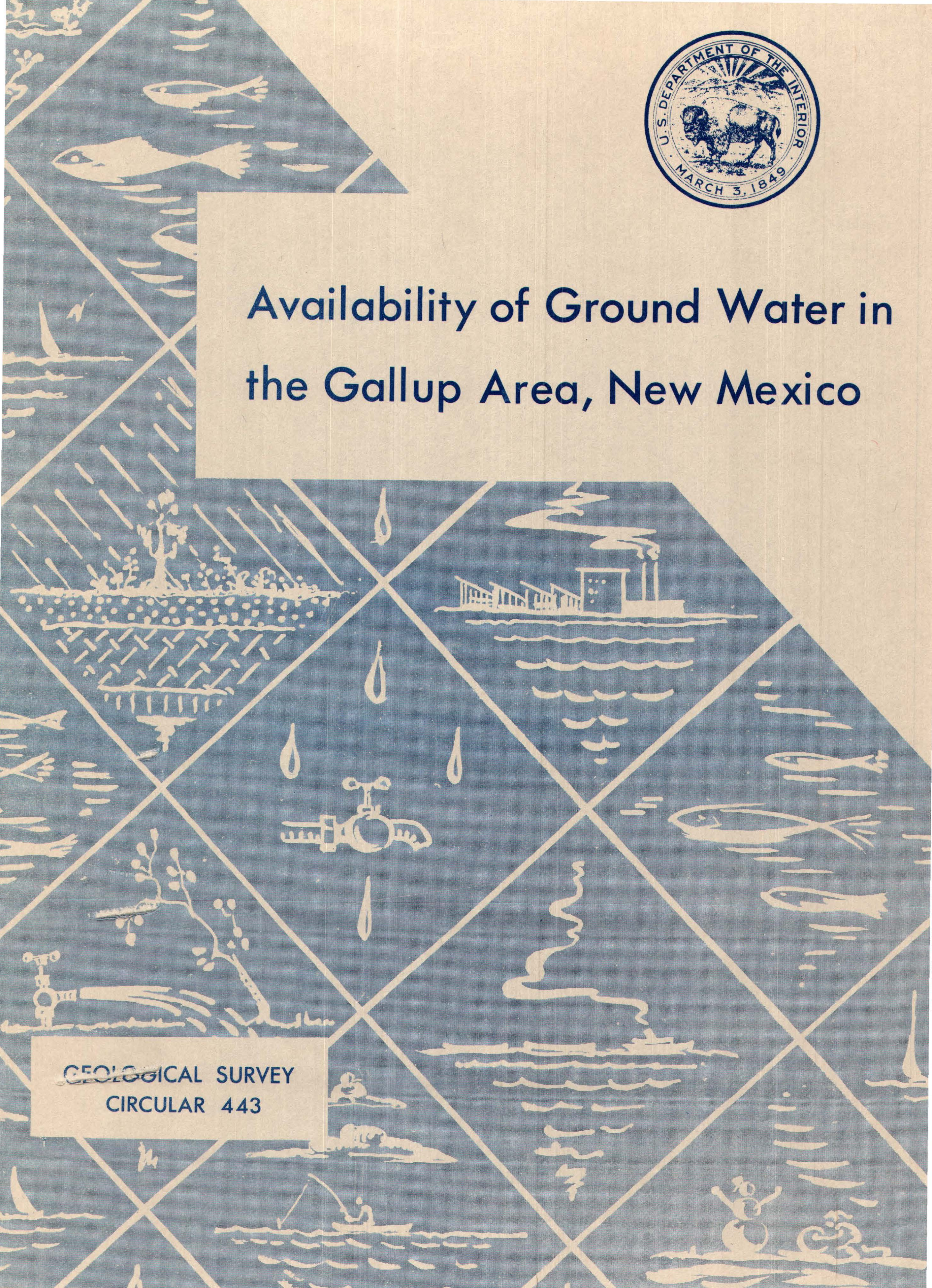
Availability of Ground Water in the Gallup Area, New Mexico



GEOLOGICAL SURVEY
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PREPARED IN COOPERATION WITH THE NEW MEXICO STATE ENGINEER AND THE TOWN OF GALLUP

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By S. W. West

Prepared in cooperation with the New Mexico State Engineer and the town of Gallup

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By S. W. West

ABSTRACT

A thick succession of sedimentary rocks (about 6,000 feet) underlies the town of Gallup and crops out nearby. Although all the sedimentary rocks are capable of yielding some water, only a few units of sandstone and limestone yield water in sufficient quantity and of acceptable quality to be considered as sources of large supplies. The five stratigraphic units that are most productive of ground water form three aquifers, as follows: (a) the Glorieta sandstone and San Andres limestone, (b) the Westwater Canyon member of the Morrison formation and the Dakota sandstone, and (c) the Gallup sandstone.

The Glorieta sandstone yields only small amounts of water to wells, except where it is intensely fractured. It probably contributes large amounts of water to the overlying, more permeable San Andres limestone by slow vertical leakage over large areas, as water is withdrawn from the San Andres.

The San Andres limestone is discontinuous in the eastern part of the area, wedging out entirely a few miles east of Gallup. Its permeability varies widely because locally the permeability has been greatly increased by fractures and solution channels. On the north flank of the Zuni Mountains, near its outcrop, the San Andres yields as much as 1,100 gpm (gallons per minute) of water to wells. The specific capacity of wells that tap the aquifer formed by this Glorieta sandstone and San Andres limestone ranges from 0.1 to 29 gpm per foot of drawdown.

In general, the water in the Glorieta sandstone and San Andres limestone is hard, because it contains much calcium. Both bicarbonate and sulfate anions are abundant. The chemical quality of the water deteriorates with increasing distance from the outcrop.

The Westwater Canyon member of the Morrison formation and the Dakota sandstone form a single hydrologic unit extending from about 5 miles east of Gallup westward into Arizona. To the east they are separated by shale of the Brushy Basin member of the Morrison formation.

The water-bearing properties of the Westwater Canyon member and the Dakota sandstone are ill defined, because few wells in the area tap either of them exclusively. The specific capacity of wells that tap the Westwater Canyon member, the Dakota sandstone, or both ranges from 0.02 to 2.3 gpm per foot of drawdown.

Water in this aquifer generally contains less that 1,000 ppm (parts per million) of dissolved solids. The concentration of sodium and bicarbonate typically is high, and the concentration of sulfate is high locally.

The Gallup sandstone is the principal aquifer in the immediate vicinity of, and to the north and south of, Gallup. It yields as much as 260 gpm of water to wells; the specific capacity of wells that tap the Gallup sandstone ranges from 0.08 to 4.7 gpm per foot of drawdown. In general, the water in the Gallup sandstone is potable, although in places it yields water high in iron, sulfate, and dissolved solids; the concentration of dissolved solids generally is less than 1,000 ppm.

Because the yields of all the formations tested at Gallup are small, the town needs a better source of water. The San Juan River discharges annually a larger volume of water than is available from any other source in northwestern New Mexico. Gallup has applied for 15,000 acre-feet of San Juan River water a year, an average of 13,400,000 gpd (gallons per day). This water would be expensive, because about 50 miles of pipeline would be required to transport the water, and it would have to be lifted about 1,000 feet over a high ridge north of town.

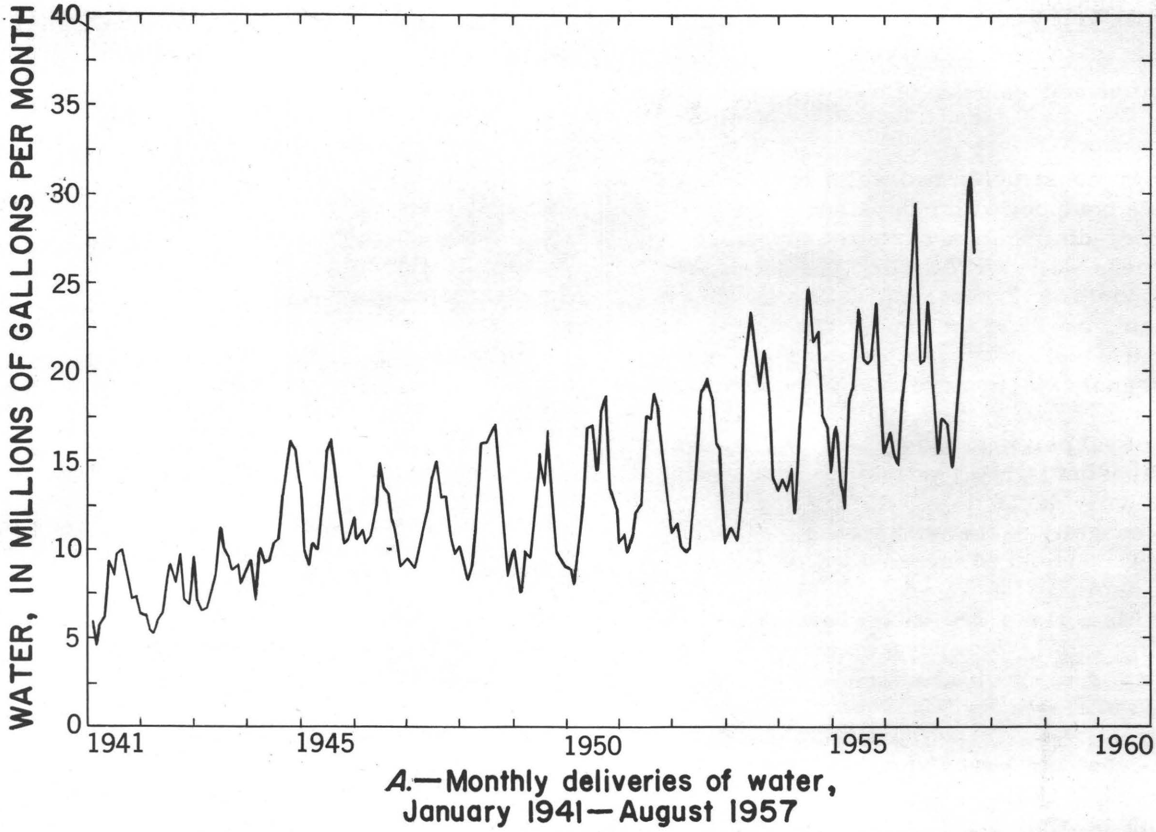
Despite the expense involved, at this time the San Juan River seems to offer the most secure long-term supply of water for the Gallup area.

