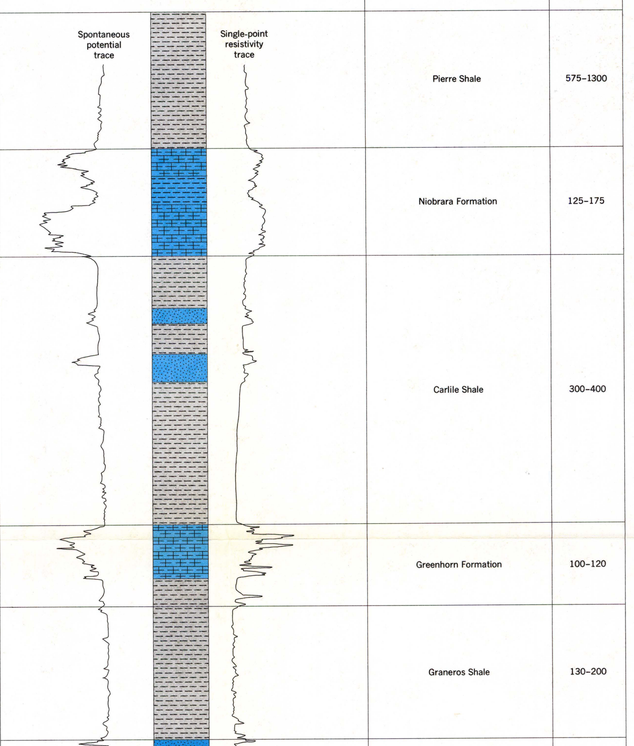
ELECTRIC LOG SHOWING STRATIGRAPHY OF SUBSURFACE FORMATIONS

ERA	SYSTEM	FORMATION	RANGE IN THICKNESS (FEET)
MESOZOIC	Cretaceous	Pierre Shale	575–1300
		Niobrara Formation	125–175
		Carlile Shale	300–400
		Greenhorn Formation	100–120
		Graneros Shale	130–200
		Dakota Sandstone	270–360
		Skull Creek Shale	95–150
		Inyan Kara Group (undifferentiated)	100–250
	post-Permian pre-Cretaceous	post-Minnelusa Formation pre-Inyan Kara Group deposits	20–70
PALEOZOIC	Permian	Minnelusa Formation	300–530
	Pennsylvanian		
	Mississippian	Madison Group	90–240
	Ordovician	Red River and Winnipeg Formations (undifferentiated)	0–170
	Precambrian igneous and metamorphic rocks undifferentiated		



EXPLANATION

Sandstone and shaly sandstone
Includes interbedded shales and sandy shales

Shale
Includes thin beds of sandstone and shaly limestone

Marl and shaly limestone
May include thin beds of calcareous shale

Limestone and dolomite
Includes thin beds of sandstone, shale, and evaporites

Beds which are not known to be water bearing in South Dakota

Beds in which artesian wells are completed in other parts of South Dakota, but are not known to be water bearing in the project area

Beds in which artesian wells are completed in the project area

ARTESIAN AQUIFERS

Artesian aquifers.—The specific rock layers within a stratigraphic unit that yields water under artesian conditions in the project area cannot be differentiated with the available data; therefore, in this report, the stratigraphic units are designated as aquifers. In order of depth below the land surface, they are: Dakota Sandstone of Cretaceous age; Inyan Kara Group, undifferentiated, of Cretaceous age; and the Minnelusa Formation and the Madison Group, of Permian-Pennsylvanian and Mississippian age, respectively, which seem to function as a single aquifer in the project area. (See electric log.) The generalized electric log is typical of those obtained in the area.

High dissolved solids and sodium content of water from the Dakota Sandstone and the Inyan Kara Group precludes its use for any type of irrigation. Water from the Minnelusa Formation and the Madison Group can be used for supplemental irrigation of salt tolerant crops on well-drained soils, but, even then, the high dissolved solids content will require some special management for salinity control. The water from all three aquifers is satisfactory for watering livestock.

Hardness and high dissolved solids content are limiting factors in municipal and some domestic uses of water from the three artesian aquifers. High sulfate, chloride, fluoride, iron, and manganese contents, also, may impose serious limitations on the use of the water for municipal and many domestic uses. A summary of the concentrations of these ions in water from each of the aquifers is given in the following table.

