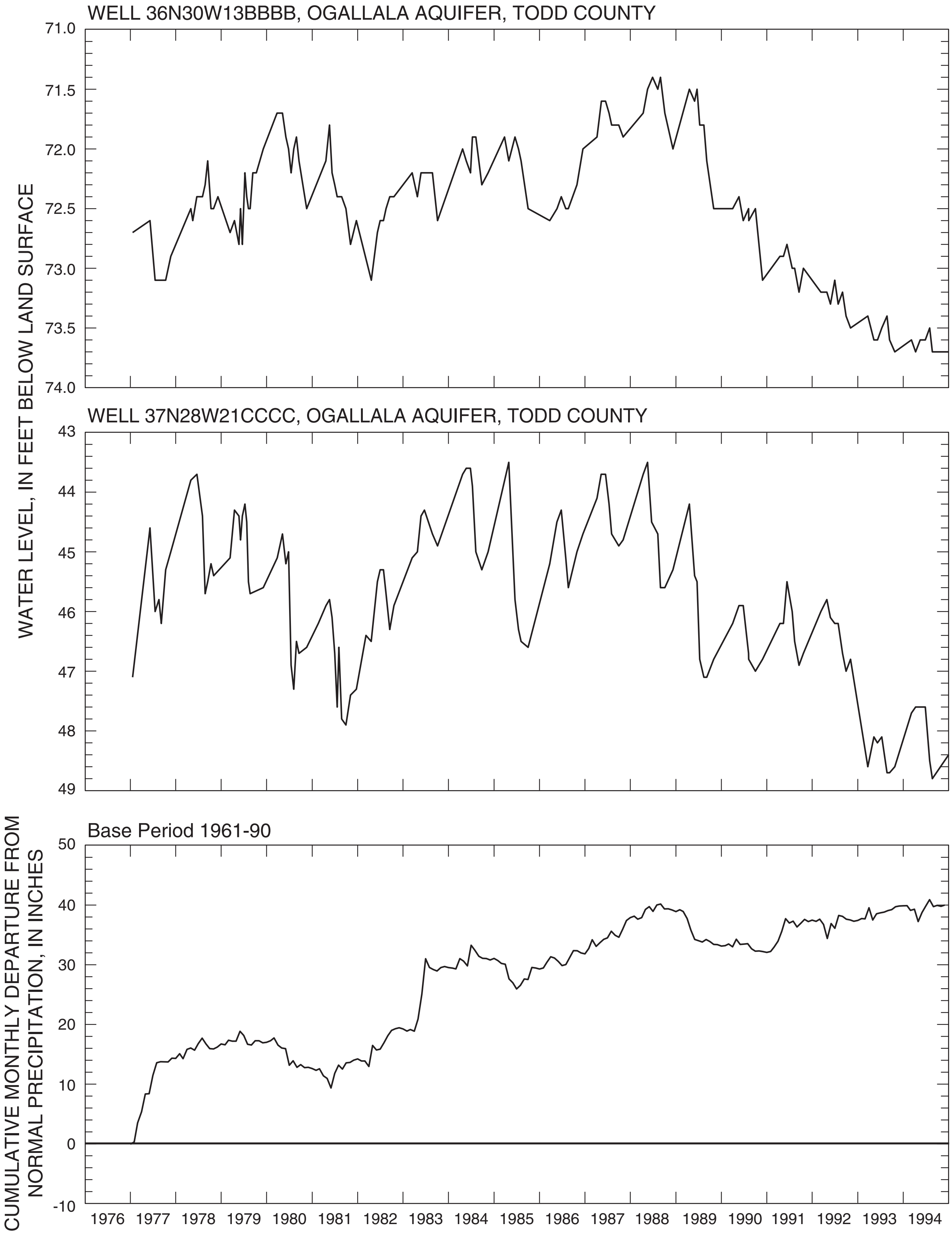


Figure 19. Water-level fluctuations in the Ogallala aquifer and cumulative monthly departure from normal precipitation at Valentine, Nebraska.

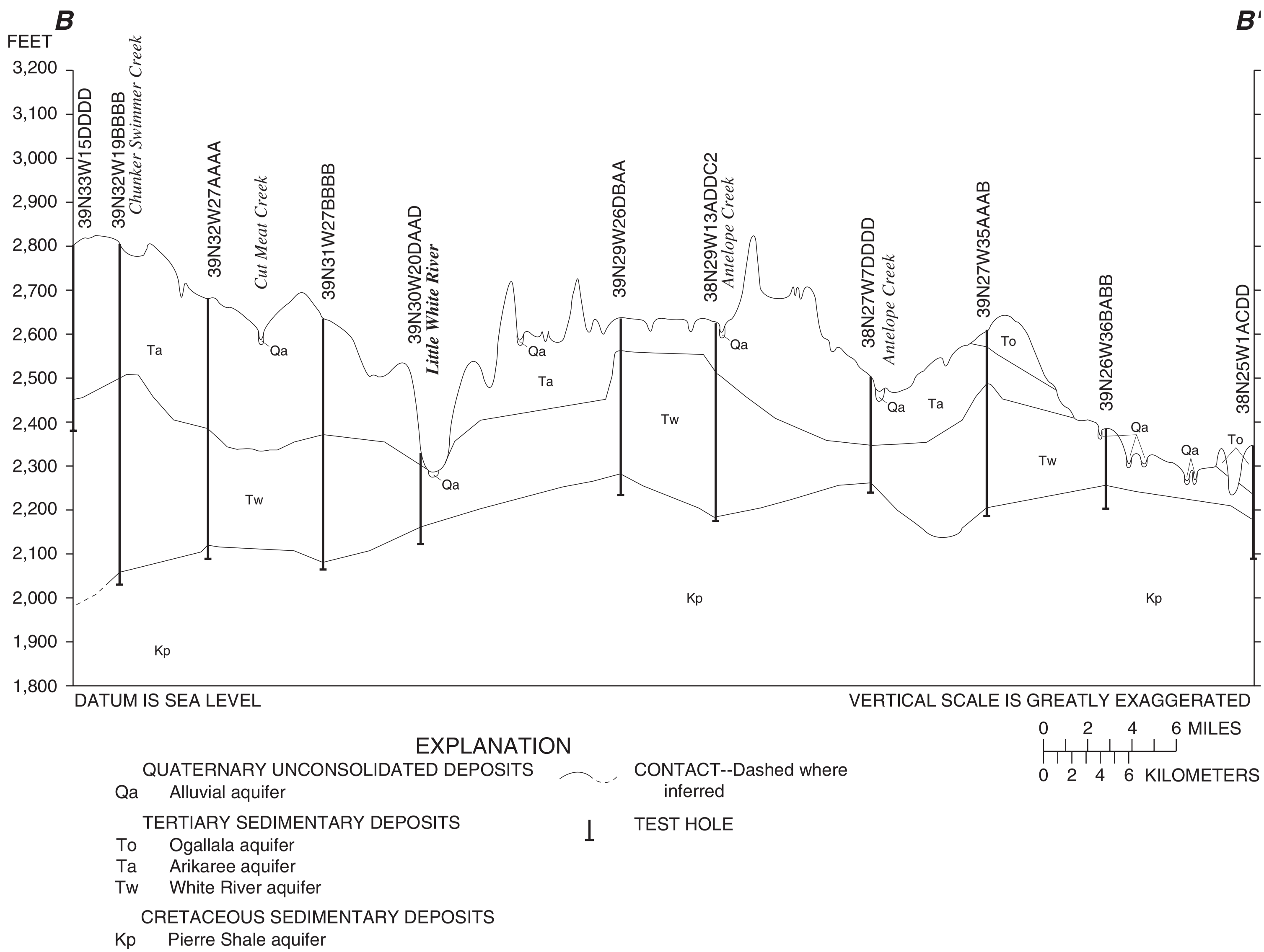


Figure 20. Hydrogeologic section B-B′ showing aquifers of Quaternary, Tertiary, and Cretaceous age in Todd County. (The location of section B-B′ is shown in fig. 2.)

50 million acre-feet of water in storage. The aquifer is thickest in southern Todd County. The potentiometric surface of the Arikaree aquifer is shown in figure 21. About one-half of the aquifer is under water-table conditions and one-half is confined. The aquifer is confined where overlain by impermeable materials in the Ogallala Formation, and the deeper part of the aquifer is under confined conditions where impermeable material exists in the upper part of the formation. Two flowing observation wells completed in the Arikaree aquifer are located at 36N33W17BACA. Water levels in the aquifer generally are within 60 feet of land surface under confined conditions, and range from 3 to greater than 150 feet under water-table conditions. Yields from the aquifer, which range from 1 to 1,005 gallons per minute (table 4), are dependent on the percentage of clay in the formation, consolidation of the materials, and well construction. Yields usually are not as great as those from the Ogallala aquifer, but are substantially greater than yields from the under-lying White River aquifer (table 4).

Records of long-term water-level fluctuations in well 40N32W21BBBB in Mellette County (fig. 22) correlate well with long-term precipitation data; records from well 37N29W22CCCC in Todd County do not correlate as well possibly because of distance from the outcrop. The Arikaree Formation is exposed at land surface at the well site in Mellette County (fig. 4), and infiltration of precipitation directly recharges the aquifer; therefore, the water-level fluctuations correlate well with precipitation data. Water-level fluctuations at both wells show the typical cyclic pattern of higher water levels during the spring due to precipitation recharge and lower water levels in the fall due to evapotranspiration and decreasing precipitation.

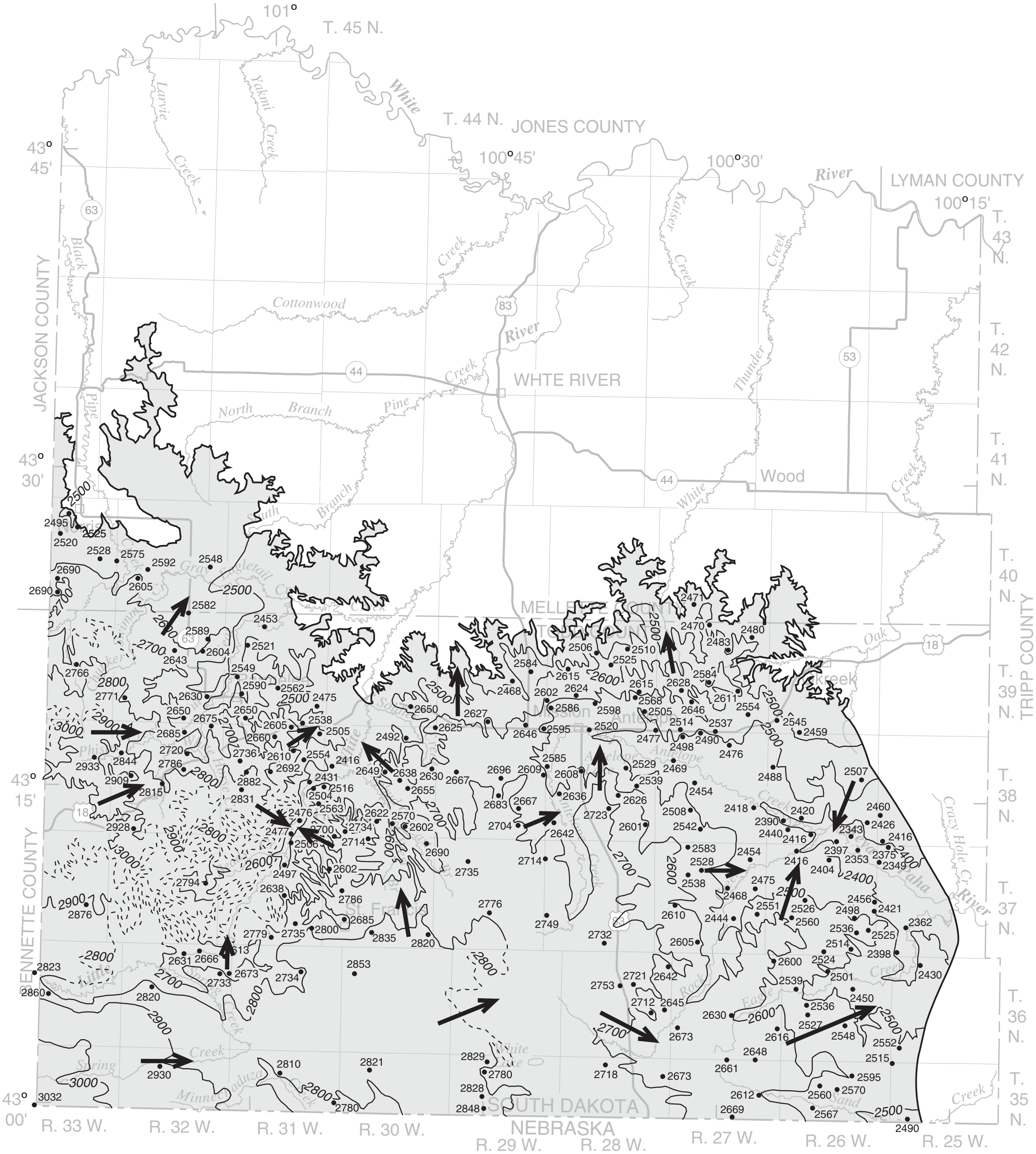
Recharge to the Arikaree aquifer primarily is by infiltration of precipitation on the outcrops of the Arikaree Formation (fig. 4) and by stream loss as streams cross the outcrop of the Arikaree Formation when the stream stage is higher than the hydraulic head in the aquifer. The greatest recharge to the aquifer occurs during the spring after snowmelt and during storm events. Infiltration rates generally range between 0.6 and 1.2 inches/hour (U.S. Soil Conservation Service, 1974, 1975). Discharge from the aquifer is through withdrawals from domestic, stock, and irrigation wells; by evapotranspiration where the aquifer is at or near land surface; and by discharge from springs to alluvial aquifers and streams when the hydraulic head in the Arikaree aquifer is higher than the hydraulic head in the alluvial aquifers or stage in the streams.

Specific capacity data stored in the USGS NWIS ground-water database for 184 wells completed in the Arikaree aquifer ranged from 2 to 2,000 square feet per day, with an average of 90 square feet per day. Analyses of four aquifer tests conducted near Pine Ridge, South Dakota, by Greene and others (1991) yielded a hydraulic conductivity of 13 feet per day and a transmissivity of 1,250 square feet per day in the unconfined Arikaree aquifer. In the confined Arikaree aquifer, the hydraulic conductivity was reported as 1 foot per day and the transmissivity was 300 square feet per day (Greene and others, 1991). A core sample from the Arikaree Formation in Nebraska had a hydraulic conductivity of about 2 feet per day (Bradley, 1956).

White River Aquifer

The White River aquifer is present throughout most of Todd County and in western and south-central Mellette County. The White River aquifer is used as a water source in northern Todd County where the Ogallala and Arikaree aquifers are not present. The aquifer is used in Mellette County where present because it is usually the shallowest source of water. A hydrogeologic section (C-C') from the northwestern boundary of Mellette County to the south-central part of Todd County (fig. 23) shows the White River aquifer where present.

The White River aquifer consists predominantly of the saturated, poorly consolidated siltstones and claystones and interbedded sand layers within the White River Group. The depth to the top of the aquifer ranges from 0 to 789 feet below land surface, and the average thickness is 229 feet (table 4). This aquifer underlies approximately 1,720 square miles of the study area and contains about 50 million acre-feet of water in storage. The White River aquifer is thickest in western Todd County and southwestern Mellette County. The potentiometric surface of the aquifer is shown in figure 24. The aquifer is under water-table conditions where it is at or near the land surface, and is confined where overlain by the Ogallala Formation and/or the Arikaree Formation (fig. 4). Thus, most of the aquifer is confined in the study area. One observation well (107 feet deep) completed in the aquifer at 37N25W24BCBB currently flows. Two shallower observation wells (less than 60 feet deep) completed in the aquifer at this same location do not flow, but water levels in both wells are within 10 feet of land surface. Water levels in the aquifer generally are less than 100 feet below land surface under both water-table and confined conditions, but water-level depths exceeding



Base from U.S. Geological Survey
digital data 1:100,000

0 2 4 6 MILES
0 2 4 6 KILOMETERS

EXPLANATION

APPROXIMATE AREA UNDERLAIN BY THE ARIKAREE AQUIFER (modified from Ellis and others, 1971)

2900 POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased, nonpumping wells in 1996. Dashed where inferred. Contour interval 100 feet. Datum is sea level.

