GROUNDWATER CIRCULATION IN THE SOCORRO GEOTHERMAL AREA*

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ABSTRACT

Thermal springs at Socorro, New Mexico, issue from fractures in a Miocene complex of continental sediments and volcanics where these strata have been upfaulted against Miocene fill of the Rio Grande graben. A pronounced geothermal anomaly exists in the area underlain by the volcanics. In order to establish the relation of these springs to the regional groundwater system, a systematic study of springs and wells was undertaken. Tritium activity and major chemical constituents were measured and mapped. Deuterium and oxygen-18 were determined in 17 selected samples of springs, groundwater, and precipitation. A watertable map was constructed. The correlation of tritium activity in groundwater with that in precipitation, and the regional distribution of tritium activity in groundwater indicate that the spring water contains a minor component of relatively fast recharge (4 years) superposed on a major component of slow recharge (>12 years). The slow component is linked to precipitation on the Magdalena range about 15 to 20 miles to the west. As the groundwater crosses the Miocene complex and its geothermal anomaly, it undergoes cation exchange, sodium for calcium. The deuterium and oxygen-18 makeup of all groundwater in the region, including the thermal springs, indicates a purely meteoric origin. This agrees also with the water quality characteristics and the geological evidence. Hence, no hydraulic connection with a deep geothermal system has been established.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGMENT

We are heavily indebted to Drs. Richard Chamberlin and Charles Chapin (N.M. Bureau of Mines and Mineral Resources) for much insight into the geology of the area. Led by Prof. Clay Smith and Mr. Richard Griego, sanitarian for the City of Socorro, we were able to visit the springs which are accessible only with difficulty through underground workings. Lynn Brandvold, chemist for the N.M. Bureau of Mines and Mineral Resources, did water quality analyses. Dave Goodrich, Paul Davis, Steve Mizell, Roger Ward, and John Beasley assisted with the collecting of water samples. The City of Socorro allowed sampling of Socorro and Sedillo Springs. Our appreciation goes especially to Messrs. James Cole, Director of Utilities, and Richard Griego, Sanitarian, for their support. We also thank the ranchers who gave consent to sample their wells and who supplied well data, notably Joyce Gaines, J. B. Kelly, Allie Strozzi, Tom Kelly, Nathan Hall, and Zeke Armijo.

The manuscript of this report was critically read by Drs. Chapin, Gelhar and Sanford who suggested many improvements. The responsibility for any errors or omissions rests with the authors.

INTRODUCTION

Purpose

With a growing interest in geothermal energy resources of the Socorro area it has become necessary to study the physical setting which will affect possible exploration and development of these resources.

Socorro and Sedillo springs contribute a major portion of the water supply for the town of Socorro. This paper will attempt to define more precisely the groundwater system contributing to these thermal springs with the aid of geological, hydrological, groundwater quality, and tritium activity and stable isotope data. An important question is whether there exists or not a hydraulic connection between the shallow groundwater system and the deep geothermal system. This study is partly an extension of the work of Holmes (1963), in which he attempted to determine groundwater residence time and approximate groundwater velocities using tritium activity in spring water and precipitation.

Physiography

The study area, a rectangular section of 247 square miles in central New Mexico, (Fig. 1), lies in the eastern portion of the Basin and Range Province. The area is typical of basin and range topography. Two north-south trending fault-block mountain ranges are bounded by alluvial fill basins. The western boundary of the area is made up by the Magdalena Mountains (Fig. 2). This westward dipping fault-block range reaches a height of about 10,900 feet on South Baldy. East of this range lies La Jencia basin which is a graben filled to an unknown depth with alluvial sediments. Physiographically, Snake Ranch Flats is the southern extension of La Jencia basin. The Flats are relatively featureless, except where dissected by major arroyos, with a gentle eastward slope, and an average elevation of 6,000 feet. The Flats are bordered on the east by the Socorro-Lemitar Mountains. This horst-block mountain range is approximately 7,200 feet high. East of this range lies the Rio Grande alluvial valley, and the town of Socorro with an elevation of 4,600 feet. The southern boundary of the study area is where the Snake Ranch Flats pinch out, and the Magdalena and Chupadera Mountains combine to form a group of hills. The northern boundary is determined on the Flats where groundwater seems to be flowing northward (into the La Jencia Creek drainage basin) away from areas which could contribute to the thermal springs.

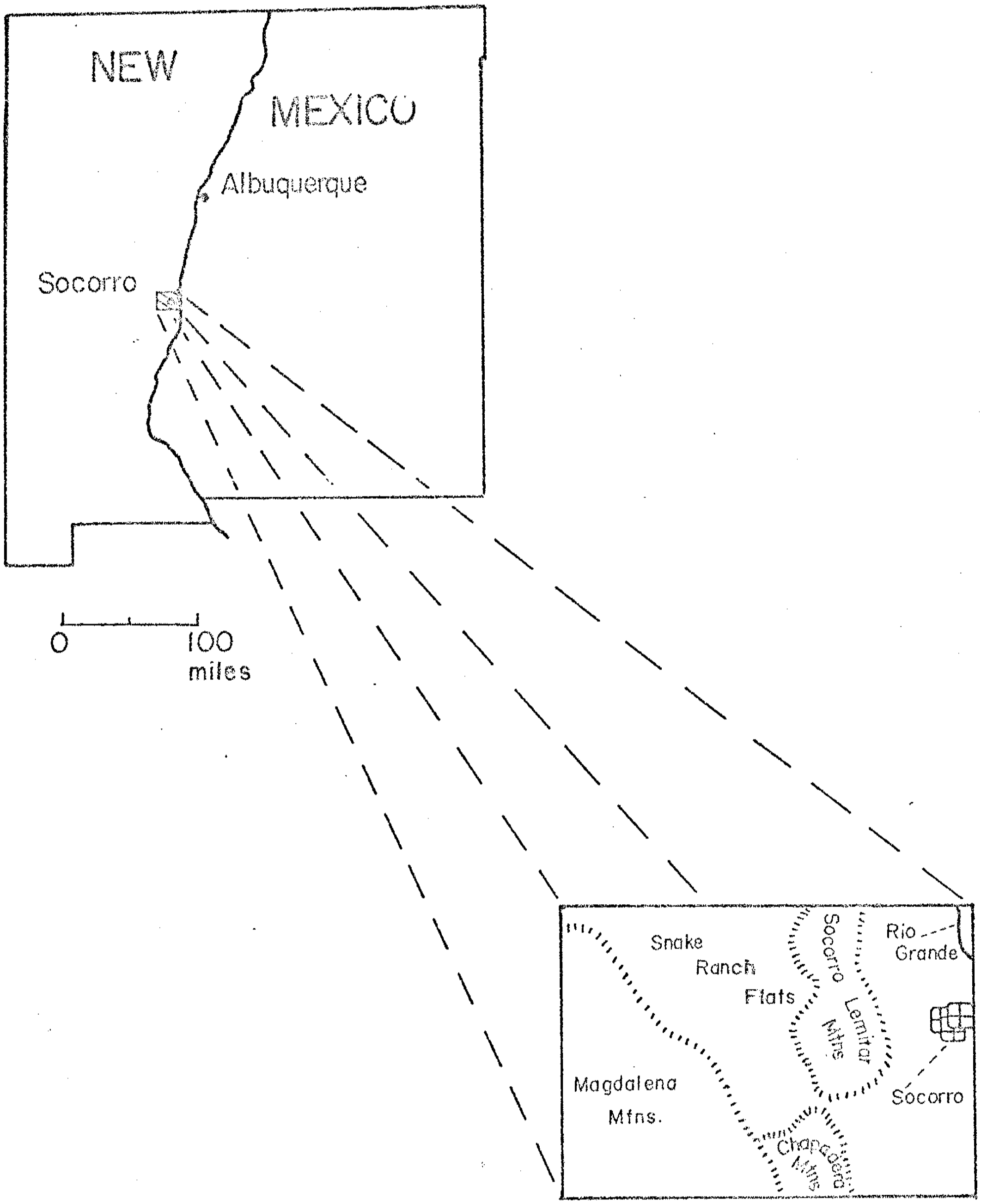

Figure 1. Location of study area.

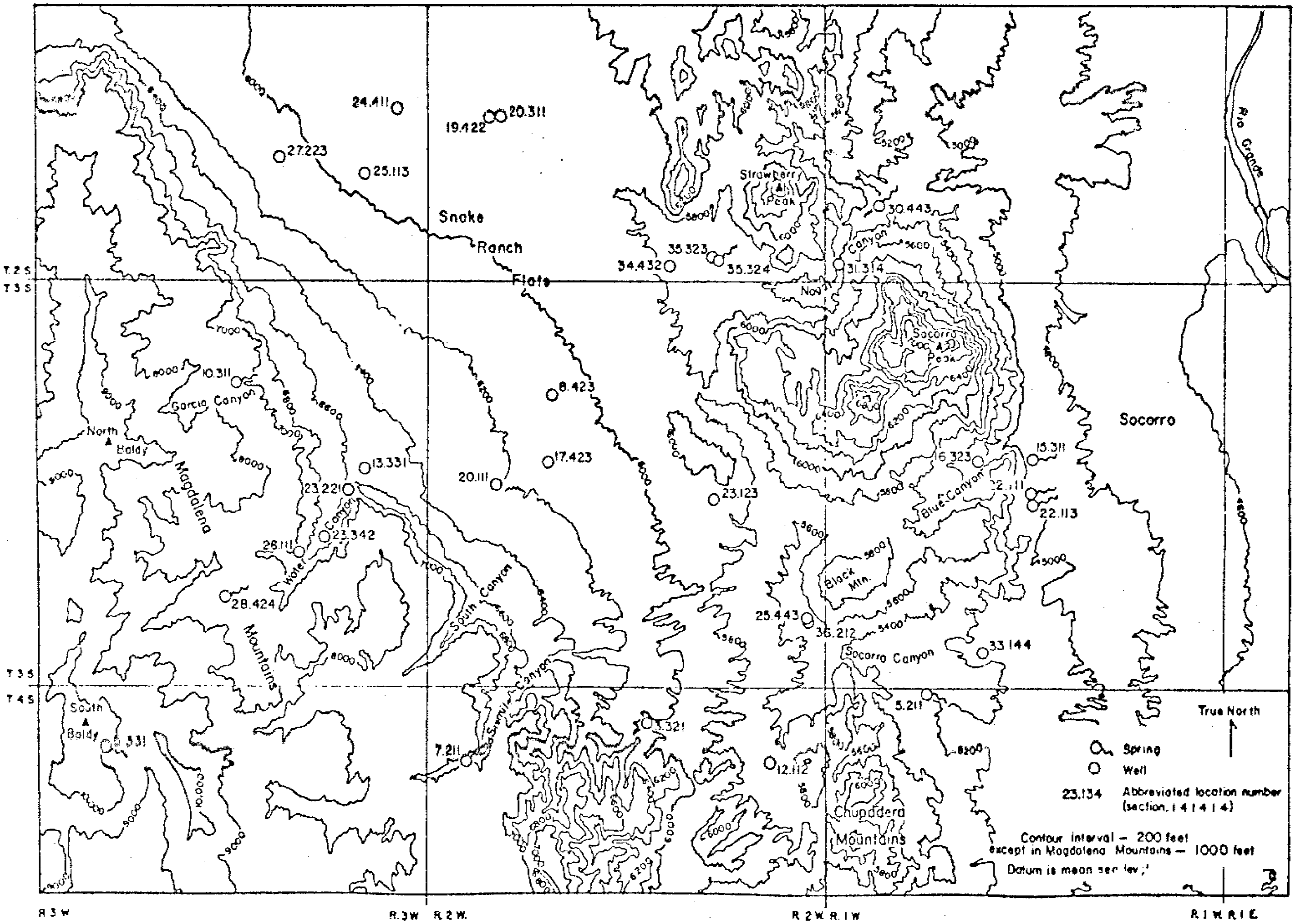

Figure 2. Physiography and sampling locations.

Setting of thermal springs

As mentioned, Socorro Mt. forms the eastern rim of the Snake Ranch Flats structural basin. It has a core of Precambrian and Paleozoic rocks but consists mainly of lower and middle Miocene continental basin sediments (Popotosa Fm.) interbedded with and overlain by upper Miocene rhyolitic domes, tuffs, and flows. This complex is intensely faulted and fractured, and to the east it is bounded by the fault system delimiting the Rio Grande graben (Chapin et al., 1978, Plate 1). The volcanic complex is characterized by an intense geothermal anomaly which, from seismic studies, is related to magma chambers at depth (Chapin et al., 1978). The thermal springs which are a main objective of this study, issue from a fracture system in this complex where it is upfaulted against basin fill. There are presently three springs, from north to south: Cook (3.1.15.311), Socorro (22.111), and Sedillo (22.113). It is the latter two which supply water to the City of Socorro. Cook Spring is nearly dry. In addition, there is Blue Canyon well (16.323) which also produces water of above-normal temperature and of dissolved solids content similar to the springs.

Surface drainage

The Magdalena Mountains drain into the Snake Ranch Flats through several major canyons which dissect the range front. Nogal Canyon and Socorro Canyon provide through-drainage for the Snake Ranch Flats into the Rio Grande Valley. Without these two canyons which cut the Socorro-Lemitar and Chupadera Mountains, the Snake Ranch Flats would be essentially a closed basin, which it probably was in the past. There are no perennial streams in the area, except the Rio Grande, and sections of arroyo channels near springs.

Climate

The climate of the area ranges from semi-arid in Socorro, 7.9 inches of precipitation per year, to alpine near the peaks of the Magdalena Mountains, 17.7 inches per annum (Romero and Wilkening, 1977). Continuous weather records are available from Socorro (4,600 ft) and Kelly Ranch (6,700 ft) in the eastern part of the study area. During the summer, records are also taken at Langmuir Laboratory, an atmospheric research facility of New Mexico Institute of Mining and Technology, which is located at 10,631 ft near the summit of Magdalena Mts on the west side of the study area(Romero and Wilkening, 1977).

Procedure

Sampling of Socorro and Sedillo springs, and analysis for tritium activity was done irregularly from 1957 to 1964. Socorro precipitation samples have been analyzed until the present, except for the period September 1968 to June 1971. The correlation of peaks in these two data sets may indicate a groundwater residence time within the aquifer contributing flow to the thermal springs.

Sampling of the thermal springs was resumed in February 1977 and Cook Spring was included. Based on previous work of Waldron (1956) and Hall (1963), a series of springs and wells within the Socorro-Lemitar Mountains, Snake Ranch Flats, and Magdalena Mountains, were also chosen for the study. Samples for tritium analysis were then collected from the group of wells and springs at intervals of about two months. The springs and wells, their location, and their characteristics are tabulated in Appendix A.

Where possible, water levels were measured to determine piezometric head distribution over the area. Where wells could not be measured, older data were used (Clark and Summers, 1971).

Chemical analyses of groundwater were performed for major ions for each well or spring being sampled for the study. In addition, there were older chemical data obtained from other references (Appendix B).

The stable isotopes deuterium and oxygen-18 were measured in 17 samples. Figure 3 shows the coordinate system used for locating springs and wells.

Geologic information has been compiled from previous work and from ongoing studies of the N.M. Bureau of Mines and Mineral Resources, notably the investigations by Charles Chapin and his co-workers (see below). Springflow rates have been furnished by the City of Socorro and SER, Inc., a local private consulting firm. Precipitation data were obtained from the U.S. Weather Service for the Socorro and Kelly Ranch stations (Climatological Data - New Mexico: National Oceanic and Atmospheric Administration. Environmental Data Service. National Climatic Center. Asheville, NC 28801). For other sources, see App. C.

Previous Investigations

Waldron (1956) sampled and described the thermal springs. Hall (1963) gave a close account of springwater quality in the Socorro area. He noted the change from predominantly calcium-

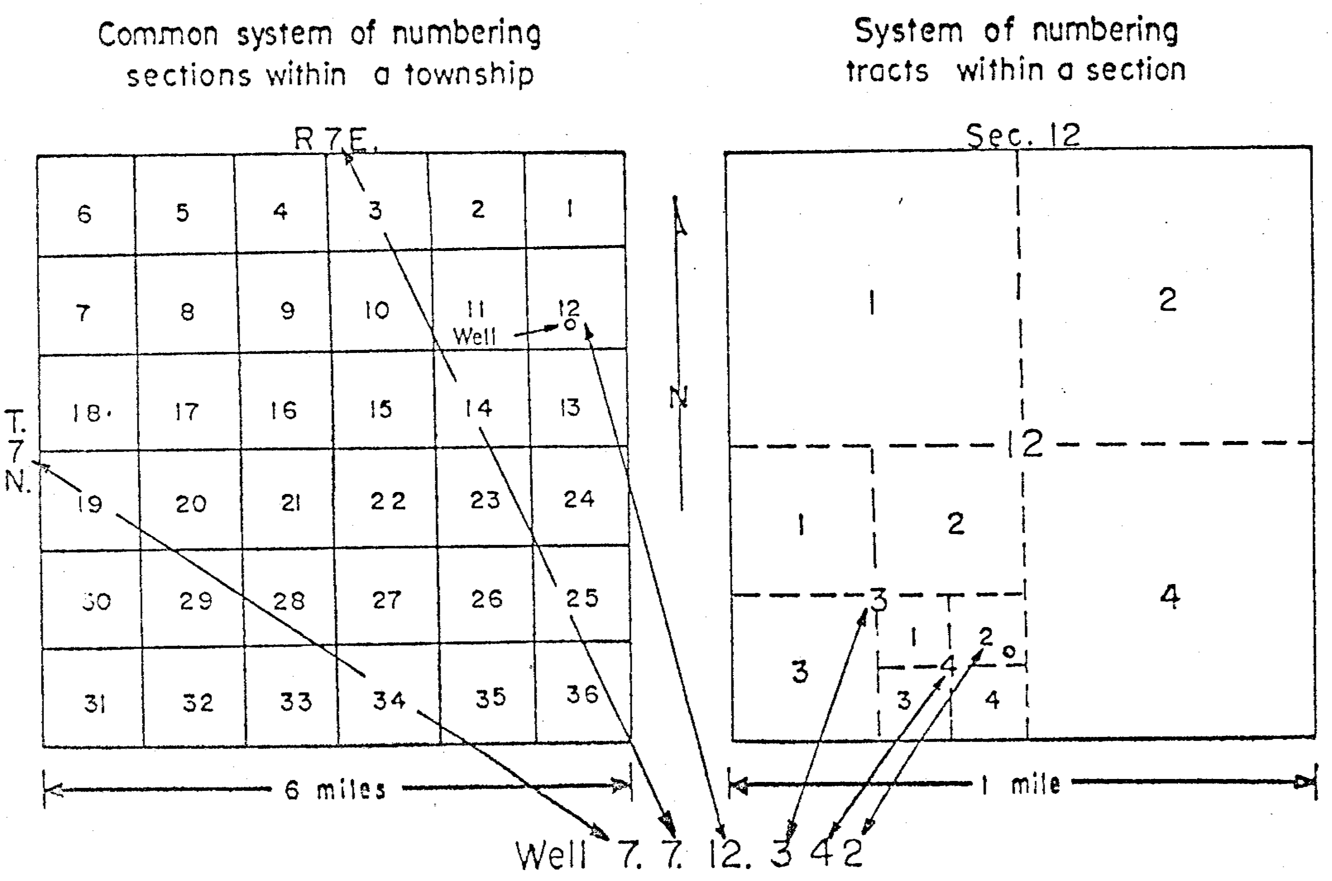

Figure 3. Coordinate system for locating springs and wells. For readability, the designations N and E (or W) are omitted throughout this report. Range and township are generally omitted in text and figures.

bicarbonate water in the western part of the study region to sodium-bicarbonate east of the Socorro-Lemitar range and attributed it to cation exchange with the Socorro-Lemitar rhyolitic volcanics. Holmes (1963) used atmospheric tritium as a tracer in an attempt to determine the residence time of spring water underground. Summers (1976) described the thermal characteristics of the springs. Denny (1940, 1941) detailed the Tertiary and Quaternary geology of the area just north of the Lemitar Mts. Machette (1978) mapped the San Acacia quadrangle and redefined the Santa Fe Group (Miocene to Pleistocene) in this area. Bruning (1973) described the Popotosa Formation in detail. Osburn (1978) mapped the western part of the study area and Chamberlin (1978) the eastern portion. Chapin et al. (1978) discussed the Socorro geothermal area in the context of regional tectonic history. They showed that the Socorro geothermal area occupies the site of an Oligocene cauldron. Their work is fundamental for an understanding of the study area. It creates the conceptual framework within which geologic, geothermal, and seismic phenomena relate to each other and to present-day groundwater circulation.

