GEOHYDROLOGY OF THE MORRISON FORMATION IN THE WESTERN SAN JUAN BASIN, NEW MEXICO

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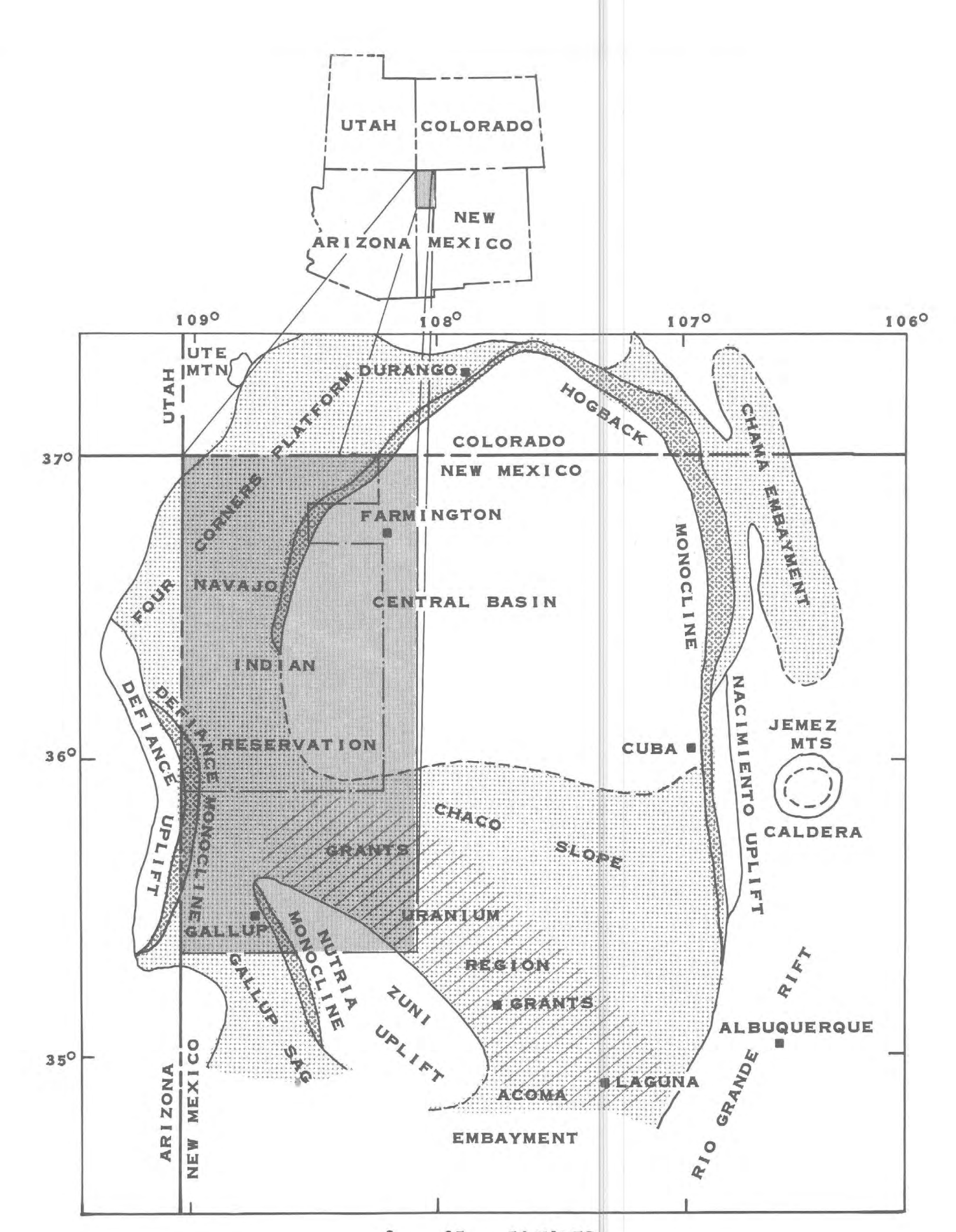

Figure 1.--San Juan Basin showing major structural features, Grants uranium region, and location of the study area (modified from Kelley, 1951; Santos and Turner-Peterson, 1986).

