OPEN-FILE REPORT 33

Hydrogeology and Water Supply of the Pueblo of Zuni McKinley and Valencia Counties, New Mexico

MASTER COPY

(Contains originals of typescript and drawings)

by

W. K. Summers
Ground-Water Geologist
Box 684
Socorro, New Mexico 87801

Prepared for

New Mexico State Bureau of Mines and Mineral Resources
Campus Station
Socorro, New Mexico 87801

September 1972

CONTENTS

Page	
	ILLUSTRATIONS
iii	List of Tables
iv	List of Figures
v	List of Plates
vv	List of Appendices
1	INTRODUCTION
1	Purpose and Scope
1	Sources of Data and Extent of Field Work
2	Acknowledgments
3	GEOGRAPHIC SETTING
3	Location, Size, and Population
4	Topography and Drainage
4	Climate and Vegetation
7	HYDROGEOLOGY
7	Hydrologic Properties of Rocks
8	Regional Geologic Setting
9	Hydrogeologic Units
9	Precambrian Rocks
10	Paleozoic Rocks
12	Mesozoic Rocks
12	Mudstones and Sandstones of Triassic Age
15	Wingate-Entrada-Zuni-Morrison Unit
17	Hydrologic units of Cretaceous age
19	Tertiary-Quaternary Dune Sand
19	Quaternary Basalt
19	Quaternary Alluvium
20	Other Deposits
21	HYDROLOGY
21	Surface Water
23	Ground Water
23	Flow System Concepts and Definitions
24	Impact of the Allsion Syncline and Pinon Springs Anticline
25	Velocity of Groundwater
25	Springs
26	Existing Ground-Water Development in the Zuni-Black Rock area
27	Hydrologic Budget
29	Effect of Pumping Wells on the Flownet

30 HYDROGEOCHEMISTRY
30 Background
31 Temperature
32 pH
32 Dissolved Solids
35 Relation of Dissolved Solids to Specific Conductance
35 Effects of Pumping-Short Term
36 Effects of Pumping-Long Term

38 WATER QUALITY
38 Drinking Water
39 Iron
39 Nitrates
39 Fluoride
40 Sulfate
41 Dissolved Solids
41 Conclusion
41 Irrigation
41 Boron
42 Specific Conductance and Percent Sodium
42 Sodium-Salinity Hazard
42 Conclusion
43 Boiler-Feed Water

44 GROUND-WATER RESOURCE DEVELOPMENT
44 Introduction
44 Prospect Areas
45 Well Construction and Development
45 Existing Wells
47 Recommendations for Future Wells
49 Springs and Horizontal Wells

50 RECOMMENDATIONS

51 CONCLUSIONS

52 REFERENCES CITED

56 TABLES 1-11

69 FIGURES 1-24

93 APPENDICES 1-7

pocket PLATES 1-3

TABLES

Page	
56	1-Population of Pueblo of Zuni
57	2-Summary of hydrologic unit and their water-bearing and water-yielding characteristics
58	3-Stratigraphic nomenclature of Permian rocks Northern Arizona and Northwestern New Mexico (after Irwin, Stevens, and Cooley, 1971).
59	4-Description of cuttings' samples from Cities Service #1 Zuni by Roy W. Foster
60	5-Thickness of Permian Formations penetrated by wells in the vicinity of the Pueblo of Zuni, New Mexico
61	6-Concensus of Moenkopi, Moenkopi(?), and Chinle Formation lithology
62	7-Thickness of the Moenkopi, Moenkopi(?), and Chinle Formation report for Zuni Village area, Zuni Mountains, and Defiance Plateau
65	8-Summary description of mudstones and sandstones of Triassic age
66	9-Estimated hydraulic conductivity of sandstones 2 and 3 in Zuni Village well no. 4 based on effective grain size
67	10-Hydraulic conductivity and porosity of sandstone cores of the hydrologic units of Cretaceous age taken from the San Juan Basin, New Mexico
68	11-Comparison of municipal wells of the village of Zuni

FIGURES

Page

69 1-Location of Pueblo of Zuni in New Mexico

70 2-Map showing the relation of the Pueblo of Zuni to regional drainage and topographic and tectonic features

71 3-Mean annual temperature and precipitation in the vicinity of the Pueblo of Zuni

72 4-Relation of mean annual precipitation to altitude in the vicinity of Pueblo of Zuni

73 5-Mean monthly potential evapotranspiration and precipitation of Zuni (after Tuan, Everard, and Widdison, 1969)

74 6-Relation of specific capacity to transmissivity for wells in northwestern New Mexico

75 7-Map showing structural contours on the surface of rocks of Precambrian age in the vicinity of the Pueblo of Zuni

76 8-Map showing structural contours on the surface of rocks of Paleozoic age in the vicinity of the Pueblo of Zuni

77 9-Distribution, thickness, and significant hydrologic features of the Zuni hydrologic unit in the Pueblo of Zuni

78 10-Thickness of Tertiary-Quaternary dune sand and Quaternary alluvium

79 11-Relation of depth-to-water to interval-of-open-hole during drilling of village of Zuni well no. 4

80 12-Sketch of a typical spring or seep at Pueblo of Zuni

81 13-Relation of water temperature to depth-of-wells, Pueblo of Zuni

82 14-Relation of field pH to laboratory pH of water samples collected from wells and springs, Pueblo of Zuni

83 15-Relation of dissolved solids in discharge from springs and wells in the alluvium and the recharge area of the Zuni River Basin

84 16-Depth versus dissolved solids in water, Pueblo of Zuni

85 17-Relation of ratio $\frac{Ca+Mg}{Ca+Mg+Na+K}$ to dissolved solids in water, Pueblo of Zuni

86 18-Relation of ratio $\frac{HCO_3+CO_3}{HCO_3+CO_3+SO_4+Cl+F+NO_3}$ to dissolved solids in water, Pueblo of Zuni

87 19-Relation of chloride concentration to depth of wells, Village of Zuni

88 20-Relation of dissolved solids and specific conductance of water of wells, springs, and reservoirs, Pueblo of Zuni

89 21-Irrigation classification diagram for Zuni water based on percent sodium and specific conductance.

90 22-Sodium-salinity hazard diagram for Zuni waters

91 23-Effect of well inefficiency on the drawdown of wells at Zuni and Black Rock

92 24-Interference due to pumping a Village of Zuni well 25 gpm for 10, 100, 1000, and 10,000 days, assuming conditions somewhat poorer than those thought to exist

APPENDICES

Page

93 1 - Records of wells, Pueblo of Zuni

2 - Springs, Pueblo of Zuni

3 - Chemical Analyses of Water Samples from Wells, Pueblo of Zuni

4 - Chemical Analyses of Water Samples from Springs, Pueblo of Zuni

5 - Chemical Analyses of Water Samples from Reservoirs, Pueblo of Zuni

6 - Chemical Analyses of Water Samples from Miscellaneous Sources, Pueblo of Zuni

7 - Drillers' Logs of Water Wells, Pueblo of Zuni

PLATES (in pocket)

1 - Well and spring locations and water table contours of Zuni Pueblo

2 - Outcrop pattern of hydrogeologic units and major geologic structures of Zuni Pueblo

3 - Cross sections

4 - Overlay base map for figs. 2, 3, 7-10, 15

INTRODUCTION

Water use at the Pueblo of Zuni increases daily. Population growth coupled with the industrialization and urbanization of the Zuni-Black Rock area should substantially increase the demand for water there within the next few years. Installation of more stock wells with pipeline water systems as functional range management tools will increase the use of water. Although irrigation within the Pueblo is based upon the use of surface runoff, the availability of irrigable land and the need for cash crops could easily increase the need for water for irrigation in the near future.

Purpose and Scope

This report summarizes and interprets the data available through August 30, 1972, on the water resources of the Pueblo of Zuni, New Mexico. It has two complimentary purposes. The first purpose is to define and describe the water resources of the Pueblo in as quantitative a fashion as possible. The second purpose is to outline a program of data collection, research, and water-supply development that will satisfy the need for water in the rapidly developing Zuni-Black Rock area and provide a basis for developing stock and domestic water supplies elsewhere on the reservation.

Sources of Data and Extent of Field Work

Data for this report derived from three sources: (1) published reports, (2) unpublished records, and (3) supplementary field work.

Published data utilized are listed under References Cited. Topographic maps of the U. S. Geological Survey including the $1^{o} x 2^{o}$ St. Johns and Gallup Quadrangles, (1:250, 000) and parts of the Upper Nutria (1963) and Pinehaven (1963) $7\frac{1}{2}'$ quadrangles.

Unpublished records included:

(1) Records of stock and domestic wells drilled on the reservation by the Bureau of Indian Affairs (BIA).

(2) Records of the wells at Black Rock obtained from the Department of Land Operation, BIA.

(3) Records of the wells of Zuni in the files of the field engineer, U. S. Public Health Service (U. S. P. H. S.)

(4) Records of oil tests provided by the New Mexico Bureau of Mines and Mineral Resources.

(5) Streamflow records and miscellaneous notes on wells and springs obtained from the Water Resources Division, U. S. Geological Survey.

(6) Information for 143 uranium test holes drilled in 1967 by the Bokum Corporation including 30 statements of formation tops, 49 lithologic logs, 85 SP logs, 108 single point resistivity logs, and 141 natural gamma ray logs.

(7) Topographic maps of selected areas of the reservation available from the resident engineer, U. S. P. H. S., and the engineering division, Zuni Agency, BIA. (see Plate 1)

Field work consisted of: (1) A field inventory of wells, during which the depth to water at each well was measured, if possible, and water samples were collected for chemical analyses. Whenever possible the temperature, pH, and specific conductance of the discharging waters were measured and the bicarbonate and carbonate concentration on the water was obtained by titration. (2) The altitudes of wells and springs were obtained by an altimeter survey. (3) Pumping test of selected wells to learn aquifer properties. During the pumping tests temperature and specific conductance of the discharging waters were measured and a water sample was collected for chemical analysis. (4) Reconnaissance mapping of the surficial geology.

Acknowledgments

A report of this sort, which depends so much upon existing data and data that can be generated in a short time, can be produced only with the help and cooperation of many individuals.

I am indebted to the Tribe of Zuni for providing extra manpower to measure water levels, collect water samples and determine elevations; to Lujan Ondelacy, who made the pumping tests possible; to Robert D. Robertson, Range Conservationist; Joseph P. Donahue, Director of Engineering; and Augustin Ponteah, Acting Plant Manager, Zuni Agency, Bureau of Indian Affairs and Terrence O. Hausken, Field Engineer, Public Health Service, who made so much of the data on file available; and to Claude W. Lester, Supervisory Soil Scientist, and his staff of the BIA Soil, Water and Material Testing Laboratory, Gallup, New Mexico for the chemical analyses.

I am especially indepted to H. B. Simpson, Jr., Director of Resources Management, Zuni Agency, Bureau of Indian Affairs, for his coordinating efforts and continuing enthusiastic support. Without his help this report would never have been written.

GEOGRAPHIC SETTING

Location, Size, and Population

Figure 1 (see page 69)

The Pueblo of Zuni occupies all or parts of 27 townships in McKinley and Valencia Counties, New Mexico. Its area is 407,997 acres (about 1120 square miles), which the BIA classifies as follows:

Area	Acres
Irrigable	4,727
Grazing	
open grazing	187,659
commercial timber	17,232
noncommercial timber	185,117
Dry Farm	2,627
Wildlands	8,878
Other uses (non-agricultural)	3,884
total	407,997

Less than 2600 acres of the irrigable land is currently being utilized. In 1970 only 2027 were irrigated.

The population of the pueblo is centered at the villages of Zuni and Black Rock with only a few dwellings at Ojo Caliente, Pescado, and Nutria. Table I shows the population growth.

Table I (see page 56)

The current population, according to tribe officials, is 5760 Zuni Indians and about 250 non-Zuni residents.

Livestock grazing on the reservation is limited to sheep, cattle, and horses plus 200-400 wild horses. Goats are not herded.

Topography and Drainage

Drainageways incised in rock walled canyons with striking water gaps give the topography a rugged appearance that belies its accessibility. On dry summer days it is possible to drive a conventional automobile to within a mile of most points on the reservation.

Although the landscape of the Pueblo of Zuni is dominated by steep cliffs and vertical rock walls, the altitude range is relatively narrow--from about 6100 to a maximum of about 7500 feet. In the eastern two-thirds of the Pueblo questa ridges are common. Steep nearly vertical rock faces give way to dip slopes of less than 200 feet per mile. A sharp hogback ridge in T. 12 N., R. 16 E. defines the western extent of the Zuni Mountains.

The western third of the Pueblo is a flat to gently rolling plain upon which badlands are forming locally.

As Figure 2 shows the Pueblo of Zuni lies almost entirely with-

---

Figure 2 (see page 70)

---

in the drainage basin of the Zuni River. Only a small portion of the reservation in T. 11 N., R. 20/21 E. drains to the Rio Puerco. However, both the Zuni River and Rio Puerco are tributaries of the Little Colorado River of Arizona and are west of the continental divide.

Although many springs occur within the reservation the Zuni River and its principal tributaries are, for the most part, intermittent influent streams.

The drainage pattern seems to be controlled predominately by fractures in sandstones. A trellis drainage pattern develops where streams flow over sandstone, but where streams flow over shales the pattern becomes more dendritic. Along the Arizona border and in the northwest corner of the reservation dune sand covers the land surface. In this area drainageways are fewer in number and may terminate in an undrained depression.

The present drainage pattern has been established for some time as evidenced by the presence in the Pescado drainageway of basalt which flowed down the valley from North Plains during Quaternary time. The topography of the valley seems to have changed very little since the flow occurred. Locally, however, incised meanders suggest that in relatively recent time erosion has been renewed.

Climate and Vegetation

The mean average maximum temperature at the Pueblo of Zuni for a 49-year period according to the National Weather Service is 64.3^{o}F and the average annual air temperature is 49.9^{o}F. The mean number of days when air temperature equals or exceeds 90°F is about 31 days per year. The mean number of days the temperature is equal to or less than 32°F is about 174 days.

Figure 3 shows the mean annual temperature and precipitation

Figure 3 (see page 71)

for those stations in the vicinity of the Pueblo. As the following table shows more precipitation falls during thunderstorms in the summer months than during any other season.

Season distribution of rainfall at Black Rock
(Juan, Everard, and Widdison, 1969)

Period	Inches
December January February	2.41
March April May	2.11
June July August	3.84
September October November	2.84
Average Annual	12.4

Within the Zuni River Basin precipitation increases rather uniformly with altitude (fig. 4). Therefore, since the mean altitude

Figure 4 (see page 72)

is about 6800 feet, 12.5 inches per year is a conservative estimate of the mean annual precipitation on the entire Pueblo.

Figure 5 shows the mean monthly precipitation at Zuni. It also

Figure 5 (see page 73)

shows the mean monthly potential evapotranspiration. The average annual potential evapotranspiration is about 24.9 inches. The summer moisture deficit of Zuni is 13.9 inches, the winter surplus about 2.7 inches.

The BIA recognizes three climatic floral zones within the Pueblo: Juniper woodland, Pinon-Juniper woodland, and Ponderosa Pine Forest. These zones correspond to the upper Sonoran, and lower transition life zones recognized elsewhere in New Mexico. At lower altitudes juniper, sagebrush, cactus, and fourwing saltbush are common; at higher altitudes Pinon and Gambel Oak become more common. Ponderosa Pine occur only at the highest altitudes in the southeast corner of the Pueblo. Chaining has eliminated extensive areas of brush.

HYDROGEOLOGY

Hydrologic Properties of Rocks

The hydrologic properties of rocks are those physical characteristics that determine the rock's capacity to transmit and store water. Three parameters are sufficient to describe the hydrologic properties of a rock--effective porosity, hydraulic conductivity (permeability to water), and specific storage.

Effective porosity is a measure of the interconnected void space in the rocks through which the water moves. It is the ratio of that void space to total volume and is usually expressed in percent. Hydraulic conductivity is a measure of the rate under standard conditions at which water will move through the rocks. It is expressed here in gpd/ft^2 (gallons per day per square foot). Specific storage refers to the amount of water a unit volume of saturated rock will release from (or take into) storage due to a unit change in pressure. Specific storage is expressed here simply in units of (1/ft).

In discussing the hydraulic properties of rocks of the Pueblo of Zuni care must be taken to distinguish between these properties as measured in hand specimens and those measured in situ. A large part of the effective porosity of the consolidated rocks derives from fracture. In the limestone a part of the effective porosity derive from solution phenomena.

For example, Cooley et al. (1969, p. A49) found that permeabilities of samples of rocks of Permian to Cretaceous age, obtained from outcrops and similar to those at Zuni were much larger than the permeability computed from pumping tests. They attributed the difference to weathering. Conversely, Summers (1970) found that pumping tests produced much larger valves for permeability for the Morrison and Dakota formations than laboratory analysis of cores from the producing formation. The difference here was attributed to the influence of fractures. Thus, hand or laboratory sized specimens of the rock will suggest values of the hydraulic parameters that differ considerably from those observed in situ.

The specific capacity of a well is the ratio of pumping rate to drawdown. It is a quasi quantitative measure of a well's yield. However, in many instances it's the only parameter available. In general a well with a large specific capacity taps a water-yielding amount with large hydraulic conductivity, and those with small specific capacities tap units with small hydraulic conductivity. Figure 6 shows the relation of specific capacity to transmissivity for wells in northwestern New Mexico.

Figure 6 (see page 74)

Porosity of rocks within the Pueblo determined from analysis of the electric logs ranges from 10 to 20 percent. In all probability the dune sands and alluvium have higher porosities.

The hydraulic conductivity and specific storage of a water-yielding unit multiplied by the unit's thickness become the transmissivity and the storativity. These parameters are generally determined with a pumping test. The storativity requires the use of observation wells during the test; the transmissivity does not. Of the several tests made within the reservation only one included an observation well. Thus, although the transmissivity of several lithologic units was sampled, the storativity was determined for only one. In general the character of the tests--low pumping rate and relatively short duration--eliminated many extraneous effects such as those caused by partial penetration and nearby hydrologic boundaries. I believe that dividing the transmissivity by the open interval of the well produced reasonable values for the hydraulic conductivity. These values are given in Table 2 and discussed below. Also included in Table 2 are the values presented by Cooley et al. (1969, table 7, p. 46-47) for these lithologic units in northeastern Arizona.

Table 2 (see page 57)

In general, the yield of a well is determined not only by the hydraulic properties of the rock tapped by the well, but also by the mode of construction of the well. This feature of well yield is discussed in the section on well construction.

Regional Geologic Setting

The Pueblo of Zuni lies in the transition zone between the Gallup sag and Zuni uplift to the north and the Mogollon slope to the south (fig. 2). The North Plains lava field is less than 10 miles from the southeast corner of the reservation.

The principle structural features within the Pueblo of Zuni are the Allison syncline, the Pinon Springs anticline and an anticline and a fault which in this report are called the Ojo Caliente Anticline and the Ojo Caliente Fault (Plate 2 and Figure 7).

The Allison Syncline is an asymmetrical fold that extends northwest from near Pescado almost to Gallup. Its east limb has dips up to 76°W and forms the Nutria Monocline. The dip of west limb is much less--the maximum being only about 16°E and the average being about 5°E. This west limb of the Allison Syncline is also the east limb of the Pinon Springs Anticline--a broad symmetrical feature.

The Ojo Caliente anticline is a small elliptical dome which has been faulted on its west side. Dips of as 18° were measured in the vicinity of the dome. Immediately west of the fault dips of as much as 37° were measured. Dune sand conceal the rocks west of the fault. Cross-section CC' (plate 3) based on only a few logs show one interpretation of the structure west of the fault. Maximum displacement along the fault is on the order of 2000 feet.

Hydrogeologic Units

The Geologic map (Plate 2) is based on the work of Sears (1925), soils maps (BIA, 1970), drill hole data including some electric logs, driller's logs of water wells, and reconnaissance mapping by the author. It is at best a preliminary effort. Field mapping can be expected to change many details.

The units mapped are hydrogeologic units, that is, the rock units were mapped more on the similarity of their hydrologic character than on their stratigraphic significance. This mapping results in some units being identical to stratigraphic units and some rocks of different ages being lumped together. Plate 3 contains three cross-sections that show representative vertical slices of the ground-water reservoir.

Precambrian Rocks

Rocks of Precambrian age do not crop out within the Pueblo and only two oil tests on the Pueblo were drilled sufficiently deep to penetrate rocks of Precambrian age. Cities Service #1 Zuni "A" (Sec. 5, T. 9 N., R. 18 W.) penetrated quartzite and schistose quartzite at a depth of 2518 feet and the William G. Coffee #1 Coffee-Federal (Sec. 35, T. 11 N., R. 19 W.) penetrated quartzite at a depth of 1860 feet.

Granite is the principle rock of Precambrian age cropping out in the Southern Zuni Mountains (Foster, 1971, p. 5); whereas granite, granite gneiss, metarhyolite, and schist crop out in the northern Zuni Mountains (Smith and others, 1958 and 1959). The nearest outcrops of Precambrian rocks in Arizona (Hunters Point-23 miles west of Gallup and Bonito Canyon--25 miles northwest of Gallup) contain granite, quartzite, and metasediments (Cooley et al. 1969, p. 10-11).

We can expect, therefore, that when other wells are drilled to the Precambrian, that they will find that granite and metasediments also occur within the boundaries of the Pueblo.

Because Precambrian rocks are rarely called upon to yield water and their permeabilities are generally very low, in this report these rocks are taken to be the lower boundary of the ground-water systems affecting the Pueblo.

Figure 7 shows structural contours on the rocks of Precambrian

---

Figure 7 (see page 75)

age in the vicinity of the Pueblo. These contours are based on depth obtained from wells that cut the Precambrian surface plus estimates obtained by using the elevation of known horizons subtracting the thickness of underlying sedimentary units as given by Foster (1957, p. 65 and 68).

Paleozoic Rocks

Rocks of the Permian Series are the only rocks of Paleozoic age that occur within the Pueblo (Foster, 1957; Kottlowski, 1959). These rocks include in ascending order the Abo Formation, Yeso Formation, Glorieta Sandstone, and San Andres Limestone. Table 3

Table 3 (see page 58)

compares this nomenclature with that used in northeastern Arizona. Only two wells in the Pueblo penetrate this entire section.

Figure 8 shows the areas in which these rocks crop out and

Figure 8 (see page 76)

gives structural contours on their top in the vicinity of the Pueblo.

The Abo formation consists of sandstone, siltstone and shales, deposited upon the Precambrian surface. Its thickness is therefore irregular. Its maximum thickness is probably not greater than 1000 feet and probably averages about 500 feet.

Table 4 gives Roy Foster's, New Mexico Bureau of Mines and Mineral Resources petroleum geologist, description of the cuttings

Table 4 (see page 59)

from the Abo, Yeso, and Glorieta Formations obtained from the Cities Service #1 Zuni A in Sec. 5, T. 9 N., R. 18 W.

Table 5 summarizes the information on the thickness of these

Table 5 (see page 60)

Permain Formations in the vicinity of the Pueblo.

The Yeso Formation consists of sandstone, limestone, and gypsum. Its uppermost beds may be very much like the overlying Glorieta Sandstone, making the top of the formation difficult to define. Similarly the basal beds grade into those of the Abo Formation. Thus the measurements of thickness of the Yeso Formation are variable.

In the northern Zuni Mountains the average thickness of these rocks is 250 feet (Smith, 1954, p. 6). In the Zuni area their thickness ranges from 275 to 530 feet (table 5). The maximum thickness is probably about 600 feet and average about 500 feet.

The hydraulic properties of the Abo and Yeso Formations are not known for the reservation. However, wells in other areas that tap these Formations have low yields (less than 10 gpm). Because these formations occur at relatively great depths and can be expected to have low yields of relatively poor quality water, more information about them will not be forthcoming in the near future.

Although the Glorieta Sandstone is sometimes regarded as the lowermost member of the San Andres Limestone (because the limestone and the sandstone interfinger). In this report these formations are recognized as distinct formations but are treated as one hydrogeologic unit.

In the northern Zuni Mountains according to Smith (1954, p. 7), "The Glorieta is a very pure, well-sorted, quartz sandstone with grains averaging about 1 mm in diameter; the grains are well rounded and smooth, although many are frosted and all are quite fresh and unaltered. The lower part of the formation is friable; the upper part is hard and well-cemented with silica." Its thickness ranges from 120 to 220 feet due to variation in the selection of the contact between the Glorieta Sandstone and the underlying Yeso Formation.

The Glorieta Sandstone penetrated by wells at the Pueblo is described as buff, pale orange, very pale orange, and white; very fine-to-medium grained, well sorted sandstone composed of subanguler to rounded quartz grains with few accessory minerals. It includes both well cemented and friable beds. One driller reports using four bits to drill 160 feet, thus suggesting silica cement; whereas another report says it is a calcerous cement.

The San Andres Limestone crops out in the Zuni Mountains and in T. 12 N., R. 16 W. and T. 8 N., R. 20 W. of the Pueblo (Plate 2). In the Zuni Mountains according to Smith (1954, p. 7-8) the San Andres divides easily into three units, an upper and lower limestone and a middle sandstone. The lower limestone is 20-35 feet thick, massive blue-gray to white and weathers gray. The sandstone, which is 10-25 feet thick, resembles the Glorieta. The upper unit is 60-80 feet thick and is a massive gray limestone which is very cherty in the upper portion. Smith also says the upper surface of the upper limestone shows sink holes filled with Triassic rocks and that relief of 25-50 feet on this buried karst topography is common.

The thickness of the outcropping San Andres within the Pueblo was not measured, but Sears (1925, p. 10) describes it as 40-75 feet of light-gray, cream colored, and brown fossiliferous limestone. In the subsurface the San Andres is a yellowish gray and white limestone in the upper part that grades into dark gray limestone in the lower part. As Table 5 shows, its thickness is erratic, due to the erosional unconformity that developed at the end of Paleozoic time. In the Zuni-Black Rock area the limestone was completely eroded away in places.

Within the Pueblo water wells completed in the San Andres are nearly always completed in the Glorieta. A pumping test conducted on the Black Rock Well No. 3, which taps this unit, indicates that its transmissivity is 520 gpd/ft. Since this thickness of the unit is 260 feet, its average permeability is about 2 gpd/ft^2. This value, however, is probably near the lower limit for the unit.

In the Grants-Bluewater area the San Andres has very high transmissivity (400,000-2,000,000 gpd/ft) and yields of 1000 gpm are common (Reeder, 1961). Cooper and Jahns (1968, p. 20) noted that San Andres wells in eastern McKinley County had yields of less than 200 gpm and they attributed the difference in the two areas to solution phenomena. They argued that near its outcrop, the San Andres develops cavernous zones and solution channels; whereas these features do not develop where the limestone is deeply buried. We can expect, therefore, that near its outcrop (especially in the valley parallel to the hogback northeast of Nutria), the San Andres will have a somewhat larger permeability; perhaps as large as that in the Grants-Bluewater area.

Mesozoic Rocks

Mesozoic rock unconformably overlie the Paleozoic rocks. They crop out extensively in the Zuni Mountains and over a large part of the Pueblo (Plate 2). They are the consolidated rocks immediately beneath the unconsolidated Tertiary-Quaternary sand and Quaternary alluvium. The hydrogeologic units of Mesozoic age include the mudstones and sandstone of Triassic age, the Wingate-Entrada-Zuni-Morrison sandstones of Triassic and Jurassic age, and the Dakota Sandstone, Mancos Shale, Gallup Sandstone and Crevasse Canyon Formation of Cretaceous age.

Mudstones and sandstones of Triassic age

The mudstones and sandstones of Triassic age form a complex hydrogeologic unit. The rocks are mixtures of clay, silt, sand, and gravel in every proportion imaginable. They were deposits by aggrading stream flowing west and north through the Pueblo from highlands only a few miles south and east. Unconformities are common, as are channel sandstones and conglomerates. Beds of any lithology may grade laterally or vertically into another lithology, may interfinger with beds having other lithologies, or may occur as discrete lenses.

As Table 6 shows, in northwestern New Mexico and northeastern

Table 6 (see page 61)

Arizona these rocks have been subdivided into the Moenkopi, Moenkopi(?), and Chinle formations. However, the differentiation of these units in the field is another matter (table 7).

Table 7 (see page 62)

Near the outcrop within the Pueblo these rocks seem to divide into 11 units; 6 of which are continuous beds of silty sandstone, siltstone, shale, claystone, and limestone conglomerate that sandwich 5 more or less continuous beds of sandstone and conglomerate. An effort to equate these units to those of Table 6 and 7 created more confusion than clarity, so for this report these units are referred to as Mudstone 1 through 6 and Sandstone 1 through 5; unit 1 being the lowermost.

The definition of these units is complicated by three factors. First, the units thicken and thin rapidly so that locally two or more beds may come together to form one thick bed. Thus, in Sec. 4, T. 9 N., R. 18 W., a test hole penetrated 600 feet of sandstone below Mudstone 6. Apparently Sandstone 2-5 thickens to form one sandstone unit from 4. Similarly in T. 8 N., R. 18 W. only a few miles south, Mudstones 3-6 thicken at the expense of the sandstone units to form a continuous Mudstone unit.

Second, the topography of the underlying Paleozoic rocks may cut out one or more units.

Third, the interpretation of cuttings samples is very difficult because of the similarity of the sandstone units. For about half of the test holes for which both cuttings and electric logs were available the electric log showed sandstones that were overlooked in the cuttings logs. Apparently the sandstone in the sample was interpreted to be particles sloughing off sandstone beds previously penetrated.

The outcrop pattern also reflects the variability of the units. Sandstone units form cliffs, walls, ridges, and benches; whereas the mudstone units occupy slopes and valleys. Badlands develop on some of the mudstone units. Thus topographic change occurs whenever a sandstone or mudstone loses its distinguishing characteristic.

Table 8 summarizes the salient feature of these units.

Table 8 (see page 65)

Three pumping tests have been conducted at the village of Zuni; one on Sandstone 2, 1 on Sandstone 3 and one on Sandstones 2 and 3 jointly. The tests on Sandstone 2 produced hydraulic conductivity values of 19 gpd/ft^2. During the drilling of village well No. 4 Sandstone 3 was tested and the hydraulic conductivities was found to take in the range of 3 to 20 gpd/ft^2, depending upon whether the driller's reported thickness 15' or the interval of open hole (95 feet) is used in the calculation.

Village well No. 2 is open to both Sandstone 2 and Sandstone 3. The transmissivity determined for this test was much larger. Suggesting a hydraulic conductivity on the order of 50-100 gpd/ft^2 for Sandstones 2 and 3. The sample descriptions for Well No. 1 and Well No. 2 are similar. Certainly on the basis of these logs alone we would not expect such a large difference in the hydraulic conductivity in the sandstones tapped by these two wells. Well No. 4 is about 4100 feet from Well No. 2. The test on sandstone 3 was conducted during the drilling of the well, when the well was 225 deep and cased to 130 feet. The test involved 95 feet of open hole.

Only a driller's log is available for Well No. 4. The driller reports 15 feet of sandstone in the uncased interval. The lithologic log of Well 2 indicates only 20 feet of sandstone in that interval. Lithologic differences, per se, do not provide a very satisfying explanation for the observed range of hydraulic conductivity.

Moreover particle size analyses were made by the BIA soils laboratory for samples of Sandstone 2 and 3 obtained from Well No. 4. Freeze (1969, p. 32-34) has demonstrated that for unconsolidated sediments permeability is directly related to the effective grain size (the 10 percent-finer-than size). Using his diagram (p. 35) to estimate permeability to one significant digit we would expect Sandstone 2 to have a permeability of about 100 gpd/ft^2 and Sandstone 3 to have a permeability of about .01 gpd/ft^2 (table 9). The values for a consol-

Table 9 (see page 66)

idated sediment should be less.

The differences among the hydraulic conductivities obtained by well tests and the difference between the hydraulic conductivity obtained by well tests and those estimated from particle size analyses probably reflect the effect of fractures. The following analysis is, then, the most probable explanation of the data.

The construction of Well #1 sealed any fractures that might have contributed so the short term test sampled only Sandstone 2, so that the hydraulic conductivity is 19 gpd/ft^2.

Well 2, which is open in three intervals, benefits from fractures in the siltstones and shales as well as those in the sandstones. The test was longer and at a larger pumping rate so it of necessity sampled a large part of the water bearing rocks. Thus, the conductivities was overestimated because the contribution interval was taken on 50 feet instead of 500 and the average hydraulic conductivity is really 5-10 gpd/ft^2. Because there is no record of the Well No. 4 filling or caving as a result of this test, I believe, therefore, the rock is competent but the fractures were partially plugged so that the interval tested by the relatively short pumping test, effectively sampled a shorter interval and the hydraulic conductivity is then between 4 and 20 gpd/ft^2.

In addition to the tests at Zuni, which were made some years ago, a test was made of a 5' thick sandstone in the Chinle at Well RWP-Z-35 (8N. 20W. 4). The hydraulic conductivity determined by this test was 4 gpd/ft^2.

In practice, therefore, the hydraulic conductivity of the sandstone and mudstone of Triassic age is determined by the degree of fracturing.

The degree of fracturing in a rock is determined by its lithology, depth, and geologic structure. Fractures occur frequently where the rocks are lithologically dense and brittle, infrequently where the rocks are soft and plastic. Fractures frequently generally decrease with depth. With respect to geologic structure, fracture frequency is above average near the crests of anticlines and near the troughs of synclines. We should expect, therefore, that the hydraulic conductivity of the mudstones and sandstones of Triassic age will be largest where competent beds of sandstone, siltstone, and shale occur along the axis of the Pinon Springs Anticline. To be lowest where incompetent claystone and shale make up a large part of the total interval or are deeply buried. More important the hydraulic conductivity of these rocks should not be discounted for reasons of texture.

Wingate-Entrada-Zuni-Morrison hydrogeologic unit

This hydrogeologic unit consists of four formations. The Wingate Sandstone of Triassic age plus the Entrada Sandstone, Zuni Sandstone, and Morrison Formation of Jurassic age. The reasons for treating them as a single unit are:

1. In outcrop the distinctions between the sandstones are based on color, topographic expression, bedding features, and textural characteristics. Of these parameters only color and textural characteristics can be discerned in drill hole samples. In examining the available hydrologic logs, it became apparent that neither color

nor textural fractures were definitive criteria for distinguishing these formations on sample logs. That is to say a stratigrapher examining the samples with a microscope might distinguish these formations satisfactorily using these criteria, but the lithologic logs and driller's logs in hand did not lend themselves to consistent formation identification.

2. These rocks are all cliff formers and one may follow them for miles without interruption. In such an overview one finds that the character of the sequence changes from north to south. The Morrison Formation which is distinguished by its green, greenish gray, or red shale and green or greenish white sandstone disappears completely (Fig. 9).

Figure 9 (see page 77)

The white and gray Entrada sandstone seems to thicken at the expense of the reddish brown and white Zuni Sandstone. To further complicate matters the Wingate, which is a distinctive brown and has distinctive bedding near Zuni, apparently consists of two members. Flying along the Nutria Hogback and along the western Questa one can see that at any given location the interval may be entirely occupied by one member or the other or some combination of the two. In general the thickness of the Wingate appears uniform but in places an erosional unconformity is evident and the interval is occupied by the Entrada Sandstone. Thus, a stratigraphic sequence that seems relatively simple becomes somewhat complex upon closer inspection.

3. The hydrologic properties of this unit are most probably determined by fractures rather than the character of the sand grains and their size distribution. Since the unit with the overlying Dakota Sandstone forms cliffs, it is obviously more competent than the underlying mudstones and sandstones of Triassic age. We expect fracture frequency and distribution to be similar throughout the interval.

The Wingate-Entrada-Zuni-Morrison unit, hereafter called the Zuni Hydrogeologic Unit for brevity and labeled J (for Jurassic) on figures, ranges from about 500 to 800 feet thick. Its thickness diminishes from north to south and from west to east. Where the underlying sandstones of Triassic age coalesce to form thick beds, they combine with the Zuni Unit to make as much as 1200 feet of uninterrupted sandstone.

Although most of the uranium test holes reached the Zuni Unit, few went through it. Only seven water wells tap it. Thus detailed information is lacking on its hydrologic properties. Two pumping tests were made using wells tapping it, with significantly differing results. In Well No. E. C. W. No. 1 (11 N. 18 W. 21) the hydraulic conductivity is about 12 gpd/ft^2, whereas in Well E. C. W. No. 17 (10 n. 18 W. 22) the hydraulic conductivity is 78 gpd/ft^2.

One explanation is that the larger value is for the Wingate Sandstone whereas the smaller value is for the Morrison Formation and Zuni Sandstone, but experience with these rocks on the Colorado Plateau of Arizona and New Mexico (Table 2) shows that, while these rocks exhibit differences from place to place, none are so extreme as that observed in the two Zuni Wells. A more probable explanation is that these high values occur at the north end of a highly fractured zone. Although most of the Bokum Corp. test holes penetrated the Zuni unit, circulation was lost in only 5. These 5 test holes together with Well E. C. W. #17 form a NW-SE trend that parallels the extended axis of the Pinon Springs Anticline.

The test of Well E. C. W. #1 revealed the hydraulic conductivities of 12 gpd/ft^2 near the well, it also revealed the presence of a nearby boundary condition of significantly low hydraulic conductivity. This well is probably near the northern end of the fracture zone.

The area of the inferred fracture zone is shown in figure 9. Within this area hydraulic conductivity should be significantly above average for sandstones in and around Zuni. Throughout the remaining area fractures in the outcrop appear to be relatively far apart. The low fracture frequency should result in a relatively low hydraulic conductivity, so the average hydraulic conductivity of the Zuni Unit is probably in the range 1-5 gpd/ft^2 suggested by Table 2.

Hydrogeologic units of Cretaceous age

The units of Cretaceous age crop out in the eastern half of the Pueblo and a small area southwest of the Ojo Caliente Fault. (Plates 2 & 3). The regional stratigraphic relation of these rocks are complex and have been studied extensively (O'Sullivan et al., 1972), so there is no need to discuss them here.

Gregory's (1917, p. 2) description of the Dakota Sandstone of northwestern New Mexico describes the Dakota Sandstone at Zuni very well. He wrote,

"The Dakota sandstone is highly variable in structure, texture, and composition. It is characterized more by a persistent combination of features than by the persistence of any given bed. The base is commonly but by no means universally marked by conglomerate and the top is in many places a coarse brown or gray sandstone bed but may be a group of interbedded sandstone and shales or wholly sandy shales of yellow or gray tones. Coal lenses occur prevailingly in the middle of the Dakota but are found in all positions from top to bottom. The formation is everywhere lenticular; lenses and wedges of sandstone, of conglomerate, of shale, and of coal tens of feet or a few inches thick overlap, appear, and disappear along the strike and vertical in a most capricious manner."

Within the Pueblo the Dakota's thickness ranges from 46 to 200 feet. It is tapped by only a few wells, because it occurs within the Allison syncline and over much of this area wells are more easily completed in overlying hydrologic units.

