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LOGICAL SURVEY WATER-SUPPLY PAPER 1576-H

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GROUND-WATER RESOURCES OF THE SOUTHERN PART OF JICARILLA APACHE INDIAN RESERVATION AND ADAJACENT AREAS, NEW MEXICO

By ELMER H. BALTZ and S. W. WEST

ABSTRACT

The southern part of the Jicarilla Apache Indian Reservation and the adjacent areas to the south and east include about 1,300 square miles in parts of Rio Arriba, Sandoval, and McKinley Counties, N. Mex. This region is in the eastern part of the San Juan Basin, a large structural and drainage basin in the east-central part of the Colorado Plateaus physiographic province. For convenience in describing the ground-water resources, the area studied was divided into six physiographic sectors—the Penistaja Cuestas, Largo Plains, Tapicitos Plateau, Yeguas Mesas, San Pedro Foothills, and Northern Hogback Belt. The area studied is in the Central basin of the San Juan Basin and is bounded on the east by the French Mesa–Gallina uplift and the Nacimiento uplift, where rocks ranging in age from Precambrian to Cretaceous crop out. Rocks of Late Cretaceous age crop out along the south and east sides, and rocks of Tertiary age crop out in most of the area.

The oldest rocks that were mapped are those of the Mesaverde Group of Late Cretaceous age. Other Upper Cretaceous rocks mapped include, in ascending order, the Lewis Shale, the Pictured Cliffs Sandstone, and the Fruitland Formation and Kirtland Shale undivided. The Mesaverde Group might yield potable water at shallow depth along the east side, but in most of the area these rocks are deeply buried and contain saline water. The Lewis Shale and the Pictured Cliffs Sandstone do not yield potable water to wells; the Pictured Cliffs contains saline water and natural gas at places.

Sandstone beds in the Fruitland and Kirtland might yield amall amounts of water to wells at places in the southern and northeastern parts, but in most of the area these rocks are not potential aquifers. In the subsurface of the northern half of the area, sandstones in the lower part of the undivided Fruitland and Kirtland contain natural gas and some saline water.

Rocks of Tertiary age include, in ascending order, the Ojo Alamo Sandstone, the Nacimiento Formation, the San Jose Formation, and several dikes of igneous rocks. The Ojo Alamo Sandstone of Paleocene age is an important aquifer in the southern part of the area, and generally it is the deepest aquifer from which large amounts of potable water may be expected. The Nacimiento Formation of Paleocene age consists mostly of shale with a few intercalated beds of sandstone in the southern half of the area, where it does not yield water to wells.

In the northern half of the area, the Nacimiento consists of shale and thick be of sandstone which yield potable water to wells at a few places. These sandsto beds may be potential sources or large supplies of water from deep wells.

The San Jose Formation of Eocene age has been divided into four litholog units: the Cuba Mesa, the Regina, the Llaves, and the Tapicitos Members. T Cuba Mesa Member, the basal part of the formation, is mostly conglomera arkosic sandstone. The Cuba Mesa Member intertongues with the overlyi Regina Member, which consists of variegated shale with interbedded thick to th sandstone. In the northern third of the area the Regina Member grades nort ward into the lower part of the Llaves Member, which consists mainly of co glomeratic arkosic sandstone. A persistent medial sandstone unit of the Llav Member overlies the Regina Member in most of the northern part of the are The upper part of the Llaves Member grades westward into the Tapicitos Memb which consists of red shale and interbedded thin to thick sandstone. The Ta citos Member is present only in the northern third of the area. Sandstone be in all the members of the San Jose yield water to wells, and the thick sandston of the Cuba Mesa and Llaves Members probably would be practical sources large amounts of water for deep wells in parts of the area.

Mafic igneous rocks of Miocene(?) age occur as dikes in the north-central pa of the area. These rocks do not yield water to wells, but they may locally impe the westward movement of water in the San Jose Formation and older rocks.

Unconsolidated gravel of Tertiary or Quaternary age caps several high terrac at the foot of San Pedro Mountain. Gravel of Quaternary age caps lower lev terraces and occurs in stream channels and valleys in the same part of the are The gravel yields small supplies of potable water to wells and springs. Alluviu occurs in all the major valleys and contains small amounts of water at many plac

In most of the area the rocks dip gently northeast toward the northwest-trendi axis of the San Juan Basin, which extends diagonally across the northern part the area. A staggered system of northwestward-plunging anticlinal noses occu in the eastern part near the Nacimiento uplift. These folds were formed mair in late Paleocene time, as the result of right shift between the San Juan Basin an the Nacimiento uplift. Near the Nacimiento uplift, the rocks dip steeply we and at places are vertical or are overturned and dip steeply east along a maj north-trending synclinal bend which lies immediately west of the Nacimiento faul The synclinal bend was formed mainly in early Eocene time, although furth deformation occurred after deposition of the San Jose Formation. A sinuo west-facing monocline lies north of the Nacimiento uplift at the east side of th San Juan Basin and the west side of the contiguous French Mesa–Gallina upli The rocks are broken by faults at a few places in the eastern part of the area, b the stratigraphic displacements on the faults are mostly 200 feet and less.

The principal sources of ground-water recharge are precipitation and strea flow on outcrops of the aquifers in the eastern and southern parts of the area altitudes of 7,000–8,000 feet. Most of the ground water moves northwest and discharged from outcrops at lower altitudes, where the water is dissipated b evapotranspiration. Seepage investigations of the San Juan River indicate th the increment of ground-water discharged to the river relative to the river flo is too small to detect. Therefore, withdrawal of ground water from the Jicaril Reservation would not measurably affect the flow of the San Juan River.

Water in the Ojo Alamo Sandstone and the San Jose Formation varies wide in chemical quality from one unit to another, and also within a unit from o place to another. High concentrations of sodium as compared with calcium an magnesium make some of the water undersirable for irrigation, and high conce trations of sulfate make some of the water undesirable for drinking.

PREVIOUS WORK

The geology of parts of the area had been mapped prior to this study and described briefly in several reports. The southern and eastern parts of the area were included in reconnaissance mapping by Gardner (1909), who also described briefly the stratigraphic relations of Cretaceous and Tertiary rocks in this area (Gardner, 1910). Renick (1931) mapped the rocks along the west side of Sierra Nacimiento and San Pedro Mountain, studied the stratigraphy and structure of these rocks, and discussed ground-water conditions in the east-central and southeastern part of the area. Dane (1936) described briefly the latest Cretaceous and Paleocene rocks of the region, and mapped the rocks in Tps. 20 and 21 N., Rs. 1–5 W., as a part of a study of the La Ventana–Chacra Mesa coal field to the south.

Dane (1946) also published a chart and description of the latest Cretaceous and Tertiary rocks of the east side of the San Juan Basin, including a description of the rocks along a narrow belt in the eastern part of the area of the present report. Wood and Northrop (1946) mapped the Nacimiento Mountains (Sierra Nacimiento), San Pedro Mountain, and the foothills to the west, which had been mapped previously by Renick (1931). The Dulce-Chama area, which was mapped by Dane (1948), includes T. 26 N., Rs. 1 E. and 1 W.

Several earlier investigations were made of the ground-water resources in and near the Jicarilla Reservation. A brief reconnaissance study was made by G. C. Taylor, Jr., in 1939 to determine the availability of potable water in the southeastern part of the reservation. Fred A. F. Berry (unpub. report to Jicarilla Tribe, 1957) summarized briefly the ground-water potential of the reservation. S. W. West and J. R. Rapp made a reconnaissance of the geology and ground-water hydrology in and near the southern part of the reservation in 1958.

PRESENT WORK

Fieldwork for this report was done from May to October 1959 and in May 1960 by E. H. Baltz, assisted by S. R. Ash. The geology was mapped, wells and springs were inventoried in the part of the area adjacent to the Jicarilla Reservation, and water levels in the wells were measured where possible. Much information on wells was supplied by the owners and other residents, and by the following well drillers: Branch Drilling Co., C. W. Dunn, L. J. Ingram, J. C. Leeper, J. G. Mathews Drilling Co., L. Messer, F. I. Northcutt, R. L. Reed, T. W. Stevenson, and Turner Drilling Co. Samples of water were obtained from wells and springs and were analyzed by the U.S. Geological Survey for their principal chemical constituents. Records of wells and springs and chemical analyses of water from the southern

part of the Jicarilla Reservation had been obtained previously b
G. C. Taylor, Jr., S. W. West, and J. R. Rapp.

The surface geology (pl. 1) was studied to define aquifers and dete mine their areal extent, and to determine the probable areas of recharg discharge, and saturation of the rock units. The subsurface geolog of the area was studied by comparing electric logs of wells drilled fo oil and gas with surface stratigraphic sections measured in the fiel Structure contours (pl. 1) and stratigraphic correlation diagram (pls. 2, 3, 4) also were drawn to illustrate the subsurface geology.

The geology of the area is described in detail in U.S. Geologica Survey Professional Paper 552 (Baltz, 1967), a companion to th report.

WELL-NUMBERING SYSTEM

In this report wells are designated mainly by location numbers, but i part by oil-company lease numbers. The location number used by th U.S. Geological Survey and the State Engineer in designating wat wells in New Mexico is a description of the geographic location of th well based on the Federal system of subdivision of the public lan The location number consists of a series of numbers corresponding t the township, range, section, and tract within a section, respectivel as illustrated by figure 2. If the location of a well within a particula tract has not been determined, a zero is used for that part of the numbe In an area transected by the New Mexico principal meridian, the lette "E" or "W" is used in the second segment of the number to designat the direction (east or west) from the meridian. Springs are numbere in the same manner, except that the letter "S" precedes the numbe

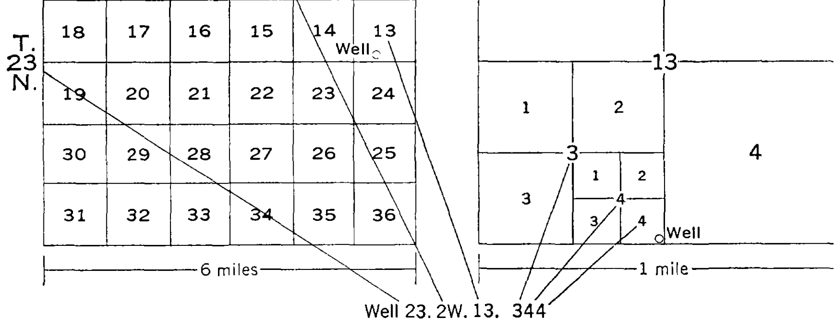

FIGURE 2.—Well-numbering system in New Mexico.

PHYSIOGRAPHY

DRAINAGE

The area investigated is in the eastern part of the San Juan Basin, a structural basin most of which is drained by the San Juan River and its tributaries. About two-thirds of the area is west of the Continental Divide (pl. 1) and is drained by intermittent streams that flow westward and northwestward to Canon Largo, which discharges intermittently into the San Juan River.

The region east of the Continental Divide is drained by intermittent streams in the Rio Grande watershed. La Jara Creek and Rito de los Pinos both are perennial streams in their upper courses but become intermittent before reaching San Jose Creek. San Jose Creek, which is intermittent for most of its length, flows southward between San Pedro Mountain and the Continental Divide to the vicinity of Cuba, where it joins the Rio Puerco.

The Rio Puerco flows southward and is the master stream for drainage of the southern and southeastern parts of the area. The Rio Puerco is intermittent below Cuba. Encino Wash and Arroyo San Ysidro drain intermittently southward, and outside the area they join Torreon Arroyo, a southeastward-flowing intermittent tributary of the Rio Puerco. Several small westward-flowing streams such as Rito Leche, Nacimiento Creek, and Senorito Creek (in Señorito Canyon) are perennial in their upper courses on Sierra Nacimiento but become intermittent before reaching the Rio Puerco. The Rio Puerco joins the Rio Grande almost 120 miles south of Cuba.

LANDFORMS

The landforms of the area are dependent directly on the geologic structure of the thick units of shale and interbedded thick to thin units of sandstone. Nearly horizontal units of shale and interbedded sandstone have been stripped from wide areas adjacent to the major streams. Outlying sandstone-capped mesas, buttes, and cuestas remain between the streams. Locally, the major streams have eroded deeply into Cretaceous and Tertiary rocks of the San Juan Basin, and where the rocks are mostly sandstone, the streams have steep-walled canyons. Where the rocks are tilted steeply and eroded deeply, the resistant sandstone beds form hogback ridges between valleys cut in shale.

The area was divided into six relatively distinct physiographic sectors—the Penistaja Cuestas, Largo Plains, Tapicitos Plateau, Yeguas Mesas, San Pedro Foothills, and Northern Hogback Belt—by Baltz (1967). The physiography of each sector reflects the geologic structure and the stratigraphy, both of which affect the occurrence of ground water. The boundaries of the physiographic sectors are shown on plate 5.

The altitude of the land surface ranges from a little less than 6,600 feet near the southwest corner to as much as 8,500 feet in the northeastern part of the area. The altitude of most of the area is between 6,800 and 7,500 feet. Topographic relief from tops of mesas to bottoms of adjacent canyons is as much as 1,000 feet in half a mile at some places.

CLIMATE

Precipitation has been measured at several stations in and near the southern half of the Jicarilla Apache Indian Reservation. The precipitation records of some stations are short, and those of most stations are intermittent. The average monthly precipitation and the periods of record at six stations are listed in table 1. The average annual precipitation ranges from 11.91 inches at Otero Ranch (alt 6,600 ft) to 16.71 inches at Gavilan (alt 7,350 ft). The average monthly precipitation at the six stations is least in June and greatest in July and August. According to published records of the New Mexico State Engineer (1956) the average frost-free season near the southern part of the reservation ranges from 77 days (June 25–Sept. 10) at Gavilan (alt 7,350 ft) to 128 days (May 27–Oct. 2) at Gobernador (alt 6,700 ft). In the west half of the southern part of the reservation, the frost-free season is probably about 128 days because this part of the reservation is similar in altitude and terrain to the Gobernador area.

June, July, and August constitute the major part of the growing season; hence, about one-third of the average annual precipitation occurs during the growing season. Therefore the quantity of irrigation water needed per unit area is small but essential for growing crops. The irrigable acreage is large, however, and thus the total amount of water needed is large.

GEOLOGY

REGIONAL SETTING

The area of this report is in the east-central part of the San Juan Basin, a large structural basin in northwestern New Mexico and southwestern Colorado. The east-west width of the basin is about 135 miles, and the north-south length is about 180 miles. The structural elements of the basin were named and described by Kelley (1950, p. 101–104) and are shown in modified form on figure 3.

The area of this report is in the southeastern part of the Central basin. The Central basin (a basin within the San Juan Basin) is bounded at the west and north by monoclinal structures, and it is enclosed mainly by gently inward-dipping platforms or structural

TABLE 1.—*Average monthly precipitation at stations in and near the Jicarilla Apache Indian Reservation, N. Mex.*

[New Mexico State Engineer, Tech. Rept. 6]

	Altitude (feet)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average annual [1]	Years of record
Gavilan	7,350	1.05	1.21	1.32	1.17	1.07	0.89	2.05	2.59	1.94	1.10	0.95	1.37	16.71	1923–25, 1927, 1929–54.
Gobernador	6,700	.87	1.17	1.08	.96	.78	.63	1.24	1.32	1.61	1.02	.60	.95	12.23	1925–27, 1932–54.
Lindrith	7,300	.59	.48	.72	.69	.86	1.13	3.27	3.20	1.79	.79	1.19	.87	15.58	1921–31.
Lybrook	7,200	.66	.36	1.35	.74	1.01	.40	2.09	1.54	.60	.82	1.00	.78	11.35	1951–54.
Otero	6,600	.68	.60	.81	.77	.62	.70	2.28	1.72	1.12	1.31	.41	.89	11.91	1910–18, 1920–26, 1953–54.
Cuba	6,945	.93	.71	1.32	1.07	.92	.71	1.89	2.42	1.41	1.22	.51	1.03	14.14	1938–54.
Average of all stations		.80	.75	1.10	.90	.88	.74	2.14	2.13	1.41	1.04	.78	.98	13.65	

[1] The sum of the average precipitation for each month.

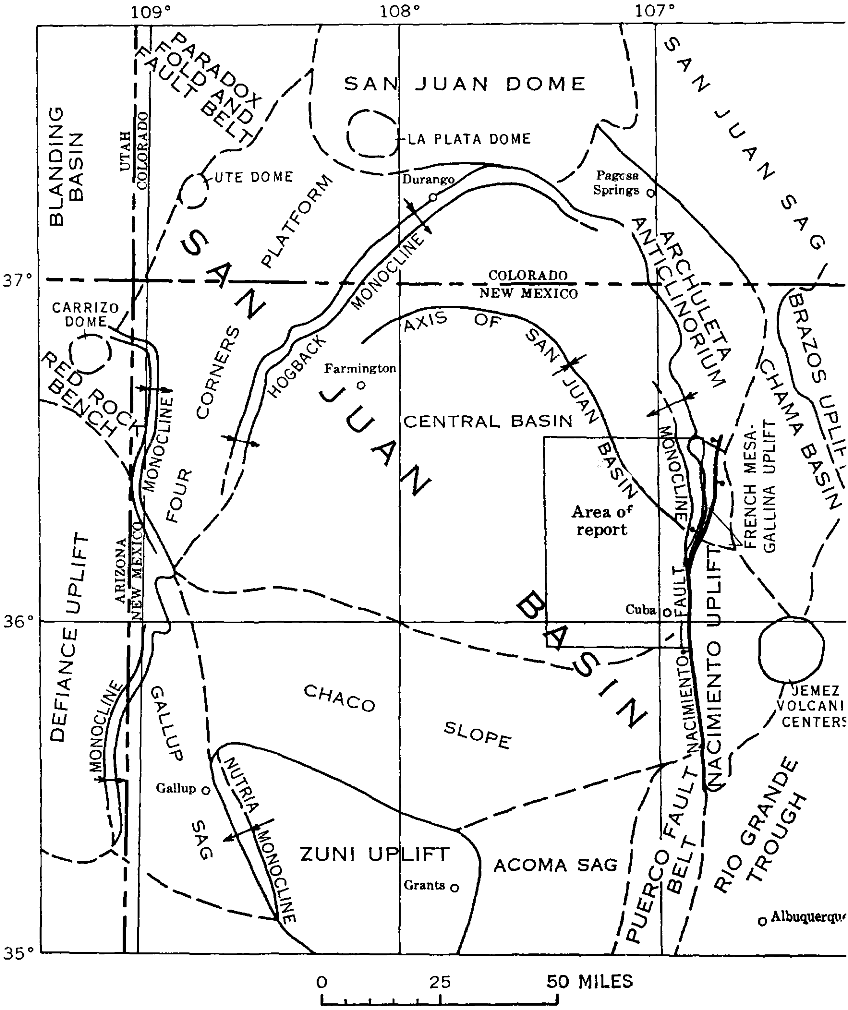

FIGURE 3.—Structural elements of the San Juan Basin. Modified from Kelley (1951, p. 125; 1955, fig. 2) and Kelley and Clinton (1960, fig. 2).

slopes. The southeast structural boundary of the Central basin is the Nacimiento fault which separates the basin from the Nacimiento uplift, of which Sierra Nacimiento and San Pedro Mountain are parts. North of the Nacimiento uplift, the east-central margin of the Central basin is a low monoclinal flexure on the west side of the French Mesa–Gallina uplift (Kelley and Clinton, 1960, p. 50). North of this uplift the northeastern boundary is the southwest edge of the Archuleta anticlinorium (Wood and others, 1948).

The rocks in the Nacimiento uplift and the eastern part of the San Juan Basin range in age from Precambrian to Recent (table 2).

TABLE 2.—*Age, nomenclature, and thickness of rock units in the Nacimiento uplift and the eastern part of the San Juan Basin, N. Mex.*

[Compiled in part from Renick, 1931; Dane, 1936; Wood and Northrop, 1946]

Era	System		Series	Lithologic unit		Thickness (feet)	
Cenozoic	Quaternary		Pleistocene and Recent	Alluvium in valleys		0–100+	
				Unconformity			
			Pleistocene	Terrace gravel, colluvium, and gravelly stream-channel alluvium in the upper parts of some valleys		0–100±	
				Unconformity			
	Tertiary or Quaternary		Pliocene or Pleistocene	Gravel capping high terraces		0–100±	
				Unconformity			
	Tertiary		Miocene(?)	Dikes of igneous rocks			
				Unconformity			
			Eocene	San Jose Formation		200±–1,800	
				Unconformity			
			Paleocene	Nacimiento Formation		<537–1,750	
				Ojo Alamo Sandstone		70–200	
				Unconformity			
Mesozoic	Cretaceous		Upper Cretaceous	Kirtland Shale and Fruitland Formation undivided		100±–450	
				Pictured Cliffs Sandstone		0–235	
				Lewis Shale		500–1,900	
				Mesaverde Group	La Ventana Tongue of Cliff House Sandstone	37–1,250	Total 560–1,825±
					Menefee Formation	347–375	
					Point Lookout Sandstone	110–200±	
				Mancos Shale		2,300–2,500	
			Lower and Upper Cretaceous	Dakota Sandstone		150–200	
				Unconformity			
	Jurassic		Upper Jurassic	Morrison Formation		350–600	
				Todilto Limestone		60–125	
				Entrada Sandstone		≤227	
				Unconformity			
	Triassic		Upper Triassic	Chinle Formation (including Poleo Sandstone Lentil of Wood and Northrop, 1946)		1,050±	
				Unconformity			
Paleozoic	Permian		Lower Permian	Cutler Formation		500–950	
				Local unconformity			
	Carboniferous systems	Pennsylvanian	Middle and Upper Pennsylvanian	Magdalena Group	Madera Limestone	0–800+	
			Lower Pennsylvanian		Sandia Formation (upper clastic member of Sandia Formation of Wood and Northrop, 1946)	0–200	
				Unconformity			
		Mississippian	Upper Mississippian	Arroyo Penasco Formation (lower limestone member of Sandia Formation of Wood and Northrop, 1946)		0–158	
				Unconformity			
Precambrian				Granite and metamorphic rocks			

Granite and metamorphic rocks of Precambrian age form a basement on which younger sedimentary rocks rest. The Precambrian rocks form the bulk of San Pedro Mountain and Sierra Nacimiento, and they are present at depths of 13,000 feet or more in wells drilled in the eastern part of the San Juan Basin. Paleozoic rocks, which lie on the Precambrian basement rocks, consist of thick beds of limestone, shale, sandstone, and conglomerate of Mississippian, Pennsylvanian, and Permian ages. These rocks crop out on Sierra Nacimiento and San Pedro Mountain (Renick, 1931; Wood and Northrop, 1946; Fitzsimmons and others, 1956). The Paleozoic rocks are present also in the subsurface of the San Juan Basin, but they are buried too deeply there to be considered practical sources of ground water.

The Paleozoic rocks are overlain by a thick sequence of Mesozoic rocks consisting of sandstone and shale of Triassic, Jurassic, and Cretaceous ages. Triassic rocks that are mainly red beds crop out in a structural sag between San Pedro Mountain and Sierra Nacimiento and in the belt of steeply dipping rocks along the west side of the mountains. Jurassic rocks, consisting of sandstone, variegated shale, and thin units of limestone and gypsum, also crop out in this belt. Cretaceous rocks, consisting of thick units of sandstone and shale, crop out in the belt of steeply dipping rocks and are the surface rocks in much of the San Juan Basin outside the Central basin. The Mesozoic rocks are also present in the subsurface of the Central basin. Some of these rocks are potential sources of ground water on the southern and eastern margins of the Central basin (Renick, 1931), but in the southern part of the Jicarilla Apache Indian Reservation most of the Mesozoic rocks are at depths of more than 3,000 feet, so they are not considered to be practical sources of ground water in that region.

Cenozoic rocks, consisting of thick units of sandstone and shale of early Tertiary (Paleocene and Eocene) age, are the surface rocks in most of the Central basin and are the main aquifers from which potable water may be obtained in this region.

STRATIGRAPHY

The oldest rocks mapped in the present investigation are those of the Mesaverde Group of Late Cretaceous age. Rocks older than the Mesaverde are shown on the geologic map (pl. 1) as Cretaceous and older rocks, undivided, and they range in age from Precambrian to Late Cretaceous, as shown in table 2.

ROCKS OF CRETACEOUS AGE

MESAVERDE GROUP

The Mesaverde Group in the area of this report consists of the

Point Lookout Sandstone, the Menefee Formation, and the La Ventana Tongue of the Cliff House Sandstone, in ascending order (Beaumont and others, 1956). The group was not subdivided during the mapping for this investigation, but the three formations seem to be present throughout the area. The Mesaverde Group crops out nearly continuously from south to north along the east side of the area (pl. 1) and is distributed continuously in the subsurface west of the outcrops. The group ranges in thickness from about 560 feet in sec. 35, T. 21N., R. 1 W. (Renick, 1931, p. 43–44) to almost 1,700 feet at the Shell Oil 1 Pool Four well in sec. 22, T. 21 N., R. 5 W. In the northeastern part of the area, at outcrops in sec. 5, T. 24 N., R. 1 E. (Fitter, 1958, p. 19, 49–51), the Point Lookout Sandstone is 95 feet thick, the Menefee Formation is 375 feet thick, and the La Ventana Tongue is about 110 feet thick.

The Point Lookout Sandstone consists of buff, gray, and tan sandstone which is generally thick to massive in bedding and forms ledges. The sandstone is mainly medium grained, but it contains a few beds of fine-grained sandstone and some thin beds of shale. The Menefee Formation consists of dark-gray and generally carbonaceous shale and interbedded thin to thick sandstones and thin coals. The La Ventana Tongue consists of gray, buff, and orange-brown thick to thin medium-grained ledge-forming sandstone and some interbedded gray shale near the top.

Although data are not available on the water-bearing properties of the Mesaverde Group in the area, the beds of sandstone in the Mesaverde are porous, and they should be good aquifers. Renick (1931, p. 49) reported that the porosity of several rock samples analyzed ranged from 13.71 to 28.32 percent, and that water of good quality issues from springs in sandstone of the Mesaverde Group south of the area of this report. Areas of recharge are at outcrops on the margins of the Central basin at altitudes higher than the altitude of the Mesaverde within the basin. Thus, artesian pressures that would cause the water to rise above the top of the formation are to be expected where the Mesaverde is in the subsurface, but surface flow would not be likely at most places. Except at places on the south and east sides, the Mesaverde Group is at depths of 2,000–6,000 feet, and the group is not considered to be a practical source of ground water where it is deeply buried.

Deep wells in the San Juan Basin have produced natural gas from the Mesaverde Group at places, and saline water at other places. Fresh water has encroached downdip along the margins of the basin and has replaced part of the saline water. However, the depth to which this flushing has taken place has not been determined, and

245-663—67——2

it may vary because of local conditions. Potable water is to be expected in the Mesaverde near outcrops only.

