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AVAILABILITY OF GROUND WATER AT GRAN QUIVIRA NATIONAL MONUMENT, NEW MEXICO

By

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U. S. Geological Survey

INTRODUCTION

Gran Quivira National Monument, a site of extensive Indian and Spanish ruins, is near the geographical center of New Mexico on the Torrance-Socorro County line 65 airline miles southeast of Albuquerque and 50 miles northeast of Socorro (fig. 1). At the request of the National Park Service a 2-day field study in the vicinity of the monument was made in order to determine the possibility of developing an adequate supply of ground water for use at the monument headquarters, which is in the NW$\frac{1}{4}$ sec. 3, T. 1 S., R. 8 E.

According to Mr. Channing T. Howell, Superintendent of the monument, the number of visitors has increased steadily in recent years and the present water supply is to be augmented as the first step in a plan to enlarge the facilities at the monument. Plans call for the construction of two additional houses for full-time Park Service employees, two small houses for summer employees, a visitor center, and a campground with drinking water and toilet facilities. Additional water is needed now to provide adequate fire protection. It is estimated that the total number of visitors will be 25,000 per year by 1966.

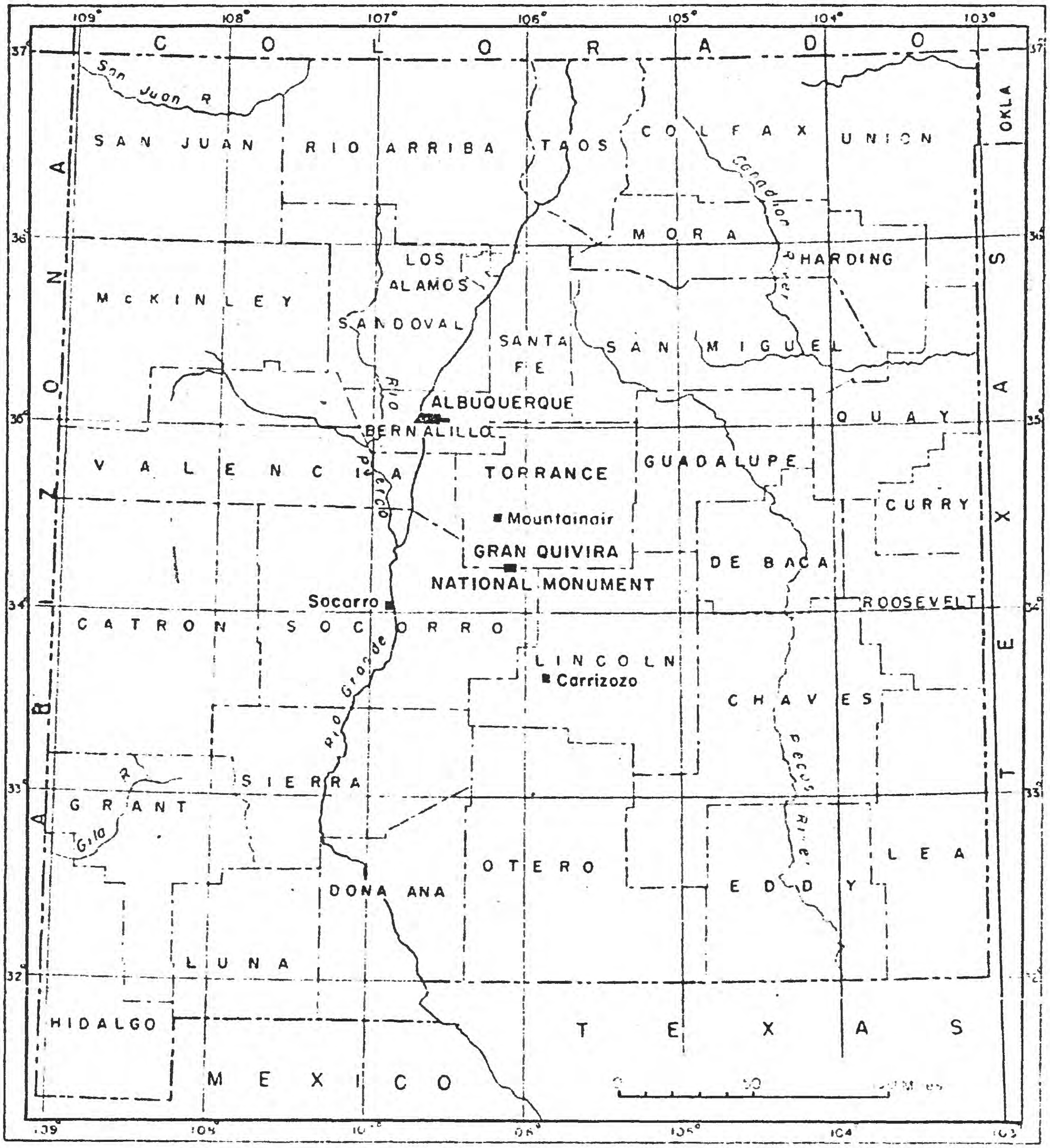

Figure 1.--Location of Gran Quivira National Monument, New Mexico.

A single well 875 feet deep at the monument headquarters (table 1) supplies water of such poor chemical quality, containing about 3,800 parts per million (ppm) of dissolved solids, that it can be used only for sanitary and similar uses. With present equipment the well yields 4 gallons per minute (gpm), but pumps air after only 2½ hours of pumping. The 600-gallon storage tank into which the water is pumped can be filled again after an interval of about 3 hours. A sustained yield of about 2 gpm is indicated. Drinking water is hauled by truck from Mountainair, 26 miles away, at a total cost of about $12 per thousand gallons. The water costs $2 per thousand gallons at Mountainair; the remainder of the cost is in the hauling. At present about 500 gallons is hauled every two weeks. This amount supplies the needs of the one resident family at the monument and the needs of visitors. It is estimated that a well capable of a sustained yield of 10 gpm (15,000 gallons per day) would meet the current demand quite adequately and would also meet the demand of a substantially increased number of visitors.

Previous and Present Investigations

The geology of the area in the vicinity of the monument is discussed in several published reports, (Bates and others, 1947; Wilpolt and Wanek, 1951; and Wilpolt and others, 1946). These studies laid emphasis on areas to the northwest, west, and southwest, where a greater thickness of rocks is exposed. The geology and ground-water resources of Torrance County have been investigated by the U. S. Geological Survey (Smith, 1957). Smith's report, together with unpublished data collected by Smith in Socorro County, provided basic information for the present study.