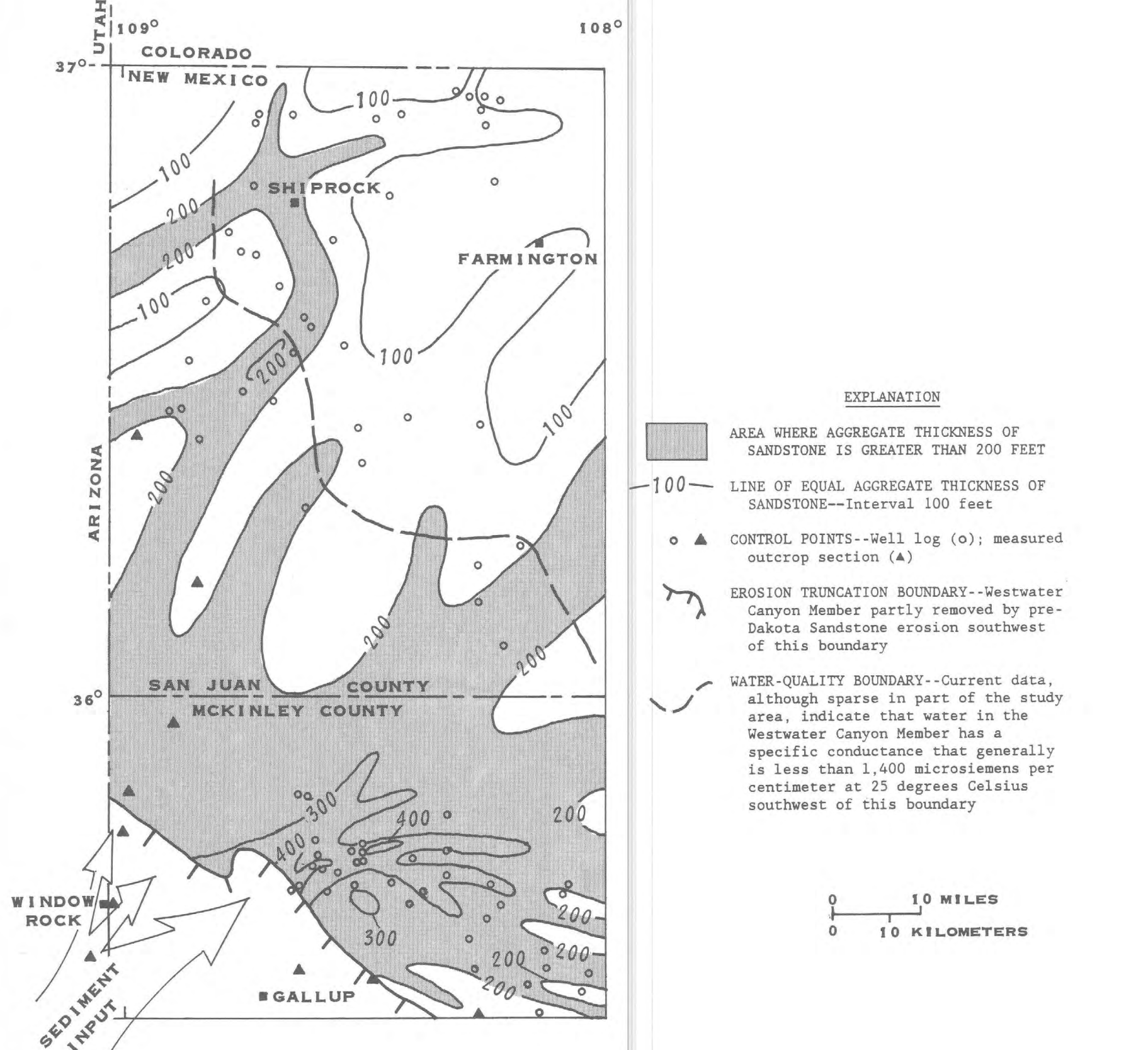

Figure 2.--Generalized aggregate thickness of sandstone in the Westwater Canyon Member of the Morrison Formation based on subsurface well logs and measured outcrop sections (modified from Galloway, 1980, fig. 1).

STRATIGRAPHIC NAME				NORTH-WEST	SOUTH-WEST	SOUTH
Cretaceous		Dakota Sandstone		P[1]	P	P
		Burro Canyon Formation[2]		P		
Upper Jurassic		Morrison Formation	Brushy Basin Member[3]	P		P
			Westwater Canyon Member	P	P	P
			Recapture Member	P	P	P
			Salt Wash Member	P		
Middle Jurassic	San Rafael Group	Cow Springs Sandstone[4]			P	P
		Wanakah Formation	Horse Mesa Member	P		
			Beclabito Member	P		P
			Todilto Limestone Member	P		P
		Entrada Sandstone	Upper sandy member	P	P	P
			Medial silty member	P	P	P
			Iyanbito Member		P	P

GENERAL THICKNESS AND LITHOLOGY OF THE MORRISON FORMATION MEMBERS

Brushy Basin Member--(0-350 feet) Heterogeneous unit of dominant bentonitic and calcareous claystone and mudstone with lesser sandstone and thin limestone lenses; weathers to poorly exposed slopes; deposited in a complex fluvial-lacustrine environment. Sandstone, fine to medium grained, locally conglomeratic, moderately to poorly sorted, friable to firmly cemented, thin to medium bedding. Least potential for ground-water development.