HYDROGEOLOGY

A simplified stratigraphic column and geologic map are shown in Figs. 4a and 4b.

The study area is located within the Rio Grande rift. The two fault-block mountain ranges, Magdalena and Socorro-Lemitar, consist of thick Tertiary volcanic piles with some interbedded basin fill sediments, underlain by a thin sequence of Paleozoic sedimentary rocks, and by a Precambrian basement of metasedimentary, metavolcanic, and plutonic rocks (Chapin et al., 1978, Fig. 3). The Snake Ranch Flats is a graben type feature which probably has the same sequence of rocks underlying a thick unit of Tertiary-Quaternary basin fill sediments. In outcrop, the area is characterized by dipping strata and an abundance of northwest-southeast trending normal faulting.

Through most of the Tertiary period, this area has been tectonically active with periods of intense volcanism. High degrees of fracture permeability have developed in most well indurated rocks (Chapin et al., 1978). Stratigraphic throw as a result of faulting has created very jumbled lateral relationships between rock units. All of these factors have combined to produce a geologically complicated groundwater system from which Socorro and Sedillo springs issue. Even though the system is geologically complex, the high degree of fracturing associated with the tectonism may have created relatively homogeneous intervals of permeability corresponding with depth of burial.

Since most of the water analyzed in this study was derived from basin fill sediments, lower Popotosa Formation and upper Santa Fe Group, these sediments will be considered in more detail.

Popotosa Fm. (Lower Santa Fe Group). Miocene

According to Chapin et al. (1978), the Socorro cauldron was formed about 27 m.y. ago. Its formation was related to the tectonism that created the Rio Grande graben. A potassium anomaly in volcanic rocks of the cauldron is believed to be related to the geothermal system of that time.

A broad sedimentary basin, the Popotosa basin, spanned the Rio Grande rift in the Socorro area 26 million years ago. The basin extended from the Gallinas uplift in the west to the mesas east of the Rio Grande; and from the Ladron Mountains in the north to the Magdalena and Chupadera Mountains to the southwest and southeast. The lowest part of this basin is presently occupied by the Socorro-Lemitar Mountains. From the surrounding

LEGEND

	Qa	Upper Quarternary alluvium; gravel, sand, and mud of major arroyos and of the Rio Grande valley; local alluvium and colluvium.
Santa Fe Group	QTa	Sierra Ladrones Fm. Pliocene-Pleistocene basin and valley fill; poorly consolid. piedmont-slope fanglomerates intertonguing with ancestral Rio Grande sandstone and floodplain siltstone and mudstone.
	Tb	Basalt flows of Sedillo Hill (4 m.y.); interbedded in QTa.
	Ts	Rhyolite to rhyodacite domes, flows, necks, and tuffs of Socorro Peak (12-7 m.y.); tuffs interbedded in upper Popotosa included in Tpu.
	Tpu	Upper Popotosa Fm. (upper Miocene); gypsiferous playa clays with minor intertonguing fanglomerates and channel sandstones; interbedded basalt flows.
	Tpl	Lower Popotosa Fm. (lower Miocene); indurated red mudflow deposits and fanglomerates intertonguing with minor purple-gray fanglomerates and lacustrine clays and silts.
	Ti	Intrusive rocks; silicic to andesitic stocks and dikes (Oligocene-Miocene).
	Tv	Unit of Luis Lopez. Volcanic rocks (26-20 m.y.); lithic-rich tuffs, andesite flows, and rhyolite domes. Tuff of Lemitar Mts. (27 m.y.); densely welded rhyol. ashflow tuffs. Older volcanic rocks (37-32 m.y.; lithic-andesitic conglomerates capped by densely welded rhyolite ashflow tuffs.
	P	Paleozoic limestones, shales, and sandstones (Mississippian-Pennsylvanian).
	pЄ	Precambrian granites, gabbros, diabase dikes, metavolcanic and metasedimentary rocks.

Figure 4a. Stratigraphic column and legend.

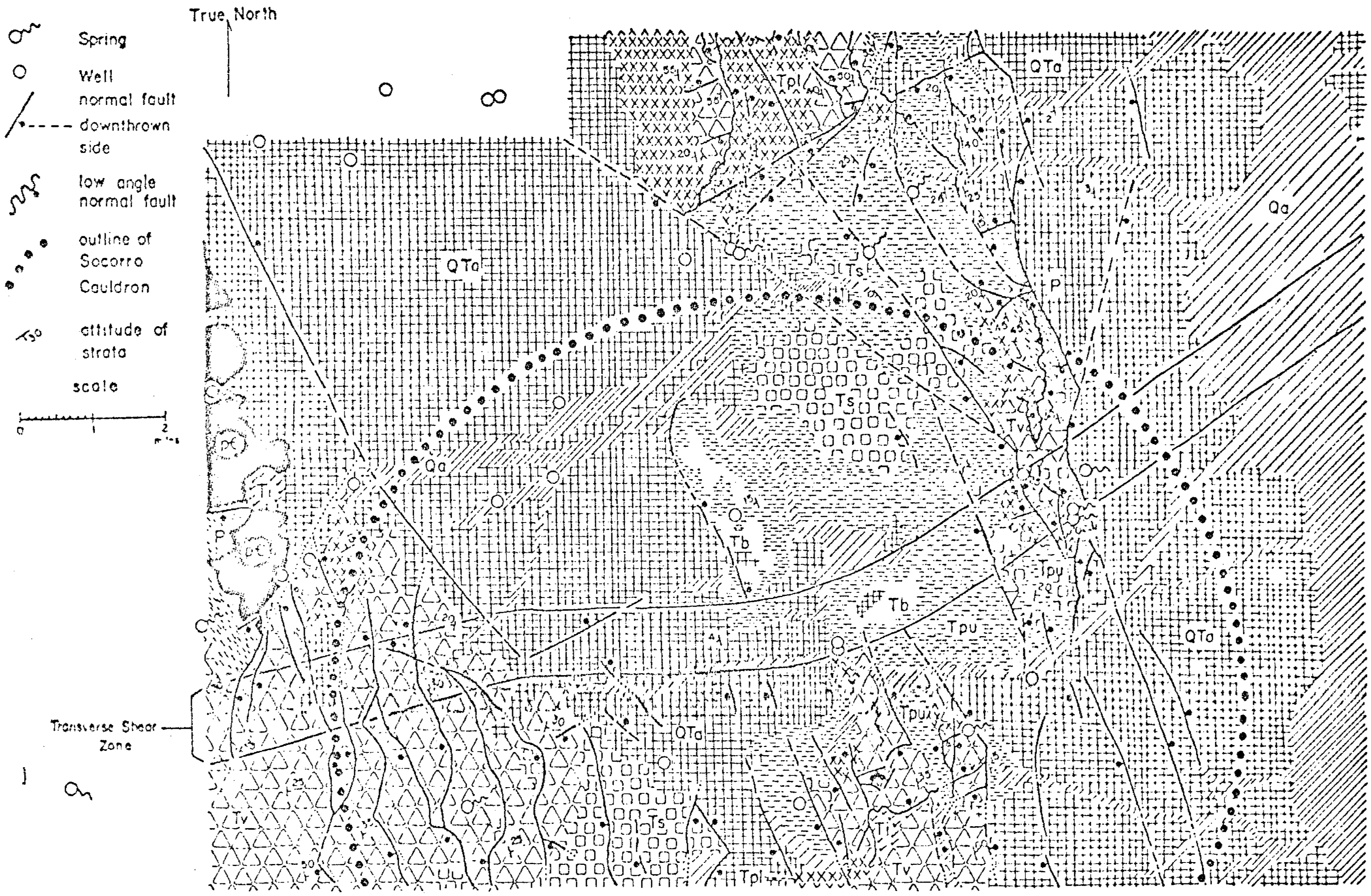

Figure 4b. Geologic map (after Chapin et al., 1978).

mountain ranges, the basin was filled by up to 1500 ft of alluvial-fan and piedmont-slope deposits (lower Popotosa) and these in turn were topped with playa lake deposits (800-2500 ft). Rhyolitic intrusions and volcanism along the northern moat of the Socorro cauldron (buried under the Popotosa basin) occurred sometime between 12 and 7 m.y. ago and spilled into and over the basin sediments.

According to Chapin and Seager (1975, Fig. 3), the Magdalena uplift was a faulted horst within the Popotosa basin prior to 10 m.y. ago. Its erosion contributed to the basin fill (Bruning, 1973; Chapin and Seager, 1975). In the Socorro Mountain area fanglomerate and playa sediments of the Popotosa Formation are intruded with and overlain by volcanic domes and flows. One flow overlying the Popotosa Formation on Socorro Peak has been dated at 10.7 million years ago. There is no evidence of any Popotosa deposition younger than the Socorro Peak volcanism.

In the Socorro area the Popotosa Formation consists of a lower member mostly of poorly sorted, well indurated fanglomerates, and some playa sediments, and an upper member of mostly gypsiferous playa silts and clays.

Sierra Ladrones Formation (Upper Santa Fe Group). Pliocene/Pleistocene

Present day structure and relief of the Socorro-Lemitar mountains was defined either contemporaneously with or shortly following the volcanism in the area (7-4 m.y. ago). The Popotosa Formation was tilted and faulted during this activity. Creation of the Snake Ranch Flats as a structural basin was accomplished by renewed uplift of the Magdalena Mountain fault block. Downwarping of the basin, and basin fill processes have gone on more or less continuously since early Miocene time.

Formation of an ancestral Rio Grande drainage system possibly occurred during the breakup of the Popotosa basin. Broad, gently sloping piedmont planes descended toward the river and were covered with granular piedmont-slope deposits, the Sierra Ladrones Fm.

The Sierra Ladrones Formation (Machette, 1978) represents the upper Santa Fe Group in the study area. It overlies the Popotosa with an angular unconformity. It consists of river channel and flood plain deposits of the ancestral Rio Grande (mainly sand), laterally intertongued with piedmont-slope fanglomerates and sands derived from the present highlands. Basalt flows (4 m.y.) are intercalated in these sediments, deformation is very much less than in the Popotosa Fm. The Sierra Ladrones Fm. is an important aquifer along the eastern flank of the Rio Grande graben in the study area.

Quarternary Sediments

Quarternary sediments on the Flats are very similar to the Upper Santa Fe Group. Waldron (1956) divided the Quarternary deposits of the Snake Ranch Flats into three groups: (1) the alluvial fans adjacent to the eastern flank of the Magdalena Mountains, and alluvium deposited in arroyos on the Flats; (2) peripediment gravels on the flanks of the Socorro-Lemitar mountains, and at the southern end of the Flats; and (3) lake sediments in the interior of the Flats.

On the east slope of the Magdalena mountains alluvial fans composed of pebbles and boulders of granite, gneiss, schist, limestone, and volcanics are set in an unconsolidated matrix of sands and silts. Waldron estimated that the thickness of the Quarternary alluvial cover varied from 100 to 400 feet over the basin. Since basin fill processes have been going on more or less continuously since the creation of the basin, it would be virtually impossible to draw the line between Upper Santa Fe Group and Quarternary alluvium. Peripediment gravels on the flanks of the Socorro-Lemitar mountains and at the southern end of the Flats are composed of volcanic pebbles, cobbles, and boulders over and in an unconsolidated matrix of sand and silt. This gravel veneer is a deflation lag deposit. The lake deposits are confined to a one square mile patch in the lowest part of the basin. They consist of red-brown silts and silty clays. There is no evidence that the lake was ever larger.

Possible Thickness of Santa Fe Group on Snake Ranch Flats

There are no wells on the Flats which penetrate the entire Santa Fe Group. The deepest well on the Flats (20.111) is 550 feet (Appendix A, Table A-I), and it does not completely penetrate the Upper Santa Fe Group. Driller's logs were located for wells 20.111, 27.223, and 20.311 (Table A-I) on the Snake Ranch Flats.

Sanford (1968) ran a gravity survey over the Snake Ranch Flats and discovered that the residual Bouguer anomalies indicated a depression nearly as deep as the Rio Grande depression. He concluded that this structure probably is the result of step faulting, and possibly tilting over a broad zone from the mountain front to near the center of the depression. Step faulting has been detected as far as two miles basinward from the fault-line scarp of the Magdalena mountains. A seismic reflecting horizon has been dropped about 100 feet in this area (Waldron, 1956, p. 96). The results of recent step faulting can be seen on the alluvial fans in the northeastern part of the Magdalena Mountains. This faulting has cut the fans along a nearly north-south trend and created a terrace 20 feet high in places. There are some anomalously high water table gradients (Waldron, 1956), as evidenced by well levels, in the northern part of the Flats. These are suspected to be the result of step faulting.

In order to determine the depth of the basin, Sanford first compiled a pre-Santa Fe Group geologic section for the basin (Sanford, 1968, Fig. 6). The section was based primarily on lithologies and thicknesses of rocks exposed in the low hills east of the Rio Grande valley. The total thickness of this section from Precambrian to the base of the Santa Fe was 8,700 feet. This was divided up into 1,000 foot sections, and percentages of sandstone, shale, limestone, and volcanics for each section were determined. These percentages were then multiplied by mean densities of each rock type, and totaled to obtain the average density for each 1,000 foot section.

Whether or not the basin actually contains the rock section he assumed, could not be ascertained with geological and geophysical data available at the time. However, detailed geological work of recent years supports the contention that the section is not all present in the Snake Ranch Flats. A broad uplift during Laramide times took place in what is now the southern part of La Jencia basin covering the area west of the Rio Grande presently occupied by Socorro Mt., Snake Ranch Flats, and the Magdalena range. This explains why the upper Permian and all of the Mesozoic are missing in the Socorro-Lemitar and in the southern Magdalena mountains (Smith, 1963; Chamberlin, personal communication). It is therefore likely that these strata are also missing in the basement of the Snake-Ranch Flats depression.

Sanford then constructed cross-sections of the basin using a simple geometric model (Sanford, 1968, Figs. 7 and 8). The faulted basin was represented as having one normal fault at each margin to reduce the labor involved in computing gravity anomalies.

To estimate the thickness of the Santa Fe Group under the Snake Ranch Flats, Sanford's model will be used, but his geologic column will be altered. The assumption is that the Abo Formation through Baca Formation (Sanford, 1968, Fig. 6) are not present in the Snake Ranch Flats depression. This is a section of 4,280 feet with a mean density of 2.41. Then, in order to arrive at the same computed anomaly, a thickness of Santa Fe Group must be added to the column on top of the Datil volcanics, as follows. Gravity defect of removed material:

$$\Delta g_R = 2\pi k \Delta\rho h_R = 2\pi k(2.67 - 2.41)\ 4,280$$

where k = universal gravitational constant;

gravity defect of added material:

$$\Delta g_A = 2\pi k \Delta\rho h_A = 2\pi k(2.67 - 2.20)\ h_A$$

$$\Delta g_R = \Delta g_A \quad ,$$

from which

$$h_A = 2,367 \text{ ft.}$$

This must be added to 1000 ft of Santa Fe already there, for a total of 3,367 ft.

Sanford notes that at a first glance the comparison between observed and computed anomalies does not appear too good. He ascribes most of the mismatch as resulting from using one fault at the basin margins instead of using multiple faults. A thickness of 1,000 feet of Santa Fe Group will result in an anomaly of about 6 milligals. The first order fit between observed and computed gravity profiles can thus be improved by adding an additional few hundred feet of Santa Fe Group to the structural depression model.

Structural Controls of the Ground Water System

The generalized geologic map (Fig. 4b) shows that all of the springs in and adjacent to the Socorro-Lemitar mountains are fault-controlled. Impermeable, aquitard rocks have been downfaulted against permeable, aquifer rocks in each case. Socorro and Sedillo springs (22.111) and (22.113), respectively, issue from fractures in the lower member (?) of the Popotosa Formation where it is interbedded and/or in fault contact with rhyolitic ash-flow tuffs, and the downfaulted aquitard is the upper member (?) of the Popotosa Formation*. The upper member of the Popotosa Fm. also appears to be the aquitard for lower Nogal Canyon

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*There is some disagreement among investigators about the detailed stratigraphic correlation and structural relationships in the vicinity of the springs. For the conclusions of this report, these relationships are not decisive and will not be explored further.

spring (30.443), upper Nogal Canyon spring (31.314), and Snake Ranch spring (35.324).