• 2749 WELL--Number is altitude of water level, in feet above sea level

GENERAL DIRECTION OF GROUND-WATER FLOW

Figure 21. Potentiometric surface of the Arikaree aquifer.

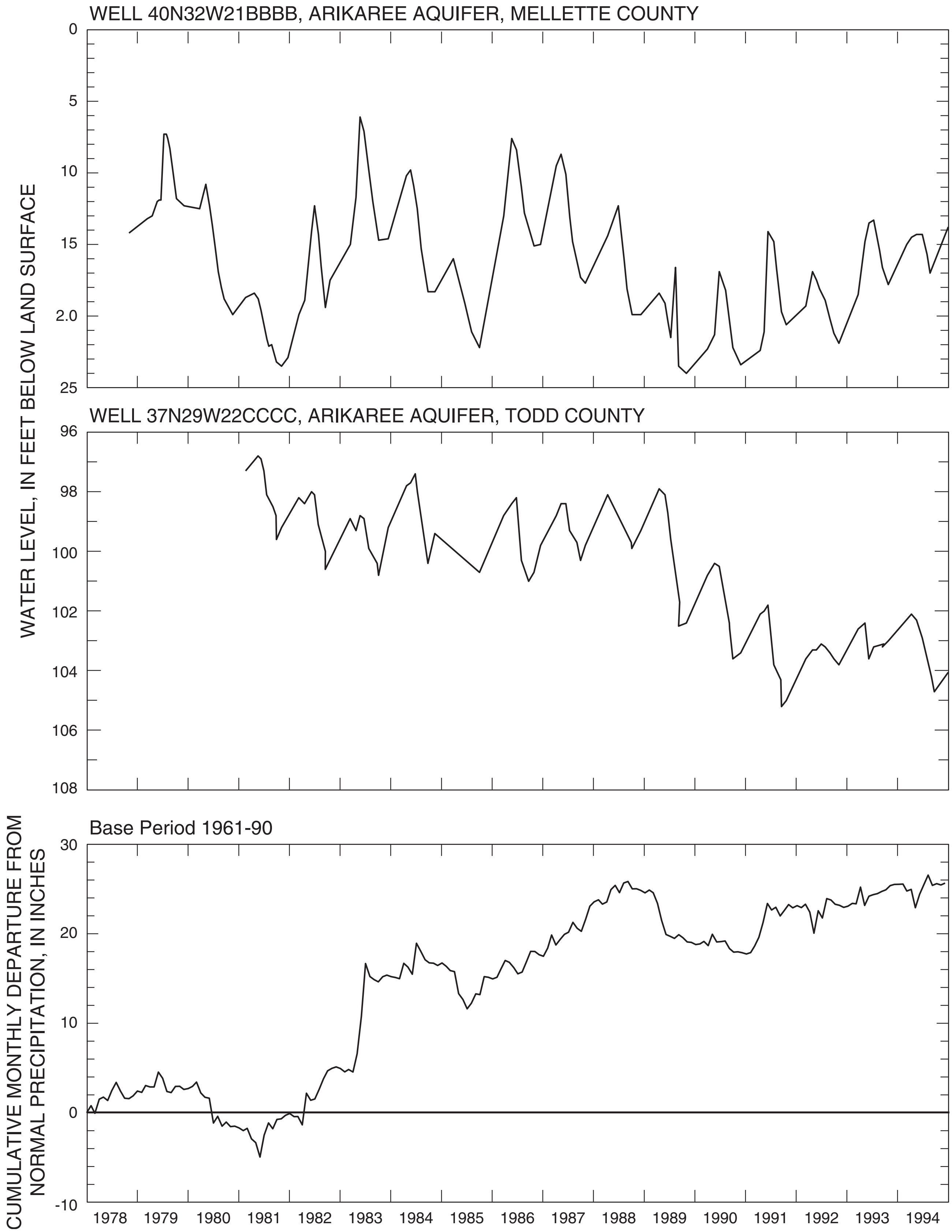


Figure 22. Water-level fluctuations in the Arikaree aquifer and cumulative monthly departure from normal precipitation at Valentine, Nebraska.

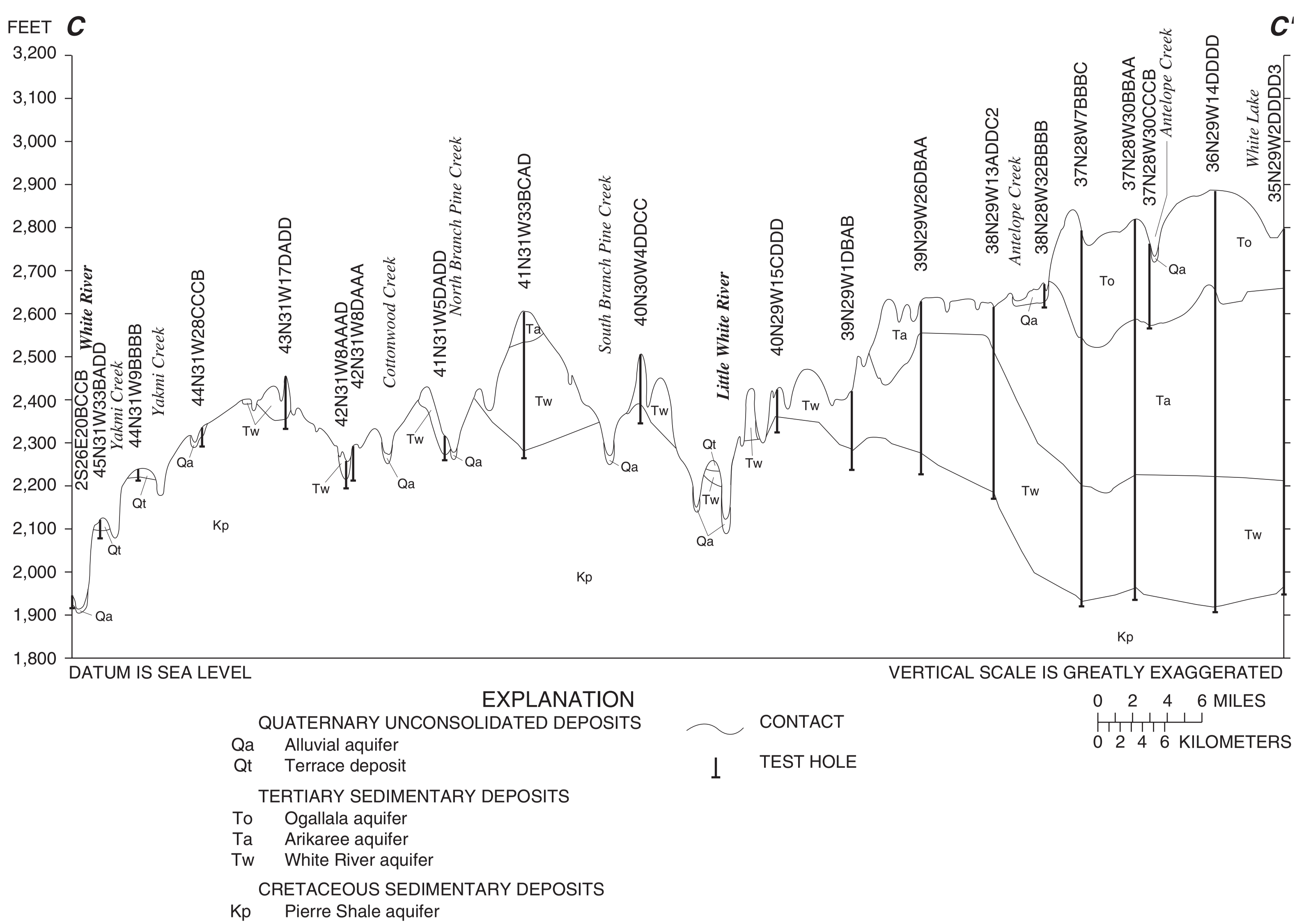
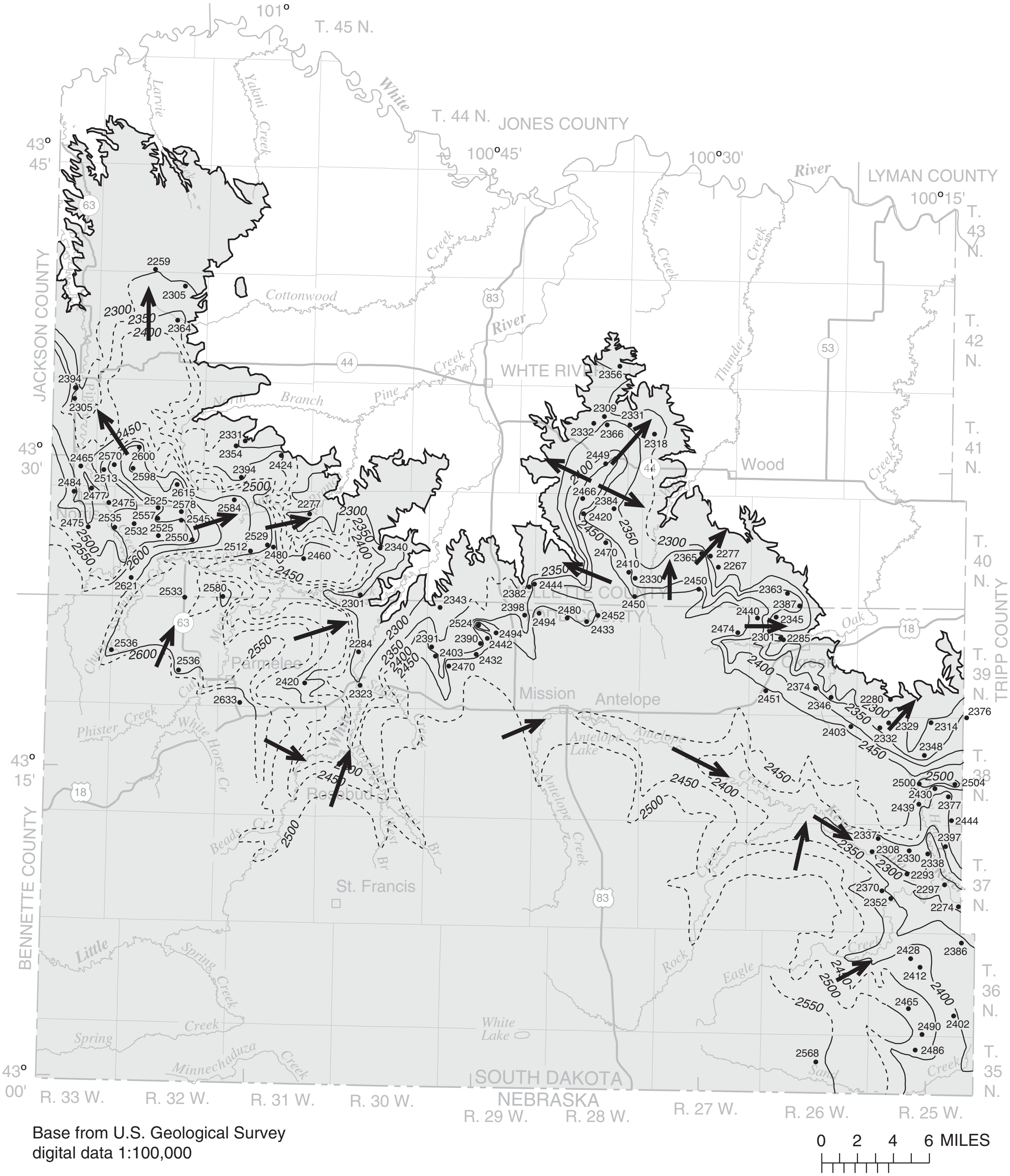


Figure 23. Hydrogeologic section C-C′ showing aquifers of Quaternary, Tertiary, and Cretaceous age in Mellette and Todd Counties. (The location of section C-C′ is shown in fig. 2.)



EXPLANATION

APPROXIMATE AREA UNDERLAIN BY THE WHITE RIVER AQUIFER (modified from Ellis and others, 1971)

—2900- - - POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased, nonpumping wells in 1996. Dashed where inferred. Contour interval 50 feet. Datum is sea level.

• 2912 WELL--Number is altitude of water level, in feet above sea level

Figure 24. Potentiometric surface of the White River aquifer.

200 feet below land surface have been recorded in northwestern Todd County and southwestern Mellette County. Yields from the aquifer range from 1 to 30 gallons per minute (table 4), and are dependent on the percentage of clay in the formation, consolidation of the siltstones and sandstones, thickness of the siltstones and sandstones, and well construction. Yields generally are sufficient for domestic and stock-watering purposes.

Records of long-term water-level fluctuations in well 40N32W32BBBB in Mellette County and in well 37N25W23ADAD in Todd County (fig. 25) correlate reasonably well with long-term precipitation data. However, the below-normal precipitation during 1974-76 does not correlate with water-level fluctuations in the Todd County well, and the cause of the water-level decline in the Mellette County well in 1979 is not known. Both wells show an increase in water levels due to above-normal precipitation beginning in 1992-93 through the end of the period shown.

Recharge to the White River aquifer primarily is by infiltration of precipitation on the outcrops of the White River Group (fig. 4), and by stream loss as streams cross the outcrop of the White River Group when the stream stage is higher than the hydraulic head in the aquifer. The greatest recharge to the aquifer occurs during the spring after snowmelt and during storm events. Infiltration rates range from less than 0.06 to 0.6 inches/hour (U.S. Soil Conservation Service, 1974, 1975). Discharge from the aquifer is through withdrawals from domestic and stock wells, by evapotranspiration where the aquifer is at or near land surface, and by discharge from springs to alluvial deposits and streams when the hydraulic head in the aquifer is higher than the hydraulic head in the alluvial deposits or the stage in the streams.

Specific capacity data stored in the USGS NWIS ground-water database were available for 26 wells completed in the White River aquifer. The specific capacity ranged from 2 to 2,500 square feet per day, with an average of 160 square feet per day.

Bedrock Aquifers

The bedrock aquifers in the study area include the Pierre Shale, Dakota Sandstone, Inyan Kara, and Minnelusa and Madison aquifers. The Pierre Shale aquifer, which is the shallowest bedrock aquifer in the study area, generally is used only in Mellette County as a source of ground water. Few wells have been completed in the deeper aquifers because of cost and because water usually can be obtained from a shallower aquifer or from other sources. Most of the available bedrock-aquifer information in the study area is from wells located in northern Mellette County. Test drilling for this study usually stopped just below the upper contact of the Pierre Shale. Therefore, other than the Pierre Shale, the deeper bedrock aquifers were not penetrated during the test drilling.

Pierre Shale Aquifer

The Pierre Shale aquifer is present throughout the study area. The upper part of the Pierre Shale generally is weathered and fractured. The Pierre Shale typically is not considered an aquifer in South Dakota, except in localities like Mellette County where individuals rely on the aquifer because it is the shallowest source of ground water available. Where the Pierre Shale is used to supply water, wells usually are completed in the weathered shale. The shale is exposed at the land surface throughout most of Mellette County and is overlain by the Tertiary deposits throughout most of Todd County (fig. 4). A hydrogeologic cross-section (D-D') from north to south along the eastern edge of Mellette and Todd Counties (fig. 26) shows that the Pierre Shale aquifer is the shallowest water source in eastern Mellette County, except where alluvial deposits are present. In eastern Todd County, the Pierre Shale is overlain by the White River Group and Ogallala Formation. As previously discussed, the Arikaree Formation is not present in eastern Todd County.

The Pierre Shale predominantly is a black shale. The depth to the top of the Pierre Shale in the study area ranges from 0 to greater than 1,200 feet (table 4). The aquifer contains an estimated maximum of 1.5 million acre-feet of water in storage (table 4). This aquifer generally is not a viable source of ground water because the aquifer is relatively impermeable, yields are low, and water usually can be obtained from shallower aquifers, especially in Todd County. The potentiometric surface of the aquifer is shown in figure 27. The potentiometric surface for the aquifer throughout most of Todd County could not be drawn because of insufficient data. Because the aquifer is used as a water source mainly in Mellette County, where the formation generally is present at or near the land surface, the aquifer is under water-table conditions. The general direction of ground-water flow in the Pierre Shale aquifer is to the north. Yields from the aquifer ranged from 1 to 8 gallons per minute (table 4) and are dependent on the amount of fracturing and the percentage of clay and sand present in the shale. No long-term water-level records were available for wells completed in the Pierre Shale.