The Mancos Shale consists of gray to black shale, silty shale and a few beds of sandstone. The sandstone beds are in most cases near the base of the Mancos and may be confused with the Dakota. However, these sandstone beds lack persistence and may be entirely encased by the shale. Within the Pueblo the thickness of the Mancos ranges from 280 to 600 feet.

The Gallup Sandstone consists of beds of sandstone and shale. The sandstones range from clear, light colored, medium grained cliff formers to fine-grained, dark gray carbonaceous silty sandstones. Beds of coal, which may be as much as 25 feet thick, occur throughout the Gallup. The shales are identical to those in the Mancos. Within the Pueblo the thickness of the Gallup ranges from 230 to 550 feet.

The Crevasse Canyon Formation is the mirror image of the Gallup. Whereas the Gallup consists of as much as 70 percent sandstone, the Crevasse Canyon consists of as much as 70 percent shale. The shale is identical to the Mancos and the Sandstone are like those in the Gallup.

The hydrogeologic units of Cretaceous age are very much alike in that they are composed of beds of shale and sandstone. The distinction between the units ranges from fairly precise (where a unit consists entirely of sandstone or entirely of shale) to arbitrary (where shale and sand are both present). Consequently the hydrologic properties of these units are similar. Pumping tests indicates that the hydraulic conductivity of the sandstone is about 1 gpd/ft^2. Laboratory tests, however, are much less consistent and frequently show values equal to or larger than those determined by the pump test. For example, the hydraulic conductivities observed in cores from the San Juan Basin (Table 10)

Table 10 (see page 67)

range 0.0 to 11.1 gpd/ft^2; those obtained by Cooley et al. (Table 2) from 2-25 gpd/ft^2, and those obtained by Jobin from 4 to 100 gpd/ft^2.

Two factors probably combine to produce the results we see at Zuni. (1) The fine-grained rocks with low hydraulic conductivity are fractured, but fractures are less frequent and have smaller apertures in the shales. (2) The coarse-grained rocks that have the large hydraulic conductivity observed in the laboratory constitute only a small part of the rock in the hydrologic units. Thus, the average observed through pumping tests comes about because the pumping test sampled rocks with both fractured and granular permeability. The laboratory sampled only the granular permeability and since so many values are near zero the average of laboratory values approaches the field value. Maximum yields from these hydrological units are obtained where wells tap a maximum number of fractures not from these wells which tap the thin beds in which the granular porosity produces a large hydraulic conductivity.

Tertiary-Quaternary Dune Sand

Dune sand blankets the northwestern part of the Pueblo, effectively concealing the underlying rocks (Plate 2). Sears (1925) divides this sand into two units which have come to be known as the Bidahocha Formation of Pliocene Age and dune sand of Quaternary age. Although the unit may be composed of deposits of two different ages--distinquished largely by their topography, this distinction could not be made in logs or in the soils maps. Nor can it be distinguished from alluvium, where the alluvium lies in channels that drain it.

On the surface the unit consists of very fine to coarse, permeable sand. Drillers describe it as "sand", "sand-with-pebbles", "blow sand","sandy loam","light gray sand" "light pink sand", "loose sand", "quick sand", "sand and clay", and sandy shale.

It is lithified at depth and may be described as a soft to hard "sandrock". Since it was deposited on an irregular erosion surface and has an undulating upper surface, it thickens and thins rapidly in short distance. As Figure 10 shows it is thickest near the state line,

Figure 10 (see page 78)

where a well has penetrated more than 400 feet of sand. The only pumping test in the dune sand (Bosson's well, sec. 22, T. 10 N., R. 20 W.) suggested a hydraulic conductivity of 75 gpd/ft^2, a value that is completely compatible with its appearance.

Quaternary Basalt

Quaternary basalt occurs only in the Pescado-Zuni drainageway (T. 10 N., R. 16-18 W.) (Plate 2). The basalt appears to have overflowed from the North Plains lava field. One should not expect to cut basalt anywhere else within the Pueblo--either on the surface or at depth.

The basalt is fractured and where it is saturated should yield water to wells. The only well known to tap it on the reservation has a reported yield of 25 gpm.

Quaternary Alluvium

The bottom of each drainageway in the reservation has a cover of alluvium. From a water supply standpoint the alluvium is significant above Nutria Reservoir and below Black Rock (Plate 2). Data from the Nutria area are sparse. Test holes in the area cut up to 90 feet of "overburden". However, the lithologic character of the overburden was not specified. Part of this alluvium is probably composed of sand and gravel that will yield water to wells.

Below Black Rock the alluvium is as much as 145 feet thick. Its lithologic character depends upon the nature of the area drained by the stream. Where the terrane includes shales, the alluvium contains clays and silts. Thus at Black Rock the alluvium consists of clay, sand, and gravel. A pumping test of Black Rock Well No. 1, which was completed in the alluvium indicate the hydraulic conductivity there is 63 gpd/ft^2. However, the hydraulic conductivity will vary according to the percent of the various constituents. Northwest of the village Zuni where the alluvium is derived from the sand dunes, it probably has a larger hydraulic conductivity.

Other deposits

Three other deposits, two of whichare shown on Plate 2, occur in the area. These are (1) travertine deposits south of Ojo Caliente, (2) lacustrine deposits associated with playas, and (3) remnant terrace gravels along the Zuni River. These deposits have little, if any, influence on the water resources of the Pueblo.

HYDROLOGY

Surface Water

Stream gaging at the Pueblo of Zuni began October 1, 1969, when the U. S. Geological Survey established two gaging stations: one on Rio Nutria (09-3869. 0) 0. 9 mile upstream from the Nutria Diversion Dam, the other on the Zuni River (09-3869. 50) 50 feet upstream from the concrete ford on State Highway 36. At this writing only the stream flow for water years 1970 and 1970 (Oct. 1969 through September, 1971) for the Rio Nutria gage are available. This recorddshows that for 21 days during October 1969 no stream flow occurred. For the remainder of the year flow varied from 0. 05 to 365 cfs. (cubic feet per second). The monthly discharge (cfs) varied as follows:

	Total		Mean		Maximum		Minimum	
	1970	1971	1970	1971	1970	1971	1970	1971
Oct.	4. 08	3. 19	. 13	. 10	1. 3	. 21	. 0	. 08
Nov.	5. 05	3. 93	. 17	. 13	2. 2	. 29	. 05	. 10
Dec.	2. 72	2. 94	. 088	. 095	. 12	. 13	. 08	. 08
Jan.	6. 15	2. 70	. 20	. 087	1. 4	. 14	. 08	. 07
Feb.	6. 14	2. 34	. 22	. 084	. 40	. 09	. 08	. 08
Mar.	15. 31	22. 43	. 49	. 72	1. 9	6. 5	. 25	. 08
Apr.	60. 06	3. 96	2. 00	. 13	8. 2	. 25	. 37	. 10
May	5. 49	2. 98	. 18	. 096	. 53	. 12	. 10	. 08
June	2. 10	2. 38	. 07	. 099	. 10	. 10	. 05	. 05
July	5. 09	1. 38	. 16	. 044	2. 3	. 09	. 05	. 02
Aug.	47. 07	1. 17	1. 52	. 038	22.	. 06	. 07	. 02
Sep.	3. 41	36. 88	. 11	1. 23	. 75	5. 2	. 08	. 05
	162. 67	86. 28						

The total for water year 1970 (162. 67 cgs) is equivalent to a mean daily discharge of 0. 4 cfs or about . 0072 inch/year from the drainage area of 71. 4 square miles. The total for water year 1971 (86. 28) is equivalent to a mean daily discharge of 0. 24 cgs or about . 0038 inch/year.

Surface runoff is controlled by small dams that create small reservoirs. The captured surface runoff is diverted to irrigation. The following table gives the area of the reservoirs and theassociated irrigation unit.

Reservoir	Stream	Estimated capacity 1972	Area (Acres)	Irrigated (Acres)
Nutria Diversion	Rio Nutria		19	1503
Nutria 3*	do	0	205	none
Nutria 4	do	8800	79	none
Nutria 2	do	1600	353	none
Pescado	Rio Pescado	368	51	1250
Black Rock	Zuni River	2600	294	3603
Bolton	do	50	26	3603
Eustance	do	50	25	3603
Tekapo	do	300	104	315
Ojo Caliente	Plumasano Wash	250	61	1553

*Flood control reservoir only

Appendix 5 gives the chemical analyses of water samples collected from the reservoirs. As the following table shows the quality of water deteriorates downstream.

Reservoir	Number of Analyses	Average Specific Conductance (µmho - cm C25°C)
Nutria Diversion	3	249
Nutria #4	3	233
Nutria #2	3	343
Pescado	3	340
Black Rock*	3	393
Bolton	2	560
Eustace	3	620
Tekapo	3	503
Ojo Caliente*	3	977

*Receives discharge from spring short distance upstream

The reservoirs were built in the 1930's except for Black Rock Reservoir which was built in 1909. They had an original capacity of about 20,000 acre feet but by 1940 the capactiy was reduced by silting to about 8,400 acre feet.

Ground Water

Flow System concepts and definitions

The basic tenet of ground-water hydrology is this: water that falls as precipitation enters the ground water reservoir and flows downstream along a flow line in response to a hydraulic gradient until it discharges at the surface. The area over which precipitation may percolate to the water table is called the Recharge area. The area in which the water leaves the ground-water reservoir is called the discharge area. The ground-water reservoir includes all the rocks which are saturated with water below the water table. It extends downward to a depth where the weight of the overlying rocks forces the conduits to close. At Zuni for engineering purposes this is presumed to be the surface of the Precambrian rocks. The water table is defined as that surface where the pressure on the water is atmospheric, and below which all effective porosity is saturated.

Water in a porous medium flows along a potential gradient and the rate of charge of potential per unit flow line length is called the hydraulic gradient. The elevation of the water level in a well or prizometer is a measure of this potential (for detail of theory see Domenico, 1972, Chapter 4). In recharge areas the components of movement are horizontal and downward. When ground water discharges to the surface the components of movement are horizontal and upward. As a consequence, in the recharge area progressively deeper wells at the same location will have progressively deeper "static" water levels, and in the discharge area progressively deeper wells will have progressively higher water levels. At Zuni the phenomena is exhibited in both the recharge and discharge areas. Deep wells in the recharge area (ECW no. 6 or ECW no. 7) have water levels as much as 500 feet below the water table. Deep wells in the discharge area flow at the surface showing that shutin water levels would be several feet above the water table. Figure 11 shows the relation between the interval of open hole and depth to water during the drilling of Village of Zuni well no. 4.

Figure 11 (see page 79)

As the well was drilled, casing was driven into the hole shutting off water in the cased interval. The water level in the well is the average of potential for the given interval from the bottom of the casing to the bottom of the hole. As the figure shows, water levels in Village of Zuni well no. 4 were 21 feet higher at 555 to 615 feet depth than at 0 to 110 feet. The vertical component of the hydraulic gradient at well 4 is $\frac{21}{\frac{615+555}{2} - \frac{0+115}{2}}$ or .04 ft/ft and is directed upward. Note that whether the water level rises or falls with increasing depth has no bearing on the yield of the well, which is determined by the water-bearing characteristics of the rock and the total hydraulic gradient.

In the recharge area, the flow path of infiltration precipitation extends from the land surface through unsaturated rock to the water table. In the discharge area the flow may be to springs, streams, plant roots, or wells. The discharge may be directly from the ground-water reservoir or it may be through the unsaturated zone to plant roots to the atmosphere. Because the vertical component is downward in the recharge area and upward in the discharge area, the shape of the water table can be used to define these areas. Where this water table is concave downward, the vertical component of the hydraulic gradient is downward and the overlying area is a recharge area. Where the water table is concave upward the overlying area may be a surface discharge area. (Discharge may also be horizontally directed out of an area through highly permeable sediment such as alluvium that lies in some valleys.) The inflection line on the water that separates the concave upward from the concave downward also define the recharge and discharge area. Plate 4 is a water table map of the Pueblo of Zuni. It is based upon the altitude of water levels in wells (although not all observed water levels were used), springs, and land-surface altitudes. It also shows the recharge and discharge areas of the Pueblo. Obviously part of the ground water derived within the Pueblo fell as precipitation on recharge areas outside the Pueblo and reached the Pueblo as it moved within a ground-water flow system.

Toth (1962) pointed out that ground-water systems can be complex. Water starting in a recharge area may move to a nearby stream or part of the water may move as underflow to a second stream at a lower elevation some distance away. He characterizes ground water flow systems as "local", "intermediate" and "regional". At Zuni the ground water moving to most springs, the Rios Pescado and Nutria, or Plumasano Wash would be part of a local system; ground water moving to the Zuni River could be derived from a local system or could be part of an intermediate system that underflow the springs or the Rios Pescado and Nutria.

Ojo Caliente spring appears to be due in part to an intermediate system being forced to the surface by the geologic structure there and in part due to the local system of Plumasano Wash. Underflow--ground water that does not discharge within the Pueblo--is part of the more deeply circulating regional system and flows toward the Colorado River.

Impact of Allison Syncline and Pinon Springs Anticline

The ground-water flow net with the reservation is distorted by the Allison Syncline and the Pinon Springs Anticline. On the one hand the thickness of sedimentary rocks within the reservation is greatist along the axis of the syncline. On the other hand the thickness of sedimentary rocks thins across the axis of anticline. Thus the vertical cross-section through which the lateral flow of ground water occurs is more than twice as large at the syncline as at the anticline. As a consequence, horizontal flow lines in the vicinity of the syncline tends to diverge, wherever they tend to converge in the vicinity of the anticline. These tendencies influence the vertical component of gradient. Vertical gradients associated with the syncline are diminished; whereas these associated with the anticline are increased. As a result near the village of Zuni, where the axis of the Pinon Springs anticline crosses the discharge area, the upward vertical component of the hydraulic gradient is much larger than elsewhere on reservation.

Velocity of groundwater

The velocity of ground water (v) at any point is determined by the hydraulic gradient (I), the hydraulic conductivity of the rocks (k) and their porosity (θ):

$$v = \frac{kI}{\theta}$$

Within the Pueblo the average hydraulic gradient is about 150 feet/mile or .03 ft/ft, the average hydraulic conductivity is about 1 gpd/ft^2 or 0.013 ft/day, and the average porosity is about 10 percent. Thus, the average velocity of the ground-water is

$$v = \left(\frac{.013\ \text{ft}}{\text{day}} \times \frac{.03\ \text{ft}}{\text{ft}}\right)/.10 = .004\ \text{ft/day or } 1,500\ \text{ft/year.}$$

The actual range is probably 150 to 15,000 ft/year under natural conditions. Near pumping wells the ground-water velocity is much faster.

Springs

The springs of the Pueblo of Zuni occur in the discharge area, where lithologies of markedly different hydraulic conductivity force flow in a local ground-water system to the surface. When flow occurs across such a contrast flow lines are deflected. At springs some of the flow is diverted to the surface. Figure 12 illustrates the relation of flow lines,

---

Figure 12 (see page 80)

---

water table, and lithology at a typical spring or seep within the Pueblo. Attempts to improve springs should not include the use of explosives or vertical borings, because both explosives and vertical bore holes will increase the hydraulic conductivity of the underlying rock and the spring will be destroyed perhaps for ever.

Horizontal wells on the other hand can be constructed to intercept and control the flow before it reaches the surface. Horizontal wells concentrate the flow so that it can be diverted to stock tanks or other storage facility, thereby reducing the surface area of water exposed to the atmosphere. Thus, they substantially reduce the evapotranspiration loss.

Existing ground water development in the Zuni-Black Rock area

Four wells supply water to the municipal water system of the village of Zuni. Two other functioning wells also occur within the villages - one used by the laundry for cold water supply and one used for irrigation by St. Anthony's School. According to Morris and Prehn (1971, p. 76), the municipal wells discharge about 50.09 million gallons per year--an average of about 100 gpm. The following table gives the average discharge for 1969 and 1970 by months:

(Million Gallons per month)

Jan.	6.63	July	3.55
Feb.	6.32	Aug.	5.33
Mar.	4.12	Sept.	5.56
Apr.	2.41	Oct.	4.22
May	2.08	Nov.	2.94
June	3.11	Dec.	3.82

The average discharge for August 21 through 25, 1972, was 252,000 gallons or 161 gpm (T. Havsken, personal communication, 9-14-72).

Table 11 compares the construction and yield of the village wells.

Table 11 (see page 68)

The other two wells probably add less than 10 gpm to the average discharge in the villages. Appendix 6 contains a chemical analysis of the water from the municipal system.

In addition to the wells equipped with pumps two other deep wells were found--both between the Zuni School and well no. 3. These wells appear to be those used before well no. 1 was constructed.

The water supply of Black Rock, which provedes water to the Hospital, BIA housing, and the industrial site derives fromm3 wells and Black Rock Spring. However, well no. 1, a shallow well, is in standby status only, because it pumps sand, and well no. 2 is used solely for irrigation, because the water the water quality is poor. On August 3, 1972, well no. 3 pumped 36,900 gal. (an average of 26 gpm). Chemical analysis in Appendix 6, which were collected from the distribution system, reflect the multiple sources.

Hydrologic budget

An absolute accounting of the water at Zuni is not possible with the available data. However, a crude estimate is feasible. Total precipitation on the Pueblo is about 12.5 inches, most of which returns almost immediately to the atmosphere through evaporation and transpiration. From the Rio Nutria gaging station we see that about .01 inch runs off. Since the streams do not have a base flow, the ground water delivered to the surface of the discharge area above Black Rock Reservoir must be less than or equal to the 13.87 inches of water deficiency predicted by the potential evapotranspiration. However, below Black Rock Reservoir the thickness and the hydraulic conductivity of the alluvium may be large enough to accomodate all the water delivered from the less permeable rocks adjacent, so that a large part of the ground water that would have discharged at the surface is actually conducted from the Pueblo as underflow in the alluvium. If we assume the average saturated thickness of the alluvium is 50 feet and the average width of 5000 feet, the vertical cross section and area is 250,000 ft^2, we can estimate the maximum underflow (U) through the use of the relation

$$U = kIA$$

The slopes of the water table below Black Rock (100 feet/6 miles or .003 ft/ft) is the hydraulic gradient and k from table 2 is 60 gpd/ft^2. Thus

$$U = \frac{60\ g}{d \times ft^2} \times \frac{A^3}{7.5\ gal} \times .003 \times 250,000\ ft^2 = 6000\ ft^3/day \qquad 45,000\ gpd$$

this amount of water could be supplied by an average recharge of .001 in/year on an area of 850 square miles. The discharge area within the Pueblo is about $\frac{1}{4}$ the total area or about 250 square miles. Since the vertical hydraulic gradient of Village well no. 4 is .004 ft/ft and the well occurs where such gradients would be a maximum, the average vertical gradient over the discharge area is probably about .001 ft/ft. The vertical hydraulic conductivity in most rocks is about one-tenth the horizontal, so if we assume an average hydraulic conductivity of 10 gpd/ft^2, an estimate of the average vertical permeability of 1 gpd/ft2 is reasonable. Substituting these values into the relation used earlier and letting A = 1 ft^2, we obtain an average groundwater discharge (D) from the older rocks into the alluvium of

$$D = \frac{1\ g}{d\ ft^2} \times \frac{1\ ft^3}{7.5\ ft} \times .001\ \frac{ft}{ft} = 1.3 \times 10^{-4} \frac{ft^3}{day}/ft^2 = 0.59\ \text{in/year/unit discharge area}$$

If we assume that underflow into the Pueblo is equal to underflow out of the Pueblo (a not unreasonable assumption) and that the discharge derives from a recharge area roughly 4 times larger than the discharge area, then the estimated recharge becomes 0.15 in/year. This estimate range .001 to .15 in/year is compatible with the lithology, terrane, and climate. Because the recharge area of the Pueblo is about 800 square miles, the average annual recharge is no more than 2.8×10^8 ft^3 or 2.2×10^9 gal. Until data has been collected to improve upon this estimate, it represents the maximum amount of water available for utilization from the Mesozoic hydrologic units. To exceed this amount would undoubtedly result in ground-water mining. Since 2.8×10^8 ft^3/year equals 6800 acre feet per year, and would irrigate only about 2000 acres, long term use of ground-water derived from recharge to these low permeability regions is precluded.

The preceeding discussion is predicated upon several reasonable assumptions. However, there are two areas where the assumptions are untenetable - the area above the Nutria hogback and the area of the Tertiary-Quaternary sand.

The recharge area above the Nutria hogback includes a large area (more than 100 square miles) of the Zuni Mountains east of the Pueblo. Using the water in this canyon area (especially if the San Andres Limestone has the anticipated large hydraulic conductivity) would not materially influence the conclusion reached above with respect to the Mesozoic hydrologic units, because these conclusions were based upon recharge within the Pueblo. Because the precipitation in the mountains is greater and summer temperatures are lower, the recharge rate could be much larger in the Zuni Mountains perhaps as much as 0.5 inch/year. So if ideal conditions prevail, properly constructed wells in this valley could produce an additional amount quantity of water which could be as much as 270 acre feet/year.

The volume of water that might be derived annually from the Tertiary Quaternary sands cannot be estimated because there are so many factors we don't know including vertical hydraulic gradients, saturated thickness, extent of the recharge area and volume of water discharged to the alluvium. The hydraulic conductivity of the Tertiary Quaternary sands is somewhat larger than that observed in the Mesozoic units and the recharge area extends north and west for an undetermined distance. A conservative educated guess is that wells in these sands could add 2000 acre feet of water per year to the Pueblo's water supply.

I conclude, therefore, that the ground-water supply available to the Pueblo of Zuni is approximately 10,000 acre feet/year of which about 8000 acre feet derives from recharge upon the Pueblo. To refine these estimates would require an extensive exploration program.

I also conclude that a water budget of the following order is reasonable:

Water available		inches/year
	Precipitation	12.5
Disposition		
	Runoff	.01
	Ground-water recharge	.15
	Evapotranspiration (including ground water discharge)	12.44

The amount of water discharged to wells is negligible.

Effect of pumping wells in the flow-net

When a well is pumped, the water level in the well lowers. This has two effects on the rock-flownet system. First, it reduces the pressure exerted by the water on the rock and the rock compresses. In most cases the compression is slight, but because it occurs over a large area and encompasses a large volume of rock, the volume of water released from storage in the rocks is fairly large. In a few cases the compressional effects are large. In these cases subsidence of the land surface occurs. Subsidence will probably never occur at Zuni because of the competence of the rocks.

Second, the water level change alters the flow system so that water originally destined for discharge at the surface is intercepted and discharged by the well. Early in the history of a well, the water is derived largely from storage; later it is derived primarily from the flow system. In practice this means that the rate of water discharged early is greater than the rate of recharge; later when a new dynamic equilibrium is established the rate of discharge to natural sinks and to wells is the same as the recharge rate. If the discharge rate continues to be larger than the recharge rate, ground-water mining occurs.

Since at Zuni the natural ground water discharge appears to be to underflow or to evapotranspiration, the development of the ground-water resource for use on the Pueblo would be advantageous on two counts. First, pumping would capture water otherwise lost to the atmosphere. Second, pumping would intercept water which otherwise might continue to acquire dissolved solids as it moves through the flow system. The section of this report on water chemistry shows, the average quality of the water in the Paleozoic and Mesozoic hydrologic units is barely adequate. The addition of more dissolved solids would generally preclude its use by possible downstream consumers.

HYDROGEOCHEMISTRY

Background

A discussion of the chemical and physical properties of natural waters must take into account both the natural factors and those created by men. The natural factors include:

(1) Flow line or path length
(2) Length of time in the ground-water reservoir
(3) Chemical characteristics of the rock through which or over which water flows
(4) Evapotranspiration
(5) Temperature
(6) Pressure

The factors created by men include as:

(1) Mixing of water in wells penetrating several hydrogeologic units
(2) Sampling techniques
(3) Sample aging in collection bottles
(4) Changes in the flownet caused by discharge.

These factors may cause one or both of the following responses in the water chemistry at a well:

(1) a change in the total concentration of dissolved constituents.
(2) a change in the concentration of individual constituents.

As water moves through the ground-water reservoir, the total load of dissolved constituents tends to increase and the character of the dissolved constituents changes. Typically the cations change from Ca rich to Na rich, whereas the anions change from Bicarbonate-carbonate rich to sulphate rich to chloride rich. This pattern is modified considerably by the composition of the rocks involved.

In general the concentration of dissolved constituent in water is thought to increase with residence time. Given two flow paths of the same length, the slower flowing water with the longest residence time will generally have the greater concentration of dissolved constituents.

Water discharging through evapotranspiration causes an increase in the concentration of dissolved constituents. In general, the solubility of the ions that occur in natural waters increases with temperature. So the chemical composition of the water varies slightly with changing temperature.

Ground water moves from low pressure (atmospheric at the water table) to a higher pressure within the ground-water reservoir and then back to low pressure at the point of discharge. These pressure changes cause significant changes in the solubility of dissolved gases and, hence, of those ions in equilibrium with these gases.

The man-induced chemical changes are frequently difficult to detect, for they may occur before any analysis of the water can be made. For example, water discharging at a well may have lost all its dissolved gas. When wells have several contributing zones the chemistry of the water is a weighted average of the contribution of each zone and may not be representative of the water in any one zone in the ground-water reservoir.

Water samples tend to age, that is they tend to change for various reasons with residence time in the sample bottle (Summers, 1972) so that water from identical sources unless handled identically may be reported to have different compositions.

When a well is pumped, the flownet of necessity alters, continued pumping may result in the capture of water from an increasing number of flow lines. If these flow lines are of different lengths or the water has different residence times the chemical characters of the water will change as the water from these flow lines discharges from the well.

In the following discussion these various factors are discussed in so far as possible. In too many instances we lack the data to be quantitative or defineative.

Temperature

Temperature data for ground water within the Pueblo of Zuni consists of (1) measurements of the temperature of water discharging from a well or spring and (2) a temperature log made shortly after casing was cemented into Exploration Oil #1 (Cities Service #1 Zuni A, sec. 5, T. 9 N., R. 19 W.) to determine the top of the cement. The temperatures of discharging water are given in Appendixes 1 and 2.

Figure 13 relates the temperature of the water to the production-

Figure 13 (see page 81)

interval or depth of wells within the Pueblo, shows selected values from the temperature log, and indicates the range of the temperatures of springs.

The temperatures to a depth of 100 feet and the spring temperatures show the typical response to ambient air temperature variations. Below 100 feet the temperature distribution suggests an average gradient of about 1.2^{o} c/100 feet. As the figure shows, wells in the recharge area tend to have temperatures less than there predicted by the gradient line; whereas those wells in discharge areas tend to have higher temperatures.

In general the range of temperature is relatively small, less than 25^{o}C so we should not expect to distinquish variations in water chemistry caused by temperature.

pH

The pH of water samples obtained from wells and springs within the Pueblo and measured in the field ranges from 6.1 to 8.6. The pH of water samples observed in the laboratory is always higher (fig. 14). This phenomena has been observed many times (Summers, 1972; Summers, Schwab, and Brandvold, 1972; Rittenhouse et al., 1969, p. 206). The difference appears to be unrelated to position in the flownet. Moreover as the following tabulation shows, the average difference by hydrologic unit is about the same. In general the only pH measurements that describe subsurface conditions are those obtained immediately as the water discharges and even these may be suspect if the water must rise a long distance up a pump column.

Figure 14 (see page 82)

Hydrologic units	pH Range Field	pH Range Laboratory	Av. Diff.
Qal & Qb	7.2-7.4	7.9-8.4	.75
TQs	7.0-7.2	7.5-8.3	.7
K (Cretaceous rocks)	7.1-8.5	8.1-9.0	.75
J (Jurassic rocks)	-	8.0-8.3	-
ꝶ (Triassic rocks)	6.1-8.7	7.5-9.0	.85
P (Permian rocks)	-	7.6-8.4	-

In general the pH of ground water in the ground-water reservoir at Zuni is probably in the range of 7.0-7.5 and probably increases with flow line length and residence time; large values probably reflect sampling conditions rather than hydrogeologic phenomena. The laboratory values reflect the pH of the water at the time of use. In determining pH effects on pipes and plumbing one should use a value in the range of 7.5-8.5.

Dissolved solids

The following tabulation compares the range of dissolved solids observed for reservoirs, springs and wells.

Source	Range of dissolved solid (mg/1)
Reservoirs	166-738
Springs	242-1584
Wells	215-2899

The low values observed for the reservoir reflect surface runoff over relatively insoluble rocks. Downstream reservoirs in general have the higher concentrations. Probably the results of increasing evapotranspiration at lower altitudes and longer average flow paths of water reaching reservoirs at low altitudes. Ground water may discharge to some of the reservoirs. We should expect the ground water discharging at low altitudes to include increasing proportions of longer flow lines.

Springs in the pueblo of Zuni constitute the terminus of a local or a local and intermediate flow systems and they discharge water derived from recharge within the hydrologic divides of these systems. Those with low dissolved solids have recharge areas that are relatively near and hence flowlines are short. Those with large dissolved solids are springs terminating systems that have a more remote recharge area. The chemistry reflects the union of flow from a distance of several miles with flow from lesser distances (fig. 15).

Figure 15 (see page 83)

Wells discharge water from any part of the flow system. Low dissolved solids suggest a nearby recharge area. High dissolved solids suggest flow from a greater distance. The highest and some of the lowest dissolved solid concentrations were obtained in samples of water from alluvium. This suggests that two opposing processes operate in the alluvium. First, the low values reflect a dominance of short flow lines plus the diluting influence of infiltration from stream flow or reservoirs. Second, the large values suggest that the water in alluvium is derived from remote recharge areas and reaches where infiltration is negligible. In those reaches where infiltration is minimal evapotranspiration may further increase the concentrations of the dissolved constituents. Figure 16 shows the

---

Figure 16 (see page 84)

---

relation of dissolved solids to depth of wells. Because the deeper wells, reach a deeper part of the flow system, the dissolved solid concentration generally increases with depth. The smallest increase with depth occurs in the recharge area; the largest in the discharge area.

Figures 17 and 18 illustrate the change of the principle cations

---

Figures 17 and 18 (see page 85, 86)

---

and anions as the dissolved solid concentration increases in the Pueblo of Zuni. At low concentrations calcium and magnesium ions dominate, but as the total concentration increases calcium and magnesium constitute a progressively small proportion of the cations. Three exceptions are evident in Figure 17. One is the dominance of the calcium and magnesium ion in areas where evapotranspiration is a factor. Another is the dominance of calcium and magnesium ions in water discharging from the San Andres Limestone (Permian age).

The third exception is two samples obtained from the Zuni hydrogeologic unit. In these samples only, large calcium concentrations occur along with extremely large sulfate concentrations--suggesting the presence of hitherto unsuspected beds of anhydrite or gypsum in this hydrogeologic unit. Solution of a bed of gypsum and subsequent collapse of the overlying rocks could explain the elongate fracture zone (Fig. 9) discussed previously, since it is only a few miles west of these wells.

At low concentrations bicarbonate plus carbonate ions dominate the anions but as the total dissolved solid concentration increases, bicarbonate plus carbonate constitute a progressively smaller proportion of the anions. Figure 18 shows the relationship is generally independent of hydrogeologic units. The scatter is probably related to lithology, to sample aging, to the proportion of the other anions present, and to well construction.

Figure 19 relates the concentration of chloride to depth at Zuni.

Figure 19 (see page 87)

The concentration appears to decrease with depth. This probably reflects the concentrating effect of evapotranspiration. Bicarbonate and carbonate may combine with calcium to precipitate as the mineral calcite. Calcium may combine with sulphate and precipitate the mineral gypsum allowing the bicarbonate and carbonate to escape as CO_2 and H_2O. These minerals form a white crust on drainageways where evapotranspiration is severe which is washed away when surface runoff occurs. The salts of the chloride ion are far more soluble, hence rarely precipitate from ground water. The shallow well at BlackRock has low chloride becauses it discharges water that infiltrates from Bolton and Black Rock Reservoir

The difference in the dissolved solids of Black Rock Well #2 (1561 ppm from a production interval 624-932 feet) and Black Rock Well #3 (1045 to 1096 ppm from a production interval 810-1060 feet) probably reflects the residence time factor. Well #3 reached the San Andres limestone. One might argue, therefore, that east of Black Rock solution phenomena in the limestone make it permeable, whereas the weight of the overlying rocks tend to close fractures in the overlying rocks and reduce their permeability. Water whose travel path included the limestone would, therefore, have a lesser travel time and smaller concentration of dissolved solids than water whose travel path did not include the limestone.

Relation of dissolved solids to specific conductance

Figure 20 shows the realtionship of dissolved solids and specific

Figure 20 (see page 88)

conductions for water samples from wells, springs, and reservoirs. In general the realtionship

Dissolved solids = 0.64 x specific conductance

estimates the dissolved solid concentrations in water samples from the Pueblo fairly well.

Effects of Pumping - short term

Data on the short term effects of pumping are scant. When the oil test in sec. 5, T. 9 N., R. 18 W. (Fig. 8 and Pl. 3) was completed as a water well in April 1964, it was pumped for short periods at various rates on April 17, 20, and 27 and multiple samples were collected each day. The following tabulation gives the results obtained.

Date	time since pumping began (min)	Sp. Cond.
4/17/64	about 1	800
	60	550
	120	460
	140	340
	200	1600
4/20/64	about 1	1550
	150	1870
4/27/64	about 1	1210
	130	1180
	164	1190
	205	1110
	250	1210
	330	1190
	490	1140
	555	1140

The samples collected the first two days apparently contained water from another source, probably drilling fluid. The third day's results show only minor variation with time. Clearly to obtain a representative sample, one must be sure the well has pumped long enough to eliminate such superfluous water.

As village of Zuni well #4 was drilled, a pumping test when the well was 245 feet deep (uncased interval 160-245). Two water samples were collected one after 60 minutes of pumping, the other after 727 minutes. The analyses are compared below.

Constituent	Concentration (my/1)	
	60 min	727 min
Boron (B)	.35	.43
Iron (Fe)	.14	.14
Calcium (Ca)	18.04	17.03
Magnesium (Mg)	6.08	4.86
Sodium (Na)	314.04	310.37
Potassium (K)	.82	.82
Phosphorous (P)	Trace	Trace
Bicarbonate (HCO_3)	589.45	543.08
Carbonate (CO_3)	35.71	34.51
Sulfate (SO_4)	93.18	92.22
Chloride (Cl)	104.96	97.16
Fluoride (F)	.35	.25
Nitrate (NO_3)	1.30	1.30
Dissolved solids	868	818
Specific Conductance	1400	1350
pH	7.9	.7799

The differences do not exceed those one might expect in identical samples (Summers, 1972).

Effects of Pumping - long term

Chemical analyses of water from wells samples at intervals of at least one year are available for 7 wells.

Of these stock well E. C. W. no. 17 (sec. 22, T. 10 N., R. 18 W.) and Black Rock Well no. 3 show no significant changes.

The change that occurred in other wells are:

Black Rock Well #1	Na increases, Ca+Mg decreases
Village of Zuni Well #1	Na, SO_4, and dissolved solids increase
Village of Zuni Well #3	Na, SO_4, Cl and dissolved solids increase
Irrigation well no. 1 (sec. 18, T10N., R20W.)	NO_3 increased substantially

Village of Zuni Well #2 illustrates the difficulty in rationalizing long term changes. Samples collected before and after a redevelopment effort in 1968, (appendix 3) show a substantial increase in dissolved solids (682 to 940 ppm). This suggests that redevelopment opened a zone in which the dissolved concentration is higher. Samples obtained in 1970 and 1972 are very much alike the "after" sample of 1968. This suggests that the zones contributing to the well have not changed. Since well no. 2 is open in several zones we expect that the water chemistry will remain essentially the same as long as these zones contribute in the same proportion. Village well no. 1 is open over a narrow range and water from adjacent beds is being drawn into the well. Well no. 3 is open over a longer range than well no. 1, but a shorter range than well no. 2. Since both wells experienced increasing sodium and sulfate concentrates, they may be drawing water from either overlying or underlying rock. The increase in chloride in well no. 3 shows clearly that water from overlying beds has been induced to flow to the well.

WATER QUALITY

The term "water quality" implies water use. In general, standards of water quality have been established for virtually every water use. This discussion will be limited to a consideration of three uses: (1) drinking, (2) irrigation, and (3) boiler feed. The U. S. Public Health Service (1962) established standards for drinking water; the U. S. Laboratory of Salinity (1954) and Wilcox (1955) established standards for irrigation water. A committee on Quality Tolerance of water for industrial uses (1940) established standards for boiler feed water. Only those standards for which we have data from the pueblo will be cited here.

No analyses were made for micro-organisms; the discussion here is directed only at the chemical character of the water.

Drinking water

The following tabulations compare U. S. Public Health Standards with the Range observed in New Mexico Water Supplies (N. M. Dept. of Public Health, Environmental Factors, Water & Liquid Waste Division, 1967) for selected constituents.

Constituent	U. S. P. H. S. limit or recommendation	Range in New Mexico
Na	-	2.0 to 817 mg/l
K	-	0.0 to 78
Ca	-	0.6 to 673
Mg	-	0.0 to 182
Fe	0.3 mg/l	0.0 to 13.2
Cl	250.0 mg/l	0.5 to 784
F	1.5 mg/l	0.05 to 5.00 mg/l
NO_3	45.0 mg/l	0.0 to 32.0 mg/l
HCO_3	-	43.9 to 1215.0 mg/l
CO_3	-	0.0 to 185.4 mg/l
SO_4	250 mg/l	1.0 to 2044.0 mg/l
Dissolved solids	500 mg/l	67.0 to 4500.0 mg/l

Each of the U. S. Public Health Service standards has been exceeded in at least one public water supply in New Mexico. The sulfate and dissolved solid standards are exceeded routinely.

The only constituents for which we have data from the Pueblo of Zuni to compare with standards are: iron, sulfate, nitrate, fluoride, and total dissolved solids.

Iron

With relatively few exceptions, iron occurs at trace concentrations in water samples from Zuni. Concentration larger than 0.3 mg/l have been observed in samples from wells: E. C. W. No. 5 (sec. 12, 8N, 19W,; 0.43 mg/l), village of Zuni Well No. 1 (2.5 and .316 mg/l), village of Zuni Well No. 3 (1.3 and 0.7 mg/l); from springs: none; from reservoir: Tekapo (.480 mg/l), Black Rock (.460 mg/l), Pescado (1.9 mg/l) and Nutria diversion (1.1 mg/l).

With the exception of Well E. C. W. No. 5, for which only one analysis is available, subsequent analyses showed the iron concentration to be less than 0.3 mg/l in the wells. Iron in drinking water is not a problem on the reservations.

