Introduction

The Pine Ridge Indian Reservation and Bennett County are located in southwest South Dakota. The Pine Ridge Indian Reservation includes all of Shannon County and the part of Jackson County south of the White River. Extensive Indian trust lands are in Bennett County. For purposes of this map, the Pine Ridge Indian Reservation and all of Bennett County are included in the study area (sheet 1).

Ground water from wells and springs is the predominant source of public and domestic supply within the study area. The Arikaree aquifer is the largest source of ground water throughout this area. The Oglala Sioux Tribe is developing a ground-water management plan designed to "preserve, protect and maintain the quality of ground water for living and future members and non-members of the Oglala Sioux Indian Tribe within the internal and external boundaries of the Pine Ridge Reservation" (Michael Catches Enemy, Oglala Sioux Tribe Natural Resources Regulatory Agency, oral commun., 2007). Hydrologic information about the Arikaree aquifer is important to managing this resource.

In 1998, the U.S. Geological Survey (USGS) began working in cooperation with the Oglala Sioux Tribe to develop a potentiometric map of the Arikaree aquifer in Jackson and Shannon Counties, with a primary component of that effort being a well inventory in those counties. In 2003, the study area was expanded to include Bennett County.

Purpose and Scope

The purpose of this map is to present the potentiometric surface of the Arikaree aquifer for the Pine Ridge Indian Reservation and Bennett County, South Dakota. The map provides a tool for estimating depth to water table for many parts of the study area and also for evaluating ground-water flow directions and hydraulic gradients in the Arikaree aquifer. Water levels used to construct the generalized potentiometric surface were measured between 1929 and 2006, but most water levels were measured between 1980 and 2006.

Acknowledgments

The authors thank the Oglala Sioux Tribe Water Resources Department for their assistance with the study, particularly Mike Catches Enemy for providing guidance and staff assistance. Anthony Kathol is acknowledged for assisting with access to well information obtained through Indian Health Service drilling programs. Technical assistance from Jim Wiegel of the Bureau of Reclamation is acknowledged. The drilling of new test holes and wells in Bennett County by the South Dakota Geological Survey is acknowledged, and insights and technical assistance by Derric Iles and Dragan Filipovic are appreciated. Ken Buhler of the Water Rights Program of the South Dakota Department of Environment and Natural Resources is thanked for his help in locating records for wells in the study area. Well inventory help from Jake Vogel, Callie Raymond, Richard Hudson, Hopa Yellow Horse, and Joel Galloway (U.S. Geological Survey) is greatly appreciated. The authors thank the many residents of the Reservation and Bennett County who provided information and access to their water wells.

Description of Study Area

The topography of the study area is diverse; in the northwestern part there are numerous sod-covered tableland features that are remnants of alluvial deposits. The Badlands also are in this general area and are characterized by stark contrasts in topography, ranging from low hills to sharply rising pinnacles. Gently rolling plains are present in the southern and eastern parts of the study area, but the relief is steeper and more broken in the northwestern part of the study area along the Cheyenne and White Rivers and their tributaries.

Land use is predominantly a mixture of cropland and grazing land, with the majority of grazing land consisting of subhumid and semiarid grasses. Livestock production and dryland farming are the main agricultural enterprises on the Reservation. Livestock produced include cattle, horses, hogs, sheep, and chickens. The major crops include wheat, corn, sorghum, oats, and sunflower seed (National Agriculture Statistics Service, 2002). Substantial irrigation occurs in Bennett County where an estimated 6.35 million gallons of ground water are withdrawn per day (Amundson, 1998).

Sedimentary clays and sands of the White River Group form the sharply rising pinnacles known as Badlands within Badlands National Park (photograph by South Dakota Tourism).