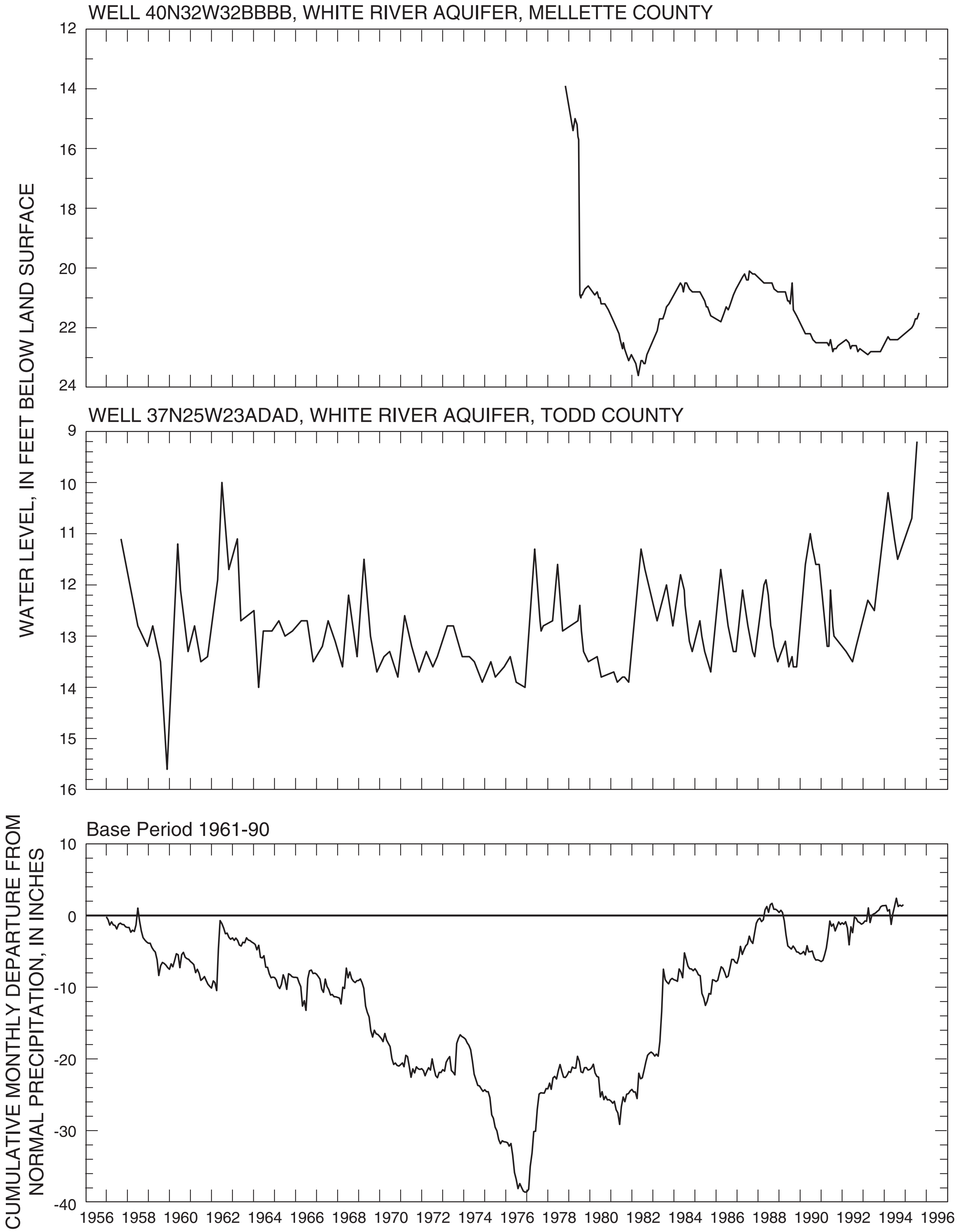


Figure 25. Water-level fluctuations in the White River aquifer and cumulative monthly departure from normal precipitation at Valentine, Nebraska.

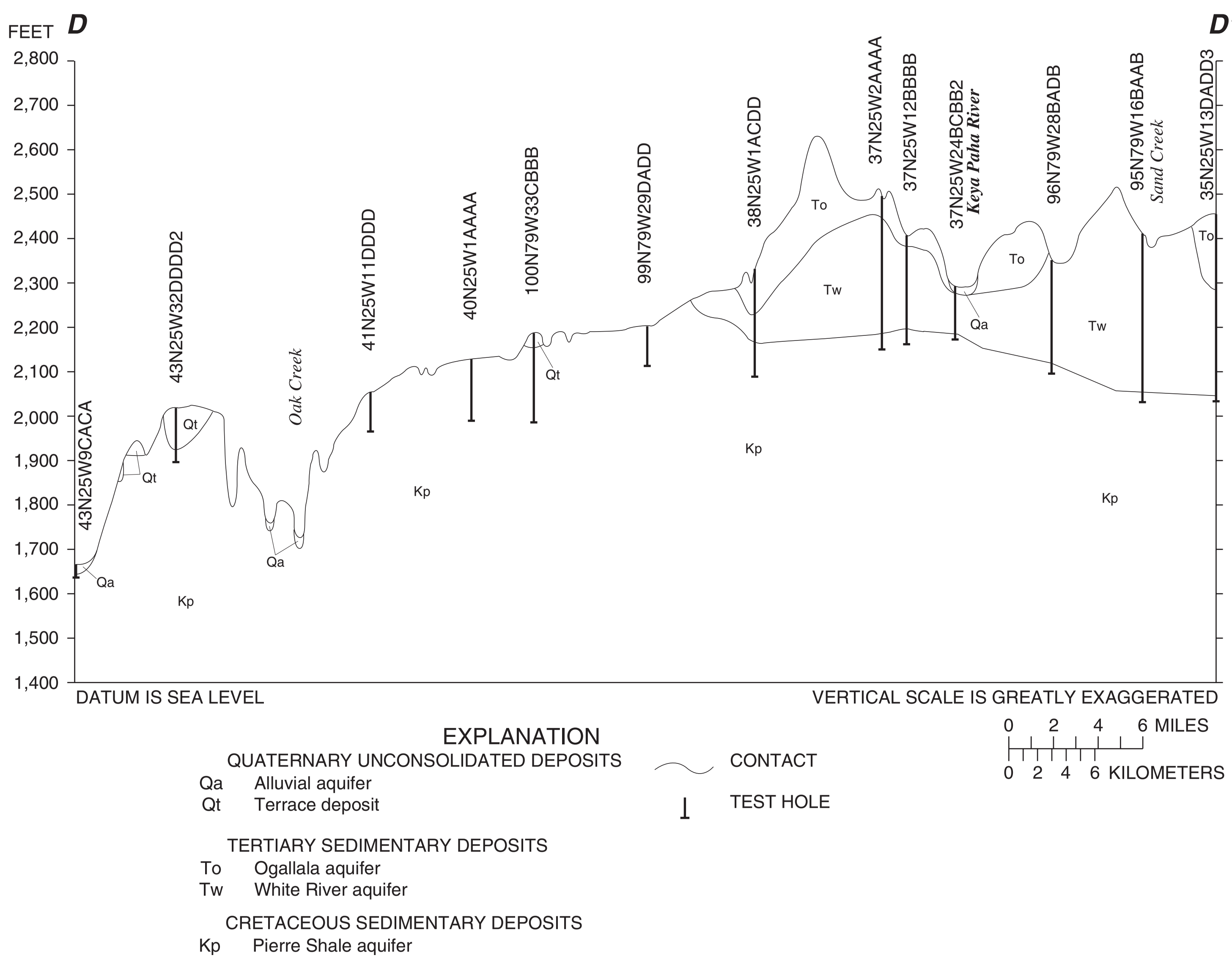
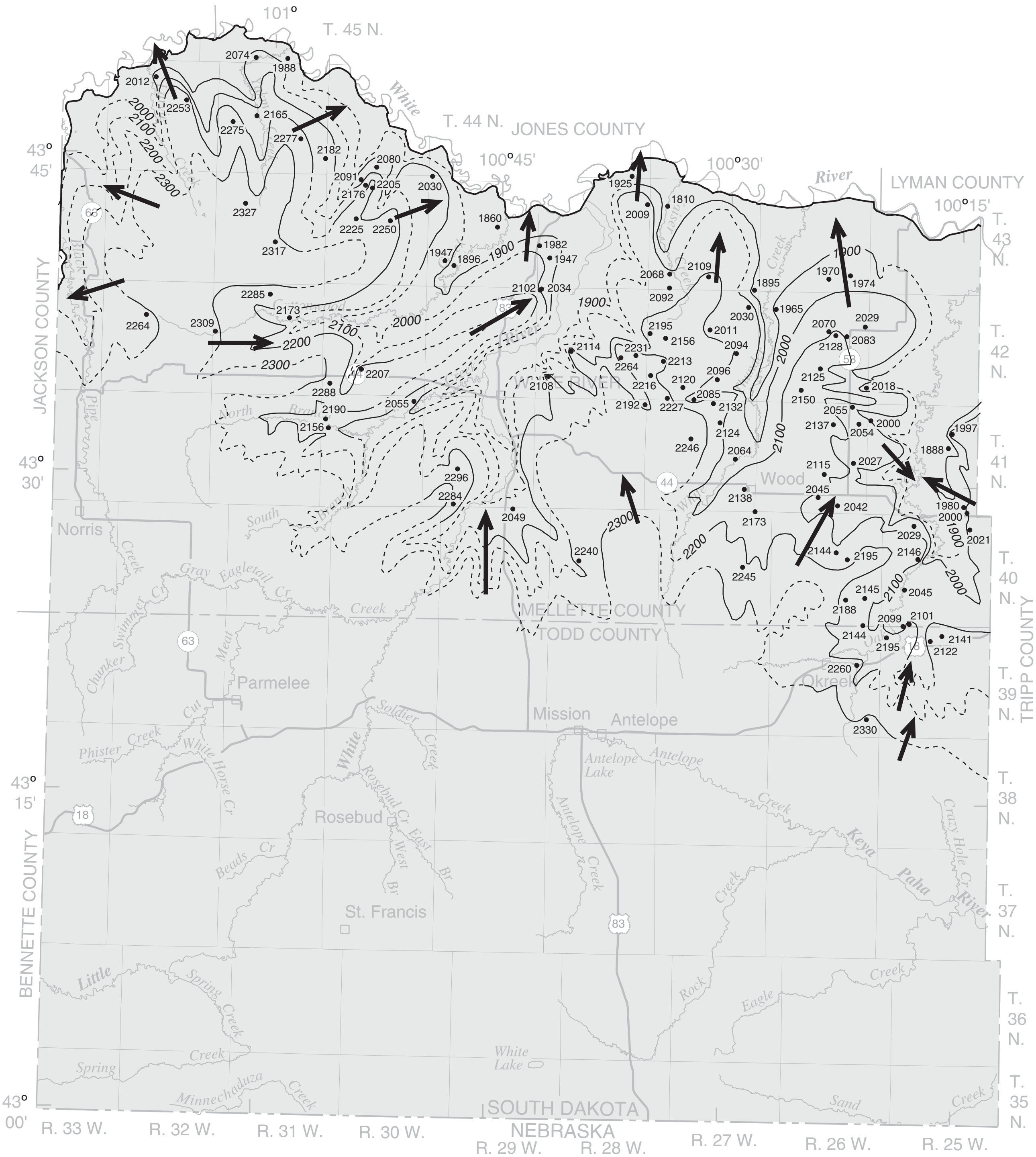


Figure 26. Hydrogeologic section D-D′ showing aquifers of Quaternary, Tertiary, and Cretaceous age in Mellette and Todd Counties. (The location of section D-D′ is shown in fig. 2.)



Base from U.S. Geological Survey
digital data 1:100,000

0 2 4 6 MILES

0 2 4 6 KILOMETERS

EXPLANATION

APPROXIMATE AREA UNDERLAIN BY THE PIERRE SHALE AQUIFER (modified from Ellis and others, 1971)

—2300- - - POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased, ninpumping wells in 1996. Dashed where inferred. Contour interval 100 feet. Datum is sea level.

• 2912 WELL--Number is altitude of water level, in feet above sea level

GENERAL DIRECTION OF GROUND-WATER FLOW

Figure 27. Potentiometric surface of the Pierre Shale aquifer.

Recharge to the Pierre Shale aquifer primarily is by infiltration of precipitation on the outcrops of the Pierre Shale (fig. 4). The greatest recharge to the aquifer occurs during the spring after snowmelt and during storm events. Infiltration rates generally are less than the lowest rate (0.06 inches/hour) measured by the U.S. Soil Conservation Service (1974, 1975). Discharge from the aquifer is through withdrawals from domestic and stock wells and by evapotranspiration where the aquifer is at or near land surface.

Based on modified slug tests conducted at a site in central South Dakota, the horizontal hydraulic conductivity of the unweathered Pierre Shale aquifer ranges from about 10^{-5} to 10^{-6} feet per day (Bredehoeft and others, 1983). Bredehoeft and others (1983) suggested that the hydraulic conductivity of the Pierre Shale aquifer decreases with depth, and that much of the flow in the shale occurs through fractures.

Dakota Sandstone Aquifer

The Dakota Sandstone aquifer underlies the entire study area and contains more than an estimated 81 million acre-feet of water in storage. However, only a few test holes and wells penetrate the Dakota Sandstone in the study area, and all but two were drilled in Mellette County. The Dakota Sandstone consists of interbedded sandstones and shales. The depth to the top of the aquifer ranges from 1,270 to 2,348 feet below land surface (table 4). Because the formation is overlain by at least five formations primarily composed of shale (table 1), the aquifer is under confined conditions, and wells completed in the Dakota Sandstone aquifer are likely to flow when drilled in topographically low areas, such as near streams. Known flowing wells completed in the Dakota Sandstone aquifer are located at 42N28W22, 43N27W14, and 43N27W3. Reported yields from the aquifer range from 10 to 100 gallons per minute (table 4).

The potentiometric surface was not constructed for the Dakota Sandstone aquifer because of insufficient data. Regional potentiometric maps of the aquifer (Schoon, 1971) approximate the hydraulic head altitude to range from 2,150 feet above sea level along the western boundary of Mellette and Todd Counties to 1,950 feet along the eastern boundary. The contours generally trend north-south; therefore, the general direction of ground-water flow in the Dakota Sandstone aquifer is from west to east in the study area.

Records of long-term water-level fluctuations in wells completed in the Dakota Sandstone aquifer located at 41N26W30DDCB and 43N30W8BBCD in Mellette County (fig. 28) correlate poorly with long-term precipitation data. Water levels in the two observation wells have declined 31 to 50 feet since 1963 because discharge has exceeded recharge.

The major sources of recharge to the Dakota Sandstone aquifer are infiltration of precipitation on outcrops of the Dakota Sandstone (mostly in the Black Hills area) and leakage from other aquifers (Schoon, 1971; Miller and Rahn, 1974). Discharge from the aquifer in the study area is through withdrawals from stock wells.

Miller and Rahn (1974) reported a hydraulic conductivity from a single-well aquifer test at Box Elder, South Dakota, of about 1 foot per day and a transmissivity of about 200 square feet per day for the Dakota Sandstone. Bredehoeft and others (1983) calculated an average hydraulic conductivity of about 5 feet per day from approximately 500 drilling records in South Dakota.

Inyan Kara Aquifer

The extent of the Inyan Kara Group in the study area is not known. The only test holes and wells that penetrate the Inyan Kara Group are located in northern Mellette County. The depth to the top of the Inyan Kara Group is greater than 1,900 feet below land surface (table 4). The Inyan Kara Group consists predominantly of sandstones and siltstones containing loose to well-cemented sand. Because the formation is overlain by the Dakota Sandstone and five shale formations (table 1), the aquifer is confined, and wells completed in this aquifer are likely to flow when drilled in topographically low areas. Known flowing wells completed in the aquifer are located in Mellette County in 42N28W22, 42N30W12, 43N26W33, and 45N32W36. Reported yields from the aquifer range from 9 to 160 gallons per minute (table 4).