Nitrates

The following tabulation shows the range of nitrate concentrations in water for reservoirs, wells, and springs.

	mg/l
Reservoirs	0.3 to 0.99
Springs	0.6 to 51
Wells	0.1 to 86

According to the U. S. Public Health Service (1962), water containing more than 45 mg/l of nitrate should not be given to infants. Water from one well in sec. 23, T. 12 N., R. 17 W., which is equipped with a hand pump, contained 86 mg/l and water from a spring in sec. 8, T. 10 N., R. 20 E., contained 51 mg/l. These concentrations reflect very local contamination of the water supply by animal waste. They are probably not due to fertilizing--since phosphorous concentrations are low. Water from two other wells RWP Z-27 (sec. 8, T. 10 N., R. 20 W.) and Irrigation #1 (sec. 18, T. 10 N., R. 20 W.) contain 33 and 34 mg/l, respectively. This level of concentration at Zuni probably reflects contamination by animal wastes. All other water sampled had nitrate concentrations less than 10 mg/l and most of them had concentrations less than 1 mg/l.

Fluoride

The following tabulation shows the range of fluoride concentration in reservoirs, springs, and wells.

	ppm
Reservoir	.25 to .57
Springs	.25 to .88
Wells	.20 to 6.00

No 0.00 values have been reported.

The U. S. Public Health Service (1962) has recommended that in areas where the average air temperature is 50°F that the ideal range of fluoride concentration is 0.9 to 1.7 mg/l (optimum 1.2 mg/l). Presence of fluoride concentrations greater than 3.4 ppm would constitute grounds for rejection of a water supply for use in interstate commerce.

Fluoride concentrations greater than 1.0, were reported for 14 wells (including three of the village of Zuni wells); 4 wells have concentrations between 1.00 and 1.50. Three of the wells were in T. 8 N., R. 19 W.; ten are in an east-west belt, 4 miles wide. The north line of this belt is just north of Black Rock; the South line is about 1 mile south of the common boundary between T. 9 N., and T. 10 N. The campground well (sec. 5, T. 11 N., R. 17 W.) is the remaining well.

The fluoride concentration in three wells (E. C. W. No. 5 (Sec. 12, T. 8 N., R. 19 W.; 4.40 mg/l), E. C. W. No. 13 (sec. 32, T. 10 N., R. 16 W.; 3.80 mg/l) and Black Rock well No. 2 (6.00 mg/l)) exceeded the 3.4 mg/l. Water from these three wells should not be used by people on a sustained basis; nor should it be used by young livestock.

No universal relationship could be established between fluoride and depth, lithology, or position in the flow net.

Sulfate

The following tabulation gives the range of sulfate concentration in reservoirs, springs, and wells in the Pueblo:

	mg/l
Reservoirs	1.4 to 364
Springs	1.6 to 722
Wells	3.36 to 2046

Only one reservoir (Ojo Caliente) showed sulfate concentrations greater than the 250 mg/l recommended maximum for drinking. Water from two of the six springs samples contained more than 250 mg/l. Of the 39 wells for which chemical analyses of water were available, 20 had less than 250 mg/l, 9 had concentrations between 250-500 mg/l; 6 had concentrations between 500 and 750 mg/l and 3 had concentrations greater than 750 mg/l.

Dissolved solids

The recommended limit (500 mg/l) for dissolved solids is routinely exceeded in water samples from Zuni wells. Of the 14 wells that discharged water contain less than 500 mg/l dissolved solids, 9 contained at least 400 mg/l. In general, the ground water in Zuni can be expected to contain more than 500 mg/l of dissolved solids.

Conclusions

Although the chemical characteristics of the ground water of the Pueblo of Zuni fails to satisfy the U. S. Public Health Service standards for use in interstate commerce. The water is within the range used by many New Mexican communities, so we may conclude that the water may not be entirely satisfactory, but with minor exceptions, it isn't harmful.

Irrigation

The applicability of water to irrigation depends not only upon the chemical character of the water, but also upon the characteristics of the soil and the crop. However, for a preliminary appraisal of the water, we may consider the boron concentration, the relation of specific conductance to percent sodium, and the relation of specific conductance to the sodium absorbtion ratio.

Boron

Wilcox (1955) created the following rating of irrigation water for various crops on the basis of the boron concentrations in the water:

Grade	Sensitive Crops (mg/l)	Semi-tolerant Crops (mg/l)	Tolerant Crops (mg/l)
Excellent	0.33	0.67	1.00
Good	0.33 to 0.67	0.67 to 1.33	1.00 to 2.00
Permissible	0.67 to 1.00	1.33 to 2.00	2.00 to 3.00
Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
Unsuitable	1.25	2.50	3.75

Following this rating system, water from wells in the Pueblo of Zuni rate (base on the most recent chemical analysis) as follows:

Grade	Number of wells in range Sensitive Crops	Semitolerant crops	Tolerant Crops
Excellent	20	30	37
Good	10	8	3
Permissible	7	2	0
Doubtful	1	0	0
Unsuitable	2	0	0

The water sample of springs and reservoirs all contained less than 0.33 mg/l of Boron.

Specific Conductance and percent sodium

Figure 21 is an irrigation water classification diagram

Figure 21 (see page 89)

(Wilcox, 1948) on specific conductance and percent sodium. The points plotted on the diagram are based on the most recent chemical analyses for each well. The array of points shows that only 13 wells supply water in at least the permissible or better class. By contrast, water from 6 of the 8 reservoirs fall in the good-to-excellent class.

Sodium-salinity hazard

Waters rich in sodium tend to defloculate soils and create an impermeable crust. The sodium absorbtion ratio is a measure of the relative availability of sodium in a water sample. Figure 22 is sodium-salinity hazard diagram based on the sodium absorbtion ratio and specific conductance.

Figure 22 (see page 90)

Both the salinity hazard and the sodium hazard ranges from low to very high. Only samples from two reservoirs occupy the ideal low-low region. Most of the ground waters fall in the medium to high range of salinity hazard, samples from wells tending to fall in the high range.

Conclusions

The prospect of obtaining additional supplies of quality irrigative water from the consolidated-rock hydrology units economically is remote. Some additional supplies of irrigation water may be obtained from the Tertiary-Quaternary sands, Quaternary basalt, or Quaternary alluvium in some reaches of the Zuni River. In general, the quality of the ground water when considered in terms of the total supply available probably precludes the economic development of ground water for irrigation except for small local areas or for those crops that are extremely tolerant to salinity.

Boiler-feed water

The Committee on Quality Tolerances of Water For Industrial Uses (1940) established the following limits for boiler feed water:

Pressure, psi	0-150	150-250	250-400	over 400
Total hardness (as $CaCO_3$)	80.0	40.0	10.0	2.0
Bicarbonate mg/l	50.0	30.0	5.0	0.0
Carbonate mg/l	200.0	100.0	40.0	20.0
Total solids mg/l	500-2000	500-2000	100-1500	50.0
pH value (minimum)	8.0	8.4	9.0	9.6

We do not have data to discuss the other standards, which the committee established.

The chemical analyses in Appendix 3-6 show that the relatively few of the water samples fit these criteria. Water from every source including the reservoirs will require some treatment before it can be used for boiler feed or other industrial use.

GROUND WATER RESOURCE DEVELOPMENT

Introduction

To develop the Pueblo of Zuni's ground-water resources, we need to consider the following factors: (1) the location of wells and well fields, (2) well construction and development, (3) the consequences of development including possible or potential environmental hazards and possible variations in water quality and well yields, and (4) protective monitoring measures.

Prospect areas

Small water supplies for stock or domestic use can be developed throughout the reservation. Therefore, this discussion will be limited to the prospects of developing wells and well fields for municipal and industrial use in the Zuni-Black Rock Area. These prospects include the upper Nutria area, the Fractured area of the Zuni hydrologic unit, the Zuni-Black Rock area and the Tertiary-Quaternary sand area.

The Upper Nutria area can be discounted from immediate consideration for two reasons. First, it is so remote from the village area where the water is needed that economic barriers will preclude its use for sometime. Second, the conclusions about this region are speculations. Much new data must be generated from the area before it can be actively considered.

The fractured area of the Zuni hydrogeologic unit offers fair opportunity for large yield wells. These wells would be on the order of 1000 to 1400 feet deep; would be relatively costly to construct, and would probably deliver water containing only slightly less dissolved solids than that now obtained from well in the Zuni-Black Rock area. This area should be prospected when such prospecting can be justified by economic factors.

The Zuni-Black Rock area, itself, can be made to produce more water efficiently through improved well construction techniques, appropriate well spacing, and controlled well yields. However, the water quality can be expected to deteriorate as the sustained discharge induces infiltration from above and as more and more of the deeply circulating under flow is diverted to the wells. Moreover over a long period of development (50 to 100 years) interference between wells will reduce the net discharge of the field and increase pumping lift costs.

The Tertiary-Quaternary sand extends over an area of about two townships. Although our information about this unit is sparse, it has several characteristics that suggest it should be the primary target for future development. First, wells would be relatively shallow, ranging from 100 to 400 feet deep. Second, because it consists of unconsolidated sand, the coefficient of storage is probably larger than for any other hydrologic unit and wells could be drilled closer together. Third, recharge occurs locally, so ground-water travel paths are short and the concentration of dissolved solids in the water should be significantly lower than the present supply. Fourth, few wells will be required to deliver the volume of water needed and pumping equipment and pumping costs should be less.

The adverse features of this area are its distance from the Zuni-Black Rock area. (The water will have to be piped 4 to 10 miles.) Wells will have to be constructed with screens and gravel or sand packed--a technique not commonly used in the area. Controls may be required to prevent ground-water pollution. Before the first water supply well is constructed, an exploration program should be conducted to define precisely the saturated thickness and hydrologic properties of the sand. Despite these difficulties, the Tertiary-Quaternary sands constitute the best long term solution to the water-supply problem of the Zuni-Black Rock area.

Well construction and Development

Existing wells

Well construction within the Pueblo of Zuni has consisted of drilling a hole with either cable tools or a rotary drilling machine and setting casing. In some wells the casing extends to the bottom of the hole and water is produced through perforations; in others the casing does not extend to the bottom and production is from the uncased part of the hole. In a few wells perforated casing and open hole are both used. The perforation in the casing range from torch cut slots at random intervals to milled cuts at precise intervals. In-hole gun perforations have also been used.

Development generally consisted of pumping the well until clean water discharged. This procedure tends to produce inefficient wells.

When a well is pumped, the water level in the well declines. The amount of decline is determined by the hydraulic characteristics of the water-bearing rocks and by the well construction technique. This concept is expressed

$$s = BQ + CQ^n$$

where s is the drawdown in the well

Q is the discharge of the well

B is a factor determined by the hydraulic properties of the rocks

C is a factor determined by the well construction and is a constant

For Zuni (as in many other areas) setting n = 2 is a good first approximation. So for Zuni we may write:

$$s = BQ + CQ^2$$

If a well is 100 percent efficient then C = 0 and all drawdown is due to the hydraulic characteristics of the water-yielding rocks. However, the drilling procedure can plug the well face pores so that water may not enter the well at the rate the rock is capable of producing. In this case the value of C determines the additional drawdown we can expect because of the plugging. In the extreme case where all the entry pores are plugged CQ^2 is larger than the depth of the well and no water enters the well. The value of C was established from step pumping tests made on village of Zuni wells and on Black Rock Well #3. It can also be estimated from specific capacity tests made at different times. The analyses for the wells in the Zuni-Black Rock area produced the following results:

Well	Value of "C" (ft/gpm^2)	Remarks
Village of Zuni #1	.03	Based on two step tests and several specific capacity test. Good value.
Village of Zuni #2	.00	Based on test after redevelopment. Good value.
Village of Zuni #3	.00?	Based on poor specific capacity test. Questionable.
Village of Zuni #4	.01	Based on one step test. Fair value.
Black Rock #3	.06	Based on one step test. Fair value.

Figure 23 illustrates the affect of well inefficiency on the drawdown of

Figure 23 (see page 91).

village of Zuni Wells #1 and 4 and Black Rock Well #3. The test on village of Zuni Well #4 was made when the well was being drilled. The discharging zone was the interval 160 to 245 feet. Thus, it does not describe the finished product. The curves for the other two wells reflect their present condition. Clearly, had these wells been constructed so as to minimize well inefficiency, their yield at a given drawdown would be larger. Clearly too, at least part of the problem of water supply in the Zuni-Black Rock area is well inefficiency. Similar analyses for other wells were not possible, because no step pumping tests had been made and generally, there was at most only one specific capacity cited per well. Petroleum engineer approach the problem of well efficiency by utilizing recovery data following well discharging to determing the "skin effect." This is a measure of the drawdown caused by the well and not by the formation. However, to apply this technique quantitatively to water wells requires that we know accurately the specific storage of the water yielding rocks. Since we don't know the specific storage of the rock at Zuni, we can only use the technique qualitatively. By inspection of the recovery data, we can ascertain whether the skin effect occurred and whether the skin effect is more or less than the effect obtained in another well pumping at the same rate.

In general, each well test pumped during August 1972 showed the influence of the skin effect. Moreover wells in the fractured zone of the Zuni hydrologic unit had a negative "skin effect" (the presence of the fracture made the effective diameter of the well much larger.) In all other wells, however, the recovery data suggests a substantial skin effect. Thus improving the quality of the wells constructed would increase their yield.

Pumping a well induces a water level decline in nearby wells. To predict the rate of decline due to nearby wells accurately, we need to know details of construction of the two wells, the horizontal and vertical hydraulic conductivities, specific storage, and thickness of the water-bearing rocks, and the distance between them. Figure 24

Figure 24 (see page 92)

shows the interference that might be expected under idealized conditions and assuming (1) continuous pumping at 25 gpm (the current average rate for the 4 village wells) and, (2) hydraulic properties of the rock less than those thought to occur. This figure presents conditions in the Zuni-Black Rock area pessimistically. However, until additional multiple well tests can be made to define the hydraulic properties of the water-bearing rocks more accurately, it is a conservative estimate for engineering purposes.

Recommendations for Future Wells

Wells drilled on the Pueblo of Zuni can be divided into two categories--those in consolidated rocks and those in unconsolidated rocks. Those in consolidated rocks should be drilled with an eye to keeping pores open. If rotary tools are used drill with water wherever practical. If mud is used, use a variety that will break down in a few days. Be sure that all mud and all fine particles are flushed from the well bore. A complete suite of electric logs, including gamma ray and caliber logs should be obtained. A multiple step test should be conducted.

If the test shows the well is efficient, no development is required, but if the test shows the well to be inefficient, several developmental techniques are available. These include chemical treatments, swabbing, surge pumping, and underreaming.

In those rocks composed of alternating hard and soft beds, light explosive (primacord) opposite the hard beds may aid considerably in developing the well. In rocks composed of thick beds of competent rock, larger charges of high velocity dynamite will open and extend the fracture locally, thereby increasing the yield. Hydro-fracturing may prove useful. However, the development program should not be undertaken unless a full suite of electric logs has been analyzed first. Each well will have its own unique conditions and these must be thoroughly understood before development can be accomplished most economically.

The casing in a well should be cemented to at least 40 feet below the water table. In the consolidated rocks, fracture form the major pores for hydraulic conductivity. Therefore, coarsely slotted casing may work well if enough of it is used and if the development activity can be made to remove the loose particles between the casing and the rock. A complete suite of electric logs will help solve the well completion problem. To establish a well design before these logs are available will lead to inefficient wells and a false economy. The most practical procedure would be to drill a test hole in which electric logs are run. Then on the basis of those logs designs the construction of the well including both the casing and development programs.

In unconsolidated rocks wells should be drilled with reverse rotary, using large (30-36") diameter bits. Commercially available screens (10 to 14" diameter) should be used--slotted casing is inappropriate. The annulus between the screen and the rock should be sand or gravel packed. A preliminary test hole should be drilled and gamma ray and resistivity logs obtained. With this data, the size of the screen and the sand or gravel pack can be established. Actual well construction should take only a few days. Cable tools may be used but will take longer to make a finished well. Rotary drilling should not be used to drill wells in unconsolidated rocks. They are satisfactory for test holes.

Two tests should be made for each well drilled. The first should be a carefully controlled step pumping test with water level measurements being measured frequently (1 or 2 minutes apart beginning the first part of the step and at least every ten minutes during the latter part of each step) and discharge should be constant for each step and measured frequently. Steps should be at least 1 hour long and there should be at least 4 steps. Each step should see the pumping rate increased by 25 to 50 percent. Recovery should be measured.

The second test should consist of pumping the new well for at least 24 hours at a constant rate. Drawdown and recovery in the new well and in every nearby well should be measured often. Discharge should be carefully monitored, including measurements of rate, temperature, specific conductance, pH, alkalinity, and chlorides. Several water samples should be obtained for complete chemical analyses.

With these data the well field design can be improved. Should changes occur in the system the amount of change can be determined.

Springs and horizontal wells

Springs on the reservations are an important facet of the hydrologic cycle. Many springs or seeps might be made to produce more water, if horizontal wells were installed. Initially, they discharge more water than the springs or seep, because they obtain part of their yield by locally depleting groundwater storage. Their long term yield, however, should be the same as that of the springs or seep, but they should produce more water for stock because these wells capture water that previously had been lost to evaporation.

Dynamite should never be used on springs or seeps in the reservation. If the integrity of the rock underlying the spring is damaged, the spring could be destroyed forever. No amount of permeability increase at the spring will cause a substantial long term increase as ground-water storage is locally depleted. Once this is accomplished the yield will return to that before any development was attempted. The yield of springs and horizontal wells is determined by flow systems and regional character of the rock.

RECOMMENDATIONS

This report interprets ground-water conditions within the Pueblo of Zuni from the available data. To improve the interpretation (as opposed to simply changing it) a great deal of new work must be done. This work should include:

(1) Detailed surface geological mapping using $7\frac{1}{2}$ min. quadrangles with at least 20 foot topographic contours. This mapping would be made considerably easier if low level color aerial stereo photography were available.

(2) A systematic data collection program including:

(a) short term pumping tests on all stock wells. These tests should provide water samples for chemical analysis and data on temperature, pH, and specific conductance of water.

(b) systematic collection of well data. Well depths should be measured, resistivity and gamma ray logs would be useful. Water levels should be measured at least once a year. The location and history of each well within the Pueblo boundarys should be kept in a central file for future reference. When a new well replaces an old one, a new file should be started and the old one should be preserved. Driller's reports should be obtained for each new well whether drilled by an individual or by the tribe. The record of every drill hole on the reservation should be retained.

(3) A carefully controlled pumping test involving all the wells at the village should be made as soon as possible.

(4) An exploratory drilling and testing program for the Tertiary-Quaternary sands should be initiated.

(5) A complete field inventory of springs should be made. This inventory should provide location, description, flow, temperature, specific conductance and pH. The flow, temperature, and specific conductance of some springs should be monitored routinely.

(6) To obtain better water budgets, more long term weather data for the reservation must be obtained from stations of various altitudes.

CONCLUSIONS

The ground-water resources of the Pueblo of Zuni are adequate in quantity if not in quality to satisfy the demand for stock, domestic and light industrial needs. The quality of the ground-water together with the cost to obtain a sufficient supply will probably preclude the use of ground-water for irrigation.

In addition to the Triassic rocks currently being tapped by the Village of Zuni, other areas show potential. These areas should be explored in detail. The most prominent area is Ts. 10-11 N., Rs. 20-21 W., where there is an extensive deposit of wind blown sand. Properly constructed wells in this area could produce enough water of excellent quality to satisfy the Pueblo's municipal industrial needs for the next century. Provided it is properly developed and protected.

The alluvium in the immediate area of Black Rock and Zuni could be developed, but water quality problems may be insurmountable, especially if flood control activity further reduces flood runoff.

Improved well construction techniques must be developed if the water-supply is to be developed efficiently.

REFERENCES CITED

Ash, S.R., 1959, The Indians of west-central New Mexico: New Mexico Geol. Soc., Guidebook Tenth Field Conf., West-Central New Mexico, p. 154-56.

Bureau of Indian Affairs, 1970, Map atlas, soil, and range inventory of the Zuni Indian Reservation: Albuquerque area, Branch of Land Operations, Zuni Pueblo, 20 sheets.

Committee on Quality Tolerances of Water for Industrial Uses, 1940, Progress Report, J. New Engl. Water Works Assoc., v. 54, p. 261-272.

Cooley, M.E., 1969, Triassic stratigraphy in the state line region of west-central New Mexico and east-central Arizona: New Mex. Geol. Soc., Guidebook Tenth Field Conf., West-Central New Mexico, p. 66-73.

------, Harshbarger, J.W., Akers, J.P., and Hardt, W.F., 1969, Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geol. Surv., Prof. Paper 521-A, 61 p.

Cooper, James B. and John, Edward C., 1968, Geology and ground-water occurrence in southeastern McKinley Coungy, New Mexico: N. Mex. St. Engr., Tech. Rept. 35, 108 p.

Dinwiddie, G.A. and Motts, W.S., 1964, Availability of ground-water in parts of the Acoma and Laguna Indian Reservations, New Mexico: U.S. Geol. Surv., Water-Supply Paper 1576-E, 62 p.

------, Mourant, W.A., and Baster, J.A., 1966, Municipal water supplies and uses Northwestern, New Mexico: New Mex. St. Engr., Tech. Rept. 29C, 197 p.

Domenico, Patrick A., 1972, Concepts and Models in Groundwater Hydrology: McGraw-Hill Book Company, 405 p.

Foster, Roy W., 1957, Stratigraphy of west-central New Mexico: Four Corners Geol. Soc., Second Field Conf., Guidebook, Geology of Southwestern San Juan Basin, p. 62-72.

------, 1971, Southern Zuni Mountains, New Mexico: New Mex. Institute Mining and Tech., New Mex. Bur. Mines Mineral Res., Scenic Trips to the Geological Past, No. 4, 75 p.

Freeze, R.A., 1969, Regional groundwater flow-- Old Wives Lake Drainage Basin, Saskatchewan: Canadian Dept. of Energy, Mines, and Resources, Inland Waters Branch, Scientific Series No. 5, 246 p.

Gregory, H.E., 1917, Geology of the Navajo Country, a reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geol. Surv., Prof. Paper 93, 166 p.

Irwin, J.H., Stevens, P.R., and Cooley, M.E., 1971, Geology of the Paleozoic rocks, Navajo and Hope Indian Reservations, Arizona, New Mexico, and Utah; U.S. Geol. Surv., Prof. Paper 521-C, 32 p.

Jobin, D.A., 1962, Relation of the tranmissive character of the sedimentary rocks of the Colorado Plateau to the distribution of uranium deposits; U.S. Geol. Surv., Bull. 1124, 151 p.

King, Vernon L. and Wengard, Sherman A. (1957) The Hospah Oil Field, McKinley County, New Mexico: Four Corners Geol. Soc., Second Field Conf. Guidebook, Geology of Southeastern San Juan Basin, p. 155-168.

Kottlowski, Frank E., 1959, Pennsylvania rocks on the northeast edge of the Datil Plateau: New Mex. Geol. Soc., Guidebook Tenth Field Conf., West-central New Mexico, p. 57-62.

Morris, Donald E. and Prehn, W. Lawrence, Jr., 1971, Chap.VIII, The Potential for desalting in Zuni Pueblo; (in The Potential Contribution of desalting to Future water supply in New Mexico): A report prepared for office of the State Engineer, State of New Mexico and Office of Saline Water, U.S. Department of the Interior, OSW Contract No. 14-30-2580, p. 73-82.

New Mexico Department of Public Health, Environmental Factors, Water and Liquid Waste Division, 1967, A compilation of chemical analyses of the Municipal Drinking Supplies of the State of New Mexico: Santa Fe, 47 p.

O'Sullivan, R.B., Repenning, C.A., Beaumont, E.C., and Page, H.G., 1972, Stratigraphy of the Cretaceous rocks and the Tertiary Ojo Alamo Sandstone, Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geol. Surv., Prof. Paper 521-E, 65 p.

Reeder, H.O., 1961, Aquifer characteristics (in Gordon, Ellis D, Geology and Ground-water resources of the Grande-Bluewater Area, Valencia County, New Mexico): N. Mex. St. Engr., Tech. Rept. 20, p. 57-63.

Reneau, Wilbur E.,Jr., and Harris, James D., Sr., 1957, Reservoir characteristics of Cretaceous sands of the San Juan Basin: Four Corners Geol. Soc., Guidebook Second Field Conf., Geology of Southwestern San Juan Basin, p. 40-43.

Reppenning, C.A., Cooley, M.E., and Akers, J.P., 1969, Stratigraphy of the Chinle and Moenkopi Formations, Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geol. Surv., Prof. Paper 521-B, 34 p.

Rittenhouse, Gordon, Fulton, Robert B.,III, Grabowski, Robert J. and Bernard, Joseph L., 1969, Minor elements in oil-field waters: Chem. Geol., b. 4, p. 189-209.

Sears, Julian D., 1925, Geology and coal resources of the Gallup-Zuni Basin, New Mexico: U.S. Geol. Surv., Bull. 767, 53 p.

Smith, Clay T., 1954, Geology of the Thoreau Quadrangle, McKinley and Valencia Counties, New Mexico: N. Mex. Institute Mining and Tech., N. Mex. Bureau Mines Mineral Resources, Bull. 31., 36 p.

------, 1958, Geologic Map of Inscription Rock Fifteen Minute Quadrangle, N. Mex. Institute Mining and Tech., N. Mex. Bureau Mines Mineral Resources, Geol. Map 4.

------, and others, 1959, Geologic Map of Foster Canyon Quadrangle, Valencia and McKinley Counties, New Mexico: New Mex. Institute Mining and Tech., N. Mex. Bureau Mines Mineral Resources, Geol. Map 9.

Summers, W.K., 1970, Survey of ground-water conditions that might affect the institute mining of the North Windship Area, Laguna Pueblo, Valencia County, New Mexico: Socorro, N.M., N. Mex. Tech. Research Foundation, 46 p.

------, 1972, Factors affecting the validity of chemical analyses of natural water; Ground Water, v. 10, no. 2, p. 12-17.

------, Schwab, Geraldine E., and Brandvold, L.A., (1972) Ground-water characteristics in a recharge area, Magdalena Mountains, Socorro County, New Mexico: N. Mex. Institute

Mining and Tech., N. Mex. Bureau Mines and Mineral Resources, Circular 124, ___p.

Toth, J., 1962, A theory of groundwater motion in small drainage basins in central Alberta, Canada: Jr. Geophysical Research, v. 67, p. 4374-4387.

Tuan, Yi-Fu, Everard, Cyril E., and Widdison, Jerold G., 1969, The climate of New Mexico: Santa Fe, N.M., State Planning Office, Resources Planning Division, 170 p.

U.S. Public Health Service, 1962, Public Health Service Drinking Water Standards: U.S. Dept. H.E.W., Public Health Service, Publ. 956.

U.S. Salinity Laboratory, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. Agriculture, Handbook 60.

Wilcox, L.V., 1948, The quality of water for irrigation use: U.S. Dept. Agric., Tech. Bull. 962, 40 p.

------, 1955, Classification and use of irrigation waters, U.S. Dept. of Agriculture, Circular 969, 19 p.

Table 1. Population of Pueblo of Zuni

	Total Pueblo	Village of Zuni
1920	1700+	
1950		2563*
1958	3708++	
1960	3934#	3585*
1970	3958#	
1972	6010± ±	
1980	6200#	
2000	7600#	
	9000#	

+ Sears (1925, p. 7)

* Census figures in Dinwiddie, Mourant, and Basler (1966)

Morris and Prehn (1971, p. 73)

++ Ash (1959, p. 156)

±± Tribal figures

Table 2—*Summary of hydrologic units and their water-bearing and water-yielding characteristics*

					At Zuni				Northeastern Arizona-Northwestern New Mexico										
									Cooley, et al., 1969									Jobin, 1962	
										Field Tests								Range of Average K (gpd/ft²)	
										Pumping Tests				Bailing Tests		Pressure Tests			
Age	Hydrologic Unit	Stratigraphic Unit	Thickness (feet)	Lithology	T (gpd/ft)	K (gpd/ft²)	Yield (gpm)	Specific Capacity (gpm/ft)	Laboratory K (gpd/ft²)	T	K	Sp. Cap.	(gpm)	Sp. Cap.	Yield	Sp. Cap.	Yield	From	To
Quaternary	Alluvium	Alluvium (Qal)	0-200?	Gravel, sand, silt, clay	2640	63	125	1.2	-	375 to 63800	-	.8-68.9	10-241	.12-75	5-275	-	-	-	-
	Basalt	Basalt (Qb)	0-93	Basalt	-	-	25	-	-	-	-	-	-	-	-	-	-	-	-
Quaternary Tertiary	Dune Sand	Dune Sand (TQs)	0-318	Well sorted, sand	1550	75	44	.3	-	-	-	-	-	-	-	-	-	-	-
Cretaceous	Crevasse Canyon	Crevasse Canyon Fm (Kcc)	0-600	Shale and sandstone with coal	-	-	-	-	-	-	-	-	-	.03-.64	2-45	1.02-1.7	6-15	-	-
	Gallup	Gallup Sandstone (Kg)	230-550	Sandstone and shale with coal	15	1	10	.04	.4-2	-	-	.03-4.78	13-264	.07-4.84	4-150	.04-.28	7-11	4	100
	Mancos	Mancos Shale (Km)	280-630	Shale with sandstone	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dakota	Dakota (?) Sandstone (Kd)	40-200	Sandstone with shale	53 & 100	.62 & 1.2	15	.04-.11	.7-25	-	-	-	-	.02-.40	3-36	.06-.16	3-8	3	9
Jurassic	Wingate-Entrada-Zuni Morrison	Morrison Fm (Jm)	0-360	Sandstone with shale and siltstone					.1-15	677	5.4	.45-.92	13-350	.07-2.2	6-19	0-44	15	.2	40
		Zuni Sandstone (Jz)	445-660		1800 &	12	15	.27-.84	.4-2	20.7	<1	.07-.16	9-16	.07-.27	8-40	-	-	3	10
		Entrada Sandstone (Je)			800	78			1-65	-	-	-	-	.02-3.5	5-35	-	-	.1	35
		Wingate Sandstone (TRw)	105-275						-	-	-	-	-	.02-.7	7-8	-	-	.1	7
Triassic	Triassic Mudstones and Sandstones	Chinle Fm Moenkopi Fm (TRc)	1000?-1800?	Conglomerate sandstone, siltstone, shale, mudstone, limestone	20-5000?	1-20	125	.013-1.25	-	150 & 2000	1.5	.25-1.35	50-100	.03-3.3	1-60	-	-	.8	18
Permian	San Andres-Glorieta	San Andres Ls (Psa)	0-289	Limestone					-	61.2 &	-	-	-	-	-	-	-	4	
		Glorieta SS (Pg)	120-280	Sandstone	520	2	50	.17-.23	.2-.9	6600-15800	3-7	-	228	.05-.23	5-34	.03	2	3	
Precambrian	Yeso	Yeso Formation (Py)	275-530	Sandstone, limestone, shale, gypsum	-	-	-	-	4.2-40*	310-755*	1-5*	.21-1.21*	25-150*	.01-3.0*	3-200*	-	-	.2'	
	Abo	Abo Formation (Pa)	300?-1000?	Sandstone, siltstone, shale	-	-	-	-	-	-	-	-	-	.01-.92‡	1-24‡	-	-	-	
	Precambrian	Precambrian (p-C)	- -	Granite and quartzite	-	-	-	-											

*Values for DeChelly Formation of Arizona.
‡Values for Supai Formation of Arizona.

Table 3. Stratigraphic nomenclature of Permian rocks, Northeastern Arizona and Northwestern New Mexico (after Irwin, Stevens, and Cobler, 1971, p. 10).

Epoch	Defiance Plateau Area		Pueblo of Zuni	
Leonard			Erosion	
Leonard	San Andres (?) Limestone / Redbeds in Bonito Canyon		San Andres Limestone	
Leonard	De Chelly Sandstone	Upper Member	Glorieta Sandstone	
Leonard	De Chelly Sandstone	Lower Member	Yeso Fm.	San Ysidro Member
Wolfcamp	Supai Fm.		Yeso Fm.	Meseta Blanca SS Member
Wolfcamp	Supai Fm.		Abo	
Wolfcamp	Erosion		Erosion	

Table 4. Description of cuttings samples from Cities Service #1 Zuni A by Roy W. Foster.

Cities Service #1 Zuni A (McKinley County)
1980 S, 1980 W, sec. 5, T. 9 N., R. 18 W.
Elev. 7,027'; T. D. 2, 591'
Spud: 11-7-63; Comp: 11-22-63
Triassic at surface: Samples begin at 1,230 feet in San Andres Limestone

Glorieta Sandstone: Top: 1,270'; Thickness: 120'. White, fine-to medium-grained, friable sandstone.

Yeso Formation: Top: 1,390'; Thickness: 530'. Fine-grained, orange sandstone in upper part with some fine-to coarse-grained intervals; and thin beds of gypsum. Dark-yellowish brown limestone, orange, medium to coarse sandstone, and gypsum interval from 1,685 to 1,800 feet. Lower part fine-to medium-grained, orange sandstone of Mesita Blanca Member.

Abo Formation: Top: 1,920'; Thickness: 600'. Pale red siltstone, very fine-grained sandstone, dark red shale, and minor arkosic conglomerate. Basal interval of pale reddish gray siltstone.

Precambrain: Top: 2,520'; Thickness: 71'+. Quartzite and schistose quartzite.

Table 5. Thickness of Permian Formations penetrated by wells in the vicinity of the Pueblo of Zuni, New Mexico (+ indicates incomplete penetration)

Well Name	Location			Formation thickness (feet)			
	Sec.	T.N.	RW	Abo Fm	Yeso Fm.	Glorieta SS.	San Andres LS.
Roy M. Eidal #32 State	32	9	15	--	--	--	146
Cities Service #1	5	9	18	600	530	120	263
Robert O. Lister #1 Zuni	2	10	19	--	--	--	--
Black Rock Water Well #2	24	10	19	--	--	160+	100
Village of Zuni Water Well #1	28	10	19	--	--	280+	0
Carter Oil Co Santa Fe #2	7	11	19	350+	275	255	80
William G. Coffey #1 Coffee Federal	35	11	19	--	--	--	289

Table 6. Consensus of Moenkopi, Moenkopi(?), and Chinle Formations lithology

		Stratigraphic Unit	Lithology	Remarks
Chinle Formation	Petrified Forest Member	Owl Rock Member	calcareous stilstone, limestone silty sandstone	some beds traced 20 miles
Chinle Formation	Petrified Forest Member	Upper beds	silty sandstone, siltstone, mudstone with limestone conglomerate	lower bed flat and lenticular to $\frac{1}{4}$ mile long
Chinle Formation	Petrified Forest Member	Sonsela sandstone bed	sandstone and conglomerate with mudstone and siltstone	channel deposit
Chinle Formation	Petrified Forest Member	Lower beds	mudstone and siltstone	broad channel deposits
Chinle Formation		Lower Red (Monitor Butte)Member	siltstone and mudstone alternating with conglomeratic sandstone, includes limestone conglomerate	discontinuous beds, lenticular beds, and channel deposits.
Chinle Formation		Mesa Redondo Member	mudstone, siltstone, sandstone and conglomerate	interfingering channel deposits
Chinle Formation		Shinarump Member	sandstone and conglomerate with some mudstone	channel deposits and lenticular beds
		Moenkopi(?) Formation	siltstone, mudstone, sandstone conglomerate	channel deposits and lenticular beds
		Moenkopi Formation	sandstone, siltstone some conglomerate	channel deposits

Table 7. Comparison of thickness of the Moenkopi, Moenkopi(?), and Chinle Formations reported for Zuni Village area, Zuni Mountains, and Defiance Plateau

Zuni Village Area

		Unit	Thickness (feet) ~~Log of~~ Well #1 1954	~~Cooley~~ (1959)	~~*Repenning, Cooley~~ & Akers (1969)
Chinle Formation		Owl Rock Member	--	0	20+
Chinle Formation	Petrified Forest Member	Upper Petrified Forest	135 (495 handwritten, bracketing 135, 40, 325)	NS	550
Chinle Formation	Petrified Forest Member	Correo SS	40	NS	60
Chinle Formation	Petrified Forest Member	Middle Petrified Forest	325	NS	170
Chinle Formation	Petrified Forest Member	Sonsela SS	105	NS	130
Chinle Formation	Petrified Forest Member	Lower Petrified Forest	530 (bracketed with next row)	NS	30
Chinle Formation		Lower Red (Monitor Butte) Member		300	250
Chinle Formation		Mesa Redondo Member	0	present	200
Chinle Formation		Shinarump Member	60	60	70
		Moenkopi(?) Formation	--	--	--
		Moenkopi Formation	30	NS	30#

{ } interpreted from sample description

* Scaled from plate 2

NS Not specified

\+ map in text shows 0 foot

\# map in text shows about 100 feet

Table 7 (cont'd)

Zuni Mountains

	Unit	Smith (1954, 1957)	Thickness (feet) Cooley (1959)	Repenning, Cooley & Akers (1969) *plate 2	text
Chinle Formation	Owl Rock Member	300	50	40	0-140[+]
Chinle Formation; Petrified Forest Member	Upper Petrified Forest	1000 364	364	370	
Chinle Formation; Petrified Forest Member	Correo SS	NS	NS	20	1100
Chinle Formation; Petrified Forest Member	Middle Petrified Forest	336-	NS	460	
Chinle Formation; Petrified Forest Member	Sonsela SS	100-200	Present	60	50-200
Chinle Formation; Petrified Forest Member	Lower Petrified Forest		125	290	100
Chinle Formation	Lower Red (Monitou Butte) Member	300-500	NS	190	390
Chinle Formation	Mesa Redondo Member		NS	0	NS
Chinle Formation	Shinarump Member	0	0-thin	0	0-80
	Moenkopi(?) Formation	0	100+	40	100+
	Moenkopi Formation	0	0	0	100+

* Scaled from plate 2

{ } interpretation of units from Smith's description of lithology

NS not specified

\+ from map in text

Table 7 (cont'd)

Defiance Plateau

			Thickness (feet) Repenning, Cooley & Akers (1969)	
	Unit	Cooley(1959)	Text	*Plate 2 (Fort Defiance)
Chinle Formation	Owl Rock Member	200-300	200-300+	240
Chinle Formation – Petrified Forest Member	Upper Petrified Forest	NS	400 (Upper Petrified Forest through Middle Petrified Forest)	260
Chinle Formation – Petrified Forest Member	Correo SS	NS		40
Chinle Formation – Petrified Forest Member	Middle Petrified Forest	NS		240
Chinle Formation – Petrified Forest Member	Sonsela SS	150+	50-200	150
Chinle Formation – Petrified Forest Member	Lower Petrified Forest	NS	200-300	200
Chinle Formation	Lower Red (Monitor Butte) Member	200	200-350	240
Chinle Formation	Mesa Redondo Member	0	30	0
Chinle Formation	Shinarump Member	75	80	1000
	Moenkopi(?) Formation	0	0	0
	Moenkopi Formation	65*	0-100+	0

+ from map in text

* scaled from plate 2

NS not specified

Table 8. Summary description of mudstones and sandstones of Triassic Age.