There are two major crustal lineaments which intersect in the Socorro area (Chapin et al., 1978, Fig. 1), the Morenci and the Capitan Lineaments. These lineaments are deeply penetrating flaws in the lithosphere which influence the deformation of brittle near-surface rocks. One of these, the Morenci Lineament has a near-surface expression as a transverse shear zone (Fig. 4b) in the study area (Chapin et al., 1978). To the north of a line extending from Socorro to South Baldy in the Magdalena Mountains, strata are dipping to the west and are down faulted to the east. South of this line strata dip to the east and are down faulted to the west. It is not known how this shear zone affects the groundwater system, but it seems reasonable to assume that along this shear zone a high degree of fracturing and brecciation has occured. This could have created a high-permeability zone which channels groundwater flow. It can be seen on Fig. 4b that Socorro and Sedillo springs issue along the transverse shear zone. It must be kept in mind, however, that the shear zone location is only approximate (Chamberlin, personal communication).

Another major geological structure which may affect the study area's groundwater system is the Socorro cauldron referred to earlier. This elliptical subsidence structure (Fig. 4b) was formed by the collapse of the roof of a large magma body as the result of huge ash-flow eruptions. After collapse, the floor of the cauldron was probably domed upward by magma pressure to create a central resurgent dome separated from the cauldron walls by a topographic low called a moat. This moat was underlain by deeply penetrating ring fractures which allowed magma an easy path to the surface. The moat filled with lava flows and domes, tuffs, and sedimentary debris from the cauldron walls and resurgent dome. These moat deposits (unit of Luis Lopez of Chapin et al., 1978) are a permeable sequence of rocks which may be a significant part of the groundwater system today. The moat deposits are found throughout the Socorro Mountains in the study area, and they overlie the Tuff of Lemitar Mountains which is also very permeable (Chamberlin, personal communication).

Characteristics of the thermal springs

Both Socorro and Sedillo Spring probably issue from the lower member of the Popotosa Formation. Socorro Spring issues from a series of joints (Summers, 1976) in a gallery which has been dug to intercept spring flow. Sedillo Spring probably issues from the same joint set. The water issuing from these springs is of excellent quality and consistently ranges between 90 and 92°F in temperature.

Spring flow has been monitored inconsistently since 1953 by the City of Socorro (Fig. 5). The values on this figure are questionable, however, because the city's gauges have always given conflicting values when the springs were gauged by some other means. Fig. 5 shows that Socorro Spring usually issues about 315 gpm. When recent gauge readings were obtained, and monthly average flow values calculated, the following results were obtained:

Year	Month	Socorro Spring	Sedillo Spring
1977	July	274.5	107.8 gpm
	August	272.8	---
	September	282.7	94.6
	October	276.0	98.9
	November	265.2	97.4
1978	February	299.6	109.4

These values are lower than those in Fig. 5, and it seems that they are more correct, at least for Socorro Spring, since the values are closer to values measured by Hall (1963), and Summers (1965).

Fig. 6 shows the elevation of the water table in the study area. The two elliptical contours going around Socorro Mountain have been drawn to indicate that there is some local recharge to the springs.

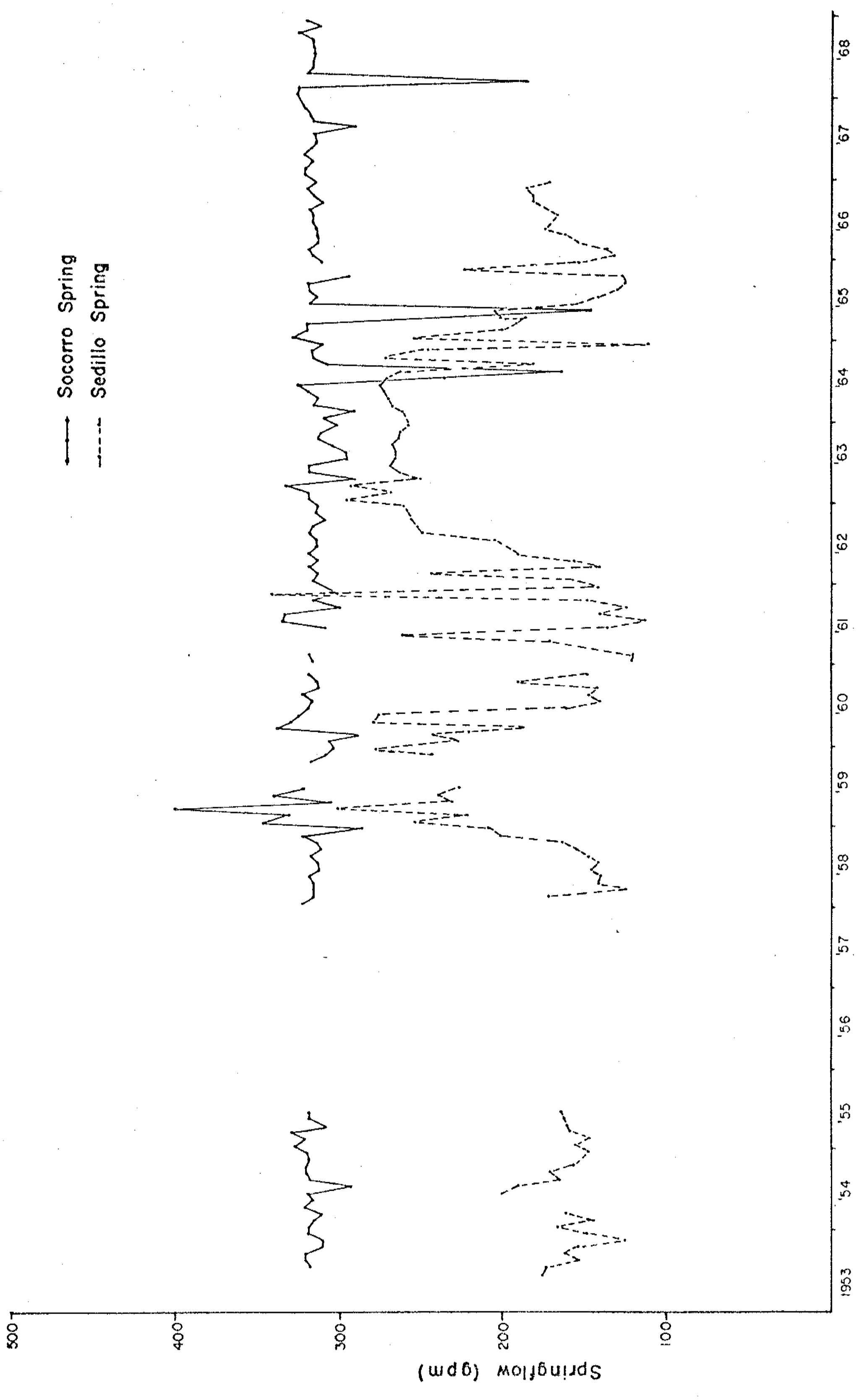

Figure 5. Socorro and Sedillo springflow, 1953-1968.

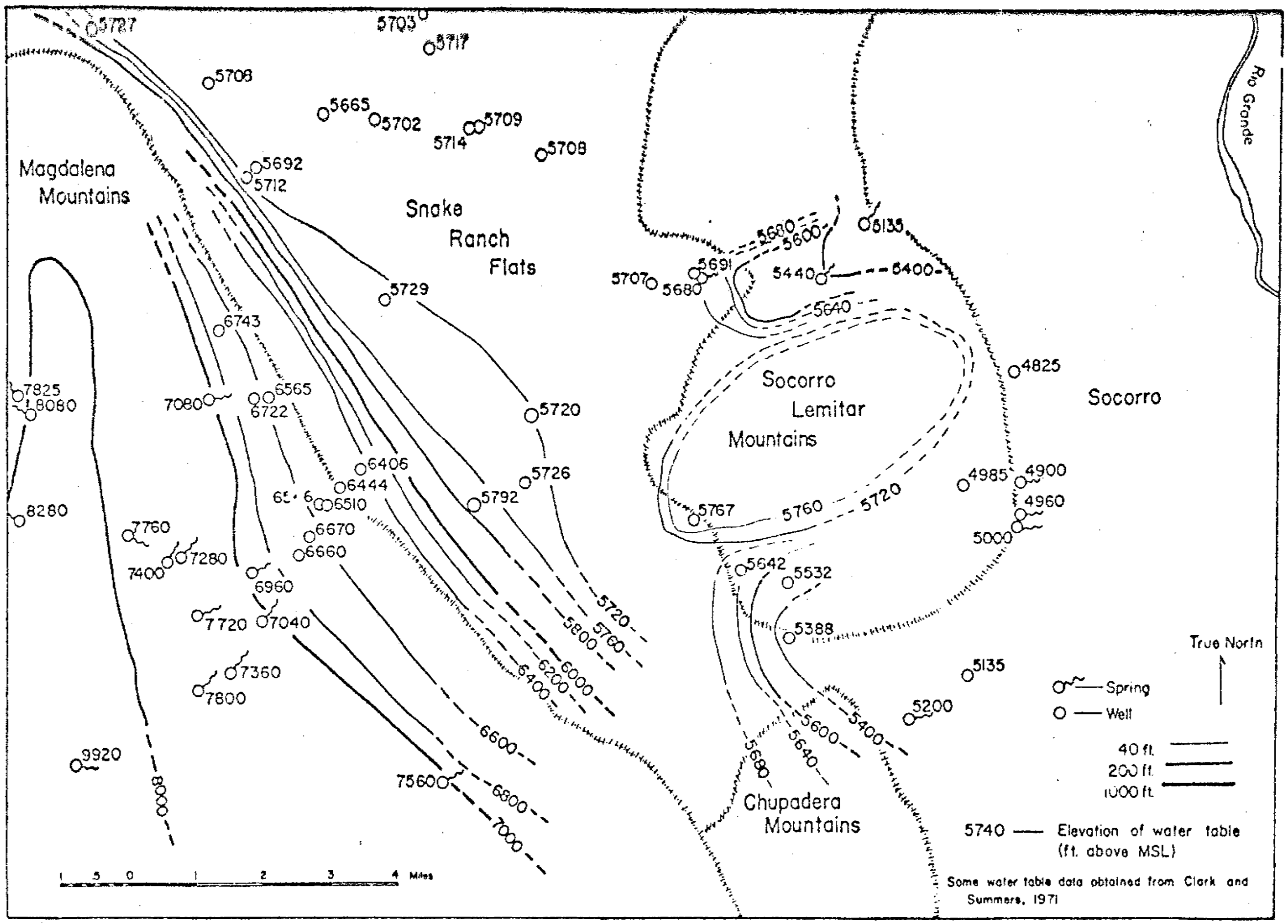

Figure 6. Water table map.

GROUNDWATER QUALITY

Hall (1963) devised a method of chemical classification which is adopted here. A water quality type is derived from dominant ions, in terms of percentages of equivalents per million (epm) as 100 percent cations and 100 percent anions. Hall's criteria used for both cations and anions are: (1) if one ion is greater than 50 percent, then it determines the water quality type, and (2) if no ion is greater than 50 percent, then the ions greater than 25 percent are given in decreasing order from left to right. Figure 7 shows the range of water quality types for the study area. Fig. 8 shows water chemistry and total dissolved solids represented by pie diagrams. Chemical analyses data are presented in Appendix B.

Spring and well water from the Magdalena Mountains is all of the Ca-HCO_3 type except for Garcia Canyon Spring (10.311) which is of Mg,Ca-HCO_3 type. Hall noted that the thermal springs (22.111 and 22.113) along with Cook Spring (15.311) and thermal Blue Canyon well (16.323) discharged Na-HCO_3 type water, and that ion exchange, sodium for calcium, must be going on somewhere within the system between the Snake Ranch Flats and the location of these springs and wells. Two wells in Socorro Canyon, (33.144 and 36.212) yield Na,Ca-SO_4 and Na-HCO_3 type waters, respectively. Also, well (12.112) and spring (5.211) within the Chupadera Mountains issue Na,Ca-SO_4 and Na-HCO_3 type waters, respectively. Hall has also observed that Domingo Spring (3S.1W.6.331), which receives recharge from local precipitation only, discharges Na-HCO_3 type water. In this instance, the Na-HCO_3 type water is due to leaching of the rhyolitic material through which the spring issues, rather than ion exchange. This spring was not sampled for this report and is not shown in the figures. A rough line has been drawn through the Socorro-Lemitar and the Chupadera Mountains to indicate where the ion exchange is taking place (Fig. 8).

Springs and wells which have water high in sulfate, such as lower Nogal Canyon spring (30.443), Chupadera spring (5.211) and Gianero windmill (12.112), tap groundwater which has probably had prolonged contact with the upper gypsiferous member of the Popotosa Formation.

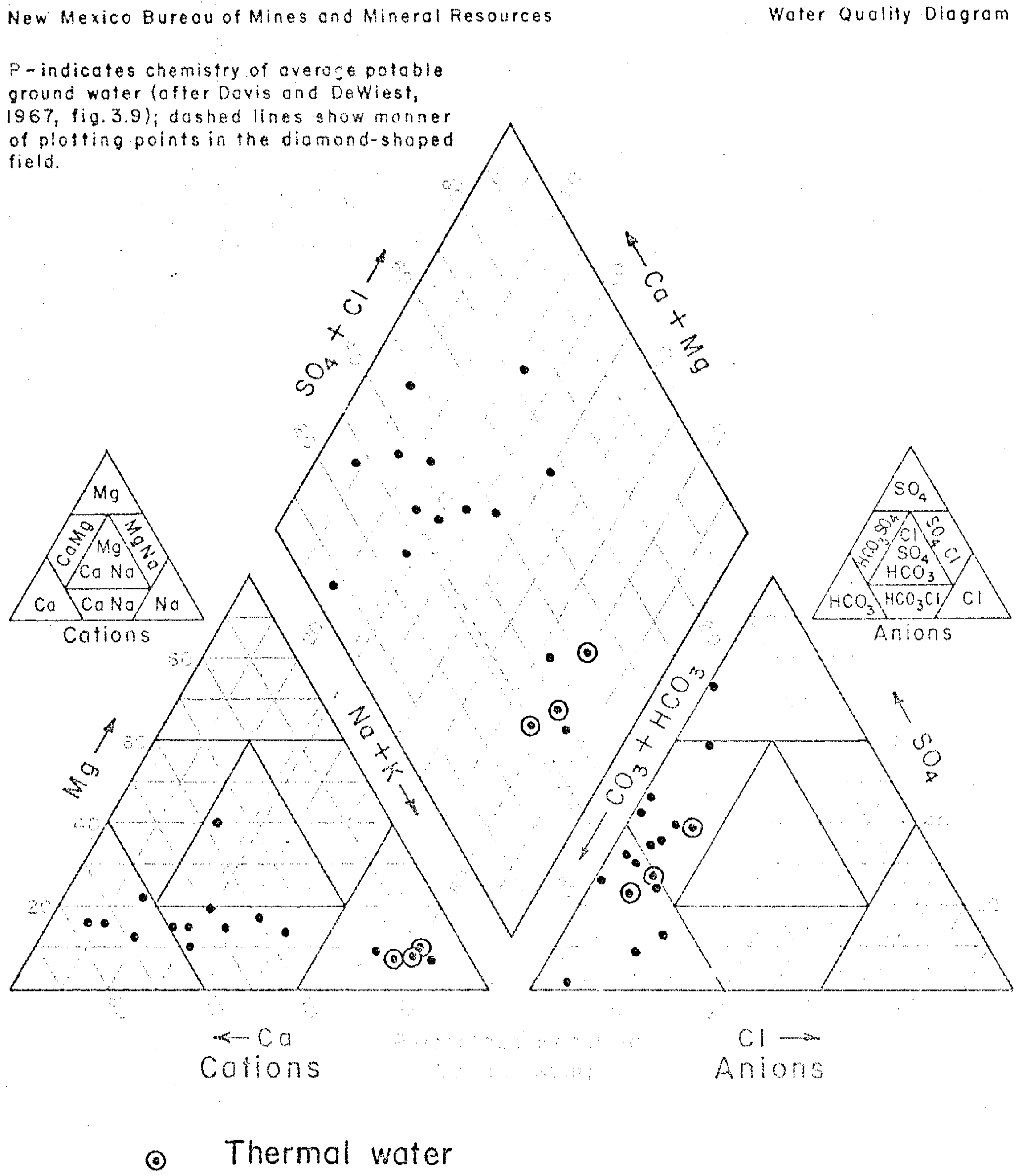

Figure 7. Water quality diagram.