NATURE OF THE PROBLEM

A rapid increase in population from 1950 to 1955 and a decline in well yields caused the peak daily demand for water in Gallup, N.Mex., to approach the maximum capacity of the well system. As the population increased, the rate of water consumption per capita also increased (fig. 1). To aid in planning, the town of Gallup requested that the U.S. Geological Survey, as a part of its statewide investigation in cooperation with the State Engineer, study the availability of ground water for municipal supply and other uses in the Gallup area. In the summer of 1955 the Geological Survey began the study of ground-water resources and geology in the vicinity of Gallup. The project area includes Tps. 13–16 N., Rs. 14–21 W., New Mexico principal meridian (pl. 1). This project was coordinated with a study of the ground-water resources of the Navajo country by the Arizona district of the Geological Survey.

The availability of ground water to supply the town of Gallup was studied by the Hatfield Engineering Co. in 1952.[1] Before fieldwork by the Geological Survey was concluded in December 1957, an interim report on water wells at Gallup and on the general geology and ground-water supplies in the area was prepared in response to an immediate need

[1]Hatfield, C. R., 1952, Report on municipal water utility, Gallup, N. Mex.: Albuquerque, N. Mex., Hatfield Engineering Co., 29 p.



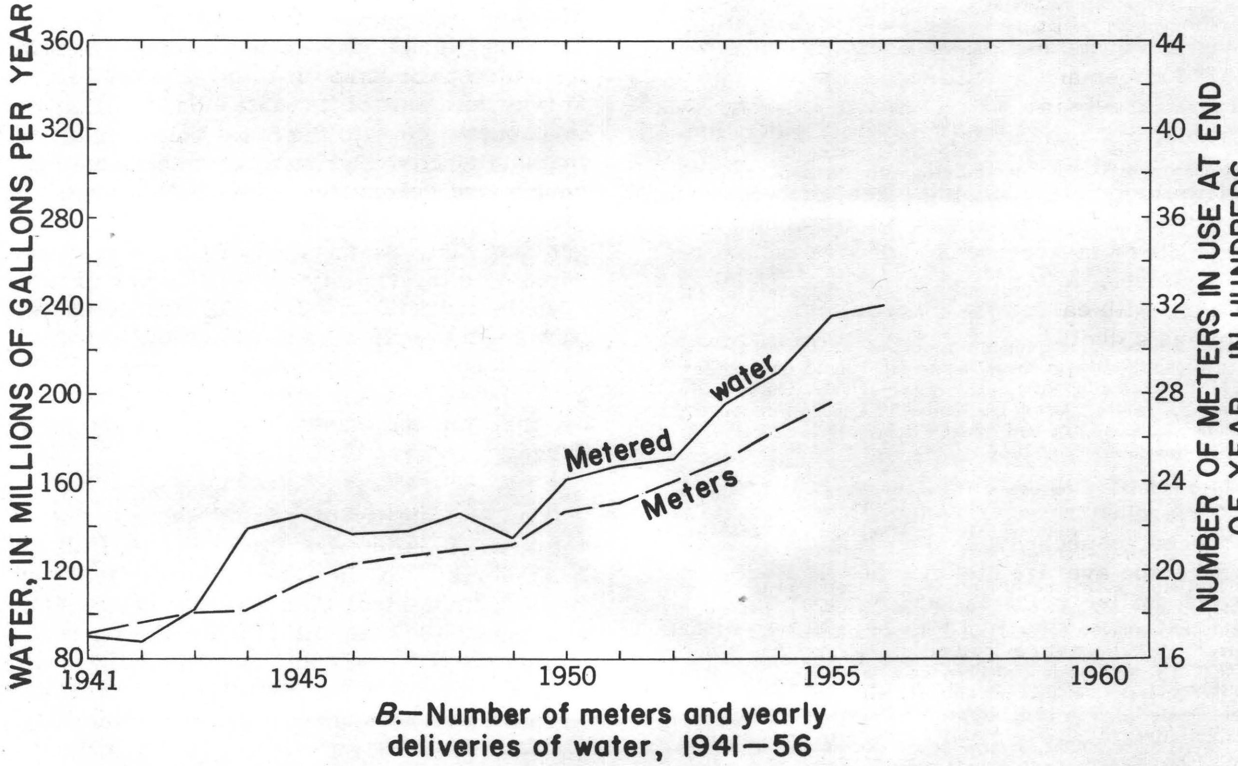


Figure 1.—Monthly and yearly deliveries of water to customers and number of meters in Gallup, New Mexico.

for such information.[2] This is the second brief report prepared to serve an immediate need for specific information, pending the preparation and release of a comprehensive report.

The town constructed two wells in 1957, and they were equipped with pumps and connected to the water-distribution system early in 1958. Before these wells were drilled, the combined potential yield of 12 municipal wells was about 1,230 gpm, or 1,770,000 gpd. The two new wells had a potential yield of about 500 gpm (720,000 gpd), which increased the combined well-system capacity to 2,490,000 gpd, an increase of 40 percent. Since 1955 Gallup has gained substantially in population, and again the peak daily demand for water is approaching the capacity of the well system. Prompt action is considered necessary to avert a serious shortage of water in the immediate future. Also, plans are to be formulated as soon as possible to assure an ample supply of water for a much larger city in the more distant future.

Because of the absence of large perennial streams near Gallup, development of ground water for municipal supply has been emphasized. As Gallup has grown, more and more wells have been drilled in and adjacent to town in an attempt to keep production of water ahead of demand. Drilling has been concentrated largely in two well fields, one near the east end of town and the other extending westward from the center of town. Information on water levels, pumping rates, drawdown in wells during pumping, and amounts of water pumped from each well field are lacking or incomplete. A comparison of current information with early well records, however, indicates a decline of water levels in both well fields and a marked decrease in the yields of several wells, especially of those in the east well field. The decreasing yields are caused largely by declining water levels and dewatering of shallow water-bearing strata. Pumping interference between wells at Gallup is pronounced, especially in the west well field, where the average distance between adjacent wells drilled prior to 1957 is about 450 feet; the two new wells, 15.18.20.211 and 15.18.20.-221, are 1,200 and 1,500 feet from the nearest well.

The chemical quality of ground water at Gallup also has been a problem (table 4). The water in both well fields contains dissolved solids and sulfate in concentrations near the upper limits (1,000 and 250 ppm, respectively) for drinking water recommended by the U.S. Public Health Service.[3] Also, the water in the east well field generally contains more iron than is recommended (more than 0.3 ppm), and the water is hard. The ratio of sodium to calcium and magnesium in water of the west well field is undesirably high for water used for irrigation, including that of lawns.

Because the yields of wells at Gallup are small and the quality of water is only fair, the town is exploring the possibility of obtaining a large supply of good water from distant sources. Two means of increasing the water supply are being considered. One is development of a well field near the head of Four Mile Canyon on the Prewitt Ranch, 20 to 25 miles southeast of Gallup, where as much as 1,100 gpm has been pumped from at least one well. The other is construction of facilities to transport water from the San Juan River.

The length of a pipeline to the ground-water reservoir southeast of Gallup would be about half the length of one from the point (the end of a proposed irrigation canal) where the town might obtain water from the San Juan River. Also, storage facilities at the end of the irrigation canal might be necessary to assure a water supply in the nonirrigation season. A minimum of pumping would be required for delivery of water to Gallup from the ground-water reservoir, because the site is at a higher altitude than the town. Water from the San Juan River would have to be pumped over a high ridge, and the lift might exceed 1,000 feet. The reliability of the ground-water supply on the Prewitt Ranch has not been proved by sustained withdrawal of a large volume of water; however, the San Juan River, on the other hand, discharges annually a larger volume of water than is available from any other source, either surface or ground water, in northwestern New Mexico.

Should the town obtain permission to develop a well field on the Prewitt Ranch, test

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[2] West, S. W., 1957, Interim report on water wells, Gallup, New Mexico: U.S. Geol. Survey open-file rept., 38 p., 2 pls., 8 figs.