Two days were spent in the field by the writer in company with Mr. Howell, and Mr. J. L. Kite, local rancher and part-time employee of the Park Service. A cursory examination was made of rocks exposed at the surface; data on existing wells (including driller's logs on several wells) were obtained; samples of water were collected from a few wells; and altitudes of a number of wells were determined by an aneroid barometer. The cordial assistance of Mr. Howell, Mr. Kite, and Mr. K. A. Huey, driller, of Claunch, N. Mex., is gratefully acknowledged.

In the course of altimeter traverses between the monument and points of known altitude at Mountainair and at the end of the pavement in sec. 6, T. 1 N., R. 8 E., it was noted that the datum used for the Park Service map of the monument grounds ($\frac{NM}{Q\text{-}4937}$) is 140±5 feet higher than true sea level datum. This fact should be considered if the map accompanying this report is used in conjunction with maps based on that assumed datum.

Well-Numbering System

The well-numbering system used by the Geological Survey in this and other reports on areas in New Mexico is based on the common subdivision of surveyed land into townships, ranges, and sections. The well number consists of 4 segments, (see fig. 2) each separated by periods. The first 3 segments denote, successively, the township, range, and section. The letter "S" is used as a suffix to the first segment to denote townships south of the New Mexico base line (coincident with the Torrance-Socorro County line in the vicinity of Gran Quivira).

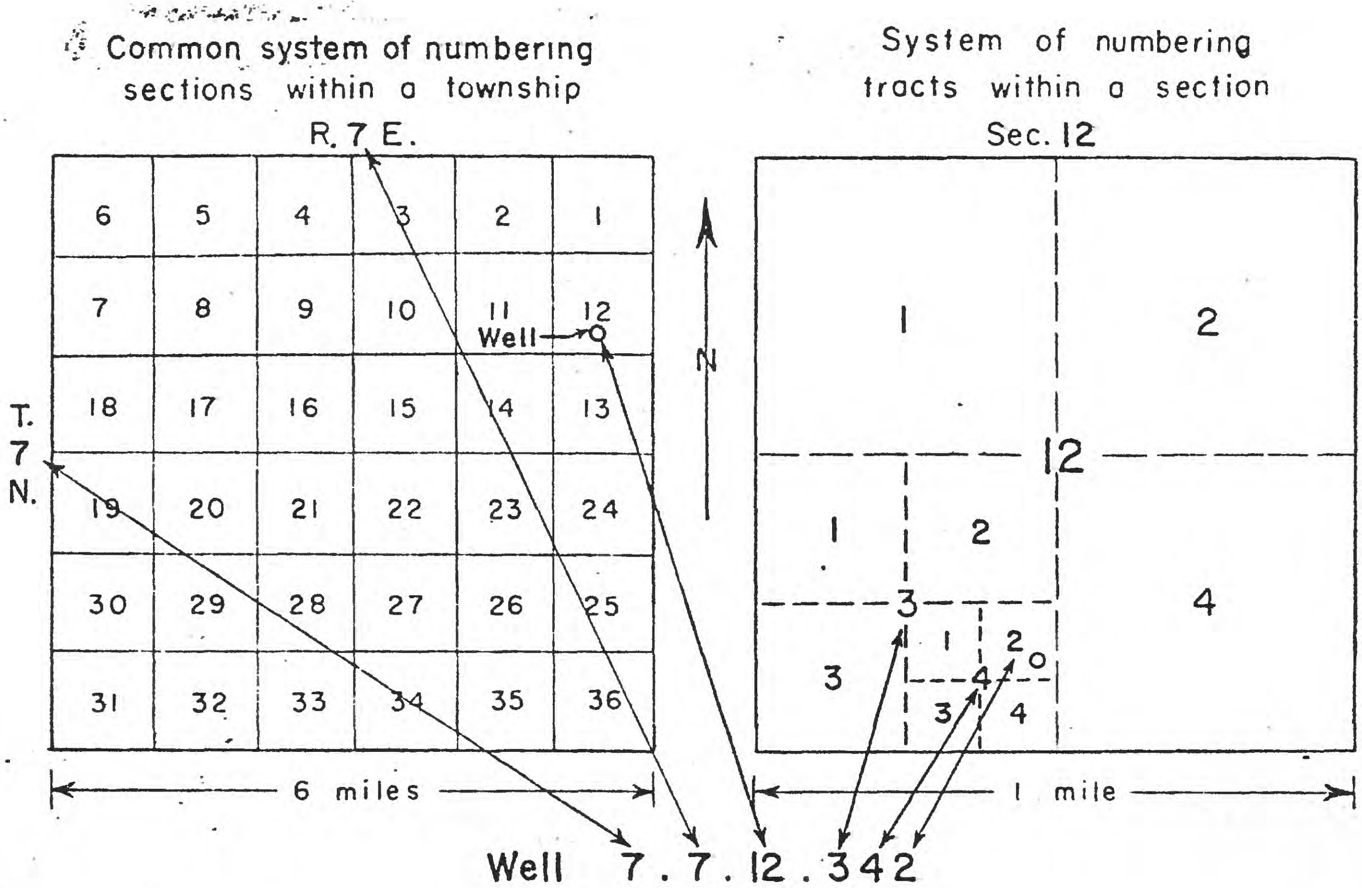

Figure 2 -- System of numbering wells in New Mexico

The fourth segment contains 3 digits and locates the well within the section. The four 160-acre tracts within a section are numbered 1, 2, 3, and 4 in the normal reading order. Each 40-acre tract within the quarter-section is designated in the same manner, and each 10-acre tract within each 40-acre tract is similarly numbered. If a well cannot be located more accurately than to the nearest 40 acres, a zero is used in place of the last digit.

TOPOGRAPHY AND DRAINAGE

The land surface in the vicinity of the monument is a typical rolling to hilly karst topography, whereon the surface features are controlled largely by the solution of limestone, which underlies the entire area. Surface drainage is poorly developed. There are no perennial streams. The courses of most of the intermittent streams are short, and runoff from the juniper- and piñon-covered rocky slopes drains into closed depressions (see fig. 3), where the water evaporates or disappears beneath the surface. Gentle slopes are covered with a moderately thick sandy soil that has been cultivated extensively in past years by dry farming methods. At present little land is under cultivation, but many of the old fields show the effects of cultivation; drift sand is common and the natural vegetation has not returned even to fields that have lain fallow for many years.