Physiography and Climate

The study area is located within the Great Plains physiographic province (Fenneman, 1946). The climate, which is characteristic of the northern Great Plains, is semiarid with cold winters and hot summers. The wettest months typically are May and June. The average precipitation (1971–2000) is 19.3 inches at Manderson in Shannon County, 18.67 inches at Martin in Bennett County, and 17.52 inches at Porcupine in Shannon County (South Dakota State University, 2006a). Monthly precipitation data for stations at Manderson, Martin, and Porcupine (South Dakota State University, 2006a, 2007) were used to graph monthly cumulative departures from normal for the periods of record available (fig. 1). Precipitation data for the Martin station were combined with data from the Martin 5E station to create a longer period of record. The graphs show generally below-normal precipitation during 1980–1992 and 2000–2006 and generally above-normal precipitation during 1992–2000. The average annual air temperature (1971–2000) is about 48 degrees Fahrenheit (°F), with an average of about 73°F for July and an average of about 23°F for January (South Dakota State University, 2006b).

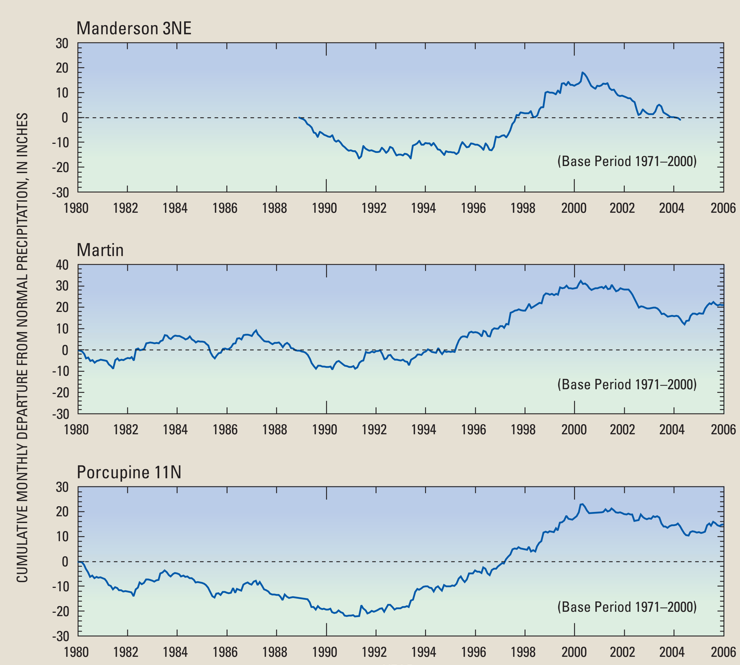

Figure 1. Cumulative monthly departure from normal precipitation at Manderson, Martin, and Porcupine, South Dakota (data from South Dakota State University, 2007).

Geologic Setting

The geology of the Pine Ridge Reservation and the part of Bennett County north of U.S. Highway 18 was mapped at a scale of 1:100,000 by Ellis and Adolphson (1971), and was used as the basis of where the Arikaree Formation is absent in the study area as shown on the potentiometric map on sheet 1. The surficial geology of South Dakota was recently mapped at a scale of 1:500,000 by Martin and others (2004). The map by Martin and others (2004) was the basis for the map showing the surficial geology in the study area (fig. 2).