Unit	Thickness (ft)	Common Lithology	Remarks
Mudstone 6	0-400	red clay shale	includes beds of limestone
Sandstone 5	0-100	light colored sandstone	similar to Entrada SS
Mudstone 5	0-300	purple & brown shale and siltstone	badland topography
Sandstone 4	0-100	red and brown sandstone	
Mudstone 4	0-200	purple & brown shales, siltstone	badland topography
Sandstone 3	0-100	red and brown sandstone	
Mudstone 3	100-300	sandy siltstone, silty sandstone	may be green
Sandstone 2	0-100	light colored & red sandstone	conglomerate in outcrop
Mudstone 2	200-500	siltstone & shale	may be green
Sandstone 1	0-100	light colored sandstone	conglomerate in outcrop
Mudstone 1	0-300	siltstone and mudstone	

Table 9. Estimated hydraulic conductivity of Sandstones 2 and 3 in Zuni Village Well No. 4 based on effective grain size.

BIA Sample	Interval (feet)	Effective grain diameter (mm)		Estimated Hydraulic Conductivity(gpd/ft^2)
Sandstone 3				
295	155-160	.001	(10^{-3})	.01
296	160-165	.001	(10^{-3})	.01
297	165-170	.002	(2×10^{-3})	.1
298	170-175	.001	(10^{-3})	.01
Sandstone 2				
1006	575-580	.149	1.5×10^{-1}	200
1007	580-588	.080	8×10^{-2}	100
1008	585-590	.080	8×10^{-2}	100
1009	590-595	.080	8×10^{-2}	100
1010	595-600	.080	8×10^{-2}	100
1011	600-605	.005	5×10^{-3}	.02
1012	605-610	.002	2×10^{-3}	.01

Table 10. Hydraulic conductivity and porosity of sandstone cores of the hydrologic units of Cretaceous age taken from the San Juan Basin, New Mexico

Hydrologic Unit	Source	Porosity (%) Range	Porosity (%) Average	Hydraulic Conductivity (gpd/ft^2) Range	Hydraulic Conductivity (gpd/ft^2) Average
Gallup Sandstone	1	5.0-27.2	14.7	0.0-7.4	.53
		3.9-18.8	12.6	0.0-.12	.0055
		7.3-38.5	13.3	0.036-8.0	.55
		6.8-19.5	13.7	.11-6.2	.91
		11.4-16.8	13.9	.018-11.0	1.2
	2	24-29	--	.6-11.1	--
		24-30	--	3.5-9.1	--
Dakota Sandstone	1	--	11	--	.24.

1 = Reneau and Harris (1957)

2 = King and Wengerd (1957)

Table 11. Comparison of Municipal Wells at the Village of Zuni

Distance (in feet) from well — Well	1	2	3	4
1	----	830	3550	3300
2	830	--	4370	4080
3	3550	4370	--	2250
4	3300	4080	2250	--

	1	2	3	4
Perforations	500-530 1500 plugged	195-250 320-340	244-259 516-556	well screen at bottom length?
Depth	back 707? 650(USGS)	492	556	610
Year drilled	1953	1953	1957	1967
Original Flow (gpm)	6-10	0	$4\frac{1}{2}$-6	*
Original ? (gpm)	51	100	60	70?
est. 5/72	60	90	30	55
Initial Sp. Cond	936	?	?	1350-1400
1968	1130	1130-1500	?	--
1972	1250	1300	1700	1400

* did not flow but water level was above land surface.

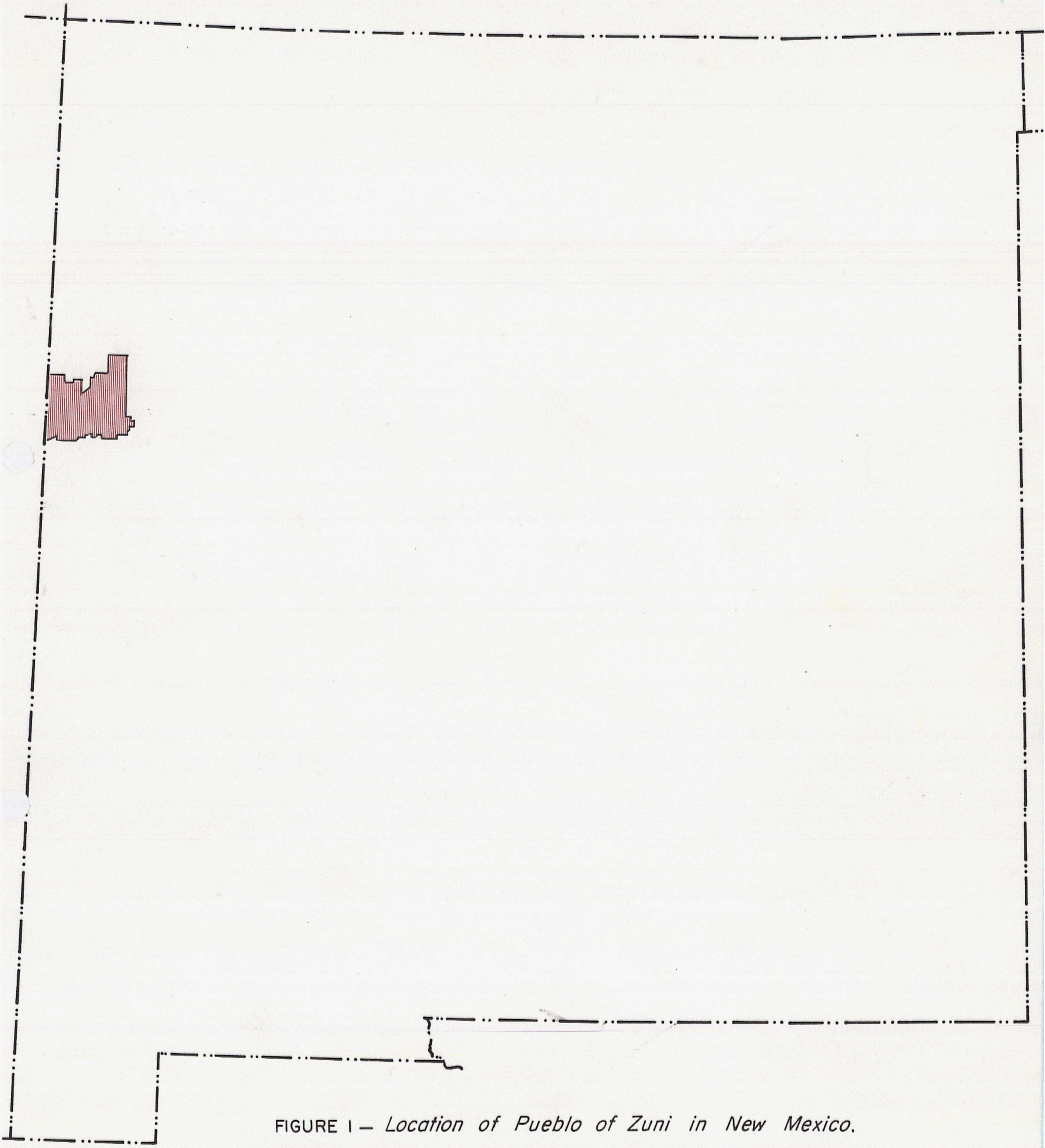


FIGURE 1 – *Location of Pueblo of Zuni in New Mexico.*

Fig 1

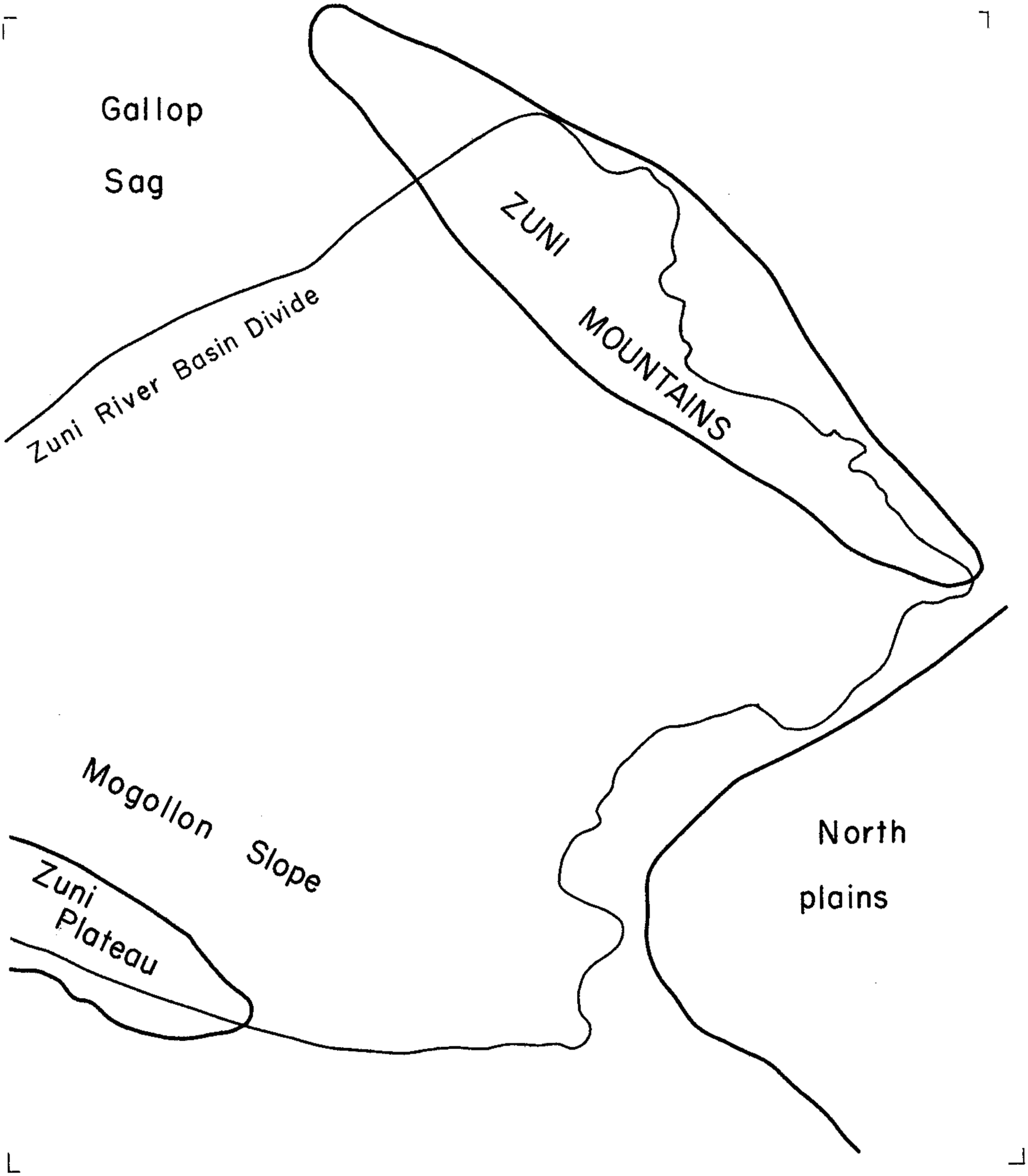


FIGURE 2— *Map showing the relation of the Pueblo of Zuni to regional drainage and topographic and tectonic features.*

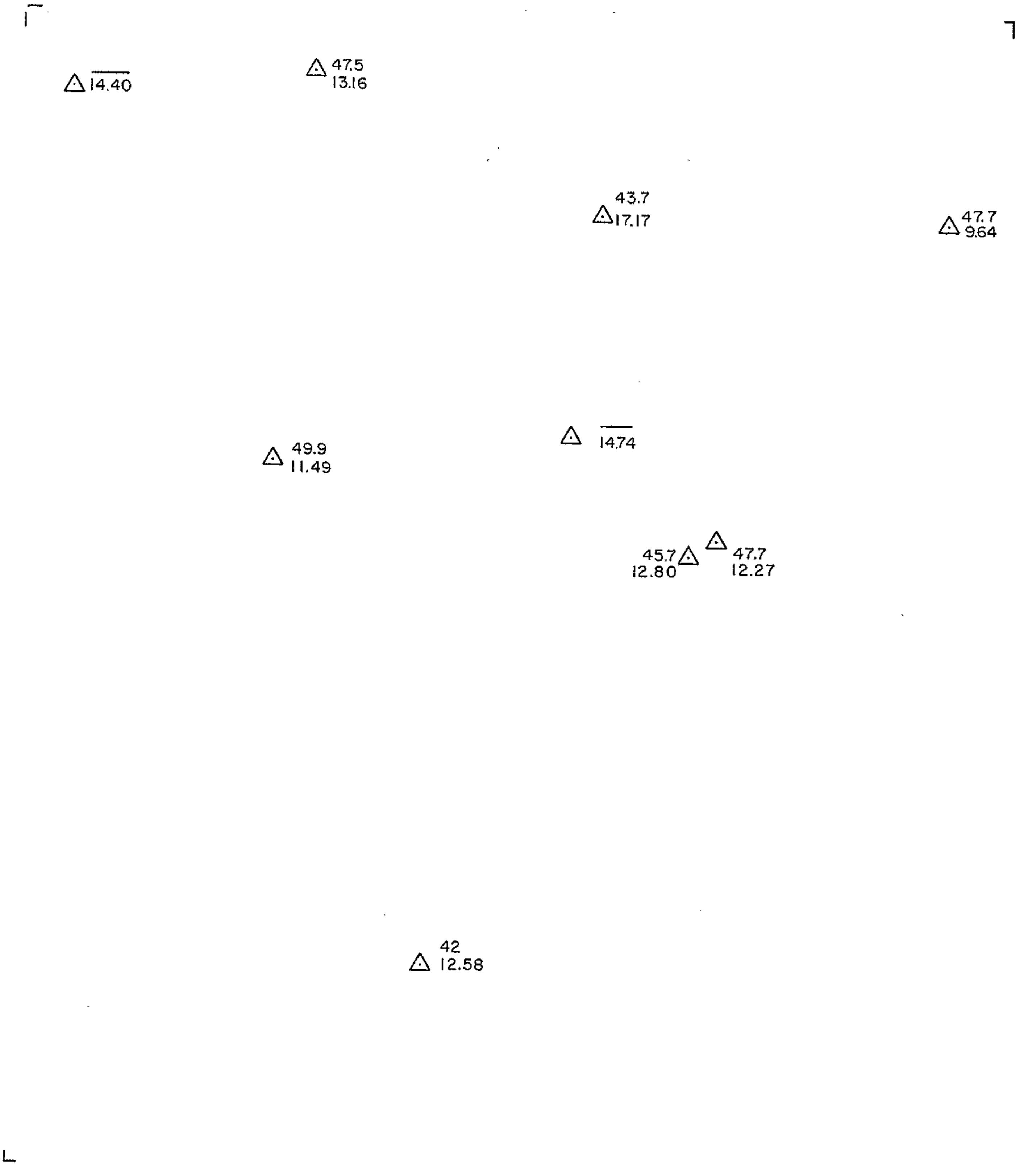


FIGURE 3— *Mean annual temperature and precipitation in the vicinity of the Pueblo of Zuni.*

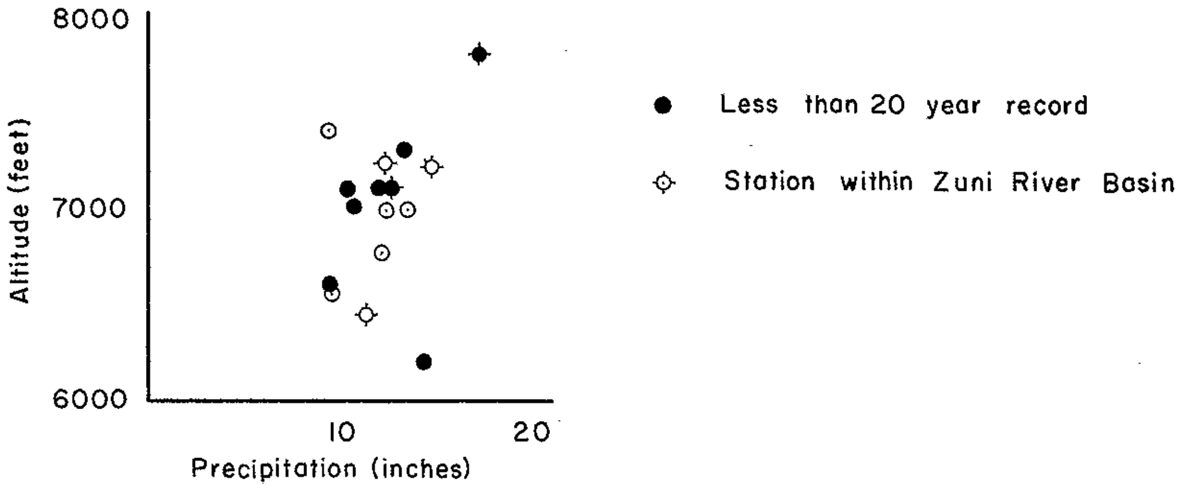


FIGURE 4—*Relation of mean annual precipitation to altitude in the vicinity of the Pueblo of Zuni.*

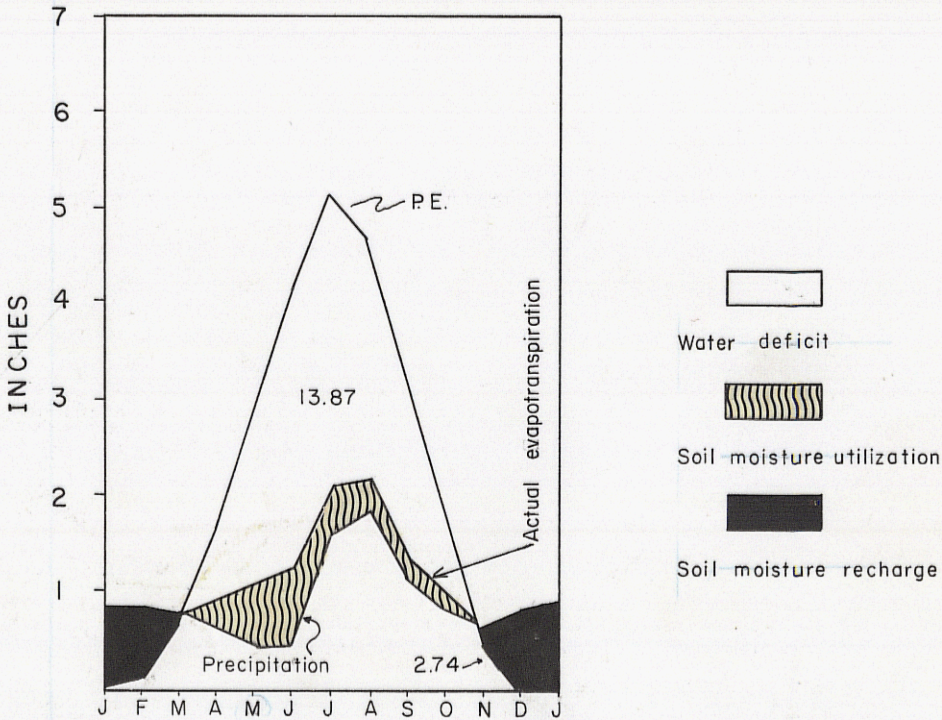


FIGURE 5 — *Mean monthly potential evapotransporation and precipitation of Zuni (after Tuan, Everard, and Widdison 1969.)*

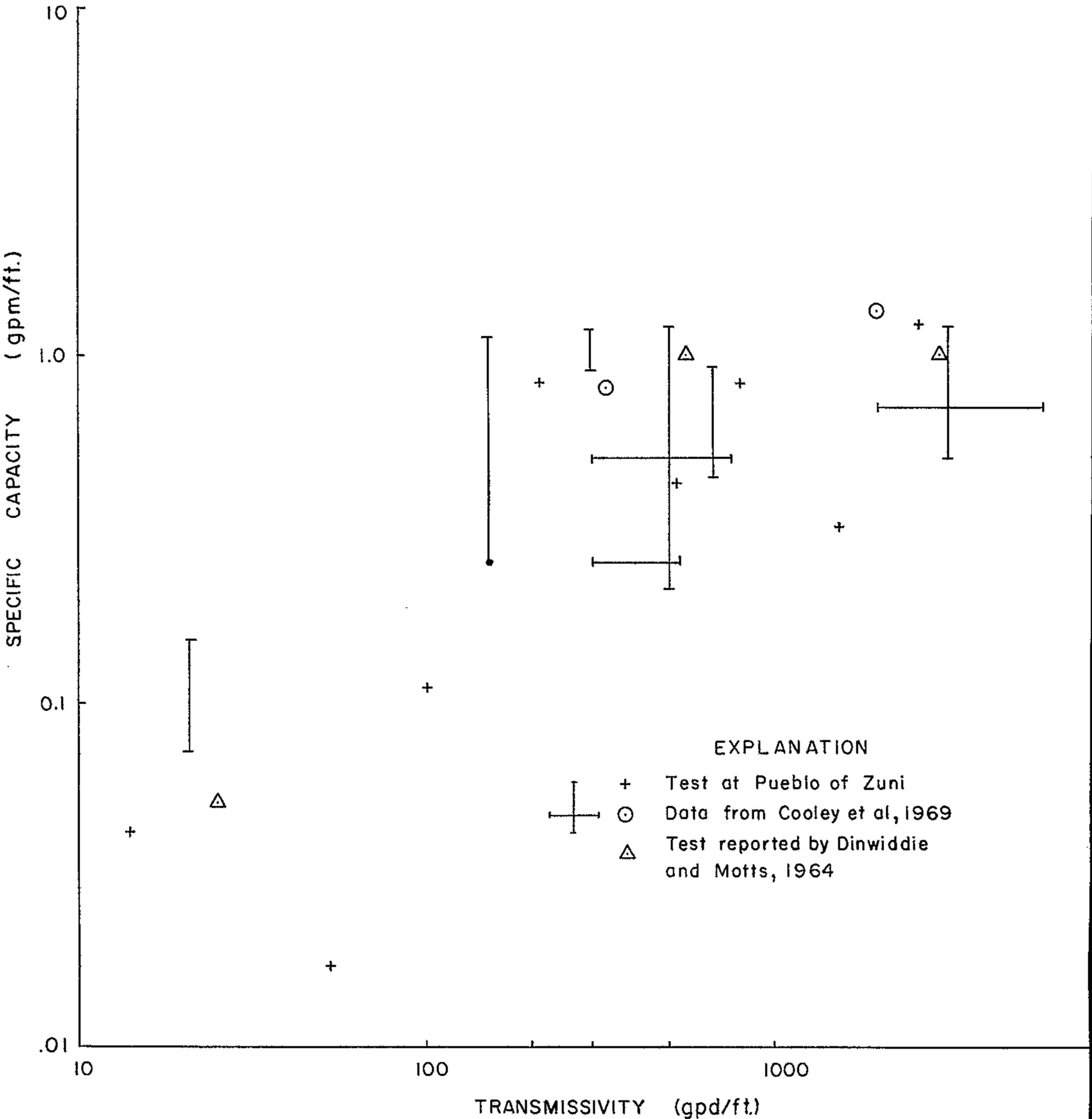


FIGURE 6— *Relation of specific capacity to transmissivity for wells in northwestern New Mexico.*

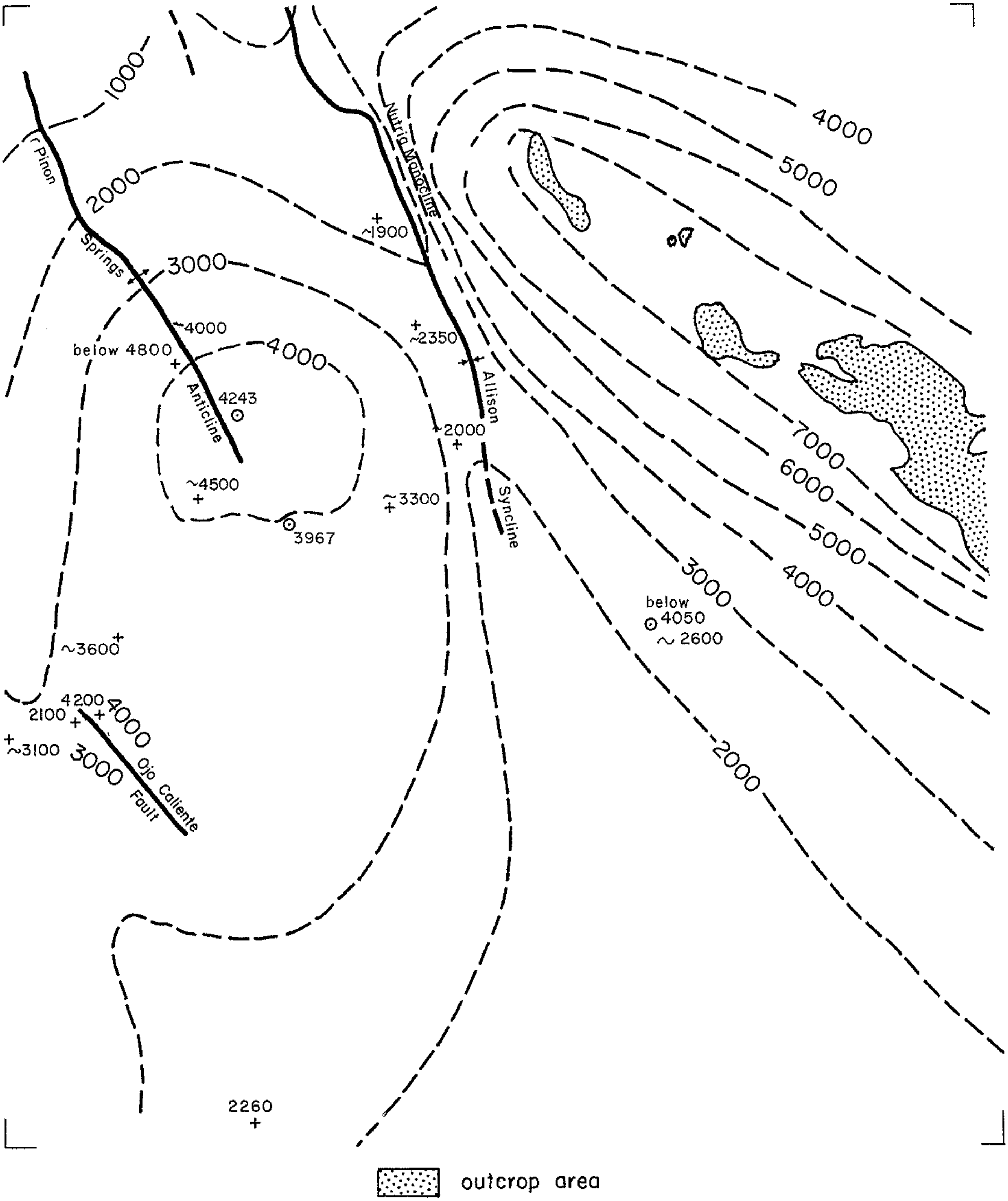


FIGURE 7— *Map showing structural contours on the surface of rocks of Precambrian age in the vicinity of the Pueblo of Zuni.*

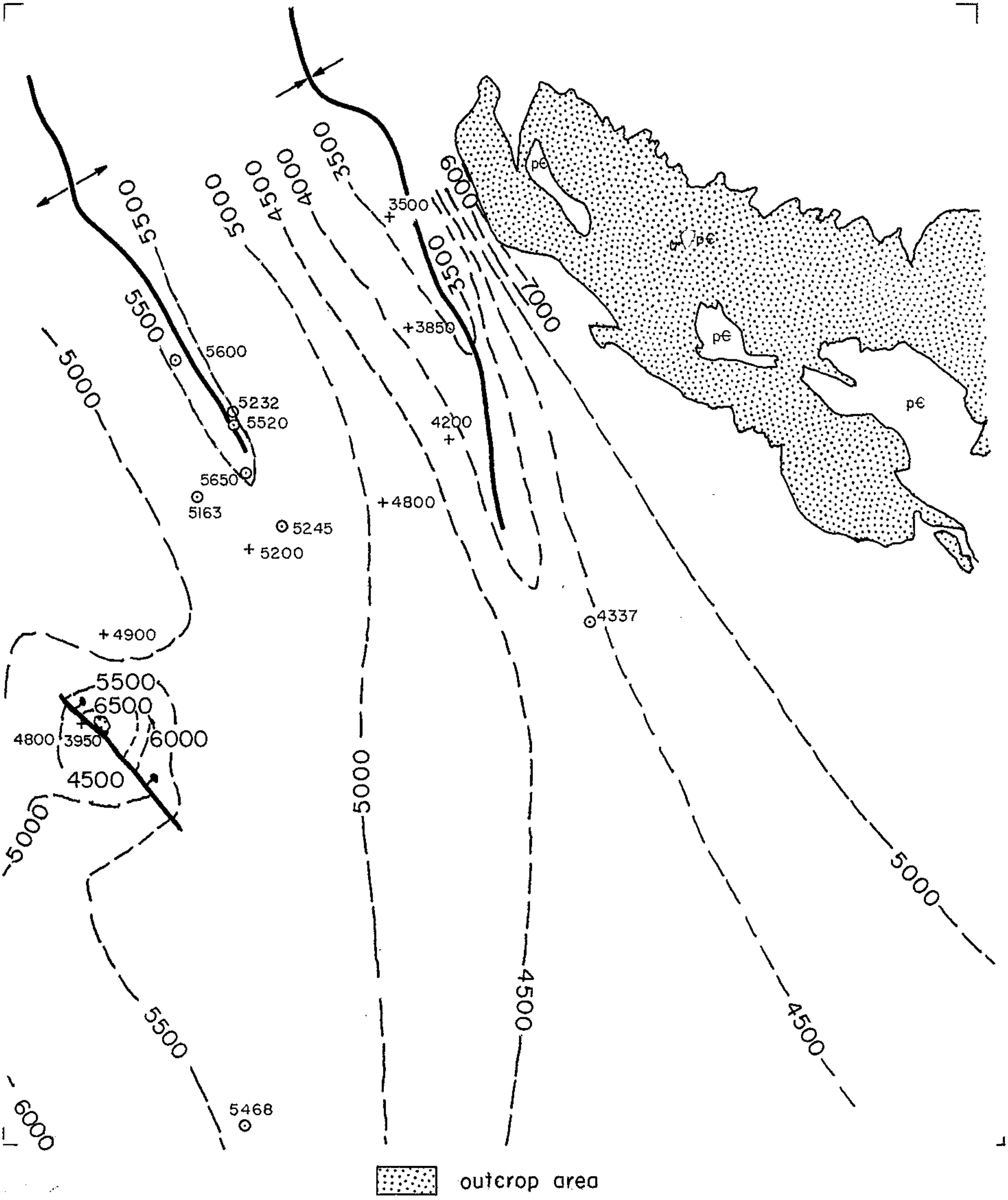


FIGURE 8— *Map showing structural contours on the surface of rocks of Paleozoic age in the vicinity of the Pueblo Zuni.*

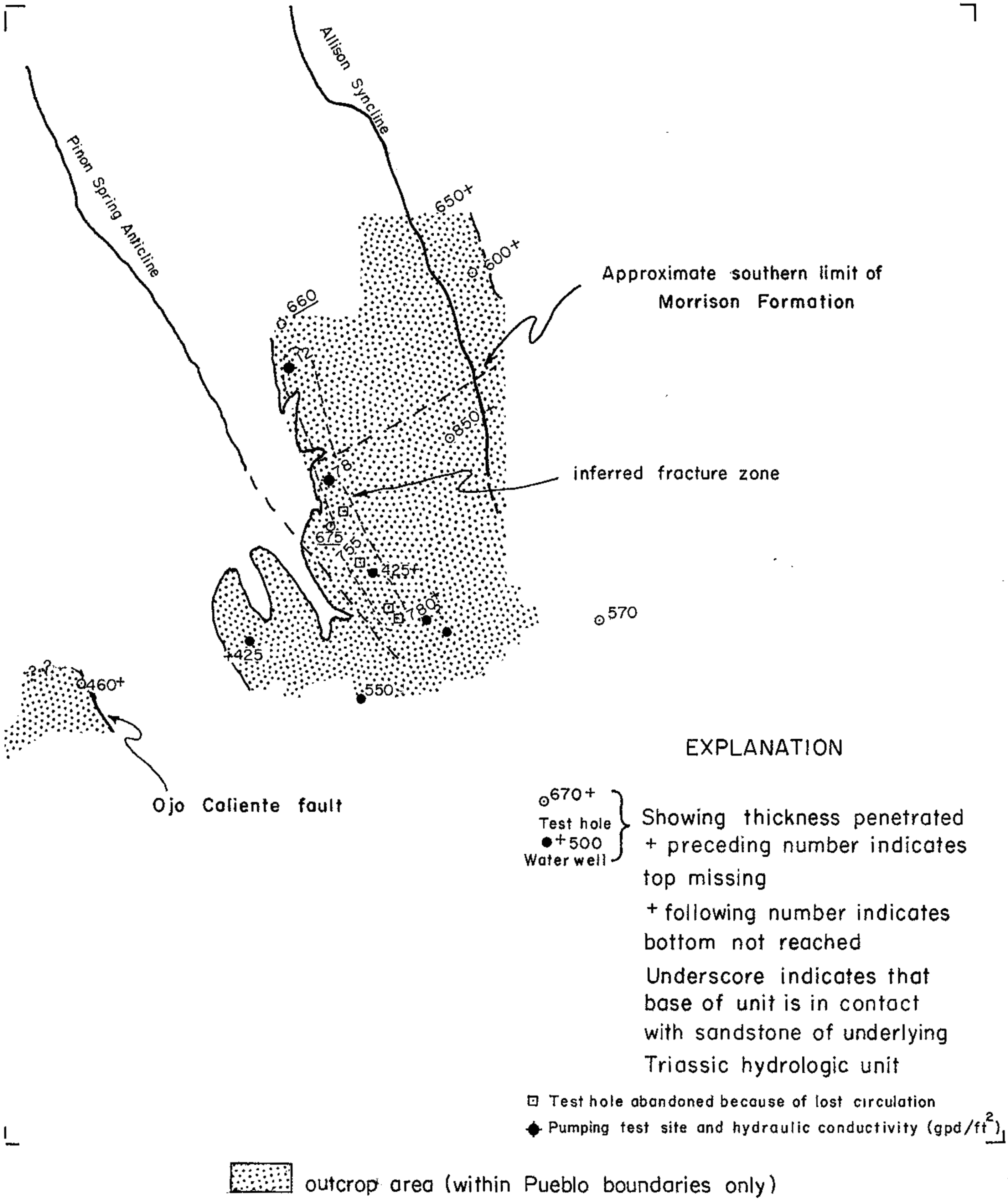


FIGURE 9 — *Distribution thickness and significant hydrologic features of the Zuni hydrologic unit in the Pueblo of Zuni.*

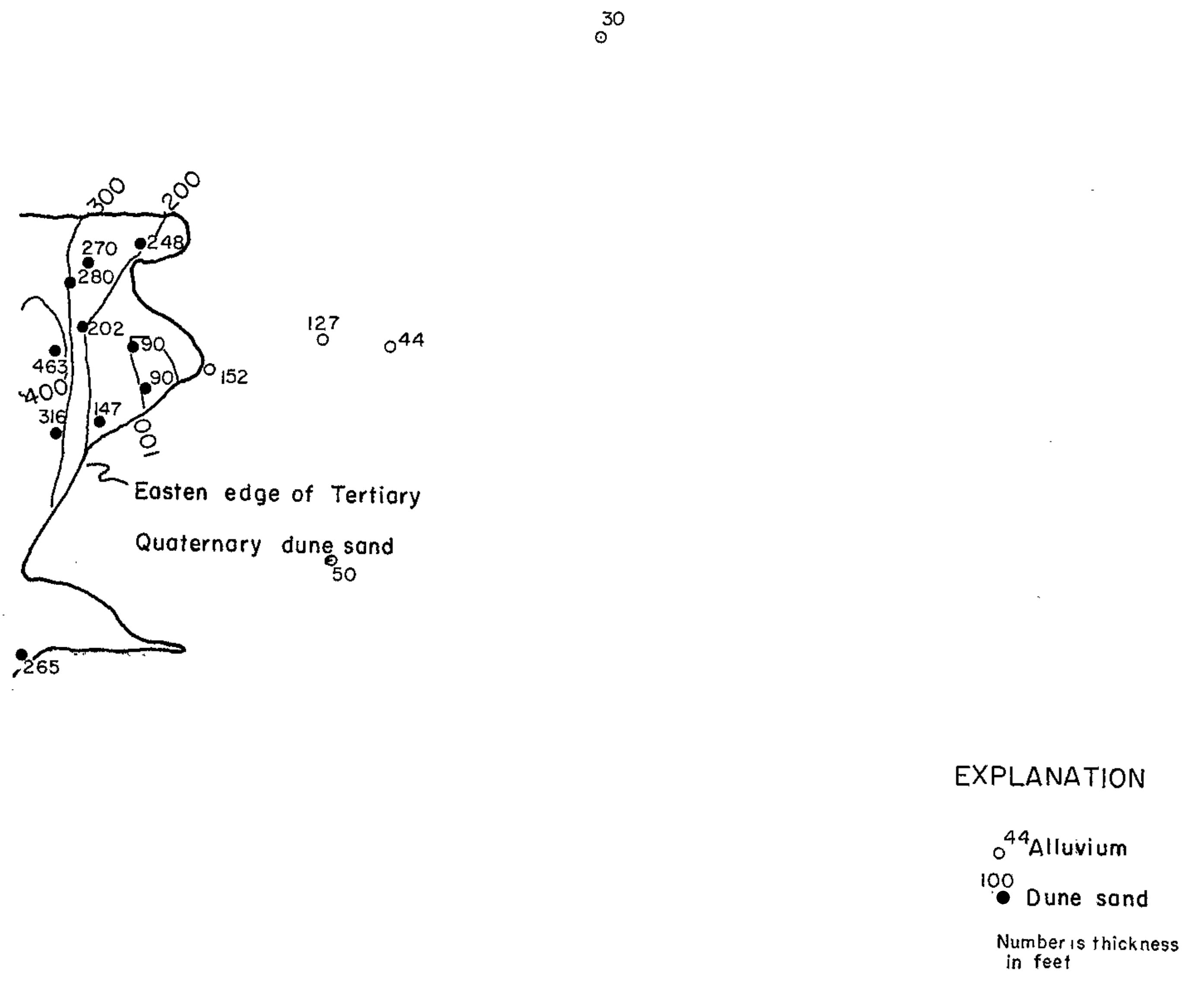


FIGURE 10—*Thickness of Tertiary—Quaternary dune sand and Quaternary alluvium.*

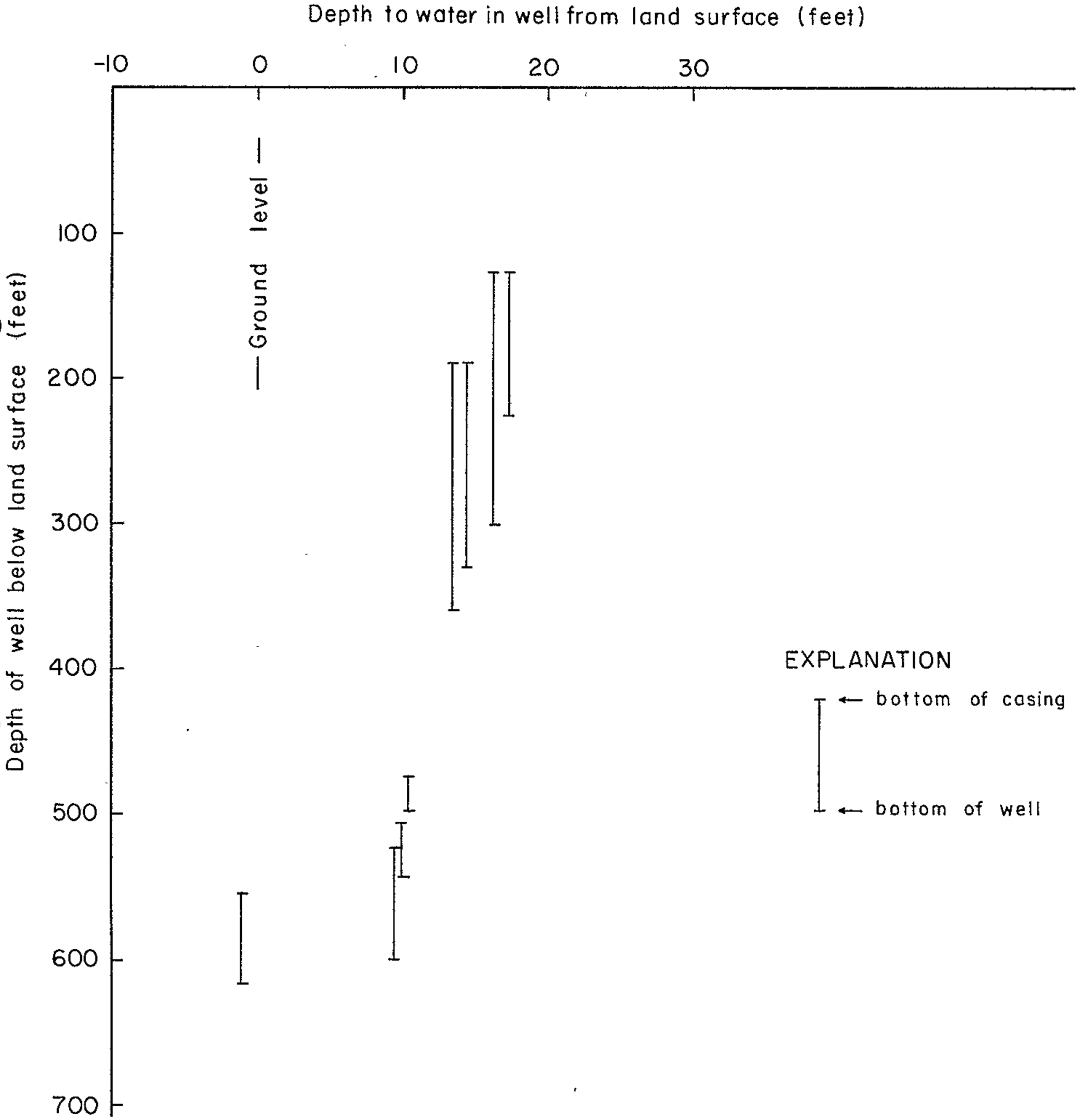


FIGURE 11— *Relation of depth-to-water to interval-of-open-hole during drilling of village of Zuni well No. 4.*