LEWIS SHALE

The Lewis Shale of Late Cretaceous age lies conformably on the Mesaverde Group. The Lewis crops out in a north-south belt along the east side of the area (pl. 1), and it is distributed continuously in the subsurface west of the outcrops. The Lewis Shale ranges in thickness from about 1,900 feet at the Reading and Bates 1 Duff well (24.1W.24.424) in the northeastern part of the area to about 550 feet south of Mesa Portales (Dane, 1936, p. 111). The shale thins southwestward in the subsurface. It is about 1,470 feet thick at the Magnolia Petroleum 1 Jicarilla D well (26.3W.24.), but only 500 feet thick at the Shell Oil 1 Pool Four well (21.5W.22.44 center). Much of the thinning takes place in a short distance in the subsurface of the southwestern part of the area. The thinning is largely the result of a facies change (Renick, 1931; Dane, 1936). The lower part of the Lewis Shale intertongues with the upper part of the La Ventana Tongue of the Cliff House Sandstone and grades laterally into it. Thus, as the Lewis Shale becomes thinner (to the south), the La Ventana becomes thicker by an approximately equivalent amount. The contact of the Lewis Shale and the overlying Pictured Cliffs Sandstone also is transitional and intertonguing (pls. 2, 3, 4).

The Lewis is composed of light to dark-gray fissile clay shale and some interbedded siltstone, fine-grained sandstone, and nodular concretionary limestone, containing marine invertebrate fossils. At most places the lower 100 feet of the Lewis Shale contains several thin beds of sandstone which are tongues of the La Ventana. In the subsurface of the southwestern part of the area, the Lewis Shale is very sandy and silty and is only 500–600 feet thick. These beds are believed to be stratigraphically equivalent to the clay shale of the upper part of the Lewis Shale in the northern part of the area.

The Lewis Shale is not utilized as a source of water in this area, and several water wells drilled in this formation in T. 24 N., R. 1 E., were unproductive. Because the formation is composed largely of clay shale, it has very low porosity and permeability. Some of the thin sandstones in the lower part of the formation might yield small amounts of water, but the water is probably saline.

PICTURED CLIFFS SANDSTONE

The Pictured Cliffs Sandstone of Late Cretaceous age lies conformably on the Lewis Shale. The Pictured Cliffs crops out in the southeastern part of the area (pl. 1), and a zone of thin sandstone, siltstone, and interbedded shale that probably represents the Pictured Cliffs was traced along the east side of the area as far north as sec. 4, T. 25

N., R. 1 E. The Pictured Cliffs is present in the subsurface of most of the area.

The Pictured Cliffs Sandstone ranges in thickness from about 65 feet in sec. 25, T. 20 N., R. 2 W., to about 35 feet in the southern part of the San Pedro Foothills. North of sec. 23, T. 21 N., R. 1 W., the outcrop belt of the Pictured Cliffs is very narrow. Here the formation was not mapped as a separate unit but was included with the overlying undivided Fruitland Formation and Kirtland Shale of Late Cretaceous age as far north as sec. 4, T. 25 N., R. 1 E. North of this locality the Pictured Cliffs is not a well-defined lithologic unit, and the shale and thin siltstone beds representing the Pictured Cliffs were excluded from the undivided Fruitland Formation and Kirtland Shale and were mapped with the Lewis Shale. In the subsurface (pls. 2, 3, 4) the Pictured Cliffs Sandstone thins to the east-northeast and ranges in thickness from about 235 feet at the J. D. Hancock 1 Brown well (21.5W.33.332) to about 80 feet at the Magnolia Petroleum 1 Cheney-Federal well (26.2W.8.223).

The Pictured Cliffs Sandstone is composed of varied proportions of thin- to thick-bedded, fine- to medium-grained sandstone, siltstone, and shale. In the subsurface of the southwestern part of the area the Pictured Cliffs is mainly sandstone, but it contains beds of siltstone, and shale. The formation thins notheastward and, as determined from interpretation of electric logs of wells, the thinning is accompanied by a gradual change from a predominantly sandstone facies to one of thin argillaceous fine-grained sandstone, siltstone, and interbedded shale. A similar northward change from a sandstone facies to a shaly facies occurs also at outcrops in the eastern part of the area.

The Pictured Cliffs Sandstone does not yield potable water to wells in this area. In much of the area the sandstones are thin, fine grained, and clayey, and they seem to have low porsity and permeability. The sandstone in the subsurface of the southern part of the area is thicker and more porous, but here interpretation of electric logs of wells indicates that the water is probably saline. In the area investigated, and elsewhere in the San Juan Basin, deep wells have produced natural gas or highly saline water from the Pictured Cliffs.

FRUITLAND FORMATION AND KIRKLAND SHALE UNDIVIDED

The undivided Fruitland Formation and Kirtland Shale are present above the Pictured Cliffs Sandstone at the surface and in the subsurface throughout the area. The Fruitland and Kirtland crop out in the southwestern and southern parts of the area (pl. 1) where they form low rounded hills and benches, and steep slopes beneath cuestas held up by the overlying Ojo Alamo Sandstone of Tertiary age. The

Fruitland and Kirtland form poorly exposed soft slopes in the San Pedro Foothills and the Northern Hogback Belt. Between sec. 23, T. 21 N., R. 1 W., and sec. 4, T. 25 N., R. 1 E., thin beds of soft sandstone and shale that represent the Pictured Cliffs Sandstone were mapped with the Fruitland and Kirtland on plate 1.

West of the area of this report, in T. 20 N., R. 6 W., the combined thickness of the Fruitland and Kirtland is slightly less than 600 feet (Dane, 1936, p. 114). The sequence thins eastward, and in secs. 8, and 9, T. 20 N., R. 1 W., it is about 130 feet thick. In the San Pedro Foothills and the Northern Hogback Belt, the thickness of the Fruitland and Kirtland is varied, ranging from about 84 feet in sec. 2, T. 23 N., R. 1 W., to 280–300 feet in secs. 17 and 29, T. 25 N., R. 1 E. In the subsurface of the northwestern part of the area the Fruitland and Kirtland are about 450 feet thick at the Northwest Production 1–7 Jicarilla 152 well (26.5W.7.332).

The undivided Fruitland Formation and Kirtland Shale consist of varied proportions of dark to light-gray and olive-green clay shale; carbonaceous shale; bentonitic clay; sandy shale and siltstone; interbedded white, buff, brown, and greenish-gray, fine-grained to very coarse grained sandstone; and, in the subsurface, coal. Locally, the sandstone and shale beds contain silicified wood. In the Northern Hogback Belt, north of sec. 4, T. 25 N., R. 1 E., the upper part of the Fruitland and Kirtland was eroded prior to deposition of the Ojo Alamo Sandstone. The lower part of the Fruitland and Kirtland consists mainly of sandstone, 50–100 feet thick, that contains some interbedded thin shale. This sandstone is overlain unconformably by the massive cliff-forming Ojo Alamo, which caps the high cuestas in T. 26 N., R. 1 E.

Only one well (20.3W.35.244; see pl. 5) is known to have obtained potable water from the undivided Fruitland Formation and Kirtland Shale in the area. This well, which is no longer in use, yielded only small amounts of water. Elsewhere in the southern part of the area, sandstone beds in the upper part of the Fruitland and Kirtland would probably yield small quantities of water to wells where these rocks are below the water table.

In the southeastern part of the area, east of the Rio Puerco, the Fruitland and Kirtland contain only a few beds of sandstone. These beds are clayey and probably have low porosity and permeability. The sandstones would yield only very small quantities of water, if any, and the water probably would be very saline. Similar conditions are to be expected in the San Pedro Foothills and the southern part of the Northern Hogback Belt. The sandstone beds of the middle and lower parts of the Fruitland and Kirtland might yield small amounts of water where they are thick, in the Northern Hogback Belt.

Deep wells drilled for oil and gas have yielded highly saline water and natural gas from the Fruitland and Kirtland. Rocks of the lower part of the Fruitland and Kirtland and the underlying Pictured Cliffs Sandstone are reservoirs for some of the extensive natural gas fields of the eastern part of the San Juan Basin.

ROCKS OF TERTIARY AGE

OJO ALAMO SANDSTONE

The Ojo Alamo Sandstone of Paleocene age (Baltz and others, 1966) rests unconformably on the undivided Fruitland Formation and Kirtland Shale and crops out in an irregular band almost continuously across T. 20 N., Rs. 1–5W. (pl. 1). East of the Rio Puerco it forms northwest-sloping cuestas. In the San Pedro Foothills the Ojo Alamo dips steeply west, and at places it is vertical or slightly overturned. It forms low, rounded ridges exposed in the walls of the canyons which drain San Pedro Mountain in this sector. The Ojo Alamo Sandstone is poorly exposed or covered at many places in the Northern Hogback Belt, but the outcrops are adequate to establish its identity and persistence in this region. The Ojo Alamo caps the high cuestas from sec. 33, T. 26 N., R. 1 E., to the northern boundary of the area, and it rests unconformably on sandstone of the Fruitland and Kirtland, from which it can be differentiated with certainty at only a few places.

At outcrops in the southern part of the area, the thickness of the Ojo Alamo ranges from about 170 feet (locally) in the southwest part of T. 20 N., R. 3 W. (Dane, 1936, p. 121) to about 70 feet in sec. 23, T. 20 N., R. 2 W. In the San Pedro Foothills and the southern part of the Northern Hogback Belt the thickness ranges from 90 to 113 feet. In the northern part of the area the Ojo Alamo thickens considerably, and it is almost 200 feet thick in the SE¼ sec. 33, T. 26 N., R. 1 E.

The Ojo Alamo Sandstone is distributed continuously throughout the area in the subsurface. In the subsurface of the southern part of the area the Ojo Alamo ranges in thickness from 80 to 100 feet. It thickens to the north and northeast as thin tongues of sandstone in the lower part of the Nacimiento Formation of Paleocene age thicken northward and merge with the underlying Ojo Alamo Sandstone (pls. 2, 3). In the subsurface of the northern part of the area the Ojo Alamo generally ranges in thickness from 180 to 200 feet.

The Ojo Alamo Sandstone is composed of several beds of buff, tan, and brown medium-grained to very coarse grained sandstone containing local lenses of olive-green to gray shale. The sand is mostly angular to subangular quartz. Other common constituents are coarse grains and granules of pink feldspar and red, gray, and green chert.

Pebbles ranging from half an inch to several inches in diameter are scattered through the sandstones at many places, and locally the lower few inches to several feet of the formation is pebble-to-cobble conglomerate. Logs replaced by silica or limonite are common in the Ojo Alamo at many localities. These fossils are similar to those found in sandstone of the Fruitland and Kirtland. At outcrops the Ojo Alamo Sandstone is cemented moderately by silica, clay, and iron minerals. Tangential crossbedding characterizes the formation, but the several beds of sandstone tend to weather as massive units.

The Ojo Alamo Sandstone rests with erosional unconformity on the undivided Fruitland Formation and Kirtland Shale in the area of this report. Evidence of scouring and channeling at the base of the Ojo Alamo may be observed at many places.

The coarse-grained conglomeratic sandstone of the Ojo Alamo is porous and permeable and has the physical characteristics of a good aquifer. The sandstone is only moderately well cemented at outcrops. In the northern Hogback Belt the Ojo Alamo is friable, and at many places it forms low rounded hills covered by sandy soil. Where the Ojo Alamo forms broad slopes, as in T. 26 N., R. 1 E., and across the southern part of the area in T. 20 N., Rs. 1–5 W., the upper part of the Ojo Alamo is only moderately cemented, and in places it weathers to soft sandy soil and dune sand. This characteristic of the Ojo Alamo probably facilitates infiltration by water from precipitation and from streams flowing across the outcrops in the southern and eastern parts of the area. Water-well drillers reported that the Ojo Alamo beneath the surface is soft at places, and that it behaves like quicksand during drilling. This observation indicates that the Ojo Alamo at places in the subsurface is highly porous and permeable because the spaces between sand grains are only partly filled with cementing material The yields of wells that tap the Ojo Alamo Sandstone are given in table 3.

The Ojo Alamo Sandstone is underlain at most places by clay shale or silty, sandy shale of the Fruitland and Kirtland; it is overlain by clay shale and silty sandy shale of the Nacimiento Formation. In the subsurface the underlying and overlying shale beds tend to confine the water in the Ojo Alamo so that the water is artesian.

Most of the water from the Ojo Alamo Sandstone is potable (table 9), but its chemical quality varies. In the Penistaja Cuestas west of the Rio Puerco the water from springs and wells is soft and of good chemical quality. Water from the Ojo Alamo near Cuba is hard and contains much dissolved iron.

The Ojo Alamo Sandstone probably is saturated with water in the subsurface of the area. Electric logs of wells drilled for oil and gas indicate that the water is not highly saline. However, data on the

TABLE 3.—*Yields and specific capacities (per foot of aquifer penetrated) of wells that tap the Ojo Alamo Sandstone and the Nacimiento Formation in and near the southern part of the Jicarilla Apache Indian Reservation, N. Mex.*

[Most yields are normal pumping rates reported, which may be less than potential yields of wells. gpm, gallons per minute]

Location No.	Depth of well (ft)	Depth to water (ft)	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm per ft)	Thickness of aquifer penetrated (ft)	Yield per foot of drawdown per foot of aquifer penetrated (gpm per ft)
Ojo Alamo Sandstone							
20.1W. 6.432	70	22	16				
20.2W.17.132	240	160	2.5				
19.124	300	80	20				
21.1W.15.322	300	53	2				
28.143	148	24	13.4	16.4	0.82	81	0.010
28.211	110	43	8			103	
28.233	70	28	16				
29.223	104	33	18				
29.240	100	33	30				
23.1W.27.233	48	10	[1] 25	4	6.25	47	.133
Nacimiento Formation							
24.5W.18.421	796	203	42	562	0.07	21	0.004
18.421a	789	233	16	542	.03	17	.002
25.1E.17.314	117	108	3.5			15	

[1] Part of yield from overlying alluvium.

yield and quanity of water are not available except in or near the outcrop area.

NACIMIENTO FORMATION

The Nacimiento Formation of Paleocene age lies conformably on the Ojo Alamo Sandstone throughout the area. Dane (1946) traced the Nacimiento Formation from its type locality near Cuba northward along the east side of the San Juan Basin and found that it is equivalent to part of the rocks mapped as the Animas Formation of Late Cretaceous and Paleocene age by investigators in Colorado. For this reason Dane (1946) restricted the use of the term Nacimiento Formation to the area south of Canoncito de las Yeguas in T. 25 N, R. 1 E., and applied the term Animas Formation to approximately the same rocks north of Canoncito de las Yeguas. However, in this report, beds above the Ojo Alamo in the northern part of the area that were designated as the Animas Formation by Dane (1946, 1948) are designated as the Nacimiento Formation, and the name Animas Formation is not used. (See Baltz, 1967, for a discussion of the terminology.)

The Nacimiento Formation crops out in a broad band in the Penistaja Cuestas sector across the southern part of the area (pl. 1). In the San Pedro Foothills the formation is exposed discontinuously in the walls of canyons and sides of valleys where its beds of somber clay and sandstone are vertical to slightly overturned, or dip steeply west. The Nacimiento Formation dips west and is poorly exposed in discontinuous low ridges separated by alluvial valleys in the Northern Hogback Belt.

The Nacimiento Formation in the southern part of the area ranges in thickness from about 850 feet at the Shell Oil 1 Pool Four well (21.5W.22.44 center) to about 800 feet in sec. 11, T. 20 N., R. 2 W. (loc. 1c and 1d, pls. 1, 4). The formation thickens generally northward and is as much as 1,750 feet thick in the subsurface near the northern boundary. At the outcrops in the San Pedro Foothills the thickness is 537 feet in sec. 11, T. 21 N., R. 1 W; a little less than 500 feet thick to the north; about 1,000 feet in sec. 34, T. 23 N., R. 1 W.; and about 600 feet in sec. 20, T. 24 N., R. 1 E. The Nacimiento Formation thickens northward in the Northern Hogback Belt; it is about 1,250 feet thick in sec. 8, T. 24 N., R. 1 E. (pl. 3), and about 1,400 feet thick in secs. 17 and 18, T. 25 N., R. 1 E.

The variations in thickness of the Nacimiento Formation are the result of erosional and regional angular unconformity between the Nacimiento and the overlying San Jose Formation of Eocene age (pls. 2, 3, 4). The erosional nature of the contact is apparent at most exposures, and the angular nature of the unconformity can be observed at outcrops in a branch canyon of one of the tributaries of the Rio Puerco in the SW¼NE¼SW¼ sec. 11, T. 21 N., R. 1 W. (Baltz, 1967). Here the beds of the Nacimiento Formation are overturned and dip steeply east, whereas the basal sandstone of the San Jose Formation dips steeply west. The difference between the angles of dip of the two formations is about 30° at this point on the margin of the San Juan Basin. Within the basin the angular discordance in dip is slight.

The Nacimiento Formation consists of shale and interbedded soft to resistant sandstone. These rocks are of two different lithologic facies in the southern and northern parts of the area; however, the lateral change in facies takes place so gradually and exposures are so discontinuous on the east side of the area that it was impossible to map a logical lithologic boundary between facies. The formation at outcrops in the southern part of the area consists mainly of clay shale, siltstone, and soft sandstone, and a few resistant sandstone beds. In contrast, in the northern part of the area as much as 50 percent of the formation is sandstone.

In the subsurface the lithologic character of the Nacimiento Formation is similar to that of the surface exposures. In the southern part of the area the Nacimiento consists mainly of shale, but the proportion of sandstone increases northward. The proportion of sandstone in the Nacimiento Formation increases markedly northeastward from a line extending diagonally across the area from about Otero Ranch (sec. 32, T. 24 N., R. 5 W.) to upper La Jara Creek (sec. 29, T. 22 N., R. 1 W.). The northeastward increase in the proportion of sandstone takes place in the lower half, approximately, of the formation, and as much as 30–40 percent of the lower half is sandstone (pls. 2, 3, 4). Five to seven miles north of the diagonal line, the proportion of sandstone in the upper part of the Nacimiento Formation increases abruptly, and in the northwestern and north-central parts of the area as much as 40–50 percent of the Nacimiento is sandstone. Most of the sandstone beds range in thickness from less than 50 feet to about 100 feet, but some beds in the upper part of the formation are as much as 200 feet thick.

The water-bearing properties of the Nacimiento Formation vary from south to north because of the lithologic change from a predominantly shale facies at the south to one of thick sandstones with interbedded shales at the north. Surface exposures and logs of wells show that most of the Nacimiento Formation is clay shale and clayey siltstone in the southern part of the area. These rocks have low permeability and porosity and are not good aquifers. The shale contains interbedded soft lenticular sandstone, but these sandstone beds are clayey and are probably poor aquifers, although they might yield small quantities of water to wells. Several beds of lenticular coarse-grained sandstone in the middle and upper parts of the Nacimiento Formation in the southern part of the area may contain some usable ground water.

Where the sandstone beds of the Nacimiento Formation crop out in the northern part of the San Pedro Foothills and Northern Hogback Belt, they are coarse grained and conglomeratic, and they appear to be fairly porous and permeable; thus, they should be good aquifers in the subsurface of the northern half of the area. The sandstones in the upper half of the formation are especially coarse grained and conglomeratic and are friable, which indicates that they are porous and permeable and are not tightly cemented. The only well (24.5W.18.421) known to obtain water from the upper part of the Nacimiento reportedly yields 42 gpm. The water is used for domestic and industrial purposes. The yields of other wells that tap the Nacimiento Formation are given in table 3. Electric logs of wells indicate that sandstone beds lower in the Nacimiento in much of the area are probably saturated with water. Data on the quality of water in the deeper beds are not available.

The sandstone beds of the Nacimiento Formation are interbedded with relatively impermeable shale, and the water in the sandstones is under artesian pressure. Because of the shaly nature of the Nacimiento Formation in outcrops along the southern margin of the Central basin, it is doubtful that much recharge of the formation occurs there. Most of the recharge probably occurs in the Northern Hogback Belt, where the sandstone facies crops out at higher altitudes than the altitude of the Nacimiento in the basin. The main areas of discharge of water from the Nacimiento Formation are in the deep canyons west and northwest of the area of investigation.

SAN JOSE FORMATION

The San Jose Formation of Eocene age lies unconformably on the Nacimiento Formation throughout the area. The San Jose Formation was named and defined by Simpson (1948, p. 281, 367) and consists of the same rocks mapped as the Wasatch Formation by Dane (1936, 1946, 1948) and by Wood and Northrop (1946).

The San Jose Formation consists of several intergrading lithologic facies. This fact was recognized by Dane (1946) and by Simpson (1948, p. 367–374), both of whom briefly described some of the stratigraphic relations but did not map the facies of the formation. During the present investigation, four complexly related lithologic units in the San Jose were distinguished, named, and mapped as members of the formation (Baltz, 1967). These members were named: The Cuba Mesa Member; the Regina Member; the Llaves Member; and the Tapicitos Member.

The San Jose Formation has been eroded deeply, and the differential resistance to erosion of its units of sandstone and shale has produced a varied and, in places, rugged physiography. Thus, the thickness of the San Jose varies considerably. The thickness of the preserved parts of the San Jose ranges from less than 200 feet in the south and west to 1,700–1,800 feet in the Tapicitos Plateau in the north-central part of the area.

CUBA MESA MEMBER

Throughout the area of this investigation, and elsewhere in the San Juan Basin, the lower part of the San Jose Formation consists of buff and yellow pebble-bearing conglomeratic arkosic fine-grained to very coarse grained sandstone containing a few lenticular beds of reddish, green, and gray shale. These rocks were named the Cuba Mesa Member of the San Jose Formation (Baltz, 1967). The Cuba Mesa Member rests unconformably on the Nacimiento Formation, and in most of the area the member is overlain by the Regina Member of the San Jose Formation and intertongues with it.

At the type locality at the north end of Mesa de Cuba, the composite thickness of the Cuba Mesa Member is 782 feet, as determined from a stratigraphic section measured along State Highway 44 from the NE¼NW¼ sec. 20, T. 21 N., R. 1 W., to the SW¼ sec. 2, T. 21 N.,

R. 2 W. The upper part of the member is split by two tongues of the Regina Member that consists of shale containing thin beds of soft sandstone. These shale tongues wedge out into the Cuba Mesa Member south of State Highway 44. The Cuba Mesa Member intertongues with the Regina Member at many other places in the area, as shown on plate 1.

The Cuba Mesa Member is much thicker at the north end of Mesa de Cuba and in the subsurface northwest of the mesa (pl. 4) than it is elsewhere in the area. Near Arroyo Chijuilla the upper part of the member is split into tongues which wedge out westward into the Regina Member (pl. 1). The lower part of the Cuba Mesa Member persists to the west and is about 300 feet thick in sec. 33, T. 21 N., R. 2 W. Farther west this part of the Cuba Mesa Member is split into two persistent units of sandstone by a thick shale tongue of the Regina Member. The lower sandstone unit of the Cuba Mesa Member is 50–75 feet thick, and the upper sandstone unit is locally more than 60 feet thick. An upper tongue of sandstone of the Cuba Mesa Member occurs in parts of T. 21 N., Rs. 3 and 4 W. In T. 21 N., R. 5 W., and farther northwest, the Cuba Mesa Member is mostly cliff-forming thick-bedded sandstone, 220–300 feet thick.

Northeastward from Mesa de Cuba, the upper part of the Cuba Mesa Member splits into tongues that wedge out into the Regina Member, and the lower part of the Cuba Mesa Member, about 490 feet thick, is split into two units by a northeastward-thickening shale tongue of the Regina Member. In the SW¼ sec. 2, T. 21 N., R. 1 W., the lower sandstone, containing several beds of shale, is 152 feet thick; the tongue of the Regina Member is about 200 feet thick; and the overlying sandstone tongue of the Cuba Mesa Member is only 37 feet thick. The tongue of the Cuba Mesa Member wedges out northward, but the lower sandstone unit of the Cuba Mesa Member persists to the north in the San Pedro Foothills, where it dips steeply west or is vertical and averages about 150 feet in thickness.

In T. 24 N., R. 1 E., the Cuba Mesa Member consists of three sandstone units separated by shale tongues of the Regina Member. The medial and upper sandstone units are tongues that wedge out southward into the Regina Member. In the SW¼NE¼ sec. 1, T. 25 N., R. 1 E., the persistent lower sandstone of the Cuba Mesa Member is 27 feet thick; the lower tongue of the Regina Member is 51 feet thick; the medial sandstone of the Cuba Mesa Member is 61 feet thick; the upper tongue of the Regina Member is 144 feet thick; and the upper sandstone of the Cuba Mesa Member, containing thin shale beds, is 65 feet thick. Logs of wells in the vicinity of Arroyo Blanco indicate that the sandstone units of the Cuba Mesa Member persist in the subsurface and merge westward into a thick unit that is mainly sandstone. At the surface south of Canoncito de las Yeguas, the shale tongues of the Regina Member wedge out as the three sandstone units of the Cuba Mesa Member merge northward and form a unit that is mostly ledge-forming sandstone and is 335 feet thick in the SW¼NE¼ sec. 18, T. 25 N., R. 1 E. At the east side of the Yeguas Mesas the Cuba Mesa Member is overlain by the Llaves Member, which consists mainly of sandstone.

In the western part of the area, where the base of the Cuba Mesa Member is not exposed, the average thickness of the member is estimated to be about 200 feet, on the basis of well logs. Near Otero Ranch the Cuba Mesa Member is overlain by light-gray and variegated shale of the Regina Member. However, to the north, the lower shale beds of the Regina become sandy, and in the southwestern part of T. 26 N., R. 5 W., the Cuba Mesa Member is overlain by lenticular sandstone and shale assigned to the Regina Member.

The Cuba Mesa Member is 200–250 feet thick in the subsurface of most of the area. The thick upper tongues of sandstone of the Cuba Mesa Member persist northwestward in the subsurface for 8–10 miles from the northern part of Mesa de Cuba, but the sandstones become thinner and they are separated by westward-thickening shale tongues of the Regina Member. Where the sandstones seem to be lenticular, they are assigned to the Regina Member (pl. 4). In the subsurface of the northern part of the area, the Cuba Mesa Member thickens northward as the result of merging with northward-thickening tongues of sandstone in the lower part of the Regina Member (pl. 2).

REGINA MEMBER

In most of the area the Cuba Mesa Member is overlain by the Regina Member of the San Jose Formation (Baltz, 1967). The Regina Member consists mainly of soft beds of clay shale, siltstone, mudstone, shaly sandstone and sandy shale, but it also contains numerous beds of soft fine- to coarse-grained argillaceous sandstone, and a few beds of resistant conglomeratic arkosic cliff-forming sandstone. Most of the shaly beds are light gray, tan, or olive gray, but bands of purple, maroon, and green shale are common and are typical of the member. Pale-red to maroon shale is most common in the upper quarter of the member throughout the region. The color of the sandstones varies from white to buff, gray, and brown.