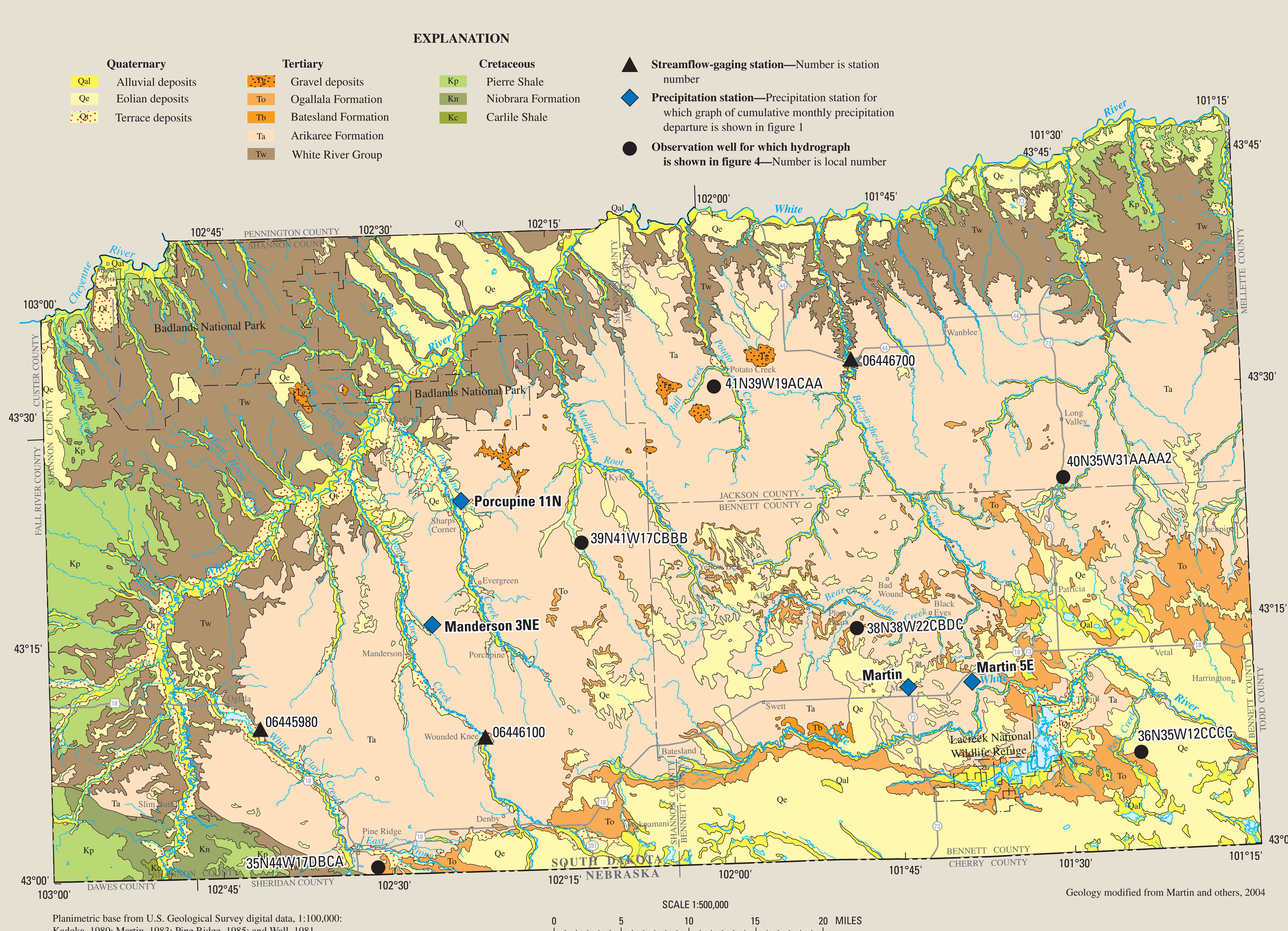

Figure 2. Surficial geology of study area and locations of selected observation wells and precipitation stations.

The geologic formations exposed at land surface in the study area range from bedrock sedimentary rocks of Cretaceous age to unconsolidated deposits of Quaternary age (see map showing surficial geology). Deposits during the Cretaceous period primarily are shale (Darton, 1905). The bedrock units exposed within the study area are the Upper Cretaceous-age Carlile Shale, Niobrara Formation, and Pierre Shale. Tertiary rocks generally consist of poorly consolidated claystones, siltstones, sandstones, and shale deposited in fluvial and lacustrine environments. The Tertiary rocks include the Oligocene-age White River Group, Miocene-age Arikaree and Batesland Formations, Pliocene-age Ogallala Formation, and some gravel deposits. Unconsolidated deposits of Quaternary age include terrace gravels, graded fluvial sand and gravels (alluvium), landslide deposits (not shown on the surficial geology map because deposits are too small to be visible), and eolian (windblown) sand. A summary of the generalized stratigraphy and characteristics of exposed geologic formations is provided in table 1 on this sheet.

Part of the Badlands National Park is located within the Reservation in northern Shannon County. Thick deposits of clays and sands accumulated in the Badlands area at the end of the Eocene. The sedimentary clays and sands compose the White River Group. Outcrops of the White River Group and older formations generally delineate the area where the Arikaree Formation is absent in the northern and western parts of the study area as shown on sheet 1 and figure 2.

The Arikaree Formation has been divided into five geologic subdivisions by Ellis and Adolphson (1971). These units, from oldest to youngest, have been designated A through E as shown in table 1 on this sheet and correspond to members or formations described by Harksen and Macdonald (1969).