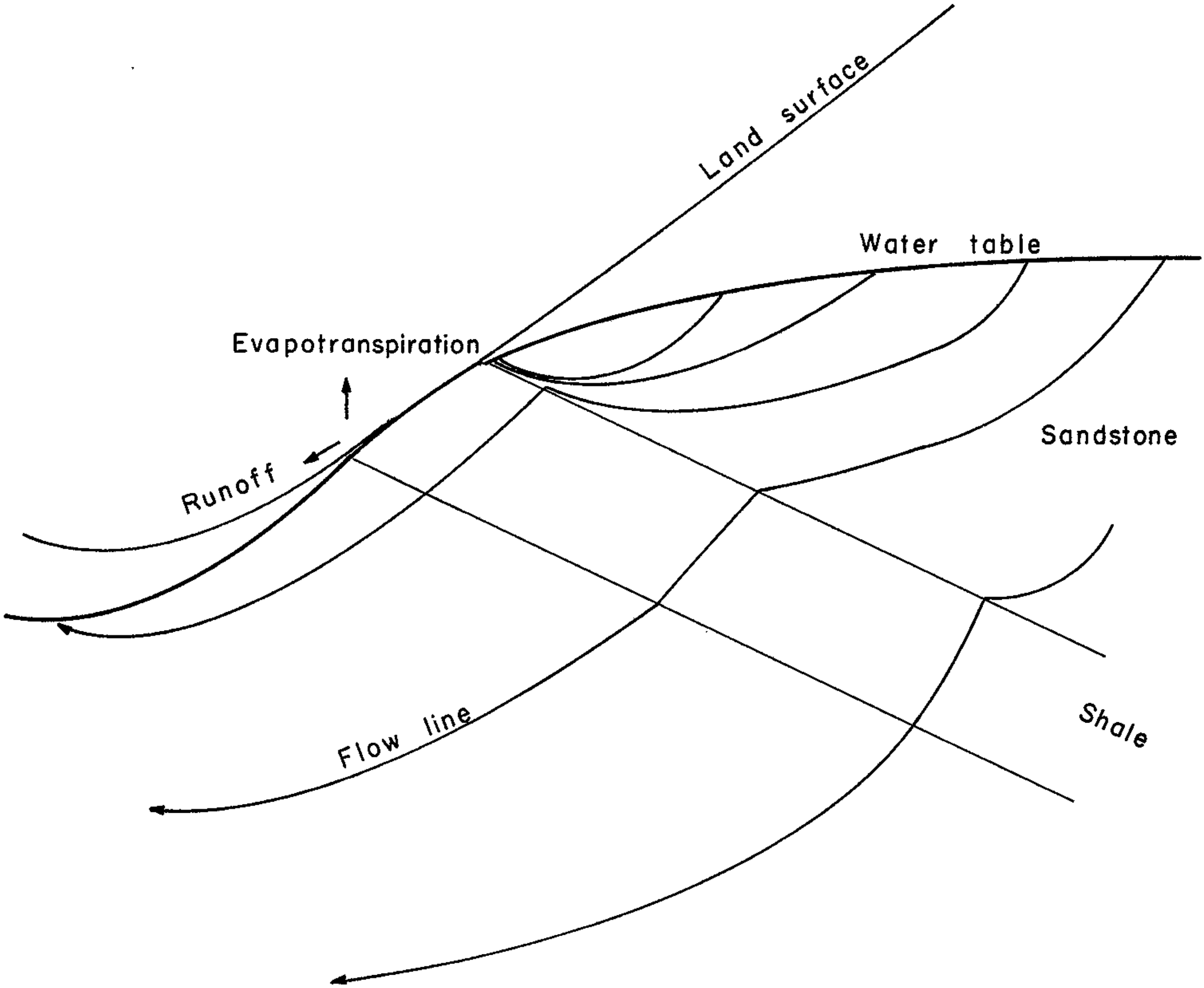


FIGURE 12 — *Sketch of a typical spring or seep at Pueblo of Zuni.*

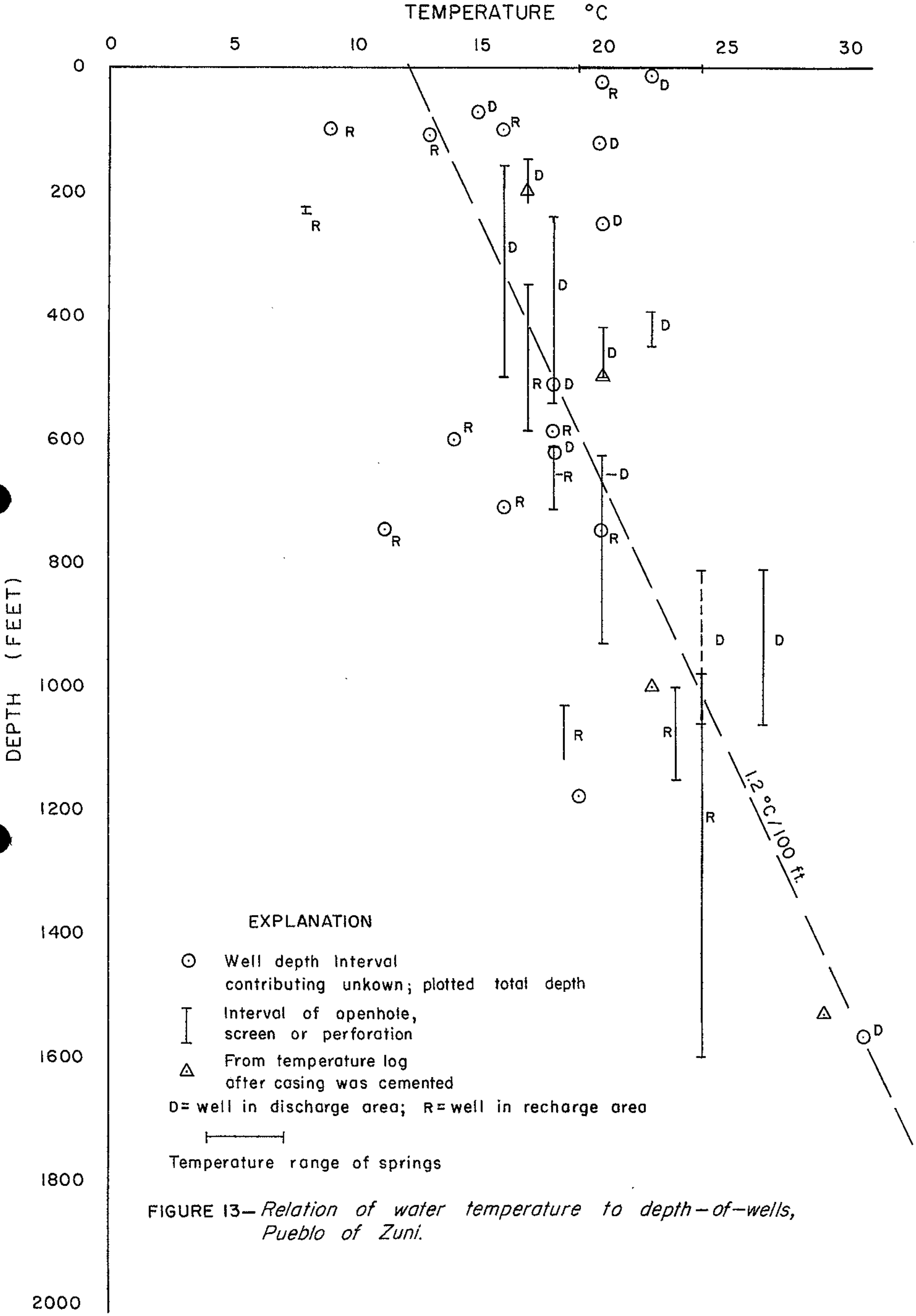


FIGURE 13— *Relation of water temperature to depth-of-wells, Pueblo of Zuni.*

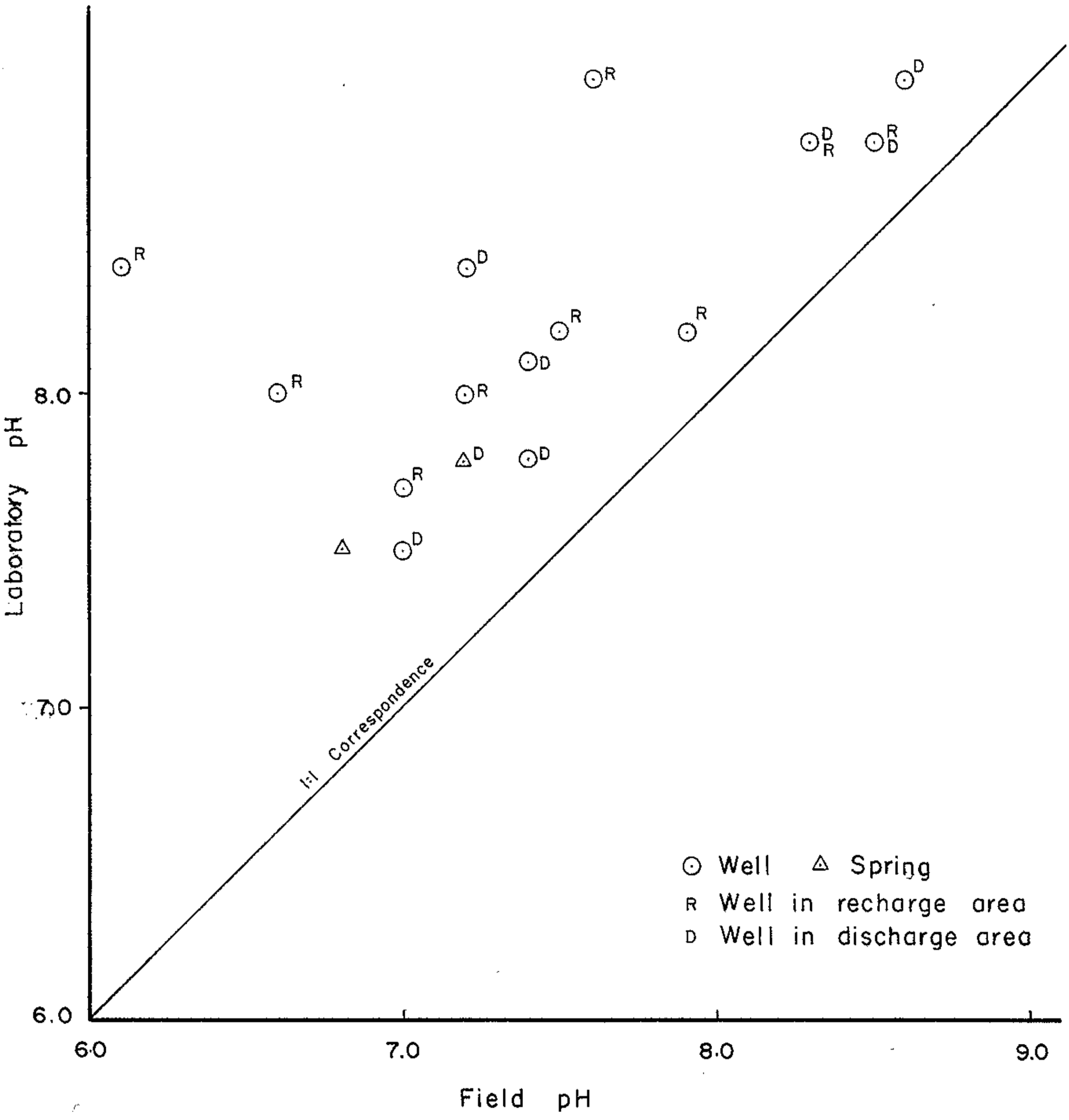
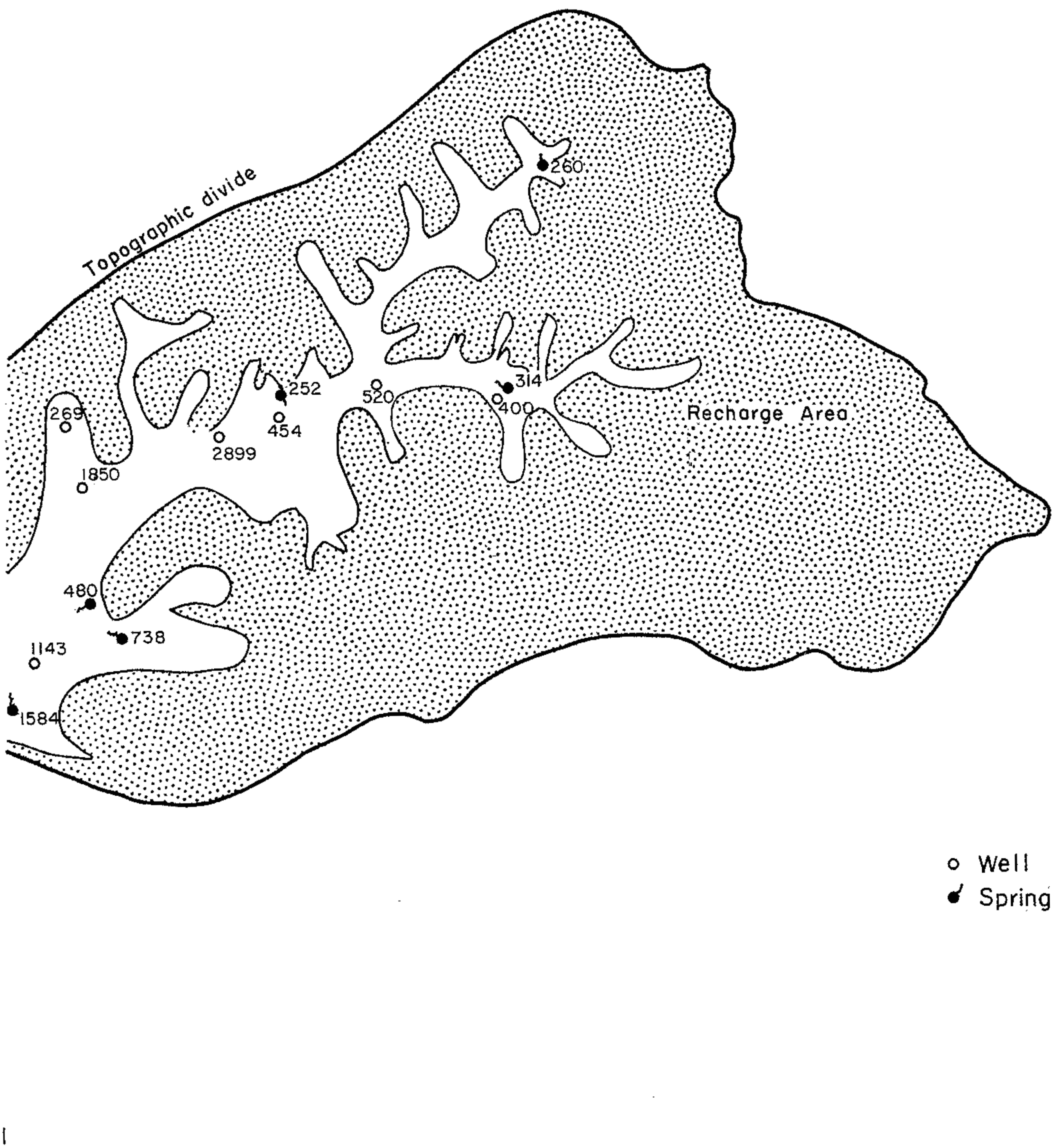


FIGURE 14 *Relation of field pH to laboratory pH of water samples collected from wells and springs, Pueblo of Zuni.*



Recharge area

FIGURE 15— *Relation of dissolved solids in discharge from springs and wells in the alluvium and the recharge area of the Zuni River Basin.*

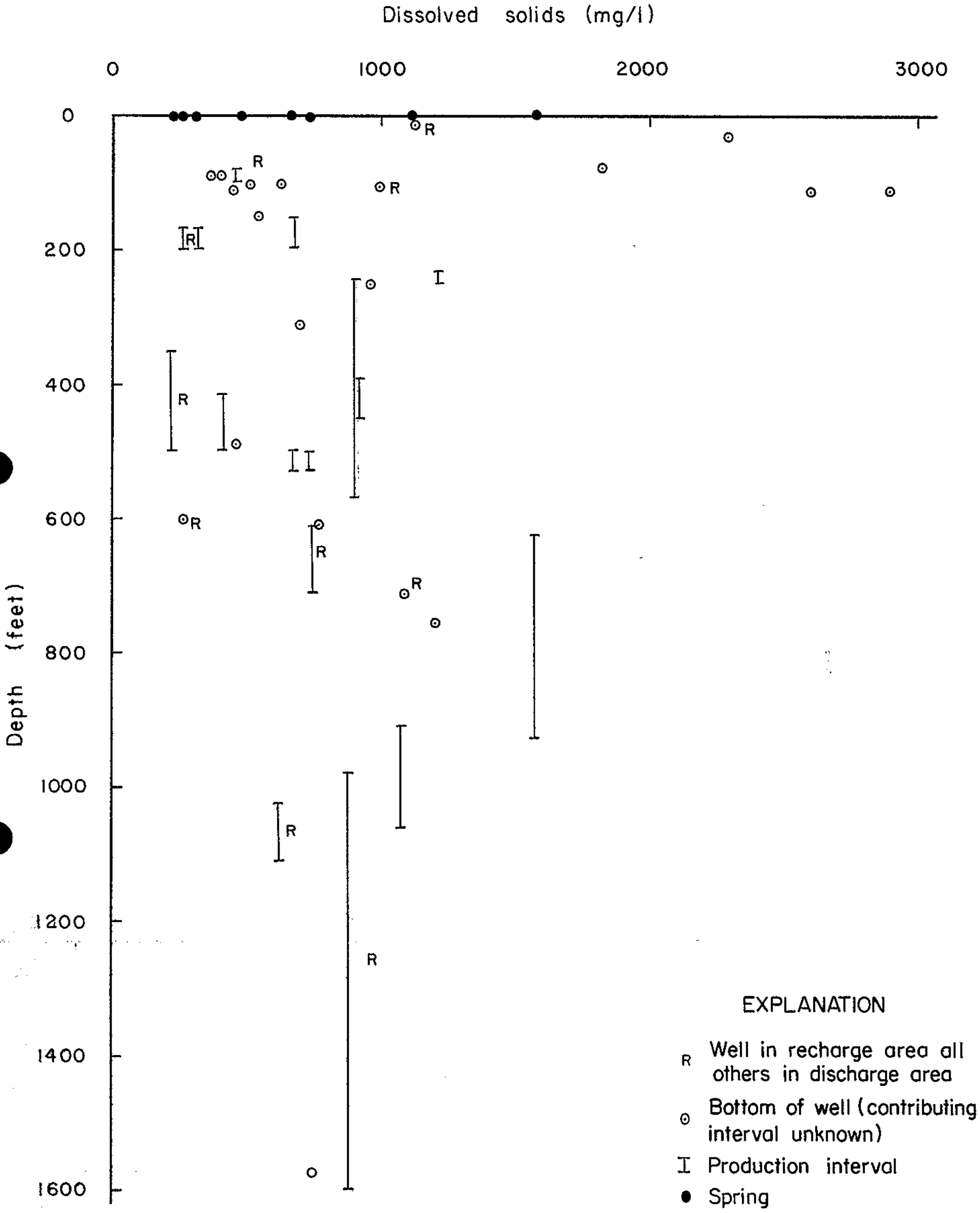


FIGURE 16— *Depth versus dissolved solids in water, Pueblo of Zuni.*

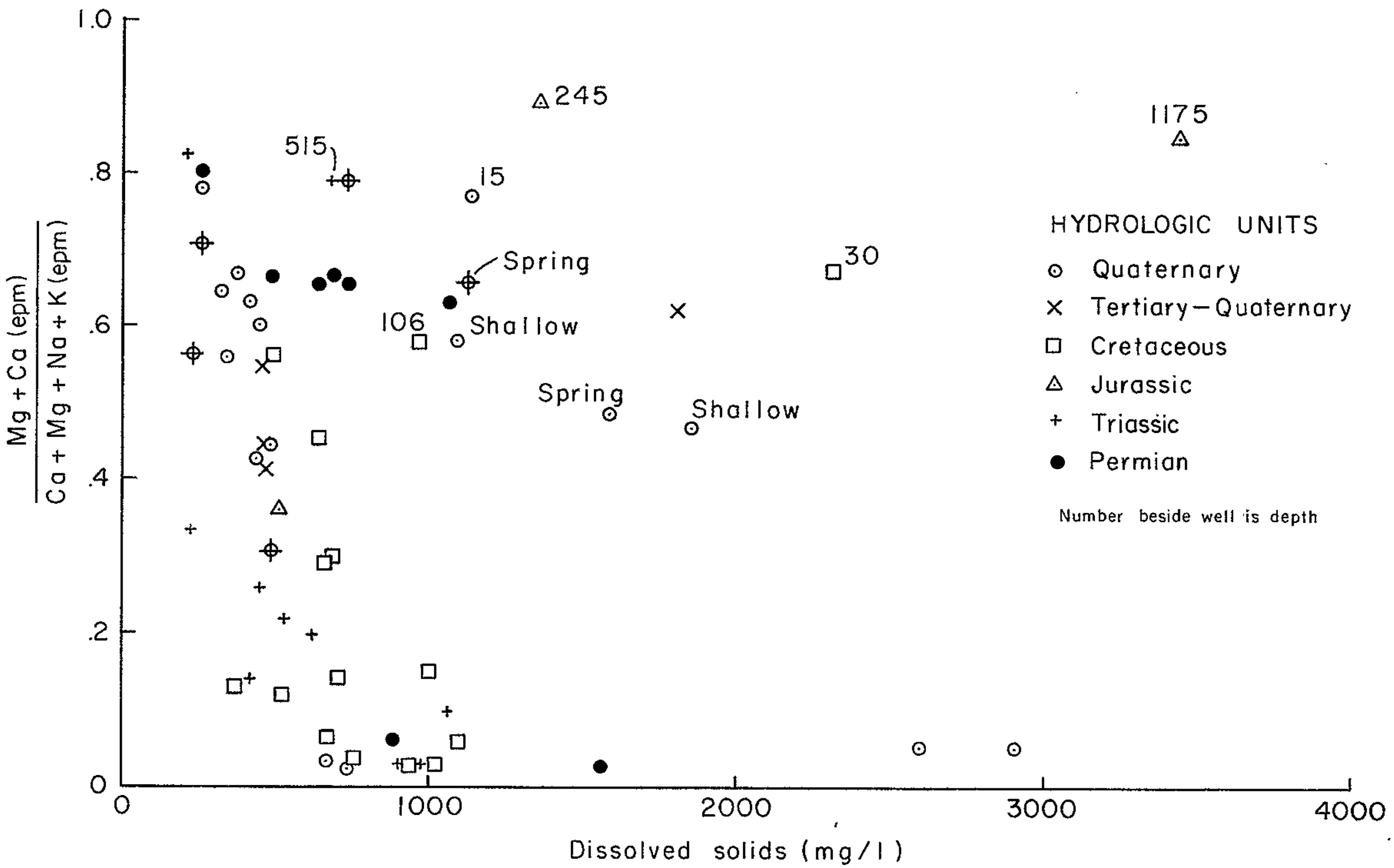


FIGURE 17— *Relation of ratio* $\frac{Ca+Mg}{Ca+Mg+Na+K}$ *to dissolved solids in water, Pueblo of Zuni.*

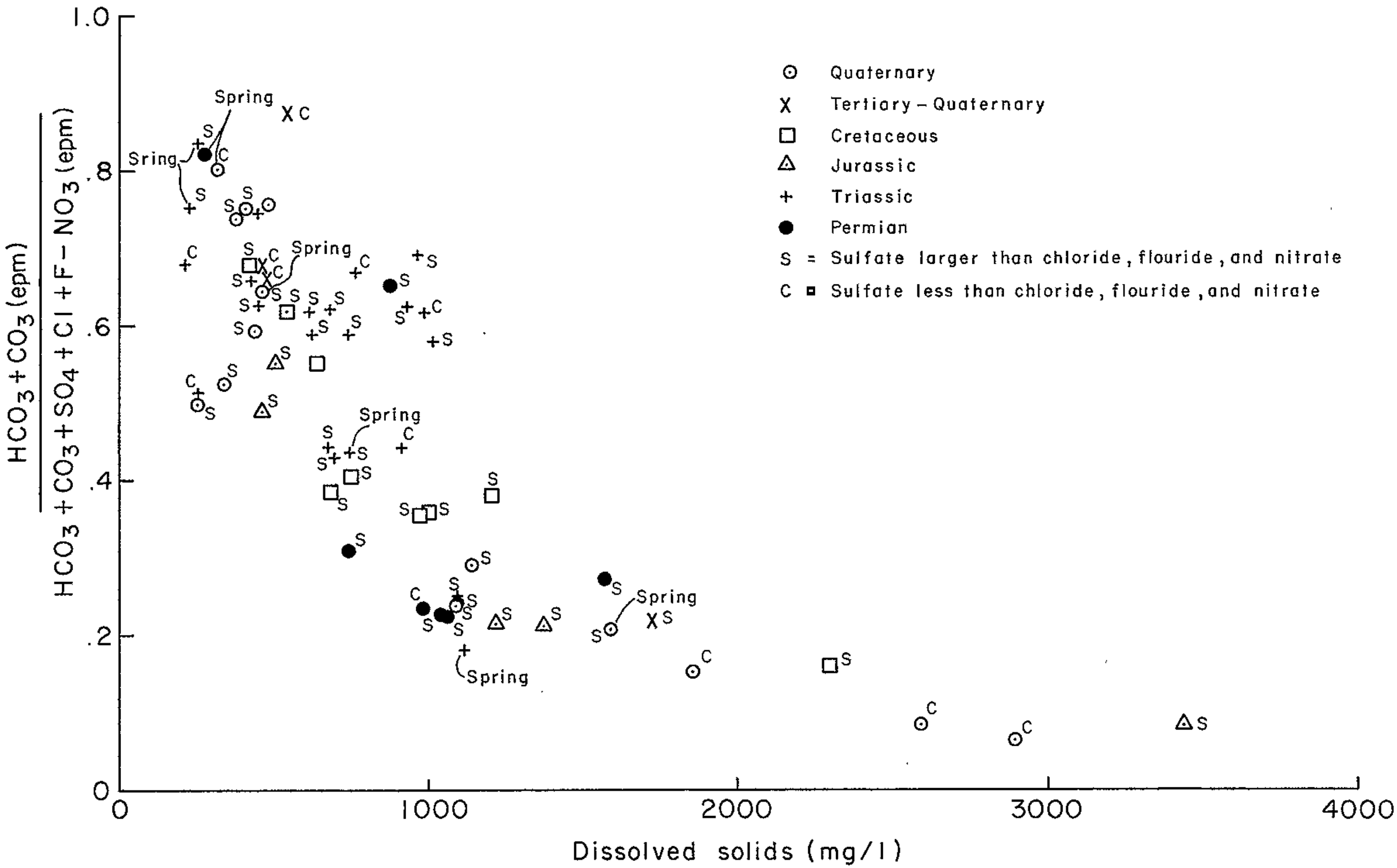


FIGURE 18— *Relation of ratio* $\frac{HCO_3 + CO_3}{HCO_3 + CO_3 + SO_4 + Cl + F + NO_3}$ *to dissolved solids in water, Pueblo of Zuni.*

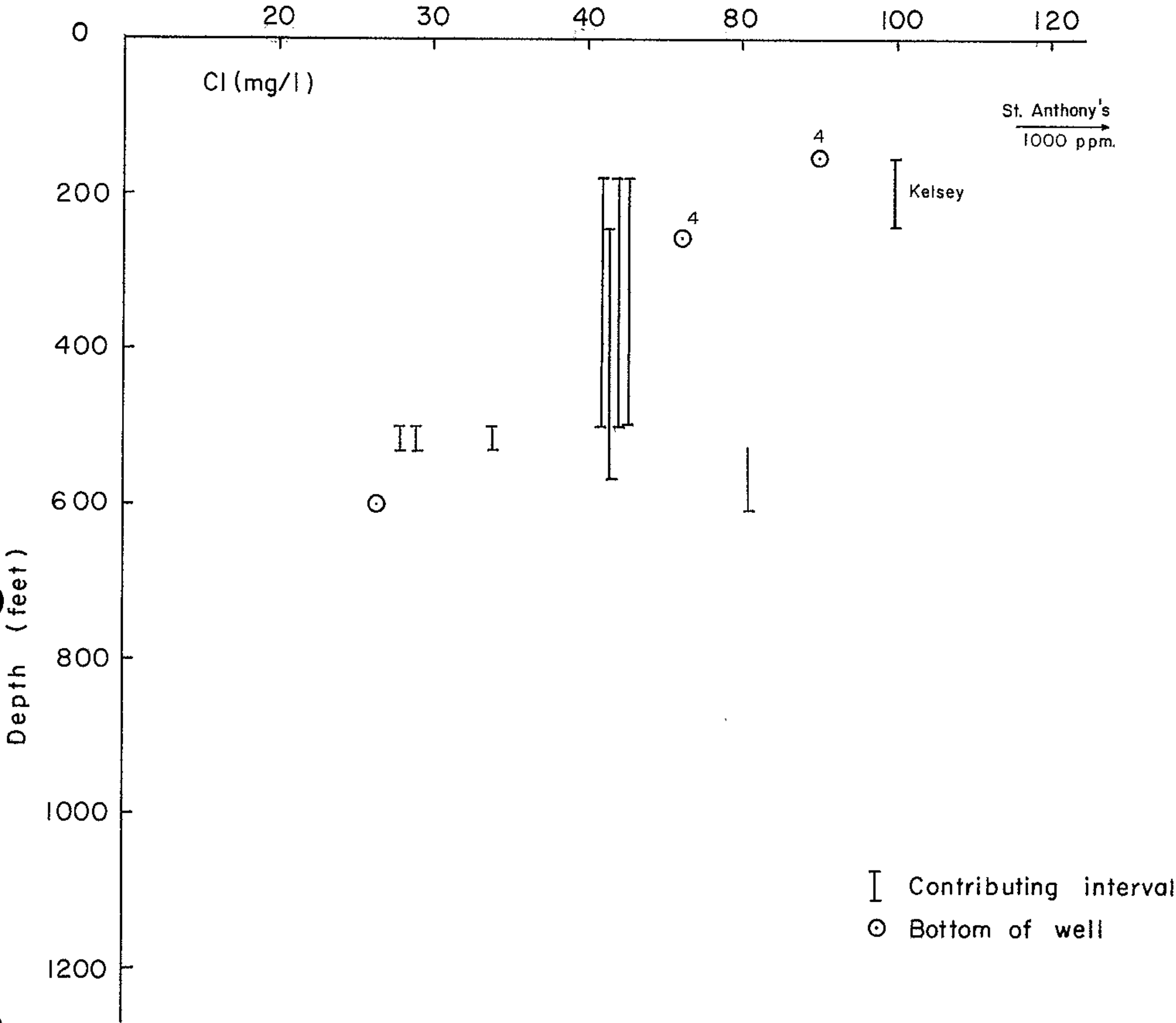


FIGURE 19— *Relation of chloride concentration to depth of wells, Village of Zuni.*

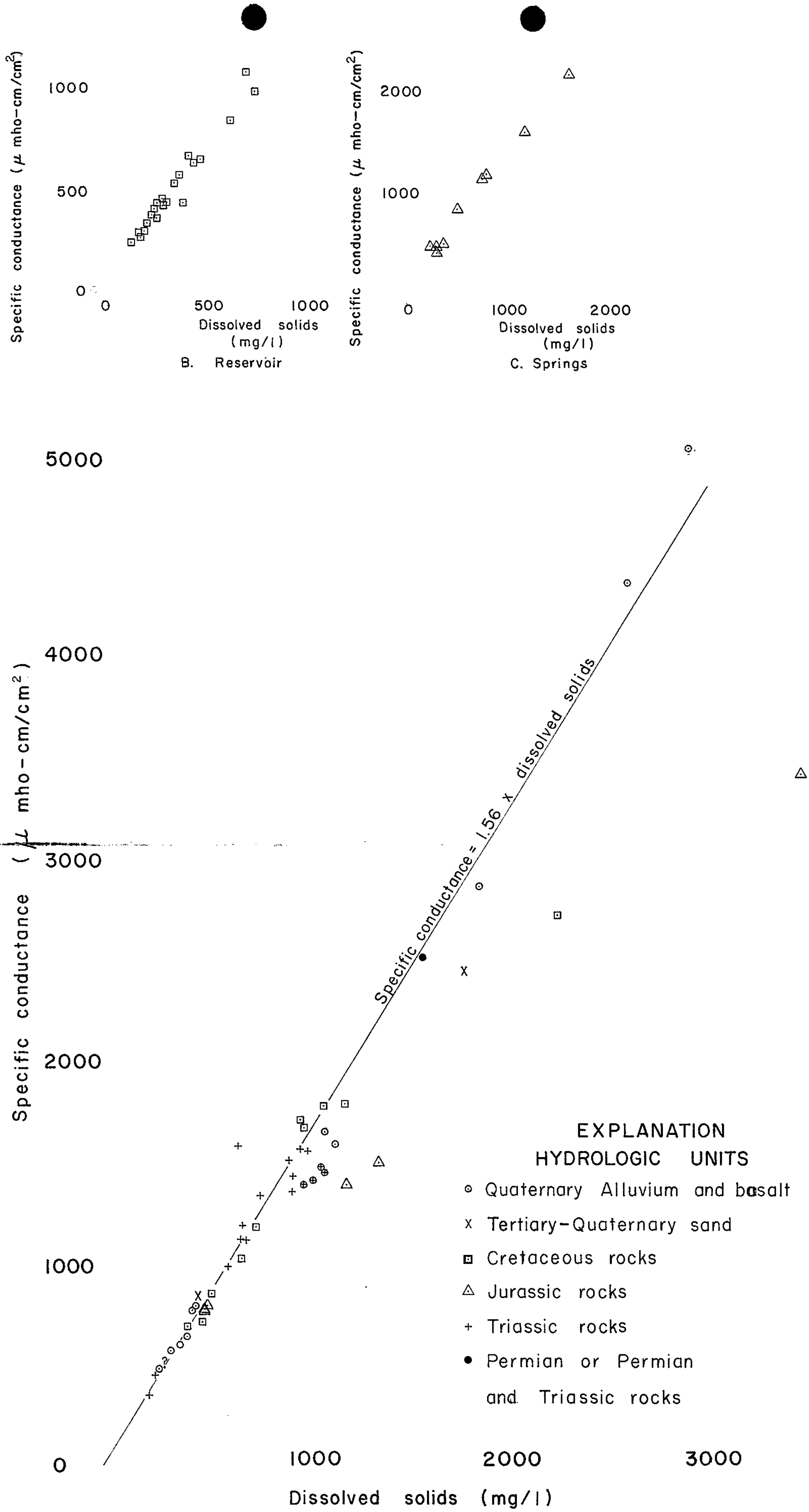


FIGURE 20—*Relation of dissolved solids and specific conductance of water of wells, springs, and reservoirs, Pueblo of Zuni.*