The average annual precipitation at Gran Quivira is about 14.62 inches, but for the past several years precipitation has been below average.

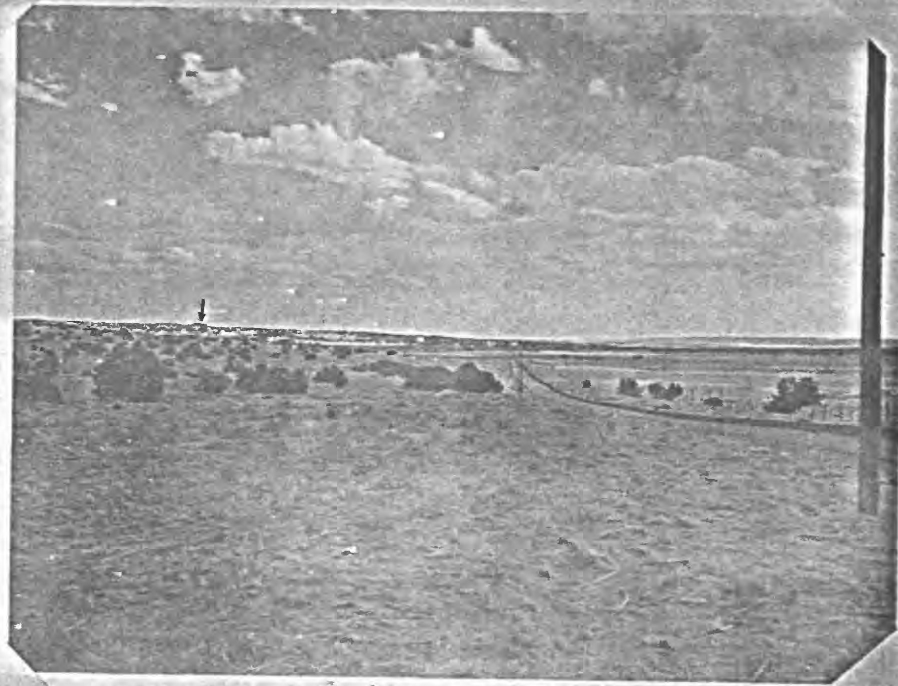

Figure 3.--Broad open valley northwest of Gran Quivira National Monument. Ruins of San Buenaventura Mission are visible on the skyline in left background. Village of Gran Quivira is near the vanishing point of State Highway 10. The northern end of Monte Prieto is in right background. Camera in $W\frac{1}{2}$ sec. 23, T. 1 N., R. 8 E. View south. March 13, 1957.

ROCK FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS

Most of the rocks exposed at the surface and to a depth of at least 1,500 feet below the surface in the vicinity of Gran Quivira are Permian in age. The San Andres limestone is exposed at the surface and is underlain by the Glorieta sandstone, which in turn is underlain by the Yeso formation. All these formations are cut by diorite dikes of Tertiary age. Recent alluvium covers the older rocks in the broader valleys. The geology of the area is shown on plate 1.

Although slumping of the limestone exposed at the surface gives the impression that every hill is an anticline, actually the sedimentary rocks in the Gran Quivira area dip gently to the southeast. Because of the intensity of solution and subsidence activity, it is impossible to measure the degree of dip by surface methods, and subsurface data are inadequate for reliable determination.

Permian Rocks

The Yeso formation is the principal water-bearing formation in the vicinity of Gran Quivira; it is not exposed in the immediate area, but crops out in the western escarpment of Chupadera Mesa about 10 miles west-southwest of the monument. Outcrops of the Yeso were not examined in the field during this investigation; therefore, the following description is adapted largely from Bates and others (1946). The Yeso is made up of siltstone, fine-grained sandstone, gypsum, and some limestone. The pink, gray, buff, or tan sandstones and siltstones are generally gypsiferous. The gypsum beds range in color from white to gray and are commonly impure, containing some shale, siltstone, or fine-grained sandstone. The limestones are gray, buff, or brown. In the northern half of the Gran Quivira quadrangle a composite section shows the Yeso to be about 680 feet thick. The formation thickens markedly to the south and in the vicinity of the monument it may be as much as 1,000 feet thick.

All the wells listed in table 1 except the shallow wells in sec. 33, T. 1 N., R. 8 E. obtain water from the Yeso. The permeability of the sandstones and siltstones in the Yeso is generally low, but the limestones are highly permeable in some places. The great depth to water and poor chemical quality of water in the Yeso in many areas has apparently discouraged prospecting for large quantities of water; however, yields of more than 100 gpm have been obtained in the vicinity of Mountainair and at a site about 40 miles south of Gran Quivira.

The Glorieta sandstone, which overlies the Yeso formation, is exposed in the northern and western escarpment of Chupadera Mesa. It is well cemented, cross-bedded buff to brown, medium-grained quartz sandstone which ranges in thickness from 275 feet on the northern edge of the mesa, about 14 miles north-northwest of the monument, to about 175 feet in sections exposed about 14 miles southwest of the monument. An interpretation of the driller's logs of wells indicates that the Glorieta sandstone is about 100 feet thick in the vicinity of the monument.

No wells in the area obtain water from the Glorieta sandstone. The formation lies entirely above the main zone of saturation and the possibility of obtaining perched water in the Glorieta appears rather slight, because of the likelihood that solution of gypsum and limestone in the Yeso, with subsequent collapse or subsidence of overlying beds into the caverns thus formed, would rupture any impermeable beds in the upper Yeso and permit water to percolate to the main zone of saturation.

The San Andres limestone overlies the Glorieta sandstone and extends from the surface to a depth of more than 400 feet in the Gran Quivira area. The San Andres is a light gray to black fine-grained, thick-bedded to slabby limestone that contains gray to white gypsum beds, and some sandstone. A brown to black shale bed 3 to 12 feet thick was reported at a depth of 200 to 300 feet in 3 of the 4 logs of wells (table 3) in the vicinity of the monument. The San Andres is intensely jointed, and weathered surfaces have a blocky appearance. Cavities are reported in the logs of wells penetrating the San Andres, and the joints and crevices might cause difficulty in keeping a drill hole straight. The San Andres is not known to be water bearing in the Gran Quivira area although there may be local zones of perched water in the formation, inasmuch as "seeps" are reported in the San Andres on driller's logs.