The potentiometric surface was not constructed for the Inyan Kara aquifer because of insufficient water-level data. The potentiometric surface of the Inyan Kara aquifer in northern Mellette County is presented in Ellis and others (1971). The altitude of the potentiometric surface ranges from 2,250 feet above sea level in northwestern Mellette County to 2,150 feet in central Mellette County. The potentiometric contours generally trend east-west; therefore, the general direction of ground-water flow in the aquifer is from north to south (Ellis and others, 1971). No long-term water-level records were available for wells completed in the Inyan Kara aquifer in either Mellette or Todd County.

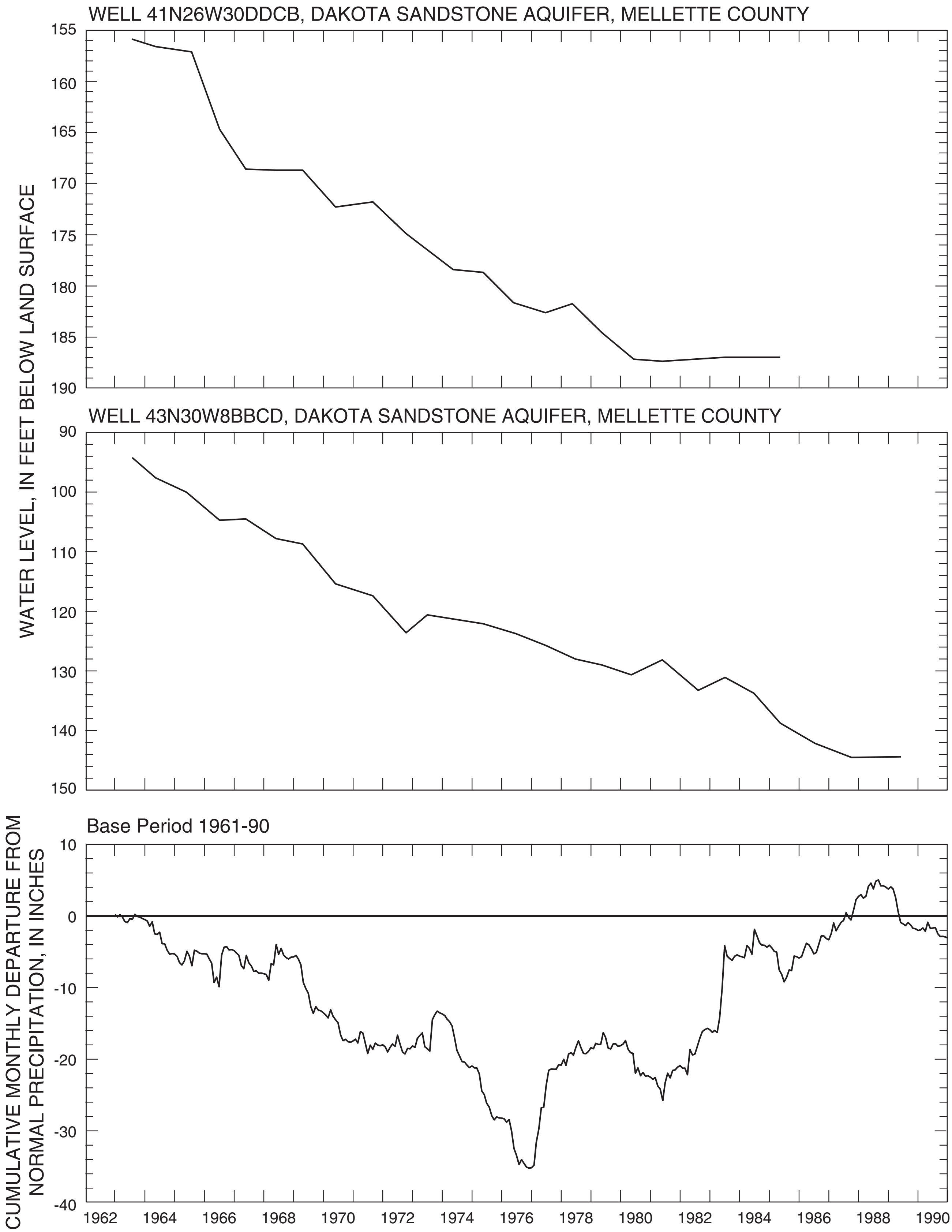


Figure 28. Water-level fluctuations in the Dakota Sandstone aquifer and cumulative monthly departure from normal precipitation at Valentine, Nebraska.

The major source of recharge to the aquifer is by infiltration of precipitation on outcrops of the Inyan Kara Group (mostly in the Black Hills area), ground-water inflow mostly from Wyoming and North Dakota, and leakage from underlying units (Case, 1984). Discharge from the Inyan Kara aquifer in the study area is through withdrawals from stock wells.

No specific-capacity or aquifer-test data were available for wells completed in the Inyan Kara aquifer in or near the study area. Aquifer properties of hydraulic conductivity and transmissivity possibly are similar to those in the Dakota Sandstone aquifer based on conductivity values compiled by Case (1984).

Minnelusa and Madison Aquifers

The Minnelusa Formation and Madison Limestone are combined for purposes of this report because almost all wells at this depth are completed in both the Minnelusa and Madison aquifers. The extent of the Minnelusa and Madison Formations in the study area is not known. The Minnelusa Formation consists primarily of interbedded sandstone, siltstone, limestone, dolomite, anhydrite, and shale. The composition of the Madison Limestone varies from pure limestone to pure dolomite with combinations of the two. The aquifers are confined because they are overlain by many confining deposits. Wells completed in the Minnelusa and/or the Madison aquifers are likely to flow when drilled in topographically low areas. Known flowing wells are located in Mellette County at 42N28W22, 42N28W30, 42N25W32, and 42N26W34. Yields from the aquifers range from 25 to 40 gallons per minute (table 4).

The major source of recharge to the Minnelusa and Madison aquifers is infiltration of precipitation and streamflow on outcrops of the these formations in the Black Hills area (Peter, 1985). Discharge from the aquifers in the study area is through withdrawals from stock wells and leakage to other aquifers (Case, 1984).

The potentiometric surface for the Minnelusa and Madison aquifers was not drawn because of insufficient water-level data. Ellis and others (1971) approximate the potentiometric surface of the Minnelusa and Madison aquifers throughout most of Mellette County. The altitude of the potentiometric surface in Mellette County ranges from 2,400 feet above sea level in the northwest to 2,150 feet in the southeast. The general trend of the contours is southwest-northeast; therefore, the general direction of ground-water flow in the aquifers is from the northwest to the southeast (Ellis and others, 1971). No long-term water-level measurements were available for either aquifer in the study area.

Although the hydraulic properties of the Minnelusa and Madison aquifers have been studied extensively in the Black Hills area, no known information exists for these aquifers in areas in or near the study area. Because the hydraulic properties determined in the Black Hills would not be comparable to those in this study area due to the uplift and karstification in the Black Hills, no hydraulic properties are given in this report for the Minnelusa and Madison aquifers.

Water Quality

The chemical quality of water in the aquifers in the study area varies widely, both within and between aquifers. The chemical quality among the aquifers of Tertiary age is the most similar. A summary of chemical analyses of water for each aquifer, based on data stored in the USGS NWIS water-quality database, is presented in table 5.

In the following discussions, hardness and salinity are used to characterize the quality of water from the aquifers. Water that has a hardness less than 61 mg/L (milligrams per liter) is considered soft; 61 to 120 mg/L, moderately hard; 121 to 180 mg/L, hard; and more than 180 mg/L, very hard (Heath, 1983). Salinity is based on the dissolved solids concentrations. Water that has a dissolved solids concentration less than 1,000 mg/L is considered fresh; 1,000 to 3,000 mg/L, slightly saline; 3,000 to 10,000 mg/L, moderately saline; 10,000 to 35,000 mg/L, very saline; and more than 35,000 mg/L, briny (Heath, 1983).

The quality of water in the alluvial aquifers varies greatly between locations and is dependant on the deposits that underlie the unconsolidated deposits. The alluvial aquifers generally yield water that has low concentrations of dissolved solids, is fresh, and is soft to moderately hard where underlain by the Ogallala and Arikaree Formations; has moderate concentrations of dissolved solids, is slightly saline, and is hard where underlain by the White River Group; and has high concentrations of dissolved solids, is slightly saline, and is very hard where underlain by the Pierre Shale. Because of this variation, calcium and bicarbonate generally are the dominant species in the alluvial water where underlain by the deposits of Tertiary age, and sodium and chloride generally are the dominant species where underlain by the Pierre Shale (fig. 29).

Table 5. Summary of chemical analyses for ground water

[Results based on data stored in USGS NWIS water-quality database. Results in milligrams per liter except as indicated. One milligram per liter (mg/L) is approximately equal to one part per million. One microgram per liter (µg/L) is approximately equal to one part per billion; µS/cm, microsiemens per centimeter at 25° Celsius; --, not analyzed or not determined; <, less than indicated detection limit; ND, specifically analyzed for but not detected, and detection limit unknown]

Property or dissolved constituent	Alluvial aquifers				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance (µS/cm)	46	1,580	1,210	229	4,600
pH (standard units)	51	7.3	7.5	6.6	8.3
Carbon dioxide	20	12	9.9	1.7	24
Hardness, as $CaCO_3$	52	518	273	77	2,060
Solids, residue at 180° C	48	1,140	724	175	3,820
Solids, sum of constituents	43	1,200	1,040	177	3,440
Calcium	52	156	94	25	527
Magnesium	52	31	14	2	196
Sodium	50	152	81	8.1	570
Potassium	47	14	13	6.5	33
Bicarbonate	26	326	317	117	600
Alkalinity	25	323	318	107	668
Sulfate	52	478	194	ND	2,000
Chloride	52	28	13	ND	160
Fluoride	49	0.5	0.4	0.1	4
Silica	36	33	31	12	60
Nitrogen, nitrate	40	1.0	0.3	ND	9.2
Phosphorus, orthophosphate	11	0.04	0.04	ND	0.12
Aluminum (µg/L)	4	--	<5	<5	7.5
Arsenic (µg/L)	17	13	7	<1	44
Barium (µg/L)	5	127	124	12	330
Boron (µg/L)	17	409	354	20	940
Cadmium (µg/L)	9	--	<1	<1	2.4
Chromium (µg/L)	9	--	<1	<1	<10
Cobalt (µg/L)	0	--	--	--	--
Copper (µg/L)	6	6.2	<1	4.5	18
Iron (µg/L)	29	627	60	ND	3,200
Lead (µg/L)	9	--	<1	<1	2
Lithium (µg/L)	0	--	--	--	--
Manganese (µg/L)	23	597	250	<1	4,400
Mercury (µg/L)	7	--	<1	<1	<1
Molybdenum (µg/L)	3	2.4	2	1.8	3.4
Nickel (µg/L)	0	--	--	--	--
Selenium (µg/L)	16	7.7	2	<1	60
Silver (µg/L)	2	--	31	<1	60
Strontium (µg/L)	0	--	--	--	--
Vanadium (µg/L)	3	2.1	2.1	1.1	3.2
Zinc (µg/L)	9	38	29	<3	120

Table 5. Summary of chemical analyses for ground water—Continued

Property or dissolved constituent	Ogallala aquifer				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance (µS/cm)	150	397	361	227	911
pH (standard units)	157	7.5	7.5	6.8	8.4
Carbon dioxide	93	10	8.6	0.8	33
Hardness, as $CaCO_3$	143	171	164	21	415
Solids, residue at 180° C	70	280	256	180	619
Solids, sum of constituents	126	237	210	134	632
Calcium	143	55	52	7.3	130
Magnesium	143	8.0	8.0	ND	42
Sodium	142	12	6.0	ND	180
Potassium	139	8.6	8.0	1.0	24
Bicarbonate	102	217	215	109	453
Alkalinity	41	183	174	129	340
Sulfate	142	9.2	4.0	ND	145
Chloride	147	7.0	3.6	ND	220
Fluoride	54	0.4	0.3	0.2	4.6
Silica	45	60	59	50	73
Nitrogen, nitrate	92	5.5	1.3	<0.1	44
Phosphorus, orthophosphate	28	0.06	0.02	<0.01	2.3
Aluminum (µg/L)	2	--	<5	<5	<5
Arsenic (µg/L)	20	4.8	3.8	1.0	12
Barium (µg/L)	8	166	115	98	360
Boron µg/L)	30	94	40	ND	780
Cadmium (µg/L)	8	--	<1	<1	3.5
Chromium (µg/L)	8	1.0	1.0	<1	2.9
Cobalt (µg/L)	0	--	--	--	--
Copper (µg/L)	3	4.0	5.0	ND	7.0
Iron (µg/L)	47	40	8	<0.1	320
Lead (µg/L)	8	2.7	1.0	<1	13
Lithium (µg/L)	0	--	--	--	--
Manganese (µg/L)	29	2	0.3	<1	20
Mercury (µg/L)	4	--	<0.1	<0.1	<0.1
Molybdenum (µg/L)	0	--	--	--	--
Nickel (µg/L)	0	--	--	--	--
Selenium (µg/L)	23	1.2	<1	<1	10
Silver (µg/L)	4	--	<1	<1	<2
Strontium (µg/L)	0	--	--	--	--
Vanadium (µg/L)	0	--	--	--	--
Zinc (µg/L)	6	24	20	12	54

Table 5. Summary of chemical analyses for ground water—Continued

Property or dissolved constituent	Arikaree aquifer				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance (µS/cm)	68	510	425	238	1,730
pH (standard units)	80	7.6	7.6	7.1	8.5
Carbon dioxide	20	7.9	6.9	2.2	25
Hardness, as $CaCO_3$	73	104	91	10	499
Solids, residue at 180° C	67	357	300	172	1,200
Solids, sum of constituents	67	347	299	140	1,180
Calcium	78	34	31	3.6	170
Magnesium	78	4.0	2.9	ND	19
Sodium	74	68	66	4.1	170
Potassium	71	11	10	1.1	26
Bicarbonate	44	243	234	122	587
Alkalinity	52	211	192	109	534
Sulfate	75	31	20	ND	170
Chloride	77	9.6	3.9	<0.1	110
Fluoride	58	0.7	0.5	<0.1	3.1
Silica	57	64	65	31	77
Nitrogen, nitrate	45	2.1	1.1	<0.05	39
Phosphorus, orthophosphate	26	0.24	0.09	0.007	1.1
Aluminum (µg/L)	7	--	<5	<5	39
Arsenic (µg/L)	46	29	13	2	110
Barium (µg/L)	3	110	140	39	150
Boron µg/L)	25	141	105	30	630
Cadmium (µg/L)	26	--	<1	<1	<1
Chromium (µg/L)	26	0.7	<1	<1	2
Cobalt (µg/L)	0	--	--	--	--
Copper (µg/L)	23	4.1	2	<1	17
Iron (µg/L)	51	24	<3	ND	230
Lead (µg/L)	26	--	<1	<1	2.0
Lithium (µg/L)	0	--	--	--	--
Manganese (µg/L)	44	31	7	ND	500
Mercury (µg/L)	25	--	<0.1	<0.1	0.6
Molybdenum (µg/L)	15	2.2	1.4	<1.0	5.3
Nickel (µg/L)	0	--	--	--	--
Selenium (µg/L)	42	1.7	1.0	<1.0	20
Silver (µg/L)	0	--	--	--	--
Strontium (µg/L)	0	--	--	--	--
Vanadium (µg/L)	15	25	12	6	150
Zinc (µg/L)	26	71	11	<3	960