Westwater Canyon Member--(150-450± feet) Thickest in south part of study area (fig. 3; Kirk and Condon, 1986, pl. D). Mainly fluvial sandstone with thin lenses of siltstone and mudstone. Sandstone, fine to very coarse grained, locally conglomeratic, poorly to well sorted, firmly cemented to friable, very thin to very thick bedding. Deposited in a braided-stream environment as indicated by a large sandstone to mudstone ratio (Kirk and Condon, 1986, pl. D) and lack of lateral accretion surfaces, clay-filled channel plugs, and fining-upward sequences (Turner-Peterson, 1986, p. 52). Greatest potential for ground-water development.

Recapture Member--(300-500 feet) Heterogeneous unit of interbedded sandstone, siltstone, mudstone, claystone, and limestone; mainly fluvial deposition with a major eolian facies in southeast part of study area. Fluvial sandstone, fine to medium grained, locally conglomeratic, poorly to well sorted, friable, thin to very thick bedding. Fluvial claystone, mudstone, and siltstone, flatbedded, lenticular, subfissile to structureless. Eolian sandstone, fine to medium grained, moderately well to well sorted, friable to firmly cemented, medium to very thick bedding, local claystone laminae, and siltstone beds. Slight potential for ground-water development.

Salt Wash Member--(9-200 feet) Interbedded sandstone and mudstone with minor limestone; mainly fluvial deposition with lesser eolian and lacustrine. Sandstone, very fine to medium grained, locally conglomeratic, moderately to well sorted, firmly cemented, thin to moderately thick bedding. Mudstone, locally carbonaceous, structureless. Slight potential for ground-water development.

[1] P indicates that the geologic unit to the left is present in the northwest, southwest, or south parts of the study area. The Dakota Sandstone, one or more members of the Morrison and Wanakah Formations, and the Entrada Sandstone crop out along the east side of the San Juan Basin and are present in the subsurface of the study area.

[2] The Burro Canyon Formation is known to be present in the north part of the study area, but has not been definitely identified in the south part.

[3] The Brushy Basin Member has been completely removed and the Westwater Canyon Member has been partly removed by pre-Dakota erosion in the southwest part of the study area (fig. 4). In that area, the Dakota Sandstone directly overlies the Westwater Canyon Member and the two units probably form one aquifer.

[4] The Cow Springs Sandstone and Wanakah Formation are equivalent.

Figure 3.--Stratigraphic nomenclature of the Morrison Formation and adjacent geologic units in the western part of the San Juan Basin (modified from Molenaar, 1977; Condon and Peterson, 1986; and Condon and Huffman, 1988).

INTRODUCTION

One or more members of the Morrison Formation of Late Jurassic age underlie the San Juan Basin and the Navajo Indian Reservation in northwestern New Mexico (fig. 1). That part of the reservation has an area of about 3,700 square miles. The study area, which encompasses an area of 5,406 square miles, extends west to east from the New Mexico-Arizona State line to several miles east of Farmington and north to south from the New Mexico-Colorado State line to several miles south of Gallup. Well records in the files of the U.S. Geological Survey and of the New Mexico State Engineer Office, along with reports by Cooper and West (1967), Kelly (1977), Lyford and others (1980), Frenzel and Lyford (1982), Stone and others (1983), and Welder (1986), indicate that the Morrison Formation is a valuable source of water on the Navajo Reservation. The formation also is the principal source of uranium in the area.

This report presents information about the geohydrology of the Morrison Formation, based on historical data. Additional data and assessment of the water-yielding properties of the formation, however, are needed for the development of conservation measures and water-resource management practices by Indian, State, and local agencies. The report is a product of a study conducted by the U.S. Geological Survey in cooperation with the New Mexico State Engineer Office and the Navajo Nation during 1985-87.

GEOLOGY

The Morrison Formation, which crops out along much of the periphery of the San Juan Basin, is overlain by successively younger rocks toward a deep trough in the northeastern part of the basin (Kelley, 1957, fig. 1). During Late Jurassic time, coarser grained sediments (fig. 2) were deposited in the south and west (Santos and Turner-Peterson, 1986, fig. 4). As a result, rocks of Jurassic age generally are 300 to 400 feet thinner in the northeastern part of the San Juan Basin than in the southern and western parts (Santos and Turner-Peterson, 1986, fig. 4). However, accurate thicknesses are difficult to determine in many places where the base of the formation is indistinct on geophysical logs. Geophysical logs do indicate the thickness of the Morrison Formation to range from 500 feet near Gallup to 1,000 feet in the subsurface where there has been no extensive pre-Dakota erosion.