At outcrops in the northeastern part of the area between Arroyo Blanco and Canoncito de las Yeguas, the Regina Member contains, near the middle and near the top, several beds of resistant conglomeratic sandstone. These sandstones are tongues of the Llaves Member, and they wedge out to the south or become soft discontinuous lenses enclosed in shale of the Regina Member. The sandstone beds thicken northward as the intervening shale units of the Regina thin or grade laterally into shaly sandstone. North of sec. 19, T. 25 N., R. 1 E., the rocks laterally equivalent to the Regina Member are mostly sandstone and shaly sandstone assigned to the Llaves Member. In the subsurface of the northern part of the area, the Regina Member intertongues with the lower part of the Llaves Member and grades northward into the Llaves, as it does at the surface in the eastern part of the area (pl. 2). A persistent medial sandstone unit of the Llaves Member extends southward from the main part of the Llaves and directly overlies the Regina Member in the northern part of the Tapicitos Plateau in the northern part of the area.

Thick ledge-forming lenticular beds of sandstone interbedded with red and variegated shale occur in the upper part of the Regina Member at places along the Continental Divide nearly as far south as Cuba, and in the southern part of the Tapicitos Plateau south of Cañada Larga. The sandstone beds in the upper part of the Regina south of Cañada Larga are difficult to differentiate from the persistent medial sandstone of the Llaves Member except by continuous tracing of beds. Thick lenticular sandstone beds are also present in the upper part of the member in the western part of the Tapicitos Plateau in the northwestern part of the area. Relatively continuous resistant sandstones interbedded in thick shale are fairly common in the lower third of the member as well as in the upper part.

In the subsurface of the northern part of the Tapicitos Plateau, the Regina Member is about 1,040 feet thick at the Humble Oil and Refining 1 Jicarilla M well (25.4W.23.441). Most of the Regina Member is replaced to the northeast by thick sandstone of the Llaves Member (pl. 2). The Regina Member has been eroded deeply in the southern part of the Northern Hogback Belt and in the San Pedro Foothills and is 400–500 feet thick in the eastern part of the area. The Regina Member (including the tongues of the Llaves and Cuba Mesa Members) is about 900 feet thick at the type locality in sec. 31, T. 25 N., R. 1 E., and sec. 36, T. 25 N., R. 1 W. In the high hills west of the Continental Divide, at the Abraham 1 Abraham well (24.1W.17.414), the Regina Member is about 1,640 feet thick. This southward thickening is partly the result of the southward rise of the upper contact of the Regina Member because of the intertonguing with the overlying Llaves Member. However, the thickening is due mainly to southward thickening of rocks within the Regina Member, and the member appears to be thickest near the axis of the San Juan Basin.

The part of the Regina Member that is preserved along the Continental Divide in the northern part of the Penistaja Cuestas is no more than 500–600 feet thick. In the western part of the Largo Plains th preserved part of the Regina is only 100–300 feet thick, but th thickness is greater to the north and northeast, because the lan surface rises toward the Tapicitos Plateau. The Regina Member about 1,100 feet thick at the U.S. Smelting, Refining, and Mining 2– Jicarilla 137 well (23.4W.2.441).

In secs. 2 and 11, T. 21 N., R. 1 W., conglomeratic sandston coaly shale, and gray, olive-green, and maroon shale tentativel assigned to the Regina Member occur at the tops of narrow divid between the deep canyons. These rocks dip about 10° W. and ar overlain with erosional unconformity by high-level terrace gravel c Tertiary or Quaternary age. The rocks assigned to the Regin Member lie with angular unconformity on overturned beds of th Nacimiento Formation, Ojo Alamo Sandstone, Fruitland Formatio and Kirtland Shale, and the Lewis Shale. Similar faulted west dipping rocks assigned to the Regina Member rest unconformably o overturned beds of the Lewis Shale in the SW¼ sec. 23, T. 22 N., F 1 W. These angular unconformities indicate that there was struc tural deformation and erosion along the eastern margin of the are both during and after the deposition of the Regina Member.

LLAVES MEMBER

In the Yeguas Mesas in the northeastern part of the area, the part c the San Jose Formation above the Cuba Mesa Member is compose mainly of resistant arkosic pebble- and cobble-bearing conglomerati sandstone, which forms massive ledges. This unit was named th Llaves (pronounced yah-ves) Member of the San Jose Formatio (Baltz, 1967). The Llaves Member is about 1,300 feet thick in th Yeguas Mesas type area.

Most of the Llaves Member is very coarse grained arkosic con glomeratic sandstone. However, the member contains numerou thin beds of clay shale and mudstone, which are predominantl maroon but also green and gray. Thin beds of red sandstone, sand shale, and shaly sandstone are common also, and at places, especiall in the upper 500 feet of the member, rocks of this type form units a much as 50–60 feet thick. Red sandstone with red shaly parting forms the basal unit, 85 feet thick, of the Llaves Member on the eas side of the Yeguas Mesas. The lower part of the Llaves Membe tongues out to the south into the Regina Member at the surface an in the subsurface. However, the lower part of the Llaves persist northwestward in the subsurface (pl. 2) where it is 300–700 feet thick A persistent unit of sandstone, containing a few beds of shale a places and ranging in thickness from 50 to 100 feet or more, extend southward and westward from the main body of sandstone of th

Llaves Member and rests on the Regina Member in much of the northern part of the area. The stratigraphic position of this persistent unit of sandstone is near the middle of the Llaves Member.

The upper part of the Llaves Member, above the stratigraphic position of the persistent medial sandstone, occurs only in the Yeguas Mesas. The beds of the upper part of the Llaves thin to the south and west, and they are split by tongues of red shale containing lenticular sandstone. The tongues of shale and sandstone are assigned to the Tapicitos Member of the San Jose Formation.

TAPICITOS MEMBER

The Tapicitos Member of the San Jose Formation (Baltz, 1967), on the northern part of the Tapicitos Plateau, lies on the persistent medial sandstone of the Llaves Member. Exposures along State Highway 95 east of Gavilan Creek in secs. 1, 2, and 11, T. 25 N., R. 2 W., are typical of the Tapicitos Member. At this locality the Tapicitos Member is estimated to be about 450 feet thick. The lower part of the member is about 300 feet thick; it consists mostly of slope-forming pale-red to maroon clay shale, siltstone, and mudstone, and some variegated white, gray, and purple beds. The shale contains lenticular soft white and yellow sandstone and some beds of hard gray sandstone. These beds are overlain by a westward-thinning tongue of the Llaves Member that is 20–30 feet thick and consists of several beds of coarse-grained cliff-forming sandstone. The upper part of the Tapicitos Member, above the sandstone tongue of the Llaves, consists of slope-forming red clay shale, siltstone, and interbedded sandy shale and thin sandstone, all estimated to be about 120 feet thick. The Tapicitos Member is overlain by a tongue of thick cliff-forming sandstone of the Llaves Member, which caps the highest mesas on the Continental Divide to the north.

Although the Tapicitos Member consists mainly of red to maroon shale, it contains beds of thin to thick lenticular coarse-grained sandstone at all places. Some of the sandstone beds are persistent for several miles along the outcrop and locally form resistant ledges. The lower part of the Tapicitos Member locally interfingers with the upper part of the persistent medial sandstone unit of the Llaves Member. The Tapicitos Member varies considerably in thickness because its upper surface has been eroded deeply. The maximum thickness is about 500 feet, and at most places the preserved part of the member is no more than 200–300 feet thick.

WATER-BEARING PROPERTIES

Sandstone beds of the San Jose Formation yield water to wells in many parts of the area. The yields of wells that tap the San Jose are given in table 4. Most of the water is potable, although owners of some wells report that the taste of the water is objectionable. Analyses indicate that the sodium, bicarbonate, and sulfate content of water from the San Jose is generally high (table 9).

The thick coarse-grained sandstone beds of the Cuba Mesa Member yield water to wells in the southern and western parts of the area (pl. 5), and these beds are potential sources of water throughout most of the area. Rocks of the Cuba Mesa Member have not been analyzed for porosity, but their general appearance indicates that

TABLE 4.—*Yields and specific capacities (per foot of aquifer penetrated) of wells that tap the San Jose Formation in and near the southern part of the Jicarilla Apache Indian Reservation, N. Mex.*

[Most yields are normal pumping rates reported, which may be less than potential yields of wells]

Location No.	Depth of well (ft)	Depth to water (ft)	Yield (gpm)	Draw-down (ft)	Specific capacity (gpm per ft)	Thickness of aquifer penetrated (ft)	Yield per foot of drawdown per foot of aquifer penetrated (gpm per ft per ft)
Cuba Mesa Member							
21.1W.8.421	106	45	3-5				
8.422	95	74	2-3				
9.133	115	47	2-3				
17.144	46	29	4-5				
17.323a	76	36	30			46	
21.2W.9.213	235	190	3-5			45	
24.1E.6.344	98	47	12				
24.4W.6.100	290		2.3	33.4	0.07	10	.007
28.200	260		2.8				
23.422	100	54	4	33	.12	10	.012
26.7W.15.423	335	22	60	104	.58	100	.006
15.412	365	26	50	48	1.04	70	.015
Regina Member							
22.2W.15.444	112	104	2-3				
22.3W.9.323	199		10				
23.1W.3.414	734	456	.2			4	
19.244	275	216	8				
23.2W.31.121	204		8			14	
23.3W.11.333	153		8				
30.200	105		5				
24.1W.1.433	140		0.8			10	
24.2W.14.113	370	90	1.5			10	
15.331	216	184	.4				
28.122a	280		4				
28.233	250		.7				
34.111	204	77	22-25			44	
25.2W.15.342	190	100	10			35	
23.441	170	68	1.5				
25.233	225	80	3.7				
26.143	140	67	1				
27.221	118	51	3				
25.3W.35.244a	200		20				
25.5W.3.233	100	56	4	25	.16	15	.011
26.3W.7.314	370	74	11			10	
Llaves Member							
25.2W.11.141	130	68	1.5				
22.131	163	78	10			50	
25.433	165		.6				
25.3W.1.240a	302	165	25-30			10	
27.234	330	268	4				
26.2W.32.133	389	204	8			43	
34.421	400		45				
26.3W.9.132	116		1.4				
Tapicitos Member							
25.2W.17.422	165	61	2				
26.2W.14.222	140	93	7-10			30	

they are at least as porous as sandstones of the Mesaverde Group, which according to Renick (1931, p. 49) have porosities ranging from 13.71 to 28.32 percent. The Cuba Mesa Member in most of the area averages slightly more than 200 feet thick, and it is about 782 feet thick in the subsurface northwest of Cuba, where it may contain relatively large quantities of water.

Outcrops of the Cuba Mesa Member are extensive across the southern and eastern parts of the area, where the member can receive the recharge from precipitation and from water moving through thin alluvium overlying it in sandy washes. Part of the water is discharged at seeps on the outcrops, but part of it moves on through the sandstone away from the outcrops. All these outcrops are near the margins of the Central basin, and the rocks dip from the outcrops toward the deeper part of the basin. Thus, the general movement of water in the Cuba Mesa Member is toward the structurally deeper part of the basin. In the subsurface of most of the area, the Cuba Mesa Member is a confined aquifer underlain by shale of the Nacimiento Formation and overlain by shale of the Regina Member of the San Jose Formation. However, the Cuba Mesa Member is exposed along Canon Largo and the lower parts of its tributaries in the western part of the area, and water is discharged at seeps and springs on these outcrops, notably at Otero Ranch in sec. 32, T. 24 N., R. 5 W.

The water-bearing properties of the Regina Member vary with its lithologic variations. In the Penistaja Cuestas and in the Largo Plains, the lower part of the Regina Member contains several beds of fairly persistent coarse-grained sandstone interbedded with thick shale. These sandstones yield small amounts of water to domestic and stock wells.

The upper part of the Regina Member in the southern part of the Tapicitos Plateau contains numerous lenticular to relatively persistent thick coarse-grained sandstones interbedded in shale. These sandstones yield small amounts of water to domestic and stock wells. East of the Continental Divide in parts of Tps. 23 and 24 N., R. 1 W., the Regina Member is mostly shale with interbedded clayey sandstones. The lower and upper parts of the member contain thick discontinuous sandstones which yield small amounts of water, but wells drilled in the thick medial shale did not obtain water or obtained only very small amounts. Most of the wells drilled in the shale are shallow, but several were drilled to depths ranging from 345 to 734 feet. The thick shale persists westward in the subsurface beneath the Tapacitos Plateau, but in the vicinity of Lindrith, thick tongues of the Llaves Member occur in the Regina Member in the subsurface (fig. 6), and these sandstones yield water to wells.

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The lithologic character of the Llaves Member is generally similar to that of the Cuba Mesa Member, and the rocks consist largely of coarse-grained to gravelly sandstone and some thin interbedded shale and sandy shale. The sandstones appear to be porous, and they yield water to wells and springs. The water is potable and is generally reported to be of fair to good quality. Precipitation on the outcrop areas in the Yeguas Mesas is the source of recharge of much of the Llaves Member. Part of the water is discharged at numerous seeps and springs, which feed water into the alluvium at the bottom of Canoncito de las Yeguas and its deeply incised tributary canyons. The rocks of the Llaves Member dip west toward the deep axial portion of the San Juan Basin, and part of the water moves toward the deep part of the basin.

The upper part of the Llaves Member tongues out westward into the Tapicitos Member near the Continental Divide, but the persistent medial sandstone is distributed across the Tapicitos Plateau nearly to to the northwest corner of the area, and on the plateau it yields water to wells. The lower part of the Llaves Member persists to the northwest beneath the Tapicitos Plateau, where it is as much as 700 feet thick and consists mostly of thick beds of sandstone. Most of these sandstones wedge out to the south into the Regina Member before reaching outcrop areas on the margins of the Tapicitos Plateau. Several wells in the vicinity of Lindrith obtain water from thick tongues of the lower part of the Llaves Member which are confined within the shale of the Regina Member at depths of 400–500 feet or more. Reconnaissance examination outside of the area of this investigation indicates that most of the beds of the lower part of the Llaves Member tongue out northward also into shaly rocks. Thus, most of the sandstone beds of the lower part of the Llaves Member are probably confined aquifers in the area, and the available data indicate that these rocks may contain large quantities of water in the subsurface of the north-central part of the Tapicitos Plateau. Rocks equivalent to the lower part of the Llaves Member are exposed in deep canyons northwest of the area. Water moving through these rocks from recharge areas in the Yeguas Mesas is discharged into the canyons northwest of the area investigated.

Sandstone beds in the Tapicitos Member yield small amounts of water to domestic and stock wells where these rocks are preserved on the northern part of the Tapicitos Plateau. The sandstones are coarse grained and similar to those of the Llaves Member, but they are lenticular and interbedded in thick units of red shale which form 50–75 percent of the member at most places. The water from the Tapicitos Member is generally potable, but it is reported to be impotable at places. Deposits of white salts are common at seeps and around wells that produce water from the Tapicitos Member. The Tapicitos Member contains a sufficient amount of water for stock and domestic supplies at many places on the Tapicitos Plateau. However, it is doubtful that these rocks contain large bodies of ground water, particularly in the western part of the plateau, because the lenticular sandstones are of limited extent and the plateau is deeply dissected. Thus water infiltrating the sandstones discharges at the extensive outcrops along the canyons and mesas. Sandstones in the lower part of the member in the subsurface of the eastern part of the plateau probably contain confined water under artesian pressure.

IGNEOUS ROCKS

Three dikes of mafic igneous rock of Miocene(?) age occur along joints in the Tapicitos Member of the San Jose Formation on the Tapicitos Plateau (pl. 1). The southernmost dike is in secs. 24 and 25, T. 26 N., R. 3 W. It is about 1½ miles long, and it trends about N. 8° E. Another dike to the north in sec. 24 is about three-quarters of a mile long and trends N. 27° E. A third dike, north and east of the shortest one extends from the southern part of sec. 18, T. 26 N., R. 2 W., northward past the northern boudary of the area. This dike trends N. 8° E. and is about 6 miles long, including the part north of the area mapped. None of the dikes appears to be more than 50 feet wide, and all are nearly vertical. The dike rock is harder than the enclosing sedimentary rocks, and the dikes form narrow ribs rising above hills eroded in the sandstone and shale of the Tapicitos Member.

The dikes yield no water to wells, but they may have some effect on the hydrology of the northern part of the Tapicitos Plateau. Although the dikes probably do not form impermeable barriers to ground water, they may locally impede the westward movement of water in the San Jose Formation and older rocks.

GRAVEL OF TERTIARY OR QUATERNARY AGE

Gravel of late Tertiary or Quaternary age caps west-sloping high-level terraces at the foot of San Pedro Mountain. The pebbles, cobbles, and boulders which compose the gravel are mostly pink to brown coarse-grained dense hard granite. This granite is identical in appearance with the granite of Precambrian age of the core of San Pedro Mountain from which the gravel must have been derived. The high-level gravel deposits consist of local remnants, 50–100 feet thick, that are preserved at altitudes ranging from 8,000 to 8,400 feet. The gravel was deposited on a west-sloping erosional surface that beveled the folded and faulted rocks of the eastern part of the San Pedro Foothills. The high-level gravel deposits at the west side of San Pedro Mountain are probably of Pliocene or Pleistocene age. They were probably deposited as parts of alluvial fans on west-sloping pediment cut at the base of San Pedro Mountai Most of this pediment was destroyed by erosion after the depositic of the gravels.

Some of the high-level gravel contains small amounts of wat which infiltrates from precipitation on the deposits and from inte mittent streamflow at the mouths of small canyons on the side San Pedro Mountain. Small seeps of water were observed near tl west side of the gravel in sec. 11, T. 21 N., R. 1 W. None of tl remnants of high-level gravel contain much ground water, and the have not been tapped by wells.

SEDIMENTS OF QUATERNARY AGE

TERRACE GRAVEL, COLLUVIUM, AND STREAM-CHANNEL GRAVEL

Gravel of Pleistocene and Recent age caps terraces at sever topographic levels and occurs in stream channels in the upper par of valleys in the San Pedro Foothills. The gravel consists mainl of pebbles, cobbles, and boulders of granite derived from rocks Precambrian age, but some of the fragments are limestone and sanc stone derived from the Paleozoic and Mesozoic rocks exposed alon the west side of San Pedro Mountain. The gravel also contair sand, silt, and clay. At most places these deposits are less tha 100 feet thick. Slope wash on the sides of valleys and walls c canyons consists of colluvium weathered from the underlying bec rock and gravel slumped from the terraces. Gravel-capped terrace at several topographic levels indicate a complex history of erosio and deposition during the Quaternary Period. The various grav and colluvial deposits of Pleistocene and Recent age that were lai down during the several stages of cutting and filling in the San Pedr Foothills are not distinguished on the geologic map (pl. 1) but ar combined as Quaternary colluvium and gravel.

Small patches of colluvium, colluvial boulders, and pebble an cobble gravel occur on remnants of a steep east-sloping erosion surface, cut mainly on the Lewis Shale but also on younger rock in Tps. 25 and 26 N., R. 1 E. This erosion surface seems to hav been the west side of a broad valley that sloped generally soutl New valley surfaces have been cut recently 100–200 feet below th remnants of the older valley

The Quaternary gravel deposits are of limited extent in the Sa Pedro Foothills, but some of them are aquifers in that area. Wate of good chemical quality issues from springs in the gravel deposits c the upper valleys of La Jara Creek and Rito de los Pinos, and thi is used for domestic and stock supply. At the time of the fieldwor for this report, water for the public supply of the town of Cuba wa collected from springs and seeps issuing from gravel along the south side of the gravel-capped mesa in the S½ sec. 14, T. 21 N., R. 1 E. Rain and snow infiltrate the gravel deposits, and the upper parts of perennial streams, such as San Jose Creek, La Jara Creek, Rito de los Pinos, and the Rio Puerco, lose part of their surface flow because of infiltration into the gravels. The gravels feed water into alluvium at lower levels by underflow and by seeps and springs that discharge from the gravels in the lower parts of the main stream valleys. At most places the water in the gravel is perched on relatively impermeable shale underlying the gravel.

ALLUVIUM

Alluvium, consisting of sand, silt, clay, and some gravel, occurs in the valleys of all the major perennial and intermittent streams in the area. The alluvium is of Pleistocene and Recent age. Most of the deposits of alluvium are being eroded at present, and the stream channels are entrenched in arroyos cut recently in the alluvium. The alluvium shown on the geologic map (pl. 1) includes only the potentially water-bearing thicker alluvial deposits of the major valleys. Sparse data indicate that the alluvium is generally less than 100 feet thick.

Ground water occurs in alluvium in the valleys of all the major streams of the area. The yields of wells that tap the alluvium are given in table 5. The alluvium is recharged by precipitation, by infiltration of surface water, and by seepage from bedrock aquifers. The alluvium in Canon Largo, Canada Larga, Canon Ojitos, and Tapicitos Creek in the western and northwestern parts of the area contains water that is received mainly by underflow that discharges from the sandstone aquifers of the San Jose Formation. Thin deposits of alluvium near the heads of most of the small valleys of the area contain very little ground water. In places, water from the alluvium infiltrates the underlying bedrock.

The quality of water in the alluvium is somewhat varied, but at most places the water is potable. Water in the alluvium of the Rio Puerco valley near Cuba is not considered to be potable by many of the residents because of its high content of dissolved mineral matter. Also, in this populated area the risk of pollution by untreated sewage is great.

GEOLOGIC STRUCTURE

The general structure of most of the area is shown on plate 1 by structure contours which connect points on the base of the Ojo Alamo Sandstone that are of equal altitude above sea level. The interval between contours is 100 feet, except near the east margin of the map, where it is 500 feet. The structure contours are solid where sub-

TABLE 5.—*Yields of wells that tap the alluvium in and near the southern part of the Jicarilla Apache Indian Reservation, N. Mex.*

[Most yields are normal pumping rates reported, which may be less than the potential yields of the wells]

Location No.	Depth of well (feet)	Depth to water (feet)	Yield (gmp)
21.1W.20.114	75	44	26
20.233	70	38	15
20.233a	70	42	5
20.324	85	33	3
23.1W.27.233 [1]	48	10	25
24.1E.7.211	68	23	12
7.214	24	14	65–85
30.441	42	26	5
31.132	10	7	.1
24.1W.14.444	12	6	.3

[1] Part of yield is from the Ojo Alamo Sandstone.

surface data were considered to be adequate to determine their positions, and where the altitude of the base of the Ojo Alamo at outcrops could be determined from topographic maps. The structure contours are dashed where their position was determined by interpolating, by constructing geologic sections on the basis of the dip and thickness of overlying rocks, or by projecting downward from marker beds whose altitude was determined from topographic maps and whose stratigraphic position above the Ojo Alamo is known from measured stratigraphic sections.

The base of the Ojo Alamo Sandstone was chosen as the contour datum because it is easily determined and correlated by means of electric logs of most wells drilled for oil and gas in the area. The position of the base of the Ojo Alamo on the logs of a few wells was uncertain, but the questionable stratigraphic interval is less than 50 feet, which is less than half the contour interval. The contours do not depict the exact structure of rocks older than the Ojo Alamo because of the unconformity at the base of the Ojo Alamo; however, the structure of the older rocks is not greatly different from that of the Ojo Alamo except near the eastern edge of the area. Also, it should be noted that the structure of rocks of the San Jose Formation is not exactly the same as that of the Ojo Alamo, because of the unconformity at the base of the San Jose.

In addition, the base of the Ojo Alamo was chosen as the contour datum because this formation is the deepest aquifer from which it seems practical to obtain water in most of the area. The depth, at any point, to the base of the Ojo Alamo can be determined, approximately, by subtracting the altitude of the base, as shown by structure contours, from the altitude of the ground surface at that point.

Most of the area investigated lies within the Central basin of the San Juan Basin (fig. 3), and its geologic structure is simple. The structural axis of the eastern part of the basin trends southeast and extends diagonally across the northeastern part of the area from the northwest corner of T. 26 N., R. 3 W., to the southeastern part of T. 24 N., R. 1 W., where the axis terminates in the sharply folded rocks along the east side of the basin (pl. 1). Most of the area is southwest of the axis of the basin, and the rocks in this part of the area dip gently northeast. At most places on this structural slope the dip is 1° or less.

In the southeastern part of the area the structure contours bend northeastward through a series of north-northwest-plunging anticlines and anticlinal bends, and the regional dip is northwest. The regional dip is locally more than 10° in this part of the area, but it is progressively less to the northwest toward the interior of the basin.

In the western part of the San Pedro Foothills, the rocks dip 2°–20° W., and the contours trend north regionally. However, the contours are deflected locally through several north-northwest-plunging subsurface anticlinal noses. The positions of the contours on the nose in T. 22 N., R. 1 W., are based mainly on surface stratigraphic data which indicate thickening and thinning of the Nacimiento Formation in the San Pedro Foothills. The depicted positions of contours on the northwest-trending noses farther north are partly controlled by both surface and subsurface data. The north-northwest-plunging noses which lie north of the Rito Leche anticlinal nose are reflected only slightly in the San Jose Formation. The noses were formed mainly in late Paleocene time before the deposition of the San Jose Formation, as shown by the local thickening and thinning of the Nacimiento Formation. Only slight additional folding of the anticlinal noses occurred after the deposition of the San Jose.

In the eastern part of the San Pedro Foothills, rocks have been folded abruptly along a major north-trending synclinal bend (pl. 1). At most places the rocks just west of the trace of the axial plane dip 10°–30° W., whereas just east of the trace, the dip of the beds ranges from about 60° W. to vertical. South of the upper part of San Jose Creek, the Nacimiento Formation and older rocks on the east limb of the synclinal bend are overturned at places and dip east at angles ranging from 50° to nearly vertical. The angular unconformity between the Regina Member and the older rocks in secs. 2 and 11, T. 21 N., R. 1 W., and sec. 23, T. 22 N., R. 1 W., indicates that the synclinal bend was formed partly in early Eocene time during deposition of the Regina member. However, the tilting and faulting of the overlapping beds of the Regina indicate that there was also post-San Jose deformation along the east side of the area.

Renick (1931, p. 71–74) and Wood and Northrop (1946) found that the steeply folded and overturned rocks along the synclinal bend are west of the north-trending Nacimiento fault along which the rocks of the Nacimiento uplift were elevated relative to the San Juan Basin. This fault (fig. 3), is east of the outcrop belt of the Mesaverde Group and was not mapped during the present investigation. West of San Pedro Mountain the vertical component of displacement on the Nacimiento fault is as much as 10,000 feet (Baltz, 1967), but the amount of displacement on the fault is smaller farther north. North of San Pedro Mountain the Nacimiento fault passes into a north-northeast-trending normal fault in the French Mesa–Gallina uplift.

The orientation of the staggered system of north-northwest-plunging folds in the eastern part of the basin suggests that during the late Paleocene stage of deformation the folds were formed because of right shift along the Nacimiento fault; that is, the rocks of the San Juan Basin probably shifted north relative to the Nacimiento uplift (Baltz, 1967). The synclinal bend was formed mainly in Eocene time as part of a monocline that was ruptured later because of vertical movements on the Nacimiento fault.