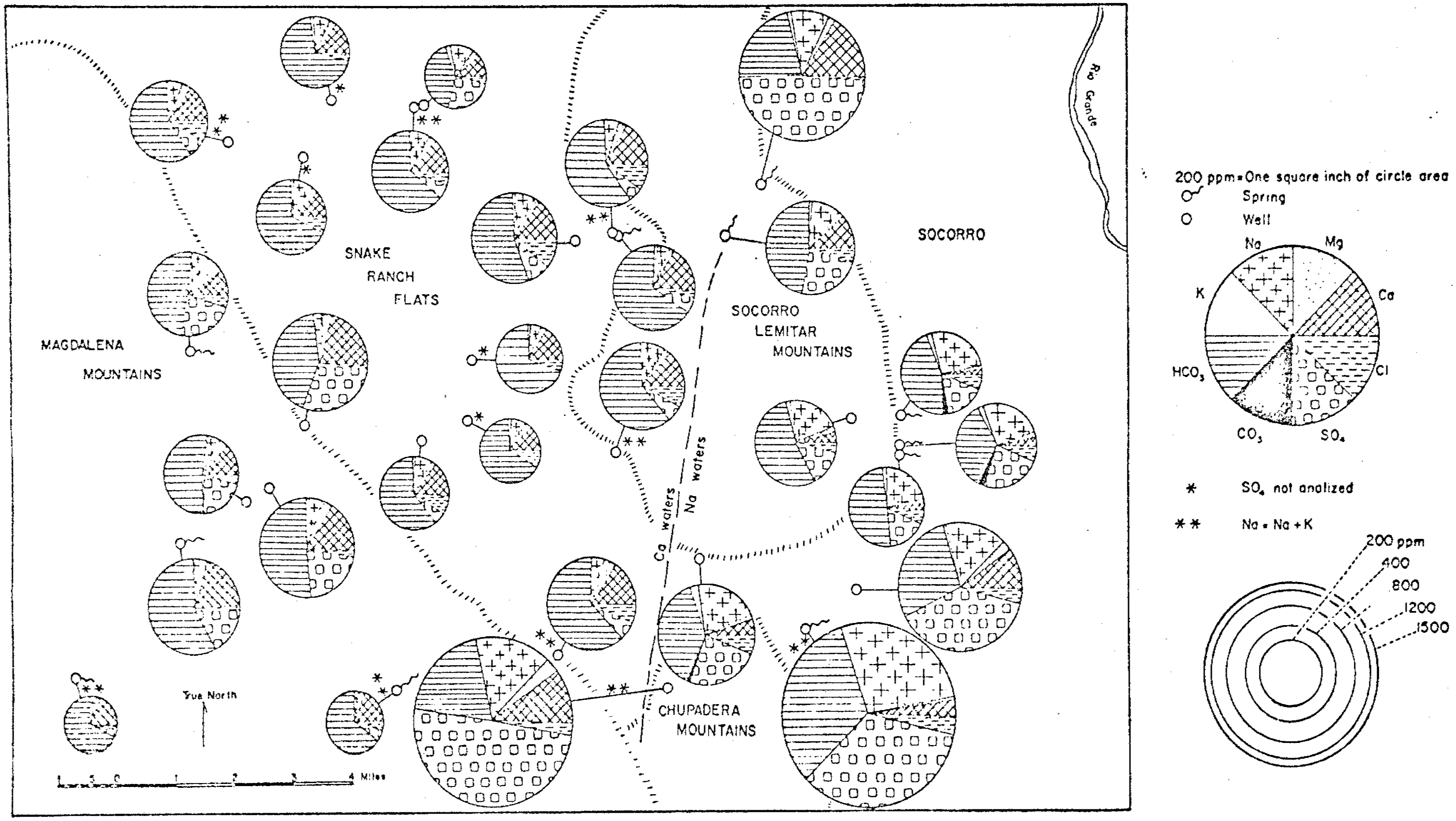

Figure 8. Distribution map of water quality and total dissolved solids.

ENVIRONMENTAL TRITIUM IN GROUNDWATER AND PRECIPITATION

The unstable hydrogen isotope tritium (H^3) is useful for understanding certain groundwater systems. Tritium is produced naturally in the earth's stratosphere when atmospheric nitrogen molecules are bombarded by cosmic rays. Tritium is readily incorporated into the vapor system of the atmosphere and falls to earth in precipitation. Because tritium has a half life of 12.3 years, it is only suitable for dating water up to about 50 years old. Natural tritium levels in atmospheric moisture were of the order of 10 TU* prior to 1954. Beginning with that year, they were dramatically increased by atmospheric testing of thermonuclear devices which ended in 1963 (Nuclear Test Ban Treaty). Tritium activity in atmospheric moisture peaked out in 1963/64 and has been decreasing since. These developments are reflected in Fig. 9, which shows tritium activity in precipitation at Socorro, NM, as a function of time for the period 1957 (when tritium measurements started at NMIMT) to 1976.

The increased levels of environmental tritium activity are the basis for a method of tracing natural waters. By correlating peaks in precipitation with peaks in groundwater, residence times and velocities have been determined (Holmes, 1963; Rabinowitz et al., 1977).

Holmes (1963) examined three years (1957 to 1959) of tritium data for Socorro Spring and Socorro precipitation. He concluded that an August 1958 peak in tritium activity in Socorro Spring water correlates with the mid-1954 tritium activity rise in precipitation, which was caused by the first, or Castle series of atmospheric thermonuclear tests. Thus, the residence time of Socorro Spring water (the time elapsed between precipitation in the recharge area and its reappearance in the spring) is at most four years.

For this paper, some of the tritium data Holmes used could not be located in the laboratory records. Other data not used by Holmes were located for the year 1957 (Fig. 9), and it appears that his 1957 line of tritium activity in spring water, though based on only 2 data points, was correct. Sampling of Socorro Spring stopped in early 1959 and was resumed for only two periods of about six months each in 1961 and 1962. There are some questionable data points within this group of samples.

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*Tritium activity is expressed in tritium units (TU), where one tritium unit equals one tritium atom per 10^{18} hydrogen atoms.

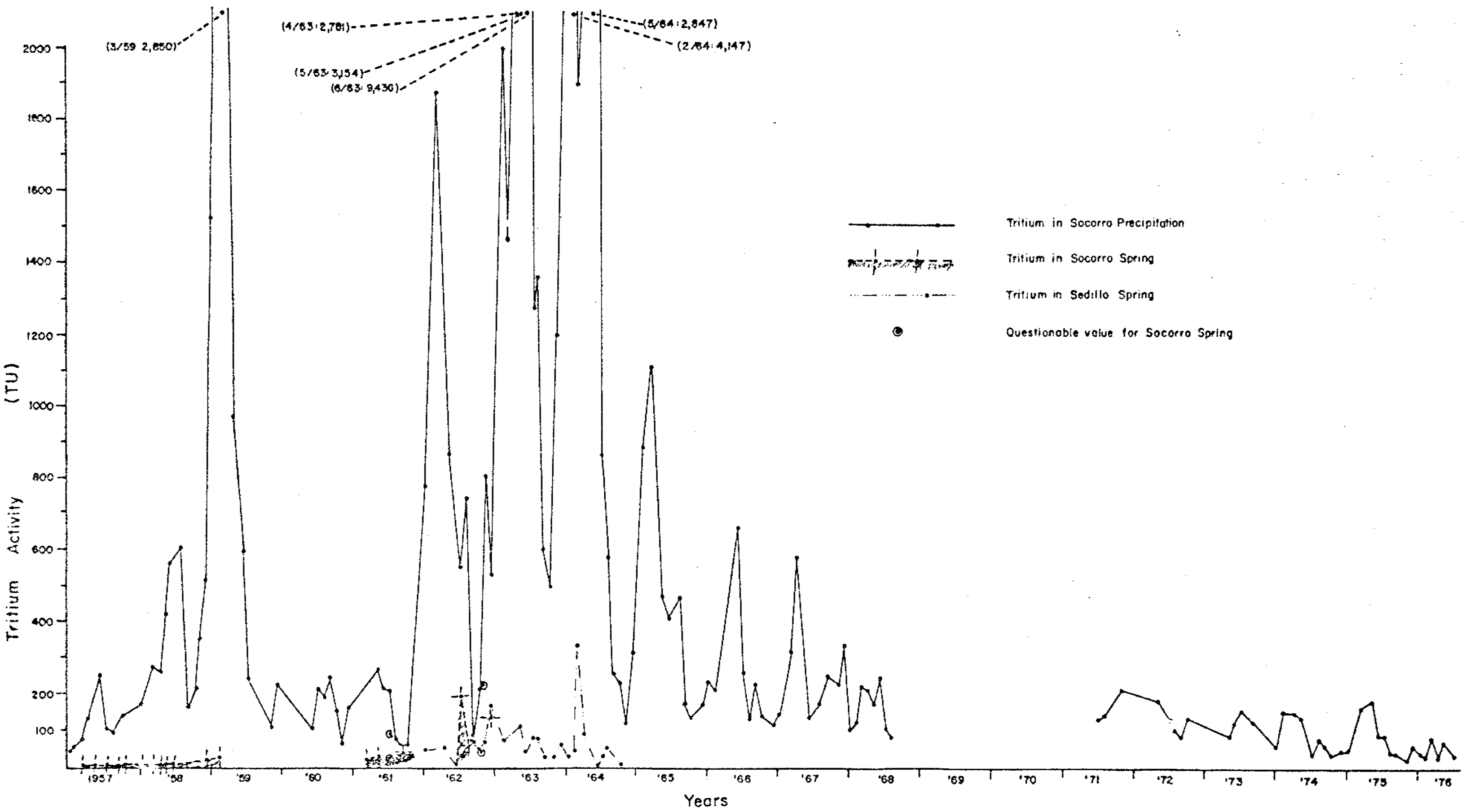

Figure 9. Tritium activity in Socorro precipitation, Socorro Spring, and Sedillo Spring.

Sedillo Spring was sampled regularly for three years (1962-1964). Socorro precipitation, on the other hand, has been sampled regularly, except for a three-year gap (mid-1968 to mid-1971) since 1957 (Fig. 9). It is characterized by seasonal peaks of tritium activity. The highest peak was seen in June 1963 (9436 TU). The peak amplitude has been steadily declining since then.

The three years of data for Sedillo Spring show very elevated levels compared to recent values (Fig. 9 and App. C), and even relative to the peak in Socorro Spring studied by Holmes. The major peak in March 1964, of 334 TU, should correspond to a tritium activity peak in precipitation in early 1960 if Holmes' (1963) hypothesis is correct. There was no significant precipitation peak observed in early 1960, but there was one in March 1959. This would correlate better with the Dec. 1962 activity peak in Sedillo Spring (165 TU). Similarly, the July 1962 peak in Socorro Spring (192 TU) correlates with the August 1958 peak in precipitation (608 TU).

For the present study, sampling of Socorro and Sedillo Springs was resumed in February 1977. Other wells and springs have also been sampled in order to investigate the nature of the groundwater reservoir. Fig. 10 shows the distribution of groundwater tritium activity in the study area determined on the basis of this sampling program.

Within the Magdalena Mountains, most of the water seems to be quite "young," TU values greater than 40. This is not surprising if one considers that the springs issue from high mountain groundwater systems in limestone; the wells are sunk into the alluvium covering of the canyon floor which is very permeable and shallow, and the water table has a high gradient going down the canyons.

In the Snake Ranch Flats, however, the groundwater is old relative to that in the Magdalena Mountains, TU values are less than 3. This seems to indicate that the groundwater reservoir in the Flats is quite large, and the recharge from the Magdalena Mountains is strongly diluted within this reservoir, or that recharge from the Magdalena Mountains is smaller than originally thought. Verhagen et al., (1970), noted the same phenomenon in the alluvial Lobatse Basin in Southern Africa. They also noted vertical stratification of tritium activity within the aquifer. Tritium values decreased to near zero with depth.

The two springs within Nogal Canyon show an interesting relationship (Fig. 11). They seem to vary somewhat in phase, with

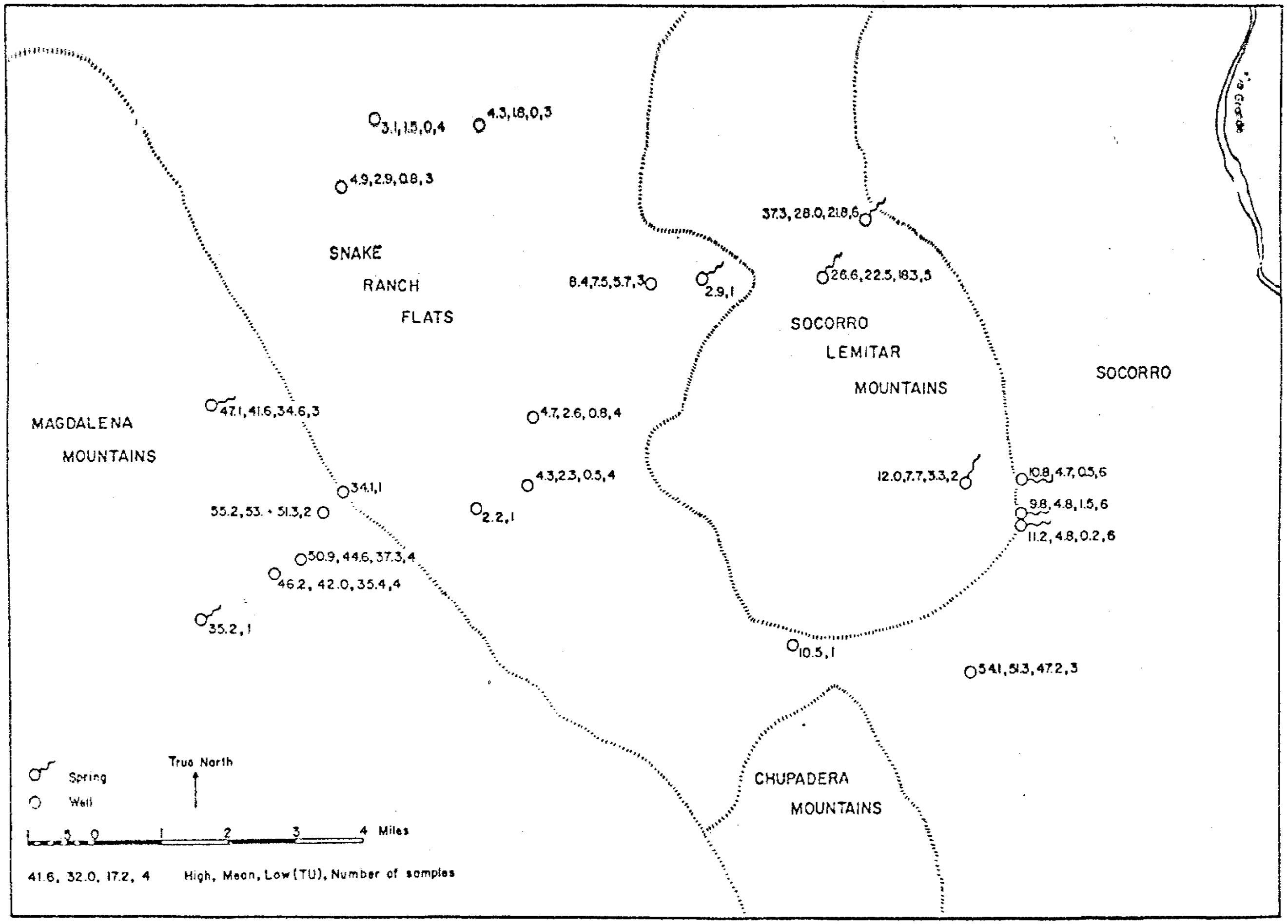

Figure 10. Distribution of tritium activity in groundwater and springs.

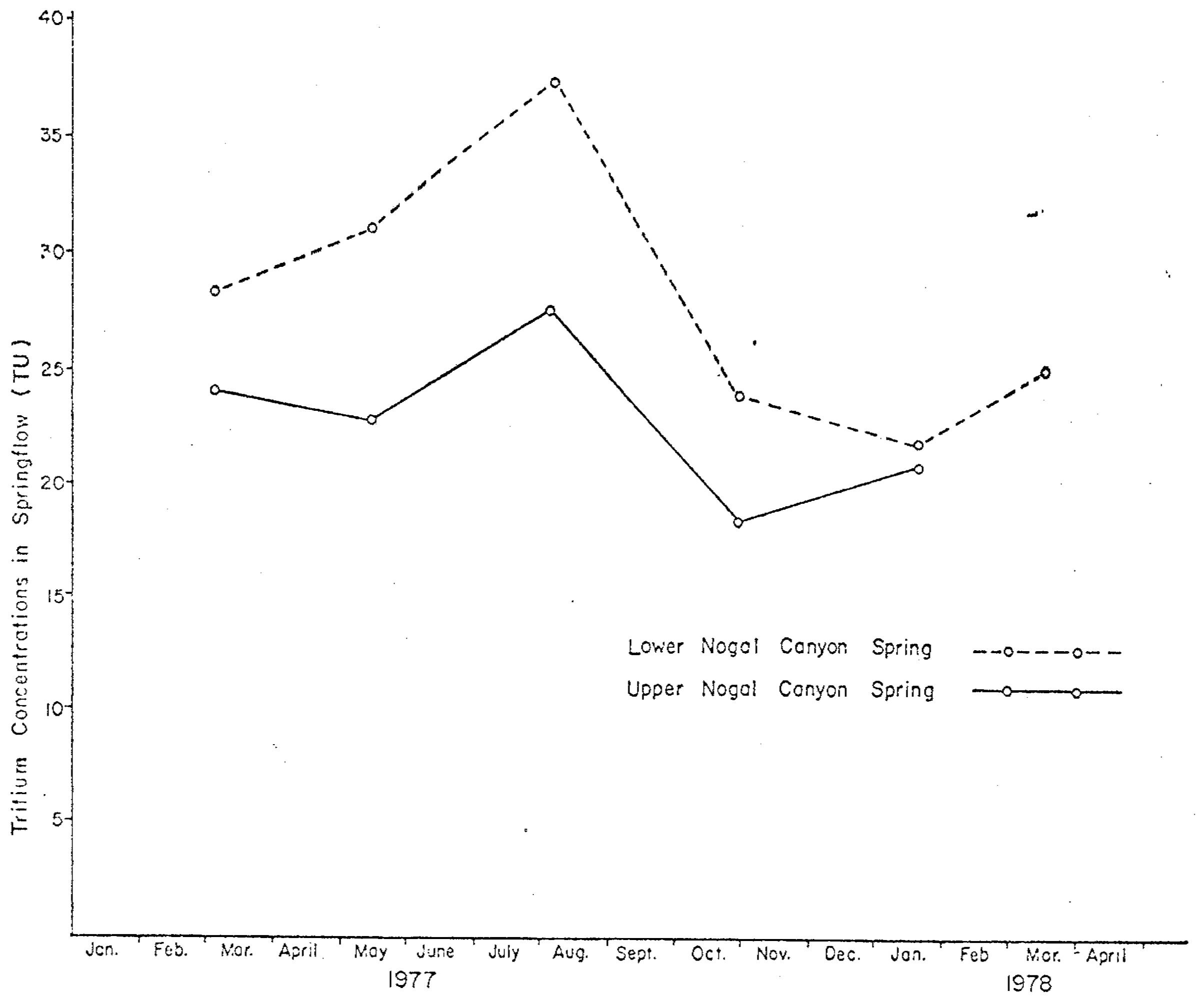

Figure 11. Tritium activity in upper and lower Nogal Canyon Springs, 1977-1978. Typical error bar is ± 1 TU. For individual values, see listing in Appendix C.

Lower Nogal Canyon Spring always being higher in tritium. These two springs are fault controlled. The water issuing from these springs is partly from the Snake Ranch Flats as evidenced by the moderate tritium values (20-30 TU). The lower spring may receive a larger component of local recharge.