The names and distribution of Jurassic rock units and formations that are stratigraphically below and above the Morrison Formation are shown in figure 3. The Morrison Formation consists of, in ascending order, the Salt Wash, Recapture, Westwater Canyon, and Brushy Basin Members (fig. 3). The Salt Wash Member pinches out between Sanostee Wash and Toadlena in the west-central part of the area (fig. 4) (Condon and Peterson, 1986, fig. 4a). The Recapture and Westwater Canyon Members are of greater areal extent than the Salt Wash and Brushy Basin Members and have been mapped to about 35 miles south of Gallup (Saucier, 1967, figs. 1 and 2). Pre-Dakota erosion has removed the Brushy Basin Member in the southwestern part of the study area (fig. 4).

The Morrison Formation consists of mudstone, claystone, siltstone, sandstone, conglomeratic sandstone, and minor limestone that were deposited in fluvial, eolian, and lacustrine environments. Lithologic descriptions of the four members of the Morrison are shown in figure 3. Colors of the lithologic units in the Morrison Formation are various shades of red, brown, yellow, gray, and green and generally are not characteristic of one rock unit throughout the entire area.

The major structural features in the study area of the San Juan Basin (figs. 1 and 5) are the following: Zuni uplift, Chaco slope, and Gallup sag in the south; Defiance uplift and Defiance monocline in the west; Four Corners platform and Hogback monocline in the northwest; and the central basin in the east. Several geologic formations in the anticlinal structures on the Four Corners platform contain petroleum. Little or none of the oil and gas produced from these structures, however, comes from the Morrison Formation (Richard Wilson, U.S. Bureau of Land Management, oral commun., 1987).

The general structure of the Morrison Formation is shown by contours drawn within an interval near the top of the Morrison Formation and the base of the Dakota Sandstone in figure 4. The configuration probably is accurate to about 50 to 150 feet. Santos and Turner-Peterson (1986, p. 27-34) and Thaden and Zech (1986, p. 35-46) discussed the problems in mapping the top of the Morrison Formation. The depth below land surface to the top of the Morrison Formation in the Gallup sag near Gallup (fig. 4) is 2,020 feet and near Tohatchi it is 2,700 feet. The depth generally is less than 2,000 feet in the Four Corners platform. In the central basin, the depth to the top of the Morrison Formation near Bisti is 5,000 feet and the maximum depth in the study area (east of Farmington) is 6,770 feet.