In the Northern Hogback Belt, the rocks dip 10°–65° W. on a sinuous west-facing monoclinal flexure which is at the west side of the French Mesa–Gallina uplift. The synclinal bend extends north from the San Pedro Foothills and marks the foot of the monocline in the Northern Hogback Belt (pl. 1). In the southeastern part of T. 24 N., R. 1 W., and the adjacent parts of T. 24 N., R. 1 E., and T. 23 N., R. 1 W., a shallow northeast-trending syncline and the parallel narrow sharply folded Schmitz anticline lie west of a northeast-trending steeply dipping segment of the monocline.

The rocks are broken by normal faults at places in the southern and eastern parts of the area. The displacements on most of these faults range from less than 50 feet to about 200 feet. Rocks in the Northern Hogback Belt are displaced at several places along normal faults that are nearly tranverse to the strike of the beds. Steeply dipping rocks of the Fruitland and Kirtland and the Ojo Alamo Sandstone are displaced along three faults of this type in parts of secs. 10, 11, and 15, T. 23 N., R. 1 W. Steeply dipping rocks of the Mesaverde Group are displaced along similar faults along the sharp bend in the monocline in secs. 21, 29, and 32, T. 24 N., R. 1 E. On all these faults, the block to the south is offset to the east relative to the block on the north.

GROUND WATER

Ground water is a renewable resource within the upper layer of the earth. In contrast with most other mineral resources, much of the ground water is in constant motion. It enters the ground as precipitation, infiltrates the soil, and percolates downward into the rocks. There it moves underground to places where it is discharged at springs and seeps, some of which may sustain perennial streams. During this process, of course, some moisture is lost by evaporation and by transpiration from plants.

The occurrence of ground water is thus dependent on the amount of precipitation and on the ability of the rocks and sediments to receive, store, and transmit water. This ability, in turn, depends on the size, shape, and arrangement of openings between grains of the rocks and sediments.

In the area of the present report, alternating beds of coarse-grained and fine-grained material store and transmit water in varying amounts. Sandstone beds and coarse alluvium are the best aquifers (water-bearing materials), whereas shale, silt, and clay are generally poor aquifers. Water that infiltrates alluvium in the area moves underground down the valleys. Water that infiltrates outcrops of sandstone commonly moves down the dip of the beds, particularly where the upper surface of the aquifer is not covered by higher less permeable materials. If water moves down the dip of the aquifer beneath a bed of less permeable material such as shale, the water becomes confined in the aquifer under artesian pressure. Nearly all the beds of sandstone in the area are artesian aquifers downdip from their outcrops.

The accessibility of ground water depends largely on the topographic situation and the structural attitude of beds. The depth to an aquifer is greater beneath the ridges and mesas than beneath the intervening valleys and plains. The depth to an aquifer increases downdip, and the dips of beds in the area range from 1° to about 90°. The dip at most places ranges from 1° to 5°, or from 92 to 462 feet per mile.

Most of the water wells in the area were drilled with percussion (cable-tool) or hydraulic rotary drills, although shallow hand-dug wells are common in the alluvium of some valleys. The wells generally are cased to their total depths, and the casings are perforated through the water-bearing zones. Data on all the wells and springs that were inventoried are given in tables 6 and 7, and the locations of most of the water wells in the area, the depths to water in them, and the principal aquifers are shown on pl. 5.

RECHARGE, MOVEMENT, AND DISCHARGE

The principal sources of ground-water recharge are precipitation and streamflow on outcrops of the aquifers. Vertical leakage of water from one aquifer to another also is a form of recharge. Any outcrop of an aquifer is a potential area of recharge, although water is rejected at some outcrops because the aquifer at those places is filled and possibly is discharging water. In general, aquifers are recharged where their outcrops are highest, and they discharge water where their outcrops are lowest.

Most of the recharge in the area occurs in the eastern and southern parts, at altitudes of 7,000–8,000 feet. The ground water moves through the rocks away from the areas of recharge toward outcrops at lower altitudes, generally to the north and northwest, where it discharges as springs and seeps in stream valleys or migrates into other stratigraphic units by vertical or lateral leakage. Much of the recharge water moves directly from recharge areas on plains, mesas, and ridges to discharge points in adjacent escarpments and canyons. A few small perennial streams are fed by ground-water discharge in the eastern part of the area. Most of the beds of sandstone are probably saturated with ground water in the subsurface of the interior of the Central basin, which includes most of the project area. The relationship of the topography and the geologic structure of the region suggests that the regional movement of deep ground water is northwestward and westward from the recharge areas through part of the Central basin to discharge points along Canon Largo and its tributaries and the San Juan River.

Future withdrawals of large amounts of ground water from wells on the Jicarilla Reservation might eventually affect the discharge of ground water to the San Juan River. The water of the San Juan River has already been allocated according to local water rights and interstate compacts, and depletion of the streamflow by ground-water withdrawal would affect the apportionment that has been made. Two seepage investigations of the San Juan River were made in December 1958 and September 1959, during periods of low flow, in an attempt to learn the magnitude of ground-water discharge to the San Juan River down the piezometric gradient from the project area. The investigations were made during periods of low flow because, at these times, increments of ground water to the river are a greater proportion of the total streamflow than in periods of precipitation and high flow of the river. Thus, the downstream increase of flow that is the result of the discharge of ground water to the river should be most easily determined during periods of low flow. The results of the seepage investigations are summarized in table 8.

The seepage investigations consisted of measuring the flow of the San Juan River at selected localities and measuring all tributary surface-water inflow to determine, if possible, the amount of ground-water discharge to the river in several parts of its length between Rosa and Bloomfield, New Mexico. A sample of water was collected from each measuring point on the river and was analyzed chemically, to determine whether ground-water discharge to the river could be detected by changes in the chemical quality of water in the river. Only the concentration of sulfate, the hardness, and the specific conductance of the water are listed in table 8, because these chemical and physical properties are probably most diagnostic of ground water intermixing with the surface water.

Neither the discharge measurements nor the chemical analyses provided conclusive evidence of ground-water discharge into the river. Some ground water probably is discharged from the Ojo Alamo Sandstone and younger formations to the San Juan River, but the amount of discharge in any particular part of the river is so small that it is within the percentage of error allowed in gaging large flows in natural channels and is within the range of fluctuations in streamflow. For example, the river appeared to lose 9 cfs (cubic feet per second) of flow (the arithmetic sum of the gains and losses) between Rosa and Bloomfield, N. Mex., when the seepage investigation was made December 2–3, 1958. The river appeared to lose 11 cfs of flow between the same two stations when the seepage investigation was made September 14–16, 1959. The flow past the regular gaging station at Rosa decreased from 110 cfs on December 2, 1958, to 90 cfs on December 3, 1958, and decreased from 98 cfs on September 14, 1959, to 85 cfs on September 16, 1959 (U.S. Geological Survey, 1959). The decreases in flow past Rosa during the seepage investigations could more than account for the apparent loss in flow between Rosa and Bloomfield.

The concentration of sulfate in the river water increased from 124 ppm at Blanco to 167 pp (parts per million) at Bloomfield, a stretch of the river where there was no surface inflow during the seepage investigation of December 2–3, 1958, and increased from 131 to 201 ppm in the same reach during the investigation of September 14–16, 1959. The hardness and specific conductance of the water increased similarly. The seepage investigations were made in 2 or 3 days each time and during the low-evaporation season, so that the concentration of dissolved solids by evaporation would have been negligible. The chemical data probably indicate that ground water, which is typically high in sulfate in the region, was discharging into this stretch of the river at the time of the investigations. This stretch of the river flows through outcropping porous and permeable sandstones of the lower part of the Nacimiento Formation that are deeply buried upstream on the San Juan River and its eastern tributaries in the Central basin of the San Juan Basin. However, part of the increase in concentration of chemical constituents may have been caused by return flow of irrigation water.

Much of the ground water that moves through the Nacimiento and San Jose Formations in the Central basin is discharged from small springs and seeps along Canon Largo and its tributaries that cut deeply into these rocks within and west of the area of investigation. George C. Taylor (written commun., 1939) estimated that in 1939, in a half-mile reach of Canon Largo near Otero Ranch, 450 gpm of water discharges from springs and seeps. Part of the water migrates from the sandstone aquifers into the valley alluvium and the soil, from which most of the water is dissipated by evapotranspiration before reaching the San Juan River. Some of the areas of evapotranspiration are indicated by accumulations of salts on the valley floors in the western part of the Jicarilla Reservation and northwest of the reservation.

In summary, the seepage investigations did not show conclusively whether or not ground water is discharged to the San Juan River down the structural slope from the area of the Jicarilla Reservation. The small change in streamflow between Rosa and Bloomfield does indicate, however, that only relatively small amounts of ground water could be entering the river in that stretch; thus, withdrawal of ground water in the Jicarilla Reservation will not measurably affect the flow of the San Juan River.

CHEMICAL QUALITY OF WATER

Water in the formations of Cretaceous and Tertiary age varies widely in chemical quality. Not only does the chemical quality of the water differ from one stratigraphic unit to another, but it also differs within the same unit (table 9). The difference in the chemical quality of the ground water is influenced by the quality of the recharge water, the relative abundance and the types of minerals with which the water comes in contact in the rocks and the amount of ground-water circulation through the rocks. The quality of water in any stratigraphic unit may be affected also by leakage from one unit to another.

Part of the recharge is from direct infiltration of outcrops by rain and snowmelt, and part is from infiltration by water from intermittent and perennial streams that cross the outcrops. The recharge water derived from direct infiltration by rain and snow is of low salinity when it begins its underground journey in the host rock, but the salinity increases progressively with movement through the rock. The recharge water which infiltrates from streams may have high salinity when it begins its underground journey, because the water contains dissolved matter derived from materials over which the streams flow or because the streams may be fed by springs discharging saline ground water. For example, a sample of water collected July 23, 1957, from the Rio Puerco, where it is crossed by State Highway 44 in Cuba, contained 587 ppm of dissolved solids. The discharge of the stream was 0.5 cfs, after a peak floodflow of 25 cfs. Another sample of water collected October 13, 1959, at the same place contained 1,220 ppm of dissolved solids. The second sample was collected from the small amount of base flow (the flow from ground-water discharge to the stream.) A sample of water collected July 23, 1957, from an unnamed tributary of the Rio Puerco 4.2 miles south of Cuba, where the stream is crossed by State Highway 44 in sec. 16, T. 20 N., R. 1 W., contained 4,840 ppm of dissolved solids. The flow of the stream was very small, and the water was derived from springs or seeps.

The large variations in the quality of water in the Rio Puerco and its tributaries must significantly affect the quality of ground water in the aquifers that are recharged by infiltration by surface water in the valley of the Rio Puerco. The wide range in quality of water in the Ojo Alamo Sandstone in the vicinity of Cuba (table 9) reflects the variations in quality of the recharge water.

As saline recharge water moves underground, the concentration of dissolved minerals may increase, ions in the water may be exchanged for ions in the rocks, or, rarely, the water may remain unchanged. Water that moves from one stratigraphic unit to another improves or degrades the quality of water in the new host rock, depending partly on the quality of water in each unit.

The dissolved solids in ground water are commonly concentrated by evaporation from capillary openings and by transpiration of plants in areas where the top of the zone of saturation is within a few feet of the land surface. Evapotranspiration probably has concentrated the dissolved solids in the shallow ground water at places in the valleys of all the major streams of the area.

Most of the samples of water collected in and near the southern part of the Jicarilla Reservation for chemical analysis were from the Ojo Alamo Sandstone and the San Jose Formation. One sample was from the Nacimiento Formation and several were from alluvium and gravel of Quaternary age. Most of the ground water is chemically similar. It is typically high in sodium relative to calcium and magnesium and is generally high in bicarbonate and sulfate. (See table 9.) All the samples of water from the Ojo Alamo Sandstone and the Nacimiento Formation and most samples from the San Jose Formation were collected from shallow wells (or springs) at places within a few miles of probable recharge areas. The quality of the water in places where the rocks are deeply buried in the interior of the Central basin is not known.

The quality or suitability of water can be evaluated only with respect to its intended use. The general suitability of ground water in the southern part of the Jicarilla Reservation for domestic, irrigation, and general industrial uses is summarized in the following paragraphs. This evaluation is based on 66 analyses of water from wells and springs that are listed in table 9. For more detailed descriptions of sources of soluble materials in natural water and water-quality criteria, see U.S. Geological Survey Water-Supply Paper 1473 (Hem, 1959), California State Water Pollution Control Board (1952) "Water Quality Criteria," and U.S. Public Health Service (1946) "Drinking Water Standards."

Silica has little effect on the stability of water for irrigation, but silica in boiler water tends to form a hard scale. Concentrations of silica (7.6–39 ppm) in the 39 samples of ground water that were analyzed for silica are not high enough to warrant further discussion.

Iron in low concentrations may impart an undesirable color and taste to water and will stain plumbing fixtures. The recommended upper limit of iron plus manganese in drinking water is 0.3 ppm (U.S. Public Health Service, 1946). The Geological Survey generally does not analyze water for manganese. The sampling and handling of water for accurate iron determinations requires special precautions which commonly are not exercised in routine sampling. For example, iron in a solid form, or as steel, may be incorporated in the water sample as pieces of scale from the pump and pipes, or as iron minerals in fine particles of sediments. If the iron introduced in the solid state is included in a determination of total iron in the sample, the value reported is not a true value of the iron content of the water. When a sample of ground water is exposed to air, some dissolved iron may be oxidized and precipitated. Precipitation of the iron can be avoided by acidifying the sample of water at the time it is collected. However, acidification may dissolve some of the iron from steel flakes or iron minerals that were collected with the sample. Thus, the laboratory determination of iron content in water is in general slightly inaccurate. The concentration of soluble iron in 20 samples from the area studied for this report (pls. 1, 5) ranged from 0.00 to 5.2 ppm. The total iron content was as high as 21 ppm (table 9). Eleven of the samples contained more than 0.3 ppm of iron.

Calcium and magnesium have similar properties; they make water hard and influence its suitability for household and some industrial uses because they contribute to the formation of boiler scale and deposits in water heaters. The recommended upper limit of magnesium in drinking water is 125 ppm (U.S. Public Health Service, 1946). Only one analysis shows concentrations of magnesium higher than this limit (well 21.1W.28.211, table 9). Drinking water which has high concentrations of magnesium along with sulfate is a mild to severe cathartic. Relatively high concentrations of calcium and magnesium can be beneficial in irrigation water, especially if the water is used on alkali soils. The concentrations of calcium and magnesium in the samples that were analyzed ranged from 1.6 to 548 ppm and from 0.0 to 126 ppm, respectively (table 9). Most of the samples contained less than 100 ppm of calcium and less than 50 ppm of magnesium.

Sodium and potassium are similar and commonly are not separated in ordinary chemical analyses. Generally, the amount of potassium relative to sodium is negligible. Potassium is essential for vigorous growth of most plants, but excessive amounts of sodium cause alkali soils. A high ratio of sodium to calcium and magnesium makes water poor for irrigation because the sodium tends to form alkali soil, especially where drainage is poor. A high concentration of sodium along with sulfate in drinking water is likely to have a laxative effect on persons unaccustomed to drinking the water. Concentrations of sodium and potassium generally found in natural waters have little effect on its industrial use. The concentrations of these elements, reported as sodium in most of the samples of water that were analyzed, ranged from 3.0 to 745 ppm (table 9).

The concentration of bicarbonate in the waters that were sampled ranged from 29 to 888 ppm, but most samples contained from 200 to 400 ppm. The carbonate concentrations as analyzed ranged from 0 to 53 ppm (table 9). Hardness due to calcium and magnesium equivalent to the bicarbonate and carbonate is generally referred to as carbonate hardness or temporary hardness. The temporary hardness can be removed by boiling the water or by adding lime. Excessive concentration of bicarbonate and sodium in irrigation water causes the accumulation of sodium carbonate (commonly termed black alkali) in soils, especially if they are poorly drained.

The recommended limit of sulfate in drinking water is 250 ppm (U.S. Public Health Service, 1946). Only 16 of 46 samples analyzed contained less than 250 ppm of sulfate, and the range was from 6.2 to 2,440 ppm (table 9). Sulfate in conjunction with calcium and magnesium contributes to the formation of hard scale in steam boilers and increases the cost of softening the water. Because of its high concentration of sulfate, much of the water in and near the southern part of the Jicarilla Reservation is to some degree undesirable for domestic use and for some industrial uses. Sulfate in the quantities found does not adversely affect the suitability of the water for irrigation.

The recommended limit for chloride in drinking water is 250 ppm (U.S. Public Health Service, 1946). The samples analyzed contained 1.0–486 ppm, but only one contained more than 250 ppm and only four contained more than 50 ppm. These concentrations are low enough to make the water acceptable for ordinary uses.

The desirable range for fluoride in drinking water is 0.5–1.5 ppm (U.S. Public Health Service, 1946). Concentrations of fluoride in the samples analyzed ranged from 0.1 to 4.0 ppm (table 9). The concentration was within the recommended limits for fluoride in 26 of the 44 samples analyzed and was above the recommended limit in only 6 samples. Fluoride has little effect on the industrial or agricultural utility of water.

The suggested upper limit of nitrate in water used for infant feeding is 44 ppm (Hem, 1959, p. 239). The concentration of nitrate in the samples analyzed ranged from 0.0 to 70 ppm (table 9). However, the nitrate exceeded 44 ppm in only one sample (well 20.1W.6.432, table 9). Nitrate commonly is associated with bacterial contamination of water, so that a high concentration of nitrate in ground water indicates that a bacterial analysis of the water should be made.

Boron is essential to normal plant growth, but the quantities required are very small. The boron concentrations in the seven samples analyzed (table 9) are below the maximum limit for even the most boron-sensitive crops (U.S. Salinity Laboratory Staff, 1954); they range from 0.04 to 0.07 ppm.

The recommended upper limit of dissolved solids in drinking water is 500 ppm, but when water of this quality is not available, water containing 1,000 ppm of solids is considered to be acceptable (U.S. Public Health Service, 1946). Many municipal and domestic water supplies in New Mexico contain more than 1,000 ppm of dissolved solids and apparently the water has no deleterious effects on the people who drink it. All but 4 of the 42 samples analyzed contained more than 500 ppm of dissolved solids, and 19 of the samples contained more than 1,000 ppm (table 9). The concentration of dissolved solids ranged from 56 to 4,010 ppm. Waters containing dissolved solids in this range generally can be used for irrigation if the individual constituents and other factors affecting irrigation are favorable. In general, industries that use large quantities of water require that it has less than 1,000 ppm of dissolved solids.

Water that exceeds 250 ppm in hardness is unsatisfactory for many industrial uses. In household use for washing, it requires large amounts of soap. Hardness in domestic, municipal, and industrial supplies preferably should be less than 100 ppm. Suggested limits of boiler water range from 2 to 80 ppm, depending on the pressure (California State Water Pollution Control Board, 1952, p. 129). Hardness has little effect on the usability of water for irrigation. The hardness of waters sampled ranged from 4 to 1,860 ppm in 64 samples (table 9); the hardness of 24 samples exceeded 250 ppm. Hardness can be removed by cation-exchange softeners for small supplies, and by lime and soda-ash treatment for large supplies.

The U.S. Department of Agriculture formerly classified water with respect to its usability for irrigation on the basis of the percent sodium and the total concentration as electrical conductivity (specific conductance) of the water. Percent sodium is the percentage ratio of the concentration of Na^+ to the sum of Ca^{++}, Mg^{++}, Na^+, and K^+, all expressed in milliequivalents per liter. The specific conductance of a water solution, which is a measure of its capacity to conduct an electric current, varies with the composition and salinity of the solution. Either a high percent sodium or a high specific conductance may indicate water of poor quality for irrigation. The percent sodium in the waters that were analyzed ranged from 7 to 99, and the specific conductance ranged from 287 to 4,490 micromhos.

The classification according to percent sodium is not wholly satisfactory because it does not directly measure the potentiality of sodium adsorption by the soil, so the U.S. Department of Agriculture (U.S. Salinity Laboratory Staff, 1954, p. 79–81) introduced a system of classification based on the sodium-adsorption-ratio (SAR) and the conductivity (specific conductance).

The SAR is defined by the equation

$$SAR=\frac{Na^+}{\sqrt{\frac{(Ca^{++}+Mg^{++})}{2}}}$$

in which, Na^+, Ca^{++}, and Mg^{++} represent respective sodium, calcium, and magnesium concentrations in milliequivalents per liter. Because sodium and potassium commonly are reported together in Geological Survey analyses, the combined concentration of sodium and potassium is treated as sodium in calculating the SAR. The SAR may be plotted against conductivity on a standard diagram from which the sodium (alkali) and salinity hazard of the water is classified (U.S. Salinity Laboratory Staff, 1954, p. 79–81). The SAR classification of 37 samples is shown in figure 4, and the analyses are summarized in table 10. The classification chart was designed for a maximum SAR of 32, and the SAR of 8 samples was more than 32.

Much of the water in and near the southern part of the Jicarilla Reservation is undesirable for domestic use because of high concentrations of dissolved solids, commonly including high concentrations of sulfate. However, the concentration of sulfate and other dissolved solids is not high enough to classify it as impotable. Water containing more than 250 ppm of sulfate is likely to have a laxative effect for a short time on persons unaccustomed to it (California Water Pollution Control Board, 1952, p. 377–378). Nearly all the water is acceptable for livestock supply.

The excess of sodium relative to calcium and magnesium in some of the shallow ground water in and near the southern part of the Jicarilla Reservation makes it unsuitable for irrigation, and special

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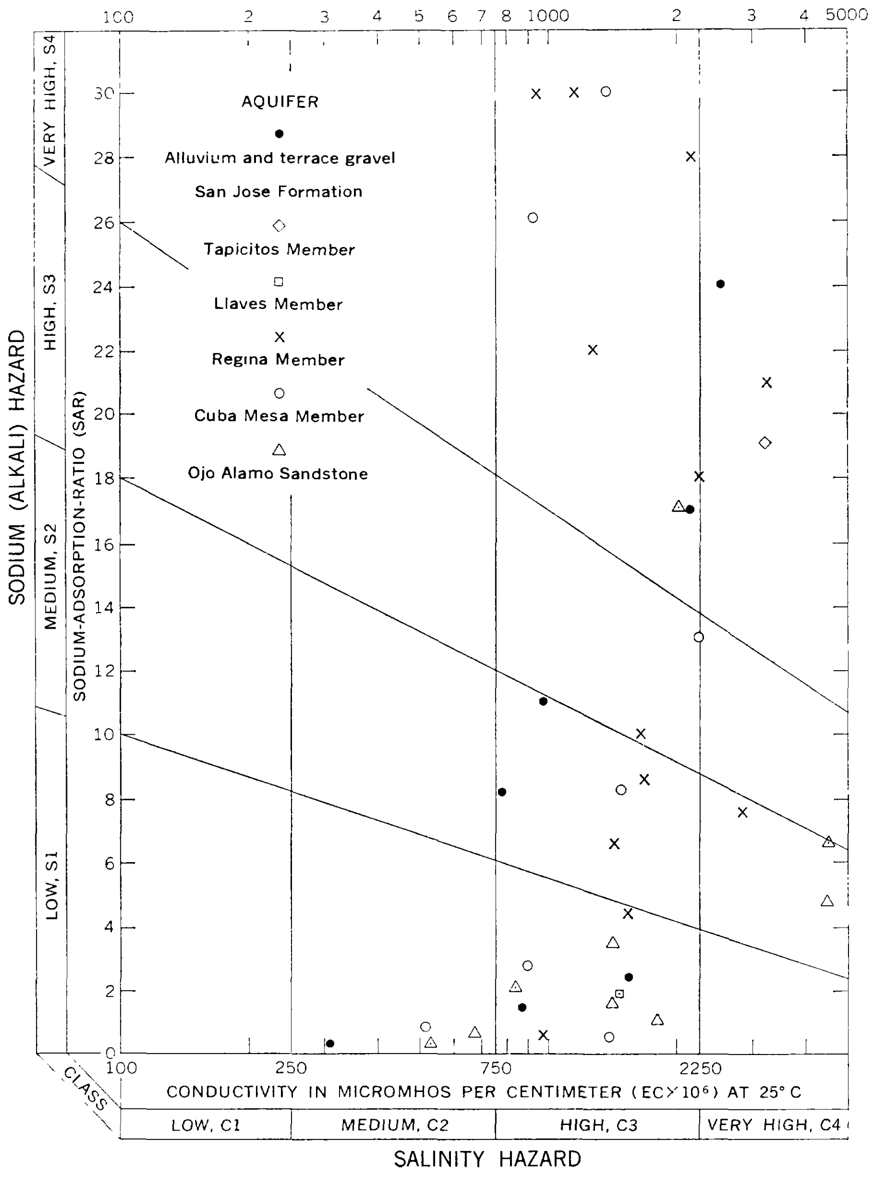

FIGURE 4.—Classification of ground water for irrigation use. Modified from U.S. Salinity Laboratory Staff (1954).

soil management would probably be necessary for successful production of irrigated crops with much of the water. All the variations in concentrations and kinds of dissolved constituents in water from different water-bearing beds at all places cannot be delineated from the data now available; however, some inferences can be made.

The quality of water in the deeply buried beds of sandstone, especially the thick beds in the San Jose and Nacimiento Formations and the Ojo Alamo Sandstone, probably does not differ greatly from that represented by the analyses in table 9 because the analyzed samples were collected from many different beds of sandstone in the San Jose Formation and from the Ojo Alamo Sandstone at widely separated places and from the various depths. The specific conductance of only 8 of 51 samples from the sandstone was more than 2,250 micromhos, the point of division between waters of high salinity hazard and very high salinity hazard (fig. 4); 3 of the 8 were from the Ojo Alamo Sandstone in the Rio Puerco Valley, where the recharge water is likely to be high in dissolved solids; 4 were from the Regina Member of the San Jose Formation, which consists predominantly of shale; and 1 was from the Tapicitos Member of the San Jose Formation, which also is predominantly shale. The concordance of the general upper limit of specific conductance of the 66 samples (table 9) from so many source beds suggests that the same range of conductance could be expected throughout the area, even where the beds are deeply buried.

Electric logs of wells in the interior of the basin show that the resistivity (conductivity is the reciprocal of resistivity) of the beds of sandstone of Tertiary age and their contained water commonly is no higher at depths as great as 3,500 feet than at depths of less than 500 feet, the zone generally penetrated by water wells. The spontaneous potential curves on the electric logs show that most of the beds of sandstone are porous, so that probably the resistivity is high because the water in the sandstone contains relatively low concentrations of dissolved solids. However, the quantity and kinds of dissolved solids cannot be determined from the electric logs.