Table 5. Summary of chemical analyses for ground water—Continued

Property or dissolved constituent	White River aquifer				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance (µS/cm)	22	1,010	764	296	3,280
pH (standard units)	22	7.2	7.4	6.7	8.0
Carbon dioxide	3	12	11	7.1	16
Hardness, as $CaCO_3$	20	187	137	19	1,130
Solids, residue at 180° C	20	659	471	211	2,450
Solids, sum of constituents	19	653	466	215	2,310
Calcium	20	64	46	6.4	360
Magnesium	20	6.7	3.6	0.1	55
Sodium	20	154	103	5.1	650
Potassium	20	9.6	9.1	1.4	20
Bicarbonate	10	309	316	161	469
Alkalinity	17	310	288	137	589
Sulfate	20	97	17	<1	1,300
Chloride	20	93	9.8	1	860
Fluoride	20	0.5	0.4	<0.1	1.7
Silica	20	42	45	11	65
Nitrogen, nitrate	18	1.5	0.7	<0.005	7.6
Phosphorus, orthophosphate	13	0.2	0.05	0.02	0.8
Aluminum (µg/L)	3	--	<5	<5	8.3
Arsenic (µg/L)	9	6.5	7	<1	14
Barium (µg/L)	2	195	195	120	270
Boron µg/L)	10	784	110	20	2,170
Cadmium (µg/L)	2	--	<1	<1	1
Chromium (µg/L)	2	--	1.5	<1	2
Cobalt (µg/L)	0	--	--	--	--
Copper (µg/L)	0	--	--	--	--
Iron (µg/L)	9	32	11	<3	92
Lead (µg/L)	2	--	<1	<1	<1
Lithium (µg/L)	0	--	--	--	--
Manganese (µg/L)	9	98	9	<1	810
Mercury (µg/L)	2	--	<0.1	<0.1	<0.1
Molybdenum (µg/L)	0	--	--	--	--
Nickel (µg/L)	0	--	--	--	--
Selenium (µg/L)	9	1.2	<1	<1	5
Silver (µg/L)	0	--	--	--	--
Strontium (µg/L)	0	--	--	--	--
Vanadium (µg/L)	0	--	--	--	--
Zinc (µg/L)	2	7.5	7.5	4	11

Table 5. Summary of chemical analyses for ground water—Continued

Property or dissolved constituent	Pierre Shale aquifer				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance (µS/cm)	21	2,350	1,740	530	6,200
pH (standard units)	21	7.0	7.1	6.6	8.0
Carbon dioxide	2	9.2	9.2	7.3	11
Hardness, as $CaCO_3$	24	739	484	25	2,230
Solids, residue at 180° C	24	1,870	1,380	336	5,990
Solids, sum of constituents	20	1,720	1,170	331	4,940
Calcium	24	216	160	7.6	582
Magnesium	24	49	27	0.9	280
Sodium	24	277	190	13	830
Potassium	21	15	12	4.3	33
Bicarbonate	2	368	368	278	457
Alkalinity	19	335	326	122	550
Sulfate	24	886	565	<1	3,000
Chloride	24	93	34	4.5	790
Fluoride	24	0.6	0.4	<0.1	2.5
Silica	21	23	21	11	45
Nitrogen, nitrate	23	4.1	0.7	<0.1	40
Phosphorus, orthophosphate	5	0.05	0.02	0.01	0.12
Aluminum (µg/L)	0	--	--	--	--
Arsenic (µg/L)	5	--	<1	<1	5
Barium (µg/L)	5	87	27	18	280
Boron µg/L)	2	195	195	130	260
Cadmium (µg/L)	5	--	<1	<1	2
Chromium (µg/L)	5	--	<1	<1	2
Cobalt (µg/L)	0	--	--	--	--
Copper (µg/L)	0	--	--	--	--
Iron (µg/L)	6	319	60	5	1,700
Lead (µg/L)	5	--	<1	<1	<1
Lithium (µg/L)	0	--	--	--	--
Manganese (µg/L)	7	188	100	<1	500
Mercury (µg/L)	5	--	<0.1	<0.1	<0.1
Molybdenum (µg/L)	0	--	--	--	--
Nickel (µg/L)	0	--	--	--	--
Selenium (µg/L)	6	4.7	3.5	<1	10
Silver (µg/L)	0	--	--	--	--
Strontium (µg/L)	0	--	--	--	--
Vanadium (µg/L)	0	--	--	--	--
Zinc (µg/L)	5	171	55	10	390

Table 5. Summary of chemical analyses for ground water—Continued

Property or dissolved constituent	Dakota Sandstone aquifer				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance (μS/cm)	15	2,880	2,780	2,440	4,080
pH (standard units)	13	7.7	7.7	7.1	8.6
Carbon dioxide	7	27	12	4	107
Hardness, as $CaCO_3$	13	92	43	19	400
Solids, residue at 180° C	12	1,910	1,890	1,450	2,900
Solids, sum of constituents	12	1,870	1,870	1,450	2,780
Calcium	13	27	13	6	130
Magnesium	13	6	2	1	19
Sodium	13	640	650	390	970
Potassium	13	12	11	7	20
Bicarbonate	11	700	670	260	1,000
Alkalinity	1	303	303	303	303
Sulfate	13	652	620	120	1,200
Chloride	13	170	100	39	440
Fluoride	11	3	4	2	5
Silica	11	23	22	12	30
Nitrogen, nitrate	8	0.07	<0.1	ND	0.25
Phosphorus, orthophosphate	2	--	0.02	<0.01	0.03
Aluminum (μg/L)	1	10	10	10	10
Arsenic (μg/L)	2	--	<1	<1	<1
Barium (μg/L)	2	--	<100	<100	<100
Boron μg/L)	10	3,100	3,300	510	5,000
Cadmium (μg/L)	2	--	<1	<1	<1
Chromium (μg/L)	2	--	<1	<1	<1
Cobalt (μg/L)	1	--	ND	ND	ND
Copper (μg/L)	1	--	ND	ND	ND
Iron (μg/L)	6	330	80	20	1,500
Lead (μg/L)	2	--	<1	<1	<1
Lithium (μg/L)	1	170	170	170	170
Manganese (μg/L)	5	--	ND	ND	130
Mercury (μg/L)	1	<0.1	<0.1	<0.1	<0.1
Molybdenum (μg/L)	1	<1	<1	<1	<1
Nickel (μg/L)	1	--	ND	ND	ND
Selenium (μg/L)	3	--	<1	<1	10
Silver (μg/L)	1	--	ND	ND	ND
Strontium (μg/L)	1	530	530	530	530
Vanadium (μg/L)	1	15	15	15	15
Zinc (μg/L)	2	--	<20	<20	<20

Table 5. Summary of chemical analyses for ground water—Continued

Property or dissolved constituent	Inyan Kara aquifer				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance (µS/cm)	3	4,130	4,320	2,480	5,590
pH (standard units)	3	7.5	7.9	7.2	7.9
Carbon dioxide	3	15	15	13	18
Hardness, as $CaCO_3$	3	473	160	130	870
Solids, residue at 180° C	3	3,090	3,060	2,140	4,070
Solids, sum of constituents	3	2,940	3,000	1,960	3,860
Calcium	3	136	51	18	340
Magnesium	3	34	7.1	3.2	93
Sodium	3	824	1,050	131	1,290
Potassium	3	16	17	9.8	20
Bicarbonate	3	580	740	130	870
Alkalinity	3	478	607	108	718
Sulfate	3	1,400	1,300	1,100	1,800
Chloride	3	207	180	180	260
Fluoride	3	3.7	3.9	2.8	4.4
Silica	3	30	30	28	32
Nitrogen, nitrate	3	0.2	0.1	0.1	0.4
Phosphorus, orthophosphate	0	--	--	--	--
Aluminum (µg/L)	0	--	--	--	--
Arsenic (µg/L)	0	--	--	--	--
Barium (µg/L)	0	--	--	--	--
Boron µg/L)	3	1,437	1,900	210	2,200
Cadmium (µg/L)	0	--	--	--	--
Chromium (µg/L)	0	--	--	--	--
Cobalt (µg/L)	0	--	--	--	--
Copper (µg/L)	0	--	--	--	--
Iron (µg/L)	3	2,733	1,300	1200	5,700
Lead (µg/L)	0	--	--	--	--
Lithium (µg/L)	0	--	--	--	--
Manganese (µg/L)	3	183	140	140	270
Mercury (µg/L)	0	--	--	--	--
Molybdenum (µg/L)	0	--	--	--	--
Nickel (µg/L)	0	--	--	--	--
Selenium (µg/L)	1	ND	ND	ND	ND
Silver (µg/L)	0	--	--	--	--
Strontium (µg/L)	0	--	--	--	--
Vanadium (µg/L)	0	--	--	--	--
Zinc (µg/L)	0	--	--	--	--

Table 5. Summary of chemical analyses for ground water—Continued

Property or dissolved constituent	Minnelusa and Madison aquifers				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance (µS/cm)	2	2,060	2,060	1,510	2,610
pH (standard units)	2	7.2	7.2	7.1	7.3
Carbon dioxide	0	--	--	--	--
Hardness, as $CaCO_3$	3	970	810	800	1,300
Solids, residue at 180° C	3	1,560	1,270	1,190	2,220
Solids, sum of constituents	3	1,440	1,170	1,160	1,990
Calcium	3	287	250	240	370
Magnesium	3	63	48	47	94
Sodium	3	60	35	27	119
Potassium	3	15	13	11	21
Bicarbonate	3	143	140	140	150
Alkalinity	3	118	114	114	125
Sulfate	3	817	680	670	1,100
Chloride	3	104	42	40	230
Fluoride	3	1.5	1.7	1.0	1.7
Silica	3	34	39	24	40
Nitrogen, nitrate	2	--	0.3	ND	0.5
Phosphorus, orthophosphate	1	<0.01	<0.01	<0.01	<0.01
Aluminum (µg/L)	1	20	20	20	20
Arsenic (µg/L)	1	3	3	3	3
Barium (µg/L)	1	<100	<100	<100	<100
Boron µg/L)	3	140	170	70	180
Cadmium (µg/L)	1	<2	<2	<2	<2
Chromium (µg/L)	1	ND	ND	ND	ND
Cobalt (µg/L)	0	--	--	--	--
Copper (µg/L)	1	ND	ND	ND	ND
Iron (µg/L)	3	2,413	890	450	5,900
Lead (µg/L)	1	3	3	3	3
Lithium (µg/L)	1	60	60	60	60
Manganese (µg/L)	3	90	50	30	190
Mercury (µg/L)	1	3.4	3.4	3.4	3.4
Molybdenum (µg/L)	1	3	3	3	3
Nickel (µg/L)	0	--	--	--	--
Selenium (µg/L)	1	<1	<1	<1	<1
Silver (µg/L)	0	--	--	--	--
Strontium (µg/L)	1	4,600	4,600	4,600	4,600
Vanadium (µg/L)	0	--	--	--	--
Zinc (µg/L)	1	330	330	330	330

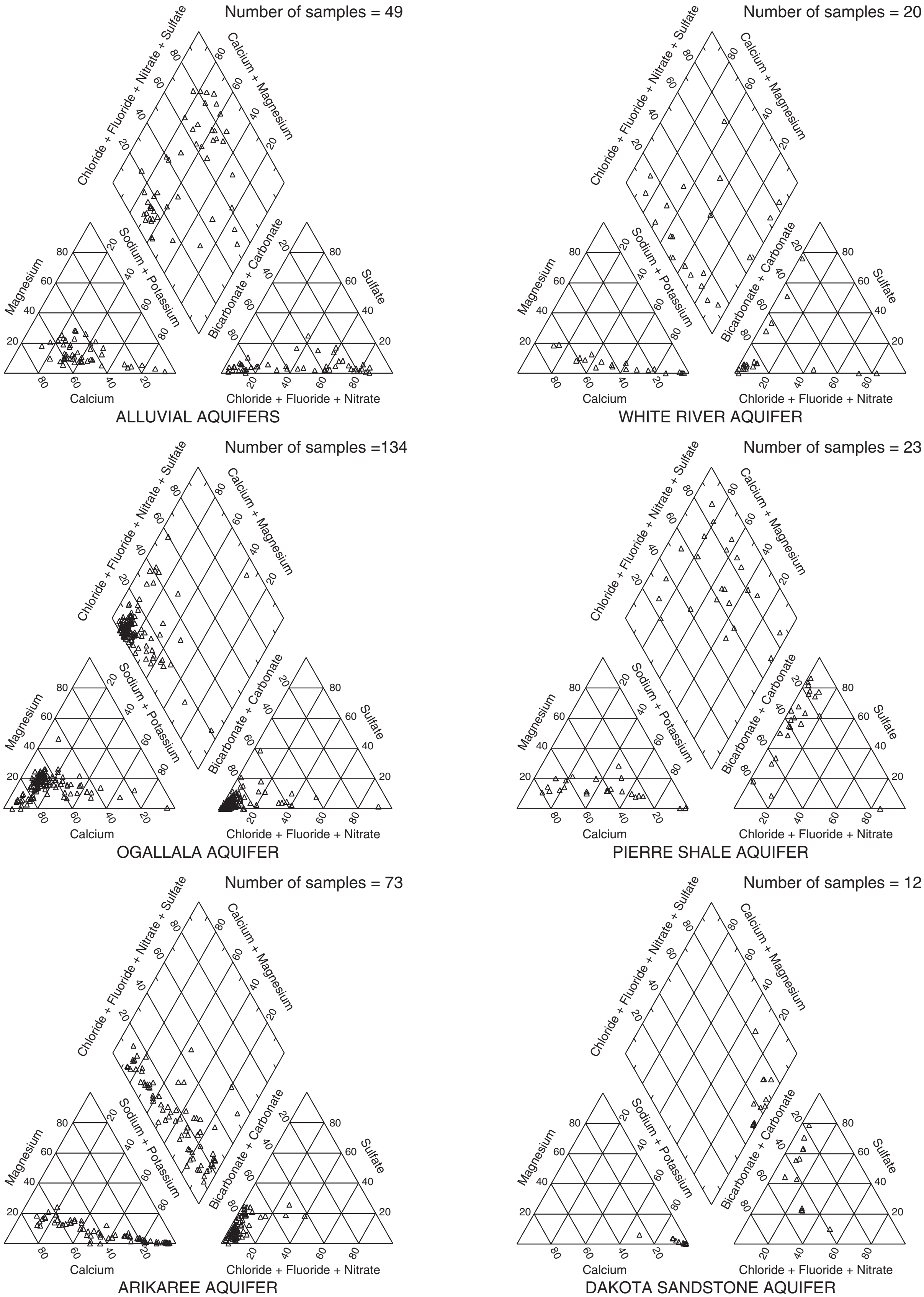


Figure 29. Trilinear diagrams showing proportional concentrations of major ions in ground-water samples.

The Ogallala aquifer is a calcium-bicarbonate water type, and the Arikaree aquifer is a calcium sodium bicarbonate water type (fig. 29). Generally, the Ogallala and Arikaree aquifers yield water that has low concentrations of dissolved solids, is fresh, and is soft to moderately hard. The dominant species in the White River aquifer generally are calcium, sodium, and bicarbonate (fig. 29). The water quality of the White River aquifer varies and is dependent on depth and proximity of the aquifer to the Pierre Shale. Like the alluvial aquifers, the closer the water-bearing deposits of the White River Group are to the Pierre Shale, the higher in dissolved solids concentrations, more saline, and harder the water.

The bedrock aquifers generally yield hard, saline water with high concentrations of dissolved solids. The dominant species in the Pierre Shale aquifer vary from calcium to sodium and from bicarbonate to sulfate (fig. 29). In the Dakota Sandstone aquifer, the dominant species generally are sodium and sulfate (fig. 29). The Dakota Sandstone aquifer generally is the only bedrock aquifer that yields soft to moderately hard water with a mean concentration of 92 mg/L (table 5). Water from all other bedrock aquifers generally is hard to very hard with means ranging from 473 to 970 mg/L (table 5). The water type of the Inyan Kara aquifer generally is a sodium or calcium sulfate type and the water type of the Minnelusa and Madison aquifer generally is a calcium sulfate type (Ellis and others, 1971). Although the concentrations of dissolved solids in the Minnelusa and Madison aquifers are lower than the other bedrock aquifers, the water is very hard ranging from 800 to 1,300 mg/L (table 5).

Boxplots are presented in figure 30 for the alluvial, Ogallala, Arikaree, White River, and Pierre Shale aquifers for each of the constituents listed in table 5 that had a minimum of 10 analyses in samples from at least two aquifers. The Inyan Kara, Minnelusa, and Madison aquifers were not included in the boxplots because the maximum number of analyses for each constituent was three. The boxplots not only show the variations of the constituents within each aquifer, but also allow a comparison of the general water-quality characteristics between the aquifers. For example, the highest nitrate concentrations were detected in the Ogallala aquifer and the highest arsenic concentrations in the Arikaree aquifer.