Summary of analyses from artesian aquifers

	Concentrations, in milligrams per liter				
	Sulfate	Chloride	Fluoride	Iron	Manganese
Water from the Dakota Sandstone					
Number of analyses	17	17	8	8	8
Concentration:					
Maximum	1170	656	4.6	8.7	0.19
Average	590	173	3.5	2.1	.10
Median	600	116	3.7	.78	.12
Minimum	0.2	38	1.9	.02	.00
Water from the Inyan Kara Group					
Number of analyses	7	7	4	7	4
Concentration:					
Maximum	1950	352	4.4	5.9	0.27
Average	1340	220	3.0	2.9	.18
Median	1150	196	—[a]	1.3	—[a]
Minimum	1010	147	1.0	.38	.14
Water from the Minnelusa Formation and the Madison Group					
Number of analyses	3	3	1	4	1
Concentration:					
Maximum	700	78	—	2.0	—
Average	667	41	—	.91	—
Median	—[a]	—[a]	—	—[a]	—
Minimum	630	2.5	1.7	.35	0.05
Standards recommended by the U.S. Public Health Service					
Maximum	250	250	1.3[b]	0.03	0.05

[a] Not given for less than seven analyses.
[b] Based on the average maximum daily air temperature for the project area.

Prior to 1950, only 3 artesian wells had been drilled in Mellette and Todd Counties, and 1 of these (drilled in 1895–97) was considered a failure and never used. The other 2 wells, drilled in 1929, were used for only a few years. Six artesian wells were drilled between 1950 and 1959, and 32 were drilled from 1959 to 1967. Most of these wells were drilled during, or shortly after, an extended dry period during which some water-table aquifers proved unreliable as sources of water. The increasing number of artesian wells reflects a growing awareness of the potential of the artesian aquifers as a reliable source of water for livestock and domestic uses; however, it also reflects an improvement in drilling techniques and pumping equipment. Data on the 41 artesian wells in the project area are summarized in the table.

Hydrogeologic maps of each of the three artesian aquifers show the approximate area where wells completed in a specific aquifer will flow. The maps also show the approximate altitude of the top surface and thickness of each aquifer and the altitude to which water will rise in wells completed in each aquifer. The structure contours are based on subsurface data for the project area and on additional data for artesian wells and oil tests in adjacent counties. Only wells completed in the aquifer are shown on the maps. The well-reference numbers shown on the hydrogeologic maps correspond with the map-reference numbers listed on the artesian well data table.

Discharges from flowing artesian wells range from 1 to 160 gpm and average about 25 gpm. Pumped, non-flowing, artesian wells usually discharge about 15 gpm, although a few wells are pumped at rates of 30 to 50 gpm. The differences in production of artesian wells are due principally to differences in the diameter of the wells, in the method of well completion, and in the type of pumping equipment used. Differences may also be due to variable water-yielding properties of the aquifers, however, such cases are probably rare since each aquifer is relatively uniform and similar to the other artesian aquifers.

Ultimate potential for further development of the artesian aquifers cannot be fully evaluated as many wells tap the aquifer outside the project area. The rise or decline in artesian pressure in an aquifer depends principally upon rates of recharge and discharge. The rise or decline is not uniform from year to year, nor is it entirely comparable between aquifers. The present water withdrawals exceed the natural recharge and have caused the water levels, or artesian heads, of the aquifers to decline. The present rate of water withdrawals from the aquifer will cause a continued decline, and additional development will accelerate the rate of this decline. Declines in water levels, or artesian heads, diminish the area in which artesian wells will flow and increase pumping lifts for non-flowing artesian wells. It seems certain, though, that many more wells can be successfully completed in the aquifers, both in the project area and in other parts of the State.