In the study area, relatively small outcrops of the Batesland Formation are present in Bennett County between Batesland and Martin. The Ogallala Formation and eolian deposits are present in the southeastern part of the study area where they overlie the Arikaree Formation.

Hydrologic Setting

Ground water from wells and springs is the predominant source of supply for domestic, municipal, stock, and irrigation wells in the study area. Ground water usually can be obtained from most of the units shown in table 1 on this sheet except for the White River Group, Pierre Shale, Niobrara Formation, and Carlile Shale. The Ogallala aquifer, which is composed of saturated sandstones and silt of the Ogallala Formation, is a reliable source of ground water but is present only in the southeastern part of the study area. The Arikaree aquifer, which is composed primarily of the saturated sandstones and siltstones within the Arikaree Formation, is the primary source of water supply in the study area.

In South Dakota, aquifers in eolian, terrace, and alluvial deposits, and in the Ogallala and Arikaree Formations, are part of the High Plains aquifer system (Kolm and Case, 1983), which extends from southern South Dakota to Texas. The aquifers that comprise the High Plains aquifer are hydraulically connected (Gutentag and Weeks, 1980; Kolm and Case, 1983).

Springs occur most commonly in the northern and western parts of the study area where the deeply eroded land surface intercepts local water tables (Ellis and Adolphson, 1971). Springs also occur in the southern part of Bennett County (Dragan Filipovic, South Dakota Geological Survey, written commun., 2007). Most of the springs are found along hillsides or in gullies, and are usually marked by brush thickets or by small groves of trees in areas normally devoid of vegetation other than grass, cactus, and sagebrush. Springs with the largest yields are in the northwestern part of the study area and are present where terrace deposits overlie either the White River Group or the Pierre Shale (Heakin, 2000). Springs and seeps also occur along the contact between the Arikaree Formation and White River Group, which constitute a discharge area for the Arikaree aquifer. Some of the more productive springs have been developed to serve as sources for domestic supply or livestock watering.

The Cheyenne and White Rivers are the major rivers within the study area. The Cheyenne River flows northeast and forms the northwestern boundary of the Reservation and continues flowing northeast to its confluence with the Missouri River. The White River flows to the northeast from Nebraska. Several major tributaries to the White River in the study area flow across the Arikaree Formation including White Clay Creek, Wounded Knee Creek, Porcupine Creek, Medicine Root Creek, Potato Creek, and Bear-in-the-Lodge Creek. Streamflow data for streamflow-gaging stations 06445980 (White Clay Creek near Oglala, water years 1987–1999), 06446100 (Wounded Knee Creek at Wounded Knee, water years 1993–1997), and 06446700 (Bear-in-the-Lodge Creek near Wanblee, water years 1994–2005) (U.S. Geological Survey, 1988–2006) shown in figure 2 indicate that perennial flow is sustained by a large component of base flow with potential but unquantified contributions from the Arikaree aquifer.

Table 1. Generalized stratigraphic column showing selected geologic units and characteristics for the study area.

[Modified from Ellis and Adolphson (1971), Heakin (2000)]