Tertiary Rocks

Igneous rocks of Tertiary age (Bates and others, 1946) crop out at many places in the area. They are dikes and sills of diorite, the dark minerals of which weather to a greenish-gray. Most exposures have a salt-and-pepper appearance because of the combination of light feldspar crystals and the dark minerals. No fresh rock was observed in outcrops, nor in an 8-foot prospect pit in which the diorite has been exposed. One exposure was noted in which the diorite completely enclosed a tabular mass of limestone less than 2 inches thick and more than 4 feet long. Exposures of the dike rock shown on plate 1 are those shown on published geologic maps plus a few small exposures noted that were not previously mapped. There are undoubtedly numerous other exposures that have not been mapped. A number of the dikes strike in an east-northeast direction in the vicinity of the monument and a distinct "grain" that appears on photo mosaics of the area might lead to the speculation that the dikes are continuous for long distances, but this cannot be verified in the field, possibly because of the high degree of weathering and locally thick soil cover, or possibly because the dikes do not persist. Diorite was reported in two of the four well logs obtained. The dikes give the appearance of having been emplaced into the San Andres after many joint cracks had been developed. The diorite is not known to be water bearing and it appears very unlikely that it would be; however, it appears possible that perched water might accumulate on top of a sill of the diorite, given a favorable structural situation, though no such occurrence was found. An unsuccessful attempt was made to find exposures of diorite in the northern part of sec. 4, T. 1 S., R. 8 E. Several places were found in which weathered fragments of the rock were more common than elsewhere, but these higher concentrations may have been the result of stream action.

Quaternary Alluvium

Recent alluvium occupies broad valleys and most of the undrained depressions in the area. Where exposed in some of the deeper gullies on the upper reaches of the valleys, the alluvium is poorly sorted and ranges in texture from silt to moderately coarse gravel. Material in the broad undrained depressions is probably fine-grained sand or silty sand. Little information is available on the thickness of the alluvium, except in sec. 33, T. 1 N., R. 8 E. At least 70 feet of alluvium was penetrated in the dug wells in this section, but the total thickness may be significantly greater. The alluvium is known to be water bearing only in this one area, therefore, general statements on its water-bearing characteristics cannot be made; in this area the dug wells usually yield 2 to 3 gpm, but the yield of some of the wells decreases to a reported five quarts per day after prolonged dry periods.

GROUND-WATER OCCURRENCE AND MOVEMENT

The depth to water in wells and the regional trend of the main water table are shown on plate 1. Contours indicate the shape of the water table; movement of water is perpendicular to the contours. Although the gradient indicated may differ from the actual gradient in detail, because of inaccuracies in reported water levels, artesian and water-table conditions, and in altitudes determined, the map is probably of fair accuracy.

In general ground water moves from northwest to southeast. All the recharge to the ground-water body is derived from local precipitation and runoff. Precipitation is probably greatest on the range of hills extending northward from Monte Prieto near the western edge of the map area and recharge is probably also greatest along the east slopes of the hills as a result of runoff. The pronounced troughs in the water table extending from near the center of T. 1 N., R. 8 E. southeastward and from sec. 4, T. 1 S., R. 8 E. southwestward may indicate relatively permeable zones in the Yeso formation.

The effect of the diorite dikes on ground-water movement can only be inferred. Inasmuch as the diorite is a dense rock of apparently low permeability, it is assumed that diorite dikes and sills serve to restrict or inhibit ground-water flow and might under particular conditions result in perched water bodies.

There are several aquifers within the Yeso formation. The first water encountered by wells is apparently under water-table conditions; wells that penetrate deeper strata in the Yeso encounter water under artesian head, which rises in the hole to an elevation higher than the first water encountered. This is indicated by the fact that in well 1S.8.11.322 the first water was encountered at a depth of about 660 feet; yet the static level of water in the well was 642 feet after completion to a depth of 840 feet.

A cross section through wells 1.8.15.111, 1.8.22.121, 1S.8.3.121, and 1S.8.11.322 is shown on plate 1. Stratigraphic correlation is based on driller's logs (table 3). Although no information is available on the rate of production and adequacy of the wells shown on the cross section, except the well at the monument, the Kite deep well (1S.8.11.322) is reported to be strong, and the principal water-bearing unit is reported to be the 30-foot sand between 810 and 840 feet. Apparently none of the other wells penetrated to this lower sand.

The only known body of perched water in the area is tapped by four producing wells in the SE¼ sec. 33, T. 1 N., R. 8 E. This body of water is of very limited extent. A reported 250-foot dry hole was drilled near the southeast corner of sec. 33, and well 1.8.33.210 apparently did not encounter the perched water. The body of perched water is recharged largely by runoff from secs. 19, 20, 28, 29, and 30, T. 1 N., R. 8 E. The mechanism of natural discharge from this perched water body cannot be determined from the data available. The amount of water in storage is undoubtedly very limited. Similar bodies of perched water may exist elsewhere in the area, but no simple criteria for recognizing the field conditions requisite for such occurrence was apparent. Several wells in the area have been drilled in similar topographic situations, such as wells 1S.8.21.431, 1S.9.4.140, and 1.9.28.333, but they are all deep wells and it is presumed that little or no shallow water existed. If other perched bodies of ground water exist in the area, it appears probable that they contain limited storage, as the general conditions favorable to the occurrance of perched water in the area are poor.

CHEMICAL QUALITY

Ground water from the Gran Quivira area shows a wide range in chemical quality (see table 2). Water from the Yeso formation is highly mineralized; that from the alluvium is of relatively good chemical quality. The principal dissolved constituents in water from the Yeso are calcium and magnesium sulfate, which cause the water to be hard, and give it a very bitter taste. Such water may have a laxative effect, particularly on people who are not used to it. Specific conductance (which provides a rough index of the amount of dissolved mineral matter) of water from the Yeso ranged from 953 micromhos in the Connell well (1S.8.9.310) to 3,800 in the Park Service well (1S.8.3.121). Water from the Kite shallow well (1.8.33.421), which is finished in alluvium, had a specific conductance of only 455 micromhos. The sulfate content, which was determined in all samples collected, also gives indication of the relative quality of the water. Sulfate content of water samples from wells finished in the Yeso formation ranged from 381 ppm in the Connell well (1S.8.9.310) to 2,490 ppm in the Park Service well (1S.8.3.121). By contrast, the sulfate content of water from the Kite shallow well (1.8.33.421) was only 45 ppm.