The temperature of water from wells completed in the artesian aquifers ranges from 74 to 142°F and averages about 110°F. No direct relationship exists between the temperature of the water and any physical or chemical properties of the individual artesian aquifers. The temperature of the water is due, rather, to the natural increase of temperature with depth below land surface—the deeper the aquifer, the warmer the water. This increase of temperature with increase in depth generally has a uniform gradient, called the geothermal gradient, at any given location. Geothermal gradient is determined as follows:

$$\text{geothermal gradient} = \frac{\text{(depth of formation below land surface in feet)}}{\text{(formation temperature)} - \text{(mean annual surface temperature)}}$$

In general, water in an aquifer has the same temperature as the rocks composing an aquifer. Therefore, the temperature of the water from a deep artesian well often can be used to approximate the formation temperature for the calculation of the geothermal gradient. Water in a flowing well, however, may move upward so slowly that a significant amount of heat is lost as it flows past the cooler overburden. Therefore, the temperatures of water from wells discharging less than about 30 gpm are often unreliable for computing a geothermal gradient. Variations in geothermal gradients based on water temperatures from 25 artesian wells in the project area, where the mean annual surface temperature is about 50°F, are summarized in the following table:

Summary of geothermal gradients from 25 artesian wells

Well discharge	Geothermal gradients in feet per degree Fahrenheit		
	Average	Maximum	Minimum
Flow >30 gpm (7 wells)	26	20	28
Flow <30 gpm (9 wells)	34	26	51
Pumped (9 wells)	53	33	84

Water from the artesian aquifers has a high dissolved solids content. The median dissolved solids content of water from the Dakota Sandstone was 1,790 mg/l (milligrams per liter); from the Inyan Kara Group, 2,560 mg/l; and from the Minnelusa Formation and the Madison Group, 1,150 mg/l. Relative proportions of the principal dissolved constituents from the three artesian aquifers are shown by the water-quality patterns in the artesian well data table.

Sodium is the predominant cation in all water from the Dakota, but there is no single predominant anion. In water from some wells, bicarbonate is the predominant anion; from others, sulfate; and from a few, chloride. Data in the artesian well data table indicate that water from the Dakota generally is soft (less than 61 mg/l) or only moderately hard 61–120 mg/l).

Based on the predominant anion and cation, water from the Inyan Kara can be divided into two chemical types; a sodium-sulfate type and a calcium-sulfate type. Dissolved solids concentrations are very high in the sodium-sulfate type, and the water is moderately hard (61–120 mg/l) to hard (121–180 mg/l). The calcium-sulfate type of water usually has a lower dissolved solids content than the sodium-sulfate type, but is extremely hard (more than 1,000 mg/l).

Wells completed in the Minnelusa Formation and the Madison Group yield a calcium-sulfate type water, which is much lower in dissolved solids content than water from the other two artesian aquifers. Water from the Minnelusa and Madison, however, is extremely hard, similar to the calcium-sulfate type water from the Inyan Kara Group.

ARTESIAN WELL DATA

Data on wells completed in the Dakota Sandstone

Map reference number	Location number	Depth of well (feet)	Water level above (+) or below (−) land surface (feet)[1]	Water level elevation, 1966 (feet above mean sea level)[2]	Dissolved solids (calculated milligrams per liter)	Hardness, calcium and magnesium (milligrams per liter as $CaCO_3$)	Water quality pattern[3]
1	44-31-20bbb	2315	−314	2025	1700	30	
2	43-30-5cac	2015	−104.7	1910	1910	19	
3	43-27-3ca	1585	+4	1750	1910	50	
4	43-27-11ad	1700	+	>1710	—	—	
5	43-27-14dbb	1605	+9.8	1840	1880	32	
6	43-26-16ca	1515	+101.6	1840	—	—	
7	43-25-24	—	—	—	1810	—	
8	43-28-36ac	1992	−170 (1960)	1940	1790	30	
9	42-27-1aaa	1600	+	>1855	1830	20	
10	42-30-13dbb	2125	−180 (1960)	2030	1730	30	
11	42-30-12cb	2110	+39.3	2045	2780	61	
12	42-27-2ccd	1998	−180 (1962)	1930	1660	30	
13	42-25-1ca	1342	+78.6	1775	—	—	
14	42-31-34aba	2300	−275	2075	1730	400	
15	42-27-23aca	1993	−225 (1962)	1935	1750	90	
16	42-26-27bda	2000	−250 (1964)	1900	1600	70	
17	42-25-34cc	1567	+	>1820	1450	43	
18	41-29-27abb	1885	−180 (1961)	2025	—	—	
19	41-27-25cb	1866	−183.4 (1957)	1945	—	—	
20	41-27-25da	1779	—	—	2030	48	
21	41-26-30ddc	1804	−165.4	1950	1910	154	
22	41-26-27	1960	−173.7	1935	1690	—	
23	41-25-31cab	1775	−140	1965	1320	60	
24	41-25-35ccd	1700	−180 (1965)	1910	1380	130	
25	40-30-3ac	2205	−398.1	2030	—	—	
26	40-29-8a	1980	−220 (1961)	2030	—	—	
27	40-25-12bd	1681	−88 (1930)	1910	1730	—	
28	40-25-20cdb	1693	−220 (1965)	1860	1640	115	
29	39-30-11dd	2490	−404	2020	—	—	
30	39-27-10cad	2500	−500 (1897)	2000	—	—	