System	Series	Mapped unit	Subdivisions	Thickness (in feet)	Lithology	Hydrology
Quaternary	Holocene	Alluvium		0–60	Light brown to gray, unconsolidated, clay, silt, and fine sand; discontinuous sandy and clayey gravel beds in lower part.	Generally water bearing. Yields are adequate for domestic and stock needs, but differ because deposits are not uniform. Along some small tributaries deposits are thin, and wells commonly go dry in late summer or early fall. Water levels, especially along rivers, respond rapidly to changes in streamflow. Quality of water is good[1] where alluvium is underlain by Tertiary deposits and generally poor[2] where underlain by Cretaceous deposits.
	Holocene and Pleistocene	Landslide deposits		0–100	Landslide, slump, and collapsed material composed of chaotically mixed boulders and finer grained rock debris.	Water-bearing traits are not known.
		Eolian deposits		0–200	Brown, unconsolidated, very fine to medium grained, uniform, quartz sand; characterized by dune topography and blowouts.	Water table generally near the base of sand. Springs are common along the margins of the deposits. Yield commonly more than adequate for domestic and stock needs. Quality of water generally is good[1].
	Pleistocene	Terrace deposits		0–80	Brown, silty clay, sand, and gravel. Commonly, the silty and sandy layers are partly cemented, and the gravel and sand beds are commonly interbedded with laminated silty clay.	The basal few feet generally is water bearing. Springs and seeps common along riverside margins. Yields generally adequate for domestic and stock needs. Quality of water generally is good[1].
Tertiary	Pliocene	Ogallala Formation		0–200	Tan to olive, fine- to medium-grained sandstone with some silty clay. Upper unit of the Ogallala Formation is also known as the Ash Hollow Formation and the lower unit as the Valentine Formation.	Upper unit relatively impermeable; water bearing only locally because of high topographic position. Lower unit generally water bearing where areally extensive. Springs and seeps common at contact with underlying Arikaree Formation. Yields of most wells adequate for domestic and stock needs and can supply irrigation wells in some areas. Quality of water generally is good[1]. Forms part of the High Plains aquifer.
	Miocene	Batesland Formation		[3]0–50	Light-gray to light-greenish, fine- to coarse-grained, bedded and cross-bedded, fossiliferous sand with interbedded silts, clays, and marls[3].	Water-bearing traits are not known.
		Arikaree Formation	Unit E (Rosebud Formation)[4]	0–235	Light-tan to brown, interbedded calcareous sand, silt, and clay; contains gray to pinkish-gray tabular concretions and small light-brown and greenish clay beds.	Lack of detailed subsurface information does not allow for determination of water-bearing properties of individual units. However, the Arikaree aquifer is the most common source of ground water on the Reservation and in Bennett County. Yields vary, probably because of well location and method of completion, but usually are adequate for domestic and stock needs. Large yields have been obtained for municipal use (towns of Martin and Pine Ridge). Springs and seeps occur at the contact between the Arikaree Formation and the underlying White River Group, and at contacts between permeable and impermeable zones within the Arikaree Formation. The quality of water is generally good[1]. Forms part of the High Plains aquifer.
			Unit D (Harrison Formation)[4]	0–125	Gray, massive, poorly consolidated, fine to very fine sand; commonly contains layers of light-gray sandy marl, largely pipey concretions, and small spherical concretions. Formation becomes silty toward the east; concretions in the lower part present only in discontinuous zones. Unit is difficult to differentiate from underlying units.	
			Unit C (Monroe Creek Formation)[4]	0–90	Buff siltstone and very fine-grained sandstone; sandier toward east. Unit is difficult to distinguish from overlying and underlying units.	
			Unit B (unnamed member of Sharps Formation)[4]	0–375	Pinkish-tan, poorly consolidated silt and very fine-grained sand; gray, small (2–4 inches) calcareous concretions are common. Lenses of limestone and channel sand and gravel occur locally throughout the unit in central and western parts of the Reservation.	
			Unit A (Rockyford Ash Member of the Sharps Formation)[4]	0–45	White, tan, buff, and reddish-brown silty volcanic ash; interbedded with thin layers of silt.	
	Oligocene	White River Group	Brule Formation	0–450	Yellow to brown, poorly consolidated siltstone and claystone with some beds of fine-grained sand.	Generally too impermeable to serve as a source of ground water; local fractured zones and channel sands yield some water. Quality of water generally is fair[5].
			Chadron Formation	0–110	Pale, gray-green bentonite clay alternating with layers of greenish-gray siltstone.	Generally too impermeable to serve as a source of ground water. Local basal sandstones in the northeastern part of Reservation yield small amounts of water. The quality of water is fair[5].
Cretaceous	Upper Cretaceous	Pierre Shale		0–1,200	Dark-gray marine shale and mudstone with some layers of bentonite.	Not a source of ground water. Quality of water generally is poor[2].
		Niobrara Formation		0–325	Tan to gray, highly calcareous shale. Commonly described by drillers as "chalk."	Not a source of ground water. Quality of water generally is poor[2].
		Carlile Shale		100–325	Dark-gray marine shale and mudstone. Middle part of the formation is sandy and contains thin limestone ledges locally.	Not a source of ground water.