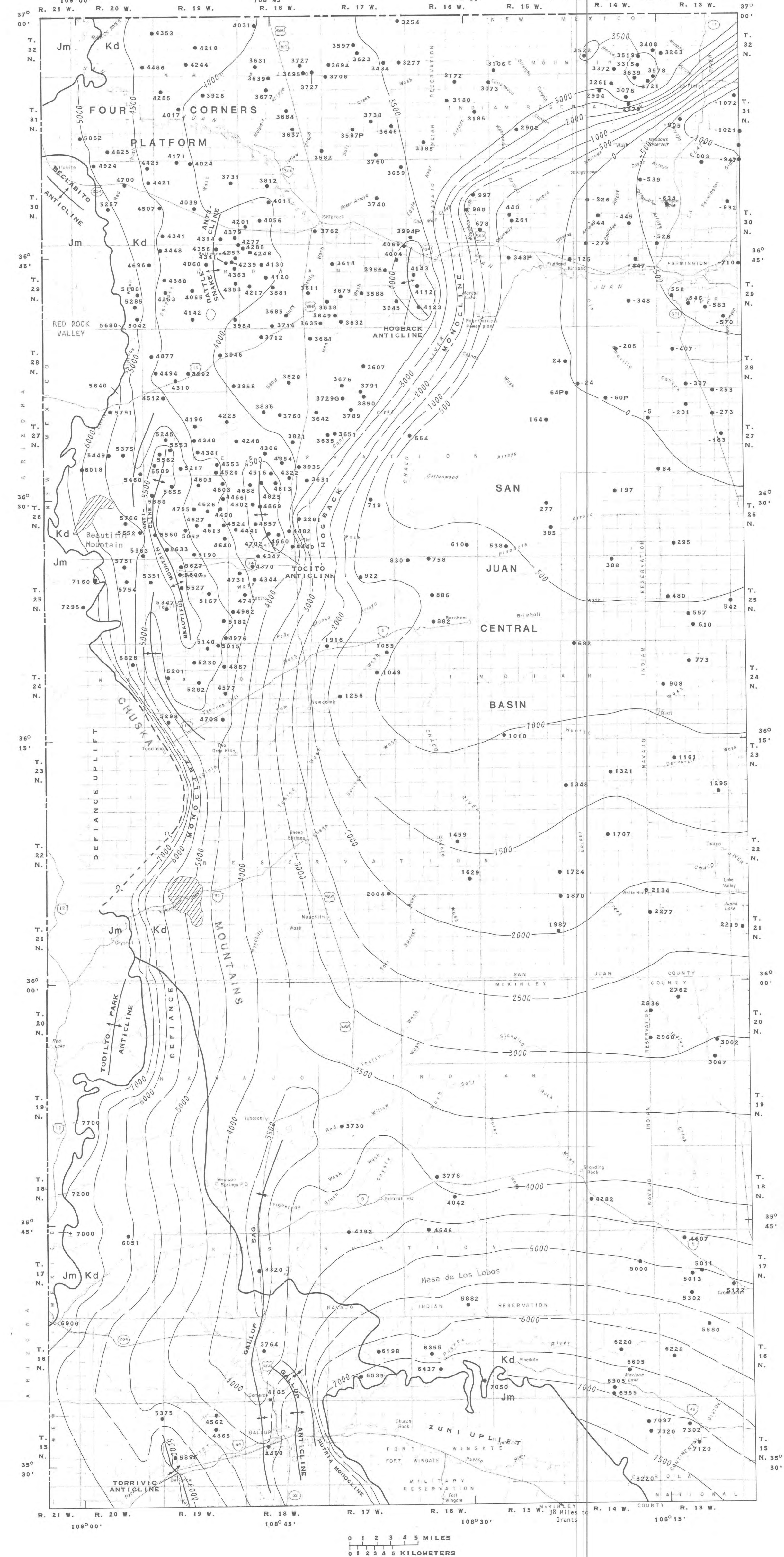

Figure 4.--Structure contours near the top of the Morrison Formation (base of the Dakota Sandstone).

EXPLANATION

▨ IGNEOUS-ROCK OUTCROP

FORMATION CONTACT--Contact of Morrison Formation (Jm) and Dakota Sandstone (Kd) at land surface (solid line) or subcrop (dashed line); approximately located. Modified from O'Sullivan and Beaumont (1957)

--6500— STRUCTURE CONTOUR--Shows approximate altitude of the top of the Morrison Formation (base of the Dakota Sandstone). Dashed where probable. Contour interval 500 feet. Datum is sea level

EROSIONAL TRUNCATION BOUNDARY--Brushy Basin Member of Morrison Formation removed by pre-Dakota erosion south and west of this boundary (Condon and Peterson, 1986, fig. 4; Kirk and Condon, 1986, pl. I)

4450 ● 6900 MAP CONTROL POINT--Number is altitude of the top of the Morrison Formation (base of the Dakota Sandstone), in feet above sea level. Determined from data reported by Petroleum Information Corporation, geophysical logs, driller's reports of wells and test holes (●), and from generalized outcrop altitudes (✗)

HYDROLOGY AND GROUND-WATER DEVELOPMENT

The generalized potentiometric surface and distribution of specific conductance of water in the Morrison Formation (fig. 5) were mapped using data collected from 1948 to 1986 (table 1). The long timeframe for data compilation was used because of the lack of sufficient data in a shorter timeframe in much of the study area and because of the lack of stress in most of the area, which would have made the use of the long timeframe inappropriate. Figure 5 is generalized, but it is a useful indicator of hydrologic conditions. The potentiometric contours indicate that the Chuska Mountains and the Zuni uplift are principal areas of ground-water recharge. Additional ground water probably flows into the Morrison Formation in the study area from the northeastern part of the San Juan Basin (Lyford and others, 1980, fig. 2).

Potentiometric contours (fig. 5) indicate that ground water flows out of the study area in the northwestern, southeastern, and probably the southwestern parts of the San Juan Basin. Water is pumped from the Morrison Formation through wells in the Grants uranium region between Navajo Highway 9 and the Zuni uplift in the southern part of the area and from the Four Corners platform between Two Grey Hills and the San Juan River in the northwestern part of the area (fig. 5).

The total pumpage from the Morrison Formation in the study area for municipal, agricultural, and domestic uses and for uranium-mine dewatering has been large (Hearne, 1977, fig. 2; Lyford and others, 1980, fig. 6). Withdrawals from numerous free-flowing artesian wells (Davis and others, 1963; Stone and others, 1983, table 1) and mineral-test holes (Kirk and Condon, 1986, pl. C) have contributed to the lowering of the potentiometric surface in the Morrison Formation.

The practice of completing wells in two or more aquifers (Stone and others, 1983, table 1) to obtain maximum production has created a condition in which water containing large concentrations of dissolved solids might contaminate an aquifer containing water with small concentrations of dissolved solids. The potentiometric-contour closures in the southeast are believed to be the effects of municipal pumpage at Crownpoint and Standing Rock and uranium-mine dewatering in the Grants uranium region (fig. 5). Water levels in the large cone of depression northeast of Church Rock have been rising since the mines in that area closed in 1986.

Most of the water in the Morrison Formation that is available to wells probably is contained in sandstone of fluvial origin that was deposited by braided streams, which is dominant in the Westwater Canyon Member (fig. 3). Although this sandstone, which was deposited by moderate- to high-energy streams (Kirk and Condon, 1986, p. 111), is poorly to well sorted (Turner-Peterson, 1986, p. 52), it can be expected to be continuous and to have a primary permeability that is moderate to substantial. This condition is conducive to extensive flow of ground water around and past the thin lenses of siltstone and mudstone (Condon and Peterson, 1986, p. 22) incorporated in the sandstone matrix.