The values for the thermal springs and Blue Canyon well are plotted in Fig. 12. There is good correlation between tritium values in Sedillo and Cook Springs. Socorro Spring and Blue Canyon well also follow that same general trend. This indicates, especially when the similar water quality is considered, that Cook Spring is part of the same groundwater system as Socorro and Sedillo Springs and Blue Canyon well. Whether or not the water issuing from Cook Spring was ever heated and cooled along its route cannot be said. These three springs have mean values of about 4.8 TU, which is about 2 TU higher than the Snake Ranch Flats system. This fact suggests that there is a local component of recharge which is, at least in part, supplying tritium to the spring water.

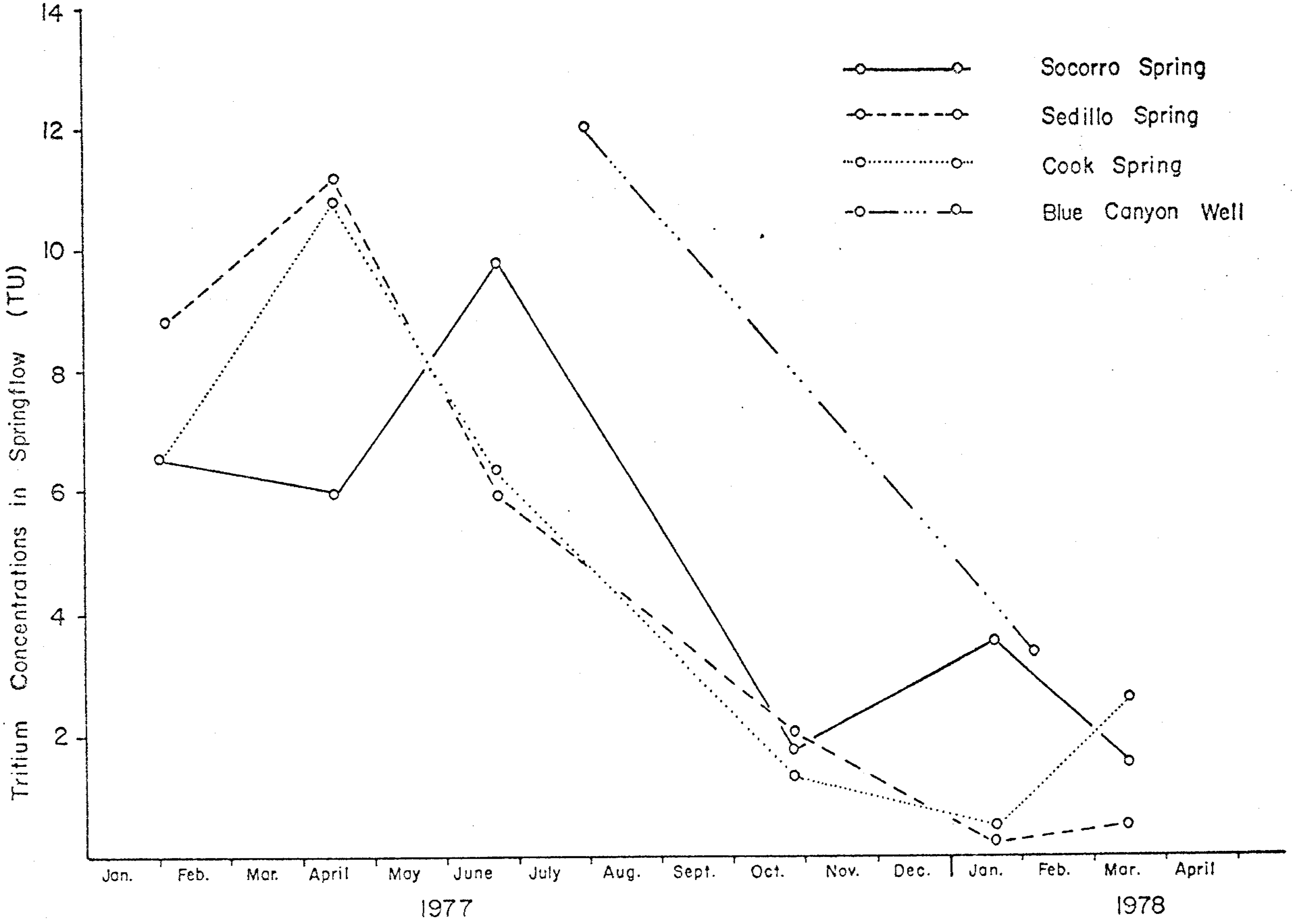

Figure 12. Tritium activity in thermal waters, 1977-1978. Typical error bar is ± 1 TU. For individual values, see listing in Appendix C.

OXYGEN-18 AND DEUTERIUM

Ten samples of thermal spring and well water were analyzed for their oxygen-18 and deuterium content. The data are exhibited in Table I and Fig. 13. Five samples from non-thermal springs and wells, and two precipitation samples are given for comparison. Tritium activity for these 17 samples is also indicated in Table I.

The data fall in two groupings. On the standard plot of δD vs. $\delta^{18}O$ (Fig. 13) both are close to and slightly to the left of Craig's (1961) meteoric line. Typical thermal waters tend to be displaced to the right of this line (Faure, 1977, Fig. 18.11). Isotopic exchange of groundwater with the reservoir rocks, which are generally low in hydrogen content, usually affects primarily the isotopic oxygen composition. On the basis of the limited evidence here available no such interaction can be detected.

Table I. Deuterium, Oxygen-18 and Tritium in Thermal and Nonthermal Waters

Location	Fig. 13 Point #	Sample No.	Date	δO^{18} ‰	δD ‰	T TU
Socorro Spring		2320	4/14/77	-10.8	-61	5.9
		2348	6/22/77	- 8.1	-51.7*	9.8
		2423	1/19/78	-10.5	-62	3.5
		2428	3/14/78	- 8.4	-41.7*	1.5
Sedillo Spring		2429	3/14/78	- 8.1	-49.8*	0.5
		2321	4/14/77	-10.2	-66	11.2
		2422	1/19/78	-11.5	-67	0.2
Cook Spring		2322	4/14/77	- 8.6	-51.0*	10.8
		2424	1/19/78	- 8.6	-50.5*	0.5
Blue Canyon well		2425	2/6/78	- 8.6	-56.7*	3.3
Upper Nogal Sprg.	(6)	2421	1/19/78	- 8.6	-52	20.8
Lower Nogal Sprg.	(7)	2420	1/19/78	-10.3	-65	21.8
Strozzi Windmill	(1)	2375	3/12/77	- 6.7	-37.8	0.0
Armijo Windmill	(2)	2325	5/13/77	- 6.1	-45.9	54.1
Kelly Ranch deep well	(3)	2381	8/19/77	- 8.2	-44.4	0.0
Socorro Rain	(4)	2537	3/21-22/77	-12.2	-76	44.5
Socorro Snow	(5)		1/19-20/78	-17.9	-120	**--

*Analysis by Dr. Gary Landis, Dept. of Geology, University of New Mexico. All others by Geochron Laboratories, Cambridge, Mass.

**Tritium activity was not measured separately from other precip. for the month (Sample #2479, 40.6 TU).

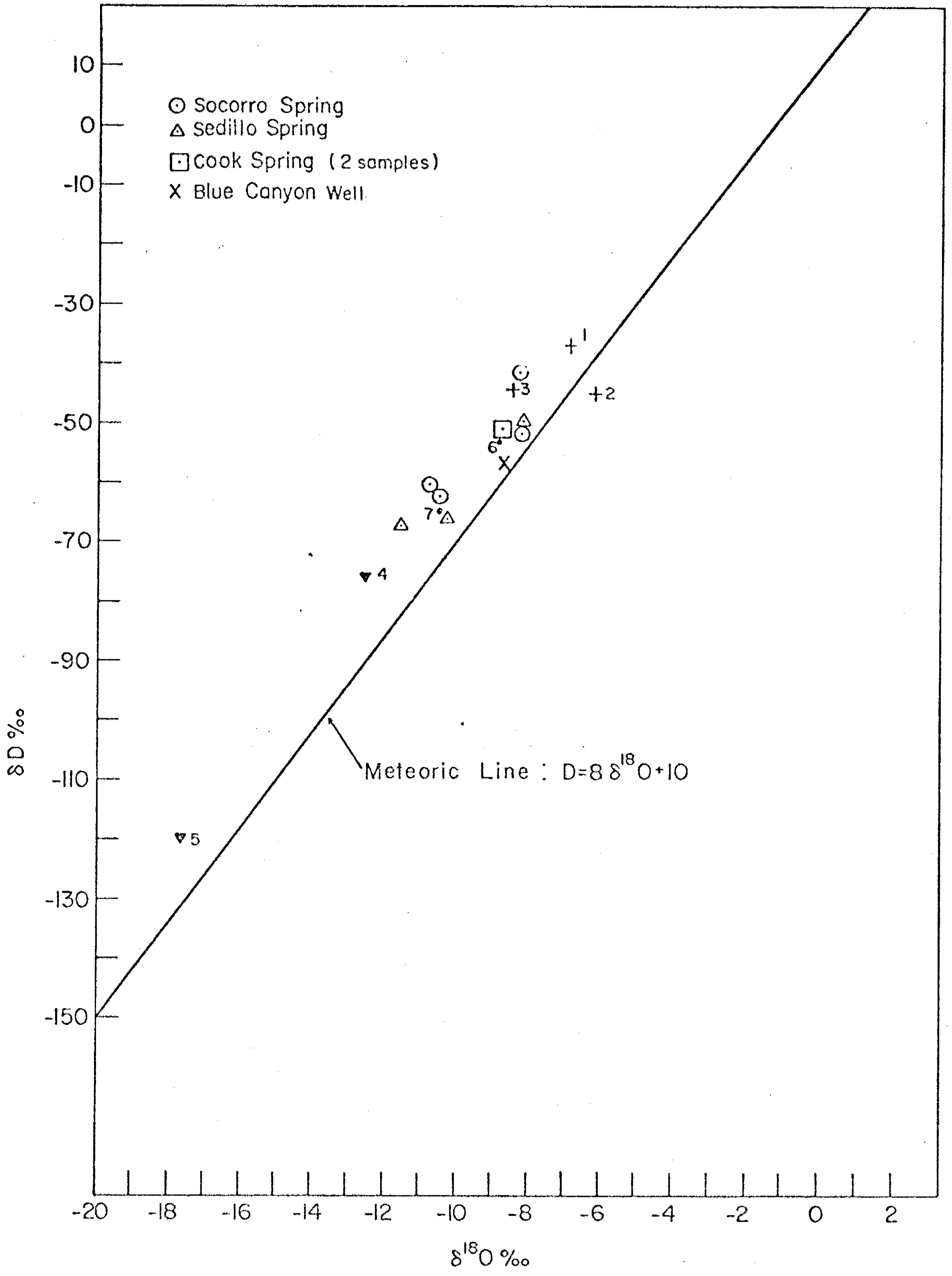

Figure 13. Deuterium and oxygen-18 in thermal and nonthermal waters. (Numbers refer to nonthermal sampling points specified in Table I).

DISCUSSION OF RESULTS

Hydrogeology

Preliminary drilling evidence (Dr. Charles Chapin, personal communication) indicates that, in Snake Ranch Flats, the permeable gravel and sand deposits which top the basin fill are underlain at 1000 ft or deeper by a thick complex of impermeable playa mudstones. These, in turn, are underlain by permeable strata. This suggests that the hydrologic system consists of two independent aquifers, a shallow aquifer above the mudstones, and a deeper aquifer below the mudstones. Within the Snake Ranch Flats, these two aquifers are not connected. Water from the Magdalena Mountains flows below the mudstones into the volcanic complex of Socorro Mountain where it feeds the springs.

Groundwater quality

The Na-HCO_3 character of the thermal springs indicates that the groundwater interacts with the volcanic complex (Hall, 1963), perhaps aided by above-normal temperatures. Chapin et al. (1978, p. 125) found a strong potassium anomaly in the feldspars of the ash-flow tuff sheets of the Socorro Mountain volcanic complex. Plagioclase feldspars have been replaced by potassium feldspar. Such alteration is typical of geothermal aqueous systems and, in this case, it is attributed to the Oligocene geothermal system. The sodium removed from the plagioclases in this metasomatic reaction may have been transported away by groundwater. Mafic flows interbedded with the ash-flow tuffs are indeed enriched in sodium. The sodium character of the present groundwater in the Socorro Mountain area, as described in this study, may indicate that a similar process is now going on in connection with the present geothermal anomaly. On the other hand, deuterium and oxygen-18 values of the thermal springs indicate that the interaction with bedrock must have been minor. These springs do not have a truly thermal character.

Tritium activity and tritium rainout

It has been shown that tritium activity in Socorro precipitation is representative of a broad region including the Snake Ranch Flats and Magdalena Mountains (Rabinowitz et al., 1977). This assertion does not, however, apply to tritium rainout, the product of tritium activity and precipitation. Tritium rainout rather than activity is the parameter determining the tritium activity of groundwater and springs.

Kelly Ranch is located at the western edge of Snake Ranch Flats, and precipitation records there may be representative of recharge to the springs. Tritium rainout at Kelly Ranch is shown in Fig. 14 and App. C. Tritium rainout computed on the basis of Socorro precipitation (Fig. 15 and App. C) shows a similar pattern but since Socorro precipitation is lower on the average, the peak amplitudes tend to be lower.

The Magdalena Mountains are believed to supply the major part of recharge to the aquifer that supplies the springs. Unfortunately, precipitation data for the Magdalena Mountains have only become available since about 1964, and then only for the summer season. They are from Langmuir Laboratory near the summit (South Baldy, Fig. 2). Because mean annual rainfall is much higher at Langmuir Laboratory (17.7 in.at 10,631 ft elev.) than at Socorro (7.9 in.at 4,600 ft elev.), tritium rainout must also be higher and may possibly show peaks that are not apparent at Kelly Ranch or Socorro. Tritium activity peaks in precipitation may not correspond to those in recharge because (1) a small precipitation event of high activity may contribute less tritium to recharge than a large precipitation event of low or intermediate activity; and (2) recharge is not linear with precipitation (Gross et al., 1976; Rabinowitz et al., 1977).

Correlation of tritium activity in springs with precipitation

For the reasons above expressed, a direct correlation of tritium activity peaks in groundwater with those in precipitation is possible only in special cases. Holmes' correlation of the Socorro Spring peak may have been such a special case because the measurements occurred so early after the onset of the rise in atmospheric tritium activity. However, even in this case the approach cannot yield quantitative information concerning the mixing (dispersion) of recharge contributions from different sources or following different flowpaths. In the case of the Socorro Spring system three possible recharge contributions were outlined in this report; viz.: (1) water from the Magdalena Mountains following a deep path (beneath the mudstone complex in the Snake Ranch Flats, of long travel time; (2) water from the Magdalena Mountains following a shallow path (above the mudstone complex), of intermediate travel time; (3) direct recharge over the Socorro Mountain complex, a fast recharge component. In order to investigate recharge quantitatively further it would be necessary to integrate all the tritium rainout contributions over the recharge area, and derive from them the effective tritium recharge as a function of time (Rabinowitz et al., 1977). The effective tritium activity in recharge deduced from this curve could then be compared to and correlated with the spring measurements.

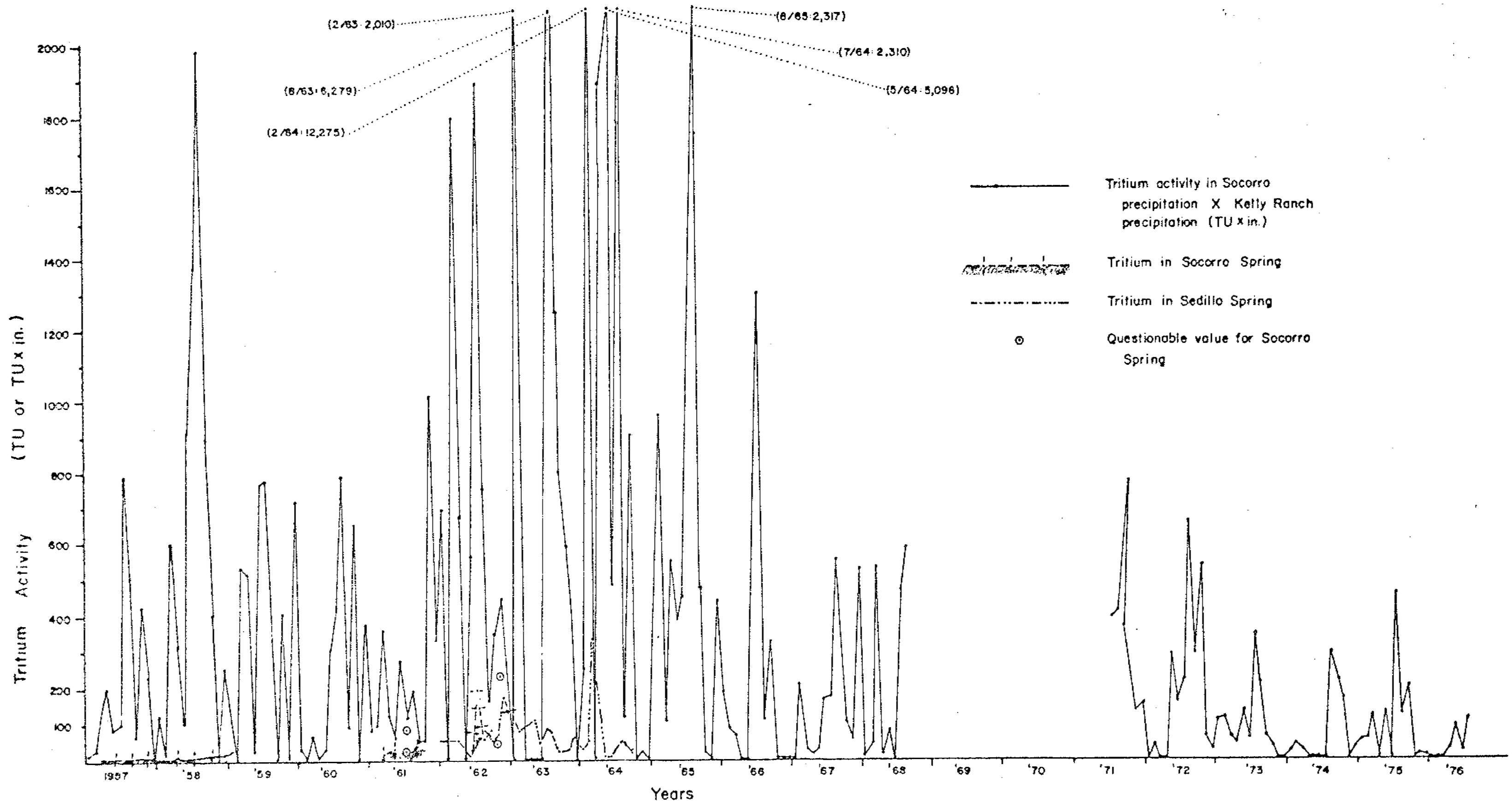

Figure 14. Tritium rainout computed from Kelly Ranch precipitation records, and tritium activity in Socorro Spring, 1956-1976.