Berry (unpublished report to Jicarilla Tribe, 1957, p. 8) reported that a sample of water obtained from the Ojo Alamo Sandstone at a depth of 2,249–2,300 feet by a drill stem test in the Humble Oil and Refining J–5 Jicarilla well (25.5W.7.114) had a resistivity of 695 ohm-cm (equal to a specific conductance of 1,440 micromhos), and that it contained 1,057 ppm (calculated) of dissolved solids. This analysis is within the range of those in table 9.

The mixed water that would be obtained from a well that taps a large number of water-bearing beds might be suitable for agricultural use, even though the water from some individual beds is unsuitable (fig. 4). Improvement can result from dilution of the unsuitable water with water of good quality. Improvement can result also from the combination of water having a high SAR value with water having a low SAR value, if the salinities of both are satisfactorily low and are approximately equivalent.

The requirements of water for industry are too diverse for simple appraisal. The ground water in and near the southern part of the Jicarilla Reservation is suitable for many types of industrial use, such as cooling water and oil-field floodwater, but it could be unsuitable or would require treatment for some industrial uses.

GENERAL AVAILABILITY OF GROUND WATER

The Upper Cretaceous and Tertiary formations studied (pl. 1) are composed almost entirely of clastic rocks. The rocks are layered in vertically alternating stratigraphic units of shale and sandstone; only the sandstone units are aquifers. The availability of ground water in the entire area cannot be described in general terms because of the variety of stratigraphic, structural, and physiographic features, all of which affect the occurrence of ground water. For this reason, the availability is discussed here for each of the physiographic sectors. The locations of most of the wells and springs inventoried are shown on plate 5, and the physiographic sectors are delineated. Areas of outcrops of the geologic formations mentioned in the following discussion are shown on plate 1. The subsurface distribution of rocks in parts of the area is shown on the correlation diagrams (pls. 2, 3, 4).

PENISTAJA CUESTAS

The Mesaverde Group, the Lewis Shale, the Pictured Cliffs Sandstone, the undivided Fruitland Formation and Kirtland Shale, the Ojo Alamo Sandstone, and the Nacimiento and San Jose Formations crop out in broad arcuate westward-trending bands in the Penistaja Cuestas sector (pl. 1, fig. 5). The rocks dip northeast, north, and northwest in the western, central, and eastern parts, respectively, of the sector, so that the depth to a formation increases generally to the north. The land surface rises irregularly, but generally to the north. Only the Mesaverde Group, the Ojo Alamo Sandstone, the San Jose Formation and the alluvium in valleys are considered potential sources of potable water in this sector.

Ground water could probably be obtained from sandstone in the upper and lower parts of the Mesaverde Group, which is 500–600 feet thick in the southeastern part of the area. The Mesaverde Group is at the surface in the southern and eastern parts of T. 20 N., R. 1 W. However, it dips north and west, and the depth to the top of the Mesaverde is 1,000 feet or more in the valley of Senorito Creek and the Rio Puerco in T. 20 N., R. 1 W.

In the eastern parts of Tps. 20–21 N., R. 1 W., potable water could probably be obtained at depths of 200 feet and less by drilling into the steeply dipping rocks of the Mesaverde Group at places where the major valleys cross its narrow outcrop belt. The Mesaverde dips steeply under the Lewis Shale, and the depth to the top of the group is probably 800–1,000 feet just a few hundred feet west of the outcrop belt on Rito Leche and Nacimiento Creek, and 1,800–2,000 feet near Cuba.

The depth to the top of the Mesaverde Group is about 1,500 feet in T. 20 N., R. 5 W. The Mesaverde Group in that part of the area is about 1,700 feet thick, and nearly half of the interval consists of sandstone beds, some of which are almost 200 feet thick. The sandstones of the Mesaverde in this part of the area would probably yield large amounts of water to deep wells, but the quality of the water is not known. Where the Mesaverde is deeply buried, the rocks are likely to contain very saline water.

The Ojo Alamo Sandstone yields potable water to numerous wells and several springs (fig. 5; tables 6, 7) on and near the outcrops of the formation in the Penistaja Cuestas. Analyses of water from well 20.2W.3.200 and from Ojo Encino (S20.5W.23.334) show that the water is potable and soft (table 9) in the southern parts of T. 20 N., Rs. 2–5 W., where the Ojo Alamo Sandstone ranges in thickness from 80 to 170 feet. Cottonwood trees growing where Penistaja Arroyo, Arroyo San Ysidro, and Arroyo Chijuilla cross the outcrop belt of the Ojo Alamo indicate shallow ground water in the sandy alluvium of the washes. This shallow water is probably discharged from the Ojo Alamo into the alluvium at the topographically lowest parts of the outcrop belt. It is doubtful that wells drilled into the Ojo Alamo on the higher parts of the cuestas in the southern part of T. 20 N., Rs. 2–5 W., would obtain more than small amounts of water because the discharge of water from the sandstone into the nearby washes tends to keep the sandstone mostly drained on the cuestas.

Domestic and stock wells near the northern margin of the outcrop belt of the Ojo Alamo Sandstone and in the outcrop belt of the Nacimiento Formation in T. 20 N., Rs. 2–4 W., obtain 2–20 gpm of water from the Ojo Alamo Sandstone (table 3). Additional supplies of potable water could be developed by drilling into the Ojo Alamo in the outcrop belt of the Nacimiento Formation. The Ojo Alamo dips to the north and northeast, and the depth to the top of the sandstone increases from a few feet in the southern parts of T. 20 N., Rs. 2–5 W., to more than 1,000 feet in the southern parts of T. 21 N., Rs. 2–5 W. The Ojo Alamo is confined in the subsurface between relatively impermeable shales so that the water is under artesian pressure. Greater yields of water might be developed from the Ojo Alamo where it is at greater depth than where it is at or near the surface, because the deep wells would permit large drawdown.

In the Penistaja Cuestas east of the Rio Puerco, the Ojo Alamo Sandstone is 60–90 feet thick; it dips to the west and northwest and forms cuestas that slope toward the Rio Puerco. It is doubtful that the sandstone on the cuestas contains much ground water in Tps. 20 and 21 N., R. 1 W., except near the valley of the Rio Puerco. Wells that obtain water from the Ojo Alamo Sandstone near Cuba yield 14–30 gpm (table 3). These wells are mostly in the valley of the Rio Puerco, where the top of the Ojo Alamo lies at depths from a few feet at the east side of the valley to 100–200 feet near the Rio Puerco. The depth to the top of the Ojo Alamo near the west side of the valley west of Cuba is probably 300–500 feet but farther south the depth is less, and the Ojo Alamo crops out in the channel of the Rio Puerco in sec. 7, T. 20 N., R. 1 W.

Additional supplies of potable water can be obtained from the Ojo Alamo Sandstone in the valley of the Rio Puerco west of its outcrops. However, the shallow ground water in the overlying alluvium may be organically contaminated, and some of this water may filter into the Ojo Alamo on the east side of the valley where the alluvium lies on the sandstone. The danger of obtaining possibly contaminated water from wells in this part of the area would be lessened if the water in the alluvium were cased out. Most of the water obtained from the Ojo Alamo Sandstone near Cuba is potable, but it has an unpleasant taste, it is hard, and it contains enough dissolved iron to damage plumbing fixtures (table 9).

The sandstones of the Cuba Mesa Member of the San Jose Formation yield amounts of water adequate for domestic and stock supplies from shallow depths in T. 21 N., Rs. 2–5 W. (table 4). The Cuba Mesa Member will yield less water to wells on the cuestas near the south margin of the outcrop belt than to wells near the north margin of the outcrop belt, or to wells in the outcrop area of the Regina Member (pl. 1). Wells that penetrate all the sandstone will yield more water than wells that penetrate only the upper part. The Cuba Mesa Member is 200–220 feet thick west of T. 21 N., R. 2 W., and it is about 750 feet thick northwest of Mesa de Cuba.

The top of the Cuba Mesa Member at places along the drainage divide at the north boundary of the Penistaja Cuestas sector is as much as 400 feet below the land surface, but at most places it is shallower. The lower part of the Regina Member contains several beds of coarse-grained sandstone which also will yield small amounts of water to wells at shallower depth than the Cuba Mesa Member in the northern and central parts of T. 21 N., Rs. 1–5 W.

The top of the Cuba Mesa Member in the valley of San Jose Creek west of La Jara is about 150–200 feet beneath the surface, and the member is about 500 feet thick, including several thick tongues of shale of the Regina Member. Water wells have not been drilled through the Regina Member into the Cuba Mesa Member in the valley of San Jose Creek, except in and near its outcrop (pl. 1). Shallow domestic and stock wells that obtain water from the Cuba Mesa Member northwest of Cuba yield 3–5 gpm. The water is potable, but it contains much dissolved iron.

Wells drilled as deep as 500 feet into the Regina Member near Regina did not obtain water. The Regina Member east of the Continental Divide is composed mainly of shale and contains very few beds of sandstone that might be aquifers. Near Regina the Cuba Mesa Member is the greatest potential source of water; it is about 1,200 feet below the surface. Larger yields could be obtained from wells that penetrated all the beds of sandstone in the San Jose and Nacimiento Formations and the Ojo Alamo Sandstone near Regina. However, in most of the Penistaja Cuestas the Nacimiento Formation does not contain enough sandstone to be considered a source of more than small amounts of ground water.

Small supplies of water can be obtained from alluvium at depths of less than 100 feet in the valleys of all the major intermittent and perennial streams of the Penistaja Cuestas. The alluvium at most places is probably less than 100 feet thick, but its thickness is difficult to estimate at any particular place because of the irregular topographic surface on which the alluvium was deposited. Wells are more likely to be successful near the present arroyos or stream channels. Most of the water from the alluvium is potable. However, many of the residents of Cuba report that the water in the alluvium in the Rio Puerco valley is not suitable for domestic use. The shallow ground water in the vicinity of Cuba may be polluted by organic matter.

LARGO PLAINS

The San Jose Formation crops out in the Largo Plains, and the Nacimiento Formation and the Ojo Alamo Sandstone are present in the subsurface. The rocks dip northeast, but the dip is so gentle as to be nearly imperceptible north of Canon Largo. All these formations are potential aquifers in parts of the Largo Plains, but at most places the Nacimiento Formation and the Ojo Alamo Sandstone are buried too deeply to be practical sources of small ground-water supplies. Nevertheless, they would contribute significantly to the yield of deep wells which penetrate all the beds of sandstone to the base of the Ojo Alamo. The Ojo Alamo Sandstone is 80–160 feet thick and is present in the subsurface of the Largo Plains at depths ranging from 1,400–1,500 feet at the south to about 2,400–2,600 feet at the northeast. No wells are known to obtain water from the Ojo Alamo in the Largo Plains.

The Nacimiento Formation is about 1,100 feet thick at the south and almost 1,800 feet thick in the northern part of the Largo Plains. Near Otero Ranch, the top of the Nacimiento Formation is 200 feet and less below the surface, but in the northern and eastern parts of the plains the top of the Nacimiento is 600–1,000 feet below the surface, depending on local topography. Most of the Nacimiento Formation consists of shale south of the latitude of Otero Ranch. However, farther north the Nacimiento contains thick sandstone beds which are aquifers. Two wells of the El Paso Natural Gas Co. obtain water from sandstone near the middle of the Nacimiento Formation in the SE¼ sec. 18, T. 24 N., R. 5 W. The chemical quality of the water is acceptable for domestic use. One of the wells, 796 feet deep, yielded 42 gpm with a drawdown of 562 feet after 12 hours of pumping. The water is obtained from a sandstone between the depths of 765 and 785 feet.

Stock wells in the Largo Plains obtain water from thin sandstones interbedded in shale of the lower part of the Regina Member of the San Jose Formation and from sandstone of the underlying Cuba Mesa Member. These wells yield 2–10 gpm from depths of less than 300 feet. Small supplies of water could be developed almost anywhere in the Largo Plains from sandstones of the San Jose Formation at depths of 300 feet or less. The water is potable, although some of it has a slightly unpleasant taste. Deposits of white salts around wells and tanks are common.

The Cuba Mesa Member of the San Jose Formation is 200 feet or more thick and is the shallowest aquifer in which fairly large amounts of ground water can be expected. The Cuba Mesa Member crops out in the western part of the Largo Plains, but the depth to the member increases toward the east and south. The top of the Cuba Mesa Member may be 300–400 feet below the surface at some of the mesas south of Canon Largo in T. 22 N., Rs. 4 and 5 W., but in the deeper washes and valleys it is 250 feet or less below the surface. Some of the sandstones of the lower part of the Regina Member, that are exposed on the low mesas south of Canon Largo, may contain small quantities of ground water at depths of 200 feet or less.

In the southeastern part of the Largo Plains, the depth to the main part of the Cuba Mesa Member may be as much as 700 feet in part of T. 23 N., R. 3 W. However, in part of this township thick upper sandstone tongues of the Cuba Mesa Member are present in the Regina Member, and these sandstones would yield water to wells. The top of the upper tongue of the Cuba Mesa Member is about 300 feet below the valley of Canon Largo in sec. 10, T. 23 N., R. 3 W. The upper tongues of the Cuba Mesa Member are not present in the southwestern part of the township, but lenticular sandstones in the Regina Member probably contain water at depths of 200–300 feet. The top of the main part of the Cuba Mesa Member in the southwestern part of T. 23 N., R. 3 W., is about 590–700 feet below the surface. Wells that tap the Cuba Mesa Member in the southern and southeastern parts of the Largo Plains would yield 8–10 gpm and probably more.

Along the east side of the Largo Plains, the top of the Cuba Mesa Member is generally 400–600 feet below the surface. Some of the wells obtaining water from the upper part of the Cuba Mesa Member east of Canon Largo yield 2–7 gpm. Deeper wells at the same places would penetrate a thicker section of sandstone and would have greater yields. Water can be obtained at depths of 100–400 feet from beds of sandstone in the Regina Member in the eastern and northern parts of the plains, especially in T. 26 N., R. 5 W., and the northern part of T. 25 N., R. 5 W., where the lower part of the Regina Member contains several thick beds of sandstone interbedded in shale.

Water occurs at shallow depth in the alluvium of all the major canyons. Part of the water probably filters into the alluvium from precipitation and from surface runoff. However, much of the water is discharged from sandstone beds of the San Jose Formation into the alluvium where the sandstones crop out in the valleys and canyons. At some of these places the water is close enough to the surface to be obtained in shallow bulldozed pits. The water in the alluvium is probably similar in chemical quality to the water in the San Jose Formation, but the water in the alluvium may have higher mineral content because of salts concentrated by evapotranspiration at shallow depths.

TAPICITOS PLATEAU AND YEGUAS MESAS

The Tapicitos Plateau and Yeguas Mesas are formed of rocks of the San Jose Formation, which is the principal aquifer in these sectors. The rocks are nearly horizontal in much of the Tapicitos Plateau, but they dip gently north in the southern part, and they dip gently west in the eastern part of the plateau and in the Yeguas Mesas. The Ojo Alamo Sandstone and the Nacimiento Formation extend throughout the sectors in the subsurface, but they are too deep to be considered practical sources of small supplies of ground water. At most places they would contribute to the yield of deep wells. The Ojo Alamo Sandstone ranges in thickness from 150 feet to a little more than 200 feet, and the depth to the top of the sandstone ranges from about 2,450 feet in the northwestern part of T. 22 N., R. 2 W., to about 3,450 feet in the east-central part of T. 26 N., R. 3 W. The Nacimiento Formation is about 1,000 feet thick in the southern part of the Tapicitos Plateau and 1,700–1,800 feet thick in the northern part of the plateau. The depth to the top of the Nacimiento Formation is 1,300–1,400 feet in the southern part of the plateau and 1,500–1,700 feet in the northern part. The Nacimiento Formation consists mainly of shale in the southern part of the plateau, but north of the central parts of T. 23 N., Rs. 1–3 W., this formation contains thick sandstone beds which would yield water to deep wells.

Wells obtain water from sandstones of the Llaves, Regina, and Tapicitos Member of the San Jose Formation in the Tapicitos Plateau and the Yeguas Mesas. The Cuba Mesa Member is present at the base of the formation, but it has not been tapped by water wells in this part of the area. The yields of the wells in the San Jose Formation in the Tapicitos Plateau and Yeguas Mesas range from less than 1 gpm to 45 gpm, and the water is obtained from depths of 111–753 feet. Most of the water is potable, but it contains relatively large amounts of sodium and sulfate (table 9). Small supplies of water probably could be obtained from beds of sandstone in the San Jose Formation at depths of less than 400 feet in most of the Tapicitos Plateau and Yeguas Mesas sectors.

South of the latitude of Lindrith, the high mesas of the Tapicitos Plateau are capped by thick lenticular beds of sandstone with interbedded shale in the upper part of the Regina Member. Only two wells are known to obtain water from these sandstones. Well 23.3 W.11.333 is 153 feet deep and yields 7 gpm. The zone of thick sandstones persists eastward as far as the Continental Divide. Additional small supplies could be obtained from these sandstones at depths of 250 feet or less.

Thick lenticular sandstones in the upper part of the Regina Member yield small supplies of potable water to domestic and stock wells from depths of 100–275 feet in the upper valley of Canada Larga south of Lindrith and in the hills east and southeast of Lindrith. Yields range from less than 1 gpm to 8 gpm. Additional water for stock and domestic supplies could be obtained in most of this area, probably at depths of 300 feet or less. Larger supplies could be obtained from deep wells, particularly if they tapped sandstone beds in the lower part of the Regina Member and the Cuba Mesa Member. The top of the lower zone of sandstones in the Regina Member is about 500 feet below the surface in Canada Larga near Lindrith, and is 700–800 feet deep in areas to the east and southeast. The Cuba Mesa Member is about 200 feet thick and is about 1,100 feet below the surface in Canada Larga south of Lindrith.

The municipal supply well of the Lindrith Mutual Water Users Association (24.2W.15.244) is about 753 feet deep. It obtains water from a sandstone tongue of the Llaves Member enclosed in the Regina Member. North and northeast of Lindrith the upper part of the Regina Member consists mainly of shale, and at most places between Oso Canyon and Canada Jaques the depth to water is 300–500 feet. Thick beds of sandstone are present in the lower part of the Regina Member at depths of 800–1,000 feet in this part of the plateau.

In the northern part of the Tapicitos Plateau, north of Oso Canyon, wells obtain water for domestic and stock supplies from the San Jose Formation at depths of 50–510 feet. Additional supplies can be obtained at most places at depths of 300 feet or less. The reported yields of wells range from less than 1 gpm to about 45 gpm. The yield of most wells in this part of the plateau is probably about 2–5 gpm.

The Cuba Mesa Member of the San Jose Formation has not been tapped by water wells in the northern part of the Tapicitos Plateau. The member is 250–350 feet thick and consists mainly of sandstones that are probably good aquifers. The depth to the top of the Cuba Mesa Member is 600–800 feet in the canyons of the northwestern part of the plateau and 1,000–1,500 feet in the north-central and northeastern parts.

The upper part of the Regina Member contains a few beds of sandstone that yield small amounts of water to wells in the northern part of the Tapicitos Plateau The lower part of the Regina Member contains thick sandstone tongues of the lower part of the Llaves Member that would yield larger amounts of water to wells 700–1,000 feet deep.

The persistent medial sandstone of the Llaves Member is present in the subsurface throughout the northern part of the plateau. The sandstone is as much as 100 feet thick at places and, compared with other sandstone beds tapped by wells in this part of the area, it yields relatively large amounts of water. A well at Ojitos (25.3W.1.240a) yields 25–30 gpm from the medial sandstone at a depth of 302 feet. Another well in the upper part of Canon Ojitos (26.2W.34.421) yields 45 gpm from the medial sandstone at a depth of about 400 feet. Other wells that obtain water from the medial sandstone yield 1–10 gpm. The water from the medial sandstone unit of the Llaves Member is reported to be more suitable for domestic use than water from the overlying Tapicitos Member. The depth to the medial sandstone of the Llaves Member is less than 100 feet in the deeper valleys of the northwestern part of the plateau and 400–500 feet on the mesas in the northeastern part of the plateau. In most of Tps. 25 and 26 N., Rs. 1–3 W., the lower part of the Llaves Member and the underlying Cuba Mesa Member consist mainly of sandstone that would yield large amounts of water to wells 1,000–1,800 feet deep.

The lenticular sandstone beds of the Tapicitos Member yield water at depths ranging from 50 to 260 feet. The water contains much sodium and sulfate, and the owners of some wells do not consider it to be suitable for domestic use. In the northeastern part of the plateau the Tapicitos Member contains thick sandstone tongues of the Llaves Member, and water can be obtained from these sandstones at depths of 300 feet or less. Wells are reported to yield 2–10 gpm from the sandstone tongues.

In the Yeguas Mesas sufficient amounts of water for domestic and stock supplies can be obtained at depths of 250 feet or less at most places. It is likely that the sandstones of the Llaves and Cuba Mesa Members would yield relatively large amounts of water to wells drilled to depths of several hundred feet in the deeper canyons. The water is soft and potable. Relatively large supplies of water could be obtained from deep wells that penetrate all the beds of sandstone to the base of the Ojo Alamo Sandstone throughout the sector.

Water occurs in sandy alluvium in all the major valleys at depths of 50 feet or less at most places in the Tapicitos Plateau and Yeguas Mesas. However, the alluvium may be too thin or too deeply entrenched by arroyos to contain water in the upper parts of some of the canyons. At these places water probably can be obtained by drilling into the underlying bedrock, and at most places the depth to water is 250 feet or less.

SAN PEDRO FOOTHILLS

Rocks of the Mesaverde Group, the Lewis Shale, the undivided Fruitland Formation and Kirtland Shale, the Ojo Alamo Sandstone, the Nacimiento Formation and the lower part of the San Jose Formation are tilted steeply and crop out discontinuously at the foot of San Pedro Mountain in the eastern part of the sector. The upper part of the San Jose dips gently west and crops out in most of the western two-thirds of the sector. Gravel of Tertiary and Quaternary age caps high terraces and is present in the upper valleys of some streams, and alluvium occurs in the valleys of all major streams. The Mesaverde Group, the Ojo Alamo Sandstone, parts of the Nacimiento and San Jose Formations, and terrace gravels and valley alluvium are potential aquifers in the sector.

Potable water probably could be obtained at shallow depths from steeply tilted sandstone beds of the Mesaverde Group, Ojo Alamo Sandstone, and Cuba Mesa Member of the San Jose Formation by drilling where the deep canyons cross the outcrop belts of these formations in the eastern part of the sector (pls. 1, 5). North of La Jara Creek the Nacimiento Formation also contains several thick beds of sandstone which may be aquifers. Because these rocks dip steeply, they are deeply buried just a short distance west of their outcrop belts. In the western part of the sector the top of the Mesaverde Group is 3,700–4,000 feet below the surface, the top of the Ojo Alamo is 1,500–2,000 feet, and the top of the Nacimiento Formation is 700–1,000 feet below the surface. The Mesaverde Group, Ojo Alamo Sandstone, and Nacimiento Formation have not been utilized as sources of water in the San Pedro Foothills, but they would yield relatively large amounts of water to deep wells drilled west of their outcrop belts. The water in the Mesaverde Group may have a high mineral content where it is deeply buried west of its outcrop belt, and the Ojo Alamo is the deepest aquifer likely to contain potable water in the subsurface of the central and western parts of the foothills sector.

The San Jose Formation yields potable water to a few domestic and stock wells in the San Pedro Foothills. These wells obtain water at depths ranging from 40 to 300 feet from coarse-grained sandstone beds in the Regina Member near La Jara (table 6). Additional small supplies of water could be obtained from these lenticular sandstone beds at depths of 200–300 feet, or a little less, in most of the southern part of the San Pedro Foothills. However, in the northern part of the San Pedro Foothills near Regina, no permeable sandstones were found in dry holes (23.1W.33.112) that were drilled as deep as 345 feet in the Regina Member. Electric logs of wells west of Regina indicate that only a few thin beds of permeable sandstone occur in the Regina Member, which is more than 1,200 feet thick in this part of the area.

The Cuba Mesa Member is the shallowest bedrock aquifer from which fairly large amounts of water can be obtained in most of the San Pedro Foothills. The Cuba Mesa Member consists mainly of sandstone and is 150–200 feet thick at outcrops in the eastern part of the sector and 400–500 feet thick in the subsurface of the western part of the sector. The top of the Cuba Mesa Member just west of its outcrop belt is 500–700 feet below the surface, and at the western margin of the San Pedro Foothills sector near Regina the top of the member is about 1,100 feet below the surface. Farther south it is shallower. In the San Pedro Foothills the Cuba Mesa Member has been utilized as a source of water only near its outcrops on Rito de los Pinos.

The high-level deposit of terrace gravel at the foot of San Pedro Mountain in secs. 2 and 11, T. 21 N., R. 1 W., may contain a small quantity of ground water as indicated by the presence of seeps along its western margin, but the other high-level deposits probably do not.

The lower deposits of terrace gravel and gravelly alluvium in stream channels in the eastern part of the sector (pls. 1, 5) yield water to wells and springs at places in the San Pedro Foothills. Additional supplies could be obtained at depths of 50 feet or less by wells drilled into the gravel in the topographically lower parts of the upper valleys of Rito de los Pinos, La Jara Creek, and San Jose Creek.

The water supply for the town of Cuba was collected at the time of fieldwork for this report (1959–60), from springs and seeps that issue from a large erosional remnant of stream-channel gravel that caps the mesa called Vallecito del Rio Puerco in the S½ sec. 14, T. 21 N., R. 1 W. These springs are on the south side of the mesa. Other springs and seeps occur on the mesa and at its west and north sides. Most of the springs and seeps are not being utilized, or are only partly utilized. Additional small supplies could be developed at depths of less than 50 feet by drilling into the gravel on the mesa. The water body in the gravel is perched on shale beds and receives recharge from precipitation and from infiltration of some of the surface flow of the upper part of the Rio Puerco just east of the mapped area.

Several domestic and stock wells obtain small amounts of water from alluvium in the valleys in the San Pedro Foothills. Most of the wells are less than 50 feet deep. Water is most likely to occur where the alluvium is thickest and where it is not deeply trenched by arroyos. In general, wells drilled near the present streams and arroyos are most likely to obtain water from the alluvium.

NORTHERN HOGBACK BELT

The Mesaverde Group, the Lewis Shale, the undivided Fruitland Formation and Kirtland Shale, the Ojo Alamo Sandstone, the Nacimiento Formation, and the lower part of the San Jose Formation crop out in a belt of west-dipping rocks in the Northern Hogback Belt (pls. 1, 5). The upper part of the San Jose Formation dips gently west. Outcrops of these rocks are separated by the broad alluviated valleys of intermittent east-flowing streams. The Mesaverde Group, parts of the Fruitland Formation and Kirtland Shale, the Ojo Alamo Sandstone, parts of the Nacimiento and San Jose Formations, and valley alluvium are potential aquifers in the sector.