The proportion of fluvial-derived sandstone decreases in the Salt Wash, Recapture, and Brushy Basin Members of the Morrison Formation. On the basis of the proportion of fluvial-derived sandstone, the Westwater Canyon Member has the greatest potential for ground-water development, the Salt Wash and Recapture Members have a slight potential for ground-water development, and the Brushy Basin Member has the least potential for ground-water development (fig. 3). More information is needed to assess the potential for ground-water development from the eolian sandstone in the Morrison Formation. Stone and others (1983, p. 40) suggested that eolian deposits in the Cow Springs Sandstone have a slight potential for ground-water development. Condon and Peterson (1986, fig. 5) identified the upper Cow Springs Sandstone as a major eolian facies of the Recapture Member. If fracturing is as extensive in the San Juan Basin as indicated by Kelley (1957, fig. 2), any member of the Morrison Formation may yield water locally.

All except two or three of the wells listed in table 1 probably are completed in the Westwater Canyon Member of the Morrison Formation. The yields of wells completed in the Morrison probably range from a few to about 500 gallons per minute. According to Frenzel and Lyford (1982, fig. 6), transmissivity values of the Morrison Formation range from less than 50 to about 400 feet squared per day in the western part of the San Juan Basin. These values are based on a few aquifer and specific-capacity tests, most of which were concentrated in the northwestern and southeastern parts of the study area. Although data are few, the potential for developing large ground-water supplies from the Morrison Formation appears to be greatest in the large area of thick fluvial-sandstone deposition (fig. 2) between Townships 18 and 24 N. Well 23 near Tohatchi (fig. 5) flowed at the rate of 508 gallons per minute in 1985, and well 25 near Bisti flowed at the rate of about 400 gallons per minute in 1973. Completion and flow records for the well near Tohatchi indicate that most if not all of the present discharge is from the Westwater Canyon Member. Records for the well near Bisti also identify the Westwater Canyon Member as the source of water.