[1]Good quality is indicated by fresh water that has low dissolved-solids concentrations (generally less than 500 milligrams per liter) and is soft to moderately hard.

[2]Poor quality is indicated by saline water that has high dissolved-solids concentrations (generally greater than 1,000 milligrams per liter) and is very hard.

[3]From Harksen and Macdonald (1967).

[4]Corresponding unit from Harksen and Macdonald (1969).

[5]Fair quality is indicated by slightly saline water that has moderate dissolved-solids concentrations (generally between 500 and 1,000 milligrams per liter) and is hard.

Description of Arikaree Aquifer

The Arikaree aquifer is present throughout most of the study area as shown on sheet 1. Because the Arikaree Formation is structurally flat-lying (dipping less than 1 degree) and regionally continuous, the configuration of the potentiometric surface is controlled locally by topography and major streams (Rahn and Paul, 1975). The Arikaree aquifer is mostly under water-table conditions (unconfined) in the study area. The aquifer can be confined where overlain by impermeable materials in the Ogallala Formation in the southern and southeastern parts of the study area. In the area underlain by the Arikaree Formation, and including all of the younger units that overlie the Arikaree Formation, a single continuous water table was assumed by Ellis and Adolphson (1971). However, in adjacent Todd County, the Arikaree aquifer and overlying Ogallala aquifer were mapped as separate units with distinct water-table altitudes (Carter, 1998). In the northern and western parts of the study area, where the Arikaree Formation has been removed by erosion, there is no continuous aquifer. The potentiometric-surface map shows the area where the Arikaree Formation is absent.

Depth to the water table is usually greatest (150 to 275 feet) beneath hills and ridges and shallowest (0 to 50 feet) beneath stream valleys and other low areas. Depth to water is not necessarily an indication of the depth to which a well must be drilled to obtain an adequate water supply (Ellis and Adolphson, 1971).

Recharge to the Arikaree aquifer is primarily by infiltration of precipitation on the outcrops of the Arikaree Formation. The greatest recharge to the aquifer occurs during the spring after snowmelt and during storm events. Discharge from the aquifer primarily is through withdrawals from domestic, stock, municipal, and irrigation wells; by evapotranspiration where the aquifer is at or near land surface; by discharge to streams; and by discharge from springs and seeps (Carter, 1998). Yields from the Arikaree aquifer in the study area range from 1 to 1,542 gallons per minute (see boxplots of well yields in figure 3). The largest yields were from wells in Bennett County where the mean yield is about 76 gallons per minute, compared with mean yields of 13 gallons per minute in Jackson and Shannon Counties.

Hydrographs from selected observation wells (fig. 4) measured as part of the Water Rights Program of the South Dakota Department of Environment and Natural Resources show long-term water-level trends (Ken Buhler, South Dakota Department of Environment and Natural Resources, written commun., 2006). The water levels of some wells, such as well 36N35W12CCCC in Bennett County and well 40N35W31AAAA2 in Jackson County, correlate well with climatic conditions when well hydrographs are compared with the graph of cumulative monthly departure from normal precipitation (fig. 1). Water-level fluctuations at well 39N41W17CBBB in Shannon County show a typical cyclic pattern of higher water levels during the spring owing to precipitation recharge and lower water levels in the fall owing to evapotranspiration and decreasing precipitation. Hydrographs for a pair of wells at 35N44W17DBCA in Shannon County, one well with a depth of 180 feet and the other with a depth of 837 feet, show that the water levels in the shallower well correlate well with climatic conditions but that the water levels in the deeper well do not.

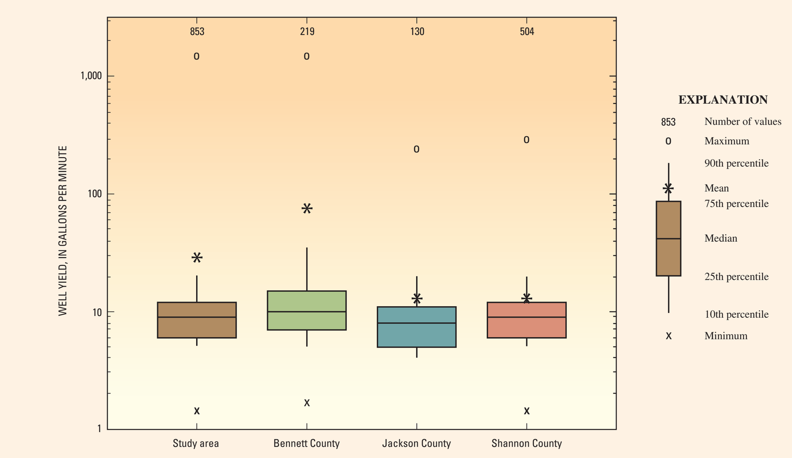

Figure 3. Boxplots of yields from wells completed in Arikaree aquifer.