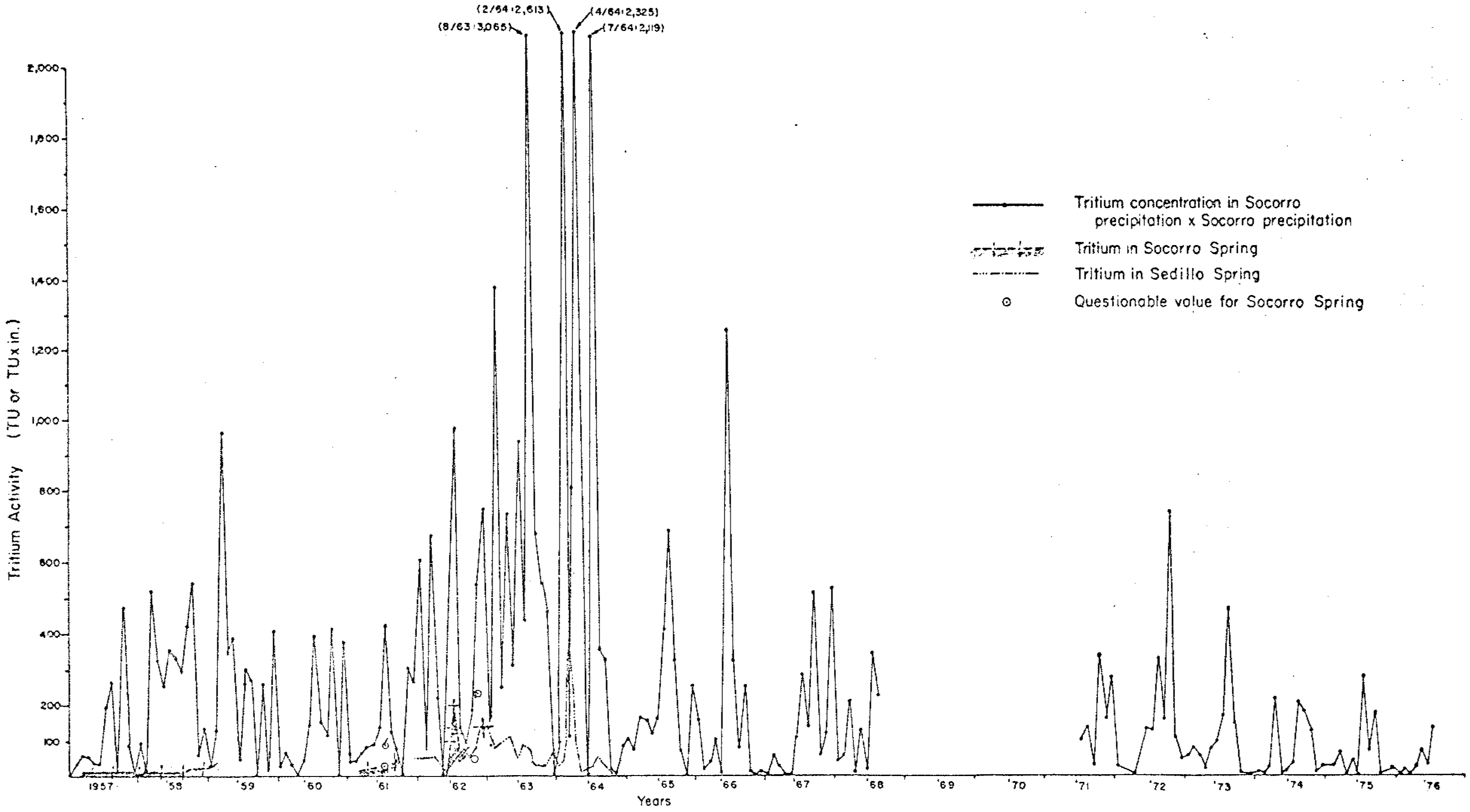

Figure 15. Tritium rainout computed from Socorro precipitation records, and tritium activity in Socorro Spring, 1956-1976.

Data required for these computations include precipitation distribution over the recharge area, for the appropriate time interval; recharge fraction; size, configuration, and storage coefficient of the aquifer, or, alternatively, a dispersion coefficient for the latter. Most of this information is not available and, in fact, one purpose of isotope studies is to obtain the very parameters (such as recharge fraction, residence time, and aquifer size) needed for the computation. When long series of measurements are available for tritium activity in both groundwater and precipitation, a mean mixing ratio may be computed (Gross et al., 1980) without explicitly including other parameters. An adequate series is available for precipitation but measurements for the springs are inadequate in total time span, continuity, and frequency. The discussion of what these tritium measurements mean in terms of the hydrologic characteristics of the aquifer system is therefore somewhat speculative.

Alternative interpretation of spring recharge

The correlation proposed by Holmes for the 1958 tritium peak in spring water with the 1954 rise of tritium activity in atmospheric water sets a maximum time frame for the tritium activity in the spring (it cannot be older than 4 years), but it does not account for the activity amplitude in relation to the amplitude of tritium activity in precipitation*. Two main factors determine the amplitude ratio, (1) mixing (dispersion) of the labeled water in the groundwater reservoir (assumed to be unlabeled initially) and (2) radioactive decay. For a residence time of 4 years, radioactive decay alone would reduce tritium activity to about 80% of its initial value. Subsequent peaks (e.g.: that of 1962) appear to conform moderately well to the 4-year delay pattern. The 1964 peak in Sedillo Spring activity poses some difficulty for correlation. The greatest problem is to account for the relative amplitudes. For the years in question, atmospheric activity shows very large fluctuations from month to month (Fig. 9), and these are averaged out in springflow to a certain extent. The reduction due to this averaging is likely to be larger than that due to radioactive decay. However, if all recharge occurs at the western edge of the Snake Ranch Flats and has a residence time of 4 years, then the spring water should after 4 years (that is, starting in 1958) begin to approach the mean tritium activity of precipitation. This is clearly not the case, and is evident especially from the most recent data because the seasonal fluctuations in tritium activity are becoming progressively smaller .

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*No measurement of tritium activity in 1954 precipitation at Socorro is available.

For this reason we offer two alternative interpretations. (1) All recharge to the springs originates in the Magdalena Mountains or near the western edge of the Snake Ranch Flats. It follows paths of different lengths (travel times) across the Snake Ranch Flats and the Socorro Mountain complex. These streamlines converge in the discharge zone so that they appear mixed in the springs. The tritium activity of the spring water therefore represents the diluted activity of the shallowest (shortest) of these streamlines. The residence time of water along this shallow path is of the order of 4 years.

(2) The tritium activity of the spring water is the label of local recharge, that is, precipitation that falls on the Socorro Mountain complex and/or surface runoff following large thunderstorms that crosses the Snake Ranch Flats and is absorbed by the highly fractured and permeable volcanics forming the eastern edge of the Flats. That is to say, the major portion of springflow represents water that was recharged at the eastern edge of the Magdalena Mountains and took the long path, as discussed in the Hydrogeology section, but a minor component of the springflow represents local recharge around the western flank and southern end of Socorro Mountains. This does not seem unreasonable considering the size of the possible recharge area around Socorro Mountains. The shallow recharge contribution is roughly estimated at 10% to 20% of total springflow. It would vary from year to year with local climatic conditions.

Of the two alternative hypotheses we favor the second one because the tritium activity of groundwater in Snake Ranch Flats is lower than the activity of springflow (Fig. 10) and also because the geologic structure of the sedimentary basin of Snake Ranch Flats seems to indicate long residence times.

The combined geological, geochemical, and isotope evidence therefore indicates that a major component of spring recharge proceeds along a relatively deep path. Temperature and residence time along the path are such that:

1. Cation exchange with bedrock takes place, and this accounts for the Na-HCO_3 character of the water.

2. The residence time for this deep component appears to be much longer than the half-life of tritium (12.3 years).

3. Oxygen-18 and deuterium exchange with bedrock are negligible.

SUMMARY OF CONCLUSIONS

Recharge to the thermal spring system of Socorro consists of two main components that follow different paths of different travel times. A regional component is fed by precipitation on the Magdalena Mountains which is transmitted to the fracture system of the springs through permeable strata of the Santa Fe Group (3,000 to 4,000 ft). The residence time of this component is probably longer than the half-life of tritium (12.3 yrs).

A local recharge component is fed by precipitation that falls directly on the volcanic complex of Socorro Mountains and/or is transmitted from the Magdalena Mountains as surface runoff across the Snake Ranch Flats basin. Its residence time is of the order of 4 years.

These recharge components were differentiated on the basis of their tritium label which yields a mixing ratio of the order of 9:1 for the regional vs. the local component.

Cation exchange, sodium for calcium, takes place along a roughly north-south trending line in the Socorro and Chupadera Mountains. It is related to the geothermal anomaly of Socorro Mountains. Deuterium and oxygen-18 determinations in samples of spring and well waters of the geothermal anomaly indicate that these waters are of meteoric origin and have not been mixed with deep thermal waters.

RECOMMENDATIONS FOR FUTURE WORK

Chemical equilibrium computations with the water quality data might make it possible to determine a temperature for the cationic exchange reaction and thus the depth of groundwater flow to the thermal springs.

The water table map should be subjected to statistical computations (kriging) which allow one to determine the most likely contour patterns for a limited set of data points and to place confidence limits on alternative contour configurations. It may also be possible to obtain additional water table measurements in the field in wells not studied for this report.

Tritium measurements should continue in order to detect systematic time variations in the tritium content of the springs and relate these to recharge processes.

An important related question is the role of the through-flowing arroyos for the recharge to the Socorro Spring aquifer and to the Rio Grande aquifer. This question has broader implications for an understanding of recharge processes in the basin-and-range environment.

It was pointed out in this report that flow measurements at Socorro Spring have been unreliable in the past. Accurate monitoring of springflow is very important for future investigations.

The fracture system from which the three springs (Cook, Socorro, Sedillo) issue, should be mapped and correlated between the springs. There is some evidence that they are closely coupled hydraulically, and this question needs to be addressed to gain a better understanding of the hydraulic system. The question is likely to come up in problems of management of the spring waters.

Another topic for investigation is the relation between the aquifer that feeds the thermal springs and the aquifer or aquifers in the Rio Grande graben.

Water chemistry of the Socorro thermal system should be compared with other thermal springs, especially those along the Rio Grande. In particular the tritium, oxygen-18 and deuterium values should be investigated. This could lead to broader conclusions concerning regional aquifer systems.

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APPENDIX A

SPRING AND WELL DATA

SPRING DATA

Location Number	Name	Geologic Source	Yield Rate (gpm)	Date	Use	Altitude (feet)	Remarks
3.1.22.111	Socorro Spring	Lower member Popotosa Formation	310	----	Municipal	4,960	This spring is fault controlled. It issues warm water (91°F) from an adit at base of shaft dug to intercept water. Issues through joints.
3.1.22.113	Sedillo Spring	Lower member Popotosa Formation	100-300	----	Municipal	5,000	This spring is fault controlled. It issues warm water (91°F) from an adit at base of shaft dug to intercept water.
3.1.15.311	Cook Spring	Rhyolite of Socorro Peak	15	1974	Stock watering	4,900	Adit dug several hundred feet to intercept water. (Billings, 1974)
2.1.30.443	Lower Nogal Canyon Spring	Quaternary Alluvium or Socorro Peak Volcanics	1	3-78	Stock watering	5,135	This spring is fault controlled.
2.1.31.314	Upper Nogal Canyon Spring	Quaternary Alluvium or Older Volcanic Rocks	1	1-78	Stock watering	5,440	This spring is fault controlled.
4.1.5.211	Chupadera Spring	Lower member Popotosa Formation	1	5-62	Stock watering	5,200	This spring has dried up since 1962. (Hall, 1963)
4.2.7.211	Box Spring	Older Volcanic Rocks	1	2-63	Stock watering	7,560	Dried up since 1963.
2.2.35.324	Snake Ranch Spring	Upper Santa Fe Group	1-2	11-77	Stock watering	5,680	This spring is fault controlled (Fig. 4b).

SPRING DATA (Continued)

Location Number	Name	Geologic Source	Yield		Use	Altitude (feet)	Remarks
			Rate (gpm)	Date			
3.3.10.311	Garcia Canyon Spring	Paleozoic limestone	2	7-62	Stock watering	7,080	This spring is controlled by a limestone bed crossing an arroyo.
3.3.28.424	Copper Canyon Spring	Paleozoic limestone	1	10-77	Stock watering	7,720	This spring issues from a black limestone.
4.3.5.311	Baldy Spring	---------	-	----	Domestic and stock watering	9,920	

WELL DATA

Location Number	Name	Geologic Source	Altitude (feet)	Depth (feet)	Depth to Water (ft)	Date Measured	Use	Remarks
3.1.16.323	Blue Canyon well	Lower member Popotosa Formation	5,200	300	219	8-77	Domestic	This well yields warm water (91°F). See log for this well in Table A-1.
3.1.33.144	Armijo windmill	Quaternary alluvium or Upper Santa Fe Group	5,155	58	20	8-77	Stock watering	-------------------------
2.2.20.311	B. Kelly Ranch (deep well)	Upper Santa Fe Group	5,842	275	131	8-77	Stock watering	This well is equipped with an electric pump. See driller's log for this well (Table A-I).
2.2.18.422	B. Kelly Ranch well	Upper Santa Fe Group	5,835	160	---	----	Stock watering	This well seems to have caved in from 125 feet down.
2.2.34.432	Snake Ranch windmill	Upper Sante Fe Group	5,797	134	90	8-77	Stock watering	-------------------------
2.2.35.323	Snake Ranch windmill	Upper Sante Fe Group	5,715	---	24	8-77	not used	-------------------------
3.2.8.423	Water Canyon Lodge well	Upper Sante Fe Group	5,075	400	355	6-60	Domestic	Electric pump. (Clark and Summers, 1971)

WELL DATA (Continued)

Location Number	Name	Geologic Source	Altitude (feet)	Depth (feet)	Depth to Water (ft)	Date Measured	Use	Remarks
3.2.17.423	South Canyon windmill	Upper Santa Fe Group	6,106	400	380	6-60	Stock watering	(Clark and Summers, 1971).
3.2.20.111	Upper South Canyon windmill	Upper Santa Fe Group	6,232	540	440	6-60	Stock watering	See driller's log for this well in Table A-I (Clark and Summers, 1971).
3.2.23.123	Sedillo windmill		5,879	173	112	8-77	Stock watering	--------------------------
3.2.25.443	Sedillo windmill		5,520	180	122	8-77	Stock watering	--------------------------
4.2.3.321	Gianero windmill		5,955	115			Domestic	--------------------------
4.2.12.112	Gianero windmill		5,652	300			Stock watering	See driller's log for this well in Table A-I.
2.3.24.411	Allie Strozzi well	Upper Santa Fe Group	5,860	160	158	6-60	Domestic	(Clark and Summers, 1971).
2.3.25.113	J.B. Kelly windmill	Upper Santa Fe Group	5,955	217			Stock watering	--------------------------
2.3.27.223	Courtney well	Upper Santa Fe Group	6,040	415	348	8-67	Stock watering	See driller's log for this well in Table A-I (Clark and Summers, 1971).