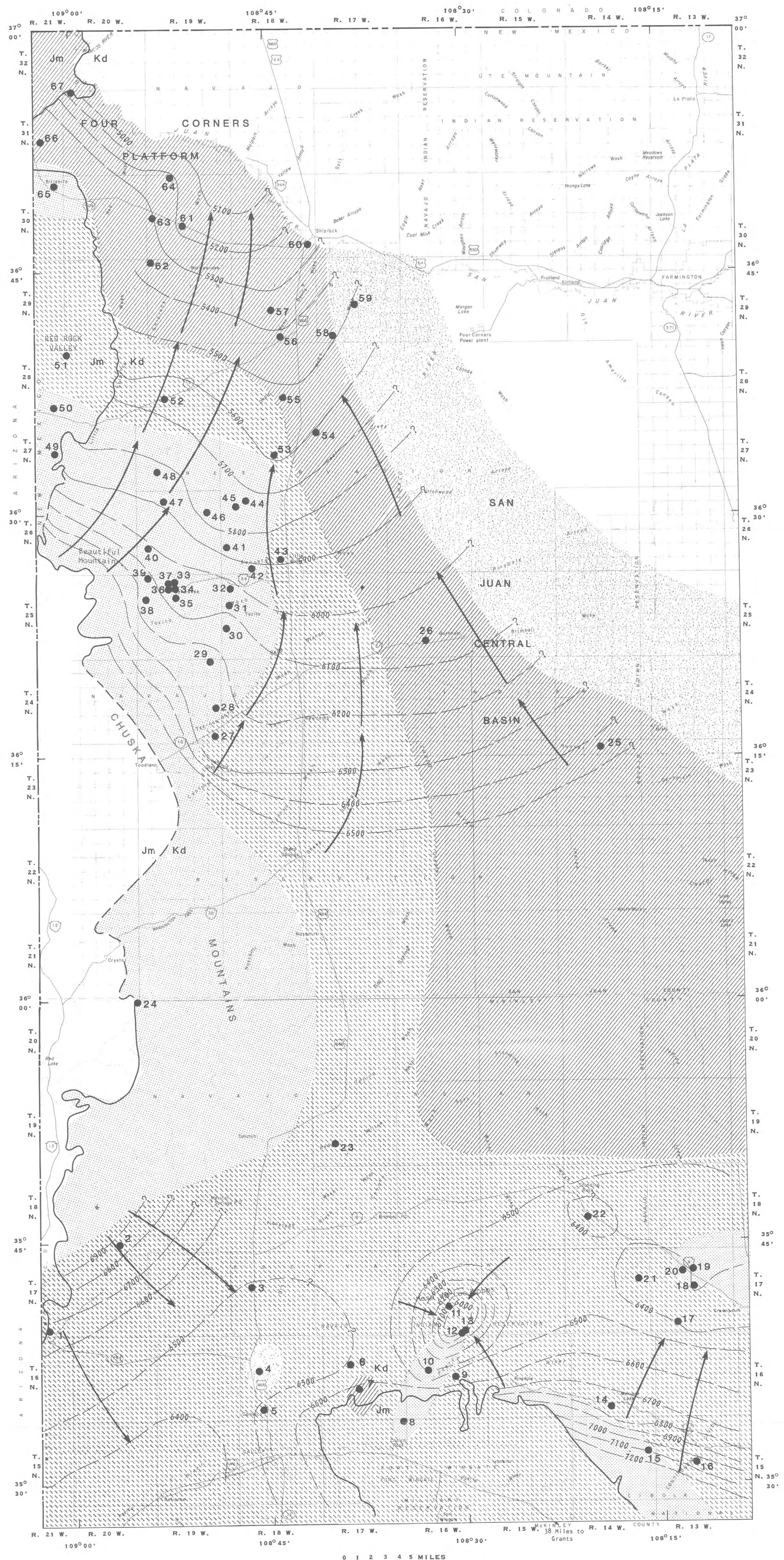

Figure 5.--Generalized potentiometric surface and distribution of specific conductance of water in the Morrison Formation.

EXPLANATION

SPECIFIC CONDUCTANCE, IN MICROSIEMENS PER CENTIMETER AT 25 DEGREES CELSIUS

- ░ 200-500
- ▧ 500-1,000
- ▨ 1,000-5,000
- ▒ More than 5,000
- □ No data

FORMATION CONTACT--Contact of the Morrison Formation (Jm) and Dakota Sandstone (Kd) at land surface (solid line) or subcrop (dashed line); approximately located. Modified from O'Sullivan and Beaumont (1957)

--6500— POTENTIOMETRIC CONTOUR--Shows approximate altitude at which water would stand in tightly cased wells. Dashed where probable; queried (?) where questionable. Contour interval 50 and 100 feet. Datum is sea level

→ FLOW DIRECTION--General direction of ground-water flow

● 5 CONTROL POINT--Number refers to potentiometric-surface and specific-conductance data from 65 wells, 1 spring, and 1 mine shaft listed in table 1. Most of the data were collected by the U.S. Geological Survey; other data from the files of the Navajo Nation, the New Mexico Bureau of Mines and Mineral Resources, and the New Mexico State Engineer Office

WATER QUALITY

The dissolved-solids concentrations in water in the Morrison Formation were inferred by mapping the distribution of specific conductance of water samples from wells (table 1 and fig. 5). Specific conductance, in microsiemens per centimeter at 25 degrees Celsius, multiplied by 0.65 (W.L. Dam, Hydrologist, U.S. Geological Survey, oral commun., 1988) gives a general approximation of the dissolved-solids concentration, in milligrams per liter. Water having a specific conductance less than about 700 microsiemens is preferred for domestic use. Water having a specific conductance of about 1,400 microsiemens may be usable if harmful chemical constituents are not present in large concentrations (U.S. Environmental Protection Agency, 1986). On the basis of specific-conductance data, water in the Morrison Formation is least mineralized in the western and southern parts of the study area and is most mineralized in the northeastern part of the study area (fig. 5). Mineralization of the water apparently increases with depth and distance from the outcrop due to less circulation and flushing in finer grained deposits that may contain more soluble minerals. Surprising exceptions are well 3 (fig. 5), which yields water having a specific conductance of 710 microsiemens from a depth of 3,246 feet, and well 25 (fig. 5), which yields water having a specific conductance of 1,260 microsiemens from a depth of 5,250 feet. Obviously, the Morrison Formation in the area between Townships 18 and 24 N. contains large quantities of water that may be suitable in quality for many uses.

ADDITIONAL DATA NEEDS

More data are needed to adequately describe the hydrology of the Morrison Formation throughout the study area. Drilling and testing of new wells in remote areas and the testing of existing wells would provide valuable data. A thorough investigation of the free-flowing wells would provide information on how much the aquifers are being affected by pumpage and what action is needed by Indian, State, and local agencies to alleviate any detrimental effects.

CONVERSION FACTORS

In this report, all measurements except chemical concentrations are given in inch-pound units. The following table contains factors for converting to metric units.

Multiply inch-pound units	By	To obtain metric units
foot	0.3048	meter
foot squared per day	0.09290	meter squared per day
mile	1.609	kilometer
gallon per minute	0.06309	liter per second

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.