Chemical quality of all the water samples collected in the Gran Quivira area was inferior to that of a sample taken from one of the Mountainair public supply wells (table 2), but water from the Kite shallow well (1.8.33.421) is only slightly more mineralized than the Mountainair water.

Standards as to chemical characteristics recommended by the U. S. Public Health Service (1946) for drinking water used on interstate carriers and for public supplies have been adopted by the New Mexico Department of Public Health for drinking water. Listed below are the recommended concentration limits, the range in concentration in samples from the Yeso formation in the Gran Quivira area, and the concentrations in the Kite shallow well for common ions on which there are limits. These limits are set intentionally low and are exceeded in many domestic and public water supplies in New Mexico. A sample of water collected in December 1956 from a Carrizozo public supply well contained dissolved solids and sulfate in concentrations of 1,230 ppm and 620 ppm, respectively.

	Recommended limits (ppm)	Water from Yeso formation (ppm)	Kite shallow well (1.8.33.421) (ppm)
Sulfate	250	381 to 2,490	45
Chloride	250	3.4 to 47	4.0
Magnesium	125	37 to 233	13
Fluoride	1.5	0.2 to 1.9	.4
Dissolved solids (sum)	500*	753 to 3,550	283

*1,000 ppm permissible when water of better quality is not available.

Maximum figures for the samples from the Yeso are all from the Park Service well. Minimum figures for sulfate, magnesium, and dissolved solids are from the Connell well (1S.8.9.310). The above data show that the only water within the recommended standards for dissolved mineral matter is that from the Kite shallow well (1.8.33.421). However, water from the Connell well (1S.8.9.310) and the Jackson well (1.8.33.210) exceed only the recommended limits for sulfate and dissolved solids, being within the permissible limits for dissolved solids.

Bacteriological analyses of the waters were not made, and the chemical analyses do not indicate bacteriological quality of the water. It is unlikely that a properly constructed deep well would yield bacterially polluted water, but a bacteriological analysis should be made of any water to be used for human consumption. Presence of decayed organic matter in water may cause the nitrate content of water to be higher than normal, in which case there may be danger of cyanosis in infants who are taking the water in formula (Waring, 1949). However, the nitrate content is not considered particularly dangerous until it reaches a concentration of 44 ppm. The highest nitrate content noted in the samples analyzed was 7.3 ppm in the sample from well 1.8.33.421, but the nitrate content in shallow wells can and does vary with time, and might increase in the perched aquifer at a later time.

POSSIBILITY FOR ADDITIONAL DEVELOPMENT

Although the problem is principally one of obtaining an adequate quantity of potable water for use at the monument, consideration has also been given to the possibility of increasing the yield of the present well by cleaning, rehabilitating, or deepening it, because larger numbers of visitors will undoubtedly increase the need for water for use in sanitary facilities.

Although it was reported that the existing well at the monument had been weak from the time it was drilled, the possibility that the yield of the well has decreased cannot be ruled out. The excessive drawdowns noted in recent years may have caused scale to be precipitated at the casing slots as a result of prolonged exposure to air, thus decreasing the size and effectiveness of the openings. If this is the case, the quantity problem might be partially solved by cleaning the well -- swabbing and possibly acidizing or treating with dispersing agents. However, the low yield probably results from low permeability of the aquifer or failure to penetrate an adequate thickness of the aquifer. The well is between two dikes. The log of the well (table 3) indicates that dike rock was penetrated only between 223 and 250 feet; however, it is possible that the "black limestone" reported between 840 and 875 feet was actually dike rock. This would help to explain the low yield and poor chemical quality. Another possibility is that the "black limestone" is not water bearing, and that water can enter the well only through the bottom of the hole. This is borne out by the statement on the log that water was encountered at a depth of 875.3 feet.

The water sand in well 1S.8.11.322 penetrated between 810 and 8[illegible]0 feet was not penetrated in the well at the monument (1S.8.3.121) but it may be present at greater depth. Deepening the present well by 50 to 75 feet probably would be an adequate test for the presence of the sand, but this possibility is also subject to limitations imposed by the possible occurence of the diorite.

The presence of perched water of good chemical quality in the SE¼ sec. 33, T. 1 N., R. 8 E., raises the question as to its lateral extent. The reported dry hole near the southeast corner of section 33 suggests that the perched water is of very limited extent in a southeastward direction from its known area of occurence. The alluvium is probably thin in the southeast corner of section 33. The alluvium in which the perched water is found is continuous into the northern part of sec. 4, T. 1 S., R. 8 E., but it may be thin in the vicinity of the section line common to secs. 33 and 4, owing to a possible subsurface extension of the diorite dike in section 33. Alluvium is probably thickest along the arroyo that enters section 4 near the northwest corner of the section and ends in the intermittent lake near the center of section 4. The northern extent of the perched water is almost certainly south of well 1.8.33.210. The western limit is determined by the alluvium-San Andres contact, which trends north-south through the west half of section 33.

The extent of the perched water probably could be delineated fairly accurately by 6 to 10 shallow test holes drilled to a depth of 50 to 100 feet, but if the underlying confining bed were penetrated, provision to plug the test holes would have to be made to insure that the aquifer would not be drained. Even if the lateral extent of the perched water were known accurately, a controlled pumping test would be necessary to determine the hydraulic characteristics of the aquifer before the adequacy of the aquifer could be estimated. Also, if a well were developed in this perched zone the availability of water to the existing four wells would be decreased.

It appears that even though the best water to be obtained from the main aquifer may be of marginal chemical quality with respect to potability, the probability of obtaining an adequate and permanent yield is considerably greater from a deep well drilled to the main zone of saturation than from a shallow well in the perched water. The fact that water from wells 1.8.33.210 and 1S.8.9.310 is of much better chemical quality than that from other wells tapping the Yeso formation probably indicates a local source of recharge that has percolated to the main water table with relatively little contact with or movement through gypsum-bearing beds. The source of this recharge cannot be determined with the data at hand, but it may be infiltration of runoff from one or more of the canyons flowing eastward off Monte Prieto. The area between the center of sec. 4, T. 1 S., R. 8 E., and well 1S.8.9.310 appears to be the most favorable for testing the main zone of saturation. The main water table is 500 to 550 feet below the surface in the central part of section 4. The water-table trough extending through sections 4, 9, and 17 suggests that the aquifer is relatively permeable in this area. Water moving from the west may be of generally better quality than that moving toward the trough from the east; therefore, a well on the western flank of the trough appears more likely to encounter water of acceptable quality that could be produced in adequate quantity.