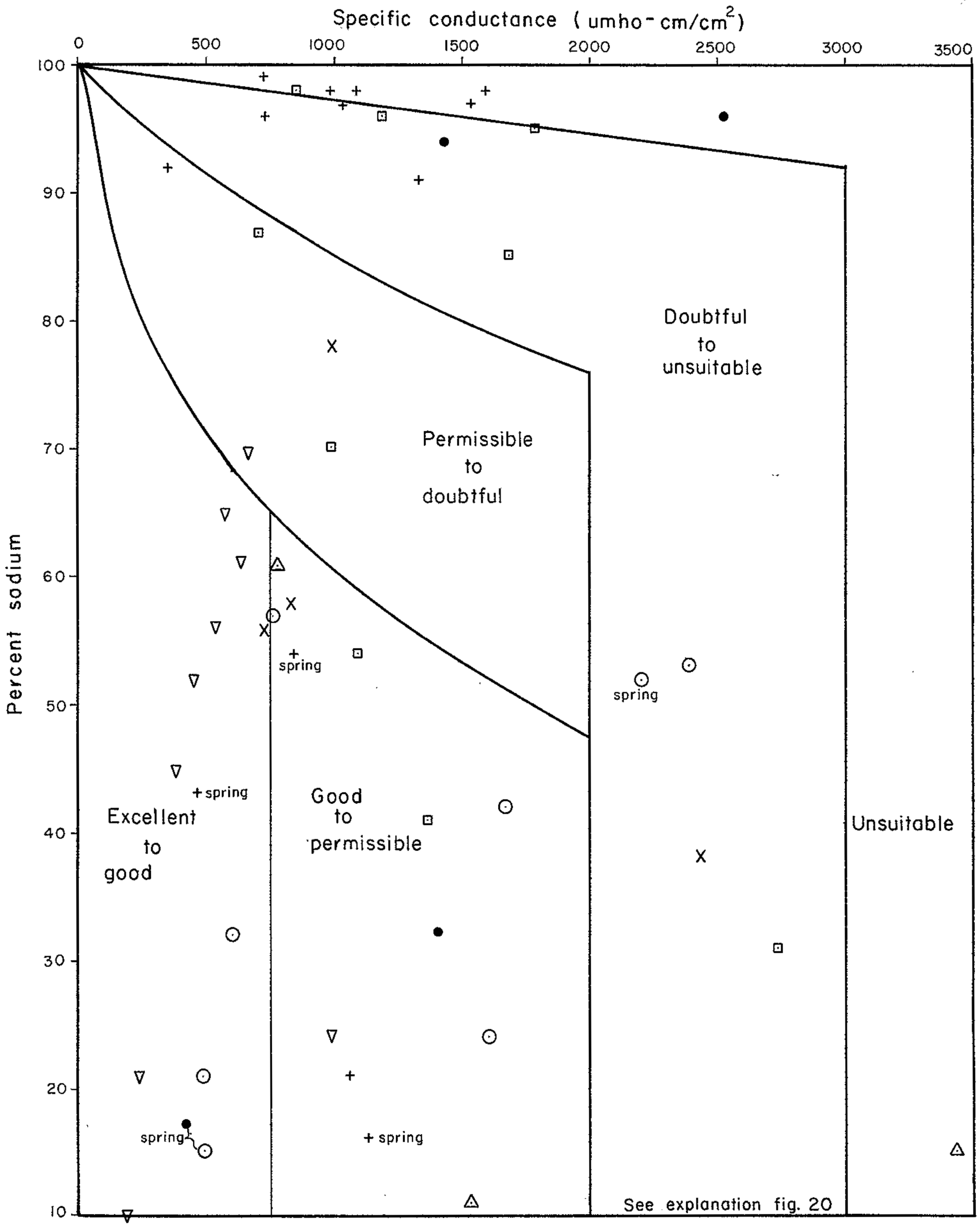


FIGURE 21— *Irrigation classification diagram for Zuni water based on percent sodium and specific conductance.*

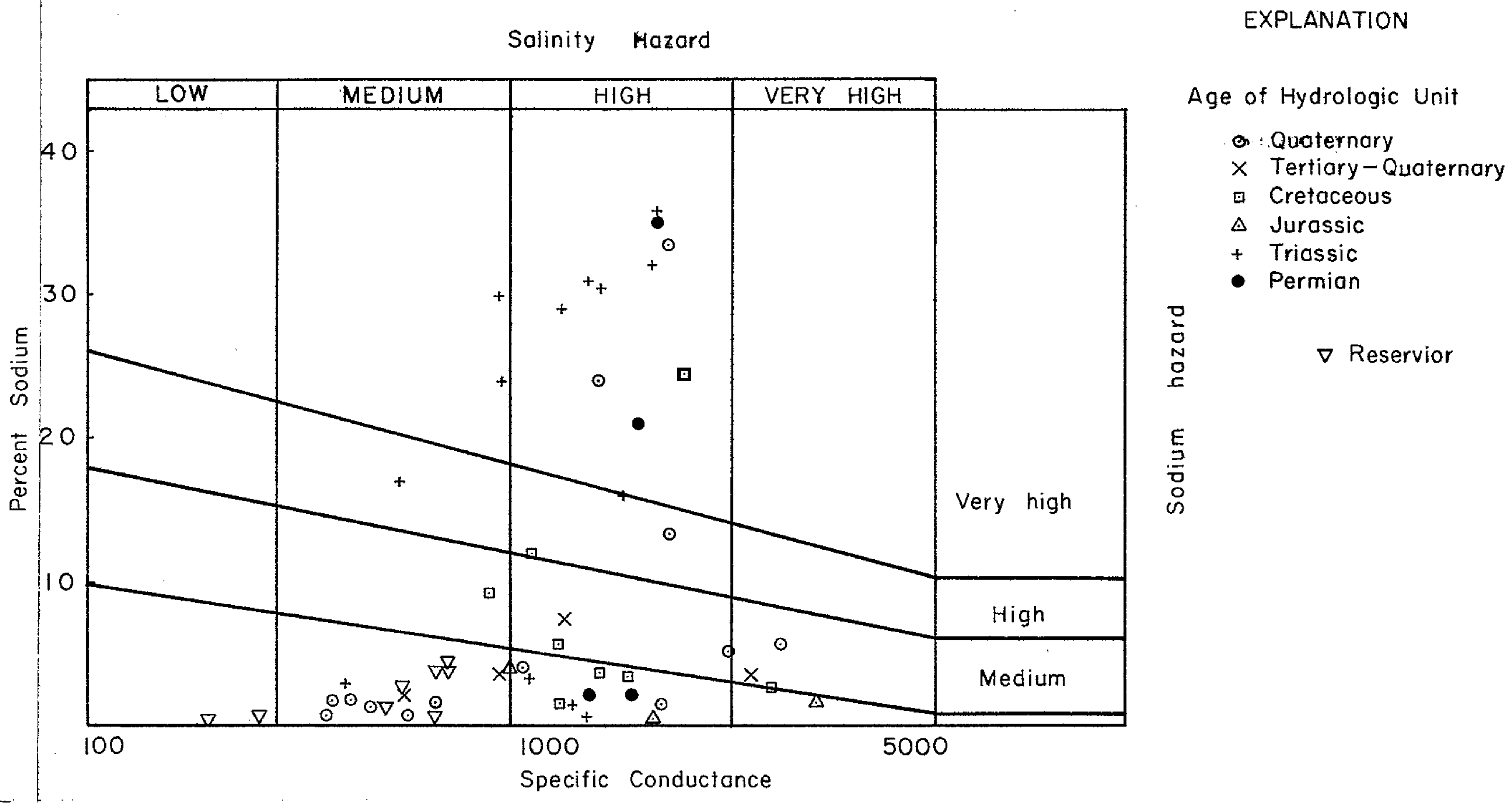


FIGURE 22 — *Sodium–salinity hazard diagram for Zuni waters.*

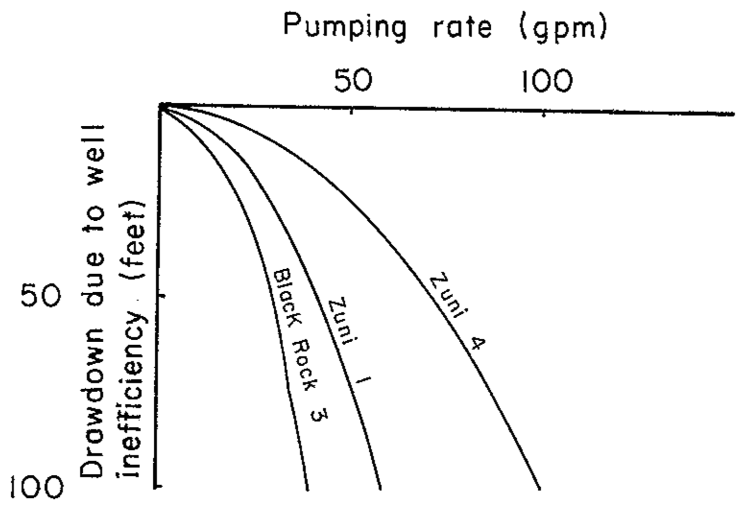


FIGURE 23 — *Effect of well inefficiency on the drawdown of wells at Zuni and Blackrock.*

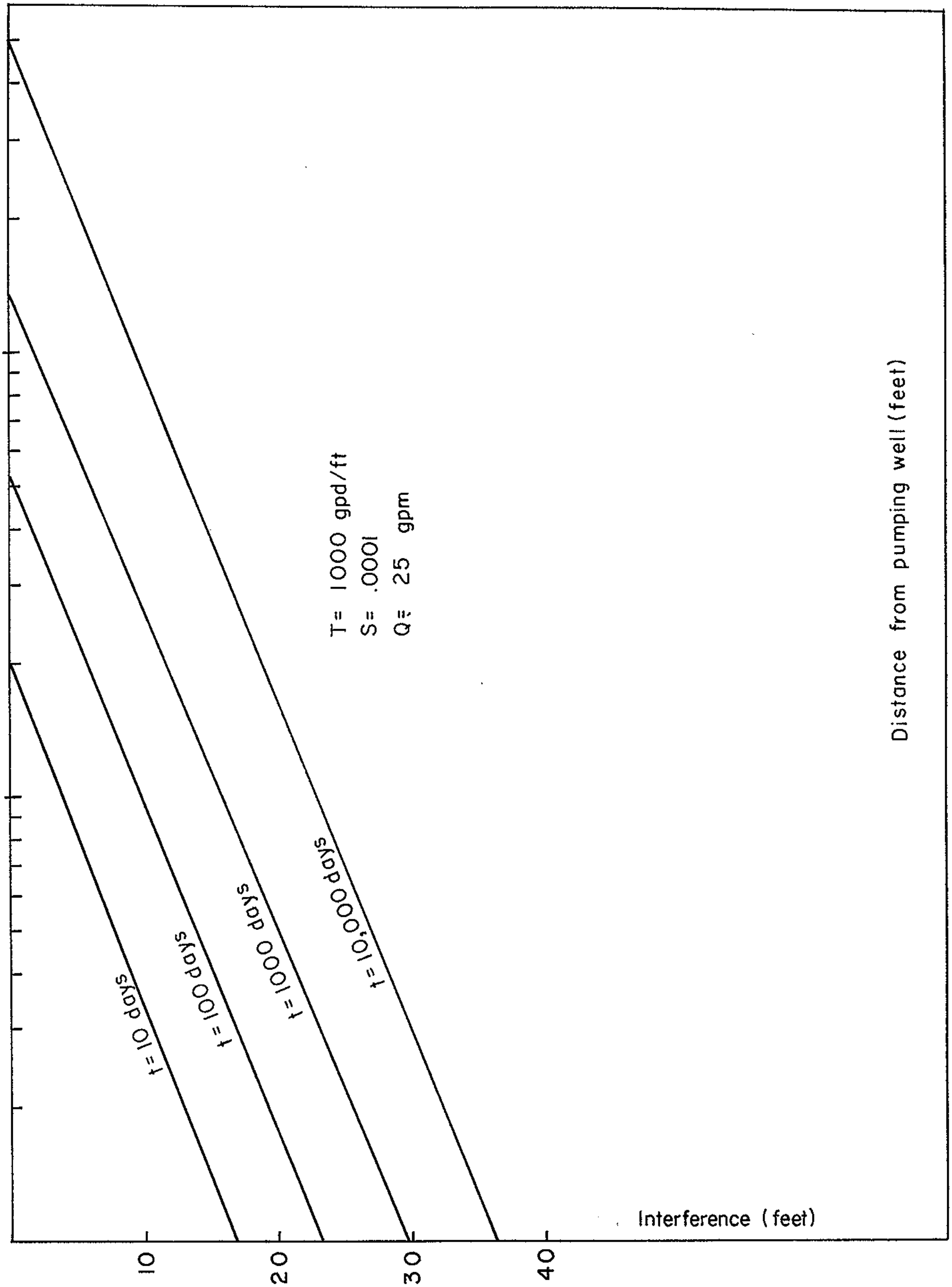


FIGURE 24— *Interference due to pumping a Village of Zuni well 25 gpm for 10, 100, 1000, and 10,000 days, assuming conditions are some what poorer than those thought to exist.*

1—Records of wells in pueblo of Zuni, New Mexico

Altitude: a = altimeter; b = topographic map; c.i = 200 feet;
Log: D = drillers' log; E = electric log; S = sample description or lithologic log; T = temperature log

Well Name or Owner	Location			Altitude	Depth	Casing			Producing Interval		Depth to Water	Date	Production Data			Field Observations (meq/l)					LOG	Date Sampled for Chemical Analysis	Probable Producing Unit	Remarks
	T.N.	R.W.	Sec.			Dia.	From	To	From	To			Yield	Sp.Cap.	Date	Temp. °C	Sp. Cond.	pH	HCO_3	Date				
R.W.P. Z-25	8	17	2	7353a	1175	6-5/8	0	1000	-	-	196	7-28-72	3	-	-	23	1750	-	-	7-28-72	D	-	Jz	Stock well
---	8	17	3	7321a	-	-	-	-	-	-	40	7-28-72	-	-	-	-	-	-	-	-	-	-	-	Unused well
---	8	17	8	7266a	-	-	-	-	-	-	14	8-1-72	-	-	-	-	-	-	-	-	-	-	-	Stock well
E.C.W. 7	8	18	24	7213a	1460	6-5/8 5	0 1360	1400 1460	1400	1460	606	1935	12	.27	1935	-	-	-	-	-	D	-	Jz	Stock well 5" liner perforated
E.C.W. 4	8	19	4	6881a	590	6-5/8 5	0 490	493 590	-	-	351	1934	12.5	.27	1934	18	860	8.3	5.3	8-1-72	D	8-1-72	TRC	Stock well
E.C.W. 5	8	19	12	7323a	1115	6-5/8 5	0 1002	1027 1115	1027	1115	360	1935	6	-	-	18	1100 950	8.5	5.1	8-1-72 2-12-70	D	8-1-72	TRC	Stock well 5" liner perforated
E.C.W. 18 Pomosana Well	8	19	22	6741a	500	6-5/8	0	416+	-	-	221.0	7-28-72	-	-	-	22 20	850 830	8.7 8.6	- 5.1	8-1-31 8-2-31	D	8-1-72	TRC	20' of perforated casing Stock well
R.W.P. Z-35	8	20	4	6360a	515	5	0	515	-	-	30 45.8	1961 7-27-72	8 8	- .027	1961 8-9-72	18	1250	-	-	8-9-72	D	8-9-72	TRC	Stock well - pumping test 8-9-72
Irr #3	8	20	31	-	112	-	-	-	-	-	-	-	10	-	1939	-	-	-	-	-	-	-	TQs	Windmill removed April 1964
R.W.P. Z-26	8	20	34	6499a	600	6-5/8	-	-	-	-	GT300	1972	-	-	-	-	-	-	-	-	-	-	Kd	Stock well
Romansito Well	8	21	1	-	-	-	-	-	-	-	17.8	8-2-72	-	-	-	-	-	-	-	-	-	-	-	
R.W.P. Z-31	8	21	12	6151a	75	6-5/8	-	-	-	-	45.9	7-27-72	-	-	-	15	2900	7.0	4.8	7-27-72	-	7-27-72	TQs?	Stock well
E.C.W. 20	8	21	26	6076a	15	-	-	-	-	-	1.1	7-27-72	-	-	-	22	1750	7.4	5.9	7-27-72	-	7-27-72	Qal	Stock well
Old Artesian Well	8	21	34	6066a	-	-	-	-	-	-	0.4	7-27-72	-	-	-	-	-	-	-	-	-	-	TRC	Not used
Miller's Well (A. J.Crocket's place)	9	16	34	7150b	-	-	-	-	-	-	153+	7-28-72	-	-	-	20	990	7.6	4.5	7-28-72	-	7-28-72	Kg?	Stock well
E.C.W. 19	9	17	5	6955a	29½ m	-	-	-	-	-	6.8	7-31-72	-	-	-	20	2700	7.3	5.3	7-31-72	-	7-31-72	Km	Stock well
E.C.W. 8	9	17	19	7185a	650	6-5/8	0	112			440	1935	5	-	1935	-	-	-	-	-	D		Jz	Stock well - filled in to 250' (7-31-72)
C.O.A. 21 Jack's Lake Canyon	9	17	24	7312a	22 m	-	-	-	-	-	11	7-31-72	-	-	-	-	-	-	-	-	-	-	Km	Stock well
Ditto - Old Well?	9	17	24	7312a	-	-	-	-	-	-	9	7-31-72	-	-	-	-	-	-	-	-	-	-	-	Not used
R.W.P. Z-25	9	17	33	7266a	1175	-	-	-	-	-	46.7	7-28-72	-	-	-	19	4000	6.6	4.4	7-28-72	-	7-28-72	Jz	Stock well
Exploration Oil Well #1	9	18	5	6460a	2591	7-5/8	0	1574	-	-	235	1963	10	.012	4-27-64	30.5	980	-	-	4-27-64	E,S,T	4-17-64	Jz-Pg?	Oil test completed as stock well. Cement plug 2591-1521'. Cutting samples 1230-2590'.
Cities Service #1 Zuni A											250	8-1-72										4-20-64 4-27-64		Temperature log 0-1532' Perforations @ 500'?
R.W.P. Z-33	9	19	19	6914a	400	5	0	366	366?	400?	131.4	7-28-72	10	-	1961	-	-	-	-	-	D	-	TRC	Stock well
-- A-1	9	20	8	6293a	-	-	-	-	-	-	17	7-26-72	5	-	7-26-72	14	3000	7.2	4.9	7-26-72	-	7-26-72	Qal	Hand pump; strong odor
-- A-2 75' from A-1	9	20	8		-	-	-	-	-	-	15.2	7-26-72	-	-	-	-	-	-	-	-	-	-	-	New well; not used
-- A-3 50' from A-2	9	20	8		-	-	-	-	-	-	?	-	-	-	-	-	-	-	-	-	-	-	-	Original well; not used
Bowman Peywa	9	20	8		352	-	0	169	169	352	34	1971	5	-	-	-	-	-	-	-	D	-	TRC	
Tekapo Well	9	20	9	6215	-	-	-	-	-	-	16.3	7-26-72	-	-	-	-	-	-	-	-	-	-	-	
Chavez Well	9	20	18	6165a	-	-	-	-	-	-	18	7-27-72	-	-	-	-	-	-	-	-	-	7-27-72	-	Stock well
E.C.W. 3 (old)	9	20	22	-	640	6-5/8 5	0 87	457 528	461	640	flows flows	1935 1972	5	.05	1935	-	-	-	-	-	D	-	TRC	67' of perforated casing, 112' of open hole Well in stock tank
E.C.W. 3 (new)	9	20	22	6280a	-	-	-	-	-	-	3.2	7-27-72	-	-	-	-	-	-	-	-	-	-	TRC	Stock well drilled 1968 approximately 200' from old well. Construction thought to be similar to old well.
E.C.W. 2	9	21	11	6287a	582	5	0	351	351	582	131.2	7-26-72	9	.013	1934	17	510	6.1	.95	8-2-72.	D	8-1-72	TRC	Stock well
--	9	21	25	6176a	-	-	-	-	-	-	2.1	7-27-72	10	-	1972	13	990	7.2	5.3	7-27-72	-	7-27-72	Qal?	Stock well
E.C.W. 13	10	16	32	6993a	707 m	-	-	-	-	-	-	-	-	-	-	16	2250	-	-	7-31-72	-	7-31-72	Kg?	Stock well
Old Sawmill Well	10	17	8	6735a	-	-	-	-	-	-	46.1	8-2-71	-	-	-	-	-	-	-	-	-	-	Km?	
E.C.W. 22 (Coal Mine)	10	17	10	6811a	282	7 5	0 199	220 282	240 240	282	187	1942	4	-	1942	-	-	-	-	-	D	-	Kg	Stock well

Appendix 1—*Records of wells in pueblo of Zuni, New Mexico*—continued

Well Name or Owner	Location T.N.	Location R.W.	Location Sec.	Altitude	Depth	Casing Dia.	Casing From	Casing To	Producing Interval From	Producing Interval To	Depth to Water	Date	Production Data Yield	Production Data Sp.Cap.	Production Data Date	Field Observations (meq/l) Temp. °C	Sp. Cond.	pH	HCO_3	Date	LOG	Date Sampled for Chemical Analysis	Probable Producing Unit	Remarks
Fidel Ghahate	10	17	13		93	6-5/8	-	-	-	-	<25	1970	25	-	1970	-	-	-	-	-	D	12-15-70 1-4-71	Qb	Domestic well
E.C.W. 6	10	17	35	6917a	712	6-5/8 5	0 592	610 712	610	712	279.	7-31-72	.14	-	1935	18	1250	8.3	4.2	7-31-72	D	7-31-72	Kd	Stock well
E.C.W. 17 (old)	10	18	22	-	37	30	0	37	36	37	33.5	8-8-72												Unused dug well
E.C.W. 17 (new)	10	18	22	6595a	112	5	-	-	-	-	94.2 60.8	7-31-72 8-8-72	8.8	0.73	8-8-72	13	850	-	-	8-8-72	D	6-24-66 8-8-72	Jz	Stock well - pumping test 8-8-72
Robert D. Lister Jr. No. 1-X	10	19	2	6554c	1636	4-1/2	0	1288	980 1033 1084 1502 1560 1591	986 1039 1090 1508 1570 1597	8.5	7-26-72	-	-	-	24	1250	7.8	8.4	7-26-72	T	7-26-72	TRC, Psa, Pg, Py	Oil test, converted to water well with hand pump
Mormon Church	10	19	22	6308c	27	6	0	27	-	-	16.0	8-3-27	-	-	-	-	-	-	-	-	-	-	Qal	Domestic well
Black Rock Well #1 (VA #1)	10	19	24	6350c	156	13	0	114					125	1.21	1966	-	-	-	-	-	-	7-22-66 10-22-69	Qal	Unused; pumps sand
Black Rock Well #2	10	19	24	6454c	932	11 6	0 0	187 804	624	932	-	-	25	.17	1957	20	2500	-	-	8-3-72	D	8-3-72	TRC, Pg	Perforated casing and open hole irrigation well
Black Rock Well #3	10	19	24	6350c	1060	8	0	810	810	1060	168.3	3-27-68	50	.23	1968	26.6				3-27-67	D,L	3-28-68 10-22-69	Psa, Pg	Municipal well; pumping test 3-27/28-68
						6	800	1060								24°C	1450	-	-	8-3-72		9-10-70 8-3-72		
Village of Zuni Well #1	10	19	28	6287c	1500	10	0	340	500	530	flowed	1953	51	.33	1953	20	-	-	-	1953	L	9-29-64 3- -68	TRC	Municipal well; pumping tests 5-15-66 & 8-26/28-69
						8-5/8	0	707					60 20	.29 1.25	1968 1969	20°C	1250			9-29-64 8-3-72		8-3-72		
Village of Zuni Well #2	10	19	28	6292c	492	-	-	-	180	200	6	1953	100	-	1953	16.1	1420	-	-	1953	L	3- -68	TRC	Municipal well; pumping tests 7-6-66 & 8-20/21-69
									320	340			96	1.2	7-6-66 8-20/	16	1300	-	-	8-3-72		4-9-68 4-21-70		
									490	500			125	.71	21-69							8-3-72		
Village of Zuni Well #3 (Zuni Day School)	10	19	28	6286c	556	6	0	556	244 516	259 566	flowed	1957	60	.36	1957	18	1700	-	-	8-3-72	D	5-24-57 9-26-63 8-3-72	TRC	Municipal well
Village of Zuni Well #4	10	19	28	6274c	610	10	0	610	-	-	flowed	1967	70±	-	1967	- 18	1400 1400	- -	- -	1967 8-3-72	D	8-3-72	TRC	Municipal well
St. Anthony's Well	10	19	28	6281c	120	-	-	-	-	-	-	-	-	-	-	20	5000	-	-	8-3-72	-	8-3-72	Qal?	Irrigation well; used for swimming pool
Pat Kelsey's Well	10	19	28	6274c	250	6	-	-	-	-	-	-	-	-	-	20	1500	-	-	8-3-72	-	8-3-72	TRC	Laundry well; strong H_2S
Leo Nastacio Well	10	19	30	6275a	152	6-5/8	0	152	-	-	40 30.0	1972 7-26-72	30	-	1972	-	-	-	-	-	D	-	Qal	Domestic well
R.W.P. Z-27	10	20	8	6568a	600	6-5/8	-	-	-	-	154.9	7-25-72	3	-	1972	14	510	7.0	2.9	7-25-72	-	7-25-72	TRC	Stock well
Irrigation 1	10	20	18	6502a	200	8 6-5/8	0 0	43 170	-	-	175 196.5	1939 7-26-72	44	-	1972	-	510	7.2	3.3	7-27-72	D	6-10-66 7-27-72	TQs	Stock well
Bossom's Well	10	20	22	6345a	102	6-5/8	0	102	82	102	61.1	7-25-72	6	-	1964	16	880	7.4	5.3	7-25-72	D	7-25-72	TQs	Stock well; pumping test 8-17-72
													5.5	.31	8-17-72							8-17-72		
E.C.W. 9	10	20	33	6331a	575	6-5/8	0	509			122.59	7-26-72	18	.14	1936	-	-	-	-	-	D	-	TRC	Stock well
R.W.P. Z-30	10	21	1	6662a	551	6-5/8	0	500?	517	546	85 <300	1960 1972	-	-	-	-	-	-	-	-	D	-	TRC	Stock well
R.W.P. Z-24	10	21	23	6596a	600	6-5/8	0	463	431	462	324.0	7-26-72	11	-	1956	-	-	-	-	-	D	-	TQs	Stock well
R.W.P. Z-28	11	16	8	7046a	106.	6-5/8	0	106	-	-	48	1958	5	-	1958	9	1750	-	-	8-16-72	D	8-16-72	Kd	Stock well; pumping test 8-16-72
											60.51 58.8	8-1-72 8-16-72	1.5	.042	8-16-72									
Campground Well	11	17	5	6881a	451	6-5/8	0	451	396	451	220 231.5	1963 7-31-72	10	-	1963	22	800	8.5	.8	7-31-72	D	7-31-72	Kg	Domestic well
--	11	17	8	6700b	-	-	-	-	-	-	25.6	7-31-72	-	-	-	-	-	-	-	-	-	-	Kg	Hand pump
Solomon Well	11	17	12	6977a	-	-	-	-	-	-	49.8	8-1-72	-	-	-	-	-	-	-	-	-	-	Kg	Stock well
E.C.W. 14	11	17	24	6947a	438	6-5/8	0	205	193	258	<222	8-1-72	1	-	1970	-	-	-	-	-	D	-	Kg	Stock well; appears to have caved to 222' (8-1-70)

Appendix 1—*Records of wells in Pueblo of Zuni, New Mexico*—continued

Well Name or Owner	Location T.N.	Location R.W.	Location Sec.	Altitude	Depth	Casing Dia.	Casing From	Casing To	Producing Interval From	Producing Interval To	Depth to Water	Date	Production Data Yield	Production Data Sp.Cap.	Production Data Date	Field Observations (meq/l) Temp. °C	Sp. Cond.	pH	HCO_3	Date	LOG	Date Sampled for Chemical Analysis	Probable Producing Unit	Remarks
						5	172	440	301 366	323 410														
E.C.W. 10	11	17	29	7250b	760	6-5/8 5	0 620	? 750	-	-	130 93.1 77.8	1935 7-31-72 8-15-72	6 1.6	.073 .017	1935 8-14-72	20 11	2400 1850	7.1 -	6.3 -	7-31-72 8-14-72	D	7-31-72 8-14-72	Kd	Stock well
--	11	18	13	6700b	-	-	-	-	-	-	27.1	7-31-72	-	-	-	-	-	-	-	-	-	-	Qal	Open well with bucket
E.C.W. 1	11	18	.	6726a	245	6-5/8	0	233	233	245	45 47.9	1934 7-31-72	32 8.4	- .84	1935 8-11-72	8	2000	-	-	8-11-72	D	6-14-66 8-11-72	Jz	Stock well
R.W.P. Z-34	11	18	27	6641a	220	6-5/8	0	150	150	220	76.1	8-10-72	15 8.9	- .11	1961 8-10-72	17 9.5	1150 1250	7.2 -	3.5 -	7-31-72 8-10-72	D	7-31-72 8-10-72	Kd	Stock well
Oil test Carter Oil Co. Santa Fe #2	11	19	17	6800b	1980	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D	-	-	Plugged & abandoned
Gonzales' Well	11	19	29	6599a	60	6-5/8	-	-	-	-	39.9	7-26-72	-	-	-	-	-	-	-	-	-	-	TQs	Stock well
Oil test William G. Coffee #1 Coffee Federal	11	19	35	6600b	2235	4½	0	1732	1174 1554	1278 1636	-	-	-	-	-	-	-	-	-	-	T	-	Pg, Py	
R.W.P. Z-36	11	20	27	6629a	248	6-5/8	0	248	138	165	150 150.03	1964 7-26-72	12	-	1964	-	340	-	-	7-26-72	D	-	TQs	Stock well
Irrigation 2	11	20	31	6590a	668	8	0	647	600	668	<300	7-26-72	15	-	1939	-	1250	-	-	7-26-72	D	-	TRC	Stock well
Sam Pablano Well	12	16	5	7000b	423	6-5/8	0	423	-	-	10	1972	-	-	-	-	-	-	-	-	D	-	Pg	Stock well
R.W.P. Z-32	12	16	7	6872a	100	6-5/8	-	-	-	-	69.2	8-1-72	-	-	-	16	1400	7.9	7.3	8-1-72	-	-	Kg?	Stock well
R.W.P. Z-29	12	16	30	6900b	229	6-5/8	0	229	-	-	40 71.75	1950 8-1-72	6	-	1958	-	-	-	-	-	D	-	Kg	Stock well
R.W.P. Z-16	12	17	15	6905a	594	6-5/8	0	298	-	-	106.0	8-1-72	5	-	1936	-	-	-	-	-	D	-	Kd	Stock well
--	12	17	23	6780	-	-	-	-	-	-	13.03	8-1-72	-	-	-	12	2800	-	-	8-1-72	-	8-1-72	Qal	Hand pump

Appendix 2—*Springs, pueblo of Zuni, New Mexico*

Spring Name or Owner	Sec.	T.N.	R.W.	Alt.	Yield	Field Measurements: Temp. °C	Sp. Cond.	pH	HCO3	Date	Date Sampled for Chem.
–	3	7	21		–	19	2500	7.2	4.6	7-27-72	
	1	8	20	6405							
	1	8	20								
	8	8	20			24	650	7.2	5.3	7-27-72	
	16	8	20								
Ojo Caliente	21	8	20		500-1500	21	1350	6.8	4.3	7-27-72	11-13-63
	15	8	21								9-8-67
	24	8	21								7-27-72
	34	8	21								
Pain Spring	8	9	18	6451							
Frank Vacit Spring	14	9	18	6474							
	32	9	18		1	6.7	3400	–	–	2-10-70	
	1	9	19								
Spring SE Pescado	18	10	16	6732							
Pescado Spring w/handpump	12	10	17	6752							
Pescado Spring	12	10	17	6767							11-13-63
Black Rock Spring	13	10	19	6413	140	20	520			8-3-72	9-26-63
	29	11	19								8-3-72
	23	11	20								
	6	12	16	6995							
Nutria Spring	8	12	16	6860							9-12-68
Spring @ Nutria village	24	12	17	6735							

Appendix 3—Chemical analyses of water samples from wells, pueblo of Zuni

Well Name or Owner	E.C.W. No. 4		E.C.W. No. 5		Ponosana Well E.C.W. No. 18		R.W.P. Z-35		R.W.P. Z-31		E.C.W. No. 20		Miller's Well (A. J. Crockett's place)		E.C.W. No. 19		R.W.I. Z-2?	
T. N., R. W., Sec.	8 N. 19 W. 4		8 N. 19 W. 12		8 N. 19 W. 22		8 N. 20 E. 4		8 N. 21 W. 12		8 N. 21 W. 26		9 N. 16 W. 34		9 N. 17 W. 5		9 N. 17 W. 33	
Hydrologic Unit	TRC		TRC		TRC		TRC		TQs?		Qal		Kg?		Km		Jz	
Date Sampled	8-1-72		8-1-72		8-1-72		8-9-72		7-27-72		7-27-72		7-28-72		7-31-72		7-28-72	
Date Received by Lab	8-2-72		8-2-72		8-2-72		8-10-72		7-28-72		7-27-72		8-2-72		8-2-72		8-2-72	
Date Analysis Complete	9-15-72		9-15-72		9-15-72		9-15-72		9-15-72		8-24-72		9-15-72		9-15-72		9-15-72	
Laboratory	BIA		BIA		BIA		BIA		BIA		BIA		BIA		BIA		BIA	
Lab No.	73-Z-BLO-67		73-Z-BLO-68		73-Z-BLO-72		73-Z-BLO-109		73-Z-57		73-Z-59		73-Z-BLO-77		72-Z-BLO-73		73-Z-BLO-74	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)																		
Boron (B)		.82		1.16		.72		Trace		.42		0.12		.42		.05		Trace
Iron (Fe)	.004	.08	.02	0.43	.004	.08	.001	.02	.001	.02	0.001	0.01	.01	.18	.001	.02	.001	.03
Calcium (Ca)	.10	2.00	.10	2.00	.10	2.00	6.40	128.26	13.90	278.56	11.10	222.44	.10	2.00	18.00	360.72	27.80	557.11
Magnesium (Mg)	.10	1.22	.10	1.22	Trace	Trace	3.10	37.70	3.80	46.21	3.30	40.13	.10	1.22	5.80	70.53	17.80	155.65
Sodium (Na)	7.64	175.64	9.30	213.81	7.13	163.92	2.46	56.56	10.65	244.84	4.45	97.71	8.52	195.87	10.86	249.67	7.43	170.82
Potassium (K)	.04	1.56	.06	2.35	.07	2.74	.10	3.91	Trace	Trace	0.130	5.08	.03	1.17	.13	5.08	.16	6.26
Sum cations	7.88		9.58		7.30		12.06		28.35		18.78		8.76		34.79		48.19	
Phosphorus (P)		Trace		Trace		.05		Trace		Trace		Trace		.02		Trace		.02
Bicarbonate (HCO_3)	4.95	302.05	4.86	296.56	4.05	247.13	5.38	328.29	5.08	309.98	4.43	270.32	4.46	272.15	4.90	299.00	4.26	259.95
Carbonate (CO_3)	1.01	30.31	1.09	32.71	1.05	31.51	Trace	Trace	.88	26.41	1.05	31.51	1.09	32.71	.59	17.71	.59	17.71
Sulfate (SO_4)	1.46	70.12	3.50	168.11	2.10	100.86	6.17	296.35	17.98	863.58	11.53	553.79	3.15	151.29	27.98	1343.88	42.61	2046.56
Chloride (Cl)	.45	15.96	.35	12.41	.40	14.18	1.00	35.46	3.30	117.02	1.90	67.37	.25	8.87	.50	17.73	2.10	74.47
Fluoride (F)	.06	1.16	.23	4.40	.12	2.24	.03	.58	.02	0.29	0.01	0.28	.05	.92	.03	.52	.02	.42
Nitrate (NO_3)	.07	4.34	.01	.62	.01	.62	.01	.62	.03	1.86	0.005	0.31	.01	.62	.02	1.24	.01	.62
Sum anions	8.00		10.04		7.73		12.59		27.29		18.93		9.01		34.02		49.59	
Dissolved solids		455		621		431		694		1821		1143		531		2290		3440
Specific conductance		740		990		730		1050		2450		1600		850		2720		3440
pH		8.8		8.8		9.0		7.5		7.5		7.9		9.0		8.2		8.0
Hardness mg/l(Ca, Mg)		10		10		5		475		885		720		10		1190		2030
Hardness, noncarbonate		-		-		-		206		631		498		-		945		1817
Percent sodium (Na)		96		98		99		21		38		23		98		31		15
Sodium absorption ratio		24.16		29.41		30.59		1.13		3.58		1.58		26.94		2.61		1.65

Well Name or Owner	Exploration Oil Well No. 1				Cities Service No. 1 Zuni A		A-1		Chavez Well		E.C.W. No. 2		-		E.C.W. No. 13		Fidel Chahate			
T. N., R. W., Sec.	9 N. 18 W. 5						9 N. 20 W. 8		9 N. 20 W. 18		9 N. 21 W. 11		9 N. 21 W. 25		10 N. 16 W. 32		10 N. 17 W. 13			
Hydrologic Unit	Pg to Jz						Qal		TQs		TRC		Qal		Kg(?)		Qb			
Date Sampled	4-17-64		4-20-64		4-27-64		7-26-72		7-27-72		8-1-72		7-27-72		7-31-72		12-15-70		1-4-71	
Date Received by Lab	4-20-64		4-20-64		5-4-64		7-27-72		7-28-72		8-2-72				8-3-72		12-15-70		1-6-71	
Date Analysis Complete	-		-		-		8-24-72		8-24-72		9-15-72				9-15-72		12-16-70		1-11-71	
Laboratory	BIA		BIA		BIA		BIA		BIA		BIA				BIA		BIA		BIA	
Lab No.	JC-7		JC-9		JC-18		73-Z-49		73-Z-55		73-Z-BLO-66				73-Z-BLO-71		Z-369		Z-396	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)																				
Boron (B)	-	-	-	-	-	.5	-	0.72		.20		Trace				.66	-	-	-	0.12
Iron (Fe)	-	-	-	-		0.00	Trace	Trace	Trace	Trace	Trace	Trace			Trace	Trace	0.02	0.35	0.01	0.11
Calcium (Ca)	-	-	-	-	6.20		10.70	214.43	3.10	62.12	.90	18.04			.70	14.03	2.90	58.12	3.05	61.12
Magnesium (Mg)	-	-	-	-	2.10		2.70	32.83	.60	7.30	.30	3.65			.20	2.43	1.55	18.85	1.45	17.63
Sodium (Na)	9.03	-	8.88	-	4.06		15.18	348.99	5.08	116.79	2.29	52.65			16.35	375.89	2.12	48.75	2.12	48.74
Potassium (K)	-	-	-	-	.26		0.05	1.96	Trace	Trace	.06	2.35			.12	4.69	0.09	3.52	0.02	0.78
Sum cations	-	-	-	-	12.62		28.63		8.78		3.55				17.37		6.68		6.65	
Phosphorus (P)	-	-	-	-		Trace	-	Trace	-	.017		.02				Trace	-	0.04	-	0.01
Bicarbonate (HCO_3)	-	-	-	-	3.58		4.13	252.01	5.17	315.47	2.23	136.07			5.51	336.22	4.65	283.74	5.25	320.36
Carbonate (CO_3)	-	-	-	-	.31		0.55	16.51	.34	10.20	.34	10.20			.92	27.61	0.51	15.31	Trace	Trace
Sulfate (SO_4)	-	-	-	-	8.23	3.49	10.31	495.19	2.62	125.84	.51	24.50			6.94	333.33	1.46	70.12	1.36	65.32
Chloride (Cl)	-	-	-	-	.50		14.50	514.17	.65	23.05	.50	17.73			4.83	171.27	0.33	11.67	0.35	12.41
Fluoride (F)	-	-	-	-			0.05	0.92	.03	.64	.01	.25			.20	3.80	0.02	0.44	0.02	0.45
Nitrate (NO_3)	-	-	-	-	.004		0.034	2.11	.002	0.12	.16	9.92			.01	.62	0.03	1.86	0.02	1.24
Sum anions	-		-		12.62		29.57		8.81		3.75				18.41		7.00		7.00	
Dissolved solids		-		-		730		1850		457		215				1085		370		405
Specific conductance	-	1600		1870		1140		2880		830		350				1780		600		640
pH		-		-		7.9		7.8		7.9		8.4				8.8		8.4		8.0
Hardness mg/l(Ca, Mg)		-		-		-		670		185		60				45		223		225
Hardness, noncarbonate		-		-		-		463		-		-				-		-		-
Percent sodium (Na)		9.03		13.70		4.06		53		58		92				95		32		32
Sodium absorption ratio		6.31		8.19		1.99		5.86		3.73		2.89				24.38		1.42		1.41