Table 1.--Potentiomentric-surface and specific-conductance data for 65 wells, 1 spring, and 1 mine shaft completed in the Morrison Formation

[microsiemens, microsiemens per centimeter at 25 degrees Celsius; --, no data]

Number of control points shown in figure 5	Local control-point number or name	Reported depth (feet)	Altitude of potentiometric surface (feet above sea level)	Date potentiometric surface measured	Onsite specific conductance (microsiemens)	Date specific conductance measured
1	16K-322	220	6,680	05-11-55	--	--
2	18T-591	1,472	6,871	11-09-83	850	07-29-85
3	14T-531	3,246	6,470 est.	1986	710	09-27-65
4	Munoz-1 test hole	3,450	6,440	03-13-68	1,150	03-13-68
5	Lockhart-1	2,265	6,578	05-24-56	717	05-24-56
6	16T-532	450	--	--	820	02-07-74
7	16T-534	410	6,626	08-17-84	1,110	10-26-83
8	Kit Carson spring	--	--	--	268	08-30-49
9	16T-513	318	6,556	08-17-84	710	02-07-74
10	Old Church Rock mine shaft	900	6,385	02-21-86	--	--
11	Kerr McGee observation well	2,374	6,011	10-09-86	--	--
12	UNC supply well	1,650	--	--	513	03-23-71
13	UNC drill hole C-3 drift	--	--	--	508	11-13-73
14	Mariano Lake	1,200	6,703	06-22-60	840	03-06-73
15	16T-553A	1,162	7,130	11-24-70	472	07-19-74
16	16T-519	1,275	7,017	01-14-81	880	12-03-63
17	Pathfinder	1,924	6,445	06-25-81	--	--
18	Mobil-15m35	2,075	6,452	08-15-82	740	04-06-77
19	Mobil-15L73	2,100	6,457	02-27-85	415	08-17-82
20	Mobil-9U279P	2,060	6,428	06-28-85	480	09-03-80
21	UNC observation well	2,220	6,408	08-15-85	--	--
22	Standing Rock	2,638	6,351	03-01-85	553	06-01-80
23	Pure 14T-515	2,700	--	--	655?	08-28-85
24	14T-517	887	7,541	04-25-61	--	--
25	El Paso-Bisti BWW-1	5,250	6,449	08-27-73	1,260	10-31-86
26	Gulf-Burnham	9,204	6,051	1955	--	--
27	12T-632	2,518	6,236	05-21-85	825	06-04-86
28	12T-640	2,349	--	--	430	06-04-86
29	12T-634	1,908	6,240	06-11-85	245	06-11-85
30	12T-635	2,108	--	--	310	05-22-85
31	12T-651	1,691	--	--	302	06-24-86
32	12T-633	2,125	6,057	10-23-86	300	05-07-85
33	12T-512	1,490	--	--	440	11-30-79
34	12M-25	2,679	--	--	286	11-10-48
35	12T-655	1,530	--	--	450	05-07-85
36	12K-311	1,475	6,082	10-23-86	300	09-16-54
37	PM-3	1,100	--	--	300	09-15-67
38	12T-631	1,794	--	--	300	01-05-78
39	12T-662	1,751	6,173	05-07-85	350	08-08-80
40	12T-570	1,150	6,008	07-11-84	--	--
41	12T-649	2,047	5,872	05-07-85	360	05-07-85
42	12T-647	1,912	--	--	450	07-18-85
43	12T-620	2,034	5,883	02-26-86	620	06-30-86
44	12T-654	1,656	5,739	07-18-85	--	--
45	12R-84	1,430	5,745	06-13-85	422	08-12-49
46	12T-644	1,912	5,754	06-13-85	375	06-18-86
47	12T-582	902	5,894	07-19-85	--	--
48	12T-354	675	5,830	07-19-85	280	11-29-62
49	12T-501	553	5,832	09-25-85	457	09-25-85
50	12T-323	551	--	--	430	09-24-74
51	12T-329	555	5,599	09-25-85	550	05-16-58
52	Mittenrock	1,587	5,677	09-25-85	1,045	09-25-85
53	12K-320	1,992	5,586	06-12-85	510	06-17-86
54	12T-626	2,920	--	--	2,130	05-29-86
55	12T-638	2,682	--	--	1,425	07-01-86
56	12T-628	2,597	5,416	09-26-85	3,800	06-18-86
57	12T-627	2,555	5,377	10-22-86	3,490	01-04-78
58	12T-629	2,520	--	--	4,070	06-19-86
59	12T-630	2,300	5,501	01-22-81	6,000	06-19-86
60	12T-520	1,777	--	--	4,000	06-16-86
61	12T-636	2,035	5,130	09-13-85	3,700	07-02-86
62	12T-658	1,721	--	--	1,040	09-27-85
63	12T-659	1,681	--	--	1,040	09-27-85
64	12T-637	2,000	5,215	09-13-85	680	06-24-86
65	12R-7A	14	5,555	09-21-54	490	08-31-49
66	12K-335	604	5,418	08-28-84	570	07-09-80
67	12T-340	802	5,049	09-13-85	550	01-18-60

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