[3] U.S. Public Health Service, 1946, Drinking water standards: Public Health Repts., v. 61, no. 11, p. 371-384.

wells could be drilled and, if they are successful, a pipeline and treatment plant could be constructed and the water delivered to the municipal system in a relatively short time. Should the town obtain permission to use water from the San Juan River, the water would not be available until the Navajo Dam and irrigation canals were completed, which would take several years. In the meantime the town would have to be supplied with water from wells.

To aid in planning, the most productive geologic formations, their accessibility and yield, and the chemical quality of their waters are described in following sections of this report. Selected information on wells and selected chemical analyses of water are listed in tables 1–4. The density and distribution of wells in the Gallup area in 1957 are shown on plate 1.

WELL-NUMBERING SYSTEM

All wells referred to in this report are identified by a location number used by the Geological Survey and the State Engineer for numbering water wells in New Mexico. The location number is a description of the geographic location of the well, based on the system of public land surveys. It indicates the location of the well to the nearest 10-acre tract, when the well can be located that accurately. The location number consists of a series of numbers corresponding to the township, range, section, and tract within a section, in that order. (See fig. 2.) If a well has not been located closely enough to be placed within a particular section or tract, a zero is used for that part of the number. The letter "S" preceding a location number is used to indicate a spring.

WATER-BEARING FORMATIONS

The geologic section in the Gallup area includes dense crystalline rocks of Precambrian age and sedimentary rocks ranging in age from Permian to Recent, all of which crop out in the area studied. A generalized stratigraphic section is given below. The Precambrian rocks form the core of the Zuni Mountains and crop out discontinuously from McGaffey southeastward for about 35 miles. These crystalline rocks form a relatively impervious foundation on which a thick succession of shale, sandstone, and some limestone was deposited. The sedimentary strata dip radially from the central part of the Zuni Mountains.

Erosion has carved a series of concentric as well as radial valleys, slopes, and steep escarpments on the flanks of the Zuni Mountains. Because the shale is more easily eroded than the sandstone and limestone, in general the valleys are indicative of thick units of shale and the slopes and escarpments are indicative of sandstone or limestone.

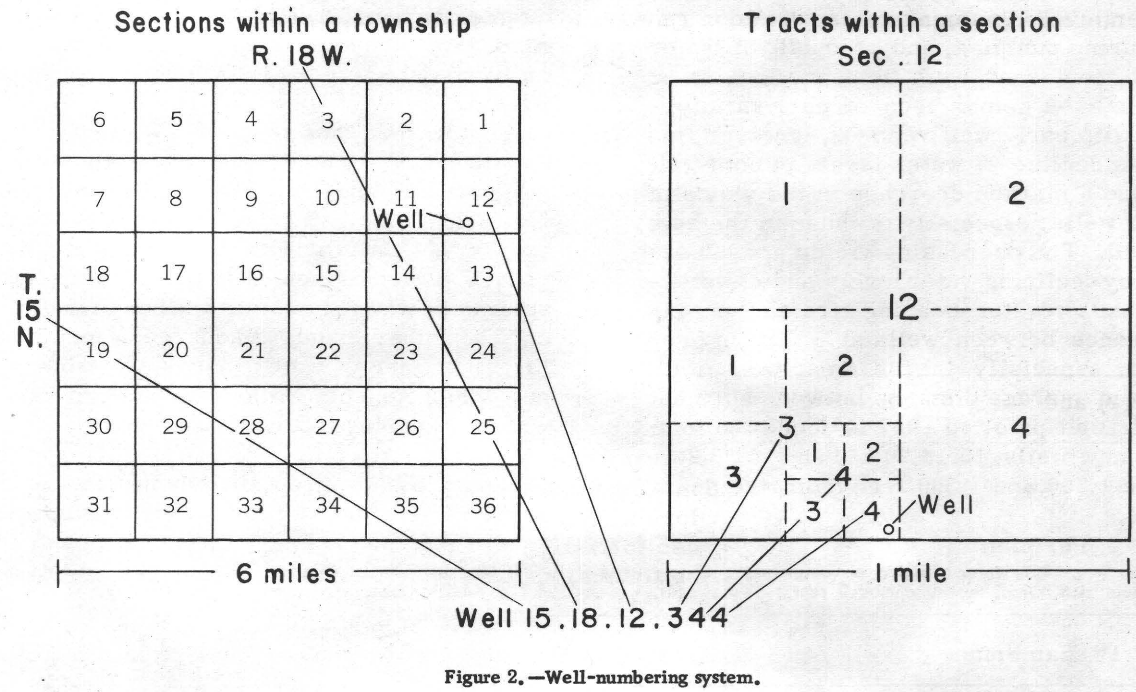

Figure 2.—Well-numbering system.

Generalized stratigraphic section in the Gallup area, New Mexico

Age		Stratigraphic unit	Thickness (feet)
Quaternary		Alluvium	0–200
		Unconformity	
Tertiary		Bidahochi formation	0–400±
		Unconformity	
Late Cretaceous	Mesaverde group	Menefee formation:	
		Allison member	0–800
		Cleary coal member	
		Point Lookout sandstone	----------
		Crevasse Canyon formation:	
		Gibson coal member	150–175
		Bartlett barren member	330–400
		Dalton sandstone member	----------
		Dilco coal member	240–300
		Gallup sandstone	180–350
		Mancos shale	500–700
Early(?) and Late Cretaceous		Dakota sandstone	125–250
		Unconformity	
Late Jurassic		Morrison formation:	
		Brushy Basin member	0–195
		Westwater Canyon member	100–220
		Recapture member	0– 60
		Zuni sandstone	280–425
	San Rafael group	Summerville formation	0– 60
		Todilto limestone	0– 5
Late and middle Jurassic		Entrada sandstone and Carmel formation, undifferentiated	295–370
		Unconformity(?)	
Late Triassic		Wingate sandstone:	75–360
		Lukachukai member	
		Chinle formation:	
		Owl Rock member	40
		Petrified Forest member, upper part	880
		Sonsela sandstone bed	20– 65
		Petrified Forest member, lower part	180
		Lower member	235
		Shinarump member	25
Middle(?) and Early Triassic		Moenkopi(?) formation	25–100±
		Unconformity	
Permian		San Andres limestone	0–100
		Glorieta sandstone	100–300
		Yeso formation	0–425
		Abo formation	----------
		Unconformity	
Precambrian		Crystalline rocks	----------

All the sedimentary formations are capable of yielding some water, although only a few units of sandstone and limestone yield water in sufficient quantity and of acceptable quality for consideration as possible sources of large supplies. The three most productive aquifers, consisting of five stratigraphic units, are described in the following sections of the report.

GLORIETA SANDSTONE AND SAN ANDRES LIMESTONE

The Glorieta sandstone and the overlying San Andres limestone, both Permian in age, form a single hydrologic unit, but one of marked variation in both vertical and horizontal permeability.

The Glorieta sandstone consists of grayish-orange-pink to moderate-orange-pink, very fine to fine grained well-sorted quartz sandstone, ranging in thickness from 100 to 300 feet. (See log of well 15.17.12.300.) Generally it is tightly cemented by calcite and silica and is strongly resistant to erosion. Because of severe crustal deformation in the Zuni Mountains, the Glorieta is intensely fractured locally.

The Glorieta sandstone crops out on the north and west flanks of the Zuni Mountains as a caprock on high escarpments and broad dip slopes. In places it forms the walls of deep, narrow canyons. It crops out at the Sheep Laboratory in sec. 7, T. 14 N., R. 16 W. The top of the formation is about 1,800 feet below the land surface at the El Paso Natural Gas Co. plant in sec. 16, T. 15 N., R. 17 W., about 3,700 feet below the land surface in the eastern part of Gallup, and about 4,600 feet below the land surface in the western part of Gallup.

In general the Glorieta sandstone yields only small supplies of water. It is so fine grained and so tightly cemented that storage and movement of water are confined largely to fractures. Although the Glorieta transmits only small amounts of water per square foot of cross section, it probably contributes large amounts of water to the overlying San Andres limestone by slow leakage, as water is withdrawn from the San Andres.

The San Andres limestone consists of light- to medium-gray and pale-brown limestone and limy sandstone 100 feet or less in thickness. (See log of well 15.17.12.300.) The San Andres was exposed to a long period of erosion, during which a karst topography and innumerable solution channels were formed before the overlying Mesozoic rocks were deposited. The San Andres crops out on the flanks of the Zuni Mountains, largely on broad dip slopes, and in places it forms the walls of deep, narrow canyons. The San Andres is discontinuous northwestward from McGaffey and it wedges out entirely a few miles east of Gallup. It crops out at the Sheep Laboratory and the top of the formation is 1,725 feet below the land surface at the Church Rock School in sec. 12, T. 15 N., R. 17 W. It was not identified in wells at the El Paso Natural Gas Co. plant in sec. 16, T. 15 N., R. 17 W., and it has not been observed in outcrops of Permian formations just west of the Arizona boundary.