CONCLUSIONS

Inasmuch as the existing well at the monument may be finished in diorite, rehabilitation or deepening of the well does not appear to be a feasible solution to the problem of increasing the quantity and improving the quality of the monument water supply. It is doubtful that the yield of the well could be increased. The quality of the water probably would not be significantly improved. However, there is a possibility that the water sand encountered in well 1S.8.11.322 might be penetrated in the monument well by deepening it to about 950 feet.

Because of the limited areal extent and probable limited thickness of the perched aquifer in sec. 33, T. 1 N., R. 8 E., additional wells in it might lower the water table to the extent that existing wells would go dry. However, a well less than 100 feet deep in the NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 4, T. 1 S., R. 8 E., might encounter perched water, which should be of good quality. This area is not considered the best place in which to test the main zone of saturation; however, because of possible subsurface westward extensions of the two dikes that cross monument land to the east.

The most favorable areas for drilling a deep well to the main water table are the central and southwestern part of sec. 4, T. 1 S., R. 8 E., the southeastern part of section 5, the eastern part of section 8, and the northwestern part of section 9. A properly constructed and developed well about 600 to 650 feet deep would probably produce a minimum of 5 to 10 gpm (7,500 to 15,000 gallons per day). Sections 5 and 8 are apparently State-owned land. Chemical quality to be expected is open to some question; the water can be expected to contain dissolved mineral matter in concentrations that are near or exceed the concentrations in the standards recommended by the U. S. Public Health Service (p. 19).

A possible compromise location, at which the occurrence of perched water might be tested, and, if insufficient water or no water is encountered, drilling could be continued to the main water table, is in the north-central part of sec. 4, T. 1 S., R. 8 E. This location is considered less favorable for developing perched water.

If the concentrations of dissolved mineral matter exceed those recommended in the standards by 20 to 50 percent, the water could still be used, probably without harmful effects. The concentrations could exceed those in the standards by substantial amounts and still be comparable in quality to the water of many of the towns and cities in New Mexico. If the water does not meet Park Service requirements for drinking-water quality, consideration could still be given to using the water in sanitary facilities, inasmuch as the prospects are good for a yield substantially greater than that from the present well.

If a deep well is drilled, it would be desirable to plan for occasional sampling of the water for chemical analysis as drilling progresses, so that if zones yielding very highly mineralized water are encountered they could be cased off. Permeability of the Yeso formation varies from place to place and may be low. Therefore, a well should not be abandoned as inadequate until intensive efforts have been made to develop the well by surging, acidizing, and treating with clay-dispersing agents such as sodium hexametaphosphate.

Consideration might be given also to the possibility of perforating the casing opposite any bodies of perched water, even though they are very thin, and to perforating above any beds of shale, diorite, or other impermeable rock. This would permit perched water to drain into the well and might make available to the well seasonally occurring perched water that collected on impermeable beds. Such a procedure would require a detailed driller's log, including rock description, drilling time, and notations of the presence of any seeps or crevices, and should be based on a careful analysis of drill cuttings, sampled every 10 feet and at changes in formation.

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Table 1.--Records of wells in the vicinity of Gran Quivira National Monument, Torrance and Socorro Counties, [illegible]

Location: See text for explanation.

Altitude: Altitude of land surface at well determined by barometric altimeter.

Type of well: Dr, drilled. Du, dug.

Depth of well and water: [illegible]

Use: D, domestic, Dl, [illegible]

All equipped wells have [illegible] gasoline motors.

Location number	Owner or name	Driller	Date completed	Topographic situation	Altitude (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Principal aquifer	Water level (feet)	Use of water	Quality
1.7.26.332	E. V. Cain	K. A. Huey	-	Hilltop	-	Dr	740	-	Yeso formation	692	S	Poor
1.7.35.310	-	-	-	-	-	Dr	970	-	do.	Less than 400	N	-
1.8.4.133	Bill Hamilton	K. A. Huey	-	-	-	Dr	790	-	do.	465	S	-
1.8.4.222	-	-	Before 1921	-	6,540	Dr	520	-	do.	500±	S	-
1.8.15.111	C. E. Fulfer	K. A. Huey	1955	Rolling upland	6,550	Dr	710	8 5/8	do.	5850 670	S	-
1. .22.121	J. A. Connell	do.	1958	do.	6,450±	Dr	720	7	do.	5760 690	S	-
1.8.33.210	Homer Jackson	-	-	Valley floor	6,350±	Dr	500-600	-	do.	500+	S	Hard, [illegible]
1.8.33.421	J. L. Kite	-	Before 1930	do.	6,340±	Du	55	36±	Alluvium	50	S	Good
1.8.33.421a	do.	-	Before 1930	do.	6,335±	Du	63.5	36±	do.	52.5	S	Good
1.8.33.423	do.	-	Before 1930	do.	6,330±	Du	60	36±	do.	52.0	S	Good
1.8.33.423a	do.	-	Before 1930	do.	6,330±	Du	57.1	36±	do.	43.1	S	Good
1.8.36.222	Frank Stephens	-	-	Rolling upland	-	Dr	600	-	Yeso formation	580	S	-
1.9.20.333	Joe Atkinson	K. A. Huey	-	Closed depression	6,330±	Dr	510	-	do.	480	S	-

Table 1.--Records of wells in the vicinity of Gran Quivira National Monument, Torrance and Socorro Counties, N. Mex.--Continued