The significance of the chemical and physical properties of water and, if applicable, the U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) and Secondary Maximum Contaminant Level (SMCL) are presented in table 6 and shown in figure 30. The MCL's are established for contaminants that, if present in drinking water, may cause adverse human health effects; MCL's are enforceable health-based standards (U.S. Environmental Protection Agency, 1994a). The SMCL's are established for contaminants that can adversely affect the odor or appearance of water and result in discontinuation of use of the water; SMCL's are nonenforceable, generally non-health-based standards that are related to the aesthetics of water use (U.S. Environmental Protection Agency, 1994a).

Water samples collected from wells completed in alluvial aquifers exceeded the USEPA MCL's for the following regulated constituents: 1 sample out of 49 analyzed for fluoride exceeded the MCL of 4.0 mg/L, and 1 sample out of 16 analyzed for selenium exceeded the MCL of 50 μg/L (micrograms per liter). The median concentrations for dissolved solids and manganese exceeded the SMCL's for these constituents. Almost one-half of the samples collected from alluvial wells exceeded the SMCL for sulfate and about one-third exceeded the SMCL for iron.

Two constituents analyzed in samples collected from the Ogallala aquifer exceeded the respective MCL's: 1 sample out of 54 exceeded the fluoride MCL, and 13 samples out of 92 exceeded the nitrate MCL of 10 mg/L. Only a few samples exceeded the SMCL's for dissolved solids (5 out of 70 samples) and iron (1 out of 48 samples). The Rosebud Sioux Tribe reported high nitrate concentrations in the Ogallala aquifer in a small area of Todd County (Huq, 1989). An investigation of ground-water quality, with emphasis on nitrate concentrations, in shallow aquifers (including the Ogallala, Arikaree, and White River aquifers) in parts of Mellette and Todd County was conducted by Hammond (1994). This investigation concluded that both point and non-point sources of contamination were impacting the ground water in Todd County, and that point sources of contamination were impacting the ground water in Mellette County. The USGS also investigated nitrate concentrations in a small area of Todd County that had high concentrations in the Ogallala aquifer; the data from this investigation is presented by Carter (1997).

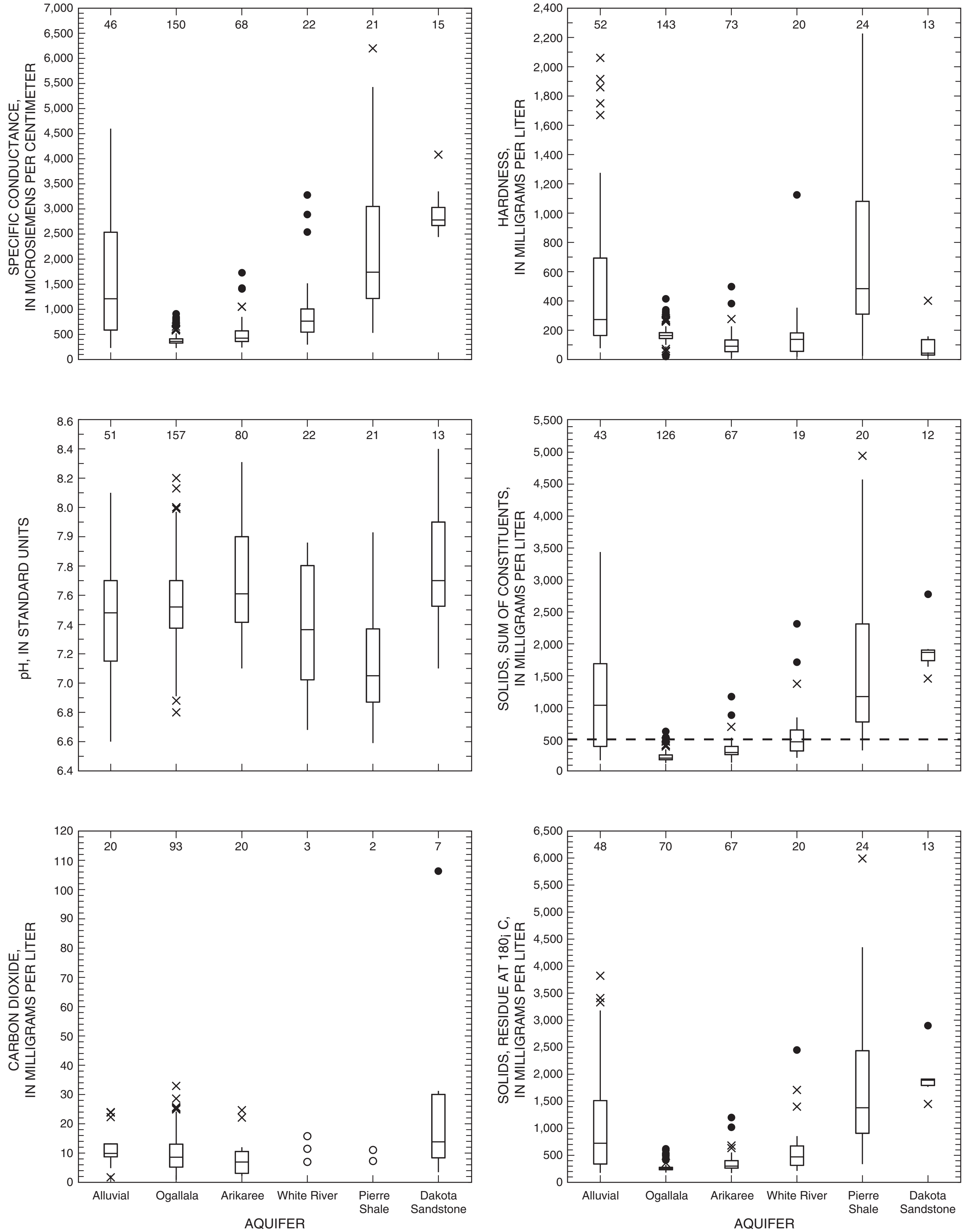


Figure 30. Boxplots of chemical constituents in ground-water samples.