The permeability of the San Andres limestone has been greatly increased in places by solution channels and fractures which serve as conduits for water. Many wells that tap the San Andres in the Gallup area yield water by natural flow. On the north flank of the Zuni Mountains, near its outcrop, the San Andres yields moderate to large supplies of water to wells. The wells on the Prewitt Ranch tap this formation. Farther from the outcrops the formation yields much less water, probably because ground-water circulation has been less vigorous and, consequently, open channels are not as common. Because the San Andres generally is thin and discontinuous northward and northwestward from Fort Wingate, wells in that area probably will not penetrate more than a few feet of the San Andres, if any.

The specific capacity (yield of water, in gallons per minute per foot of drawdown) of some wells that tap the Glorieta sandstone and San Andres limestone are listed in table 1.

The Glorieta sandstone and San Andres limestone are recharged by infiltration of precipitation and runoff on the outcrops. The annual volume of recharge cannot be determined readily, but recharge to the dense Glorieta sandstone necessarily is small. Recharge to the San Andres limestone may be large locally, but not generally.

Table 1.—*Specific capacity of wells that tap the Glorieta sandstone and San Andres limestone in the Gallup area*

Well no.	Date of measurement	Duration of test (hours)	Pumping or flow rate (gpm)	Drawdown (feet)	Specific capacity (gpm per foot of drawdown)
13.14.5.311	10–28–54	------	65	100±	0.65±
13.14.16.330	------	------	10	30±	.33±
14.15.29.120	2– 52	3	1,100	38	29
15.15.33.130b	9– 56	------	90	346	.26
15.16.23.430	6–29–55	------	2.2	196	.01
15.17.16.222	8–26–55	------	15	200	.08
15.17.16.224a	9–26–55	------	45	200	.22
15.17.16.310	6–22–56	10.5	47	369	.13
15.17.24.440	------	------	240	157	1.5

Water is discharged naturally from the Glorieta sandstone and San Andres limestone by vertical leakage into overlying formations and by flow from springs on the flanks of the Zuni Mountains. The flows of Santa Fe spring (S14.16.6.120), Sheep Laboratory spring (S14.-16.7.440), Bear spring (S14.16.8.220), and Fort Wingate spring (S14.16.9.120) probably rise from the San Andres limestone along fault zones.

Development and use of wells near these springs eventually would affect their flow, possibly to the extent of stopping the flow entirely.

The chemical quality of water in the Glorieta sandstone and San Andres limestone varies widely (table 4). In general, the water is hard because it contains much calcium. Among the anions, both bicarbonate and sulfate are abundant. The calcium and bicarbonate content can be reduced by treatment with lime and filtration. The sulfate cannot be removed economically. Generally, the chemical quality of water in the Glorieta and San Andres deteriorates with increasing distance from their outcrops.

WESTWATER CANYON MEMBER OF MORRISON FORMATION AND DAKOTA SANDSTONE

The Morrison formation of Late Jurassic age, consists of three members in the Gallup area. In ascending order they are the Recapture member, consisting mainly of red and variegated beds of shale; the Westwater Canyon member, consisting mainly of white to red sandstone; and the Brushy Basin member, consisting mainly of light-greenish-gray shale. Only the Westwater Canyon member yields water to wells. The Brushy Basin member wedges out about 5 miles east of Gallup, and from there westward into Arizona the Dakota sandstone of Early(?) and Late Cretaceous age lies directly on the Westwater Canyon member. These two lithologic units form a single hydrologic unit where they are in contact. To the east the relatively impervious shale of the Brushy Basin member separates them into two distinct hydrologic units.

The Westwater Canyon member consists of white to red very fine to coarse-grained partly conglomeratic sandstone and ranges in thickness from 100 to 220 feet. The sand grains are mainly quartz, although grains of feldspar are common to abundant. Much of the feldspar has been altered in place to clay minerals. (See log of well 15.18.20.211.) The Westwater Canyon member is tightly cemented. Fractures in this unit are common, but they are somewhat indistinct in many places.

The Westwater Canyon member crops out in the hogback east of Gallup, in high escarpments trending eastward from the hogback, and in escarpments southwest of Gallup, extending into Arizona. In the eastern part of Gallup the top of the member is about 1,200 feet below the land surface and in the western part, about 2,060 feet.

The water-bearing properties of the Westwater Canyon member are ill defined, because few wells in the Gallup area tap that member exclusively. Its poor sorting and

Table 2.—*Specific capacity of wells that tap the Westwater Canyon member of the Morrison formation, the Dakota sandstone, or both, in the Gallup area*

Well no.	Date of measurement	Duration of test (hours)	Pumping or flow rate (gpm)	Drawdown (feet)	Specific capacity (gpm per foot of drawdown)
14.20.16.130	----------	----------	6	30	0.20
14.21.26.220	2–15–54	0.5	25.6	76.5	.33
16.14.16.140	10– 51	2.5	11	211	.05
16.14.33.220	3– 52	.5	11.3	5	2.3
16.16.1.200	12–16–48	3	7.8	490	.02

tight cementation preclude large yields of water to wells. However, it may transmit large volumes of water locally by slow vertical leakage to the overlying, more permeable Dakota sandstone.

The Dakota sandstone consists of light-gray to buff fine-to medium-grained quartz sandstone and some beds of shale and coal, and ranges in thickness from 115 to 250 feet. Generally, the grains of sand are well sorted and firmly cemented. (See log of well 15.18.-20.211.) Fractures are abundant locally, especially in places where the formation has been sharply folded.

The Dakota sandstone crops out as a sharp ridge in the hogback east of Gallup and as the caprock in escarpments and on broad slopes eastward from the hogback and southwest of Gallup, extending into Arizona. In the eastern part of Gallup the top of the Dakota is about 750 feet below the land surface and in the western part, about 1,940 feet.

The water-bearing properties of the Dakota sandstone are poorly defined, because few wells in the Gallup area tap it solely. Its fine texture and tight cementation preclude large yields of water, except possibly where fracture systems are well developed.

The combined yield of the Westwater Canyon member of the Morrison formation and the Dakota sandstone generally is small. (See table 2.)

The Westwater Canyon member and the Dakota sandstone are recharged by infiltration of precipitation and runoff on the outcrops. The annual volume of recharge has not been determined, but it necessarily is small.

Water in the Westwater Canyon member and the Dakota sandstone is discharged naturally through small springs and seeps in outcrop areas, and the water is dissipated by evaporation and transpiration.

Water in the Westwater Canyon member and Dakota sandstone generally contains less than 1,000 ppm of dissolved solids in the Gallup area (table 4). The concentration of sodium bicarbonate typically is high, and that of sodium sulfate is high locally.

GALLUP SANDSTONE

The Gallup sandstone of Late Cretaceous age consists of light-gray, buff, and pale-red very fine to very coarse grained sandstone and thin to thick beds of shale, and ranges in thickness from 180 to 350 feet. The grains of sand are angular, poorly sorted, and firmly cemented. The grains are mainly quartz, but feldspar is common in some beds. (See log of well 15.18.20.211.)

The Gallup sandstone crops out in small patches in the center of Gallup, as sharp ridges along the west side of the hogback east of Gallup, as a caprock in escarpments and broad dip slopes eastward from the hogback, and in large areas south, southwest, and west of Gallup, extending into Arizona. A relatively thin layer of unconsolidated silt and sand covers the Gallup sandstone in places along the Puerco River valley in the eastern part of Gallup and about 5 miles west of town. South of Gallup a thick unit of unconsolidated sand, silt, and clay of Pliocene age, the Bidahochi formation, overlies the Gallup sandstone. In the western part of town the top of the Gallup sandstone is about 950 feet below the land surface.

Table 3.—*Specific capacity of wells that tap the Gallup sandstone in the Gallup area*

Well no.	Date of measurement	Duration of test (hours)	Pumping rate (gpm)	Drawdown (feet)	Specific capacity (gpm per foot of drawdown)
14.18.8.430	5–10–51	3	72	118	0.60
14.19.11.320	9– 6–56	1.5	18.9	178	.11
14.19.17.140	3– 54	14	34.6	78.5	.43
15.18.13.132	3–30–56	1	70	45.3	1.5
15.18.14.144a	2–13–56	4	11	45.1	.24
15.18.14.232	2–14–56	5	42	19	2.2
15.18.14.242	2–20–56	7	147	31.5	4.7
15.18.16.421a*	1– 39	----------	91.5	186	.49
15.18.20.211*	9–15–57	24	264	438	.62
15.18.20.221*	5–20–57	24	255	370	.69
15.19.16.410a	1941	----------	20	251	.08
15.19.24.430	2– 5–42	3	60	73	.82
15.20.24.440	8– 54	----------	34	47	.72
16.20.9.400	10–29–57	12	33	176±	.19±

*Well which taps the Gallup Sandstone mainly but also penetrates the Westwater Canyon member of the Morrison formation and the Dakota sandstone.

The Gallup sandstone, the principal aquifer at Gallup, yields as much as 260 gpm of water to wells in the area (table 3).

The Gallup sandstone is recharged in its outcrop areas by infiltration of precipitation and runoff. Locally, it is recharged by downward percolation of water from the overlying unconsolidated sediments. The annual volume of recharge has not been determined, but declining water levels in the vicinity of well fields indicate that recharge is small.

Water is discharged naturally from the Gallup sandstone through small springs and seeps in the outcrop areas and by vertical or lateral leakage into adjacent unconsolidated deposits. The discharged water is dissipated largely by evaporation and transpiration, although some moves laterally out of the area in the unconsolidated deposits.