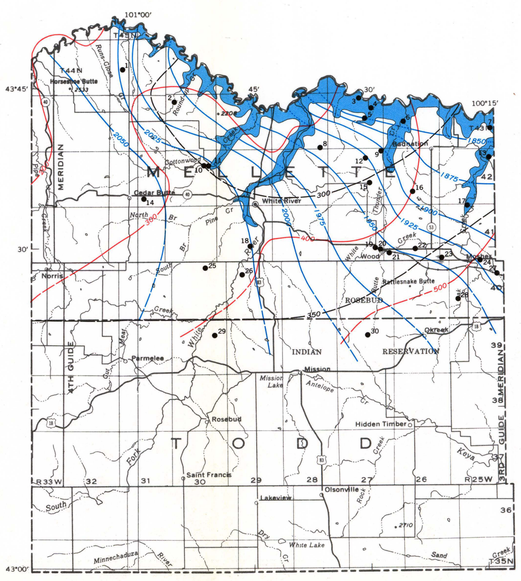
Data on wells completed in the Inyan Kara Group

1	45-32-36b	2387	+138.6	2175	4180	100	
2	43-30-29a	2555	−153 (1964)	2220	3000	58	
3	43-26-33add	2172	+256.4	2155	1990	1310	
4	42-30-15b	2430	−14 (1964)	2125	3860	156	
5	42-29-7c	2460	−6	2080	2560	140	
6	42-28-30bbb	2400	+17.6	2165	2390	490	
7	42-28-22b	2360	+55.4	2155	1960	1240	

Data on wells completed in the Minnelusa Formation and the Madison Group

1	42-26-21cdc	2730	+41.6	2245	1130	920	Minnelusa Formation and the Madison Group
2	42-26-34ab	2934	+73.9	2250	1060	770	Minnelusa Formation and the Madison Group
3	42-25-32cc	2690	+78.6	2190	1170	806	Madison Group
4	41-26-8aa	2875	−1.1	2225	1260	980	Minnelusa Formation

[1] Measured water levels reported to nearest tenth of a foot, reported values to nearest foot. All water levels are for summer of 1966, unless otherwise indicated.
[2] Water level elevations are given to nearest 5 feet. Elevation of water levels in wells measured prior to 1966 have been adjusted to approximate 1966 values by interpolation from regional rate of decline in artesian water level.
[3] Patterns show general chemical character of water and are based on analyses of water from indicated data-collection points. Concentrations, in milliequivalents per liter are plotted for calcium (Ca), sodium (Na), magnesium (Mg), bicarbonate (HCO_3), chloride (Cl), and sulfate (SO_4). Anions (negatively charged ions) are plotted to the right of the center line and cations (positively charged ions) to the left. The area of the pattern is an indication of dissolved-solids content. Changes in configuration reflect changes in chemical character.