Wells could obtain supplies of potable water for domestic and stock use at depths of 200 feet or less from the Mesaverde Group and the Ojo Alamo Sandstone in the eastern part of the sector, where the outcrop belts of these rocks are crossed by streams. Water probably could be obtained from these rocks in the interstream areas also, but the wells would have to be drilled a short distance west of the outcrops in order to intercept the west-dipping rocks where they are below the water table. The fact that wells drilled for oil and gas in the Northern Hogback Belt tapped highly saline water at shallow depth in the Mesaverde Group a short distance west of its outcrop belt indicates that the Mesaverde may not have been flushed to a very great depth by infiltrating meteoric water. Data are not adequate to predict the depth to which the saline water may have been flushed. In the western part of the Northern Hogback Belt the Mesaverde Group is deeply buried and is not a source of potable ground water.

North of sec. 20, T. 24 N., R. 1 E., the undivided Fruitland Formation and Kirtland Shale dip steeply west and contain a unit of fine-to coarse-grained sandstone as much as 70 feet thick at places. Wells drilled west of the outcrop belt of the Fruitland and Kirtland probably would intercept the sandstone below the water table, and this sandstone might yield sufficient amounts of water for domestic and livestock use. No wells are known to have obtained potable water from this sandstone. In the western part of the Northern Hogback Belt the undivided Fruitland Formation and Kirtland Shale are more than 2,500 feet below the surface and at places contain mineralized water and natural gas.

The Ojo Alamo Sandstone is 100–200 feet thick and probably contains large amounts of water under artesian pressure in the subsurface of the western part of the Northern Hogback Belt south of T. 25 N., but the top of the sandstone is 2,200–3,000 feet below the surface, depending on local topography. North of Canoncito de las Yeguas, well 25.1E.17.234 (table 6) yields 5–6 gpm of water from the coarse sand and gravel between 85 and 100 feet below the surface. This sand and gravel are probably part of the Ojo Alamo Sandstone, which is covered by alluvium in a small valley. Additional supplies probably could be obtained north of Canoncito de las Yeguas by wells drilled one-quarter of a mile or less west of the outcrop of the Ojo Alamo Sandstone. These wells would intercept the sandstone at depths ranging from a few feet near the outcrop to 200–500 a little farther west. The thick unit of sandstone probably would yield moderate amounts of water under artesian pressure. Water moves from the Ojo Alamo Sandstone into overlying alluvium north of Canoncito de las Yeguas in T. 25 N., R. 1 E., and feeds Mud Spring (S26.1E.17.333, table 7) and other seeps. Chupadera Spring (S26.1E.33.314) discharges water directly from the Ojo Alamo. The water from the springs and from well 25.1E.17.234 is potable and only moderately hard.

The Nacimiento Formation has not been utilized as a source of water south of Canoncito de las Yeguas. Wells 23.1W.22.222 and 23.1W. 22.411 (table 6) in the southern part of the sector were drilled to depths of 328 and 330 feet, respectively, and were bottomed in hard sandstone of the lower part of the Nacimiento Formation without obtaining water. The sandstones are fine grained to medium grained and appear to be tightly cemented. Farther north, several dry holes, ranging in depth from 40 to 241 feet, were drilled in coarse-grained sandstones in the upper part of the Nacimiento. However, these holes were on well-drained hills where the possibility of local recharge is small, and the wells apparently did not reach the water table.

The only well known to obtain water from the Nacimiento Formation in the Northern Hogback Belt is in the valley north of the mouth of Canoncito de las Yeguas. This well (25.1E.17.314, table

6) is 117 feet deep and is bottomed in sandstone. The well yields less than 0.5 gpm of potable water. Water probably could be obtained at depths of 200 feet or less from sandstone beds of the Nacimiento Formation in the topographically lower parts of the broad valleys crossing its outcrop in the Northern Hogback Belt.

The San Jose Formation crops out in the western part of the Northern Hogback Belt from Canoncito de las Yeguas south. Rocks of the San Jose Formation dip steeply west in the eastern part of their outcrop belt, but the San Jose dips gently west in most of the sector. Well 24.1E.6.344 (table 6) is 98 feet deep and yields 12 gpm of potable water from the basal sandstone of the Cuba Mesa Member. Additional supplies could be obtained from the Cuba Mesa Member from depths of 100–500 feet a short distance west of its outcrops at most places in the Northern Hogback Belt. Wells drilled into the Cuba Mesa Member where it is overlain by alluvium in the major valleys would also yield adequate supplies of water for domestic and stock use. The depth to the Cuba Mesa Member becomes greater to the west, and in the upper parts of Arroyo Blanco and Almagre Arroyo, the top of the member is 800–1,200 feet below the surface.

Lenticular sandstone in the lower part of the Regina Member yields water to three wells in the sector. Well 24.1E.18.333 (table 6) yielded only a small amount of water from a depth of 80 feet. The water was reported to be too saline for domestic or livestock use, and the well was abandoned. Well 24.1E.19.111 yields water suitable for domestic use from a depth of 95 feet. Well 24.1W.1.433 (table 6) yields 1 gpm from a depth of 140 feet. Well 23.1W.3.414 (table 6), which was drilled to a depth of 734 feet in the Regina Member, yielded less than 0.25 gpm from a sandstone between the depths of 520 and 524 feet. A few other wells drilled in the Regina Member were dry.

Alluvium in the major valleys and in some of the smaller valleys yields potable water to several wells at depths of 4 to 50 feet (tables 5, 6). Additional supplies adequate for domestic and stock use can be obtained from the alluvium at many places. Water is most likely to be obtained where the alluvium is thickest near the present stream channels in the topographically low parts of the valleys.

In most of the western part of the Northern Hogback Belt, if water is not obtained in alluvium in the valleys, the only reliable source of water to be expected is in the Cuba Mesa Member at depths ranging from a few feet at the east margin of the outcrop belt of the Regina Member to 1,200 feet in the western part of the sector. Relatively large supplies of water could be obtained from deep wells that penetrate all the beds of sandstone to the base of the Ojo Alamo Sandstone in the western part of the sector.

POTENTIAL YIELD OF DEEP WATER WELLS

The potential yield of deep water wells in the southern part of the Jicarilla Reservation would depend largely on the cumulative thickness of beds of water-bearing sandstone penetrated, because the specific capacity (yield in gallons per minute per foot of drawdown) of a well is largely a function of the permeability and the thickness of water-bearing material that the well penetrates. All the water wells in the region are shallow, and none tap all the beds of sandstone to the base of the Ojo Alamo Sandstone, except where the Ojo Alamo is near the surface. Accordingly, the potential yield of deep wells can only be estimated. For comparison, data are presented on the yields of similar sandstone aquifers in another part of the San Juan Basin.

Deep wells at Gallup, N. Mex., tap beds of sandstone that are somewhat similar to those in the Jicarilla Reservation. The cumulative thickness of the sandstone beds at Gallup is 500 feet. The wells yield an average of about 250 gpm with a drawdown of 500 feet and, thus, have a specific capacity of about 0.5. In terms of unit measure relative to thickness of aquifer, the average specific capacity is 0.001 gpm per foot of drawdown, per foot of sandstone (West, 1961, p. 9). Data on 49 other wells that obtain water from similar beds of sandstone in the San Juan Basin indicate that the average specific capacity per foot of sandstone may be in the same order of magnitude. The apparent range is from 0.0002 to 0.009.

The Ojo Alamo Sandstone and many beds of sandstone in the Nacimiento and San Jose Formations are coarser textured and less firmly cemented than many of the older sandstone units in the San Juan Basin; therefore the Ojo Alamo and younger formations should be better aquifers than many of the older formations. The specific capacity per foot of sandstone penetrated was determined for eight wells that tap the Ojo Alamo and younger formations in or near the Jicarilla Reservation (tables 3, 4). The specific capacity of these wells ranged from 0.002 (well 24.5W.18.421a) to 0.015 (well 26.7W. 15.412) gpm per foot of water-bearing sandstone penetrated; the average was 0.008.

The range from 0.0002 to 0.015 gpm per foot of drawdown per foot of sandstone penetrated is used in the following hypothetical example of a method of estimating the probable range in yields from a unit of sandstone, if the specific capacity per foot of sandstone penetrated and the cumulative thickness of sandstone are known. Assuming that the total thickness of the beds of sandstone is 500 feet, and assuming that a drawdown of 300 feet could be tolerated, the yield of a well tapping all the sandstone beds could range from 30 to 2,250 gpm (0.0002 × 500 × 300 and 0.015 × 500 × 300). The average value of 0.008 gpm per foot of drawdown per foot of sandstone penetrated gives a possible average yield of 1,200 gpm (0.008 × 500 × 300) under the conditions specified above. The average yield of 0.008 gpm per foot of drawdown per foot of sandstone penetrated probably is a little more than could be sustained during long periods of pumping, because the specific capacity of wells is generally determined from short periods of pumping, which may sample the water-yielding characteristics of the aquifer only in a relatively short distance from the well.

Many of the beds of sandstone in the Nacimiento and San Jose Formations are discontinuous or vary markedly in thickness. Some of the beds of sandstone are certain to thin and wedge out in some direction from any well (pls. 2–4), and there is a resulting decrease in transmissibility away from the well in the direction of thinning. This condition would cause an eventual increase in drawdown in a pumped well. However, this effect would probably be offset in part by the greater thickness and the higher transmissibility of the beds of sandstone in the directions opposite to those of thinning. After the wells had been pumped for some time, the lenses of sandstone that are enclosed completely in shale would be dewatered, except that slow vertical leakage from the enclosing shale would continue to supply a little water. A drawdown of 300 feet at most places would gradually dewater the beds of sandstone in the interval of drawdown, and the cessation of contribution from these beds would cause the yield to decrease or cause the drawdown to increase. The extent to which the yield decreased would depend largely on the thickness of sandstone that was dewatered.

This method of estimating the potential yield of deep wells in the southern part of the Jicarilla Reservation might give results that are considerably in error. Certainly, the ratio of specific capacity to thickness of water-bearing sandstone penetrated by the well would vary greatly from one unit to another. The largest departure from the average specific capacity per foot of sandstone penetrated may be expected of wells that penetrate only a few beds of sandstone, because the method of estimation is based on the average of the specific capacities of many beds. Despite the limited data, the method of relating average specific capacity to the total thickness of sandstone penetrated seems to be the best means available for estimating the potential yield of untested formations in the Jicarilla Reservation.

The Bureau of Indian Affairs suggested four tracts of land in the southern part of the reservation as suitable for irrigation, and the

Jicarilla Tribe requested an evaluation to determine which tract has the greatest potential for ground-water production. The general locations of these tracts are (1) the northwestern part of T. 22 N., R. 3 W.; (2) the vicinity of the northwest corner of T. 23 N., R. 4 W.; (3) adjacent to Lapis Canyon in T. 25 N., R. 5 W.; and (4) in northern part of T. 22 N., R. 5 W.

The three diagrams showing the correlations of rock units (pls. 2–4) were drawn along lines through or near each of the tracts in directions that best illustrate the changes in rock facies. The cumulative thickness of the sandstone units was computed from the control points (wells drilled for oil or gas) of the diagrams and can be interpolated between the control points. A depth of 200 feet (the assumed average depth to the top of the zone of ground-water saturation) below the land surface was chosen arbitrarily as the upper cutoff point for computing the thickness of saturated sandstone at all places. If the well was not logged to within 200 feet of the surface, the probable thicknesses of the upper beds of sandstone were estimated from logs of adjacent wells and outcrop data. The well nearest each of the tracts was selected as a key well to show the thickness of sandstone in each; the thickness of sandstone at other places along the lines can be compared easily with that at the key wells (pls. 2–4).

The stratigraphic units penetrated by the Reynolds Mining 1 Jicarilla D well (23.3W.33.114) (pl. 4) should be representative of those in and adjoining the northwestern part of T. 22 N., R. 3 W. This well penetrated 940 feet of sandstone above the base of the Ojo Alamo Sandstone at a depth of 2,670 feet, including 360 feet of sandstone above the base of the San Jose Formation at a depth of 1,260 feet.

The stratigraphic units penetrated by the Skelly Oil 1 Jicarilla D well (23.4W.6.332) (pl. 2) should be representative of those in the vicinity of the northwest corner of T. 23 N., R. 4 W. This well penetrated 660 feet of sandstone above the base of the Ojo Alamo Sandstone at a depth of 2,330 feet, including 140 feet of sandstone above the base of the San Jose Formation at a depth of 500 feet.

The stratigraphic units penetrated by the Amerada Petroleum 5 Jicarilla A well (25.5W.25.441) (pl. 4) are approximately representative of those along Lapis Canyon in T. 25 N., R. 5 W., except that this well was drilled on higher ground than that in Lapis Canyon. The well penetrated 1,470 feet of sandstone above the base of the Ojo Alamo Sandstone at a depth of 2,740 feet, including 600 feet of sandstone above the base of the San Jose Formation at a depth of 1,110 feet.

The stratigraphic units penetrated by the Humble Oil and Refining 1 Jicarilla B well (22.5W.1.223) (pl. 2) are approximately the same units that would be penetrated by the well in the northern part of

T. 22 N., R. 5 W. However, the units would be reached at progressively shallower depths southwestward from well 22.5W.1.223. Som of the shallower beds of sandstone that were penetrated by wel 22.5W.1.223 crop out a few miles to the southwest. This well pene trated 430 feet of sandstone above the base of the Ojo Alamo Sandston at a depth of 1,590 feet. The well penetrated 40 feet of sandston between the arbitrarily assumed depth (200 ft) to the top of the zon of saturation and the base of the San Jose Formation at a depth o 240 feet. Several of the beds of sandstone of the Nacimiento Forma tion that were penetrated by well 22.5W.1.223 are thin, and they may have low permeabilities owing to high silt and clay content. Further more, the San Jose Formation is thin in T. 22 N., R. 5 W., and mos of the sandstone beds of the San Jose are above the zone of saturation

The largest yield and the highest specific capacity of a deep well ma be expected at places where the greatest thickness of water-bearin sandstone can be tapped. However, the ratio of the thickness of sand stone to the depth of penetration should also be considered, becaus the depth of drilling required to penetrate a certain thickness of sand stone varies widely. The most favorable places for obtaining th largest yields with the least amount of drilling are those where th thickness of sandstone is great and the ratio of the thickness of sand stone to the depth to a certain horizon is high. All the ratios use in this report are based on the thickness of sandstone below a dept of 200 feet (the assumed average depth to the top of the zone o ground-water saturation), and the depth of the bases of the Ojo Alam Sandstone and the San Jose Formation below the land surface. Thes ratios are shown on plates 2–4.

The ratio of the thickness of sandstone penetrated to the depth t stratigraphic horizons indicated is derived below for a representativ well in each tract suggested as suitable for irrigation by the Burea of Indian Affairs.

Tract 1.—Northwestern part of T. 22 N., R. 3 W. (Reynolds 1 Jicarilla D well

$$\frac{\text{Thickness of sandstone (feet)}}{\text{Depth to base of Ojo Alamo Sandstone (feet)}}=\frac{940}{2{,}670}=0.35$$

$$\frac{\text{Thickness of sandstone (feet)}}{\text{Depth to base of San Jose Formation (feet)}}=\frac{360}{1{,}260}=0.29$$

Tract 2.—In the vicinity of the northwest corner of T. 23 N., R. 4 W. (Skelly O 1 Jicarilla D well)

$$\frac{\text{Thickness of sandstone (feet)}}{\text{Depth to base of Ojo Alamo Sandstone (feet)}}=\frac{660}{2{,}130}=0.31$$

$$\frac{\text{Thickness of sandstone (feet)}}{\text{Depth to base of San Jose Formation (feet)}}=\frac{140}{500}=0.28$$

Tract 3.—Adjacent to Lapis Canyon in T. 25 N., R. 5 W. (Amerada Petroleum 5 Jicarilla A well)

$$\frac{\text{Thickness of sandstone (feet)}}{\text{Depth to base of Ojo Alamo Sandstone (feet)}}=\frac{1{,}470}{2{,}740}=0.54$$

$$\frac{\text{Thickness of sandstone (feet)}}{\text{Depth to base of San Jose Formation (feet)}}=\frac{600}{1{,}110}=0.54$$

Tract 4.—The northern part of T. 22 N., R. 5 W. (Humble Oil and Refining 1 Jicarilla B well)

$$\frac{\text{Thickness of sandstone (feet)}}{\text{Depth to base of Ojo Alamo Sandstone (feet)}}=\frac{430}{1{,}590}=0.27$$

Most of the San Jose Formation has been removed from tract 4 by erosion or is above the zone of saturation.

The thickness of sandstone penetrated and the ratio of the thickness of sandstone to the depth to the base of the Ojo Alamo Sandstone and the San Jose Formation are highest in tract 3 adjacent to Lapis Canyon in T. 25 N., R. 5 W. From the data given above, the potential ground-water supply seems better along Lapis Canyon in T. 25 N., R. 5 W., than in any of the other tracts, or even in any other part of the southern half of the reservation. The ratio of thickness of sandstone to depth to the base of the San Jose is the same as the ratio of thickness of sandstone to depth to the base of the Ojo Alamo. A shallow well, however, would not draw on the reservoir that is represented by the 870 feet of sandstone between the base of the San Jose Formation and the base of the Ojo Alamo Sandstone. For this reason, a test well drilled to the base of the Ojo Alamo Sandstone would be more desirable than one that stopped at the base of the San Jose Formation. The deep well would furnish the best data for planning additional wells and would indicate whether shallow or deep wells would be more practicable. The specific capacity of any well could probably be improved by hydraulic fracturing of the aquifers.

If the value determined in this area for minimum specific capacity per foot of sandstone penetrated (0.002) could be applied to the Lapis Canyon tract in T. 25 N., R. 5 W., and if 300 feet of drawdown could be tolerated, the yield of a well that tapped all the beds of sandstone to the base of the San Jose Formation would be 360 gpm (0.002×600 ×300), and the yield of a well that tapped all the beds of sandstone to the base of the Ojo Alamo Sandstone would be 880 gpm (0.002×1,470 ×300). If the average specific capacity per foot of sandstone penetrated (0.008) that was determined in the area could be applied to the Lapis Canyon tract, and if 300 feet of drawdown could be tolerated, the yield of a well that tapped all the beds of sandstone to the base of the San Jose Formation would be 1,440 gpm (0.008×600×300), and the yield of a well that tapped all the beds of sandstone to the base of the Ojo Alamo Sandstone would be 3,530 gpm (0.008×1,470

×300). The actual yield would probably fall between the values computed above.

Greater pumping lifts for irrigation could probably be tolerated on the Jicarilla Reservation, because natural gas for power would be available at little or no cost to the tribe.

SUMMARY AND CONCLUSIONS

The rocks of latest Cretaceous and Tertiary age in the southern part of the Jicarilla Apache Reservation contain beds of sandstone that yield small amounts of water to wells from depths of 300 feet and less in most of the area. Thick units of sandstone are present at the surface and in the subsurface. However, many of these are not distributed uniformly, and their variations in thickness and distribution would cause differences in the yields of deep wells drilled at different places in the area. The present investigation of the surface and subsurface stratigraphy of the area provided data to determine the general distribution and thickness of each of the major units of sandstone that is an aquifer or potential aquifer.

The stratigraphically lowest potential aquifer, except in a few localities, is the Ojo Alamo Sandstone, which is present throughout the area. The Ojo Alamo ranges in thickness from 70 feet in the southern part of the area to a little more than 200 feet in the northern part. The Nacimiento Formation, which rests on the Ojo Alamo, ranges in thickness from 800 feet at the south to 1,700 feet at the north. In the southern part of the area the Nacimiento consists mainly of shale; however, in the northern part of the area the Nacimiento contains thick beds of sandstone which might yield relatively large amounts of water to deep wells. The Nacimiento Formation is overlain by the San Jose Formation, which consists of several units of shale and sandstone. The Cuba Mesa Member of the San Jose Formation is present throughout most of the area. It consists mainly of sandstone and is about 200 feet thick in much of the area, as much as 782 feet thick in the southeastern part of the area, and 300–350 feet thick in the northern part. The Llaves Member of the San Jose Formation consists mostly of sandstone and ranges in thickness from 300 to 1,300 feet; however, the Llaves Member is restricted almost entirely to the northern part of the area. The Regina and Tapicitos Members of the San Jose Formation are mainly shale, but they contain thick beds of sandstone at places, and some of these sandstone beds might contribute large amounts of water to deep wells.

Gravel and alluvium of late Tertiary and Quaternary age are important locally as sources of water for domestic and stock supplies, but these sediments would not yield sufficient amounts of water for large-scale irrigation and industrial use.

The principal sources of ground-water recharge are precipitation and streamflow on outcrops of the aquifers; vertical leakage of water from one bed of sandstone to another also is a form of recharge to the bed receiving the water. Most of the recharge in the area is in the eastern and southern parts, at altitudes of 7,000–8,000 feet. The ground water moves away from the areas of recharge toward outcrops at lower altitudes, where it discharges at springs and seeps or migrates into other units. Most of the beds of sandstone in the subsurface of the Central basin of the San Juan Basin are probably saturated.

Neither discharge measurements nor chemical analyses of the water in the San Juan River provided conclusive evidence that ground water is being discharged into that stream. However, the small change in streamflow between Rosa and Bloomfield, N. Mex., indicates that only a small amount of ground water could be entering the river in that reach, and it is unlikely that withdrawal of ground water from the area of investigation would significantly affect the flow of the San Juan River. Most of the ground water that is discharged in the area is probably dissipated by evaporation and transpiration in the valleys tributary to the San Juan River.

Water in the Ojo Alamo Sandstone and the San Jose Formation varies widely in chemical quality, both from one unit to another and within a single unit from one place to another. The concentrations of all the analyzed constituents of the ground water except iron, sodium, bicarbonate, and sulfate were found to be generally low enough for most uses. High concentration of iron makes some water undesirable for domestic use, because the iron tends to damage plumbing. The high concentration of sodium relative to calcium and magnesium makes some of the water undesirable for irrigation, and the high concentration of sulfate makes some of the water undesirable for drinking, because water containing a high concentration of sulfate along with sodium or magnesium has a laxative effect on many people. All the samples of water from the Ojo Alamo Sandstone and the Nacimiento Formation and most samples from the San Jose Formation were collected from within a few miles of probable recharge areas. At greater distances from the recharge areas the chemical composition of ground water in these rocks may vary considerably, but the data available are insufficient to describe significant variations.

The yield of deep water wells depends largely on the cumulative thickness of sandstone penetrated. Because none of the water wells in the area tap all the beds of sandstone to the base of the Ojo Alamo Sandstone, except where it is near the surface, the potential yield of a deep well can only be estimated. The specific capacities of 59 wells that tap sandstone aquifers in the San Juan Basin, including 8 in the project area, ranged from 0.0002 to 0.015 gpm per foot of sandstone penetrated. The average for the eight wells in the project area was 0.008.

The thickness of sandstone below 200 feet (the assumed average depth to the top of the zone of saturation) and above the base of the Ojo Alamo Sandstone ranges from 80 feet in sec. 33, T. 21 N., R. 5 W., to 1,840 feet in sec. 24, T. 26 N., R. 3 W., in the wells drilled for oil and gas that were used to construct the correlation diagrams (pls. 2–4). The thickness of sandstone below 200 feet and above the base of the San Jose Formation ranges from 0 in the southwestern part of the area to 840 feet in sec. 5, T. 25 N., R. 3 W., and in sec. 25, T. 24 N., R. 2 W.

The most favorable places in the southern part of the Jicarilla Apache Reservation for obtaining the largest yields with the least amount of drilling are those where the thickness of sandstone is great and where the ratio of the thickness of sandstone to the depth to a certain horizon is high. The ratio of the total thickness of sandstone (below 200 ft) to the depth to the base of the Ojo Alamo Sandstone in wells used in the correlation diagrams ranges from 0.13 in sec. 22, T. 21 N., R. 5 W., to 0.54 in sec. 25, T. 25 N., R. 5 W. The thicknesses of sandstone at these localities are 140 and 1, 470 feet, respectively. The ratio of the thickness of sandstone to the depth to the base of the San Jose Formation ranges from 0.17 in sec. 1, T. 22 N., R. 5 W., to 0.57 in sec. 10, T. 25 N., R. 5 W. The thicknesses of sandstone at these localities are 40 and 470 feet, respectively. One of the four tracts of land suggested as suitable for irrigation by the U.S. Bureau of Indian Affairs is adjacent to Lapis Canyon in T. 25 N., R. 5 W., and this appears to be the most favorable tract with respect to availability of water.

If the average specific capacity per foot of sandstone penetrated (0.008) could be applied to a well in sec. 25, T. 25 N., R. 5 W., in or adjacent to the Lapis Canyon tract, and if 300 feet of drawdown could be tolerated, a well that tapped all the beds of sandstone to the base of the San Jose Formation would yield 1, 440 gpm, and a well that tapped all the beds of sandstone to the base of the Ojo Alamo Sandstone would yield 3, 530 gpm. The actual yield would probably be less than the computed yield.

The data on the physical properties of the geologic formations, the chemical quality of the ground water, the yields of shallow wells, and the computed potential yields of deep wells suggest that large supplies of ground water for irrigation or industrial use could be developed at several places in and adjacent to the southern part of the Jicarilla Apache Reservation. The validity of this conclusion can be determined only by drilling and testing; the potential seems to be great enough to warrant test drilling.

The test drilling should be carefully planned and executed, in order to obtain reliable data on which future development could be based. Each thick unit of sandstone should be isolated by using a packer or by casing off all other units, and the unit should be tested for water level, yield, and quality of water. The water could be withdrawn by swabbing, bailing, or pumping, depending on the method of isolation used. A final test with all aquifers producing would be needed to fully appraise the yield. The test well should preferably be drilled to the base of the Ojo Alamo Sandstone in order to appraise all the potential aquifers. The well should be cased from the land surface to the bottom of the lowest productive zone, and the casing should be perforated adjacent to all the zones that would yield water of suitable chemical quality.

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TABLES 6–10

TABLE 6.—*Records of selected wells in and near the southern part of the Jicarilla Apache Indian Reservation, N. Mex.*

Location No.: See fig. 2 for system of numbering wells. Asterisk (*) following the number indicates that a chemical analysis is given in table 9.
Owner or name: EPNG, El Paso Natural Gas Co.; BIA, U.S. Bureau of Indian Affairs; FS, U.S. Forest Service; SCS, U.S. Soil Conservation Service.
Depth of well: Measured depth expressed to nearest tenth of a foot; reported depth expressed to nearest foot.
Water level: Measured depth expressed to nearest tenth of a foot; reported depth expressed to nearest foot; P, water level measured during pumping.
Stratigraphic unit: Qal, Quaternary alluvium; Qcg, terrace gravel and stream-channel gravel; Tsc, Cuba Mesa Member of San Jose Formation; Tsr, Regina Member of San Jose Formation; Tst, Tapicitos Member of San Jose Formation; Tsl, Llaves Member of San Jose Formation; Tn, Nacimiento Formation; Toa, *Ojo* Alamo Sandstone; Kkf, Kirtland Shale and Fruitland Formation, undivided.
Use of water: D, domestic; Ind, industrial; Irr, irrigation; N, none; P, public supply; S, stock.