Water in the Gallup sandstone varies widely in chemical quality, probably because of variations in the quality of recharge water and of ion exchange between the recharge water and the sandstone and its contained water. Oxidation of iron pyrite associated with coal beds and carbonaceous shale likely contributes to the sulfate in the water. Water in the east well field at Gallup contains 740 to 968 ppm of dissolved solids and 261 to 514 ppm of sulfate. Hardness ranges from 280 to 600 ppm. Water in the Gallup sandstone west of town in T. 15 N., R. 19 W., is of much better chemical quality in all respects.

CONCLUSIONS AND SUGGESTIONS

The history of ground-water development and production in Gallup shows that yields of all the formations tested are small. The demand for water caused by the normal growth of Gallup repeatedly has threatened to exceed the capacity of the municipal well system. Periodically, it has been necessary to drill more wells. To date, at least 34 wells have been drilled by the town, or drilled by private companies and later transferred to the town. Only 14 of these wells are in use at the present time (March 1960). The yields of the others are so small that their use is impractical. Obviously, Gallup must find a better source of water or continue periodically to drill more wells to keep pace with the normal population growth and decline in yields. Furthermore, the ground-water supply in the immediate vicinity of Gallup could be depleted eventually.

The San Juan River discharges annually a larger volume of water than is available from any other source, either surface or ground water, in northwestern New Mexico. If Gallup's application for 15,000 acre-feet of water per year (an average of 13,400,000 gpd) is approved, the town will have available an ample supply of water for many years, barring an unforeseen increase in population. This water would be costly, however. A pipeline about 50 miles long and, possibly, a large storage reservoir at one end of the pipeline would be necessary. Also, the water would have to be lifted vertically about 1,000 feet over a high ridge north of town. Should it become necessary to store water in an open reservoir, evaporation losses would be large. Despite the adverse factors, at this time the San Juan River seems to offer the most secure long-term supply of water for the Gallup area.

If Gallup's application for water from the San Juan River is approved and if facilities to transport the water are justified economically, 10 to 15 years may elapse before the supply can be utilized. First, the Navajo Dam and irrigation system must be completed. In the meantime, the town must be supplied from wells, either by expanding the present well system or by developing a new source of ground water.

A temporary supply of water for at least 10 to 15 years can be obtained by increasing the capacity of the present well system. Pumps having larger capacities and deeper settings than those in some of the wells in the western part of town could deliver much more water. The average specific capacity of wells 15.18.20.211 and 15.18.20.221 (table 3) was 0.65 gpm per foot of drawdown when tested—that is, the pumping rate theoretically would be increased by 0.65 gpm for each foot of additional drawdown. In practice the ratio of yield to drawdown commonly becomes smaller as the drawdown becomes greater. The decrease in ratio of yield to drawdown would be partly offset as the water declined below the top of the Gallup sandstone, at a depth of about 950 feet. When the water level is above the top of the Gallup sandstone, the aquifer is artesian; when the water level declines below the top of the Gallup, gravity drainage of the sandstone would begin and the specific capacity should increase slightly. By lowering the pumping level from 800 to 1,200 feet, the yield of each of these wells should be increased by about 250 gpm. Thus, the increment to the water supply would be about 500 gpm, or about 700,000 gpd. The discharge of other wells in the western part of town could be increased, but possibly to a lesser extent.

The water supply could be increased also by drilling additional wells. In the western part of town a well drilled to the base of the Gallup sandstone at a depth of about 1,300 feet should yield about 350 to 450 gpm (500,000 to 650,000 gpd) with a pumping lift of 1,200 feet or less. New wells would have to be at least 1,500 feet from other wells to avoid excessive interference.

Should Gallup's application for water from the San Juan River not be granted or should a much greater temporary supply of water be needed, more distant sources of ground water could be developed. A large supply of ground water may be stored in the Glorieta sandstone and San Andres limestone in the vicinity of the Prewitt Ranch, 20 to 25 miles southeast of Gallup. This possibility has not been fully explored by sustained pumping of a large volume of water.

Only one well (14.15.29.120) on the Prewitt Ranch, near the head of Four Mile Canyon, has demonstrated a large yield. During a 3-hour test this well yielded 1,100 gpm of water with 38 feet of drawdown in water level. The water level undoubtedly would have declined farther, had the same pumping rate been maintained longer. The geologic conditions that make possible this large yield may be restricted to a small area; if so, the large yield of the well could not be sustained indefinitely. A comparison of the yield and the specific capacity of well 14.15.29.120 with that of other wells in the area that tap the Glorieta sandstone and San Andres limestone suggests that the yield of this well is influenced favorably by local geology. (See table 1.) The nonpumping water level in well 14.15.29.120 declined 16 feet between 1941 and 1956. This decline may have been caused by continuous flow from nearby wells that tap the same aquifer, and perhaps also by the effects of several years of drought.

To appraise the ground-water supply at this locality, two or more test wells would be needed. A well, such as well 14.15.29.120, could be pumped and the effects noted by measuring water levels in the test wells. Test pumping should be continuous at a uniform rate for at least 72 hours. Preferably, at least one of the other wells should be tested by pumping.

In exploration for a supply of ground water east of Gallup, these facts should be considered: (a) The Glorieta sandstone and San Andres limestone constitute the most productive aquifer in that area; (b) the aquifer is shallowest, its permeability is greatest, and the chemical quality of its water is best near the outcrops on the north slope of the Zuni Mountains. However, a production well should not be drilled within a mile of an outcrop of the aquifer, as wells too near the outcrop would have limited storage to draw on.

LOGS OF SELECTED WELLS IN THE GALLUP AREA

The following logs were prepared by S. W. West from examinations of drill cuttings and by stratigraphic correlation with other geologic data. The logs contain color symbols in parentheses following the color of the rock. These numbers are from the "Rock-Color Chart," 1948, distributed by the National Research Council, Washington, D. C.

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
15.17.12.300		
McKinley County School at Church Rock. Casing record: 10-inch casing from 0 to 1,965 feet. Casing perforated from 1,725 to 1,965 feet.		
Quaternary:		
Alluvium:		
Sand, light-brown (5YR 6/4), fine to coarse, subrounded to rounded, fairly well sorted; chiefly clear and red-stained quartz, dark minerals rare; pebbles rare	60	60
Upper Triassic:		
Wingate sandstone:		
Lukachukai member:		
Sandstone, light-brown (5YR 6/4), fine- to coarse-grained, subrounded to rounded, fairly well sorted; chiefly clear and red-stained quartz, dark minerals rare, gypsum rare to common; lighter colored and finer grained in lower part	100	160
Mudstone, moderate-red (5R 5/4) to pale-red (5R 6/2) and light-greenish-gray (5G 8/1); some silt and very fine to coarse sand	20	180
Sandstone, light-brown (5YR 6/4), fine- to coarse-grained, subrounded to rounded, fairly well sorted; chiefly clear, frosted, and red-stained quartz, dark minerals rare; weakly cemented	60	240
Chinle formation:		
Owl Rock member:		
Samples not recovered	40	280
Petrified Forest member, upper part:		
Samples not recovered	20	300
Mudstone, pale-reddish-brown (10R 5/4), very light gray (N8), and grayish-red (5R 4/2); highly calcareous; some layers are silty; samples not available from 530–590 feet	320	620
Mudstone, sandy, grayish-red (10R 4/2) flecked with very light gray (N8); sand is chiefly fine to medium, subrounded grains of quartz; some pebbles of mudstone; some gypsum; calcareous	60	680
Mudstone, pale-reddish-brown (10R 5/4) and light-gray (N7); compact; calcareous; some light-gray, sandy siltstone	160	840
Siltstone, sandy, pale-red (10R 6/2) intermixed with very light gray (N8); sand grains chiefly clear and red-stained quartz, dark minerals common, mica rare to common; weak calcareous cement	20	860
Mudstone, grayish-red (10R 4/2) flecked with light-gray (N7) and some pale-brown (5YR 5/2); grains of coarse quartz sand rare	40	900
Samples not available	40	940
Sandstone, clayey, very light gray (N8), very fine to fine grained, subangular to subrounded, fairly well sorted; chiefly clear and frosted quartz, dark minerals rare to common; very weak calcareous cement; some grayish-red (10R 4/2) and greenish-gray (5GY 6/1) mudstone in lower part	20	960