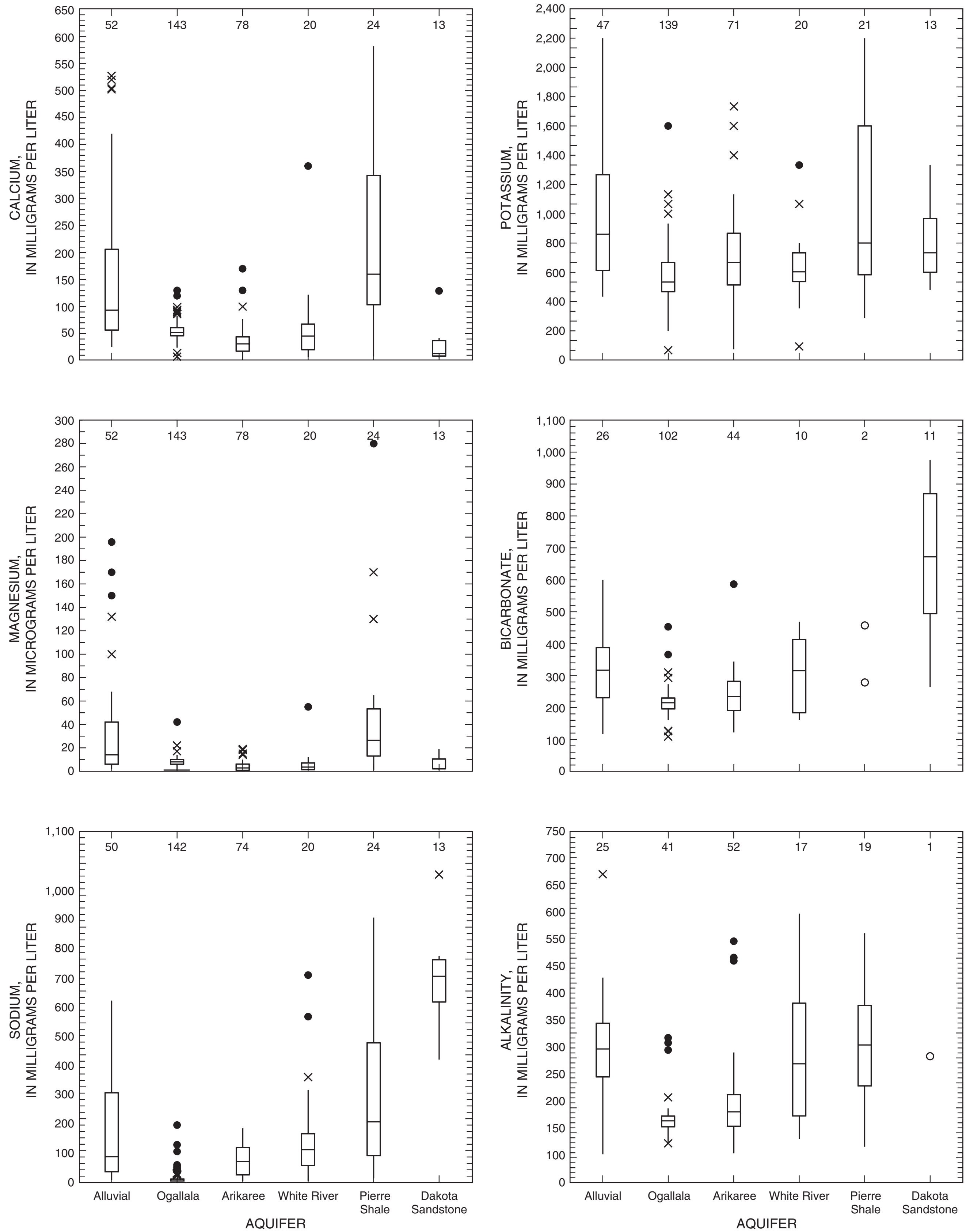


Figure 30. Boxplots of chemical constituents in ground-water samples.--Continued

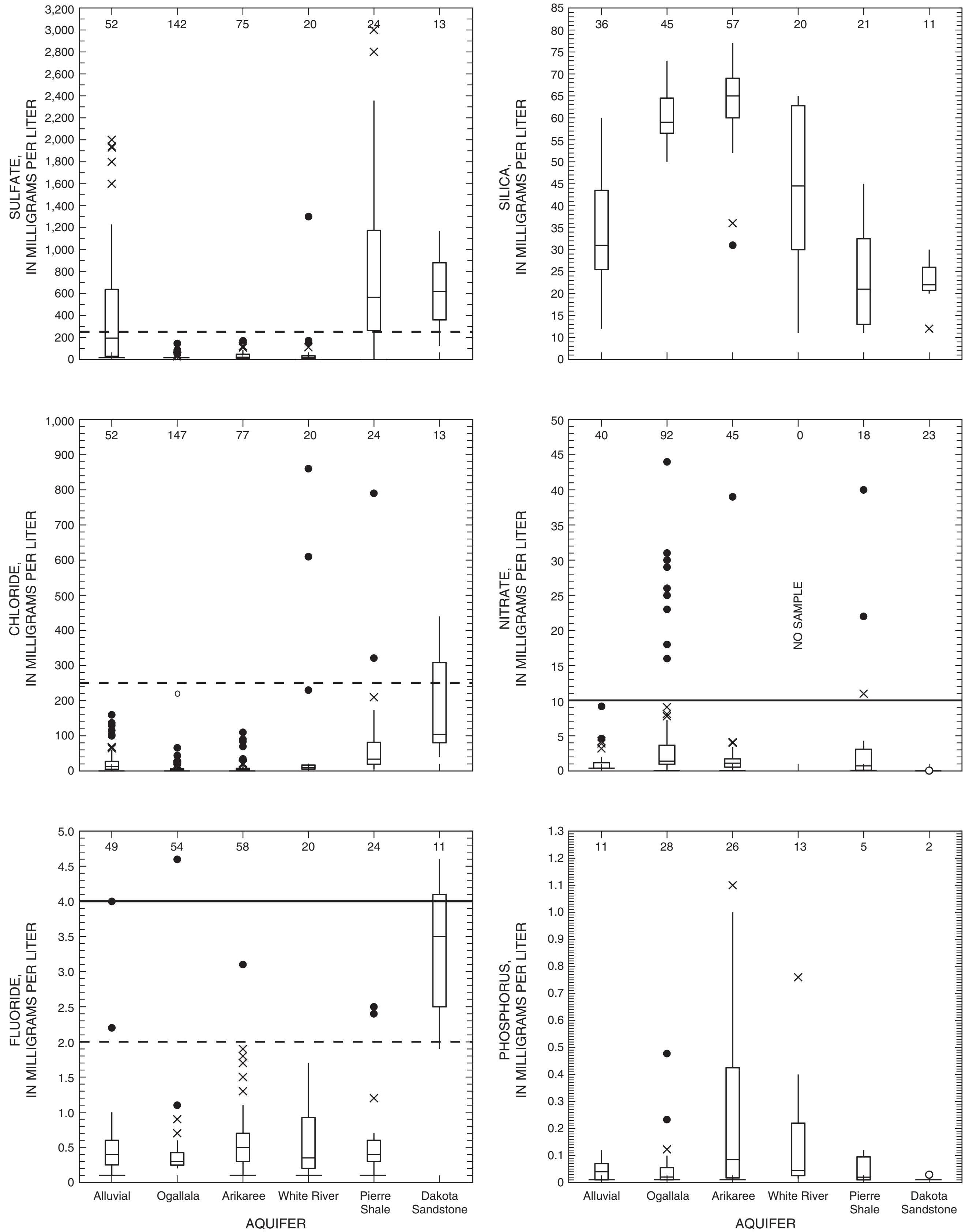


Figure 30. Boxplots of chemical constituents in ground-water samples.--Continued

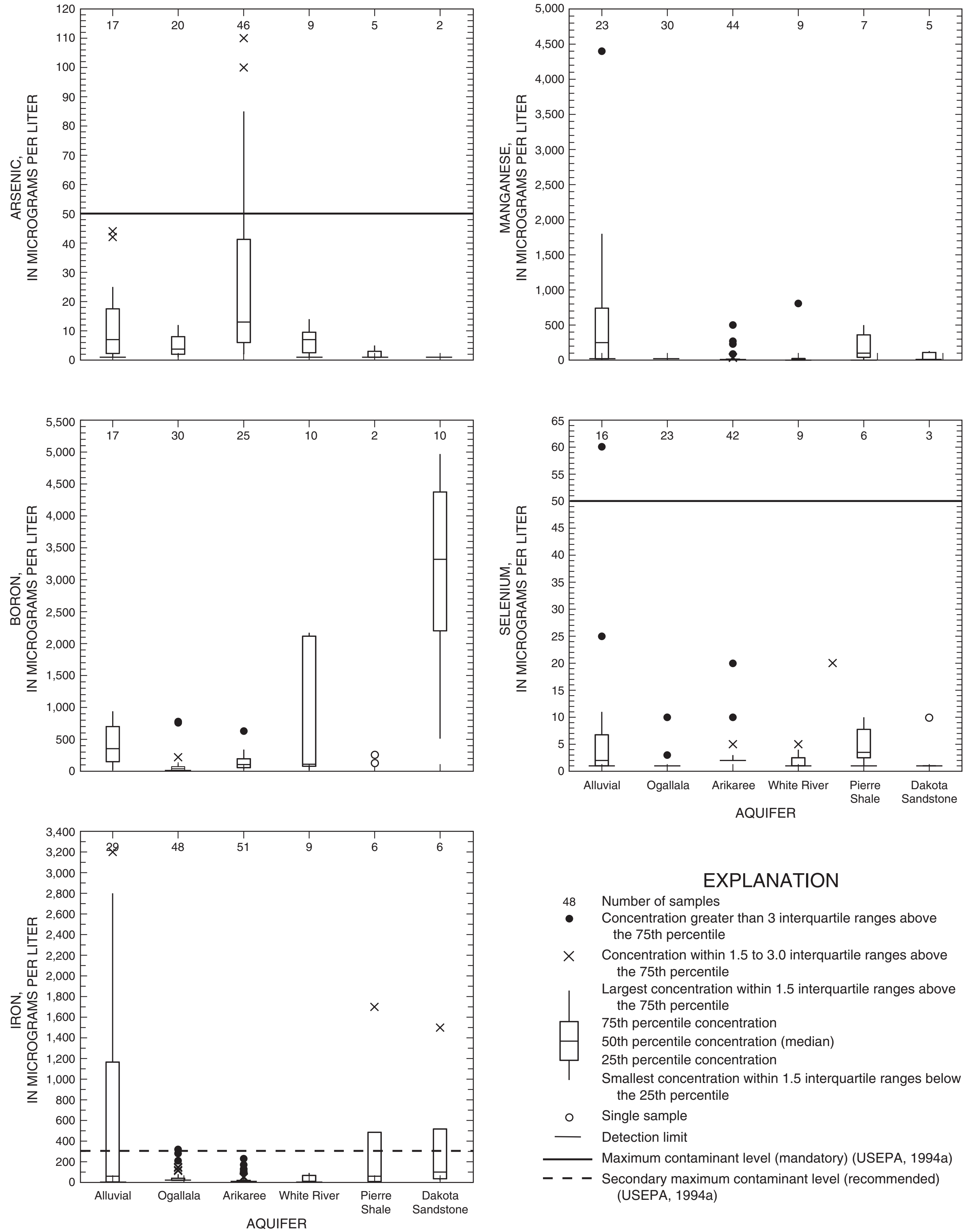


Figure 30. Boxplots of chemical constituents in ground-water samples.--Continued

Table 6. Significance of chemical and physical properties of water

Constituent or property	Limit	Significance
Specific conductance		A measure of the ability of water to conduct an electrical current; varies with temperature. Magnitude depends on concentration, kind, and degree of ionization of dissolved constituents; can be used to determine the approximate concentration of dissolved solids. Values are reported in microsiemens per centimeter at 25° Celsius.
pH	6.5-8.5 units (recommended)	A measure of the hydrogen ion concentration; pH of 7.0 indicates a neutral solution, pH values less than 7.0 indicate acidity, pH values greater than 7.0 indicate alkalinity. Water generally becomes more corrosive with decreasing pH; however, excessively alkaline water also may be corrosive.
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.
Hardness (as $CaCO_3$)		Related to the soap-consuming characteristics 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 concentration is called noncarbonate 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 (Heath, 1983).
Calcium plus magnesium		Cause most of the hardness and scale-forming properties of water (see hardness).
Sodium plus potassium		Large concentrations may limit use of water for irrigation and industrial use and, in combination with chloride, give water a salty taste. Abnormally large concentrations may indicate natural brines, industrial brines, or sewage.
Percent sodium		Ratio of sodium to total cations in milliequivalents per liter expressed as a percentage. Important in irrigation waters; the greater 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 greater the SAR, the less suitable the water for irrigation.
Bicarbonate		In combination with calcium and magnesium forms carbonate hardness.
Sulfate	250 mg/L (recommended)	Sulfates of calcium and magnesium form hard scale. Large concentrations of sulfate have a laxative effect on some people and, in combination with other ions, give water a bitter taste.
Chloride	250 mg/L (recommended)	Large concentrations increase the corrosiveness of water and, in combination with sodium, give water a salty taste.
Fluoride	4.0 mg/L (mandatory) 2.0 mg/L (recommended)	Reduces incidence of tooth decay when optimum fluoride concentrations present in water consumed by children during the period of tooth calcification. Potential health effects of long-term exposure to elevated fluoride concentrations include dental and skeletal fluorosis (U.S. Environmental Protection Agency, 1994b).
Silica (as SiO_3)		Forms hard scale in pipes and boilers and may form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Dissolved solids	500 mg/L (recommended)	The total of all dissolved mineral constituents, usually expressed in milligrams per liter. 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 no taste. The dissolved solids concentration commonly is called the water's salinity and is classified as follows: fresh, 0 to 1,000 mg/L; slightly saline, 1,000 to 3,000 mg/L; moderately saline, 3,000 to 10,000 mg/L; very saline, 10,000 to 35,000 mg/L; and briny, more than 35,000 mg/L (Heath, 1983).
Nitrite (as N)	1 mg/L (mandatory)	Commonly formed as an intermediate product in bacterially mediated nitrification and denitrification of ammonia and other organic nitrogen compounds. Thus it often, though not always, may indicate pollution by sewage, feedlot or barnyard drainage, or some similar source. Nitrite has a toxic effect similar to that of nitrate, but stronger for given concentrations.

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

Constituent or property	Limit	Significance
Nitrate (as N)	10 mg/L (mandatory)	Concentrations greater than local background levels may indicate pollution by feedlot runoff, sewage, or fertilizers. Concentrations greater than 10 mg/L, as nitrogen, may be injurious when used in feeding infants.
Phosphate		Essential to plant growth. Concentrations greater than local background levels may indicate pollution by fertilizer or sewage.
Aluminum	0.05-0.2 mg/L (recommended)	No known necessary role in human or animal diet. Nontoxic in the concentrations normally found in natural water supplies. Elevated dissolved aluminum concentrations in some low pH waters can be toxic to some types of fish (Hem, 1985).
Arsenic	50 µg/L (mandatory)	No known necessary role in human or animal diet, but is toxic. A cumulative poison that is slowly excreted. Can cause nasal ulcers; skin cancer; damage to the kidneys, liver, and intestinal walls; and death.
Barium	2,000 µg/L (mandatory)	Toxic; used in rat poison. In moderate to large concentrations can cause death; smaller concentrations cause damage to the heart, blood vessels, and nerves.
Boron		Essential to plant growth, but may be toxic to crops when present in excessive concentrations in irrigation water. Sensitive plants 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. The recommended limit is 750 µg/L for long-term irrigation on sensitive crops (U.S. Environmental Protection Agency, 1986).
Cadmium	5 µg/L (mandatory)	A cumulative poison; very toxic. Not known to be either biologically essential or beneficial. Believed to promote renal arterial hypertension. Elevated concentrations may cause liver and kidney damage, or even anemia, retarded growth, and death.
Chromium	100 µg/L (mandatory)	No known necessary role in human or animal diet. In the hexavalent form is toxic, leading to intestinal damage and to nephritis.
Copper	1,000 µg/L (recommended)	Essential to metabolism; copper deficiency in infants and young animals results in nutritional anemia. Large concentrations of copper are toxic and may cause liver damage. Some people can detect the taste of as little as 1 to 5 mg/L of copper.
Iron	300 µg/L (recommended)	Forms rust-colored sediment; stains laundry, utensils, and fixtures reddish brown. Objectionable for food and beverage processing. Can promote growth of certain kinds of bacteria that clog pipes and well openings.
Lead	50 µg/L (mandatory) 15 µg/L (recommended)	A cumulative poison, toxic in small concentrations. Can cause lethargy, loss of appetite, constipation, anemia, abdominal pain, gradual paralysis in the muscles, and death. If 1 in 10 samples of a public supply exceed 15 µg/L, the USEPA recommends treatment to remove lead and monitoring of the water supply for lead content (U.S. Environmental Protection Agency, 1991).
Lithium		Reported as probably beneficial in small concentrations (250 to 1,250 µg/L). Reportedly may help strengthen the cell wall and improve resistance to genetic damage and to disease. Lithium salts are used to treat certain types of psychosis.
Manganese	50 µg/L (recommended)	Causes gray or black stains on porcelain, enamel, and fabrics. Can promote growth of certain kinds of bacteria that clog pipes and well openings.
Mercury	2 µg/L (mandatory)	No known essential or beneficial role in human or animal nutrition. Liquid metallic mercury and elemental mercury dissolved in water are comparatively nontoxic, but some mercury compounds, such as mercuric chloride and alkyl mercury, are very toxic. Elemental mercury is readily alkylated, particularly to methyl mercury, and concentrated by biological activity. Potential health effects of exposure to some mercury compounds in water include severe kidney and nervous system disorders (U.S. Environmental Protection Agency, 1994b).
Molybdenum		In minute concentrations, appears to be an essential nutrient for both plants and animals, but in large concentrations may be toxic.
Nickel	100 µg/L (mandatory)	Very toxic to some plants and animals. Toxicity for humans is believed to be very minimal.

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

Constituent or property	Limit	Significance
Selenium	50 µg/L (mandatory)	Essential to human and animal nutrition in minute concentrations, but even a moderate excess may be harmful or potentially toxic if ingested for a long time (Callahan and others, 1979). Potential human health effects of exposure to elevated selenium concentrations include liver damage (U.S. Environmental Protection Agency, 1994b).
Silver	100 µg/L (recommended)	Causes permanent bluish darkening of the eyes and skin (argyria). Where found in water is almost always from pollution or by intentional addition. Silver salts are used in some countries to sterilize water supplies. Toxic in large concentrations.
Strontium		Importance in human and animal nutrition is not known, but believed to be essential. Toxicity believed very minimal--no more than that of calcium.
Vanadium		Not known to be essential to human or animal nutrition, but believed to be beneficial in trace concentrations. May be an essential trace element for all green plants. Large concentrations may be toxic.
Zinc	5,000 µg/L (recommended)	Essential and beneficial in metabolism; its deficiency in young children or animals will retard growth and may decrease general body resistance to disease. Seems to have no ill effects even in fairly large concentrations (20,000 to 40,000 mg/L), but can impart a metallic taste or milky appearance to water. Zinc in drinking water commonly is derived from galvanized coatings of piping.

Water samples collected from wells completed in the Arikaree aquifer did not exceed the USEPA MCL's for any regulated constituent with the following exceptions: 1 sample out of 45 analyzed for nitrate exceeded the MCL, and 11 samples out of 46 analyzed for arsenic exceeded the MCL of 50 µg/L. In samples from the Arikaree aquifer, 1 out of 58 samples exceeded the SMCL for fluoride, 7 out of 67 samples for dissolved solids, and 4 out of 44 samples for manganese. An investigation of high arsenic concentrations in the Arikaree aquifer in the Grass Mountain area, located about 5 miles northwest of Rosebud in Todd County, was conducted by the USGS in cooperation with the Rosebud Sioux Tribe and the South Dakota Geological Survey during 1991-96. The results of the investigation indicate that the source of arsenic is natural and probably sourced by volcanic ash in the Arikaree Formation (Carter and others, 1998). Arsenic may be high in the aquifer in other parts of Mellette and Todd Counties because two of the samples with arsenic concentrations that exceeded the MCL were not collected near the Grass Mountain area but were located in eastern Todd County (Carter, 1997).

No water samples collected from wells completed in the White River aquifer exceeded the USEPA MCL's for any regulated constituent, although almost one-half of the samples exceeded the SMCL for dissolved solids. A few samples also exceeded the SMCL's for sulfate (4 out of 20 samples), manganese (1 out of 9 samples), and chloride (3 out of 20 samples).

The only constituent concentration that exceeded an MCL in samples collected from the Pierre Shale aquifer was nitrate (3 out of 23 samples). The median concentrations for dissolved solids, sulfate, and manganese exceeded the SMCL's for these constituents. Some samples from the Pierre Shale aquifer also exceeded the SMCL's for chloride (2 out of 24 samples), fluoride (2 out of 24 samples), and iron (1 out of 7 samples).

Water samples collected from wells completed in the Dakota Sandstone aquifer exceeded the USEPA MCL's for fluoride. Of the 11 samples analyzed for fluoride, 5 equalled or exceeded the MCL and 10 exceeded the SMCL. The median concentrations for dissolved solids and sulfate exceeded the SMCL's for these constituents. Concentrations from some of the samples collected from the Dakota Sandstone aquifer also exceeded the SMCL's: 4 out of 13 for chloride, 1 out of 6 for iron, and 2 out of 5 for manganese.

In samples collected from the Inyan Kara aquifer, the MCL for fluoride was exceeded in 1 of the 3 samples, and the SMCL for fluoride was exceeded for all 3 samples. For the 3 samples collected, the minimum concentrations for dissolved solids, sulfate, iron, and manganese exceeded the SMCL's for these constituents. One sample exceeded the SMCL for chloride.

The MCL for mercury was exceeded in one sample collected from the Minnelusa and Madison aquifers. The minimum concentrations of the three samples exceeded the SMCL's for dissolved solids, sulfate, and iron. Two of the 3 samples exceeded the SMCL for manganese.

The general suitability of water for irrigation from the aquifers in the study area can be determined by using the South Dakota irrigation-water diagram (fig. 31). The diagram is based on South Dakota irrigation-water standards (revised January 7, 1982) and shows the State's water-quality and soil-texture requirements for the issuance of an irrigation permit. Generally, most water from the Ogallala and Arikaree aquifers is suitable for irrigation. The quality of water from alluvial aquifers and the White River aquifer generally is suitable for irrigation, but yields probably are not sufficient in most areas. Limited irrigation may be supported by alluvial aquifers in areas where the permeability is very high and in areas where the aquifer is hydraulically connected to a perennial stream. A few wells completed in the White River aquifer are used to support irrigation in Mellette County. The Pierre Shale, Dakota Sandstone, and Inyan Kara aquifers are unsuitable for irrigation because of high sodium-adsorption ratios coupled with high specific conductances. Water from the Minnelusa and Madison aquifers can be used for irrigation under certain soil conditions (fig. 31), although currently no irrigation-use data have been reported for either aquifer in Mellette and Todd Counties.

Water from eight aquifers in the study area generally is suitable for livestock watering. Suitability of water for domestic and municipal purposes is limited in the bedrock aquifers because of high dissolved solids. Generally, water from the shallow aquifers (alluvial, Ogallala, Arikaree, and White River aquifers) is suitable for all water uses, except where constituent concentrations exceed the MCL's.

WATER USE

Withdrawal of water during 1995 for use in Mellette and Todd Counties was about 10,560 acre-feet (table 7). The withdrawal was about 1,220 acre-feet in Mellette County and about 9,340 acre-feet in Todd County. Surface-water withdrawal was about 780 acre-feet in Mellette County, of which 54 percent was used for livestock and 46 percent for irrigation. Surface-water withdrawal was about 630 acre-feet in Todd County, of which 59 percent was used for livestock and 41 percent for irrigation. About 60 percent of the water used for stock watering in both counties was derived from surface-water sources and 40 percent from ground-water sources. In Mellette County, 86 percent of the water used for irrigation was derived from surface-water sources and 14 percent from ground-water sources. In Todd County, only 3 percent of the water used for irrigation was from surface-water sources, and 97 percent was from ground-water sources. Ground water was the source of all water used for municipal and rural-domestic purposes in both counties.

Table 7. Ground- and surface-water withdrawals in Mellette and Todd Counties during 1995

[From F.D. Amundson, U.S. Geological Survey, written commun., 1997]

Source	Total		Municipal		Rural-domestic		Livestock		Irrigation	
	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent
Mellette County										
Ground water	437	4.1	45	0.4	56	0.5	280	2.7	56	0.5
Surface water	784	7.4	0	0	0	0	426	4.0	358	3.4
Todd County										
Ground water	8,713	82.5	123	1.2	582	5.5	246	2.3	7,762	73.5
Surface water	627	5.9	0	0	0	0	370	3.5	257	2.4
Total, both counties	10,561	[1]100	168	1.6	638	6.0	1,322	12.5	8,433	[1]79.9

[1]Total percentage may not equal sum of components because of rounding.