Location No.	Owner or name (when inventoried)	Year completed	Depth of well (feet)	Water level: Depth below land surface	Water level: Date of measurement	Water level: Approximate altitude (feet)	Stratigraphic unit	Use of water
20.1W.6.432*	Ignacio Garcia	1958	70	21.7	Aug. 28, 1959	6,793	Toa	D
7.212	Max Pena			24.4	do	6,773	Qal	N
7.222	Eugene Johnson			33.6	do	6,783	Qal	N
18.113	Wiese			23.3	do	6,727	Qal	S
19.332	do			15.6	do	6,684	Qal	S
20.2W.17.132*	B. B. Johnson		240	159.8	Dec. 15, 1950		Toa	D, S
19.124*	Eugene Johnson	1958	300	80	1958		Toa	D, S
21.212			8.8	5.5	Sept. 9, 1959		Qal	S
29.210			30	9.2	Dec. 13, 1950		Qal	S
31.200*	G. E. Conlisk		7	4	Sept. 29, 1925		Tn	
20.3W.17.444*	Rudy Velarde	1958	72.4	53.9	Sept. 9, 1959		Qal	S
20.143	Magnolia Petroleum Co. (seismic shot hole).	1950	345	260			Toa	D
30.330	SCS	1923	25	11.9	Dec. 13, 1950		Qal	N
35.230	Ross Chacon		160	93.3	do		Kkf	N
20.4W.26.143	SCS	1933	290	180.0	June 18, 1959		Toa	N
21.1W.4.322	J. J. Cordova			39.0	Aug. 14, 1959	7,311	Tsc	N
4.441	Mrs. Lydia Gutierrez.		265	178.5	do	7,122	Tsc	N
7.211	J. F. Herrera	1958	125	64.0	Aug. 20, 1959	6,986	Tsc	N
7.412*	Bert Herrera, Sr.		155	65.0	June 18, 1959	6,965	Tsc	P
8.211*	W. R. McGuire	1956	168	125.4	Aug. 17, 1959	6,955	Tsc	D
8.421	E. N. Maxey	1959	106	45.3	Aug. 15, 1959	6,995	Tsc	D
8.422*	R. D. Phillips	1954	95	73.7	do	7,076	Tsc	D, S
9.112	Clotano Casaus		280				Tsc(?)	D
9.133	R. D. Phillips	1952	115	47.2	Aug. 15, 1959	7,083	Tsc	D
9.214	J. Ingram	1955(?)	73.0	20.5	Aug. 17, 1959	7,160	Tsc	D
14.412	Tranquilino Chavez.	1939(?)	5	2.0	Aug. 12, 1959	7,508	Qcg	D, S
15.113	Leon Montoya		11.5	10.0	do	7,050	Qal	S
15.133	G. Garrison	1928	22	11.8	Aug. 15, 1959	7,058	Qal	D
15.322*	J. K. McEwen		300	53.0	do	7,057	Toa	D
16.213	D. G. Wilcox	1953	100	32.6	Aug. 28, 1959	7,044	Tn, Qal (?)	N
16.214	do	1953	100	Dry			Tn	
16.244	Gurule		8	6.0	Aug. 12, 1959	7,044	Qal	D
17.142*	Girt Maxey	1951	115	55		7,025	Tsc	D
17.144	Ben Sawyer	1959	46	28.8	Aug. 20, 1959	7,016	Tsc	D
17.321*	William Eastlake	1950	65	21.6	Aug. 14, 1959	6,988	Tsc(?)	N
17.323	William Eastlake			45	Aug. 15, 1959	6,975	Tsc	D
17.323a*	do	1954	76	36.2	Aug. 14, 1959	6,974	Tsc	D
20.114*	FS	1956	75	44.5	Aug. 13, 1959	6,910	Qal(?)	N
20.233	J. C. Leeper	1957	70	37.6	do	6,902	Qal(?)	D
20.233a	Sam Garcia	1957	70	42.2	do	6,898	Qal	D
20.322*	Raphael Duran	1952	85	41.8	do	6,878	Qal	D
20.323	Caswell Silver	1957	140	31.3	do	6,884	Qal	Ind
20.324	O. Meeks	1958	85	33.2	do	6,882	Qal	D
28.143*	Cuba Schools 1	1956	148	23.7	Aug. 12, 1959	6,906	Toa	P
28.144	Robert Johnson	1955	60	37.1	do	6,903	Toa	D
28.211*	Cuba Schools 2	1957	110	42.6	do	6,917	Toa	P
28.233	Robert Johnson	1958	70	27.6	do	6,907	Toa	D
28.342	Emiliano Martinez.	1950	50	17.8	Aug. 29, 1959	6,922	Toa	D
28.411	Jemez Mountains Electric Co-op.	1953	90	18.2	Aug. 12, 1959	6,932	Toa	D
29.223*	Mel Gallegos	1954	104	33.3	Aug. 21, 1959	6,887	Toa(?)	D
29.240*	Standard Oil Co.	1954	100				Toa(?)	N

TABLE 6.—*Records of selected wells in and near the southern part of the Jicarill Apache Indian Reservation, N. Mex.*—Continued

Location No.	Owner or name (when inventoried)	Year completed	Depth of well (feet)	Water level: Depth below land surface	Water level: Date of measurement	Water level: Approximate altitude (feet)	Stratigraphic unit	Use of water
21.1W.29.414	Modesto Chavez	1959	30	24.1	Sept. 11, 1959	6,874	Qal	N
29.423	State of New Mexico.	1954	152	16.2	Sept. 3, 1959	6,879	Toa	Ind
29.432*	G. H. Holmes	1953	94	20.0	Aug. 15, 1959	6,878	Toa(?)	Ind
29.433*	L. B. Chandler		90				Toa(?)	Ind
32.132	Basilio Aragon	1958	150	65		6,795		D
32.132a	Cris Vigil	1958	90	28		6,832		D
32.141	John Hernandez	1959	105	35.1	Aug. 12, 1959	6,855	Toa	P
34.142	George Jaramillo			19.8	Aug. 29, 1959	7,040	Qal	D
34.232	A. Dominguez	1949	15	10		7,100	Qal	D
35.443	Felix Atencio		30	20.7	Aug. 29, 1959	7,389	Qal	D
21.2W 9.213	Homer Smeltzer	1955	235	189.5	Sept. 7, 1959		Tsc(?)	S
17.442	Donna Zalega		63.0				Qal	S
22.214	FS		11.0	5.5	Aug. 30, 1959		Qal	N
28.123			112.0	49.6	Sept. 4, 1959		Tsc(?)	N
29.131			8.3	5.5	Sept. 7, 1959		Qal	N
21.6W. 3.200*	BIA	1953					Toa(?)	
22.1W.17.444	Myrtle Oxsheer			26.5	Aug. 21, 1959	7,319	Qal(?)	S
19.142	E. Mora	1935		17.0	Aug. 20, 1959	7,208	Tsr	D
19.411	Tomas Duran	1939		21.0	Aug. 19, 1959	7,179	Qal	D, S
20.134	Juan Montoya	1947	40.0	23.4	do	7,217	Tsr	N
28.334	Fecundo Garcia	1959	33	19.1	do	7,231	Qal	D
30.232	Genoveno Jaques	1922		10.8	do	7,164	Tsr	D
30.232a	do	1958	35	10.8	do	7,164	Tsr	N
31.234	Gurule		300				Tsr	
31.244	Juan Garcia	1959	18	7.0	Aug. 19, 1959	7,113	Qal	D
32.222	D. B. Lovato	1920	25	17.5	do	7,212	Qal	D
32.241	Amadeo Lovato	1953	20	13.0	do	7,207	Qal	D
32.241a	Donald Garcia			13.5	do	7,206	Qal	D, S
32.242	Ray Lovato	1959	10.0	8.0	do	7,217	Qal	S
32.242a	do	1959	12.0	8.0	do	7,217	Qal	N
32.242b	H. C. Lasate	1956	26	11.5	Aug. 21, 1959	7,213	Qal	D
32.243	La Jara Public School.		13.0	8.9	Aug. 20, 1959	7,209	Qal	P
32.323	E. Trujillo	1959	7.0	5.0	Aug. 19, 1959	7,165	Qal	D
32.331	Robert Taylor	1951	20	16.5	Aug. 17, 1959	7,109	Qal	D
32.331a*	Nu Way Bar		30.0	17.4	do	7,108	Qal	D
32.331b	La Jara Bar	1958	25	2		7,108	Qal	S
32.333*	La Jara Store		192	160.0	Aug. 17, 1959	6,990	Tsr	D
22.2W.15.444	BIA		112.0	107.5	Aug. 31, 1959		Tsr	S
22.3W. 9.323*	do		199				Tsr	D, S
29.333*	do		202	160.4	Oct. 11, 1959		Tsr	S
22.4W. 9.131*	do						Tsr(?)	S
22.5W. 3.233	do	1934	350				Tsc(?)	N
15.344*	do		210	50			Tsc(?)	S
28.200	do	1934	430	Dry			Tsr	
23.1W.2.132	W. T. Northcutt		17.5	15.4	Aug. 20, 1959	7,240	Qal	N
3.222	Schmitz		7.0	5.8	do	7,254	Qal	N
3.414	H. B. Browning	1958	734	456		6,864	Tsr	N
3.421	do	1958	57.5	10.7	Aug. 21, 1959	7,269	Qal	N
3.423	do	1951	12.5	7.9	do	7,292	Qal	N
3.423a*	do	1947	14.3	10.8	do	7,284	Qal	D, S
4.123	do		14.0	12.0	1959	7,348	Qal	N
16.442	H. E. Schultz	1956	100	Dry			Tsr	
19.244	Oribie Bridge	1950	275	216.4	Sept. 3, 1959	7,194	Tsr	D
22.322	R. L. Reed		328	Dry			Tn	
22.411	do		330	Dry			Tn	
27.212	R. L. Reed	1959	190	Dry			Tn	
27.233*	W. C. Schmitt	1955	48	10.0	Aug. 21, 1959	7,580	Qal, Toa	D
28.213	O. T. Despres		500	Dry			Tsr	
28.233	do		12.5	11.0	Aug. 21, 1959	7,509	Qal	N
28.341	D. A. Evans	1959	50	12.7	Aug. 11, 1959	7,485	Qal	N
28.342	Mrs. Shorter	1958	44.4	9.9	do	7,485	Qal(?)	D
28.342a	do	1945		4.8	Aug. 21, 1959	7,485	Qal	N
28.343	C. E. Fish		80	Dry			Qal, Tsr	
32.224	E. N. Conwell	1954	85	30		7,420	Qal	D
32.224a	C. E. Fish	1954	32.0	23.0	Aug. 21, 1959	7,427	Qal	D
32.242	H. B. Foster	1951	40	13.0	do	7,437	Qal	D
32.242a*	Helmar Co	1952	34	12.1	do	7,438	Qal	D
32.242b	do	1953	34	10.5	do	7,440	Qal	N
32.242c	H. C. Lasate, Sr.	1939	30	11.8	do	7,439	Qal	D

TABLE 6.—*Records of selected wells in and near the southern part of the Jicarilla Apache Indian Reservation, N. Mex.*—Continued

Location No.	Owner or name (when inventoried)	Year completed	Depth of well (feet)	Water level			Stratigraphic unit	Use of water
				Depth below land surface	Date of measurement	Approximate altitude (feet)		
23.1W.32.242d	H. C. Lasate, Jr.		300	Dry			Tsr	
33.112	C. E. Fish	1954	345	Dry			Tsr	
33.113	Lon Higgins	1954	70	Dry			Tsr	
33.113a	R. Thomason	1954	65	Dry	1959		Qal	D
33.130	Lon Higgins	1957	50	13.6	Aug. 21, 1959	7,441	Qal	S
23.2W.13.333*	BIA						Qal	S
14.233	do			15.7	Sept. 22, 1959		Qal	N
14.441	do			4.0	Sept. 2, 1959		Qal	N
31.121	do	1934	204				Tsr	N
23.3W.11.333*	do	1934	153				Tsr	D, S
30.200	do	1934	105				Tsr	
23.4W.21.432*	BIA			200	1949		Tsr(?)	S
24.432*	do						Tsr	S
23.5W.1.232*	do	1934	198				Tsr	S
23.332*	do	1934	198				Tsc	S
24.1E.6.344	Ed Sabrowski	1958	98	47		6,950	Tsc	N
6.432	Jim Woodworth			36.0	Aug. 14, 1959	6,969	Qal	N
6.442	do		21.5	20.0	Aug. 13, 1959	6,960	Qal(?)	N
7.142*	Harold Schmidt		26.0	17.0	do	6,983	Qal	D, S
7.211	J. S. Simmons	1958	68.0	22.7	Aug. 14, 1959	6,967	Qal(?)	D
7.214	Harold Schmidt	1954	24.0	13.5	Aug. 13, 1959	6,966	Qal	S
7.321	Noah Askew	1940(?)	12	3.5	Aug. 14, 1959	6,996	Qal	N
8.112	F. I. Northcutt	1950	35	12		6,948	Qal	N
8.414	do		302	Dry			Kl	N
18.333	W. S. Greathouse	1939	80	70		7,045	Tsr	N
19.111	W. E. Schmitz		95.0	92.0	Aug. 15, 1959	7,028	Tsr	D
29.113	F. I. Northcutt	1948	741	Dry			Tn	N
30.411*	do	1950	42	26		7,114	Qal	S
31.132	do		10	7		7,163	Qal	N
24.1W.1.433	E. J. Hooten	1953	140				Tsr	S
14.444	Reece Walker	1922	12	6.0	Aug. 15, 1959	7,084	Qal	D
31.124	H. D. Payne		84.0	21.3	Sept. 22, 1959	7,405	Tsr	S
36.311	C. M. Schmitz		160	Dry			Tn	
36.331	do		50.0	40.5	Aug. 20, 1959	7,179	Qal	N
24.2W.1.422	Palmer Bros		123.0	58.5	Aug. 15, 1959	7,301	Tsr	N
2.134	J. Woodfill		145.0	64.7	Sept. 15, 1959		Tsr	D
2.334*	J. B. Hardy	1955	254.5	68.2	do		Tsr(?)	S
3.134	J. B. Hardy			72.3	Sept. 16, 1959		Tsr	N
3.321	do		110.5	66.7	do		Qal(?)	N
4.312	C. S. Compton	1945(?)	139.5	65.1	Sept. 28, 1959		Qal	N
5.243	do		60	42.3	do		Qal	S
5.442	do	1956	310	213.9	do		Tsr	D
11.442	J. B. Hardy	1954	510	263	Sept. 27, 1959		Tsr	S
13.142	do	Before 1945	132.5	113.9	do		Tsr	N
14.113	E. M. Hardy	1950(?)	370	90			Tsr	D
14.443	T. W. Stevenson	1954		95.8	Sept. 27, 1959		Tsr	N
15.133	Mollie Ingram	1948	422	251.8	Oct. 9, 1959		Tsr	D
15.331	Bert Price	1946	216	183.5	Sept. 28, 1959		Tsr	D
15.344	do	1952	200	45.9	Sept. 27, 1959		Tsr	N
16.444*	Lindrith Mutual Water Users' Association.	1949(?)	753	240			Tsl	P
19.434	S. Dees		48.0	12.4	Sept. 25, 1959		Qal	N
19.444	do	1957	78	10			Qal	D
21.100	Mrs. Grigsby		220	98.0	Oct. 18, 1938		Tsr	D, S
21.211	J. B. Hardy	1947	460				Tsr	N
21.213	do	1932	250	92.2	Sept. 29, 1959		Tsr	N
21.222	E. E. Bridge	1935(?)	120	96			Tsr	D
21.242	Harry Carson			23.8	Sept. 27, 1959		Qal	N
21.244	T. W. Stevenson	1958	150	28.8	do		Qal	N
21.311	do	1954	110	46.0	do		Qal	N
26.412*	J. D. Nelson	1951	125	84.1	Sept. 24, 1959		Tsr	S
27.121	do		176	30.3	do		Tsr	N
27.123	do	1953	125				Tsr	D
28.122	EPNG			106.5	Sept. 23, 1959		Tsr	P
28.122a	do	1959	280				Tsr	P
28.231	L. R. Oleson	1956	127	82.3	Sept. 23, 1959		Tsr(?)	D
28.233	W. O. Hughes	1957	250	100			Tsr	D
30.111	S. Dees	1951	70	14			Tsr(?)	S
30.222	do			14			Qal	D, S
32.221	Warren Howard			36.9	Sept. 22, 1959		Qal	S
33.000	do	1959	65.0	44.0	do			N

TABLE 6.—*Records of selected wells in and near the southern part of the Jicarilla Apache Indian Reservation, N. Mex.*—Continued

Location No.	Owner or name (when inventoried)	Year completed	Depth of well (feet)	Water level			Stratigraphic unit	Use of water
				Depth below land surface	Date of measurement	Approximate altitude (feet)		
24.2W 34.111*	Paul Brown	1956	204	76.8	do		Tsr	D, S
34.114	do	1953	100	59			Tsr	N
35.134	Clyde King			28.0	Sept. 22, 1959		Qal	N
24.3W. 8.443	O. Hughes						Qal	N
11.314	Ben Leeson		8.5	5.2	Sept. 26, 1959		Qal	N
13.331	S. Dees	1956	43	18			Qal	S
14.111	Ben Leeson		99.5	27.6	Sept. 26, 1959		Tsr	N
15.122	O. Hughes			39.1	do		Tsr	N
16.223	do			19.5	do		Qal	N
21.333	A. P. Mauzy	1947(?)	77				Qal	D, S
21.333a	do		19.0	15.4	Sept. 25, 1959		Qal	D, S
22.314	O. Hughes		144.0	135.7	do		Tsr	N
26.122	S. Dees	1949	252				Tsr	S
28.344	Lee Dalton			58.4	Sept. 25, 1959		Qal	S
28.413	S. White		24	6.2	do		Qal	D
33.331	C. Cook		65	Dry	do		Tsr(?)	N
24.4W. 6.100*	BIA	1935	290				Tsc(?)	
28.200*	BIA	1934	260				Tsc(?)	
24.5W.18.421	EPNG Lindrith 1	1957	796	203	1957	6,283	Tn	Ind
18.421a	EPNG Lindrith 2	1957	789	233	1957	6,257	Tn	Ind
23.422*	BIA	1936	100.0	54.3	Nov. 4, 1938		Tsc	D, S
25.1E 17.234*	Jack Davis	1952	150	71.0	Aug. 17, 1959	7,009	Toa(?)	S Irr
17.314	Clyde Averill	1950(?)	117	108.0	Aug. 13, 1959	6,967	Tn	D, S
20.233	Euginio Mestas	1954	18	15.0	do	6,940	Qal	D, S
20.244	Paul Casados	1959	56.0	28.0	do	6,917	Qal	D
20.432	George Lamb		16	13.0	do	6,937	Qal	S Irr
29.212	Clayton Schmidt		39.0	24.5	do	6,916	Qal	S
32.443	Jack Davis	1952	100	10.5	Aug. 12, 1959	6,940	Qal	S
25.1W. 5.324	E. M. Collins	1915	54.0	42.7	Sept. 25, 1959	7,370	Tsl	D, S
6.243	do	1955	150	91.7	do	7,388	Tsl	S
8.111*	do	1956	152.0	43.0	Sept. 27, 1959	7,387	Tsl	S
17.131	FS	1956	250.0	119.4	do	7,361	Tsl	N
25.2W.11.141*	Nazarene Indian School.		130	68.4	Oct. 10, 1959		Tsl	S
11.142	do		130				Tsl	D
11.341	Fred Davis			8.9	Oct. 9, 1959		Tsl	N
11.411	do		50.0	42.7	do		Tsl(?)	N
11.412	do						Tsl	S
15.134	Bud Dunham		51.0	48.5	Oct. 9, 1959		Qal	D
15.342	G. B. Locer	1958	190	100	Sept. 24, 1959		Tsr	N
15.423	Bill Bursh		79.0	56.4	Oct. 9, 1959		Tsl	N
17.422	J. M. Pearce	1958	165	61.0	Oct. 12, 1959		Tst	D, S
22.131	Walter Howard	1957	163.0	78.3	Sept. 18, 1959		Tsl	D, S
23.141	do	1918	58	55.0	Sept. 16, 1959		Qal	N
23.441*	D. W. Hatley	1955	170	68.2	Sept. 18, 1959		Tsr	D, S
24.424	Bill Hatley		11.3	5.1	do	7,430	Qal	D
24.431	do		100	49.6	Sept. 16, 1959	7,340	Qal	S
25.233	Wayne Hatley	1954	225	79.5	do	7,360	Tsr	N
25.433	do	1953	165				Tsl	D
26.143	L. J. Ingram	1957	140	66.9	Sept. 24, 1959		Tsr	S
27.221	do	1958	118	50.8	do		Tsr	D
27.324	Don Howard	1956	233.0	187.2	Sept. 23, 1959		Tsl(?)	D, S
30.432	J. C. Post	1957	52				Qal	D, S
34.311	G. E. Boring	1956	200	144.6	Sept. 23, 1959		Tsr	N
35.314	Chester Hepner	1922	74.5	37.4	Sept. 16, 1959		Qal	N
25.3W.1.240	Fred Davis		165				Tst	S
1.240a*	do		302	165	Oct. 12, 1959		Tsl	D, S
12.244	F. C. Conley	1953	180	119.0	do		Tst	N
12.442*	do	1956	147	109.9	do		Tst	D, S
23.414	Bechdol						Tsl(?)	D, S
24.444	Warren Howard		111	88.8	Oct. 13, 1959		Tsl(?)	D, S
26.144	D. Bishop	1956	175	107.9	Sept. 28, 1959		Tsl(?)	S
27.234	G. W. Leeson	1956	330	267.7	Sept. 26, 1959		Tsl(?)	N
27.321	do		18.0	Dry			Qal	N
30.214	D. Bishop	1958	210.0	104.2	Sept. 28, 1959		Tsl	S
33.124	G. W. Leeson	1932	144	112.4	Sept. 25, 1959		Tsl	S
35.244	D. Bishop		30	22.8	Sept. 28, 1959		Qal	N
35.244a	do	1957	200				Tsr	D
36.334	Carson			5.9	Sept. 28, 1959		Qal	N
36.412	B. H. Gartin		17.9	15.8	Oct. 12, 1959		Qal	N
25.4W.23.340*	BIA						Tsr	S
25.5W.3.233*	do	1935	100	55.9	Nov. 8, 1938		Tsr	S
29.200*	do		225				Tsc(?)	

TABLE 6.—*Records of selected wells in and near the southern part of the Jicarilla Apache Indian Reservation, N. Mex.*—Continued

Location No.	Owner or name (when inventoried)	Year completed	Depth of well (feet)	Water level: Depth below land surface	Water level: Date of measurement	Water level: Approximate altitude (feet)	Stratigraphic unit	Use of water
26.1W.21.442	Walter Howard		39.0	21.9	Sept. 26, 1959	7,448	Qal(?)	S
27.322	do		67.0	35.1	do	7,395	Qal(?)	S
1.423	Fred Davis		390	315		7,070	Tsl(?)	S
26.2W.2.433	do		100				Qal	N
3.444	Robert Imel	1955	160	41.1	Oct. 10, 1959		Tst	N
5.141	W. J. Bassett	1950	50	41.4	Oct. 13, 1959		Tst	D
5.141a	do	1958	60	45.3	do		Tst	D
5.233	do		9.0	6.6	do		Qal	N
10.122	Fred Davis						Qal	N
12.213	Bonnie Imel	1955	260	112.3	Oct. 10, 1959	7,248	Tsl(?)	N
14.222	do	1954	140	92.9	do		Tst	S
21.313	Tucker		157	94.1	Oct. 13, 1959		Tst	S
26.241	W. R. Huffman	1950	133	68-70			Tst	D, S
32.133	G. J. Huffman	1956	389	204.2	Oct. 12, 1959		Tsl(?)	S
34.234	E. S. Rogers	1956	260				Tst	S
34.421*	C. Quintana	1959	400				Tsl(?)	D, S
36.433	J. H. Carson	1945	122	106.9	Sept. 26, 1959	7,483	Tsl	D, S
26.3W.4.000	Magnolia Oil Co		250				Tsl	Ind
7.314*	BIA	1936	370	74	Oct. 21, 1938		Tsr	S
29.132	do	1934	116				Tsl	S
26.4W.15.321*	do						Tsr	S
17.440*	BIA		100				Tsr	S
26.7W.15.412	EPNG Largo 1		365	26		6,092	Tsc	Ind
15.423	EPNG Largo 2	1957	335	22			Tsc(?)	Ind

TABLE 7.—*Records of springs in and near the southern part of the Jicarilla Apache Indian Reservation, N. Mex.*

Location No.: See fig. 2 for system of numbering wells and springs. Asterisk (*) following number indicates that a chemical analysis is given in table 9.
Yield: E, estimated; R, reported.
Stratigraphic unit: Qal, alluvium; Qcg, terrace gravel and stream-channel gravel; Tsc, Cuba Mesa Member of San Jose Formation; Tsr, Regina Member of San Jose Formation; Tst, Tapicitos Member of San Jose Formation; Toa, Ojo Alamo Sandstone.
Use of water: D, domestic; N, none; P, public supply; S, stock.