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
15.17.12.300—Continued		
Upper Triassic —Continued		
Wingate sandstone —Continued		
Chinle formation —Continued		
Petrified Forest member, upper part —Continued		
Mudstone, grayish-red (10R 4/2), greenish-gray (5GY 6/1), grayish-red-purple (5RP 4/2), and pale-reddish-brown (10R 5/4); some pale-brown (5YR 5/2), very fine to fine grained sandstone and very light gray (N8) sandy siltstone	210	1,170
Sonsela sandstone bed:		
Sandstone, silty, very light gray (N8) to light-brownish-gray (5YR 6/1), very fine to fine grained, subangular to subrounded, fairly well sorted; chiefly clear and frosted quartz, red- and green-stained quartz common, dark minerals rare to abundant; weak calcareous cement; some grayish-red-purple (5RP 4/2) mudstone and siltstone	50	1,220
Mudstone, silty, grayish-red (10R 4/2); sand grains rare	20	1,240
Sandstone, silty, very light gray (N8) to light-brownish-gray (5YR 6/1), very fine to medium grained, subangular to subrounded, fairly well sorted; chiefly clear and frosted quartz, dark minerals rare to abundant; weak calcareous cement	30	1,270
Petrified Forest member, lower part:		
Mudstone, grayish-red (5R 4/2), grayish-purple (5P 4/2), white, and light-gray (N7); sand grains rare	90	1,360
Mudstone, grayish-red (10R 4/2) and grayish-red-purple (5RP 4/2) flecked with white and greenish-gray (5GY 6/1)	20	1,380
Mudstone, grayish-red (10R 4/2); some very light-gray (N8), fine- to medium-grained, silty sandstone	50	1,430
Mudstone, grayish-red-purple (5RP 4/2) mottled white and very light gray (N8); mica common	10	1,440
Lower member:		
Sandstone, silty, light-brownish-gray (5YR 6/1), very fine to fine grained, subangular to subrounded, well sorted; chiefly clear and frosted quartz, dark minerals rare to abundant; some white clay; weak calcareous cement	10	1,450
Mudstone and siltstone, grayish-red (10R 4/2), grayish-red-purple (5RP 4/2), and dark-reddish-brown (10R 3/4); sand grains rare	70	1,520
Sandstone, silty, light-brownish-gray (5YR 6/1) to brownish-gray (5YR 4/1), very fine to fine grained, subangular to subrounded, some crystal faces, well-sorted; chiefly clear quartz, dark minerals rare; weak calcareous cement	20	1,540
Mudstone, grayish-red (10R 4/2), dark-reddish-brown (10R 3/4), and very light gray (N8); mica common	30	1,570
Sandstone, silty, brownish-gray (5YR 4/1), very fine to coarse grained, subangular to subrounded, poorly sorted; frosted and stained quartz; weak calcareous cement	20	1,590
Mudstone, grayish-red (10R 4/2), pale-reddish-brown (10R 5/4), light-greenish-gray (5GY 8/1), and grayish-purple (5P 4/2); some grayish-red siltstone and light-brownish-gray (5YR 6/1), very fine to fine grained sandstone; some pyrite in lower part	90	1,680

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
15.17.12.300—Continued		
Upper Triassic —Continued		
Chinle formation —Continued		
Shinarump member:		
Sandstone, light-brownish-gray (5YR 6/1), fine-grained, subangular to subrounded, crystal faces common, poorly to well sorted; some chert, limestone, mudstone, and quartzite pebbles; chiefly clear quartz, very finely to coarsely crystalline pyrite rare to abundant, some carbonaceous material; some mudstone; firmly cemented	40	1,720
Middle(?) and Lower Triassic:		
Moenkopi formation:		
Sandstone, conglomeratic, light-brownish-gray (5YR 6/1), fine-to coarse-grained, subangular to subrounded; pebbles are chert, limestone, mudstone, and quartzite; pyrite common, some hematite; firmly cemented	60	1,780
Mudstone, pale-reddish-brown (10R 5/4) to grayish-red (10R 4/2) and light-greenish-gray (5GY 8/1); partly sandy; some siltstone	20	1,800
Permian:		
San Andres limestone:		
Limestone, pale-brown (5YR 5/2), finely crystalline, fairly porous; some vein calcite; partly sandy and silty	40	1,840
Glorieta sandstone:		
Sandstone, grayish-orange-pink (10R 8/2) to moderate-orange-pink (10YR 8/4), fine-grained, subangular to subrounded, well-sorted; chiefly clear quartz, hematite rare; firmly cemented; weakly calcareous; partly silty	95	1,935
Samples not available	30	1,965

15.18.20.211

Town of Gallup. Casing record: 18-inch casing to 100 feet; 12-inch casing to 1,319 feet; 8-inch casing from 1,305 to 2,307 feet.

Quaternary:		
Alluvium:		
Samples not available	-----	-----
Upper Cretaceous:		
Mesaverde group:		
Samples not available	-----	123
Crevasse Canyon formation:		
Gibson coal member:		
Siltstone, sandy, yellowish-gray (5Y 8/1), poorly sorted; sand chiefly clear quartz, dark minerals common; some fragments of coal; calcareous	10	133
Mudstone, medium-gray (N5); grains of clear quartz and dark minerals rare; fragments of coal abundant; weakly calcareous	5	138
Sandstone, clayey, very light gray (N8), fine-grained; chiefly clear and stained quartz, gypsum and dark minerals rare; noncalcareous	10	148

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
15.18.20.211—Continued		
Upper Cretaceous —Continued		
Mesaverde group —Continued		
Crevasse Canyon formation —Continued		
Gibson coal member —Continued		
Siltstone, light-olive-gray (5GY 6/1), well-sorted, compact, noncalcareous	10	158
Sandstone, silty, light-olive-gray (5GY 6/1), poorly sorted, subangular to subrounded; chiefly clear and stained quartz, dark minerals rare, calcareous	5	163
Mudstone, olive-gray (5Y 4/1); limonite stains common, crystalline calcite abundant	5	168
Mudstone, medium-light-gray (N6), noncalcareous; some coal between 180 and 185 feet	17	185
Siltstone, medium-light-gray (N6), fairly well sorted; clear quartz grains common, dark minerals rare; noncalcareous	5	190
Mudstone, medium-gray (N5), noncalcareous; some coal and some light gray (N7) to very light gray (N8) sandy siltstone	50	240
Sandstone, clayey, very light gray (N8), fine-grained, well-sorted, subangular to subrounded; chiefly clear and stained quartz, dark minerals common; noncalcareous	15	255
Mudstone, olive-gray (5Y 4/1) and medium-light-gray (N6); carbonaceous material common; some coal; noncalcareous	20	275
Bartlett barren member:		
Sandstone, light-olive-gray (5Y 6/1) to black, very fine to fine grained, angular to subangular, fairly well sorted; chiefly clear quartz, dark minerals rare; some white clay; noncalcareous; some siltstone	10	285
Mudstone, medium-light-gray (N6); noncalcareous	20	305
Sandstone, light-gray (N7), fine to very coarse grained, poorly sorted, subrounded; clear quartz; calcareous	10	315
Mudstone, medium-gray (N5); noncalcareous	5	320
Siltstone, medium-light-gray (N6), well-sorted; dark minerals common; calcareous; some coal between 334 and 339 feet	29	349
Sandstone, clayey, medium-light-gray (N6), very fine to fine grained, poorly sorted, subangular to subrounded; chiefly clear and stained quartz, dark minerals common; coal in lower part	6	355
Mudstone, medium-light-gray (N6)	14	369
Sandstone, light-gray (N7), very fine to fine grained, poorly sorted, subangular to subrounded; chiefly clear quartz, stained quartz and dark minerals rare to common; some clay; some coal between 384 and 389 feet	20	389
Mudstone, medium-light-gray (N6); some coal	21	410
Siltstone, sandy, medium-light-gray (N6), poorly sorted; sand grains chiefly fine to medium, clear quartz; some mudstone in lower part	25	435
Sandstone, silty, very light gray (N8), very fine to fine grained, poorly sorted; chiefly clear quartz, stained quartz and dark minerals rare; calcareous; some coal in lower part	25	460
Mudstone, medium-dark-gray (N4); carbonaceous material abundant; some coal	15	475

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
15.18.20.211—Continued		
Upper Cretaceous —Continued		
Mesaverde group —Continued		
Crevasse Canyon formation —Continued		
Bartlett barren member —Continued		
Siltstone, light-gray (N7), fairly well sorted; some very fine quartz sand; calcareous	10	485
Mudstone, olive-gray (5Y 4/1); carbonaceous material abundant	20	505
Siltstone, light-olive-gray (5Y 6/1), fairly well sorted; some very fine sand; weak calcareous cement	10	515
Mudstone, medium-light-gray (N6)	20	535
Sandstone, silty, light-olive-gray (5Y 6/1), very fine to fine grained, fairly well sorted, subangular to subrounded; chiefly clear quartz, stained quartz common, dark minerals rare, very weak calcareous cement	10	545
Mudstone, medium-gray (N5)	10	555
Siltstone, sandy, light-olive-gray (5Y 6/1), poorly sorted; sand grains chiefly clear quartz, stained quartz and dark minerals rare; very weak calcareous cement; some coal between 570 and 575 feet	20	575
Sandstone, silty, light-gray (N7), very fine to fine grained, poorly sorted, subangular to subrounded; chiefly clear quartz, carbonaceous material abundant; weak calcareous cement	10	585
Mudstone, medium-gray (N6); some carbonaceous material; some coal	15	600
Siltstone, light-gray (N7); well sorted in upper part, less well sorted in lower part; some very fine quartz sand, increases in lower part; some light-olive-gray (5Y 6/1) mudstone; some fragments of coal; very weak calcareous cement	88	688
Dilco coal member:		
Mudstone, light-olive-gray (5Y 6/1) to medium-gray (N5); partly carbonaceous; coal in upper part	27	715
Siltstone, light-olive-gray (5Y 6/1), fairly well sorted; sand chiefly very fine quartz grains, dark minerals rare; calcareous; some coal and mudstone between 725 and 730 feet	15	730
Siltstone, medium-light-gray (N6), well-sorted; very weak calcareous cement	5	735
Mudstone, medium-light-gray (N6); partly carbonaceous	15	750
Sandstone, silty, light-olive-gray (5Y 6/1), very fine to fine grained; well-sorted, subrounded; chiefly clear quartz, stained quartz and dark minerals rare; weak calcareous cement	10	760
Siltstone, light-olive-gray (5Y 6/1), well-sorted; weak calcareous cement; some coal between 760 and 765 feet and between 785 and 795 feet	35	795
Sandstone, silty, light-gray (N7) to medium-dark-gray (N4), very fine to fine grained, fairly well sorted, subangular to subrounded; chiefly clear and frosted quartz, carbonaceous material abundant; calcareous	10	805
Siltstone, light-olive-gray (5Y 6/1), well-sorted; mica rare; weak calcareous cement; some coal between 815 and 820 feet	20	825
Mudstone, medium-dark-gray (N4); some coal	5	830