Location number	Owner or name	Driller	Year completed	Topographic situation	Altitude (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Principal aquifer	Water level (feet)	Use of water	Quality	Remarks
1S.8.1.433	James Wells	-	-	Rolling upland	-	Dr	670	8	Yeso formation	-	S	-	No pump. Chemical analysis, table 2.
1S.8.3.111	U. S. Dept. of Interior, National Park Service	K. A. Huey and Sheets Drilling Co.	1934	Near crest of hill	6,430	Dr	875	5	do.	-	D	Poor	92 feet of [illegible]-inch casing; 5-inch casing to total depth. Pumps air after [illegible] hours at 4 gpm. Chemical analysis, table 2; driller's log, [illegible] yield 3/13/57 - 4 gpm.
1S.8.7.332	E. V. Cain	-	Before 1928	Rolling	6,404	Dr	500	-	do.	480?	S	Poor	Cased to 6 ft.
1S.8.9.310	Mrs. Minnie Connell	K. A. Huey	1934	do.	6,263	Dr	510	6	do.	5685 505	S,D	Fair	Chemical analysis, table 2.
1S.8.11.322	J. L. Kite	do.	1952	do.	6,432	Dr	842	6	do.	642	S	Poor	Pump at 71- ft. Chemical analysis, table 2; driller's log, table 3. Cased to 60 ft.
1S.8.21.431	E. V. Cain	-	-	Gently sloping valley floor	6,216	Dr	800+	-	do.	650?	-	-	Caved at 200 ft. Chemical analysis, table 2. Abandoned. No pump.
1S.8.21.431a	do.	K. A. Huey	1956	do.	6,216	Dr	650	6	do.	520	S	Poor	Quality reported better than well 431.
1S.8.23.111	Kinley Galloway	-	-	Rolling	6,348	Dr	620	-	do.	600	S	Poor	-
1S.9.4.140	-	-	-	do.	-	Dr	630	-	do.	600	S	Poor	-
1S.9.7.144	James Wells	Mack Wells(?)	-	do.	-	Dr	650	6	do.	619	U	-	Unused. No pump. Dry at 600 ft. 3/12/57
1S.9.9.132	Frank Wells	-	-	Hilly	-	Dr	832	-	do.	657	S	Poor	-

Table 2.--Chemical analyses of water from wells in the vicinity of Gran Quivira National Monument, Torrance and Socorro Counties, N. Mex.
(Chemical constituents in parts per million. Dissolved solids is sum of determined constituents)

Analyses by U. S. Geological Survey

Location number	Owner or name	Date collected	Stratigraphic unit	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium, potassium (Na+K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Dissolved solids	Specific conductance (micromhos at 25°C)	pH
1.7.26.332	B. V. Cain	3/12/57	Yeso formation	-	-	-	-	172	0	1,450	3.0	-	-	860	719	-	2,320	7.2
1.[illegible].4.222	-	8/2/50	do	7.8	336	150	12	110	0	1,320	11	0.6	0.2	1,460	1,370	1,890	2,170	-
1.[illegible].33.210	Homer Jackson	6/7/57	do	9.1	157	64	13	15	0	[illegible]	[illegible]	1.1	0.2	654	644	887 1/	1,110	6.1
1.[illegible].33.421	J. L. Kite	3 13 57	Alluvium	10	57	13	20	220	0	45	4.0	.4	7.2	196	15	283	455	7.8
[illegible].312	Town of Mountainair	7 27 51	Yeso formation	24	43	13	14	132	0	17	10	.2	3.7	161	-	220	360	-
1[illegible].1.433	James Wells	8 2 50	do	21	340	171	15	273	0	1,250	34	0.2	3.6	1,550	1,320	1,970	2,270	-
1[illegible].121	National Park Service	3 1[illegible] 57	do	7.3	504	233	231	66	0	2,490	47	1.9	.3	2,220	2,160	3,550 2/	3,800	7.2
1[illegible].7.322	State of New Mexico	6/8/57	do	-	403	113	7.6	200	0	1,220	55	0.6	2.0	1,470	1,310	1,880	2,150	7.3
1[illegible].9.310	Mrs. Minnie Connell	[illegible] 13/57	do	-	-	-	-	149	0	301	14	-	-	553	436	-	953	7.5
Do	do	[illegible]/57	do	18	158	37	8.3	154	0	395	14	1.1	5.6	546	420	713 3/	920	7.5
1[illegible].11.322	J. L. Kite	3 12/57	do	-	-	-	-	278	0	1,[illegible]	3.4	-	-	1,960	1,730	-	2,770	7.6
1[illegible].21.[illegible]	B. V. Cain	8 2 50	do	19	476	103	2.5	157	0	1,[illegible]	34	0.8	1.5	1,630	1,500	2,120	2,350	-

1/ Residue on evaporation = 948 ppm.

2/ Residue on evaporation = 3,830 ppm.

3/ Residue on evaporation = 773 ppm.

Table 3.--Logs of wells, Gran Quivira area, New Mexico. Stratigraphic correlation is by the writer. Other terminology is that of the driller.

Well number: 1.8.15.111 Owner: C. H. Fulfer
Use: Stock
Casing record: 8-5/8"--101 ft.
Driller: K. A. Huey Drilled: December 1955

Material	Thickness (feet)	Depth (feet)
Quaternary alluvium:		
Soil	2	2
Clay	5	7
Permian:		
San Andres limestone:		
Caliche	6	13
Boulders	3	16
Clay	10	26
Caliche	8	34
Sandy clay	6	40
Red clay	8	48
Green shale	12	60
Cave space	2	62
Cavy (?) Red	28	90
Gyp	18	108
Yellow sandstone	4	112
Gyp and shells	16	128
Hard lime	61	189
Gyp	7	196
Broken	9	205
Lime	14	219
Broken	21	240
Gyp and shells	46	286
Clay fill	23	309
Lime	6	315
Broken	16	331
Black shale	3	334
Broken	16	350
Yellow clay	28	378
Yellow sandstone	38	416
Hard lime	4	420
Caves and shells	8	428

Table 3.--Logs of wells, Gran Quivira area, New Mexico.--continued
Stratigraphic correlation is by the writer.
Other terminology is that of the driller.
Well 1.8.15.111 -- Continued

Material	Thickness (feet)	Depth (feet)
Glorieta sandstone:		
Hard lime	42	470
Hard sandstone	8	478
Gray sandstone	7	485
Yellow sandstone, soft	17	502
Hard gray sandstone	5	507
Soft yellow sandstone	9	516
Hard gray sandstone	31	547
Yeso formation:		
Soft yellow sandstone	74	621
Hard gray sandstone	9	630
Yellow sandstone, cavy	20	650
Gray sandstone	11	661
Yellow sandstone	19	680
Hard gray sandstone	10	690
Yellow sandstone	20	710

Table 3.--Logs of wells, Gran Quivira area, New Mexico.--continued
Stratigraphic correlation is by the writer.
Other terminology is that of the driller.