WELL DATA (Continued)

Location Number	Name	Geologic Source	Altitude (feet)	Depth (feet)	Depth to Water (ft)	Date Measured	Use	Remarks
3.3.23.221	Nathan Hall windmill	Quaternary alluvium	6,593	95	47	8-77	Stock watering	-------------------------
3.3.13.331	Cibola Nat'l Forest windmill	Quaternary alluvium	6,520		76	8-77	Stock watering	-------------------------
3.3.23.342	Tom Kelly well	Quaternary alluvium	6,677	65	17	7-67	Domestic	Electric pump (Clark and Summers, 1971).
3.3.26.111	Water Canyon Campground well	Quaternary alluvium	6,800				Domestic	Hand Pump

Table A-I. Well Logs

Blue Canyon well (16.323) from Clark (1971)

Section penetrated	Top	Bottom	Thickness
Gravel	0	25	25 ft.
Rhyolite tuff breccia in part welded	25	295	270
Andesite	295	300TD	5

Upper South Canyon windmill (20.111) from Waldron (1956)

Section penetrated	Top	Bottom	Thickness
Red clay, gravel	0	400	400
Sand (water)	400	550TD	150

Gianero windmill (12.112) from Waldron (1956)

Section penetrated	Top	Bottom	Thickness
Fill, with black volcanic rock at base	0	96	96
Clay (water at top of clay)	96	250	154
"Shaly rock"	250	300	50
Clay	300TD		

(Present aquifer at top of clay at 96 feet)

Courtney well (27.223) from Waldron (1956)

Section penetrated	Top	Bottom	Thickness
Boulders	0	240	240
Coarse to med. sand	240	360	120
Fine sand	360	420TD	60

(First water at 385 feet, separated from second aquifer by thin black seam 2 feet thick)

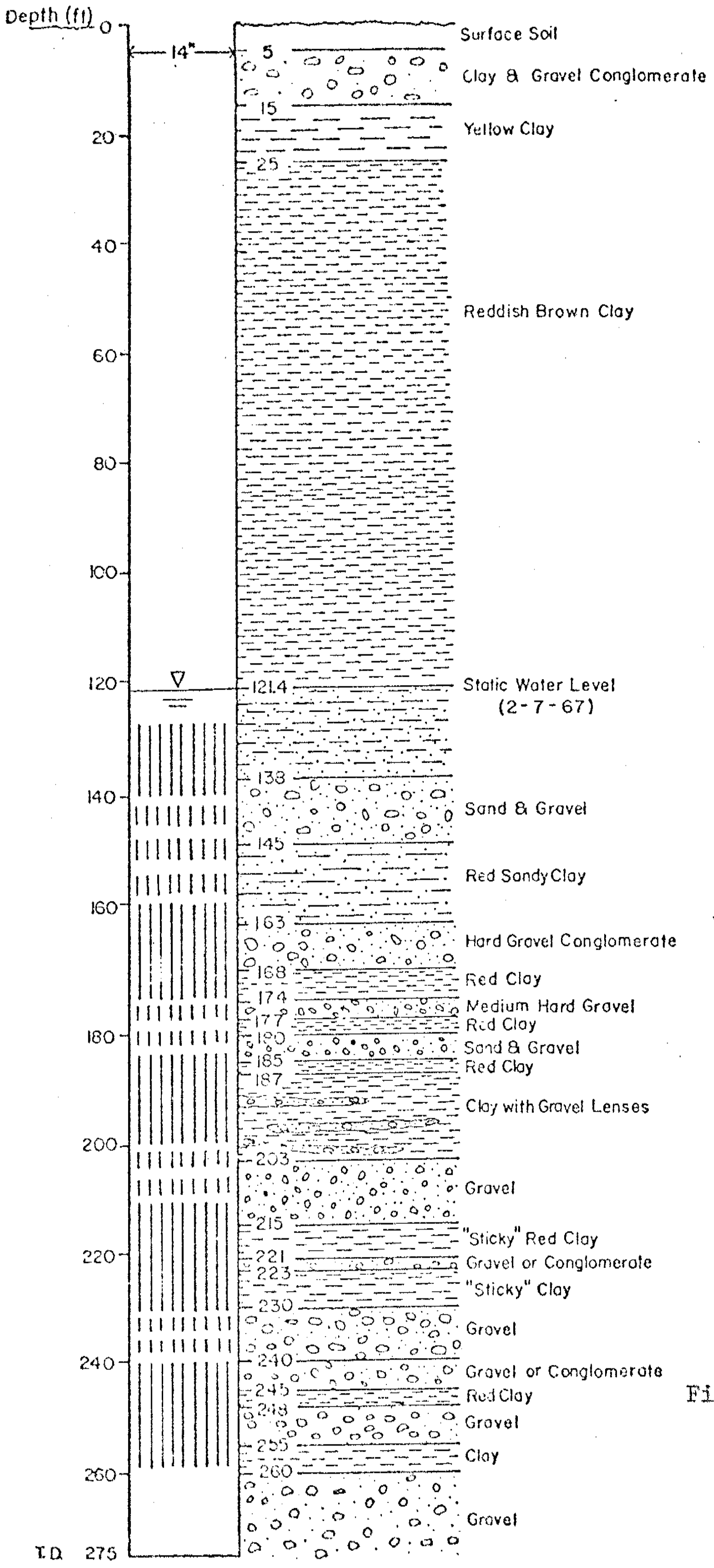

Figure A-1. Driller's log of J. B. Kelly ranch deep well (2.2.20.311).

APPENDIX B

WATER QUALITY DATA

All concentrations in ppm

Hardness expressed as $CaCO_3$

REFERENCE NUMBERS FOR WATER QUALITY DATA

1. Hall, 1963
2. Waldron, 1956
3. Scofield, 1939
4. Scott & Barker, 1962
5. USGS (unpublished data)
6. City of Socorro, Water Department
7. New Mexico Bureau of Mines and Mineral Resources
8. Billings, 1974
9. Summers, 1965

WATER QUALITY ANALYSES

Location Number	Name	Date Collected	Temp. (°F)	pH	SiO$_2$	Ca	Mg	Na	K	HCO$_3$	CO$_3$	SO$_4$	Cl	F	B	Fe	Hardness	Conductivity (μmhos/cm)	T.D.S.
3.1.22.1113	Socorro Spring (8)	1903	---	---	28	22	3.0	27	56	114	---	79	16	---	----	----	68	-----	286
	(6)	5-24-31	---	---	33	42	27.0	12	C	85	22	102	38	---	----	----	215	-----	318
	(3)	2-17-36	---	---	----	19	4.0	55	5	168	---	30	14	---	----	----	63	340	210
	(3)	12- 4-36	---	---	----	18	5.0	53	C	156	---	30	13	1.0	----	----	64	347	---
	(8)	2-10-48	---	---	28	20	4.7	54	C	165	---	31	13	---	----	----	70	352	233
	(2)	1952	91	8.2	----	19	5.0	53	C	163	---	30	13	---	----	----	68	-----	---
	(4)	1-24-57	90	7.8	27	18	3.9	52	2.8	154	0	28	15	0.6	----	----	61	348	224
	(5)	3-20-58	90	8.4	39	---	---	55	3.0	160	5	33	16	0.7	0.06	----	74	362	231
	(1)	12-12-61	91.4	8.1	----	18	5.0	50	C	163	0	28	8	---	----	----	64	370	---
	(9)	2- 5-63	91	7.8	----	13	5.0	52	C	156	0	20	12	---	----	----	52	356	---
	(8)	1-10-64	---	7.8	31	18	4.6	52	3.0	164	0	31	13	0.6	0.09	0.12	64	352	236
	(5)	4-10-65	91.6	7.8	18	4.4	---	---	---	155	---	---	---	---	----	----	63	346	---
	(8)	10-23-65	91.4	8.4	18	18	4.0	53	3.0	133	1.0	0	16	0.55	0.07	0.13	---	-----	232
	(7)	2- 4-77	90	---	----	10.6	3.6	79	4.0	109	5.0	75	20	---	----	----	---	370	---
	(6)	7- 77	---	7.81	25	18	4.2	50	3.4	150	---	23	12	---	0.8	----	---	342	---
3.1.22.1131	Sedillo Spring (5)	3-20-58	---	8.2	27	---	---	54	2.9	159	0	33	14	0.8	0.05	----	63	---	211
	(1)	12-12-61	88	8.4	----	18	5.0	50	C	154	5	24	10	---	----	----	64	370	---
	(8)	1-22-64	90	7.9	31	20	3.2	54	3.0	164	0	31	12	0.6	0.08	0.07	63	352	237
	(8)	10-23-65	---	8.6	17	18	4.0	55	3.1	109	8	[illegible]	---	---	0.10	1.04	60	336	249
	(7)	2- 4-77	---	8.4	----	8.3	3.8	59	3.9	137	1.2	48	16	---	----	----	---	360	---
	(6)	7- 77	91.4	7.9	25	17	4.4	51	3.3	151	---	22	15	---	0.12	----	---	340	---
3.1.15.3114	Cook Spring (5)	3-20-58	---	8.1	28.0	---	---	66	3.0	175	---	44	14	1.0	0.08	----	62	393	243
	(1)	3-23-62	---	8.8	----	17	5.0	63	C	163	5.0	40	12	---	----	----	62	412	---
	(8)	9-24-64	---	8.4	26.0	13	4.0	68	3.4	158	3.0	42	14	0.8	0.13	0.58	49	391	250

WATER QUALITY ANALYSES (Continued)

Location Number	Name		Date Collected	Temp. (°F)	pH	SiO_2	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	B	Fe	Hard-ness	Conductivity (μmhos/cm)	T.D.S.
3.1.15.3114	Cook Spring	(8)	5-20-74	---	7.8	----	17	6.7	67	2.0	198	---	41	21	0.8	----	<0.25	72	446	264
		(7)	2- 4-77	---	8.8	----	6.7	3.6	82	3.9	142	5.0	53	20	---	----	----	---	420	---
		(6)	7- 77	75	7.69	22.5	18	4.2	65	3.4	168	---	32	17	---	0.13	----	---	396	---
3.1.16.323	Blue Canyon Well	(5)	7-24-56	40.4	---	26	---	---	---	---	145	8	37	14	0.6	0.08	----	78	380	---
		(1)	12-20-61	88	8.0	----	18	5	---	---	166	0	32	17	---	----	----	68	390	---
		(5)	4-10-65	89	7.6	27	20	4.6	56	3	163	0	36	14	---	----	----	69	375	---
		(7)	8- 1-77	---	8.4	----	13.4	3.5	70	4.0	167	0	44	12	---	----	----	---	410	---
2.2.31.314	Upper Nogal Canyon Spring	(1)	5- 3-62	61	7.9	----	62	9	32	---	239	0	40	16	---	----	----	192	505	---
		(7)	3- 4-77	---	7.8	----	45	8.3	38	3.0	178	0	85	16	---	----	----	---	460	---
2.2.30.443	Lower Nogal Canyon Spring	(1)	5- 3-62	66	7.0	----	89	11	62	---	268	0	136	20	---	----	----	256	727	---
		(7)	3- 4-77	---	8.0	----	120	12.1	73	4.9	162	0	352	4	---	----	----	---	770	---
3.1.33.144	Armijo Windmill	(7)	5-13-77	---	8.0	----	72	17.5	110	4.3	195	0	271	28	---	----	----	---	1,000	---
3.2.36.212	Armijo Windmill	(7)	5-13-77	---	8.4	----	22	6.2	90	10.5	165	2.5	103	28	---	----	----	---	620	---
4.1.5.211	Chupadera Spring	(1)	5-17-62	63	8.3	----	39	3	372	---	444	0	476	42	---	----	----	110	1,872	---
4.2.7.211	Box Spring	(1)	2- 8-63	46	7.8	----	30	5	3	---	102	0	10	6	---	----	----	95	219	---
4.3.5.331	Mt. Baldy Spring	(1)	6-11-62	---	7.8	----	25	3	5	---	90	0	8	2	---	----	----	74	159	---
4.2.12.112	Gianero Windmill	(2)	1952	68	7.6	----	123	35	185	---	230	---	608	24	---	----	----	---	-----	792
4.2.3.321	Gianero Windmill	(2)	1952	72	7.5	----	58	16	17	---	230	---	24	24	---	----	----	---	-----	316

WATER QUALITY ANALYSES (Continued)

Location Number	Name	Date Collected	Temp. (°F)	pH	SiO_2	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	B	Fe	Hard-ness	Conductivity (μmhos/cm)	T.D.S.
3.2.25.443	Sedillo Windmill (2)	1952	---	---	----	29	8	---	---	----	---	108	22	---	----	----	---	-----	---
3.2.23.123	Sedillo Windmill (2)	1952	64	7.7	----	47	8	34	---	205	---	20	26	---	----	----	---	-----	280
3.3.28.424	Copper Canyon Spring (7)	10-29-77	--	7.9	----	79	11.0	9.2	1.2	228	0	65	4	---	----	----	---	400	---
3.3.26.111	North Fork, Water Canyon (1)	5-10-62	64	8.5	----	62	12	19	---	229	5	34	10	---	----	----	206	440	---
3.3.27.211	North Fork, Water Canyon (1)	2- 8-63	43	8.2	----	105	16	5	---	355	0	44	0	---	----	----	326	632	---
3.3.26.113	Water Canyon (1)	5-10-62	73	8.7	----	54	9	15	---	188	10	20	8	---	----	----	170	358	---
3.3.34.332	Water Canyon (1)	2- 8-63	45	7.8	----	65	10	10	---	237	0	10	15	---	----	----	202	430	---
3.3.26.111	Water Canyon Campground Well (7)	3- 4-77	---	8.1	----	33	12.0	15.3	1.2	142	0	53	8	---	----	----	---	300	---
3.3.23.342	Tom Kelly Well (7)	3- 4-77	---	7.9	----	68	14.9	18.8	1.6	213	0	87	10	---	----	----	---	520	---
3.3.13.331	Cibola National Forest Well (7)	10-29-77	---	7.8	----	91	12.2	14.1	1.3	178	0	125	4	---	----	----	---	450	---
3.2.20.1111	Strozzi Windmill (7)	5-13-77	---	7.7	----	35	5.2	19.1	2.4	137	0	12	18	---	----	----	---	310	---
3.2.17.423	Strozzi Windmill (7)	5-13-77	---	8.0	----	25	6.2	17.3	2.2	122	0	---	14	---	----	----	---	260	---
3.3.10.311	Garcia Canyon Spring (1)	7-26-62	63	7.8	----	106	23	9	---	388	0	48	8	---	----	----	358	705	---
	(7)	5-16-77	---	8.0	----	31	20.2	21.2	1.4	152	0	70	12	---	----	----	---	420	---

WATER QUALITY ANALYSES (Continued)

Location Number	Name		Date Collected	Temp. (°F)	pH	SiO_2	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	B	Fe	Hard-ness	Conductivity (µmhos/cm)	T.D.S.
3.2.8.423	Water Canyon Lodge Well	(2)	1952	64	7.7	----	61	8	40	---	278	---	24	14	---	----	----	186	-----	234
		(1)	3- 4-77	---	7.9	----	35	6.4	12.0	1.7	152	0	---	12	---	----	----	---	300	---
2.2.35.324	Snake Ranch Spring	(5)	6-25-60	---	7.4	31	---	---	23	---	201	0	12	15	0.4	----	----	150	353	---
		(1)	5-10-62	61	8.2	----	---	---	26	---	237	0	20	12	---	----	----	176	414	---
		(7)	11-29-77	---	7.9	----	55	5.6	16	1.5	218	0	20	10	---	----	----	---	370	---
2.2.35.323	Snake Ranch Windmill	(2)	1952	60	7.9	----	59	9	20	---	200	---	16	34	---	----	----	186	-----	270
2.2.34.432	Snake Ranch Windmill	(2)	1952	66	7.8	----	68	10	19	---	244	---	16	26	---	----	----	210	-----	290
		(7)	5-16-77	---	7.9	----	54	8.3	26	2.0	195	0	30	36	---	----	----	---	430	---
2.2.19.422	B. Kelly Ranch Well	(2)	1952	64	7.8	----	38	9	24	---	181	---	16	14	---	----	----	132	-----	188
2.2.20.311	B. Kelly Ranch Well	(7)	5-16-77	---	8.0	----	21	5.5	23.6	3.0	74	0	45	8	---	----	----	---	260	---
2.3.24.411	Allie Strozzi Well	(2)	1952	---	8.3	----	35	9	35	---	190	---	20	14	---	----	----	126	-----	196
		(7)	5-12-77	---	7.9	----	34	6.4	17.9	1.9	157	0	---	8	---	----	----	---	300	---
2.3.25.133	J. B. Kelly Windmill	(2)	1952	68	7.7	----	34	11	25	---	171	---	20	16	---	----	----	128	-----	188
		(7)	5-12-77	---	8.0	----	26.1	6.5	22.8	1.5	157	0	---	16	---	----	----	---	290	---
2.3.27.223	Courtney Well	(2)	1952	73	7.8	----	44	10	18	---	166	---	22	22	---	----	----	150	-----	206

APPENDIX C

TRITIUM AND PRECIPITATION DATA

Most precipitation data are from the U. S. Weather Service monthly reports for the Socorro and Kelly Ranch stations. In some instances the Socorro precipitation data had not been recorded, although tritium activity was measured in Socorro precipitation. In these cases, precipitation amounts from other stations were used, viz.: Albuquerque, Mount Withington, Snake Ranch Flats, and Langmuir Laboratory. The last three were atmospheric physics research stations operated in the study area by New Mexico Institute of Mining and Technology Physics Department which has the files. The Albuquerque data are from the U. S. Weather Service (see Procedures section for address).

Tritium activities were measured at New Mexico Institute of Mining and Technology. Listings of tritium in precipitation were given by Rabinowitz and Gross (1972) and by Gross et al. (1976). These data were carefully checked against the original Tritium Laboratory records. Some were recomputed. However, the original records for sample numbers approximately between #1113 and #1233 could not be located. Tritium data for 1977 and 1978 are new determinations.

Monthly average tritium activity in precipitation was computed as follows. Where only one event was measured for tritium in a month then that value was used as the monthly value. When more than one event was measured for a month, then a weighted average value was used for that month.

$$Tm = \sum_{i}^{n} \left(Ti \times \frac{Pi}{\sum_{i}^{n} P} \right)$$

where: n = number of events analyzed for tritium during a month
Ti = tritium activity for the i^{th} event. (TU)
Pi = precipitation amount for the i^{th} event (inches)
Tm = monthly weighted average tritium activity in precipitation

For months where no tritium in precipitation was measured, tritium activities were determined by linear interpolation from adjacent monthly values. The interpolated data are starred (*).

Tritium activities of springs and wells in the Socorro area prior to 1977 have never been compiled systematically before. They also have been carefully checked against the original laboratory records.

* Interpolated value

(1) Albuquerque precipitation

(2) Mt. Withington precipitation

(3) Langmuir Laboratory and Snake Ranch Flats precipitation

(4) Langmuir Laboratory precipitation

(5) Samples are a combination of Garcia Canyon Spring and S. Strozzi Windmill.

NOTE: Some data for sources (2), (3), and (4) are from Romero and Wilkening (1977).