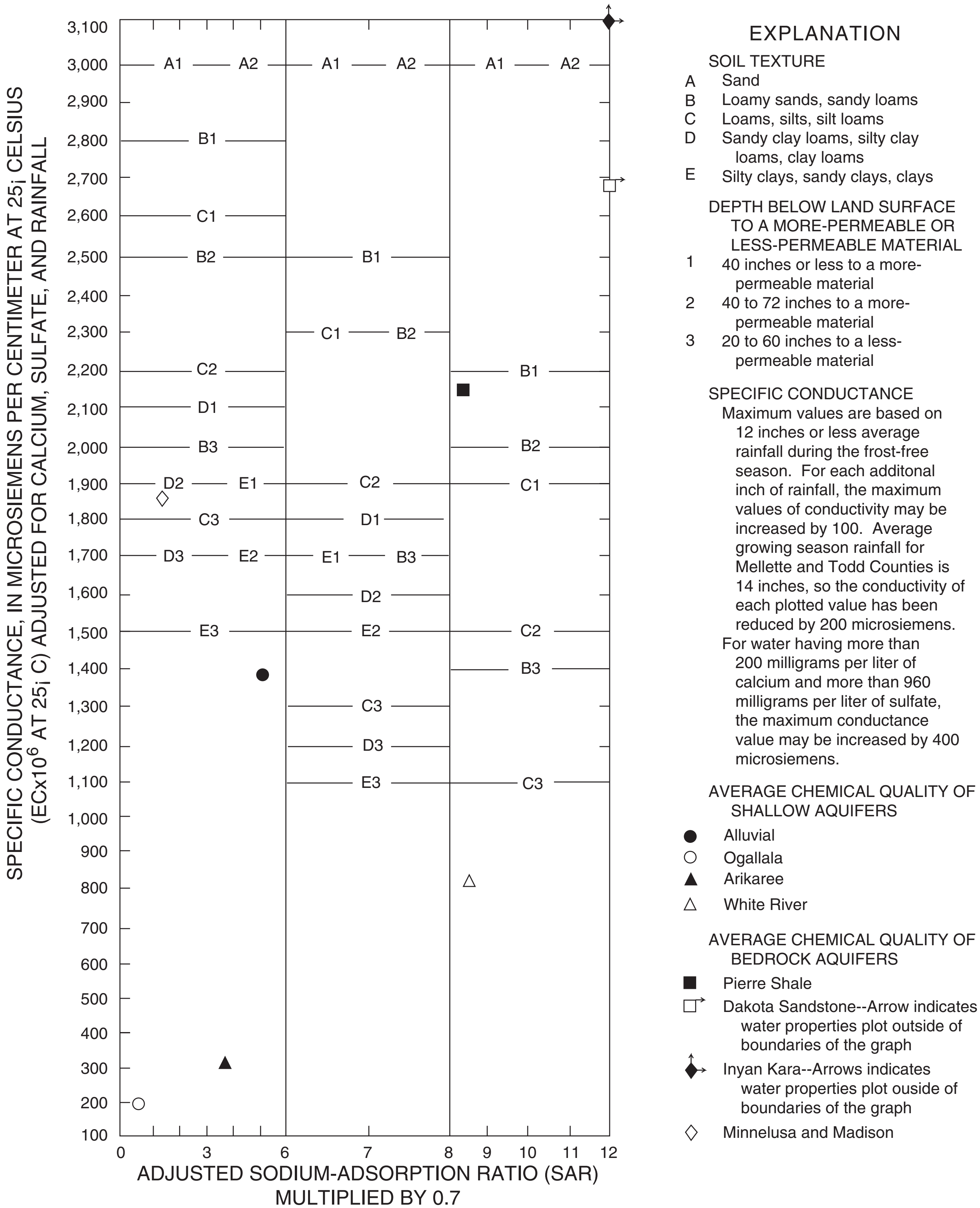


Figure 31. South Dakota irrigation-water classification diagram (based on South Dakota standards (revised Jan. 7, 1982) for maximum allowable specific conductance and adjusted sodium-adsorption-ratio values for which an irrigation permit can be issued for applying water under various soil-texture conditions. Water an be applied under all conditions at or above the plotted point, but not below it, provided other conditions as defined by the State Conservation Commission are met (from Koch, 1983)).

Withdrawal of ground water in Mellette County during 1995, summarized in table 8, was almost 440 acre-feet. Aquifer withdrawals were estimated from available water-use data in the USGS NWIS ground-water database. About 66 percent of the ground water used was supplied by shallow aquifers, and about 34 percent was supplied by bedrock aquifers. Most of the ground water was supplied by alluvial aquifers (about 31 percent) and the Pierre Shale aquifer (about 24 percent). The deeper bedrock aquifers only supplied about 9 percent of the ground water. Most of the ground water used in Mellette County was for stock-watering purposes (64 percent).

Withdrawal of ground water in Todd County during 1995, summarized in table 9, was about 8,710 acre-feet. Almost 100 percent of the ground water used was supplied by shallow aquifers. The Ogallala aquifer supplied about 84 percent of the ground water used in Todd County. Other than the Pierre Shale, no bedrock aquifers supply water in Todd County. Most of the ground water (89 percent) was used for irrigation.

Table 8. Estimated withdrawal of ground water in Mellette County during 1995

Source	Total		Municipal		Rural-domestic		Livestock		Irrigation	
	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent
Shallow aquifers										
Alluvial	134	30.7	31	7.0	11	2.5	73	16.7	19	4.3
Arikaree	73	16.7	3	0.7	25	5.7	20	4.6	25	5.7
White River	83	19.0	4	1.0	8	1.8	59	13.5	12	2.7
Subtotal	290	66.4	38	8.7	44	[1]10.1	152	[1]34.8	56	[1]12.8
Bedrock aquifers										
Pierre Shale	106	24.2	0	0	10	2.3	96	22.0	0	0
Dakota Sandstone	26	5.9	7	1.6	2	0.5	17	3.9	0	0
Inyan Kara	10	2.3	0	0	0	0	10	2.4	0	0
Minnelusa and Madison	5	1.1	0	0	0	0	5	1.1	0	0
Subtotal	147	[1]33.6	7	1.6	12	[1]2.7	128	[1]29.3	0	0
Total, all aquifers	437	100	45	10.3	56	12.8	280	64.1	56	[1]12.8

[1]Total percentage may not equal sum of components because of rounding.

Table 9. Estimated withdrawal of ground water in Todd County during 1995

Source	Total		Municipal		Rural-domestic		Livestock		Irrigation	
	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent
Shallow aquifers										
Alluvial	44	0.5	0	0	38	0.4	6	0.1	0	0
Ogallala	7,355	84.4	41	0.5	125	1.4	102	1.2	7,087	81.3
Arikaree	1,228	14.1	82	0.9	357	4.1	114	1.3	675	7.8
White River	81	0.9	0	0	59	0.7	22	0.2	0	0
Subtotal	8,708	[1]100	123	1.4	579	6.6	244	2.8	7,762	89.1
Bedrock aquifers										
Pierre Shale	5	0	0	0	3	0	2	0	0	0
Subtotal	5	0	0	0	3	0	2	0	0	0
Total, all aquifers	8,713	100	123	1.4	582	[1]6.7	246	2.8	7,762	89.1

[1]Total percentage may not equal sum of components because of rounding

SUMMARY AND CONCLUSIONS

Mellette and Todd Counties, located in south-central South Dakota, have a combined area of 2,694 square miles. The main source of income is ranching. The average annual precipitation is about 19 inches. The White River forms the northern boundary of Mellette County and the South Dakota-Nebraska border forms the southern boundary of Todd County. The major water resources of the counties are surface water and ground water from shallow and bedrock aquifers.

The major rivers in Mellette and Todd Counties are the White, Little White, and Keya Paha Rivers. All of Mellette County and 51 percent of Todd County is drained by the White River, in Nebraska, and its tributaries; 49 percent of Todd County is drained by the Niobrara River and its tributaries, which include the Keya Paha River. The average flow of the Little White River is about 56 cubic feet per second as the river enters Todd County, and the average flow of the Little White River is 131 cubic feet per second at the most downstream streamflow-gaging station in Mellette County. The Keya Paha River near Keyapaha (just outside Todd County) has an average flow of about 39 cubic feet per second. The average annual runoff for the counties ranges from 0.94 to 2.36 inches and averages 1.62 inches based on records from nine gaging stations in and near the counties. Bicarbonate, calcium, and sulfate are the dominant chemical species in the water of the Little White River. Surface-water quality varies seasonally with volume of streamflow. Generally, the concentrations of dissolved constituents increase from upstream to downstream.

The geology of Mellette and Todd Counties consists mostly of marine, fluvial, and eolian deposits. The major shallow aquifers in the counties are the alluvial, Ogallala, Arikaree, and White River aquifers. The bedrock aquifers include the Pierre Shale, Dakota Sandstone, Inyan Kara, and Minnelusa and Madison aquifers.

In Todd County, ground water generally can be obtained from shallow wells completed in the alluvial, Ogallala, Arikaree, or White River aquifers. In Mellette County, the Pierre Shale is present at the land surface throughout most of the county, which means that the Ogallala, Arikaree, and White River aquifers are not present. Because shallow ground-water sources in Mellette County often are not available, deep bedrock aquifer wells, often greater than 1,000 feet, are sometimes installed.

The boundaries of four shallow aquifers (alluvial, Ogallala, Arikaree, and White River) and one bedrock aquifer (Pierre Shale) were delineated for this study. Alluvial aquifers are present in both Mellette and Todd Counties; however, the water has high concentrations of dissolved solids, is saline, and is very hard in Mellette County where the alluvial deposits are underlain by the Pierre Shale. Also, deposits overlying the Pierre Shale are relatively impermeable and may not yield an adequate supply of water. The major alluvial aquifers are located along the Keya Paha, Little White, and White Rivers. The average thickness of the alluvial aquifers is 29 feet. Alluvial aquifers underlie about 440 square miles of the study area and store an estimated 1.6 million acre-feet of water. Recharge to the alluvial aquifers is by infiltration of precipitation, stream loss, and discharge from springs originating in the Tertiary deposits. Discharge from the alluvial aquifers is through withdrawals from domestic and stock wells and by evapotranspiration from the aquifer. Water from the alluvial aquifers primarily is used for stock-watering and rural-domestic purposes; however, it can be used to support irrigation in some areas of Mellette County.

The Ogallala aquifer is present throughout most of Todd County, but not in Mellette County. The aquifer underlies 950 square miles in Todd County and contains an estimated 17 million acre-feet of water in storage. The depth to the top of the Ogallala aquifer ranges from 0 to 164 feet below land surface, and the average thickness is 137 feet. The aquifer is thickest in central Todd County, and is under water-table conditions except in southwestern Todd County, where it is confined. Recharge to the Ogallala aquifer is by infiltration of precipitation on the outcrops of the Ogallala Formation or overlying windblown sand deposits and by stream loss. The primary discharge from the aquifer is through withdrawals from domestic, public, stock, and irrigation wells; by loss to streams and springs; and by evapotranspiration. The aquifer has the highest yield potential of the eight aquifers in the study area; the maximum reported well yield is 1,250 gallons per minute.

The Arikaree aquifer is present throughout most of Todd County, although it is absent in the eastern part of the county. The Arikaree is present in only a small part of southwestern Mellette County. The Arikaree aquifer underlies about 1,360 square miles in Mellette and Todd Counties and contains an estimated 50 million acre-feet of water in storage. The depth to the top of the aquifer ranges from 0 to 406 feet below land surface, and the average thickness is 290 feet. About one-half of the aquifer is under water-table conditions and one-half is confined. Yields from the Arikaree aquifer range from 1 to 1,005 gallons per minute and generally are not as high as those from the Ogallala aquifer, but yields are often sufficient to support irrigation. Recharge to the Arikaree aquifer is by infiltration of precipitation on the outcrops of the Arikaree Formation and by stream loss. Discharge is through withdrawals from domestic, stock, and irrigation wells; by evapotranspiration; and by discharge from springs to alluvial aquifers and streams.

The White River aquifer is present throughout most of Todd County and in western and south-central Mellette County. Other than alluvial aquifers, the White River aquifer, where present, is the shallowest source of ground water in Mellette County. In Todd County, the White River aquifer is used mostly where the Ogallala and Arikaree aquifers are not present. The White River aquifer underlies approximately 1,720 square miles of the study area and contains an estimated 50 million acre-feet of water in storage. The depth to the top of the White River aquifer ranges from 0 to 789 feet below land surface, and the average thickness is 229 feet. Most of the aquifer is confined. Although the water quality of the White River aquifer generally is suitable for irrigation purposes, well yields are not sufficient. The reported yields of the White River aquifer in the counties range from 1 to 30 gallons per minute. Recharge to the aquifer is by infiltration of precipitation on outcrops of the White River Group and by stream loss. Discharge from the aquifer is by withdrawals from domestic and stock wells, evapotranspiration, and discharge from springs to alluvial deposits and streams.

The Pierre Shale is the shallowest bedrock aquifer and is exposed at the land surface throughout most of Mellette County. Although the Pierre Shale is present throughout both counties, it is used as an aquifer only in Mellette County to supply rural-domestic and stock wells. The aquifer contains an estimated maximum of 1.5 million acre-feet of water in storage; however, it is not a viable source of ground water because water can usually be obtained from shallower aquifers, yields are low, and the aquifer is relatively impermeable. Reported yields from the Pierre Shale aquifer range from 1 to 8 gallons per minute. The depth to the top of the Pierre Shale ranges from 0 to greater than 1,200 feet in the study area. The Pierre Shale aquifer, where used, is under water-table conditions. Recharge to the aquifer is primarily by infiltration of precipitation on outcrops of the Pierre Shale, and discharge is through withdrawals from domestic and stock wells and by evapotranspiration.

Little is known about the deeper bedrock aquifers (Dakota Sandstone, Inyan Kara, and Minnelusa and Madison) because few test holes and wells penetrate below the Pierre Shale. All but two of the deeper test holes and wells are located in Mellette County so the extent of some of the bedrock aquifers in Todd County is not known. Recharge to all of the deeper bedrock aquifers primarily is by infiltration of precipitation on outcrops of the formations, which occurs mainly in the Black Hills. In the study area, discharge from the bedrock aquifers is through withdrawals from stock wells.

The Dakota Sandstone aquifer underlies both counties and contains more than 81 million acre-feet of water in storage. The depth to the top of the Dakota Sandstone ranges from 1,270 to 2,348 feet below land surface. Reported yields from the Dakota Sandstone aquifer range from 10 to 100 gallons per minute.

The areal extent of the Inyan Kara, and Minnelusa and Madison aquifers in Todd County is not known. The depth to the top of these aquifers generally is at least 1,900 feet below land surface. The Minnelusa and Madison aquifers are the only bedrock aquifers that generally are suitable for irrigation. Reported yields from the Inyan Kara aquifer range from 9 to 160 gallons per minute, and yields from the Minnelusa and Madison aquifers range from 25 to 40 gallons per minute.

The chemical quality of water in the aquifers in the counties varies widely, both within and between aquifers. The chemical quality among the aquifers of Tertiary age is the most similar. The quality of water from the alluvial aquifers is dependant on the underlying deposits; the water generally has low concentrations of dissolved solids, is fresh, and is soft to moderately hard where underlain by the Ogallala and Arikaree Formations; has moderate concentrations of dissolved solids, is slightly saline, and is hard where underlain by the White River Group; and has high concentrations of dissolved solids, is saline, and is very hard where underlain by the Pierre Shale. Calcium and bicarbonate generally are the dominant species in alluvial water where underlain by the Tertiary deposits, and sodium and chloride are the dominant species where underlain by the Pierre Shale. One out of 49 samples from the alluvial aquifers exceeded the

USEPA Primary Drinking-Water Regulations Maximum Contaminant Level (MCL) for fluoride, and 1 out of 16 samples exceeded that MCL for selenium.

Calcium and bicarbonate are the dominant species in water from the Ogallala aquifer; calcium, sodium, and bicarbonate are the dominant species in water from the Arikaree aquifer. The water of both the Ogallala and Arikaree aquifers generally has low concentrations of dissolved solids, is fresh, and is soft to moderately hard. In samples collected from the Ogallala aquifer, 1 out of 54 exceeded the MCL for fluoride, and 13 out of 92 exceeded the MCL for nitrate. In samples collected from the Arikaree aquifer, 1 out of 45 samples exceeded the MCL for nitrate, and 11 out of 46 samples exceeded the MCL for arsenic.

The dominant species in water from the White River aquifer are calcium, sodium, and bicarbonate. The water quality from this aquifer is dependant on depth and proximity of the aquifer material to the Pierre Shale. The water is higher in dissolved solids, more saline, and hard where the water-bearing deposits are close to the Pierre Shale.

The bedrock aquifers generally yield a hard water with high concentrations of dissolved solids. The Dakota Sandstone aquifer yields the softest water of the bedrock aquifers. Concentrations of dissolved solids in the bedrock aquifers are lowest in the Minnelusa and Madison aquifers, which would allow water from these aquifers to be used for irrigation.

Withdrawal of water during 1995 in Mellette and Todd Counties was about 10,560 acre-feet. More surface water than ground water was used by Mellette County, although all water used for municipal and rural-domestic purposes was from ground water. Most of the ground water used in Todd County (89 percent) was for irrigation.

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