EXPLANATION

12
Artesian well and reference number
Completed in the Dakota Sandstone

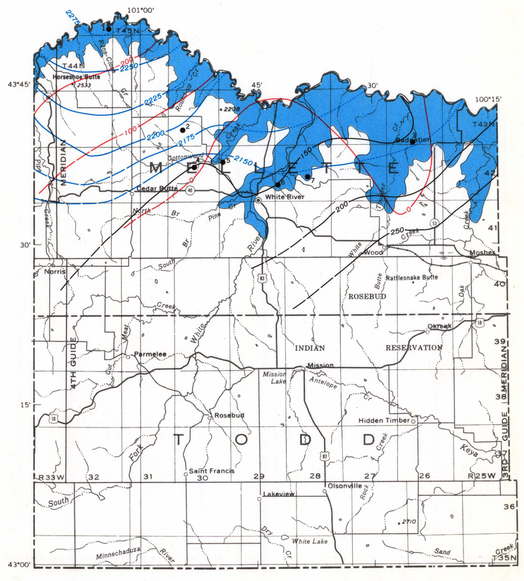
Area where wells completed in the Dakota Sandstone probably will flow

2000
Piezometric contour
Shows altitude to which water will rise in wells completed in the Dakota Sandstone (1966). Dashed where approximately located; dotted where projected above land surface. Contour interval 25 feet. Datum is mean sea level

500
Structure contour
Shows altitude of top of the Dakota Sandstone. Dashed where approximately located. Contour interval 100 feet. Datum is mean sea level

350
Approximate line of equal thickness
Shows thickness of Dakota Sandstone. Interval 50 feet

HYDROGEOLOGIC MAP OF THE DAKOTA SANDSTONE



EXPLANATION

2
Artesian well and reference number
Completed in the Inyan Kara Group

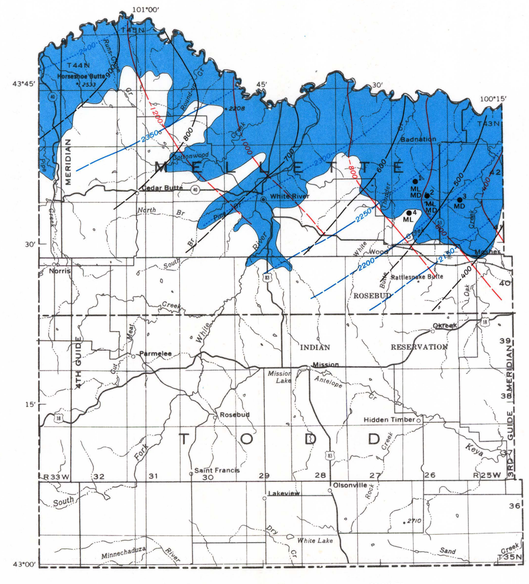
Area where wells completed in the Inyan Kara Group probably will flow

2150
Piezometric contour
Shows altitude to which water will rise in wells completed in the Inyan Kara Group (1966). Dashed where approximately located; dotted where projected above land surface. Contour interval 25 feet. Datum is mean sea level

200
Structure contour
Shows altitude of top of the Inyan Kara Group. Dashed where approximately located. Contour interval 100 feet. Datum is mean sea level

250
Line of equal thickness
Shows thickness of Inyan Kara Group. Dashed where approximately located. Interval 50 feet

HYDROGEOLOGIC MAP OF THE INYAN KARA GROUP



EXPLANATION

4 ML — Completed in the Minnelusa Formation
3 MD — Completed in the Madison Group
1 ML MD — Completed in the Minnelusa Formation and the Madison Group

Artesian well and reference number

Area where wells completed in the Minnelusa Formation and the Madison Group probably will flow

2150
Piezometric contour
Shows altitude to which water will rise in wells completed in the Minnelusa Formation and the Madison Group (1966). Dashed where approximately located; dotted where projected above land surface. Contour interval 50 feet. Datum is mean sea level

1200
Structure contour
Shows altitude of top of the Madison Group. Dashed where approximately located. Contour interval 200 feet. Datum is mean sea level

600
Line of equal thickness
Shows thickness of the Minnelusa Formation and the Madison Group. Dashed where approximately located. Interval 100 feet

HYDROGEOLOGIC MAP OF THE MINNELUSA FORMATION AND THE MADISON GROUP

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HYDROLOGY OF THE ROSEBUD INDIAN RESERVATION, SOUTH DAKOTA

By
M. J. Ellis, J. H. Ficken, and D. G. Adolphson

1971