Precipitation

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
1-1957	42 ± 4	0.21	0.34	9	14	74
2	58 ± 1.7	0.60	0.40	35	23	89
3	74 ± .7	0.80	1.58	59	117	99
4	133 ± 8	0.40	1.48	53	197	113
5	194*	0.20	0.44	39	85	
6	254 ± 14	0.15	0.38	38	97	137,139
7	103 ± 1.7	1.92	7.70	198	793	141,142, 147,192
8	96 ± 1.2	2.73	5.30	262	509	153-157, 175,194
9	119*	0.12	0.57	14	68	
10	141 ± 4.2	3.34	3.00	471	423	167,168, 171,173
11	152*	0.57	1.52	87	231	
12	163*	0.06	0.0	10	0	
1-1958	173 ± 4	0.55	0.70	95	121	196
2	224*	0.05	0.09	11	20	
3	275 ± 7.8	1.89	2.21	520	608	209,213, 216,223

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
4	261 ± 41.3	1.25	1.25	326	326	225,226
5	420 ± 11.5	0.60	0.25	252	105	229,230 236,238
6	561 ± 21.6	0.63	1.64	353	920	243,260 (?)
7	585*	0.57	2.34	333	1369	261 (?)
8	608 ± 57.3	0.49	3.27	298	1988	262 (?), 263 (?), 278,280, 281,283
9	165 ± 14.67	2.56	5.42	422	894	270-272, 284,287, 301
10	218 ± 11.0	2.48	1.84	541	401	291,291B, 299
11	354 ± 35	0.16	0.00	57	0	305 (?)
12	514 ± 51	0.27	0.50	137	257	308 (?)
1-1959	1526	0.02(1)	0.10	31	153	383
2	2188*	0.06	0.00	131	0	
3	2850	0.34(1)	0.19	969	542	384
4	971 ± 2	0.35	0.53	340	515	409,410
5	781*	0.50	0.03	391	23	

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
6	591 ± 2	0.08	1.31	47	774	416
7	242 ± 3	1.26(2)	3.22	305	779	404
8	209*	1.30	2.95	272	617	
9	176*	0.00	0.00	0	0	
10	143*	1.87	2.79	267	399	
11	109 ± 4	0.11(2)	0.09	12	10	405
12	233 ± 4	1.75	3.09	408	720	403
1-1960	212*	0.11	0.14	23	30	
2	191*	0.36	0.00	69	0	
3	170*	0.19	0.40	32	68	
4	149*	0.00	0.00	0	0	
5	128*	0.33	0.20	42	26	
6	108 ± 2	1.35(2)	2.86	146	309	408
7	220 ± 4	1.80	1.93	396	425	422
8	193 ± 2.7	0.78	4.10	151	791	412,413, 426
9	247 ± 5.5	0.46	0.40	114	99	429,433
10	155 ± 5.8	2.66	4.24	412	657	431,433, 434,436
11	64 ± 4	0.01(2)	0.00	1	0	438

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
12	162 ± 2	2.34	2.30	379	373	439
1-1961	184*	0.22	0.44	40	81	
2	206*	0.20	0.48	41	99	
3	228*	0.29	1.55	66	353	
4	250*	0.33	0.51	83	128	
5	271 ± 27	0.32	0.19	87	51	457
6	219 ± 8	0.63	1.26	138	276	456,530, 531
7	211 ± 9.3	2.01	0.57	424	120	514,532, 540,571, 581,663
8	75 ± 14	1.68	2.55	126	191	515,646
9	61 ± 9	1.24	0.87	76	53	544
10	60 ± 32.3	0.08	0.90	5	54	469,605, 647,759-I
11	361 ± 8.3	0.85	2.82	307	1018	587,603, 616,643
12	569*	0.45	0.59	256	336	
1-1962	777 ± 14	0.78	0.90	606	699	478,618, 793-I
2	1326*	0.04	0.00	53	0	
3	1874 ± 2	0.36	0.96	675	1799	488

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
4	1373*	0.16	0.49	220	673	
5	872 ± 3	0.00(2)	0.00	0	0	584
6	714*± 1	0.46	0.79	328	564	505
7	555 ± 2	1.76	3.41	977	1893	506,508-511
8	743 ± 3	0.19	1.02	141	758	564,574,591
9	82 ± 7.7	1.10	2.06	90	169	543,568,570
10	213 ± 10.2	0.87	1.65	185	351	539,541,572,606,638
11	805 ± 18.5	0.67	0.55	539	443	635,640
12	536 ± 3.5	1.40	9.48	750	257	567,634
1-1963	1259*	0.07	0.00	89	0	
2	2001 ± 4.6	0.69	1.10	1381	2201	592,593,597,599,633
3	1464 ± 20	0.17	0.00	249	0	644
4	2781 ± 3	0.26	0.00	723	0	632
5	3154 ± 16	0.10	0.00	315	0	1107
6	9436 ± 24	0.10(2)	0.00	940	0	651,1106

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
7	1274 ± 29.4	0.34	2.62	433	3338	661,664, 667,940-I, 941-I
8	1362 ± 10.3	2.25	4.61	3065	6279	682,712, 722,730, 956
9	602 ± 4	1.13	1.34	680	807	957-I
10	504 ± 2	1.07	1.18	539	595	942-I,958, 959
11	1200 ± 19.6	0.38	0.34	455	408	901-I, 901-A, 943-I
12	2182*	0.00	0.00	0	0	
1-1964	3164*	0.03	0.08	95	253	
2	4147 ± 14	0.63	2.96	2613	12,275	738
3	1897 ±418	0.06	0.00	114	0	903-U
4	2372*	0.98	0.80	2325	1898	1108 (?)
5	2847 ± 62	0.35	1.79	996	5096	1109
6	1856*	0.00	0.29	0	483	
7	865	2.45	2.67	2119	2310	
8	580	0.61	0.21	354	122	
9	258	1.28	2.75	330	908	
10	233	0.07	0.00	16	0	

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
11	120 ± 40	0.05	0.19	5	23	898-I
12	314 ± 14	0.27	0.00	85	0	906-I
1-1965	600*	0.17	0.00	102	0	
2	885 ± 99	0.08	1.09	71	965	937-I
3	1116 ± 84	0.15	0.10	167	112	938-I
4	794*	0.20	0.71	159	564	
5	471	0.25	0.83	118	391	
6	410 ± 1	0.40	1.10	164	451	970
7	439*	0.93	2.31	409	1014	
8	468 ± 2	1.47	4.95	688	2317	980-A
9	178 ± 1	1.81	2.67	322	475	993
10	134 ± 1	0.50	0.18	67	24	1006
11	155*	0.02	0.00	3	0	
12	175 ± 4.5	1.44	2.52	252	441	1003,1046
1-1966	234 ± 3	0.67	0.82	157	192	1045
2	217 ± 12	0.06	0.41	13	89	1044
3	329	0.10	0.20	33	66	
4	440*	0.24	0.00	106	0	
5	552*	0.01	0.00	6	0	

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
6	663 ± 18	1.90	1.13	1260	749	1078
7	262 ± 7.7	1.23(3)	4.99	322	1307	1083,1084, 1186
8	132 ± 6	0.60(4)	0.84	79	111	1187,1190
9	230 ± 8	1.09	1.44	251	331	1191
10	140 ± 7	0.05	0.00	7	0	1113
11	129*	0.00	0.00	0	0	
12	117 ± 5	0.06(4)	0.00	7	0	1114
1-1967	147 ± 14	0.00	0.00	0	0	1119
2	233*	0.24	0.90	56	210	
3	319 ± 9.5	0.07	0.09	22	29	1130,1155
4	583 ± 10	0.00	0.03	0	17	1153
5	358*	0.00	0.09	0	32	
6	133 ± 7.5	0.81	1.30	108	173	1151,1154
7	157*	1.81	1.12	284	176	
8	180 ± 6	0.76	3.66	137	559	1218
9	253 ± 6	2.01	2.39	509	605	1217
10	243*	0.23	0.45	56	109	1215,1216
11	232 ± 10	0.51	0.26	118	60	1188,1189
12	340 ± 29.5	1.54	1.56	524	530	1192,1193

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
1-1968	100 ± 5	0.40	0.16	40	16	1212,1233
2	127 ± 8	0.48	0.37	51	47	1226
3	226 ± 8	0.91	2.38	206	538	1213,1227
4	214 ± 6	0.03	0.08	6	17	1214
5	174 ± 6	0.71	0.49	124	85	1207
6	244 ± 7	0.05	0.00	12	0	1208
7	103 ± 6.5	3.32	4.60	342	474	1200,1205, 1206,1232
8	80 ± 5	2.81	7.47	226	598	1210,1211
9	———	————	————	———	———	
10	———	————	————	———	———	
11	———	————	————	———	———	
12	———	————	————	———	———	
1-1969	———	————	————	———	———	
thru						
6-1971	———	————	————	———	———	
7	138	0.72	1.97	99	399	1374
8	144	0.91	2.86	131	412	1375
9	168*	1.39	2.89	25	270	
10	192*	1.43	2.17	336	774	

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
11	216	0.72	0.65	156	140	1429
12	211*	1.21	0.78	274	152	
1-1972	206*	0.12	0.00	25	0	
2	202*	0.07	0.20	14	40	
3	197*	0.02	0.00	4	0	
4	192*	0.00	0.00	0	0	
5	187 ± 1.9	0.38	1.55	71	290	1428, 1454C
6	161*	0.81	0.95	130	153	
7	135 ± 1.7	0.93	1.65	126	223	1433, 1455C
8	103 ± 1.5	3.20	6.45	330	664	1435,1437, 1440, 1456C
9	81 ± 1.8	1.94	3.60	157	292	1441, 1457C
10	138 ± 1.4	5.37	3.94	741	544	1458C
11	131*	0.80	0.52	105	68	
12	124*	0.33	0.19	41	24	
1-1973	117*	0.46	0.98	54	115	
2	109*	0.71	1.12	77	122	
3	102*	0.53	0.61	54	62	

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
4	95*	0.16	0.50	15	48	
5	88 ± 0.3	0.87	1.50	77	132	1493
6	124 ± 0.4	0.77	0.47	95	58	1494,1526
7	161 ± 0.4	1.03	2.18	166	351	1495, 1497C
8	144*	3.24	1.49	467	215	
9	127 ± 1.6	1.12	0.54	142	69	1525
10	110*	0.04	0.30	4	33	
11	93*	0.00	0.00	0	0	
12	76*	0.00	0.00	0	0	
1-1974	59 ± 1.7	0.10	0.41	6	24	1852,1853
2	158 ± 2.1	0.03	0.30	5	47	1854
3	157*	0.14	0.18	22	28	
4	155 ± 2.4	1.38	0.06	214	9	1855
5	140 ± 2.7	0.01	0.06	1	8	1856,1857
6	88*	0.11	0.04	10	6	
7	36 ± 0.9	0.85	1.69	31	1	1730,1850, 1851
8	81 ± 0.5	2.52	3.60	204	292	1731 (CR8)
9	65 ± 0.5	2.67	3.39	174	220	1732,1733

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
10	39 ± 0.6	3.32	4.37	129	170	1734
11	45 ± 0.7	0.05	0.07	2	3	1738
12	50 ± 0.5	0.48	0.63	24	32	1739,1740
1-1975	50 ± 0.5	0.46	1.05	23	53	1741
2	109*	0.23	0.54	25	59	
3	168 ± 3	0.40	0.73	67	123	1860
4	179*	0.00	0.05	0	9	
5	189 ± 2	0.23	0.69	43	130	1858,1859
6	93 ± 2.5	0.00	0.09	0	8	1861
7	90 ± 2.4	3.07	5.09	276	458	1862,1864, 1940
8	46 ± 2.1	1.47	2.63	68	121	1863,1939, 1942,1943
9	43 ± 1.4	4.12	4.68	177	201	1941,1944-1947,2176
10	33*	0.01	0.21	0	7	
11	23 ± 1.1	0.25	0.65	6	15	2177
12	67 ± 1.7	0.24	0.15	16	10	2178
1-1976	45 ± 1.7	0.00	0.00	0	0	2184
2	34 ± 1.1	0.48	0.00	14	0	2179
3	84 ± 2	0.00	0.00	0	0	2182

Date	TU in Socorro Precipitation	Socorro Precipitation (inches)	Kelly Ranch Precipitation (inches)	TU times Socorro ppt	TU times Kelly Ranch ppt	Sample #
4	30 ± 1.5	0.60	1.05	18	32	2180
5	74 ± 1.3	0.94	1.27	70	94	2183
6	55*	0.48	0.43	26	24	
7	36 ± 1.3	3.61	3.12	120	112	2181

Springs and Wells

Location	Date Sampled	TU	Sample No.
Socorro Spring (22.111)	18 March 57	4 ± 0.5	98
	16 May 57	2 ± 0.4	122
	26 July 57	4 ± 0.3	146
	4 Sept 57	5 ± .3	180
	7 Nov 57	11 ± 0.1	177
	16 Jan 58	2 ± .5	217
	5 Mar 58	3 ± 0.4	211
	21 Apr 58	5 ± 0.5	228
	28 May 58	50.5± 3.2	239
	26 July 58	11 ± 0.7	254
	10 Dec 58	18.8	307
	2 Feb 59	28	310
	28 Mar 61	20 ± 1	450
	11 May 61	27 ± 3	454
	5 July 61	24 or 92? ± 1 or 3	595,602
	11 Sept 61	39 ± 3	716
	1 June 62	15	
	2 July 62	192 ± 3	(601)
	1 Aug 62	57 ± 2	590
	5 Sept 62	68	
	31 Oct 62	38 or 231? ± 13 or 1	728,611
	3 Dec 62	135 ± 3	614

Springs and Wells

Location	Date Sampled	TU	Sample No.
Socorro Spring (22.111)	4 Feb 77	6.5 ± 0.6	2312
	14 Apr 77	5.9 ± 0.8	2320
	22 June 77	9.8 ± 0.9	2348
	25 Oct 77	1.7 ± 0.8	2384
	19 Jan 77	3.5 ± 1	2423
	14 Mar 78	1.5 ± 0.7	2428
Sedillo Spring (22.113)	8 Jan 62	50 ± 6	579
	27 Apr 62	54 ± 6	580
	1 Jun 62	11 ± 2	528
	2 July 62	27	
	5 Sept 62	77	
	9 Oct 62	48 ± 3	586
	8 Nov 62	69 ± 3	589
	3 Dec 62	165 ± 4	612
	9 Feb 63	72 ± 4	598
	1 May 63	111 ± 3	627
	2 Jun 63	45 ± 37	641
	1 July 63	82 ± 25	668
	2 Aug 63	75 ± 14	678
	4 Sept 63	27 ± 17	708
	3 Nov 63	27 ± 2	736
	5 Dec 63	69 ± 68	752-I

Springs and Wells

Location	Date Sampled	TU	Sample No.
Sedillo Spring (22.113)	4 Jan 64	98 ± 26	789-I
	31 Jan 64	45 ± 89	772-I
	3 Mar 64	334 ± 7	835
	31 Mar 64	91 ± 14	861
	30 Apr 64	3 ± 20	872
	3 June 64	0	888
	1 July 64	33 ± 6	889
	4 Aug 64	56 ± 5	893
	1 Oct 64	10 ± 4	896
	4 Feb 77	8.8 ± 0.7	2313
	14 Apr 77	11.2 ± 1	2321
	22 June 77	5.9 ± 0.8	2338
	25 Oct 77	2.0 ± 0.9	2385
	19 Jan 78	0.2 ± 0.9	2422
	14 Mar 78	0.5 ± 0.7	2429
Cook Spring (15.311)	4 Feb 77	6.5 ± 0.8	2314
	14 Apr 77	10.8 ± 1	2322
	22 June 77	6.3 ± 0.7	2349
	25 Oct 77	1.3 ± 0.9	2386
	19 Jan 77	0.5 ± 0.5	2424
	14 Mar 78	2.6 ± 1	2427

Springs and Wells

Location	Date Sampled	TU	Sample No.
Blue Canyon Well (16.323)	1 Aug 77	12.0 ± 0.8	2350
	6 Feb 78	3.3 ± 0.8	2425
Lower Nogal Canyon Spring (30.443)	4 Mar 77	28.3 ± 1.0	2316
	13 May 77	31.2 ± 1.2	2323
	3 Aug 77	37.3 ± 1.4	2351
	29 Oct 77	24.0 ± 0.8	2411
	19 Jan 78	21.8 ± 1.3	2420
	14 Mar 78	25.1 ± 1.4	2426
Upper Nogal Canyon Spring (31.314)	4 Mar 77	24.0 ± 1.0	2315
	13 May 77	22.8 ± 0.9	2324
	3 Aug 77	26.6 ± 1	2352
	29 Oct 77	18.3 ± 0.8	2412
	19 Jan 78	20.8 ± 1.2	2421
Armijo Windmill (33.144)	13 May 77	54.1 ± 1.8	2325
	5 Aug 77	52.6 ± 1.1	2353
	25 Oct 77	47.2 ± 1.6	2387
Sedillo Windmill (25.443)	13 May 77	10.5 ± 0.8	2326
Snake Ranch Windmill (34.432)	16 May 77	7.9 ± 0.8	2330
	19 Aug 77	8.4 ± 0.9	2380
	25 Oct 77	5.7 ± 0.9	2388
Water Canyon Lodge Well (8.432)	4 Mar 77	4.7 ± 0.7	2319
	13 May 77	3.4 ± 0.8	2327

Springs and Wells

Location	Date Sampled	TU	Sample No.
Water Canyon Lodge Well (8.432)	5 Aug 77	0.8 ± 0.7	2379
	25 Oct 77	1.5 ± 0.7	2410
B. Kelly Ranch (deep well) (20.311)	16 May 77	4.3 ± 0.8	2331
	18 Aug 77	0.0	2381
	25 Oct 77	1.0 ± 0.7	2389
Allie Strozzi Well (24.411)	12 Mar 77	0.0	2375
	16 May 77	3.1 ± 0.9	2332
	19 Aug 77	2.0 ± 0.7	2383
	25 Oct 77	0.8 ± 0.6	2390
J. B. Kelly Windmill (25.113)	16 May 77	4.9 ± 0.9	2333
	19 Aug 77	0.8 ± 0.8	2382
South Canyon Windmill (17.423)	12 Mar 77	3.1 ± 0.8	2376
	13 May 77	4.3 ± 0.8	2329
	5 Aug 77	0.5 ± 0.7	2378
	29 Nov 77	1.4 ± 0.7	2418
Upper South Canyon Windmill (20.111)	13 May 77	2.2 ± 0.7	2328
Snake Ranch Spring (35.324)	29 Nov 77	1.8 ± 0.6	2417
Garcia Canyon(5)	16 May 77	47.1 ± 1.5	2334
	5 Aug 77	43.0 ± 1.6	2354
	29 Nov 77	34.6 ± 1.3	2419

Springs and Wells

Location	Date Sampled	TU	Sample No.
Nathan Hall Windmill (23.221)	12 Mar 77	51.3 ± 1.4	2374
	16 May 77	55.2 ± 1.7	2335
Tom Kelly Well (23.342)	4 Mar 77	50.9 ± 1.9	2317
	15 May 77	50.8 ± 1.7	2336
	5 Aug 77	39.3 ± 1.0	2355
	29 Oct 77	37.3 ± 1.4	2414
Cibola National Forest Windmill (13.331)	29 Oct 77	34.1 ± 1.4	2413
Water Canyon Campground Well (26.111)	4 Mar 77	46.2 ± 1.6	2318
	16 May 77	41.4 ± 1.6	2337
	5 Aug 77	45.0 ± 2.1	2377
	29 Oct 77	35.4 ± 1	2415
Copper Canyon Spring (28.424)	29 Oct 77	35.2 ± 1.4	2416