Well Name or Owner	E.C.W. No. 6		E.C.W. No. 17 (New)				Robert D. Lister Jr. No. 1-X		Black Rock Well No. 1 (VA No. 1)				Black Rock Well No. 2	
T. N., R. W., Sec.	10 N. 17 W. 35		10 N. 18 W. 22				10 N. 19 W. 2		10 N. 19 W. 24				10 N. 19 W. 24	
Hydrologic Unit	Kd		Jz				Py, Pg, Psa, TRC		Qal				Pg, TRC	
Date Sampled	7-31-72		6-10-66		8-8-72		7-26-72		7-22-66		10-22-69		8-3-72	
Date Received by Lab	8-2-72		6-14-66		8-10-72		7-27-72		7-25-66		10-23-69		8-4-72	
Date Analysis Complete	9-15-72		6-24-66		9-15-72		8-24-72				11-1-69		9-15-72	
Laboratory	BIA		BIA		BIA		BIA		BIA		BIA		BIA	
Lab No.	73-Z-BLO-69		Z-10-359		73-Z-BLO-108		73-Z-51				70-Z-186		73-Z-BLO-91	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)			-	-										
Boron (B)		.42	-	.02		Trace		.82		.02		0.10		1.96
Iron (Fe)	Trace	Trace	.008	.15	.001	.01	Trace	Trace	.004	.07	0.01	.011	Trace	Trace
Calcium (Ca)	.30	6.01	1.80	36.1	2.20	44.09	.80	16.03	3.55	71.14	2.35	44.09	.70	14.03
Magnesium (Mg)	.10	1.22	.90	10.9	.80	9.73	.10	1.22	1.05	12.77	0.85	10.34	.20	2.43
Sodium (Na)	10.80	248.29	5.74	132.	4.77	109.66	14.08	323.70	3.04	69.89	4.26	97.94	23.50	540.27
Potassium (K)	.12	4.69	.068	2.66	Trace	Trace	Trace	Trace	.05	1.96	0.06	2.35	.03	1.17
Sum cations	11.32		8.52		7.77		14.98		7.69		7.53		24.43	
Phosphorus (P)		Trace	-	Trace		Trace		Trace	-	.006		0.01		Trace
Bicarbonate (HCO_3)	3.76	229.44	3.41	208.	3.25	198.32	8.59	524.16	5.03	306.93	4.18	255.06	6.30	384.43
Carbonate (CO_3)	.88	26.41	.60	18.0	.62	18.61	1.30	39.01	.17	5.10	0.34	10.20	.88	31.20
Sulfate (SO_4)	6.22	298.76	2.86	185.	3.95	189.72	4.74	227.66	2.14	102.78	2.49	119.59	10.56	507
Chloride (Cl)	.60	21.28	.38	13.5	.20	7.09	.45	15.96	.70	24.82	0.64	22.69	7.80	276.59
Fluoride (F)	.11	2.10	.02	.43	.02	.44	.06	1.17	.02	.40	0.02	0.38	.32	6.00
Nitrate (NO_3)	.01	.62	.004	.25	.01	.62	.069	4.28	.02	1.24	0.01	0.62	.01	.62
Sum anions	11.58		7.27		8.05		15.21		8.08		7.68		25.87	
Dissolved solids		749		510		472		879		454		448		1561
Specific conductance		1190		770		770		1420		780		760		2510
pH		8.8		8.3		8.0		8.4		7.9		8.4		8.4
Hardness (Ca, Mg)		20		135		150		45				160		45
Hardness, noncarbonate		-		-		-		-		-		-		-
Percent sodium (Na)		96		67		61		94				57		96
Sodium absorption ratio		24.15		4.25		3.89		20.99				3.38		35.04

Well Name or Owner	Black Rock Well No. 3								Village of Zuni Well No. 1						Village of Zuni Well No. 2	
T. N., R. W., Sec.	10 N. 19 W. 24								10 N. 19 W. 28						10 N. 19 W. 28	
Hydrologic Unit	Pg, Psa								TRC						TRC	
Date Sampled	3-28-68		10-22-69		9-10-70		8-3-72		9-29-64		3- -68		8-3-72			
Date Received by Lab	3-28-68		10-23-69		9-11-70		8-4-72		-		3-8-68		8-4-72			
Date Analysis Complete	4-18-68		11-12-69		9-24-70		9-15-72		12-28-64		3-21-68		9-15-72		8-21-70	
Laboratory	BIA				BIA		BIA		USGS		BIA		BIA		USGS	
Lab No.			70-Z-185		71-Z-196		73-Z-BLO-92		55547		PH 343		73-Z-BLO-84			
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)										12						12
Boron (B)	-	.1		0.15		0.30		.28				1.00		.82		.47
Iron (Fe)	.009	.146	0.002	0.04	0.02	0.30	.001	.02		2.5	.017	.316	Trace	Trace		0.00
Calcium (Ca)	7.75	155.3	8.05	161.32	8.00	160.32	8.10	162.32	.14	2.8	.40	8.02	.20	4.01		8.0
Magnesium (Mg)	1.80	21.89	2.15	26.14	2.10	25.54	2.20	26.75	.02	.2	Trace	Trace	.10	1.22		.7
Sodium (Na)	5.40	124.15	4.96	114.03	5.10	111.25	4.95	113.80			11.36	261.17	11.78	460.60		352.
Potassium (K)	.218	8.52	0.23	8.99	0.18	7.04	.27	10.50			0.040	1.56	Trace	Trace		.7
Sum cations	15.18		15.39		15.40		15.52				11.82		12.08			
Phosphorus (P)	-	Trace		.001		Trace		Trace				.028		.02		-
Bicarbonate (HCO_3)	3.24	197.7	3.80	231.88	3.57	219.06	3.71	226.38	6.75	412	6.74	411.27	6.46	394.19		582
Carbonate (CO_3)	-	Trace	Trace	Trace	Trace	Trace	Trace	Trace	.50	15	.35	10.50	1.05	31.51		-
Sulfate (SO_4)	11.48	551.38	10.67	512.48	11.02	529.29	11.55	554.75	3.27	157	3.13	150.33	3.76	180.59		252
Chloride (Cl)	.94	33.33	0.91	32.27	0.76	26.95	.80	28.37	1.02	36	1.06	37.59	1.35	47.87		64
Fluoride (F)	.07	1.34	0.06	1.15	0.05	1.00	.07	1.30	.11	2.1	.147	2.80	.14	2.65		.4
Nitrate (NO_3)	.004	.25	0.01	0.62	0.004	0.25	.01	.62	.00	.1	.014	.87	.01	.62		.3
Sum anions	15.73		15.45		15.42		16.14		11.65		11.44		12.77			
Dissolved solids		1068		1096		1045		994		710		672		742		1060
Specific conductance		1470		1450		1400		1400		1110		1130		1190		1580
pH		7.8		7.6		7.7		7.7		8.7		8.5		8.7		8.2
Hardness (Ca, Mg)		477		510		505		515		8		20		15		
Hardness, noncarbonate		315		320		325		329		0		-		-		
Percent sodium (Na)		36		33		34		32		99		96		98		95
Sodium absorption ratio		2.48		2.19		2.27		2.18		41		25.40		30.42		

Appendix 3—*Chemical analyses of water samples from wells, pueblo of Zuni*—Continued

Well Name or Owner	Village of Zuni Well No. 2						Village of Zuni Well No. 3					
T. N., R. W., Sec.	10 N. 19 W. 28						10 N. 19 W. 28					
Hydrologic Unit	TRC						TRC					
Date Sampled	*3- -68		**4-9-68		8-3-72		5-24-57		9-26-63		8-3-72	
Date Received by Lab	3-8-68		4-11-68		8-4-72				9-26-63		8-4-72	
Date Analysis Complete	3-21-68		5-2-68		9-15-72				10-2-63		9-15-72	
Laboratory	BIA		BIA		BIA				NMPHL		BIA	
Lab No.	PH-344		PH-419		73-Z-BLO-85				1146		73-Z-BLO-86	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)												
Boron (B)		.80		.63		.34						.72
Iron (Fe)	.010	.190	.004	.072	Trace	Trace		1.3		.7	Trace	Trace
Calcium (Ca)	.50	10.02	.25	5.01	.40	8.02		2		4.6	.30	6.01
Magnesium (Mg)	.05	.61	.05	.61	.10	1.22		1		.2	.10	1.22
Sodium (Na)	10.00	229.90	15.18	348.99	15.60	356.35		218		328	14.38	330.60
Potassium (K)	Trace	Trace	Trace	Trace	Trace	Trace				4.3	.23	8.99
Sum cations	10.56		15.48		16.00						15.01	
Phosphorus (P)		.010		Trace		.002						Trace
Bicarbonate (HCO_3)	6.67	403.95	9.77	596.17	9.20	561.38		336		272	5.80	353.90
Carbonate (CO_3)	.27	8.10	.19	5.70	.63	18.91		30		26	1.05	31.51
Sulfate (SO_4)	3.00	144.09	4.10	196.92	5.23	251.20		57		215	3.93	188.76
Chloride (Cl)	1.01	35.81	1.76	62.41	1.85	65.00		63		123	4.63	164.18
Fluoride (F)	.147	2.80	.039	.75	.03	.54				2.2	.11	2.05
Nitrate (NO_3)	.014	.87	.018	1.12	.01	.62				0	.02	1.24
Sum anions	11.06		15.87		16.95						15.54	
Dissolved solids		682		940		1003		484		938		910
Specific conductance		1130		1500		1120				1345		1520
pH		8.6		8.4		8.3		8.8		8.8		8.7
Hardness (Ca, Mg)		27		15		25						20
Hardness, noncarbonate		-		-		-						-
Percent sodium (Na)		95		99		97						97
Sodium absorption ratio		19.13		39.19		31.00						32.15

Well Name or Owner	Village of Zuni Well No. 4		St. Anthony's Well				Pat Kelsey's Well	
T. N., R. W., Sec.	10 N. 19 W. 28		10 N. 19 W. 28				10 N. 19 W. 28	
Hydrologic Unit	TRC		Qal?				TRC	
Date Sampled	8-3-72		-		8-3-72		8-3-72	
Date Received by Lab	8-4-72		7-25-72		8-4-72		8-4-72	
Date Analysis Complete	9-15-72		8-21-72		9-15-72		9-15-72	
Laboratory	BIA		BIA		BIA		BIA	
Lab No.	73-Z-BLO-87		73-BF-36		73-Z-BLO-88		73-Z-BLO-89	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)								
Boron (B)		.58		1.07		.98		.34
Iron (Fe)	Trace	Trace	Trace	Trace	Trace	Trace	.003	.06
Calcium (Ca)	1.20	24.05	2.00	400.80	2.30	46.09	.30	6.01
Magnesium (Mg)	.10	1.22	.20	2.43	.20	2.43	.10	1.22
Sodium (Na)	12.70	291.97	39.70	912.70	45.35	1042.60	15.88	365.08
Potassium (K)	.05	1.96	.12	4.69	.08	3.13	Trace	Trace
Sum cations	14.05		42.02		47.93		16.28	
Phosphorus (P)		Trace		Trace		Trace		.18
Bicarbonate (HCO_3)	9.18	560.16	3.04	185.50	2.34	142.79	10.85	662.07
Carbonate (CO_3)	.80	24.01	.67	20.11	.71	21.31	1.05	31.51
Sulfate (SO_4)	2.26	108.55	14.27	685.29	15.58	740.31	3.27	157.06
Chloride (Cl)	2.48	87.94	25.50	904.23	30.56	1083.66	2.05	72.69
Fluoride (F)	.10	1.89	.10	1.91	.09	1.75	.03	.50
Nitrate (NO_3)	.01	.62	.004	.25	.01	.62	.01	.62
Sum anions	14.83		43.58		49.29		17.26	
Dissolved solids		760		2598		2899		967
Specific conductance		1330		4370		5080		1570
pH		8.2		?		8.3		8.4
Hardness (Ca, Mg)		65		110		125		20
Hardness, noncarbonate		-		-		8		-
Percent sodium (Na)		91		95		95		98
Sodium absorption ratio		15.75		37.85		40.56		35.51

*Before development
**After development

Well Name or Owner	Leo Nastacio		R.W.P. Z-27		Irrigation No. 1				Bosson's Place Well			
T. N., R. W., Sec.	10 N. 19 W. 30		10 N. 20 W. 8		10 N. 20 W. 18				10 N. 20 W. 22			
Hydrologic Unit	TQs		TRC		Qal				TQs			
Date Sampled	8-2-72		7-25-72		6-10-66		7-26-72		7-25-72		8-17-72	
Date Received by Lab	8-4-72		7-26-72		6-14-66		7-27-72		7-26-72		8-22-72	
Date Analysis Complete	9-15-72		8-24-72		6-24-66		8-24-72		8-24-72		9-25-72	
Laboratory	BIA		BIA		BIA		BIA		BIA		BIA	
Lab No.	73-Z-BLO-93		73-Z-37		Z-13-362		73-Z-50		73-Z-38		73-Z-BLO-159	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)												
Boron (B)		.58		0.12	-	Trace		1.86		0.50		.05
Iron (Fe)	.002	.03	Trace	Trace	.0005	.01	Trace	Trace	Trace	Trace	Trace	Trace
Calcium (Ca)	1.70	34.07	3.20	64.13	2.8	56.1	3.10	62.12	3.10	62.12	3.21	64.13
Magnesium (Mg)	.60	7.30	0.50	6.08	.2	2.4	0.40	4.86	0.60	7.30	.40	4.86
Sodium (Na)	8.22	188.98	0.74	17.01	2.3	52.9	0.95	21.84	4.70	108.05	4.56	104.83
Potassium (K)	Trace	Trace	0.03	1.17	.1	3.94	0.05	1.96	Trace	Trace	Trace	Trace
Sum cations	10.52		4.47		5.4		4.50		8.40		8.16	
Phosphorus (P)		.02		Trace	-	.03		Trace		Trace		Trace
Bicarbonate (HCO_3)	8.88	541.86	2.35	143.40	3.65	223.	1.91	116.55	5.02	306.32	5.03	306.93
Carbonate (CO_3)	.84	25.21	0.46	13.80	.47	14.1	0.38	11.40	0.84	25.21	.78	23.41
Sulfate (SO_4)	.07	3.36	0.44	21.13	.77	37.0	0.56	26.90	1.27	61.00	1.39	66.76
Chloride (Cl)	1.25	44.33	1.755	19.50	.53	18.8	1.20	42.55	1.50	53.19	1.40	49.64
Fluoride (F)	.06	1.05	0.01	0.21	.008	.15	0.01	0.20	0.02	0.33	.02	.30
Nitrate (NO_3)	.01	.62	0.533	33.05	.006	.37	0.547	33.92	0.026	1.61	.02	1.24
Sum anions	11.11		5.34		5.44		4.61	-	8.68		8.64	
Dissolved solids		541		256		336		269		458		473
Specific conductance		990		450		580		470		800		740
pH		8.3		7.7		7.9		8.0		7.8		8.7
Hardness (Ca, Mg)		115		185		150		175		185		180
Hardness, noncarbonate		-		67		-		79		-		-
Percent sodium (Na)		78		17		54		21		56		56
Sodium absorption ratio		7.67		0.54		1.67		.72		2.16		3.40

Well Name or Owner	R.W.P. Z-28		Campground Well		E.C.W. No. 10			
T. N., R. W., Sec.	11 N. 16 W. 28		11 N. 17 W. 5		11 N. 17 W. 29			
Hydrologic Unit	Kd		Kg		Kd			
Date Sampled	8-16-72		7-31-72		7-31-72		8-14-72	
Date Received by Lab	8-22-72		8-2-72		8-2-72		8-15-72	
Date Analysis Complete	9-25-72		9-15-72		9-15-72		9-25-72	
Laboratory	BIA		BIA		BIA		BIA	
Lab No.	73-Z-BLO-158		73-Z-BLO-78		73-Z-BLO-70		73-Z-BLO-157	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)								
Boron (B)		Trace		.20		Trace		Trace
Iron (Fe)	Trace	Trace	Trace	Trace	.001	.02	Trace	Trace
Calcium (Ca)	7.00	140.28	.70	14.03	1.70	34.07	1.80	36.07
Magnesium (Mg)	2.80	34.05	.20	2.43	1.00	12.16	1.00	12.16
Sodium (Na)	6.94	159.55	6.29	144.61	15.98	367.38	15.55	357.49
Potassium (K)	.14	5.47	.05	1.96	.16	6.26	Trace	Trace
Sum cations	16.88		7.24		18.84		18.35	
Phosphorus (P)		Trace		Trace		Trace		Trace
Bicarbonate (HCO_3)	5.17	315.47	4.37	266.66	6.35	387.48	6.07	370.39
Carbonate (CO_3)	0.41	12.30	.80	24.01	.71	21.31	.87	26.11
Sulfate (SO_4)	9.80	470.69	2.19	105.19	11.39	547.06	11.99	575.88
Chloride (Cl)	.60	21.28	.15	5.32	.35	12.41	.40	14.18
Fluoride (F)	.02	.35	.08	1.52	.02	.39	.01	.28
Nitrate (NO_3)	.01	.62	.01	.62	.01	.62	.01	.62
Sum anions	16.01		7.60		18.83		19.35	
Dissolved solids		971		428		1199		992
Specific conductance		1360		700		1810		1670
pH		8.6		8.8		8.1		8.9
Hardness (Ca, Mg)		490		45		135		140
Hardness, noncarbonate		231		-		-		-
Percent sodium (Na)		41		87		86		85
Sodium absorption ratio		3.14		9.38		13.75		13.14

Appendix 3—*Chemical analyses of water samples from wells, pueblo of Zuni*—Continued

Well Name or Owner	E.C.W. No. 1				R.W.P. Z-34				R.W.P. Z-32		-	
T. N., R. W., Sec.	11 N. 18 W. 21				11 N. 18 W. 27				12 N. 16 W. 7		12 N. 17 W. 23	
Hydrologic Unit	Jz				Kd				Kg		Qal	
Date Sampled	6-14-66		8-11-72		7-31-72		8-10-72		8-1-72		8-1-72	
Date Received by Lab	6-14-66		8-22-72		8-2-72		8-22-72		8-2-72		8-2-72	
Date Analysis Complete	6-10-66		9-25-72		9-15-72		9-25-72		9-15-72		9-15-72	
Laboratory			BIA		BIA		BIA		BIA		BIA	
Lab No.			73-Z-BLO-156		73-Z-BLO-76		73-Z-BLO-155		73-Z-BLO-75		73-Z-BLO-79	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)												
Boron (B)	-	Trace		Trace		.12		Trace		.20		.28
Iron (Fe)	.006	.12	Trace	Trace	Trace	Trace	Trace	Trace	.001	.01	Trace	Trace
Calcium (Ca)	10.7	214	13.60	275.54	2.10	42.08	2.10	42.08	3.70	74.15	6.30	126.25
Magnesium (Mg)	3.4	41.3	4.30	52.29	1.10	13.38	1.00	12.16	2.20	26.75	4.20	51.07
Sodium (Na)	1.6	37.3	2.15	49.43	7.50	172.43	7.28	167.37	6.86	157.71	7.45	171.28
Potassium (K)	.1	3.9	Trace	Trace	.12	4.69	Trace	Trace	.21	8.21	.05	1.96
Sum cations	15.8		20.05		10.82		10.38		12.97		18.00	
Phosphorus (P)				Trace		.02		Trace		Trace		.03
Bicarbonate (HCO_3)	3.18	194.	3.70	225.77	3.74	228.21	3.51	214.18	6.59	402.12	5.72	349.03
Carbonate (CO_3)	.43	12.9	.41	12.30	.50	15.01	.66	19.81	.63	18.91	.42	12.60
Sulfate (SO_4)	12.6	605	15.15	727.67	6.80	326.60	6.66	319.88	4.09	196.44	7.02	337.17
Chloride (Cl)	.48	17	.45	15.96	.05	1.77	.15	5.32	1.70	60.28	3.43	121.63
Fluoride (F)	.02	.33	.01	.15	.02	.29	.01	.25	.03	.56	.03	.52
Nitrate (NO_3)	.006	.37	.01	.62	.01	.62	.01	.62	.01	.62	1.39	86.19
Sum anions	16.72		19.73		11.12		11.00		13.05		18.01	
Dissolved solids		1206		1373		685		668		632		1098
Specific conductance		1390		1530		1030		970		1190		1660
pH		8.0		8.2		8.4		8.9		8.2		8.2
Hardness (Ca, Mg)		715		895		160		155		295		525
Hardness, noncarbonate		556		710		-		-		-		239
Percent Sodium (Na)		10		11		70		70		54		42
Sodium absorption ratio		.61		.72		5.93		5.85		3.99		33.32

Appendix 4—*Chemical analysis of water samples from springs, pueblo of Zuni*

Spring Name	-		-		Ojo Caliente Spring					
T. N. R. W. Sec.	7 N. 21 W. 3		8 N. 20 W. 8		8 N. 20 W. 21					
Hydrologic Unit	Qal-TR		TR		TR					
Date Sampled	7-27-72		7-27-72		11-13-63		8-17-67		7-27-72	
Date Received by Lab	7-28-72		7-28-72		-		8-18-67		7-28-72	
Date Analysis Complete	9-15-72		8-24-72		-		9-8-67		8-24-72	
Laboratory	BIA		BIA		BIA		BIA		BIA	
Lab No.	73-Z-58		73-Z-54		Z-3		68-E-97		73-Z-56	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)										
Boron (B)		.28		.05				.20		.28
Iron (Fe)	Trace	Trace	Trace	Trace	-		.002	.040	Trace	Trace
Calcium (Ca)	6.60	132.26	3.20	64.13	7.00		7.65	153.31	7.10	142.28
Magnesium (Mg)	4.60	559.36	.50	6.08	3.40		3.45	41.95	3.20	38.91
Sodium (Na)	12.28	282.32	4.42	101.62	2.60		5.75	132.19	1.96	45.06
Potassium (K)	.15	5.87	.10	3.91	.16		.025	.98	.154	5.87
Sum cations	23.63		8.22		13.16		16.88		12.41	
Phosphorus (P)		Trace		Trace			Trace	Trace	Trace	Trace
Bicarbonate (HCO_3)	3.81	232.49	4.85	295.95	5.71		2.90	176.96	5.04	307.54
Carbonate (CO_3)	.84	25.21	.34	10.20	0.00		Trace	Trace	.50	15.01
Sulfate (SO_4)	15.04	722.37	.70	33.62	6.11		11.18	56.68	6.19	297.31
Chloride (Cl)	3.10	109.93	1.60	56.74	1.33		2.03	71.98	.95	33.69
Fluoride (F)	.05	.88	.02	.42	-		.024	.45	.03	.58
Nitrate (NO_3)	.01	.62	.824	51.10	.014		.012	.74	.002	.12
Sum anions	22.85		8.33		13.16		16.14		12.71	
Dissolved solids		1584		480		768		1120		738
Specific conductance		2200		830		1200		1600		1130
pH		7.8		7.8		7.4		8.0		7.5
Hardness (Ca, Mg)		560		185				555		515
Hardness, noncarbonate		369		-				410		263
Percent sodium		52		54		19		34		16
Sodium absorption ratio		5.19		3.25		1.47		2.44		.86

Spring Name	Pescado Spring		Black Rock Spring						Nutria Spring	
T. N. R. W. Sec.	10 N. 17 W. 12		10 N. 19 W. 13						12 N. 16 W. 8	
Hydrologic Unit	Qal-Kg		TR						Psa	
Date Sampled	11-13-63		-		10-22-69		8-3-72		9-12-68	
Date Received by Lab	-		9-26-63		10-23-69		8-4-72		9-13-68	
Date Analysis Complete	-		10-2-63		?		9-15-72		10-14-68	
Laboratory	BIA		NMPHS		BIA		BIA		BIA	
Lab No.	Z-10		1150		70-Z-184		73-Z-BLO-90		E-127	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)										
Boron (B)	-					.15		Trace		.05
Iron (Fe)	-			.12	.01	.11	Trace	Trace	.002	0.040
Calcium (Ca)	2.10			56	2.60	52.10	2.30	46.09	2.80	56.11
Magnesium (Mg)	1.20			.6	.35	4.26	.40	4.86	.70	8.51
Sodium (Na)	1.75			45	1.18	43.22	2.01	46.21	.75	17.24
Potassium (K)	.08			1.2	.02	.48	.02	.78	.125	4.89
Sum cations	5.13				4.16		4.73		4.38	
Phosphorus (P)	-					.05		.05	.006	0.180
Bicarbonate (HCO_3)	3.41			195	4.20	256.28	3.43	209.30	3.78	230.66
Carbonate (CO_3)	.66			0	Trace	Trace	.34	10.20	Trace	Trace
Sulfate (SO_4)	.22			8	.34	16.33	.90	43.23	0.51	24.50
Chloride (Cl)	.78			23	.36	12.77	.25	8.87	.13	4.61
Fluoride (F)				.25	.01	.25	.02	.37	.02	.42
Nitrate (NO_3)	.060			5.1	.08	4.96	.07	4.34	.15	9.30
Sum anions	5.13				4.99		5.01		4.60	
Dissolved solids		314		243		272		252		260
Specific conductance		490		430		410		460		420
pH		8.2		7.8		7.8		8.0		7.9
Hardness (Ca, Mg)				148				135		175
Hardness, noncarbonate				-				-		-
Percent sodium		15.2		39				43		17
Sodium absorption ratio		1.36		1.55				1.73		.57

pueblo of Zuni

Reservoir / Stream	Ojo Caliente, Plumasano Wash						Tekapo, Zuni River						Eustace, Zuni River					
Date Sampled	-		8-7-67		8-8-68		-		8-7-67		8-8-68		-		8-7-67		8-8-68	
Date Received by Lab	11-13-63		8-9-67		8-9-68		11-13-63		8-9-67		8-9-68		11-13-63		8-9-67		8-9-68	
Date Analysis Complete	-		-		-		-		9-1-67		8-28-68		-		8-28-67		8-28-68	
Laboratory	BIA		BIA		BIA		BIA		BIA		BIA		BIA		BIA		BIA	
Lab No.	Z-1		68-E-61		69-E-73		Z-4		68-Z-60		69-Z-75		Z-5		68-Z-64		69-Z-69	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)																		
Boron (B)		-		-	Trace	Trace	-	-	-	-	-	0.10	-	-	-	.25	-	0.10
Iron (Fe)	.014		-	-	.006	.10	-	-	-	-	.03	0.480		.048	.008	.140	.006	.110
Calcium (Ca)	3.90		4.05	81.16	4.25	85.17	1.40		1.30	26.05	1.95	39.08	2.60		.85	17.03	.65	13.03
Magnesium (Mg)	4.10		2.50	30.40	3.25	39.52	.40		.30	3.65	.50	6.08	.70		1.05	12.77	1.30	15.81
Sodium (Na)	2.94		2.06	48.36	2.46	56.56	2.76		2.97	63.28	4.09	94.03	2.45		4.32	99.32	4.70	108.05
Potassium (K)	.26		.180	7.14	.706	8.05	.09		.167	6.53	.145	5.67	.12		.083	3.25	.06	2.35
Sum cations			8.79		10.18				4.74		6.72				6.31		6.72	
Phosphorus (P)			.0013	.010	Trace	Trace	-	-	.018	.556	.003	.100	-		.001	.028	Trace	Trace
Bicarbonate (HCO_3)	1.99		1.90	115.94	1.76	107.40	3.02		2.78	169.64	3.66	223.33	351		2.14	130.58	1.45	88.48
Carbonate (CO_3)	.33		Trace	Trace	.23	6.90	.54		Trace	Trace	.13	3.90	.19		.42	12.60	1.23	36.91
Sulfate (SO_4)	7.27	347	5.57	267.53	7.58	364.07	.45		1.67	80.21	2.23	107.11	1.38		3.13	150.33	3.13	150.33
Chloride (Cl)	1.60		1.20	42.55	1.15	40.78	.63		0.50	17.73	0.67	23.76	.78		.85	30.14	0.72	25.33
Fluoride (F)	-		-	-	.03	.55	-	-	-	-	.02	.35	-		.026	.56	0.02	0.45
Nitrate (NO_3)	.012		-		Trace	Trace	.012		-	-	Trace	Trace	.012		.008	.50	Trace	Trace
Sum anions			8.67		10.15				4.97		6.71				6.58		6.55	
Dissolved solids		698		608		738		275		396		434		352		466		414
Specific conductance		1090		850		990		430		440		640		550		650		660
pH		8.0		8.0		8.1		8.2		8.1		8.1		7.9		8.9		9.6
Hardness (Ca, Mg)				328		375				80		123				95		98
Hardness, noncarbonate				233		275				-		-				-		-
Percent sodium	2.94			23		24	2.76			63		61	2.45			68		70
Sodium absorption ratio		1.47		1.14		1.27		2.91		3.32		3.70		1.91		4.43		4.76

Appendix 5—*Chemical analyses of water samples from reservoirs, pueblo of Zuni*—Continued

Reservoir / Stream	Bolton, Zuni River				Black Rock, Zuni River						Pescado, Rio Pescado					
Date Sampled	8-7-67		8-8-68		-		8-7-67		7-5-68		-		8-7-67		8-8-68	
Date Received by Lab	8-9-67		8-9-68		11-13-63		8-9-67		7-10-68		11-13-63		8-9-67		8-9-68	
Date Analysis Complete	9-1-67		8- -68		-		8-28-67		8-1-68		-		8-28-67		8-28-68	
Laboratory	BIA		BIA		BIA		BIA		BIA		BIA		BIA		BIA	
Lab No.	68-Z-63		69-Z-68		Z-2		68-Z-59		69-Z-12		Z-11		68-Z-58		69-Z-74	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)																
Boron (B)	-	.25	-	.10	-		-	-	-	0.20	-	-	-	-	Trace	Trace
Iron (Fe)	.018	.140	.004	.070	.188		-	-	.026	.460	.116		-	-	.10	1.920
Calcium (Ca)	1.60	32.06	1.05	21.04	2.00		2.30	46.19	1.15	43.05	1.60		1.15	23.05	1.95	39.08
Magnesium (Mg)	.70	8.51	.80	9.73	.50		.70	8.51	.95	11.55	.40		1.00	12.16	.80	9.73
Sodium (Na)	3.05	70.12	3.67	84.37	.74		.87	20.00	2.39	54.95	.43		2.03	46.67	.66	15.17
Potassium (K)	.048	1.88	.08	3.13	.13		.155	6.06	.070	2.74	.16		.235	9.19	.203	7.99
Sum cations	5.41		5.60				4.13		4.59				4.42		3.71	
Phosphorus (P)	.001	.028	.0003	.010			.001	.028		Trace	-	-	.001	.044	.0003	.010
Bicarbonate (HCO_3)	2.73	166.58	2.00	122.04	2.07		1.77	108.01	0.84	51.26	1.89		2.62	159.87	2.06	125.7
Carbonate (CO_3)	Trace	Trace	.30	9.00	0.00		Trace	Trace	0.27	8.10	.21		Trace	Trace	Trace	Trace
Sulfate (SO_4)	2.27	109.03	2.83	135.92	.80		1.84	88.38	2.90	139.29	.03		1.20	57.64	1.63	78.29
Chloride (Cl)	.63	22.34	.60	21.28	.48		.38	13.47	.44	15.60	.45		.68	24.11	.15	5.32
Fluoride (F)	.026	.50	.03	.52	-		-	-	.027	.52	-	-	-	-	.02	.37
Nitrate (NO_3)	.016	.99	Trace	Trace	.018		-	-	.004	.25	.014		-	-	.010	.62
Sum anions	5.68		5.76		3.35		3.99		4.48				4.50		3.87	
Dissolved solids		348		352		211		232		298		166		294		330
Specific conductance		550		570		330		400	450			260		430		536
pH		8.2		8.6		7.9		8.2	8.7			8.2		8.5		7.8
Hardness (Ca, Mg)		115		93				150		105				108		138
Hardness, noncarbonate		-		-				61		39				-		35
Percent sodium		56		65	.74			22		52	.43			46		18
Sodium absorption ratio		2.84		3.82		.66		.71		2.33		.43		1.96		.56

Appendix 5—*Chemical analyses of water samples from reservoirs, pueblo of Zuni*—Continued

Reservoir / Stream	Nutria No. 2 / Rio Nutria					
Date Sampled	-		8-7-67		8-8-68	
Date Received by Lab	11-13-63		8-8-67		8-9-68	
Date Analysis Complete	-		8-28-67		8-28-68	
Laboratory	BIA		BIA		BIA	
Lab No.	Z-8		68-Z-56		69-Z-71	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)						
Boron (B)	-	-	-	-	Trace	Trace
Iron (Fe)	-	-	-	-	.01	.188
Calcium (Ca)	2.10		.90	18.04	.95	19.04
Magnesium (Mg)	.80		1.05	12.77	1.00	12.16
Sodium (Na)	1.26		1.82	41.84	1.76	40.46
Potassium (K)	.18		.126	4.93	.106	4.14
Sum cations			3.90		3.83	
Phosphorus (P)	-	-	.001	.028	.001	.040
Bicarbonate (HCO_3)	2.75		1.36	82.99	.06	3.66
Carbonate (CO_3)	0.00		.61	18.21	1.99	59.72
Sulfate (SO_4)	.85		1.16	55.71	1.24	59.56
Chloride (Cl)	.73		.78	27.66	.52	18.44
Fluoride (F)	-	-	-	-	.03	.52
Nitrate (NO_3)	.012		-	-	Trace	Trace
Sum anions			3.91		3.84	
Dissolved solids		269		258	246	
Specific conductance		420		380	380	
pH		7.9		8.2	9.5	
Hardness (Ca, Mg)				98	98	
Hardness, noncarbonate				-	-	
Percent sodium	1.26			47.	45	
Sodium absorption ratio		1.05		1.84	1.78	

Reservoir / Stream	Nutria No. 4 / Rio Nutria					
Date Sampled	-		8-7-67		8-8-68	
Date Received by Lab	11-13-63		8-9-67		8-9-68	
Date Analysis Complete	-		8-28-67		8-28-68	
Laboratory	BIA		BIA		BIA	
Lab No.	Z-12		68-E-62		69-Z-72	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)						
Boron (B)	-	-	-	0.03	Trace	Trace
Iron (Fe)		.054	.016	.300	.008	.156
Calcium (Ca)	1.40		1.20	24.05	.85	17.03
Magnesium (Mg)	.80		.90	10.94	.85	10.34
Sodium (Na)	.62		.66	15.17	.50	11.50
Potassium (K)	.17		.126	4.93	.072	2.82
Sum cations			2.91		2.28	
Phosphorus (P)	-	-	.0003	.010	.002	.060
Bicarbonate (HCO_3)	2.19		1.76	107.40	.87	53.09
Carbonate (CO_3)	.21		Trace	Trace	.49	14.70
Sulfate (SO_4)	.10		.36	41.31	.73	35.06
Chloride (Cl)	.48		.43	15.25	.18	6.38
Fluoride (F)			.026	.50	.02	.37
Nitrate (NO_3)	.006		.012	.74	.004	.25
Sum anions					2.29	
Dissolved solids		192		174		130
Specific conductance		300		280		230
pH		7.9		8.7		9.3
Hardness (Ca, Mg)				105		85
Hardness, noncarbonate				17		16
Percent sodium	.62			23		21
Sodium absorption ratio		.59		.64		.54

Reservoir / Stream	Nutria Diversion / Rio Nutria					
Date Sampled	-		8-7-67		8-8-68	
Date Received by Lab	11-13-63		8-9-67		8-9-68	
Date Analysis Complete	-		8-28-67		8-28-68	
Laboratory	BIA		BIA		BIA	
Lab No.	Z-9		68-Z-57		69-Z-70	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)						
Boron (B)	-	-	-	-	-	0.05
Iron (Fe)	-		-	-	.06	1.100
Calcium (Ca)	3.10		2.00	40.08	1.20	24.05
Magnesium (Mg)	1.20		.60	7.30	.40	4.86
Sodium (Na)	.43		.21	4.83	.22	5.06
Potassium (K)	.15		.089	3.48	.182	7.12
Sum cations			2.90		2.06	
Phosphorus (P)	-		.002	.060	.0008	.024
Bicarbonate (HCO_3)	3.78		2.31	140.96	1.36	82.99
Carbonate (CO_3)	.25		Trace	Trace	Trace	Trace
Sulfate (SO_4)	.29		.43	20.65	.73	35.06
Chloride (Cl)	.55		.33	11.70	.05	1.77
Fluoride (F)	-		-	-	.01	.25
Nitrate (NO_3)	.014		-	-	.006	.37
Sum anions			3.07		2.16	
Dissolved solids		288		174		290
Specific conductance		450		280		180
pH		8.0		8.1		7.6
Hardness (Ca, Mg)				80		130
Hardness, noncarbonate				12		14
Percent sodium	.43			11		7
Sodium absorption ratio		.29		.21		.18

Appendix 6—*Chemical analyses of water from miscellaneous sources, pueblo of Zuni, New Mexico*