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
15.18.20.211—Continued		
Upper Cretaceous —Continued		
Mesaverde group —Continued		
Crevasse Canyon formation —Continued		
Dilco coal member —Continued		
Sandstone, silty, light-olive-gray (5Y 6/1), very fine to fine grained, fairly well sorted, subrounded; chiefly clear and frosted quartz, carbonaceous material common, dark minerals rare; some coal	5	835
Mudstone, medium-gray (N5); partly carbonaceous	15	850
Sandstone, silty, very light gray (N8), very fine to fine grained, fairly well sorted, subangular to subrounded; chiefly clear quartz, dark minerals rare; some coal between 855 and 860 feet	15	865
Mudstone, medium-light-gray (N6); partly carbonaceous	5	870
Siltstone, sandy, very light gray (N8), fairly well sorted; sand chiefly very fine to fine quartz grains, stained quartz common; weak calcareous cement; some coal	10	880
Sandstone, light-gray (N7), fine-grained, well-sorted, subangular to subrounded; chiefly clear and stained quartz, mica rare; some coal	13	893
Mudstone, medium-gray; partly carbonaceous; some coal	5	898
Sandstone, silty, very light gray (N8), very fine to fine grained, fairly well sorted, subangular to subrounded; chiefly clear quartz, dark minerals common	10	908
Mudstone, light-brownish-gray (5YR 6/1) to medium-gray (N5); weakly calcareous	12	920
Siltstone, light-gray (N7), well-sorted, dense	5	925
Siltstone, clayey, light-brownish-gray (5YR 6/1), well-sorted; some very fine sand; some coal	20	945
Gallup sandstone:		
Sandstone, light-brownish-gray (5YR 6/1) and pale-red (10R 6/2), very fine to fine grained, fairly well sorted, subrounded; clear and stained quartz	10	955
Sandstone, pale-red (10R 6/2), fine-to coarse-grained, poorly sorted, subangular to subrounded; chiefly clear and red-stained quartz, dark minerals and mica rare	30	985
Mudstone, medium-gray (N5); partly carbonaceous; fragments of coal abundant	5	990
Sandstone, light-brownish-gray (5YR 6/1), fine to very coarse grained, poorly sorted, angular to subrounded; some crystal faces; chiefly clear and stained quartz, pink feldspar common	28	1,018
Mudstone, medium-light-gray (N6); partly carbonaceous; some coal in lower part	25	1,043
Siltstone, light-olive-gray (5Y 6/1), well-sorted; grains of quartz sand common, mica rare; some coal	17	1,060
Sandstone, light-gray (N7), very fine to coarse grained, poorly sorted, subangular to subrounded; clear and stained quartz; finer grained and silty in lower part	35	1,095
Siltstone, medium-light-gray (N6), well-sorted; mica common	5	1,100

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
15.18.20.211—Continued		
Upper Cretaceous —Continued		
Mesaverde group —Continued		
Gallup sandstone —Continued		
Sandstone, light-gray (N7), very fine to coarse grained, poorly sorted, angular to subrounded; chiefly clear quartz, mica common	5	1,105
Mudstone, medium-gray (N5); some coal	25	1,130
Sandstone, very light gray (N8), very fine to medium grained, fairly well sorted, subangular to subrounded; chiefly clear and smoky quartz; some white clay; calcareous	5	1,135
Mudstone, medium-gray (N5) to medium-dark-gray (N4); partly carbonaceous; some sandy siltstone	10	1,145
Sandstone, light-olive-gray (5Y 6/1), fine-grained; well-sorted, subangular to subrounded; chiefly clear quartz, stained quartz and dark minerals rare; some silt and pinkish-gray (5YR 8/1) coarse sand in lower part	30	1,175
Sandstone, light-olive-gray (5Y 6/1), very fine to medium grained, fairly well sorted, subangular to subrounded; chiefly clear quartz, stained quartz common, dark minerals rare; calcareous; some coal	10	1,185
Sandstone, silty, olive-gray (5Y 4/1), very fine to fine grained; chiefly clear quartz, stained quartz and dark minerals common; partly carbonaceous	15	1,200
Mudstone, medium-light-gray (N6); partly carbonaceous; some coal	15	1,215
Siltstone, medium-light-gray (N6), fairly well sorted; mica and quartz sand common; calcareous	15	1,230
Sandstone, light-gray (N7), very fine to fine grained, partly silty, well-sorted, subangular to subrounded; chiefly clear quartz, stained quartz and dark minerals common, mica rare; weak calcareous cement	50	1,280
Mudstone, medium-light-gray (N6) to medium-gray (N5)	5	1,285
Siltstone, medium-light-gray (N6), well-sorted; mica common; partly carbonaceous; some sandstone	5	1,290
Sandstone, very light gray (N8), very fine to coarse grained, mostly well sorted, subangular to subrounded; chiefly clear quartz, dark minerals and mica common	10	1,300
Mancos shale:		
Siltstone, medium-gray (N5), well-sorted; partly carbonaceous; grains of quartz sand common	5	1,305
Mudstone, medium-dark-gray (N4); carbonaceous	5	1,310
Sandstone, silty, light-olive-gray (5Y 6/1), very fine to fine grained, fairly well sorted, subangular to subrounded; chiefly clear and smoky quartz, dark minerals common; calcareous	5	1,315
Mudstone, medium-gray (N5); carbonaceous	5	1,320
Siltstone, sandy, light-gray (N7), fairly well sorted; sand chiefly quartz, mica common; some coal; weak calcareous cement	10	1,330
Mudstone, medium-dark-gray (N4); partly carbonaceous	5	1,335
Sandstone, silty, very light gray (N8), very fine to fine grained, fairly well sorted, subrounded; chiefly clear quartz, dark minerals common; calcareous	15	1,350

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
15.18.20.211—Continued		
Upper Cretaceous —Continued		
Mancos shale —Continued		
Mudstone, medium-dark-gray (N4); coal abundant; pyrite rare	5	1,355
Sandstone, light-olive-gray (5Y 6/1), fine to very coarse grained, poorly sorted, subangular to subrounded; chiefly clear and smoky quartz, dark minerals common, feldspar rare; calcareous	10	1,365
Mudstone, medium-dark-gray (N4); mica common	20	1,385
Sandstone, silty, light-olive-gray (5Y 6/1), very fine to fine grained, fairly well sorted, subangular to subrounded; clear and smoky quartz; calcareous	5	1,390
Siltstone, sandy, very light gray (N8); sand grains very fine, chiefly clear quartz, stained quartz and dark minerals common; calcareous; some fragments of fossil shell material	15	1,405
Mudstone, medium-gray (N5); mica common; some calcite; some siltstone	40	1,445
Sandstone, silty, very light gray (N8), very fine grained, well-sorted, subrounded; clear and smoky quartz	20	1,465
Mudstone, medium-dark-gray (N4) to dark gray (N3); mica and carbonaceous material common; some calcite and pyrite; some siltstone and very fine grained sandstone	380	1,845
Sandstone, silty and clayey, light-gray (N7), very fine to fine grained, fairly well sorted; chiefly clear and frosted quartz, dark minerals and fragments of calcite common; calcareous	35	1,880
Mudstone, medium-gray (N5) to medium-dark-gray (N4); partly carbonaceous; mica common, pyrite rare, some fragments of fossil shells; some sandy siltstone, increasing in lower part	55	1,935
Lower(?) and Upper Cretaceous:		
Dakota sandstone:		
Sandstone, silty, light-gray (N7), very fine grained, well-sorted, subrounded to rounded; chiefly clear quartz, pyrite and dark minerals rare; calcareous	10	1,945
Mudstone, medium-gray (N6)	5	1,950
Sandstone, yellowish-gray (5Y 8/1), fine-grained, well-sorted, subangular to rounded; chiefly clear quartz, dark minerals rare; calcareous	10	1,960
Siltstone, sandy, very light gray (N8); partly carbonaceous; sand very fine, chiefly clear quartz, stained quartz and dark minerals rare	10	1,970
Sandstone, very light gray (N8), very fine to medium grained, fairly well sorted; subrounded to rounded; chiefly clear quartz, dark minerals rare; some light-gray siltstone, medium-dark-gray mudstone, and coal	20	1,990
Siltstone, medium-gray (N5), well-sorted; mica and carbonaceous material common; calcareous	10	2,000
Sandstone, very light gray (N8), fine-to coarse-grained, fairly well sorted, angular to rounded, some crystal faces; clear quartz; some fragments of coarse quartz embedded in matrix of white clay	5	2,005
Sandstone, clayey, white, fine-to coarse-grained, poorly sorted, angular to rounded; clear and stained quartz grains in clay matrix	15	2,020