Location No.	Owner (when inventoried)	Yield (gpm)	Date of observation	Topography	Altitude of spring (feet)	Stratigraphic unit	Use of water	Remarks
S20.1W. 2.123	J. Herrera	0.5-1 E	Aug. 29, 1959	Bottom of arroyo	7,300	Qal	N	Several springs along bottom of arroyo.
S20.2W.23.213		2 E	Aug. 19, 1959	Overhanging cliff at north side of alluvial valley.		Toa	S	Seeps along base of medial sandstone of Toa. Water is reportedly of good quality.
S20.5W.23.334*	Bureau of Indian Affairs			Base of low cliff		Toa	P	Ojo Encino. Water supply for school.
S21.1W. 3.131	U.S. Forest Service	1-3 E	Aug. 17, 1959	Top of terrace	7,450	Qcg	N	Old La Jara Ranger Station.
3.422*	P. Benavides	1-3 E	do	Creek bottom at margin of terrace.	7,580	Qcg	D	
9.143	R. D. Phillips	2-3 E	Aug. 15, 1950	Bottom of arroyo	7,140	Tsc	S	Several seeps from sandstoue in arroyo.
14.134	Perfecto Martinez			Top of terrace near the margin	7,500	Qcg	D, S	Open collecting basin below livestock corrals.
14.331	V. McCoy	1-2 E	Aug. 12, 1959	Margin of terrace	7,400	Qcg		
14.341	Cuba Water-Users Assoc.			do	7,430	Qcg	P	Several gathering tunnels driven into terrace gravel. Unfenced and unprotected from livestock. Bacterial pollution reported by New Mexico State Health Department. Water supply for town of Cuba at time of fieldwork (1959-60).
14.413*	Martinez	1 E	do	Top of terrace near the margin	7,510	Qcg	D	Collecting pit enclosed in shelter.
15.311	P. Gurule		do	Bottom of arroyo	7,060	Qal	S	
17.114	Broderick	1-2 E	Aug. 14, 1959	Margin of low hill	7,110	Tsc	D	Dug out. Protected by curbing and roof.
17.333	William Eastlake	3-4 E	do	Bottom of arroyo	6,950	Tsc	S	Several seeps from sandstone in bottom of arroyo.
18.200		1-5 E	do	Bottom of arroyo	7,025	Tsc	N	Several seeps.
34.411	A. Montoya	2-3 E	Aug. 29, 1959	Valley floor	7,070	Qal	D, S	Covered concrete collecting basin.
S21.2W.17.333				Slight depression in small saddle		Tsr	S	Marshy pond containing rushes and grass. Probably seeping from sandstone.
19.222				On hill below small sandstone ledge.		Tsr	N	Dug out, covered, and fenced.
S22.1W. 3.332	U.S. Forest Service	1-3 E	Aug. 17, 1959	Creek bottom on terrace	7,360	Qcg	D	
11.313	La Jara Ranch			Valley floor	7,850	Qal	S	Dug out.
14.312	do	1-3 E	Aug. 21, 1959	do	7,860	Qal	D, S	Collecting basin dug out and covered with log shelter.
16.424*	do	3-4 E	do	do	7,500	Qal	S	
28.334		1-2 E	Aug. 19, 1959	Bed of La Jara Creek	7,250	Qal	S	
34.334	U.S. Forest Service	5-10 E	Aug. 17, 1959	Bed of Creek	7,450	Qcg	S	Several seeps in creek.

S23.1W.22.333*	R. L. Reed	0.25 R	Aug. 20, 1959	North slope of narrow ridge	7,550	Tsr	S	Wasson Spring. Seeping from fractures in sandstone enclosed in shale.
32.423	Regina Community Store			Margin of valley	7,400	Qal	D	Dry in summer.
32.442	L. Jaques			Floor of valley	7,430	Qal	N	Hatch Spring. Collecting pit covered by log shelter.
S24.5W.32.122*	Bureau of Indian Affairs					Tsc		Otero Spring.
S25.3W.33.341	G. W. Leeson	<1 R	Sept. 25, 1959	Base of sandstone ledge		Tsr	D, S	
S26.1E. 4.334		1–2 E	Aug. 12, 1959	Bottom of arroyo in wide valley	7,000	Qal	S	Dug out and encased with wooden box.
17.333*	U.S. Forest Service			Arroyo in narrow alluvial valley	7,300	Qal	D, S	Mud Spring. Dug out and lined with stone.
33.314*	do	3 E	Apr. 29, 1958	Narrow canyon	7,310	Toa	S	Chupadera Spring. Seeps from sandstone.
S26.2W. 5.312	W. J. Bassett	28 R	Oct. 13, 1959	Bottom of arroyo in alluvial valley.		Qal	S	Large tank dug out to form pond.

TABLE 8.—*Seepage investigations in the San Juan River valley between Rosa and Bloomfield, N. Mex., December 1958 and September 1959*

[cfs, cubic feet per second; ppm, parts per million]

San Juan River mile	Stream and location	Date	Discharge (cfs)	Discharge across San Juan Valley section (cfs)	Apparent gain (+) or loss (−) of main stem (cfs)	Selected chemical and physical properties of the water: Sulfate (ppm)	Hardness as $CaCO_3$ (ppm): Calcium, magnesium	Hardness as $CaCO_3$ (ppm): Noncarbonate	Specific conductance (micromhos at 25°C)
		1958							
171.5	San Juan River at Rosa, at regular gaging station 1 mile north of Rosa, in SW¼ sec. 21, T. 32 N., R. 5 W.	Dec. 3	192	192		110	162	54	437
	Sambrito Creek near mouth, 2 miles southwest of Rosa in NE¼ sec. 22, T. 32 N., R. 6 W.	do	4.0			308	267		1,360
	Bancos Canyon at mouth in NE¼ sec. 10, T. 31 N., R. 6 W.	do	.1						
162.5	San Juan River ½ mile below mouth of Bancos Canyon in NW¼SE¼ sec. 10 T. 31 N., R. 6 W.	do	219	219	+23	118	171	52	486
	La Jara Creek at mouth, 5½ miles northeast of mouth of Pine River in NW¼ sec. 36, T. 31 N., R. 7 W.	do	0						
147.8	San Juan River ⅛ mile above mouth of Pine River in SW¼SW¼ sec. 8, T. 30 N., R. 7 W.	do	202	202	−17	127	179	57	503
	Pine River ⅛ mile above mouth in SE¼SE¼ sec. 7, T. 30 N., R. 7 W.	do	52.4			47	133		384
142	San Juan River near Archuleta, at regular gaging station, in SE¼ sec. 11, T. 30 N., R. 8 W.	do	273	273	+19	120	177	48	508
	Gobernador Canyon at mouth in NE¼SE¼ sec. 19, T. 30 N., R. 8 W.	do	0						
136.5	San Juan River 300 feet below mouth of Gobernador Canyon in SE¼NE¼ sec. 19, T. 30 N., R. 8 W.	do	260	260	−13				
	Pump Canyon at mouth in NE¼SW¼ sec. 25, T. 30 N., R. 9 W.	do	.2						
124.8	San Juan River at Blanco, 50 feet below State Highway 17 bridge, in NW¼SE¼ sec. 18, T. 29 N., R. 9 W.	do	164	220	−40	124	170	42	508
	Citizens ditch in Blanco in SW¼SE¼ sec. 13, T. 29 N., R. 10 W.	do	56(?)						
124.8	San Juan River at Blanco	Dec. 2	184	240					
	Citizens ditch in Blanco	do	56						
	Canon Largo at mouth in NE¼NW¼ sec. 19, T. 29 N., R. 10 W.	do	0						
113	San Juan River at Bloomfield, at regular gaging station ½ mile south of Bloomfield, in NW¼ sec. 27, T. 29 N., R. 11 W.	do	232	259	+19	167	201	66	610
	Citizens ditch in NW¼SW¼ sec. 15, T. 29 N., R. 11 W.	do	27.1						
		1959							
171.5	San Juan River at Rosa, at regular gaging station 1 mile north of Rosa, in SW¼ sec. 21, T. 32 N., R. 5 W.	Sept. 14	100	100		101	142	44	406
	Sambrito Creek near mouth, 2 miles southwest of Rosa, in NE¼ sec. 22, T. 32 N., R. 6 W.	do	8.9			70	130		471
167	San Juan River ¼ mile below mouth of Sambrito Creek in NE¼SW¼ sec. 6	do							

	Bancos Canyon at mouth in NE¼ sec. 10, T. 31 N., R. 6 W	do							
162.5	San Juan River ½ mile below mouth of Bancos Canyon in NW¼SE¼ sec. 10, T. 31 N., R. 6 W.	do	110	110	+5	95	134	33	404
	Cottonwood Canyon at mouth in SE¼ sec. 17, T. 31 N., R. 6 W	do							
159.5	San Juan River ¼ mile below mouth of Cottonwood Canyon in NE¼ sec. 20, T. 31 N., R. 6 W.	do	109	109	−1	95	135	34	405
	La Jara Creek at mouth, 5½ miles northeast of mouth of Pine River, in NW¼ sec. 36, T. 31 N., R. 7 W.	do							
154	San Juan River ¼ mile below mouth of La Jara Creek in NW¼SW¼ sec. 36, T. 31 N., R. 7 W.	do	108	108	−1	96	134	32	408
	Negro Andy Canyon at mouth in NW¼SE¼ sec. 35, T. 31 N., R. 7 W	do							
	Nick Earl Canyon at mouth in SW¼ ssc. 34, T. 31 N., R. 7 W	do	0						
	Pine River ⅛ mile above mouth in SE¼SE¼ sec. 7, T. 30 N., R. 7 W	do	104			31	98		279
147.5	San Juan River ⅛ mile below mouth of Pine River in NW¼ sec. 17, T. 30 N., R. 7 W.	do	216	216	+4	34	106		296
	Navajo Dam diversion	do	4.3						
142	San Juan River near Archuleta, at regular gaging station, in SE¼ sec. 11, T. 30 N., R. 8 W.	do	209	209	−3	76	130	18	378
	Gobernador Canyon at mouth in NE¼SE¼ sec. 19, T. 30 N., R. 8 W	do							
	Ditch at Gobernador Canyon, on left bank of San Juan River, in NE¼NE¼ sec. 19, T. 30 N., R. 8 W.	do	1.3						
136.5	San Juan River 300 feet below mouth of Gobernador Canyon in SE¼NE¼ sec. 19, T. 30 N., R. 8 W.	do	216	217	+8	75	128	18	377
	Pump Canyon at mouth in NE¼SW¼ sec. 25, T. 30 N., R. 9. W	do	.14						
133	San Juan River 300 feet below mouth of Pump Canyon in NE¼SW¼ sec. 25, T. 30 N., R. 9 W.	do	81.8	204	−13	86	131	17	404
	Citizens ditch near Turley, at former gaging station, in SW¼ sec. 25, T. 30 N., R. 9 W.	do	122						
133	San Juan River 300 feet below mouth of Pump Canyon	Sept. 15	69.8	192					
	Citizens ditch near Turley	do	122						
130	San Juan River in NE¼NW¼ sec. 3, T. 29 N., R. 9 W	do	75.8	211	+19				
	Citizens ditch near Turley	do	122						
	Turley ditch in NE¼SW¼ sec. 3, T. 29 N., R. 9 W	do	13.3						
124.8	San Juan River at Blanco, 50 feet below State Highway 17 bridge, in NW¼SE¼ sec. 18, T. 29 N., R. 9 W.	do	105	200	−11	131	167	38	519
	Citizens ditch in Blanco in SW¼SE¼ sec. 13, T. 29 N., R. 10 W	do	94.5						
124.8	San Juan River at Blanco	Sept. 16	81.7	170					
	Citizens ditch in Blanco	do	88.3						
123.8	San Juan River ¾ mile below mouth of Canon Largo in SE¼SW¼ sec. 24, T. 29 N., R. 10 W.	do	81.8	170		141	170	38	552
	Citizens ditch in NE¼SW¼ sec. 24, T. 29 N., R. 10 W	do	88.3						
	Canon Largo in NE¼NW¼ sec. 19, T. 29 N., R. 10 W		0						
117.5	San Juan River in SW¼ sec. 19, T. 29 N., R. 10 W	do	117	170		150	168	35	562
	Citizens ditch below Bloomfield water supply in NE¼SW¼ sec. 18, T. 29 N., R. 10 W.	do	53.5						
113	San Juan River at Bloomfield, at regular gaging station on downstream end of bridge pier on State Highway 44 in NW¼ sec. 27, T. 29 N., R. 11 W.	Sept. 16	111	156	−14	201	196	64	661
	Citizens ditch in NW¼SW¼ sec. 15, T. 29 N., R. 11 W	do	35.6						
	Pumpage at gaging station	do	1.5						
	Kutz canal at gaging station	do	7.9						

TABLE 9.—*Chemical analyses of water from wells and springs in and near*

[Analyses by the U.S. Geological Survey.

Location number: See fig. 2 for

Principal aquifer: Qal, alluvium; Qcg, terrace gravel and stream-channel gravel; San Jose Formation—Tsc, Formation; Toa, Ojo

Dissolved solids: The sum

Location No.	Owner or name (when inventoried)	Date collected	Principal aquifer	Temperature (° F.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
20.1W.6.432	Ignacio Garcia	8-28-59	Toa	------	39	------	548	120	477	
20.2W.17.132	B. B. Johnson	4-30-58	Toa	58	15	------	42	3.8	430	
19.124	Eugene Johnson	6-18-59	Toa	55	9.6	0.70	1.6	.0	226	0.4
31.200	G. E. Conlisk	9-29-25	Tn	54	22	.58	6.8	2.4	3.0	
20.3W.17.444	Rudy Velarde	9- 9-59	Qal	------	------	------	------	------	------	
S20.5W.23.334	Bureau of Indian Affairs.	7-26-54	Toa	------	------	------	------	------	------	
S21.1W.3.442	P. Benavides	8-17-59	Qcg	52	------	------	------	------	------	
21.1W.7.412	Bert Herrera, Sr.	6-18-59	Tsc	57	15	14	77	19	104	3.6
8.211	W. R. McGuire	8-28-59	Tsc	56	------	------	------	------	------	
8.422	R. D. Phillips	8-15-59	Tsc	------	28	.11	62	9.7	29	.4
S21.1W.14.413	Martinez	8-12-59	Qcg	55	28	------	40	10	8.3	
21.1W.15.322	J. K. McEwen	8-15-59	Toa	56	------	------	------	------	------	
17.142	Girt Maxey	4-10-56	Tsc	------	------	------	------	------	------	
17.321	William Eastlake.	4-20-56	Tsc(?)	------	------	------	------	------	------	
17.323a	do	do	Tsc	------	------	3.2	------	------	36	
20.114	U.S. Forest Service.	6- ? -56	Qal	------	------	6.6	------	------	136	------
21.1W.20.322	Raphael Duran	4-10-56	Qal	52	14	.86	98	28	63	
28.143	Cuba Schools 1	6-18-59	Toa	56	22	2.1	208	20	92	4.4
28.211	Cuba Schools 2	10-19-57	Toa	------	21	.36	480	126	624	
29.223	Mel Gallegos	2-26-54	Toa(?)	52	12	------	------	------	84	
29.240	Standard Oil Co.	1-24-55	Toa(?)	42	17	------	240	65	74	
29.432	G. H. Holmes	10-19-53	Toa(?)	------	------	------	------	------	------	
29.433	L. B. Chandler	4-11-56	Toa(?)	------	------	------	------	------	------	
21.6W.3.200	Bureau of Indian Affairs.	9-13-53	Toa(?)	------	------	21	------	------	------	
S22.1W.16.424	La Jara Ranch	8-21-59	Qal	61	------	------	------	------	------	
22.1W.32.331a	Nu Way Bar	8-17-59	Qal	52	------	.32	------	------	------	
32.333	La Jara Store	4-20-56	Tsr	------	------	.07	------	------	31	
22.3W.9.323	Bureau of Indian Affairs.	5- 1-58	Tsr	54	12	------	2.8	.7	255	
29.333	do	5- 9-58	Tsr	55	11	------	2.4	1.0	218	
22.4W.9.131	do	5- 8-58	Tsr(?)	59	11	------	58	7.1	312	
22.5W.15.344	do	5- 1-58	Tsc(?)	49	10	------	2.4	1.4	209	
23.1W.3.423a	H. B. Browning	8-21-59	Qal	------	------	------	------	------	------	
S23.1W.22.333	R. L. Reed	8-20-59	Tsr	------	19	------	72	21	248	
23.1W.27.233	W. C. Schmidt	8-21-59	Qal	------	17	------	45	6.7	470	
32.242a	Helmar Co.	8-21-59	Qal	53	------	------	------	------	------	
23.2W.13.333	Bureau of Indian Affairs.	5- 7-58	Qal	49	8.7	------	19	9.0	171	
23.3W.11.333	Bureau of Indian Affairs.	5-9-58	Tsr	55	17	------	46	7.6	503	
23.4W.21.432	do	5-1-58	Tsr(?)	50	9.8	------	2.4	1.0	285	
24.432	do	5-9-58	Tsr	57	8.8	------	8.3	.7	490	
23.5W. 1.232	do	5-1-58	Tsr	52	8.1	------	2.0	.7	260	
23.332	do	5-1-58	Tsc	50	15	------	21	3.3	211	
24.1E. 7.142	Harold Schmidt	8-13-59	Qal	51	------	------	------	------	------	
30.441	F. I. Northcutt	8-17-59	Qal	56	------	------	------	------	------	
24.2W. 2.334	J. B. Hardy	9-15-59	Tsr	------	17	------	6.2	.6	291	
16.444	Lindrith Mutual Water Users Assoc.	6-30-59	Tsl	56	8.0	0.16	1.6	.0	206	.4
26.412	J. D. Nelson	9-24-59	Tsr	------	------	------	------	------	------	
34.111	Paul Brown	9-22-59	Tsr	------	14	------	62	18	718	
24.4W. 6.100	Bureau of Indian Affairs.	11-10-38	Tsc(?)	------	8.0	.06	8.3	1.1	[1] 489	5.0
28.200	do	11-11-38	Tsc(?)	------	7.6	5.2	6.3	1.4	319	4.8
24.5W.23.422	do	11-5-38	Tsc(?)	------	10	.04	4.5	.9	298	4.3
S24.5W.32.122	do	11-11-38	Tsc	------	20	.04	66	11	271	5.4

'he southern part of the Jicarilla Apache Indian Reservation, N. Mex.

Chemical constituents are in parts per million]

¨ystem of numbering wells and springs.
Cuba Mesa Member; Tsl, Llaves Member; Tsr, Regina Member; Tst, Tapicitos Member; Tn, Nacimiento
Alamo Sandstone.

of determined constituents.

Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos at 25° C.)	pH
243	0	2,440	70	0.9	70	------	3,880	1,860	1,660	36	4.8	4,230	7.3
303	6	757	5.0	.5	.4	------	1,410	120	0	89	17	2,010	8.5
324	28	164	5.0	1.8	.4	0.27	596	4	0	99	49	961	8.9
29	0	6.2	1.0	------	------	------	56	27	3	19	.3	------	------
482	0	------	4.8	------	------	------	------	183	0	------	------	1,950	7.7
219	0	------	42	1.0	.8	------	------	96	0	------	------	700	------
170	0	------	1.2	------	------	------	------	129	0	------	------	287	7.0
474	0	97	4.0	.5	.0	.06	569	270	0	45	2.8	894	7.1
171	0	------	3.2	------	------	------	------	275	135	------	------	642	7.0
154	0	93	14	.3	11	.04	323	194	68	24	.9	514	6.7
173	0	12	2.3	.5	.1	------	186	141	0	11	.3	302	7.2
888	26	------	486	------	------	------	------	63	0	------	------	2,850	8.3
------	------	------	------	------	------	------	------	------	------	------	------	362	------
------	------	------	------	------	------	------	------	------	------	------	------	473	------
120	0	958	8	------	------	------	------	1,030	932	7	.5	1,720	6.9
225	0	577	54	.9	.4	------	------	580	396	34	2.5	1,520	7.3
373	0	174	7	.4	.1	------	568	360	54	28	1.5	888	7.3
254	0	521	38	.5	.0	.06	1,030	601	393	25	1.6	1,410	7.1
608	0	2,430	31	.5	.2	------	4,010	1,720	1,220	44	6.6	4,490	7.0
390	0	150	3	.6	.0	------	------	298	0	38	2.1	839	------
405	0	631	26	.5	.1	------	1,250	866	534	16	1.1	1,790	------
438	0	------	10	------	------	------	------	529	------	------	------	1,190	------
------	------	------	------	------	------	------	------	------	------	------	------	1,440	------
320	16	------	7	------	------	------	------	34	0	------	------	953	8.4
460	0	------	17	------	------	------	------	578	201	------	------	1,280	7.5
418	0	------	41	------	------	------	------	256	------	------	------	1,270	7.3
130	0	384	11	------	------	------	------	454	348	13	.6	967	6.5
359	17	224	5.0	1.0	.2	------	694	10	0	98	35	1,080	8.8
259	30	205	4.0	1.0	.9	------	601	10	0	98	30	936	9.0
403	0	489	7.5	.9	.0	------	1,080	174	0	80	10	1,550	8.2
186	9	270	10	1.6	.2	------	605	12	0	97	26	933	8.7
856	4	------	36	------	------	------	------	54	0	------	------	1,740	8.3
539	0	302	30	.7	2.8	------	960	264	0	67	6.6	1,430	7.9
475	0	714	20	.2	1.5	------	1,510	140	0	88	17	2,160	7.8
580	0	------	184	------	------	------	------	795	320	------	------	2,840	7.7
490	0	43	4.0	1.0	2.0	------	499	84	0	81	8.1	790	8.1
411	0	857	7.0	0.4	0.7	------	1,640	146	0	88	18	2,270	7.9
327	18	304	7.5	1.6	.2	------	790	10	0	98	39	1,200	8.8
217	9	837	12	3.1	.3	------	1,480	24	0	98	44	2,120	8.7
321	16	257	9.5	.8	.0	------	712	8	0	99	40	1,090	8.6
345	0	221	7.5	.4	.4	------	650	66	0	87	11	985	7.9
506	0	------	4.0	------	------	------	------	43	0	------	------	893	8.0
542	0	------	4.4	------	------	------	------	100	0	------	------	1,390	8.1
606	10	96	26	.5	.1	------	745	18	0	97	30	1,160	8.4
382	28	71	8.0	2.0	.0	0.28	512	4	0	99	45	855	8.9
528	0	------	26	------	------	------	------	248	0	------	------	3,090	7.7
687	0	1,040	87	.7	25	------	2,300	230	0	87	21	3,220	8.0
419	5	667	32	.9	.4	.07	1,420	25	0	98	43	2,090	------
298	0	413	9.0	4.0	.2	.06	914	21	0	96	30	1,390	------
280	25	347	7.0	.8	.2	.04	831	15	0	97	33	1,290	------
355	0	466	18	.2	5.7	.07	1,040	210	0	73	8.1	1,490	------

TABLE 9.—*Chemical analyses of water from wells and springs in and near t*

[Analyses by the U.S. Geological Surv

Location number: See fig. 2
Principal aquifer: Qal, alluvium; Qcg, terrace gravel and stream-channel gravel: San José Formation—T
Formation; Toa, (

Dissolved solids: The su

Location No.	Owner or name (when inventoried)	Date collected	Principal aquifer	Temperature (° F.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K
25.1E.17.234	Jack Davis	8-12-59	Toa(?)	------	13	------	122	31	167	
25.1W. 8.111	E. M. Collins	9-25-59	Tsl	50	11	------	158	54	111	
25.2W.11.141	Nazarene Indian School.	10-10-59	Tsl	52	------	------	------	------	------	----
23.441	D. W. Hatley	9-18-59	Tsr	50	------	------	------	------	------	----
25.3W.1.240a	Fred Davis	10-12-59	Tsl	------	------	------	------	------	------	----
12.442	F. C. Conley	10-12-59	Tst	------	11	------	84	18	745	
25.4W.23.340	Bureau of Indian Affairs.	5-8-58	Tsr	53	17	------	175	67	468	
25.5W. 3.233	do	11-9-38	Tsr	------	13	.02	8.6	1.7	271	5.
29.200	do	11-10-38	Tsc(?)	------	12	.17	69	10	[1] 442	6.
S26.1E.17.333	U.S. Forest Service.	4-29-58	Qal, Toa	45	11	------	65	24	14	
33.314	do	4-29-58	Toa	48	15	------	85	26	27	
26.2W.34.421	C. Quintana	9-27-59	Tsl(?)	------	------	------	------	------	------	----
26.3W. 7.314	Bureau of Indian Affairs.	5-8-58	Tsr	52	17	------	72	18	316	
26.4W.15.321	do	5-8-58	Tsr	54	9.5	------	51	67	207	
17.440	do	11-10-38	Tsr	------	12	.13	17	2.6	470	5.
		5-8-58		57	11	------	34	6.4	579	

[1] Sodium calculated.

outhern part of the Jicarilla Apache Indian Reservation, N. Mex.—Continued

hemical constituents are in parts per million]

ystem of numbering wells and springs.
iba Mesa Member; Tsl, Llaves Member; Tsr, Regina Member; Tst, Tapicitos Member; Tr, Nacimiento
lamo Sandstone.

determined constituents.

Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos at 25° C.)	pH
353	0	457	11	.4	18	------	993	432	142	46	3.5	1,410	7.5
814	0	114	44	.3	13	------	905	618	0	28	1.9	1,460	7.5
618	0	--------	24	------	-------	------	-------	24	0	-------	-------	1,130	8.0
483	53	--------	14	------	-------	------	-------	20	0	-------	-------	1,120	9.2
421	0	--------	9.8	------	-------	------	-------	136	0	-------	-------	1,540	7.8
525	0	1,380	26	.5	.2	------	2,520	285	0	85	19	3,400	7.7
382	0	1,330	21	.5	1.1	------	2,270	712	399	59	7.6	2,860	7.6
335	9	321	7.0	1.4	.2	.06	803	28	0	94	22	1,270	------
298	0	882	12	.6	.2	.04	1,580	214	0	81	13	2,230	------
204	0	109	7.0	.4	.0	------	330	260	94	11	.4	526	7.8
298	0	115	8.5	.4	1.1	------	425	319	75	15	.7	667	7.3
466	30	--------	9.2	------	-------	------	-------	6	0	-------	-------	832	9.0
410	0	565	10	.5	.2	------	1,200	254	0	73	8.6	1,680	7.8
365	0	514	12	.5	.1	------	1,040	402	104	53	4.5	1,510	7.7
367	0	763	14	.2	.2	.04	1,460	53	0	94	28	2,170	------
408	0	969	18	.4	.1	------	1,820	112	0	92	24	2,540	8.0

TABLE 10.—*Summary of suitability of ground water in and near the southern pa[rt] of the Jicarilla Apache Indian Reservation, N. Mex., for irrigation*

Number of samples	Salinity class	Sodium class
4	C2	S1
11	C3	S1
5	C3	S2
2	C3	S3
15	C3	S4
3	C4	S2
3	C4	S4

Salinity classes:
- C2, medium-salinity water; can be used if a moderate amount of leaching occurs. Plants whose sa[lt] tolerance is moderate can generally be grown without special practices for salinity control.
- C3, high-salinity water; cannot be used on soils with restricted drainage. Special management f[or] salinity control may be necessary. Plants with good salt tolerance should be selected.
- C4, very high-salinity water; not suitable for irrigation under ordinary conditions, but may be use[d] occasionally under very special circumstances.

Sodium classes:
- S1, low-sodium water; can be used for irrigation on almost all soils with little danger of the developme[nt] of harmful levels of exchangeable sodium.
- S2, medium-sodium water; will present an appreciable sodium hazard in fine-textured soils having hig[h] cation-exchange capacity, especially under low leaching conditions, unless gypsum is present in th[e] soil.
- S3, high-sodium water; may produce harmful levels of exchangeable sodium in most soils and wi[ll] require special soil management—good drainage, high leaching, and organic matter additions. Gyp[-] siferous soils may not develop harmful levels of exchangeable sodium from such waters.
- S4, very high-sodium water; generally unsatisfactory for irrigation purposes except at low and perha[ps] at medium salinity, where the solution of calcium from the soil or use of gypsum or other amendmen[ts] may make the use of these waters feasible.

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[Italic page numbers indicate major references]