Source	Village of Zuni Distribution System		Black Rock Distribution System								Yellow House Dam Site: Rio Pescado	
Location	Sec. 28, T. 10 N., R. 19 W.		Sec. 24, T. 10 N., R. 19 W.								Sec. 11, T. 10 N., R. 18 W.	
Remarks												
Date Sampled	?		?		10-22-69		-		2-12-71		8-11-71	
Date Received by Lab	?		?		10-23-69		2-11-71		2-12-71		8-13-71	
Date Analysis Complete	?		?		11-8-69		2-26-71		3-3-71		8-19-71	
Laboratory	NMPHL		NMPHL		BIA		BIA		BIA		BIA	
Lab No.	?		?		71-Z-465		71-Z-465		71-Z-468		72-Z-75	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)												
Boron (B)						.10		.12		.12		-
Iron (Fe)		1.02		.16	.002	.04	.002	.04	.002	.04	.01	.023
Calcium (Ca)		7.		48	2.65	53.11	8.30	166.33	8.30	166.33	1.30	26.05
Magnesium (Mg)		1.1		7.9	.40	4.86	2.10	25.54	2.10	25.54	1.00	12.16
Sodium (Na)		368		41	2.00	43.98	4.84	111.27	4.96	114.03	3.90	89.66
Potassium (K)		1.6		1.6	.02	0.78	.16	6.26	0.19		-	-
Sum cation					5.07		15.40		15.55		6.20	
Phosphorus (P)		-		-	-	.03		Trace		Trace	-	-
Bicarbonate (HCO_3)		356.2		250.1	4.30	262.39	3.64	222.11	3.52	215.40	2.12	129.36
Carbonate (CO_3)		9.6		0.0	Trace	Trace	Trace	Trace	Trace	Trace	.46	13.80
Sulfate (SO_4)		348		17	0.34	16.33	10.89	523.05	10.84	520.65	3.08	147.93
Chloride (Cl)		113		9.0	.36	12.77	.78	27.66	.88	31.20	.83	29.43
Fluoride (F)		31		.25	.01	.22	.05	1.04	.06	1.15	-	-
Nitrate (NO_3)		0.00		6.1	.09	.558	.004	.25	.004	.25	-	-
Sum anions					5.10		15.36		15.31		6.49	
Dissolved solids		1200		302		276		1069		1072		426
Specific conductance		1665		460		500		1430		1410		650
pH		-		-		7.8		-		7.8		8.5
Hardness (Ca, Mg)						153		520		5200		115
Hardness, noncarbonate						-		338		34.35		-
Percent sodium (Na)						40		32		32		63
Sodium absorption ratio						1.62		2.12		2.17		3.64

Source	Yellow House Dam Site: Drill Hole #6		Yellow House Dam Site: Drill Hole #7		Village of Zuni Well No. 4		Sampled during pumping test					
Location	Sec. 11, T. 10 N., R. 18 W.						Well 245' deep					
Remarks	Qal ?		Qal?		Sampled after bailing test @ 160'		t = 5 min		t = 60 min		t = 727 min	
Date Sampled	8-11-71		8-19-71		11-28-67		12-5-67		12-5-67		12-5-67	
Date Received by Lab	8-13-71		8-20-71		11-28-67		12-15-67		12-15-67		12-15-67	
Date Analysis Complete	8-19-71		9-7-71		12-6-67		12-22-67		12-22-67		12-22-67	
Laboratory	BIA		BIA		BIA		BIA		BIA		BIA	
Lab No.	72-Z-74		72-Z-85		68-PH-251		68-PH-272		68-PH-273		68-PH-274	
	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
Silica (SiO_2)					6.08	231.28	-	-	-	-	-	-
Boron (B)		-		-		0.43	-	.35	-	.35	-	0.43
Iron (Fe)	-	0.03	-	-	.006	.110	.008	0.140	.008	.140	.008	.140
Calcium (Ca)	2.60	52.10	2.05	41.08	.75	15.03	.90	18.04	.90	18.04	.85	17.03
Magnesium (Mg)	.50	9.73	.65	7.90	.05	.61	.20	2.43	.50	6.08	.40	4.86
Sodium (Na)	5.32	122.31	6.36	146.22	11.96	274.96	14.24	327.38	13.66	314.04	13.50	310.37
Potassium (K)	-	-	Trace	Trace	.020	.78	.022	.86	.021	.82	.021	.82
Sum cation	8.72		9.06		12.79		15.37		15.09		14.78	
Phosphorus (P)	-	-	-	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Bicarbonate (HCO_3)	4.04	246.52	3.14	191.60	8.69	530.26	9.75	594.95	9.66	589.45	8.90	543.08
Carbonate (CO_3)	.46	13.80	Trace	Trace	Trace	Trace	1.30	39.01	1.19	35.71	1.15	34.51
Sulfate (SO_4)	4.07	195.48	5.20	249.76	1.33	63.88	2.18	104.71	1.94	93.18	1.92	92.22
Chloride (Cl)	.63	22.34	.90	31.91	2.53	89.71	2.80	99.29	2.96	104.96	2.74	97.16
Fluoride (F)	-	-	.04	.68	.013	.25	.018	.35	.018	.35	0.13	.25
Nitrate (NO_3)	-	-	-	-	.006	.37	.017	1.05	.021	1.30	.021	1.30
Sum anions	9.20		9.28		12.57		16.07		15.79		14.74	
Dissolved solids		561		570		716		866		868		818
Specific conductance		870		900		1250		1440		1400		1350
pH		8.3		8.3		8.5		8.0		7.9		7.9
Hardness (Ca, Mg)		170		135		40		55		70		63
Hardness, noncarbonate		-		-		-		-		-		-
Percent sodium (Na)		61		70		94		93		91		91
Sodium absorption ratio		4.08		5.47		18.91		19.20		16.32		17.08

Appendix 7—*Drillers' logs of water wells*
Pueblo of Zuni, New Mexico

Well No. R.W.P. Z-25 sec. 2, T. 8 N., R. 17 W., Alt. 7353

From	To	
0	20	Yellow sandstone
20	30	Blue shale
30	40	Shale and coal
40	170	Gray shale
170	190	Yellow sandstone
190	200	Gray shale
200	495	Gray sandy shale; small amount of water @ 255'
495	520	Gray sandstone
520	570	Blue shale
570	600	Gray sandstone
600	715	Blue sandy shale
715	800	Light gray sandstone
800	805	Buff sandstone
805	840	Gray sandstone
840	850	Buff sandstone; small amount of water @ 850'
850	1000	Gray sandstone
1000	1175	No record

Well E. C. W. No. 7 sec. 24, T. 8 N., R. 18 W., Alt. 7213

0	23	Black clay
23	65	Gray shale
65	75	Gray sandstone
75	97	Brown sandy shale
97	105	Gray sandy shale
105	145	White sandy shale
145	160	White sandstone
160	170	Gray sandstone
170	174	Black shale
174	185	Gray sandstone
185	205	White sandstone
205	225	Gray sandstone
225	385	Red sandstone
385	400	Brown sandstone
400	503	Red sandstone
503	520	Brown sandstone
520	585	Light brown sandstone
585	630	Red sandstone, water
630	736	Brown sandstone
736	1380	Layers red clay and soft shale
1380	1395	Brown sandstone
1395	1431	Gray and brown sandstone
1431	1460	Brown shale hard

2

Appendix 7—*Drillers' logs of water wells*
Pueblo of Zuni, New Mexico (continued)

Well E.C.W. No. 4 sec. 4, T. 8 N., R. 19 W., Alt. 6881

From	To	
0	45	Sandy fill
45	99	Soft red sandstone, seep
99	187	Red clay
187	395	Red shale
395	398	White sandstone, soft, seep
398	420	Red shale
420	422	Red sandstone, soft
422	493	Red shale
493	553	Red sandstone, laminated, water
553	590	Red sandstone, soft

Well E.C.W. No. 5 sec. 12, T. 8 N., R. 19 E., Alt. 7323

0	8	Brown sandy soil
8	16	Light brown sandstone
16	35	Gray sandy shale
35	220	Light brown sandstone
220	250	White sandstone
250	425	Light brown sandstone
425	470	Red sandstone
470	811	Red shale and clay
811	826	Brown sandstone
826	1005	Brown conglomerate
1005	1045	Chocolate shale
1045	1085	Chocolate sandstone
1085	1100	Brown and gray sandstone, water
1100	1115	Brown sand shale

Well E.C.W. No. 18 sec. 22, T. 8 N., R. 19 W., Alt. 6741

0	35	Red bed clay
35	55	Lighter red clay, sandy
55	95	Light red and little sandy clay
95	105	No report
105	120	Pink clay
120	180	Red sandrock, hard
180	200	Brown sandstone
200	210	Brown shale
210	220	Pinkish shale
220	225	White gray shale
225	300	Dark gray shale
300	320	Light brown shale
320	345	No report
345	370	Brown shale
370	375	No report
375	395	Brown shale
395	400	Gray shale
400	410	White sandrock

Appendix 7—*Drillers' logs of water wells Pueblo of Zuni, New Mexico* (continued)

Well E.C.W. No. 18 sec. 22, T. 8 N., R. 19 W., Alt. 6744 (continued)

From	To	
410	440	Pink shale
440	445	Black hard shale
445	450	Hard bentonitic, light tan
450	460	White sandrock
460	470	Light brown clay
470	480	Dark brown shale
480	495	White sandstone
495	500	Chalk-like substance

Well R.W.P. Z-35 sec. 4, T. 8 N., R. 20 W., Alt. 6360

0	4	Topsoil
4	55	Sand rock
55	90	Brown shale sand rock sheets
90	150	White shale
150	165	Brown shale
165	170	Gray sand; 3 gpm
170	300	Red shale
300	330	Brown shale
330	336	Limestone sheets
336	355	Red shale
355	385	Gray shale
385	425	White shale
425	460	Brown shale
460	480	White shale
480	485	Brown sand; 5 gpm
485	515	Red shale

Well E.C.W. No. 8 sec. 19, T. 9 N., R. 17 W., Alt. 7185

0	2	Yellow sand
2	12	Yellow sandstone
12	95	Dark gray shale
95	110	Light gray sandstone
110	205	Vari-colored sandstone
205	235	Light brown sandstone
235	270	No record
270	490	White sandstone
490	550	Light brown sandstone
550	560	Light red sandstone; water
560	625	Light brown sandstone
625	660	Greenish white sandstone

Appendix 7—*Drillers' logs of water wells Pueblo of Zuni, New Mexico* (continued)

Well R.W.P. Z-33 sec. 19, T. 9 N., R. 19 W., Alt. 6914

From	To	
0	3	Topsoil
3	85	Sand rock
85	105	Sand rock hard
105	155	Sand rock, 1-1/2 gpm
155	365	Red shale
365	400	Sand-making water, 15 gpm

Bowman Peywa Well sec. 8, T. 9 N., R. 20 W.

From	To	
0	47	Surface sand
47	147	Sand and clay
147	235	Red clay
235	240	Brown sandstone
240	305	Red and purple clay
305	310	White sandy clay
310	352	Red clay

Well E.C.W. No. 3 sec. 32, T. 9 N., R. 20 W., Alt. 6280

From	To	
0	55	Light pink shale
55	132	Pink shale
132	144	Reddish brown sandstone
144	159	Pink shale
159	239	Light green shale with green specks
239	249	Red conglomerate sandstone
249	469	Pink shale
469	479	Red shale with small pebbles
479	489	Red and green shale
489	497	Gray sandstone
497	507	Pink sandstone; water
507	542	Gray sandstone, hard
542	552	Pink sandstone, hard

Well E.C.W. No. 2 sec. 11, T. 9 N., R. 21 W., Alt. 6287

From	To	
0	175	Alluvium fill
175	318	Sand with black pebbles
318	389	Red beds shale
389	405	Hard red sandstone; water
405	430	Red sandstone, soft
430	475	Red clay

Appendix 7—*Drillers' logs of water wells*
Pueblo of Zuni, New Mexico (continued)

Well E.C.W. No. 22 sec. 10, T. 10 N., R. 17 W., Alt. 6811

From	To	
0	3	Surface soil
3	40	Sandstone gray
40	55	Shale dark
55	98	Shale light
98	103	Shale dark
103	121	Shale light gray
121	125	Sandy shale yellow
125	165	Shale gray
165	205	Sand gray
205	213	Shale blue dark
213	248	Sand gray hard
248	252	Shale gray
252	260	Sandy shale gray
260	272	Sand gray
272	282	Sandstone gray

Well E.C.W. No. 6 sec. 35, T. 10 N., R. 17 W., Alt. 6912

0	60	Sandy soil
60	100	Sandstone, yellow
100	115	Sandstone, blue
115	565	Shale
565	580	Sandstone, blue
580	610	Sandy shale and clay, blue
610	635	Sandstone, blue
635	683	Gray sandstone, muddy
683	688	Shale, black
688	712	Sandstone, gray

Well E.C.W. No. 17 sec. 22, T. 10 N., R. 18 W., Alt. 6595

0	44	Sand fill, little silt
44	46	Sand rock
46	51	Sandstone
51	70	Light red sandstone
70	98	Hard red sandstone
98	112	Gray sandstone making water (20 gpm)

Black Rock Test Hole #1 sec. 24, T. 10 N., R. 19 W.

0	12	Blow sand
12	14	Lava
14	16	Sand, 6 gpm
16	20	Clay and sand
20	25	Water, 1-1/2 gpm
25	30	Sandy shale
30	50	? stone, 30 gpm
50	60	Hard red sandstone

Black Rock Test Hole #1 sec. 24, T. 10 N., R. 19 W. (continued)

From	To	
60	100	Red mudstone
100	110	Purple sandstone
110	155	Red sandstone
155	173	Red shale
173	175	Hard purple sandstone
175	177	Red shale

Black Rock Test Hole #2 sec. 24, T. 10 N., R. 19 W.

0	100	Silt and sand
100	102	Hard sandstone
102	110	Soft sandstone
110	120	Hard sandstone
120	127	Sand
127	130	Hard sandstone
130	150	Medium hard, drills like shale
150	172	Shale

Black Rock Well No. 2 sec. 24, T. 10 N., R. 19 W., Alt. 6454

0	25	Sand
25	60	Gray clay
60	68	Red clay
68	75	Red sandstone
75	80	Red clay
80	100	Red shale
100	120	Red clay
120	148	Sandstone
148	360	Red clay shale
360	370	Hard gray shale
370	450	White and purple clay and shale
450	472	Hard sandy shale
472	820	Shale red, brown, purple
820	860	Hard limestone? shell?
860	900	Gray limestone broken
900	910	Pale pink sandstone
910	1060	Hard pink sandstone (used 4 bits)

Black Rock Well No. 3 sec. 24, T. 10 N., R. 19 W., Alt. 6350

0	11	Soil
11	18	Conglomerate
18	46	Lava
46	56	Brown sand rock
56	66	Conglomerate
66	118	Red clay
118	121	Gray clay

Appendix 7—*Drillers' logs of water wells*
Pueblo of Zuni, New Mexico (continued)

Black Rock Well No. 3 sec. 24, T. 10 N., R. 19 W., Alt. 6350 (continued)

From	To	
121	178	Soft red clay
178	196	Hard red rock
196	265	Soft red shale
265	277	Hard red rock
277	280	Hard red and brown rock
280	364	Hard red rock with streaks of black
364	437	Red shale
437	447	Hard gray shale
447	454	Coarse gray sand rock, some water
454	460	Red shale
460	470	Hard red sandstone
470	524	Red gray shale
524	548	Red sandstone, poor porosity, very fine
548	570	Gray shale
570	593	Red sand rock, very fine (poor porosity)
593	605	Red and gray sandy shale
605	644	Red shale with streaks of red rock
644	650	Hard red rocks
650	688	Red sandstone, very fine grained
688	697	Red shale
697	725	Red sandy shale
725	733	Red and gray sandstone
733	735	Hard red rock with streaks of limestone
735	751	Hard red rock with very fine black specks
751	804	Red streaks of soft shale
804	812	Small red rock [water sand]
812	830	Red shale
830	859	Red and gray sandstone
859	868	Red sandstone mixed with red clay
868	890	Gray sand rock
890	898	Red and pink sandstone
898	904	Red shale
904	932	Blue and red sticky shale

Leo Nostacio Well sec. 30, T. 10 N., R. 19 W., Alt. 6275

0	147	Blow sand
147	152	Gray sand, water

Village of Zuni Well No. 4 sec. 28, T. 10 N., R. 19 W., Alt. 6274

0	35	Red clay
30	65	Red sandy clay
65	110	Blue sandy clay
110	115	Brown sand and clay
115	155	Red shale
155	175	Sand layers
175	210	Red shale

Appendix 7—*Drillers' logs of water wells Pueblo of Zuni, New Mexico* (continued)

Village of Zuni Well No. 4 sec. 28, T. 10 N., R. 19 W., Alt. 6274 (continued)

From	To	
210	275	Red shale with blue
275	285	Red shale very little blue
285	300	Red shale with blue and some sandstone grains
300	330	Red shale
330	385	Red shale with blue specks
385	420	Gray blue sandy shale
420	555	Red shale
555	570	Red shale and gray shale with some sandstone grains
570	600	Gray sandstone--water bearing
600	605	Gray sandstone
605	613	Gray sandstone with 1-5% black grains of sandstone
613	615	Shale

Well Irrigation No. 1 sec. 18, T. 10 N., R. 20 W., Alt. 6502

0	170	Sandy loam
170	181	Light gray sand hard
181	202	Light pink sand, soft, water
202	204	Red shale sand, soft, water

Well @ Bossom's Place sec. 22, T. 10 N., R. 20 W., Alt. 6345

0	50	Sand
50	85	Sand, some water @ 80'
85	90	Sand
90	95	Shale
95	102	Shale

Well E.C.W. No. 9 sec. 33, T. 10 N., R. 20 W., Alt. 6331

0	90	Brown sandy loam
90	100	Red sandstone
100	175	Red shale
175	215	Red conglomerate sandstone
215	242	Red clay, sticky
242	350	Red clay and shale
350	460	Red shale with green specks
460	472	Vari-colored shales
472	505	Red shale
505	530	Red sandstone, laminated
530	535	Gray sandstone, hard
535	574	Gray sandstone, porous, water
574	575	Gray quarzite, very hard

Appendix 7—*Drillers' logs of water wells*
Pueblo of Zuni, New Mexico (continued)

Well R.W.P. Z-30 sec. 1, T. 10 N., R. 21 W., Alt. 6662

From	To	
0	110	Sand
110	200	Sandy shale
200	280	Sand
280	300	Sandy shale
300	305	Sand rock
305	420	Shale
420	490	Sandy shale
490	510	Sand rock
510	520	Shale
520	530	Sand
530	545	Sandy shale
545	551	Sand

Well R.W.P. Z-24 sec. 23, T. 10 N., R. 21 W., Alt. 6596

0	55	Sand loose
55	85	Dry loose sand
85	205	Sand loose
205	252	Soft white sandstone
252	346	Soft gray sandstone
346	383	Yellow sandstone
382	436	Loose sand
436	463	Loose sand, quick sand, water
463	480	Red shale

Well R.W.P. Z-28 sec. 8, T. 11 N., R. 16 W., Alt. 7046

0	4	Topsoil
4	40	Brown shale
40	70	Blue shale
70	81	Gray sand, water
81	105	Gray shale, 7 gpm

Recreation Well sec. 5, T. 11 N., R. 17 W.

0	2	Topsoil
2	15	Brown shale
15	45	Yellow sandstone
45	60	Gray shale
60	90	Yellow sandstone
90	105	Gray shale
105	115	Yellow sandstone
115	125	Gray shale, some coal
125	130	Gray sandstone
130	135	Gray, shale, some coal
135	160	Gray sandstone
160	190	Gray shale, some coal

Appendix 7—*Drillers' logs of water wells*
Pueblo of Zuni, New Mexico (continued)

Recreation Well sec. 5, T. 11 N., R. 17 W. (continued)

From	To	
190	215	Gray sandstone
215	240	Sand rock
240	245	Sandstone, 1 gpm
245	280	Sandstone
280	330	Gray shale
330	345	Gray sandstone
345	350	Shale
350	365	Sandstone
365	370	Coal
370	375	Gray shale
375	380	Coal
380	390	Gray shale
390	400	Sandstone
400	410	Shale
410	435	Sandstone, 5 gpm
435	450	Sandstone, 8 gpm

Well E.C.W. No. 14 sec. 24, T. 11 N., R. 17 W., Alt. 6947

0	5	Brown sandstone
5	18	Yellow clay
18	23	yellow sandstone
23	28	Yellow sandstone
28	58	Blue shale
58	68	Brown shale
68	95	Gray sandy shale
95	105	Sand gray
105	117	Gray sand, water
117	120	Gray sandy shale
120	125	Blue shale, sticky
125	150	Blue shale
150	158	White sand
158	168	Red sand
168	187	Red sandstone
187	210	Light red sand
210	237	Sandy shale gray
237	246	Sandstone gray
246	258	Sandstone pink, water
258	265	Sandy shale gray
265	275	Blue shale
275	280	Sandy shale brown
280	286	Brown shale
286	292	Sandy shale gray
292	300	Blue shale
300	312	Blue sandy shale
312	340	Blue sticky shale
340	376	Gray sandy shale
376	380	Lime shell gray
380	411	Sandy shale gray
411	425	Blue shale
425	438	Gray shale

Appendix 7—*Drillers' logs of water wells Pueblo of Zuni, New Mexico* (continued)

Well E.C.W. No. 10 sec. 29, T. 11 N., R. 17 W.

From	To	
0	5	Sandy loam
5	44	Adobe
44	54	Yellow clay
54	60	Coal and blue shale, seep
60	90	Gray sandstone, seep
90	130	Blue gray shale
130	180	Gray sandy shale, some water
180	260	Black and gray shale
260	390	Dark gray shale
390	675	Very dark gray shale
675	680	Gray sandstone
680	695	Limestone
695	715	Limestone, thin layers with shale, water
715	760	Sandstone

Well E.C.W. No. 1 sec. 21, T. 11 N., R. 18 W., Alt. 6726

0	45	Sandy fill
45	63	Blue gray shale
63	69	Hard gray sandstone
69	72	Hard gray shale
72	75	Hard brown sandstone
75	81	Soft brown sandstone, water
81	121	Light red shale and sandstone
121	123	Black shale
123	127	Fire clay
127	144	Green and white shale
144	175	Green and white sandy shale
175	203	Gray sandy shale
203	208	Hard brown sandstone
208	230	Brown sandstone with white crystals, water
230	315	Light brown sandstone
315	330	Lighter brown sandstone
330	335	White sandstone, water
335	345	Light brown sandstone

Well R.W.P. Z-34 sec. 27, T. 11 N., R. 18 W., Alt. 6641

0	4	Topsoil
4	20	Sand rock
20	130	Gray shale
130	140	Black shale
140	185	Gray sand, 20 gpm
185	220	Sand

Appendix 7—*Drillers' log of water wells Pueblo of Zuni, New Mexico* (continued)

Oil Test Carter Oil Co. Santa Fe No. 2
sec. 17, T. 11 N., R. 19 W., Alt. 6800±

From	To	
0	270	Red rock or shale
270	?	Sandstone, brown, soft
?	1006	Sandy, shale, red, soft, water
1006	1015	Sand brown
1015	1020	Shale, red
1020	1100	Lime, blue
1100	1355	Sand, gray
1355	1360	Shale, red
1360	1365	Sand, pink
1365	1550	Shale, red
1550	1565	Lime, blue
1565	1575	Sand, brown
1575	1620	Shale, red
1620	1630	Lime, blue
1630	1980	Shale or red rock

Well R.W.P. Z-36 sec. 27, T. 11 N., R. 20 W., Alt. 6629

0	30	Sand
30	50	Sand and clay layers
50	248	Sand rock

Well Irrigation No. 2 sec. 31, T. 11 N., R. 20 W., Alt. 6590

0	6	Surface soil
6	47	Sand and clay (gray)
47	75	Sand and clay
75	270	Sand
270	380	Red shale
380	405	Pink shale hard
405	575	Red shale
575	580	No report
580	642	Red shale
642	650	Red sandy shale
650	668	Sand, water

Sam Pablano Well sec. 2, T. 12 N., R. 16 W.

0	20	Clay and sand
20	30	Sand and rock
30	80	Red bed and shale
80	170	Gumbo and shale
170	180	Red bed, gumbo, and shale
180	190	Shale, fine sand, and red bed
190	225	Sandstone, shale, and red bed
225	230	Lime and shale

Appendix 7—*Drillers' logs of water wells*
Pueblo of Zuni, New Mexico (continued)

Sam Pablano Well sec. 2, T. 12 N., R. 16 W. (continued)

From	To	
230	250	Lime and shale, hard
250	255	Lime, shell and streak
255	280	Shale
280	285	Streaks of lime and shale
285	290	Shale
290	298	Lime, hard
298	305	Limestone
305	325	Heavy shale, shallow streaks lime, stone, and clay
325	335	Shale and lime, clay
335	340	Sand, shale, lime
340	350	Shale, lime, clay
350	360	Red bed
360	375	Red bed and lime
375	380	White clear rock
380	410	Sandstone
410	416	Water and some stuff, pretty fair stock well
416	420	Same stuff
420	423	Red sand and rock

Well E.C.W. No. 16 sec. 15, T. 12 N., R. 17 W., Alt. 6905

0	4	Soil
4	30	Yellow clay
30	65	Blue shale
65	96	Sandstone
96	112	Lime
112	120	Blue shale
120	132	Water sand
132	152	Sandy shale
152	193	Blue shale
193	197	Brown sandy shale
197	201	Gray shale
201	218	Blue shale
218	222	Gray shale
222	231	Blue shale
231	254	Gray sandy shale
254	260	Sandy shale
260	275	Lime
275	280	Blue shale
280	285	Lime
285	290	Blue shale
290	295	Gray shale
295	325	Water sand
325	331	Hard sandy lime
331	340	Hard sandy shale
340	357	Gray sand
357	367	Shale
367	380	Sandy lime shale, 3-1/2 gpm

Appendix 7—*Drillers' logs of water wells*
Pueblo of Zuni, New Mexico (continued)

Well E.C.W. No. 16 sec. 15, T. 12 N., R. 17 W., Alt. 6905 (continued)

From	To	
380	423	Blue shale
423	430	Brown shale
430	450	Blue shale
450	455	Dark brown shale
455	465	Gray shale
465	480	Broken shells and sand
480	495	Brown shale
495	500	Gray shale
500	505	Blue shale
505	520	Brown shale
520	535	Gray shale
535	546	Shell and shale
546	554	Sand
554	565	Gray shale
565	594	Blue shale, 5 gpm

Well R.W.P. Z-29 sec. 29, T. 12 N., R. 16 W.

From	To	
0	40	Brown shale
40	78	Gray shale
78	90	Gray sand rock, 2 gpm
90	94	Gray sand rock, 3 gpm
94	202	Gray shale
202	209	Brown sand
209	228	Gray shale, 6 gpm

PLATE 1

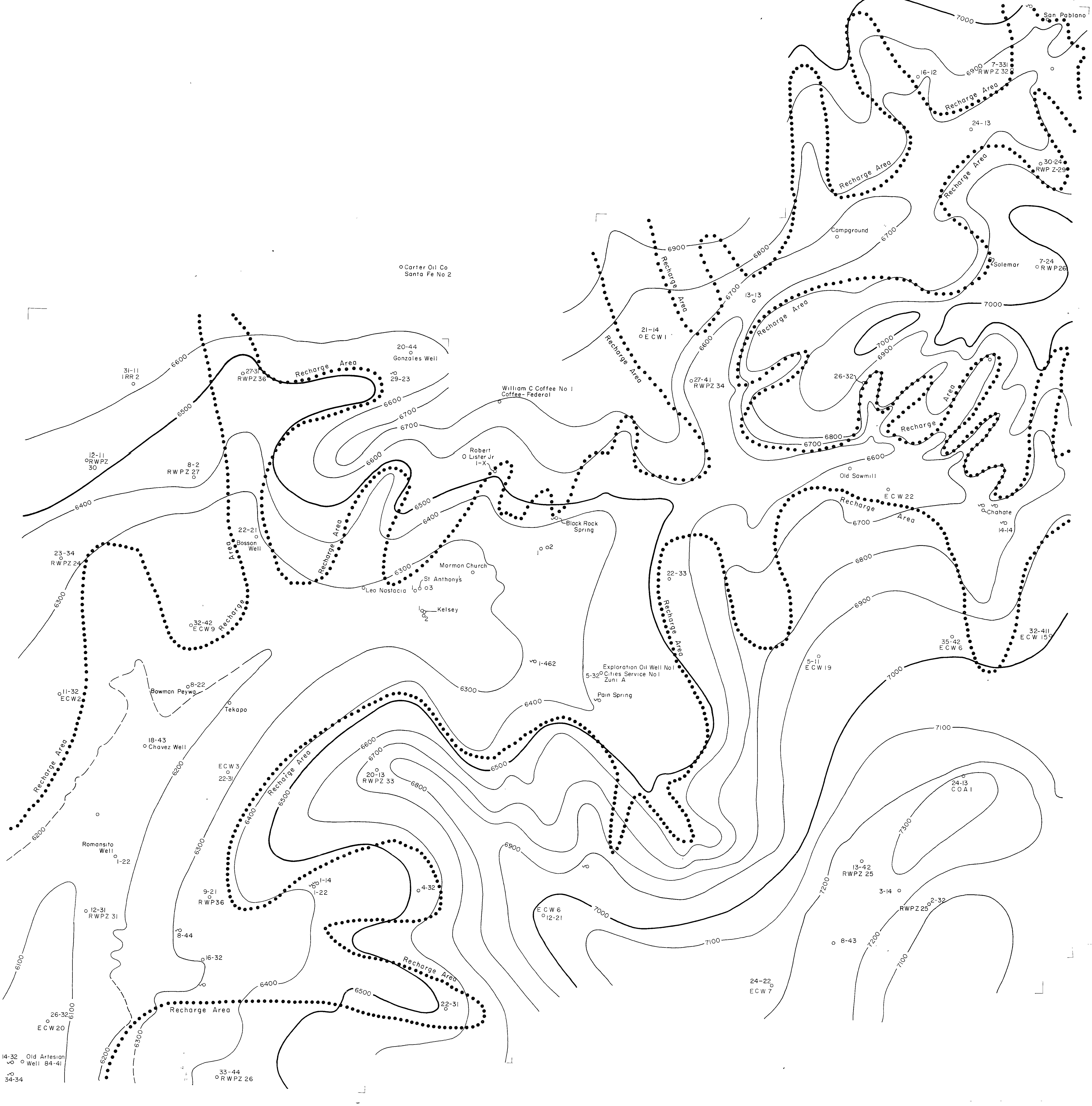


PLATE 1—Well and spring locations and water table contours of Zuni Pueblo

PLATE 2

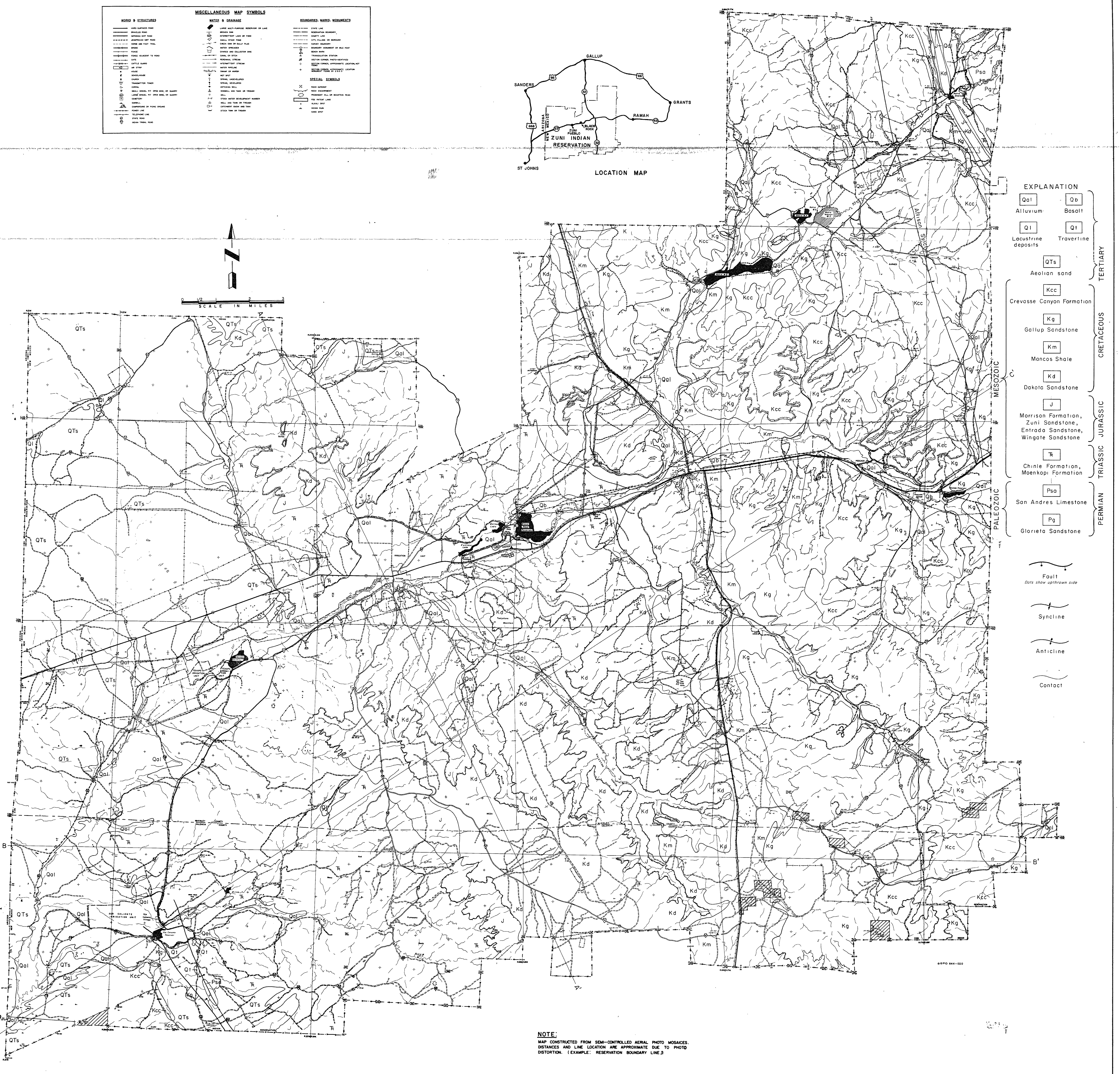


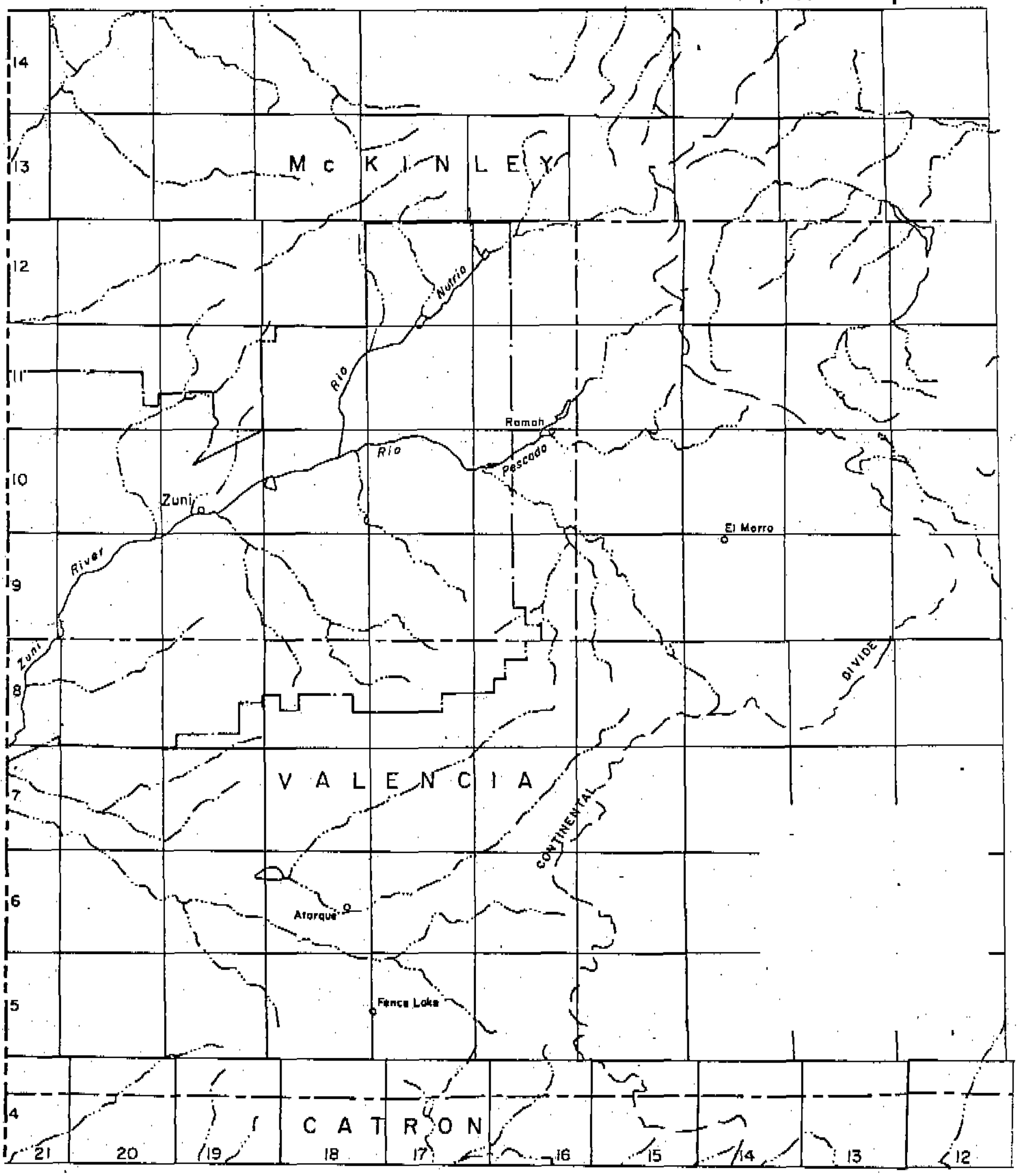
PLATE 2— Outcrop pattern of hydrogeologic units and major geologic structures of Zuni Pueblo

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF INDIAN AFFAIRS
ZUNI INDIAN RESERVATION
1970

PLATE 3

A
A'
McKinley Co.
Valencia Co.
B B'
C C'
Zuni River
Village of Zuni
Kd
QTs
J
Qal
Ꞧ
Psa
Pg
Yeso Formation
Abo Formation
Precambrian
granite and quartzite
Altitude (feet)
7000
6000
5000
4000
3000
B
B'
Zuni River
A-A'
Galestina Canyon
Kcc
Kg
Km
8000
2000
C
Ojo Caliente Fault
Ojo Caliente Reservoir
Ojo Caliente Anticline
Pinon Springs Anticline
Mullen Canyon
Galestina Canyon
Fractured zone in the Zuni Sandstone
Cheama Canyon
Horsehead Canyon
Rio Pescado
Pescado Canyon
Allison Syncline

PLATE 4



14
13
12
11
10
9
8
7
6
5
4
M c K I N L E Y
Rio Nutria
Rio
Ramah
Rio Pescado
Zuni
Zuni River
El Morro
CONTINENTAL DIVIDE
V A L E N C I A
Atarque
Fence Lake
C A T R O N
21
20
19
18
17
16
15
14
13
12