Potentiometric Surface

The potentiometric surface of an aquifer is equal to the altitude at which water will rise in tightly cased wells open to that aquifer (Lohman and others, 1972). In unconfined areas, such as outcrops of water-bearing rocks, this surface is equal to the water-table altitude. The potentiometric surface of the Arikaree aquifer, shown on sheet 1, was estimated on the basis of water levels measured in wells during 1929–2006. The potentiometric surface represents water-level altitudes in feet above the North American Vertical Datum of 1988. These water-level altitudes are referred to as hydraulic heads.

The potentiometric surface of the Arikaree aquifer was mapped by contouring altitudes of water levels in approximately 1,200 wells completed in the Arikaree aquifer and altitudes of 6 springs discharging from the Arikaree aquifer. No attempt was made to distinguish which unit of the Arikaree Formation a well was completed in because the Arikaree aquifer was considered as a single hydrologic unit. Isolated water levels that are anomalously high may represent ground water perched on impermeable layers within the Arikaree Formation. The water-level and spring altitudes shown on the map are from the Ground-Water Site Inventory database of the USGS National Water Information System at *http://waterdata.usgs.gov/sd/nwis/gw*. The water-level data used in this map also are available as supplemental data on the map's Web page at *http://pubs.usgs.gov/sim/2007/2993/*.

Observation wells measured as part of the Water Rights Program of the South Dakota Department of Environment and Natural Resources have numerous water-level measurements available, in which case an arithmetic mean value from all measurements through 2005 was calculated and used for contouring purposes. Ranges in measured water levels for these observation wells generally are less than one contour interval and in most cases are less than 10 feet as shown in the selected hydrographs in figure 4. Many of the wells in the study area have a single water-level measurement that commonly was obtained at the time of well completion (generally between 1929 and 2000). During 1998–2006, about 1,000 wells were visited in the study area as part of the well inventory effort to obtain accurate locations using a hand-held global positioning system instrument, land-surface altitudes, and recent water-level measurements. If a recent water-level measurement was made at a well with only a single water-level measurement made at the time of well completion, the recent water level was used in contouring the potentiometric surface. In more than 95 percent of the cases where both a recent water level and a well completion water level were available, the water levels differed by less than 5 feet. In cases in which a recent water level could not be obtained, the well completion water level was used in contouring the potentiometric surface.