Well number: 1.8.22.121 Owner: James A. Connell
Use: Stock
Casing record: 7"--23 ft.
Driller: K. A. Huey Drilled: November 1950

Material	Thickness (feet)	Depth (feet)
Quaternary allumium:		
Top soil	1	1
Clay	7	8
Permian:		
San Andres limestone:		
Caliche	8	16
Clay and boulders	12	28
Clay	27	55
Lime and cracks	30	85
Yellow clay	5	90
Shelly cracks	12	102
Yellow clay	4	106
Shelly cracks	11	117
Yellow clay	13	130
Gray lime	40	170
Yellow sandstone	6	176
Lime	14	190
Clay sandstone	17	207
Lime	19	226
Gyp	11	237
Blue shale	26	263
Broken lime cracks	5	268
Lime	12	280
Gray sandstone	10	290
Red clay	8	298
Brown shale	12	310
Lime	10	320
Shells and caves	58	378
Yellow sandstone	6	384
Red clay	3	387
Hard lime	6	393
Hard sandstone	7	400
Hard lime	23	423
Shell and caves	45	468
Glorieta sandstone:		
Sandstone and caves	14	482
Yellow sandstone	54	536
Gray sandstone	16	552

Table 3.--Logs of wells, Gran Quivira area, New Mexico.--continued
Stratigraphic correlation is by the writer.
Other terminology is that of the driller.
Well 1.8.22.121 -- Continued

Material	Thickness (feet)	Depth (feet)
Yeso formation:		
Yellow sandstone	18	570
Gray sandstone	14	584
Yellow sandstone	61	645
Gray sandstone	15	660
Yellow sandstone	18	678
Gray sandstone	5	683
Yellow sandstone	26	709
Water sandstone	1	710

Yield: 5 gpm.

Table 5.--Logs of wells, Gran Quivira area, New Mexico.--continued
Stratigraphic correlation is by the writer.
Other terminology is that of the driller.

Well number: 1S.8.3.121 Owner: National Park Service
Use: D.mestic
Casing record: 8¼" -- 0-92 ft.
5" -- 0-875 ft.
Driller: K. A. Huey, 0-600 ft. Drilled: 1932 and 1933
H. M. Shoats and Sons, 600-875 ft.

Material	Thickness (feet)	Depth (feet)
Quaternary alluvium:		
Sandy soil	3	3
Permian:		
San Andres limestone:		
Gypsum and limestone	5	8
Boulders and gravel	4	12
Gypsum	4	16
Boulders	19	35
Black lime	25	60
White lime	8	68
Yellow sand	17	85
Lime	5	90
Gypsum	22	112
Yellow sand	5	117
Lime	18	135
Quartz	8	143
Lime	4	147
Yellow sand	5	152
Gypsum	13	165
Lime	15	180
Gypsum	23	203
White lime	12	215
Sandstone	8	223
Tertiary dike rock:		
Malpais	27	250
Permian:		
San Andres limestone:		
Broken sand	5	255
Gypsum	15	270
Lime	7	277
No record	143	420

Table 3.--Logs of wells, Gran Quivira area, New Mexico.--continued
Stratigraphic correlation is by the writer.
Other terminology is that of the driller.
Well 1S.8.3.121 --Continued

Material	Thickness (feet)	Depth (feet)
Glorieta sandstone:		
Lime	10	430
Yellow sandstone	25	455
Yeso formation:		
Red sandstone	5	460
Yellow sandstone	25	485
Sharp sandy lime	10	495
Hard yellow sandstone	85	580
Soft white sandstone	20	600
Yellow sandstone	102	702
Red sandstone	69	771
Red clay	18	789
Lime rock	4	793
Red clay	2	795
Lime rock	5	800
White lime rock	9	809
Red clay	2	811
White lime rock	29	840
Black lime rock (water bearing)*	35	875

* A note on the log states that water was struck at 875.3 feet. Casing perforated from 855 to 875 feet. Water stands 175 feet deep in well.

Table 3.--Logs of wells, Gran Quivira area, New Mexico.--continued
Stratigraphic correlation is by the writer.
Other terminology is that of the driller.

Well number: 1S.8.11.322 Owner: J. L. Kite
Use: Stock
Casing record: 8-5/8" -- 44 ft.
Driller: K. A. Huey Drilled: August 1952

Material	Thickness (feet)	Depth (feet)
Quaternary alluvium:		
Sandy soil	3	3
Yellow soft sand	4	7
Permian:		
San Andres limestone:		
Caliche	6	13
Boulders	6	19
Caliche	9	28
Gyp	2	30
Boulders	5	35
Shell	2	37
Yellow clay and lime boulder clay	13	50
Sandstone	10	60
Lime, hard	3	63
Gyp	9	72
Sandy and shelly	12	84
Gray sandstone	12	96
Gyp and water	8	104
Lime	16	120
Gray sandstone	43	163
Blue shale	4	167
Lime	8	175
Tertiary dike rock:		
Malpais	9	184
Permian:		
San Andres limestone:		
Lime	21	205
Shelly	18	223
Lime	13	236
Black shale	7	243
Yellow sandstone	17	260
Shelly	10	270
Lime	30	300
Cracks and caves in lime	36	336

Table 3.--Logs of wells, Gran Quivira area, New Mexico.--continued
Stratigraphic correlation is by the writer.
Other terminology is that of the driller.
Well 1S.8.11.322 -- Continued

Material	Thickness (feet)	Depth (feet)
Glorieta sandstone:		
Yellow sandstone	14	350
Lime	7	357
Yellow sandstone	20	377
Hard gray sandstone	53	430
Yeso formation:		
Red sandstone	6	436
Yellow sandstone	52	488
Red sandstone	8	496
Gray sandstone	22	518
Yellow sandstone	12	530
Gray sandstone	22	552
Yellow sandstone	18	570
Blue limestone	18	588
Yellow sandstone	15	603
Gray sandstone	10	613
Brown sandstone	8	621
Gray sandstone	5	626
Yellow sandstone	12	638
Gray sandstone	9	647
Red shale	6	653
Lime	7	660
Gray sandstone. Water	10	670
Red sandstone	68	738
Red shale	14	752
Limestone	7	759
Gyp	33	792
Red shale	18	810
Water sand	30	840