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
15.18.20.211—Continued		
Upper Jurassic:		
Morrison formation:		
Brushy Basin member:		
Mudstone and sandy siltstone, greenish-gray (5GY 6/1); some medium-light-gray, very fine to fine grained silty sandstone; calcareous	10	2,030
Siltstone, sandy, greenish-gray (5GY 6/1); poorly sorted; sand grains are clear and green-stained sand, dark minerals, and mica; some greenish-gray (5GY 6/1) mudstone	25	2,055
Westwater Canyon and Recapture members undifferentiated:		
Sandstone, clayey, very light gray (N8), very fine to very coarse grained, some fine gravel, poorly sorted, subangular to rounded; some crystal faces; chiefly clear, frosted, and stained quartz, feldspar common; calcareous	55	2,110
Mudstone, sandy, dark-yellowish-brown (10YR 4/2), grayish-brown (5YR 3/2), and greenish-gray (5GY 6/1); sand chiefly very fine to medium grains of quartz	15	2,125
Sandstone, light-gray (N7), fine- to medium-grained, poorly sorted, angular to subrounded; chiefly clear and frosted quartz, feldspar common, dark minerals rare	25	2,150
Mudstone, greenish-gray (5GY 6/1), grayish-red (5R 4/2), and dark-yellowish-brown (10YR 4/2); partly sandy; sand grains chiefly quartz	10	2,160
Sandstone, clayey, light-gray (N7), very fine to fine grained, poorly sorted, subangular to rounded; chiefly clear and frosted quartz, stained quartz and feldspar common; calcareous	30	2,190
Mudstone, greenish-gray (5GY 6/1), grayish-red (5R 4/2), and dark-yellowish-brown (10YR 4/2); partly sandy	20	2,210
Mudstone, sandy, varicolored	20	2,230
Sandstone, silty, medium-gray (N5), very fine grained, fairly well sorted, angular to subrounded; chiefly clear and smoky quartz, dark minerals and mica common, pyrite rare; calcareous; some mudstone in lower part	75	2,305

Table 4.—*Chemical analyses of waters from wells, springs, and the Puerco River in the Gallup area, McKinley County, N. Mex.*

[Chemical constituents are in parts per million. Analyses are by the U. S. Geological Survey]

Location number: See "System of numbering wells" in text for explanation.
Owner or name: The owner or local designation of well, spring, or stream, generally at the time the sample was collected.
Stratigraphic unit: Symbols are in order from oldest to youngest. (See p. 5.)
g, Glorieta sandstone
sa, San Andres limestone
cl, Lower member, Chinle formation
mw, Westwater Canyon member, Morrison formation
d, Dakota sandstone
g, Gallup sandstone
Temperature: The temperature of the water when it was sampled. Some samples were taken from storage tanks, so the temperature of the water was not the same as it was in the well.
Iron: Total iron in sample. Iron in solution at time of analysis was generally less.
Dissolved solids: The sum of the analyzed constituents.

Location no.	Owner or name	Date collected	Strati-graphic unit	Tem-pera-ture (°F)	Silica (SiO_2)	Iron (Fe)	Cal-cium (Ca)	Mag-ne-sium (Mg)	So-dium (Na)	Potas-sium (K)	Bicar-bonate (HCO_3)	Car-bonate (CO_3)	Sul-fate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Ni-trate (NO_3)	Dis-solved solids	Hardness as $CaCO_3$: Calcium, magne-sium	Hardness as $CaCO_3$: Non-carbon-ate	Per-cent so-dium	Sodium-adsorp-tion ratio (SAR)	Specific conduct-ance (micro-mhos at 25°C)	pH
13.18.23.120	Navajo Tribe..........	3-15-57	g	......	16	.....	5.2	2.8	216		401	0	119	26	1.8	0.8	585	24	0	95	19	892	8.1
14.14.18.110	Al Lavasek	5-24-56	sa	65	6.7	0.0	75	25		6.9	286	0	61	4	.6	.2	320	290	56	5	.2	549	7.4
14.15.29.220	Prewitt Estate	1-20-50	sa	......	......	.....	129	36		3.0	280	0	228	6	.1	.5	540	470	240	1	.1	801	.....
S14.16.9.120	Fort Wingate spring...	8- 9-50	cl, sa	54	13	.....	141	40		7.6	276	0	283	8	.2	.9	630	516	290	3	.1	913	.....
14.18.8.430	Bureau of Indian Affairs.	5-10-51	g	58	6.7	.....	12	4.6	195		323	21	112	35	2.8	.3	548	49	0	90	12	904	.....
16.220b	R. A. Vanderwagon...	8-30-57	g	60	10	2.4	11	3.3	439		607	8	202	185	4.4	.4	1,160	41	0	96	30	1,930	8.4
14.19.17.140	Bureau of Indian Affairs.	2-26-54	g	......	13	.....	50	16	137		410	0	124	14	.8	3.2	560	191	0	61	4.3	877	.....
14.20.16.130	Dean Kirk..............	6-10-55	d, mw	55	15	.....	2.4	3.3	264		273	14	250	59	.9	.3	743	20	0	97	26	1,170	8.7
14.21.26.220	Bureau of Indian Affairs.	2-15-54	d, mw	58	24	.....	101	31	136		342	0	369	7	.5	.2	837	380	100	44	3.0	1,210	.....
15.16.21.330	A. T. & S. F. Railway Co.	4-11-56	sa, g	49	11	.71	131	77	60		172	0	603	4	.3	0	1,040	644	502	17	1.0	1,310	7.6
15.17.12.300	McKinley County Schools.	11-25-57	sa, g	72	20	1.2	74	31	243		215	0	621	11	.7	.1	1,110	312	136	63	6.0	1,540	8.1
16.22	El Paso Natural Gas Co.	8- 6-53	g	......	7.0	.....	83	35	160		168	10	489	25	.3	.1	891	351	197	50	3.7	1,310	.....
15.18.13.132	Gallup 17	3-30-56	g	60	20	1.9	148	56	82		278	0	514	10	.5	.8	968	600	372	23	1.5	1,340	7.3
14.222	Gallup 14	11-28-55	g	60	17	.34	66	28	185	3.6	434	0	261	33	.7	.8	808	280	0	59	4.8	1,210	7.5
14.242	Gallup 13	11-28-55	g	57	15	.....	84	23	193	2.0	447	0	320	23	.5	4.4	892	304	0	58	....	1,320	7.9
15.312b	Elite Laundry..........	2-24-56	g, d	66	16	.....	22	7.1	272		302	6	309	67	.6	1.3	849	84	0	88	13	1,310	8.4
16.332b	Gallup S.F. 7..........	4-14-56	g, d, mw	76	19	.05	25	11	256		354	0	322	27	.6	.3	835	108	0	84	11	1,260	7.9
20.211	Gallup S.F. 11	9-24-57	g, d, mw	77	18	1.2	31	12	197		301	0	274	15	1.2	.1	697	127	0	77	7.6	1,050	7.9
30.320	Mutual Coal Co	6-10-55	g	61	11	.....	1.2	.7	174		284	17	92	18	1.0	.1	454	6	0	98	31	724	8.8
15.19.24.430	Clarke's Dairy	12-30-55	g	62	18	.....	9.5	5.0	92		214	0	59	4.5	.6	.0	294	44	0	82	6.1	457	8.0
15.20.24.440	Navajo Tribe...........	8- 7-54	g	59	19	.....	25	5.3	224		406	0	211	14	.4	.1	699	84	0	85	11	1,050	.....
16.14.33.220	Bureau of Indian Affairs.	2-22-52	mw	......	10	.....	26	4.6	63		226	0	24	6	.4	.5	246	84	0	62	3.0	403	.....
16.16.1.200	.....do	6- 9-55	d	57	14	.....	1.6	1.9	262		518	39	74	8	1.4	1.5	658	12	0	98	33	1,060	8.9
16.18.35.140	Gallup Gamerco Coal Co.	5-24-56	g	59	14	.01	71	21	132		252	0	327	2	.6	.0	692	264	57	52	3.5	1,030	7.6
16.20.9.400	McKinley County Schools.	10-28-57	g	63	14	.....	11	3.1	247		428	13	149	30	2.4	.1	680	40	0	93	17	1,090	8.8
	Puerco River[1]..........	5-21-56	....	60	10	.....	101	19	27		181	0	215	9	1.2	1.0	472	330	182	15	.6	717	7.1
	Puerco River[2]..........	3- 1-57	....	45	14	.....	23	7.1	74		148	0	113	4	.8	.9	310	86	0	65	3.5	497	7.9

[1]Flow entirely from the North Fork of the Puerco River.
[2]Flow entirely from the South Fork of the Puerco River.