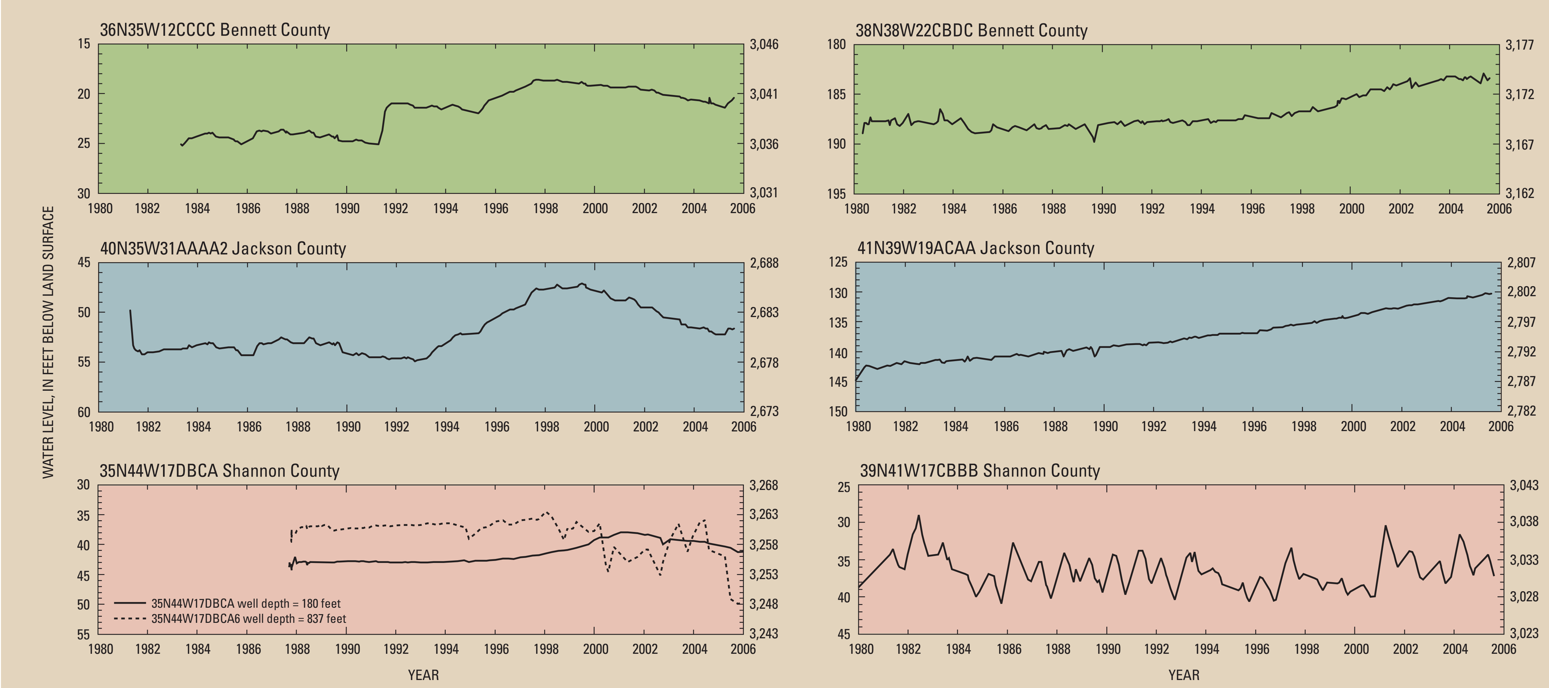

Figure 4. Hydrographs of selected obervation wells completed in the Arikaree aquifer.

Water-level data for contouring were weighted on the basis of the reliability of available water-level information. The highest weight was given to water levels from State observation wells. Wells that were field verified and had recent water levels (1998–2006) as part of the well inventory effort were given secondary weight. Tertiary weight was given to field-verified wells with completion water levels. The lowest weight was given to wells that had completion water levels but were not field verified.

The land-surface altitude of a spring in an outcrop area is approximately equal to the water-table altitude at that location, and thus selected spring locations were used in constructing the potentiometric-surface map. Most of the spring locations used in contouring are near the contact between the Arikaree Formation and the White River Group. The actual hydraulic head of the Arikaree aquifer in the vicinity of the springs probably is somewhat higher than the spring altitudes.

Ground-water flow in the Arikaree aquifer generally is towards the north and west (towards the areas with the lowest topographic altitudes and where the aquifer rocks terminate), and discharges as springs and seeps, or by evapotranspiration (Kolm and Case, 1983). Locally, ground water flows downgradient from drainage divides towards major streams, tributaries, and wetlands. The hydraulic gradient is lowest in the southern part of the study area where the distance between potentiometric contours is largest. Areas of low hydraulic gradient generally indicate zones of high hydraulic conductivity. The hydraulic gradient generally is steepest in the northern and western parts of the study area, especially near the contact between the Arikaree Formation and the White River Group.

The depth to water in the Arikaree aquifer can be estimated from the potentiometric map by subtracting the altitude of the potentiometric contour from the land-surface altitude. Additionally, the range of depth to water is indicated by color for the well symbols on sheet 1.

Stock wells powered by windmills and completed in the Arikaree aquifer are common on grazing lands within the study area (photograph by Hopa Yellow Horse).

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Generalized Potentiometric Surface of the Arikaree Aquifer, Pine Ridge Indian Reservation and Bennett County, South Dakota

By
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2007

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